Measurement of hadronic Higgs Boson branching ratios at FCC-ee with Z(ll)H events at $\sqrt{s}$=240 GeV

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Introduction

- Goals:
  - estimate sensitivity of FCC-ee to hadronic branching ratios of Higgs boson (bb / cc / gg) and to the couplings to b/c/g
  - assess impact of recently developed taggers for FCC-ee
  - compare to estimates from other proposed colliders (ILC, CEPC) and FCC-ee CDR

- Notes:
  - Work done during internship of two students in APC Paris, Paul Paquiez and Mariette Jolly (March-June 2021)
  - Started with statistical uncertainties first, will consider systematic uncertainties only later
  - Focus on Z(ll)H channel at $\sqrt{s}$=240 GeV: use recoil mass distribution to estimate signal and background after selection
    - Method developed however should be extendable easily to Z($\nu\nu$)H and Z(qq)H
  - For practical reasons we didn't use all the latest developments and samples available centrally in FCCee repositories

    ➡Plan to harmonise with other studies and use central tools/samples in next round
  - Assume an integrated luminosity of 5/ab

Current projections for future Higgs factories

- The most recent results we've been able to find about the expected sensitivities to the bb/cc/gg BRs are shown below
  - Please let us know if there are more recent ones that you're aware of!

	ILC [1] **250/fb @250 GeV**	**CEPC [2]** **5.6/ab @250 GeV**	**FCCee [3]** **5/ab @240 GeV**
Signal	Z(ll)H	Z(ll)H	Z(ll)H
Background	ZZ, WW	ZZ, WW, qq(γ)	ZZ, WW
Rel. unc. on σBR(bb) (%)	2.5	0.8	0.8
Rel. unc. on σBR(cc) (%)	17	8	5.3
Rel. unc. on σBR(gg) (%)	23	4.2	6.1

[1] Eur. Phys. J. C 73, 2343 (2013) Table 4

[2] Chinese Physics C 43 (2019) 043002 Table 6 + Table 11

[3] Eur. Phys. J. C 79, 474 (2019) Table 4.1 Z(ll+qq+vv)H rescaled using CEPC Z(ll)H/Z(ll+qq+vv)H

Analysis strategy

- The measurements proceeds in the following steps:
  - Event **reconstruction**: isolated leptons (and photons), jets and missing energy are reconstructed
  - Event **selection**: events consistent with the signature under study are kept
    - NOTE:So far optimised mainly for signal efficiency, should reoptimise for best BR sensitivity
  - Event **categorisation**: selected events are classified in categories based on the number of b-, c- and (if applicable) g-tagged jets
  - **Fit** for BR measurement:
    - the signal yield in each category and for each Higgs decay mode (bb, cc, gg, non-hadronic) is extracted through a **simultaneous extended maximum likelihood fit to the recoil mass distribution of the various tagging categories**
    - Assuming the tagging efficiencies for each flavour type to be known (measured in data from various control samples), the acceptance of each category for the various Z(ll)H(XX) is known and the system of equations relating the yields to the product σBR can be solved
    - In practice, in the likelihood the yields are expressed directly in terms of products of σBR times the acceptances and the fit returns σBR

Samples

- Signal and background samples were **privately generated** using the **FCC-ee software stack** for **Delphes+Pythia8**
- In Pythia8, **ISR and FSR** were turned **on**, while **BES** was **off**
- The FCC-ee **IDEA card** (with track covariance) was **modified**
    - to implement **custom tagging efficiencies** (b/c/g)
    - to use a **different jet clustering algorithm (Valencia)** more adapted to ee collision than anti-k_t
    - to **remove isolated electrons, muons and photons from the list of EFlow objects used for jet clustering**
- Probably all these features can now be run directly over the centrally produced samples using the latest code developed recently for re-running jet clustering and for emulating flavour tagging, but when this study started this was not possible and then we kept this approach
    - I'll move to the alternative approach ASAP
- **Signal samples**: Z(ll)H(bb), Z(ll)H(cc), Z(ll)H(gg), l=e+mu, generated separately and normalised using SM Higgs BRs
- **Background samples**: Z(ll)H(non-had), ZZ, WW
- **Cross sections** (ZH, ZZ and WW) taken from central FCCee json file

Samples (cont'd)

Process	sigma (fb)	BR1	BR2	sigma*BR (fb)	Ngen	LumiGen (fb-1)	LumiGen/Lumi
Z(ll)H(bb)	201.87	0.067316	0.5824	7.914280728	100000	12635	2.527
Z(ll)H(cc)	201.87	0.067316	0.02891	0.3928603294	100000	254543	50.909
Z(ll)H(gg)	201.87	0.067316	0.08187	1.112538055	100000	89885	17.977
Z(ll)H(nonhad)	201.87	0.067316	0.30682	4.169401808	500000	119921	23.984
ZZ	1358.99	1	1	1358.99	4000000	2943.36235	0.589
WW	16438.5	1	1	16438.5	4000000	243.3312042	0.049

Event reconstruction

```
set ExecutionPath {
  ParticlePropagator

  ChargedHadronTrackingEfficiency
  ElectronTrackingEfficiency
  MuonTrackingEfficiency

  TrackMergerPre
  TrackSmearing
  TrackMerger

  Calorimeter
  EFlowMerger

  PhotonEfficiency
  PhotonIsolation

  ElectronFilter
  ElectronEfficiency
  ElectronIsolation

  MuonFilter
  MuonEfficiency
  MuonIsolation

  EFlowFilter

  NeutrinoFilter
  GenJetFinder

  FastJetFinderAntiKt
  FastJetFinderVLC_inclusive
  FastJetFinderVLC_N2
  FastJetFinderVLC_N4

  JetEnergyScaleAntiKt
  JetEnergyScaleVLC_inclusive
  JetEnergyScaleVLC_N2
  JetEnergyScaleVLC_N4

  MissingET
  GenMissingET

  JetFlavorAssociationAntiKt
  JetFlavorAssociationVLC_inclusive
  JetFlavorAssociationVLC_N2
  JetFlavorAssociationVLC_N4

  BTaggingAntiKt
  BTaggingVLC_inclusive
  BTaggingVLC_N2
  BTaggingVLC_N4

  CTaggingAntiKt
  CTaggingVLC_inclusive
  CTaggingVLC_N2
  CTaggingVLC_N4

  GTaggingAntiKt
  GTaggingVLC_inclusive
  GTaggingVLC_N2
  GTaggingVLC_N4

  ScalarHT
  TreeWriter
}
```

Tracking

Calorimetry

Identification of isolated e, μ, γ

Remove e, μ, γ from EFlow objects for jet clustering

Truth-level jet clustering

Detector-level jet clustering (anti-kt, Valencia inclusive and 2- and 4-jet exclusive algorithms)

Jet energy scale

Missing energy (true and reconstructed)

Jet flavour labelling and flavour tagging

H_T

Flavour tagging

- Flavour tagging is implemented via basic Delphes modules, where a **jet is tagged according to whether there is a MC b, c or gluon within a given DeltaR to the jet and based on efficiency tables vs the jet true flavour**
- Previous versions of this study used efficiency tables (“FCC1") inferred from ILD plots
- The work presented here uses the latest numbers (“FCCnew”) presented by Franco, Lukas and Michele in their talk at the June 2021 FCC week: https://indico.cern.ch/event/995850/contributions/4415991/attachments/2273135/3861058/flavour_tagging_fccee.pdf

B-TAG	FCC1	FCCnew
Eff(b)	0.8	0.8
Eff(c)	0.1	0.004
Eff(g)	0.01	0.007
Eff(light)	0.01	<0.001 (*)

C-TAG	FCC1	FCC_{new}
Eff(c)	0.6	0.8
Eff(b)	0.2	0.025
Eff(g)	0.06	0.03
Eff(light)	0.06	0.009

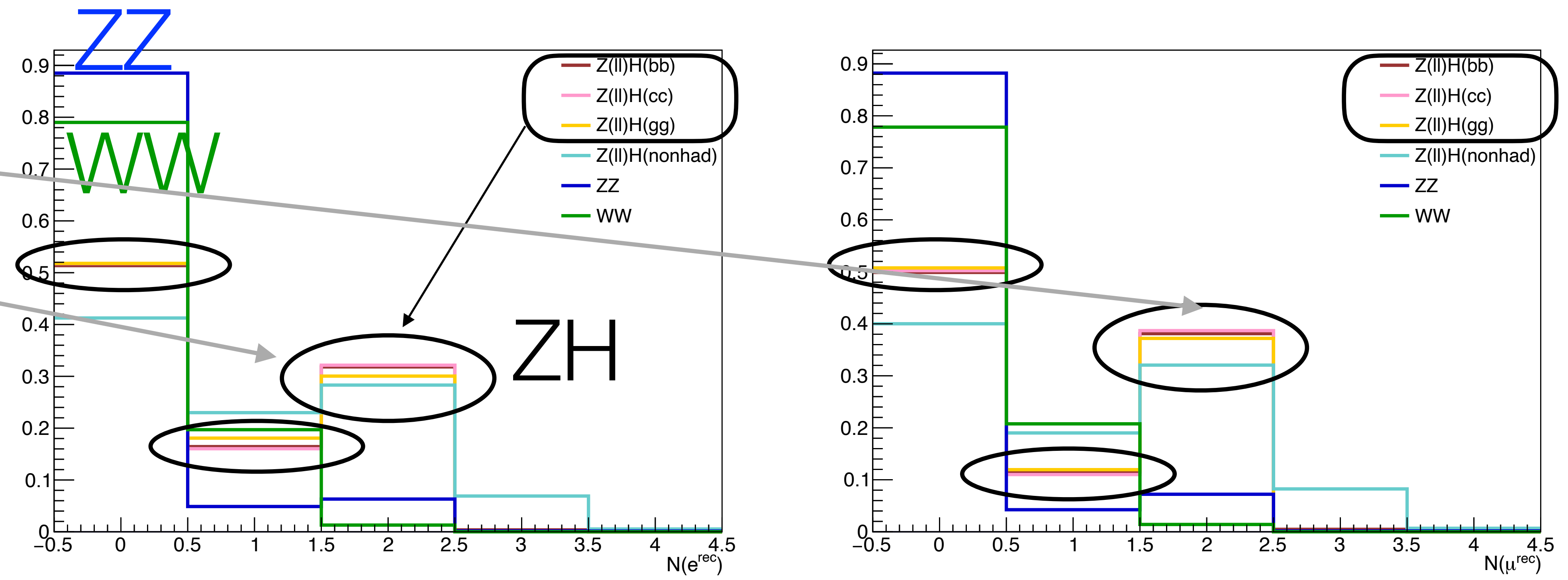
G-TAG	FCC_{new}
Eff(c)	0.05
Eff(b)	0.02
Eff(g)	0.8
Eff(light)	0.15

- I will first show results without gluon tagging, and then compare them to those with g-tagging

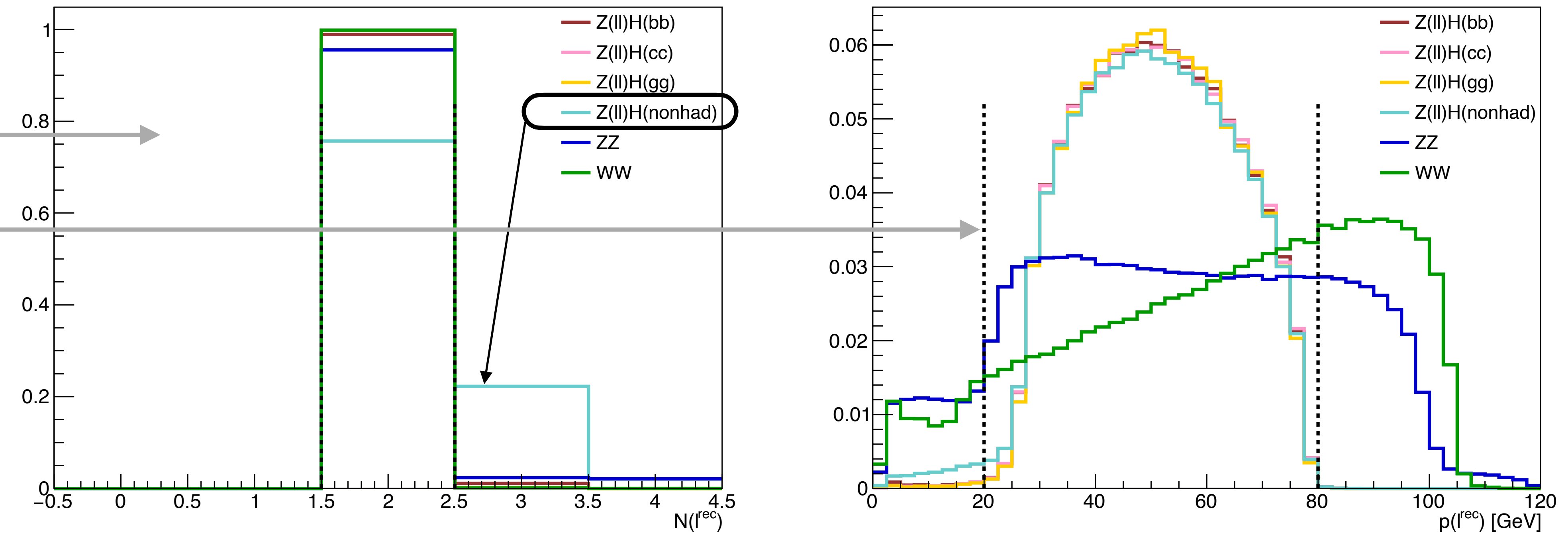
(*) due to a bug, a value of 1% was used instead of 0.1%

Event selection - Z->ll

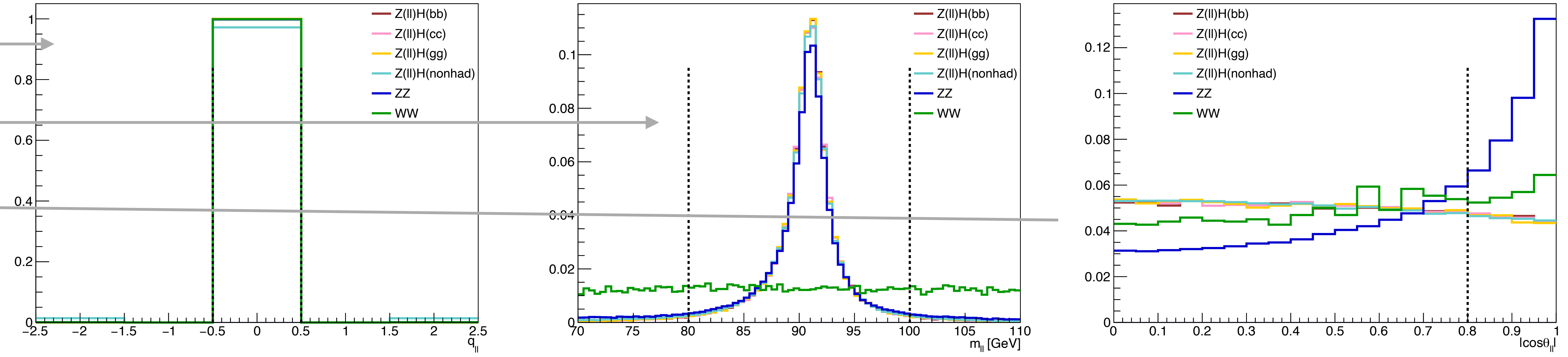
- Exactly 2 isolated electrons or muons



- No additional leptons
- Lepton momenta between 20 and 80 GeV

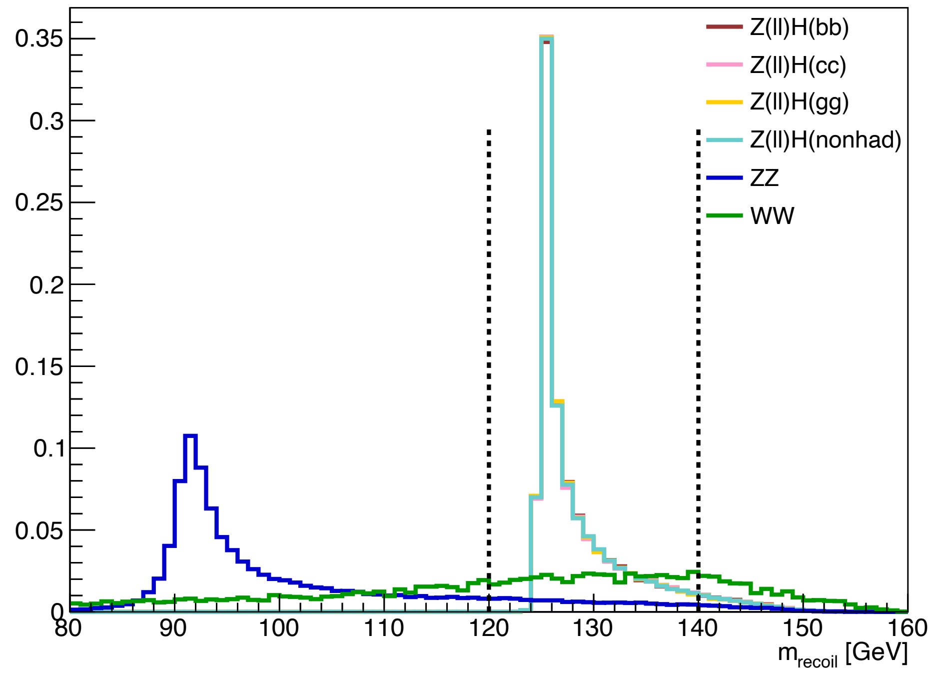


- Dilepton charge = 0
- Dilepton invariant mass in 80-100 GeV
- |cos(Polar angle of dilepton pair)|<0.8

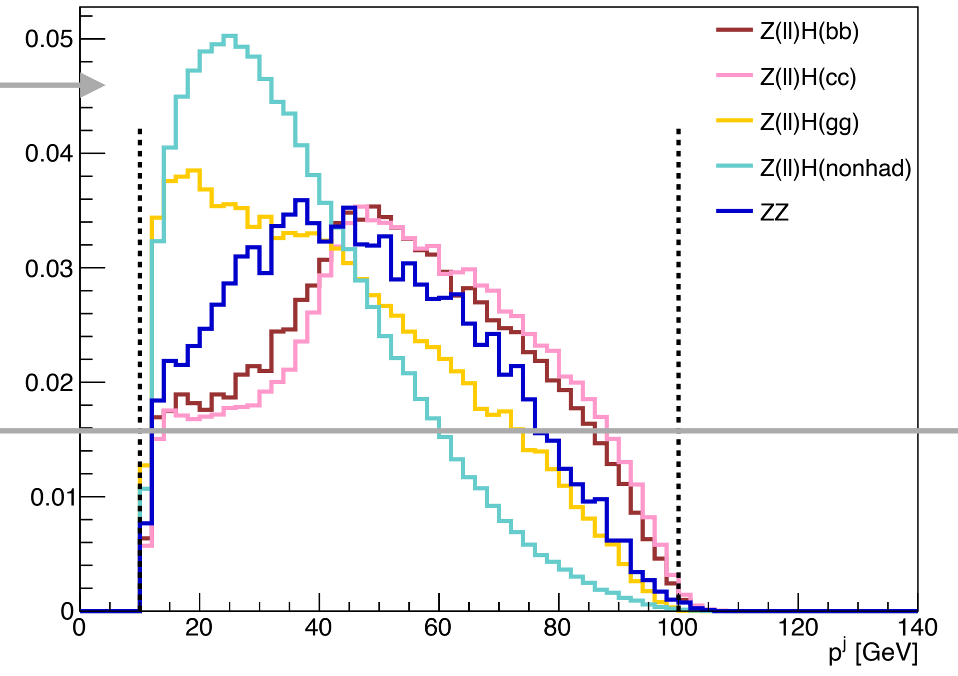


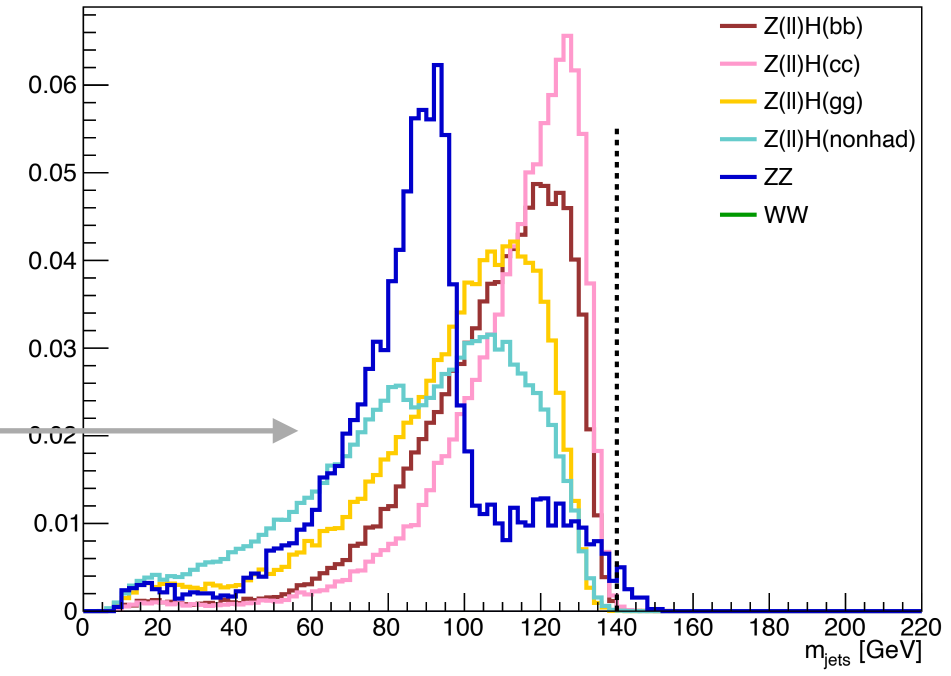
Event selection - recoil, jets

- Recoil mass in 120-140 GeV

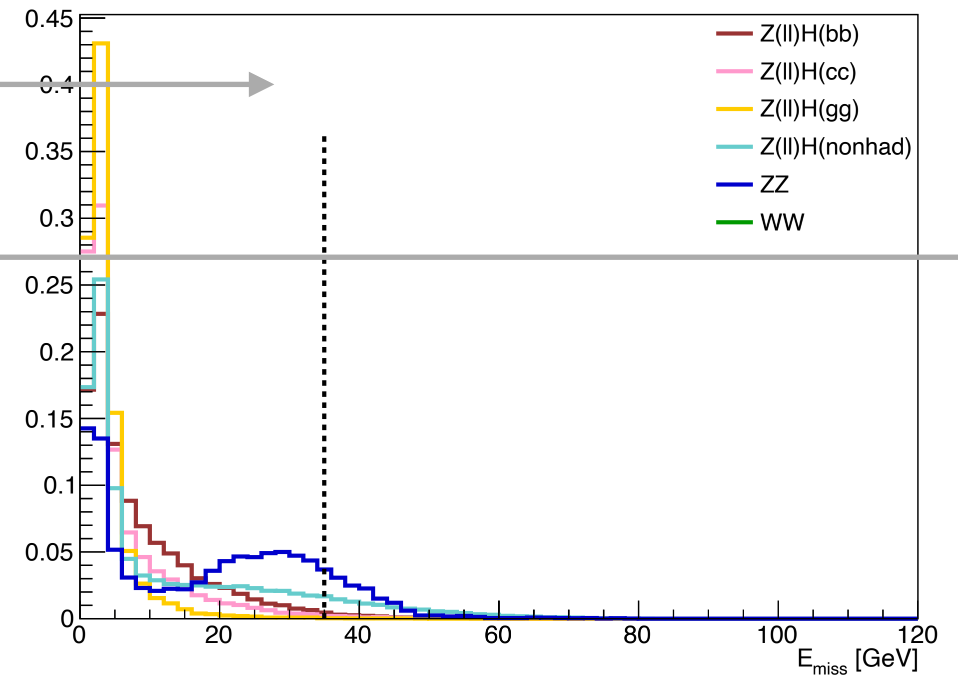


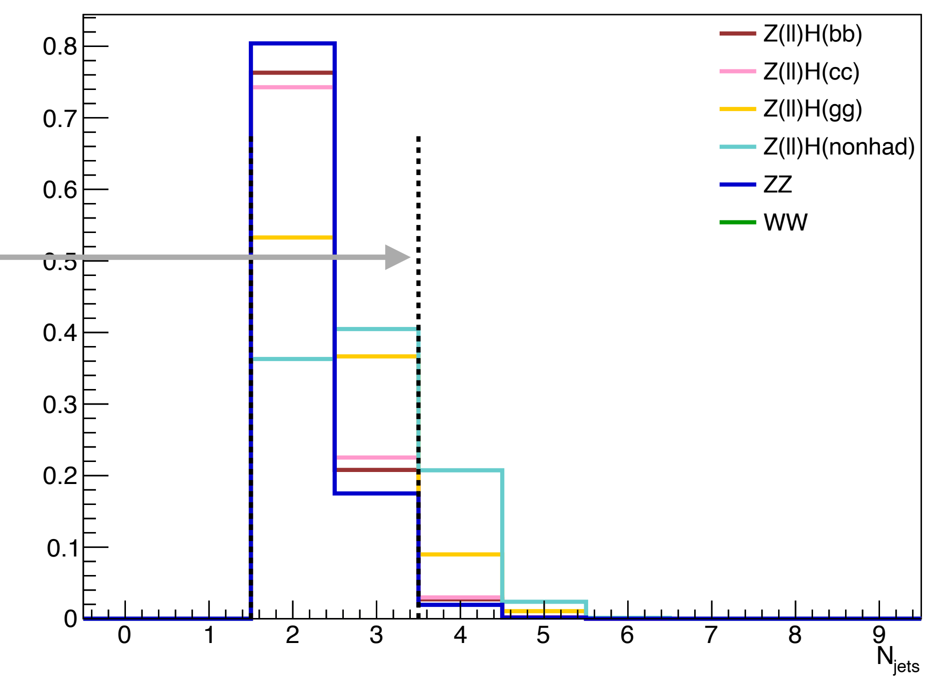
- Jet momentum in 10-100 GeV
- Hadronic mass: long tail, require only m<140 GeV





- Missing energy < 35 GeV
- <=3 jets (could actually apply a different #jet cut depending on tagging





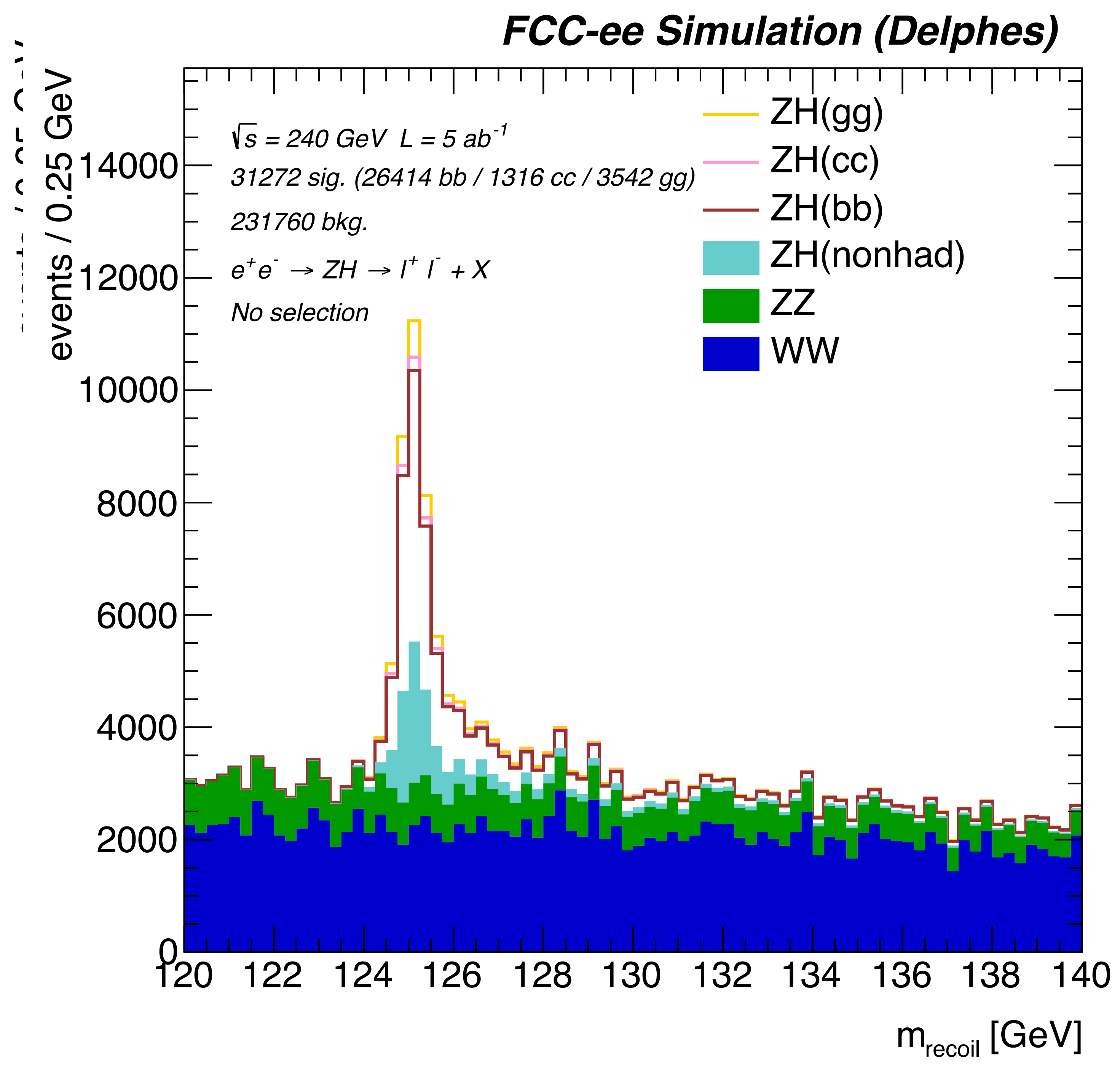
Cutflow, expected yields, efficiency

Cut	ZHbb Yield	ZHbb Sig	ZHcc Yield	ZHcc Sig	ZHgg Yield	ZHgg Sig	ZHnonhad	ZZ	WW
No cuts	39408	4	1956	0	5540	1	20761	6794950	82192500
2e or 2mu	27574	15	1385	1	3725	2	12288	900705	2256369
No extra lep	27261	15	1382	1	3717	2	9296	860375	2254006
p(lep) 20-80 GeV	27013	24	1373	1	3692	3	8989	441008	761801
q(ll)=0	27013	24	1373	1	3692	3	8733	440177	761267
m(ll) 80-100 GeV	25515	36	1297	2	3488	5	8055	292293	165556
|cos(theta_ll)|<0.8	20823	36	1058	2	2858	5	6590	182235	127768
m(recoil) 120-140 GeV	20112	62	1021	3	2759	8	6343	21759	53672
p(jets) 10-100 GeV	18382	90	954	5	2534	12	5517	14241	0
m(jets)<140 GeV	18375	90	954	5	2533	12	5516	14084	0
Emiss < 35 GeV	18081	92	944	5	2529	13	4900	12070	0
<=3 jets	17556	92	913	5	2271	12	3766	11837	0

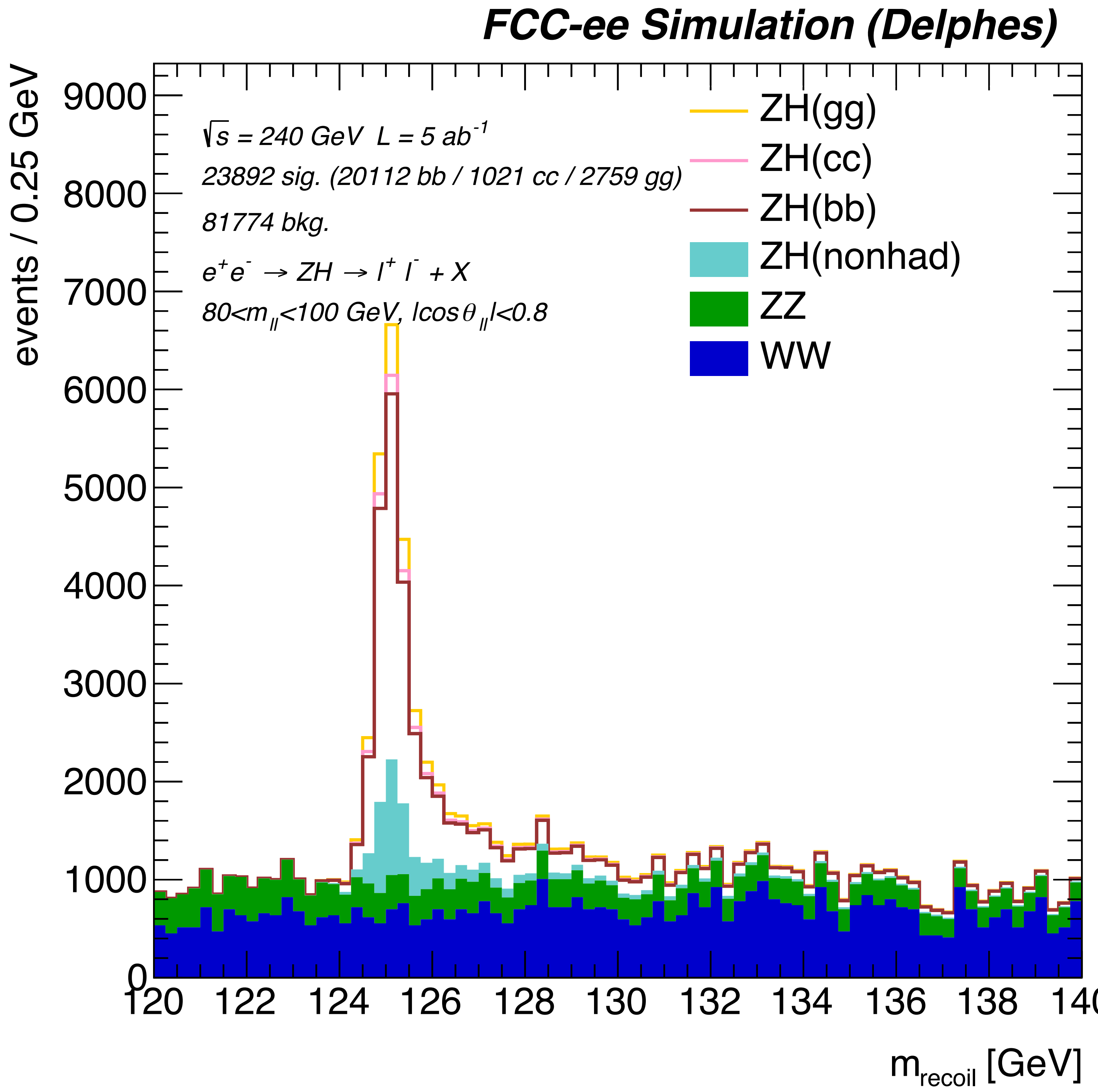
Efficiency (%)	ZHbb	ZHcc	ZHgg	ZHnonhad	WW	ZZ
	44.55	46.69	40.99	18.14	0.00	0.17

Evolution of the m_{recoil} distribution after the selection steps

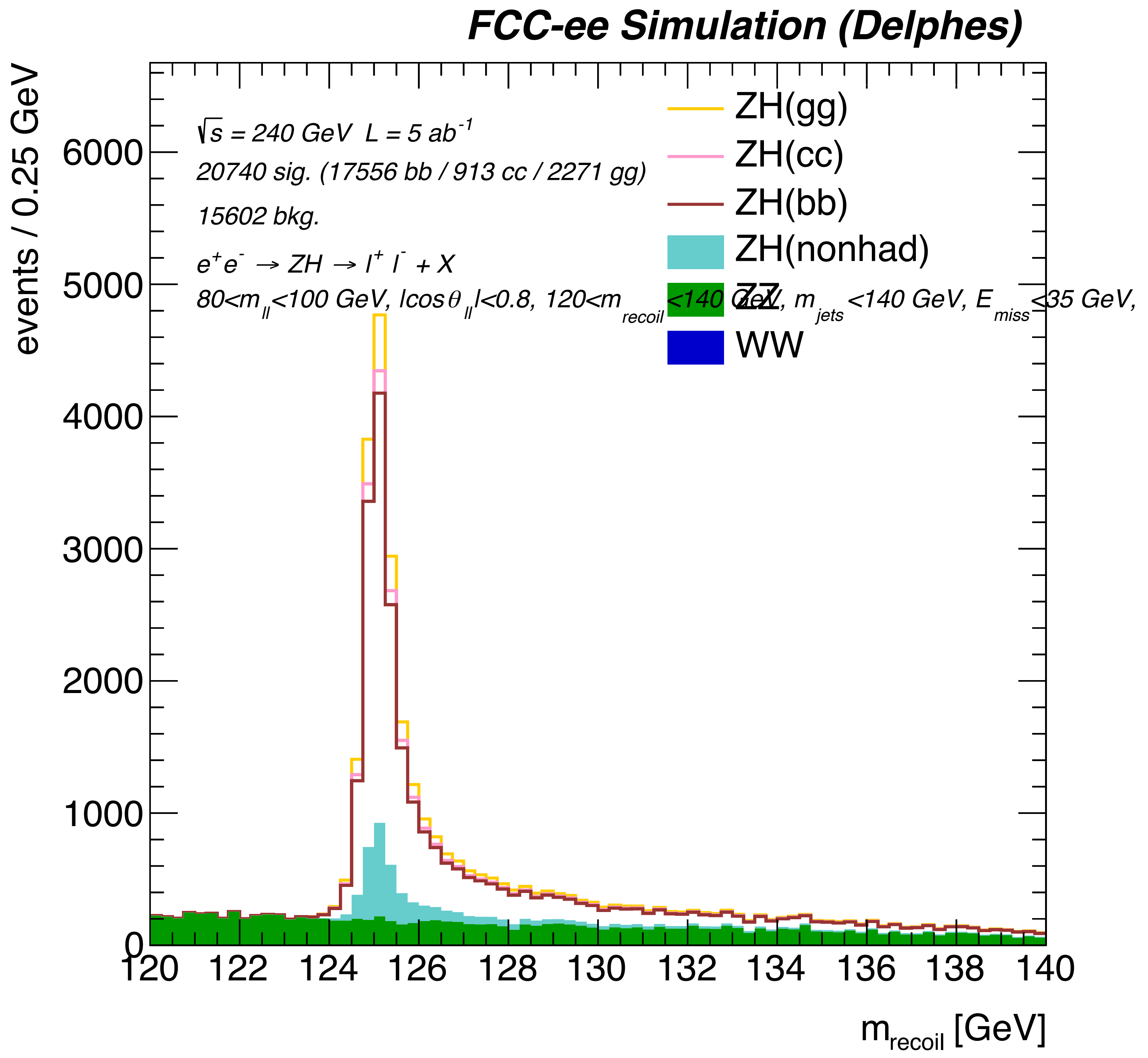
After reconstruction



After Z selection

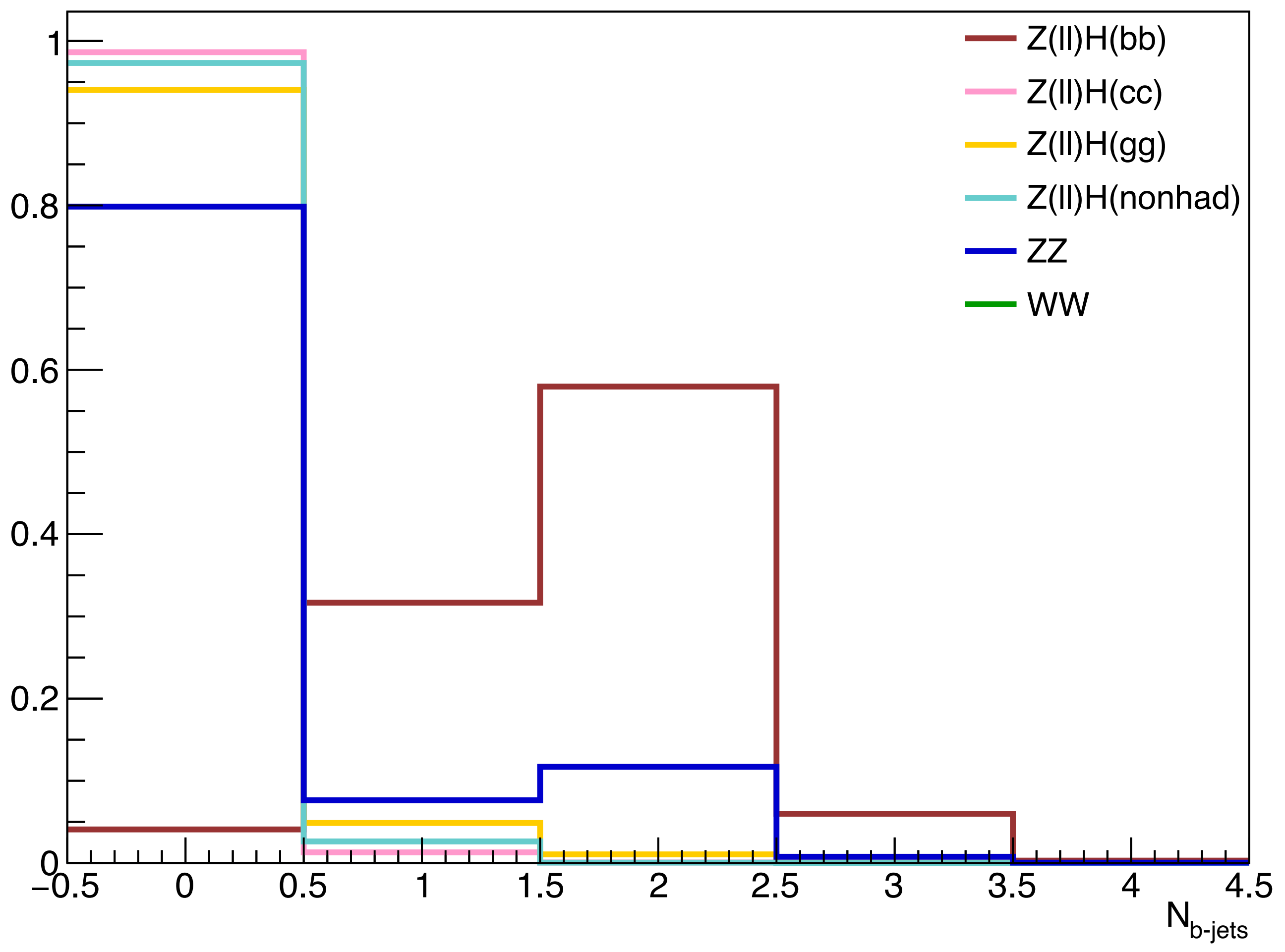


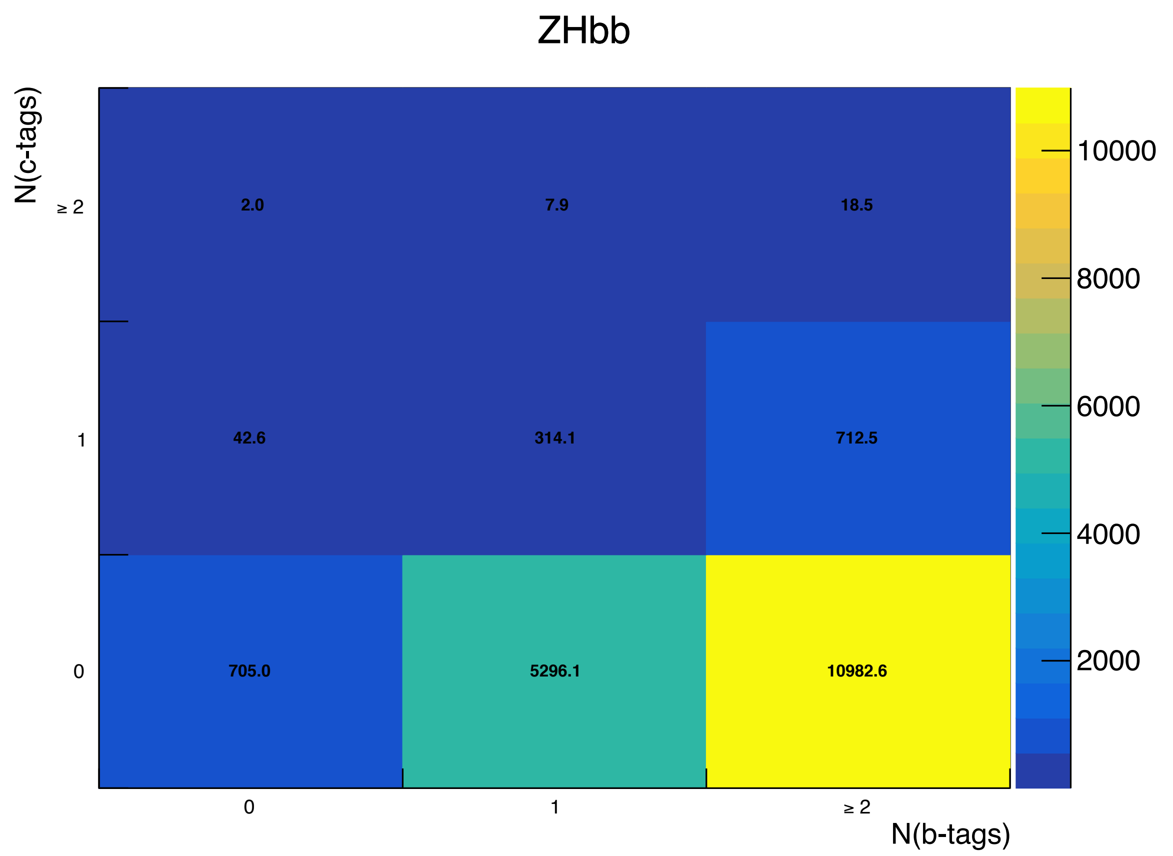
After recoil, jets, Emiss selection

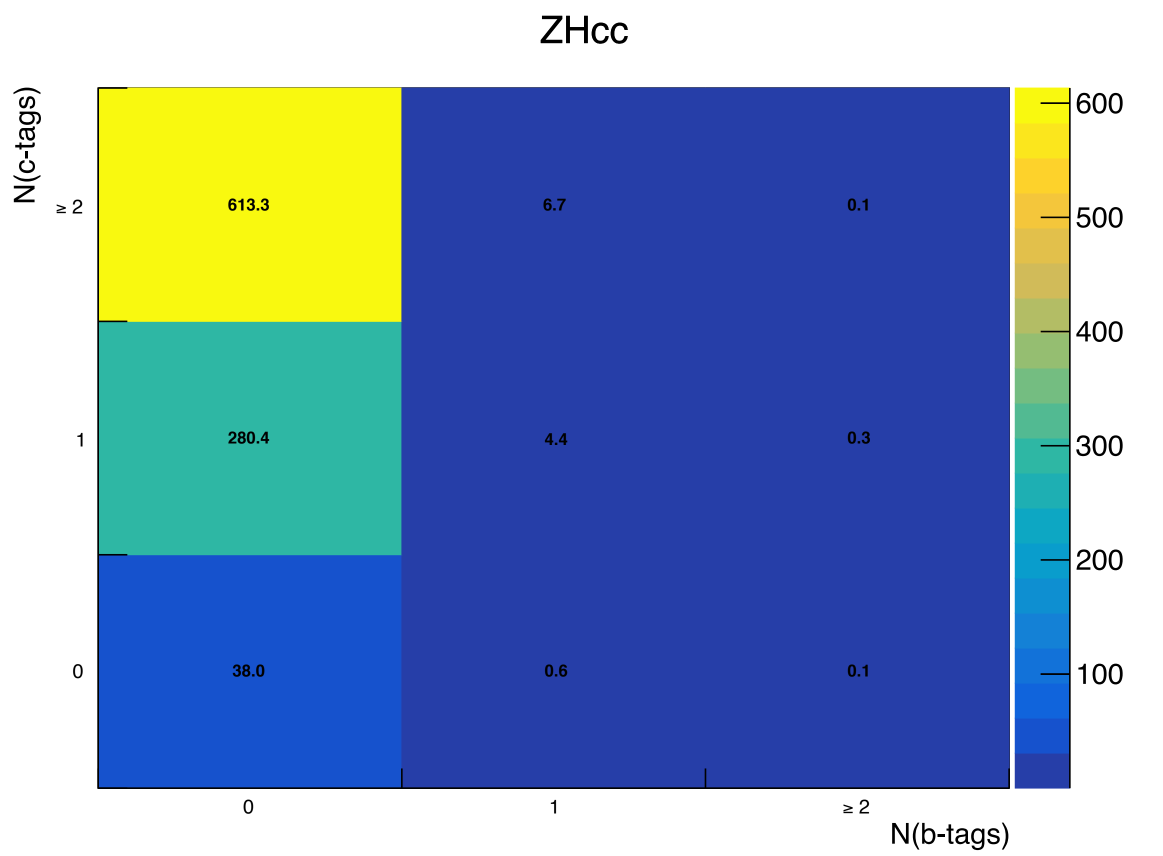


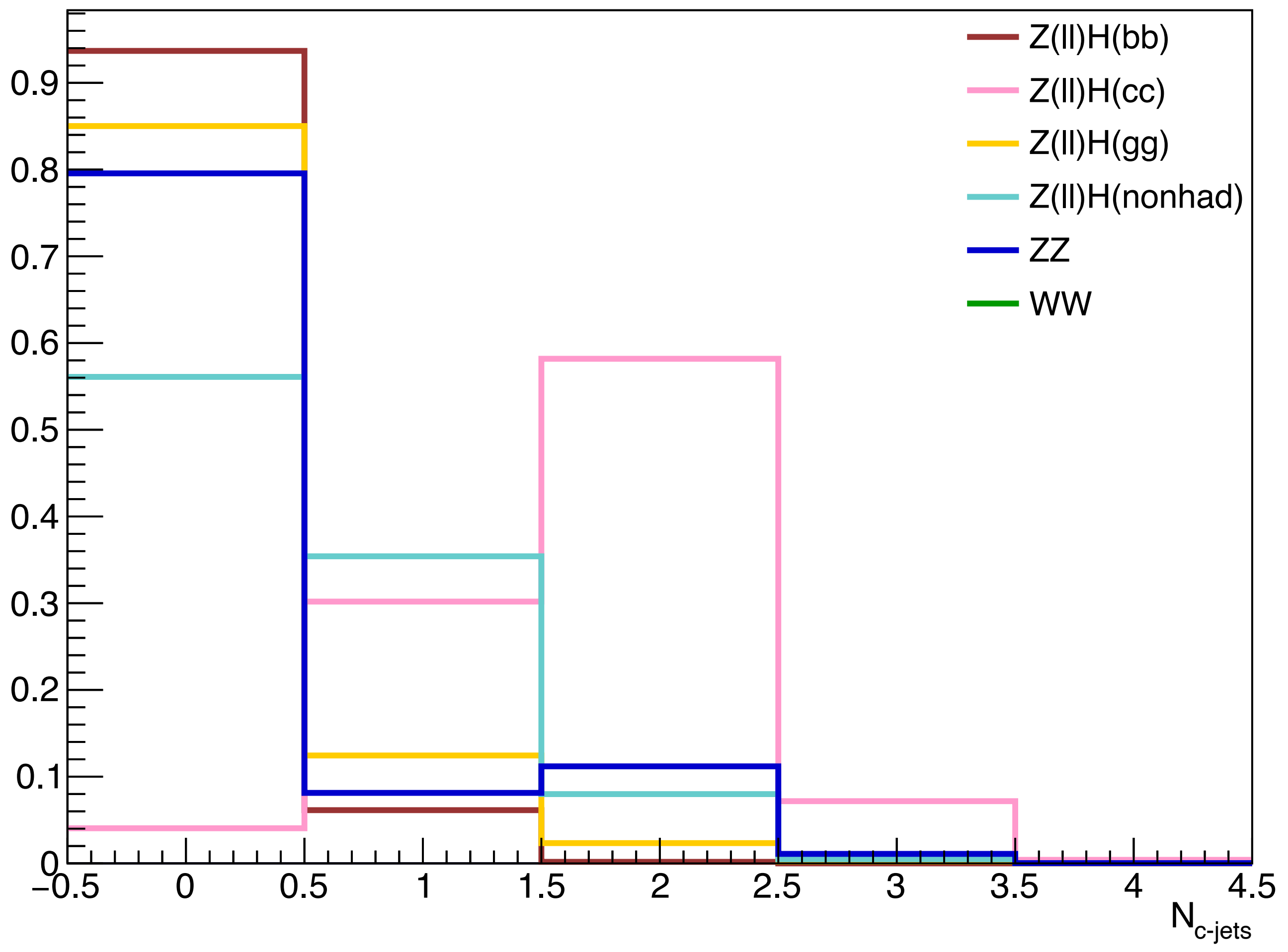
Event categorisation

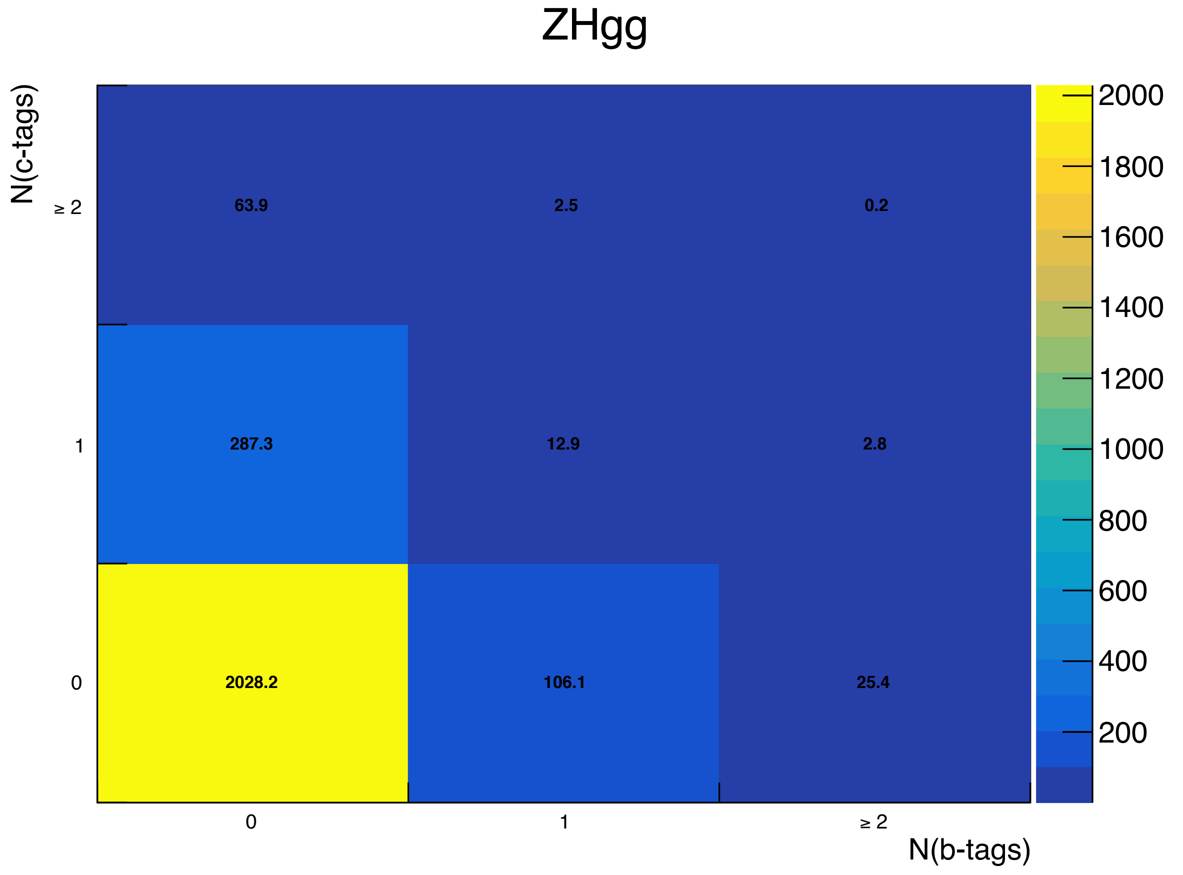
- Events are classified in mutually orthogonal categories based on the number of b- and c- tags

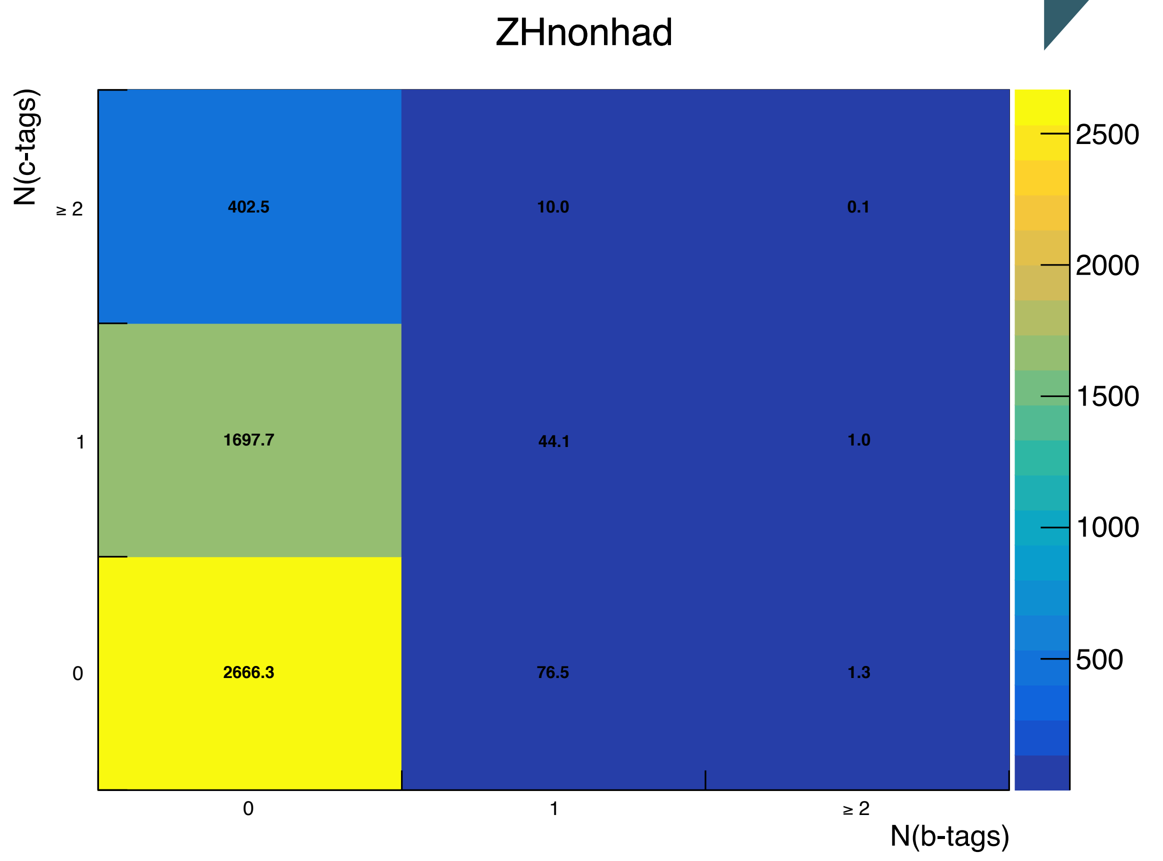


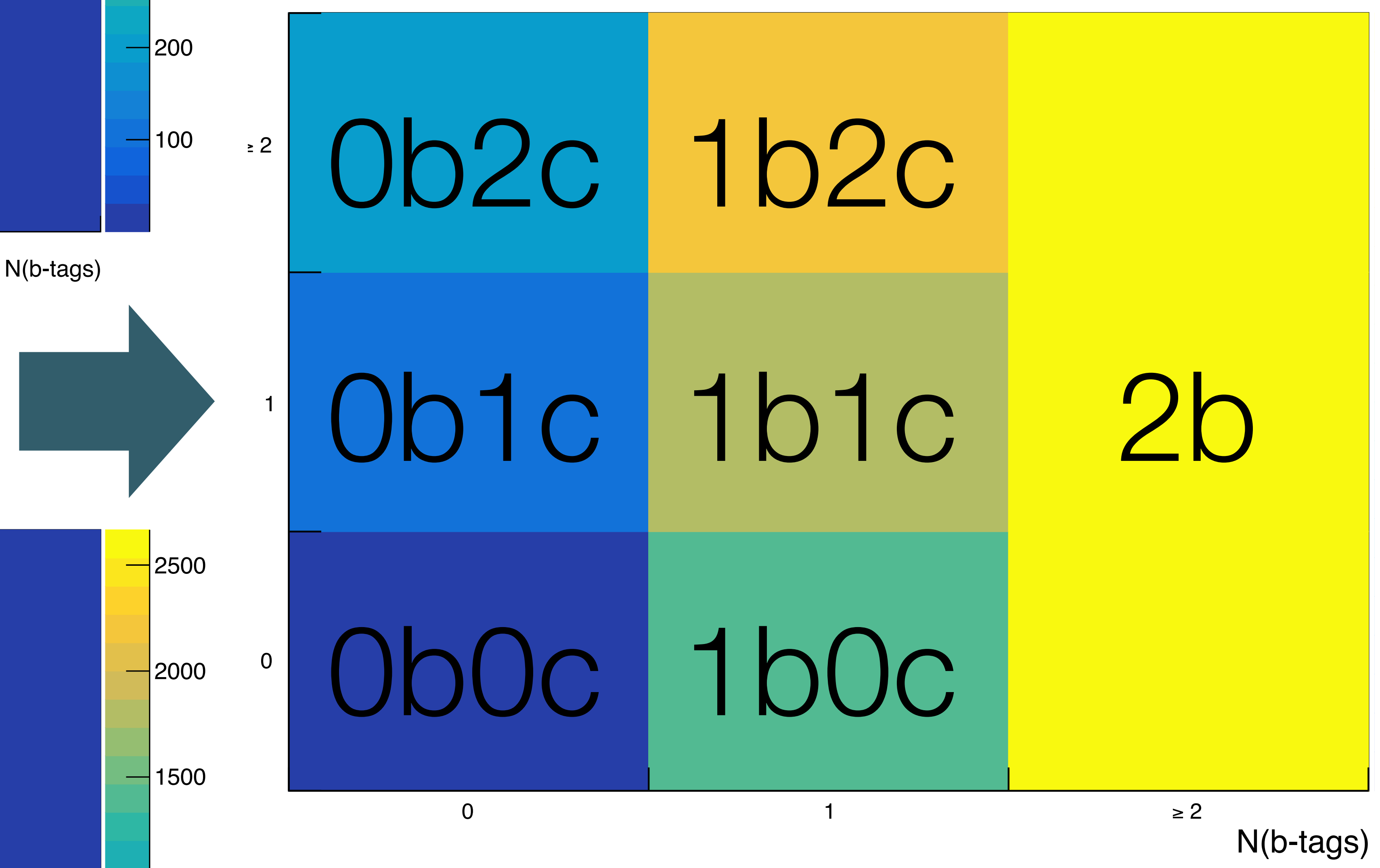












Event categorisation - expected events per category

EXPECTED YIELDS (significances in parentheses)

	ZHbb	ZHcc	ZHgg	ZHnonhad	bkg
2b	11714 (102)	1 (0)	28 (0)	2 (0)	1435
1b2c	8 (1)	7 (1)	2 (0)	10 (2)	14
1b1c	314 (15)	4 (0)	13 (1)	44 (2)	65
1b0c	5296 (66)	1 (0)	106 (1)	77 (1)	904
0b2c	2 (0)	613 (12)	64 (1)	403 (8)	1410
0b1c	43 (1)	280 (5)	287 (5)	1698 (30)	897
0b0c	705 (6)	38 (0)	2028 (18)	2666 (24)	7345
Total	18081 (123)	944 (13)	2529 (19)	4900 (39)	12070

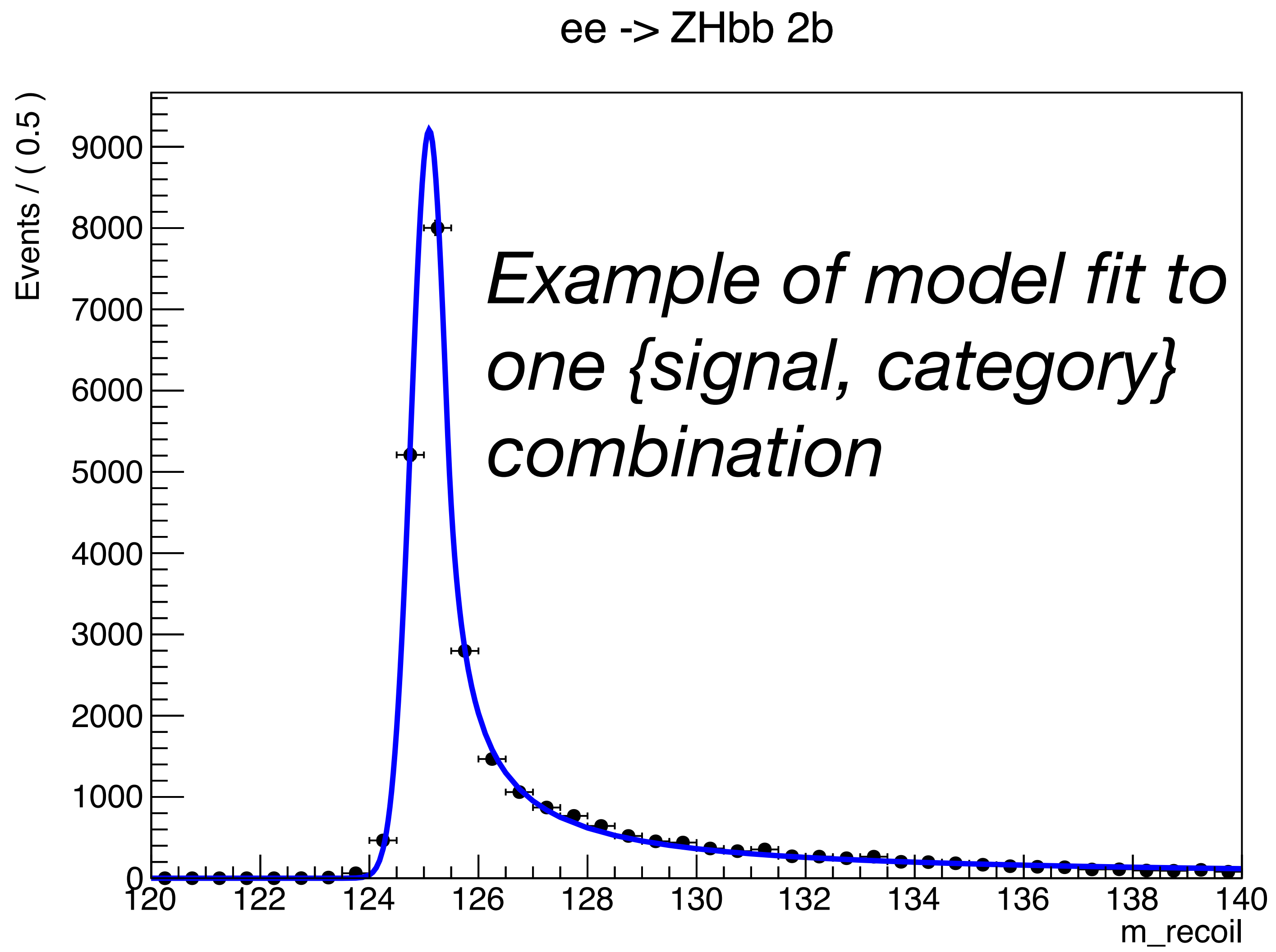
Fit - likelihood model

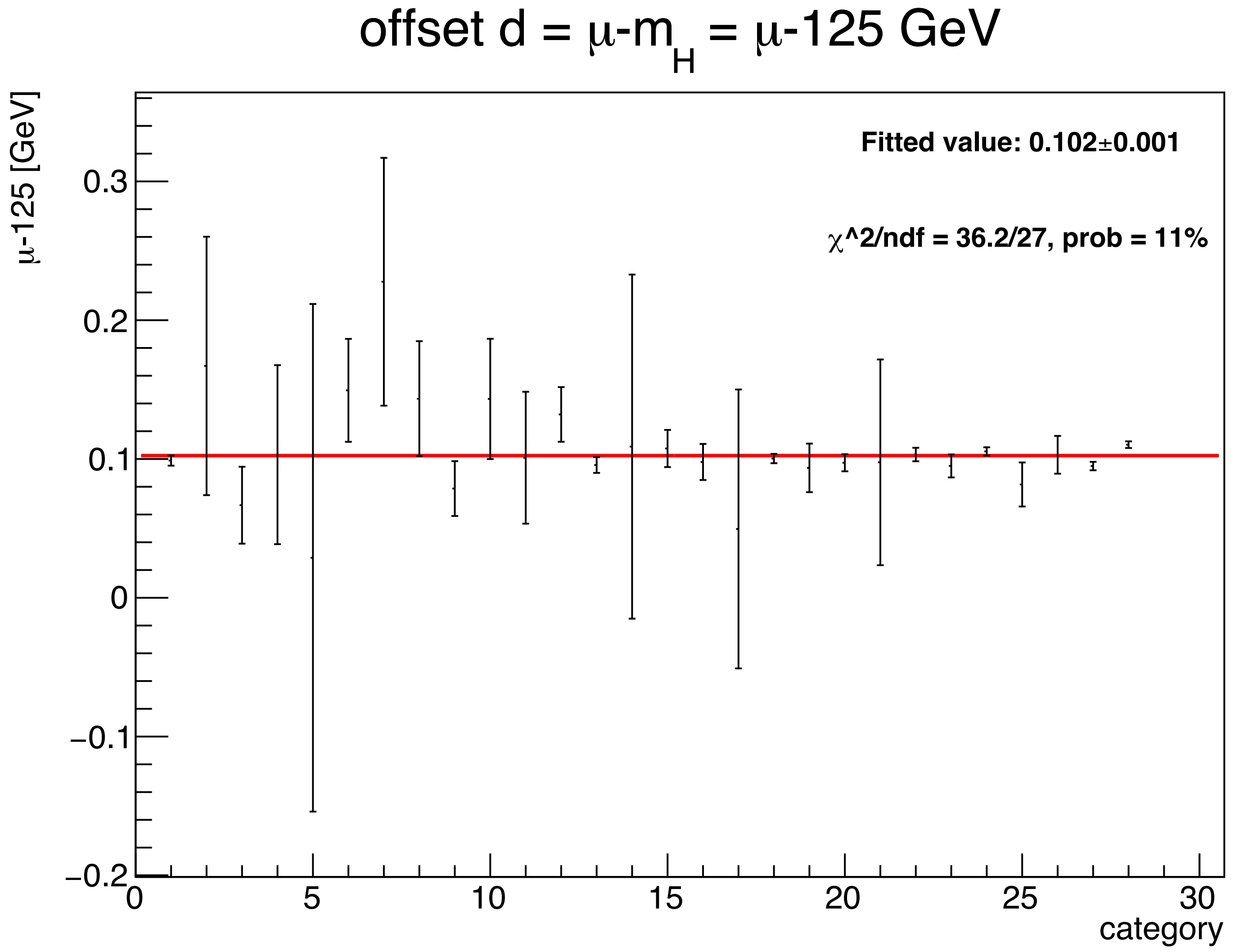
- A **simultaneous S+B fit to the recoil mass** distribution of the various event categories is performed
- The **background** is fit with simple functions (**polynomials**, exponentials) with floating parameters in each category
- The **signal** is fit with a **Crystal Ball** function (initial approximation, will move to a more sophisticated parametrisation) with the same parameters in each category
  - The **peak position is parametrised linearly as a function of mH**. It has been checked with samples generated at various Higgs masses
  - Tail parameters and peak-mH are fixed, **m_H and resolution are fitted**
- In each category the signal yield is expressed as a function of the efficiencies for the various Z(ll)H(->XX) processes of each category (fixed from the simulation) and of the cross section*BR of the various ZH signals:

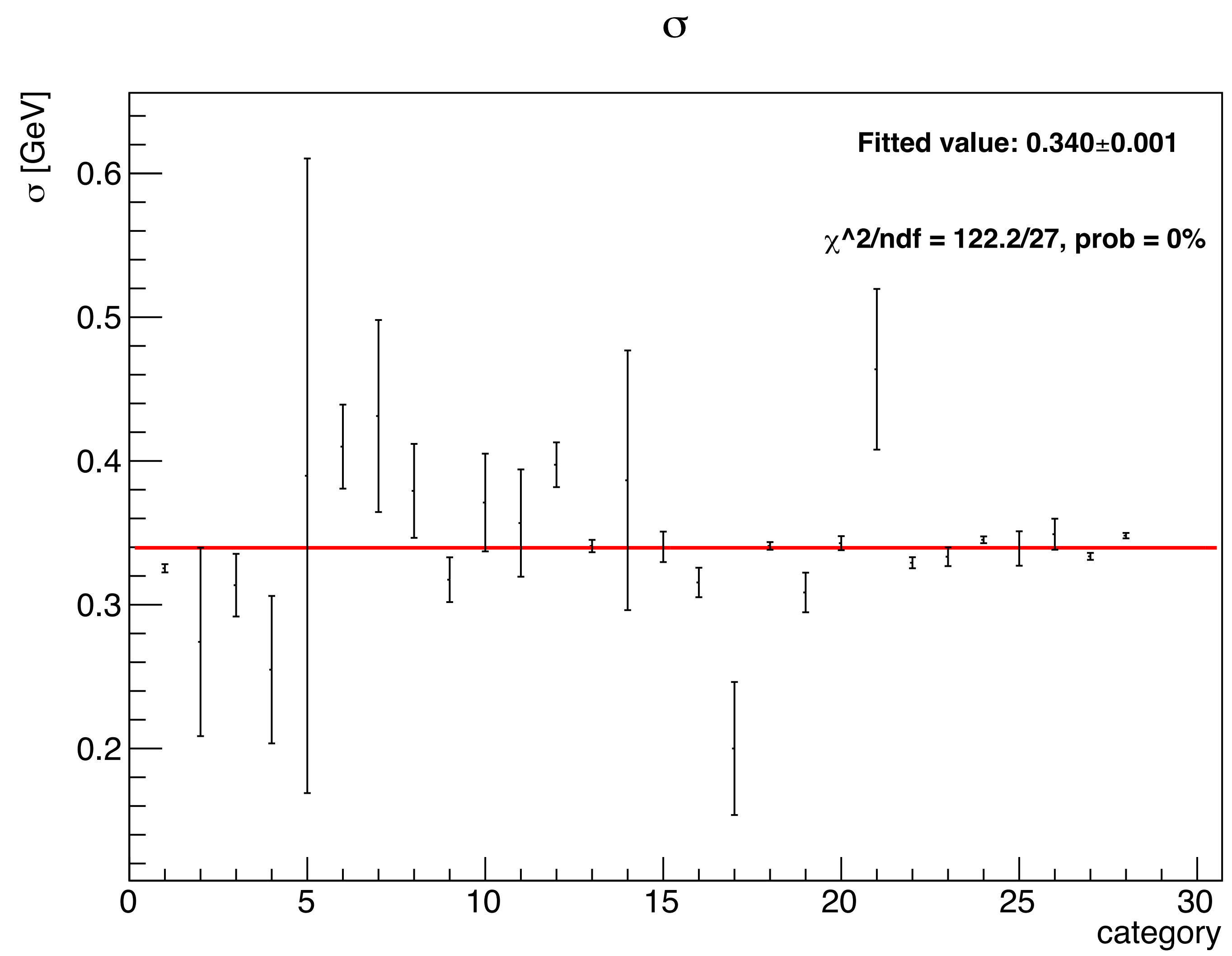
$$N_i = L \times \sigma(ee \to ZH) \times BR(Z \to ll) \times \left(BR(H \to b\bar{b})\epsilon_i^{b\bar{b}} + BR(H \to c\bar{c})\epsilon_i^{c\bar{c}} + BR(H \to gg)\epsilon_i^{gg} + BR(H \to nonhad)\epsilon_i^{nh} \right).$$

- In the fit model, **σ*BR(H->XX) = (σ*BR(H->XX))$_{SM}$*K_{XX}** => **The parameters of interest are the K_{XX}**
- The fit is performed to the output of the Pythia+Delphes simulation, not to an Asimov sample generated from the nominal models => statistical deviations from the expected values of k_{XX} are expected
- The fit is **binned**, in the m_{recoil} range **120-140 GeV**

Fit - signal model





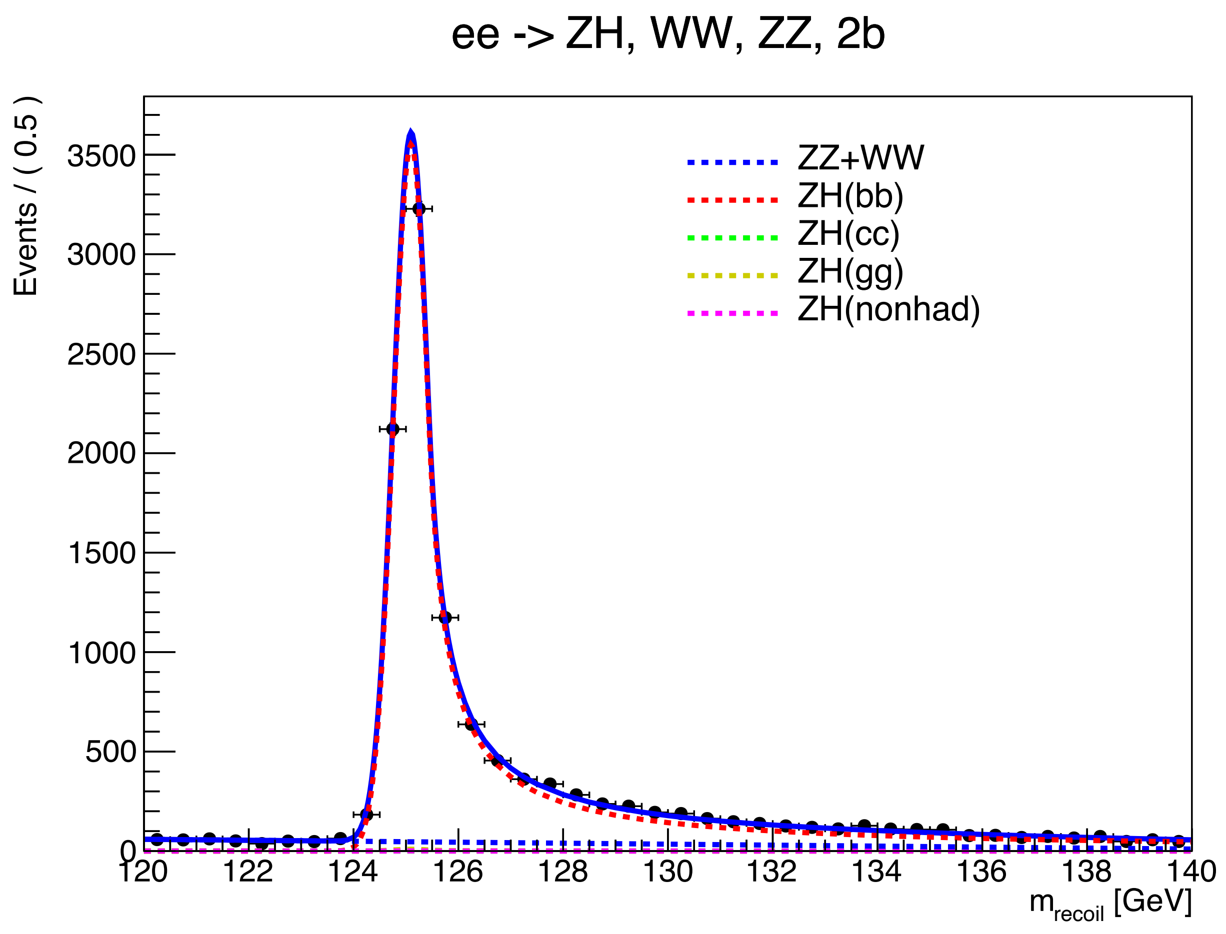


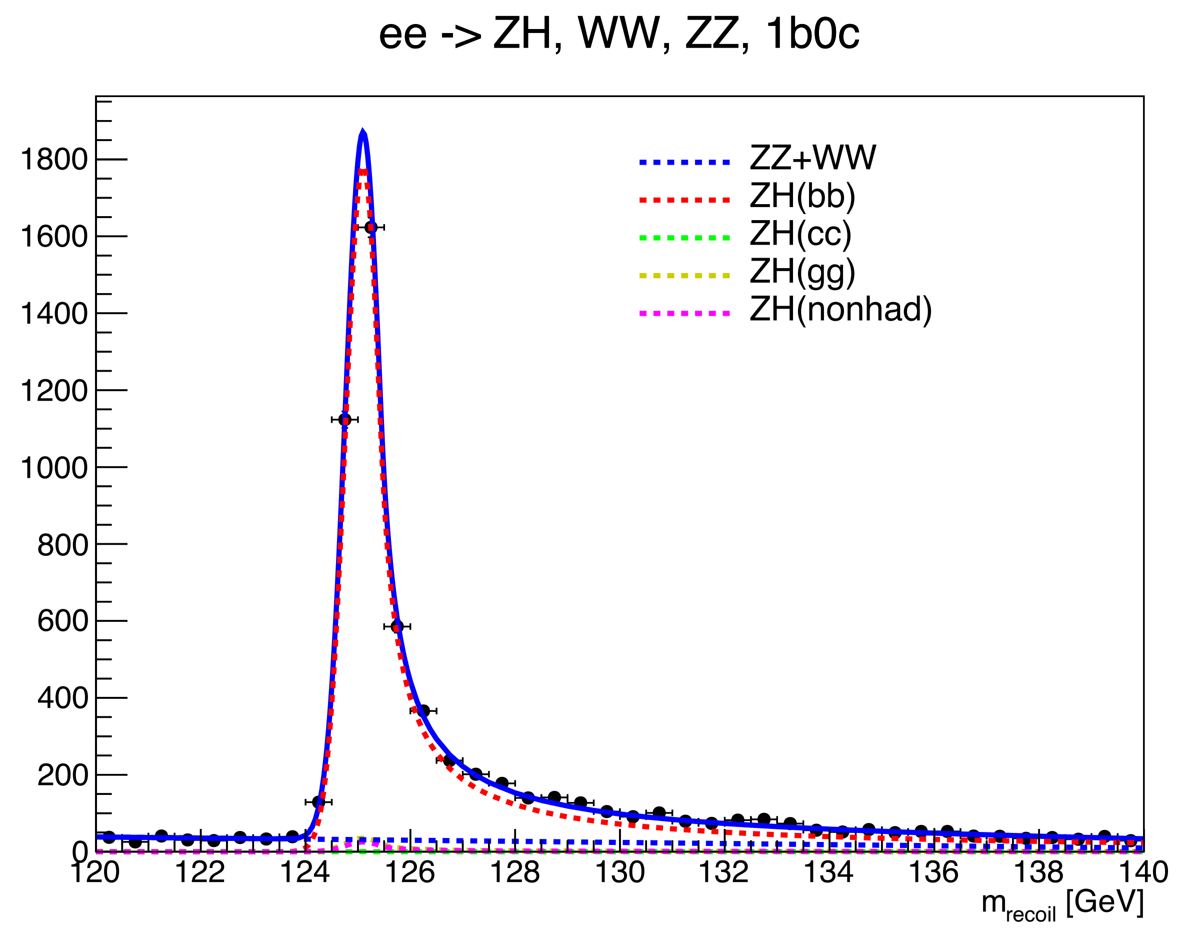
- Parameters are in decent agreement across categories, some tension for the width, seems affected by some very-low stat categories where fit is artificially too narrow - to be further investigated

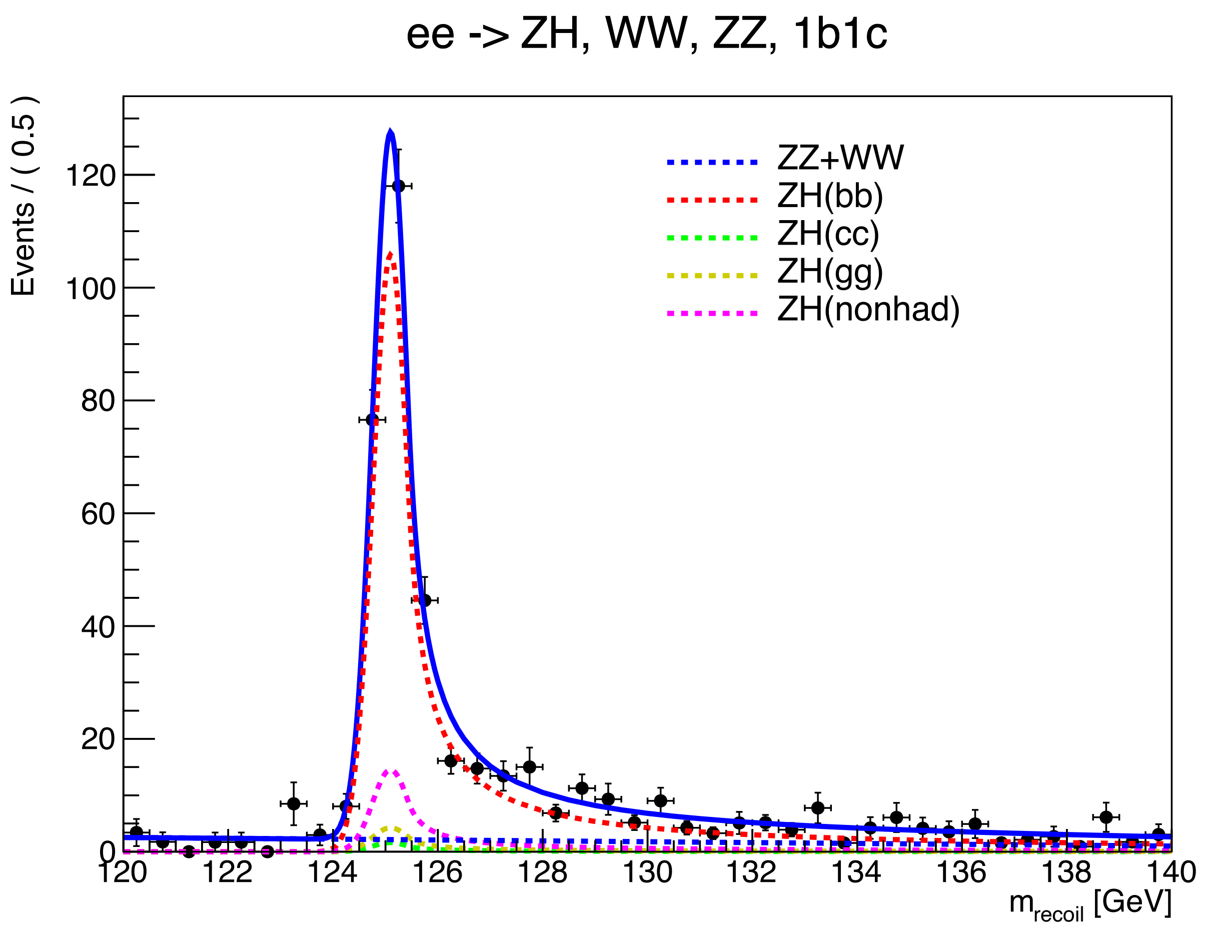
Fit - background model

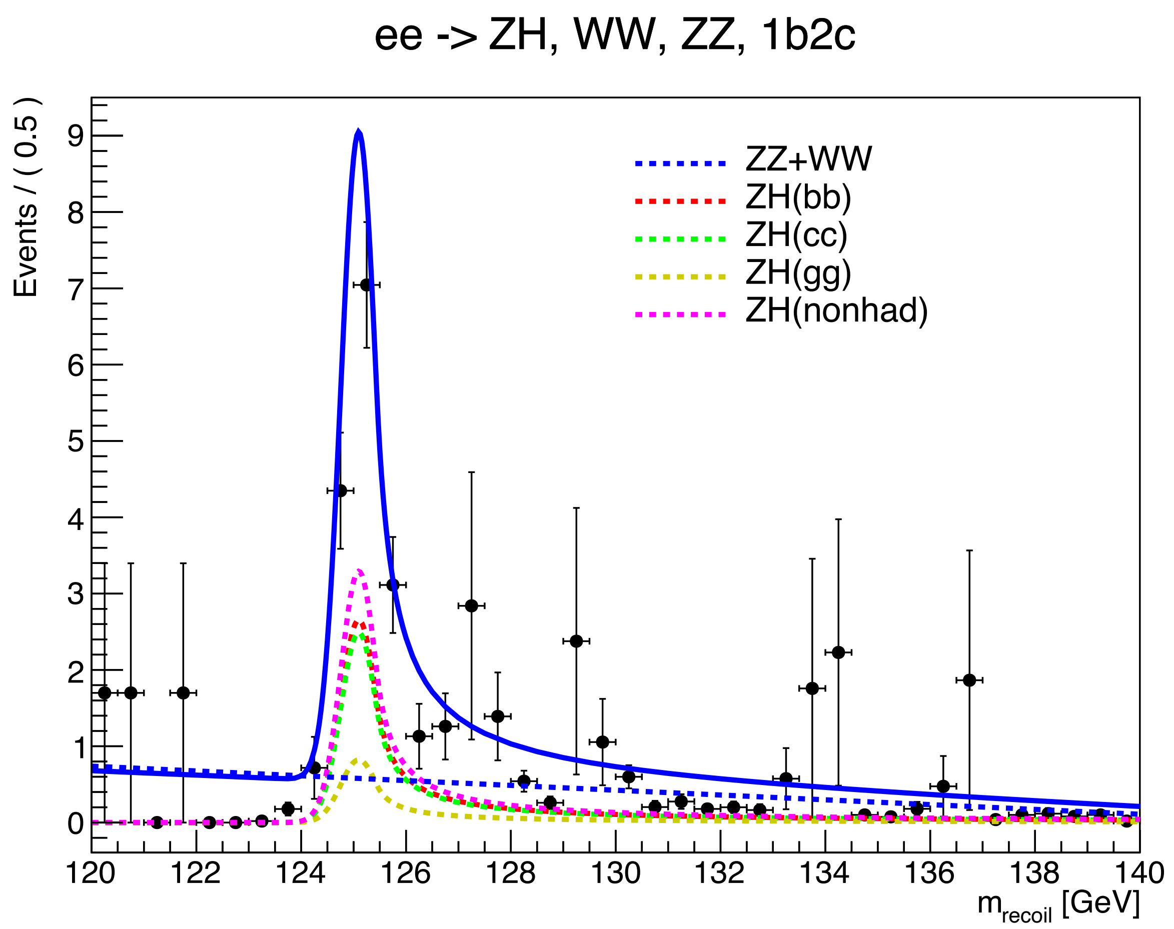
- Simple 1st order polynomial seems OK at first glance given low level of bkg

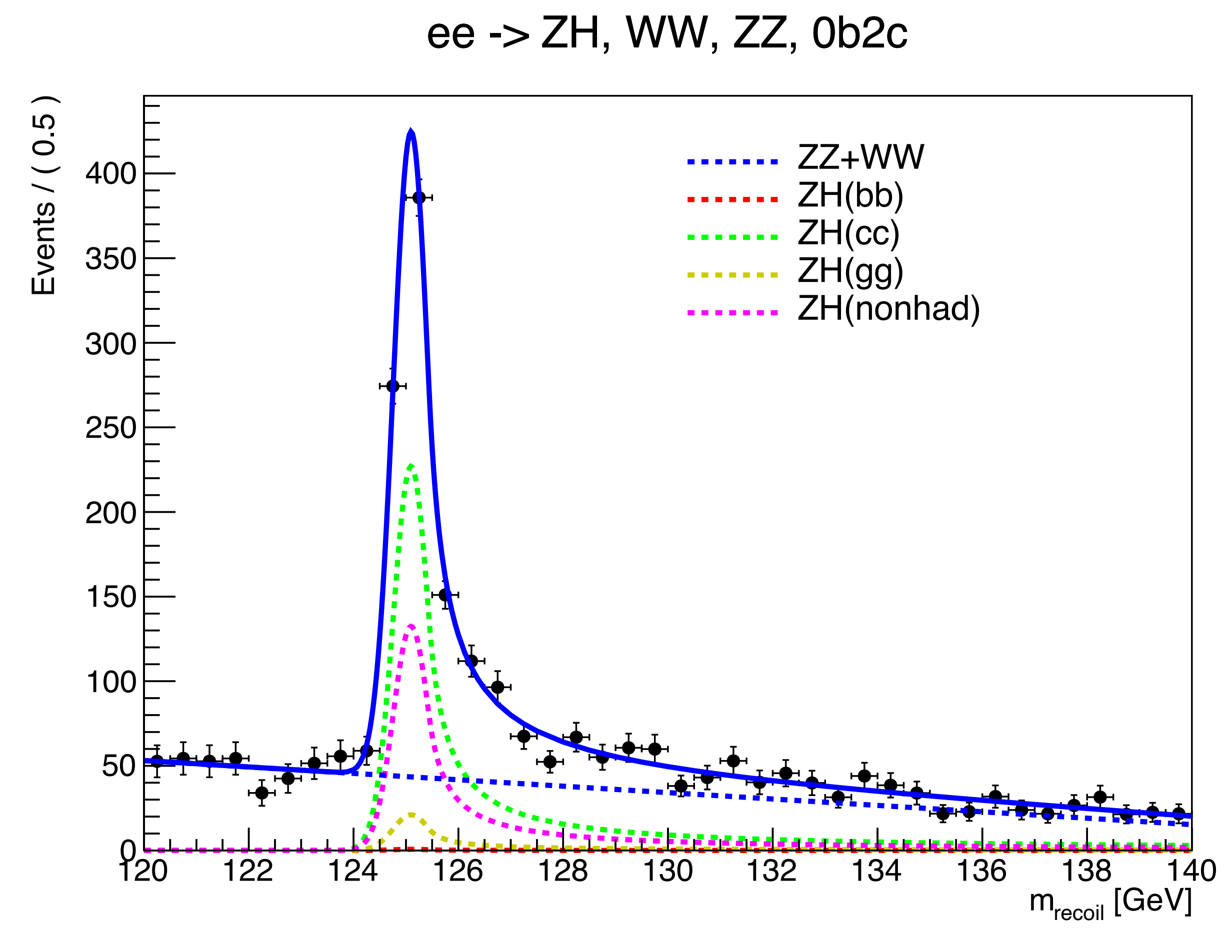
Results

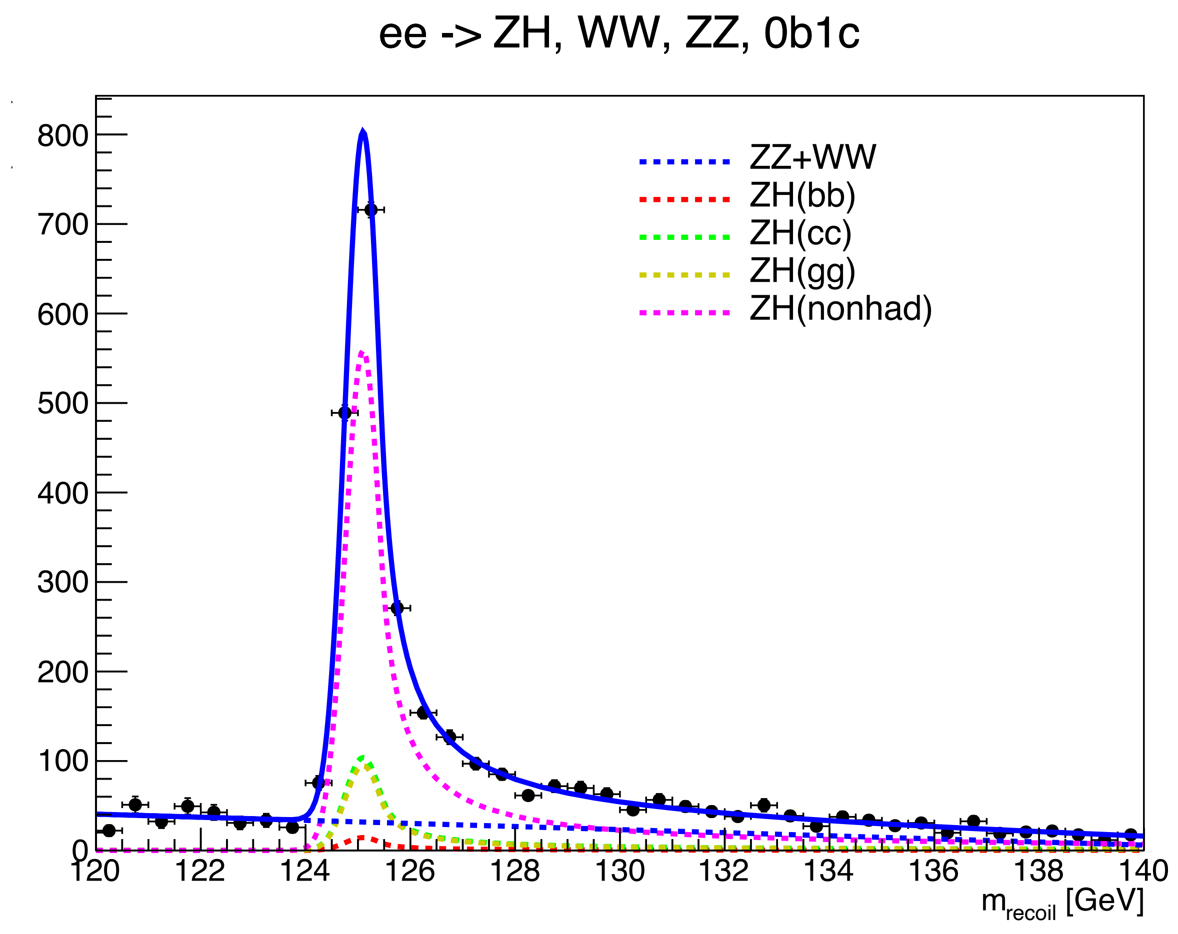


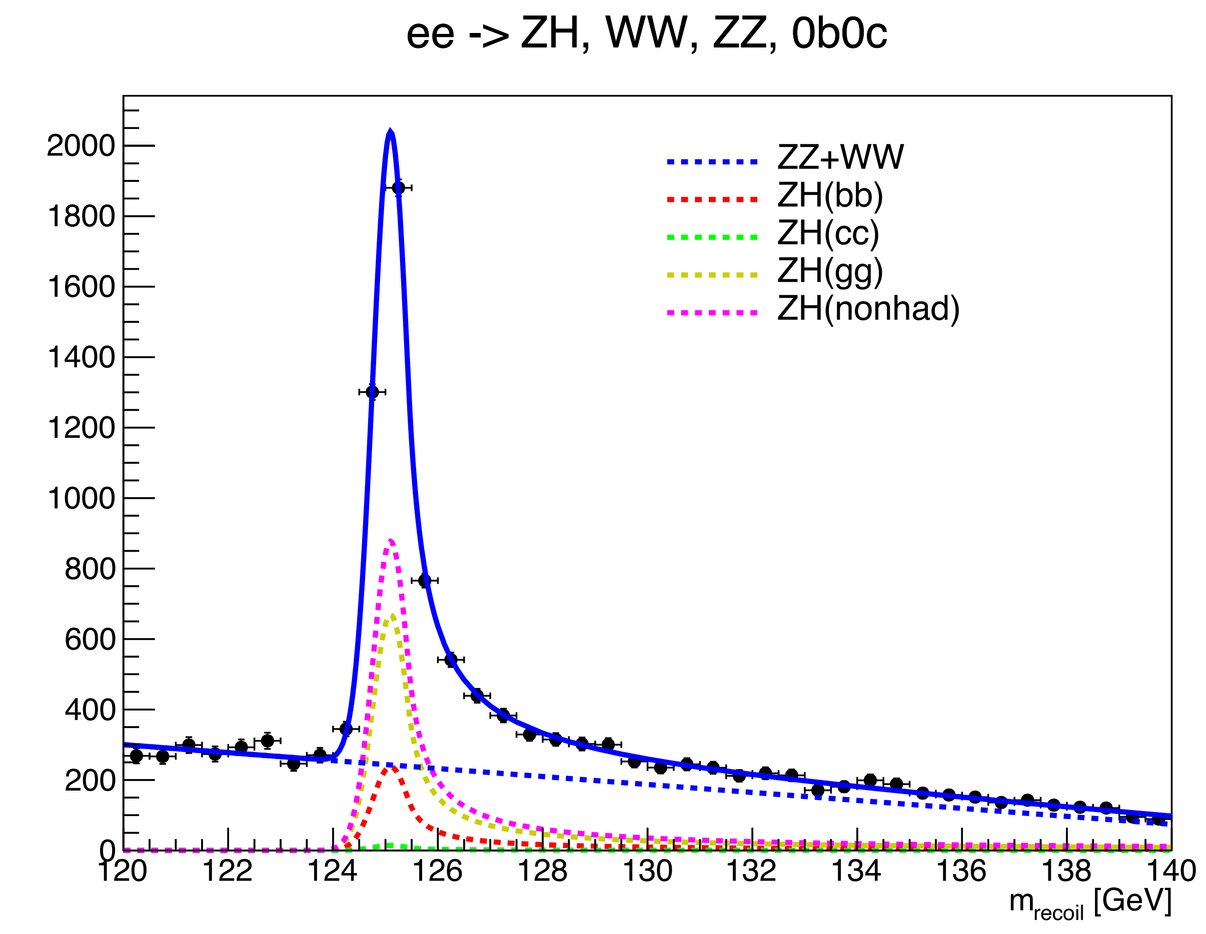












Kbb	1.0000e+00	9.8842e-01 +/-	9.18e-03
Kcc	1.0000e+00	1.0860e+00 +/-	8.68e-02
Kgg	1.0000e+00	9.6729e-01 +/-	9.36e-02
Knonhad	1.0000e+00	9.6564e-01 +/-	5.37e-02
Yield_0b0c_bkg	7.3453e+03	7.4855e+03 +/-	1.11e+02
Yield_0b1c_bkg	8.9693e+02	9.3080e+02 +/-	4.61e+01
Yield_0b2c_bkg	1.4100e+03	1.3672e+03 +/-	4.81e+01
Yield_1b0c_bkg	9.0373e+02	9.6276e+02 +/-	5.11e+01
Yield_1b1c_bkg	6.4552e+01	7.0688e+01 +/-	1.29e+01
Yield_1b2c_bkg	1.3590e+01	1.6957e+01 +/-	5.19e+00
Yield_2b_bkg	1.3182e+03	1.3818e+03 +/-	6.79e+01
mH	1.2500e+02	1.2500e+02 +/-	3.35e-03

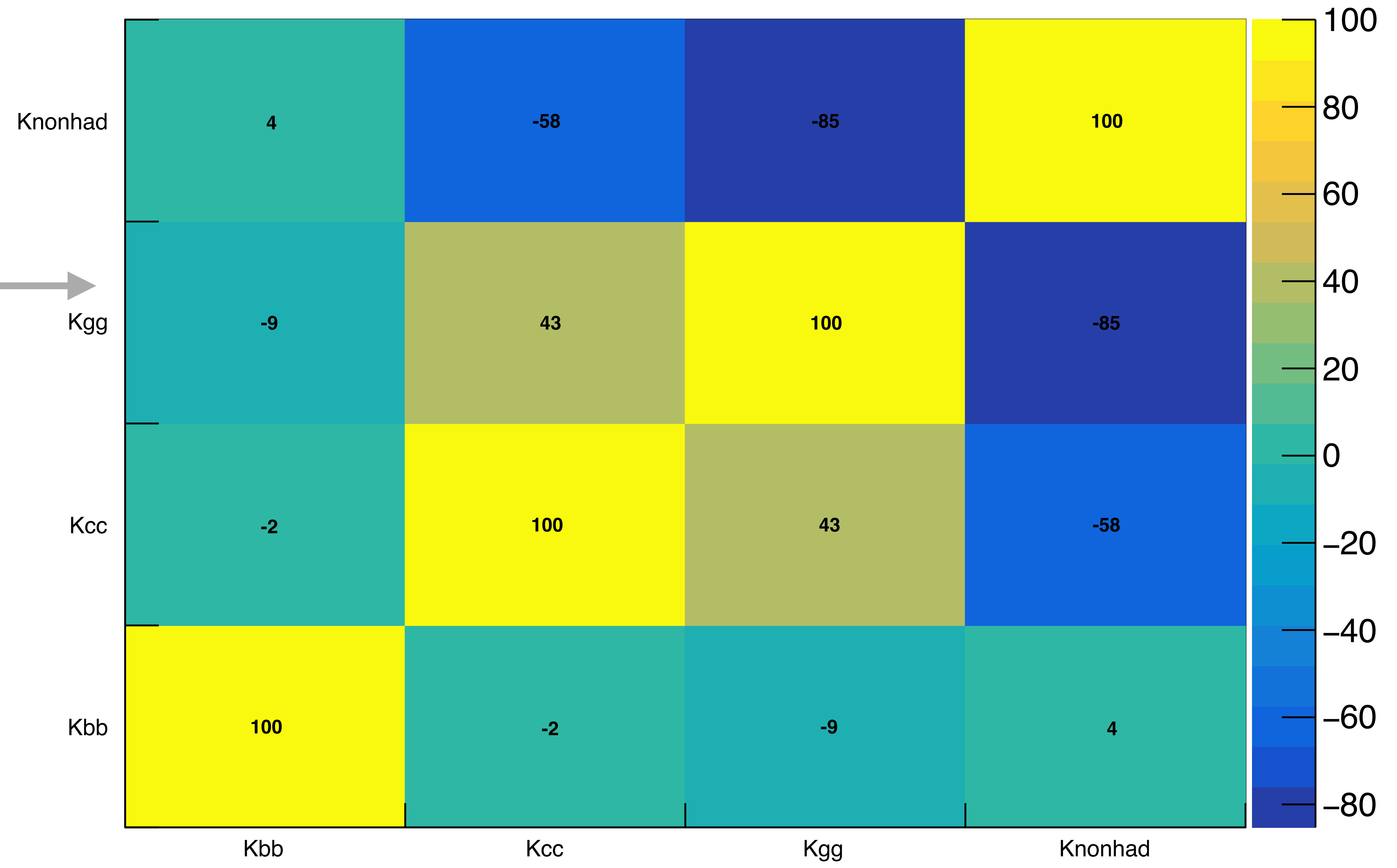
- Relative error on Kbb: 0.9%
- Relative error on Kcc: 8.0%
- Relative error on Kgg: 9.7%
- Relative error on Knonhad: 5.6%

Results with non-hadronic Higgs decays BR fixed

- Categories enriched in H->cc and H->gg have a non negligible contamination from non-hadronic Higgs decays (mainly WW & tautau with hadronic W or tau decays)
- The uncertainties in BR(cc) and BR(gg) are therefore affected by the uncertainty in BR(nonhad), to which they are largely anti correlated
- In the previous fit, BR(nonhad) was freely floating; if instead we assume that H(WW) and H(tautau) are well measured by means of dedicated studies, we can profile them in the fit (or do a global fit)
- Here we estimate what happens if we just fix BR(nonhad) to the SM:

```
          Kbb   1.0000e+00   9.8864e-01 +/-  9.17e-03
          Kcc   1.0000e+00   1.0541e+00 +/-  7.00e-02
          Kgg   1.0000e+00   9.1589e-01 +/-  4.89e-02
Yield_0b0c_bkg  7.3453e+03   7.4923e+03 +/-  1.11e+02
Yield_0b1c_bkg  8.9693e+02   9.1888e+02 +/-  4.20e+01
Yield_0b2c_bkg  1.4100e+03   1.3712e+03 +/-  4.77e+01
Yield_1b0c_bkg  9.0373e+02   9.6331e+02 +/-  5.11e+01
Yield_1b1c_bkg  6.4552e+01   7.0401e+01 +/-  1.29e+01
Yield_1b2c_bkg  1.3590e+01   1.6954e+01 +/-  5.19e+00
  Yield_2b_bkg  1.3182e+03   1.3816e+03 +/-  6.79e+01
            mH  1.2500e+02   1.2500e+02 +/-  3.35e-03
```

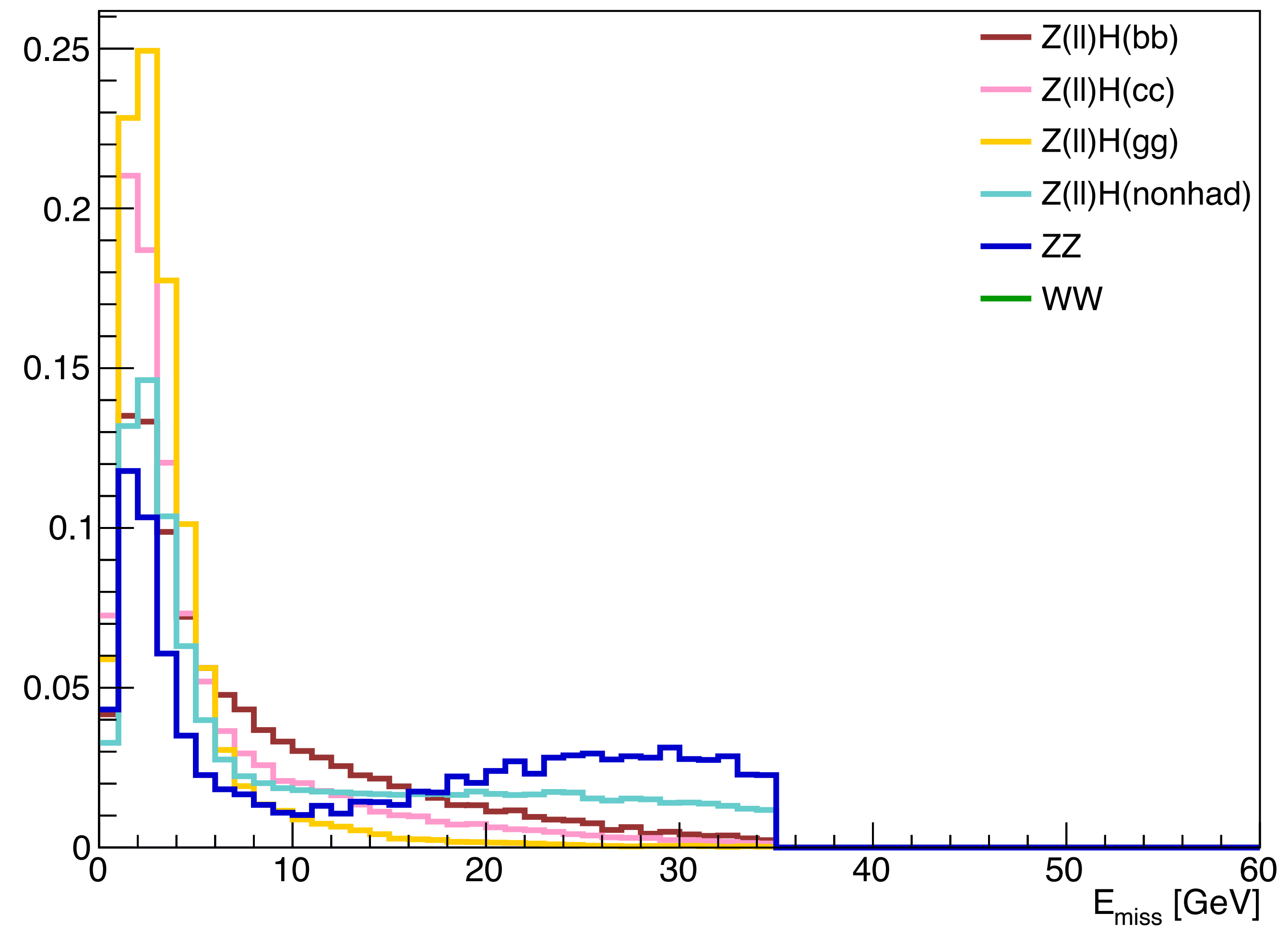
POI correlation matrix

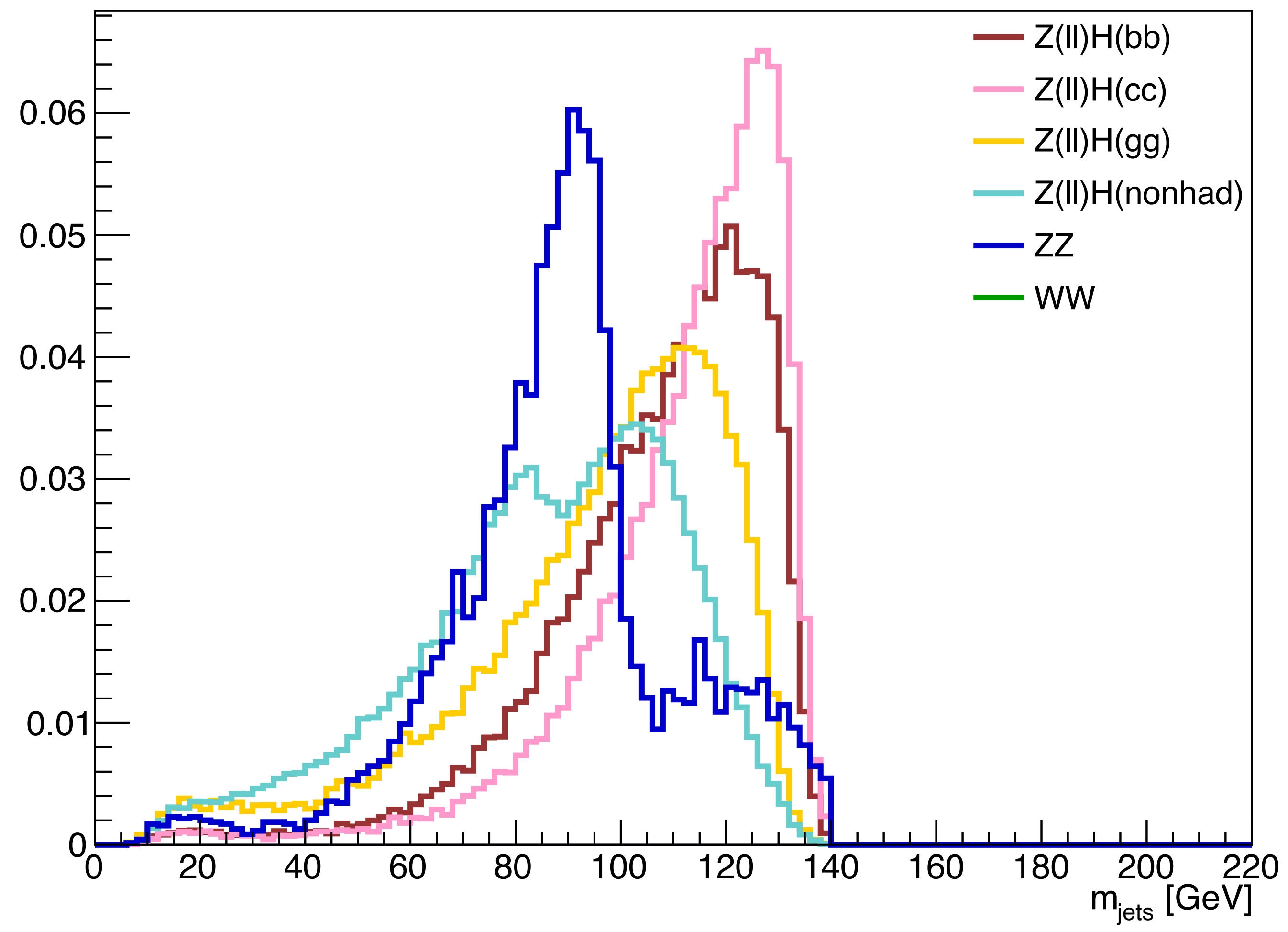



```
Relative error on Kbb: 0.9%
Relative error on Kcc: 6.6%
Relative error on Kgg: 5.3%
Relative error on Knonhad: 0.0%
```

Suppressing ZH(nonhad) with Emiss, m(jets) cuts

- H(gg) and H(cc) have lower missing energy than H(bb) and H(nonhad) -> tighter cut on Emiss in 0b0c category (15 GeV) and 0b1c, 0b2c, 1b2c categories (25 GeV)
- H(gg) and H(cc) have larger m(jets) than H(nonhad) -> tighter cut on m(jets) in 0b0c category (60 GeV) and 0b1c, 0b2c, 1b2c categories (80 GeV)






```
                 Kbb    1.0000e+00    9.8862e-01 +/-  8.84e-03  <none>
                 Kcc    1.0000e+00    1.0244e+00 +/-  8.49e-02  <none>
                 Kgg    1.0000e+00    9.7169e-01 +/-  7.50e-02  <none>
             Knonhad    1.0000e+00    9.7361e-01 +/-  5.98e-02  <none>
Yield_0b0c_emiss_mhad_bkg    3.5928e+03    3.6746e+03 +/-  8.16e+01  <none>
Yield_0b1c_emiss_mhad_bkg    4.9433e+02    5.1886e+02 +/-  3.64e+01  <none>
Yield_0b2c_emiss_mhad_bkg    8.0690e+02    7.9826e+02 +/-  3.84e+01  <none>
      Yield_1b0c_bkg    9.0373e+02    9.6228e+02 +/-  5.09e+01  <none>
      Yield_1b1c_bkg    6.4552e+01    7.0546e+01 +/-  1.29e+01  <none>
Yield_1b2c_emiss_mhad_bkg    6.7950e+00    9.7784e+00 +/-  4.03e+00  <none>
        Yield_2b_bkg    1.4354e+03    1.5036e+03 +/-  7.14e+01  <none>
                  mH    1.2500e+02    1.2500e+02 +/-  3.38e-03  <none>
```

```
Relative error on Kbb: 0.9%
Relative error on Kcc: 8.3%
Relative error on Kgg: 7.7%
Relative error on Knonhad: 6.1%
```

- Error on Kgg decreases (9.7->7.7%) but on Kcc goes up a bit (8.0->8.3%)
  - Need optimisation of the criteria

Impact of gluon tagging

- If gluon tagging is available, splitting the 0b0c category into 0b0c0g, 0b0c1g, 0b0c2g leads to improved results (mainly on Kgg) thanks to the rejection of quark jets from W and tau decays from the Higgs

Kbb	1.0000e+00	9.8890e-01	+/-	8.81e-03
Kcc	1.0000e+00	1.0844e+00	+/-	7.91e-02
Kgg	1.0000e+00	9.4885e-01	+/-	4.70e-02
Knonhad	1.0000e+00	9.7048e-01	+/-	3.25e-02
Yield_0b0c0g_bkg	4.8924e+03	4.9375e+03	+/-	8.33e+01
Yield_0b0c1g_bkg	2.1353e+03	2.2196e+03	+/-	5.72e+01
Yield_0b0c2g_bkg	3.0068e+02	3.2326e+02	+/-	2.60e+01
Yield_0b1c_bkg	8.9693e+02	9.2988e+02	+/-	4.40e+01
Yield_0b2c_bkg	1.4100e+03	1.3670e+03	+/-	4.79e+01
Yield_1b0c_bkg	9.0373e+02	9.6250e+02	+/-	5.10e+01
Yield_1b1c_bkg	6.4552e+01	7.0569e+01	+/-	1.29e+01
Yield_1b2c_bkg	1.3590e+01	1.6955e+01	+/-	5.19e+00
Yield_2b_bkg	1.4354e+03	1.5029e+03	+/-	7.13e+01
mH	1.2500e+02	1.2500e+02	+/-	3.27e-03

Relative error on Kbb: 0.9%
Relative error on Kcc: 7.3%
Relative error on Kgg: 5.0%
Relative error on Knonhad: 3.4%

Conclusions

- Preliminary study of sensitivity to hadronic BR of Higgs at FCC-ee with Z(ll)H shows <% uncertainty on H->bb and 5-10% uncertainty on H->cc and H->gg depending on various scenarios (BR h->WW and tautau measured separately, gluon tagging, …)
  - Results quite close to CEPCv4 and FCCee CDR, but CEPC has (probably?) worse tagging performance in simulation
  - Various caveats..
- Several things to be done
  - Use central samples, recommended generators, tools, harmonise selections/fit models …
  - Include beam energy spread, more backgrounds
  - Fix bug in eff(b-tag) for light jets
  - Binned vs unbinned fits
  - Investigate which signal model parameters that can / can't be correlated across categories
  - Investigate bkg model with more MC stat
  - Study fit range
  - Asimov fits
  - Systematic uncertainties
  - ….

Backup

ILC projections

- Eur. Phys. J. C **73,** 2343 (2013) - ILC250 250/fb

	$\nu\bar{\nu}H$	$q\bar{q}H$	e^+e^-H	$\mu^+\mu^-H$	Comb.
$r_{b\bar{b}}$	1.00±0.02	1.00±0.01	1.00±0.04	1.00±0.03	1.00±0.01
$r_{c\bar{c}}$	1.02±0.11	1.01±0.10	1.02±0.27	1.01±0.23	1.02±0.07
r_{gg}	1.02±0.14	1.02±0.13	1.05±0.33	1.02±0.24	1.02±0.09
$\frac{\Delta(\sigma \cdot BR)}{\sigma \cdot BR}(H \to b\bar{b})$ (%)	1.7	1.5	3.8	3.3	1.0
$\frac{\Delta(\sigma \cdot BR)}{\sigma \cdot BR}(H \to c\bar{c})$ (%)	11.2	10.2	26.8	22.6	6.9
$\frac{\Delta(\sigma \cdot BR)}{\sigma \cdot BR}(H \to gg)$ (%)	13.9	13.1	31.3	33.0	8.5
$\frac{\Delta BR}{BR}(H \to b\bar{b})$ (%)	3.0	2.9	5.7	4.5	2.7
$\frac{\Delta BR}{BR}(H \to c\bar{c})$ (%)	11.4	10.5	31.3	22.8	7.3
$\frac{\Delta BR}{BR}(H \to gg)$ (%)	14.2	13.3	33.1	24.0	8.9

- More recent document (ILD interim design report) reports update for Z(νν)H for ILC500: 4/ab at 500 GeV
  - Relative uncertainties: 0.4% bb / 3.8% cc / 1.8% gg

ILC projections

- Eur. Phys. J. C **73,** 2343 (2013) - ILC250 250/fb + ILC350 350/fb

Table 3 Summary of background reduction in the eeH and $\mu\mu H$ channels assuming $\mathscr{L} = 250\ \mathrm{fb}^{-1}$ with $P(e^-, e^+) = (-0.8, +0.3)$

CM energy		250 GeV			350 GeV		
Cut names	e/μ	Condition	Sig.	Bkg.	Condition	Sig.	Bkg.
Generated	e		3137	4512520		2740	3822410
	μ		2917	4512520		1789	3822410
# of e/μ track ID	e	$N_e \geq 2$	2717	204403	$n_e \geq 2$	2270	179580
	μ	$N_\mu \geq 2$	2668	28175	$N_\mu \geq 2$	1631	23598
Di-lepton mass	e	$70 < M_{\ell\ell} < 110$ GeV	2208	34162	$70 < M_{\ell\ell} < 110$ GeV	1425	51436
	μ	$80 < M_{\ell\ell} < 110$ GeV	2287	12901	$80 < M_{\ell\ell} < 100$ GeV	1406	13313
Z direction	e	$\lvert\cos\theta_Z\rvert < 0.8$	1797	21600	$\lvert\cos\theta_Z\rvert < 0.8$	1192	20874
	μ	$\lvert\cos\theta_Z\rvert < 0.8$	1889	8036	$\lvert\cos\theta_Z\rvert < 0.8$	1203	6250
Di-jet mass	e	$100 < M_{jj} < 140$ GeV	1394	2721	$110 < M_{jj} < 140$ GeV	865	2019
	μ	$115 < M_{jj} < 140$ GeV	1445	1955	$115 < M_{jj} < 140$ GeV	855	1197
Recoil mass	e	$70 < M_{rec} < 140$ GeV	1184	1607	$70 < M_{rec} < 140$ GeV	567	590
	μ	$70 < M_{rec} < 140$ GeV	1365	983	$70 < M_{rec} < 140$ GeV	638	465
Significance (Efficiency)	e	$S/\sqrt{S+B}$	22.4 (37.8 %)		$S/\sqrt{S+B}$	16.7 (20.7 %)	
	μ		28.2 (46.8 %)			19.2 (35.7 %)	

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%
$\mathrm{BR}_{\mathrm{inv}}^{\mathrm{BSM}}$	–	$< 0.28\%$	–	$< 0.30\%$

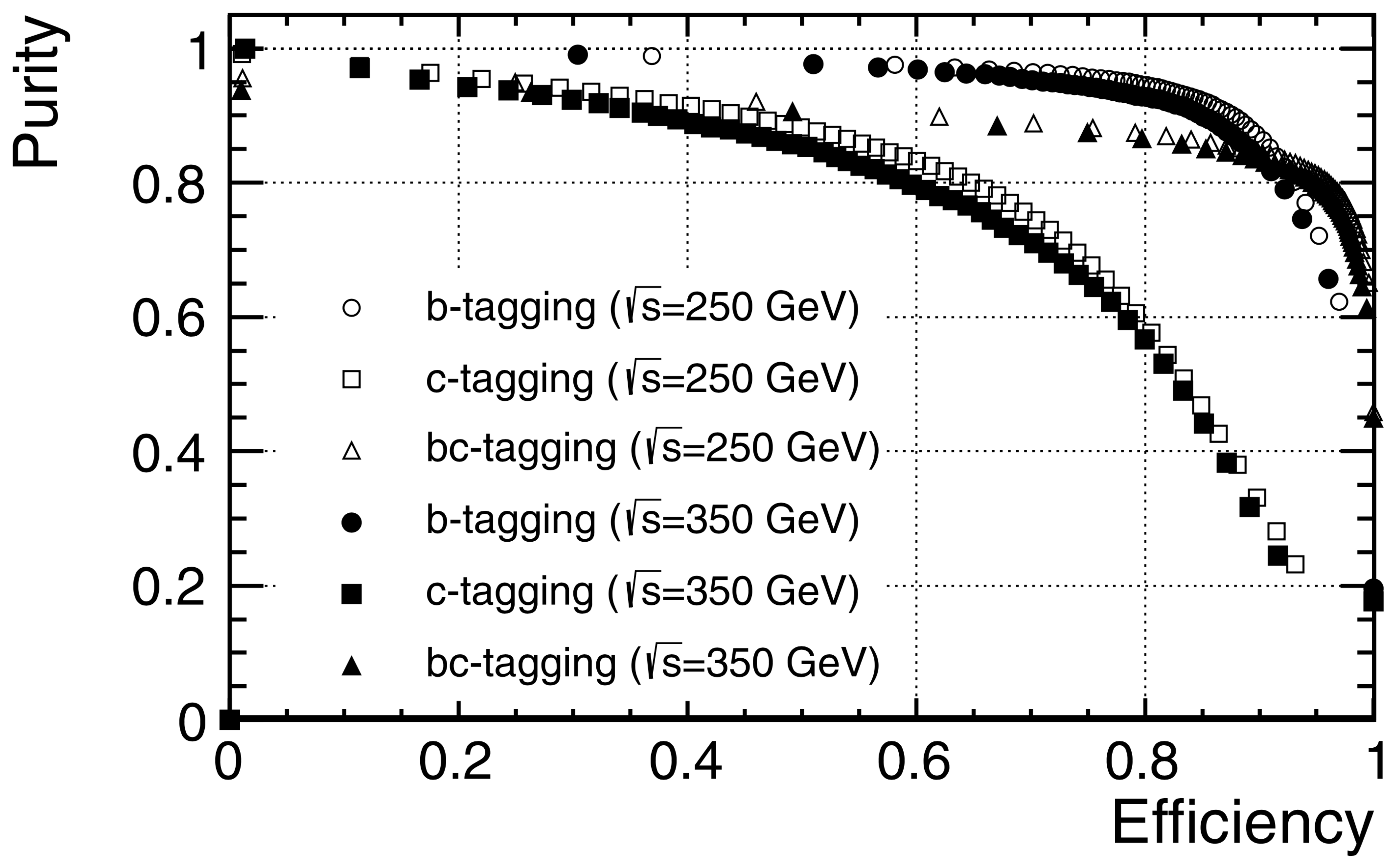
FCCee CDR projections

Table 4.1 Relative statistical uncertainty on the measurements of event rates, providing $\sigma_{HZ} \times BR(H \rightarrow XX)$ and $\sigma_{\nu\bar{\nu}H} \times BR(H \rightarrow XX)$, 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

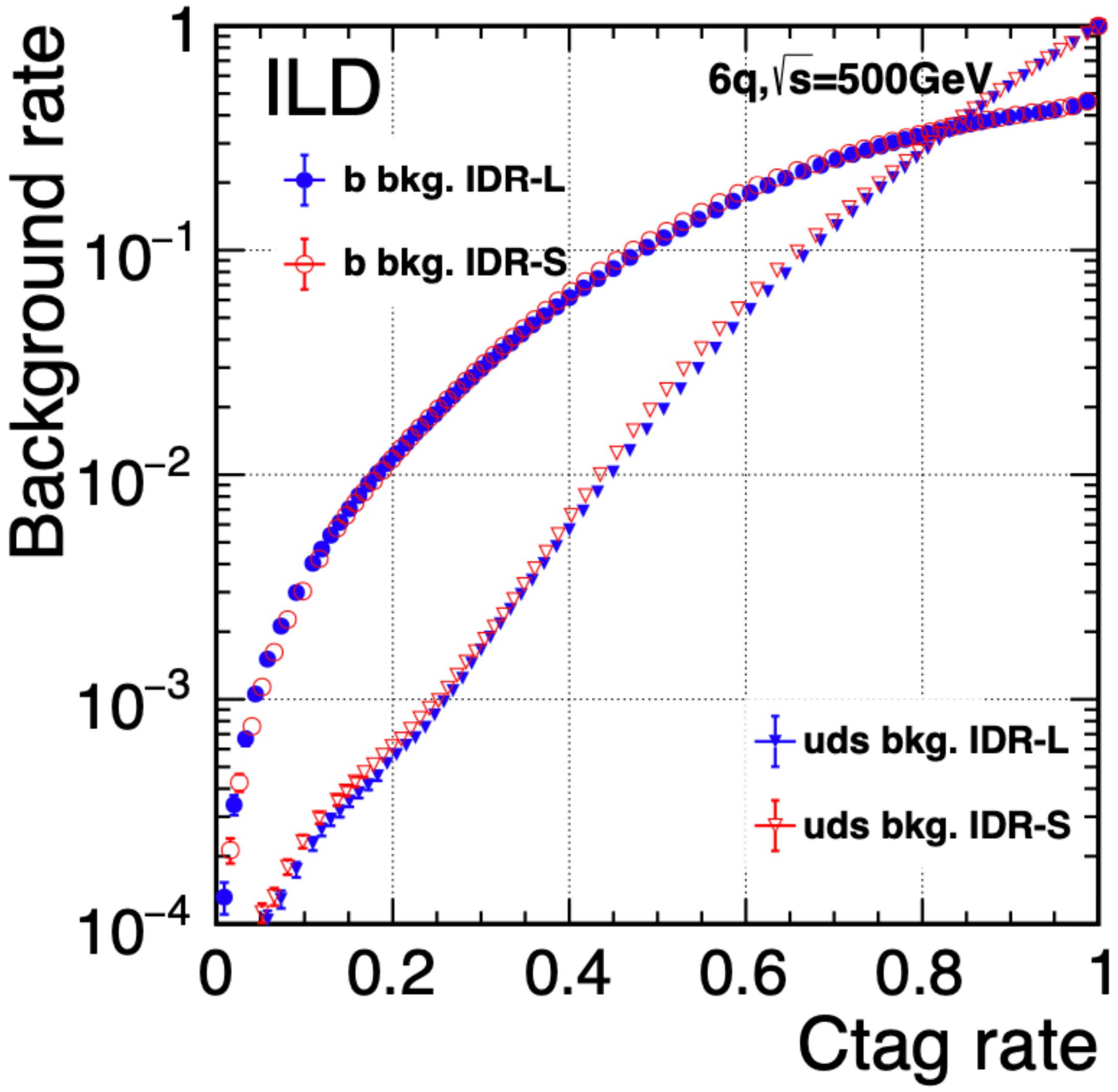
$\sqrt{s}$ (GeV)	240		365	
Luminosity (ab^{-1})	5		1.5	
$\delta(\sigma BR)/\sigma BR$ (%)	HZ	$\nu\bar{\nu}$ H	HZ	$\nu\bar{\nu}$ H
$H \rightarrow$ any	± 0.5		± 0.9	
$H \rightarrow b\bar{b}$	± 0.3	± 3.1	± 0.5	± 0.9
$H \rightarrow c\bar{c}$	± 2.2		± 6.5	± 10
$H \rightarrow gg$	± 1.9		± 3.5	± 4.5
$H \rightarrow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

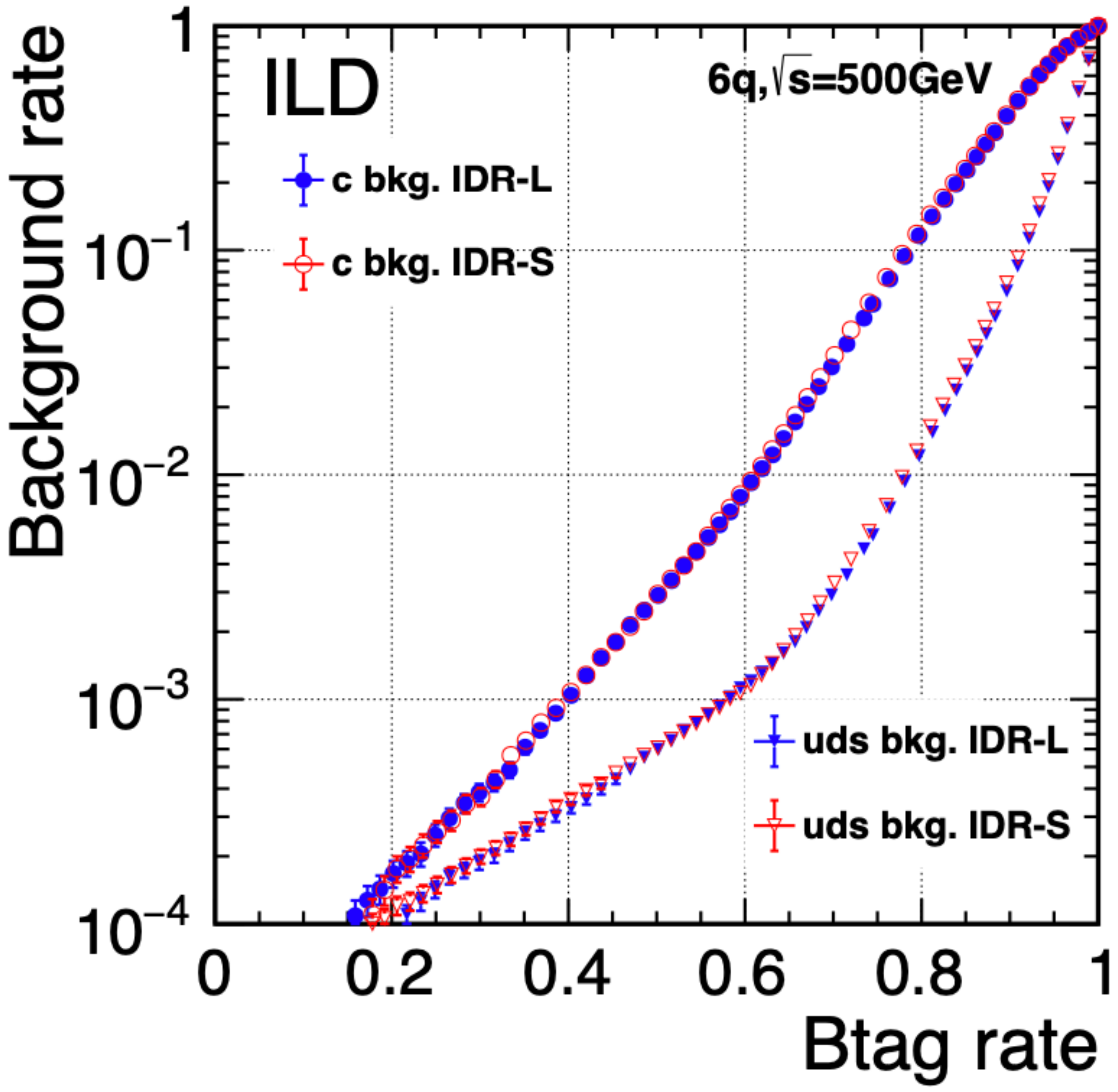
ILC flavour tagging

Eur. Phys. J. C 73, 2343 (2013)



ILD interim design report (2020)



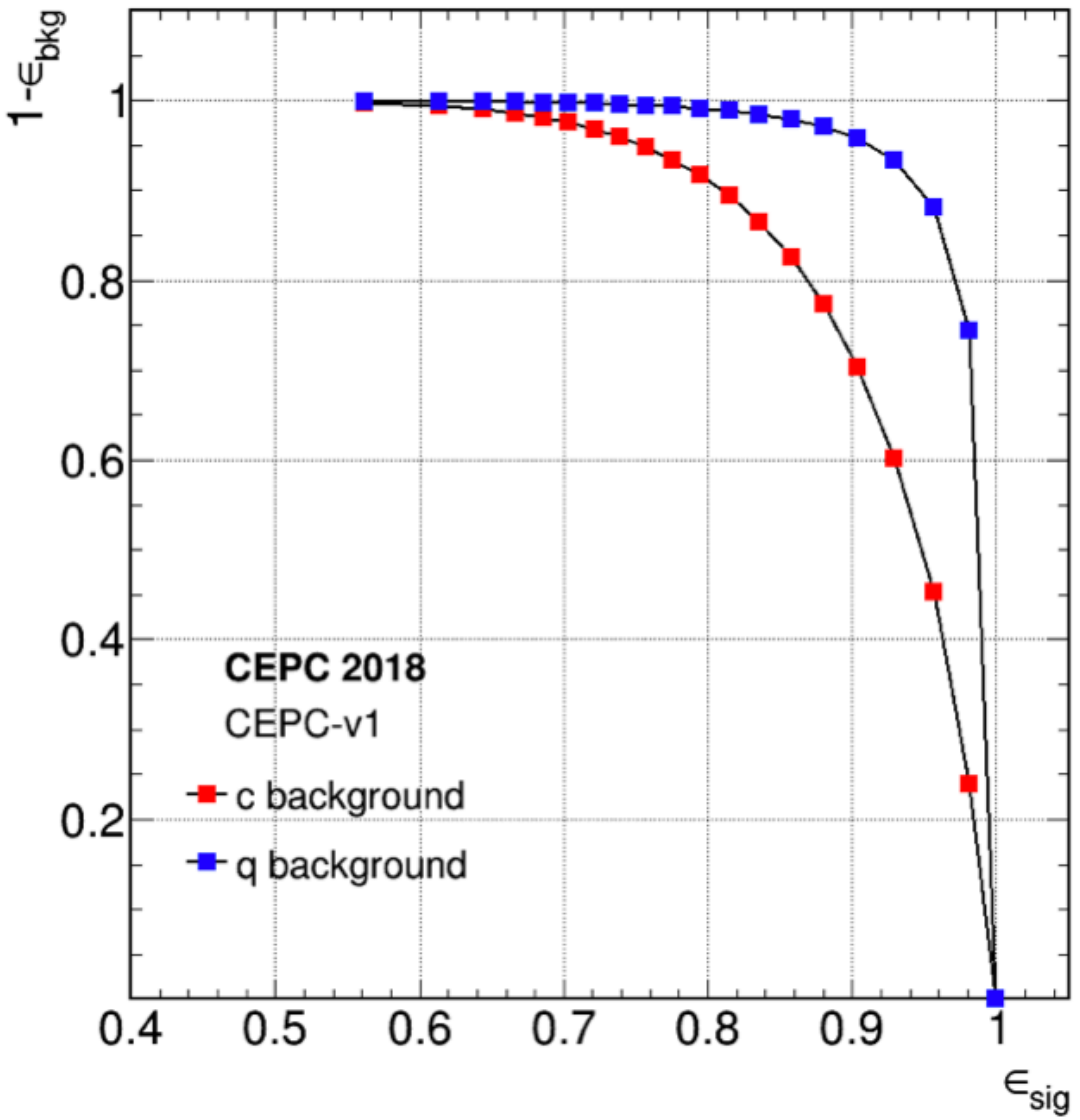


eff(c)=60%
eff(b)=20%
eff(l)=6%

eff(b)=80%
eff(c)=10%
eff(l)=1%

CEPC flavour tagging

Chinese Physics C Vol. 43, No. 4 (2019) 043002



eff(b)=80%
eff(c)=10%
eff(l)=1%

B-tagging performance seems similar to ILC
No plot found for c-tagging