Measurement of Higgs Boson Mass at FCC-ee

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Outline

I. Higgs Factory

II. Background processes

III. Background rejection

IV. Channel Z → e^+e^-

V. Higgs Decay

VI. Measurement of the Higgs Boson mass

Higgs Factory

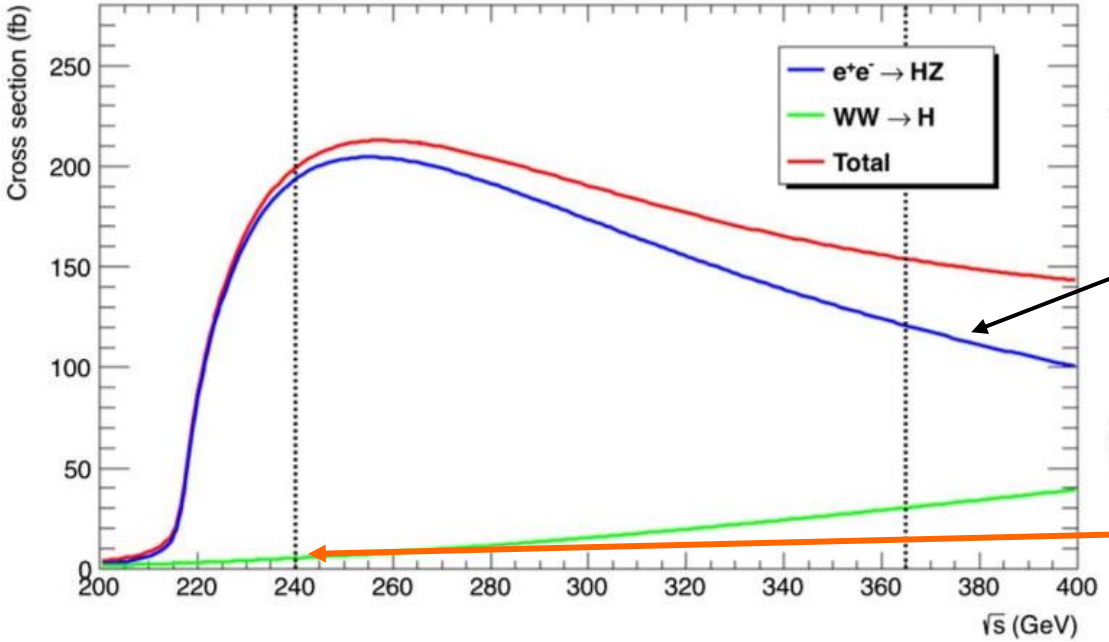
Simulation $M_H = 125\ GeV$

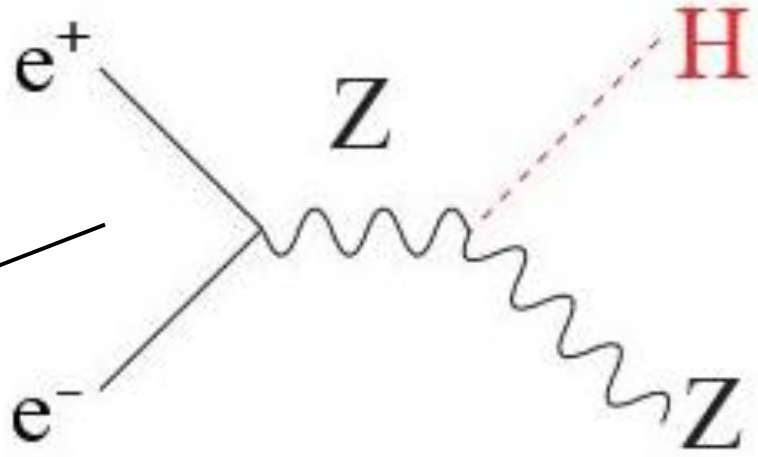
Recoil mass to measure Higgs mass

$$M^2_{rec} = s + M^2_Z - E_Z\sqrt{s}$$

→ Peak at $M_{rec} = M_H$

FCC-ee integrated luminosity : 5 ab^{-1}





$e^+e^- \rightarrow \nu\nu H$ neglected

Maximum event production ZH at $\sqrt{s}$ = 240 GeV

10^6 Higgs bosons produced at FCC-ee

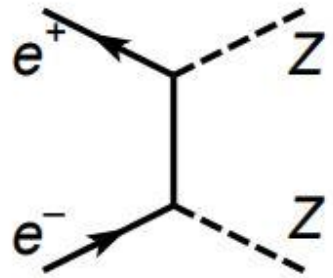
Z decay in leptons

Channel : Z → $\mu^+\mu^-$ Z → e^+e^-

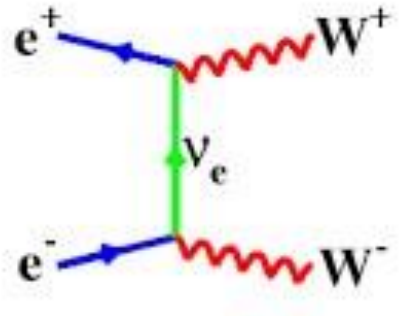
Best energy resolution

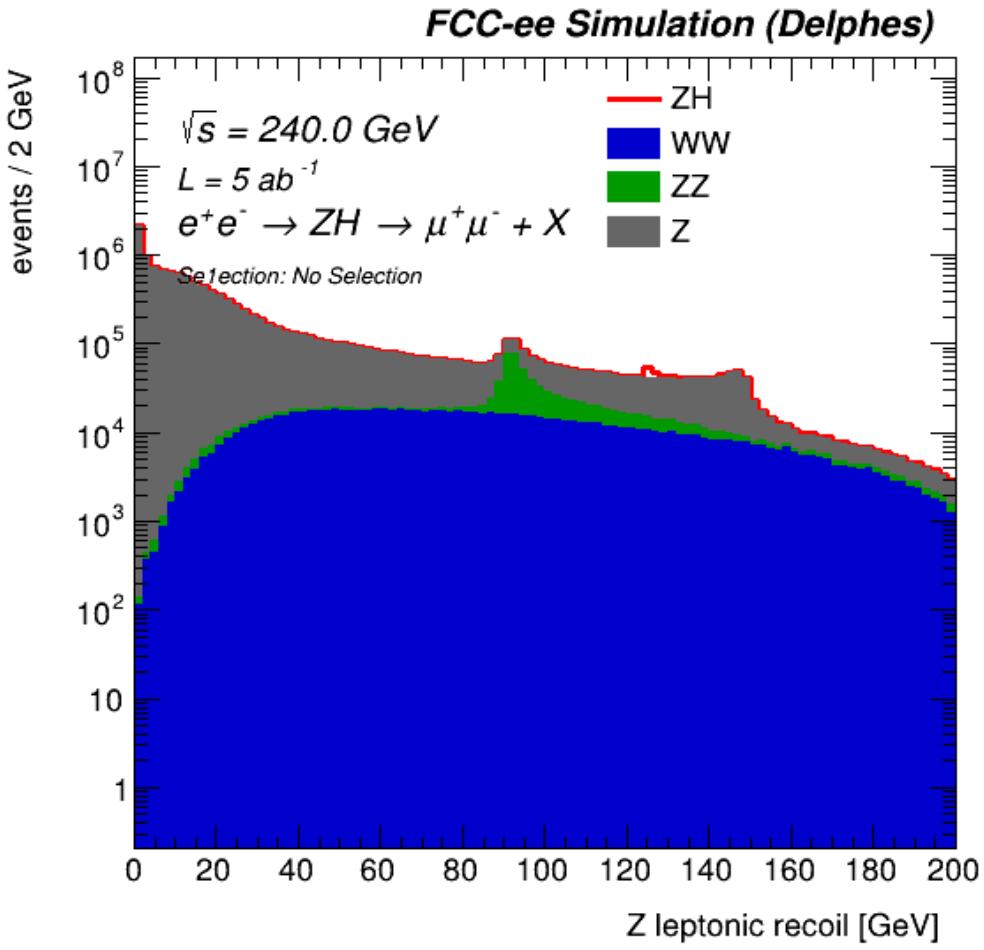
Background processes

$e^+e^- \rightarrow ZZ$



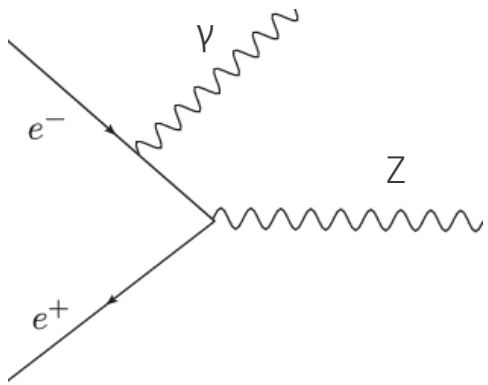
$e^+e^- \rightarrow WW$





Detector simulation : DELPHES
Standard FCC software (FCCanalyses)

$e^+e^- \rightarrow Z\gamma$



Other background processes neglected

- $e^+e^- \rightarrow e^+e^-Z$
- Bhabha $e^+e^- \rightarrow e^+e^-(\gamma)$

(background only in electron channel)

↪ CEPC studies mention it as one of the main background (to be checked)

Background rejection (1/3)

Criteria for background rejection

Basic selection	$M_{rec} \in [120.140]$ GeV $M_z \in [86.96]$ GeV $p_T^Z > 20\ GeV$	Based on Ang's studies
Kinematic selection Aim : use only Z decay in selection	Basic selection $\lvert p_z^Z \rvert < 40$ GeV $\theta \in [0.5, 2.5]$ rad $\cos(\text{acol}) \in [-0.9, -0.48]$ $\lvert \Delta\varphi \rvert < 2.7$ rad	Variables studied following ILC analysis Cut values chosen by eye on distributions θ : polar angle of the lepton pair Acollinearity : angle beteen the two leptons Δφ : angle between the two leptons in the transerve plane
Leading photon selection	Basic selection $p_T^\gamma < 20$ GeV	Expected to greatly reduce $e^+e^- \rightarrow Z\gamma$
Missing energy selection	Basic selection $p_T^\gamma < 20$ GeV $\lvert Mp_z \rvert < 10$ GeV $Mp_T < 20$ GeV	Expected to greatly reduce $e^+e^- \rightarrow Z\gamma$ $e^+e^- \rightarrow WW$ Expected to reject Higgs decays that contain neutrinos (i.e. select Higgs → visible)

Background rejection (2/3)

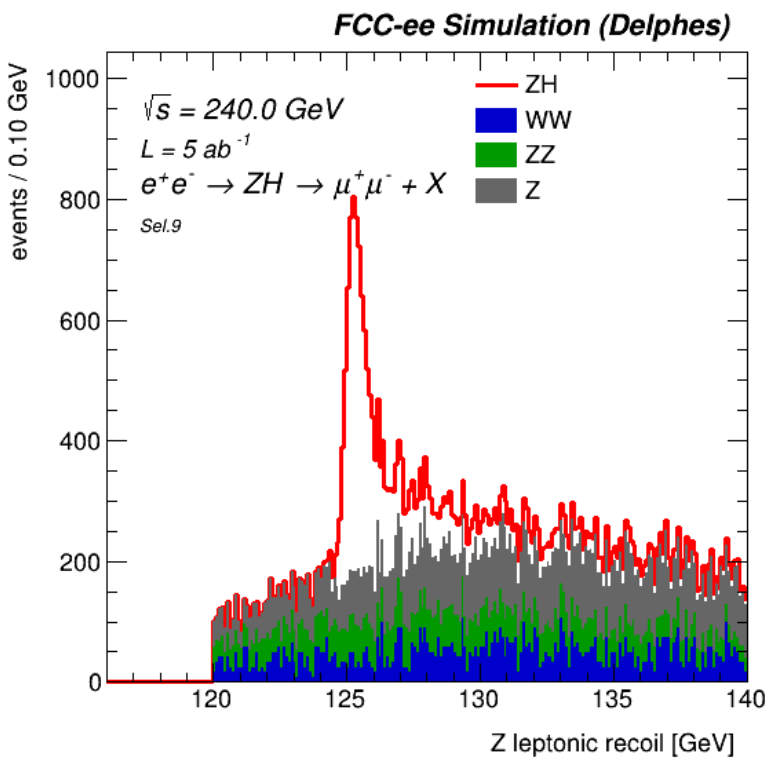
Cutflow

Z->μ+μ-, Lumi = 5 /ab , simulated:10^7	ZH	ZZ	WW	Zγ	Signal/Bkg	Significance
					rapport	S/√(S+B)
Cross section (pb)	0.201037	1,35899	16,4385	4,6		
Total number of events	1005185	6794950	82192500	23000000		
Number of μ+μ-	30084	434051	1044740	18295492	**0%**	7
Basic selection	18484	19612	16512	39288	**25%**	60
Kinematic selection	11815	9896	9674	18696	**31%**	53
Leading photon selection	17350	17265	15879	2139	**49%**	76
Missing energy	12133	4168	8,2	719	**248%**	93

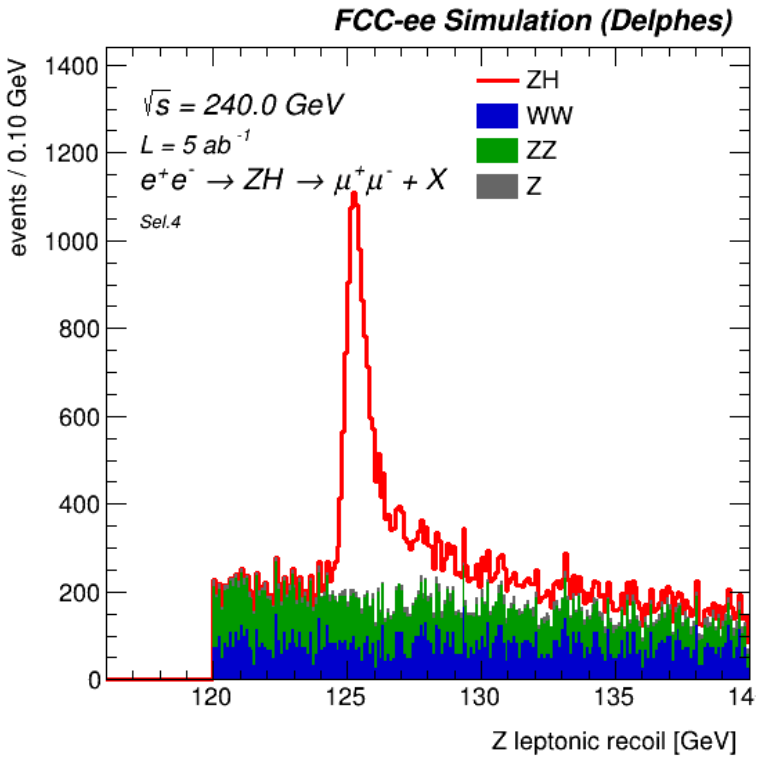
- **Kinematic selection :** reject good fraction of background processes, but reject a lot of signal
- **Leading photon selection :** reject $e^+e^- \rightarrow Z\gamma$ due to ISR, good S/B with large signal statistics
- **Missing energy selection :** reject all background process, excellent S/B but non inclusive measurement

Background rejection (3/3)

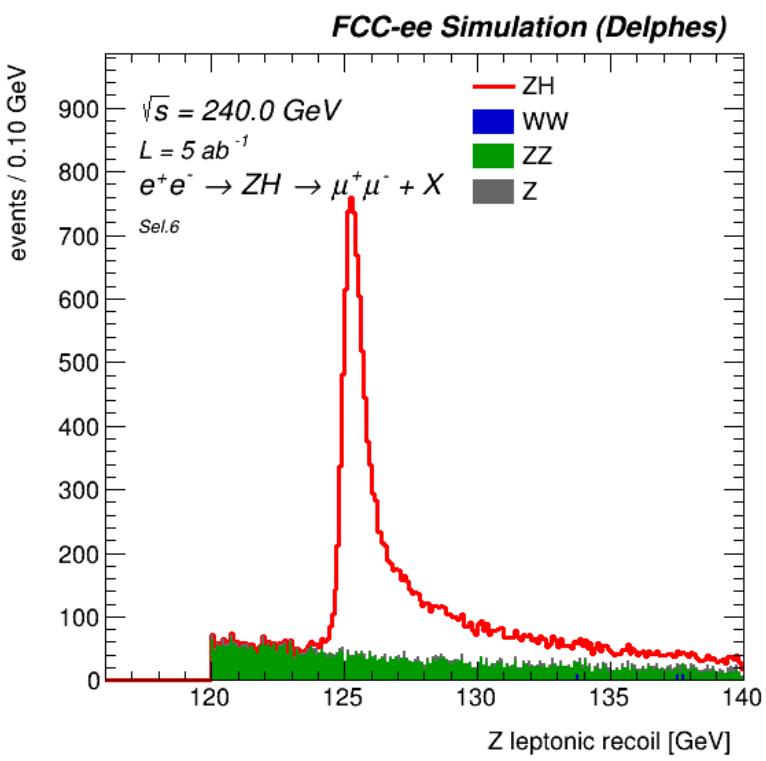
Plots of M_{rec} for each selection



Kinematic selection



Leading photon selection



Missing energy selection

Channel $Z \rightarrow e^+e^-$

Cutflow with the same cut

30084 in the $\mu^+\mu^-$ channel

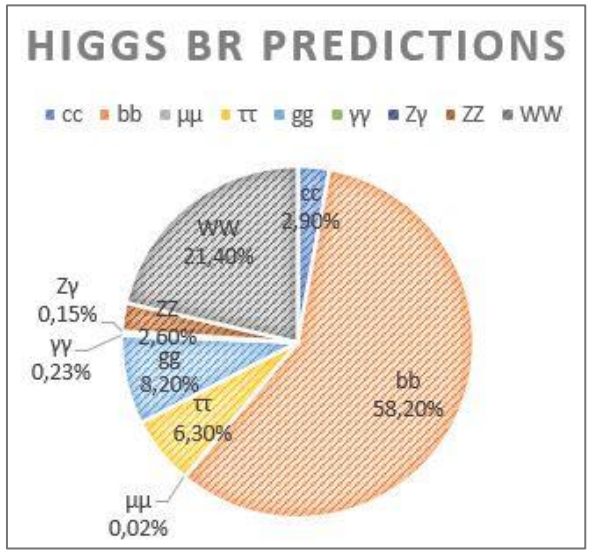
Z->e+e-, Lumi = 5 /ab , simulated:10^7	ZH	ZZ	WW	Zμ+μ-	Signal/Bkg	Significance
					rapport	S/sqrt(S+B)
Cross section (pb)	0.201037	1,35899	16,4385	4,6		
Total number of events	1005185	6794950	82192500	23000000		
Number of e+e-	23915	344811	827193	13169358	**0%**	6
Basic selection	14629	15832	14005	33189	**23%**	52
Kinematic selection	9413	8134	7841	15584	**30%**	47
Leading photon selection	13718	13844	13471	2168	**47%**	66
Missing energy	9503	3306	8	634	**241%**	82

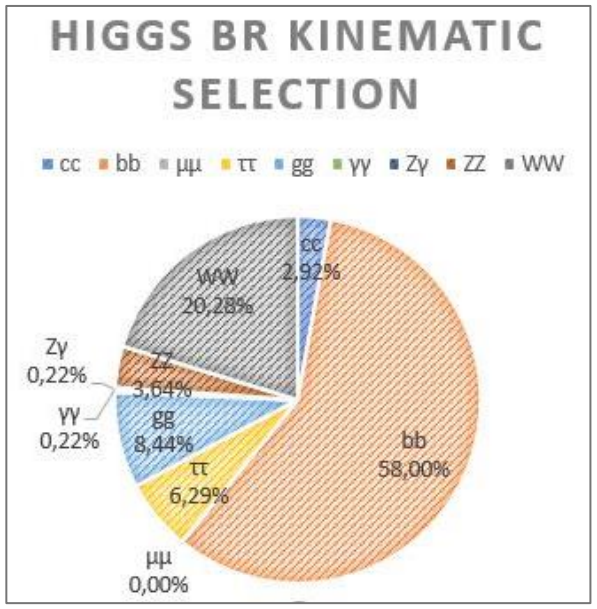
S/B similar for $Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$

2 problems :

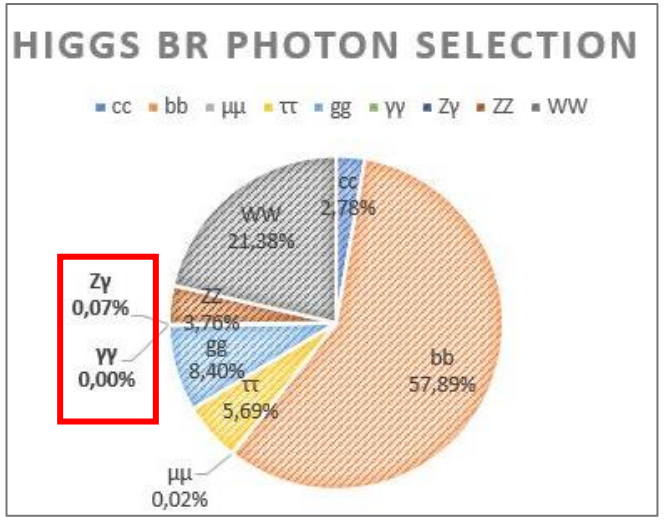
- Fewer electrons than expected → isolation criteria in DELPHES card very tight
  ↪ checked by varing isolation cut pTRatioMax (pTR) from 23915 (pTR=0,12) ⟶ 26642 (pTR=0,25)
- Electron resolution too good → Bremsstrahlung not taken into account in DELPHES
  ↪ can be emulated by degrading the resolution (smearing of the electrons)

Higgs decay

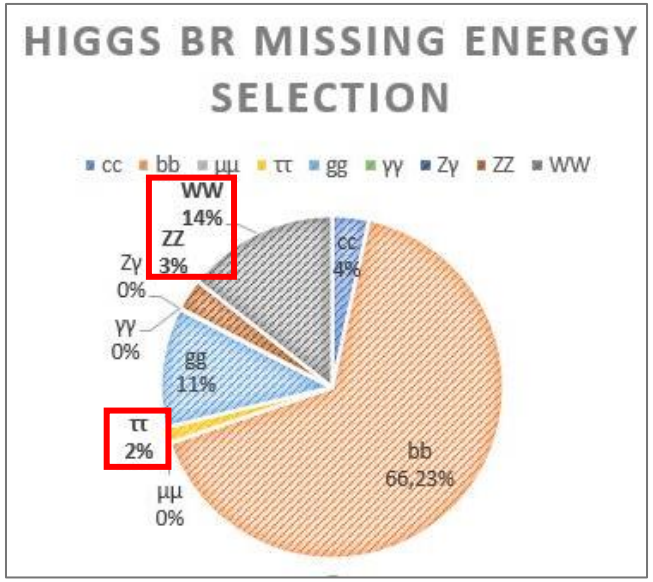




Decay similar to the prediction
Selected same proportion



Similar to prediction except , H-> γγ affected by the selection on photon

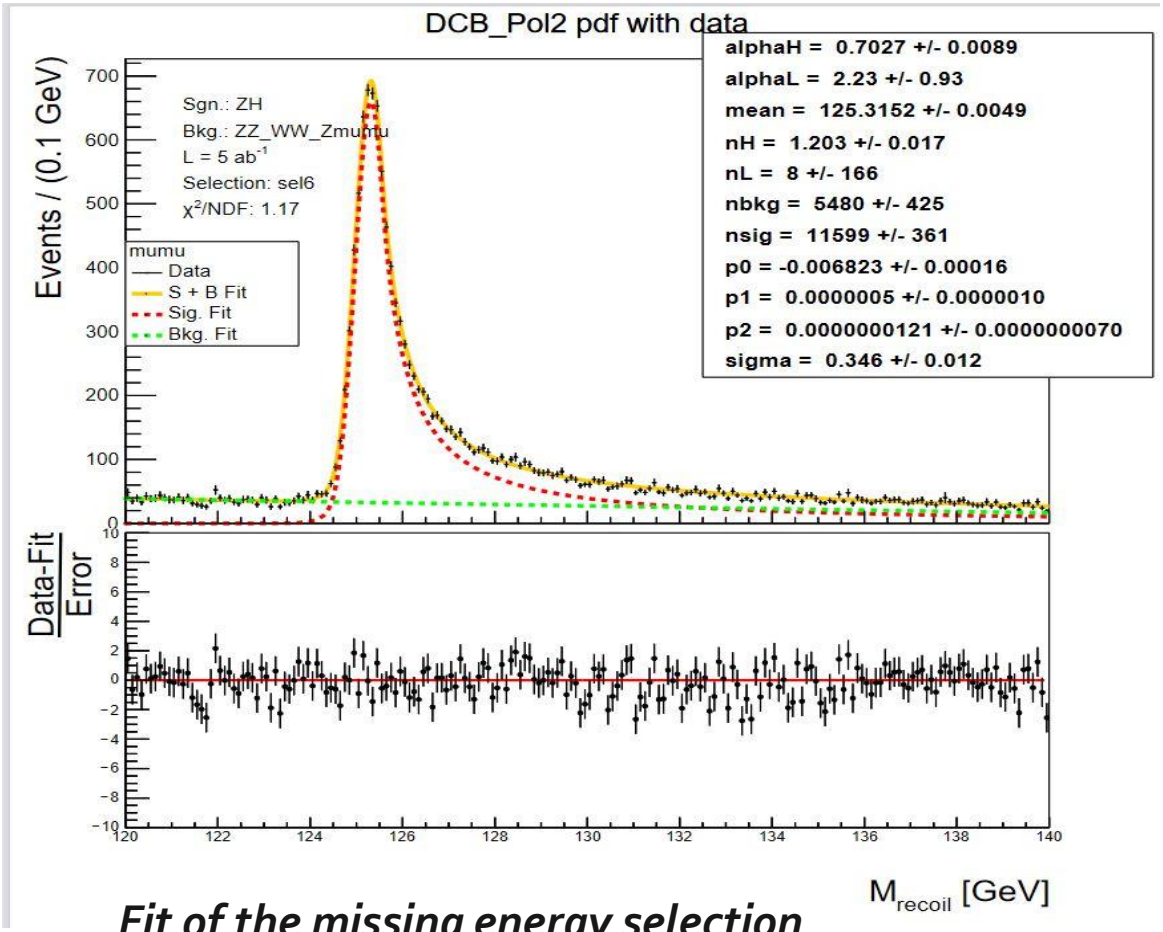


H→WW, H→ZZ, H→ ττ affected by the selection on the missing energy

Significant fraction of W,Z,τ decays contain neutrinos

Measurement of the Higgs boson mass (1/2)

Fit Model



Fit of the missing energy selection

Use Ang's fitting program to evaluate the uncertainty on the mass measurement in the different selections

Fitting function :

Signal : Two-Sided Crystal Ball

Background : Second Order Polynomial

Measurement of the Higgs boson mass (2/2)

Uncertainty in the measurement of the mass for each selection

	basic selection	kinematic selection	photon selection	Missing energy
mean (GeV)	125,303	125,307	125,296	125,314
Uncertainty (MeV)	6,6	10,1	6,2	4,9
S/B	25%	31%	49%	248%
Signal ZH	18484	11815	17350	12133

- The uncertainty in the mass decreases when S/B increases while keeping large signal statistics
- Improvement in uncertainty down to 4.9 MeV when removing backgrounds using missing momentum selections
- Bias of 300 MeV in all cases to be removed by calibration of the fitting method

Conclusion

The currently most precise measurement of the uncertainty in the Higgs boson mass is $\boldsymbol{\Delta m_H}$ **= 140 MeV** (by CMS)

At FCC-ee simulation, using missing energy selection

- Reduces greatly the background processes
- The uncertainty in the Higgs boson mass is down to $\boldsymbol{\Delta m_H}$ **= 4,9 MeV**
- Affect Higgs decay $\longrightarrow$ not suitable for inclusive σ_{ZH} measurement

The precision of the measurement of the mass can be improved by using ZH with Z → e^+e^- channel

Next step is to improve the reconstruction of the electrons :

- Requires smearing of the electron to have a more realistic resolution
- Requires loosening the isolation criteria in DELPHES in order to have the expected reconstruction efficiency