Higgs boson coupling measurements to charm quarks at FCC-ee

Paul Paquiez (ENS Paris-Saclay), Mariette Jolly (NPAC SU)
Giovanni Marchiori (APC)

June 25th, 2021

A measure of expected uncertainties for BR(H->bb,cc,gg) at FCC-ee.

- Need to measure precisely and in a model independent way the Higgs boson couplings
- This study: sensitivity to the measurement of the couplings to the charm and bottom quarks and to gluons
- Studied processus :
  - Higgs-Strahlung : ee -> ZH
  - Leptonic channel : Z->ll (l=mu,e)
  - Signal: hadronic Higgs decays (->bb, cc, gg)
  - Observable : Recoil mass -> Does not depend on how the Higgs boson Decays -> Model Independant.

	Expected uncertainties for $\frac{\Delta\sigma BR}{\sigma BR}$		
	ILC	CEPC	FCC*
Channel	Zll	Zll	Zll+$Zq\overline{q}$+$Z\nu\overline{\nu}$
Considered background	WW, ZZ, HnonHad	ZWW,ZZ,HnonHad	ZWW,ZZ,HnonHad
$\frac{\Delta\sigma BR}{\sigma BR}(H\rightarrow b\overline{b})$	3.67	0.79	0.3
$\frac{\Delta\sigma BR}{\sigma BR}(H\rightarrow c\overline{c})$	21.71	7.6	2.2
$\frac{\Delta\sigma BR}{\sigma BR}(H\rightarrow gg)$	24.4	4.0	1.9

Table 12: Expected uncertainties for $\frac{\Delta\sigma BR}{\sigma BR}$ at different collider. * : Results found by extrapolation of ILC study.

- Simulating Higgs-strahlung events : $e^+e^- \rightarrow ZH$ with the decay $Z \rightarrow e^+e^-, \mu^+\mu^-$ et $H \rightarrow b\bar{b}, c\bar{c}, gg$ and background due to processes $e^+e^- \rightarrow ZZ, WW$ and other Higgs decays using Pythia 8

- Simulate and analyse the response of a potential FCC detector using Delphes

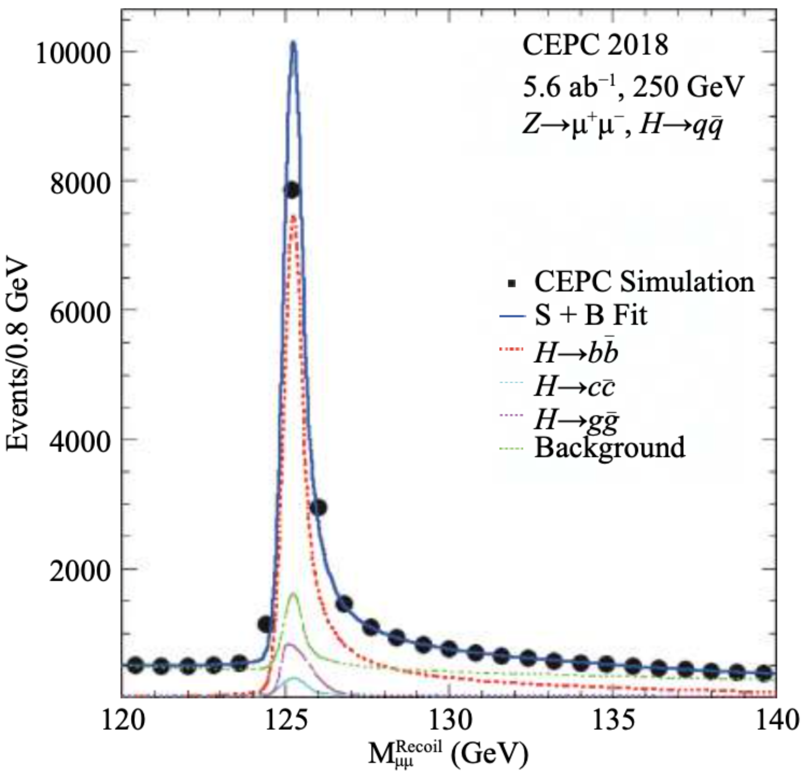
- Make cuts on variables in order to eliminate as much background as possible

- Separate total signal in portions enriched in b-tagged jets, c-tagged jets and gluons

- Do a fit on simulated data to determine the attainable precision on Higgs Branching Ratios in $b\bar{b}, c\bar{c}, gg$

Detector parameters & reconstruction flow: custom card based on IDEAtrkCov, main changes

- use Valencia jet clustering instead of anti-kt
- remove isolated electrons and muons from jet clustering



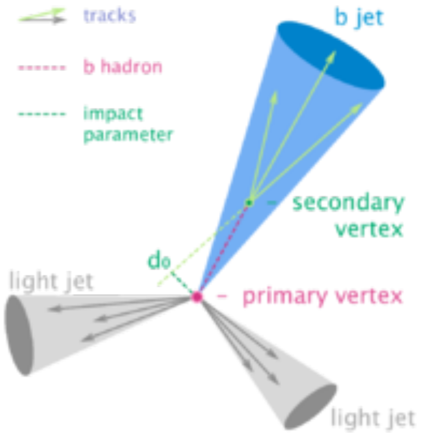
Recoil mass of the system for Higgs-strahlung events. The Higgs decay components are in dotted lines. (Image : Precision higgs physics at the CEPC, *An et al.*)

Generation parameters :

- σ(ZH)=201.87 fb
- sqrt(s) = 240 GeV
- Lum = 5000 /fb
- BR(H->bb)= 0.5824
- BR(H->cc)=0.02891
- BR(H->gg)=0.08187
- BR(H->non had) = 0.30682

	H->bb	H->cc	H->gg	H->nonhad	ZZ	WW
N_{events}	100 000	100 000	100 000	200 000	3 538 636	200 000

Expected branching ratios BR(H ->bb,cc,gg) accuracies at HLLHC, ILC, and CEPC.



Principle of Tagging : Quark C life duration is less important than B one. By detecting the distance between primary and secondary vertex, we should be able to detect between c,b,and light quarks.

	ILC	FCCee
B-TAG		
Eff(b)	0.8	0.8
Eff(c)	0.11	0.1
Eff(light)	0.01	0.01
C-TAG		
Eff(b)	0.6	0.6
Eff(c)	0.2	0.2
Eff(light)	0.05	0.06

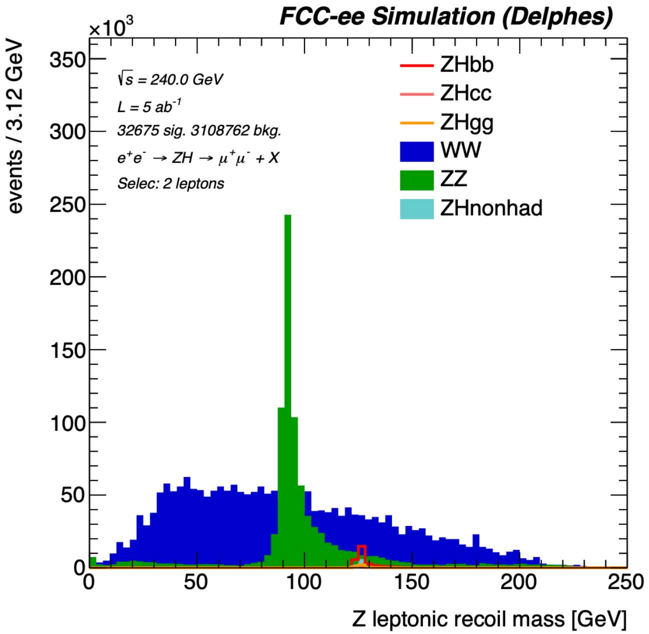
- High Luminosity LHC would enable to access a 4.4% accuracy on BR(H->bb), still with strong SM assumption on how Higgs boson decays. (no acces to letonic recoil mass).
- Due to hadronic background, no precise accuracy on BR(Hcc).
- No estimation on BR(H->gg).

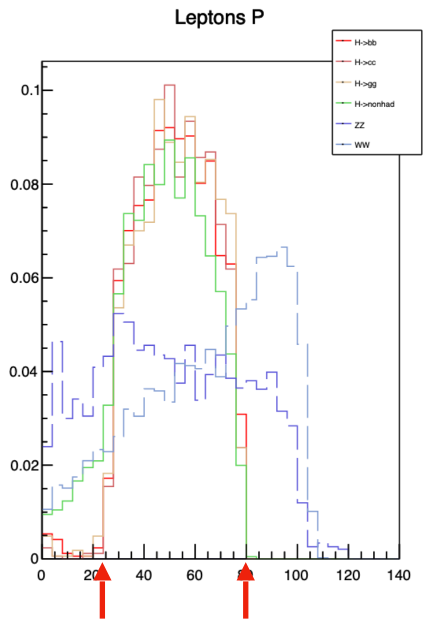
	Expected uncertainties for $\frac{\Delta\sigma BR}{\sigma BR}$		
	ILC	CEPC	FCC*
Channel	Zll	Zll	Zll+Z$q\bar{q}$+Z$\nu\bar{\nu}$
Considered background	WW, ZZ, HnonHad	ZWW,ZZ,HnonHad	ZWW,ZZ,HnonHad
$\frac{\Delta\sigma BR}{\sigma BR}(H \to b\bar{b})$	3.67	0.79	0.3
$\frac{\Delta\sigma BR}{\sigma BR}(H \to c\bar{c})$	21.71	7.6	2.2
$\frac{\Delta\sigma BR}{\sigma BR}(H \to gg)$	24.4	4.0	1.9

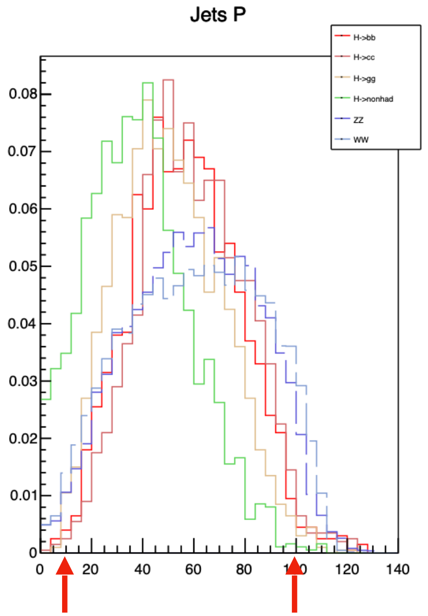
Table 12: Expected uncertainties for $\frac{\Delta\sigma BR}{\sigma BR}$ at different collider. * : Results found by extrapolation of ILC study.

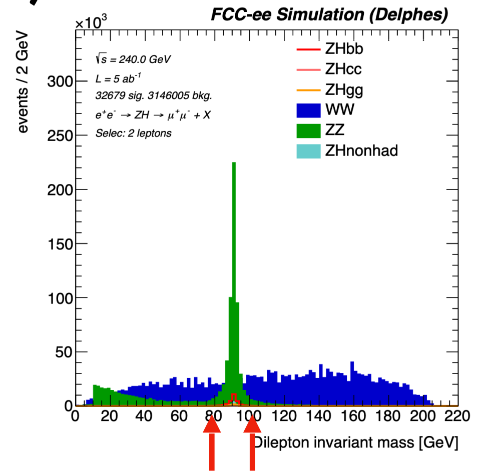
--> With a reduced hadronic background, Higgs Factories would enable to access a better accuracy on Higgs coupling coefficients to quarks and gluon.

Selections performed on the signal (H->bb, H->cc, H->gg) + background (ZZ, WW, H->Nonhad)









Selections : 2 leptons

Leptons p btw 25 and 80 GeV

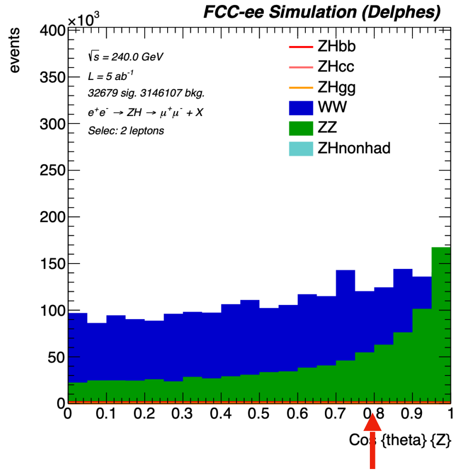
Jets p btw 10 and 100 GeV

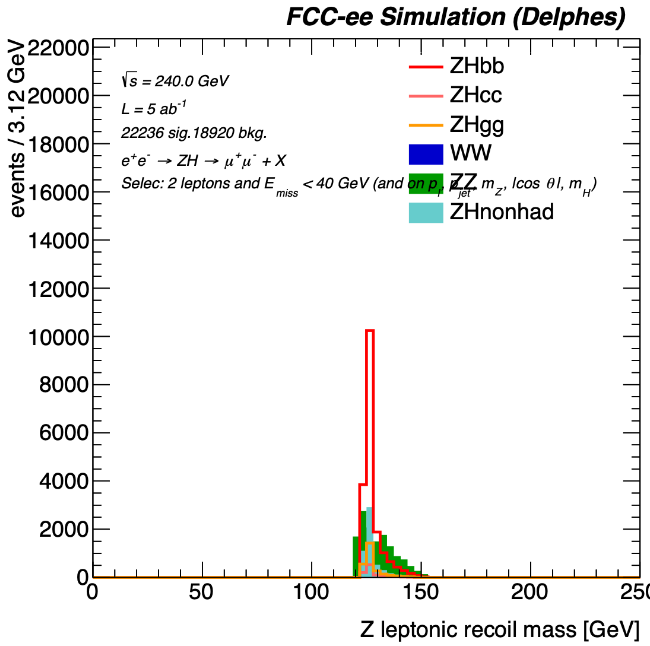
1 Z boson w/ mass btw 80 and 100 GeV

$|\cos\theta|$ < 0,8

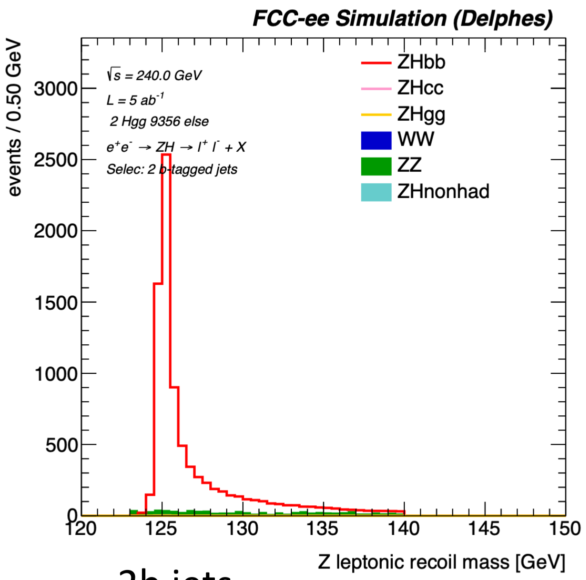
Recoil mass > 120

Missing Et < 35 GeV

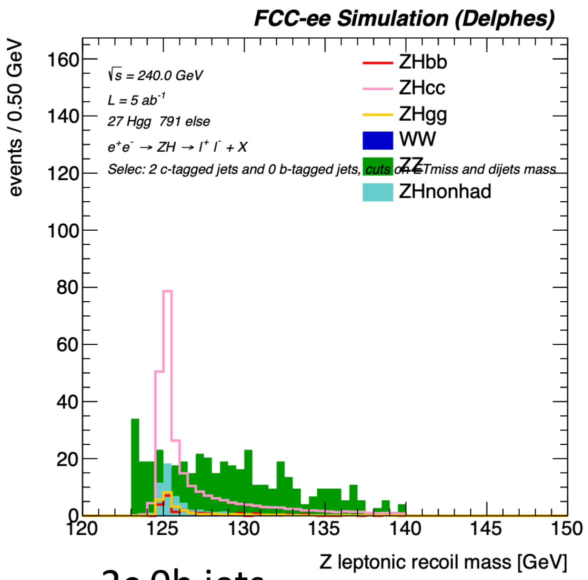




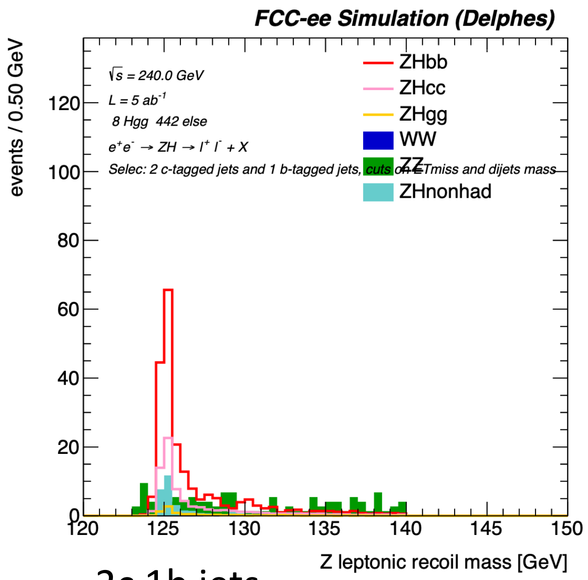
Further selections to get enriched categories



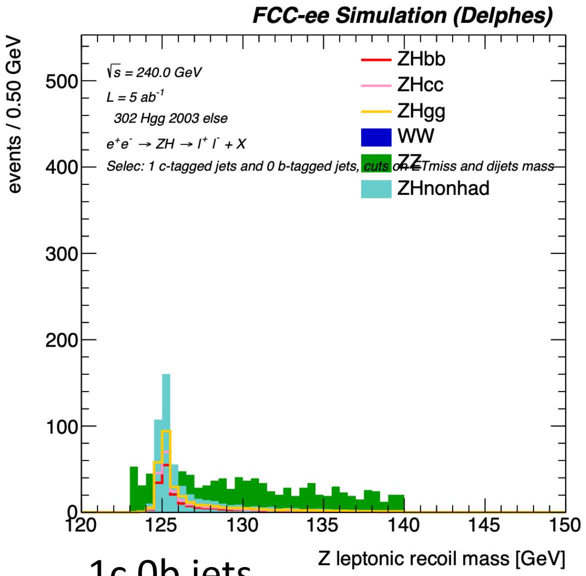
2b jets



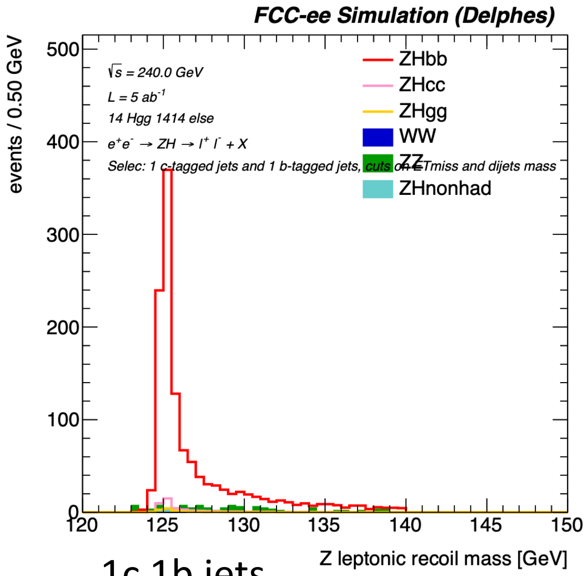
2c 0b jets



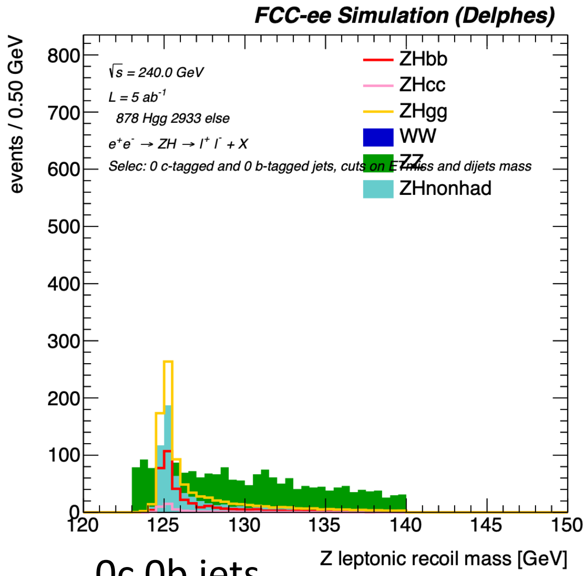
2c 1b jets



1c 0b jets



1c 1b jets



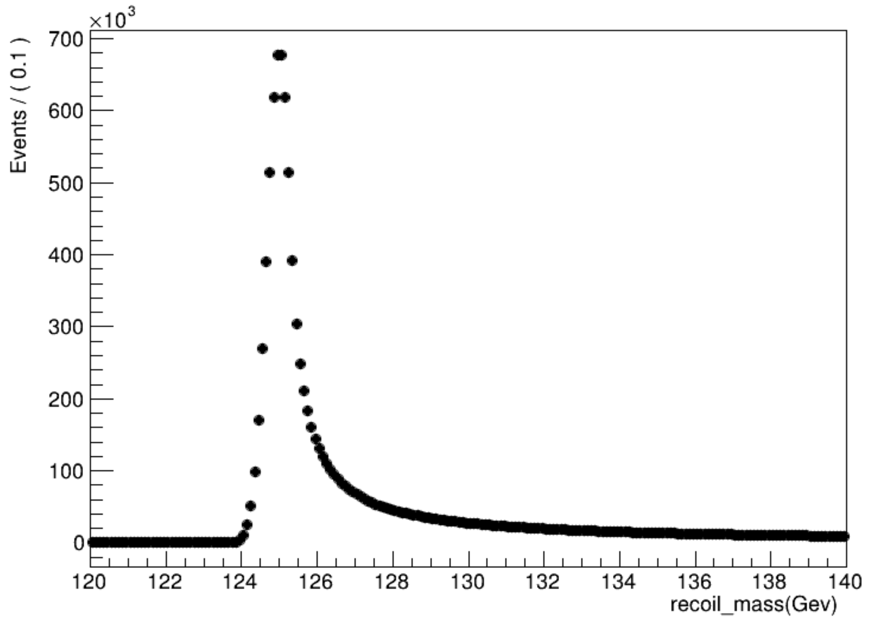
0c 0b jets

Corresponding significances

	H->bb	H->cc	H->gg
2 b	86,75	0,06	0,04
2c, 0b	0,92	8,44	0,44
2c, 1b	11,29	2,81	0,31
1c, 0b	4,41	6,16	4,26
1c,1b	31,80	1,44	0,38
0c, 0b	5,11	1,34	15,13
Quad sum	93,33	11,00	15,73

As expected, the b-tagging significance is much better than the c-tagging or the gluon identification.

Fitting Descption:



Crystal Ball Function

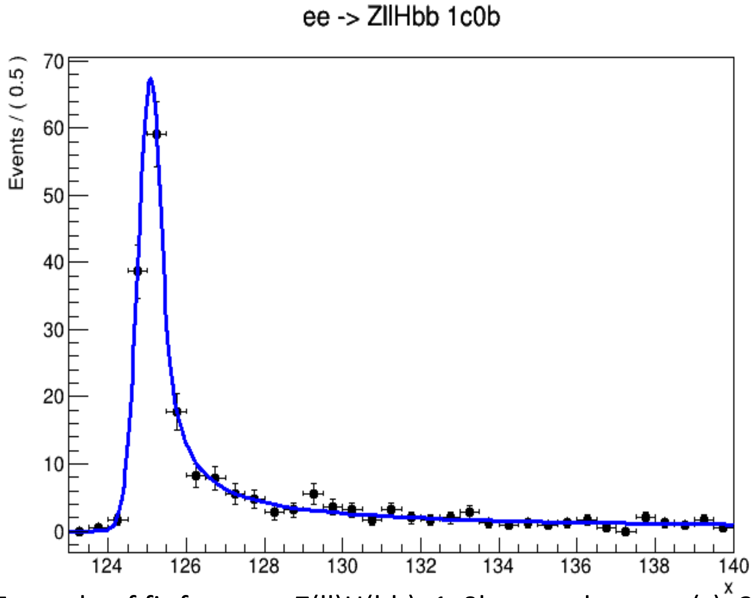
- Signal : Z(ee,μμ)H(bb,cc,gg)
- Background : ZZ,WW,H->nonhad
- Observable : Leptonic Recoil mass, cut in the interval [123,140 GeV].
- Tagging categories : 2b,2c1b, 2c0b, 1c1b, 1c0b, 0c0b.
- Method for fitting: Simultaneous Extended Likelihood on the 6 tagging categories.
- Signal model : Crystal Ball

$$f(x,\sigma,\alpha,n) = N \begin{cases} exp(-\frac{1}{2}(\frac{x-\mu}{\sigma})^2), & \text{if } \frac{x-\mu}{\sigma} < \alpha \\ (\frac{n}{|\alpha|})^n exp(\frac{-\alpha^2}{2})(\frac{n}{\alpha} - |\alpha| + \frac{x-\mu}{\sigma})^{-n}, & \text{otherwise} \end{cases}$$

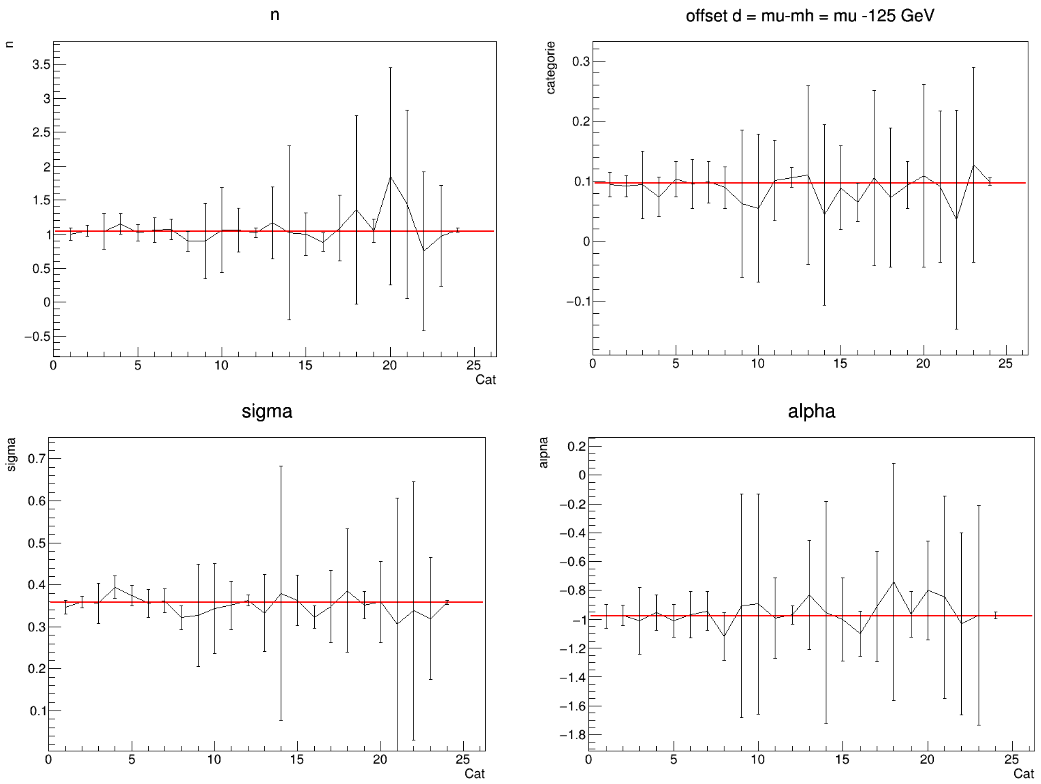
- Background model : 2^{nd} order Polynomial.
- Parameters :
  - **Background shape and normalisation : p1, p2, Nbgnd**
  - Signal shape: μ, σ, α, n
  - Signal normalisation: BR(H -> XX) = K_{XX} BR^{SM}(H->XX), XX = bb, cc, gg.

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

Determination of signal parameters μ, σ, α, n.



Example of fit for ee -> Z(ll)H(bb), 1c0b tagged, at sqrt(s)=240GeV, with custom IDEAtrkCov card



1st: Crystal Ball fit on the 24 data $[Z(ll)H(bb,cc,gg,\text{non had})]_{cat}$

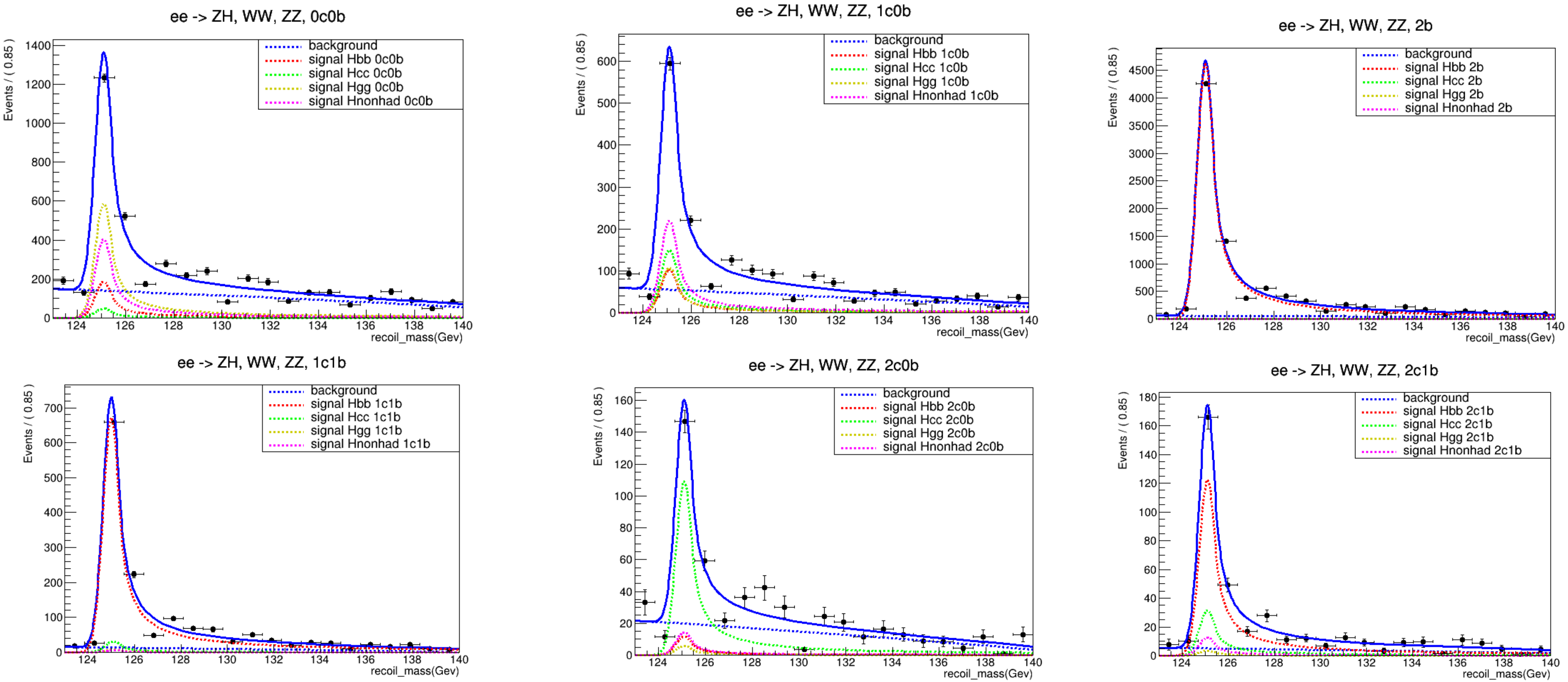
2nd : Constant fit on the Crystal Ball parameters μ-m_H(cat), σ(cat), α(cat), n(cat).

Fit Parameter

Parameter	value	$\frac{\chi^2}{Ndf}$
$\mu - m_H\ (GeV)$	0.0969435 ± 0.00483261	0.117
σ	0.357449 ± 0.00391544	0.285
n	1.04454 ± 0.0212002	0.187
α	0.975188 ± 0.0192304	0.0980

Conclusion : No correlation between the tagging category and the shape of the Crystal Ball.
--> We fix the parameters of the Crystal Ball at these values in order to apply an extended likelihood on Signal + Background.

Simultaneous Fit on the 6 tagged categories.



- Graphically, we can expect smaller uncertainties on H->bb, as b-tagging efficiency is better than c-tagging (2b)
- Discrimination between gluons and non hadronic jets are not fully optimize (0c0b). One needs to improve gluon tagging to acces better accuracy.

Results :

Parameter	Expected Value	Fitted Value	Uncertainty
Kbb	1.00E+00	9.98E-01	(+1.23e-02,-1.22e-02)
Kcc	1.00E+00	1.03E+00	(+1.32e-01,-1.28e-01)
Kgg	1.00E+00	1.07E+00	(+1.85e-01,-1.86e-01)
Knonhad	1.00E+00	1.02E+00	(+2.30e-01,-2.29e-01)
Nbgnd_0c0b	2.20E+03	2.11E+03	(+6.73e+01,-6.61e+01)
Nbgnd_1c0b	7.94E+02	7.64E+02	(+4.21e+01,-4.05e+01)
Nbgnd_1c1b	1.42E+02	1.76E+02	(+2.63e+01,-2.53e+01)
Nbgnd_2b	9.12E+02	8.54E+02	(+6.69e+01,-6.52e+01)

- Expected uncertainties are smaller for FCC-ee than for other electron collider as ILC.
- FCCee, using leptonic recoil mass, can have a direct access to the uncertainty on Branching ratios, and not only on cross section*Branching ratio.
- More work has to be done to discriminate gluons to non hadronics jets, in order to access a better accuracy on BR(H->gg).

	Expected uncertainties for $\frac{\Delta\sigma BR}{\sigma BR}$				
	FCC	FCC	ILC	CEPC	FCC*
Channel	Zll	Zll	Zll	Zll	Zll+$Zq\bar{q}$+$Z\nu\bar{\nu}$
Considered background	WW, ZZ, HnonHad	WW, ZZ	WW, ZZ, HnonHad	ZWW,ZZ,HnonHad	ZWW,ZZ,HnonHad
$\frac{\Delta\sigma BR}{\sigma BR}(H\to b\bar{b})$	1.2	1.2	3.67	0.79	0.3
$\frac{\Delta\sigma BR}{\sigma BR}(H\to c\bar{c})$	12.8	9.1	21.71	7.6	2.2
$\frac{\Delta\sigma BR}{\sigma BR}(H\to gg)$	17.3	5.9	24.4	4.0	1.9

Table 11: Expected uncertainties for $\frac{\Delta\sigma BR}{\sigma BR}$ at different collider. * : Results found by extrapolation of ILC study.

Annexes

ILC results from other channels

TABLE IV: Summary of template fitting results r_s and accuracies of $(\sigma \cdot Br)$ and Br after correcting σ for an accuracy of 2.5% at $\sqrt{s} = 250$ GeV assuming $\mathcal{L} = 250$ fb^{-1} with $(e^-, e^+) = (-0.8, +0.3)$.

	$\nu\bar{\nu}H$	$q\bar{q}H$	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