FCC-ee
ZH full hadronic final state and combination with $vvjj$ at $\sqrt{s} = 240\,\mathrm{GeV}$ and $\sqrt{s} = 365\,\mathrm{GeV}$

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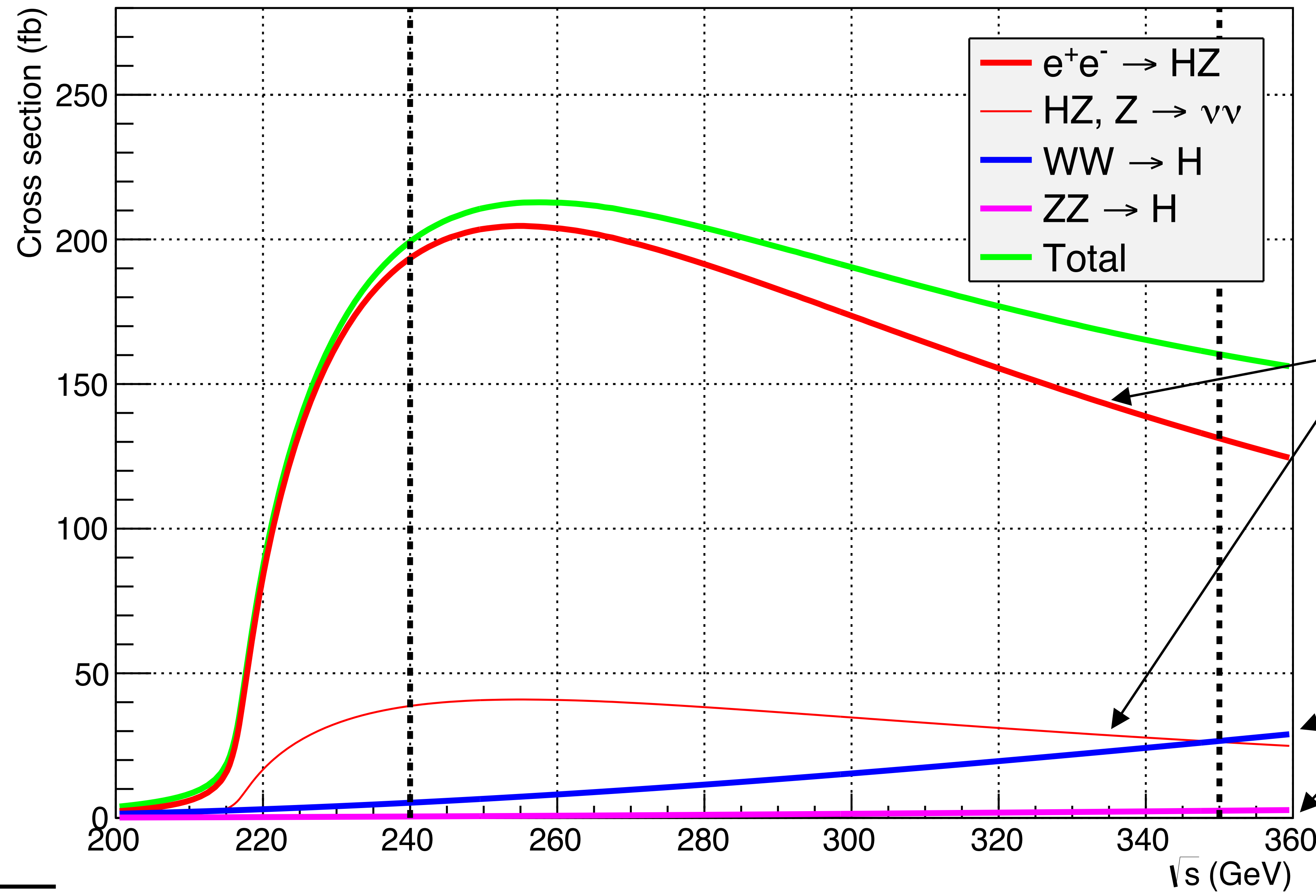
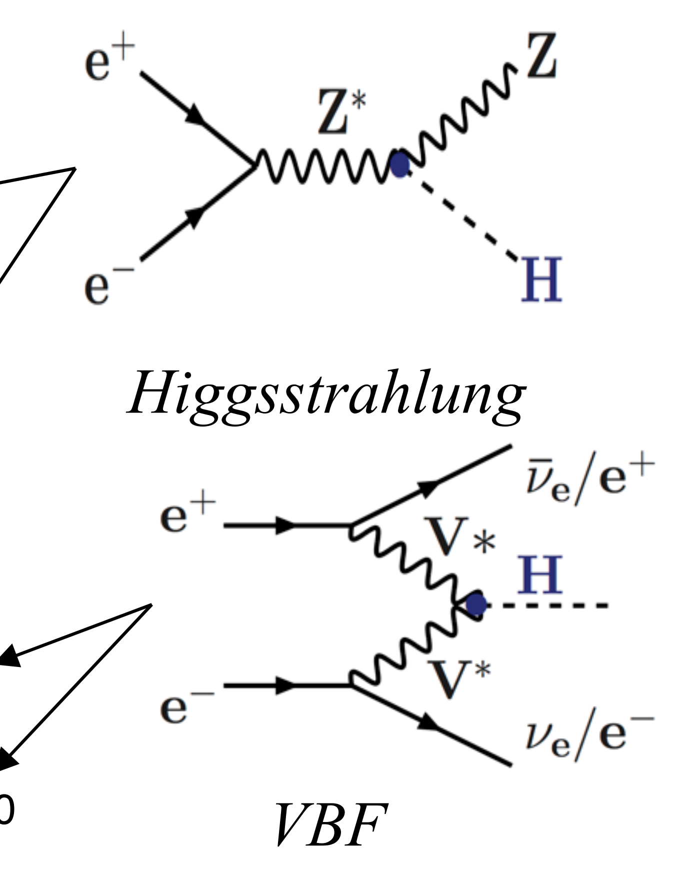
Motivation

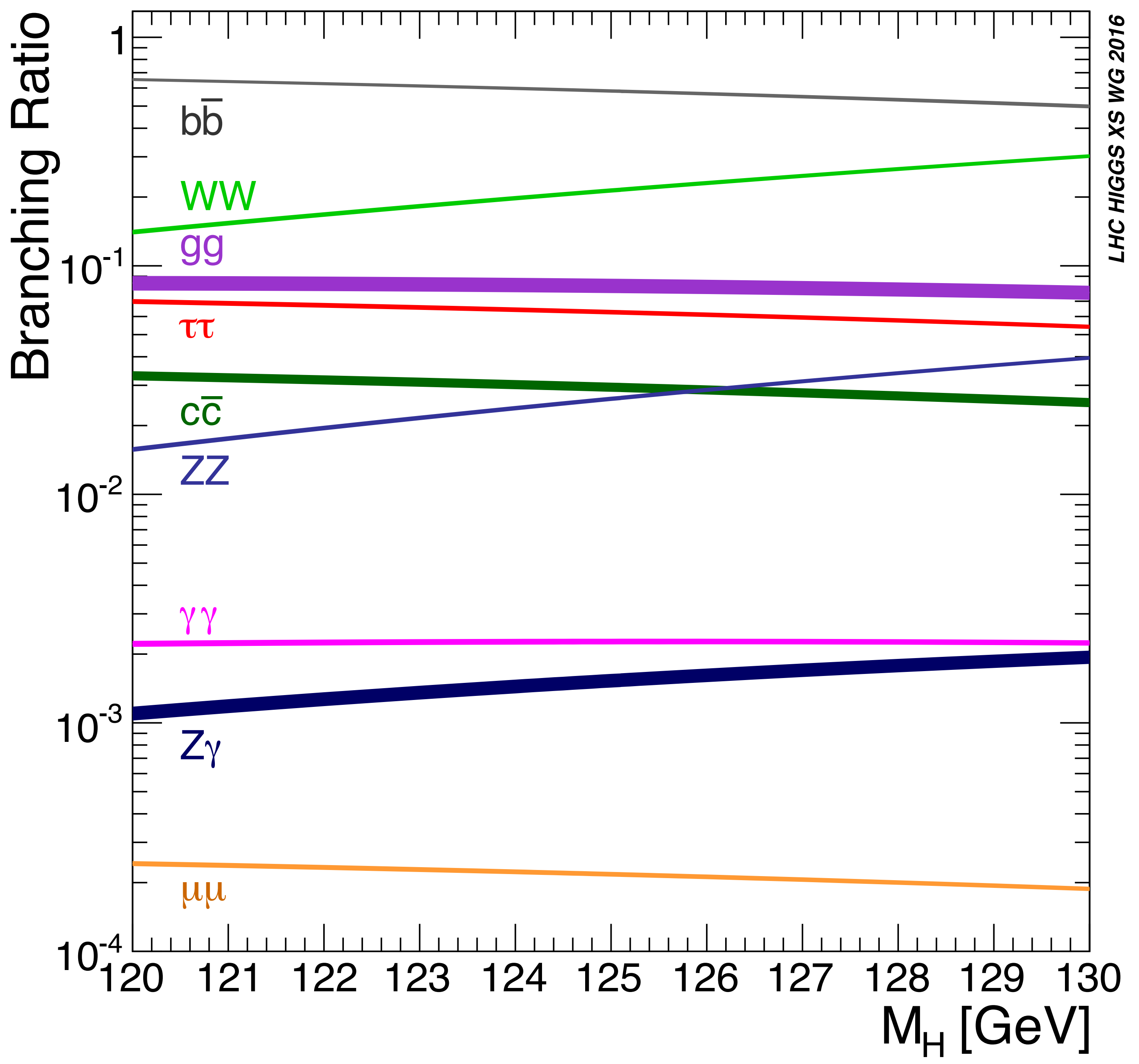
- At $\sqrt{s} = 240\,\text{GeV}$ the Higgs boson is produced in association with a Z boson → measure couplings !
- Expand the analysis at $\sqrt{s} = 365\,\text{GeV}$





First Look at the Physics Case of TLEP
arXiv:1308.6176

Handbook of LHC Higgs cross sections
arXiv:1610.07922



Process	Cross-section $[\text{pb}^{-1}]$
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

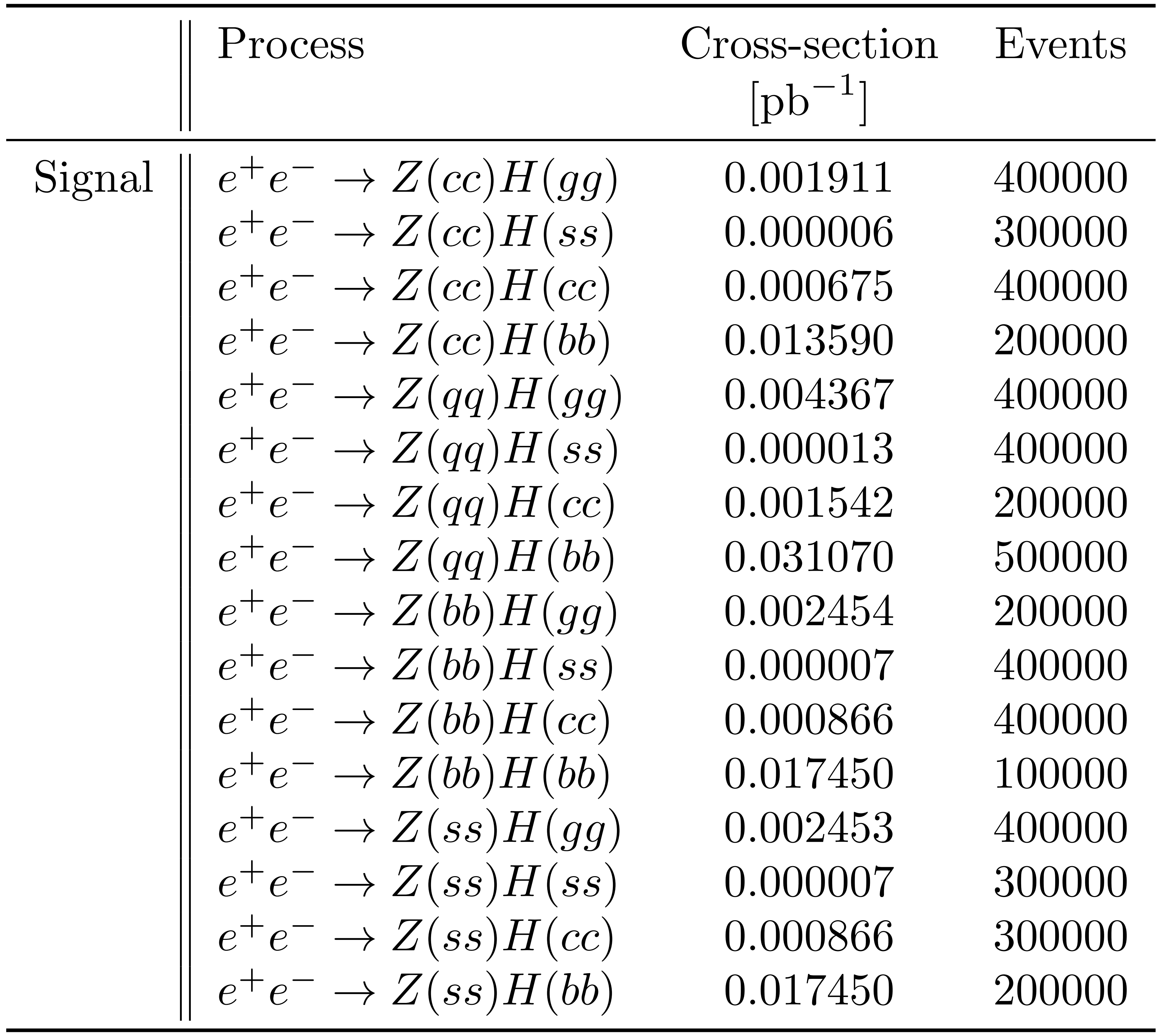
- Analysis of full hadronic final state
- $Z(ll)$(BR($Z \to ll$) ~ 6.7 %) and $Z(\nu\nu)$ (BR($Z \to \nu\nu$) ~ 20 %) channels have been already addressed
- $Z(q\bar{q})$ provides significantly higher statistics BR($Z \to q\bar{q}$) ~ 70 %
  - Greater challenge though since it depends on jet clustering
  - 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

Analysis overview

- Signal
  - $Z \rightarrow jj, H \rightarrow jj \quad (j = b, c, s, g)$
- 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

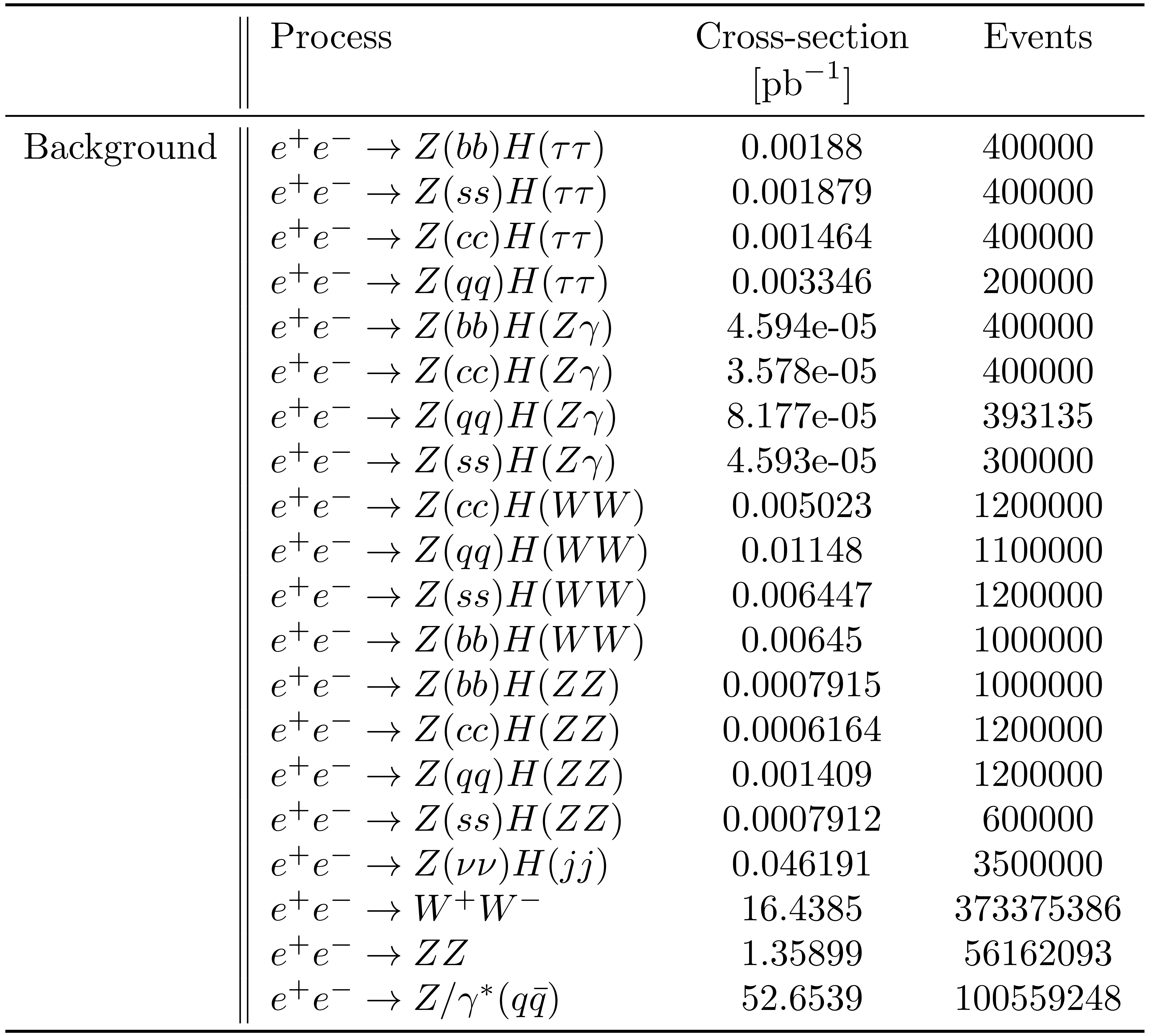
Datasets

- 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

Cuts

- Events (orthogonal to $ll, \nu\nu$ analysis)
  - $n_j = 4$ per event
  - Cuts on leptons
    - lepton (both e, μ) $p_l < 20\,\mathrm{GeV}$ & $n_{e,\mu} \leq 2$ per event
  - Cuts on $m_{\mathrm{vis}}, \theta_{\mathrm{vis}}$
    - $m_{\mathrm{vis}} > 150\,\mathrm{GeV}$,
    - $0.15 < \theta_{\mathrm{vis}} < 3$
  - Clustering merging parameter cut (d_{12}, d_{23}, d_{34})
  - χ^2 on the energy correction <30
- On the jet pairs
  - 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
  - $50 < m_{Z_{jj}} < 125\,\mathrm{GeV}, m_{H_{jj}} > 91\,\mathrm{GeV}$

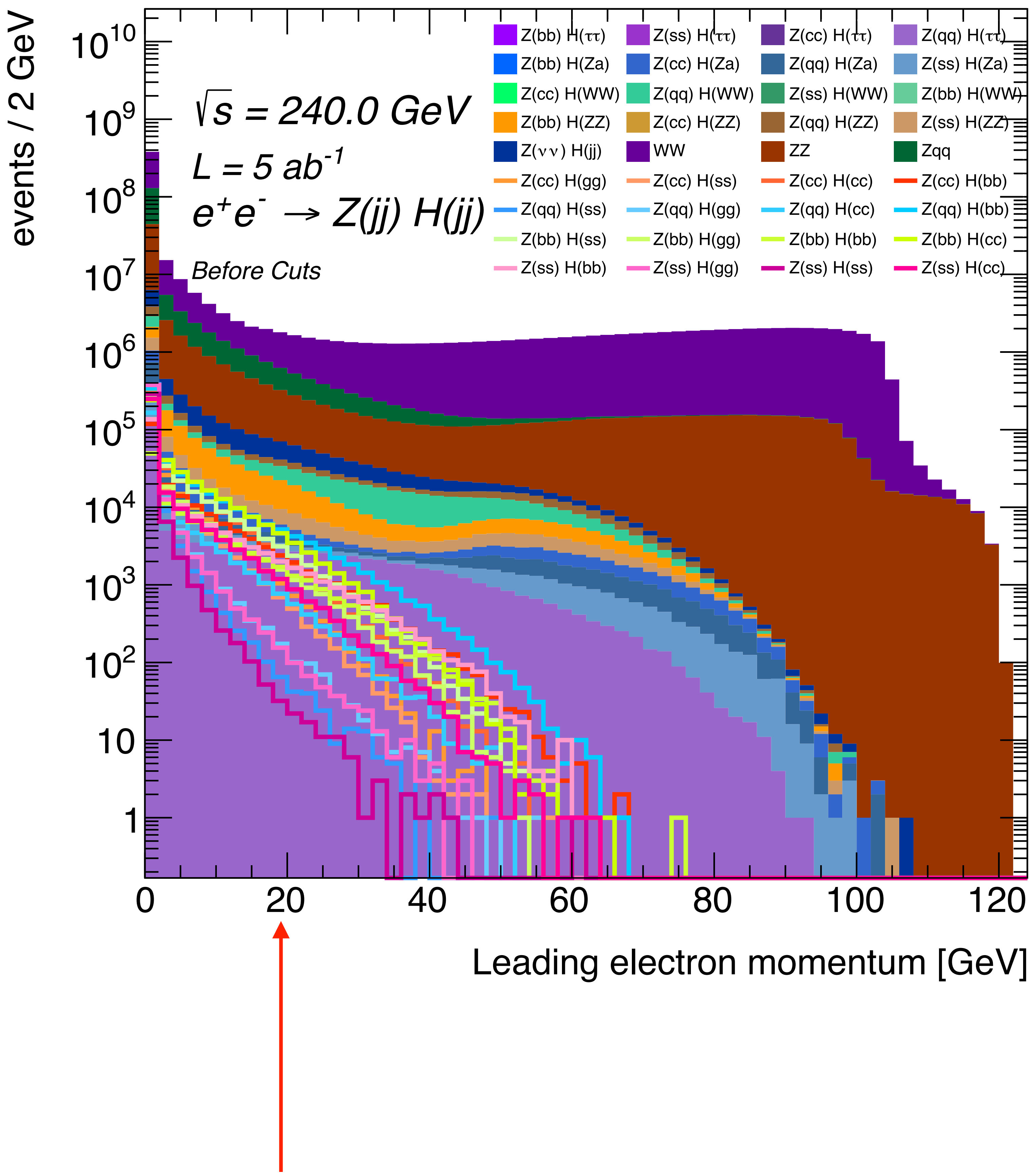
Brookhaven National Laboratory CERN FUTURE CIRCULAR COLLIDER

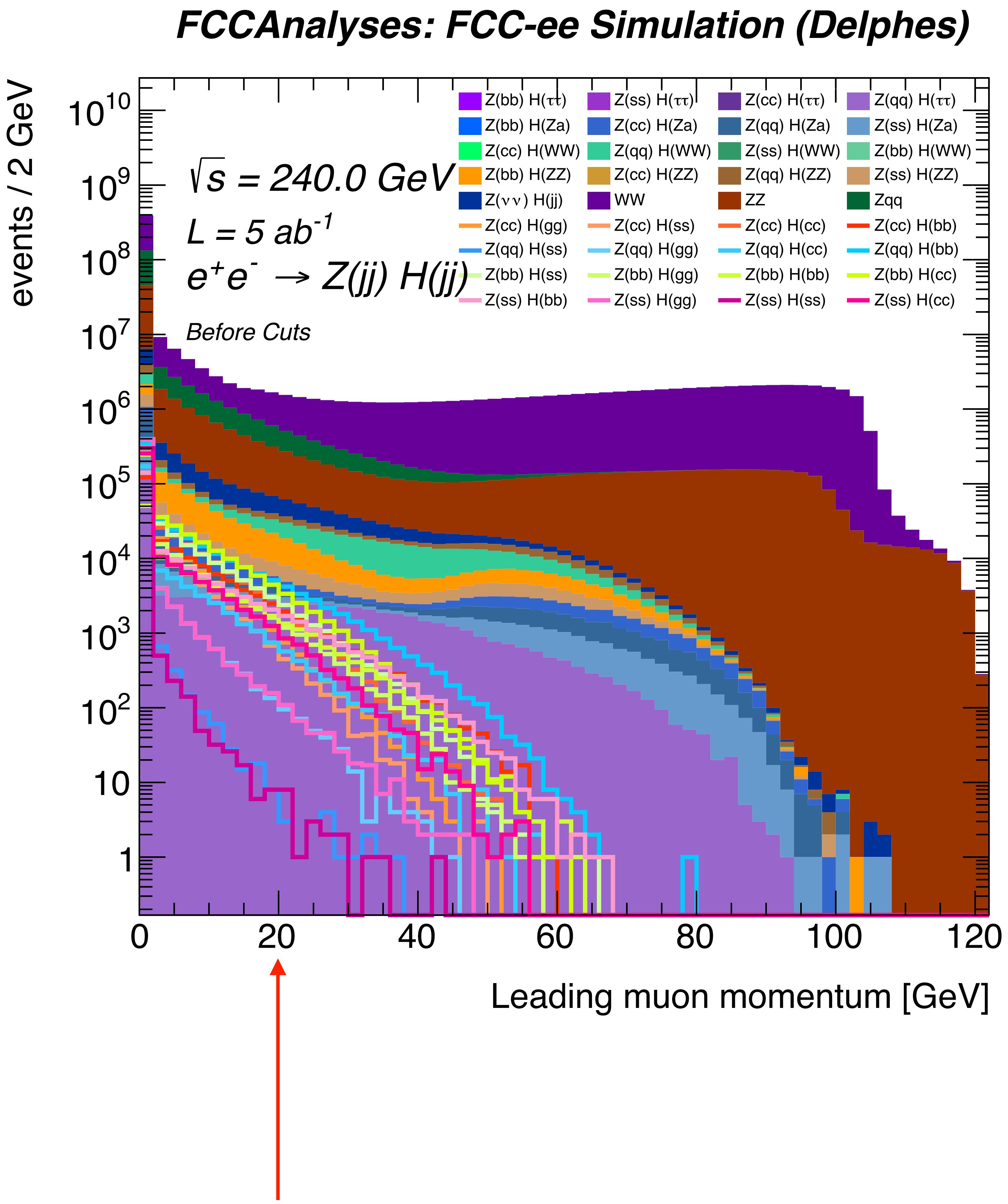
Cut efficiencies

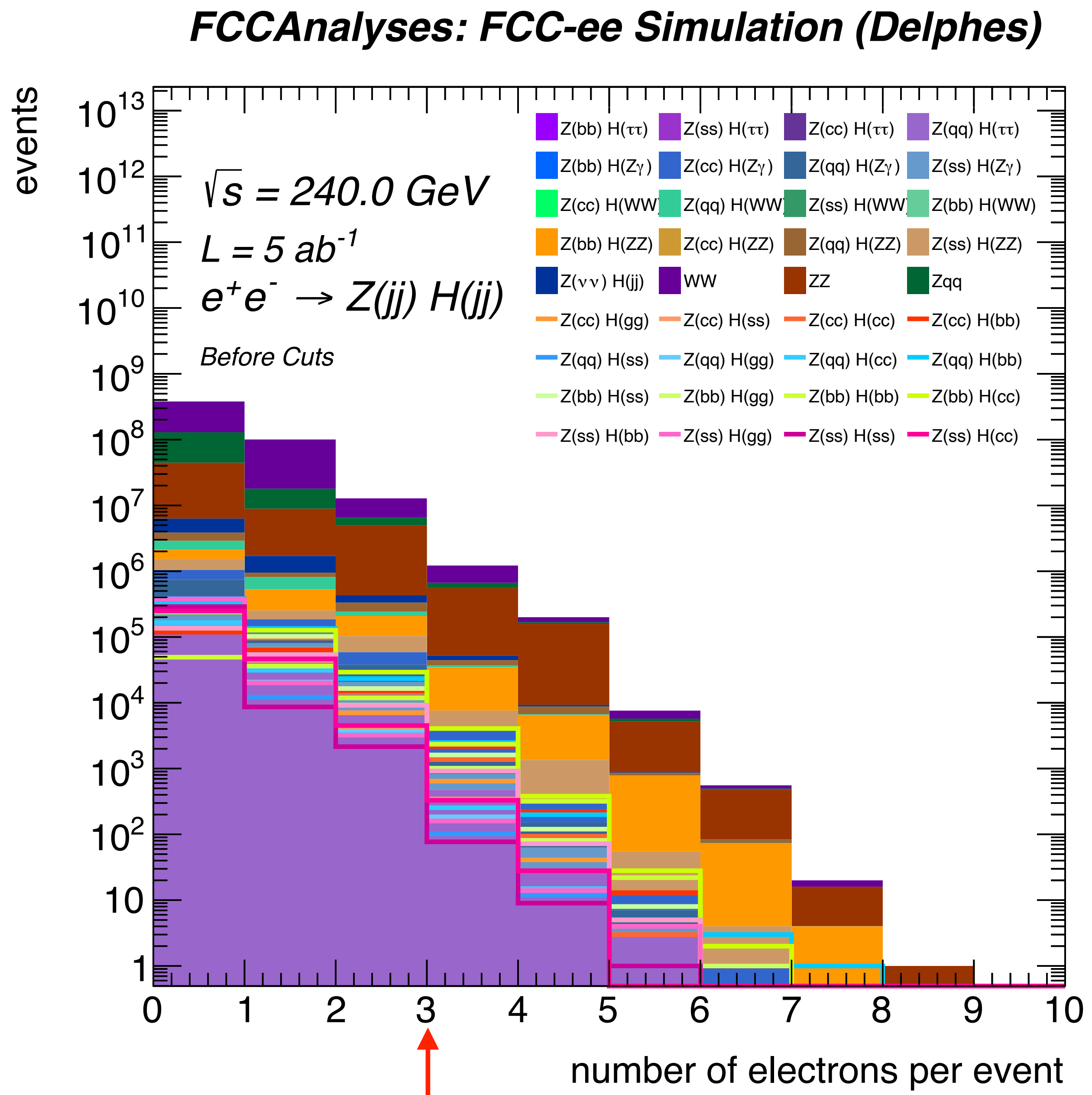
	Lepton cut	$M_{\text{vis}}, \theta_{\text{vis}}$	d_{ij}
$e^+e^- \to Z(cc)H(gg)$	98.7	88.3	87.2
$e^+e^- \to Z(cc)H(ss)$	99.0	88.4	86.3
$e^+e^- \to Z(cc)H(cc)$	96.6	88.1	86.1
$e^+e^- \to Z(cc)H(bb)$	89.7	83.5	81.2
$e^+e^- \to Z(qq)H(gg)$	99.8	86.2	85.2
$e^+e^- \to Z(qq)H(ss)$	99.9	86.6	84.6
$e^+e^- \to Z(qq)H(cc)$	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

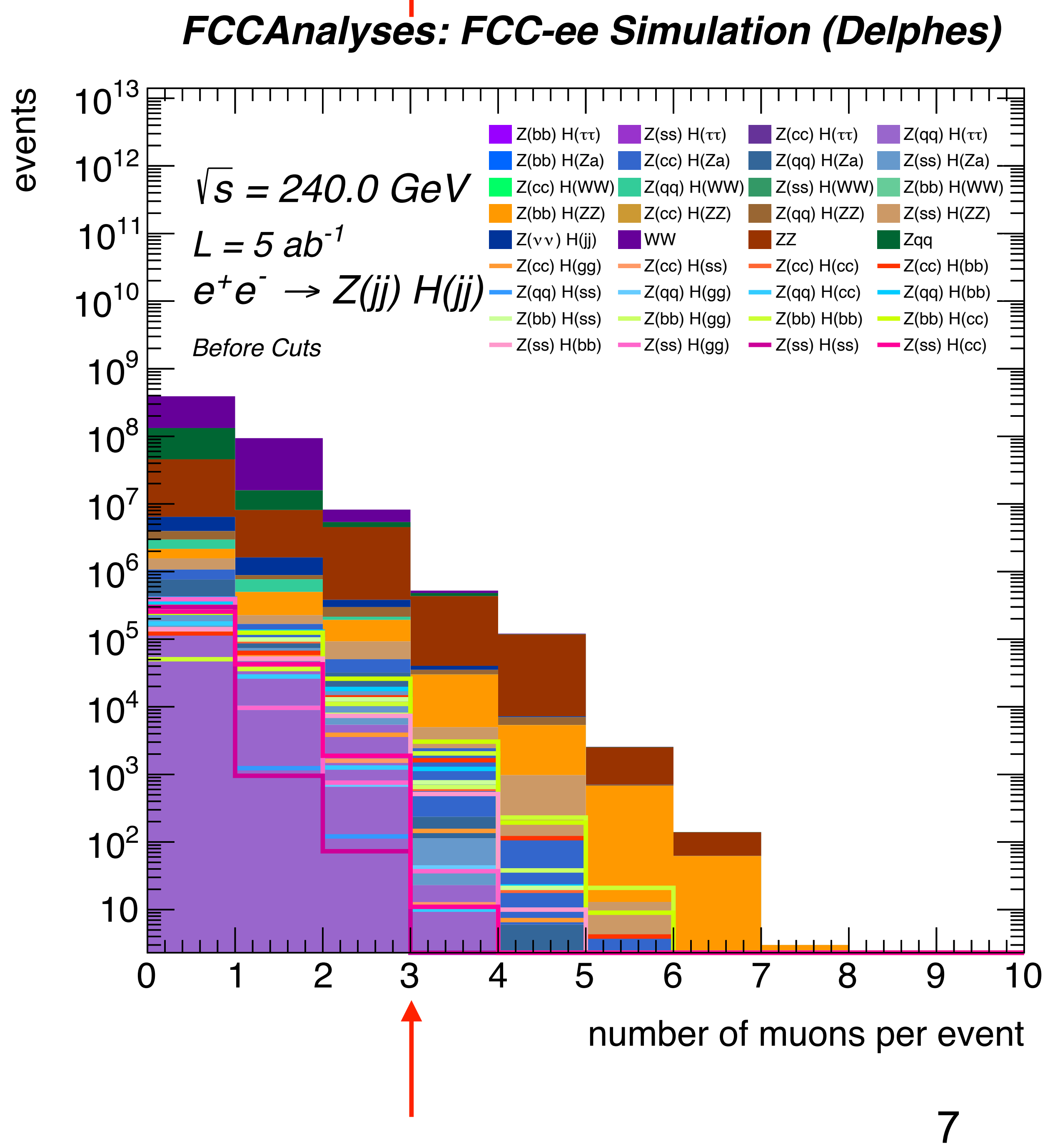
	Lepton cut	$M_{\text{vis}}, \theta_{\text{vis}}$	d_{ij}
$e^+e^- \to Z(bb)H(\tau\tau)$	63.7	43.9	32.8
$e^+e^- \to Z(ss)H(\tau\tau)$	67.1	48.3	36.4
$e^+e^- \to Z(cc)H(\tau\tau)$	68.0	50.2	38.1
$e^+e^- \to Z(qq)H(\tau\tau)$	67.9	50.1	38.1
$e^+e^- \to Z(bb)H(Z\gamma)$	86.5	62.4	61.3
$e^+e^- \to Z(ss)H(Z\gamma)$	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

Lepton distributions

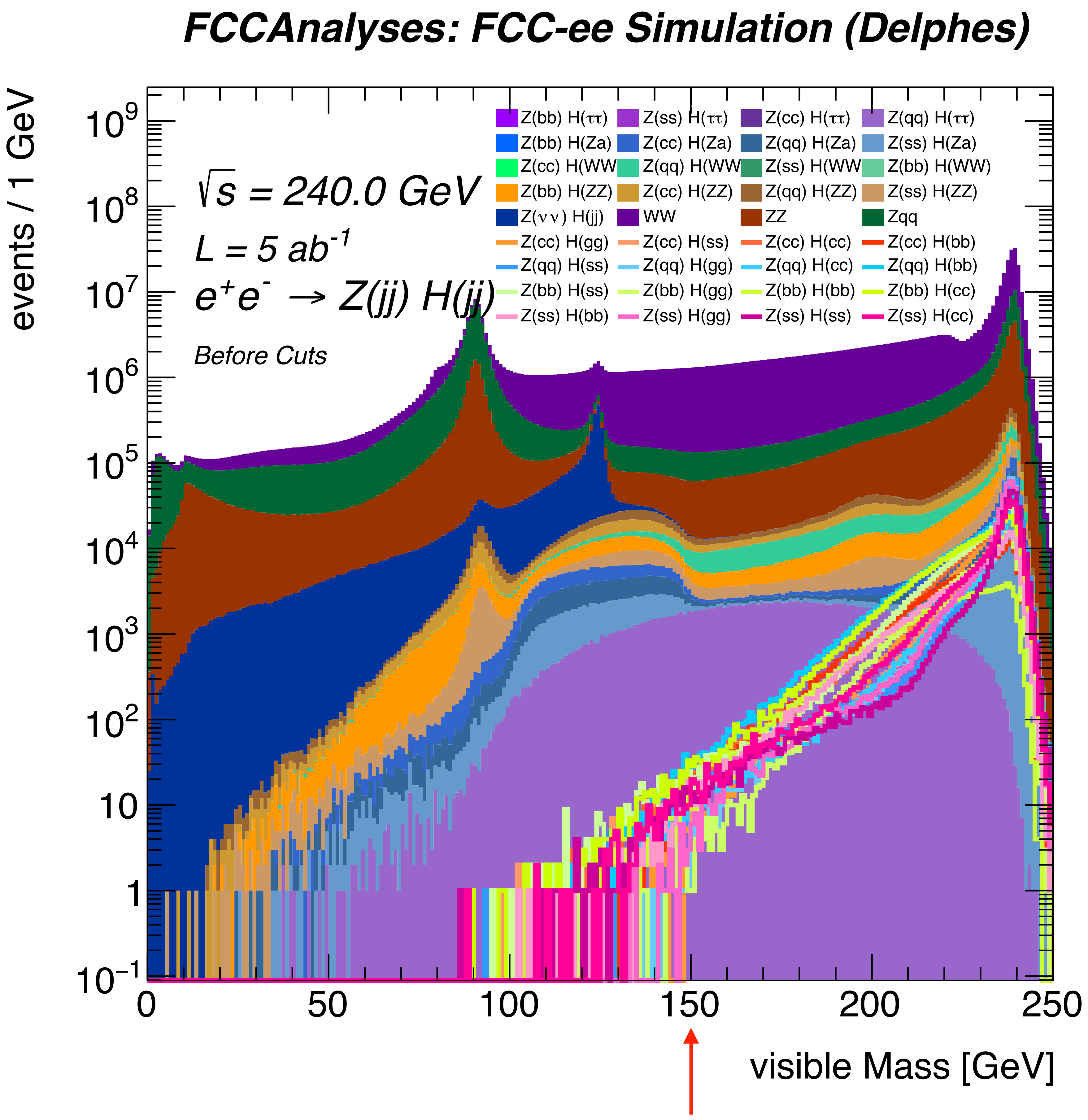


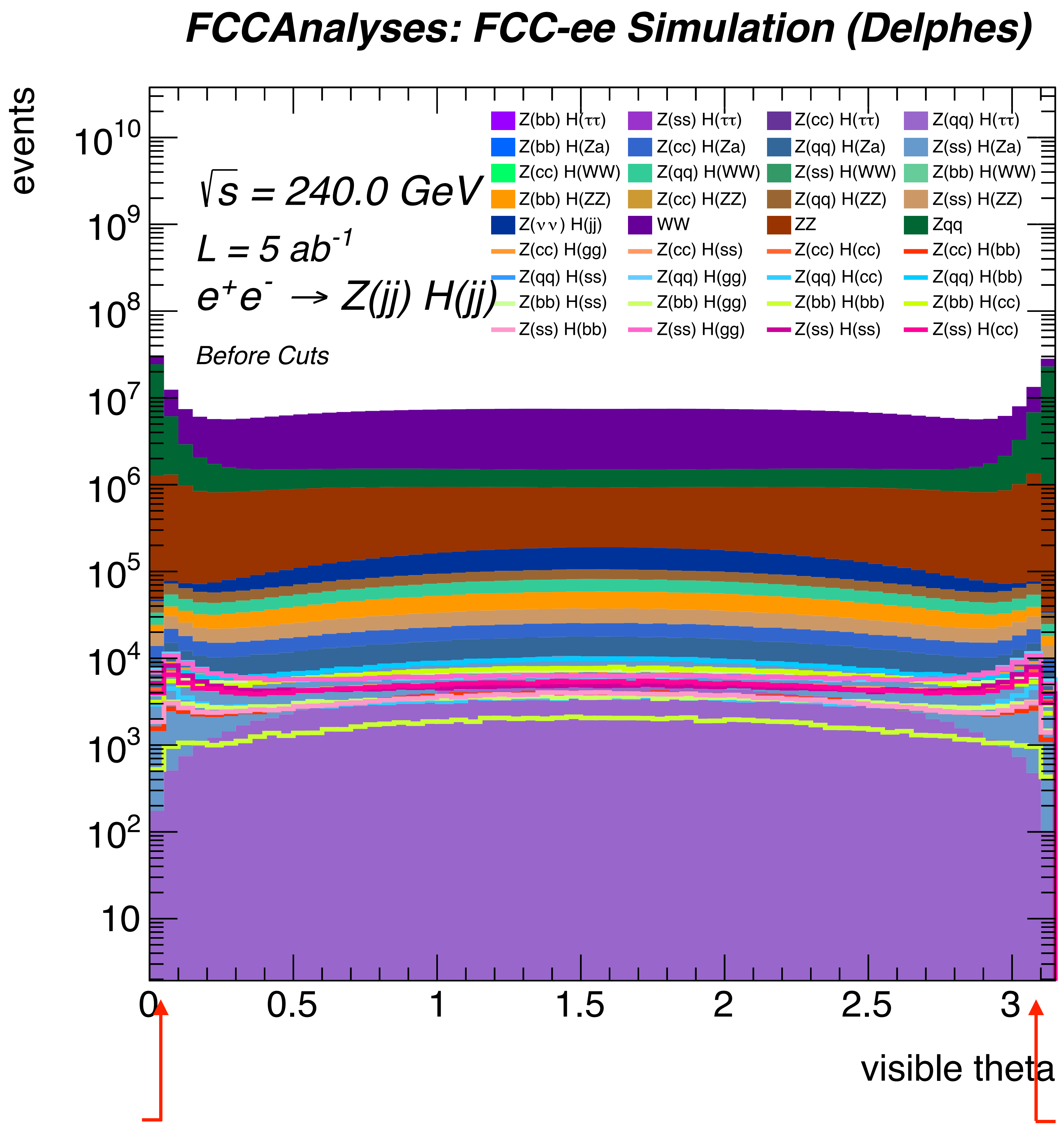




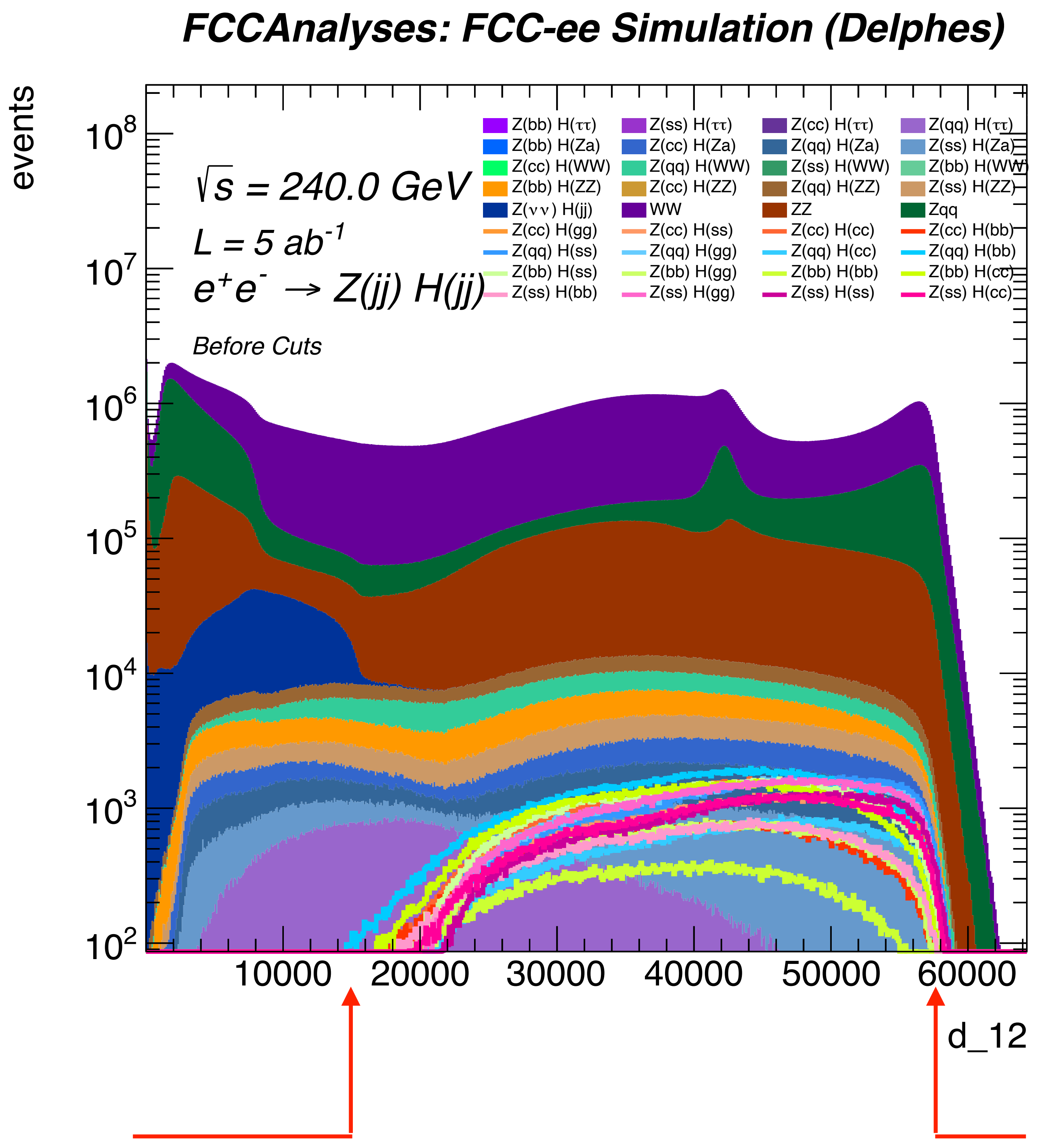


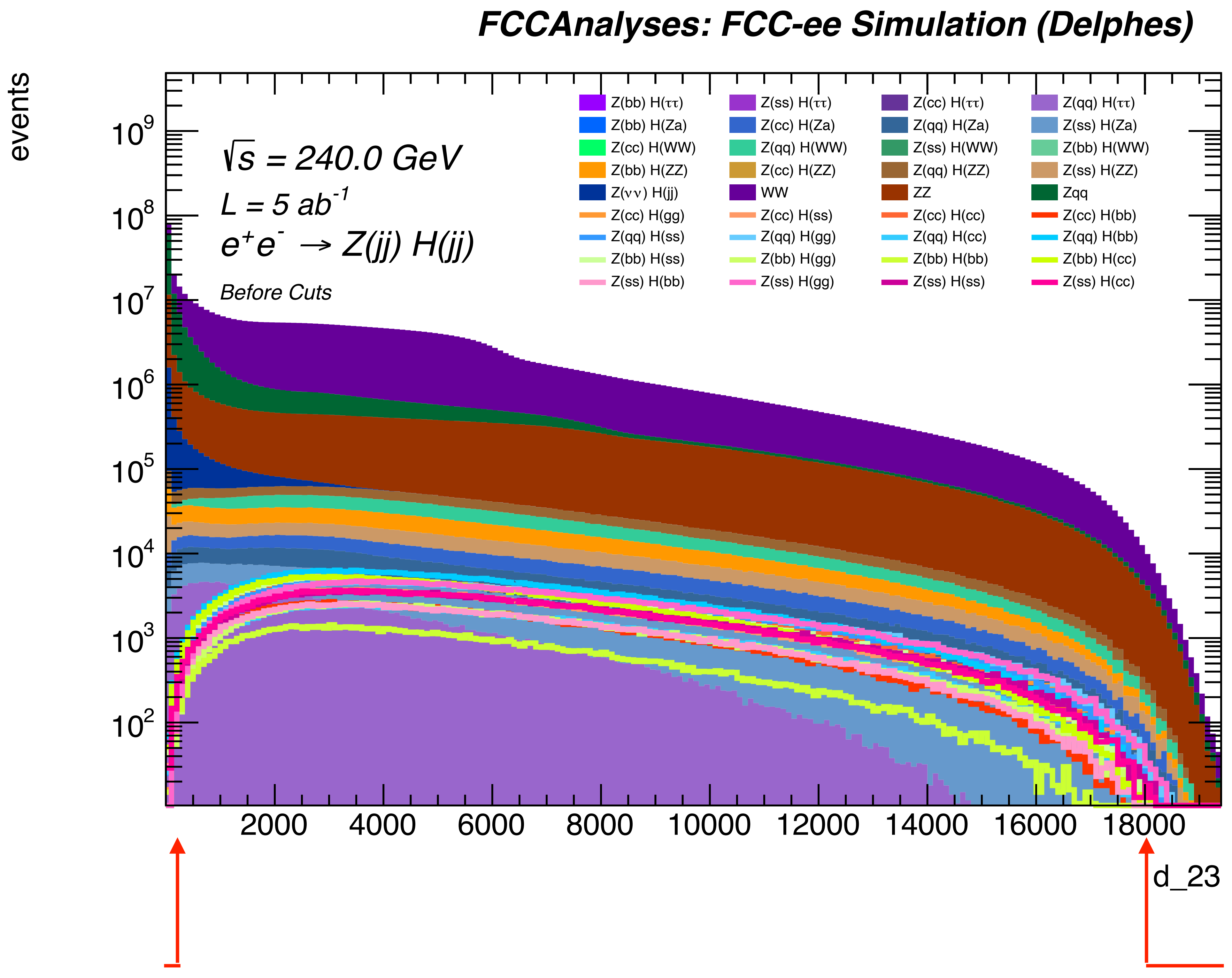
Distributions on M_{vis} and θ_{vis}

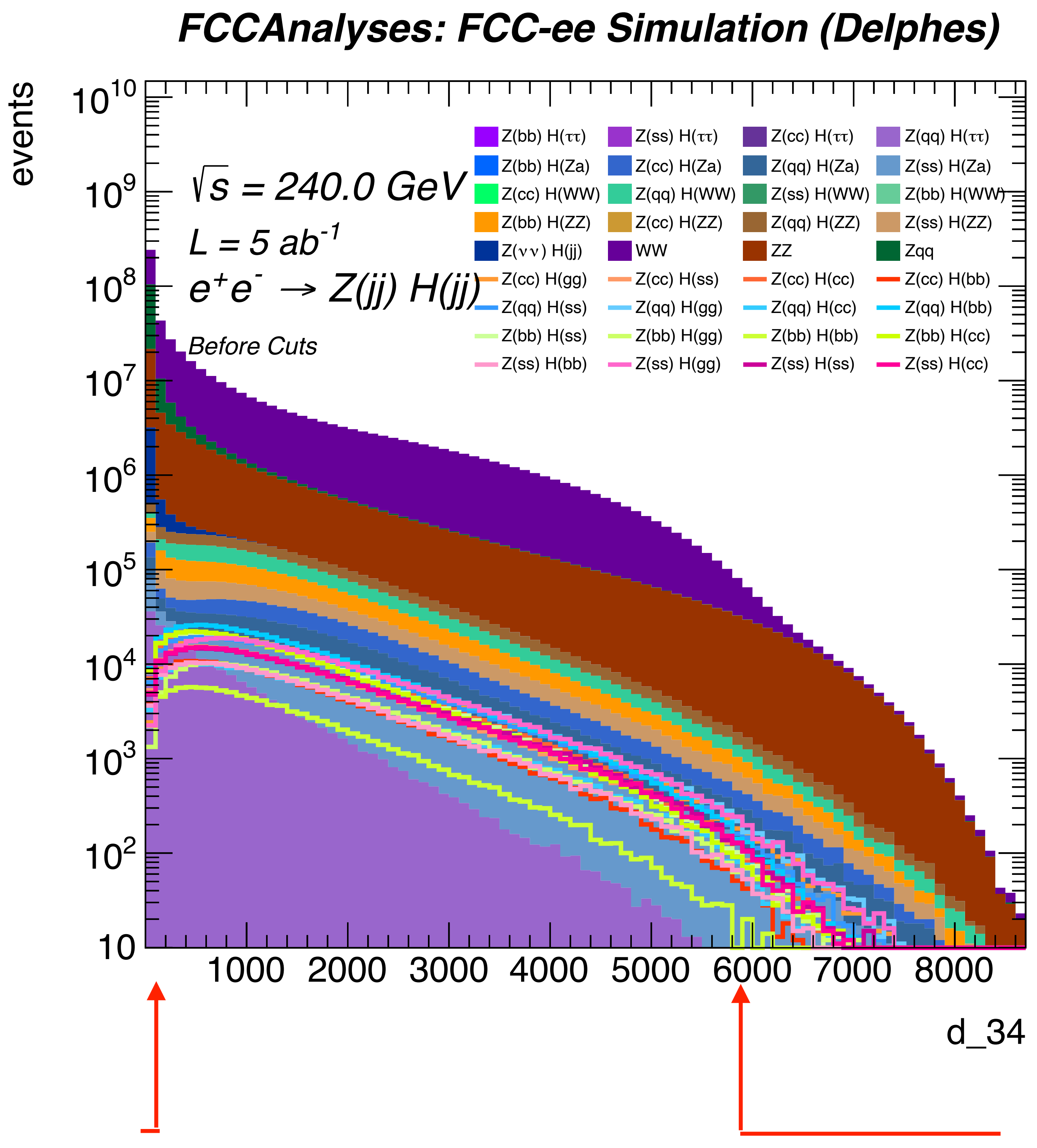




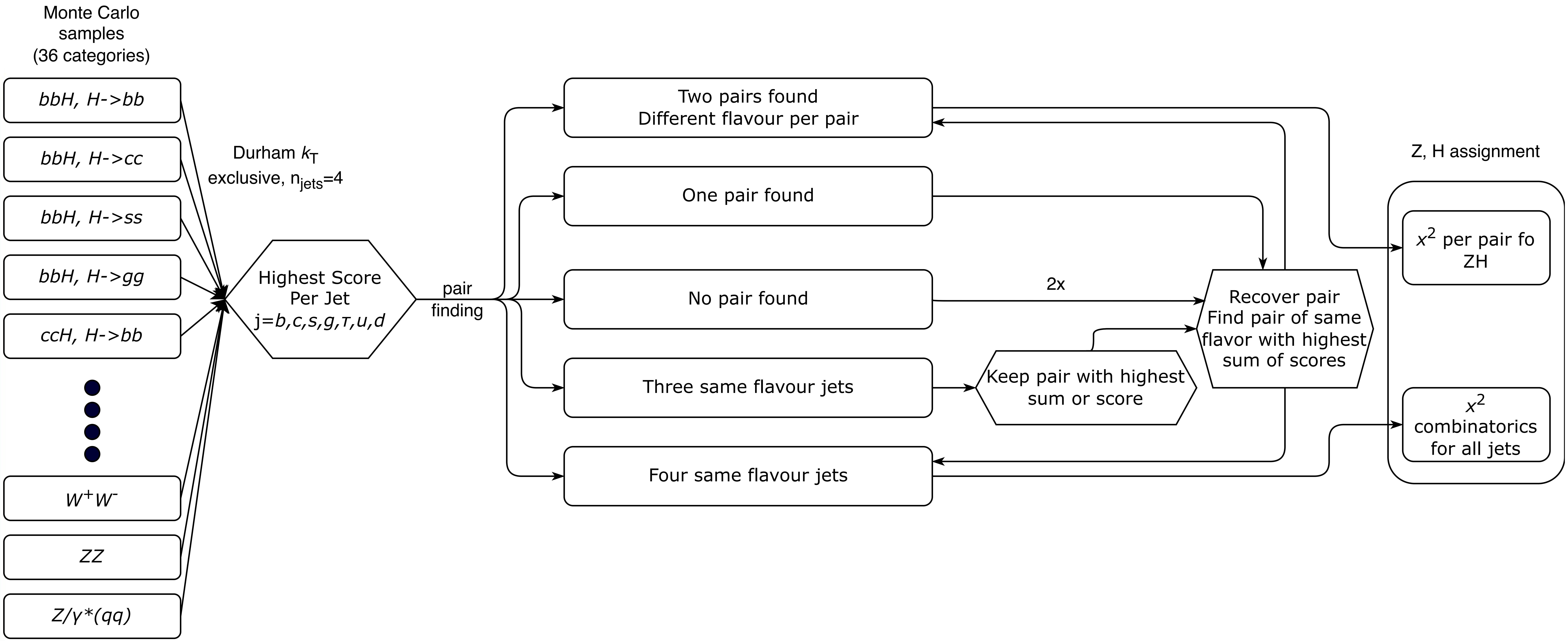
Distributions on d_{ij}







Jet pairs reconstruction flow chart



Monte Carlo samples (36 categories)

- *bbH, H->bb*
- *bbH, H->cc*
- *bbH, H->ss*
- *bbH, H->gg*
- *ccH, H->bb*
- ●
- ●
- ●
- ●
- W^+W^-
- *ZZ*
- *Z/γ*(qq)*

Durham k_T exclusive, n_{jets}=4

Highest Score Per Jet j=*b,c,s,g,τ,u,d*

pair finding

Two pairs found Different flavour per pair

One pair found

No pair found

Three same flavour jets

Four same flavour jets

2x

Keep pair with highest sum or score

Recover pair Find pair of same flavor with highest sum of scores

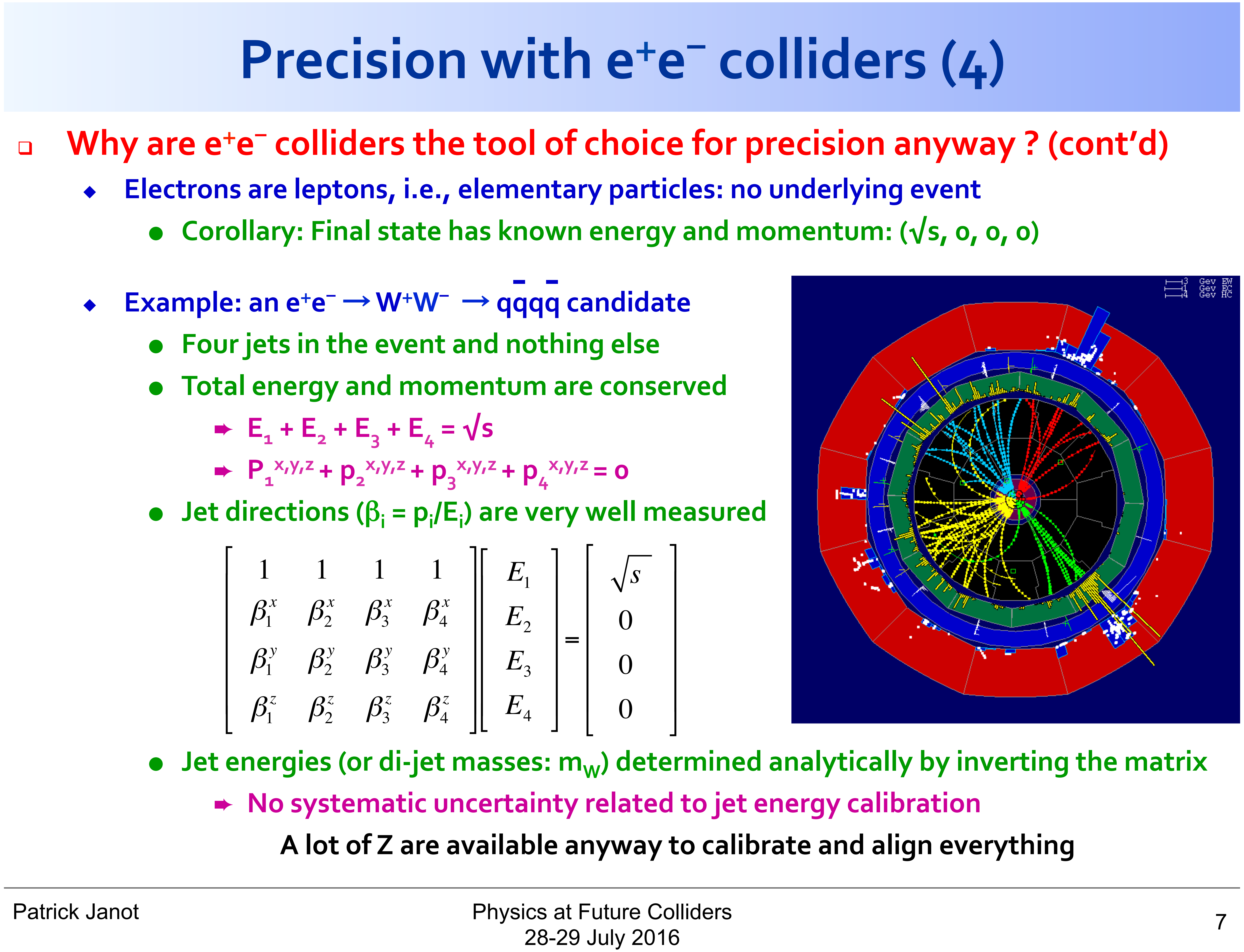
Z, H assignment

x^2 per pair fo ZH

x^2 combinatorics for all jets

Jet energies

- Technique of Jet energy “correction” by Patrick implemented
- Added the inversion of the directions matrix to FCCAnalysis
- In case of wrong calculation, use nominal values (small percentage of events)



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 $e^+e^- \rightarrow W^+W^- \rightarrow q\bar{q}q\bar{q}$ 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

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

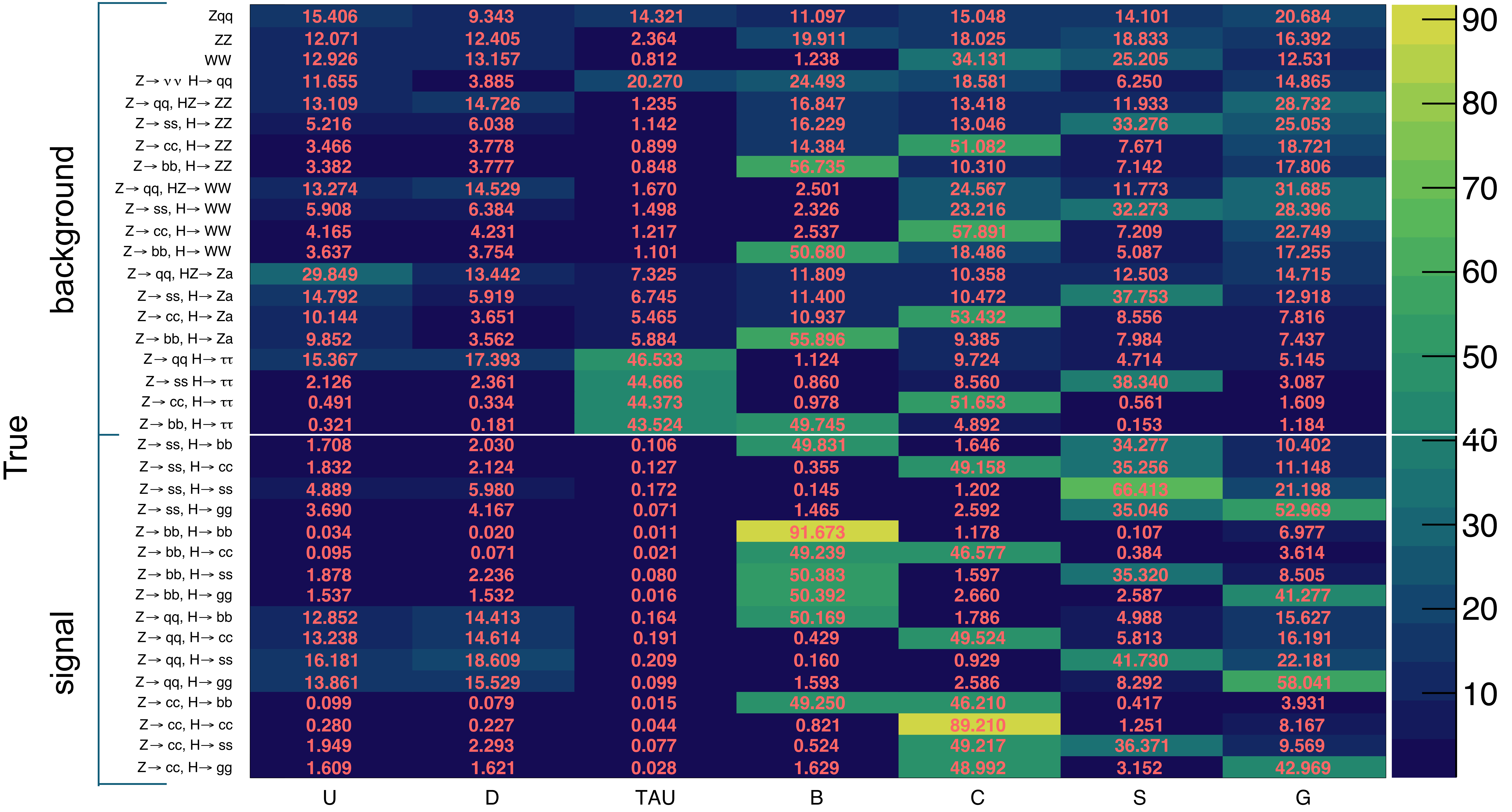
- Jet energies (or di-jet masses: m_W) determined analytically by inverting the matrix
  - No systematic uncertainty related to jet energy calibration

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

Patrick Janot

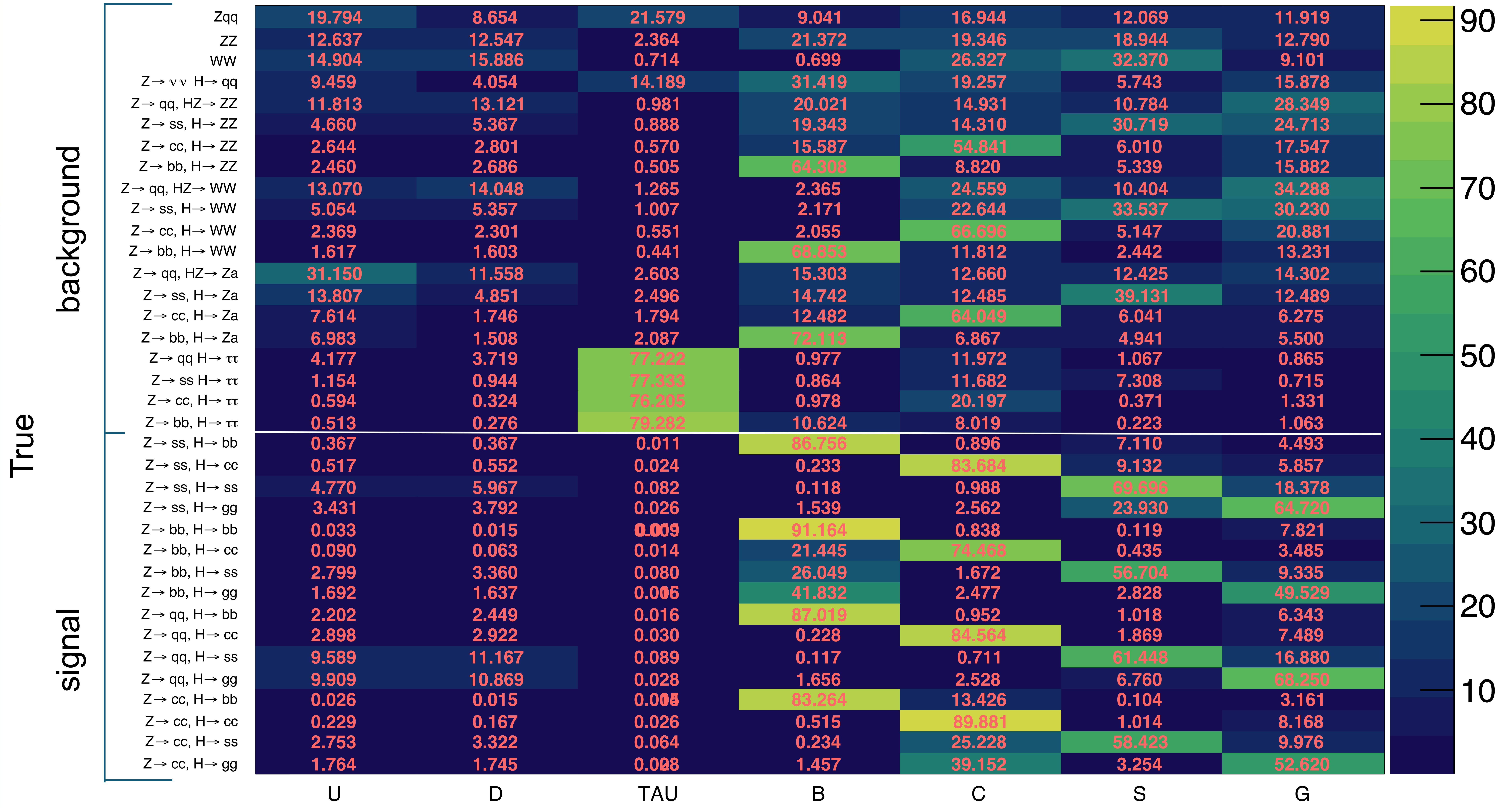
Physics at Future Colliders
28-29 July 2016

7



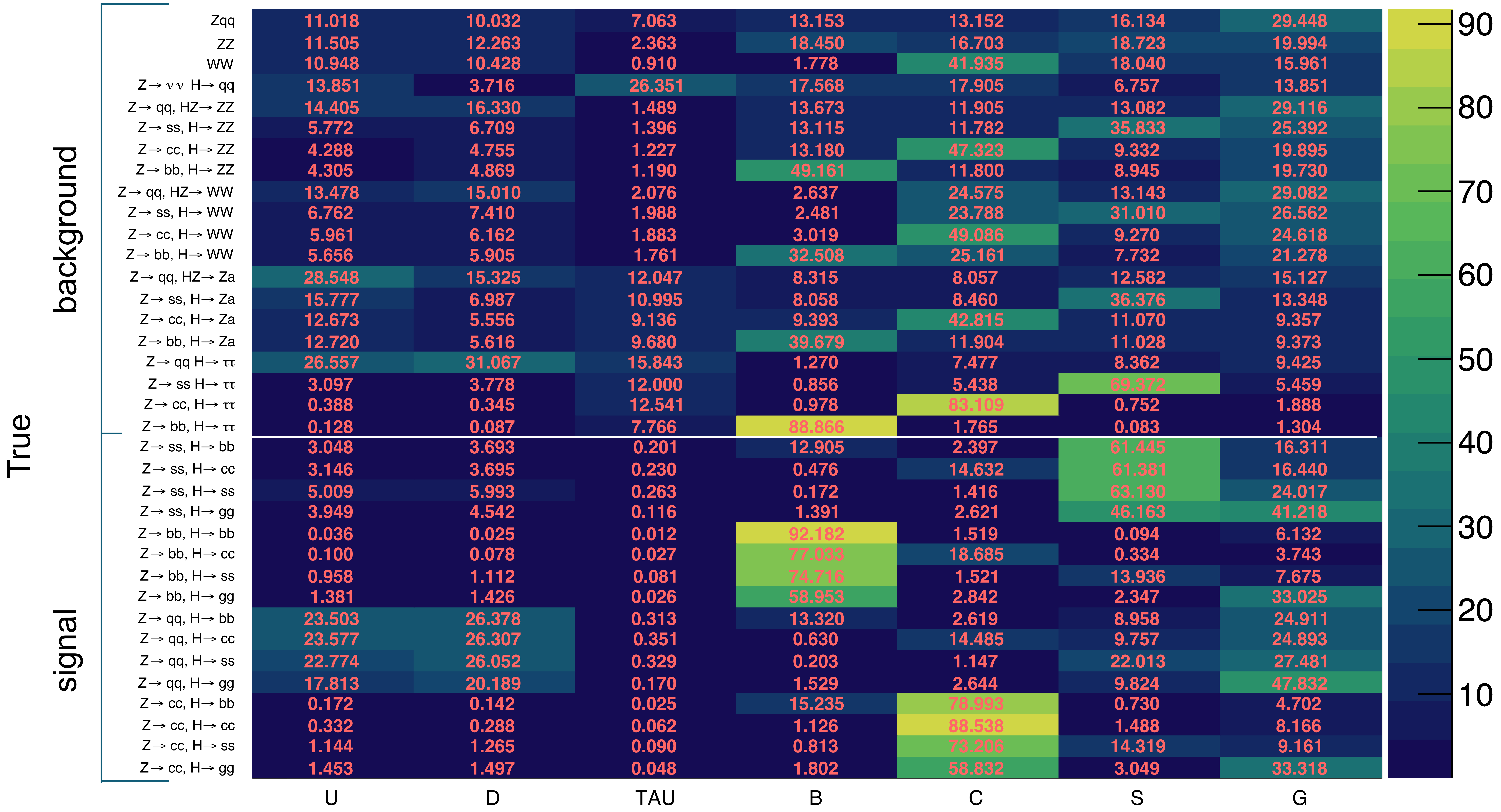
	U	D	TAU	B	C	S	G
Zqq	15.406	9.343	14.321	11.097	15.048	14.101	20.684
ZZ	12.071	12.405	2.364	19.911	18.025	18.833	16.392
WW	12.926	13.157	0.812	1.238	34.131	25.205	12.531
Z→ ν ν H→ qq	11.655	3.885	20.270	24.493	18.581	6.250	14.865
Z→ qq, HZ→ ZZ	13.109	14.726	1.235	16.847	13.418	11.933	28.732
Z→ ss, H→ ZZ	5.216	6.038	1.142	16.229	13.046	33.276	25.053
Z→ cc, H→ ZZ	3.466	3.778	0.899	14.384	51.082	7.671	18.721
Z→ bb, H→ ZZ	3.382	3.777	0.848	56.735	10.310	7.142	17.806
Z→ qq, HZ→ WW	13.274	14.529	1.670	2.501	24.567	11.773	31.685
Z→ ss, H→ WW	5.908	6.384	1.498	2.326	23.216	32.273	28.396
Z→ cc, H→ WW	4.165	4.231	1.217	2.537	57.891	7.209	22.749
Z→ bb, H→ WW	3.637	3.754	1.101	50.680	18.486	5.087	17.255
Z→ qq, HZ→ Za	29.849	13.442	7.325	11.809	10.358	12.503	14.715
Z→ ss, H→ Za	14.792	5.919	6.745	11.400	10.472	37.753	12.918
Z→ cc, H→ Za	10.144	3.651	5.465	10.937	53.432	8.556	7.816
Z→ bb, H→ Za	9.852	3.562	5.884	55.896	9.385	7.984	7.437
Z→ qq H→ ττ	15.367	17.393	46.533	1.124	9.724	4.714	5.145
Z→ ss H→ ττ	2.126	2.361	44.666	0.860	8.560	38.340	3.087
Z→ cc, H→ ττ	0.491	0.334	44.373	0.978	51.653	0.561	1.609
Z→ bb, H→ ττ	0.321	0.181	43.524	49.745	4.892	0.153	1.184
Z→ ss, H→ bb	1.708	2.030	0.106	49.831	1.646	34.277	10.402
Z→ ss, H→ cc	1.832	2.124	0.127	0.355	49.158	35.256	11.148
Z→ ss, H→ ss	4.889	5.980	0.172	0.145	1.202	66.413	21.198
Z→ ss, H→ gg	3.690	4.167	0.071	1.465	2.592	35.046	52.969
Z→ bb, H→ bb	0.034	0.020	0.011	91.673	1.178	0.107	6.977
Z→ bb, H→ cc	0.095	0.071	0.021	49.239	46.577	0.384	3.614
Z→ bb, H→ ss	1.878	2.236	0.080	50.383	1.597	35.320	8.505
Z→ bb, H→ gg	1.537	1.532	0.016	50.392	2.660	2.587	41.277
Z→ qq, H→ bb	12.852	14.413	0.164	50.169	1.786	4.988	15.627
Z→ qq, H→ cc	13.238	14.614	0.191	0.429	49.524	5.813	16.191
Z→ qq, H→ ss	16.181	18.609	0.209	0.160	0.929	41.730	22.181
Z→ qq, H→ gg	13.861	15.529	0.099	1.593	2.586	8.292	58.041
Z→ cc, H→ bb	0.099	0.079	0.015	49.250	46.210	0.417	3.931
Z→ cc, H→ cc	0.280	0.227	0.044	0.821	89.210	1.251	8.167
Z→ cc, H→ ss	1.949	2.293	0.077	0.524	49.217	36.371	9.569
Z→ cc, H→ gg	1.609	1.621	0.028	1.629	48.992	3.152	42.969

- 100% of the events (after cuts) now reconstructed
- eg $\mathrm{B} = b\bar{b}$ pair found (no H or Z assignment yet)



	U	D	TAU	B	C	S	G
Zqq	19.794	8.654	21.579	9.041	16.944	12.069	11.919
ZZ	12.637	12.547	2.364	21.372	19.346	18.944	12.790
WW	14.904	15.886	0.714	0.699	26.327	32.370	9.101
Z→ ν ν H→ qq	9.459	4.054	14.189	31.419	19.257	5.743	15.878
Z→ qq, HZ→ ZZ	11.813	13.121	0.981	20.021	14.931	10.784	28.349
Z→ ss, H→ ZZ	4.660	5.367	0.888	19.343	14.310	30.719	24.713
Z→ cc, H→ ZZ	2.644	2.801	0.570	15.587	54.841	6.010	17.547
Z→ bb, H→ ZZ	2.460	2.686	0.505	64.308	8.820	5.339	15.882
Z→ qq, HZ→ WW	13.070	14.048	1.265	2.365	24.559	10.404	34.288
Z→ ss, H→ WW	5.054	5.357	1.007	2.171	22.644	33.537	30.230
Z→ cc, H→ WW	2.369	2.301	0.551	2.055	66.696	5.147	20.881
Z→ bb, H→ WW	1.617	1.603	0.441	68.853	11.812	2.442	13.231
Z→ qq, HZ→ Za	31.150	11.558	2.603	15.303	12.660	12.425	14.302
Z→ ss, H→ Za	13.807	4.851	2.496	14.742	12.485	39.131	12.489
Z→ cc, H→ Za	7.614	1.746	1.794	12.482	64.049	6.041	6.275
Z→ bb, H→ Za	6.983	1.508	2.087	72.113	6.867	4.941	5.500
Z→ qq H→ ττ	4.177	3.719	77.222	0.977	11.972	1.067	0.865
Z→ ss H→ ττ	1.154	0.944	77.333	0.864	11.682	7.308	0.715
Z→ cc, H→ ττ	0.594	0.324	76.205	0.978	20.197	0.371	1.331
Z→ bb, H→ ττ	0.513	0.276	79.282	10.624	8.019	0.223	1.063
Z→ ss, H→ bb	0.367	0.367	0.011	86.756	0.896	7.110	4.493
Z→ ss, H→ cc	0.517	0.552	0.024	0.233	83.684	9.132	5.857
Z→ ss, H→ ss	4.770	5.967	0.082	0.118	0.988	69.696	18.378
Z→ ss, H→ gg	3.431	3.792	0.026	1.539	2.562	23.930	64.720
Z→ bb, H→ bb	0.033	0.015	0.009	91.164	0.838	0.119	7.821
Z→ bb, H→ cc	0.090	0.063	0.014	21.445	74.468	0.435	3.485
Z→ bb, H→ ss	2.799	3.360	0.080	26.049	1.672	56.704	9.335
Z→ bb, H→ gg	1.692	1.637	0.006	41.832	2.477	2.828	49.529
Z→ qq, H→ bb	2.202	2.449	0.016	87.019	0.952	1.018	6.343
Z→ qq, H→ cc	2.898	2.922	0.030	0.228	84.564	1.869	7.489
Z→ qq, H→ ss	9.589	11.167	0.089	0.117	0.711	61.448	16.880
Z→ qq, H→ gg	9.909	10.869	0.028	1.656	2.528	6.760	68.250
Z→ cc, H→ bb	0.026	0.015	0.005	83.264	13.426	0.104	3.161
Z→ cc, H→ cc	0.229	0.167	0.026	0.515	89.881	1.014	8.168
Z→ cc, H→ ss	2.753	3.322	0.064	0.234	25.228	58.423	9.976
Z→ cc, H→ gg	1.764	1.745	0.028	1.457	39.152	3.254	52.620

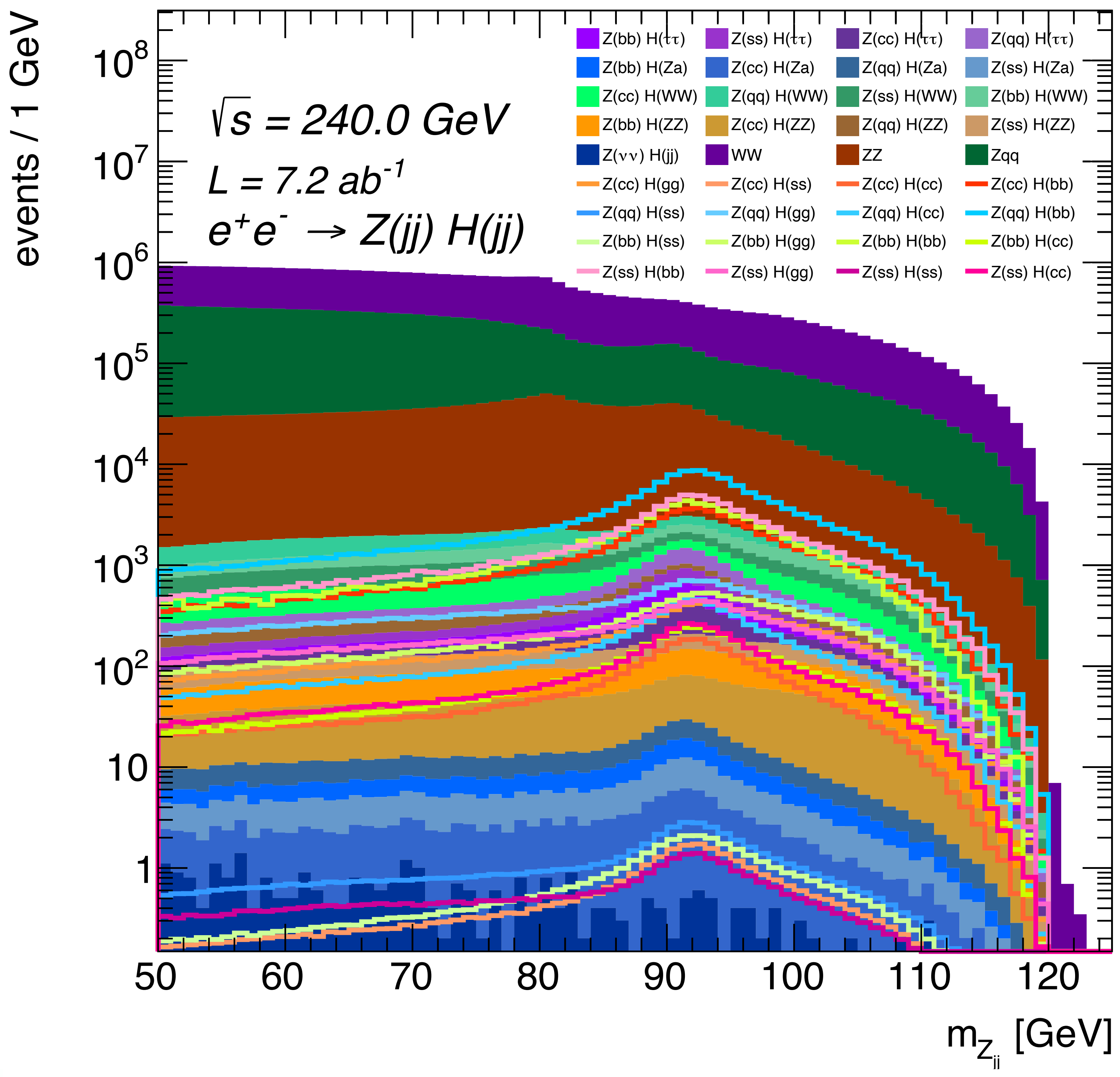
<u>pairs reconstructed as H</u>

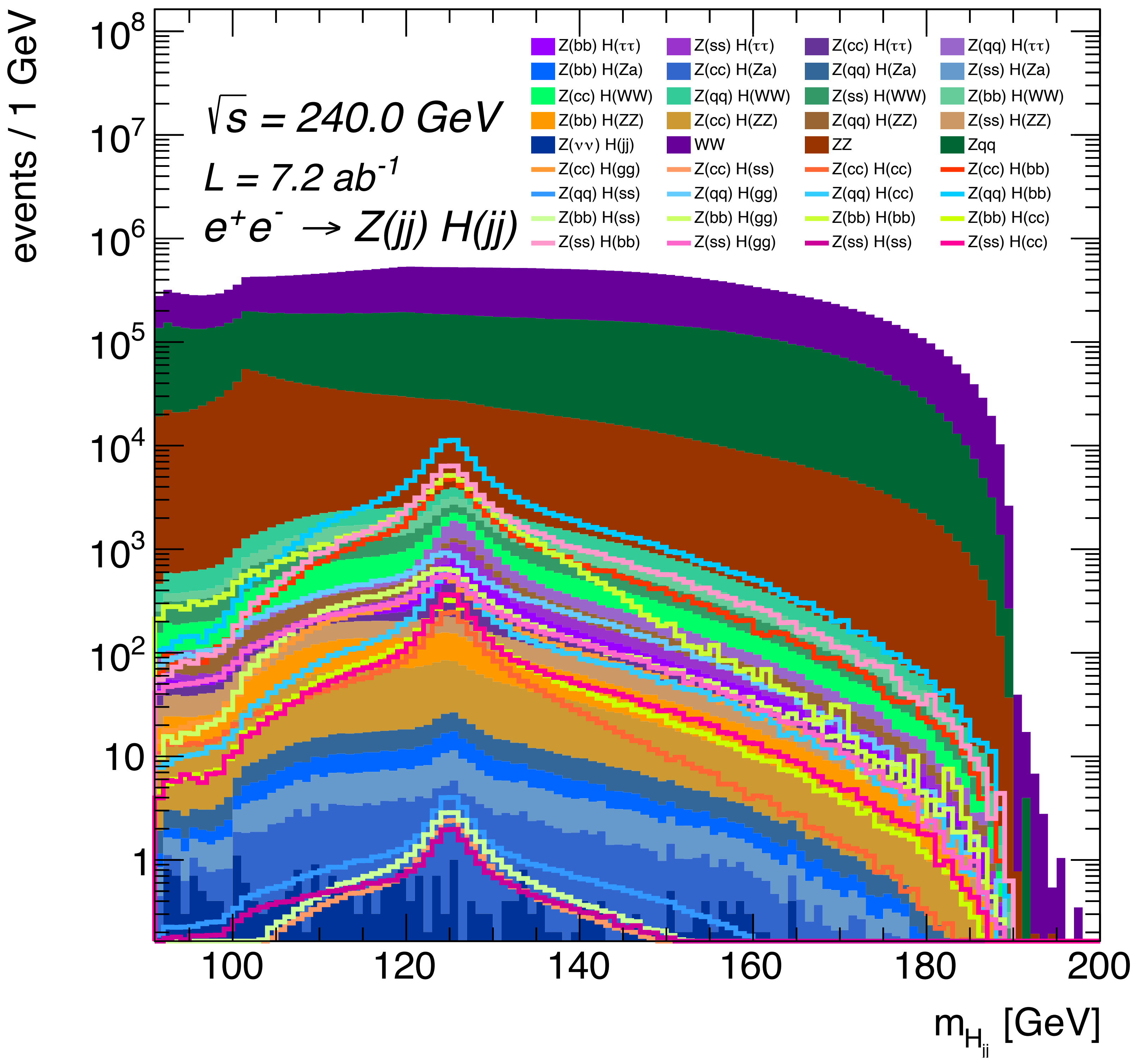


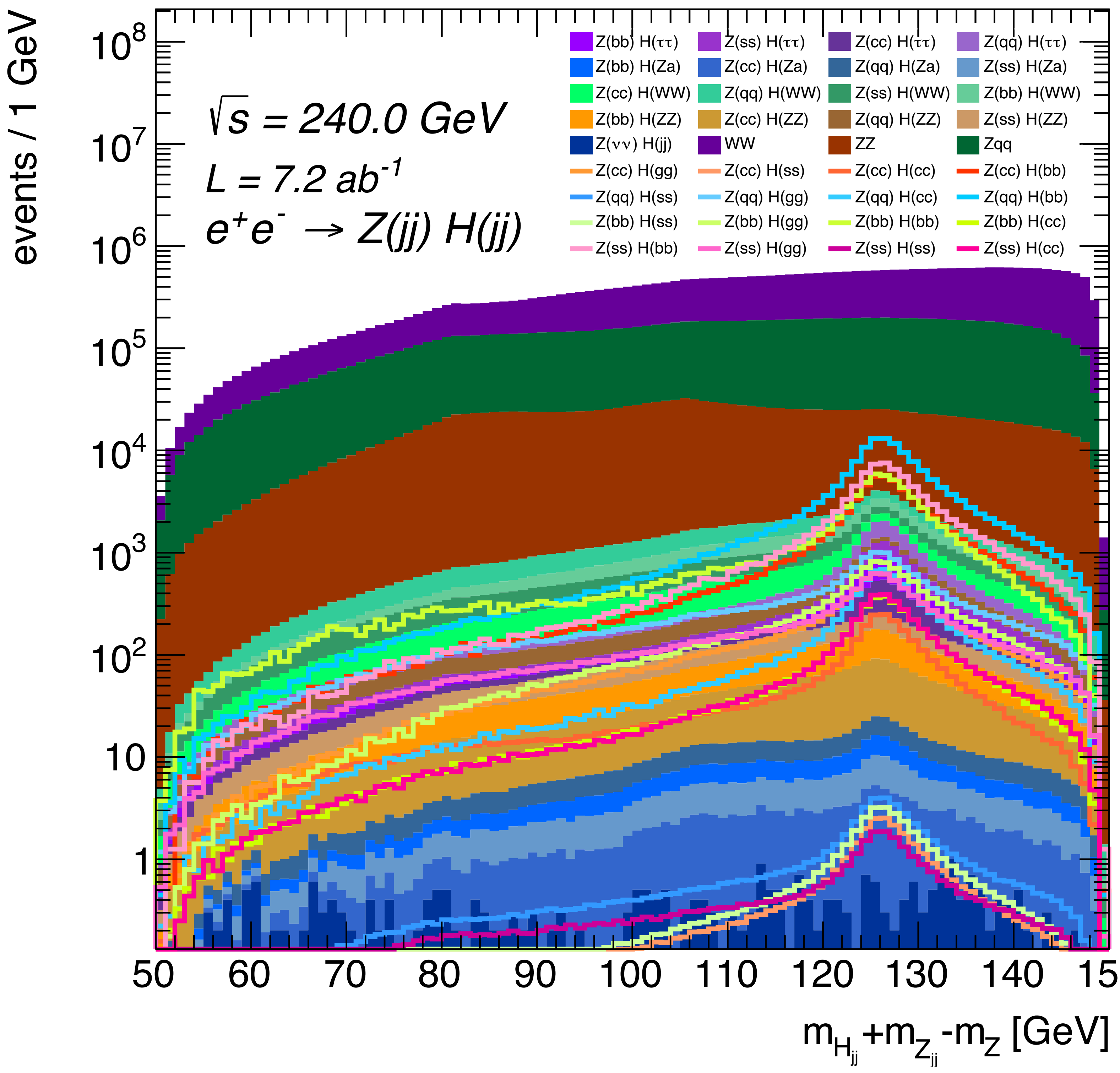
	U	D	TAU	B	C	S	G
Zqq	11.018	10.032	7.063	13.153	13.152	16.134	29.448
ZZ	11.505	12.263	2.363	18.450	16.703	18.723	19.994
WW	10.948	10.428	0.910	1.778	41.935	18.040	15.961
Z→ νν H→ qq	13.851	3.716	26.351	17.568	17.905	6.757	13.851
Z→ qq, HZ→ ZZ	14.405	16.330	1.489	13.673	11.905	13.082	29.116
Z→ ss, H→ ZZ	5.772	6.709	1.396	13.115	11.782	35.833	25.392
Z→ cc, H→ ZZ	4.288	4.755	1.227	13.180	47.323	9.332	19.895
Z→ bb, H→ ZZ	4.305	4.869	1.190	49.161	11.800	8.945	19.730
Z→ qq, HZ→ WW	13.478	15.010	2.076	2.637	24.575	13.143	29.082
Z→ ss, H→ WW	6.762	7.410	1.988	2.481	23.788	31.010	26.562
Z→ cc, H→ WW	5.961	6.162	1.883	3.019	49.086	9.270	24.618
Z→ bb, H→ WW	5.656	5.905	1.761	32.508	25.161	7.732	21.278
Z→ qq, HZ→ Za	28.548	15.325	12.047	8.315	8.057	12.582	15.127
Z→ ss, H→ Za	15.777	6.987	10.995	8.058	8.460	36.376	13.348
Z→ cc, H→ Za	12.673	5.556	9.136	9.393	42.815	11.070	9.357
Z→ bb, H→ Za	12.720	5.616	9.680	39.679	11.904	11.028	9.373
Z→ qq H→ ττ	26.557	31.067	15.843	1.270	7.477	8.362	9.425
Z→ ss H→ ττ	3.097	3.778	12.000	0.856	5.438	69.372	5.459
Z→ cc, H→ ττ	0.388	0.345	12.541	0.978	83.109	0.752	1.888
Z→ bb, H→ ττ	0.128	0.087	7.766	88.866	1.765	0.083	1.304
Z→ ss, H→ bb	3.048	3.693	0.201	12.905	2.397	61.445	16.311
Z→ ss, H→ cc	3.146	3.695	0.230	0.476	14.632	61.381	16.440
Z→ ss, H→ ss	5.009	5.993	0.263	0.172	1.416	63.130	24.017
Z→ ss, H→ gg	3.949	4.542	0.116	1.391	2.621	46.163	41.218
Z→ bb, H→ bb	0.036	0.025	0.012	92.182	1.519	0.094	6.132
Z→ bb, H→ cc	0.100	0.078	0.027	77.033	18.685	0.334	3.743
Z→ bb, H→ ss	0.958	1.112	0.081	74.716	1.521	13.936	7.675
Z→ bb, H→ gg	1.381	1.426	0.026	58.953	2.842	2.347	33.025
Z→ qq, H→ bb	23.503	26.378	0.313	13.320	2.619	8.958	24.911
Z→ qq, H→ cc	23.577	26.307	0.351	0.630	14.485	9.757	24.893
Z→ qq, H→ ss	22.774	26.052	0.329	0.203	1.147	22.013	27.481
Z→ qq, H→ gg	17.813	20.189	0.170	1.529	2.644	9.824	47.832
Z→ cc, H→ bb	0.172	0.142	0.025	15.235	78.993	0.730	4.702
Z→ cc, H→ cc	0.332	0.288	0.062	1.126	88.538	1.488	8.166
Z→ cc, H→ ss	1.144	1.265	0.090	0.813	73.206	14.319	9.161
Z→ cc, H→ gg	1.453	1.497	0.048	1.802	58.832	3.049	33.318

<ins>pairs reconstructed as Z</ins>

m_{Hjj} m_{Zjj} distributions for 7.2ab^{-1}


FCCAnalyses: FCC-ee Simulation (Delphes)


FCCAnalyses: FCC-ee Simulation (Delphes)


FCCAnalyses: FCC-ee Simulation (Delphes)

$$\sqrt{s} = 365\,\mathrm{GeV}$$

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 (365)	Cross-section [pb^{-1}]	Events
Signal	$e^+e^- \to Z(cc)H(gg)$	0.001182	1200000
	$e^+e^- \to Z(cc)H(ss)$	2.887e-06	1100000
	$e^+e^- \to Z(cc)H(cc)$	0.0004173	1100000
	$e^+e^- \to Z(cc)H(bb)$	0.008407	900000
	$e^+e^- \to Z(qq)H(gg)$	0.002701	1100000
	$e^+e^- \to Z(qq)H(ss)$	6.599e-06	1100000
	$e^+e^- \to Z(qq)H(cc)$	0.000954	1100000
	$e^+e^- \to Z(qq)H(bb)$	0.01922	1200000
	$e^+e^- \to Z(bb)H(gg)$	0.001506	1200000
	$e^+e^- \to Z(bb)H(ss)$	3.678e-06	1200000
	$e^+e^- \to Z(bb)H(cc)$	0.0005316	1200000
	$e^+e^- \to Z(bb)H(bb)$	0.01071	1200000
	$e^+e^- \to Z(ss)H(gg)$	0.001518	1200000
	$e^+e^- \to Z(ss)H(ss)$	3.708e-06	1200000
	$e^+e^- \to Z(ss)H(cc)$	0.0005359	900000
	$e^+e^- \to Z(ss)H(bb)$	0.0108	1200000

	Process	Cross-section [pb^{-1}]	Events
Background	$e^+e^- \to Z(bb)H(\tau\tau)$	0.001153	1000000
	$e^+e^- \to Z(cc)H(\tau\tau)$	0.0009054	1200000
	$e^+e^- \to Z(ss)H(\tau\tau)$	0.001163	1100000
	$e^+e^- \to Z(qq)H(\tau\tau)$	0.00207	1200000
	$e^+e^- \to Z(bb)H(Z\gamma)$	2.819e-05	1100000
	$e^+e^- \to Z(cc)H(Z\gamma)$	2.213e-05	1100000
	$e^+e^- \to Z(ss)H(Z\gamma)$	2.842e-05	1200000
	$e^+e^- \to Z(qq)H(Z\gamma)$	5.058e-05	1100000
	$e^+e^- \to Z(bb)H(WW)$	0.003957	1200000
	$e^+e^- \to Z(cc)H(WW)$	0.003107	1200000
	$e^+e^- \to Z(qq)H(WW)$	0.003989	1000000
	$e^+e^- \to Z(ss)H(WW)$	0.007101	1100000
	$e^+e^- \to Z(bb)H(ZZ)$	0.0004857	1000000
	$e^+e^- \to Z(cc)H(ZZ)$	0.0003813	1000000
	$e^+e^- \to Z(ss)H(ZZ)$	0.0004896	1100000
	$e^+e^- \to Z(qq)H(ZZ)$	0.0008715	1200000
	$e^+e^- \to Z(\nu\nu)H(jj)$	0.05394	2200000
	$e^+e^- \to W^+W^-$	10.7165	11754213
	$e^+e^- \to ZZ$	0.6428	11470944
	$e^+e^- \to Z/\gamma^*(q\bar{q})$	21.4149	6000000
	$e^+e^- \to t\bar{t}$	0.8	2700000

additional $t\bar{t}$ in backgrounds

Cuts

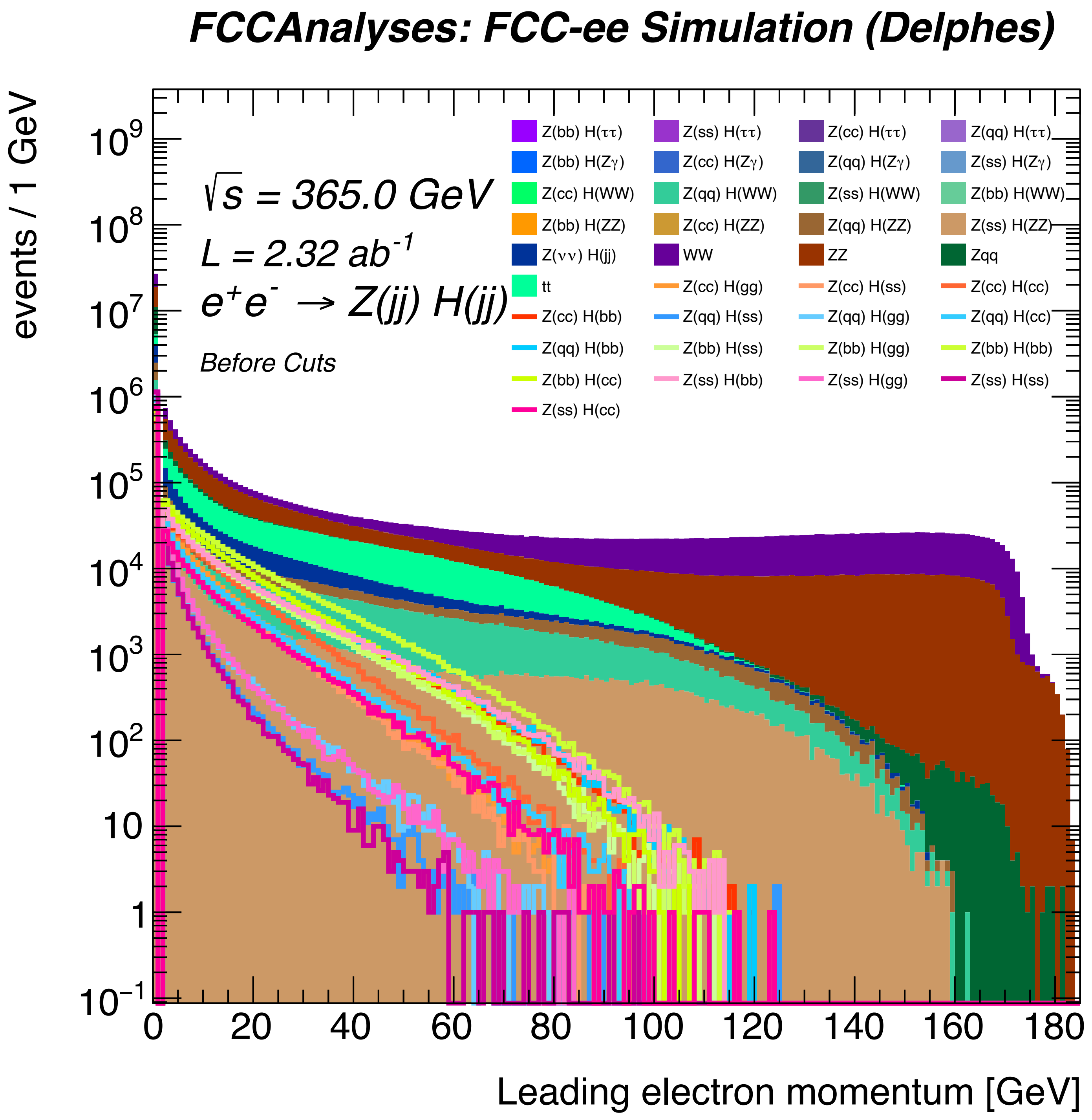
- Events (orthogonal to $ll, \nu\nu$ analysis)
  - $n_j = 4$ per event
  - Cuts on leptons
    - lepton (both e, μ) $p_l < 20\,\text{GeV}$ & $n_{e,\mu} \leq 2$ per event
  - Cuts on $m_{\text{vis}}, \theta_{\text{vis}}$
    - $m_{\text{vis}} > 150\,\text{GeV}, E_{\text{vis}} > 190\,\text{GeV}$
    - $0.15 < \theta_{\text{vis}} < 3$
  - Clustering merging parameter cut (d_{12}, d_{23}, d_{34})
  - χ^2 on the energy correction <100
- On the jet pairs
  - 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
  - $50 < m_{Z_{jj}} < 125\,\text{GeV}, m_{H_{jj}} > 91\,\text{GeV}$

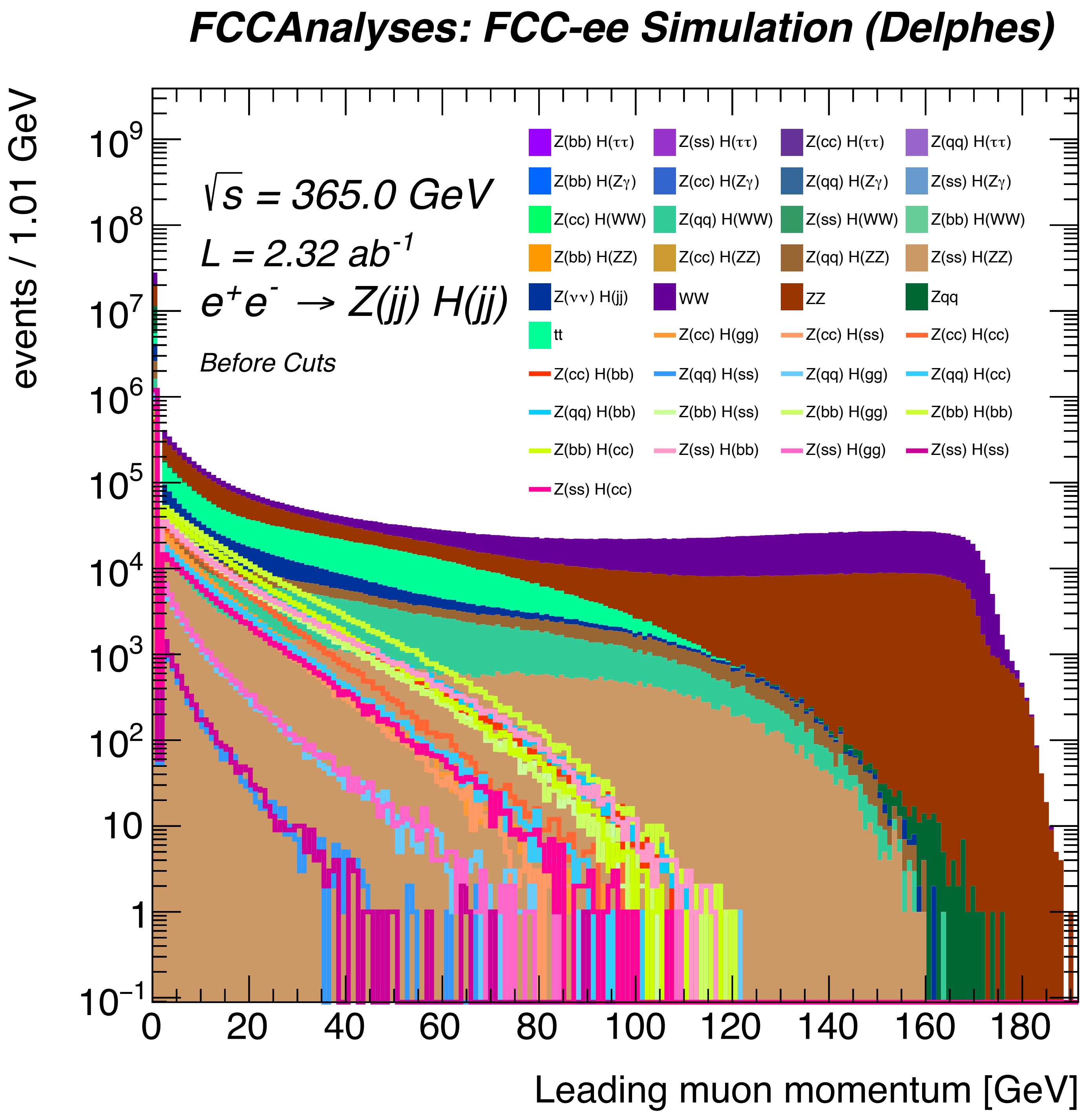
Cut efficiencies

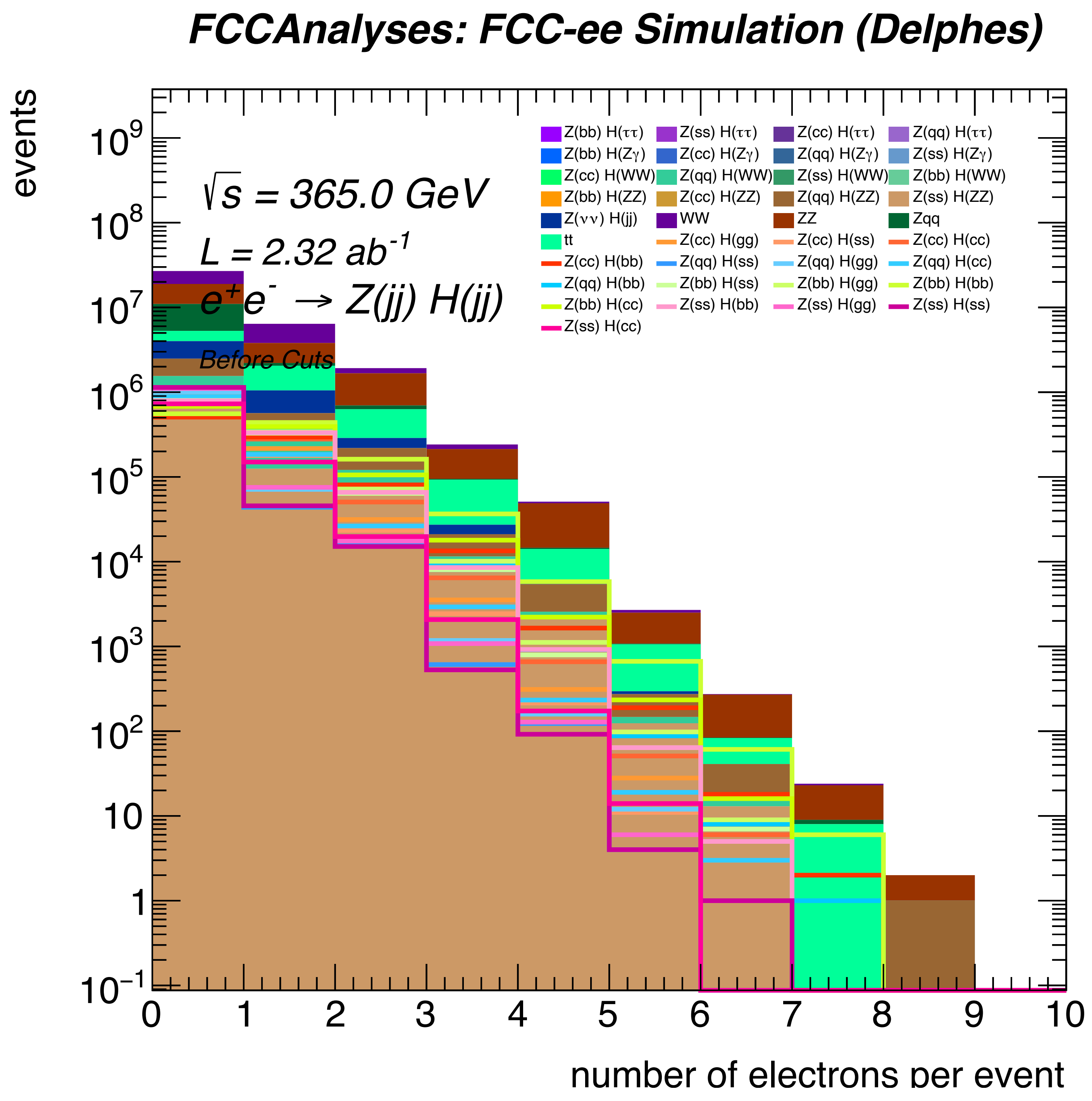
	Lepton cut	M_{vis}, E_{vis}, θ_{vis}	d_{ij}	χ^2
$e^+e^- \to Z(cc)H(gg)$	95.1	75.3	74.7	72.2
$e^+e^- \to Z(cc)H(ss)$	95.6	76.0	75.3	73.0
$e^+e^- \to Z(cc)H(cc)$	90.4	74.0	73.5	70.2
$e^+e^- \to Z(cc)H(bb)$	80.9	68.6	68.2	63.3
$e^+e^- \to Z(qq)H(gg)$	99.3	75.0	74.1	72.9
$e^+e^- \to Z(qq)H(ss)$	99.8	75.7	74.8	73.7
$e^+e^- \to Z(qq)H(cc)$	94.5	74.8	74.1	71.7
$e^+e^- \to Z(qq)H(bb)$	85.0	70.5	70.0	65.6
$e^+e^- \to Z(bb)H(gg)$	86.6	71.8	71.3	67.0
$e^+e^- \to Z(bb)H(ss)$	87.2	72.4	71.9	67.6
$e^+e^- \to Z(bb)H(cc)$	81.9	69.3	68.9	64.1
$e^+e^- \to Z(bb)H(bb)$	72.5	63.0	62.7	56.8
$e^+e^- \to Z(ss)H(gg)$	99.3	75.8	74.9	73.6
$e^+e^- \to Z(ss)H(ss)$	99.8	76.5	75.5	74.4
$e^+e^- \to Z(ss)H(cc)$	94.6	75.4	74.6	72.2
$e^+e^- \to Z(ss)H(bb)$	85.1	70.9	70.3	66.0

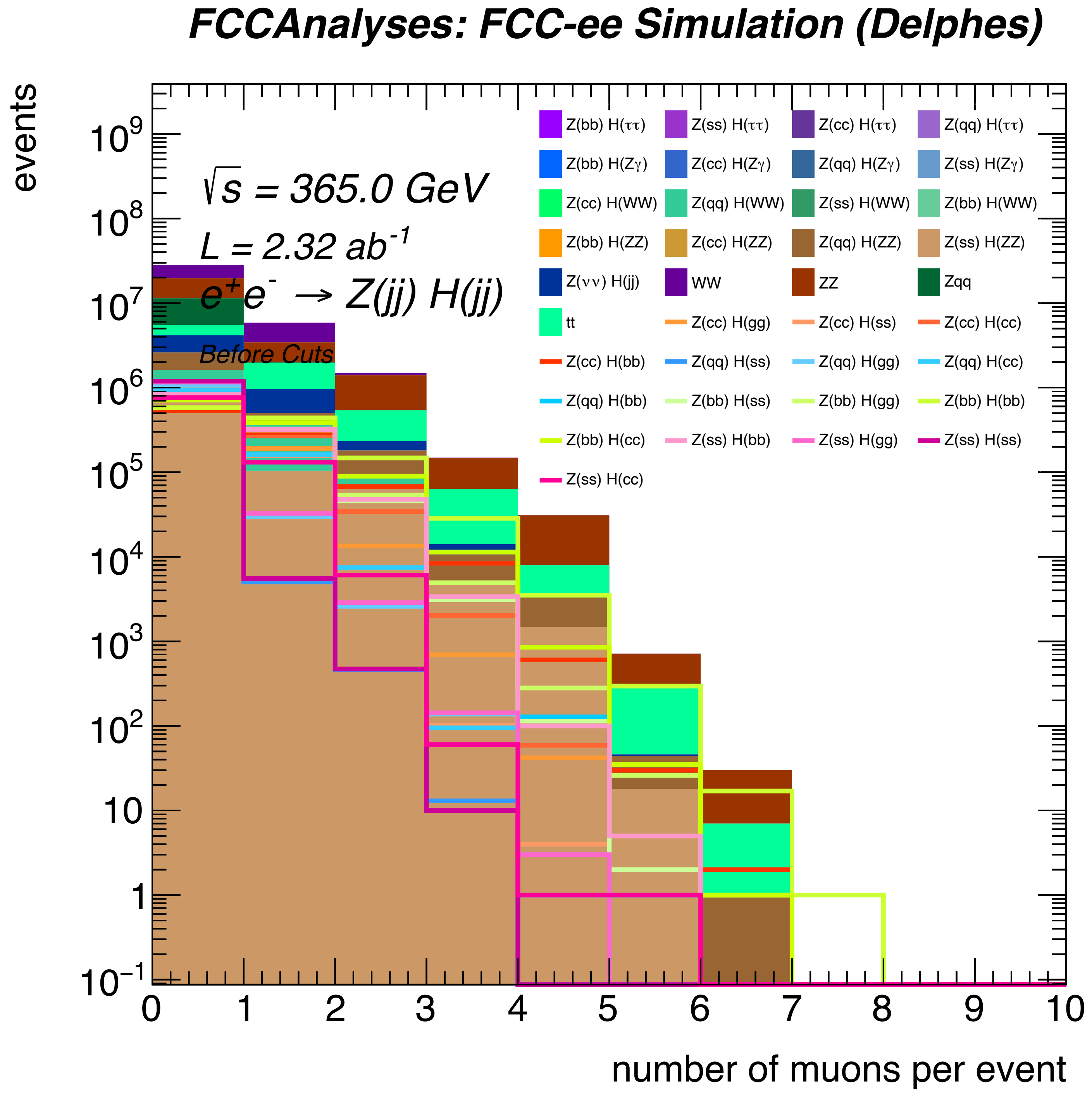
	Lepton cut	M_{vis}, θ_{vis}	d_{ij}	χ^2
$e^+e^- \to Z(bb)H(\tau\tau)$	55.2	49.5	42.5	19.6
$e^+e^- \to Z(ss)H(\tau\tau)$	61.1	55.6	47.4	22.4
$e^+e^- \to Z(cc)H(\tau\tau)$	63.8	58.5	49.9	23.6
$e^+e^- \to Z(qq)H(\tau\tau)$	63.8	58.5	49.9	23.6
$e^+e^- \to Z(bb)H(Z\gamma)$	78.5	62.4	55.0	46.7
$e^+e^- \to Z(ss)H(Z\gamma)$	86.3	67.3	58.4	50.7
$e^+e^- \to Z(cc)H(Z\gamma)$	90.3	69.1	59.4	52.0
$e^+e^- \to Z(qq)H(Z\gamma)$	90.1	68.6	58.9	51.6
$e^+e^- \to Z(bb)H(WW)$	57.8	49.8	48.1	36.6
$e^+e^- \to Z(ss)H(WW)$	63.8	53.7	51.6	40.2
$e^+e^- \to Z(cc)H(WW)$	66.8	55.0	52.6	41.2
$e^+e^- \to Z(qq)H(WW)$	66.7	54.6	52.3	40.8
$e^+e^- \to Z(bb)H(ZZ)$	73.0	60.4	53.8	39.6
$e^+e^- \to Z(ss)H(ZZ)$	80.8	65.2	58.5	43.7
$e^+e^- \to Z(cc)H(ZZ)$	84.7	67.7	60.4	45.4
$e^+e^- \to Z(qq)H(ZZ)$	84.7	67.3	60.0	45.0
$e^+e^- \to Z(\nu\nu)H(jj)$	84.5	1.8	0.8	0.0
$e^+e^- \to W^+W^-$	63.8	41.8	31.2	27.9
$e^+e^- \to ZZ$	76.8	37.7	32.7	29.9
$e^+e^- \to Z/\gamma^*(q\bar{q})$	99.6	31.2	15.9	15.4
$e^+e^- \to t\bar{t}$	53.6	50.5	49.5	37.9

Lepton distributions

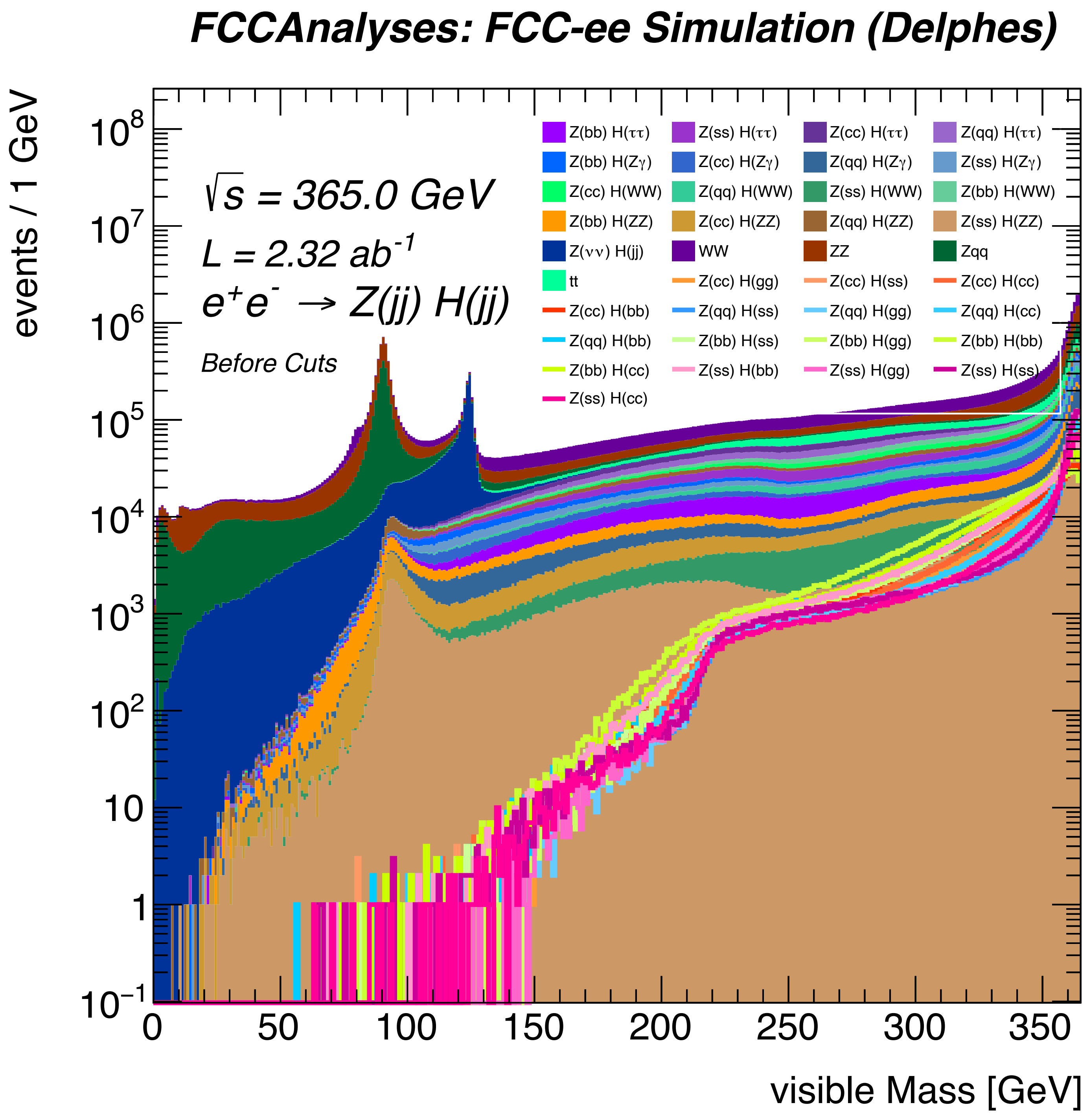


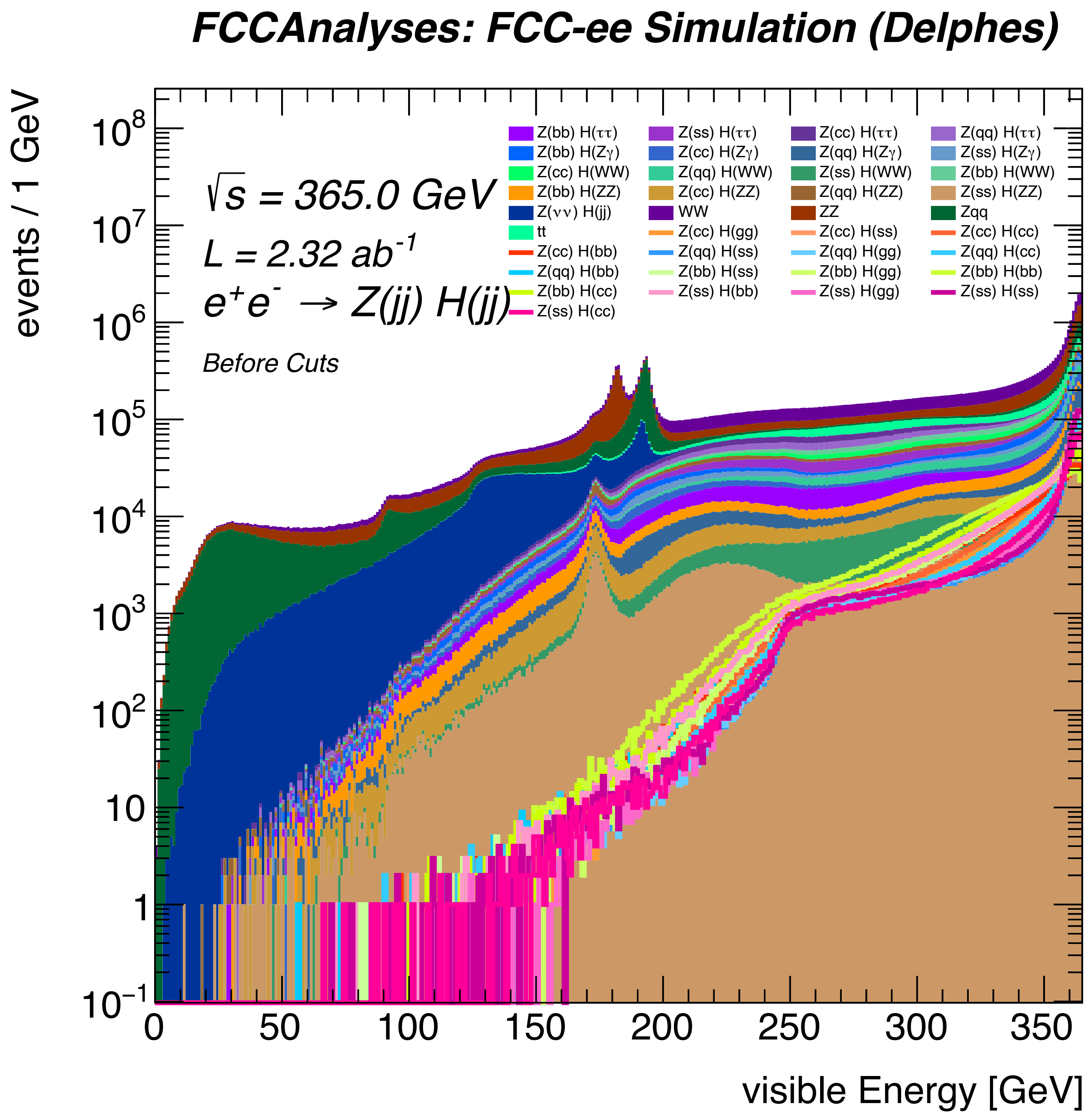


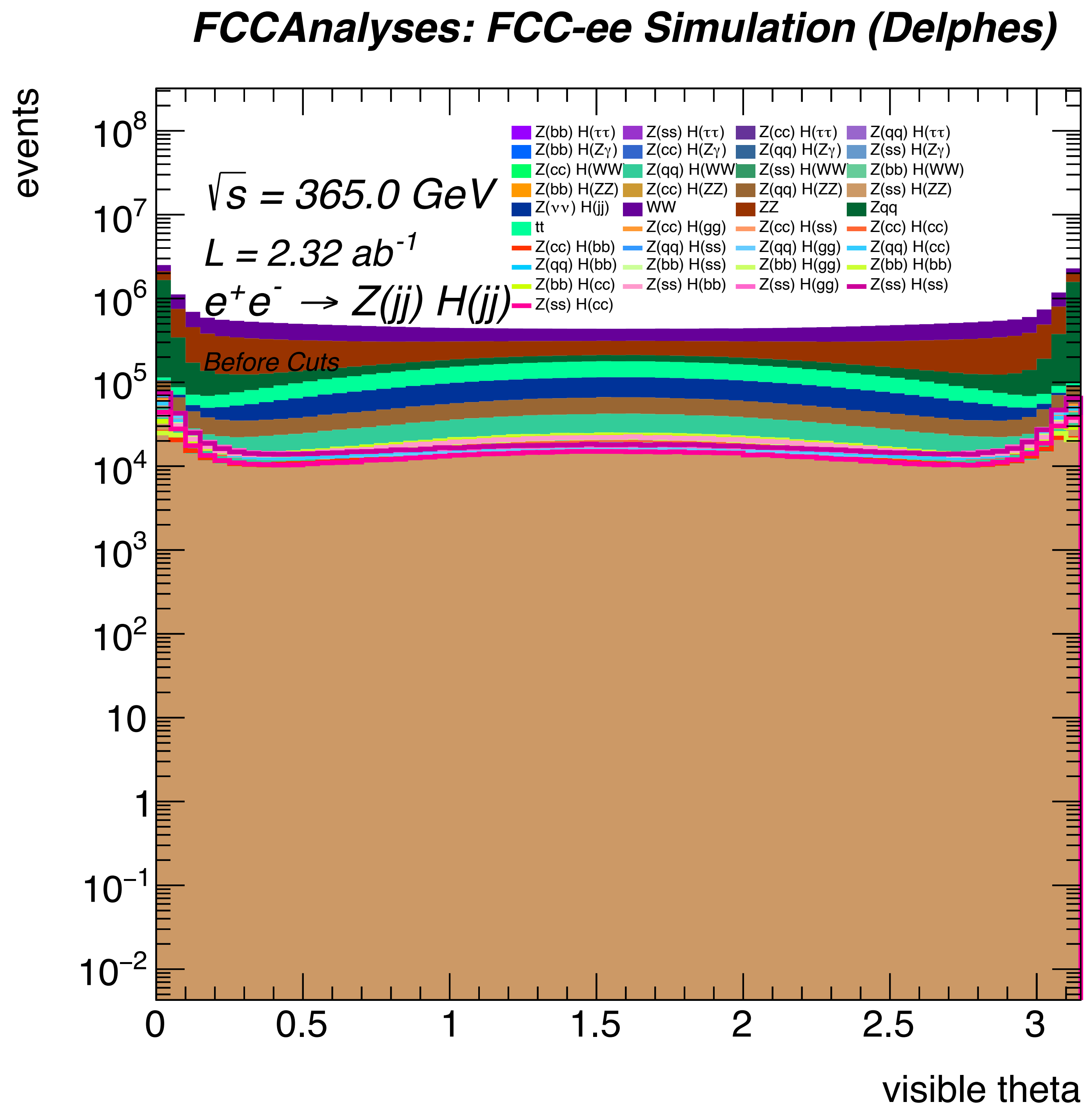




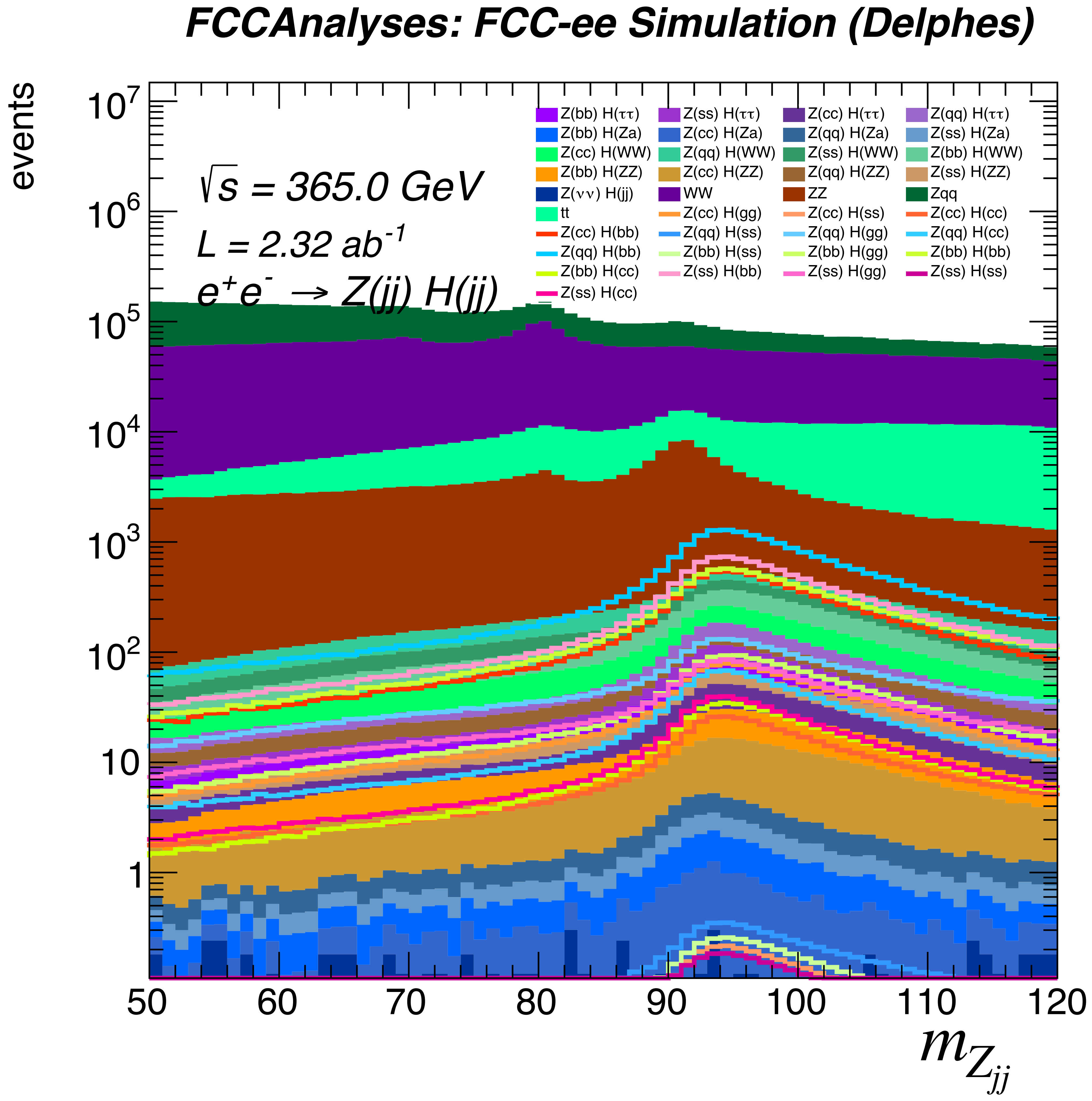
Distributions on M_{vis}, E_{vis} and θ_{vis}

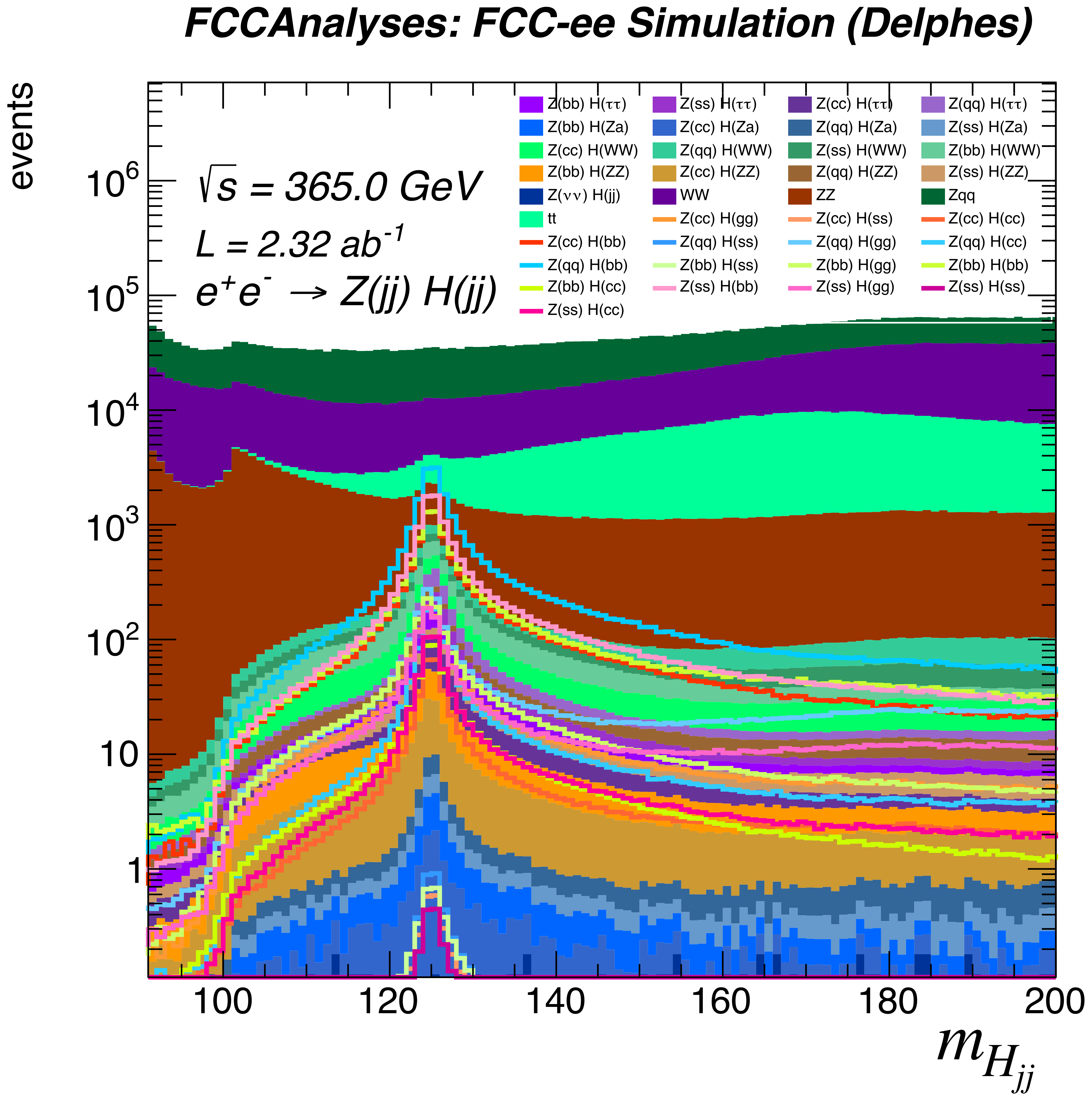






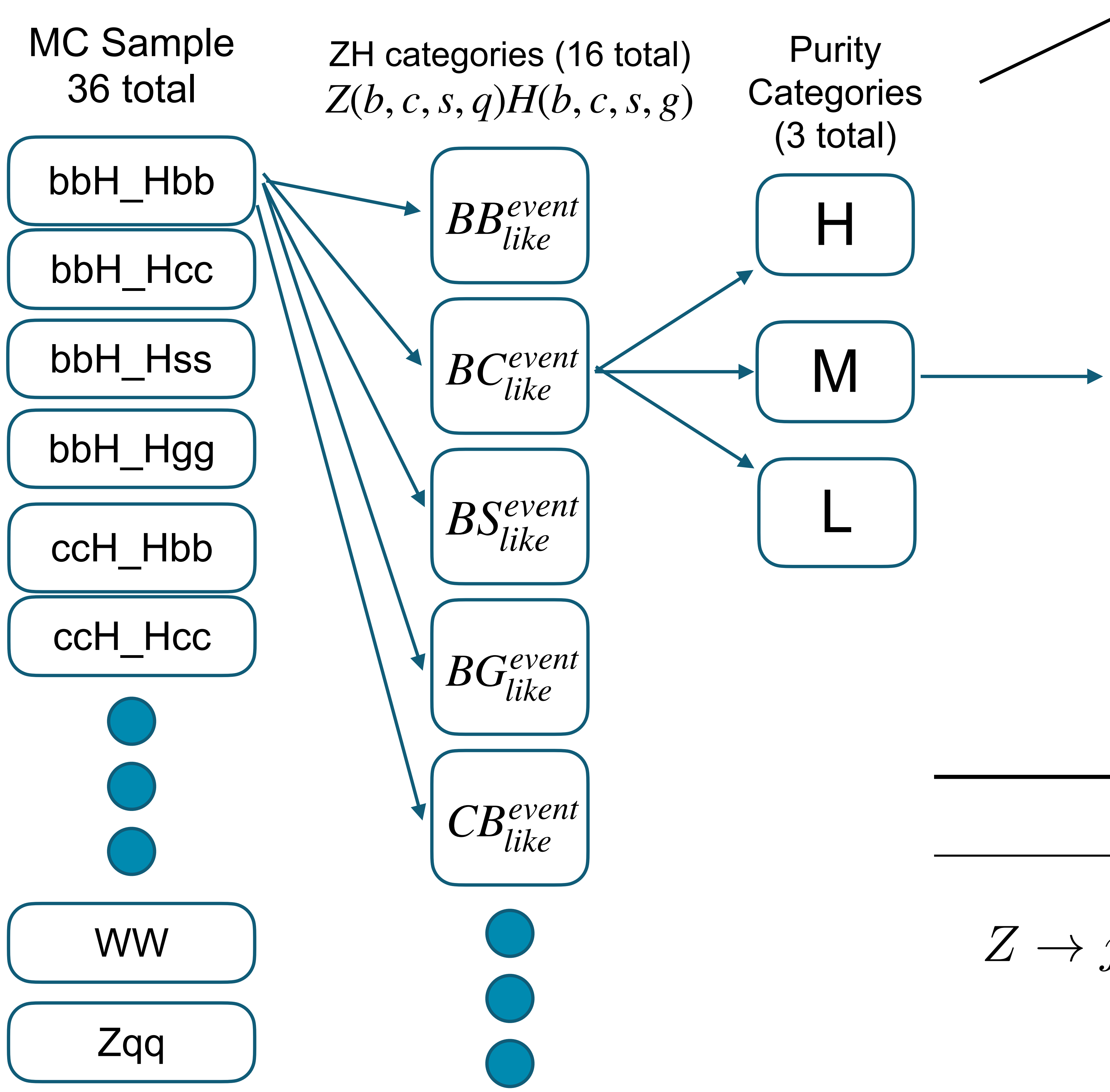
m_{Hjj} m_{Zjj} distributions





Fitting strategy

Fit now moved to combineTF



MC Sample
36 total

- bbH_Hbb
- bbH_Hcc
- bbH_Hss
- bbH_Hgg
- ccH_Hbb
- ccH_Hcc
- ●
- ●
- ●
- WW
- Zqq

ZH categories (16 total)
$Z(b,c,s,q)H(b,c,s,g)$

- BB^{event}_{like}
- BC^{event}_{like}
- BS^{event}_{like}
- BG^{event}_{like}
- CB^{event}_{like}
- ●
- ●
- ●

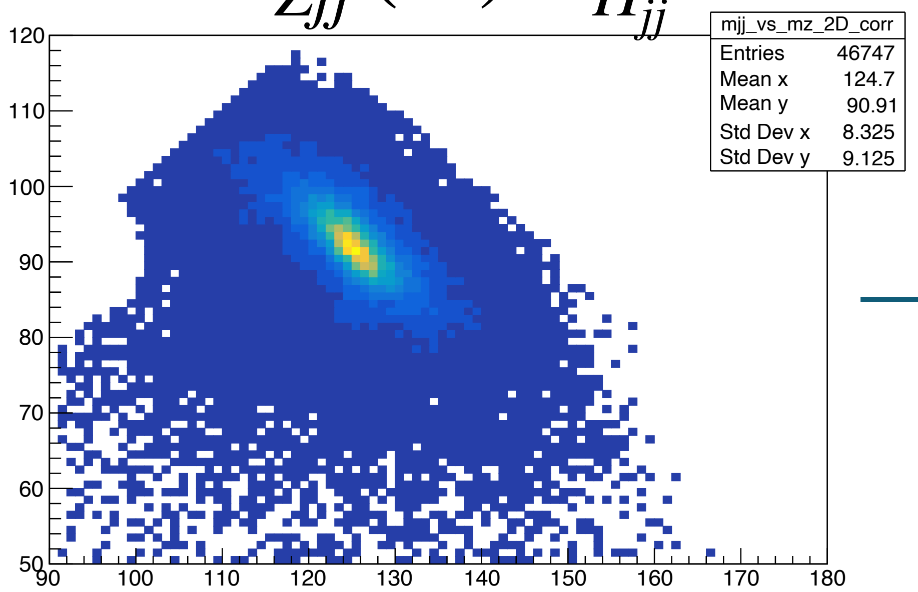
Purity
Categories
(3 total)

- H
- M
- L

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

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



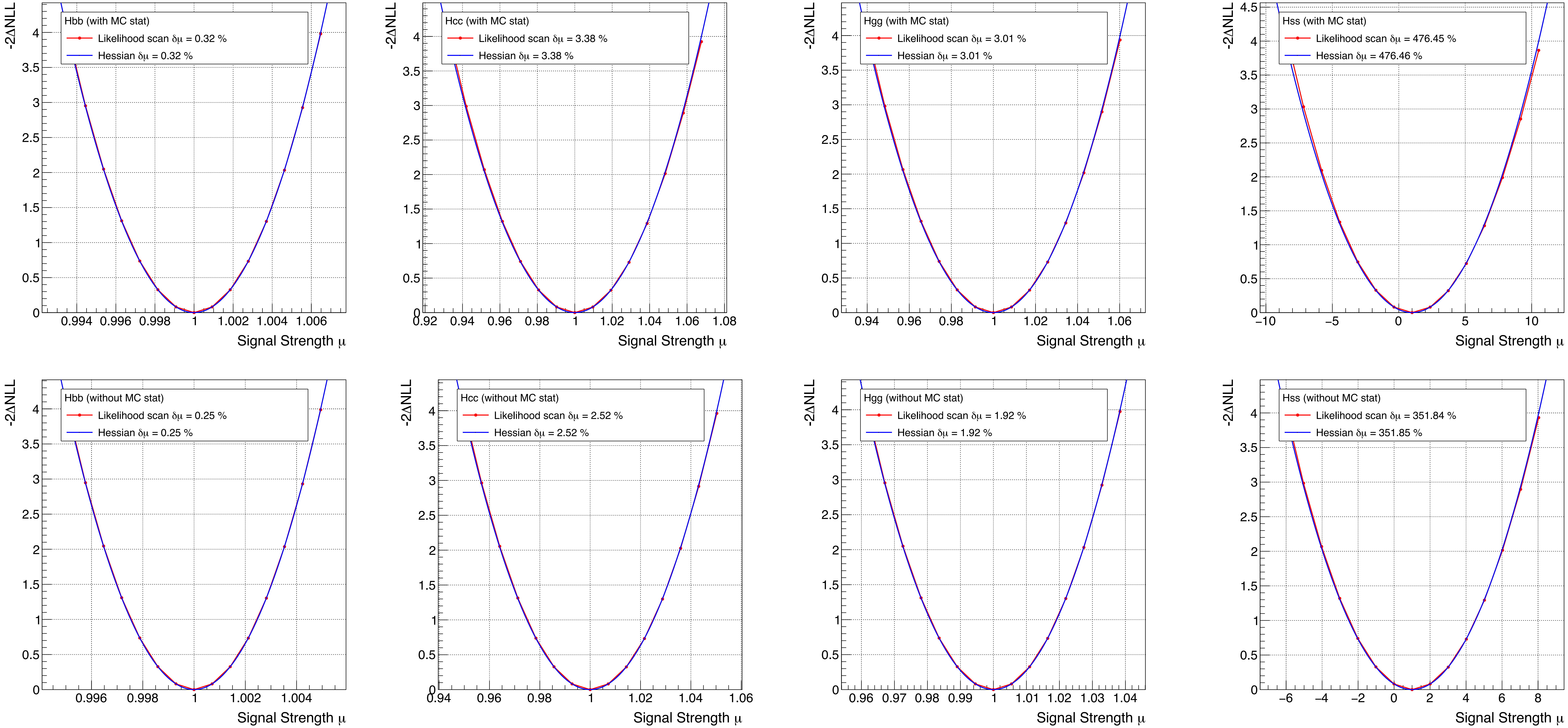
5 GeV bin on $m_{Z_{jj}}$
($m_{H_{jj}}$ bin 1 GeV)
(14 total bins)

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

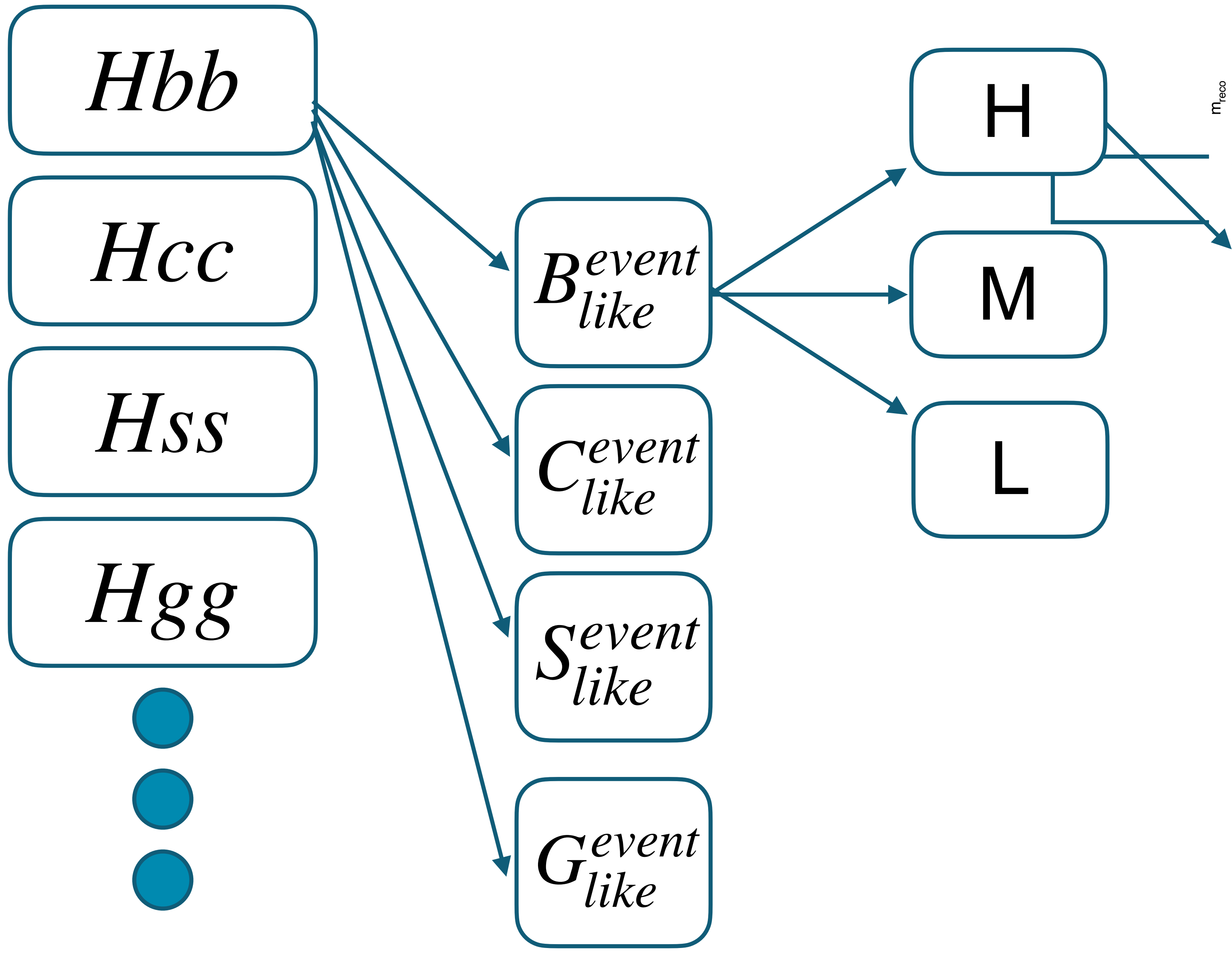
ZH final state		240	240 & MCStat	365	365 & MCStat
$Z \to jj\ (j = b, s, c, q)$	$H \to b\bar{b}$	0.25 %	0.32 %	0.50 %	0.52 %
	$H \to c\bar{c}$	2.52 %	3.38 %	3.65 %	4.68 %
	$H \to gg$	1.92 %	3.01 %	3.08 %	4.15 %
	$H \to s\bar{s}$	352 %	477 %	554 %	664 %

Likelihood scans

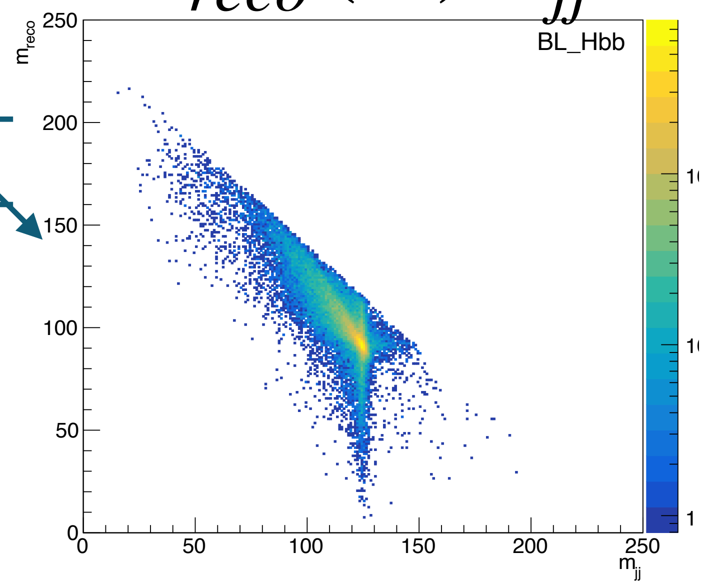


Reminder $ZH(\nu\nu jj)$ analysis now at
7.2ab^{-1} at $\sqrt{s} = 240\,\mathrm{GeV}$
2.32ab^{-1} $\sqrt{s} = 365\,\mathrm{GeV}$

	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



$m_{reco}\,(vs)\,m_{jj}$



Projection with 5 GeV bin on m_{recoil}

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

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

ZH final state		240	240 & MCStat	365	365 & MCStat
$Z \to \nu\nu$	$H \to bb$	0.31 %	0.36 %	0.81 %	0.84 %
	$H \to c\bar{c}$	2.23 %	2.68 %	4.69 %	5.01 %
	$H \to gg$	0.95 %	0.98 %	3.02 %	3.21 %
	$H \to s\bar{s}$	128 %	145 %	358 %	395 %

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

- First attempt to fit the inv. and full hadronic channels with combineTF for both $\sqrt{s} = 240\,\text{GeV}$ and $\sqrt{s} = 365\,\text{GeV}$

Preliminary

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

ZH final state		Combined	Combined & MCStat
$Z \to jj\ (j = b, s, c, q)$ $Z \to \nu\nu$	$H \to b\bar{b}$	0.19 %	0.22 %
	$H \to c\bar{c}$	1.45 %	1.77 %
	$H \to gg$	0.86 %	0.88 %
	$H \to s\bar{s}$	112 %	125 %