FCC-ee
ZH full hadronic final state

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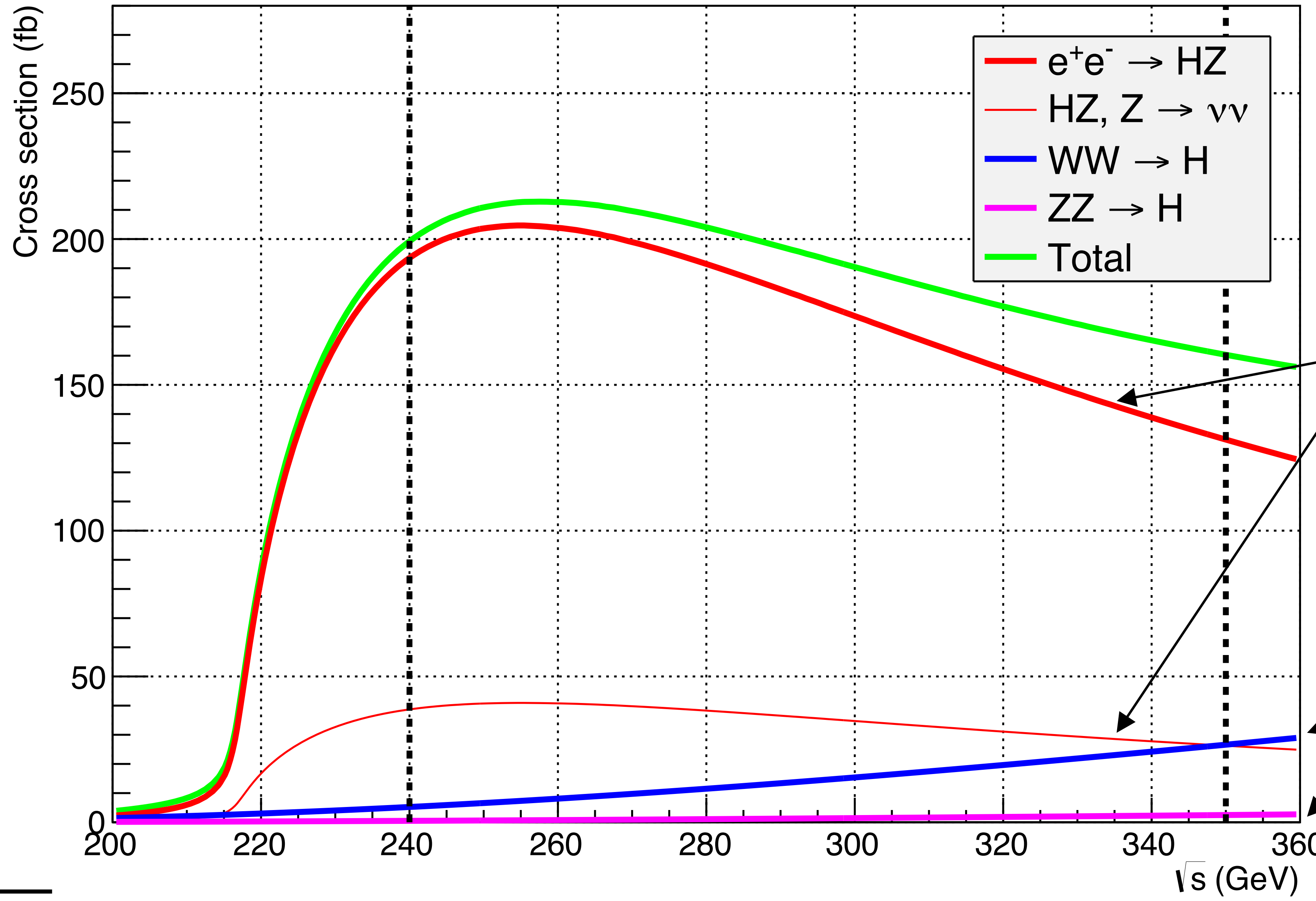
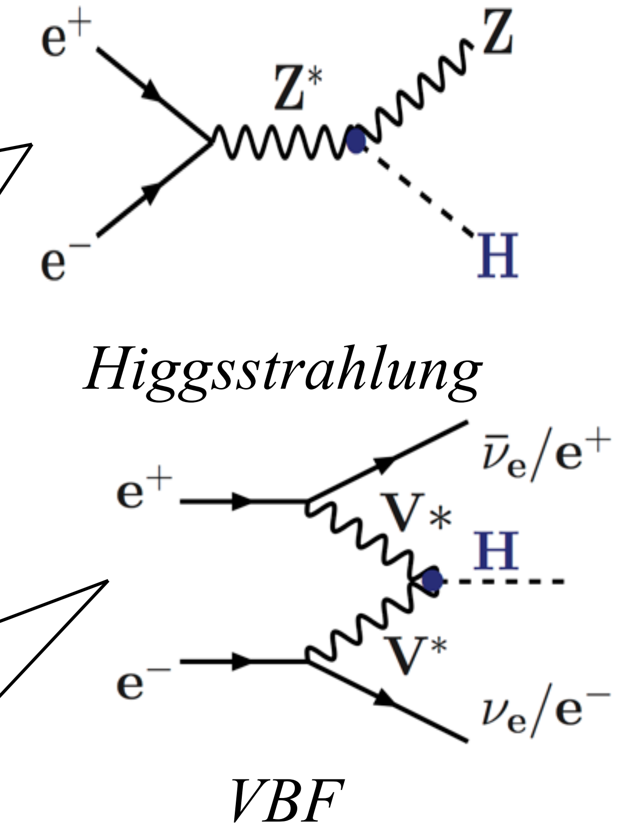
Motivation

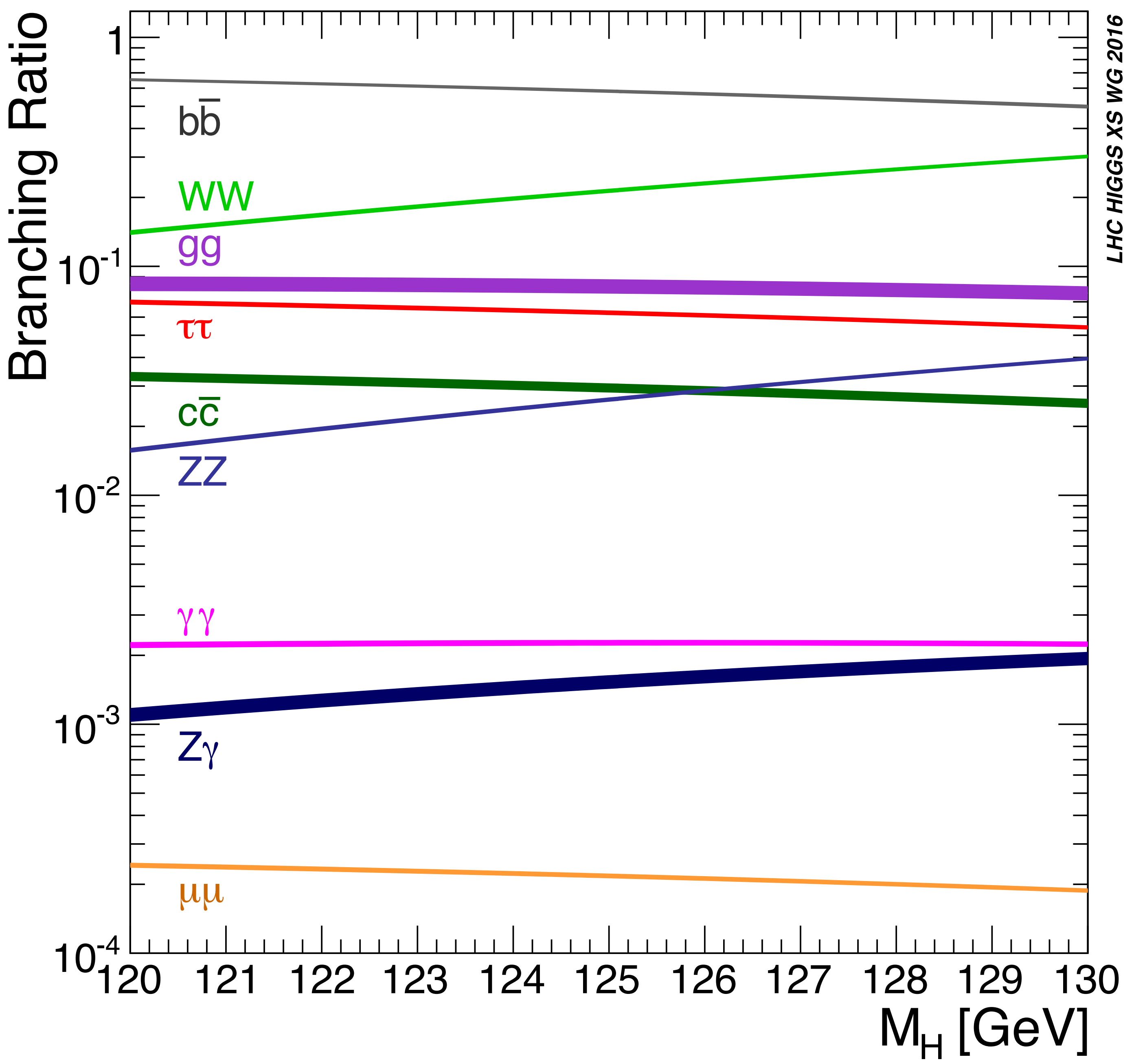
- At $\sqrt{s} = 240\,\text{GeV}$ the Higgs boson is produced in association with a Z boson →measure couplings !
- Use the analysis to study and optimise the detector performance



First Look at the Physics Case of TLEP
arXiv:1308.6176



Handbook of LHC Higgs cross sections
arXiv:1610.07922



Process	Cross-section [pb^{-1}]
ZH	0.2032195
$Z(\nu\nu)H$	0.046191
$Z(\mu^+\mu^-)H$	0.0067643
$Z(e^+e^-)H$	0.0071611
$Z(q\bar{q})H,\ q = u,d,s,c,b$	0.13635

H	BR (%) $m_{\text{H}} = 125.0\,\text{GeV}$
$b\bar{b}$	58.24
$c\bar{c}$	2.891
$s\bar{s}$ (th.)	0.024
gg	8.187
$\tau\bar{\tau}$	6.272

- Analysis of full hadronic final state
- $Z(ll)$($BR(Z \to ll) \sim 6.7\,\%$) and $Z(\nu\nu)$ ($BR(Z \to \nu\nu) \sim 20\,\%$) channels have been already addressed
- $Z(q\bar{q})$ provides significantly higher statistics $BR(Z \to q\bar{q}) \sim 70\,\%$
  - Greater challenge though since it depends on jet clustering
  - Jet energy resolution is worse than measuring a track momentum and electromagnetic energy resolution
  - Ambiguity on finding which jets are originated from Z and H

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Analysis overview

- Signal
  - $Z \to jj, H \to jj \quad (j = b, c, s, g)$
- Backgrounds:
  - $WW, ZZ, Zqq, HWW, HZZ, HZ\gamma, \nu\nu H$
- Jets reconstruction
  - N = 4 Durham *ee* k_{T} exclusive algorithm
  - ParticleNet jet tagger (7 categories: b, c, s, g, τ, u, d)
- Analysis
  - Cuts & Events selection (orthogonal to $Z(ll)H$ and $Z(\nu\nu)H$ analysis)
  - Jet pairs based on tagger scores & combinatorics
  - Fit and sensitivity extraction

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Datasets

- FCCAnalysis framework used to produce ntuples, then analysis with standalone scripts
- IDEA Detector (delphes fast sim) (winter2023 samples)
- Training model for ParticleTransformer "wc_pt_7classes_12_04_2023", tagger scores: b, c, s, g, τ, u, d

	Process	Cross-section [pb^{-1}]	Events
Signal	$e^+e^- \to Z(cc)H(gg)$	0.001911	400000
	$e^+e^- \to Z(cc)H(ss)$	0.000006	300000
	$e^+e^- \to Z(cc)H(cc)$	0.000675	400000
	$e^+e^- \to Z(cc)H(bb)$	0.013590	200000
	$e^+e^- \to Z(qq)H(gg)$	0.004367	400000
	$e^+e^- \to Z(qq)H(ss)$	0.000013	400000
	$e^+e^- \to Z(qq)H(cc)$	0.001542	200000
	$e^+e^- \to Z(qq)H(bb)$	0.031070	500000
	$e^+e^- \to Z(bb)H(gg)$	0.002454	200000
	$e^+e^- \to Z(bb)H(ss)$	0.000007	400000
	$e^+e^- \to Z(bb)H(cc)$	0.000866	400000
	$e^+e^- \to Z(bb)H(bb)$	0.017450	100000
	$e^+e^- \to Z(ss)H(gg)$	0.002453	400000
	$e^+e^- \to Z(ss)H(ss)$	0.000007	300000
	$e^+e^- \to Z(ss)H(cc)$	0.000866	300000
	$e^+e^- \to Z(ss)H(bb)$	0.017450	200000

Samples for $H \to qq(u, d)$ not there yet

	Process	Cross-section [pb^{-1}]	Events
Background	$e^+e^- \to Z(bb)H(\tau\tau)$	0.00188	400000
	$e^+e^- \to Z(ss)H(\tau\tau)$	0.001879	400000
	$e^+e^- \to Z(cc)H(\tau\tau)$	0.001464	400000
	$e^+e^- \to Z(qq)H(\tau\tau)$	0.003346	200000
	$e^+e^- \to Z(bb)H(Z\gamma)$	4.594e-05	400000
	$e^+e^- \to Z(cc)H(Z\gamma)$	3.578e-05	400000
	$e^+e^- \to Z(qq)H(Z\gamma)$	8.177e-05	393135
	$e^+e^- \to Z(ss)H(Z\gamma)$	4.593e-05	300000
	$e^+e^- \to Z(cc)H(WW)$	0.005023	1200000
	$e^+e^- \to Z(qq)H(WW)$	0.01148	1100000
	$e^+e^- \to Z(ss)H(WW)$	0.006447	1200000
	$e^+e^- \to Z(bb)H(WW)$	0.00645	1000000
	$e^+e^- \to Z(bb)H(ZZ)$	0.0007915	1000000
	$e^+e^- \to Z(cc)H(ZZ)$	0.0006164	1200000
	$e^+e^- \to Z(qq)H(ZZ)$	0.001409	1200000
	$e^+e^- \to Z(ss)H(ZZ)$	0.0007912	600000
	$e^+e^- \to Z(\nu\nu)H(jj)$	0.046191	3500000
	$e^+e^- \to W^+W^-$	16.4385	373375386
	$e^+e^- \to ZZ$	1.35899	56162093
	$e^+e^- \to Z/\gamma^*(q\bar{q})$	52.6539	100559248

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Cuts

- Events (orthogonal to $ll, \nu\nu$ analysis)
  - $n_j = 4$ per event
  - Cuts on leptons
    - lepton (both e, μ) $p_l < 20\,\text{GeV}$ & $n_{e,\mu} \leq 2$ per event
  - Cuts on $m_{\text{vis}}, \theta_{\text{vis}}$
    - $m_{\text{vis}} > 150\,\text{GeV}$,
    - $0.15 < \theta_{\text{vis}} < 3$
  - Clustering merging parameter cut (d_{12}, d_{23}, d_{34})
- On the jet pairs
  - Not same flavour pairs: Resolve Z from the minimum $(m_{jj} - m_Z)^2$ for both pairs, remaining jj as H
  - Same flavour pairs: Find minimum $(m_{j_1j_2} - m_Z)^2 + (m_{j_3j_4} - m_H)^2$ for all jet combination
  $\sqrt{(m_{z_{jj}} - m_W)^2 + (m_{H_{jj}} - m_W)^2} > 10$, $\sqrt{(m_{z_{jj}} - m_Z)^2 + (m_{H_{jj}} - m_Z)^2} > 10$, ZZ, WW rejection
  - $50 < m_{Z_{jj}} < 125\,\text{GeV}, m_{H_{jj}} > 91\,\text{GeV}$

Cut efficiencies

	Lepton cut	$M_{\rm vis}$, $\theta_{\rm vis}$	$d_{\rm ij}$
$e^+e^- \to Z(cc)H(gg)$	98.7	88.3	87.2
$e^+e^- \to Z(cc)H(ss)$	99.0	88.4	86.3
$e^+e^- \to Z(cc)H(cc)$	96.6	88.1	86.1
$e^+e^- \to Z(cc)H(bb)$	89.7	83.5	81.2
$e^+e^- \to Z(qq)H(gg)$	99.8	86.2	85.2
$e^+e^- \to Z(qq)H(ss)$	99.9	86.6	84.6
$e^+e^- \to Z(qq)H(cc)$	97.8	87.1	85.2
$e^+e^- \to Z(qq)H(bb)$	91.4	83.8	81.7
$e^+e^- \to Z(bb)H(gg)$	94.6	87.0	85.9
$e^+e^- \to Z(bb)H(ss)$	95.0	87.3	85.1
$e^+e^- \to Z(bb)H(cc)$	92.1	85.7	83.4
$e^+e^- \to Z(bb)H(bb)$	84.4	79.8	77.3
$e^+e^- \to Z(ss)H(gg)$	99.8	87.0	85.9
$e^+e^- \to Z(ss)H(ss)$	99.9	87.2	85.2
$e^+e^- \to Z(ss)H(cc)$	97.8	87.7	85.7
$e^+e^- \to Z(ss)H(bb)$	91.3	84.1	82.0

	Lepton cut	$M_{\rm vis}$, $\theta_{\rm vis}$	$d_{\rm ij}$
$e^+e^- \to Z(bb)H(\tau\tau)$	63.7	43.9	32.8
$e^+e^- \to Z(ss)H(\tau\tau)$	67.1	48.3	36.4
$e^+e^- \to Z(cc)H(\tau\tau)$	68.0	50.2	38.1
$e^+e^- \to Z(qq)H(\tau\tau)$	67.9	50.1	38.1
$e^+e^- \to Z(bb)H(Z\gamma)$	86.5	62.4	61.3
$e^+e^- \to Z(ss)H(Z\gamma)$	90.5	64.0	62.9
$e^+e^- \to Z(cc)H(Z\gamma)$	91.7	63.7	62.5
$e^+e^- \to Z(qq)H(Z\gamma)$	91.6	63.1	61.9
$e^+e^- \to Z(bb)H(WW)$	64.7	57.4	54.6
$e^+e^- \to Z(ss)H(WW)$	68.0	59.8	57.0
$e^+e^- \to Z(cc)H(WW)$	68.7	59.9	57.0
$e^+e^- \to Z(qq)H(WW)$	68.6	59.4	56.6
$e^+e^- \to Z(bb)H(ZZ)$	81.8	60.6	57.8
$e^+e^- \to Z(ss)H(ZZ)$	86.1	63.3	60.5
$e^+e^- \to Z(cc)H(ZZ)$	87.5	63.9	61.1
$e^+e^- \to Z(qq)H(ZZ)$	87.5	63.6	60.8
$e^+e^- \to Z(\nu\nu)H(jj)$	87.5	00.1	00.0
$e^+e^- \to W^+W^-$	64.1	45.1	37.9
$e^+e^- \to ZZ$	79.8	43.4	38.1
$e^+e^- \to Z/\gamma^*(q\bar{q})$	96.5	31.8	07.6

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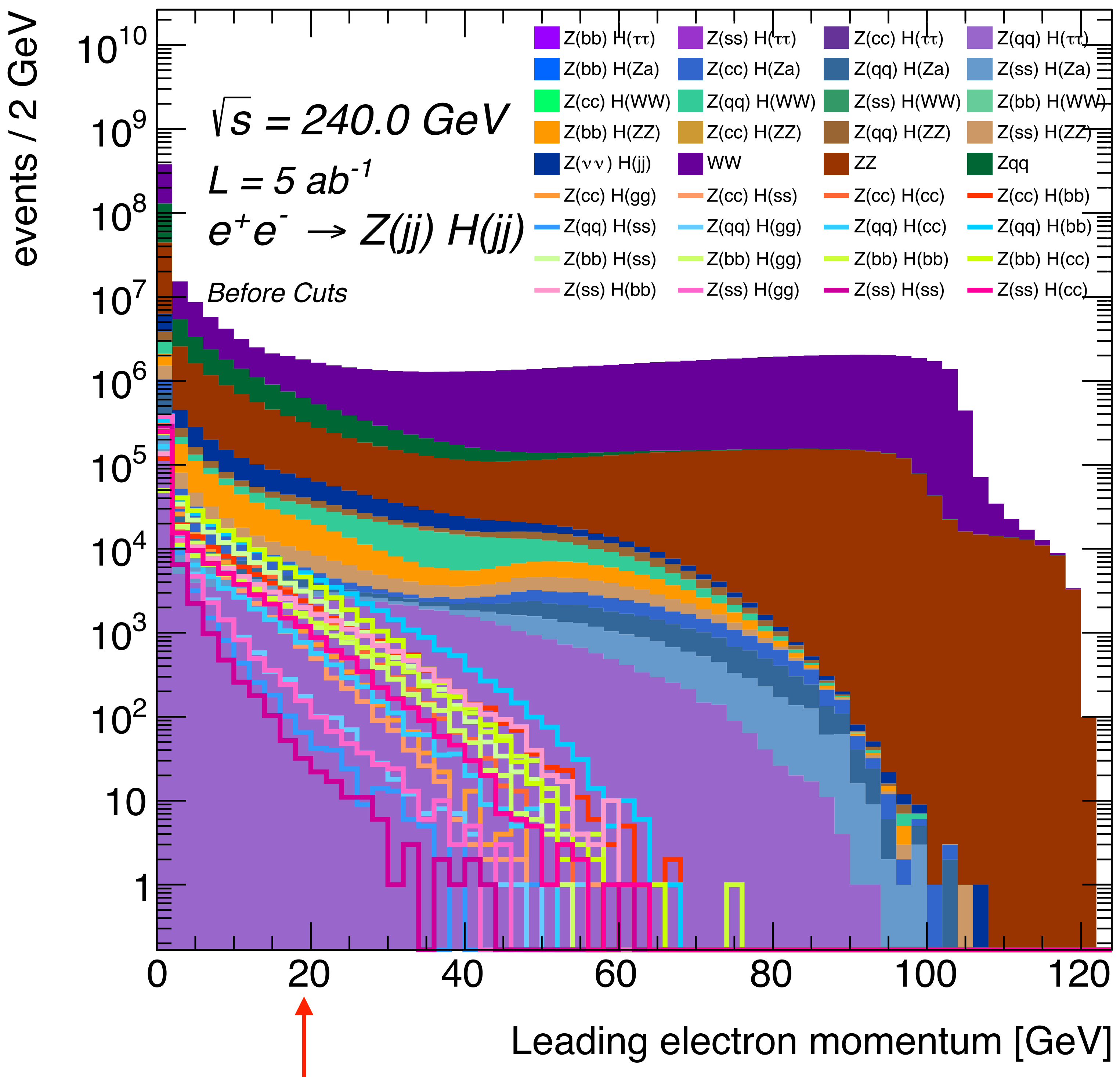
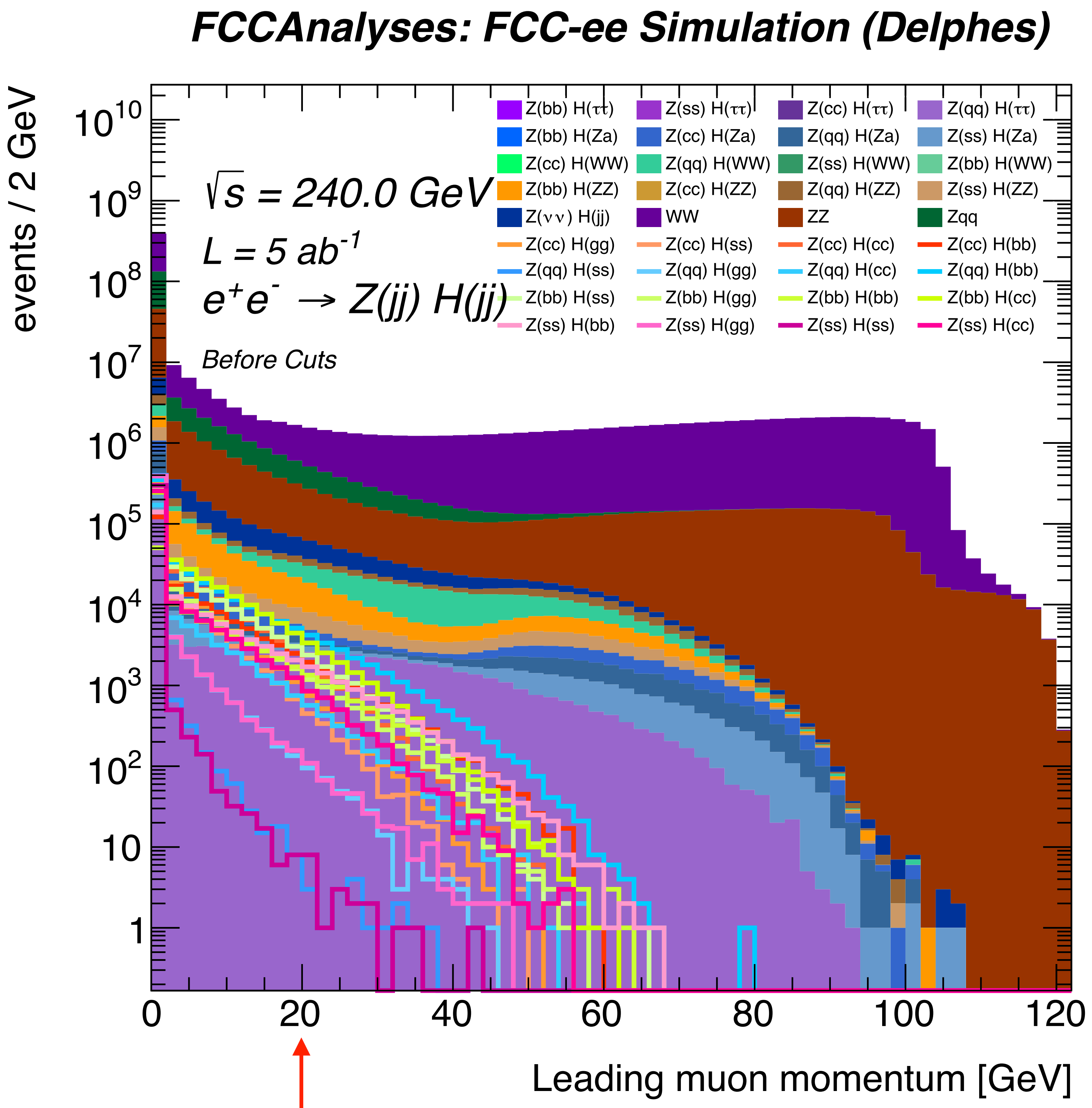
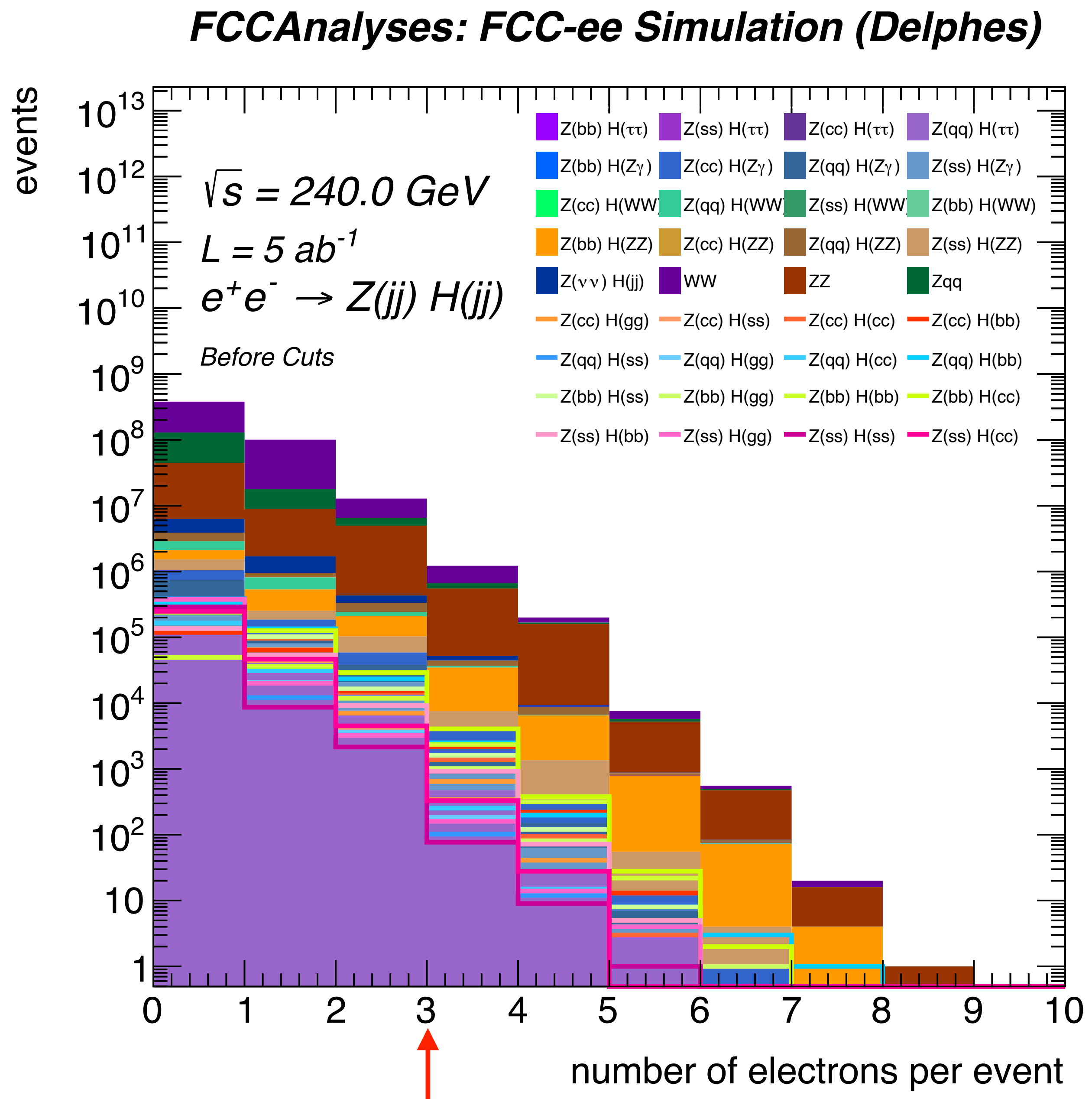
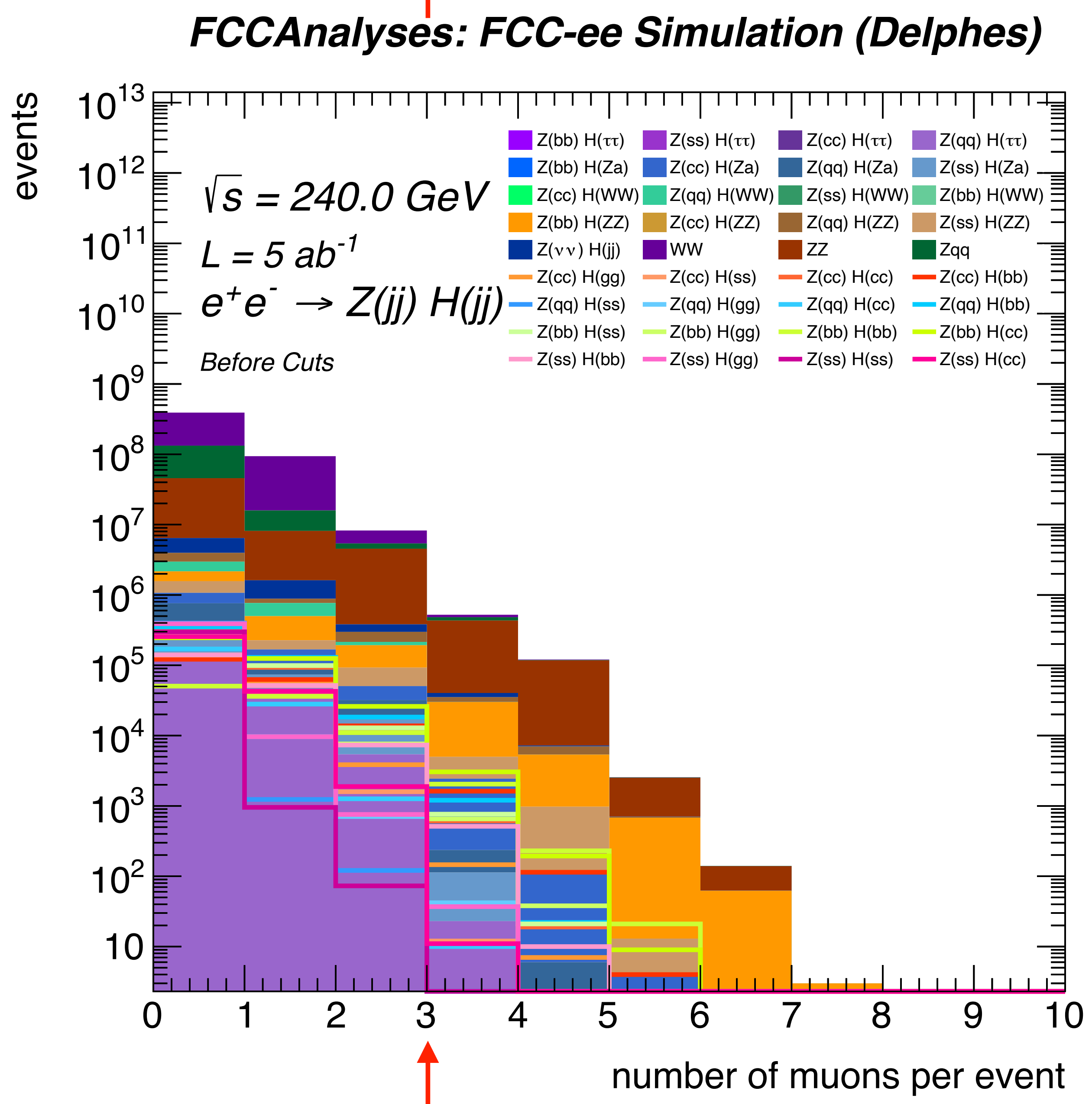
Lepton distributions









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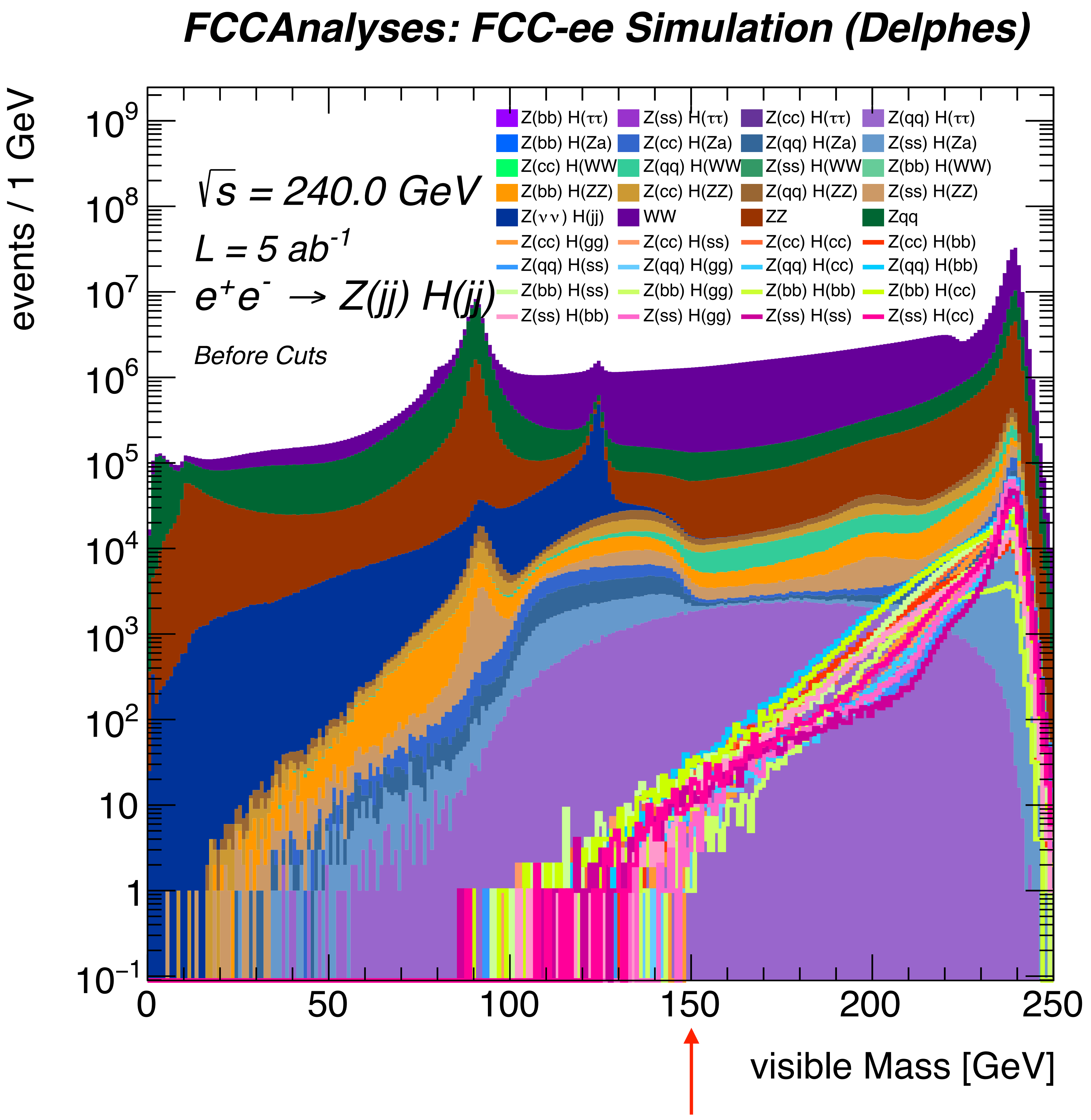
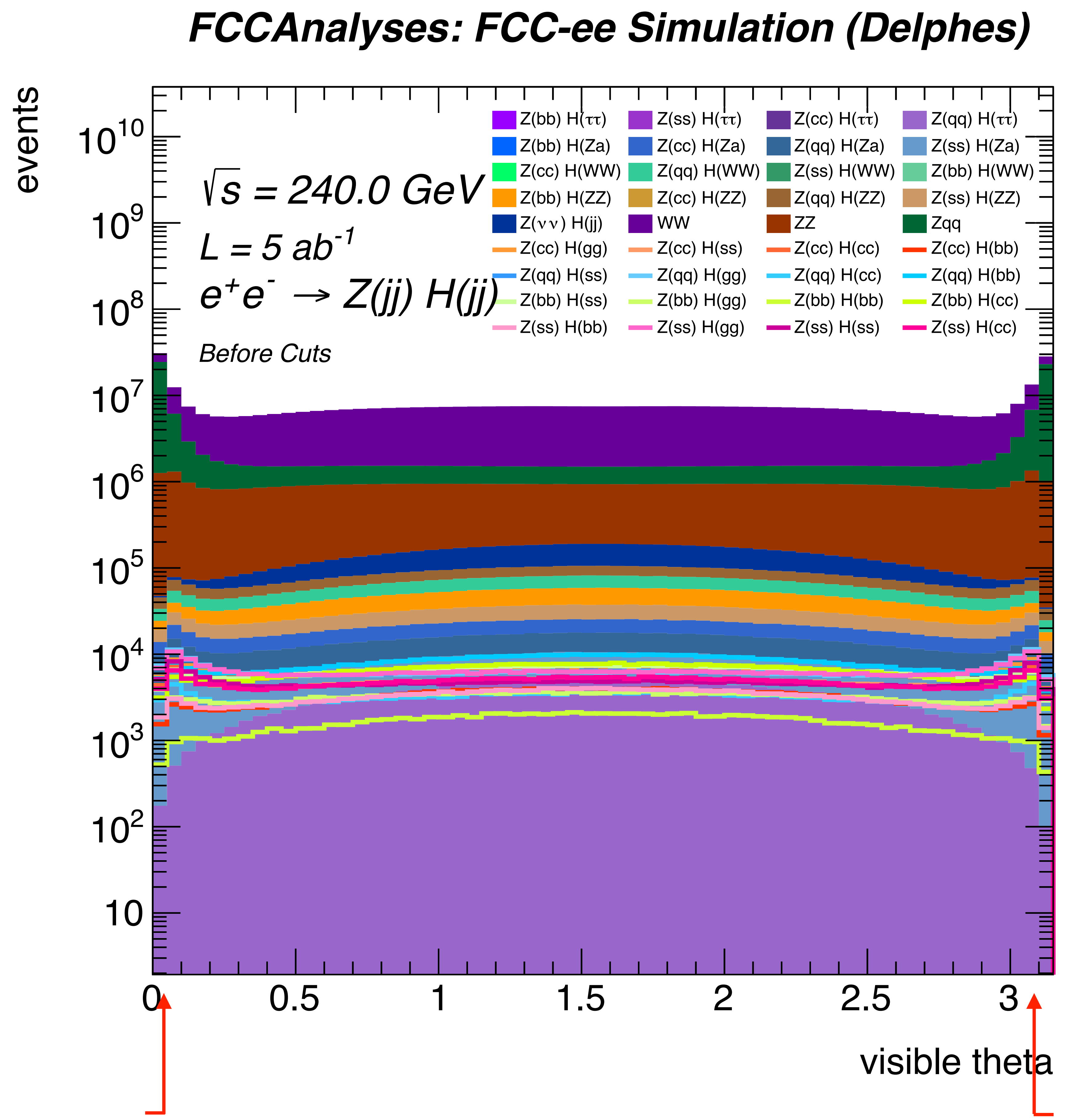
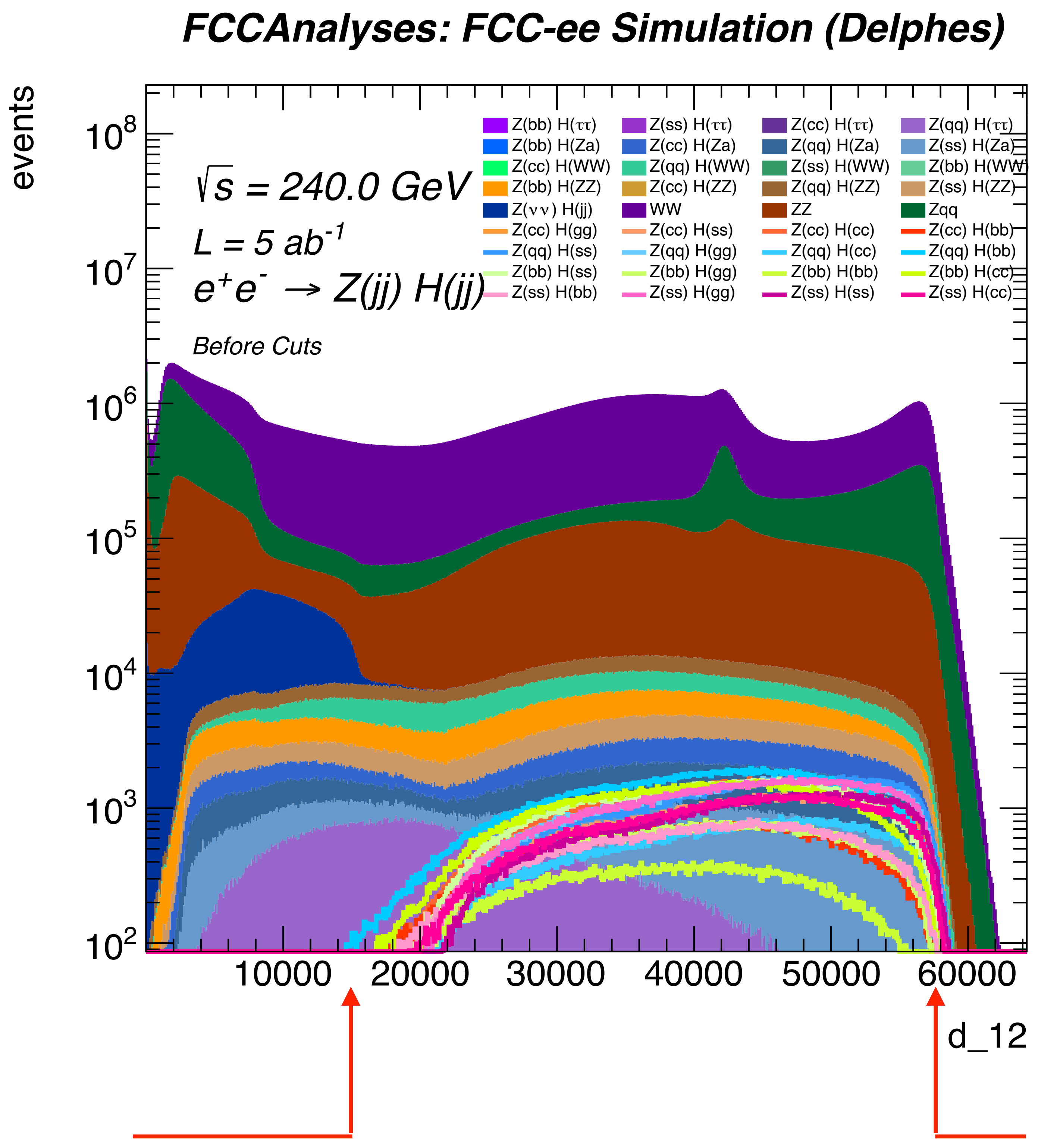
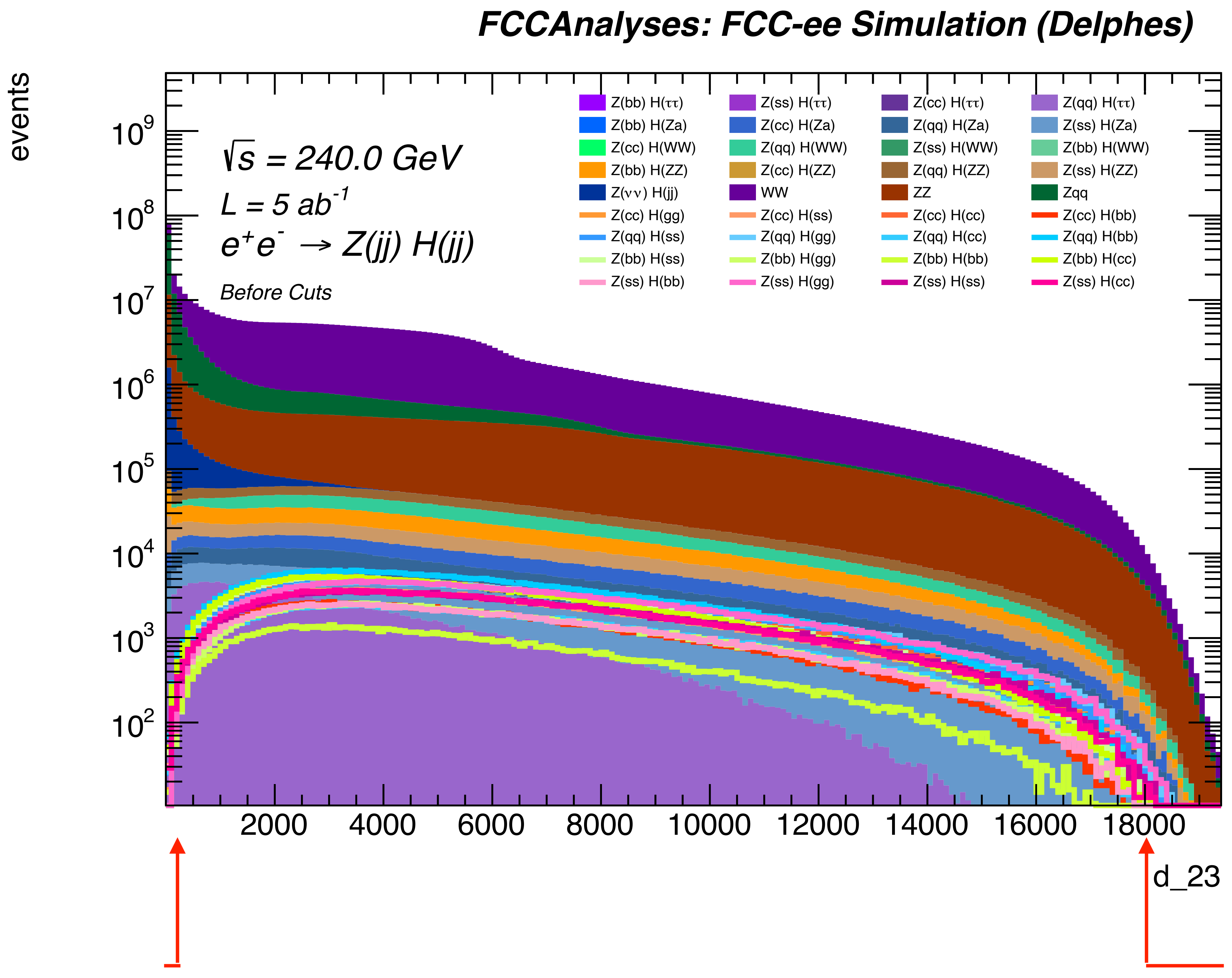
Distributions on M_{vis} and θ_{vis}

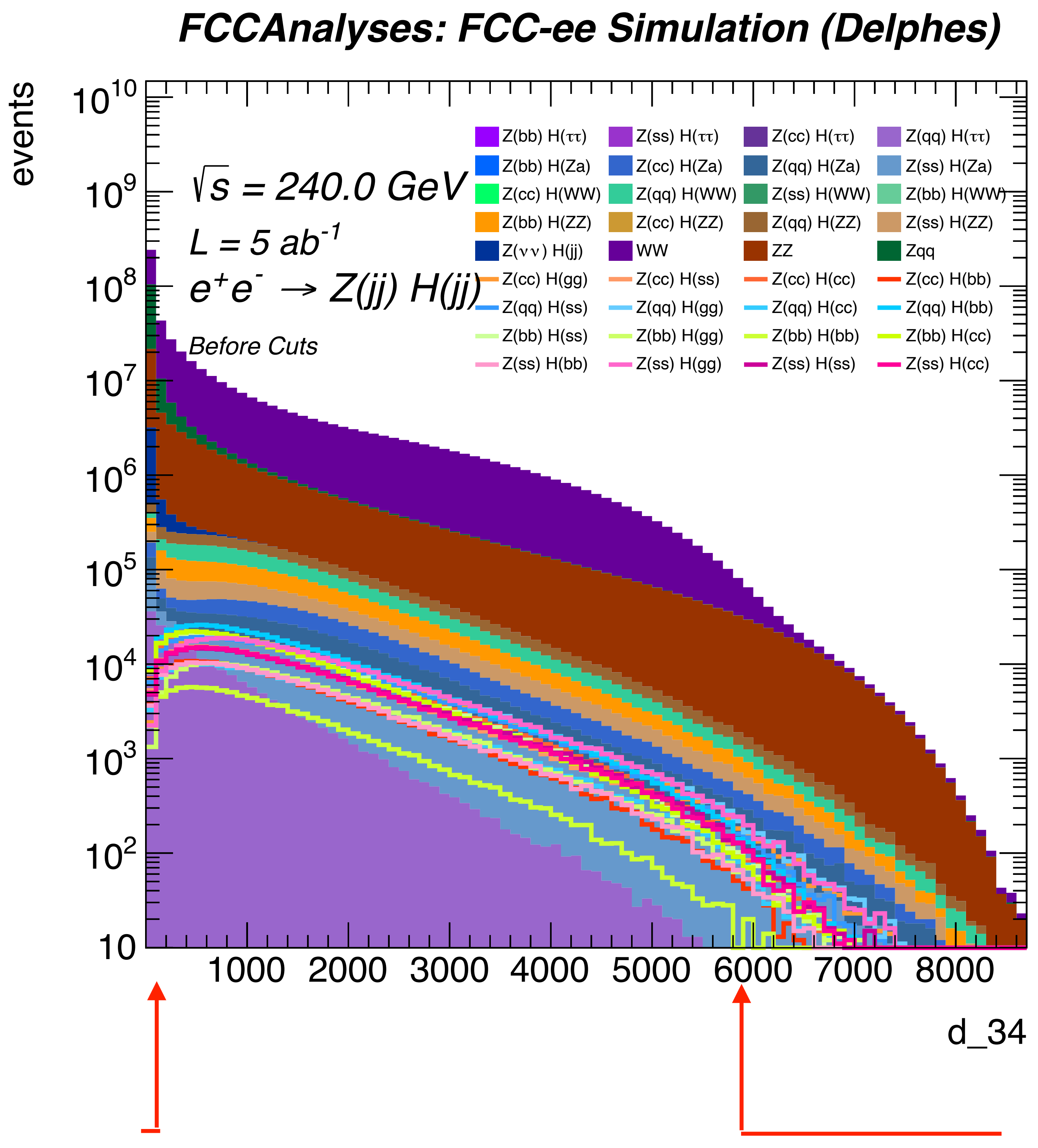




Distributions on d_{ij}







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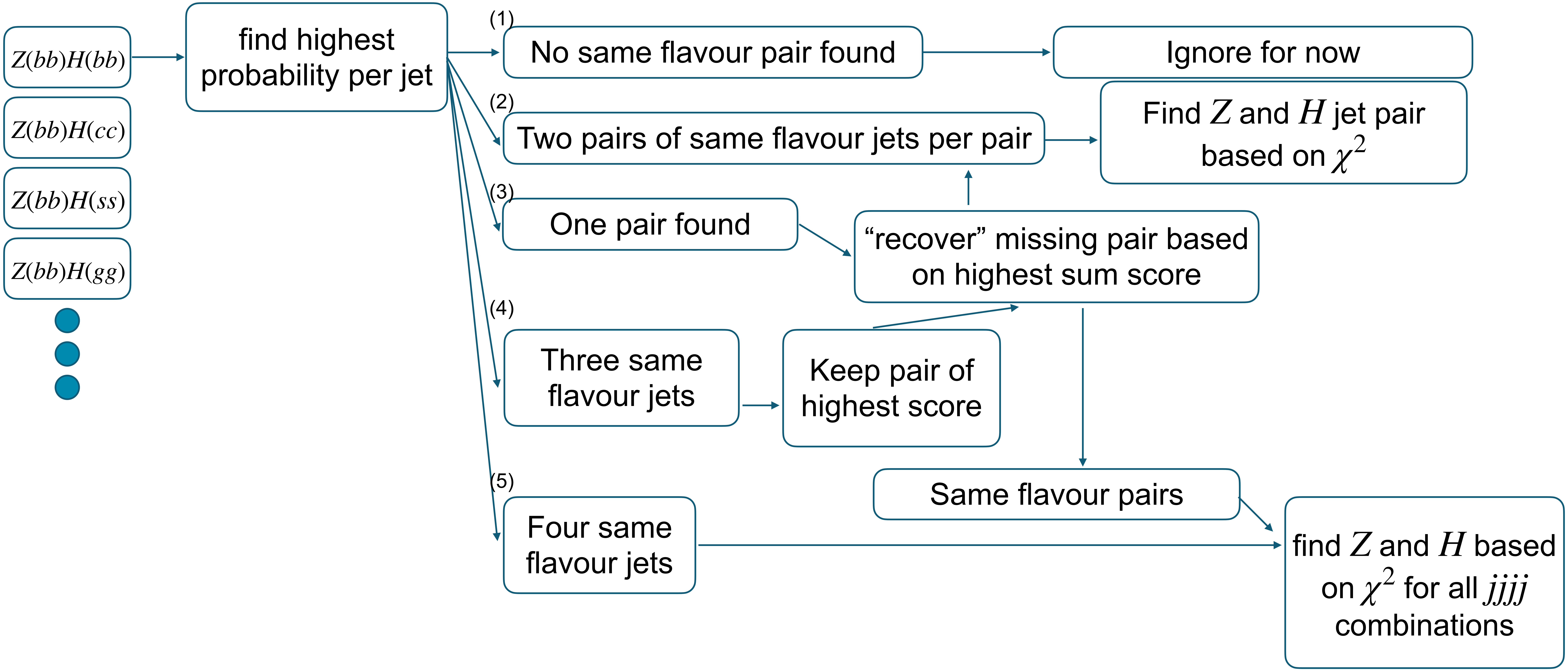
Jet pairs construction flow



True		U	D	TAU	B	C	S	G	No Pair	2 Pairs
background	Zqq	15.268	9.949	13.869	10.759	14.403	15.849	19.903	15.753	84.247
background	ZZ	12.169	13.037	2.604	20.373	18.075	19.818	13.924	8.054	91.946
background	WW	13.908	15.919	1.041	1.461	28.719	25.454	13.497	23.807	76.193
background	$Z(\nu\nu),H(jj)$	13.944	4.155	19.437	26.901	10.986	6.761	17.817	19.410	80.590
background	$Z(q\bar{q}), H(ZZ)$	13.447	15.479	0.775	15.904	12.341	12.392	29.662	11.409	88.591
background	$Z(s\bar{s}), H(ZZ)$	5.150	6.181	0.764	15.397	12.224	34.342	25.942	9.488	90.512
background	$Z(c\bar{c}), H(ZZ)$	3.342	3.730	0.881	13.928	51.115	7.635	19.369	7.116	92.884
background	$Z(b\bar{b}), H(ZZ)$	3.357	3.821	0.889	56.223	9.944	7.111	18.657	4.758	95.242
background	$Z(q\bar{q}), H(WW)$	12.940	14.884	1.482	2.565	22.826	11.614	33.689	24.295	75.705
background	$Z(s\bar{s}), H(WW)$	5.132	5.825	1.597	2.378	22.904	33.145	29.019	18.334	81.666
background	$Z(c\bar{c}), H(WW)$	3.680	3.827	1.711	2.750	58.146	7.237	22.649	7.932	92.068
background	$Z(b\bar{b}), H(WW)$	3.524	3.739	1.745	50.426	18.219	5.006	17.342	8.455	91.545
background	$Z(q\bar{q}), H(Z\gamma)$	30.189	13.781	6.788	11.735	9.730	12.132	15.644	13.664	86.336
background	$Z(s\bar{s}), H(Z\gamma)$	14.536	5.729	6.479	11.341	9.907	38.344	13.664	12.597	87.403
background	$Z(c\bar{c}), H(Z\gamma)$	10.011	3.490	5.958	10.201	53.524	8.327	8.487	9.576	90.424
background	$Z(b\bar{b}), H(Z\gamma)$	9.847	3.429	6.734	55.442	8.609	7.707	8.232	6.592	93.408
background	$Z(q\bar{q}), H(\tau\tau)$	17.177	20.281	43.998	0.678	6.388	5.505	5.973	30.470	69.530
background	$Z(s\bar{s}), H(\tau\tau)$	2.256	2.571	43.870	0.618	6.575	40.830	3.280	23.631	76.369
background	$Z(c\bar{c}), H(\tau\tau)$	0.523	0.368	43.690	1.061	50.954	0.619	2.785	7.028	92.972
background	$Z(b\bar{b}), H(\tau\tau)$	0.336	0.202	43.223	48.363	5.416	0.183	2.278	5.289	94.711
signal	$Z(s\bar{s}), H(b\bar{b})$	1.733	2.065	0.123	49.695	1.405	33.795	11.185	3.735	96.265
signal	$Z(s\bar{s}), H(c\bar{c})$	1.799	2.080	0.125	0.250	49.042	34.659	12.045	4.524	95.476
signal	$Z(s\bar{s}), H(s\bar{s})$	5.014	6.140	0.175	0.147	1.173	64.793	22.557	2.916	97.084
signal	$Z(s\bar{s}), H(gg)$	3.684	4.242	0.071	1.583	2.671	34.532	53.218	3.732	96.268
signal	$Z(b\bar{b}), H(b\bar{b})$	0.041	0.029	0.043	87.650	1.605	0.146	10.486	0.246	99.754
signal	$Z(b\bar{b}), H(c\bar{c})$	0.098	0.080	0.023	48.601	45.874	0.412	4.912	2.406	97.594
signal	$Z(b\bar{b}), H(s\bar{s})$	1.939	2.316	0.096	49.834	1.449	35.184	9.181	4.155	95.845
signal	$Z(b\bar{b}), H(gg)$	1.567	1.592	0.023	50.165	2.596	2.677	41.380	2.532	97.468
signal	$Z(q\bar{q}), H(b\bar{b})$	12.626	14.276	0.189	49.881	1.389	5.041	16.599	4.663	95.337
signal	$Z(q\bar{q}), H(c\bar{c})$	12.792	14.381	0.200	0.262	49.295	5.826	17.243	7.621	92.379
signal	$Z(q\bar{q}), H(s\bar{s})$	15.261	18.125	0.172	0.140	0.806	41.632	23.864	9.199	90.801
signal	$Z(q\bar{q}), H(gg)$	13.507	15.310	0.099	1.710	2.639	8.566	58.168	5.113	94.887
signal	$Z(c\bar{c}), H(b\bar{b})$	0.101	0.087	0.023	48.953	45.199	0.445	5.192	2.325	97.675
signal	$Z(c\bar{c}), H(c\bar{c})$	0.322	0.260	0.073	1.052	85.677	1.446	11.171	0.656	99.344
signal	$Z(c\bar{c}), H(s\bar{s})$	1.915	2.292	0.085	0.315	48.658	36.163	10.571	5.717	94.283
signal	$Z(c\bar{c}), H(gg)$	1.585	1.615	0.033	1.660	48.724	3.192	43.190	3.546	96.454

prediction

Colour scale: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90

eg $\mathrm{B} = b\bar{b}$ pair found (no H or Z assignment yet)

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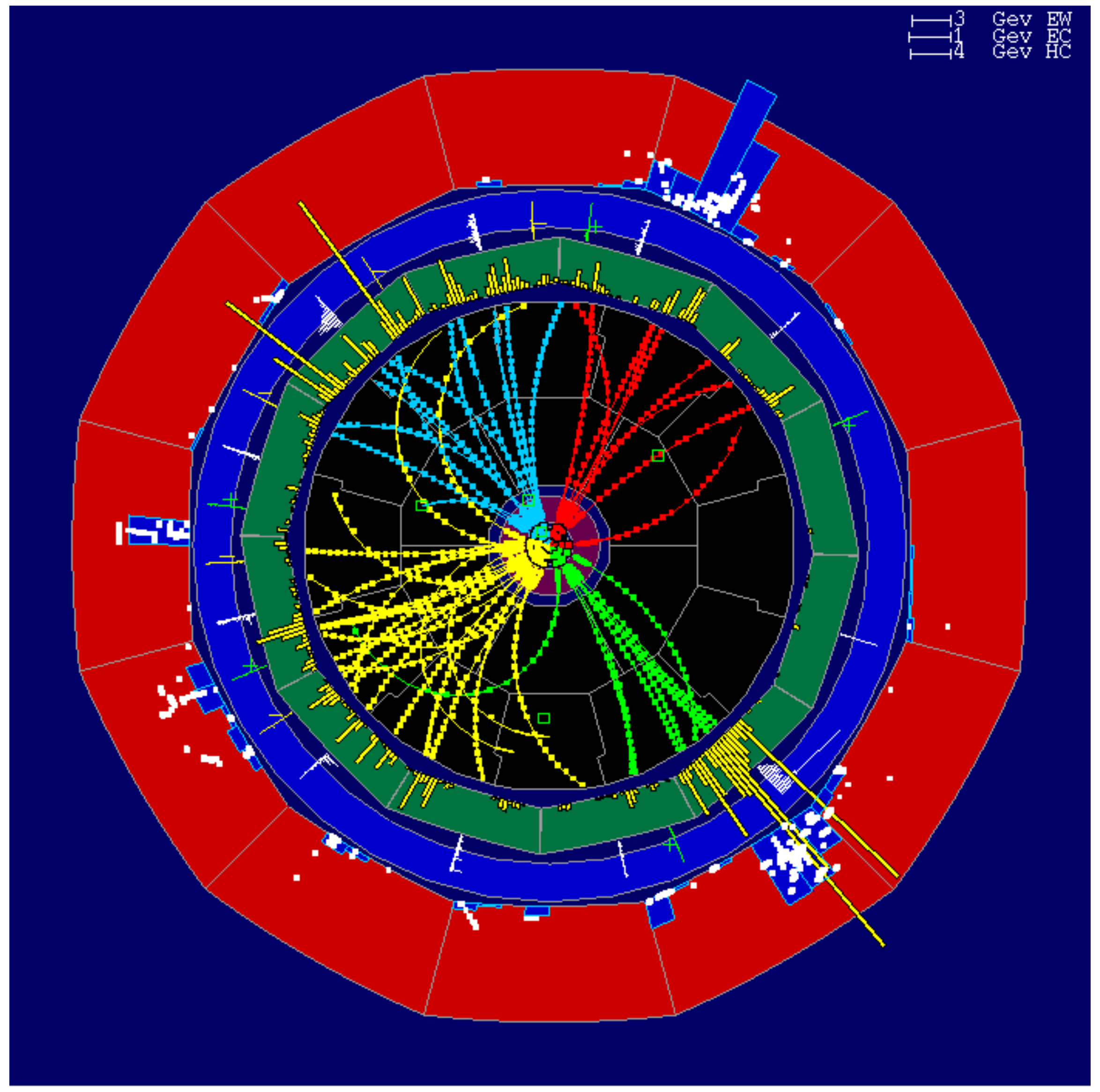
Jet energies

- Technique of Jet energy "correction" by Patrick implemented
- Added the inversion of the directions matrix to FCCAnalysis
- Observe of small percentage of events with abnormal values after matrix inversion
  - Investigating this

Precision with e^+e^- colliders (4)

- Why are e^+e^- colliders the tool of choice for precision anyway ? (cont'd)
  - Electrons are leptons, i.e., elementary particles: no underlying event
    - Corollary: Final state has known energy and momentum: ($\sqrt{s}$, 0, 0, 0)
  - Example: an $e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$ candidate
    - Four jets in the event and nothing else
    - Total energy and momentum are conserved
      - $E_1 + E_2 + E_3 + E_4 = \sqrt{s}$
      - $p_1^{x,y,z} + p_2^{x,y,z} + p_3^{x,y,z} + p_4^{x,y,z} = 0$
    - Jet directions ($\beta_i = p_i/E_i$) are very well measured



$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ \beta_1^x & \beta_2^x & \beta_3^x & \beta_4^x \\ \beta_1^y & \beta_2^y & \beta_3^y & \beta_4^y \\ \beta_1^z & \beta_2^z & \beta_3^z & \beta_4^z \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \\ E_4 \end{bmatrix} = \begin{bmatrix} \sqrt{s} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

- Jet energies (or di-jet masses: m_W) determined analytically by inverting the matrix
  - No systematic uncertainty related to jet energy calibration

A lot of Z are available anyway to calibrate and align everything

Patrick Janot — Physics at Future Colliders 28-29 July 2016 — 7

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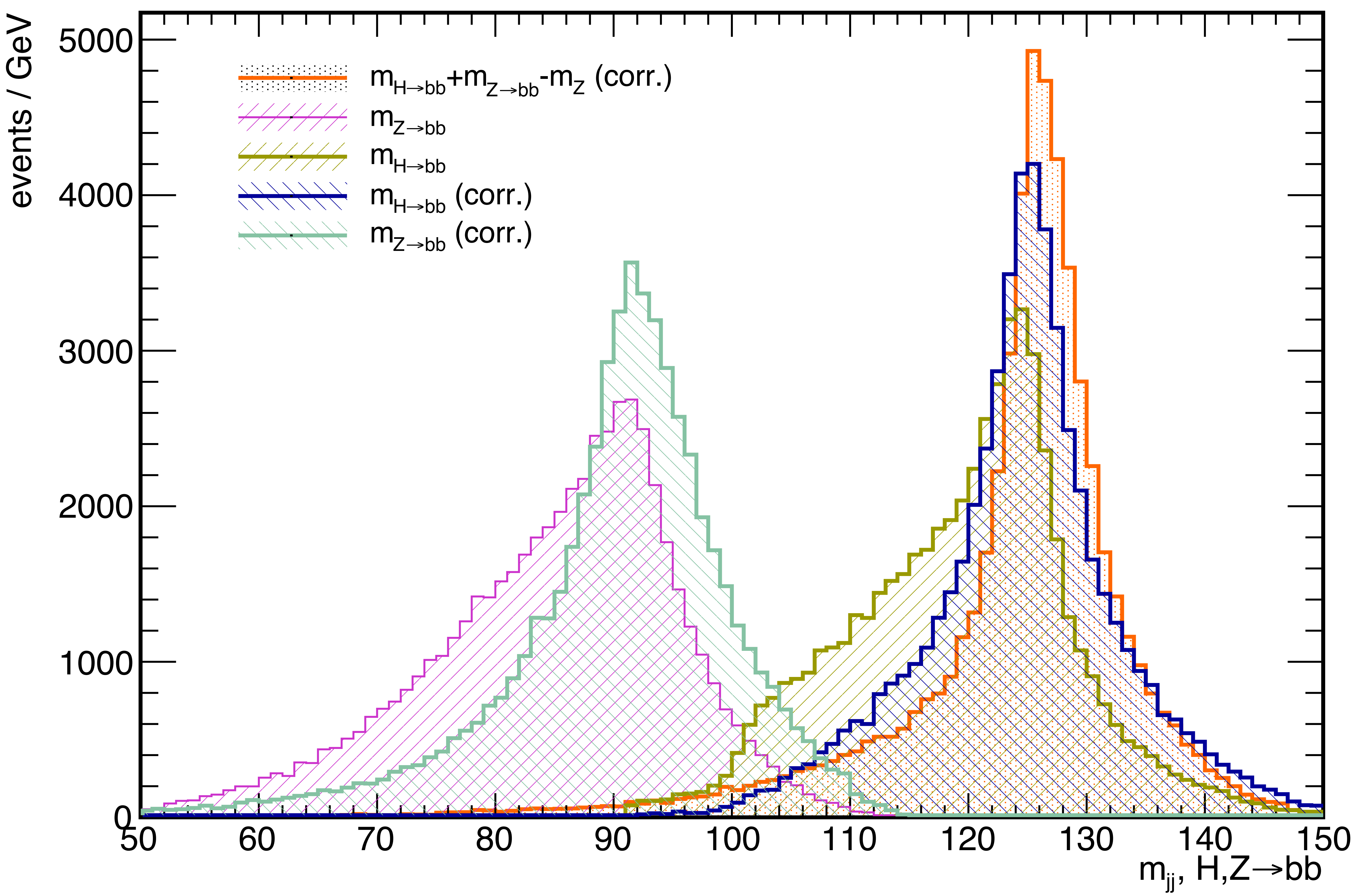
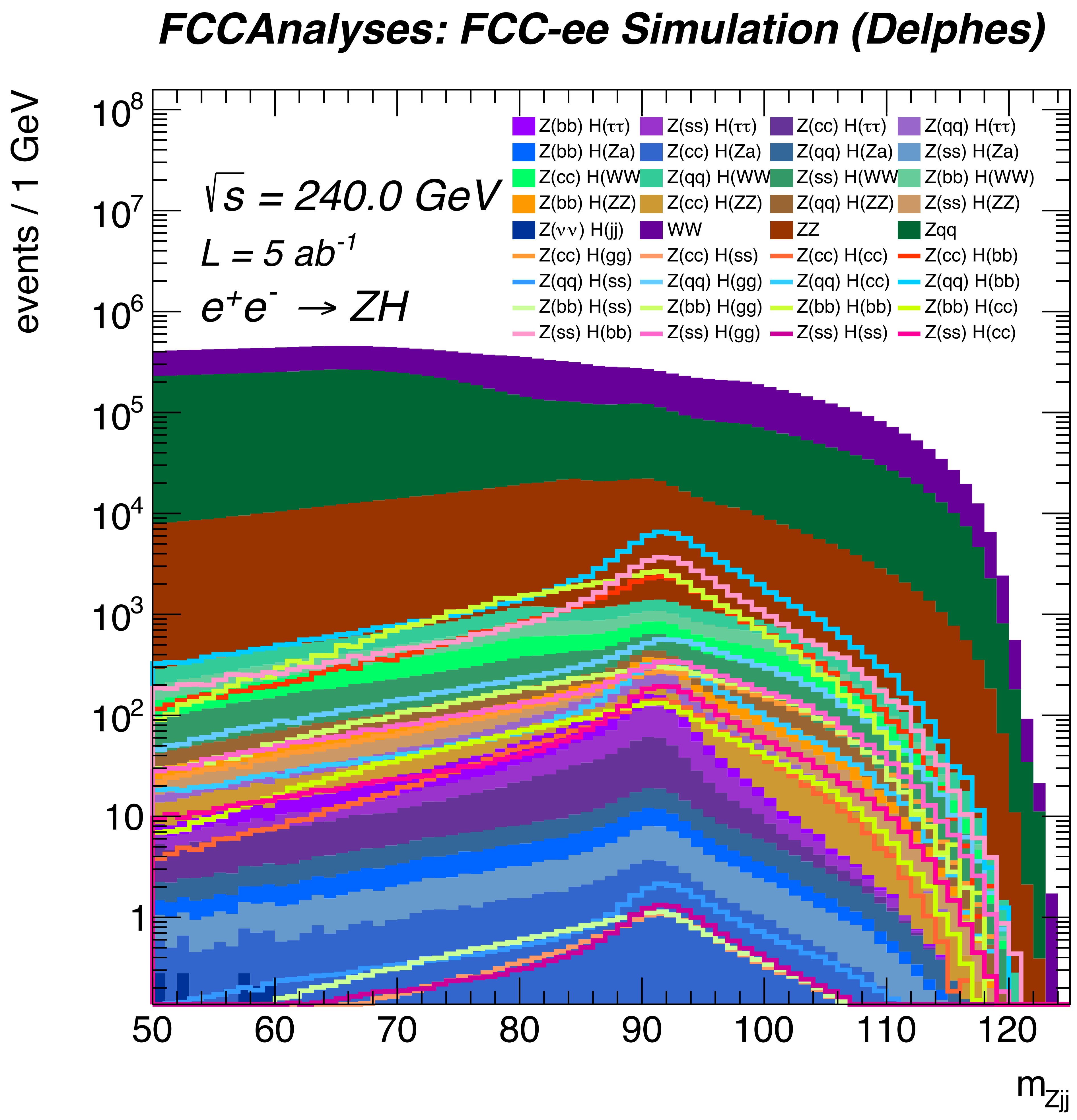
Example of m_{jj} distribution after energy correction

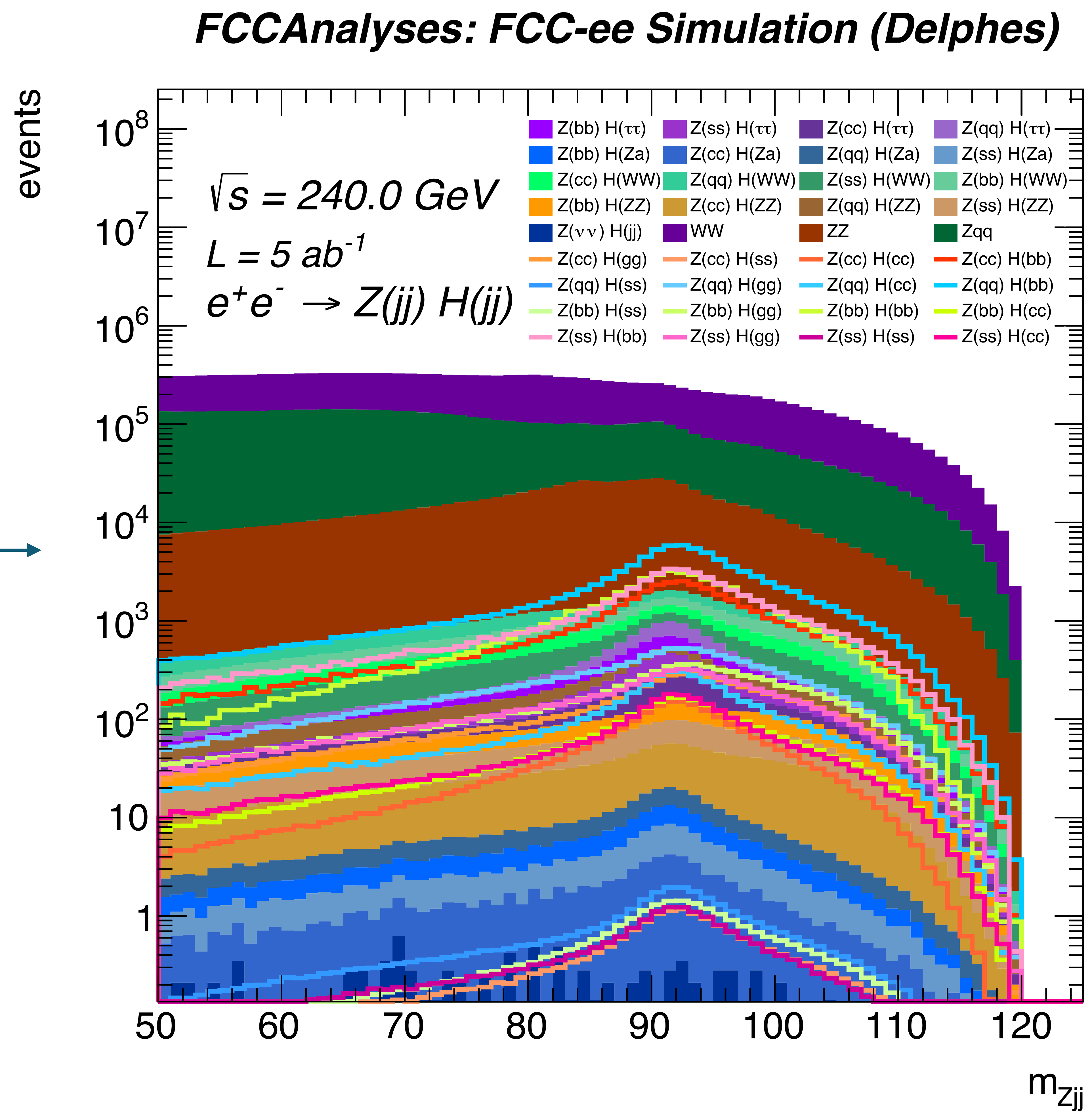
- Example histograms on the MC sample where both Z, H decay to a pair of b
- Distributions shown are after the analysis where $b\bar{b}b\bar{b}$ are found and assigned to H, Z
- The energy correction seems improve the distributions
- The corrected m_{jj} was used to perform the fit
- Plotted as well the $m_{Hjj} + m_{Zjj} - m_Z$



m_{Zjj} distributions



energy
correction



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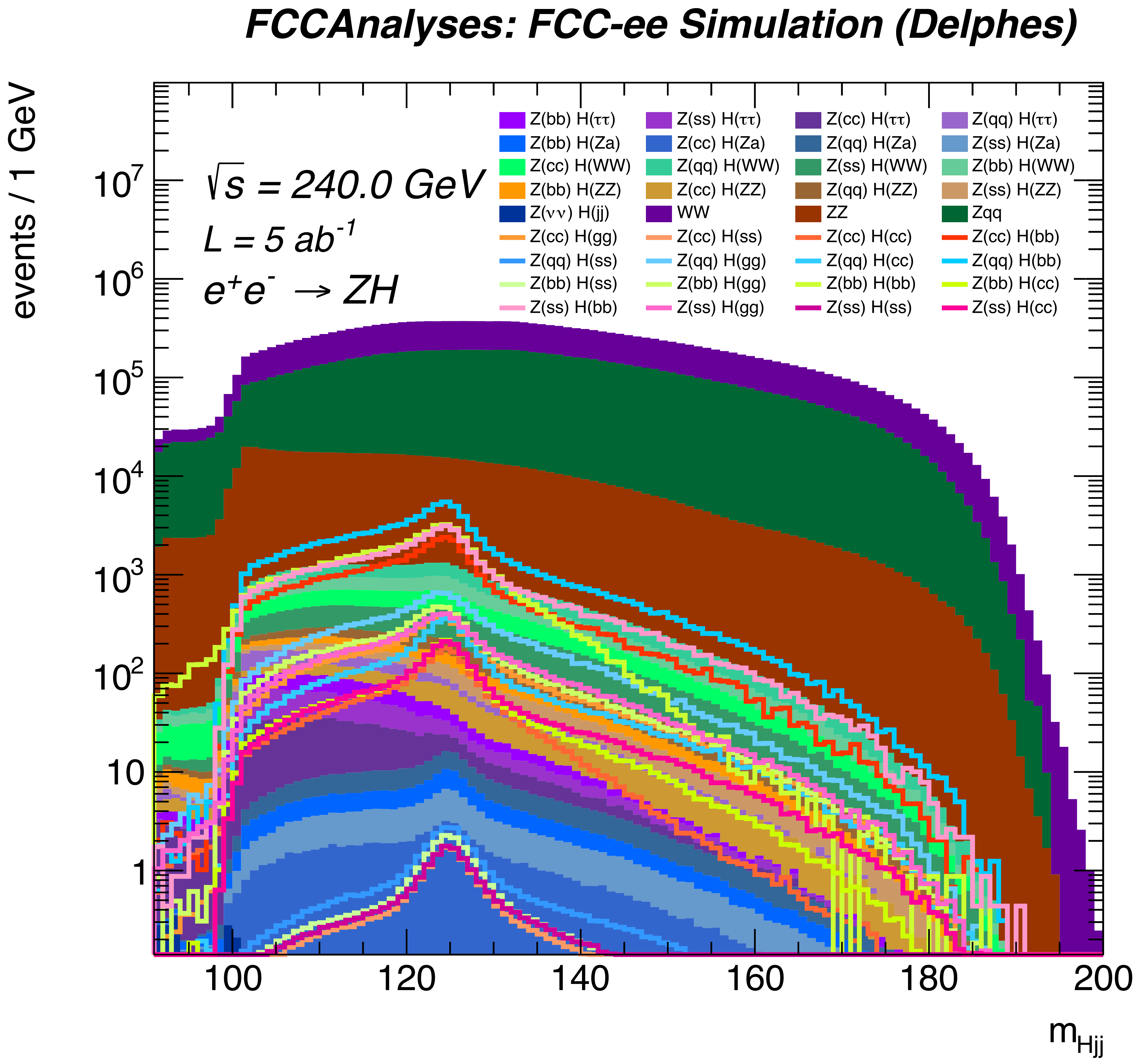
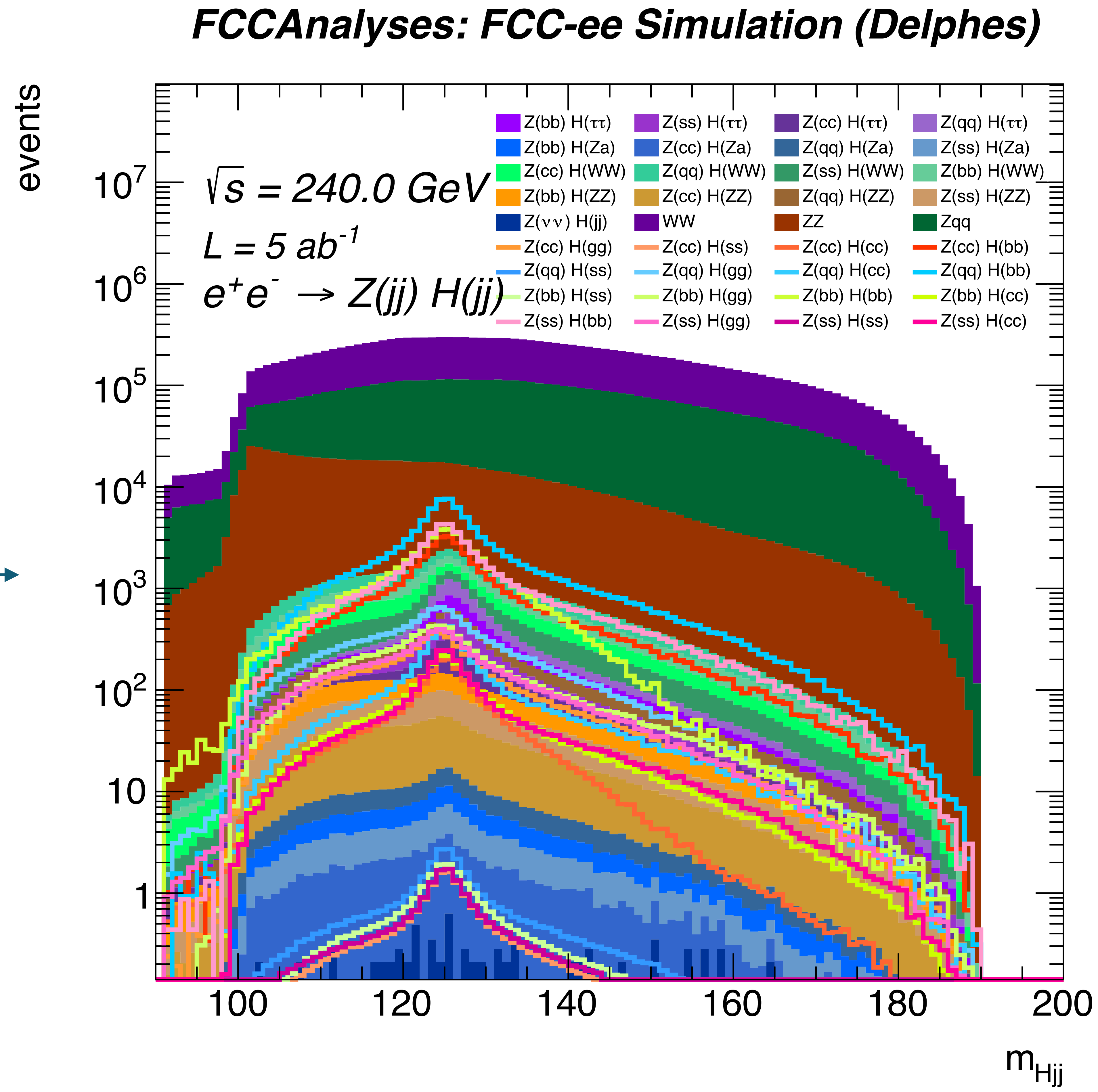
m_{Hjj} distributions



energy
correction



Yields & fit efficiencies $\sqrt{s} = 240\,\mathrm{GeV}, \mathscr{L} = 5\,\mathrm{ab}^{-1}$

- final efficiency < than cut efficiency
  - events without 2 jet pair findings
  - Requesting fitting categories discriminate further against background

		Initial	Lepton cut	$M_{\mathrm{vis}}, \theta_{\mathrm{vis}}$	d_{ij}	fit cat.	Fit
$e^+e^- \to Z(cc)H(gg)$	Yield	9555	98.7	88.3	87.2	69.3	4479
	Sig.	0.508					1.329
$e^+e^- \to Z(cc)H(ss)$	Yield	28	99.0	88.4	86.3	67.9	17
	Sig.	0.001					0.005
$e^+e^- \to Z(cc)H(cc)$	Yield	3374	96.6	88.1	86.1	70.1	2231
	Sig.	0.180					0.662
$e^+e^- \to Z(cc)H(bb)$	Yield	67950	89.7	83.5	81.2	68.0	44379
	Sig.	3.616					13.166
$e^+e^- \to Z(qq)H(gg)$	Yield	21835	99.8	86.2	85.2	60.3	6394
	Sig.	1.162					1.897
$e^+e^- \to Z(qq)H(ss)$	Yield	64	99.9	86.6	84.6	56.2	26
	Sig.	0.003					0.008
$e^+e^- \to Z(qq)H(cc)$	Yield	7710	97.8	87.1	85.2	67.8	3918
	Sig.	0.410					1.162
$e^+e^- \to Z(qq)H(bb)$	Yield	155350	91.4	83.8	81.7	68.0	79138
	Sig.	8.266					23.477
$e^+e^- \to Z(bb)H(gg)$	Yield	12270	94.6	87.0	85.9	70.3	5881
	Sig.	0.653					1.745
$e^+e^- \to Z(bb)H(ss)$	Yield	36	95.0	87.3	85.1	72.2	22
	Sig.	0.002					0.007
$e^+e^- \to Z(bb)H(cc)$	Yield	4332	92.1	85.7	83.4	69.6	2927
	Sig.	0.231					0.868
$e^+e^- \to Z(bb)H(bb)$	Yield	87250	84.4	79.8	77.3	62.8	52595
	Sig.	4.643					15.603
$e^+e^- \to Z(ss)H(gg)$	Yield	12265	99.8	87.0	85.9	62.3	4345
	Sig.	0.653					1.289
$e^+e^- \to Z(ss)H(ss)$	Yield	36	99.9	87.2	85.2	58.3	17
	Sig.	0.002					0.005
$e^+e^- \to Z(ss)H(cc)$	Yield	4330	97.8	87.7	85.7	70.1	2551
	Sig.	0.230					0.757
$e^+e^- \to Z(ss)H(bb)$	Yield	87250	91.3	84.1	82.0	69.0	50559
	Sig.	4.643					14.999

	Yields	Lepton cut	$M_{\mathrm{vis}}, \theta_{\mathrm{vis}}$	d_{ij}	fit cat.	Yield for Fit
$e^+e^- \to Z(bb)H(\tau\tau)$	9400	63.7	43.9	32.8	26.5	268
$e^+e^- \to Z(ss)H(\tau\tau)$	7320	67.1	48.3	36.4	26.8	196
$e^+e^- \to Z(cc)H(\tau\tau)$	9395	68.0	50.2	38.1	24.8	213
$e^+e^- \to Z(qq)H(\tau\tau)$	16730	67.9	50.1	38.1	22.1	286
$e^+e^- \to Z(bb)H(Z\gamma)$	230	86.5	62.4	61.3	43.5	79
$e^+e^- \to Z(ss)H(Z\gamma)$	179	90.5	64.0	62.9	43.6	63
$e^+e^- \to Z(cc)H(Z\gamma)$	230	91.7	63.7	62.5	39.6	70
$e^+e^- \to Z(qq)H(Z\gamma)$	409	91.6	63.1	61.9	38.1	113
$e^+e^- \to Z(bb)H(WW)$	32250	64.7	57.4	54.6	35.0	8672
$e^+e^- \to Z(ss)H(WW)$	25115	68.0	59.8	57.0	35.3	6622
$e^+e^- \to Z(cc)H(WW)$	32235	68.7	59.9	57.0	27.4	6077
$e^+e^- \to Z(qq)H(WW)$	57400	68.6	59.4	56.6	24.7	9133
$e^+e^- \to Z(bb)H(ZZ)$	3958	81.8	60.6	57.8	39.3	1247
$e^+e^- \to Z(ss)H(ZZ)$	3082	86.1	63.3	60.5	39.3	969
$e^+e^- \to Z(cc)H(ZZ)$	3956	87.5	63.9	61.1	36.3	1050
$e^+e^- \to Z(qq)H(ZZ)$	7045	87.5	63.6	60.8	34.8	1679
$e^+e^- \to Z(\nu\nu)H(jj)$	230955	87.5	00.1	00.0	00.0	3
$e^+e^- \to W^+W^-$	82192500	64.1	45.1	37.9	12.0	8130416
$e^+e^- \to ZZ$	6794950	79.8	43.4	38.1	12.2	640629
$e^+e^- \to Z/\gamma^*(q\bar{q})$	263269500	96.5	31.8	07.6	02.0	2295362

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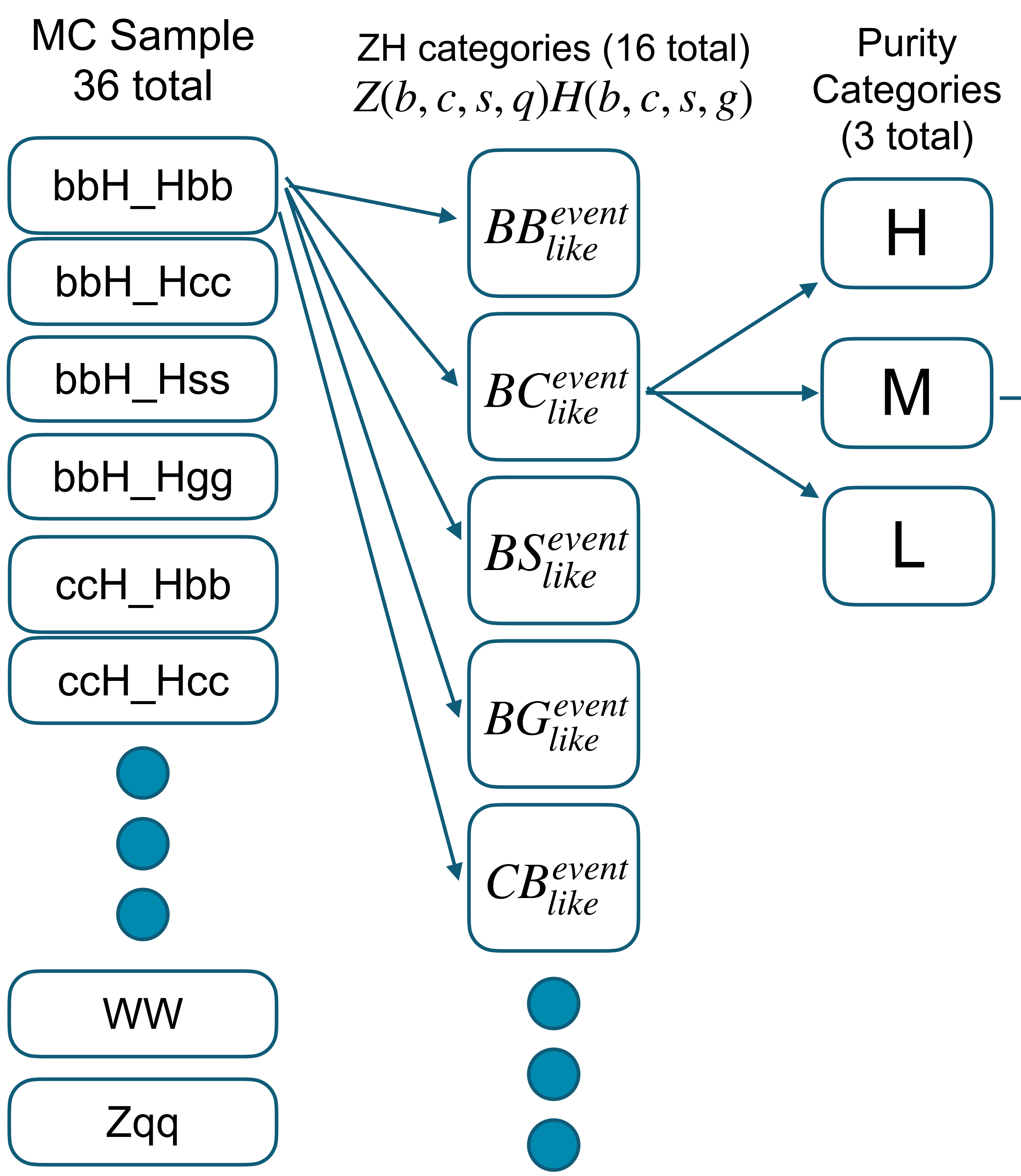
Fitting strategy

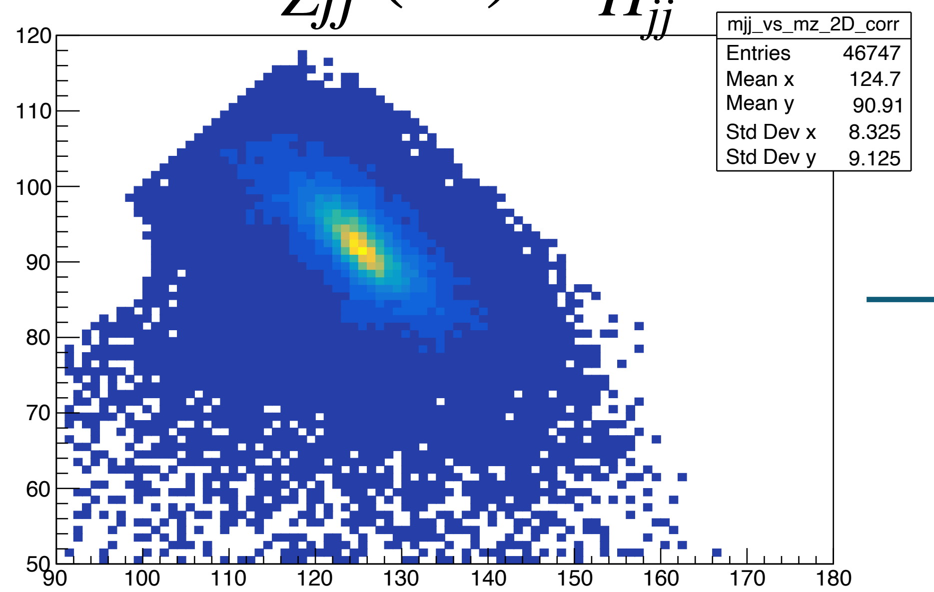
For the fit the HiggsAnalysis-CombinedLimit was used (within CMSSW - http://cms-analysis.github.io/HiggsAnalysis-CombinedLimit/ (open access)) along with CombineHarvester (http://cms-analysis.github.io/CombineHarvester/)



Purity categories for $H \to jj$

	B, C, G	S
L	< 1.1	< 0.8
M	$\in [1.1, 1.8]$	$\in [0.8, 1.4]$
H	> 1.8	> 1.4

$m_{Z_{jj}}$ (vs) $m_{H_{jj}}$



5 GeV bin on $m_{Z_{jj}}$ ($m_{H_{jj}}$ bin 1 GeV) (14 total bins)

Four signal strength $r_{Hbb}, r_{Hcc}, r_{Hgg}, r_{Hss}$ Shape-Combined fit for all S+B in the categories (25k bins)

Expected Precision for the $\sigma(ZH) \times \mathrm{BR}(H \to jj)$ at 68 % CL

ZH final state		Precision
$Z \to jj$ ($j = b, s, c, q$)	$H \to b\bar{b}$	0.3 %
	$H \to c\bar{c}$	3.5 %
	$H \to gg$	2.4 %
	$H \to s\bar{s}$	436 %

Independent fit with combineTF gives compatible results

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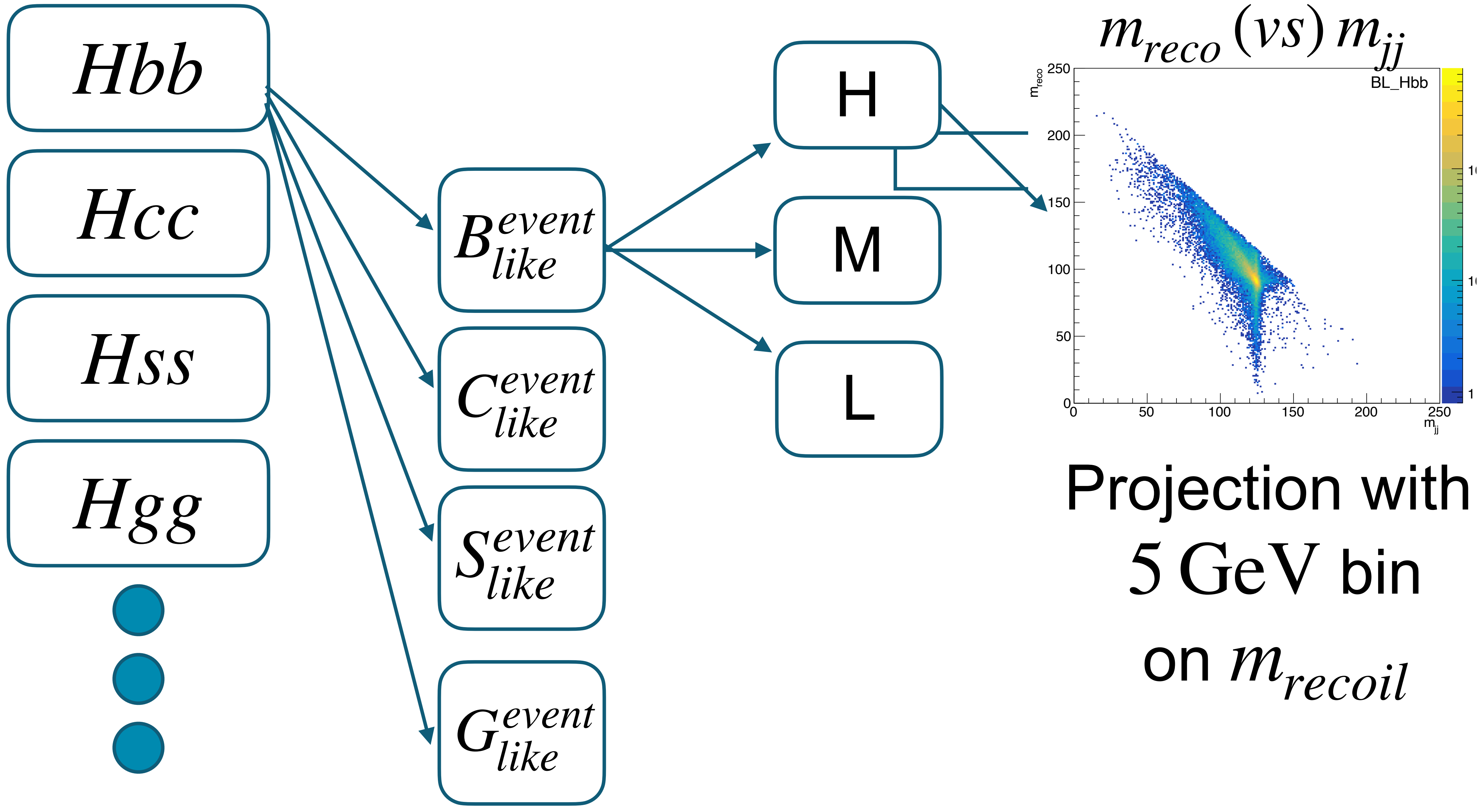
Reminder $ZH(\nu\nu jj)$ analysis

- For the fit the HiggsAnalysis-CombinedLimit was used (within CMSSW - http://cms-analysis.github.io/HiggsAnalysis-CombinedLimit/ (open access)) along with CombineHarvester (http://cms-analysis.github.io/CombineHarvester/)

	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



Projection with 5 GeV bin on m_{recoil}

Shape-Combined fit for all S+B in the 12 categories

	Precision at 68 % CL
$r(Hgg)$	1.1 %
$r(Hs\bar{s})$	137 %
$r(Hc\bar{c})$	2.6 %
$r(Hb\bar{b})$	0.36 %

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Combine $Z(\nu\nu)H$ & $Z(qq)H$

- First attempt to fit the inv. and full hadronic channels with combine
- For the fit the HiggsAnalysis-CombinedLimit was used (within CMSSW - http://cms-analysis.github.io/HiggsAnalysis-CombinedLimit/ (open access)) along with CombineHarvester (http://cms-analysis.github.io/CombineHarvester/)

Expected Precision for the
$\sigma(ZH) \times \text{BR}(H \to jj)$ at 68 % CL

ZH final state		Precision
$Z \to jj$ $(j = b, s, c, q)$	$H \to b\bar{b}$	0.2 %
	$H \to c\bar{c}$	2.1 %
$Z \to \nu\nu$	$H \to gg$	1.0 %
	$H \to s\bar{s}$	130 %

Preliminary

Summary

- Analysis performed on the *ZH* full hadronic final state using the winter2023 datasets, IDEA detector, ParticleNet tagger
- Analysis strategy on jet scores gives encouraging preliminary results
  - Work is ongoing to improve the jet pairs and "recover" events where no pairs are found (if possible)
- Analysis suffers (compared to leptonic channel) from the jet energy resolution and the ambiguities of jets originated to *Z,H* but benefits from high BR
  - Work towards to optimise method, clustering techniques to see if the result can improve
- Fit on 4 signal strength shows encouraging results (validated with other techniques)
  - First attempt to combine $ZH(\nu\nu jj)$ and $ZH(jjjj)$
- We will now be looking into the tracker layout(s) for additional improvements

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Backup

Jet energy

- We flag events that show abnormal values after the matrix inversion
- The percentage of events with this flag is shown on the tables **after the above cuts**
- Signal events are 0.1-0.2% of events
- Background events vary from 0.1-0.6%
- Not significant fraction

total events normalised to 1

	flag
$e^+e^- \to Z(cc)H(gg)$	0.012
$e^+e^- \to Z(cc)H(ss)$	0.012
$e^+e^- \to Z(cc)H(cc)$	0.015
$e^+e^- \to Z(cc)H(bb)$	0.019
$e^+e^- \to Z(qq)H(ss)$	0.008
$e^+e^- \to Z(qq)H(gg)$	0.008
$e^+e^- \to Z(qq)H(cc)$	0.012
$e^+e^- \to Z(qq)H(bb)$	0.017
$e^+e^- \to Z(bb)H(ss)$	0.018
$e^+e^- \to Z(bb)H(gg)$	0.018
$e^+e^- \to Z(bb)H(bb)$	0.022
$e^+e^- \to Z(bb)H(cc)$	0.020
$e^+e^- \to Z(ss)H(bb)$	0.017
$e^+e^- \to Z(ss)H(gg)$	0.009
$e^+e^- \to Z(ss)H(ss)$	0.009
$e^+e^- \to Z(ss)H(cc)$	0.012

	flag
$e^+e^- \to Z(bb)H(\tau\tau)$	0.032
$e^+e^- \to Z(ss)H(\tau\tau)$	0.040
$e^+e^- \to Z(cc)H(\tau\tau)$	0.037
$e^+e^- \to Z(qq)H(\tau\tau)$	0.040
$e^+e^- \to Z(bb)H(Za)$	0.017
$e^+e^- \to Z(cc)H(Za)$	0.014
$e^+e^- \to Z(qq)H(Za)$	0.012
$e^+e^- \to Z(ss)H(Za)$	0.012
$e^+e^- \to Z(cc)H(WW)$	0.060
$e^+e^- \to Z(qq)H(WW)$	0.061
$e^+e^- \to Z(ss)H(WW)$	0.061
$e^+e^- \to Z(bb)H(WW)$	0.057
$e^+e^- \to Z(bb)H(ZZ)$	0.053
$e^+e^- \to Z(cc)H(ZZ)$	0.055
$e^+e^- \to Z(qq)H(ZZ)$	0.056
$e^+e^- \to Z(ss)H(ZZ)$	0.056
$e^+e^- \to Z(\nu\nu)H(jj)$	0.000
$e^+e^- \to W^+W^-$	0.032
$e^+e^- \to ZZ$	0.012
$e^+e^- \to Z/\gamma^*(q\bar{q})$	0.009

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