Reduction of systematics uncertainties on Higgs boson mass measurement (Future Circular Collider) with decay mode $Z \to ee$ and $Z \to \mu\mu$

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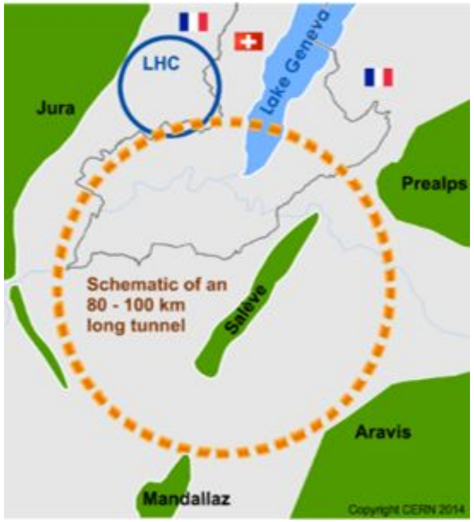
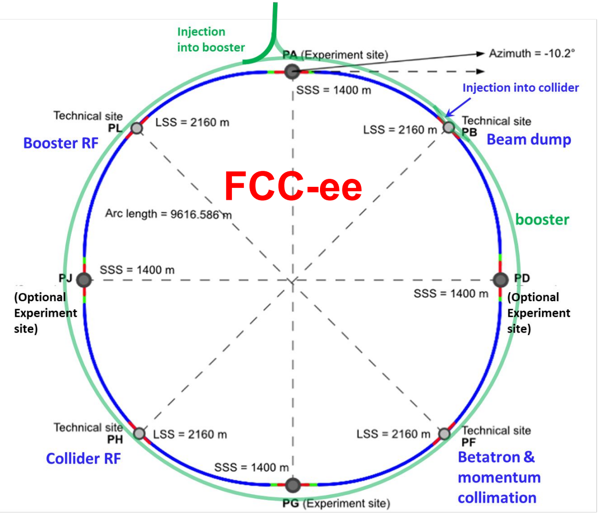
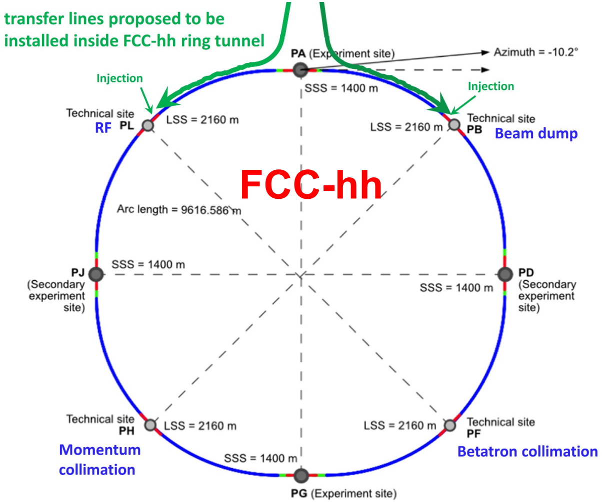
Présentation FCC

Long-term program with several physics opportunities

- **phase 1: FCC-ee (Z, W, H) →Higgs factory, electroweak & top factory at high luminosity**
- **phase 2: FCC-hh (~100 TeV) pp collisions, Increase of energy**
- complementary programs : Increase the physics reach of both collisionners (ie. Higgs coupling measurement independent of model at FCC-hh thanks to measurement done at FCC-ee)
- Civil engineering work : infrastructure built on some of already existing CERN.
- FCC project allows the start of a new, major, installation at CERN, a few years following the end of HL-LHC







2020 - 2040 | 2045 - 2063 | 2070 - 2095

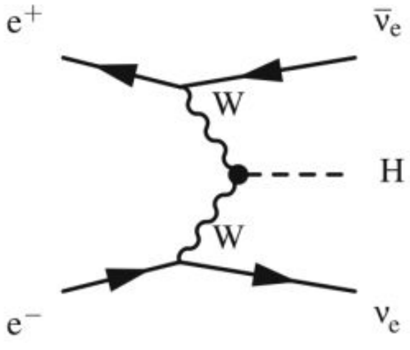
Higgs (ZH) production at FCC-ee

→Measure of Higgs boson Mass thanks to ZH reaction

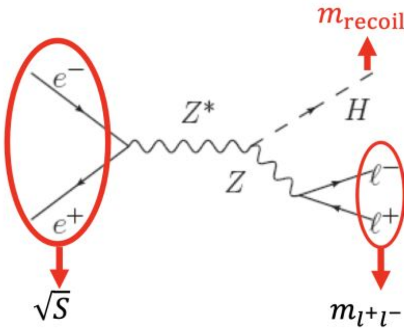
Recoil mass

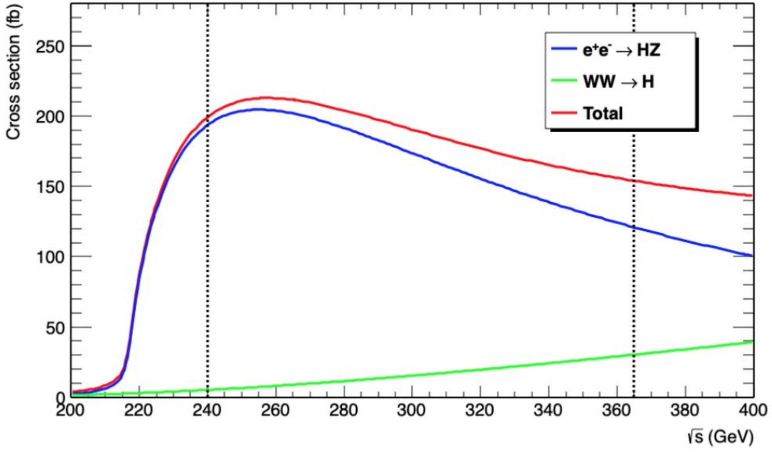
$$m_{rec}^2 = (\sqrt{s} - E_{l^+l^-})^2 - p_{l^+l^-}^2 = s - 2E_{l^+l^-}\sqrt{s} + m_{l^+l^-}^2$$

WW fusion



" ZH "





Others potential measurements at FCC-ee

Measurable

$$\boxed{\sigma_{ZH} \times B(Z \to \mu+\mu-)} \propto \frac{g_{HZZ}^2 g_{Z\mu\mu}^2}{\Gamma_Z}$$

measured yield of events

Known

Table 1 Z Decay Modes Branching Ratios, adapted from [9].

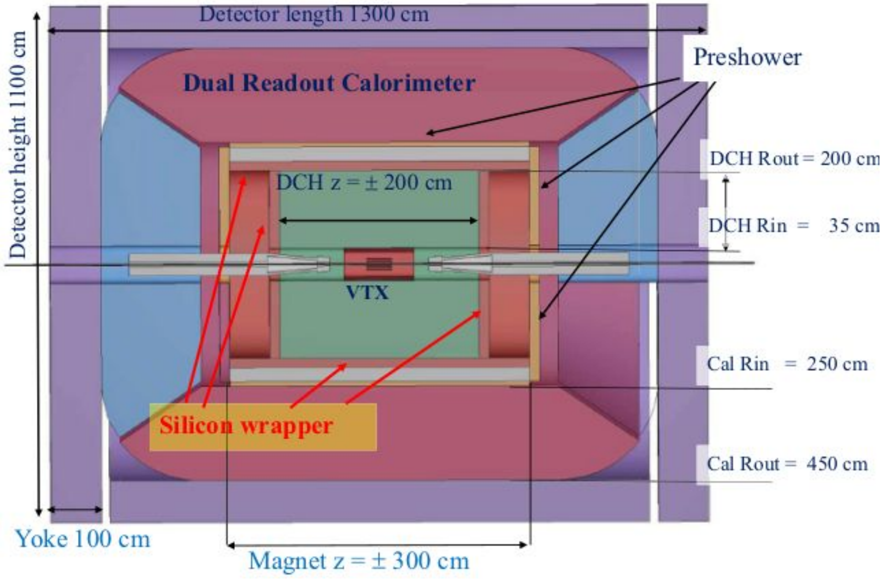
Decay Mode	Branching Ratio
$Z \to e^+e^-$	$3.3632 \pm 0.0042\%$
$Z \to \mu^+\mu^-$	$3.3662 \pm 0.0066\%$
$Z \to \tau^+\tau^-$	$3.3696 \pm 0.0083\%$
$Z \to$ invisible	$20.000 \pm 0.055\%$
$Z \to$ hadrons	$69.911 \pm 0.056\%$
$Z \to c\bar{c}$	$12.03 \pm 0.21\%$
$Z \to b\bar{b}$	$15.12 \pm 0.05\%$

$$\sigma_{ZH} \times B(H \to ZZ) \propto \frac{g_{HZZ}^4}{\Gamma_H}$$

$$\sigma_{ZH} \times B(H \to XX) \propto \frac{g_{HXX}^4}{\Gamma_H}$$

IDEA detector

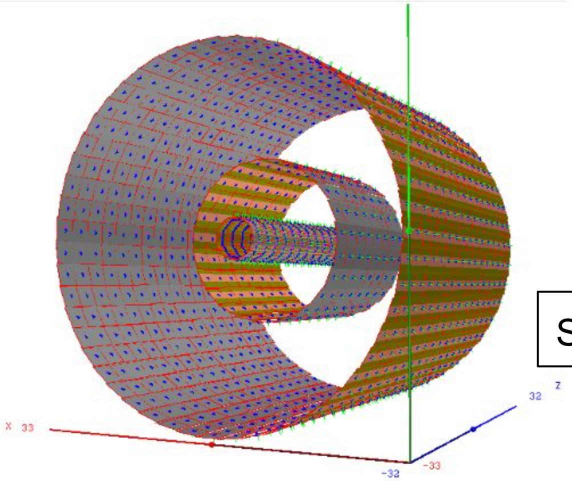
“ Innovative Detector for an Electron-positron Accelerator ”



First layer : Inner silicon pixel detector (resolution ~ 5 μm)

- \+ drift chamber (4m long, 112 layers) →silicon strip detector
- \+ 2T superconducting solenoid
- \+ preshower detector (Lead)
- \+ dual read-out calorimeter (EM & hadron)
- \+ muon chamber

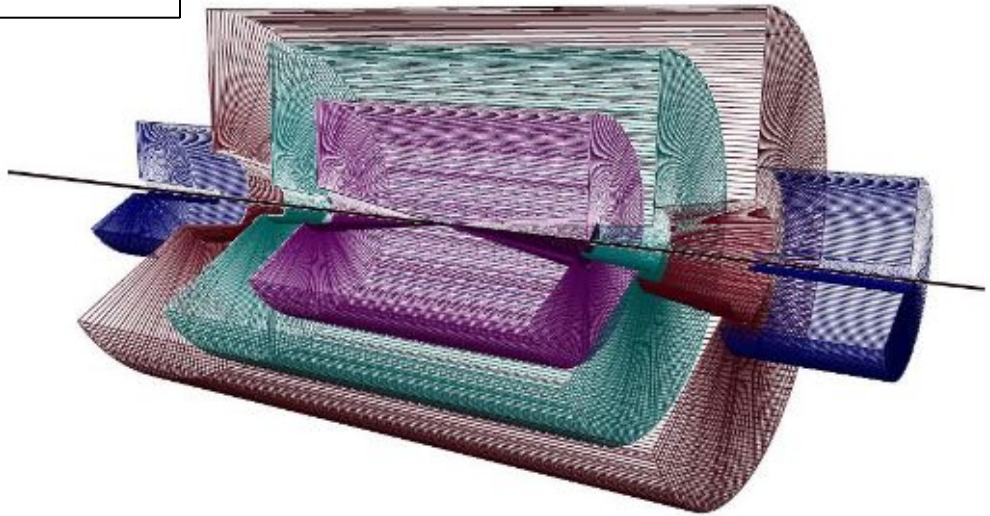
Simulation of IDEA with DELPHES



Fast Simulation of IDEA (not a complete simulation)

→Response of the detector parametrized

Simulation & Reconstruction



→Trajectories of particles
→pile-up
→particle-flow

Events Generation

<u>Generated with Pythia and Whizard</u>

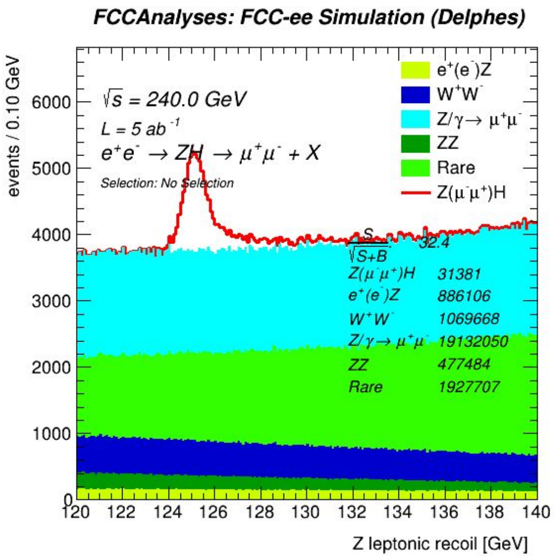
_ Signal : $\mu^+\mu^- H$

_ Backgrounds : _ WW, ZZ (Pythia only)

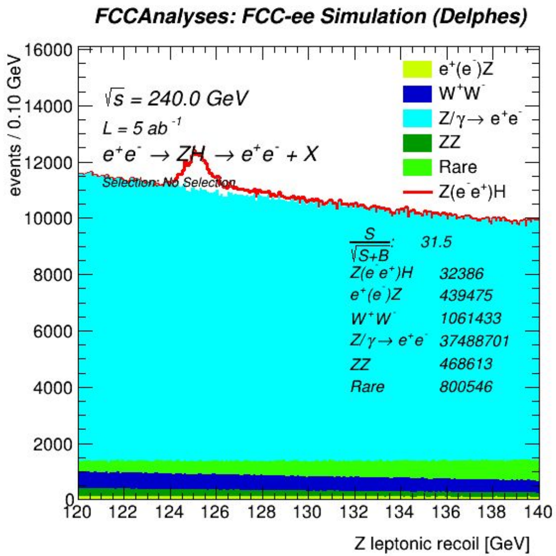
_ $ee \rightarrow Z/\gamma \rightarrow \mu^+\mu^-$

_ $e\gamma \rightarrow Ze$

Sample Name	Processes	Generator	# of events	x-section(pb)
Higgs Processes				
wzp6_ee_mumuH	$e^+e^- \rightarrow \mu^+\mu^- H$	WHIZARD + PYTHIA6	1,200,000	0.0067643
wzp6_ee_eeH	$e^+e^- \rightarrow e^+e^- H$	WHIZARD + PYTHIA6	1,200,000	0.0071611
Diboson Processes				
p8_ee_ZZ_ecm240	$e^+e^- \rightarrow ZZ$	PYTHIA8	56,162,093	1.35899
p8_ee_WW_ecm240	$e^+e^- \rightarrow WW$	PYTHIA8	373,375,386	16.4385
Dilepton Processes				
wzp6_ee_mumu	$e^+e^- \rightarrow \mu^+\mu^-$	WHIZARD + PYTHIA6	53,400,000	5.288
wzp6_ee_ee_Mee_30_150	$e^+e^- \rightarrow e^+e^-$	WHIZARD + PYTHIA6	85,400,000	8.305
wzp6_ee_tautau	$e^+e^- \rightarrow \tau^+\tau^-$	WHIZARD + PYTHIA6	52,400,000	4.668
Electron Photon Processes				
wzp6_egamma_eZ_Zmumu	$e^-\gamma \rightarrow e^- Z(\mu^+\mu^-)$	WHIZARD + PYTHIA6	6,000,000	0.10368
wzp6_gammae_eZ_Zmumu	$e^+\gamma \rightarrow e^+ Z(\mu^+\mu^+)$	WHIZARD + PYTHIA6	5,600,000	0.10368
wzp6_egamma_eZ_Zee	$e^-\gamma \rightarrow e^- Z(e^+e^-)$	WHIZARD + PYTHIA6	6,000,000	0.05198
wzp6_gammae_eZ_Zee	$e^+\gamma \rightarrow e^+ Z(e^+e^-)$	WHIZARD + PYTHIA6	6,000,000	0.05198
Photon Photon Processes				
wzp6_gaga_mumu_60	$\gamma\gamma \rightarrow \mu^+\mu^-$	WHIZARD + PYTHIA6	33,900,000	1.5523
wzp6_gaga_ee_60	$\gamma\gamma \rightarrow e^+e^-$	WHIZARD + PYTHIA6	22,500,000	0.873
wzp6_gaga_tautau_60	$\gamma\gamma \rightarrow \tau^+\tau^-$	WHIZARD + PYTHIA6	33,700,000	0.836
Other Processes				
wzp6_ee_nuenueZ	$e^+e^- \rightarrow \nu_e\bar{\nu}_e Z$	WHIZARD + PYTHIA6	2,000,000	0.033274



di-muon channel



di-electron channel

Winter2023 data campaign

- 240 GeV
- 5 ab^{-1} (2 IPs)

Higgs Mass : 125 GeV

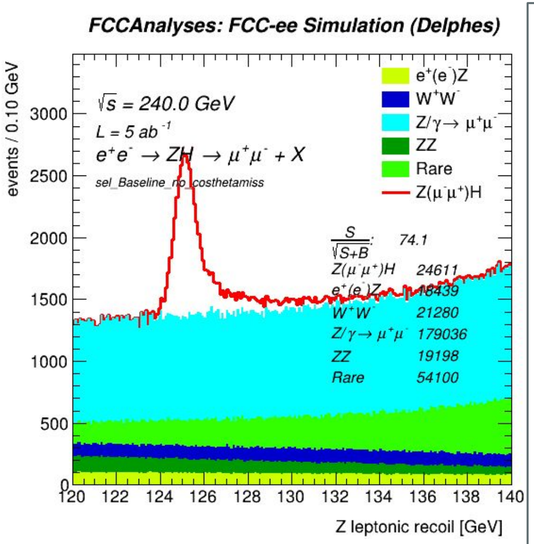
Events Preselection

→ On Reconstructed leptons (muon or electron) events

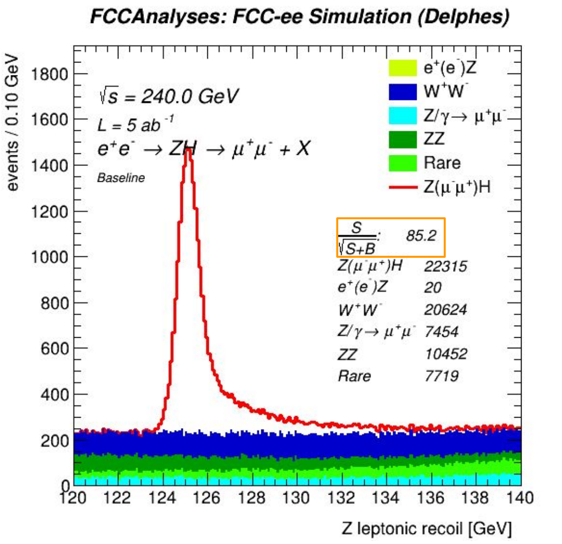
- At least 2 leptons of **opposite charges**
- At least one isolated leptons
- Momentum $p > 20$ GeV (minimize soft radiation events)

Events Selection

Example with $Z \to \mu^+\mu^-$



di-muon channel
Basics cuts



di-muon channel
Basic + cut on cos(theta miss)

Basics cut:

_ **Pre-selection cuts**

_ **Momentum of the pair of leptons [20, 70] GeV**

_ **Invariant mass of the pair [86, 96] GeV**

_ **Recoil mass [120, 140] GeV**

Baseline cut :

|cos(theta miss)| < 0.98

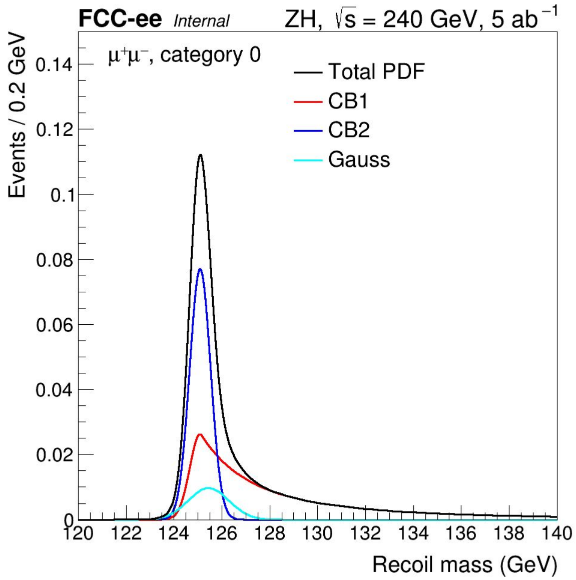
reduce ee → ll background

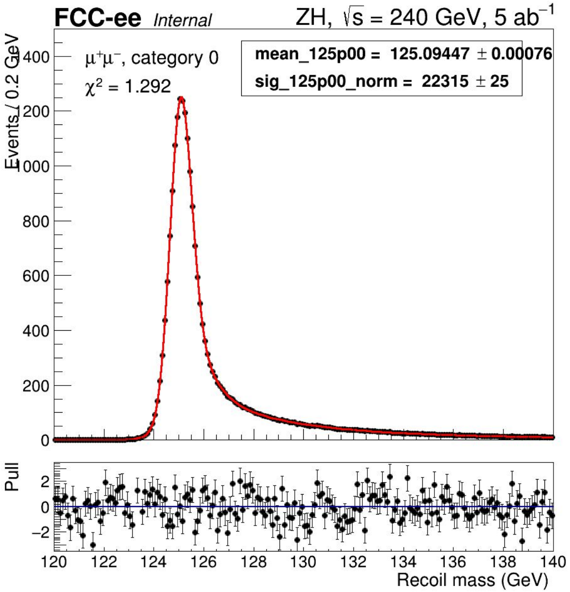
Customized pdf to fit on ZH peak

Signal fit

two “Crystal Ball” (for each tail) + one Gaussian (core)

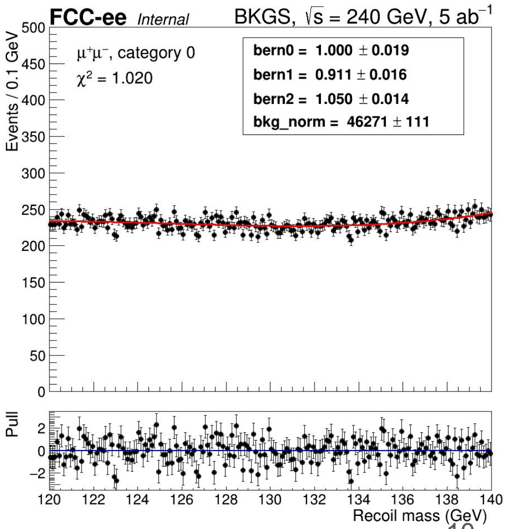
$$pdf_{rec}=cb_1\times CB(\mu,\sigma,\alpha_1,n_1)+cb_2\times CB(\mu,\sigma,\alpha_2,n_2)+Gauss(\mu_{gt},\sigma_{gt})$$





Background fit

3rd order Bernstein polynomial

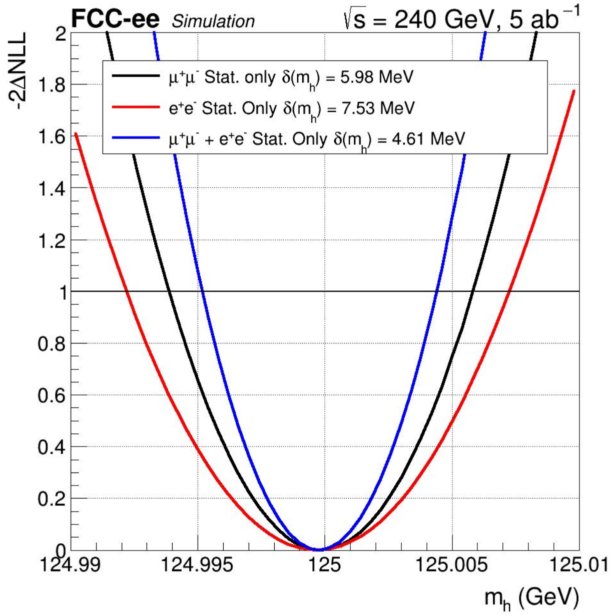


Mass uncertainty measurement

→Apply basic selections + cos(theta_miss)

→Fit on the ZH peak with a customized pdf

→**Use of Combine (CMS) : Scan likelihood to get the value of mass and its uncertainty**



→ Statistical uncertainty on mass : **4.61 MeV**

(0.0037 %)

Systematics on measurement of mass

<u>Systematic uncertainty</u>

- Beam Energy Spread (*BES*)
  +/- 1 % from the nominal value → **propagates between 0.27 and 0.60 MeV**
- Center of mass energy ($\sqrt{s}$)
  2 MeV, from accelerator → **~ 2 MeV**

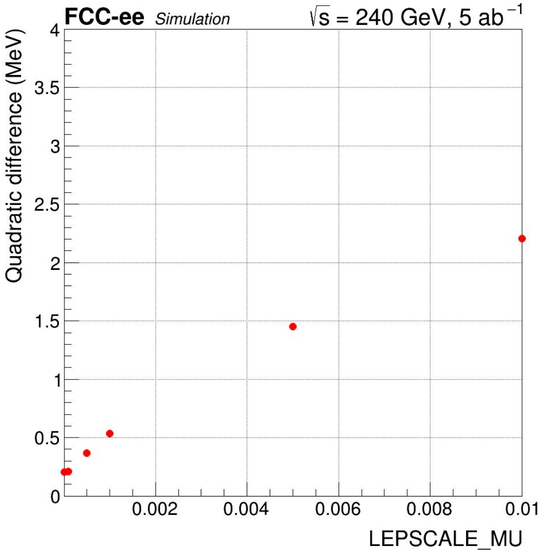
$$m_{rec} \approx \sqrt{s} - E_{l^+l^-}$$

- Lepton momentum Scale (LEPTON SCALE)
  $\frac{\Delta P}{P}$ taken between 10^{-5} and 10^{-2} considering the used detector

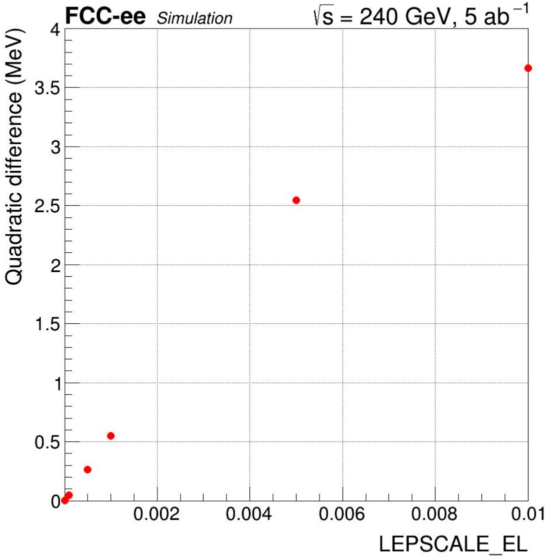
Evolution of lepton scale momentum uncertainty

Table on systematic uncertainties for lepton momentum scale (MeV)

	Lepton Momentum SCALE	
ΔP/P	**Muon**	**Electron**
10^{-5}	**0.203**	**0.003**
10^{-4}	**0.212**	**0.047**
$5x10^{-4}$	**0.368**	**0.264**
10^{-3}	**0.536**	**0.550**
$5x10^{-3}$	**1.454**	**2.547**
10^{-2}	**2.206**	**3.664**

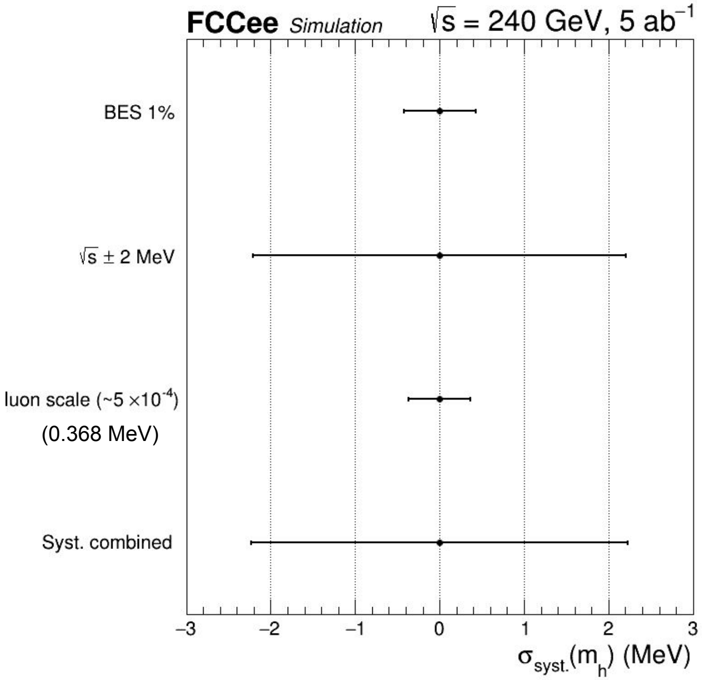


Canal di-muon

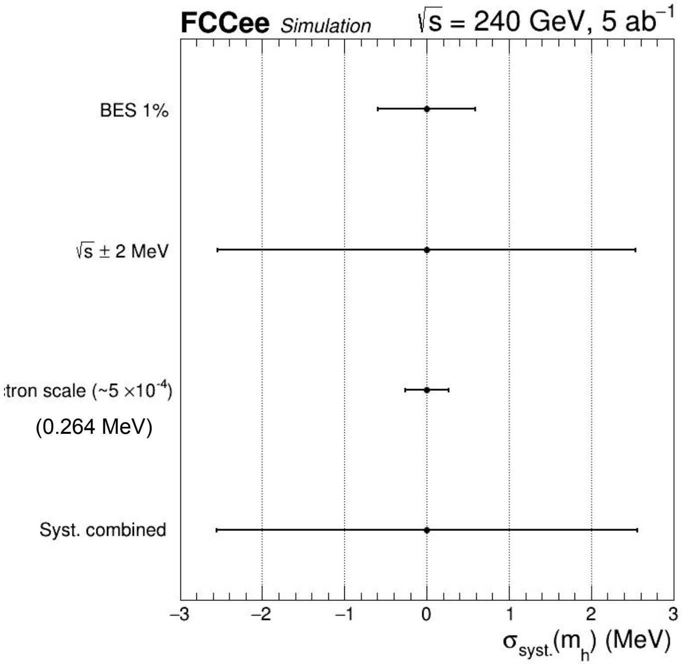


Canal di-électron

Systematics - Summary

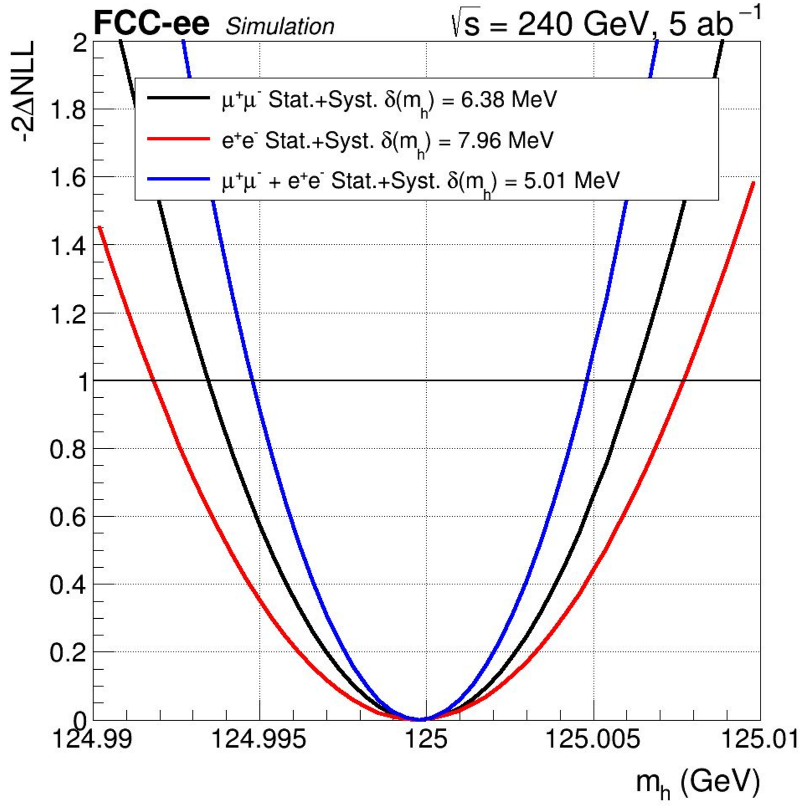


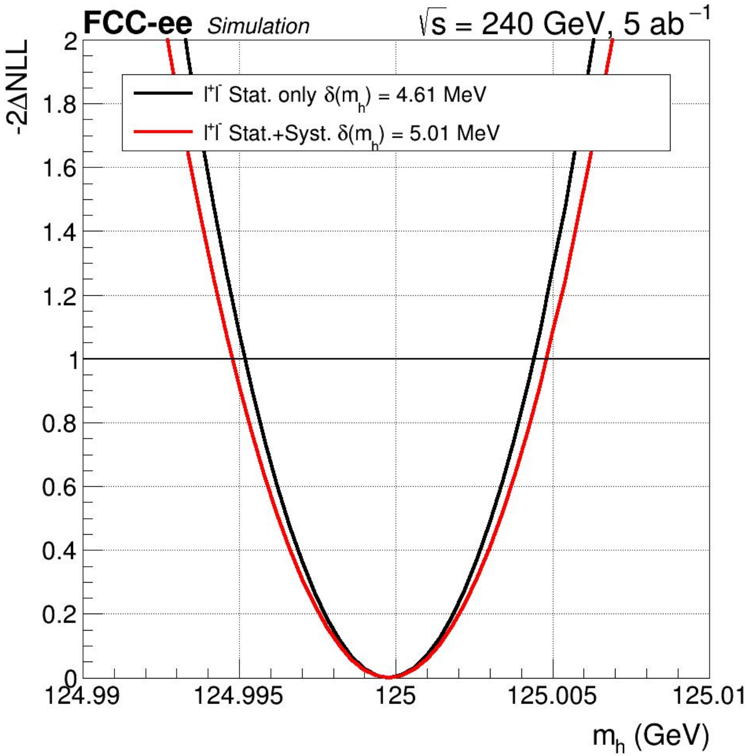
di-muon channel



di-electron channel

Preliminaries results on mass measurement





→Combined systematic uncertainty : **1.96 MeV**

→ Total uncertainty on mass :

5.01 MeV **(0.004 %)**

FCC - Summary and Perspectives

→still a bit of debugging to do on Mass & ZH analysis !

→Uncertainty on mass should be ~ 5.8 MeV (5 MeV stat + 3 MeV syst)

→possible use of BDT for mass analysis ?

→ Unify events generator to apply systematics uncertainty on background

→ Study systematics uncertainties in deep to better reduce them, in particular ISR (Initial State Radiation)

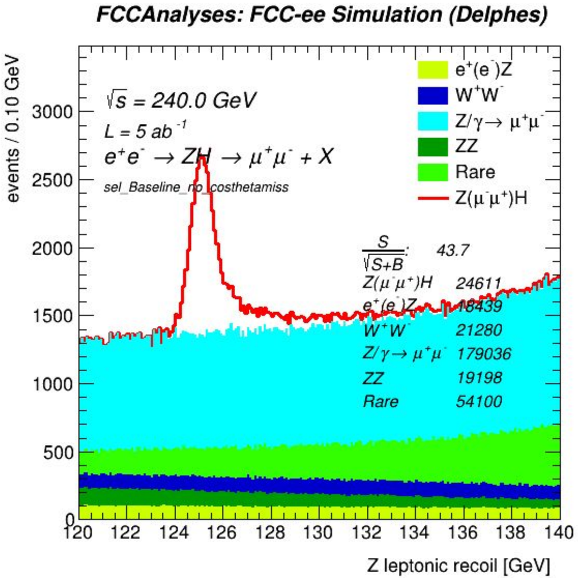
Backup

ZH cross section measurement

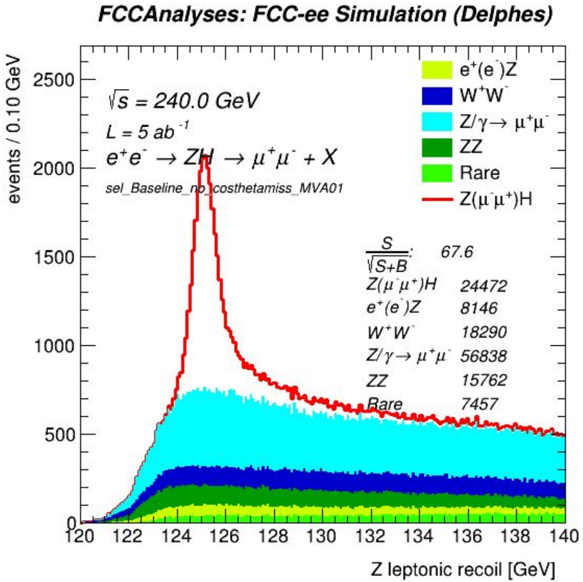
Pas de sélection sur cos(theta_miss) car invalide l'hypothèse d'indépendance du modèle du Higgs !

→se base sur l'ajustement de l'intégrale du signal

→Utilisation du BDT (Boosted Decision Tree) : algorithme de machine learning qui facilite la séparation entre signal et bruits de fond



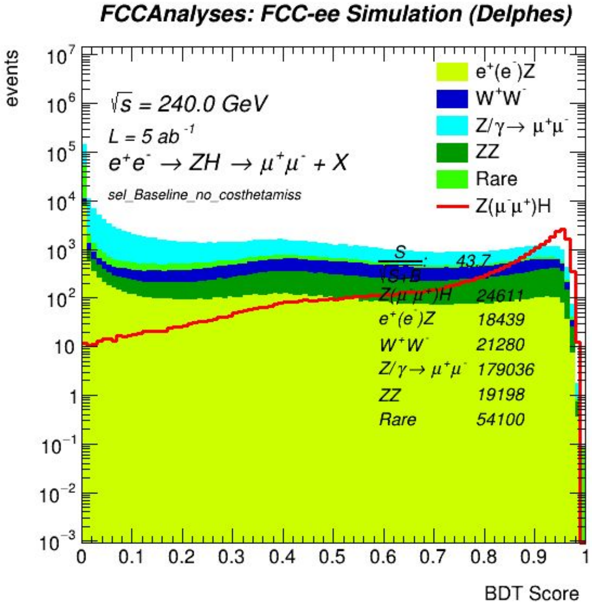
Canal di-muon
(sélections basiques)



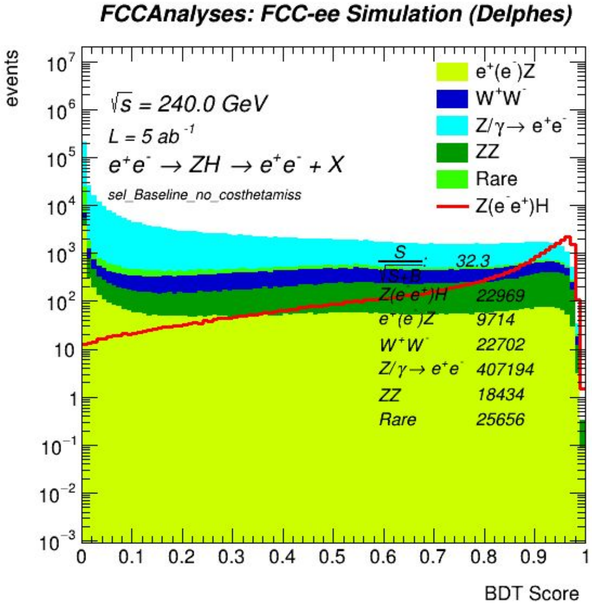
Canal di-muon
(principales **+ BDT Score > 0.1**)

Boosted Decision Tree

Association d'un **BDT Score** à chaque événement (quantification de 0 à 1)



Canal di-muon
Distribution du BDT Score

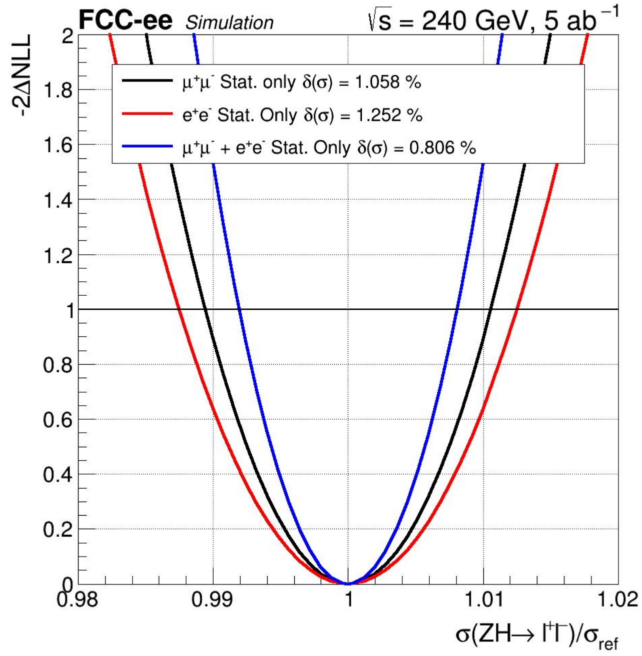


Canal di-électron
Distribution du BDT Score

Mesure de la section efficace ZH - Incertitude

→Ajustement sur la distribution du BDT Score

→Scan likelihood : Incertitudes



→ Incertitude statistique sur la section efficace ZH :

0.81 %