





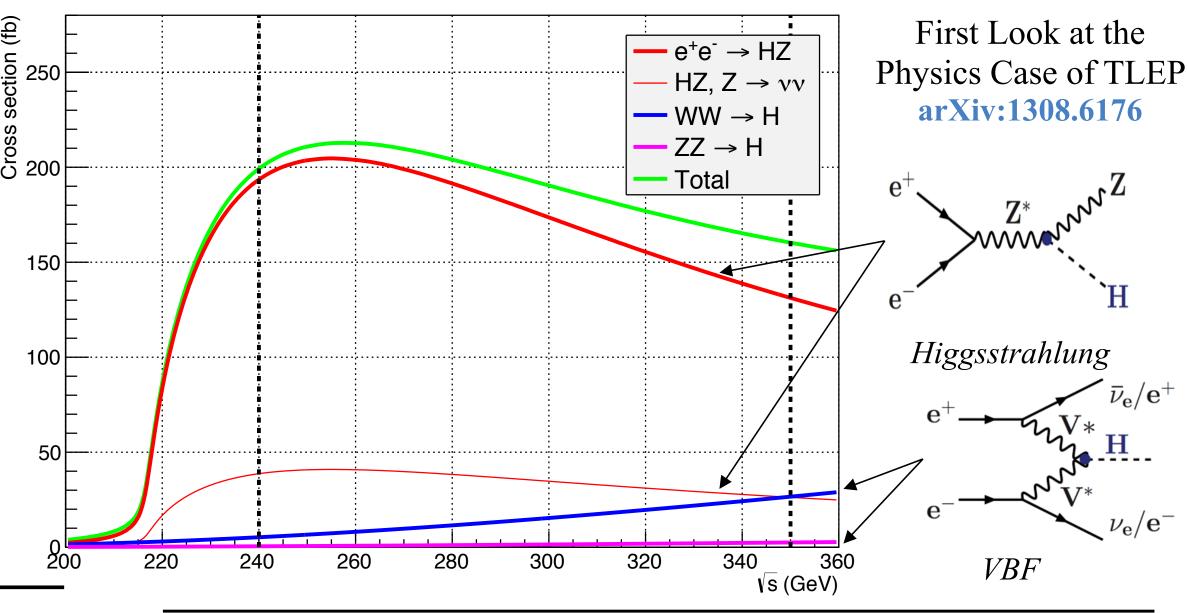


FCC-ee H(jj) in the $Z(\nu\nu)$ final state

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Motivation

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



Process

F	Handbook of LHC Higgs cross sections arXiv:1610.07922
Branching Ratio े	= bb - WW - 99
$ar{\Box}$	

H Decay	$\mathrm{BR}~(\%)$
	$m_{\mathrm{H}} = 125.0\mathrm{GeV}$
$\overline{b} \overline{b}$	58.24
$c\overline{c}$	2.891
$S\overline{S}$	0.016
$rac{gg}{ auar{ au}}$	8.187
$ auar{ au}$	6.272

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•	RR(H)	$\rightarrow c\overline{c}$	estimated	25
	DNII	\rightarrow 33	esimiated	las

$$\Rightarrow \text{BR}\left[H \to s\bar{s}\right]_{\text{SM}} \approx \left(m_s/m_c\right)^2 \cdot \text{BR}\left[H \to c\bar{c}\right]_{\text{SM}},$$

$$\frac{\text{PDG}}{120\ 121\ 122\ 123\ 124\ 125\ 126\ 127\ 128\ 129\ 130}$$

ฟ _H [GeV]	→	BR $[H \rightarrow$	$s\bar{s}]_{SM}$	≈ 0.024	% from	theorists
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Signal	$\mid ZH \mid$	0.2032195
	Z(u u)H	0.046191
	$e^+e^- \rightarrow Z(\nu\nu)H(b\bar{b})$	0.0269
	$e^+e^- \rightarrow Z(\nu\nu)H(c\bar{c})$	0.001335
	$e^+e^- \rightarrow Z(\nu\nu)H(gg)$	0.003782
	$e^+e^- \to Z(\nu\nu)H(s\bar{s})$	$1.109 \cdot 10^{-05}$
	$e^+e^- \to Z(\nu\nu)H(\tau\tau)$	0.002897
Background	$ e^+e^- \rightarrow ZZ $	1.35899
_	$e^+e^- \rightarrow W^+W^-$	16.4385
	$e^+e^- \to Z/\gamma^*(q\bar{q})$	52.6539
	$e^{+}e^{-} \to Z(\nu\nu)H(W^{+}W^{-})$	0.00994
	$e^+e^- \rightarrow Z(\nu\nu)H(ZZ)$	0.00122
	$e^+e^- \rightarrow q\bar{q}H, q=u,d,s,c,b$	0.13635







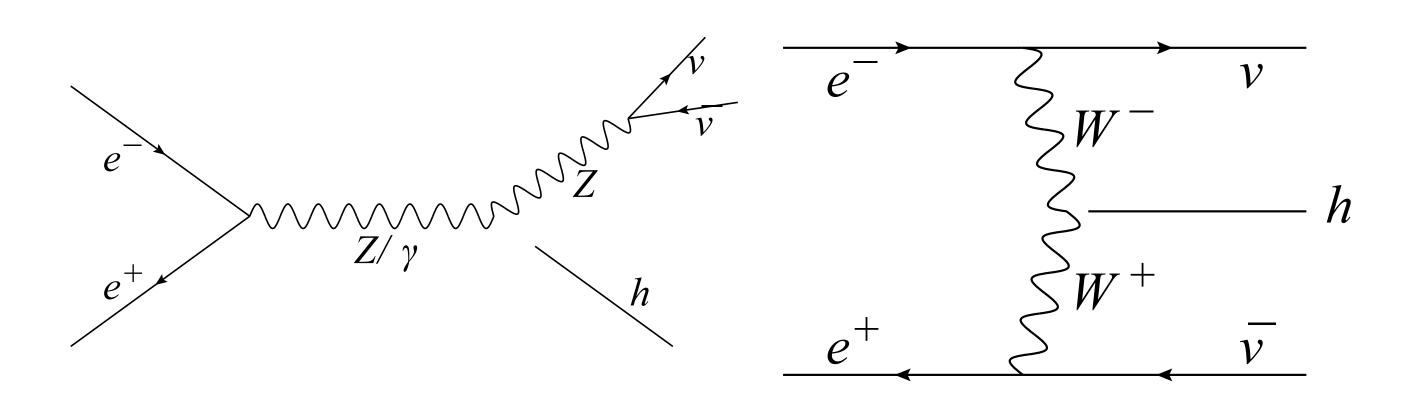
Cross-section

 $[pb^{-1}]$

Recoil mass

- At lepton colliders, the recoil mass method can be used to reconstruct the mass of a particle without measuring its decay products
- Most of the $\nu\bar{\nu}H$ events are from ZH process with $Z \to \nu\bar{\nu}$, while the WW-fusion contributes about 13%
- The signal events have only the jets from the Higgs boson decay. Therefore, if the Higgs decay products are measured, the recoil mass can be turned around to reconstruct the Z mass

$$m_H^2 = E_H^2 - |\vec{p}_H|^2 = \left(\sqrt{s} - E_Z\right)^2 - |\vec{p}_Z|^2 = s - 2\sqrt{s}E_H + m_H^2 \text{ and then the recoil mass: } m_{\text{recoil}}^2 = s - 2\sqrt{s}E_H^{\text{rec}} + \left(m_H^{\text{rec}}\right)^2$$



- Offers a way to separate the Higgsstrahlung events with an invisible Z from the WW-fusion events
- Due to finite jet res. beam energy spread and other effects, the recoil mass distribution of the events has a rather large spread
- Can be improved by some jet energy corrections
- Take advance of different shapes of backgrounds to use Z recoil mass in the fit







Dataset

- FCCAnalysis framework used with some standalone analysis scripts
- IDEA Detector (delphes fast sim)
- Training using 9M jets and ParticleTransformer
- Winter2023 samples
 - model_dir = "/eos/experiment/ fcc/ee/jet_flavour_tagging/ winter2023/ wc_pt_13_01_2022"
- tagger model_name ="fccee_flavtagging_edm4hep_wc_v1"

Sample	Generator	Events
$e^+e^- \to Z(\nu\nu)H(b\bar{b})$	wzp6	1,200,000
$e^+e^- \to Z(\nu\nu)H(c\bar{c})$	wzp6	$1,\!100,\!000$
$e^+e^- \to Z(\nu\nu)H(gg)$	wzp6	$1,\!055,\!845$
$e^+e^- \to Z(\nu\nu)H(s\bar{s})$	wzp6	$1,\!008,\!052$
$e^+e^- \to Z(\nu\nu)H(\tau\tau)$	wzp6	1,200,000
$e^+e^- \to ZZ$	p8	56,162,093
$e^+e^- \to W^+W^-$	p8	373,375,386
$e^+e^- \to Z/\gamma^*(q\bar{q})$	p8	100,559,248
$e^+e^- \to Z(\nu\nu)H(W^+W^-)$	wzp6	$400,\!000$
$e^+e^- \to Z(\nu\nu)H(ZZ)$	wzp6	200,000
$e^+e^- \rightarrow q\bar{q}H, q=u,d,s,c,b$	wzp6	5,400,000







Analysis overview

- Signal: $H \rightarrow jj \quad (j = b, c, s, g, \tau)$
- Background:
 - WW, ZZ, Zqq, qqH, HWW, HZZ
- Jets reconstruction
 - N = 2 Durham kt exclusive algorithm
 - ParticleNet jet tagger (4 categories: b, c, s, g)
- Analysis
 - Events selection (orthogonal to with Z(ll)H)
 - Categorization based on tagger scores
 - Fit to extract uncertainties





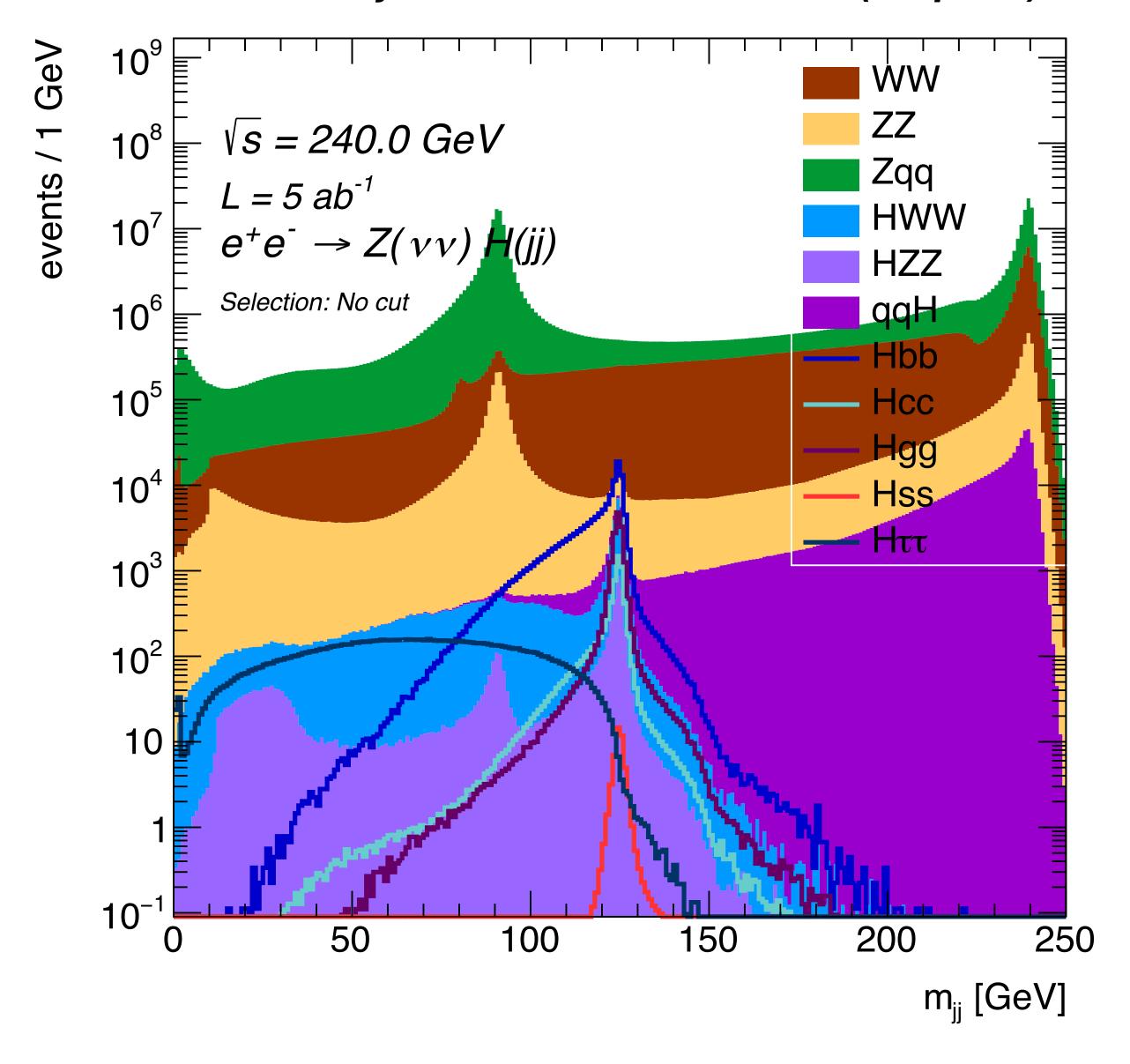


Statistics

• Initial yield at (scaled for lumi):

$$\sqrt{s} = 240 \,\text{GeV}, \mathcal{L} = 5 \,\text{ab}^{-1}$$

	Before selection
Hbb	1.34e + 05
Hcc	6.68e + 03
Hgg	1.66e + 04
Hss	5.08e + 01
$\mathrm{H} au au$	1.26e + 04
$\overline{\text{HWW}}$	4.80e + 04
HZZ	5.77e + 03
qqH	6.82e + 05
WW	7.99e + 07
ZZ	6.48e + 06
Zqq	2.62e + 08



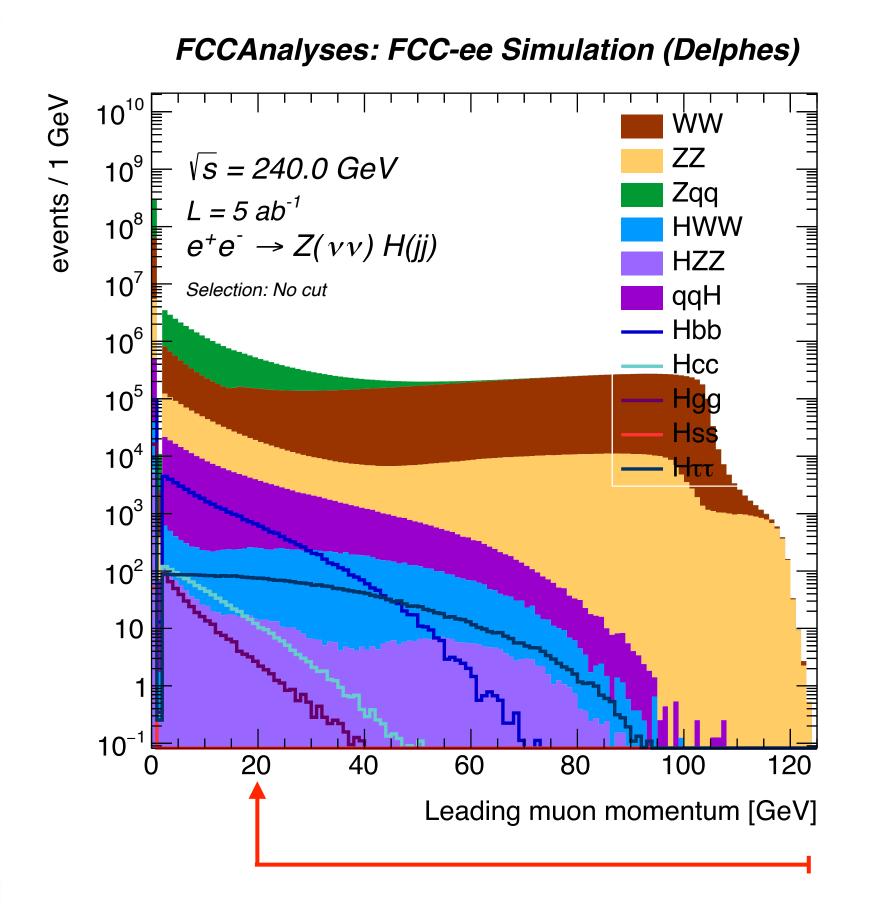


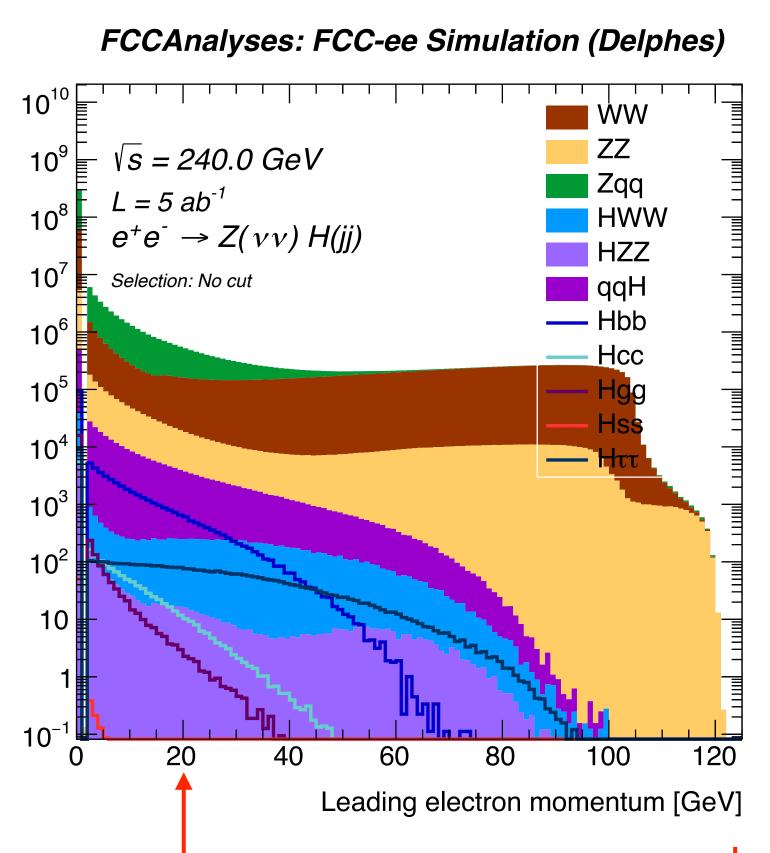


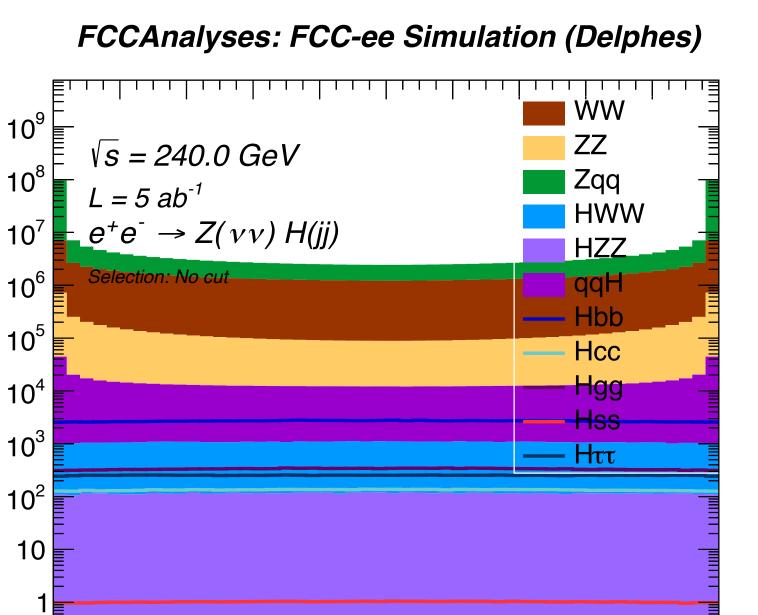


Cuts

- Cut on lepton p (<20GeV) (orthogonal to Z(ll) analysis) and $|\cos(\theta_{inv})|<0.85$
 - \Rightarrow Suppress leptonic and semi-leptonic and $\nu \bar{\nu} Z(Z \rightarrow q\bar{q})$ backgrounds







events

10⁻¹

 10^{-2}

-0.8 -0.6 -0.4 -0.2



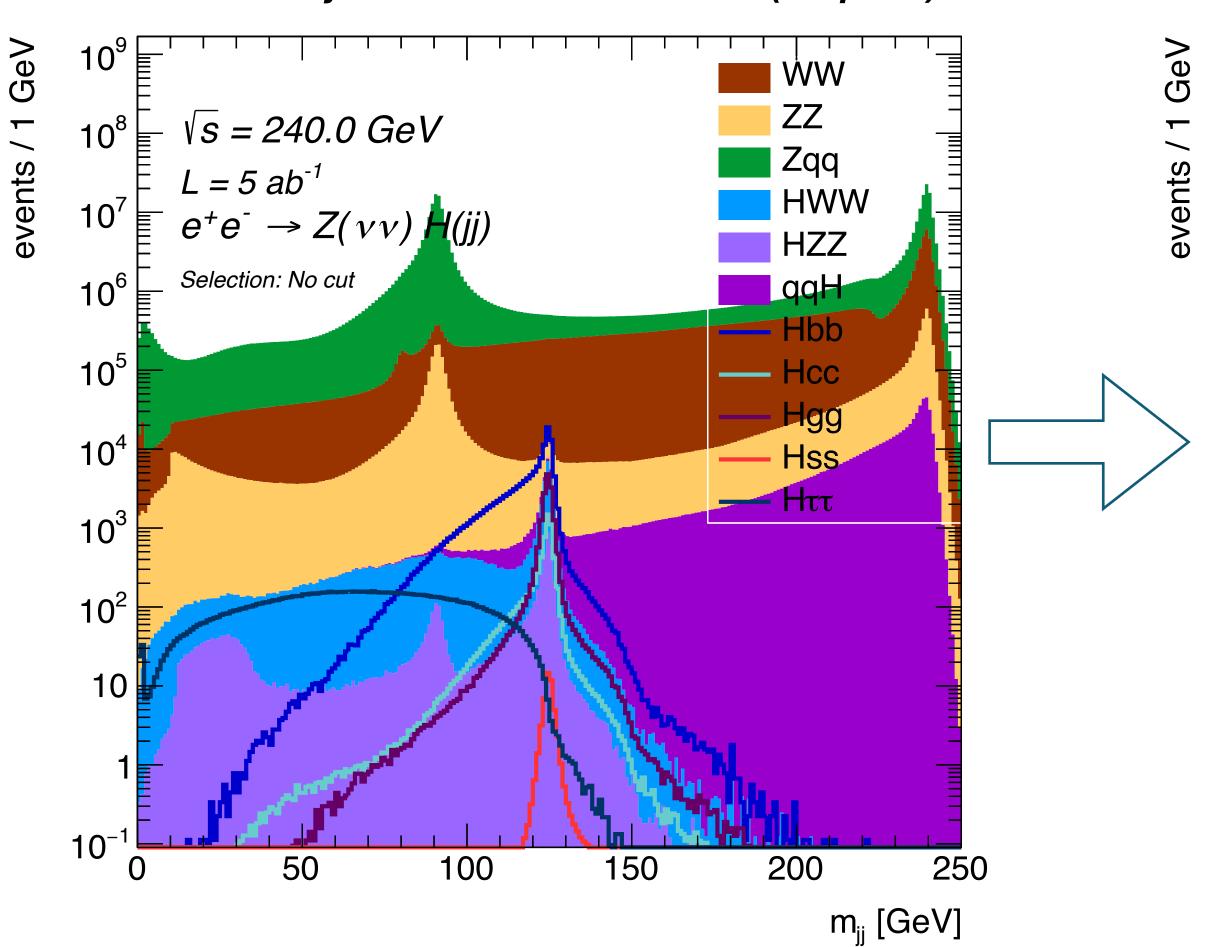


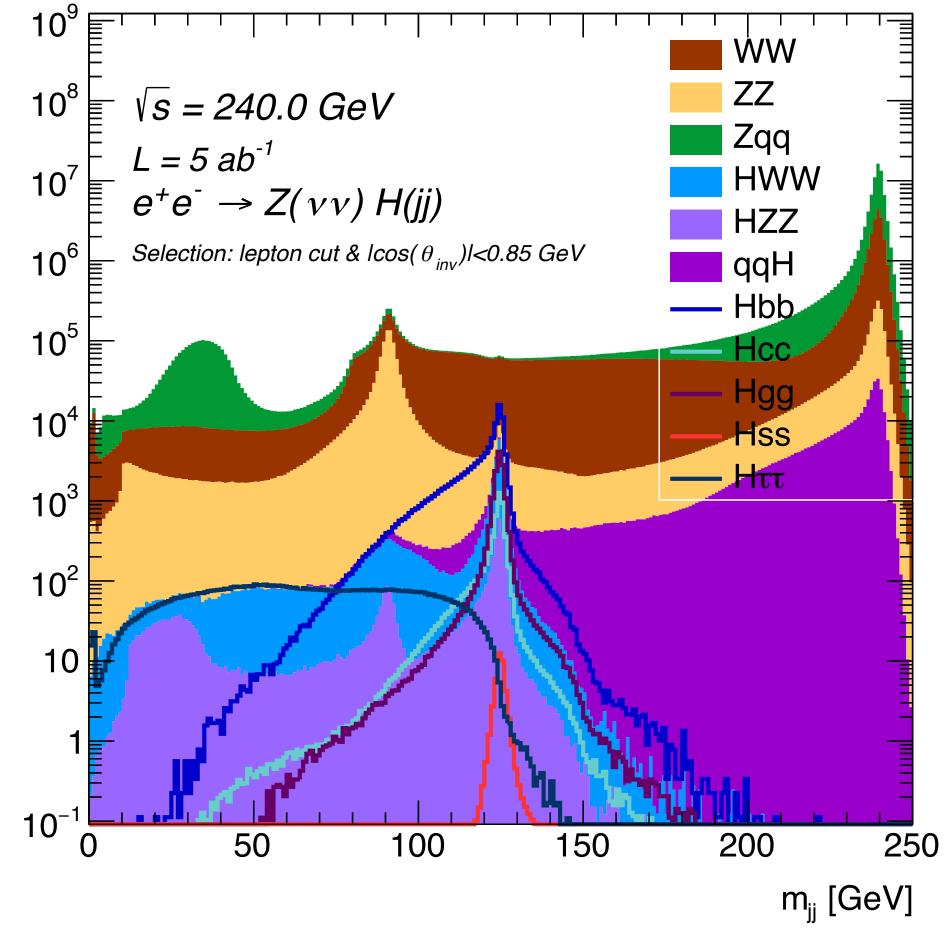


 $\cos(\theta_{inv})$

m_{jj} after initial cuts





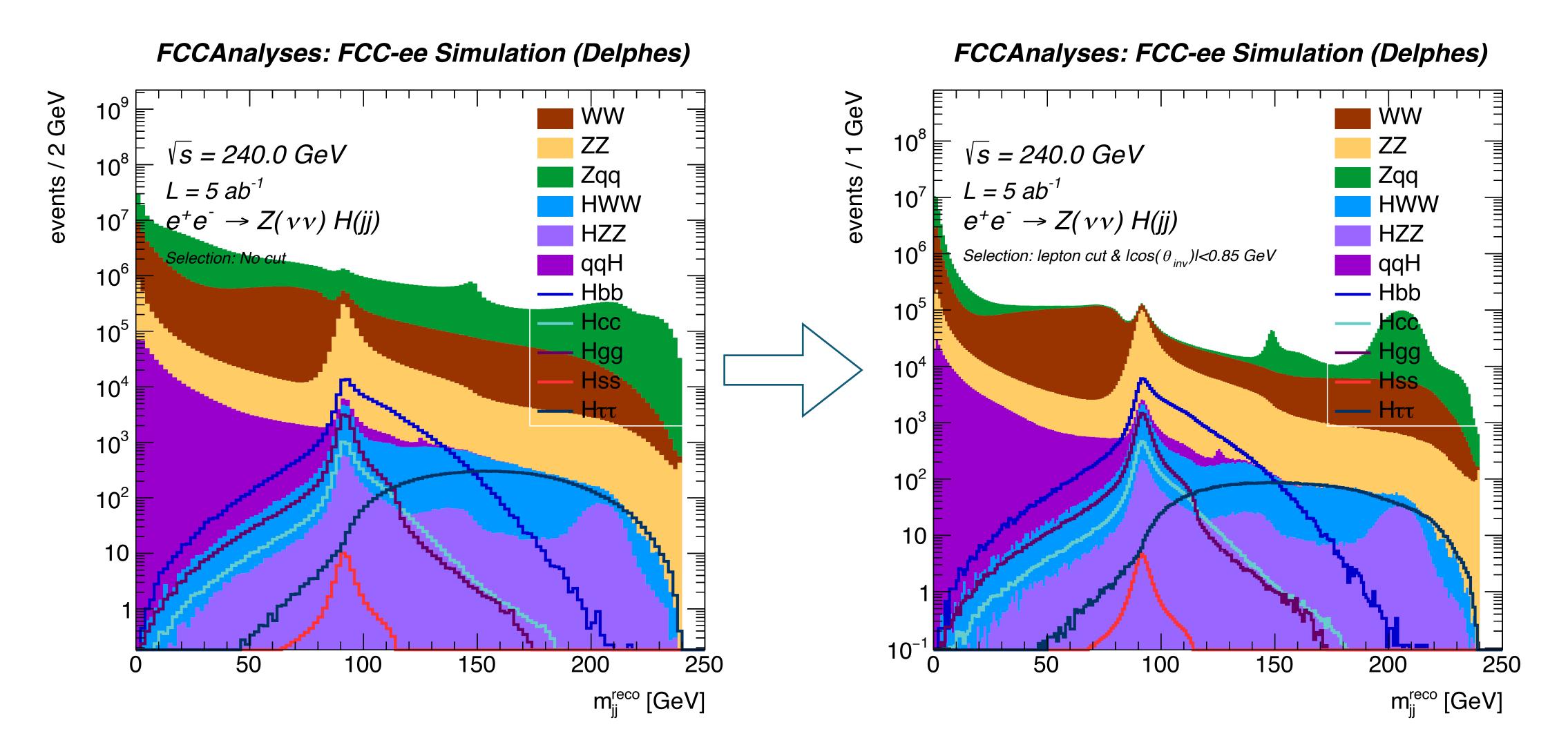








m^{recoil} after initial cuts









Yields & Cut-flow

		Before selection	$p_{\mu} < 20 GeV$	$p_e < 20 GeV$	$ cos(\theta_{inv}) < 0.85$	efficiency
Hbb	$Yield(10^5)$	1.34	1.29	1.23	1.06	0.786
1100	Sig.	7.169921	7.119619	7.011417	10.945233	0.780
Hcc	$Yield(10^3)$	6.68	6.60	6.53	5.59	0.837
11 CC	Sig.	0.357426	0.364260	0.372232	0.577206	0.007
$\boldsymbol{U}_{\alpha \alpha}$	$Yield(10^4)$	1.66	1.66	1.66	1.42	0.256
Hgg	Sig.	0.888214	0.916168	0.946256	1.466248	0.856
Hss	Yield	51	51	51	44	0.056
ΠSS	Sig.	0.002718	0.002804	0.002896	0.004492	0.856
H au au	$Yield(10^3)$	12.6	10.8	9.11	7.75	0.619
	Sig.	0.674187	0.596061	0.519301	0.800241	0.613
\overline{HWW}	$Yield(10^4)$	4.80	4.08	3.40	2.92	0.607
HZZ	$Yield(10^3)$	5.77	5.43	5.08	4.34	0.752
qqH	$Yield(10^5)$	6.82	6.27	5.76	4.14	0.607
WW	$Yield(10^7)$	7.99	6.37	4.89	2.94	0.368
ZZ	$Yield(10^6)$	6.48	5.76	5.08	3.21	0.495
Zqq	$Yield(10^7)$	26.2	25.8	25.3	6.06	0.231



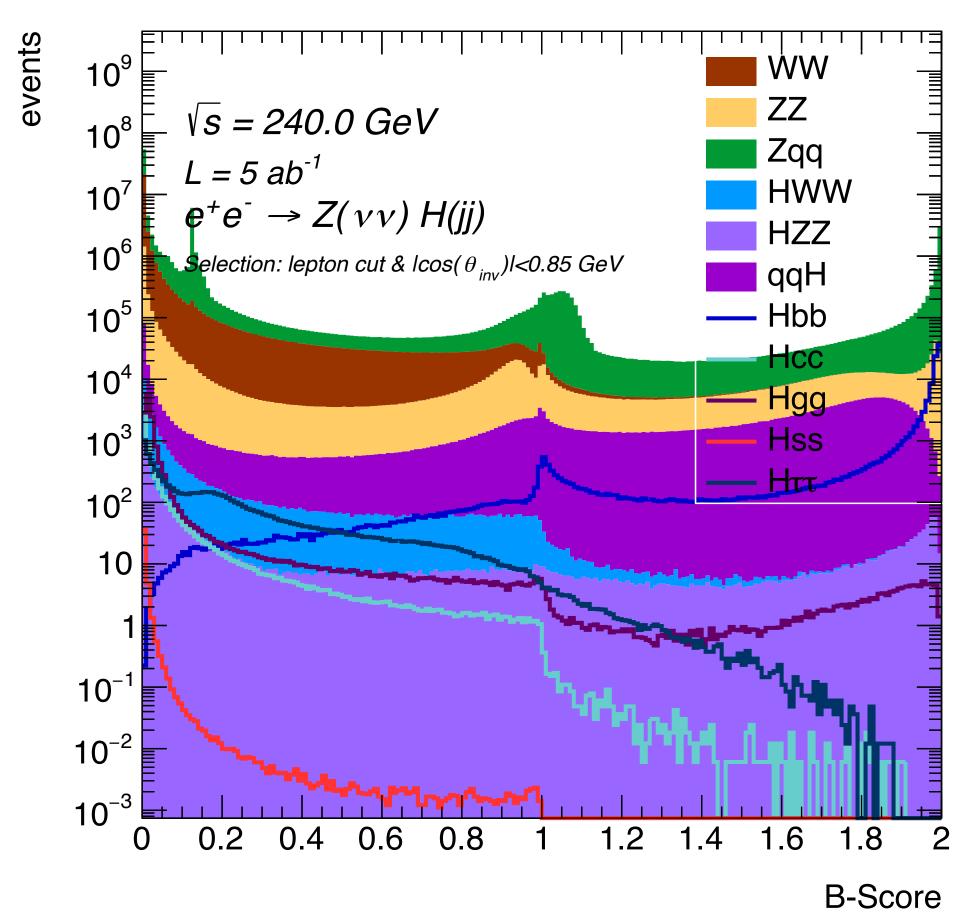


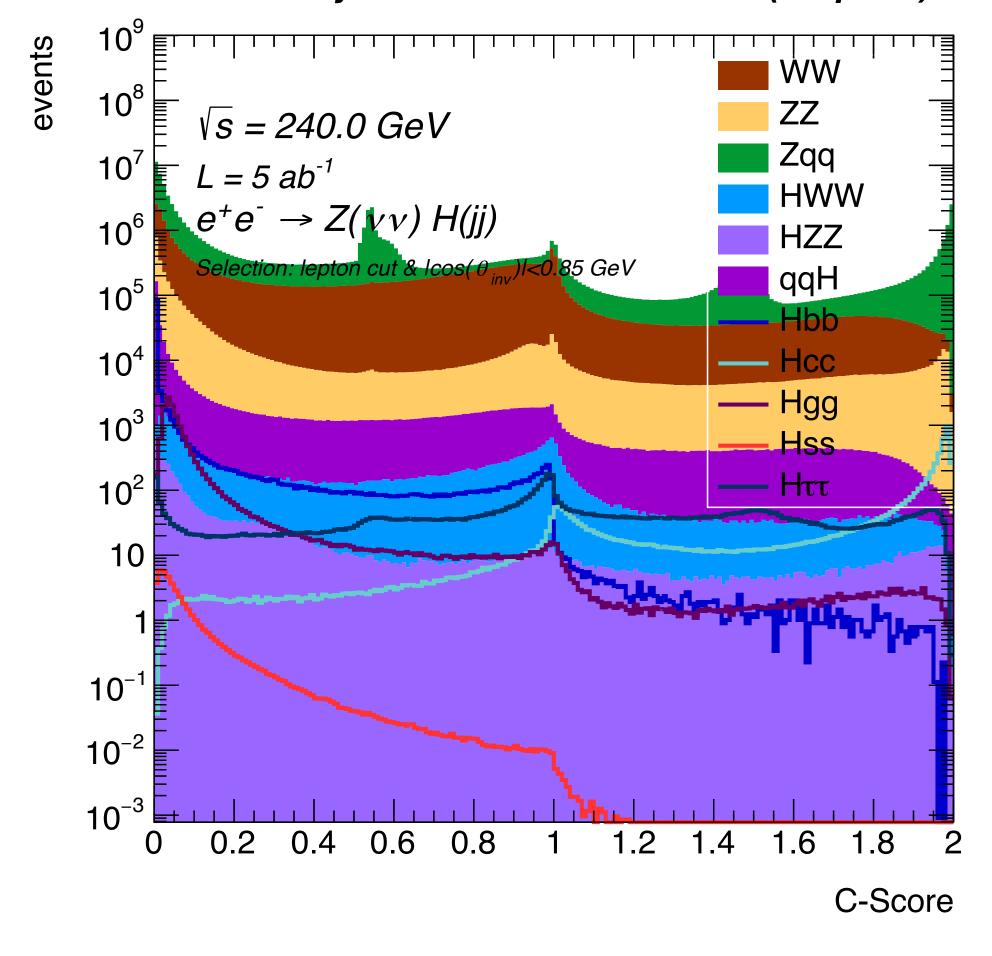


Sum of dijet Scores from the tagger (I)

• B & C









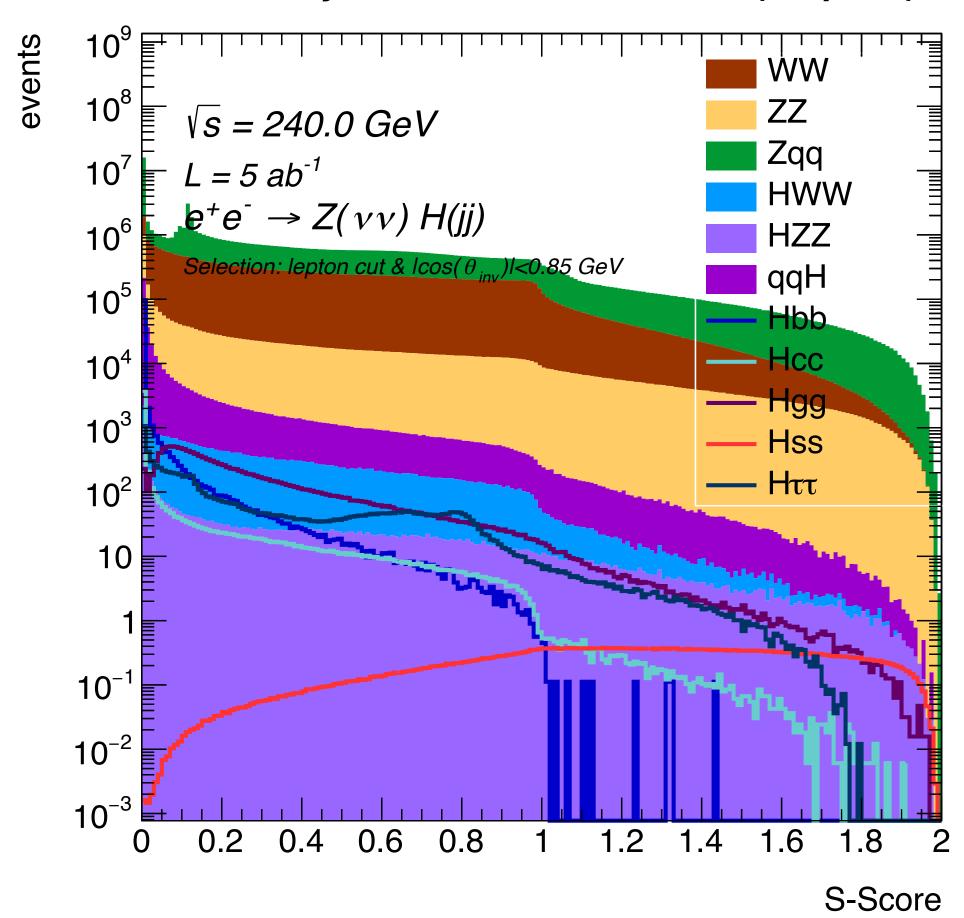


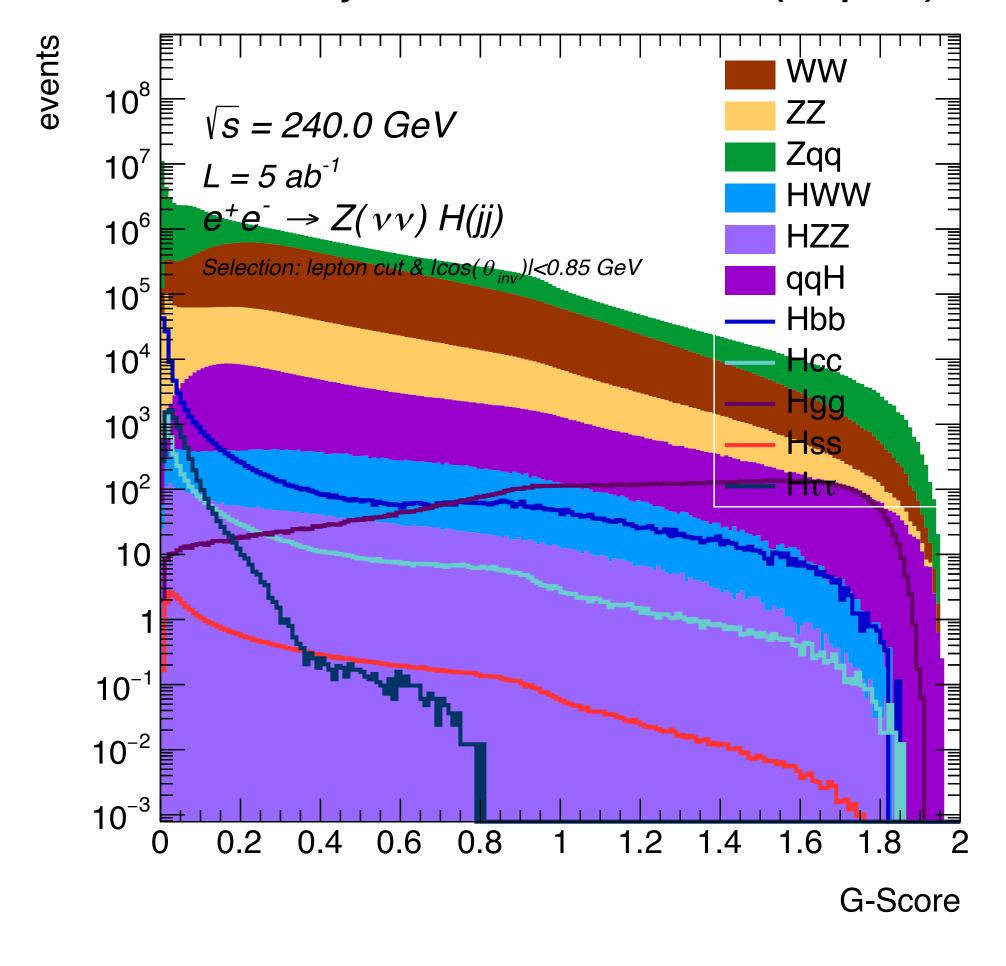


Sum of dijet Scores from the tagger (II)

• S & G

FCCAnalyses: FCC-ee Simulation (Delphes)









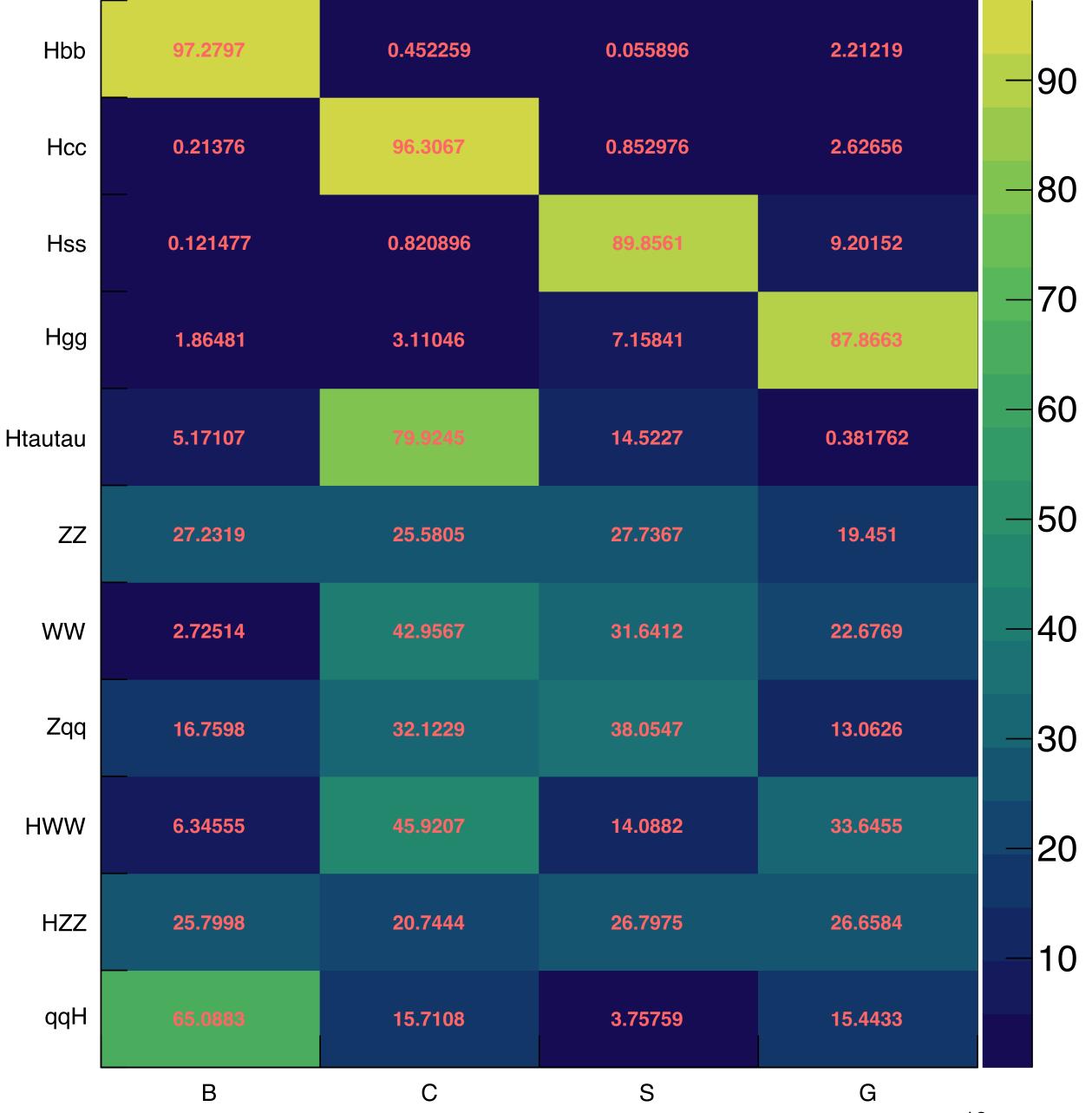


Score Map

• Events are categorised from the sum of the two jets score

$$\forall$$
 event: $J_{12}^{score} = J_{1}^{score} + J_{2}^{score}, J = b, c, s, g$
eg. if: $J_{1}^{score} = b \& J_{2}^{score} = b \Longrightarrow B_{like}^{score}$
if $B_{like}^{score} > C_{like}^{score} > S_{like}^{score} G_{like}^{score} \Longrightarrow B_{like}^{event}$

• Runs over the production processes and the jet categories



prediction

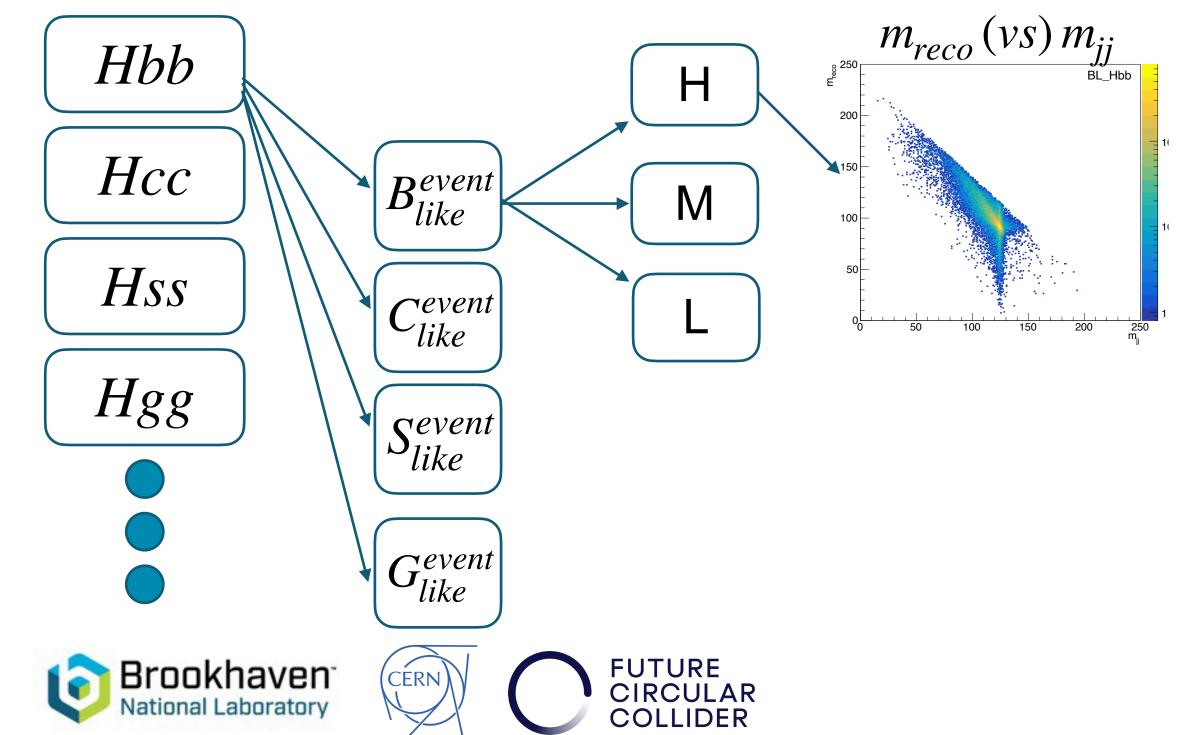




Categories

• Split the J_{like}^{score} in three bins of purity: Low, Medium, High

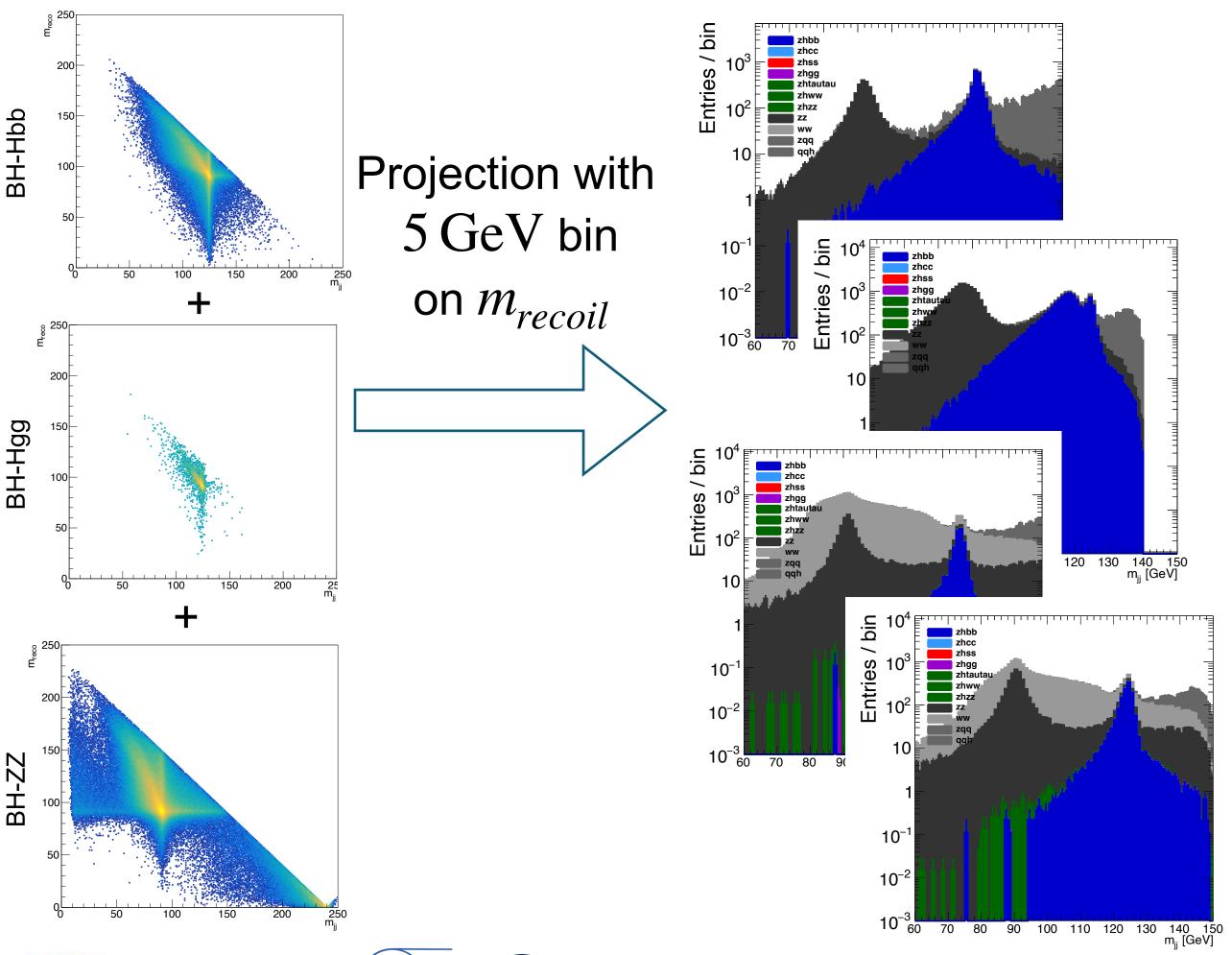
	${f B}$	\mathbf{C}	\mathbf{S}	\mathbf{G}
$oldsymbol{ ext{L}}$	< 1.1	< 1.0	< 1.1	< 1.2
${f M}$	$\in [1.1, 1.9]$	$\in [1.0, 1.8]$	$\in [1.1, 1.7]$	$\in [1.2, 1.5]$
\mathbf{H}	> 1.9	> 1.8	> 1.7	> 1.5



Hbb_H	78.2337	0.0120914		0.149233	
Hbb_M	14.573	0.19081	0.000636387	0.516004	
Hbb_L	4.47295	0.249358	0.0552596	1.54695	
Hcc_H	0.000108563	65.5984	0.00336544	0.163278	- 70
Hcc_M	0.0233409	26.6829	0.144822	0.500256	, 0
Hcc_L	0.19031	4.02539	0.704788	1.96303	
Hss_H	0.000347739	0.000695478	13.6105	0.237622	
Hss_M	0.0124027	0.105365	48.2317	1.01992	- 60
Hss_L	0.108726	0.714835	28.0139	7.94398	00
Hgg_H	0.296197	0.322641	0.0425984	25.3747	
Hgg_M	0.73059	1.22407	1.13998	26.4424	
Hgg_L	0.838027	1.56375	5.97584	36.0492	50
tautau_H		9.15248	0.00560499		50
tautau_M	0.53154	40.2424	1.39362		
ltautau_L	4.63953	30.5296	13.1235	0.381762	
$ZZ_{-}H$	5.21307	4.60467	0.972385	0.274717	40
ZZ_M	12.7687	12.1736	7.40309	1.25876	40
ZZ_{L}	9.25005	8.80219	19.3612	17.9175	
WW_H	0.000685094	1.8692	0.121344	0.213696	
WW_M	0.0733202	12.3557	4.35771	1.12064	
WW_L	2.65113	28.7318	27.1621	21.3426	— 30
Zqq_H	7.71798	12.1961	0.901308	0.305979	
Zqq_M	3.09943	9.78434	7.59515	0.780274	
Zqq_L	5.94241	10.1424	29.5582	11.9764	
HWW_H	0.00937367	1.58628	0.028121	0.672348	20
HWW_M	0.418833	14.7256	1.21133	3.43758	
HWW_L	5.91734	29.6089	12.8487	29.5356	
HZZ_H	7.76473	4.5994	0.595125	0.472868	
HZZ_M	12.1379	10.2759	5.9365	2.78732	10
HZZ_{L}	5.89715	5.86904	20.2659	23.3982	
qqH_H	5.47328	0.894871	0.0241659	1.07139	
qqH_M	47.3425	7.95693	0.696082	2.7133	
qqH_L	12.2725	6.85897	3.03734	11.6586	
	В	С	S	G	U
prediction					

Fit Categories & Signal extraction

• 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/)



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

	Precision at 68% CL
r(Hgg)	1.1%
$r(Hsar{s})$	137%
$r(Hcar{c})$	2.6%
$r(Hb\overline{b})$	0.36%







Conclusions

- Able to reproduce the full analysis of H(jj) in the $Z(\nu\nu)$ final state
 - Results look reasonable
- Looking forward to get some more experience with the tagger and study the performance in different categories (u,d is coming check here)
- Will be looking into the full hadronic final states
- We are interested to study the tracker performance in order to optimise the design and requirements for these physics cases
- We are looking for the best possible ways to collaborate and contribute to the existing effort





