Higgs → bb/cc/gg/ss with Z(ll,νν)H at $\sqrt{s}$=240 GeV

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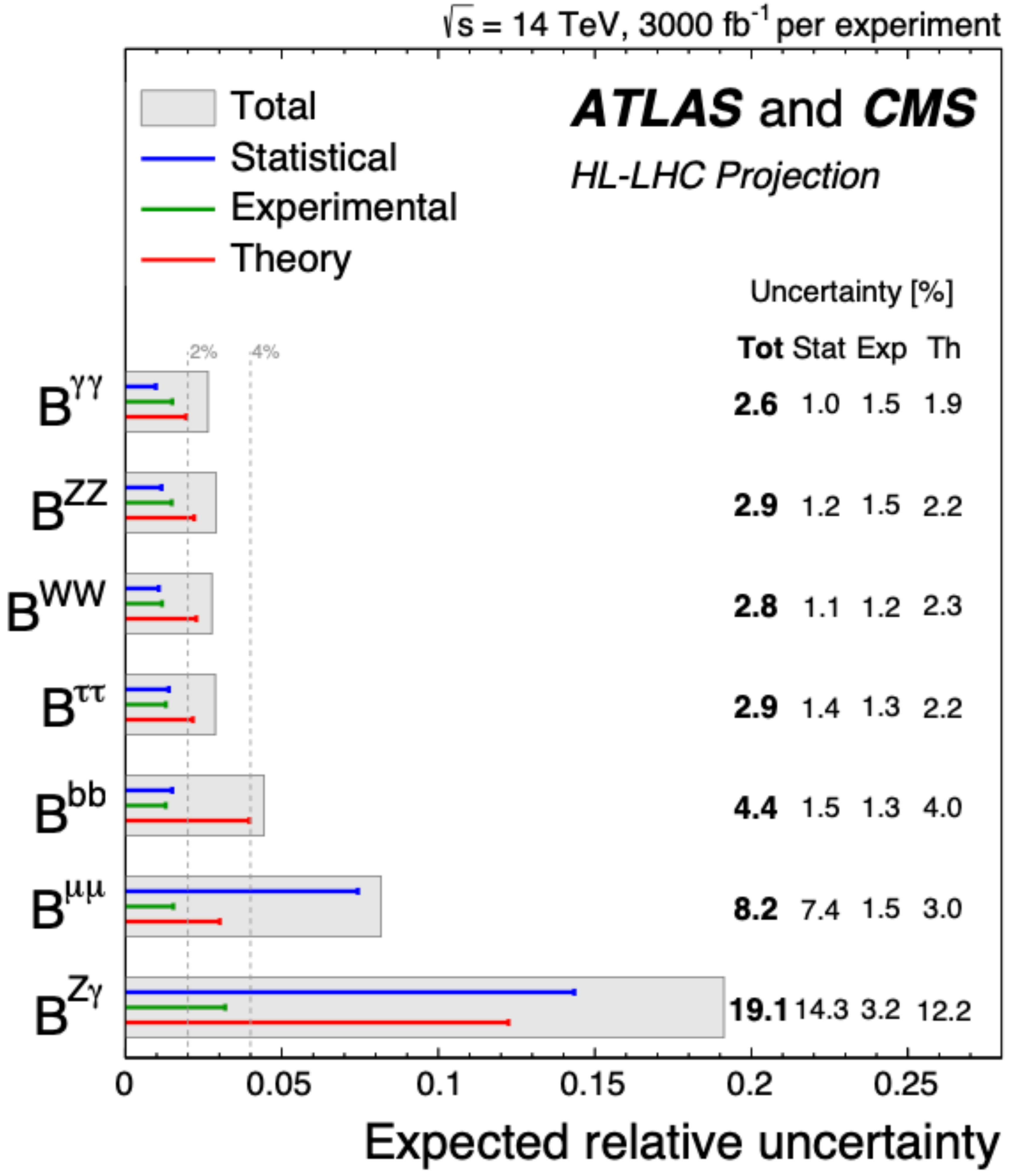
Introduction

- H → bb/cc/ss/gg decays are crucial to **measure the Higgs couplings to quarks of the 3rd (b) and 2nd (c, s) families and the effective gluon coupling** (induced in the SM by the top-Higgs coupling)

- **At HL-LHC**, projected sensitivities from ATLAS+CMS:
  - **bb ~4%**
  - **cc ~100%**
  - **ss, gg: none**



Introduction (II)

- **Higgs factories**, despite the much lower total Higgs production xsection, are expected to reach much better sensitivities
  - Significantly larger acceptance and S/B
  - Detectors optimised for tagging of various flavour hypotheses (b/c/g/…)
  - **Target: <% precision for bb and O(%) for cc, gg σBR**
- In addition, measurements of σ*BR can be converted to **model-independent measurements of the couplings** since the total Higgs boson xsection can be measured with the recoil technique

CEPC (arXiv:2203.01469v4)
5.6/ab @240 GeV

Z decay mode	$H \to b\bar{b}$	$H \to c\bar{c}$	$H \to gg$
$Z \to e^+e^-$	1.57%	14.43%	10.31%
$Z \to \mu^+\mu^-$	1.06%	10.16%	5.23%
$Z \to q\bar{q}$	0.35%	7.74%	3.96%
$Z \to \nu\bar{\nu}$	0.49%	5.75%	1.82%
combination	0.27%	4.03%	1.56%

Z(ee+μμ): 0.9% 8.3% 4.7%

Introduction (III)

- At $\sqrt{s_{ee}}$ **= 240 GeV**, main Higgs production mode is through ee→ZH
  - **σ(ZH)~200 fb → 1M ZH events in 5/ab**, 2/3 of them (almost 700k) decaying to partons

- Pros and cons of different Z boson decay modes:
  - **Z→ll (l = e, μ)**: cleanest, but lowest yield BR (Z→ll) ~ 6.7% => **~50k signal events**
  - **Z→qq**: largest yield, worse resolution, + combinatorics BR (Z→qq) ~70% => **~500k signal events**
  - **Z→νν**: intermediate yield, good S/B, no combinatorics BR (Z→νν) ~20% => **~140k signal events**

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Status of ZH(jj) analyses

- **Z(ll)**: work on analysis started by APC-Paris team around end of 2020, full analysis chain in place since July 2021, updated with more recent samples/taggers/categorisation strategy (GM, w/ contributions from various intern students: P. Paquiez, M. Jolly, P. Guimbard, A. Maloizel)

- **Z(νν)**: full analysis chain implementation in fall 2022 by APC-Paris (link) and CERN (link) teams, recently updated to latest MC samples taggers
  - APC: GM, A. Maloizel
  - CERN: A. Del Vecchio, L. Gouskos, M. Selvaggi

- **Z(qq):** work started recently (Aly, Bari), full analysis chain not yet in place

- In parallel: huge amount work on **development of flavour taggers** by CERN/Pisa team (see *talk* by Lukas yesterday)
  - F. Bedeschi, M. Selvaggi, L. Gouskous + new members: A. Del Vecchio, L. Forthomme, D. Garcia

- **Today**: show latest (preliminary) results of full analysis of Z(ll)H and Z(vv)H analyses using winter 2023 MC sample production and latest training of ParticleNet-based flavour taggers that were released just *two weeks ago..*

Analysis strategy

- The measurements proceeds in the following steps:
  - Event **reconstruction**: high-momentum leptons (for selection in ll and for veto in νν channel), jets and missing energy are reconstructed. Tagging algorithms are executed on the clustered jets.
  - Event **selection**: events consistent with the signature under study are kept
  - Event **categorisation**: selected events are classified in orthogonal categories mainly based on output of flavour taggers, discriminating between the different Higgs boson decays under study
  - Maximum likelihood **fit** to variable(s) discriminating between signal and background to extract signal strength (measured σ*BR over SM expectation)
    - Tagging efficiencies for each flavour and signal acceptance for each category assumed to be known from TH + MC

Common features

- All results assume a luminosity of **5/ab at 240 GeV**
- All results use the **winter2023 MC central production**
- The samples are normalised using **common values of cross-sections and branching ratios** from central dictionary file
  - This in particular assumes BR($H \to ss$)=0.024%
- A **consistent treatment of leptons** in ll and $\nu\nu$ analyses (veto) is performed to ensure orthogonality
- **Jet clustering** is performed using **Durham** (ee k_t) **exclusive N=2** algorithm
- **Jet flavour identification** relies on the latest version (wc_pt_13_01_2022) of the training of the tagging algorithms

MC samples

- Signal and background samples were generated centrally (**“winter2023” production**)
  - Signal + ee→ee, μμ, ννZ bkg: Whizard + Pythia6
  - ee→ZZ, WW, qqbar bkg: Pythia8
- **Fast simulation** of **IDEA detector** in **Delphes** (latest concept w/ smaller beam pipe and innermost tracker radius, crystal-based ECAL)

ννH (~7M), eeH (~3M), μμH (~3M)

Process	σ [fb]	N_{gen}	L_{gen} [fb^{-1}]	L_{gen}/L
$\nu\bar{\nu}H(bb)$	26.9000	1200000	44610	8.922
$\nu\bar{\nu}H(c\bar{c})$	1.3350	1100000	823970	164.794
$\nu\bar{\nu}H(s\bar{s})$	0.0111	1008052	90897385	18179.477
$\nu\bar{\nu}H(gg)$	3.7820	1055845	279176	55.835
$\nu\bar{\nu}H(\tau\tau)$	2.8970	1200000	414222	82.844
$\nu\bar{\nu}H(WW)$	9.9400	400000	40241	8.048
$\nu\bar{\nu}H(ZZ)$	1.2200	200000	163934	32.787
$eeH(bb)$	4.1710	400000	95900	19.180
$eeH(c\bar{c})$	0.2070	400000	1932367	386.473
$eeH(s\bar{s})$	0.0017	352836	205376019	41075.204
$eeH(gg)$	0.5863	400000	682245	136.449
$eeH(\tau\tau)$	0.4491	400000	890670	178.134
$eeH(WW)$	1.5410	400000	259572	51.914
$eeH(ZZ)$	0.1891	400000	2115283	423.057
$\mu\mu H(bb)$	3.9400	300000	76142	15.228
$\mu\mu H(c\bar{c})$	0.1956	400000	2044990	408.998
$\mu\mu H(s\bar{s})$	0.0016	400000	246305419	49261.084
$\mu\mu H(gg)$	0.5538	400000	722282	144.456
$\mu\mu H(\tau\tau)$	0.4243	400000	942729	188.546
$\mu\mu H(WW)$	1.4560	400000	274725	54.945
$\mu\mu H(ZZ)$	0.1786	400000	2239642	447.928

qqH, q=udscb (~15M)

ll, qq, VV, ννZ (~260M)

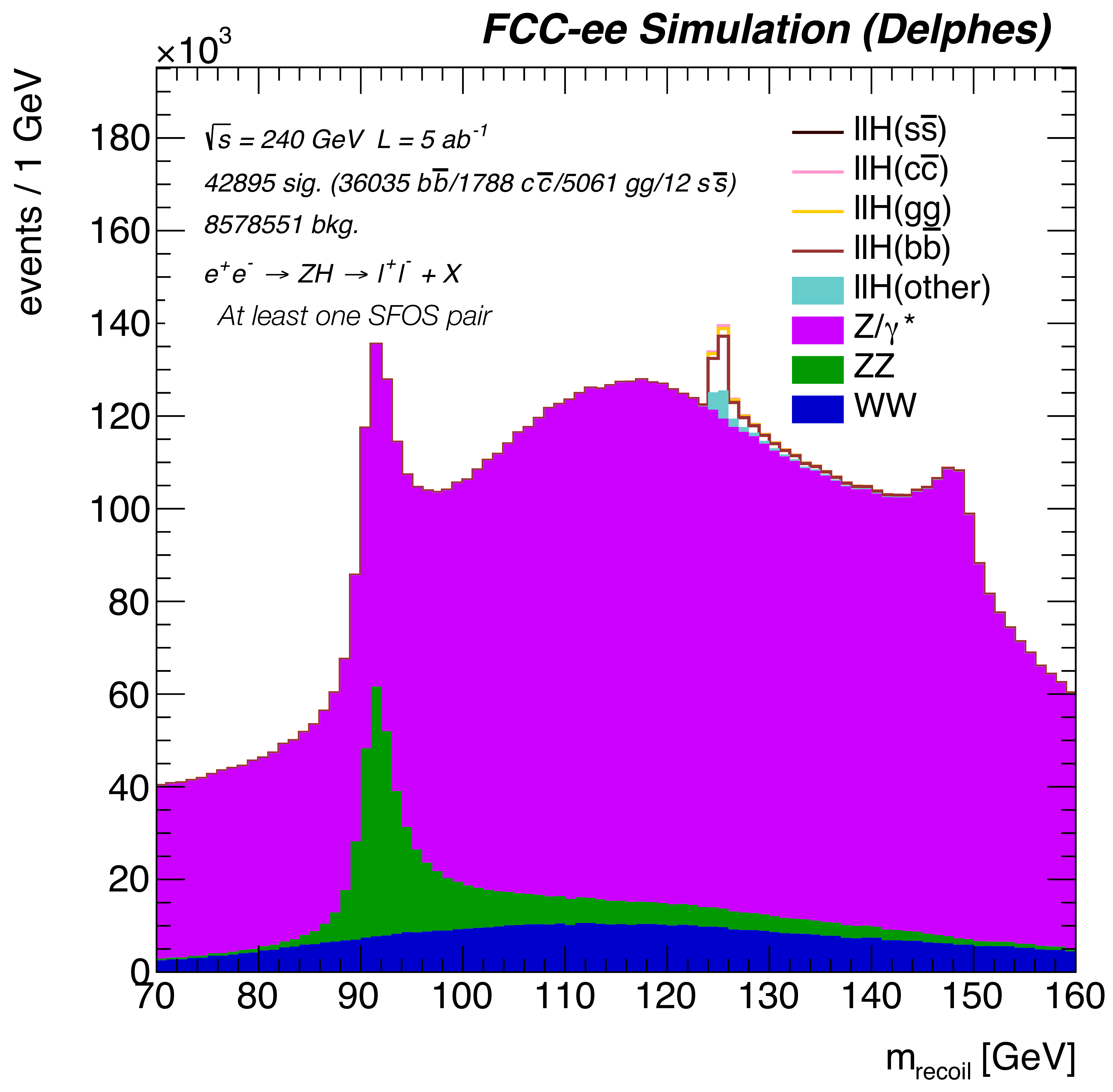
Process	σ [fb]	N_{gen}	L_{gen} [fb^{-1}]	L_{gen}/L
$q\bar{q}H(b\bar{b})$	31.0700	500000	16093	3.219
$q\bar{q}H(c\bar{c})$	1.5420	200000	129702	25.940
$q\bar{q}H(s\bar{s})$	0.0128	400000	31250000	6250.000
$q\bar{q}H(gg)$	4.3670	400000	91596	18.319
$q\bar{q}H(\tau\tau)$	3.3460	200000	59773	11.955
$q\bar{q}H(WW)$	11.4800	1100000	95819	19.164
$q\bar{q}H(ZZ)$	1.4090	1200000	851668	170.334
$s\bar{s}H(b\bar{b})$	17.4500	200000	11461	2.292
$s\bar{s}H(c\bar{c})$	0.8661	300000	346380	69.276
$s\bar{s}H(s\bar{s})$	0.0072	300000	41724618	8344.924
$s\bar{s}H(gg)$	2.4530	400000	163066	32.613
$s\bar{s}H(\tau\tau)$	1.8790	400000	212879	42.576
$s\bar{s}H(WW)$	6.4470	1200000	186133	37.227
$s\bar{s}H(ZZ)$	0.7912	600000	758342	151.668
$c\bar{c}H(b\bar{b})$	13.5900	200000	14717	2.943
$c\bar{c}H(c\bar{c})$	0.6747	400000	592856	118.571
$c\bar{c}H(s\bar{s})$	0.0056	300000	53504548	10700.910
$c\bar{c}H(gg)$	1.9110	400000	209314	41.863
$c\bar{c}H(\tau\tau)$	1.4640	400000	273224	54.645
$c\bar{c}H(WW)$	5.0230	1200000	238901	47.780
$c\bar{c}H(ZZ)$	0.6164	1200000	1946788	389.358
$b\bar{b}H(b\bar{b})$	17.4500	100000	5731	1.146
$b\bar{b}H(c\bar{c})$	0.8664	400000	461681	92.336
$b\bar{b}H(s\bar{s})$	0.0072	400000	55609620	11121.924
$b\bar{b}H(gg)$	2.4540	200000	81500	16.300
$b\bar{b}H(\tau\tau)$	1.8800	400000	212766	42.553
$b\bar{b}H(WW)$	6.4500	1000000	155039	31.008
$b\bar{b}H(ZZ)$	0.7915	1000000	1263424	252.685
$\nu_e\bar{\nu}_e Z$	33.2740	2000000	60107	12.021
WW	16438.5000	58228784	3542	0.708
ZZ	1358.9900	56162093	41326	8.265
$Z/\gamma^*(q\bar{q})$	52653.9000	9025312	171	0.034
$Z/\gamma^*(ee)$	8305.0000	85400000	10283	2.057
$Z/\gamma^*(\mu\mu)$	5288.0000	53400000	10098	2.020

Z(ll)H(jj) analysis overview

- Signature:
  - 2 high-momentum opposite-sign, same-flavour leptons with $m \sim m_Z$
  - 2 jets with $m_{jj} \sim m_H$
  - Recoil mass $\sim m_H$
- Main bkg: processes producing leptons (VV - mostly ZZ - and ee→ll). In addition, bkg from other Higgs boson decays (mainly H→WW,ZZ→4q)
- Signal: small contamination from Z-boson fusion process (σ/σ_{ZH} ~ 3%), further suppressed by selection criteria

Event selection - criteria

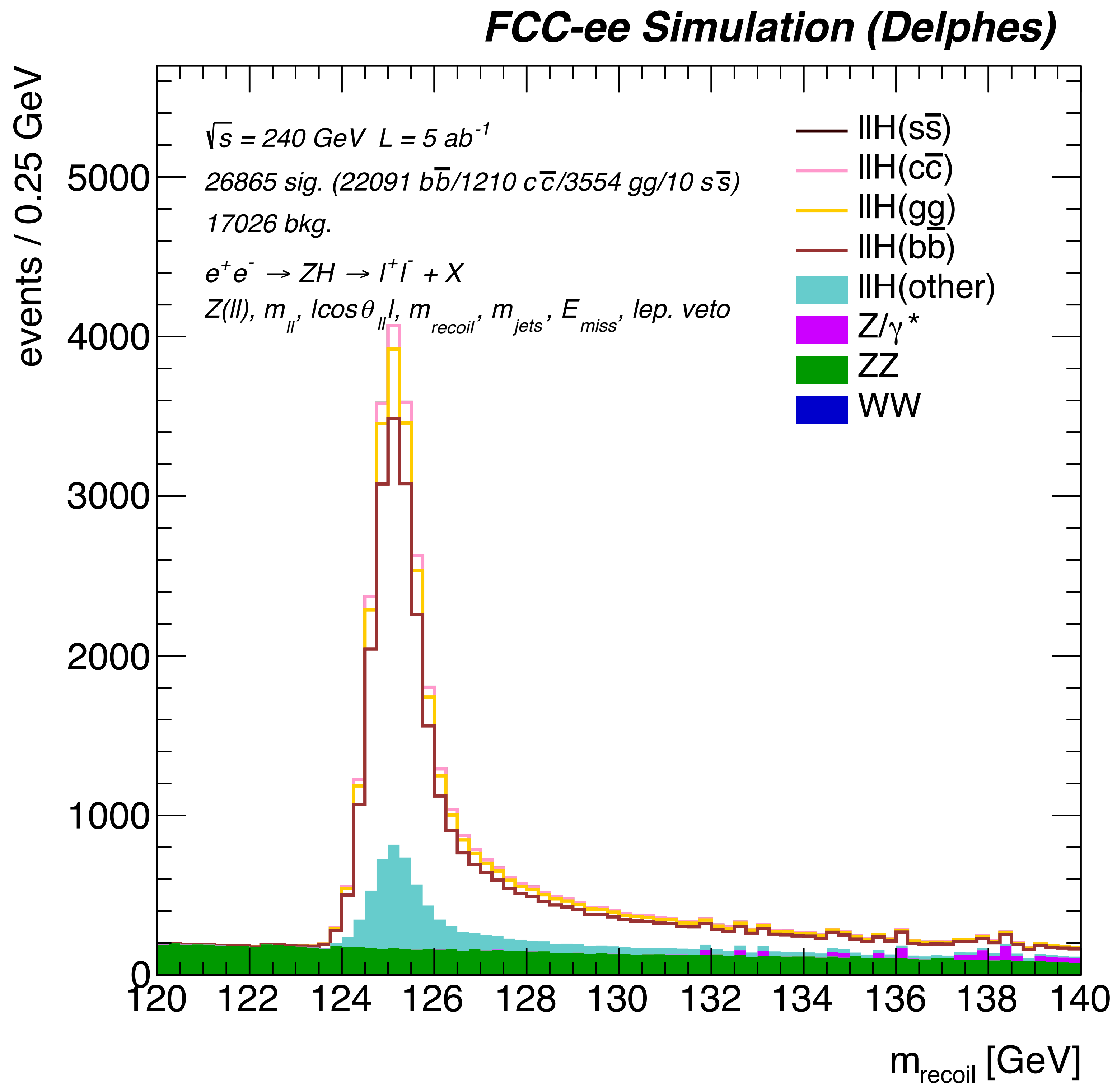
- **Z->ll selection:**
  - Select two opposite-sign, same-flavour (SFOS) leptons with 25<p<80 GeV and invariant mass closest to m_Z
  - $81 < m_{ll} < 101$ GeV
  - |cos(Polar angle of dilepton pair)|<0.8
- **Recoil and jet selection**:
  - Remove selected leptons from Z candidates from ReconstructedParticles and cluster remaining ones
  - Recoil mass in 120-140 GeV
  - Jet momentum in 15-100 GeV
  - Hadronic mass in 100-140 GeV
  - Missing energy < 30 GeV, no extra lepton with 25<p<80 GeV
  - $d_{23} > 2$ $d_{34} > 1.5$



Event selection - cutflow

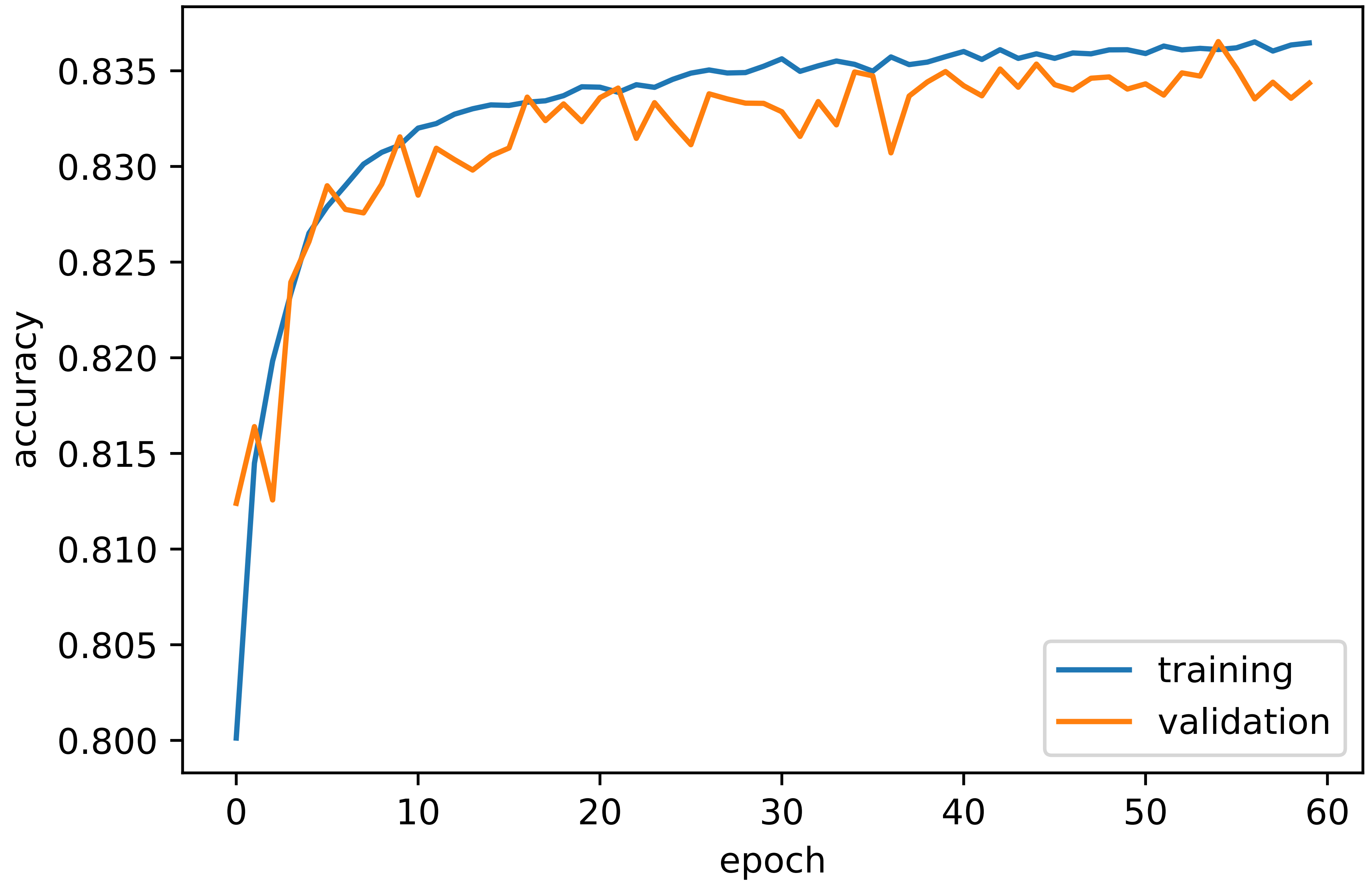
Selection	$\ell\ell H(b\bar{b})$		$\ell\ell H(c\bar{c})$		$\ell\ell H(gg)$		$\ell\ell H(s\bar{s})$		$\ell\ell H(other)$		ZZ		WW		$Z/\gamma^*(\ell\ell)$		$Z/\gamma^*(q\bar{q})$	
	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)
No cuts	40555	-	2013	-	5700	-	17	-	21190	-	6794950	-	82192500	-	67965000	-	263269500	-
one $Z(\ell\ell)$ candidate	36448	90	1808	90	5119	90	15	90	19192	91	566449	8	771701	1	13389085	20	141913	0
$m_{\ell\ell}$ in 81–101 GeV	32793	90	1627	90	4605	90	14	90	17200	90	363333	64	190167	25	5677693	42	7643	5
$\lvert\cos\theta_{\ell\ell}\rvert < 0.8$	26694	81	1327	82	3746	81	11	81	13996	81	227312	63	145246	76	906092	16	5396	71
m_{recoil} in 120–140 GeV	25497	96	1268	96	3580	96	11	96	13306	95	32182	14	62027	43	206143	23	1167	22
m_{jj} in 100–140 GeV	23245	91	1236	98	3557	99	10	99	6235	47	13284	41	30	0	39082	19	846	73
$p_{\mathrm{miss}} < 30$ GeV	23181	100	1235	100	3557	100	10	100	6196	99	13171	99	24	81	38946	100	758	90
no leptons with $p > 25$ GeV	22115	95	1224	99	3554	100	10	100	5649	91	11237	85	21	88	38946	100	642	85
$d_{23} > 2$, $d_{34} > 1.5$, $d_{45} > 1.0$	22091	100	1210	99	3554	100	10	98	5373	95	10979	98	18	87	42	0	613	95

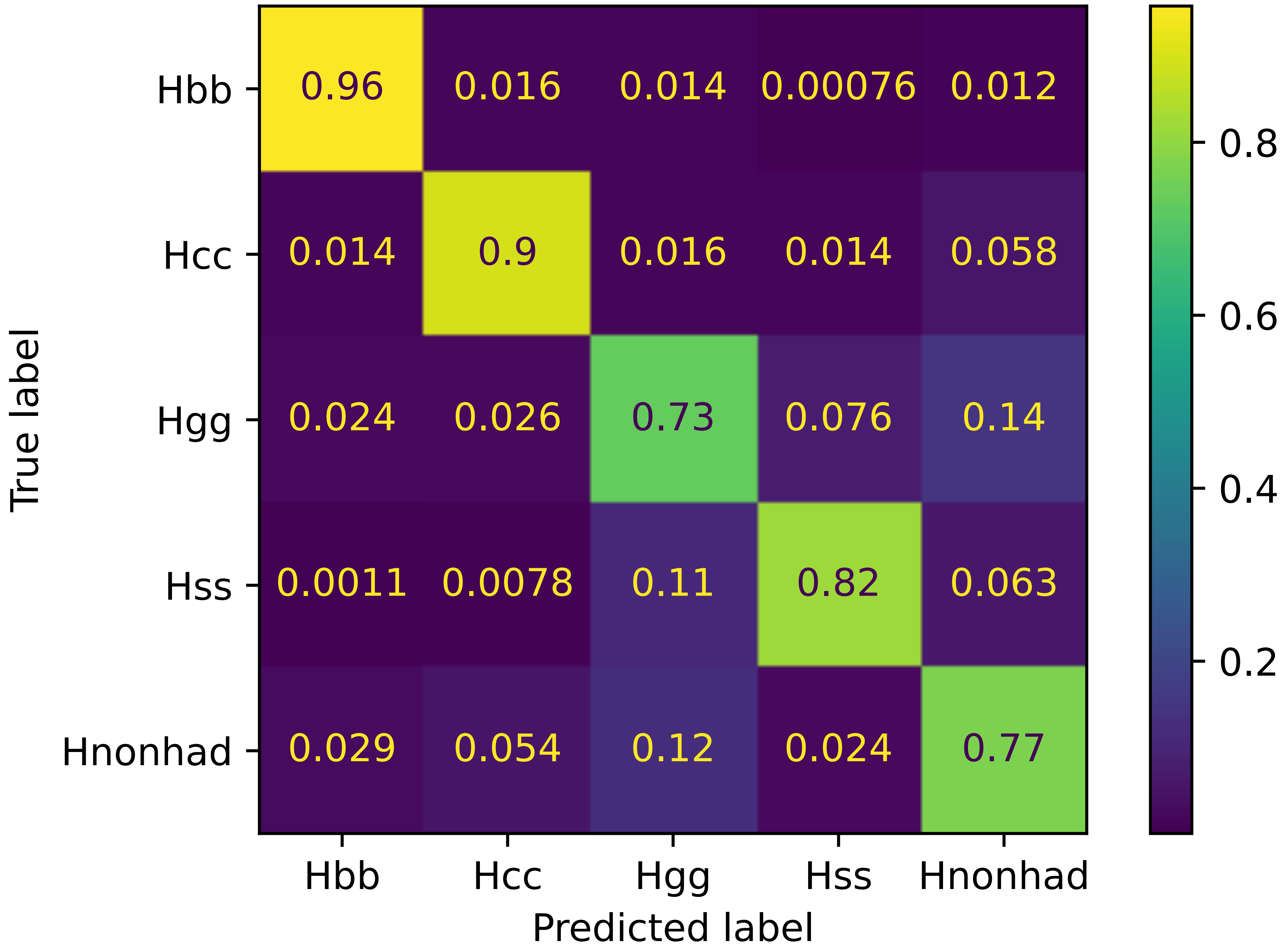
- Signal efficiency ~54-62% depending on hadronic final state
- Expect ~10 Z(ll)H(ss) events in 5/ab; >1k for other hadronic final states
- Other Higgs decays: ~5k events, mainly (90%) ZZ and WW -> 4q
- Main non-Higgs bkg: ZZ ~11k events



Event classification

- Events are classified into **5 event categories** (bb / cc / gg / ss / other) based on
    - output of tagging score (b/c/g/s/q) for the two jets
    - additional variables providing further discrimination between H(gg/ss) vs H(cc/bb) (missing momentum and diet mass) and between H(qq) and H(VV->4q): d_{23}, d_{34}
- The variables are combined in a multi-layer fully connected neural network with 5 outputs = weights for each category
- The network is trained using llH events (200k each for each), split 50:50 for training and validation





Fit model

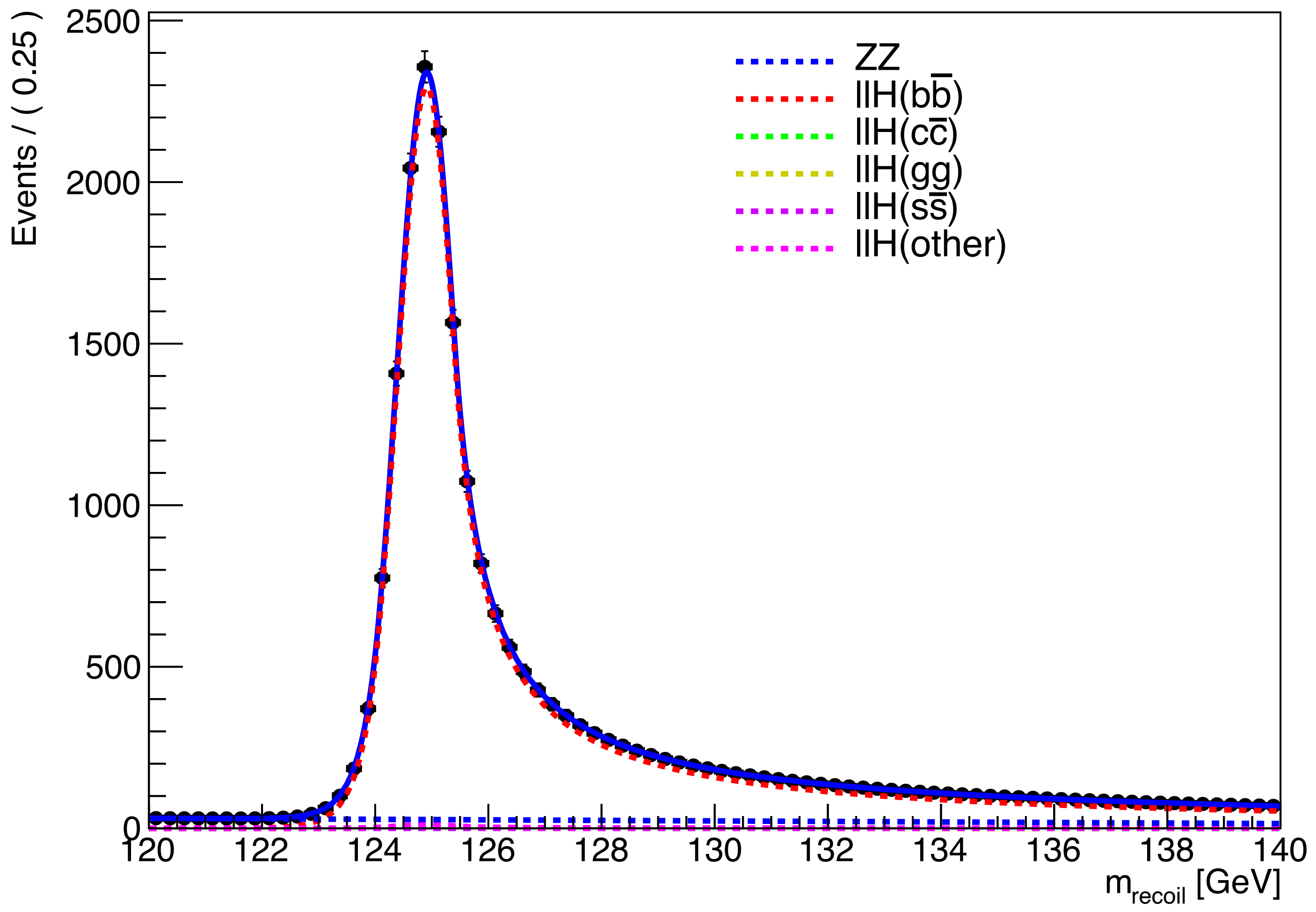
- **Simultaneous S+B fit to the recoil mass** of the event categories - 0.25 GeV bins in range 120-140 GeV
- Try to minimise assumptions (=> systematic uncertainties)
  - **Background** model: 1st order polynomial, floating shape parameter and yield in each category
  - **Signal** model: double-sided **Crystal Ball** function with same parameters in all categories, tail parameters and acceptance in each category fixed from MC, core parameters and overall signal strength floating
- Fit is performed to Asimov dataset generated from nominal models fitted to MC events passing selection
- To increase S/B and thus the final sensitivity of the measurement, for the final fit, only events with output score for the category they are assigned to greater than a certain threshold

Category	$\ell\ell H(b\bar{b})$	$\ell\ell H(c\bar{c})$	$\ell\ell H(gg)$	$\ell\ell H(s\bar{s})$	$\ell\ell H(other)$	bkg	Total
$b\bar{b}$	20830 (138)	19 (0)	54 (0)	0 (0)	105 (1)	1864	22872
$c\bar{c}$	49 (1)	879 (19)	15 (0)	0 (0)	26 (1)	1232	2201
gg	185 (3)	15 (0)	2380 (37)	1 (0)	433 (7)	1105	4119
$s\bar{s}$	2 (0)	7 (0)	66 (2)	7 (0)	12 (0)	1752	1844
other	345 (4)	93 (1)	527 (6)	0 (0)	4223 (48)	2703	7892
Total	21410 (138)	1012 (19)	3043 (38)	8 (0)	4800 (48)	8656	

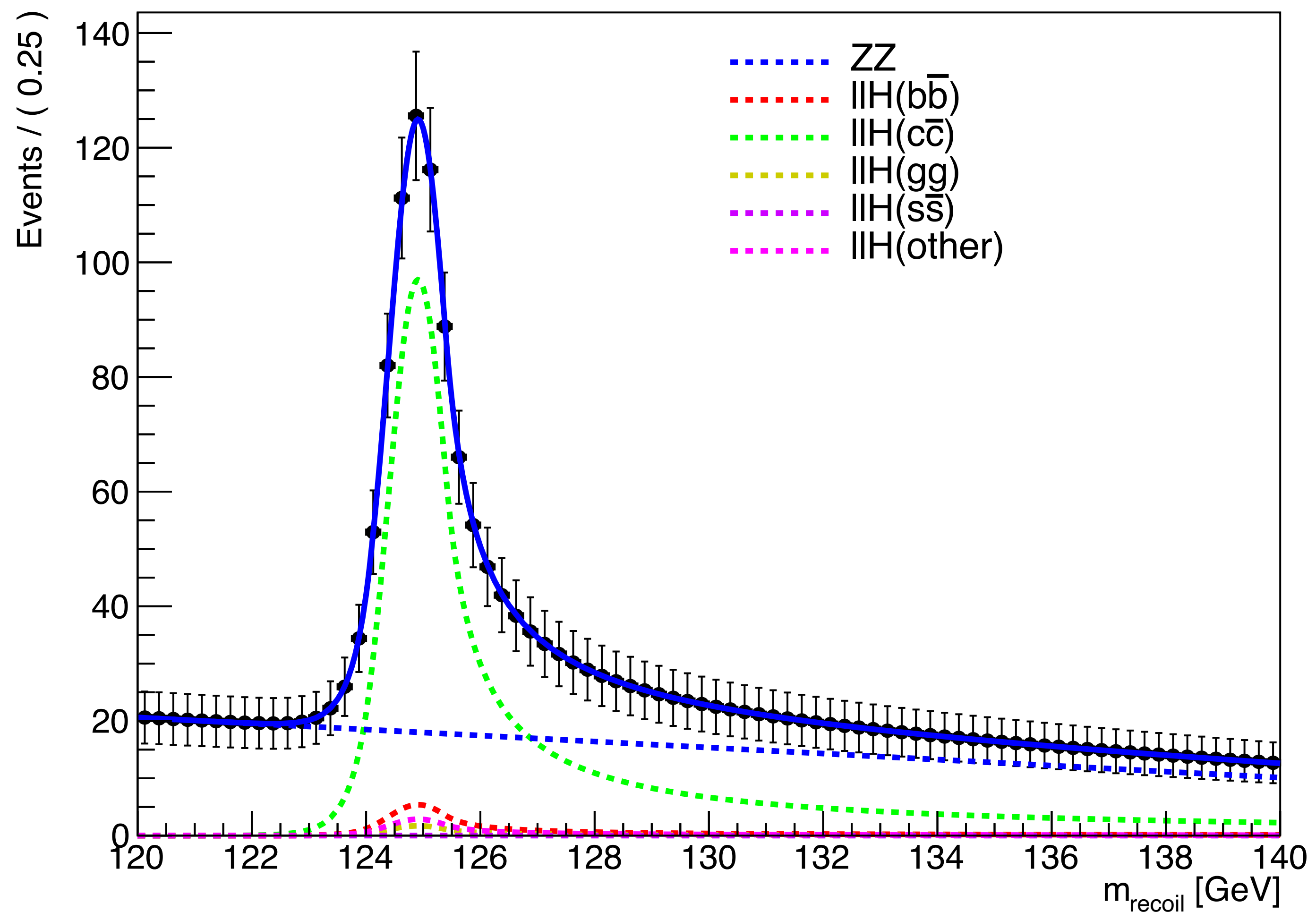
Fit results

- Nominal fit performed with 5 floating signal strengths and floating bkg normalisations
- Alternative fits performed with reduced number of floating signal strengths / bkg normalisations

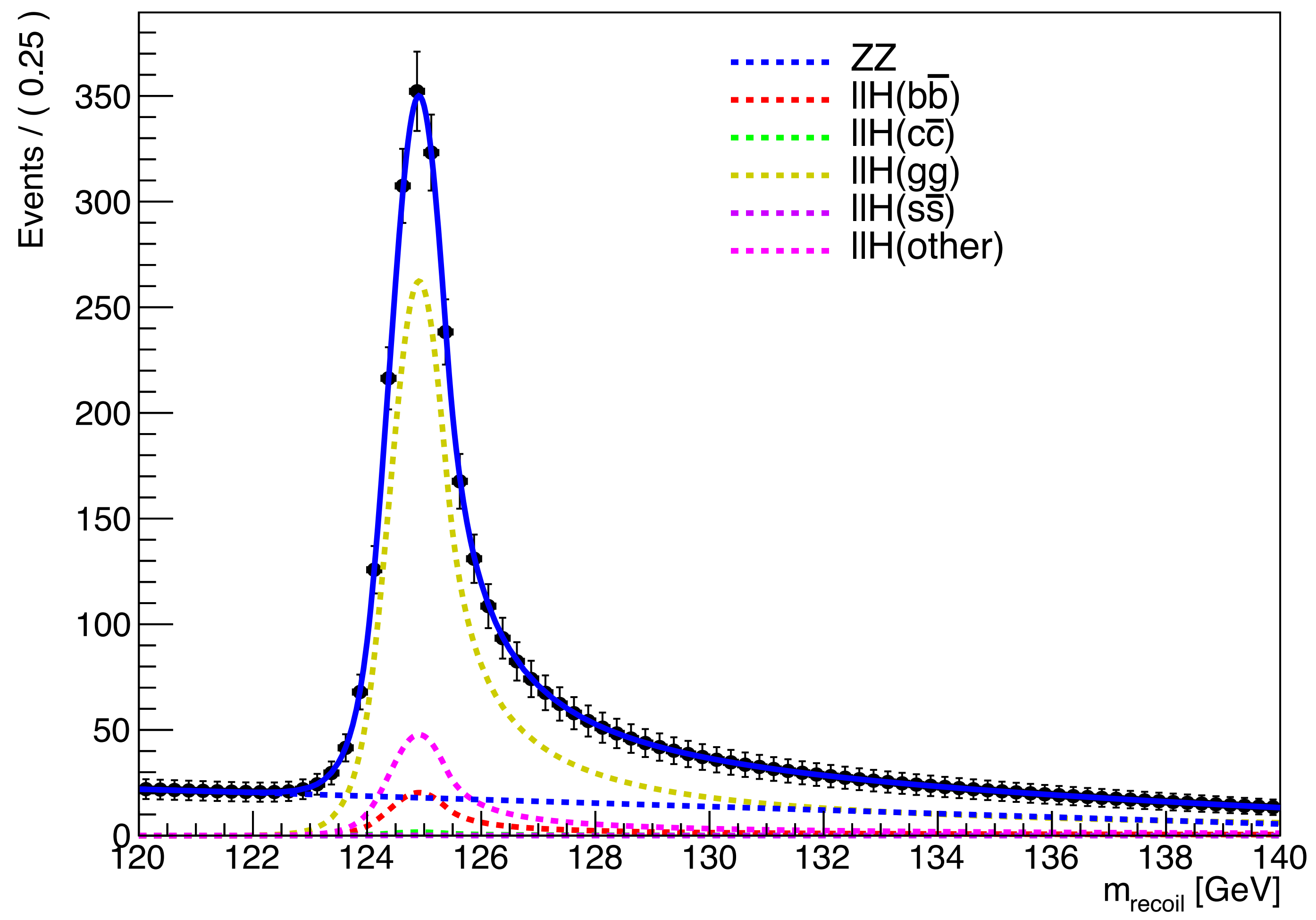
ee → llH, ZZ - bb category



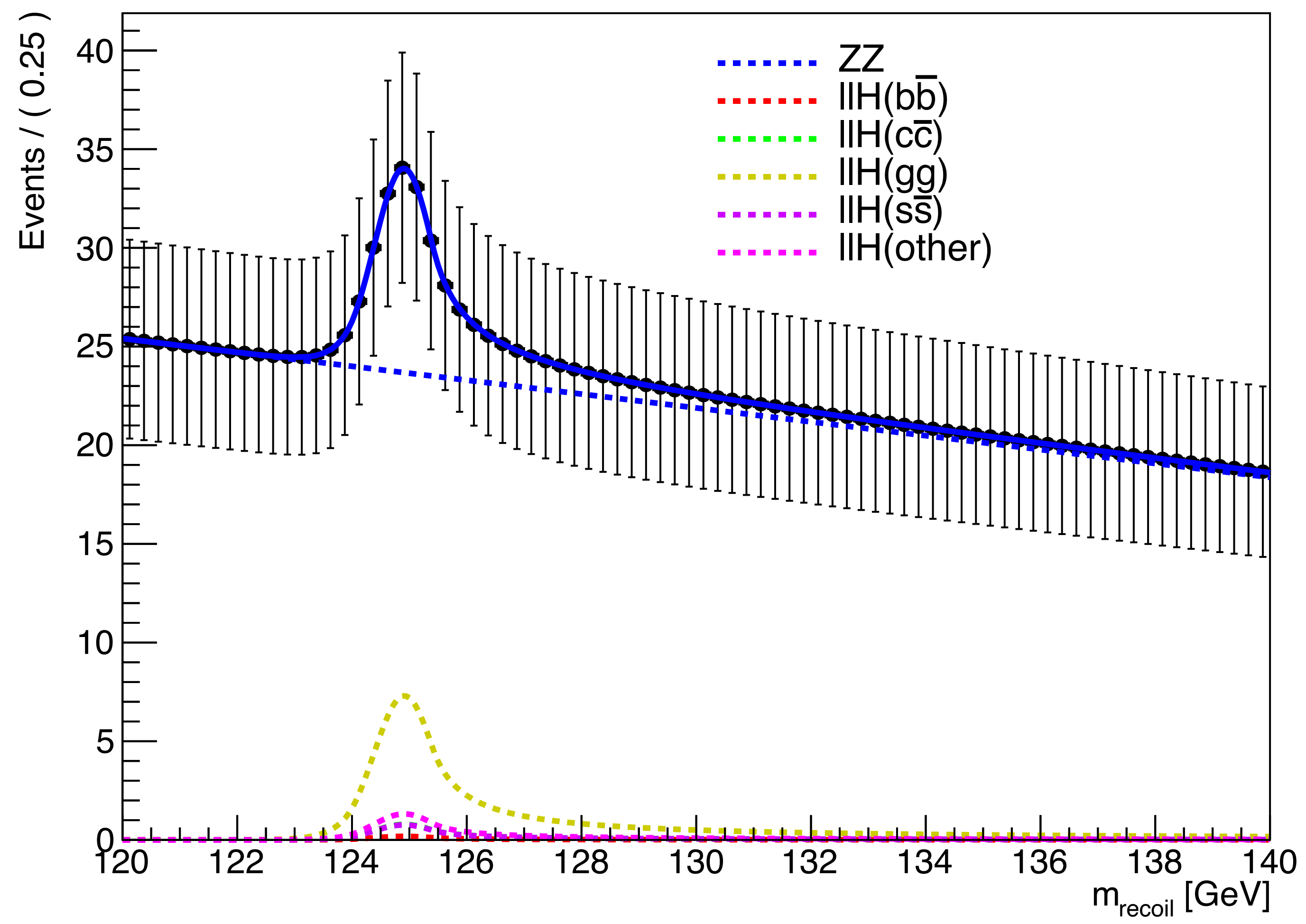
ee → llH, ZZ - cc category



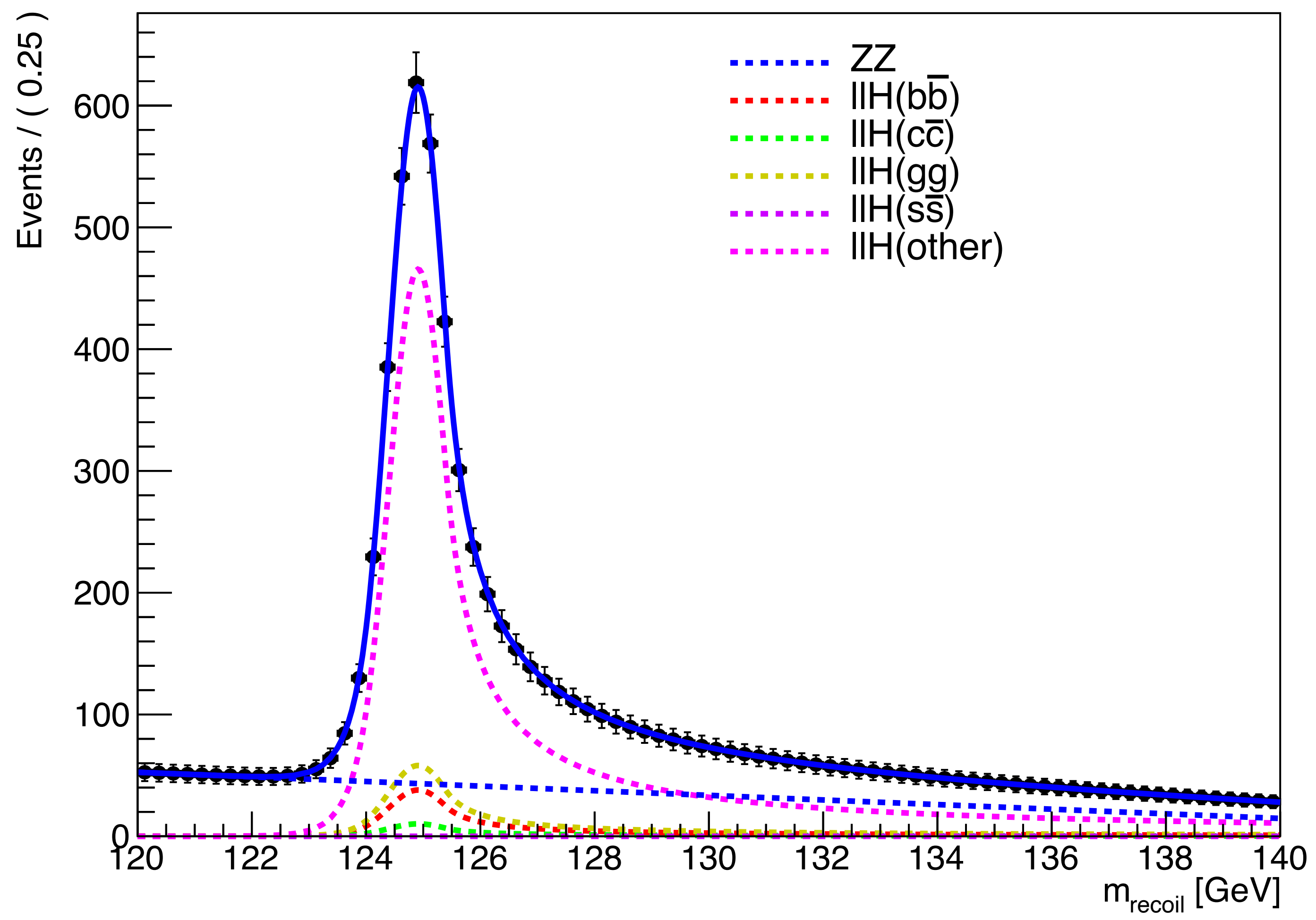
ee → llH, ZZ - gg category



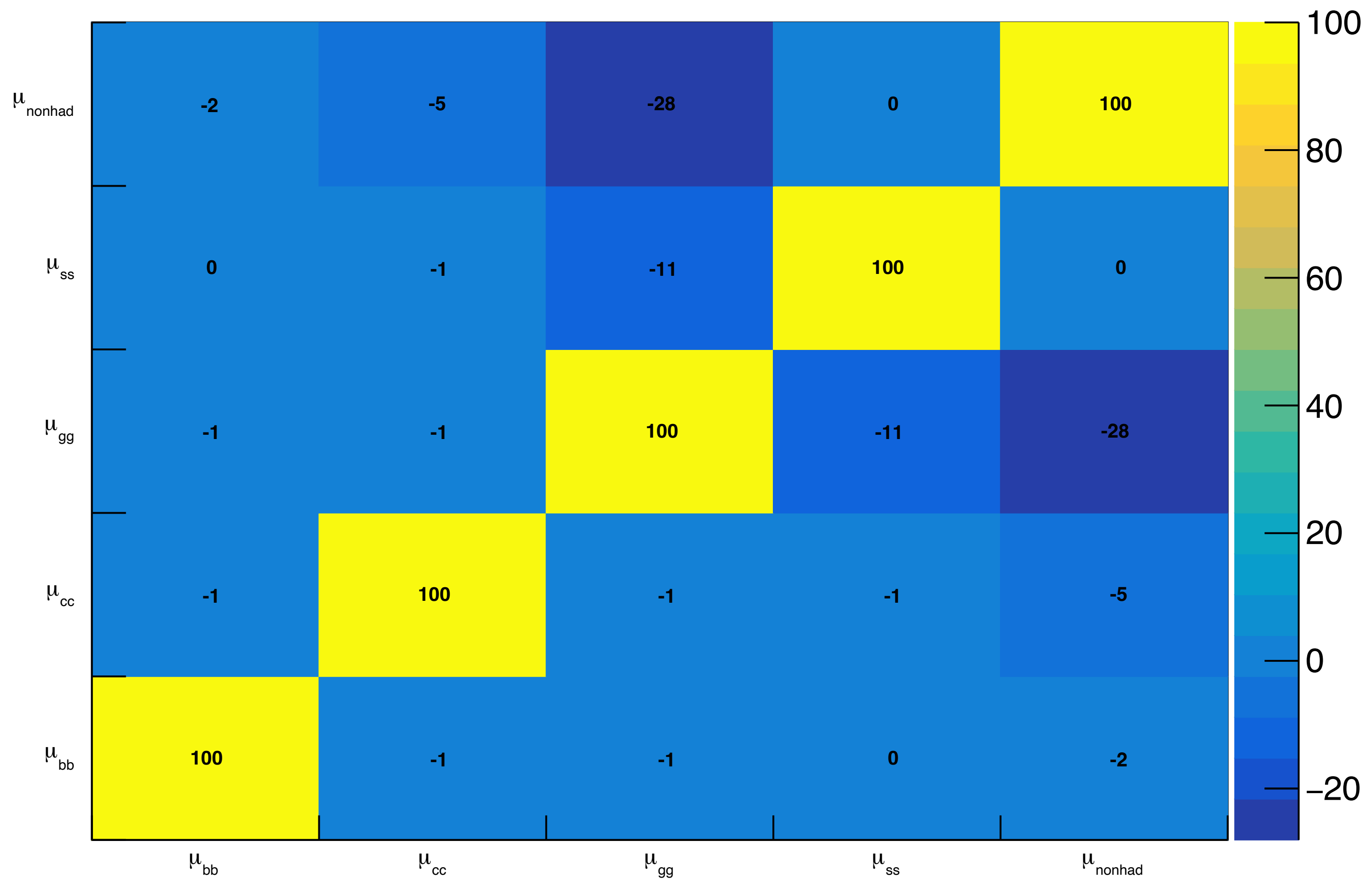
ee → llH, ZZ - ss category



ee → llH, ZZ - nonhad category



POI correlation matrix



Fit results

- Nominal fit performed with 5 floating signal strengths and floating bkg normalisations
- Alternative fits performed with reduced number of floating signal strengths / bkg normalisations

Signal strength	Uncertainty (%)			
	5 POIs	4 POIs	4 POIs	3 POIs
$b\bar{b}$	0.82	0.82	0.82	0.83
$c\bar{c}$	5.26	5.26	5.25	5.26
gg	3.08	3.07	2.96	2.94
other	2.37	2.37	-	-
$s\bar{s}$	415	-	415	-

- If bkg and H(other) normalisations are constrained, “ultimate" uncertainties are
  - 0.72% (bb) 4.50% (cc) 2.55% (gg) 360% (ss).

Z($\nu\nu$)H(jj) analysis overview

- Signature:
  - Large momentum imbalance (~50 GeV), with invisible mass ~m_Z
  - No high-momentum lepton
  - 2 jets with m_{jj}~m_H

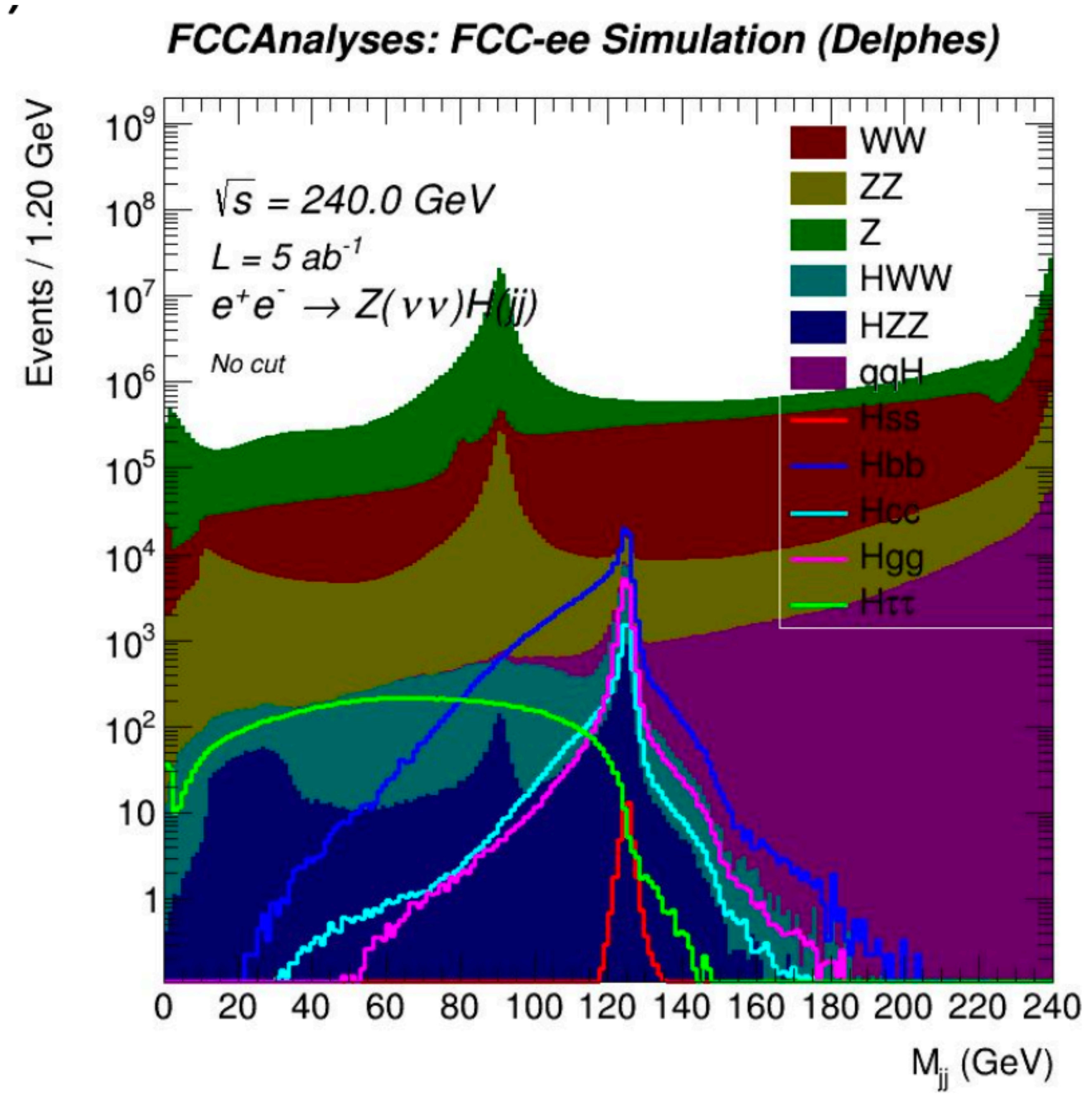
- Main bkg: processes producing high-momentum neutrinos (VV). In addition, bkg from other Higgs boson decays (mainly H→WW,ZZ→4q)

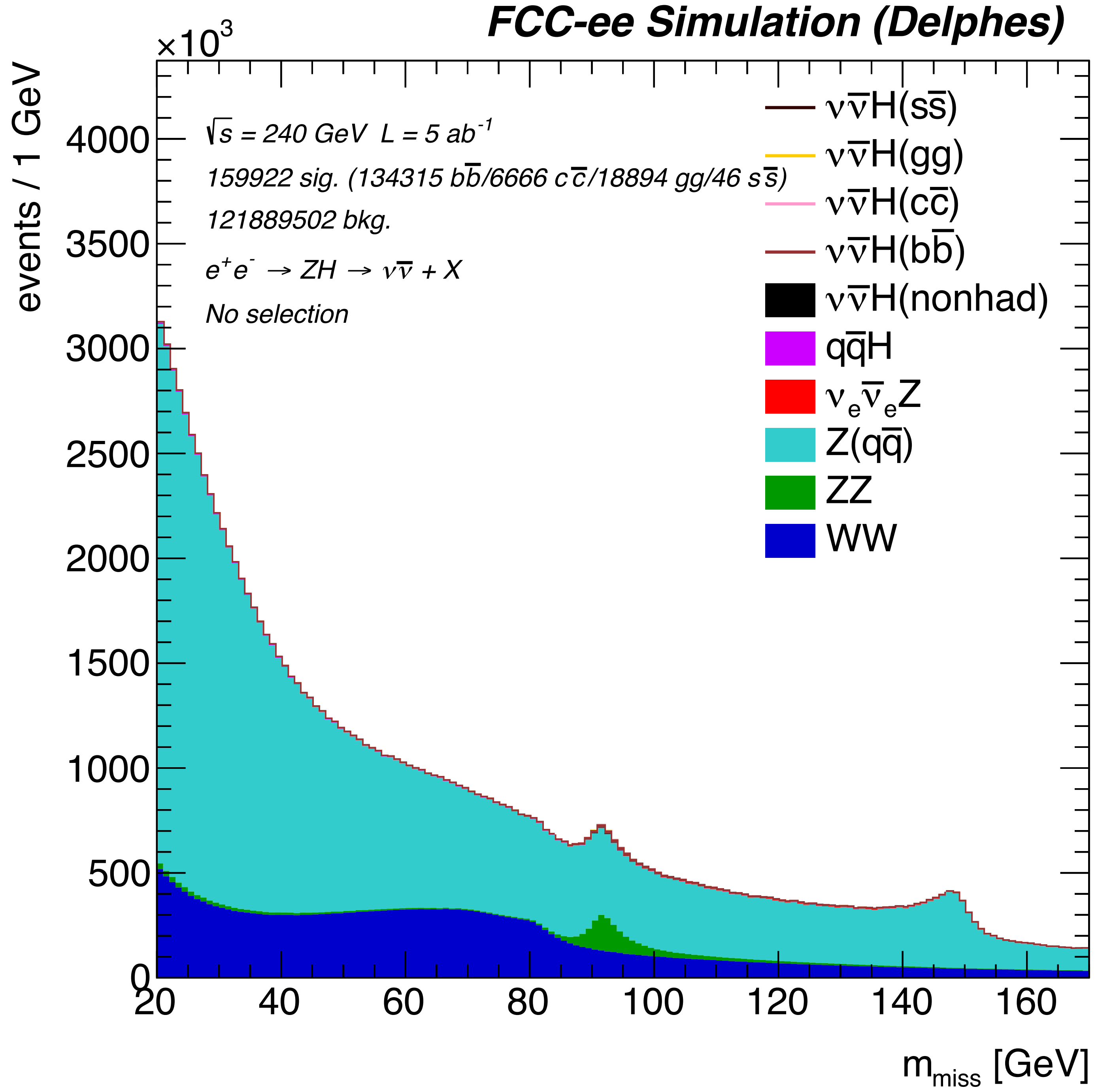
- Signal: some contamination from W-boson fusion process (σ/σ_{ZH} ~ 13%)

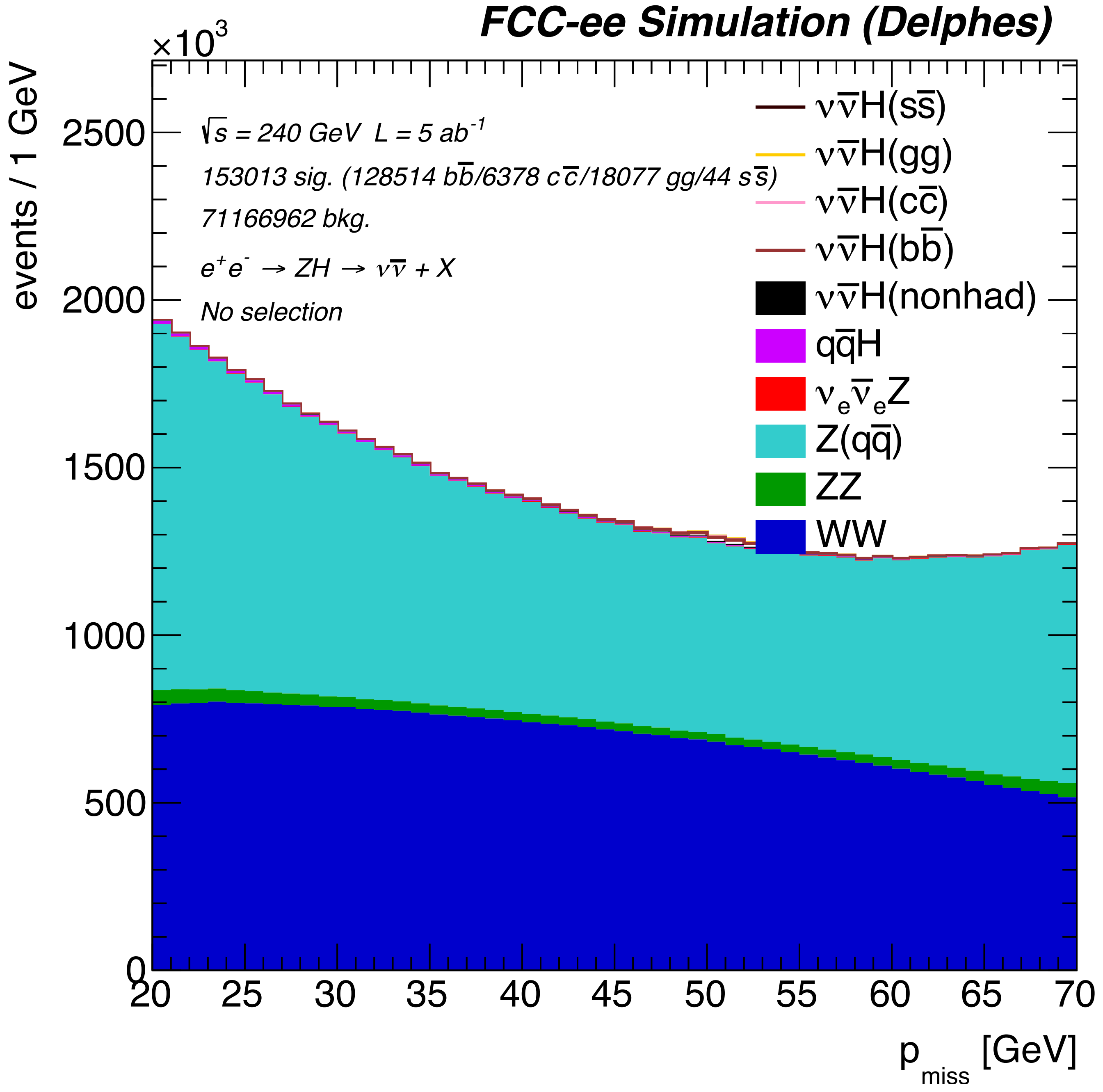
Event selection - criteria

- **CERN analysis:**
  - No μ and e with p>20 GeV
  - |cos(θ_invisible)| < 0.85

- **APC analysis:**
  - No μ and e with p>20 GeV
  - $|\cos(\theta_{jj})|<0.9$
  - $20<p_{miss}<70$ GeV
  - $100<m_{jj}<135$ GeV
  - $45<E(j_1)<105$ GeV, $20<E(j_2)<70$ GeV
  - N(constituents): $j_1>10$, $j_2>6$
  - $\cos(\theta_{j1} + \theta_{j2})>0.5$
  - $\cos(\phi_{j1}-\phi_{j2})<0.999$







Event selection - cutflow

- **CERN analysis:**

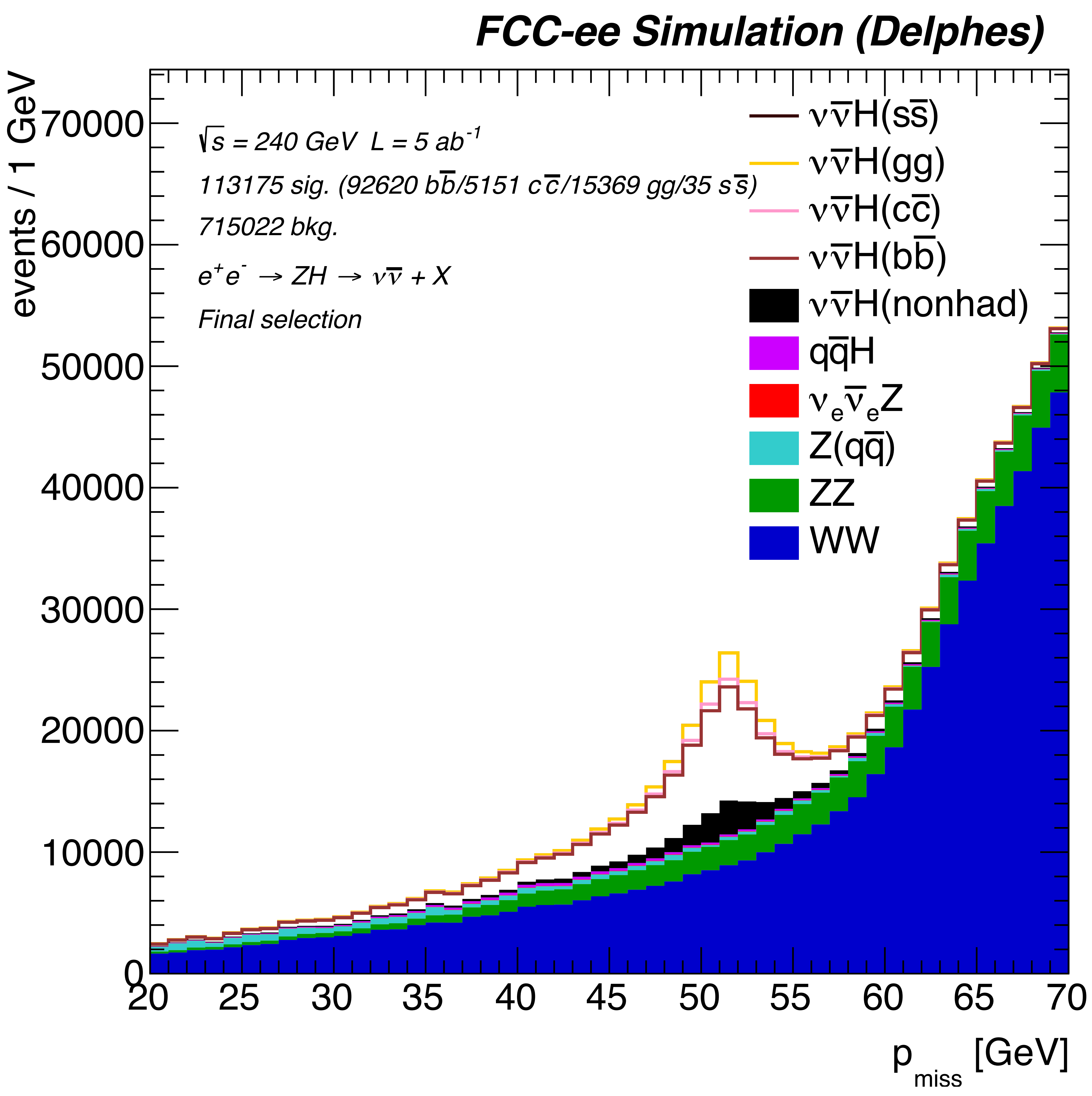
	Hbb		Hcc		Hss		Hgg		$H\tau\tau$		ZZ	WW	Z	HWW	HZZ	qqH
	Yield ($\cdot 10^5$)	Sig.	Yield ($\cdot 10^3$)	Sig.	Yield	Sig.	Yield ($\cdot 10^4$)	Sig.	Yield ($\cdot 10^3$)	Sig.	Yield ($\cdot 10^6$)	Yield ($\cdot 10^7$)	Yield ($\cdot 10^7$)	Yield ($\cdot 10^4$)	Yield ($\cdot 10^3$)	Yield ($\cdot 10^5$)
No cut	1.34	7.16	6.68	0.355	55	0.00225	1.66	0.885	14.5	0.771	6.79	8.22	26.3	4.97	6.10	6.82
$p_\mu < 20$	1.29	7.08	6.60	0.363	55	0.00232	1.66	0.913	12.4	0.683	6.04	6.55	25.9	4.23	5.74	6.27
$p_{el} < 20$	1.23	7.00	6.53	0.37	55	0.0024	1.66	0.942	10.4	0.592	5.32	5.02	25.4	3.52	5.37	5.76
$\lvert cos(\theta_{inv})\rvert < 0.85$	1.06	10.8	5.59	0.573	47	0.00371	1.42	1.46	8.89	0.911	3.36	3.02	6.09	3.02	4.59	4.14
efficiency	0.786		0.837		0.856		0.856		0.613		0.495	0.368	0.231	0.607	0.752	0.607

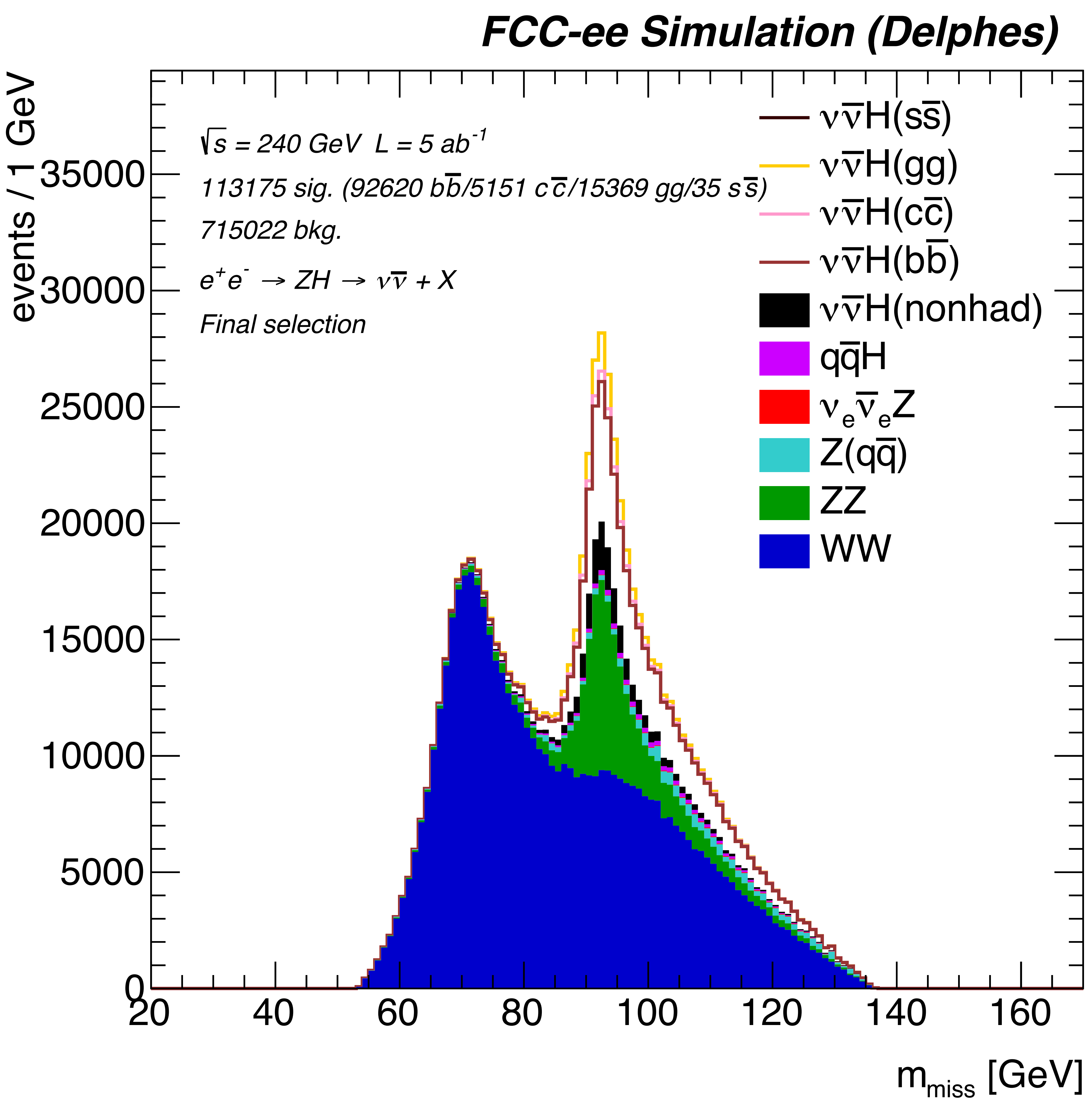
- **APC analysis:**

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	-	681493	-	6794950	-	82192500	-	263269500	-	166370	-
No lepton with $p > 20$ GeV	123364	92	6531	98	18877	100	55	100	49340	70	580183	85	5299230	78	49000066	60	254440548	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	6118697	12	99826681	39	139887	92
$n^{j1}_{\rm const} > 10$, $n^{j2}_{\rm const} > 6$	120775	100	6304	98	18480	100	51	93	32320	85	16522	97	1457666	88	5430621	89	93001950	93	101358	72
$20 < p_{\rm miss} < 70$ GeV	116283	96	6075	96	17836	97	49	96	30838	95	14970	91	409742	28	1903411	35	8977923	10	66379	65
$\lvert\cos\theta_{jj}\rvert < 0.9$	105229	90	5498	90	16162	91	44	91	27929	91	13276	89	324372	79	1396497	73	171229	2	56302	85
$\lvert\cos(\theta_{j1}+\theta_{j2})\rvert > 0.5$	104993	100	5489	100	16095	100	44	100	27351	98	13200	99	288786	89	1294547	93	155360	91	52863	94
m_{jj} in 100–135 GeV	95570	91	5315	97	15819	98	43	98	22308	82	6175	47	91912	32	595197	46	44397	29	1480	3
$\lvert\cos(\phi_{j1}-\phi_{j2})\rvert < 0.999$	92620	97	5151	97	15369	97	42	97	21756	98	6002	97	89437	97	579759	97	16627	37	1441	97
Efficiency	69%		77%.		81%.		76%		31%		0.9%		1.3%		0.7%		0.01%		0.9%	

- Expect ~45 ZH(ss) events, >5k for other hadronic final states

Event selection - cutflow

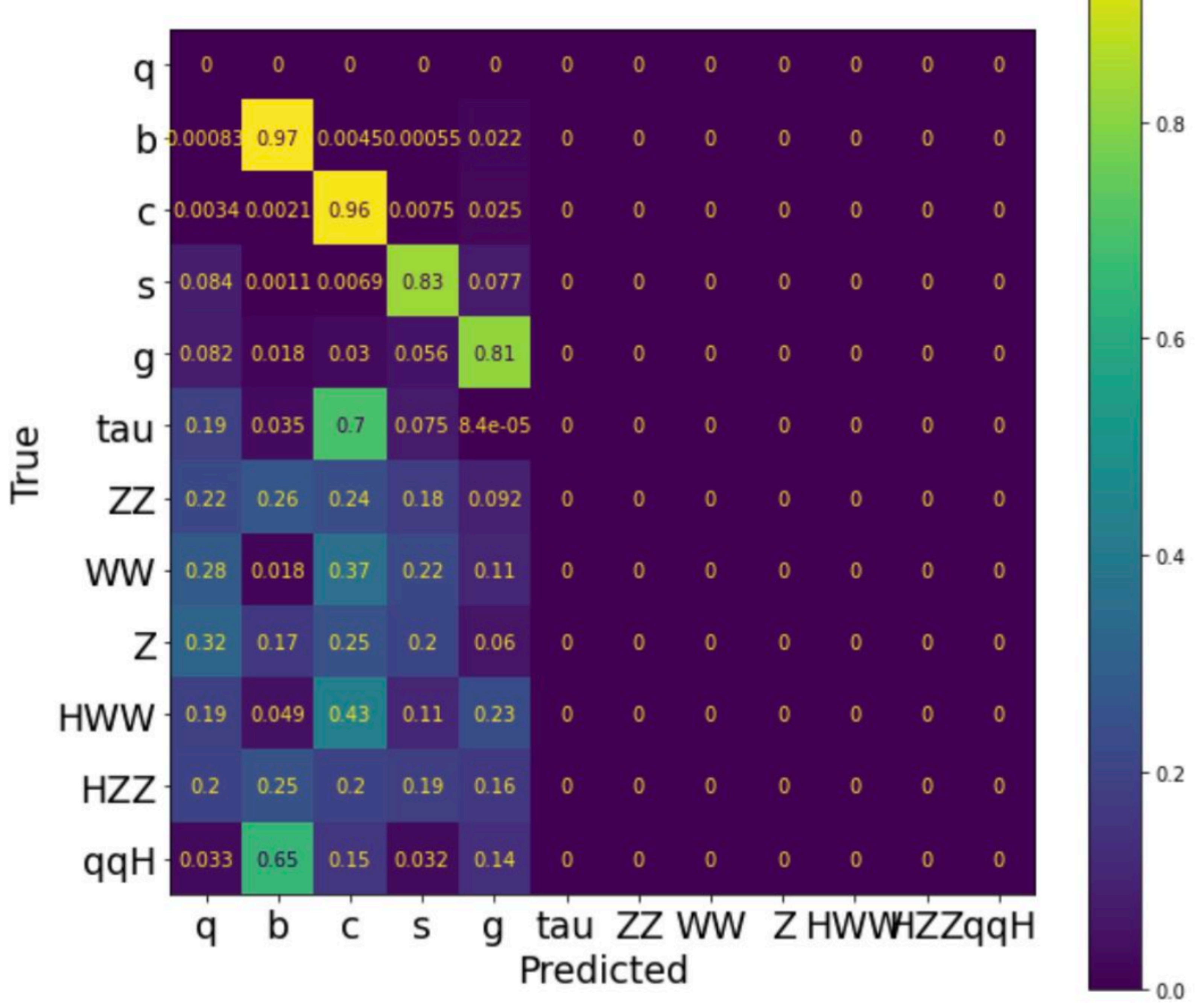




Event classification

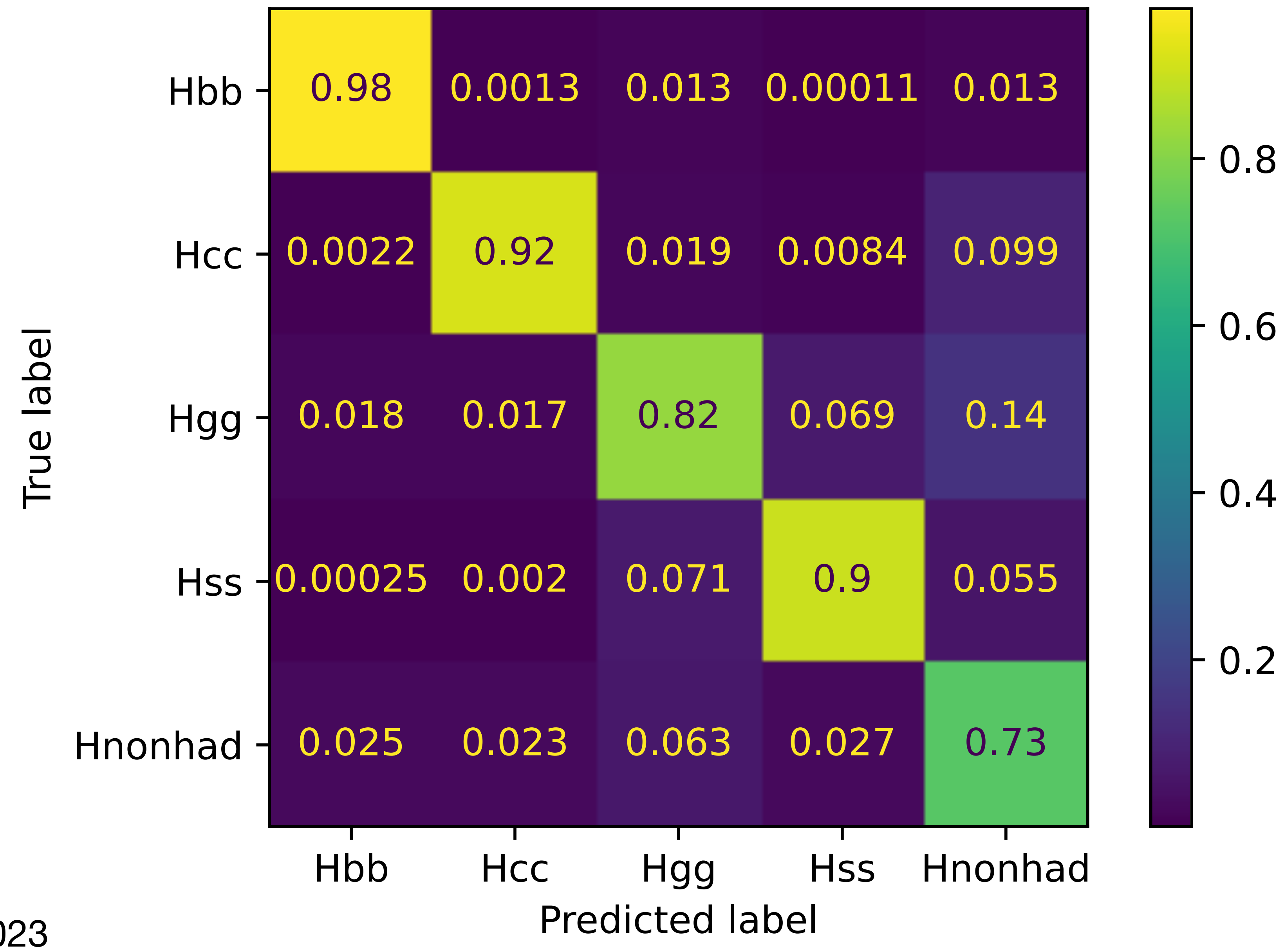
- **CERN** analysis:
  - Classify events by summing the tagger score of the two jets
  - Further subdivide events by defining three orthogonal categories with different signal purities for each output score: {b, c, s, g-like} x {LP, MP, HP}

	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



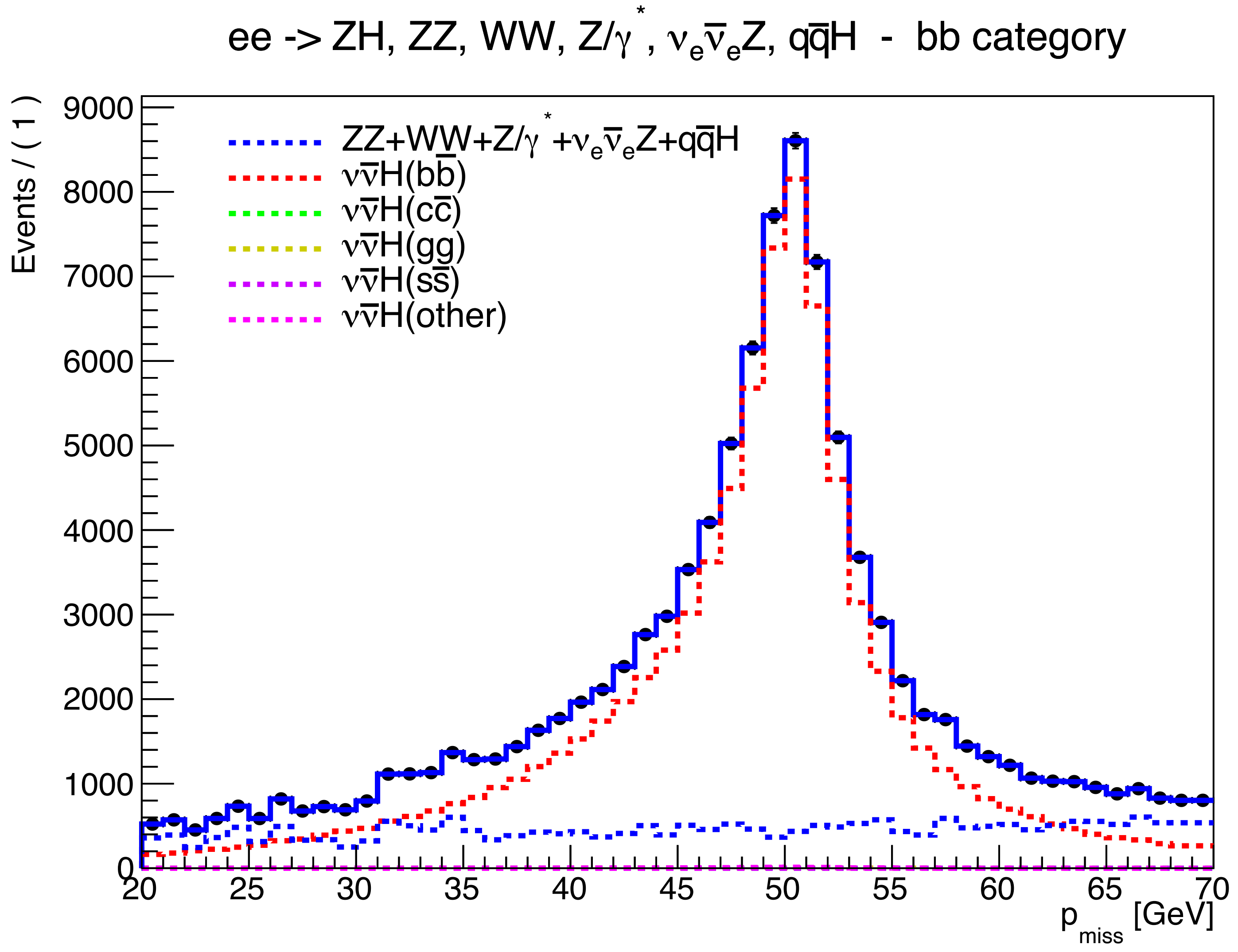
- **APC** analysis: similar approach to Z(ll)H analysis (multi-layer fully connected NN with 5 output scores)
  - classify events in 5 categories, retain only events with output score above a certain threshold of the score

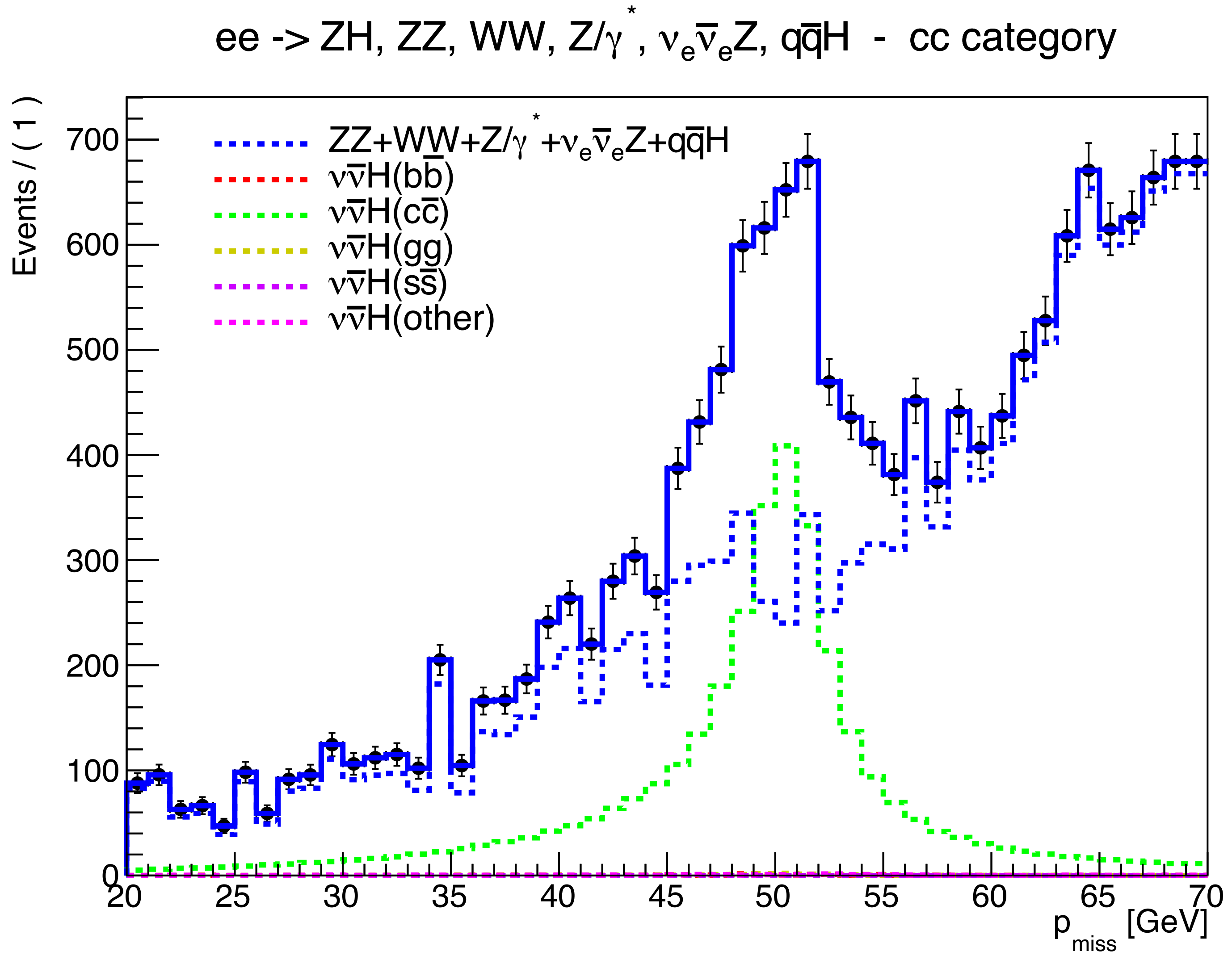
Category	$\nu\bar{\nu}H(b\bar{b})$	$\nu\bar{\nu}H(c\bar{c})$	$\nu\bar{\nu}H(gg)$	$\nu\bar{\nu}H(s\bar{s})$	$\nu\bar{\nu}H(other)$	bkg	Total
$b\bar{b}$	80748 (251)	1 (0)	59 (0)	0 (0)	116 (0)	22681	103605
$c\bar{c}$	12 (0)	3280 (25)	14 (0)	0 (0)	16 (0)	13570	16892
gg	65 (1)	10 (0)	7965 (69)	0 (0)	354 (3)	4839	13234
$s\bar{s}$	0 (0)	5 (0)	31 (0)	17 (0)	4 (0)	7626	7683
other	400 (1)	218 (0)	965 (2)	1 (0)	15971 (25)	381100	398655
Total	81225 (251)	3513 (25)	9034 (69)	19 (0)	16461 (25)	429816	

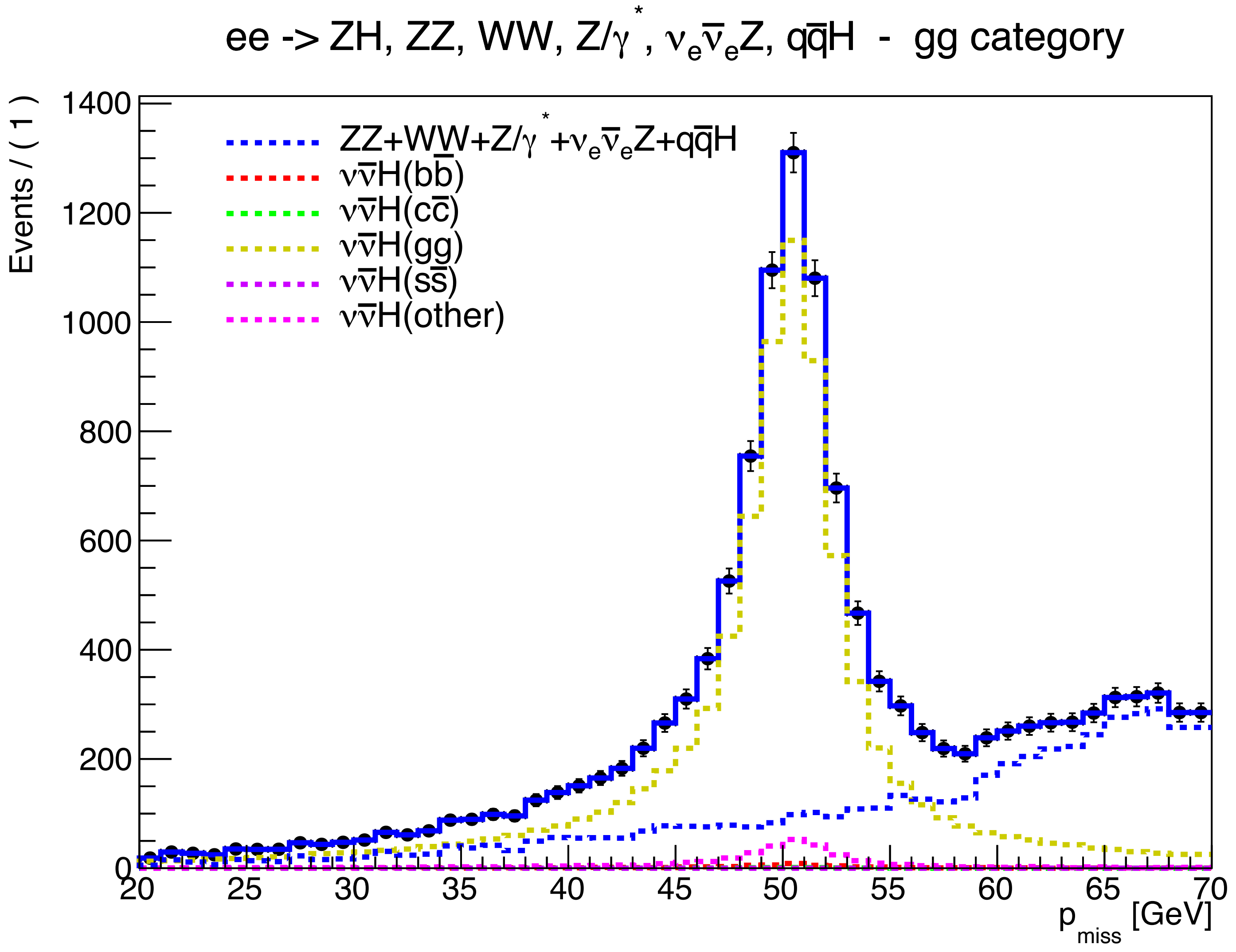


Fit model

- **CERN** analysis: template 2D fit to m_{miss} vs m_{vis} in the 12 tagging x purity categories
- **APC** analysis: template 1D fit to p_{miss} in the 5 tagging categories
- Templates taken from simulation
- Floating parameters:
  - CERN: 4 signal strengths (ννH(other) and bkg yields profiled w/ prior constraints on overall σ, acceptance from MC)
  - APC: 5 signal strengths + 5 bkg yields (one per category)







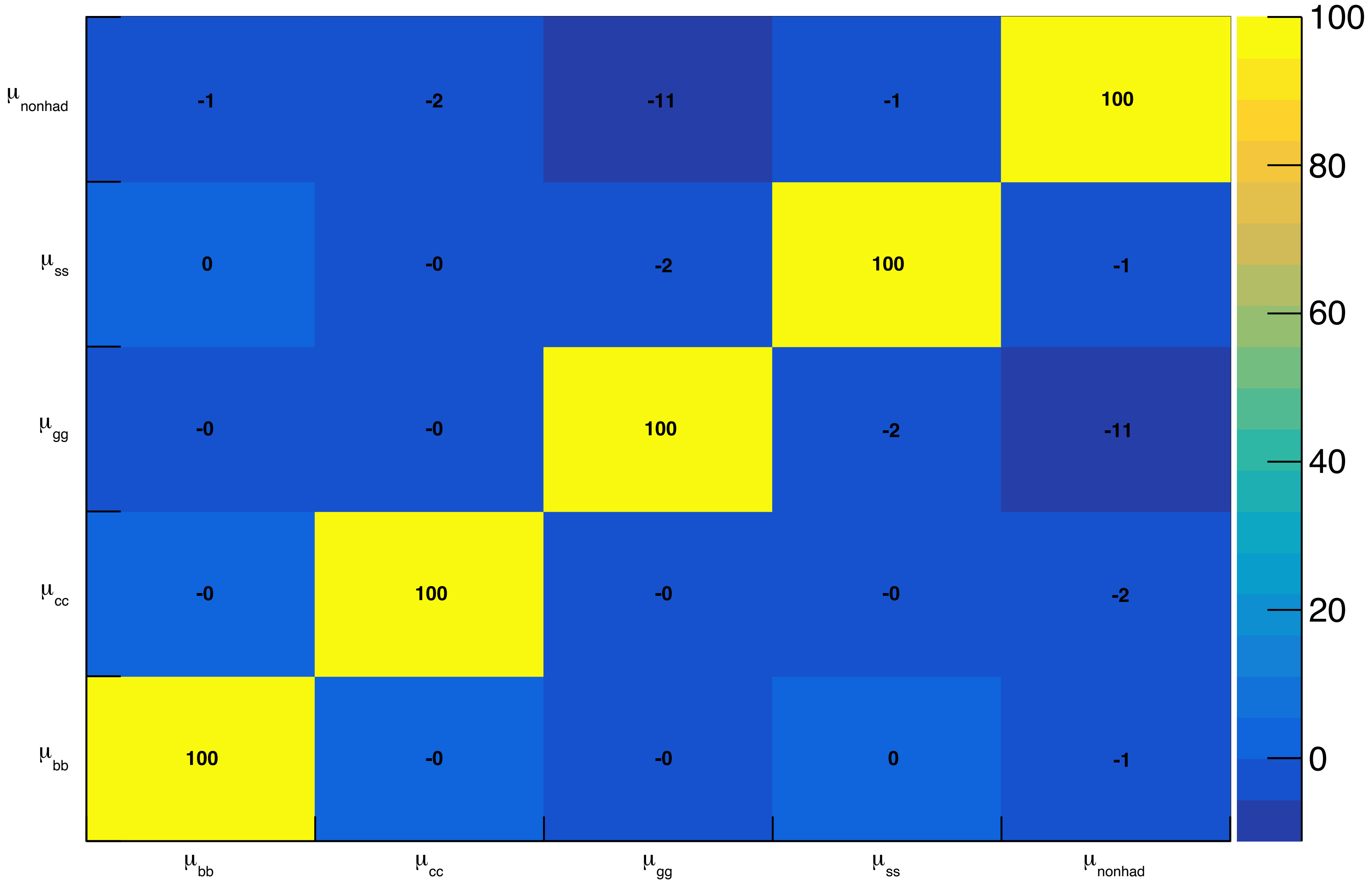
Fit results

- **CERN analysis:**

68% CL uncertainties on signal strengths:
bb: 0.4%
cc: 2.8%
gg: 1.2%
ss: +-160%

- **APC analysis:**

POI correlation matrix



Signal strength	Uncertainty (%)			
	5 POIs	4 POIs	4 POIs	3 POIs
$b\bar{b}$	0.49	0.49	0.49	0.49
$c\bar{c}$	3.48	3.49	3.48	3.49
gg	1.45	1.44	1.45	1.44
$s\bar{s}$	280	280	-	-
other	2.47	-	2.47	-

- If bkg and H(other) normalisations are constrained, uncertainties reduced to
  - 0.39% (bb) 2.89% (cc) 1.30% (gg) 235% (ss)

Conclusions

- Full analysis chain of H(bb/cc/gg/ss) decays in Z(ll) and Z($\nu\nu$) channels implemented and run over recently produced winter2023 MC samples with latest ParticleNet-based taggers
- Preliminary results indicate (~stat-only) uncertainties on the signal strengths at the level of
  - 0.4% for Hbb, 1.2% for Hgg, 2.8% for Hcc, 160% for Hss in the neutrino channel
  - 0.8% for Hbb, 3% for Hgg, 5.3% for Hcc, O(400%) for Hss in the leptonic channel, with minimal assumptions on the bkg
    - 0.4% / 1.2% / 2.7% / 150% when combining the two
- The same analysis can also provide constraints on H->WW+ZZ (->4q) (~2.5% unc. in both channels)

Conclusions (II)

- Directions for the future:
  - Analysis of Z(qq)H(qq) final state ramping up, will bring significant increase insensitivity
  - Investigate further optimisation of the two analyses, harmonise approaches / assumptions of different teams
  - Use to benchmark alternative detector designs / layouts

- More details:
  - CERN analysis ($\nu\nu$): Andrea's talk
  - APC analysis (ll,$\nu\nu$): GM's internal note

Backup

CEPC projections

- CEPCv1 (5.6/ab at 250 GeV, B=3.5T)

Z decay mode	$H\to b\bar{b}$	$H\to c\bar{c}$	$H\to gg$
$Z\to e^+e^-$	1.3%	12.8%	6.8%
$Z\to \mu^+\mu^-$	1.0%	9.4%	4.9%
$Z\to q\bar{q}$	0.5%	10.6%	3.5%
$Z\to \nu\bar{\nu}$	0.4%	3.7%	1.4%
Combination	0.3%	3.1%	1.2%

- ~5% worse results for CEPCv4 vs v1

- CEPCv1 vs CEPCv4 (5.6/ab at 240 GeV, B=3T)

	Estimated Precision			
Property	CEPC-v1		CEPC-v4	
m_H	5.9 MeV		5.9 MeV	
Γ_H	2.7%		2.8%	
$\sigma(ZH)$	0.5%		0.5%	
$\sigma(\nu\bar{\nu}H)$	3.0%		3.2%	
Decay mode	$\sigma\times$BR	BR	$\sigma\times$BR	BR
$H\to b\bar{b}$	0.26%	0.56%	0.27%	0.56%
$H\to c\bar{c}$	3.1%	3.1%	3.3%	3.3%
$H\to gg$	1.2%	1.3%	1.3%	1.4%
$H\to WW^*$	0.9%	1.1%	1.0%	1.1%
$H\to ZZ^*$	4.9%	5.0%	5.1%	5.1%
$H\to \gamma\gamma$	6.2%	6.2%	6.8%	6.9%
$H\to Z\gamma$	13%	13%	16%	16%
$H\to \tau^+\tau^-$	0.8%	0.9%	0.8%	1.0%
$H\to \mu^+\mu^-$	16%	16%	17%	17%
$\mathrm{BR}^{\mathrm{BSM}}_{\mathrm{inv}}$	–	$<0.28\%$	–	$<0.30\%$

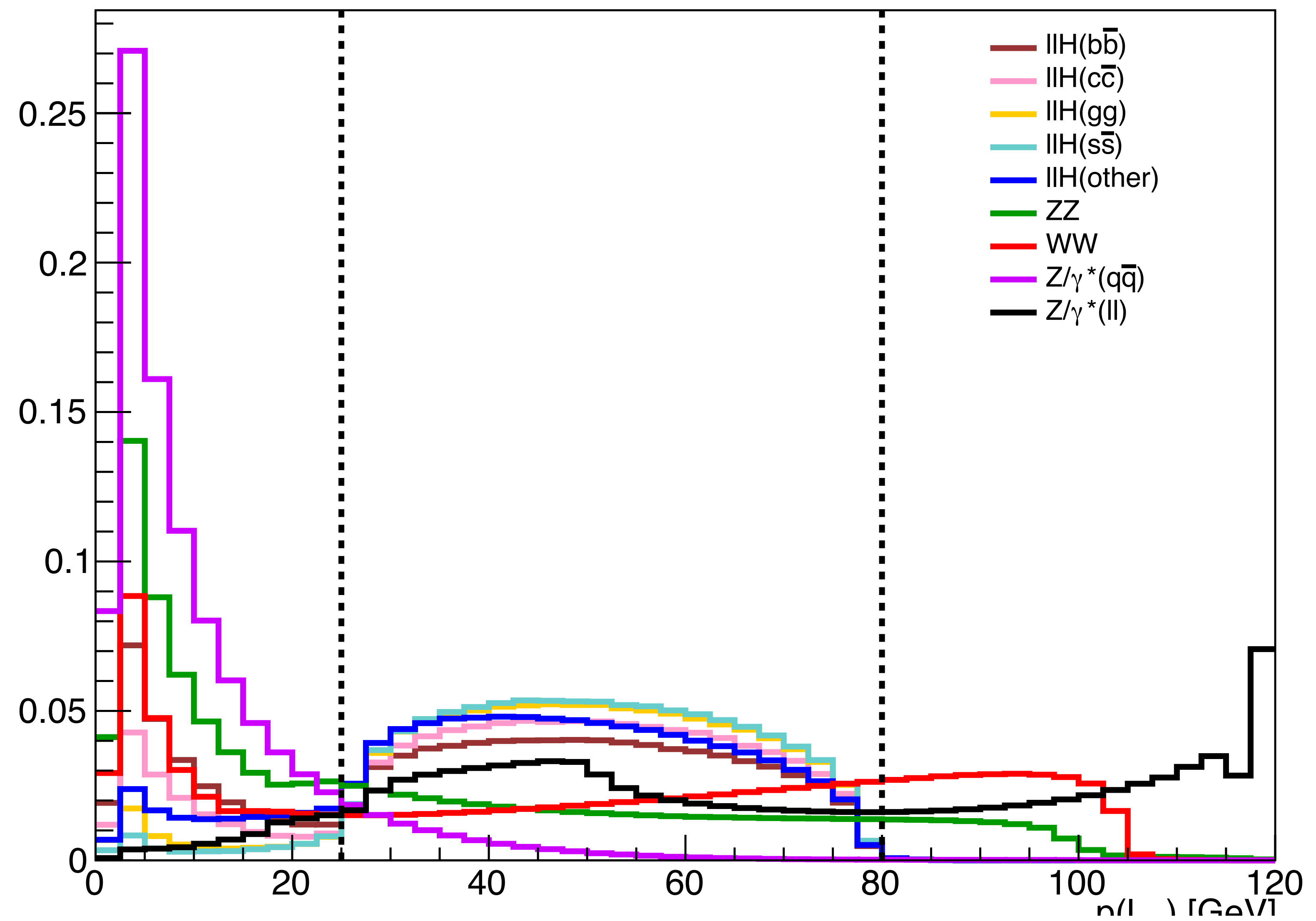
FCCee CDR projections

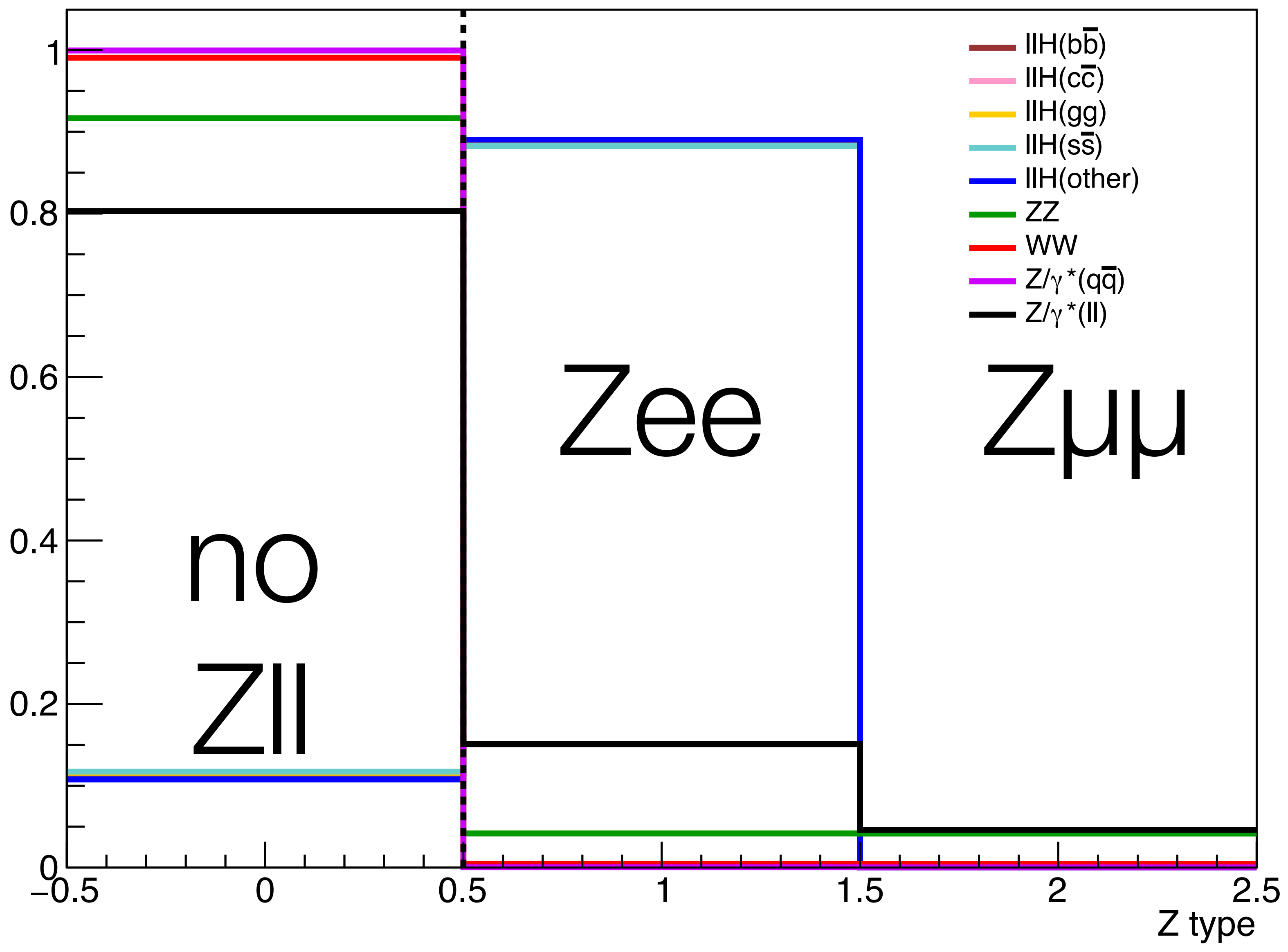
Table 4.1 Relative statistical uncertainty on the measurements of event rates, providing $\sigma_{HZ} \times BR(H \to XX)$ and $\sigma_{\nu\bar{\nu}H} \times BR(H \to XX)$, as expected from the FCC-ee data. This is obtained from a fast simulation of the CLD detector and consolidated with extrapolations from full simulations of similar linear-collider detectors (SiD and CLIC). All numbers indicate 68% C.L. intervals, except for the 95% C.L. sensitivity in the last line. The accuracies expected with 5 ab^{-1} at 240 GeV are given in the middle columns, and those expected with 1.5 ab^{-1} at $\sqrt{s} = 365$ GeV are displayed in the last columns

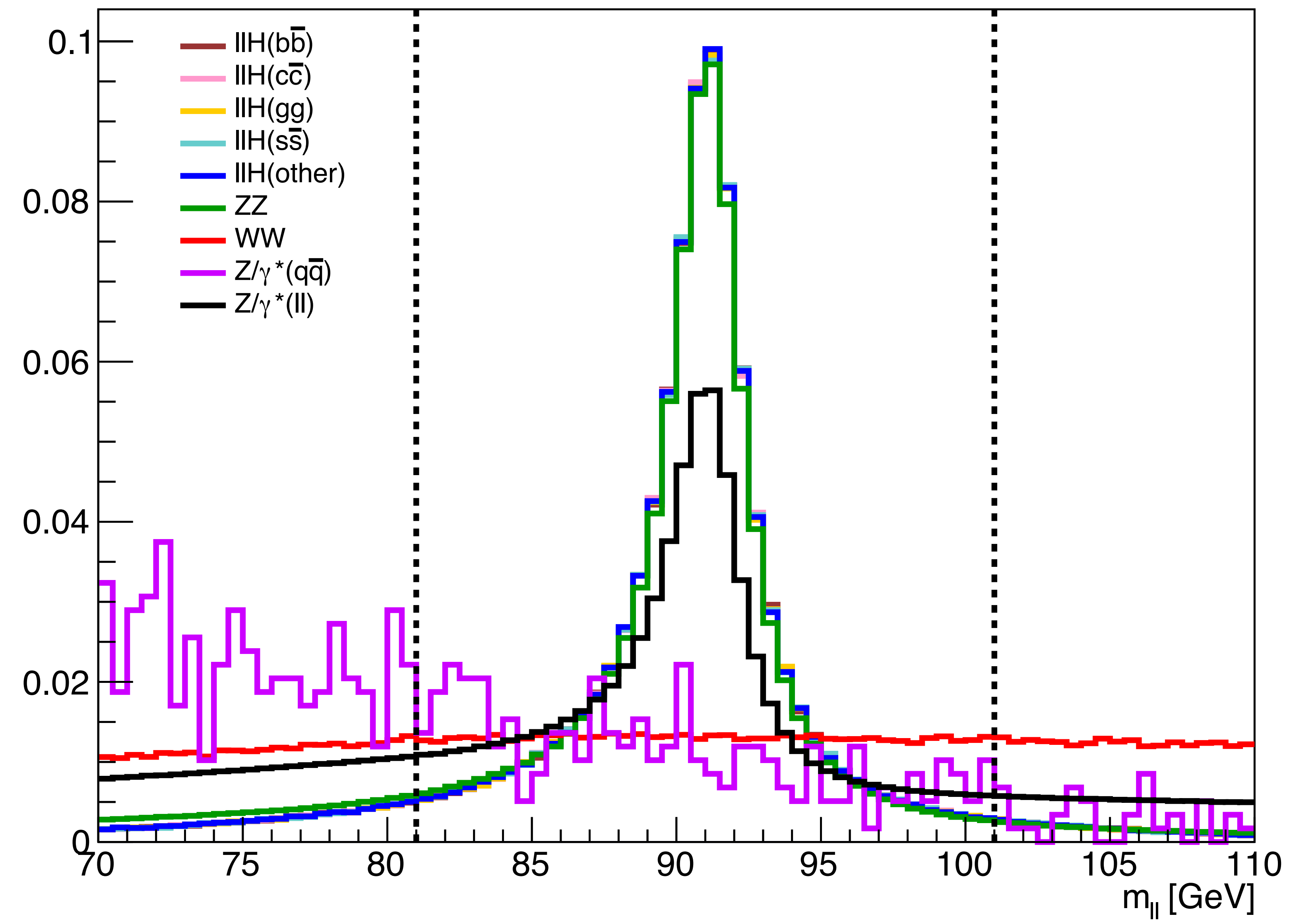
$\sqrt{s}$ (GeV)	240		365	
Luminosity (ab^{-1})	5		1.5	
$\delta(\sigma BR)/\sigma BR$ (%)	HZ	$\nu\bar{\nu}$ H	HZ	$\nu\bar{\nu}$ H
$H \to$ any	± 0.5		± 0.9	
$H \to b\bar{b}$	± 0.3	± 3.1	± 0.5	± 0.9
$H \to c\bar{c}$	± 2.2		± 6.5	± 10
$H \to gg$	± 1.9		± 3.5	± 4.5
$H \to W^+W^-$	± 1.2		± 2.6	± 3.0
$H \to ZZ$	± 4.4		± 12	± 10
$H \to \tau\tau$	± 0.9		± 1.8	± 8
$H \to \gamma\gamma$	± 9.0		± 18	± 22
$H \to \mu^+\mu^-$	± 19		± 40	
$H \to$ invis.	< 0.3		< 0.6	

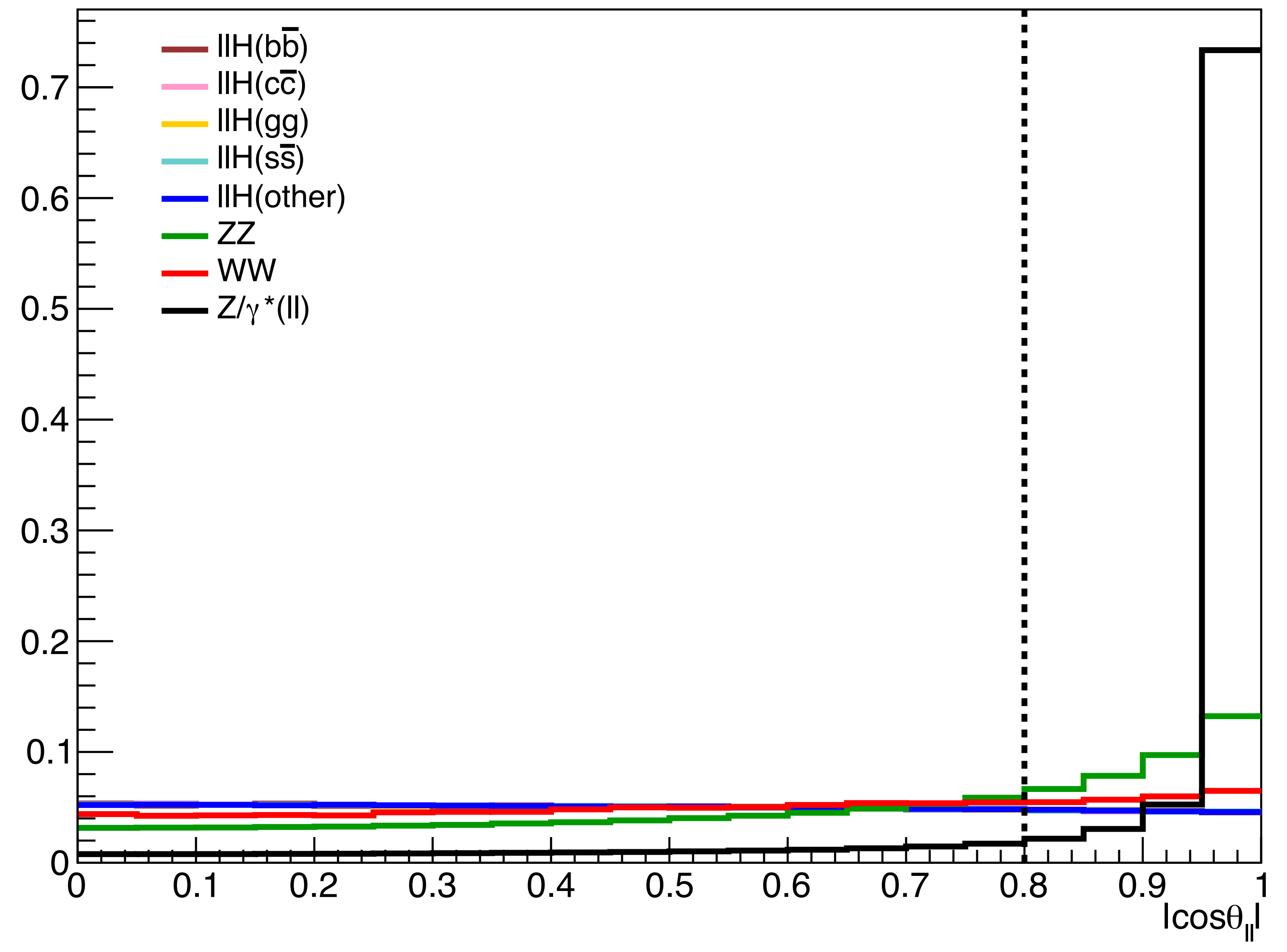
Event selection Z(ll)H

- **Z(ll) selection:**
  - Select two opposite-sign, same-flavour leptons with 25<p<80 GeV and invariant mass closest to m_Z
  - $81<m_{ll}<101$ GeV
  - |cos(Polar angle of dilepton pair)|<0.8



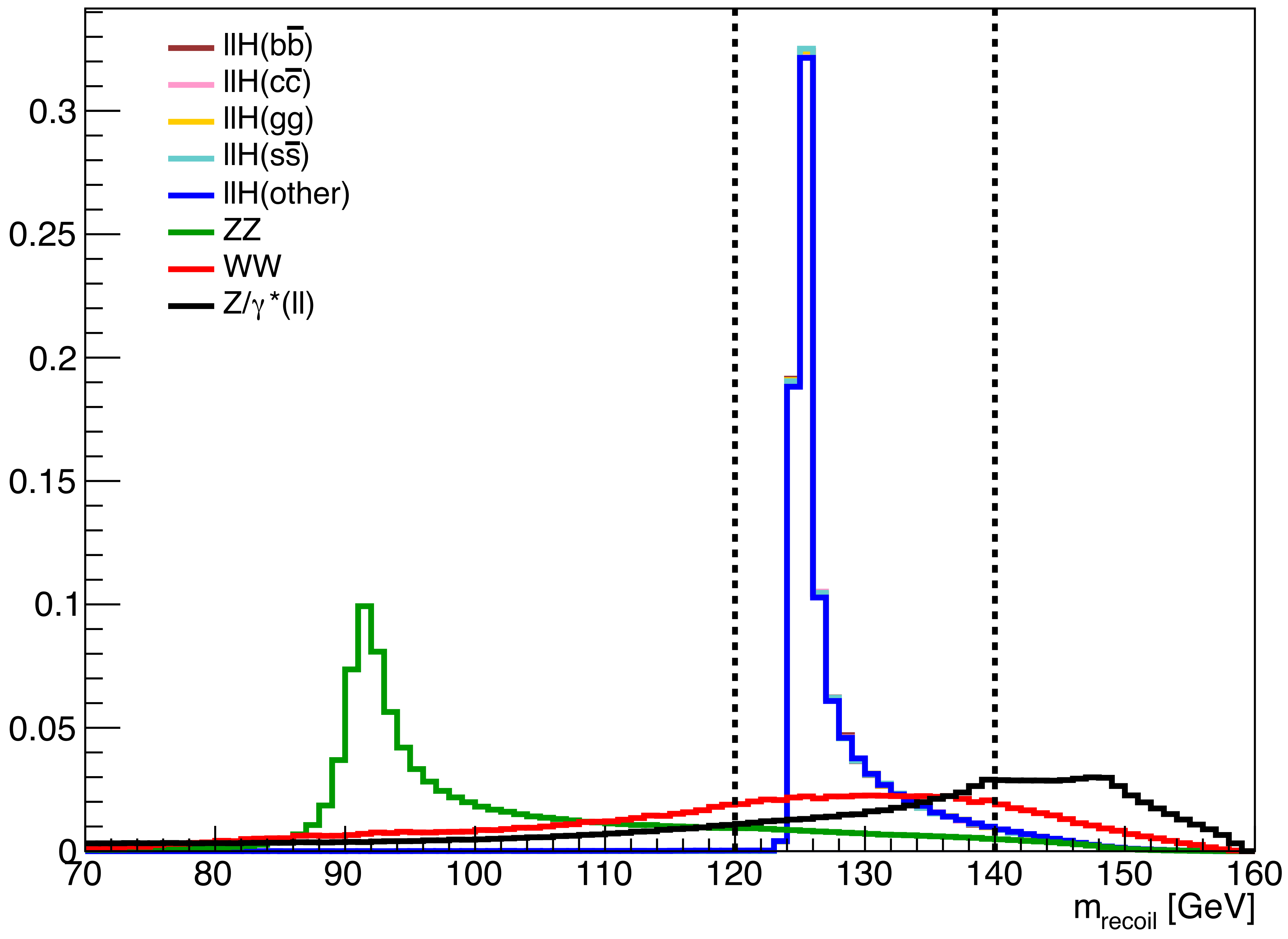


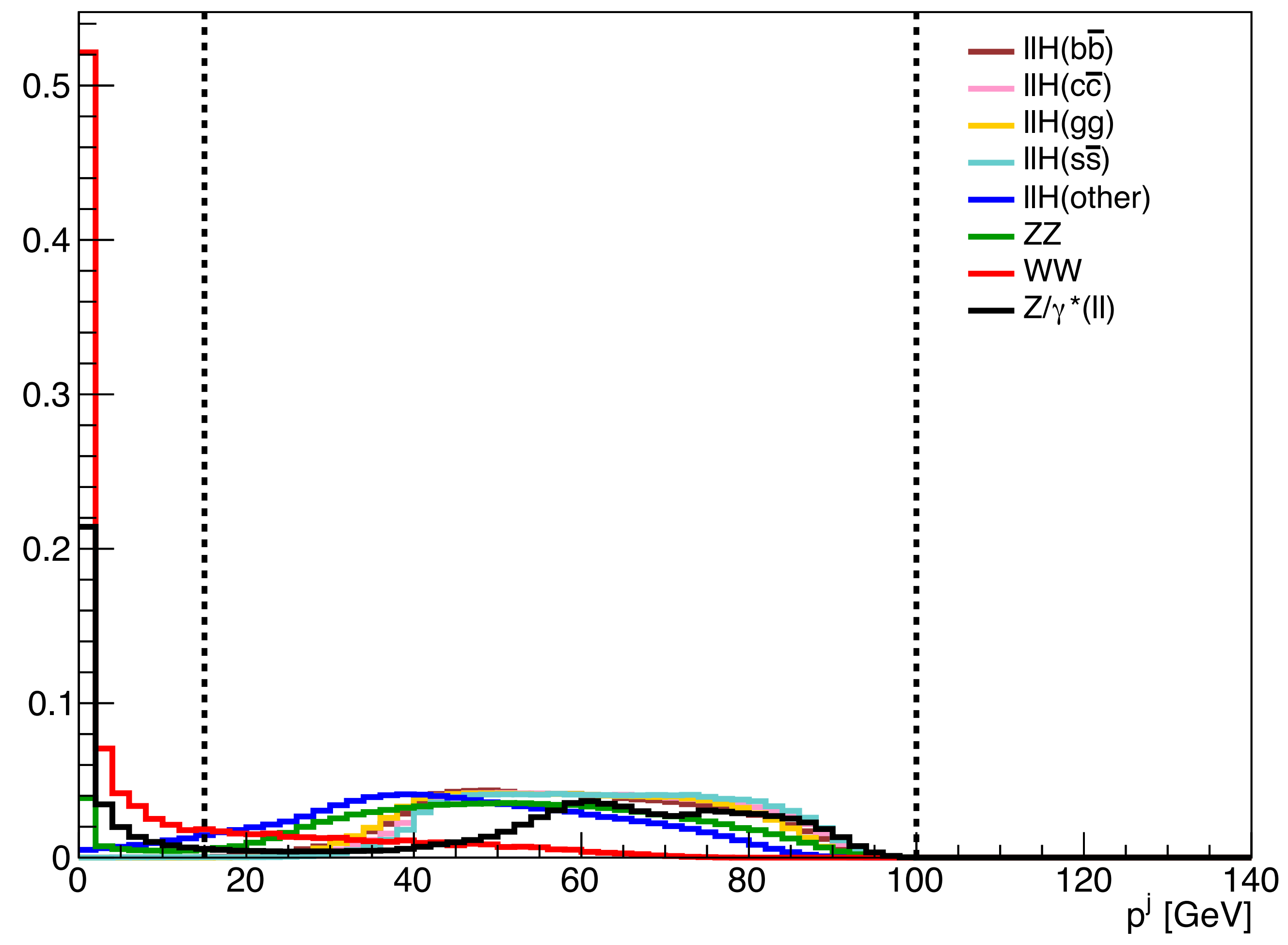


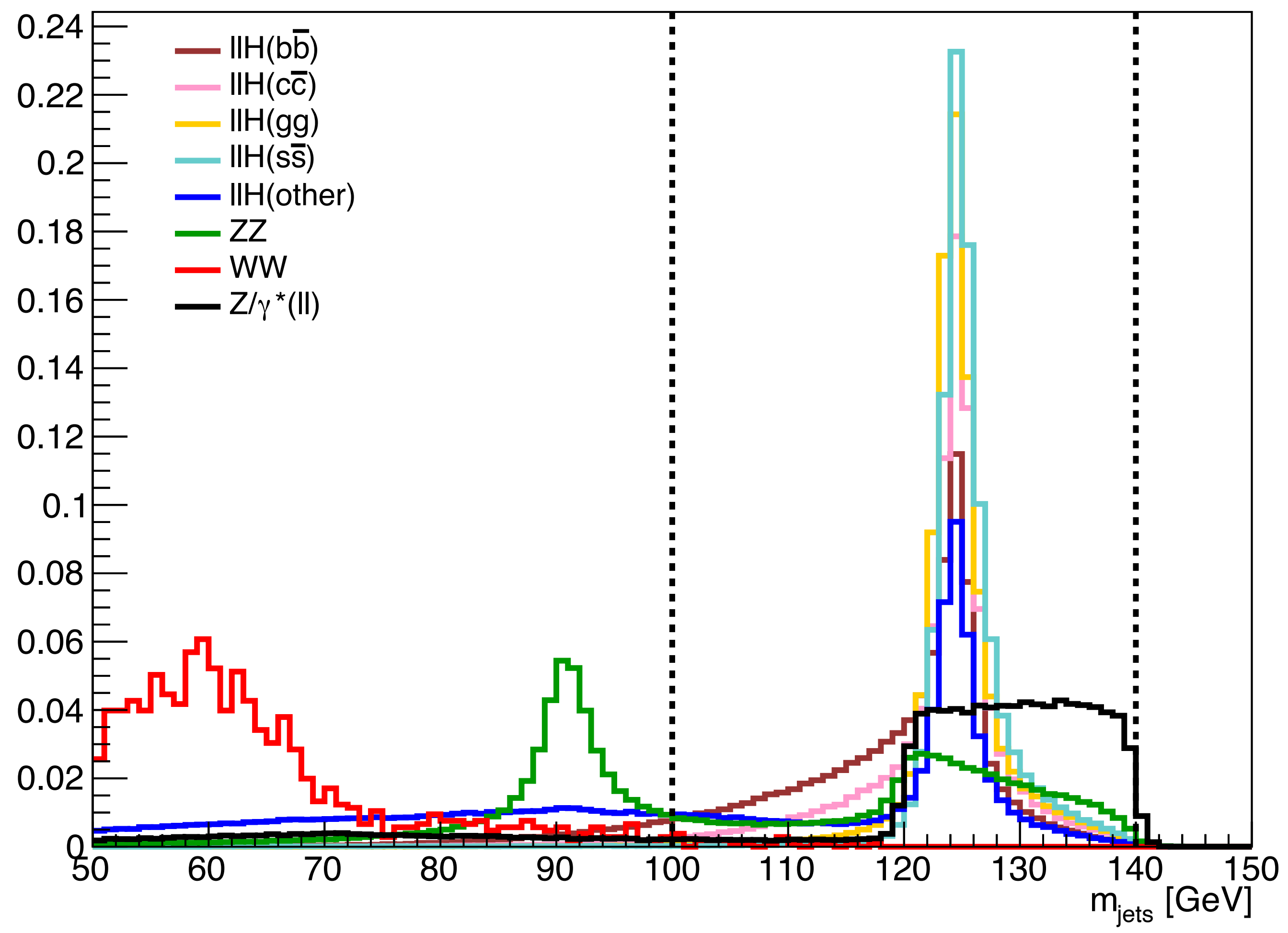


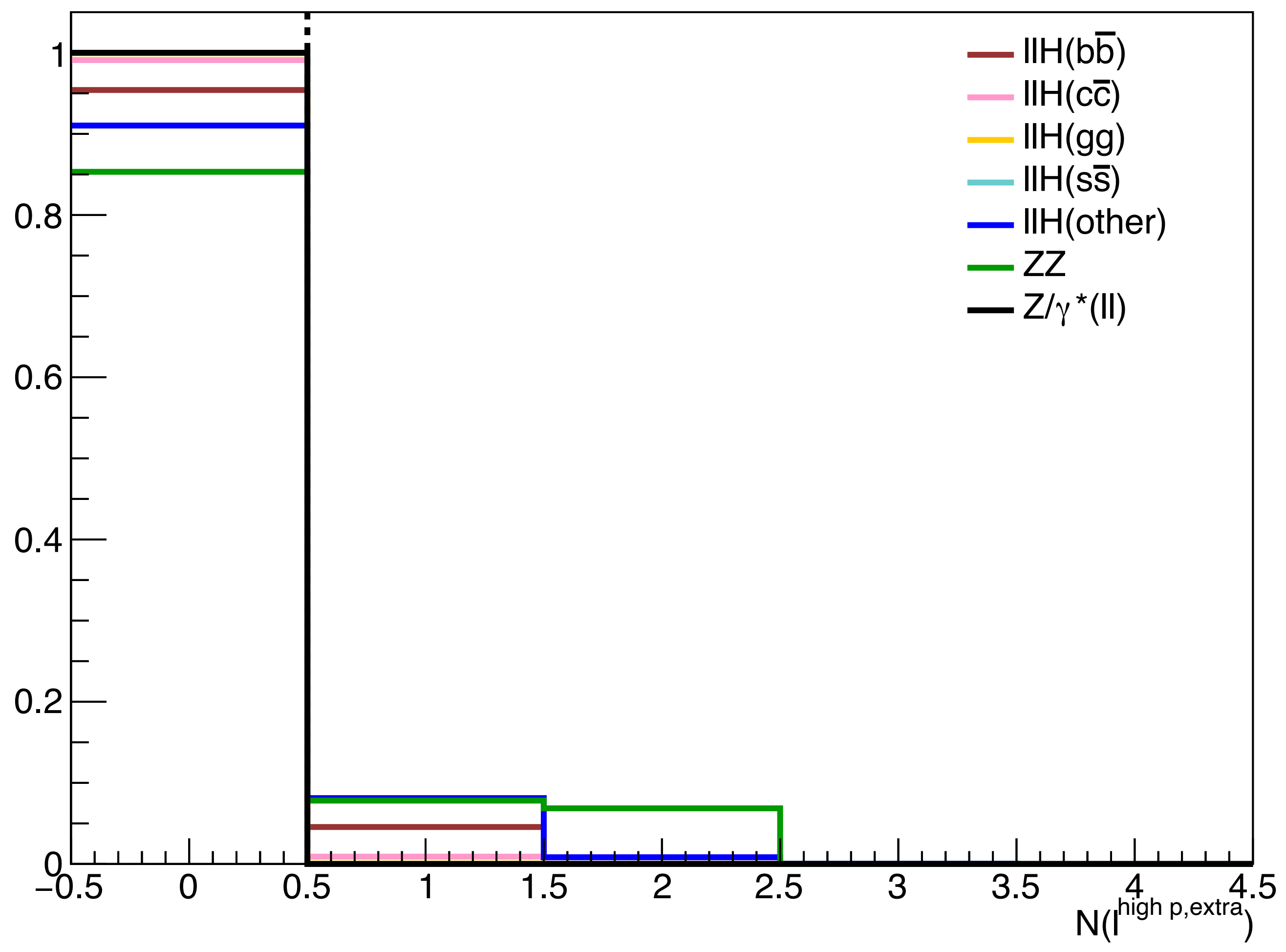
Event selection Z(ll)H

- **Recoil and jet selection:**
  - Remove selected leptons from Z candidates from ReconstructedParticles and cluster remaining ones
  - Use Durham (ee kt) exclusive N=2 clustering algorithm
  - Recoil mass in 120-140 GeV
  - Jet momentum in 15-100 GeV
  - Hadronic mass in 100-140 GeV
  - Missing energy < 30 GeV and no extra lepton with 25<p<80 Ge

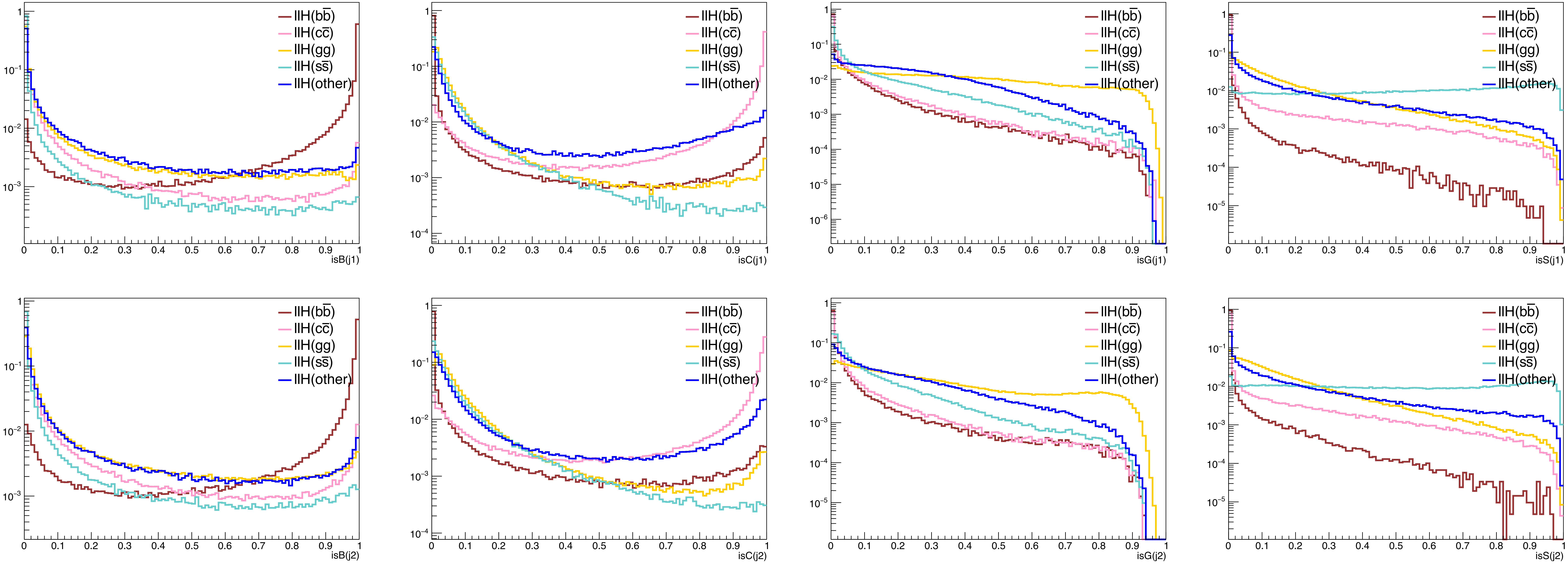




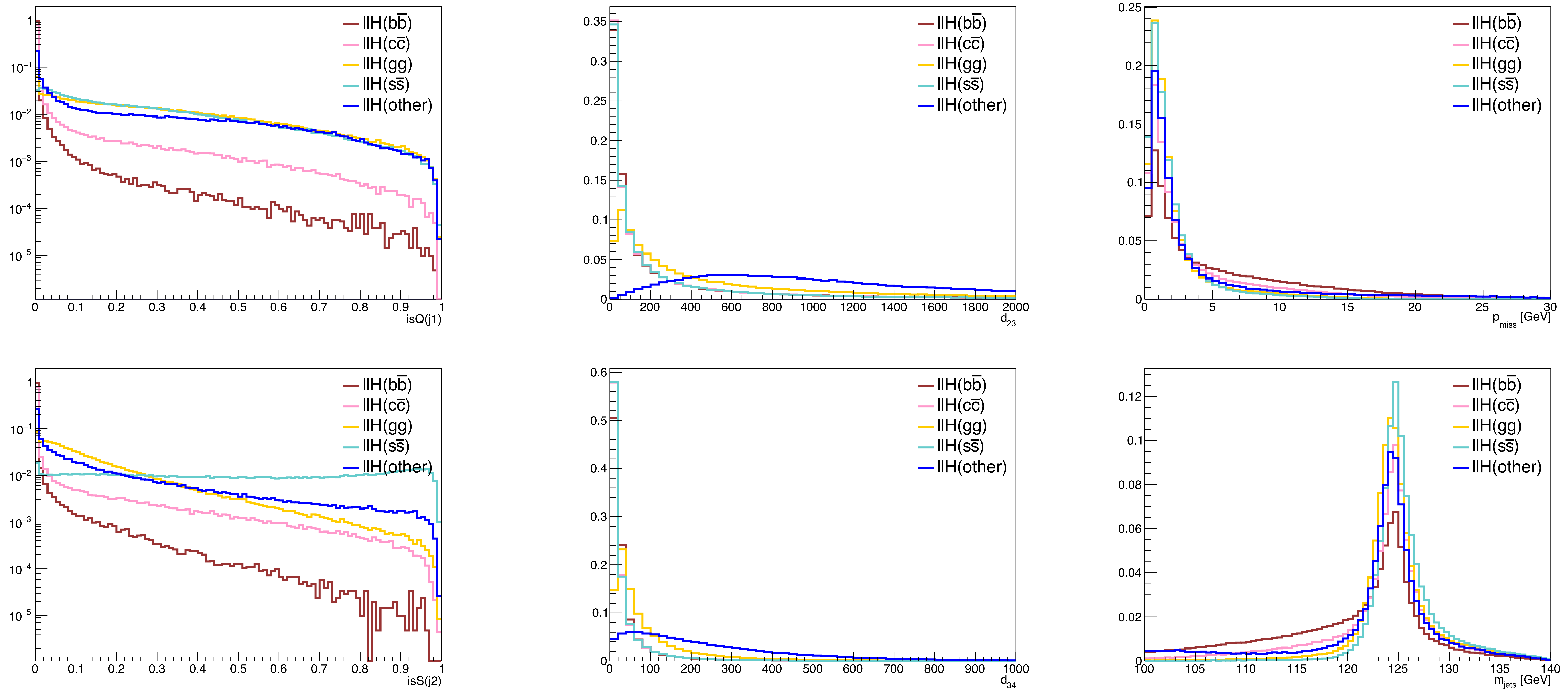




Z(ll)H - neural network inputs

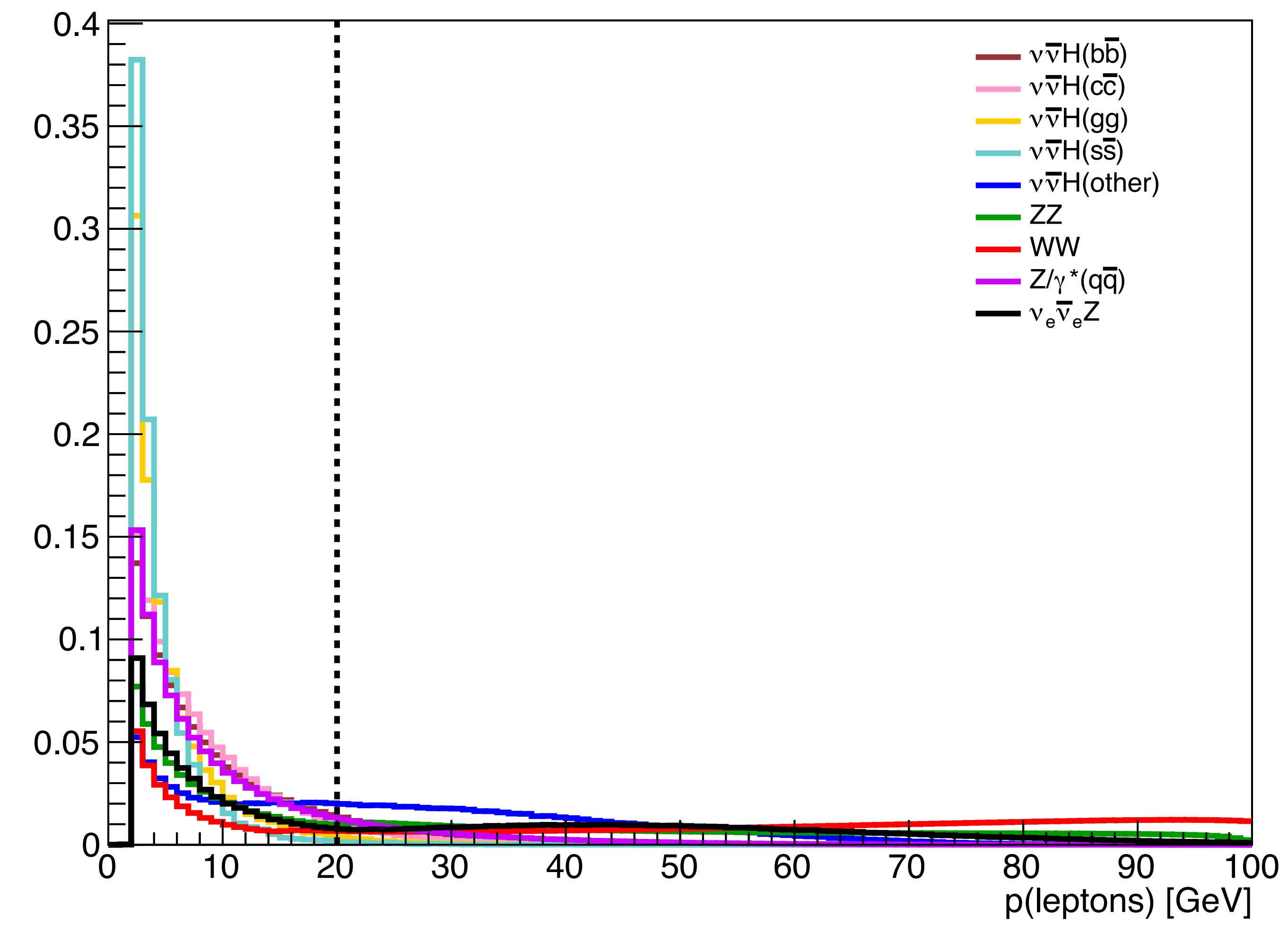


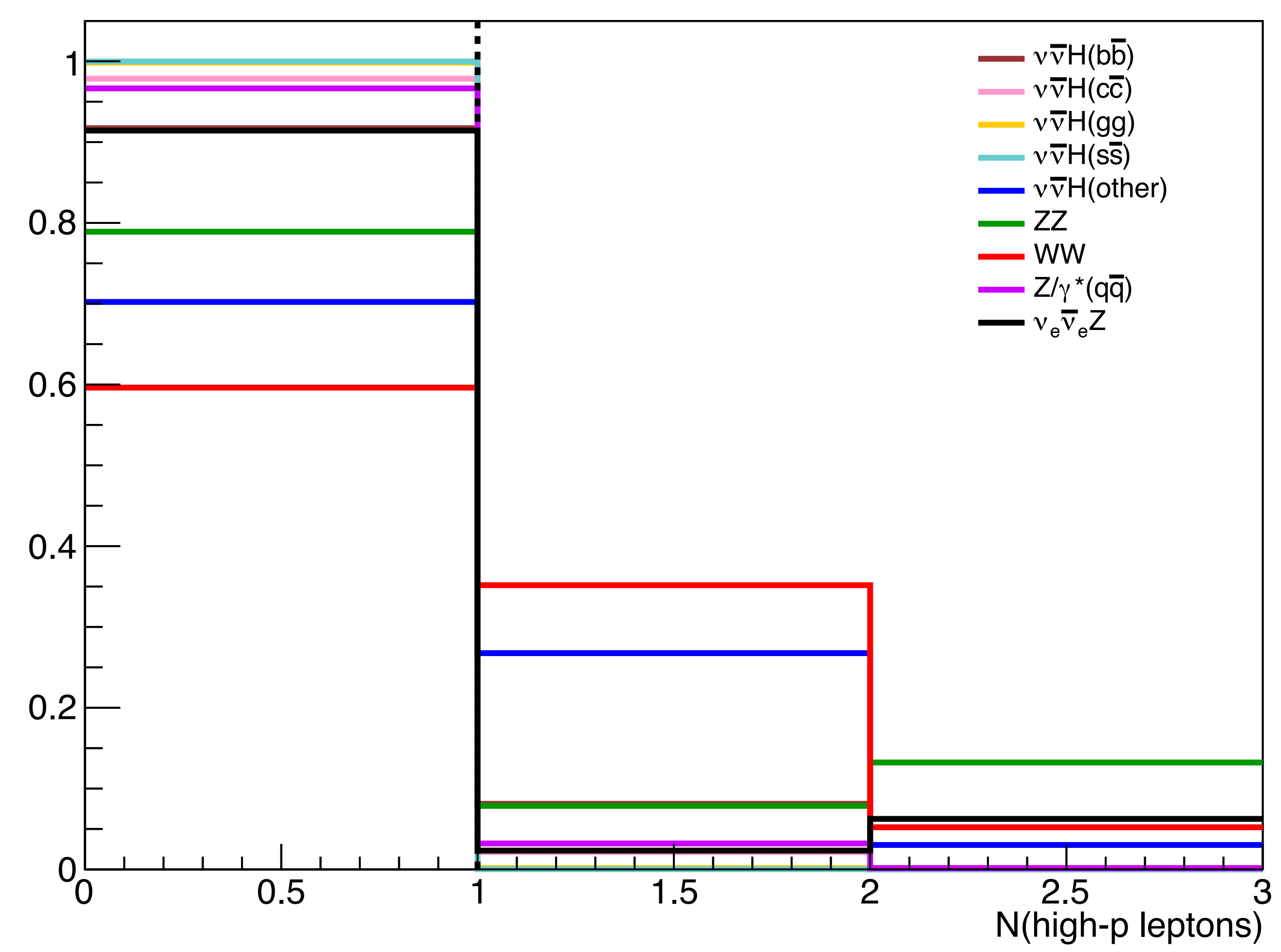
Z(ll)H - neural network inputs (II)

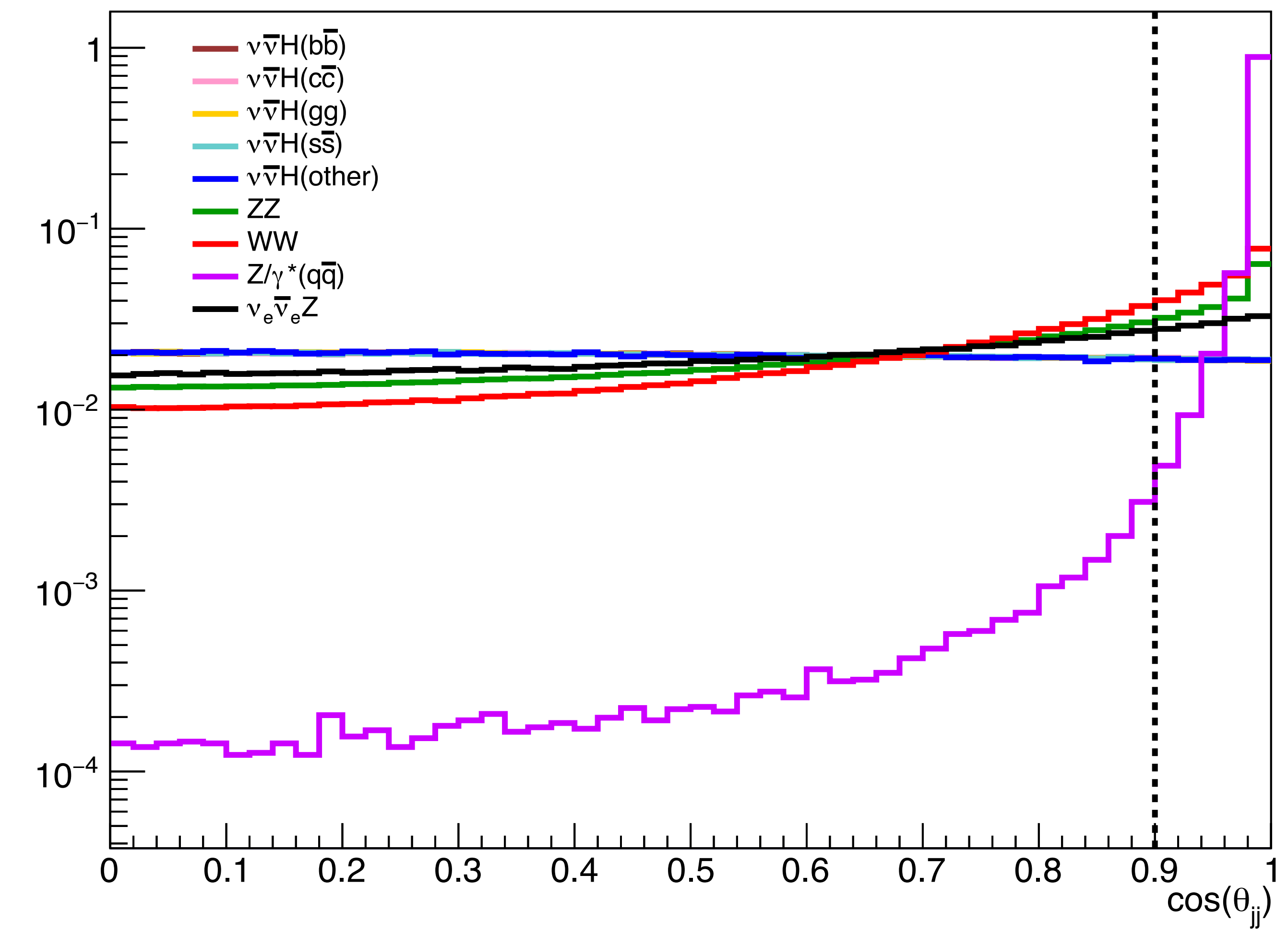


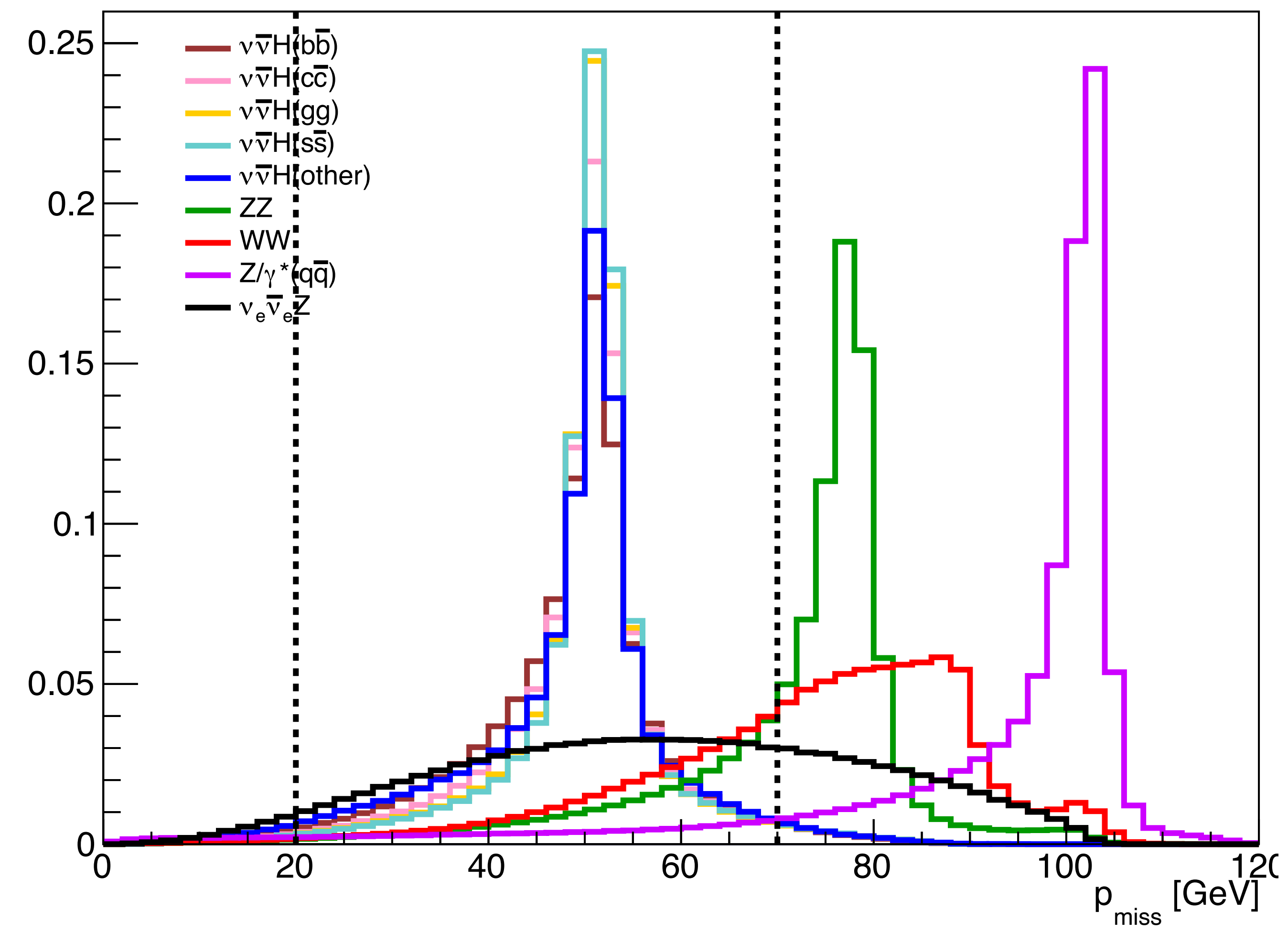
Event selection Z(νν)H

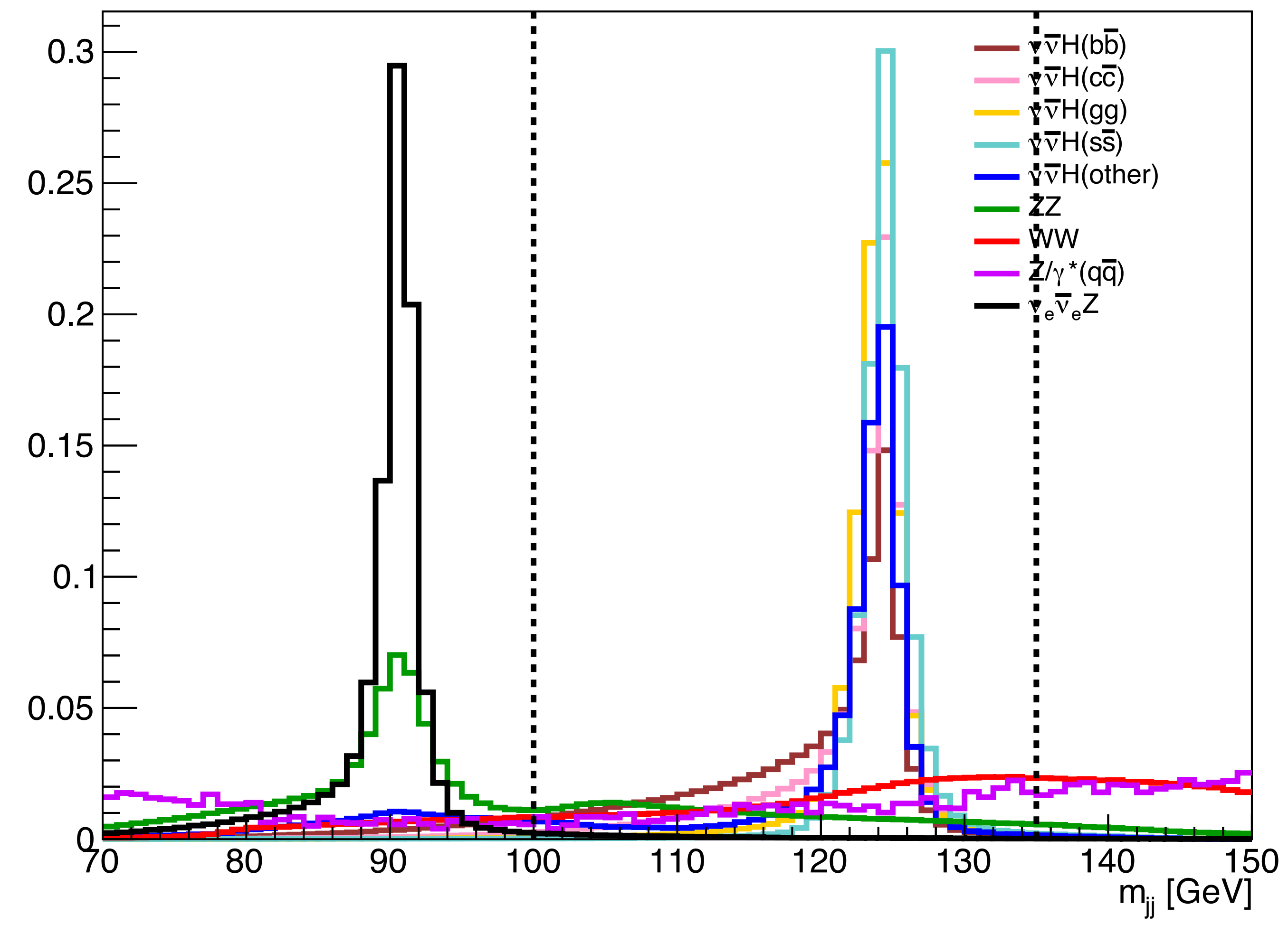
- No μ and e with p>20 GeV
- $|\cos(\theta_{jj})|<0.9$
- $20<p_{miss}<70$ GeV
- $100<m_{jj}<135$ GeV





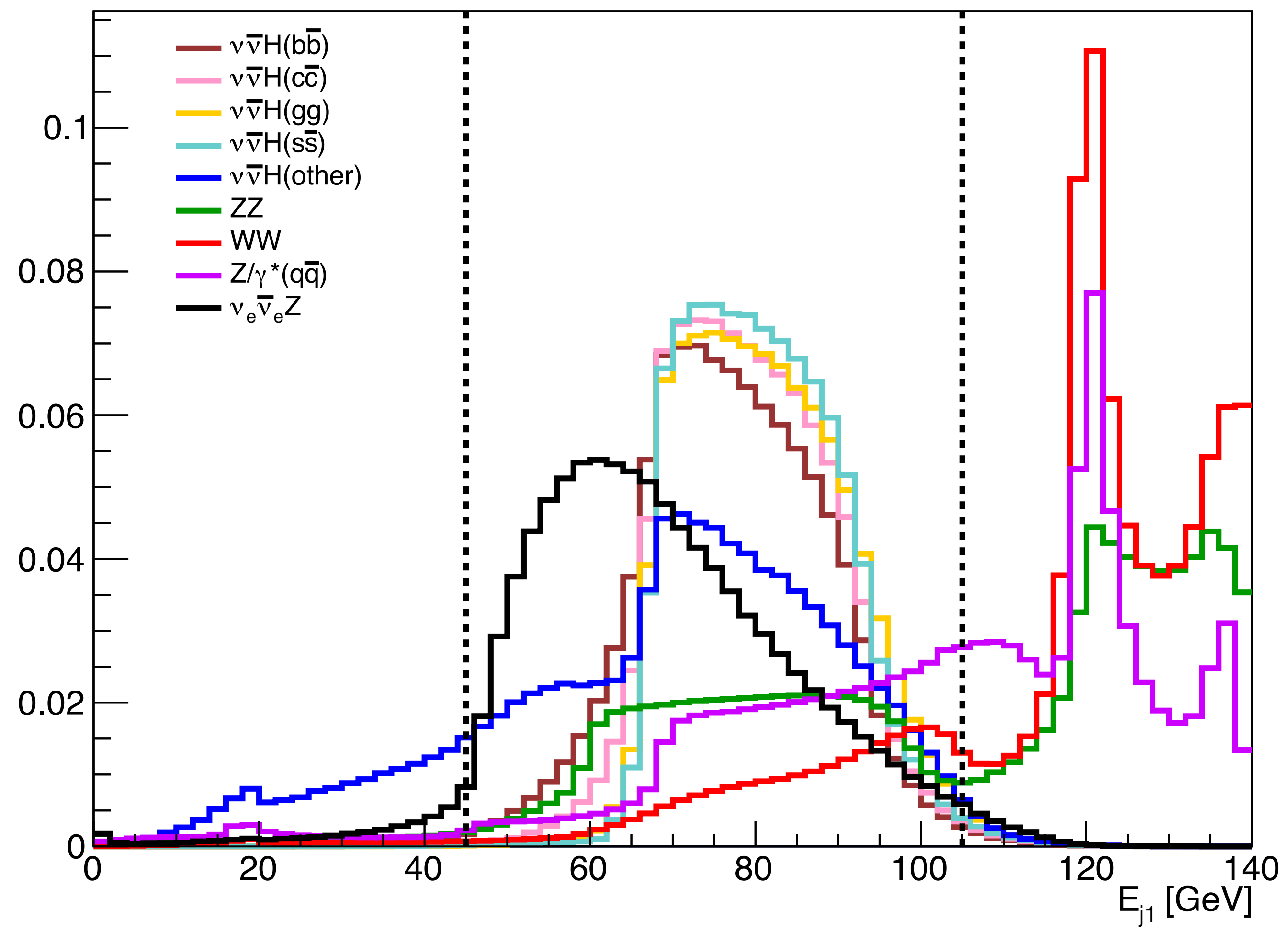


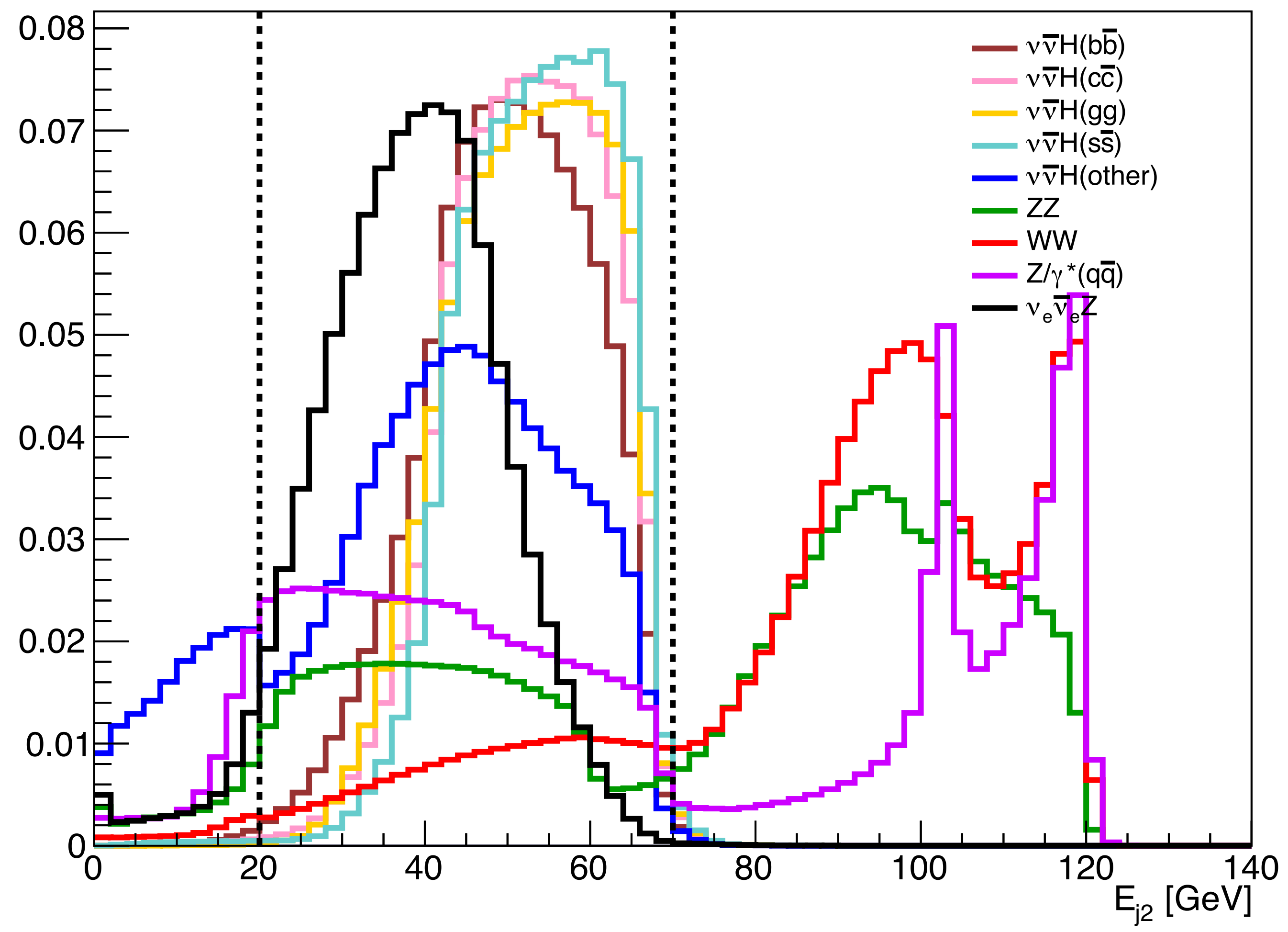


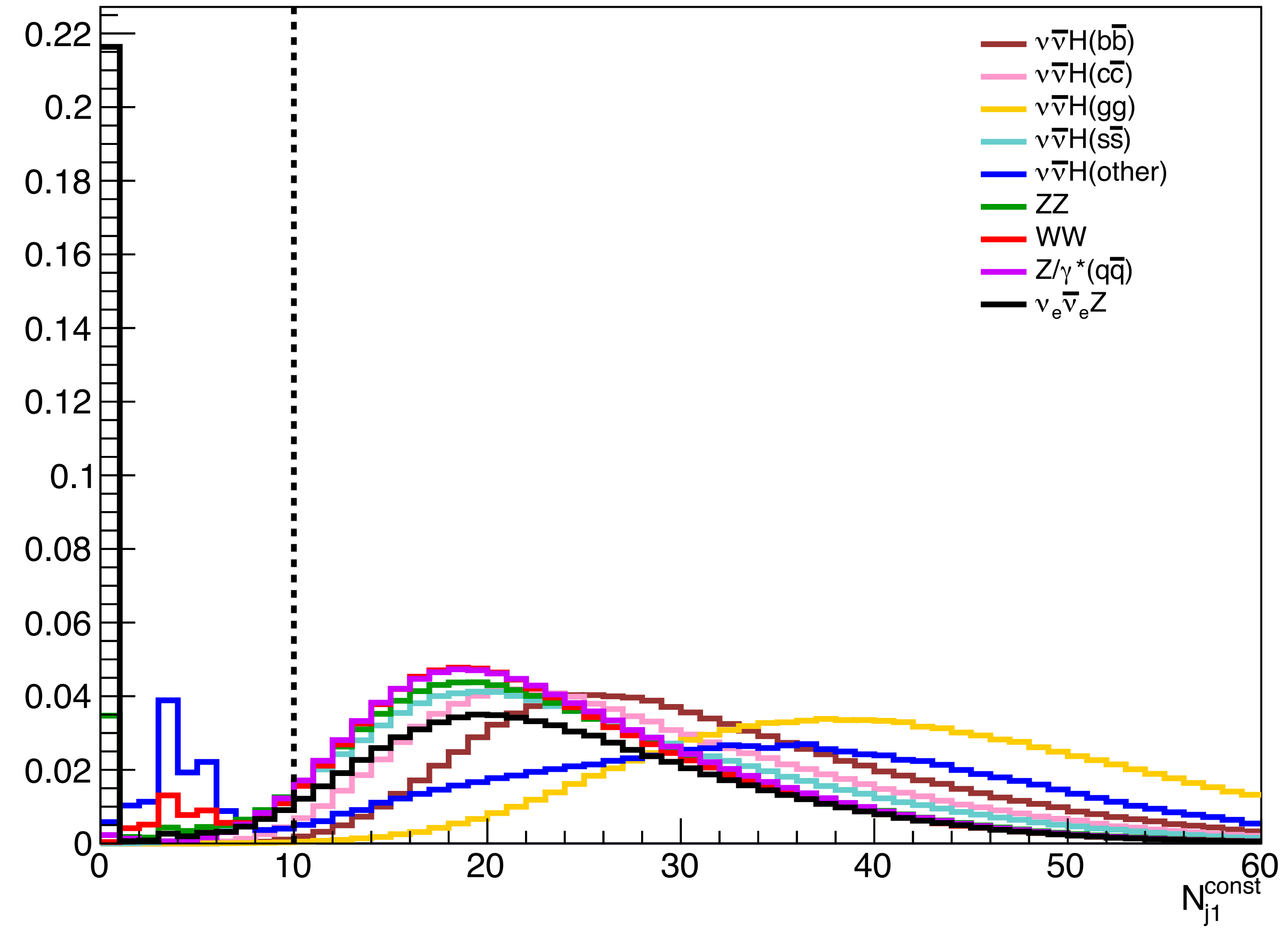


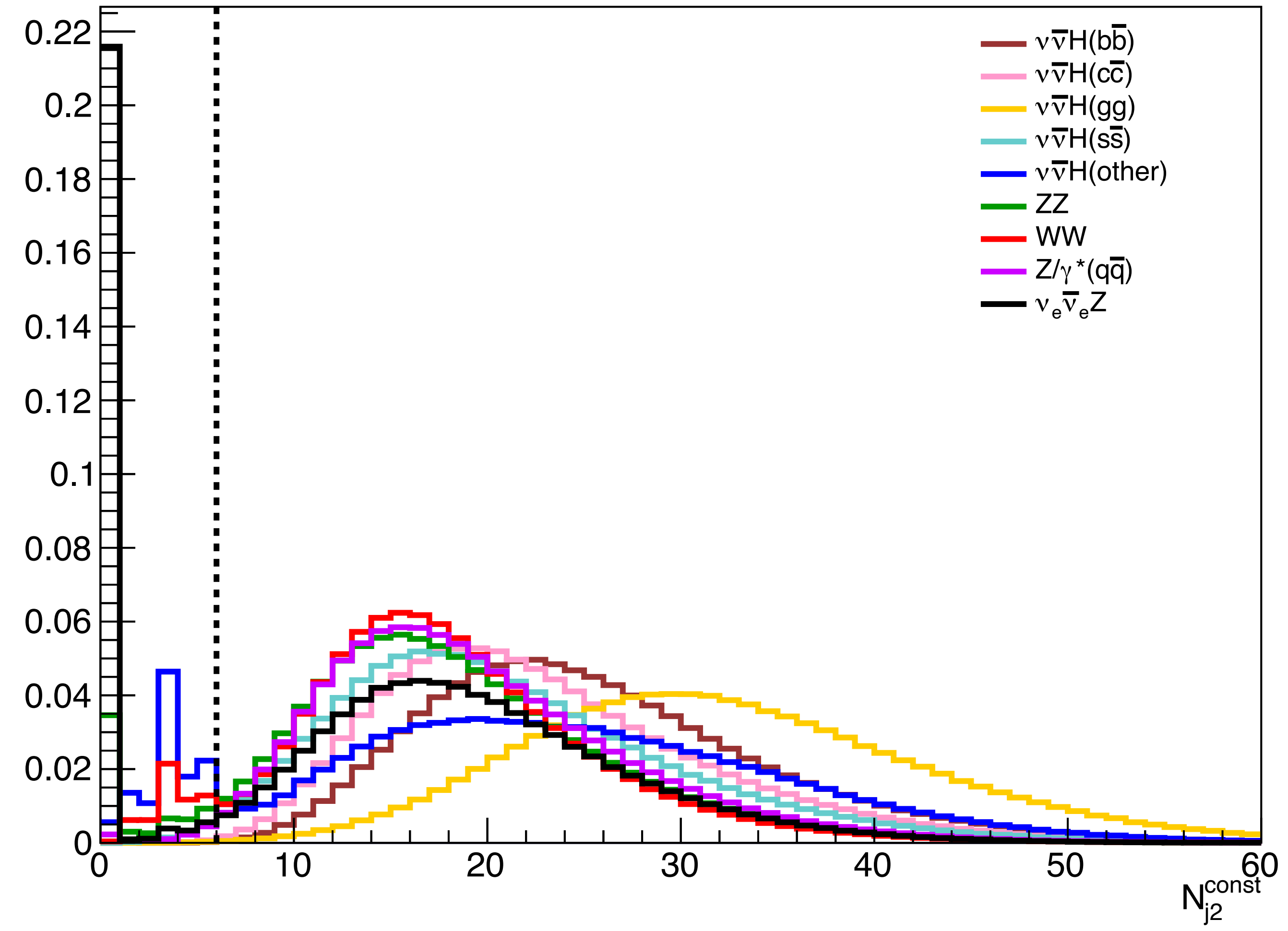
Event selection Z(νν)H

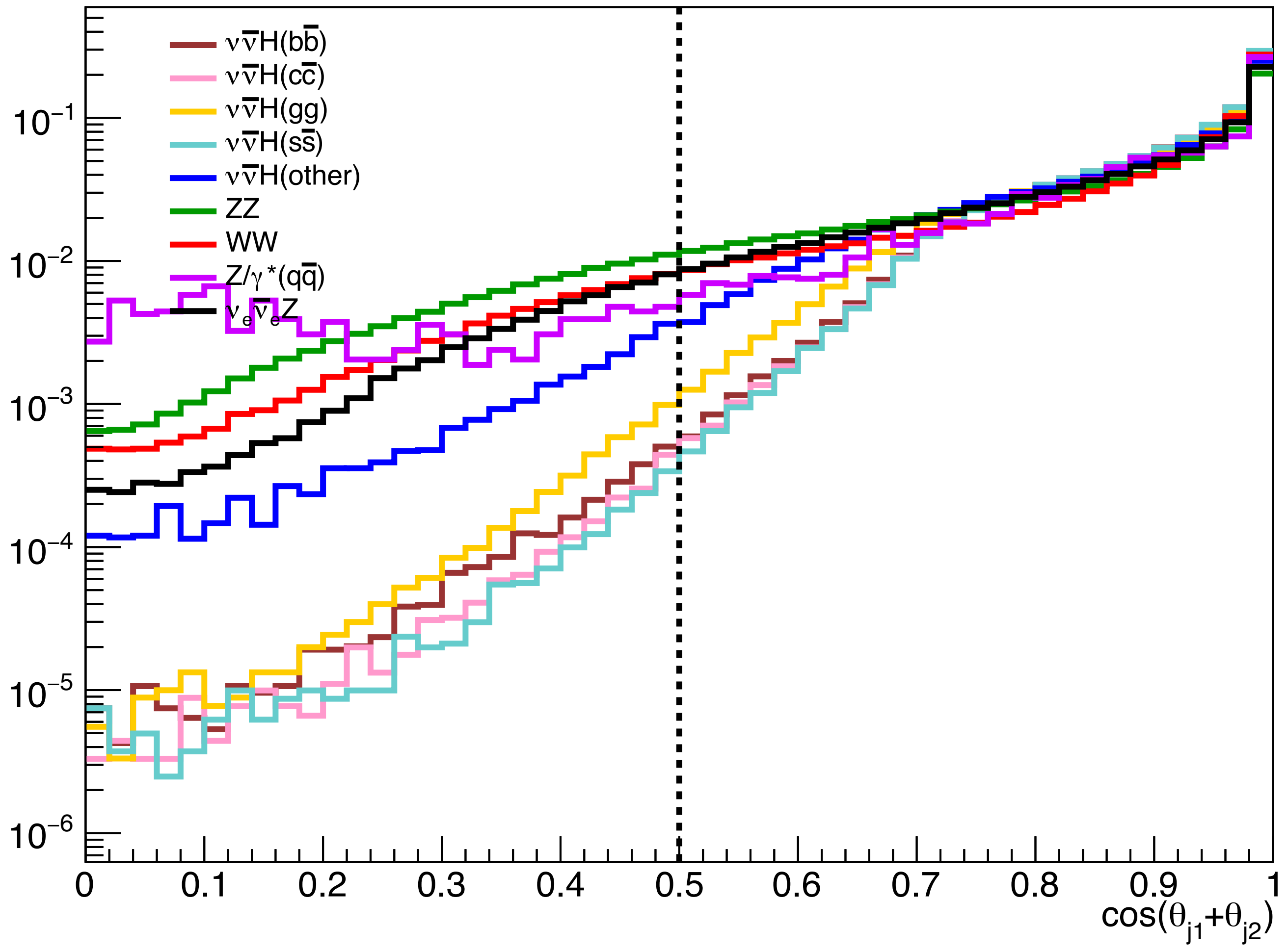
- $45<E(j_1)<105$ GeV, $20<E(j_2)<70$ GeV
- N(constituents): $j_1>10$, $j_2>6$
- $\cos(\theta_{j1} + \theta_{j2})>0.5$
- $\cos(\phi_{j1}-\phi_{j2})<0.999$

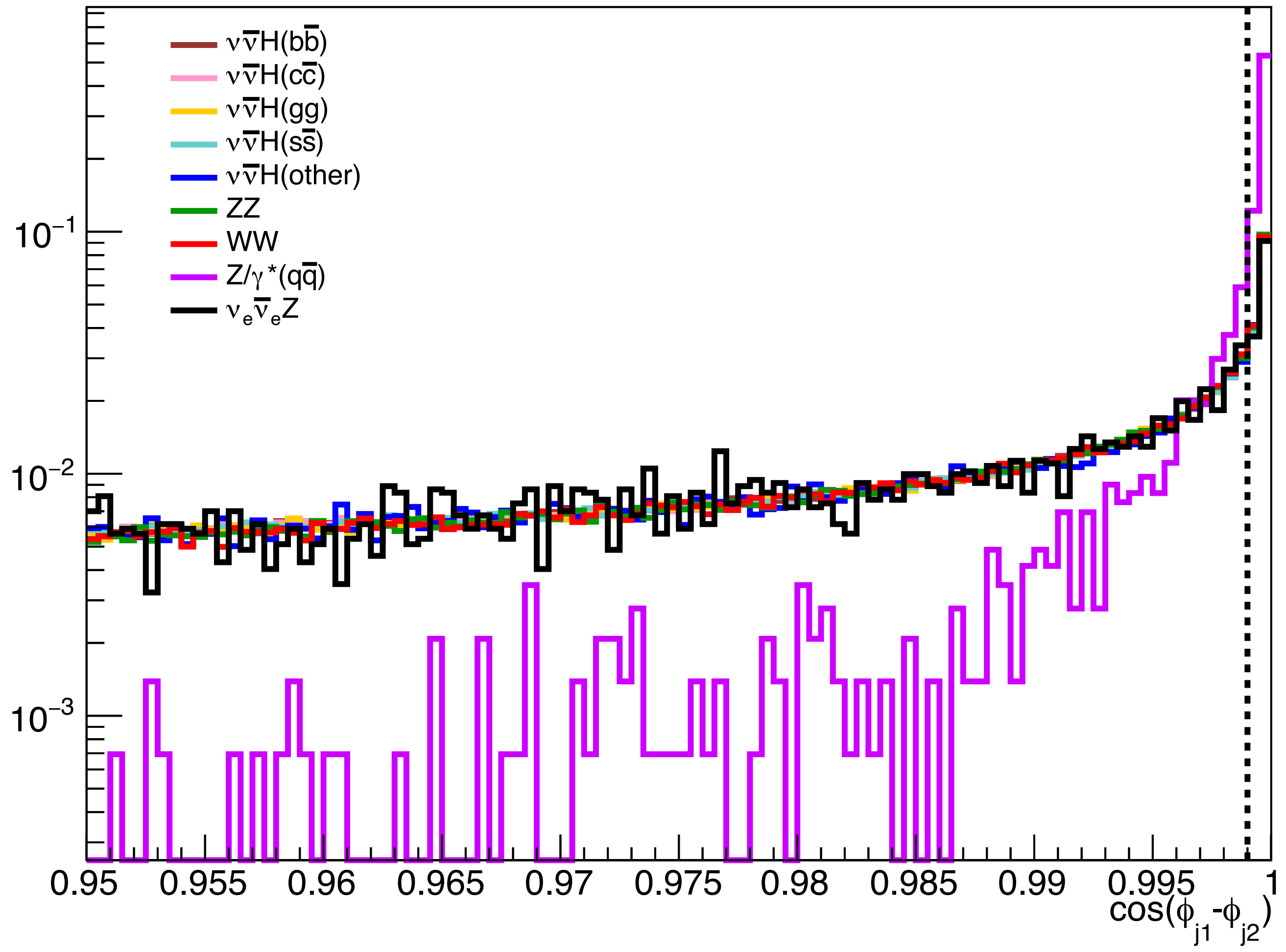




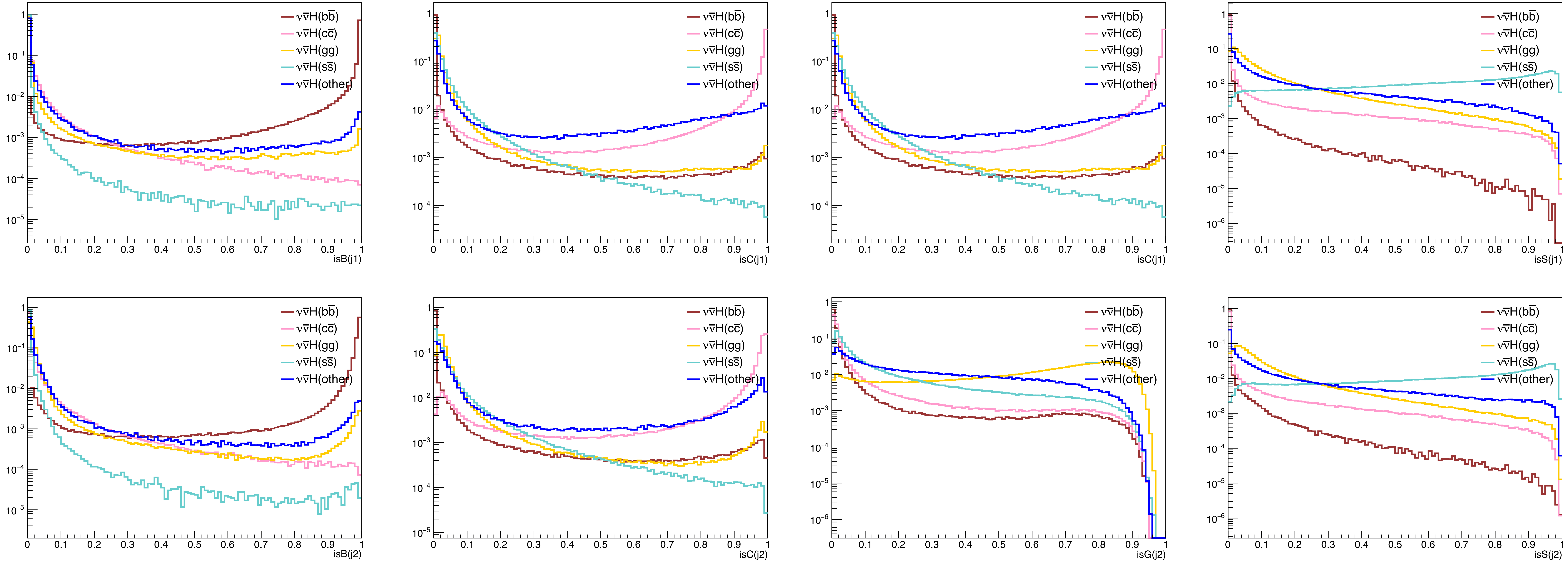




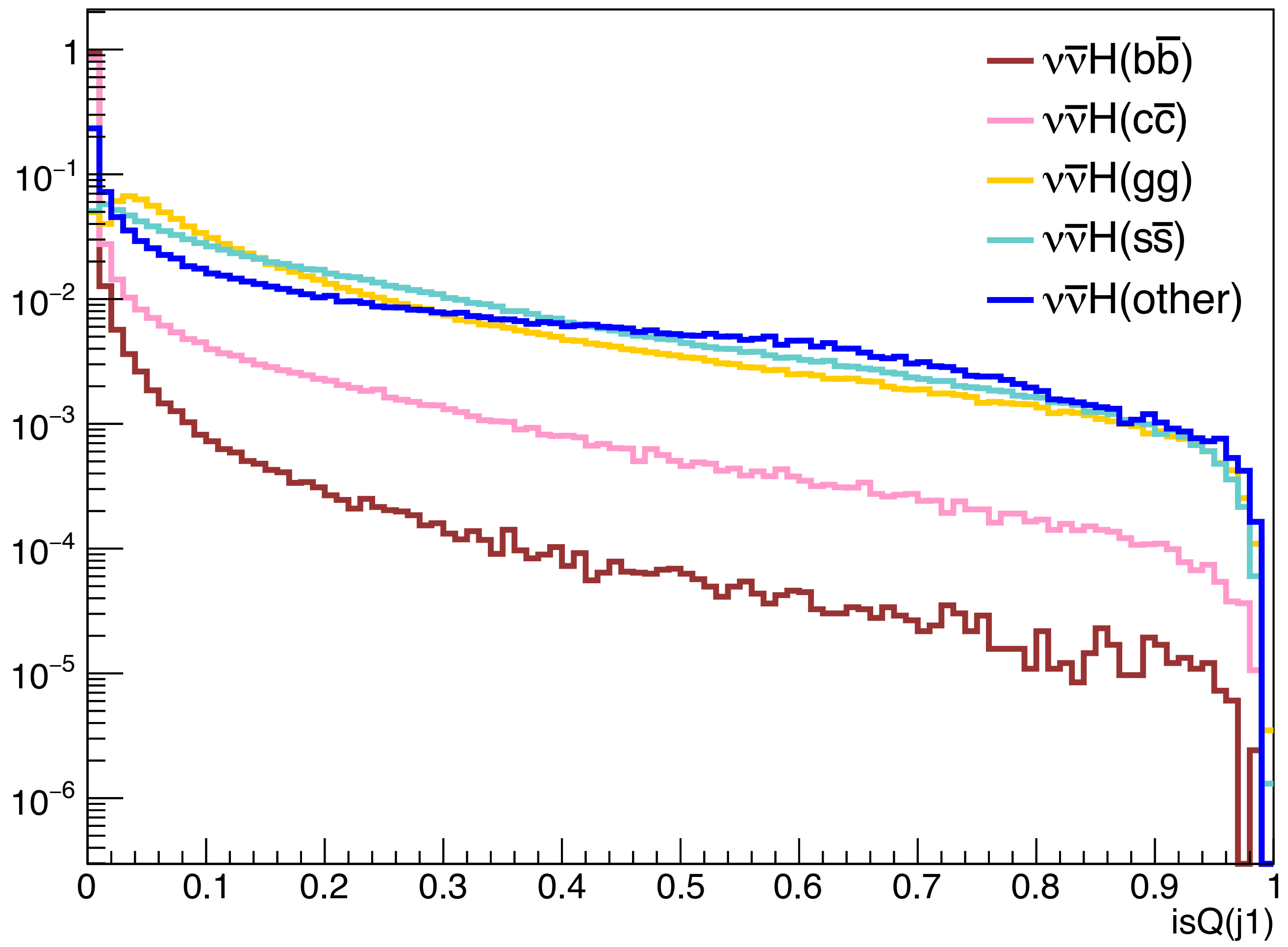


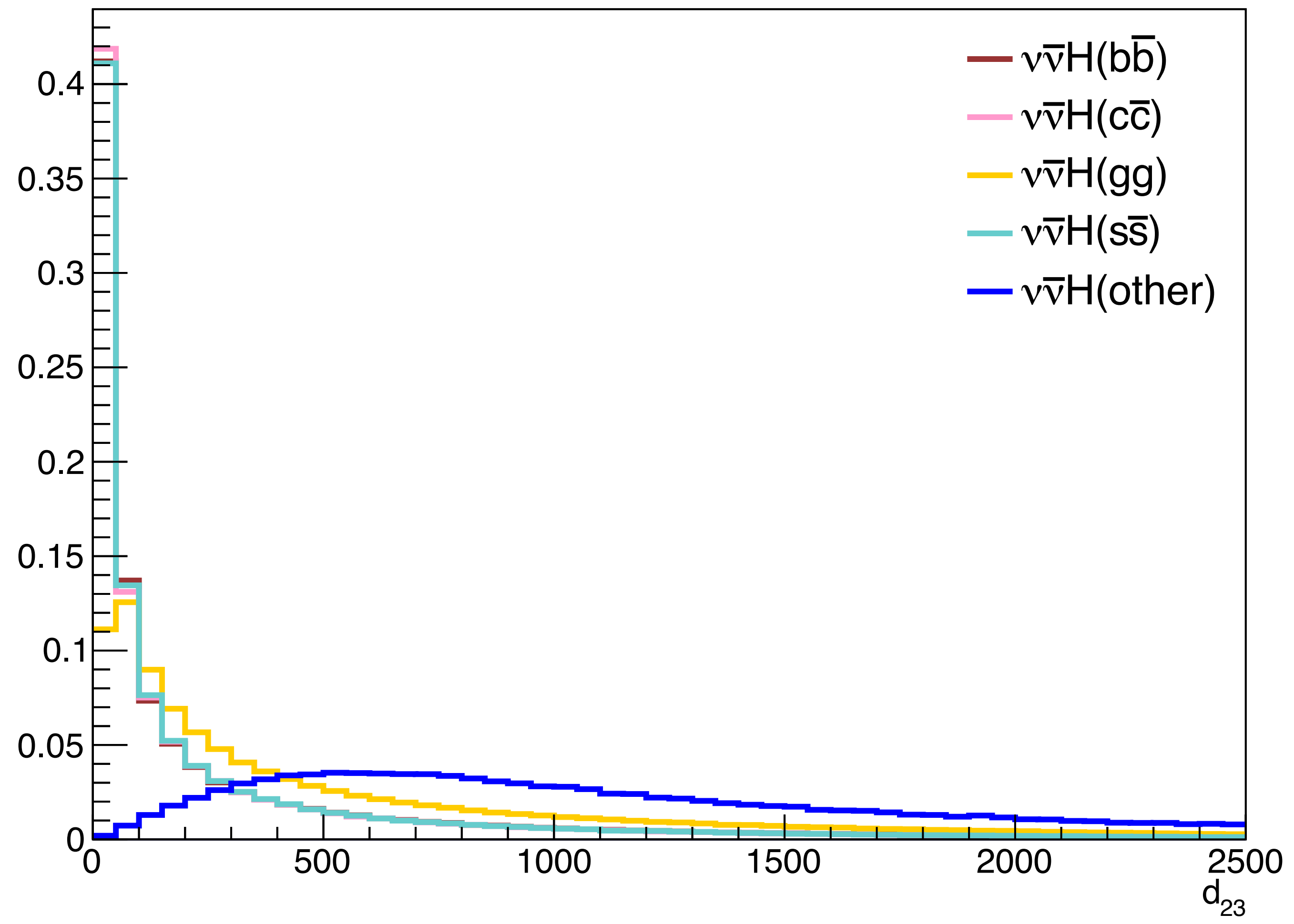


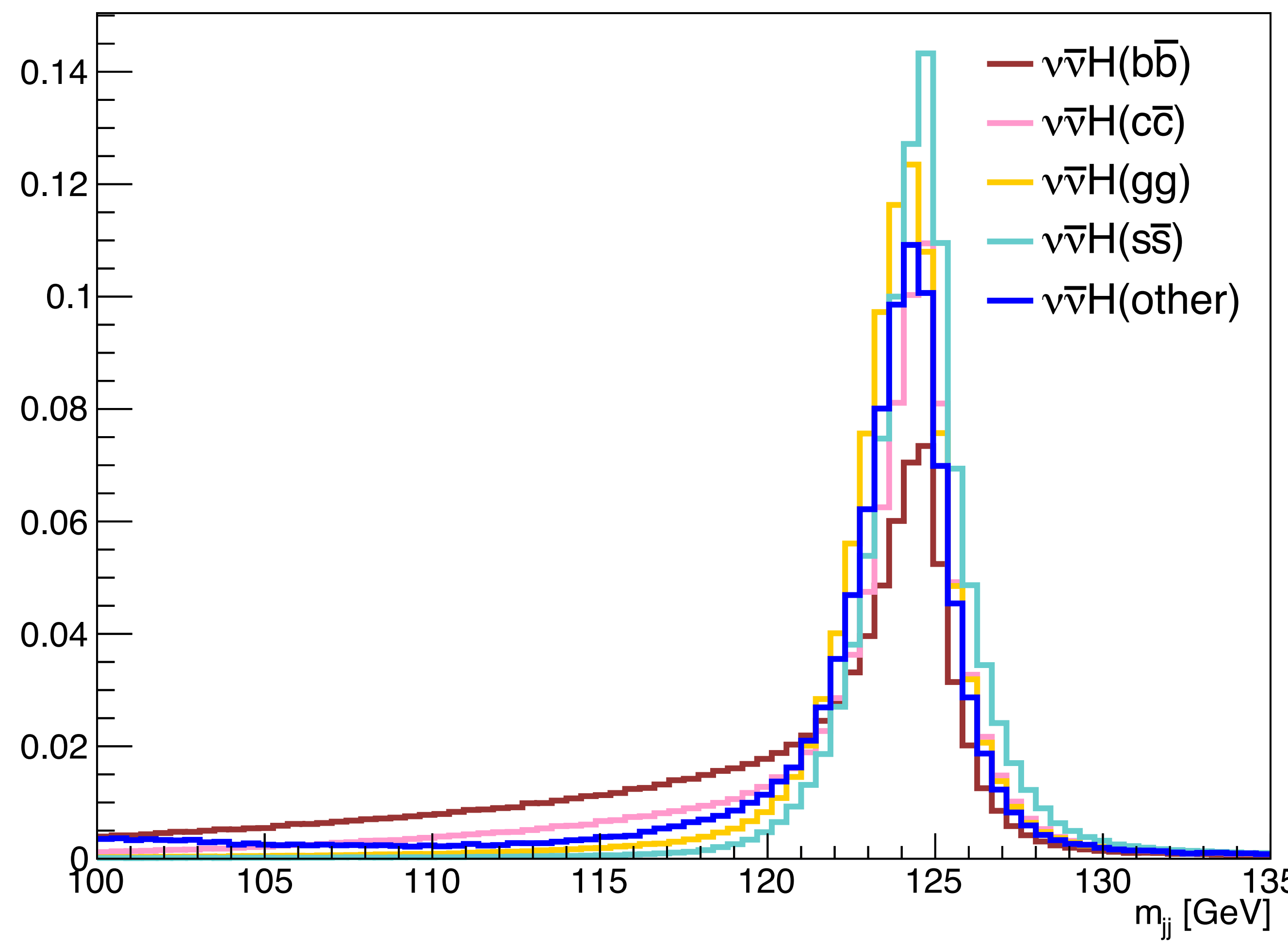
Z(νν)H - neural network inputs

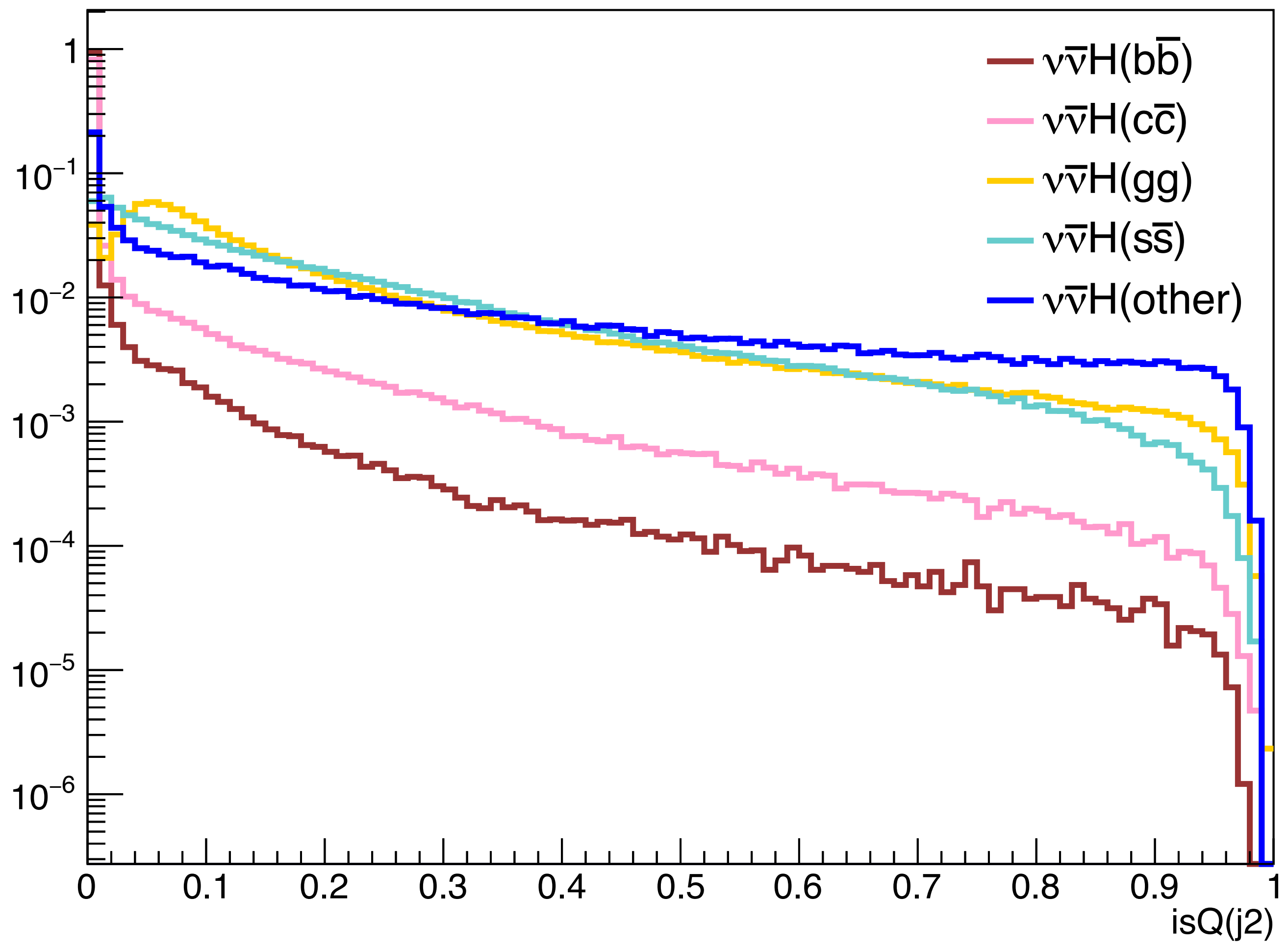


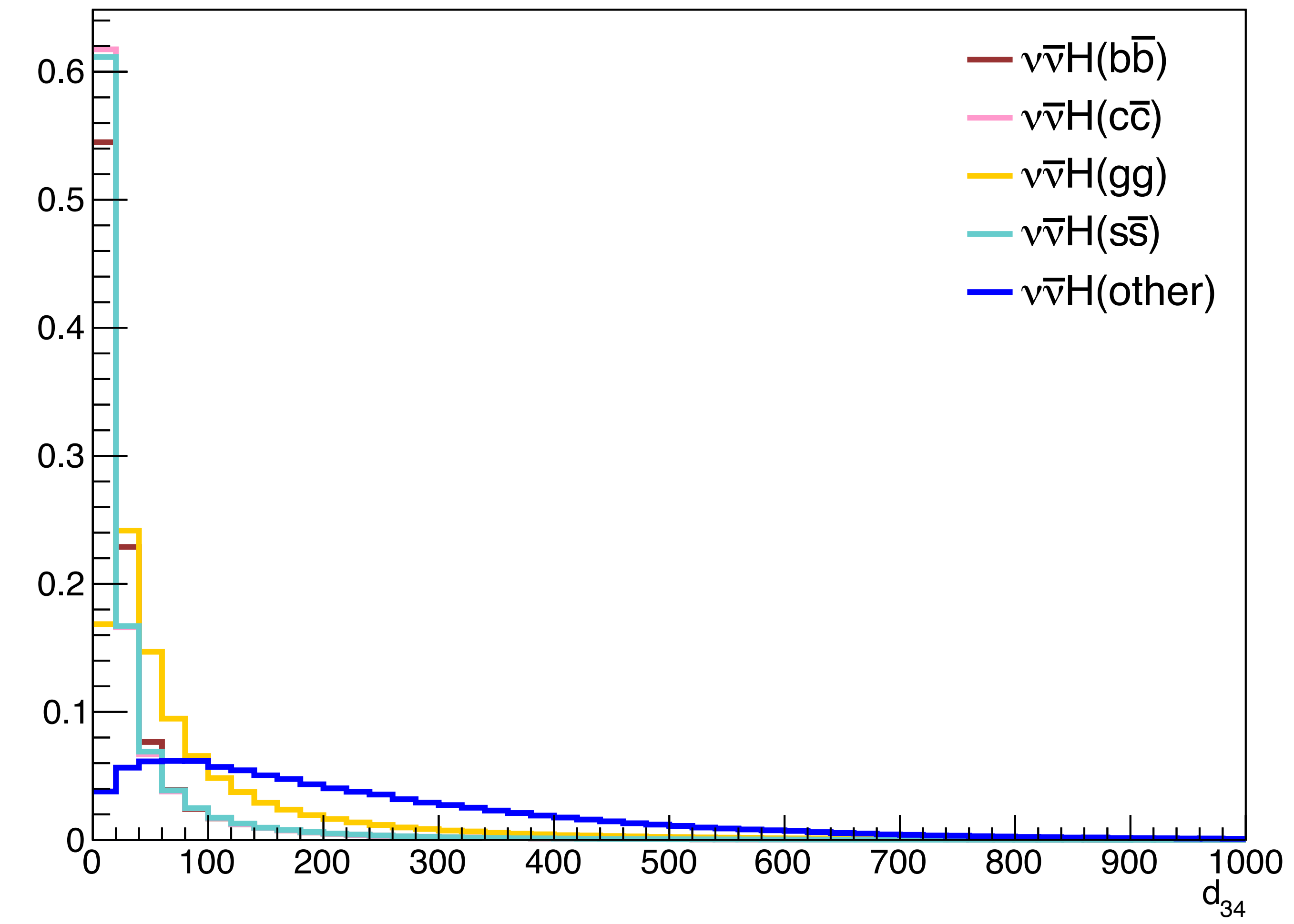
Z(νν)H - neural network inputs (II)











List of talks about the Z(ll/νν)H analyses

- Z(ll)H:
  - 18/07/2021, FCC Physics Performance meeting (link)
  - 02/12/2021, FCC-France workshop (Annecy) (link)
  - 07/02/2022, ”Liverpool” FCC Physics Workshop (online) (link)
  - 23/05/2022, FCC Higgs Performance meeting (link)
- Z(ll)H + Z(νν)H (APC)
  - 01/07/2022, FCC-France jamboree (online) (link)
  - 22/11/2022, FCC France-Italy workshop (Lyon) (link)
  - 06/12/2022, FCC Higgs Performance meeting (link)
  - 17/01/2023, FCC Higgs performance meeting (link)
- Z(νν)H (CERN)
  - 06/12/2022, FCC Higgs Performance meeting (link)
  - 17/01/2023, FCC Higgs performance meeting (link)