MESURE DE COUPLAGES DU BOSON DE HIGGS À FCC-EE

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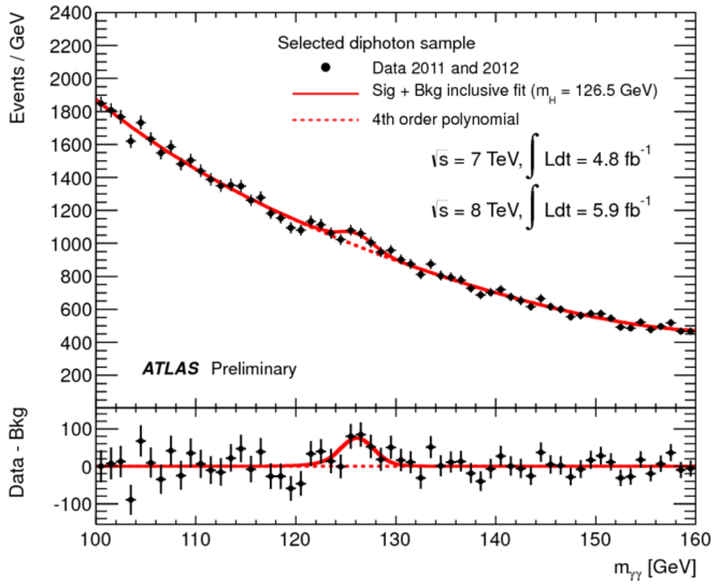
Introduction

The Higgs boson and FCC-ee

The Higgsstrahlung : $e^{+} + e^{-} \rightarrow Z + H$

The Higgs boson

- In 2012 : Higgs boson (H) discovery (ATLAS & CMS collaborations).



In the Standard Model (SM), fermions inherit their mass from their coupling with the H :

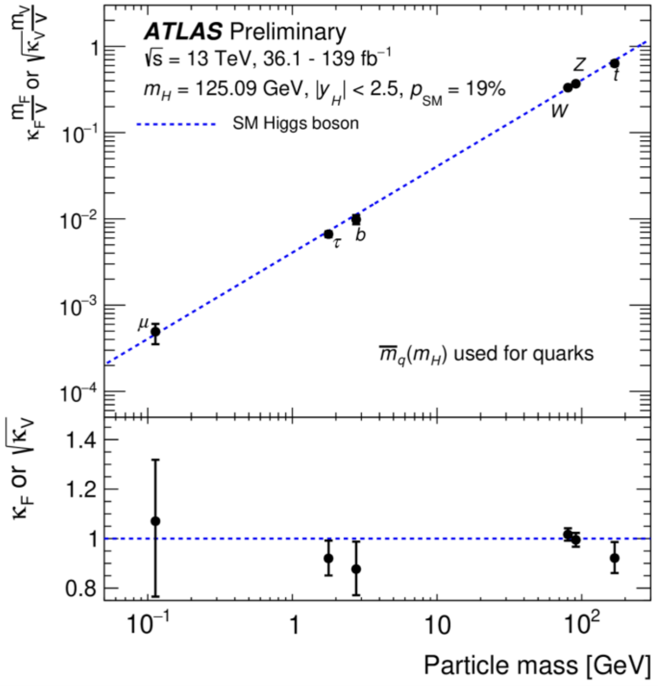
$$m_f = v\frac{y_f}{\sqrt{2}} \qquad v = 246\ GeV$$

Any deviation from the expected value would indicate possible beyond SM processes

- Higgs boson main decay channels :

Channel	SM Branching Ratio (BR)
$H \rightarrow b\bar{b}$	58.2 %
$H \rightarrow WW$	21.5%
$H \rightarrow \tau\bar{\tau}$	6.2%
$H \rightarrow c\bar{c}$	2.9%
$H \rightarrow gg$	8.2%
. . .	

2022



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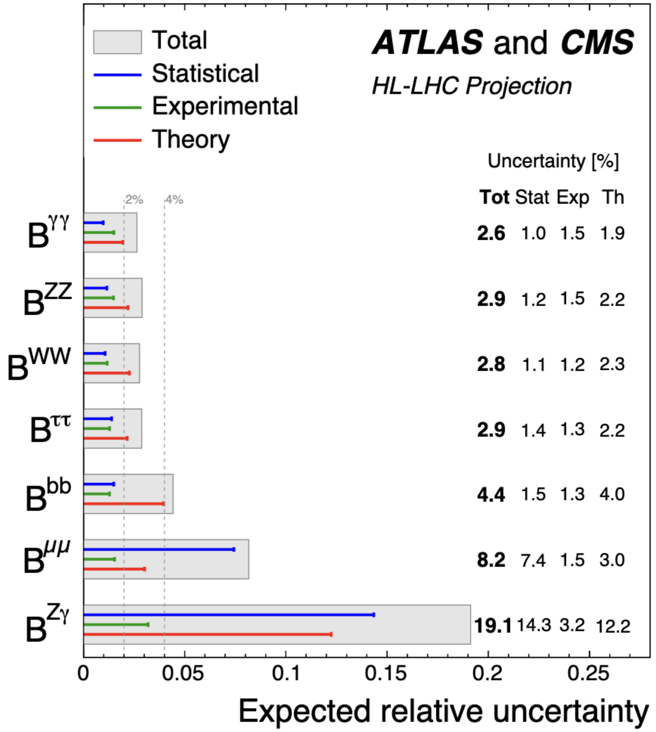
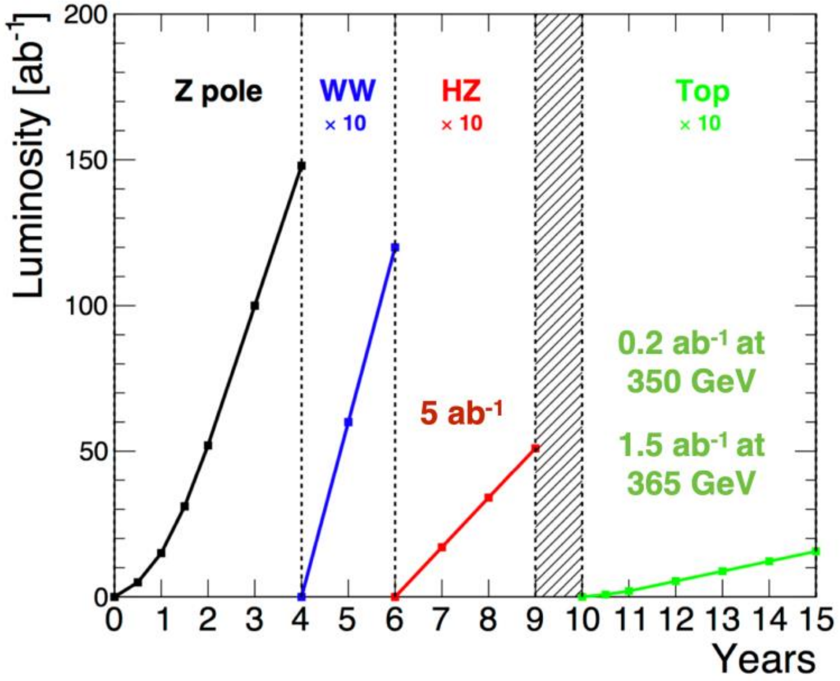
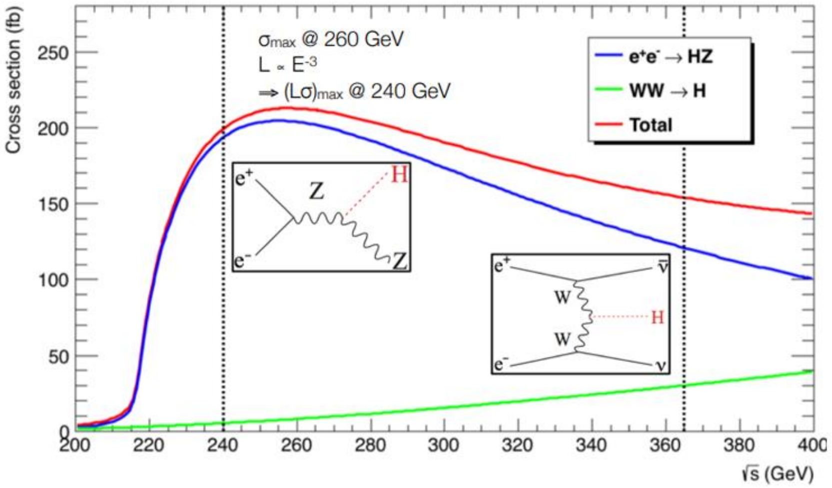


- The $H \rightarrow b\bar{b}$ channel was analysed thanks to a large Branching Ratio and great tagging performances in the detector

- $H \rightarrow$ gg and $H \rightarrow c\bar{c}$ could not be measured because of inefficiency of the detector for these channels

The FCC-ee





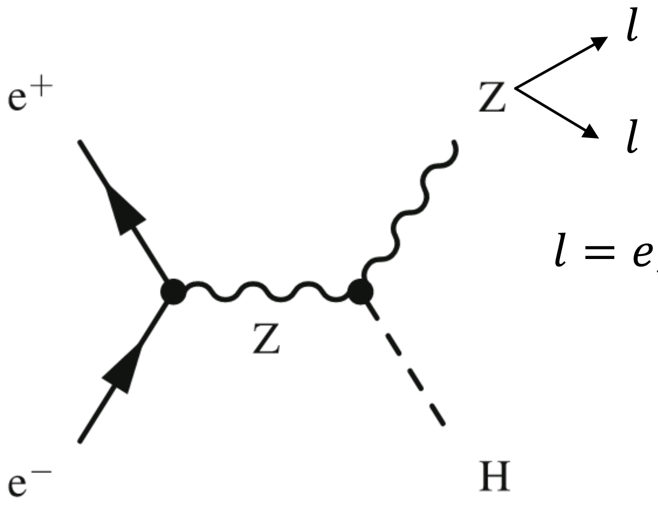
- The FCC (Future Circular Collider)
  - ~90 km circular collider project
  - Two main collisions periods : FCC-ee & FCC-hh

- FCC-ee (electron-position collisions)
  - First period at $\sqrt{s} \sim m_Z = 91.2$ GeV, to study the Z boson
  - Second period to study the W boson around $\sqrt{s} \sim 2m_W = 160$ GeV
  - Higgs factory with Higgstrahlung process at $\sqrt{s} = 240$ GeV with a Luminosity of $L = 5$ ab-1
  - Final run at $\sqrt{s} = 365$ GeV

- FCC-hh (hadron-hadron collisions)
  - Expected maximum energy of $\sqrt{s} = 100$ TeV
  - Possibility to discover directly new physics

The Higgstrahlung process

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



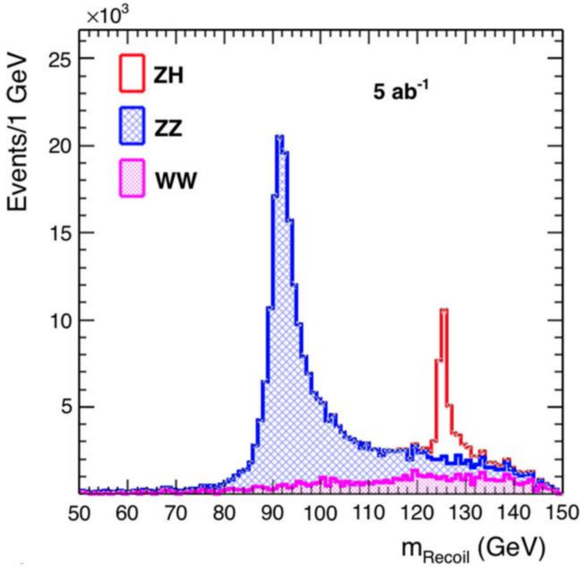
$l = e, \mu$

The Recoil Mass

$$\left(E_{ll} + E_H, \overrightarrow{p_{ll}} + \overrightarrow{p_H}\right) = \left(\sqrt{s}, \vec{0}\right) \Rightarrow M_{recoil}^2 = s + m_Z^2 - 2E_{ll}\sqrt{s}$$

- Allows model independant measurement of the total Higgs Cross-section (σ)

- Using the recoil mass is not possible in the LHC due to the composite nature of protons



Signal Channels	
$H \rightarrow b\bar{b}$	$H \rightarrow c\bar{c}$
$H \rightarrow gg$	$H \rightarrow nonhad$
Main background components	
$e^+e^- \rightarrow ZZ$	$e^+e^- \rightarrow WW$

Simulation

Event generation

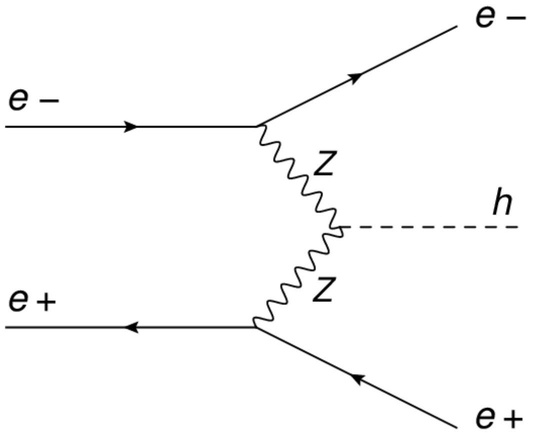
Event reconstruction & selection

Event generation

- We generated private signal samples to ensure enough statistics and ease the renormalization process
- Specific initial & final state are given to WHIZARD :
  - Generates all possible processes with these respective states

$e^+e^- \rightarrow llH$

- $e^+e^- \rightarrow \mu\mu H$ ⟶ Higgstrahlung
- $e^+e^- \rightarrow eeH$ ⟶ Higgstrahlung + Z boson fusion



The total normalization factor is then :

$$\left(\sigma(ee \rightarrow ZH) * BR(Z \rightarrow \mu\mu) + \sigma(ee \rightarrow eeH)\right) * BR(H \rightarrow XX)$$

Samples

- Summary of the samples used for the analysis

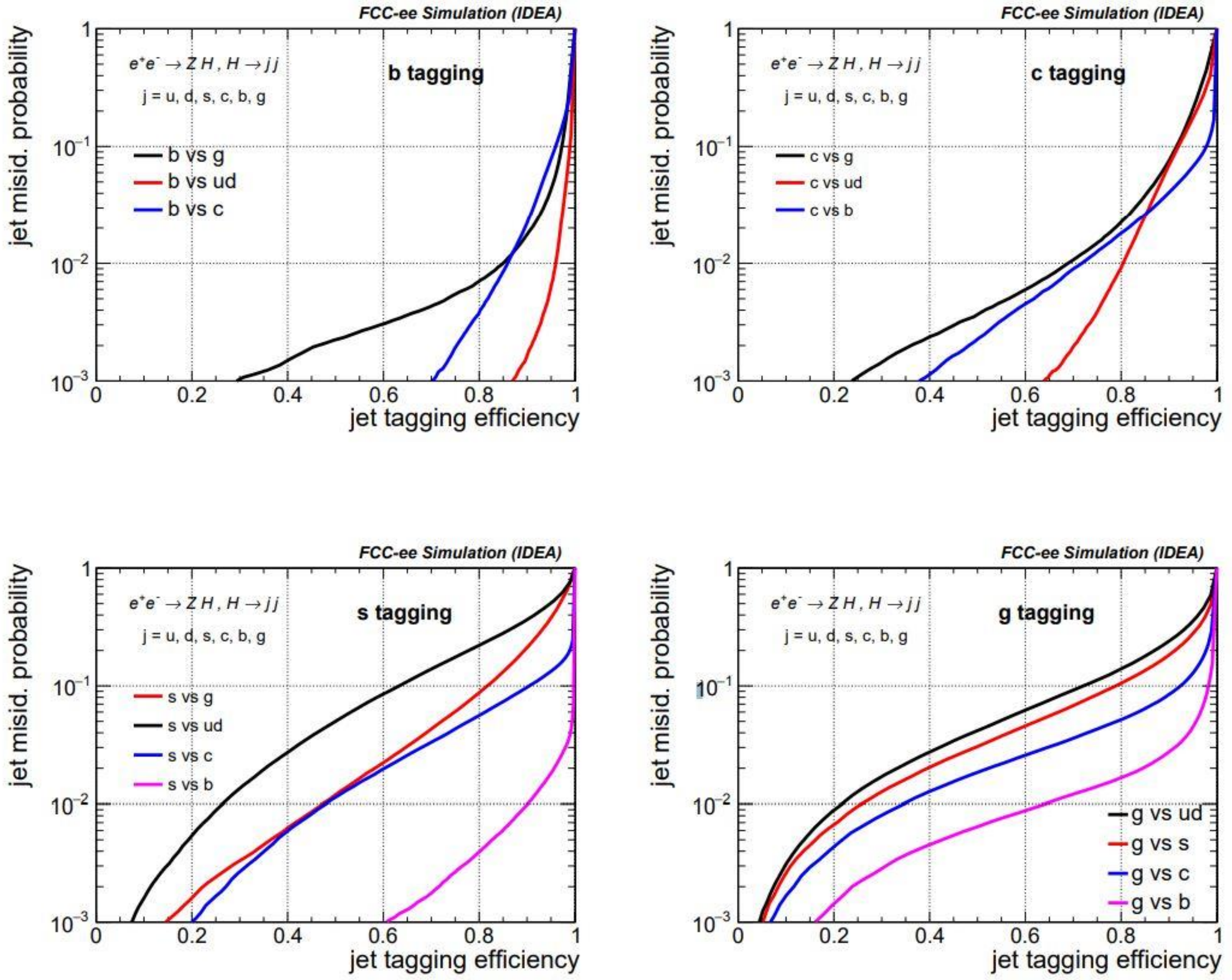
Process	sigma (fb)	BR1	BR2	sigma*BR (fb)	$N_{generated}$	$L_{generated}/L$
Z(ll)H(bb)	201.87	0.067316	0.5824	8.15008	100000	2.57
Z(ll)H(cc)	201.87	0.067316	0.02891	0.404565	100000	50.909
Z(ll)H(gg)	201.87	0.067316	0.08187	1.14569	100000	17.977
Z(ll)H(nonhad)	201.87	0.067316	0.30682	4.29363	500000	23.984
ZZ	1358.99	1	1	1358.99	59800000	8.801
WW	16438.5	1	1	16438.5	49400000	0.122

Detector simulation

- We proceed (using DELPHES) to the simulation of the detector, then reconstruct :
  - the leptons using detector simulation output
  - the jets using clustering algorithms

- Jets flavour is then tagged with efficiencies extracted from dedicated studies
  - Nominal efficiency chosen at 80%

- Our primary selection is the two leptons candidates to the Z decay

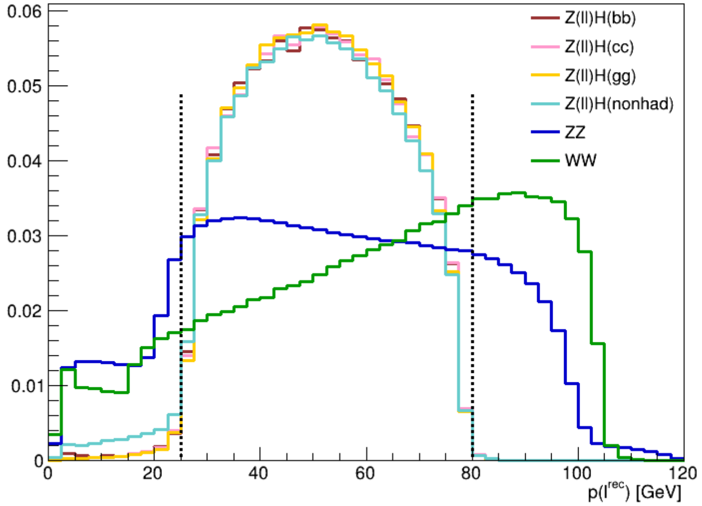


Event selection (1/3)

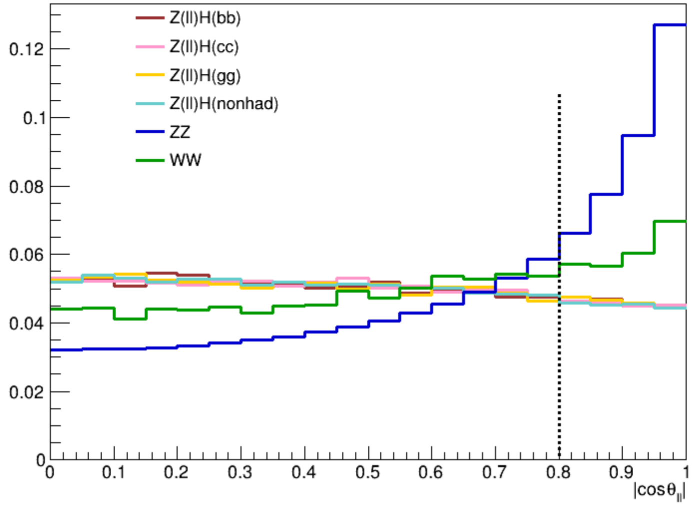
- Further selections are required to increase the signal significance

- In the lepton selection we require :
  - Two isolated electron or muons with $Q_{pair} = 0$
  - Lepton pair invariant mass between $81 - 101\ GeV$
  - $|\cos(\theta_{ll})| < 0.8$
  - Lepton momenta within $25 - 80\ GeV$

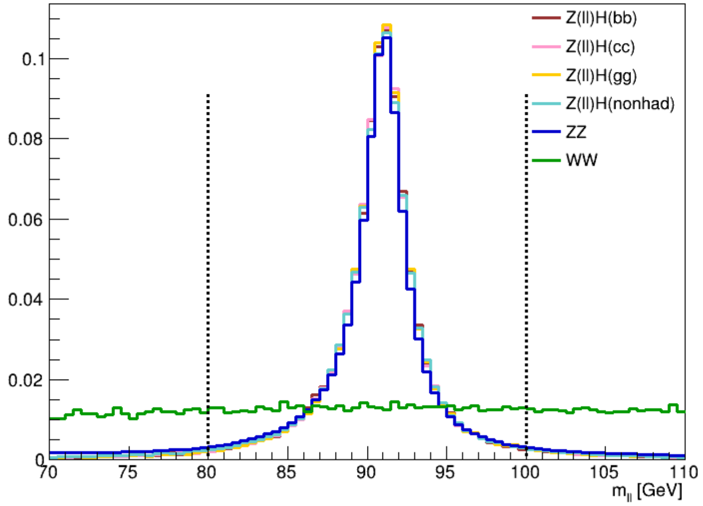
Leptons momentum



$|\cos(\theta_{ll})|$

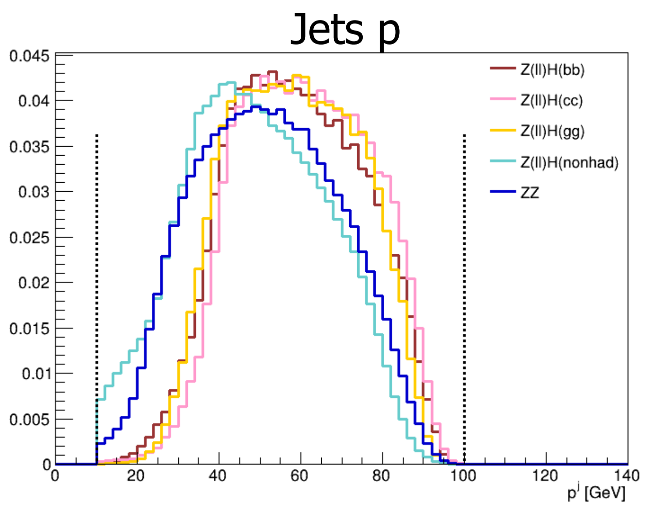


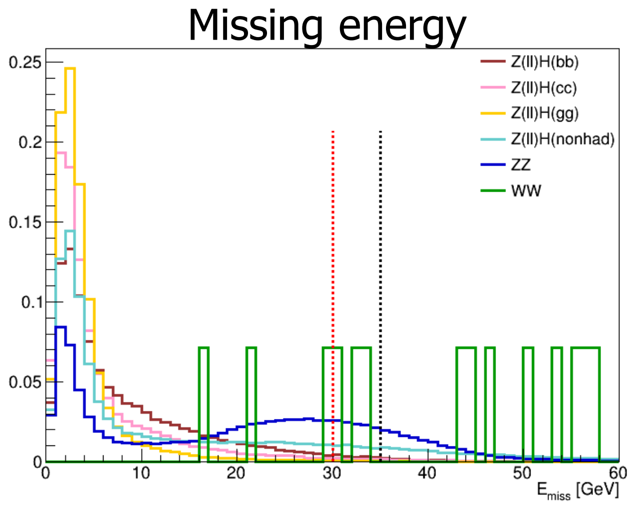
Dilepton invariant mass

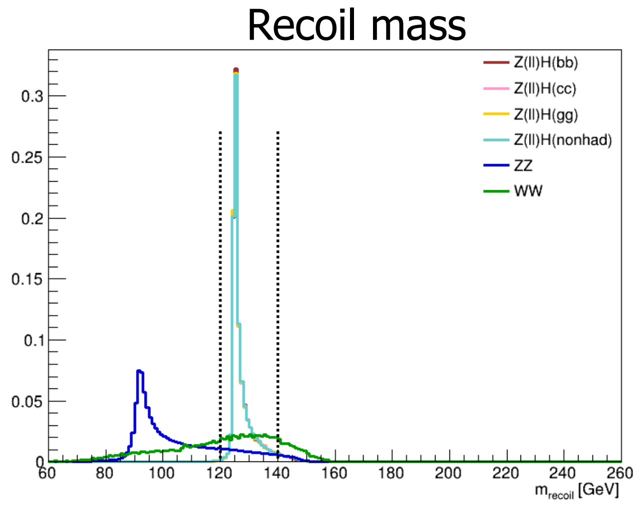


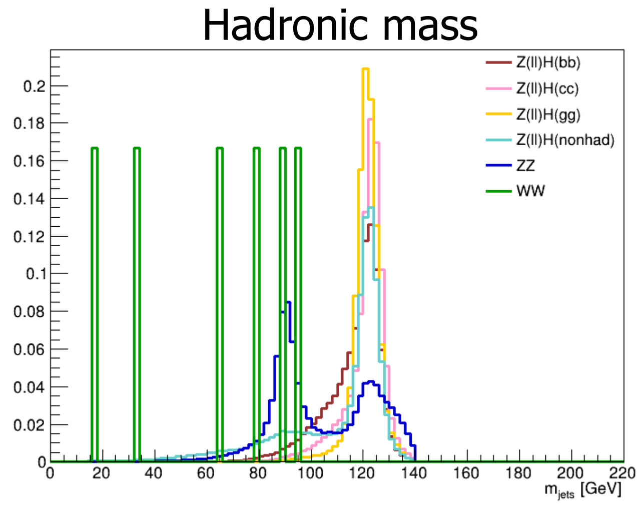
Event selection (2/3)

- In the hadronic selection we require :
  - Recoil mass between $120 - 140\ GeV$
  - Jet momentum within $10 - 100\ GeV$
  - Hadronic mass in $100 - 140\ GeV$
  - Missing energy $< 30\ GeV$

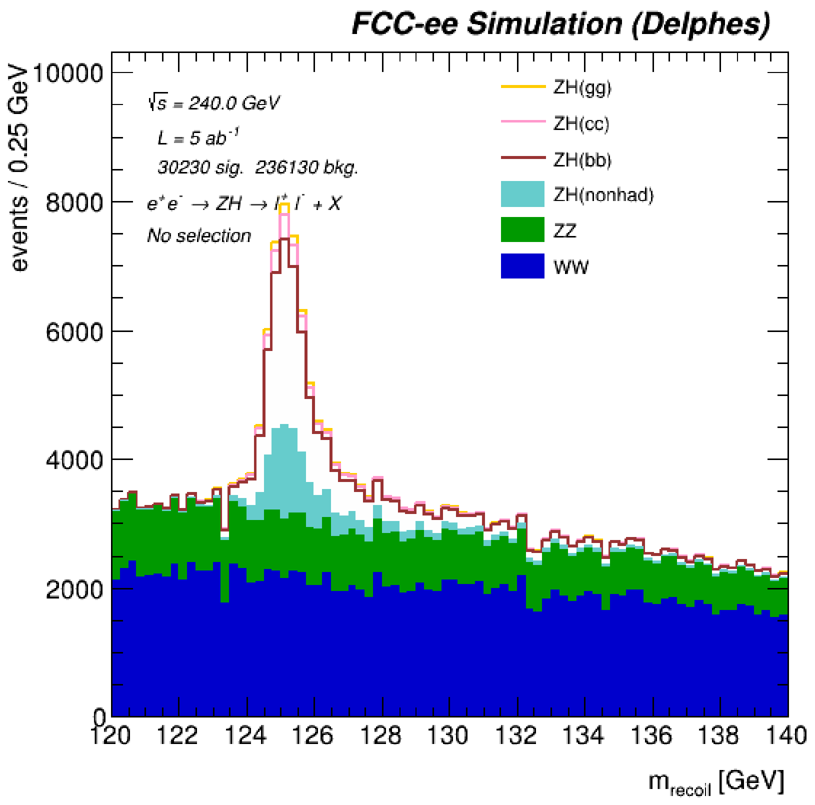




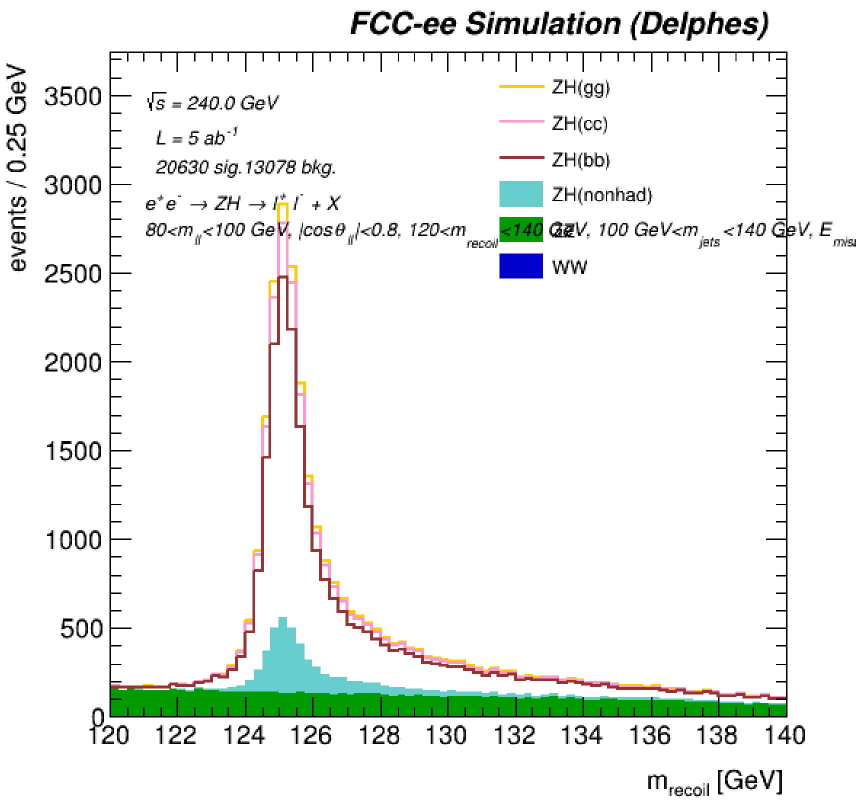




Event selection (3/3)



Two leptons candidates



Final selection

Another dominant background component that is omitted on the plots is the $e^+e^- \rightarrow Z/\gamma^*$ process.
However this component is mostly filtered thanks to our selection and its final impact is negligible

Final selection (1/2)

- We finalize our selection by considering 8 orthogonal event caterogies depending on the number of b, c or g tagged jets :

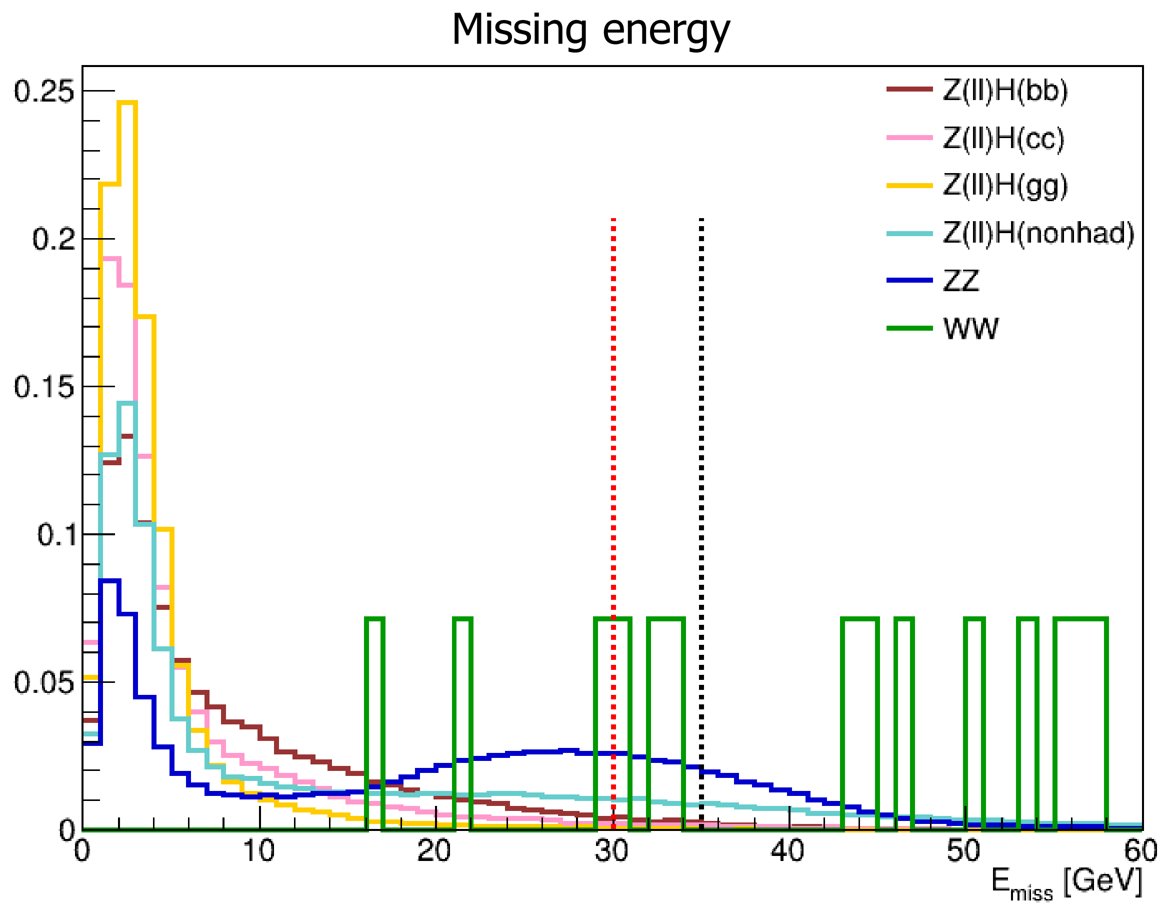
	ZHbb	ZHcc	ZHgg	ZHnonhad	background
2b	**10777** (100)	0 (0)	1 (0)	46 (0)	814
2c	2 (0)	**577** (15)	2 (0)	66 (2)	798
1b1c	**219** (13)	2 (0)	2 (0)	10 (1)	34
1b0c	**5378** (69)	0 (0)	39 (0)	40 (1)	672
0b1c	33 (1)	**292** (6)	131 (3)	**1193** (24)	798
0b0c2g	4 (0)	1 (0)	**1533** (36)	50 (1)	241
0b0c1g	60 (1)	5 (0)	**781** (14)	574 (10)	1835
0b0c0g	518 (7)	31 (0)	103 (1)	**1636** (22)	3186
Total	16992 (122)	909 (16)	2593 (38)	3615 (34)	8377

Expected signal yields for each categories

- Some categories are dominated by specific channels

Additional cut on Emiss

- For $H \to gg$ and $H \to c\bar{c}$ the hadronisation produces less neutrinos than in $H \to b\bar{b}$
  - We expect less missing energy in these channels



- Cut tighten to:
  - $< 20\ GeV$ for $H \to c\bar{c}$ dominated categories
  - $< 15\ GeV$ for $H \to gg$ dominated ones
- Furthermore it has been noticed that the selection on isolated leptons was non-optimal
  - We considered a potential gain of events of 30% by improving this part of the selection

Analysis

Fitting processes

Impact of tagging efficiency

Analysis strategy

- The goal of the analysis is to measure :
  - $BR(H \to b\bar{b})$, $BR(H \to c\bar{c})$ and $BR(H \to gg)$

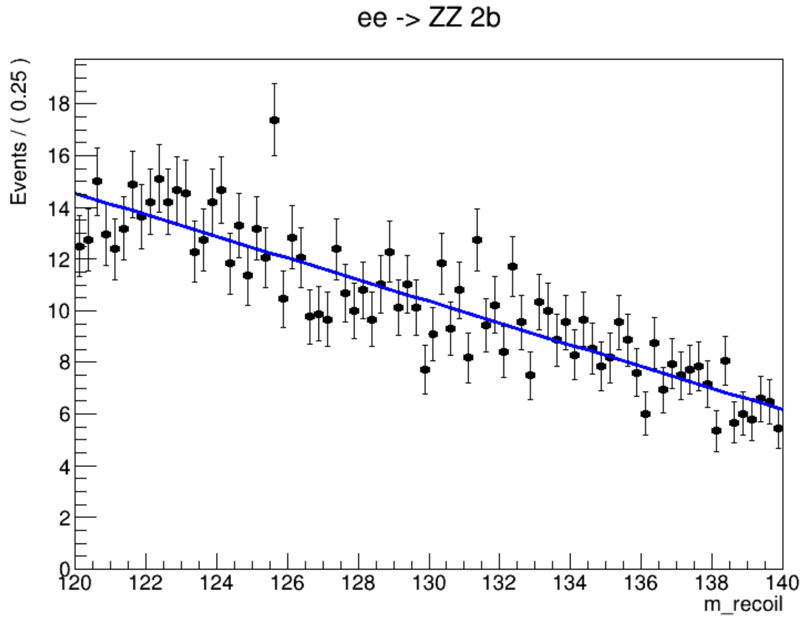
$BR(H \to nonhad)$ is set to be equal to the SM prediction

- We have the relation, where $N_{category}$ is the number of signal event in a tagging category :
  - $N_{category} = L * \sigma(ee \to llH) * \sum_{XX} BR(H \to XX)\epsilon^{XX}_{category}$, $XX \in \{c\bar{c}, b\bar{b}, gg, nonhad\}$
  - We have 3 unknowns and 8 equations (8 categories)

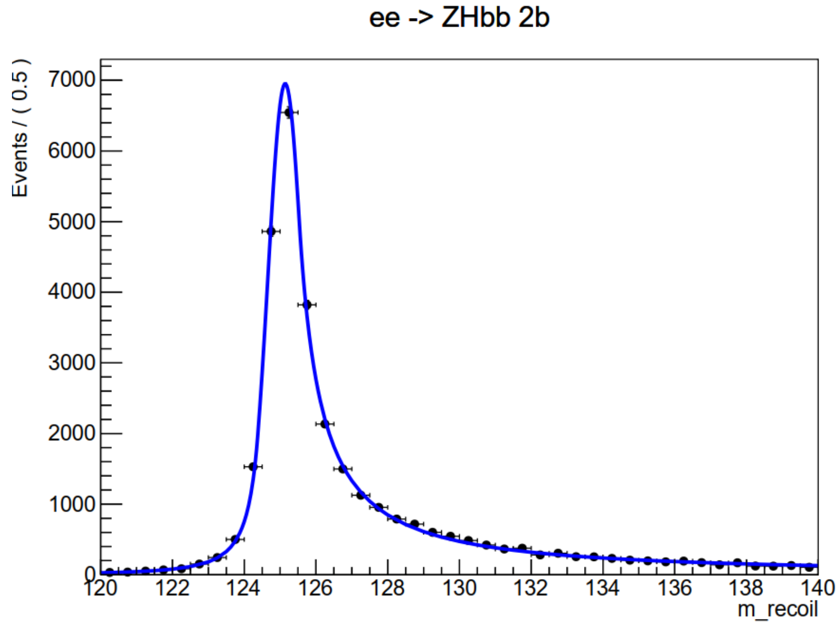
- We extract the value of the various $N_{category}$ by performing simultaneous likelihood binned fit on the recoil mass distribution within $120 - 140\ GeV$

Fit of the signal and bkg

- The background is mostly shaped by the tail of the $Z \rightarrow ll$ decay and the combination of two W leptonic decays
- This results in a flat shape fitted using first order polynomial functions

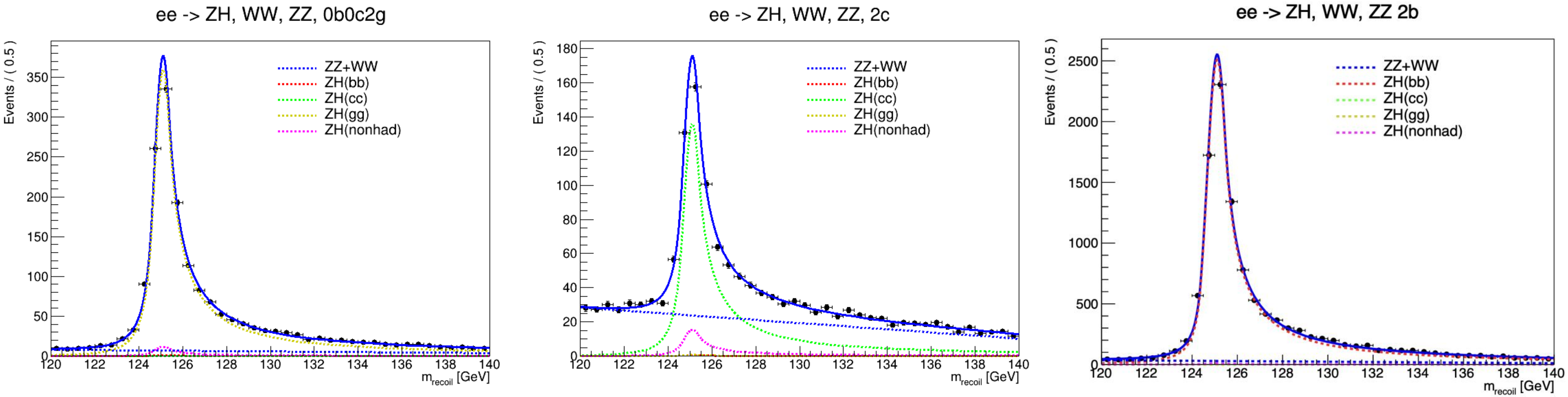


- The signal shapes were described using Double-Sided Crystal Ball functions
- All categories are fitted using the same model and parameters
- In the final fit all tails parameters are fixed to avoid migration of events between signal and background



Signal+Background fit

3 fit examples in the purest categories



With the simultaneous fit to the 8 categories we extract the following results

Channel	Expected error
$H \to b\bar{b}$	0.9%
$H \to c\bar{c}$	5.9%
$H \to gg$	2.6%

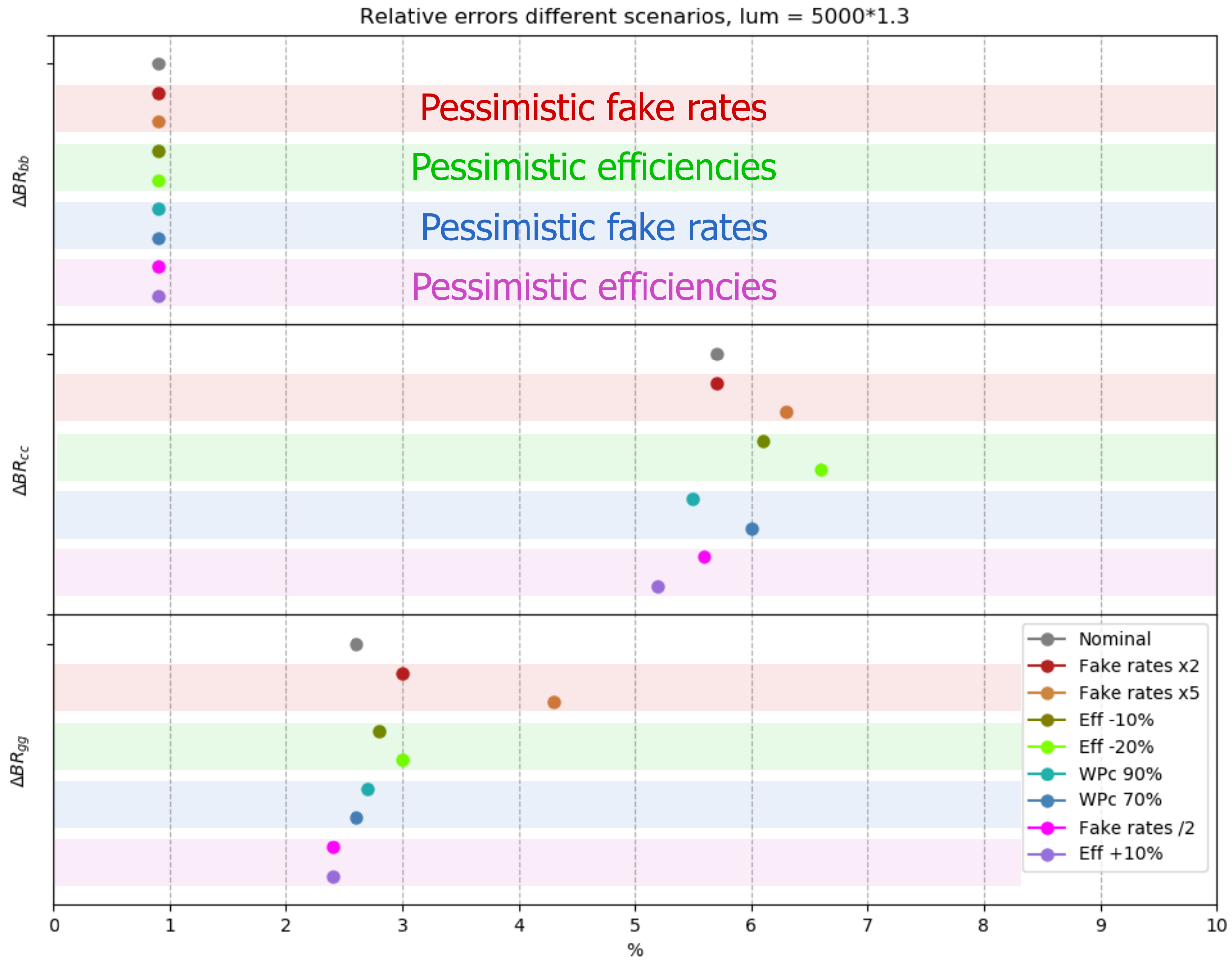
Impact of tagging efficiency

- In order to assess the impact of the tagging efficiency, we have been asked to consider various scenarios :

Strategy	**b-tag** $\epsilon_b, \epsilon_c, \epsilon_l, \epsilon_g$	**c-tag** $\epsilon_b, \epsilon_c, \epsilon_l, \epsilon_g$	**g-tag** $\epsilon_b, \epsilon_c, \epsilon_l, \epsilon_g$
Nominal	**80 / 0.4 / 0.05 / 0.7**	**2.0 / 80 / 0.9 / 2.5**	**2.0 / 5.0 / 15 / 80**
Fake rates x2	80 / **0.8 / 0.1 / 1.4**	**4.0** / 80 / **1.8 / 5.0**	**4.0 / 10 / 30** / 80
Fake rates x5	80 / **2.0 / 0.25 / 3.5**	**10** / 80 / **4.5 / 12.5**	**10 / 25 / 75** / 80
Efficiency -10%	**70** / 0.4 / 0.05 / 0.7	2.0 / **70** / 0.9 / 2.5	2.0 / 5.0 / 15 / **70**
Efficiency -20%	**60** / 0.4 / 0.05 / 0.7	2.0 / **60** / 0.9 / 2.5	2.0 / 5.0 / 15 / **60**
WPc 90%	80 / 0.4 / 0.05 / 0.7	**4.0 / 90 / 7.0 / 7.0**	2.0 / 5.0 / 15 / 80
WPc 70%	80 / 0.4 / 0.05 / 0.7	**0.9 / 70 / 0.2 / 1.0**	2.0 / 5.0 / 15 / 80
Efficiency +10%	**90** / 0.4 / 0.05 / 0.7	2.0 / **90** / 0.9 / 2.5	2.0 / 5.0 / 15 / **90**
Fake rates /2	80 / **.2 / 0.025 / 0.35**	**1.0** / 80 / **0.45 / 1.25**	**1.0 / 2.5 / 7.5** / 80

Final results

- The tagging efficiency
  - No impact on the b-channel
  - Assuming pessimistic cases lead to significant losses in precision for the c-channel and g-channel
  - Alternative WP to improve the precision in the c-channel causes losses in the g one



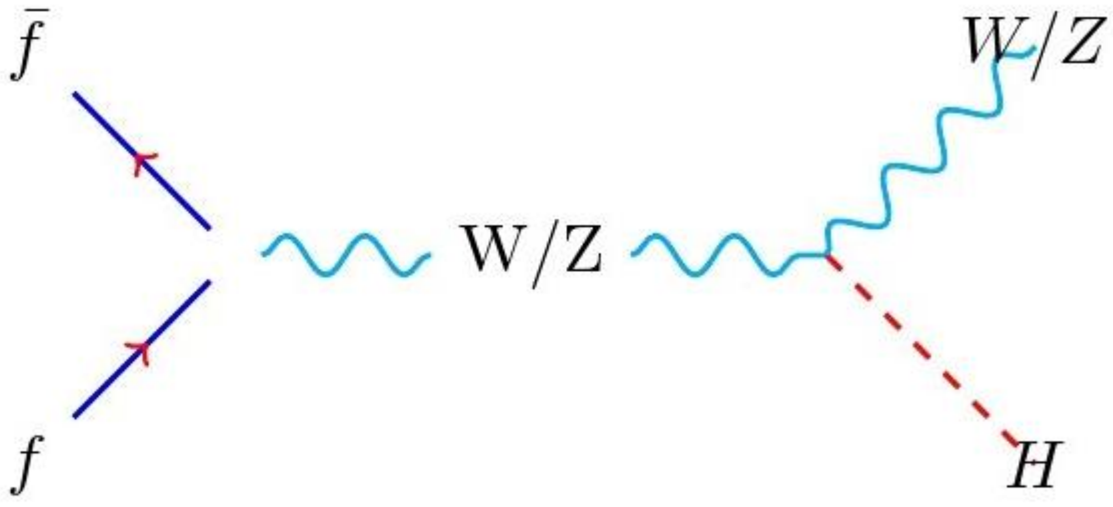
Conclusion

- Summary
  - We generated our signal and simulated the detector behaviour
  - We reconstructed the events and applied a selection on multiple variables
  - We performed simultaneous fit on background, signal, and signal+background distributions to extract errors on the Branching ratio measurement

- These results are promising not only compared to the HL-LHC predictions but also to comparable project being considered in parralel (CEPC collider in China)

- There remains many possible axes to improve these results

Our Problem



Higgs Strahlung

Why using a neural network ?

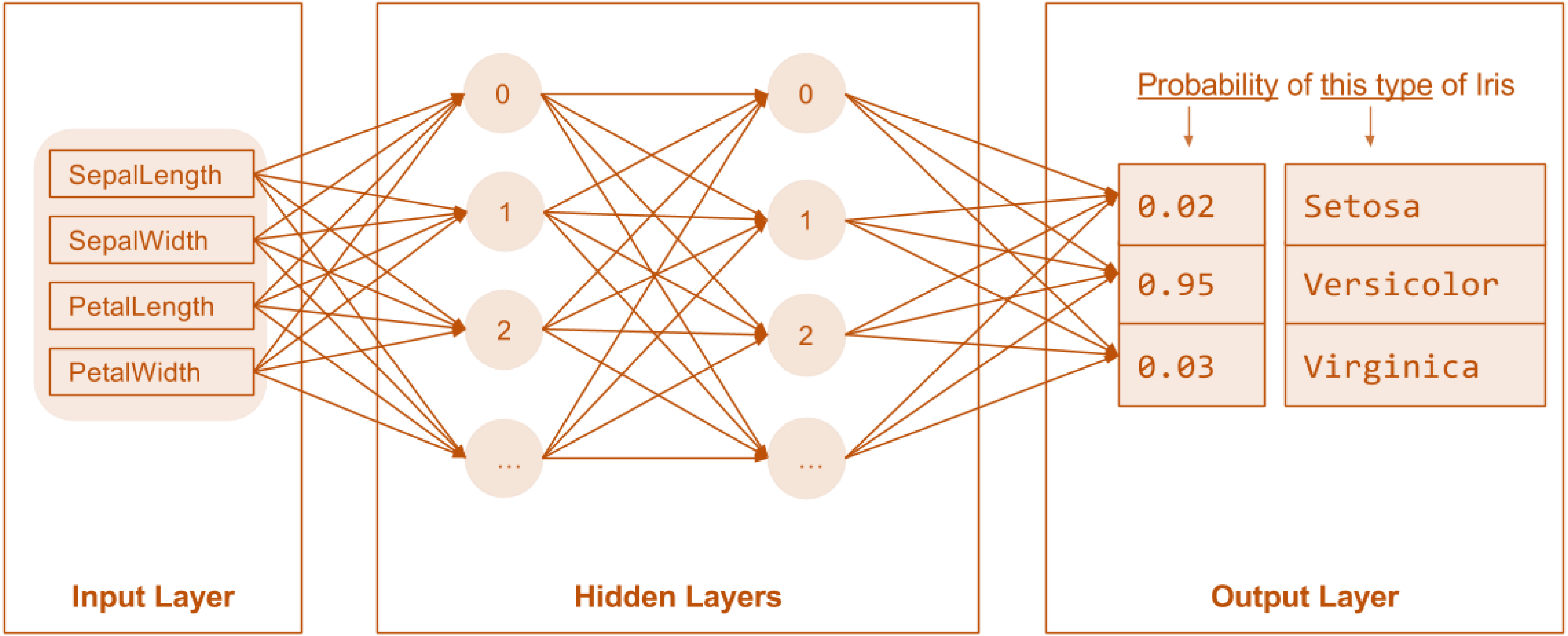
- Classification problem
- Vast amount of data
- Complex relations between inputs

- f = electron
- Z → $l\bar{l}$
- TAGS : H → $b\bar{b}$ [0] or $\bar{c}c$ [1] or gg [2] or non hadrons [3]

Neural Network

Presentation et Parameters choice

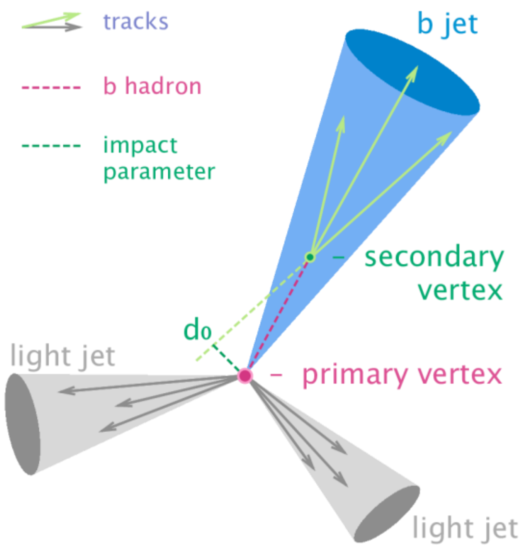
Neural Network



Classification Neural Network

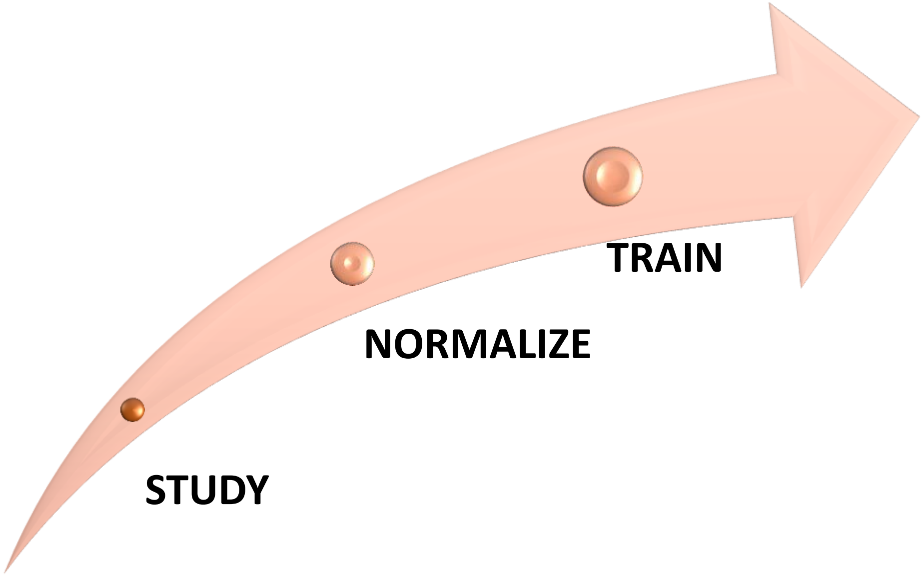
Which one ?

- Number of b, c and g tagged jets
- Distance between successive vertex

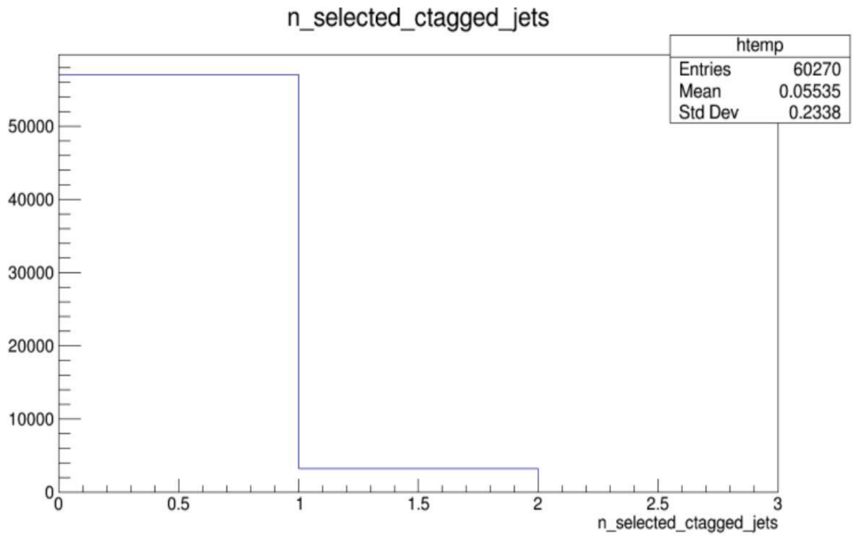


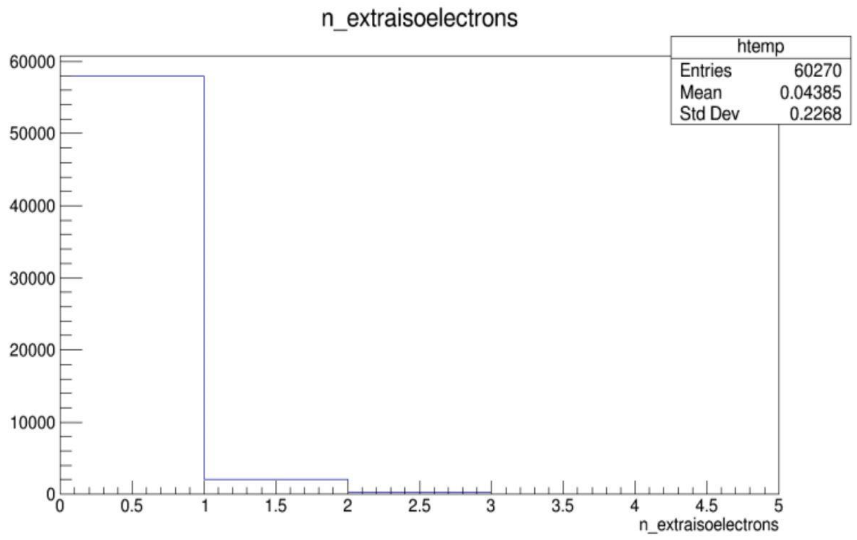
- Number of isolated electrons
- Number of isolated muons

Data processing

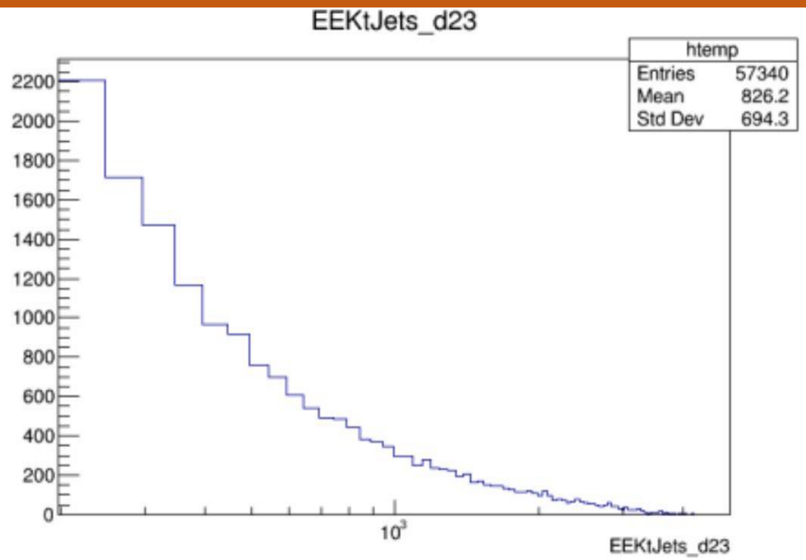


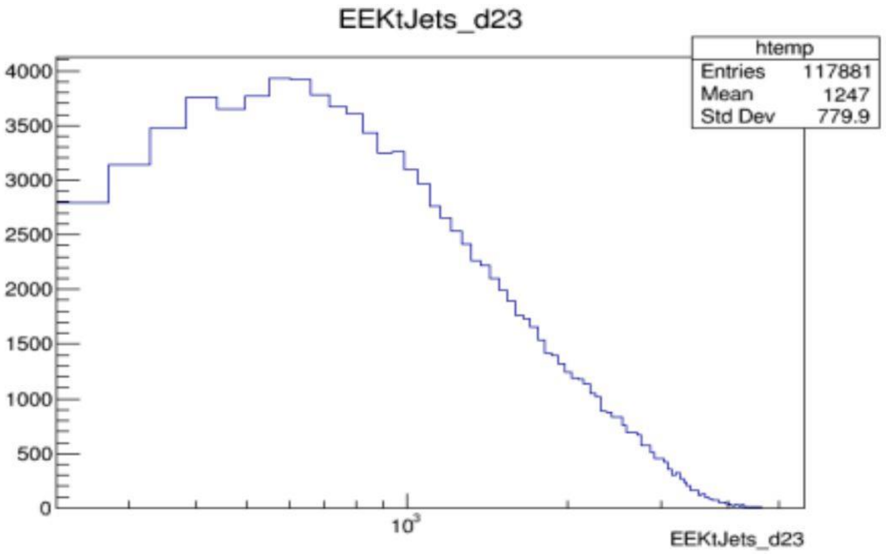
Inputs





2 inputs parameters for the H->bb data





d23 for the H->cc and H->nonhad data (logarithmic scale)

Network Parameters

var (inputs)	List_nbr_neur	nBatch	nEpoq	Activation fnct	optimizer	-> Efficiency
[b ,c , g ,logd23,d34,m_rec]	**[32,16,8]**	**32.**	**12.**	**ReLU**	**adam**	**0.891557216644287 1**
[b ,c , g ,logd23,d34,m_rec]	[16,16,16]	32.	12.	ReLU	adam	0.889518400033151
[b ,c , g ,logd23,d34,m_rec]	[16,16,16]	32.	12.	ReLU	RMSprop	0.877416511376698 8
[b ,c , g ,logd23,d34,m_rec]	[16,32,16,8]	32.	12.	ReLU	adam	0.890890439351399 8
[b ,c , g ,logd23,d34,m_rec]	[32,16,8]	32.	12.	ReLU	adam	0.891460855801900 3
[b ,c , g ,logd23,d34,m_rec]	**[32,16,8]**	**32.**	**30.**	**ReLU**	**adam**	**0.891707519690195 7**
[b ,c , g ,logd23,d34,m_rec]	[32,16,8]	20.	12.	ReLU	adam	0.891194919745127 3
[b ,c , g ,logd23,d34,m_rec]	[32,16,8]	64.	12.	ReLU	adam	0.890643795331319 2
[b ,c , g ,logd23,d34,m_rec]	[32,16,8]	100.	12.	ReLU	adam	0.889472146828969 4
[b ,c , g ,logd23,d34,m_rec]	**[128,32,8]**	**32.**	**12.**	**ReLU**	**adam**	**0.891695956389109 3**
[b ,c , g ,logd23,d34,m_rec]	[32,16,8]	32.	12.	sig (1) ReLU	adam	0.891557216644287 1
[b ,c , g ,logd23,d34,m_rec]	[32,16,8]	32.	12.	sig	adam	0.891649703184763 6
[b ,c , g ,logd23,d34,m_rec]	**[64,32,16,8]**	**32.**	**12.**	**sig / ReLU**	**adam**	**0.892528454462687 1**
[b ,c , g ,logd23,d34,m_rec]	[8,16,32,16,8]	32.	12.	sig / ReLU	adam	0.875770807266235 4
[b ,c , g ,logd23,d34,m_rec]	[256,128,64,8]	32.	12.	sig / ReLU	adam	0.891641994317372 7
[b,c,g]	[32,16,8]	32.	12.	sig	adam	0.815010945002237 9
[b ,c , g ,logd23,d34,d45,n_e, n_m,m_rec]	**[256,128,64,8]**	**32.**	**12.**	**sig / ReLU**	**adam**	**0.892917712529500 4**
[b ,c , g ,logd23,logd34,logd45n_e, n_m,m_rec]	[256,128,64,8]	32.	12.	sig / ReLU	adam	0.892270227273305 3

Final Results

$$\mu_{xx} = BR_{H\to xx\,(fit)}/BR_{H\to xx\,(SM)}$$

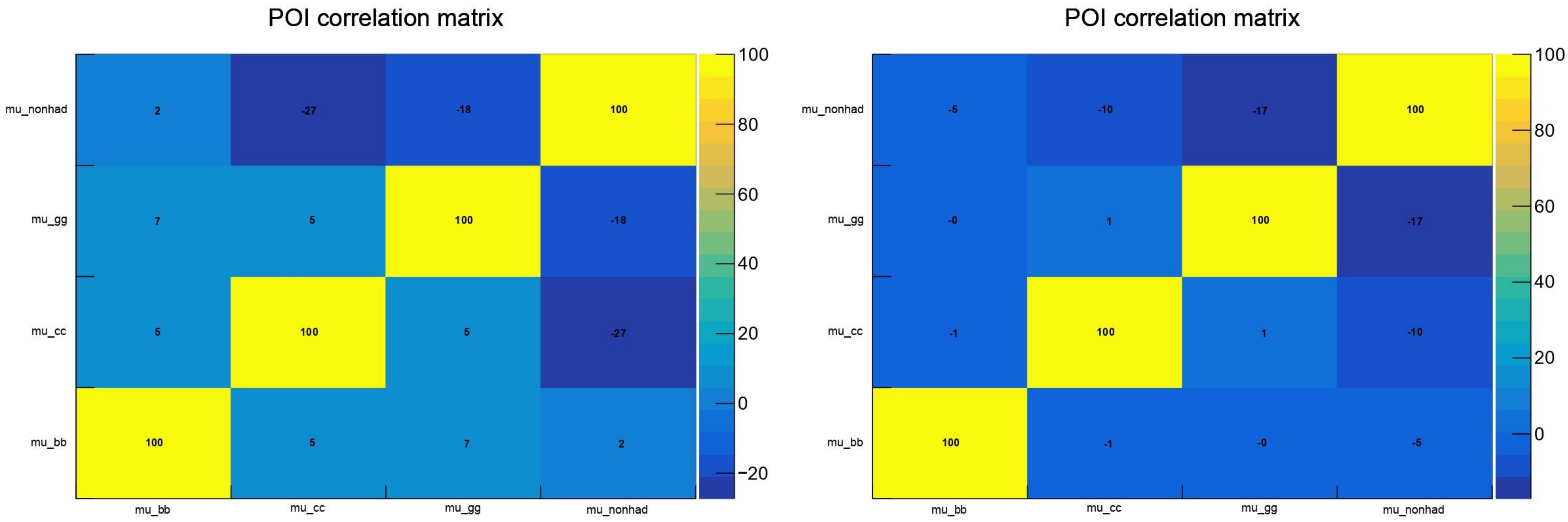
Floating Parameter	InitialValue	FinalValue +/-	Error	GblCorr.
Yield_0_bkg	6.0441e+02	6.6424e+01 +/-	8.38e+01	<none>
Yield_1_bkg	4.6274e+02	4.0651e+02 +/-	4.04e+01	<none>
Yield_2_bkg	3.8969e+02	2.5222e+02 +/-	4.90e+01	<none>
Yield_3_bkg	1.6304e+03	1.5413e+03 +/-	8.38e+01	<none>
mH	1.2500e+02	1.2506e+02 +/-	6.03e-03	<none>
mu_bb	1.0000e+00	1.0282e+00 +/-	8.21e-03	<none>
mu_cc	1.0000e+00	1.0547e+00 +/-	5.04e-02	<none>
mu_gg	1.0000e+00	1.0493e+00 +/-	2.64e-02	<none>
mu_nonhad	1.0000e+00	1.0122e+00 +/-	2.38e-02	<none>
p0_0	5.0000e+02	1.8524e-04 +/-	3.86e-01	<none>
p0_1	5.0000e+02	5.3275e+00 +/-	2.33e+00	<none>
p0_2	5.0000e+02	2.4761e+01 +/-	8.21e+01	<none>
p0_3	5.0000e+02	1.7318e+00 +/-	2.41e-01	<none>
sigma	4.3800e-01	5.1551e-01 +/-	6.77e-03	<none>

Floating Parameter	InitialValue	FinalValue +/-	Error	GblCorr.
Yield_0b0c0g_bkg	4.8417e+03	5.1001e+03 +/-	9.26e+01	<none>
Yield_0b0c1g_bkg	2.8185e+03	2.9536e+03 +/-	6.70e+01	<none>
Yield_0b0c2g_bkg	3.7202e+02	4.7720e+02 +/-	4.17e+01	<none>
Yield_0b1c_bkg	1.1976e+03	1.3416e+03 +/-	5.48e+01	<none>
Yield_1b0c_bkg	1.0260e+03	1.4082e+03 +/-	7.07e+01	<none>
Yield_1b1c_bkg	4.9263e+01	6.2025e+01 +/-	1.30e+01	<none>
Yield_2b_bkg	1.2445e+03	1.9717e+03 +/-	1.02e+02	<none>
Yield_2c_bkg	1.1684e+03	1.2116e+03 +/-	4.87e+01	<none>
mH	1.2500e+02	1.2500e+02 +/-	5.84e-03	<none>
mu_bb	1.0000e+00	9.4644e-01 +/-	9.24e-03	<none>
mu_cc	1.0000e+00	9.5898e-01 +/-	6.03e-02	<none>
mu_gg	1.0000e+00	9.4930e-01 +/-	2.67e-02	<none>
mu_nonhad	1.0000e+00	9.1629e-01 +/-	2.83e-02	<none>
p0_0b0c0g	5.0000e+02	3.0297e+00 +/-	2.00e-01	<none>
p0_0b0c1g	5.0000e+02	2.5374e+00 +/-	2.08e-01	<none>
p0_0b0c2g	5.0000e+02	1.671		

Free Parameters (NN and 8 categories)

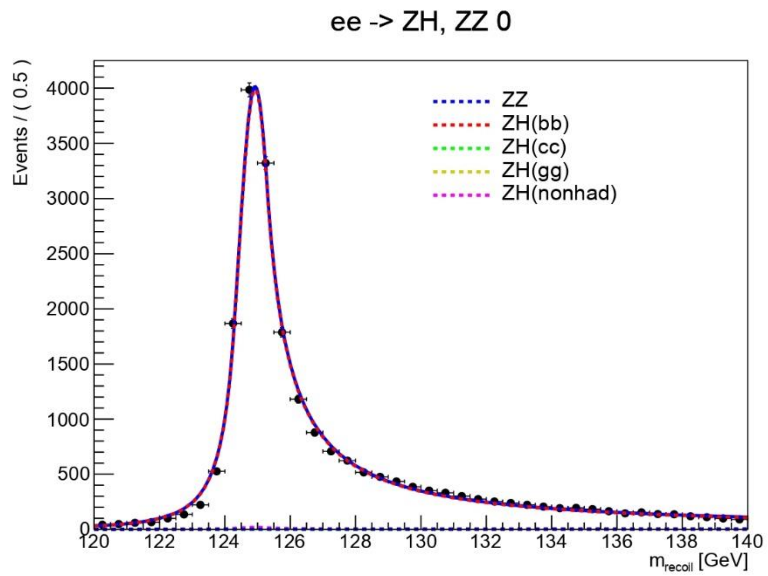
Categories	Rel. Err. cc	Rel. Err. gg	Rel. Err. bb	Rel. Err. nonhad
8 tags	6.3 %	2.8 %	1 %	3.1%
4 tags (NN)	4.8 %	2.5 %	0.8 %	2.3 %

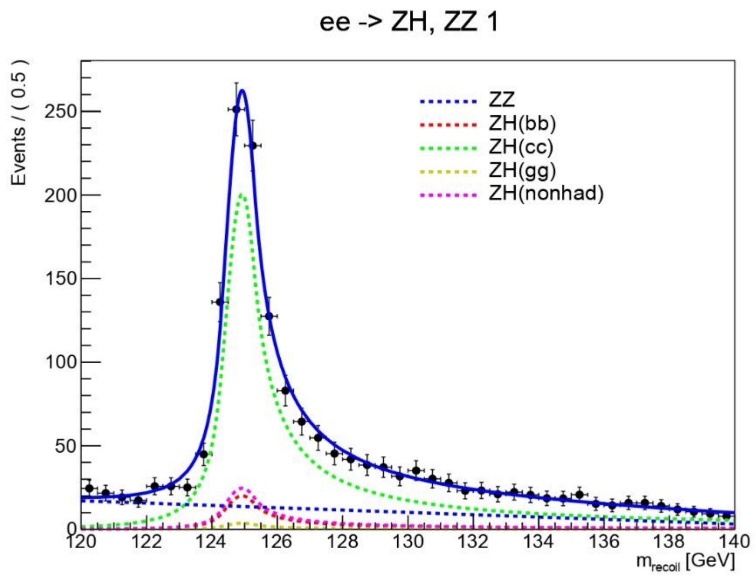
Correlation Matrices



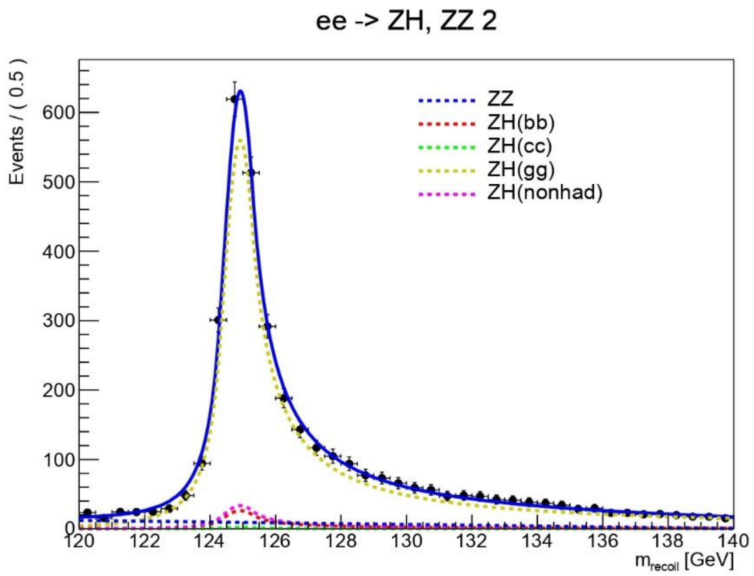
Correlation Matrices (8 tags and 4 tags (NN))

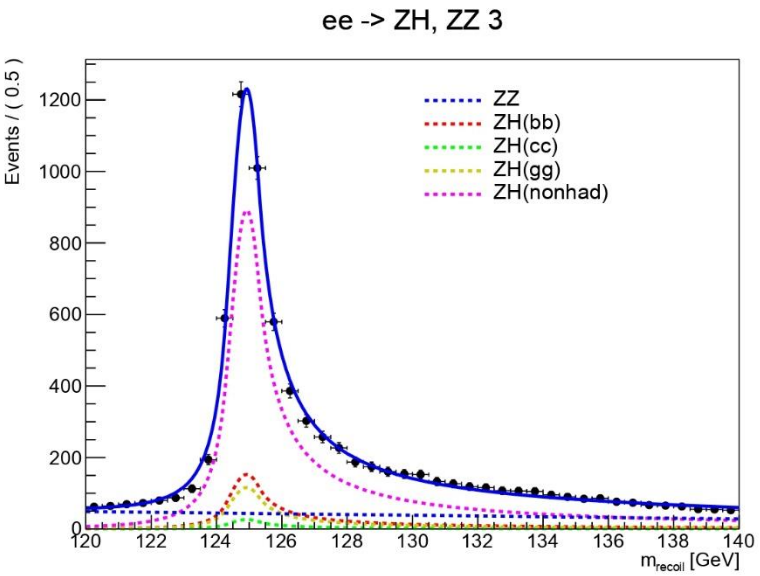
Fits for NN categories





Reconstructed signals for each categorie





Classes (with NN) :

H→bb	H→cc
H→gg	H→nonhad

Conclusion

- The Neural Network allow preciser measurements than the 8 categories
- We could improve the ability of the Neural Network

Next studies

ZeeHqq + ZmumuHqq

ZnunuHqq

ZeeHqq + ZmumuHqq

- Seperating both channels result in better significances in all categories

	ZeeHqq	ZmumuHqq	Combined	ZllHqq
Hbb	1.2	1.2	0.85	0.9
Hcc	8.4	8.0	5.8	5.9
Hgg	3.9	3.6	2.9	2.6

No assumptions on Hnonhad (ZeeHqq, ZmumuHqq, Combined)

Hnonhad = SM (ZllHqq)

- One could apply the NN selection on the two channels to improve the results even further

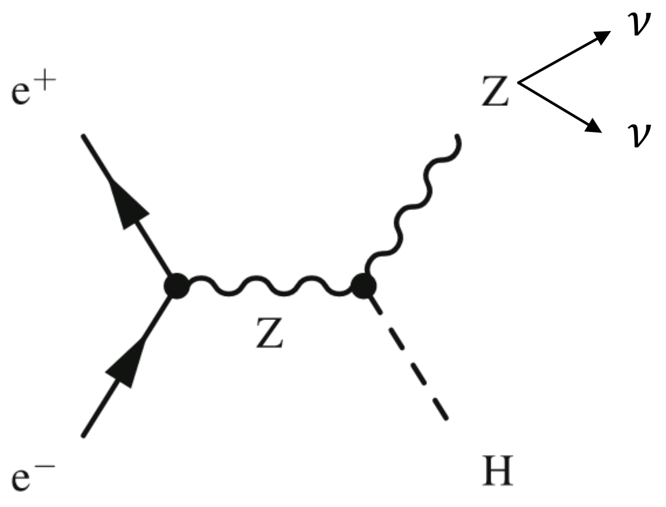
ZnunuHqq

- The recoil mass can't be reconstructed as previously
  - We consider now the system recoiling against the H

- Initial selection : 2 jets stemming from the hadronisation

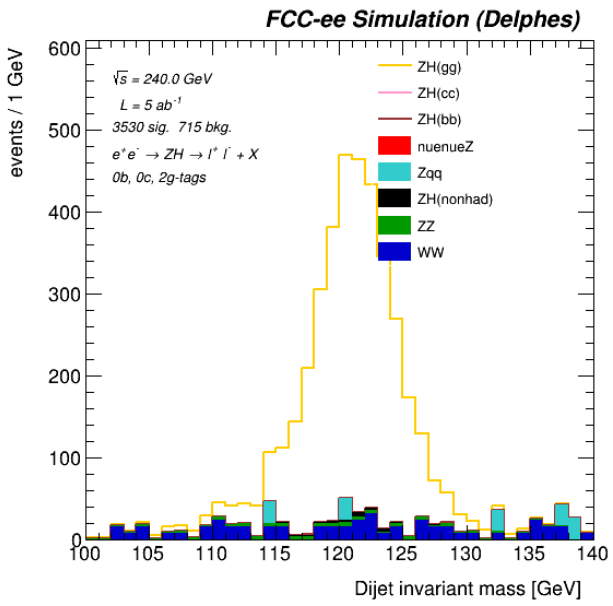
- Perfom the fit on the Dijets invariant mass

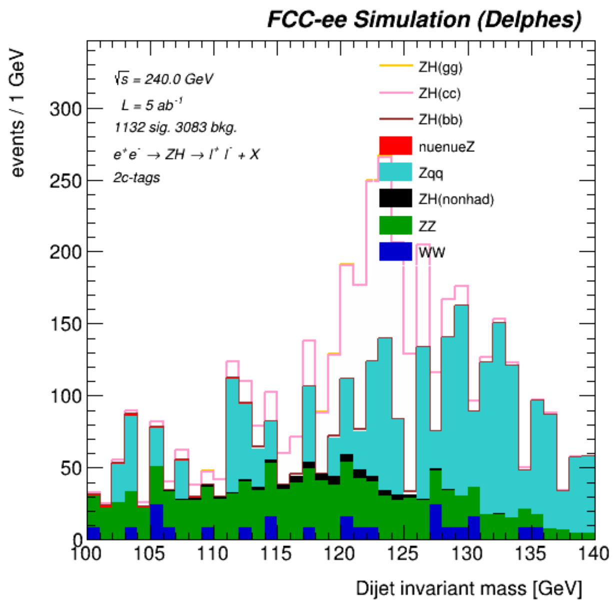
$$e^+ + e^- \to Z + H$$

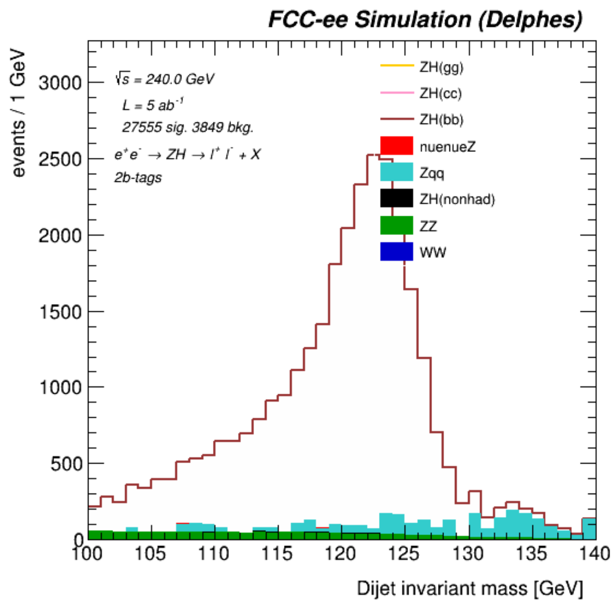


ZnunuHqq (WIP)

- Each channel purest category after selection :







- Very promising analysis for Hbb and Hgg channels
  - Hcc still requires a bit more purity but seems to be leading to what is published for CEPC

Thanks for your attention

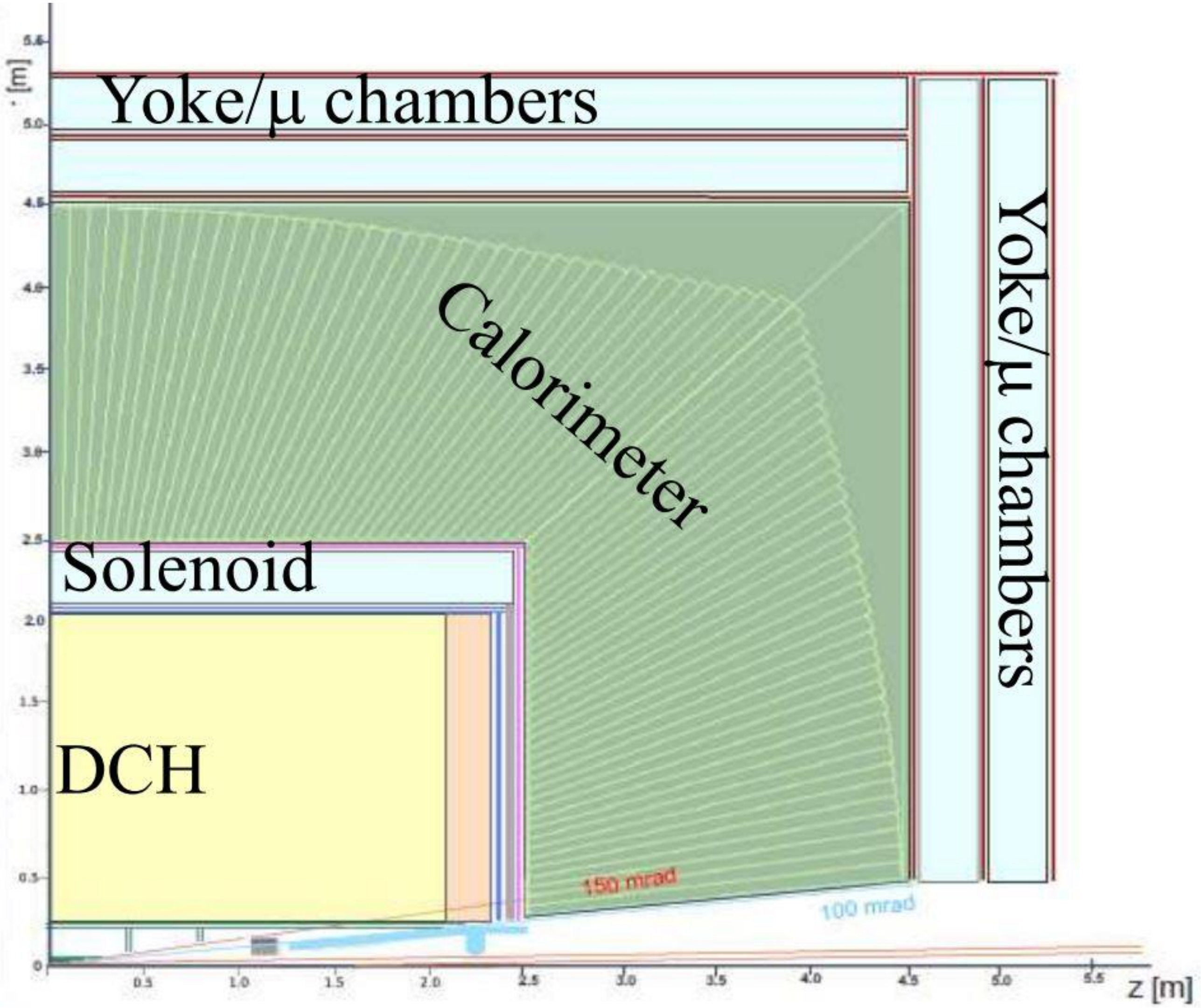
BACK UP

Normalization factors

Process	sigma*BR (fb)	$N_{generated}$	$L_{generated}/L$
Z(ll)H(bb)	8.15008	100000	2.57
Z(ll)H(cc)	0.404565	100000	50.909
Z(ll)H(gg)	1.14569	100000	17.977
Z(ll)H(nonhad)	4.29363	500000	23.984
ZZ	1358.99	59800000	8.801
WW	16438.5	49400000	0.122

Detector

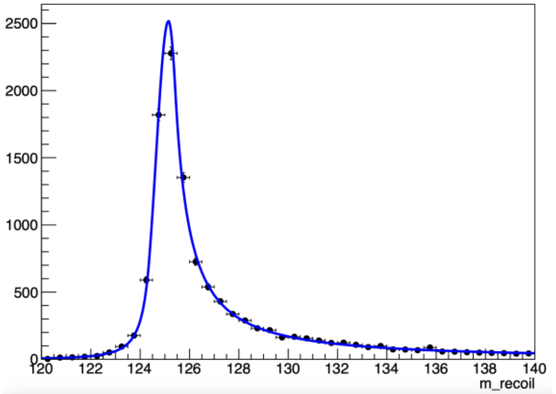
- Detector « IDEA » concept :
  - Silicon vertex detectors
  - Drift chambers
  - Calorimeters
  - External muon chambers



Fit of the signal (1/2)

- The signal shapes were described using Double-Sided Crystal Ball functions

$$CB(m_{\gamma\gamma}) = N \times \begin{cases} e^{-t^2/2}, & \text{if } -\alpha_{\text{low}} \leq t \leq \alpha_{\text{high}} \\ e^{-\frac{1}{2}\alpha_{\text{low}}^2}\left[\frac{1}{R_{\text{low}}}\left(R_{\text{low}} - \alpha_{\text{low}} - t\right)\right]^{-n_{\text{low}}}, & \text{if } t < -\alpha_{\text{low}} \\ e^{-\frac{1}{2}\alpha_{\text{high}}^2}\left[\frac{1}{R_{\text{high}}}\left(R_{\text{high}} - \alpha_{\text{high}} - t\right)\right]^{-n_{\text{high}}}, & \text{if } t > \alpha_{\text{high}} \end{cases}$$

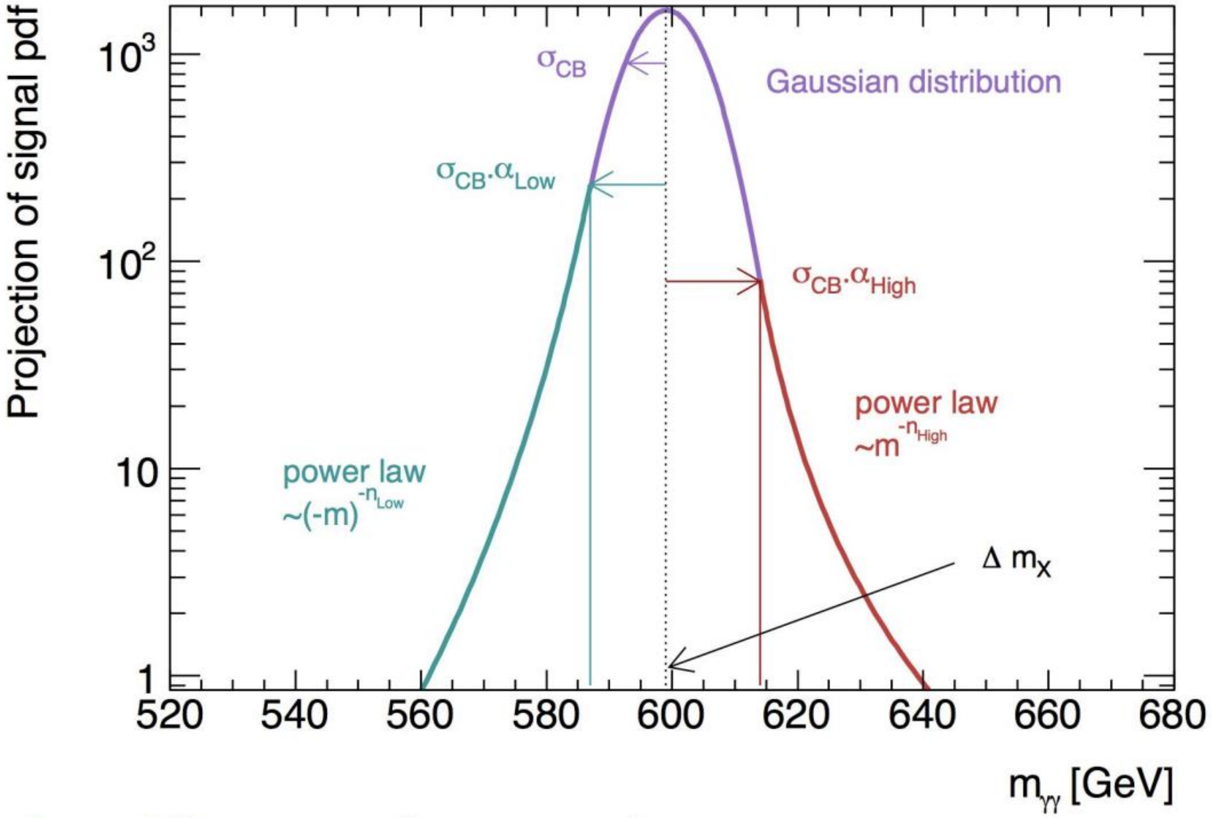


- All categories are fitted using the same model and parameters.

- All 6 parameters are let free
  - In the final fit, the tail ones will be fixed, contrarly to the peak position and resolution as they might be varying in the real data.

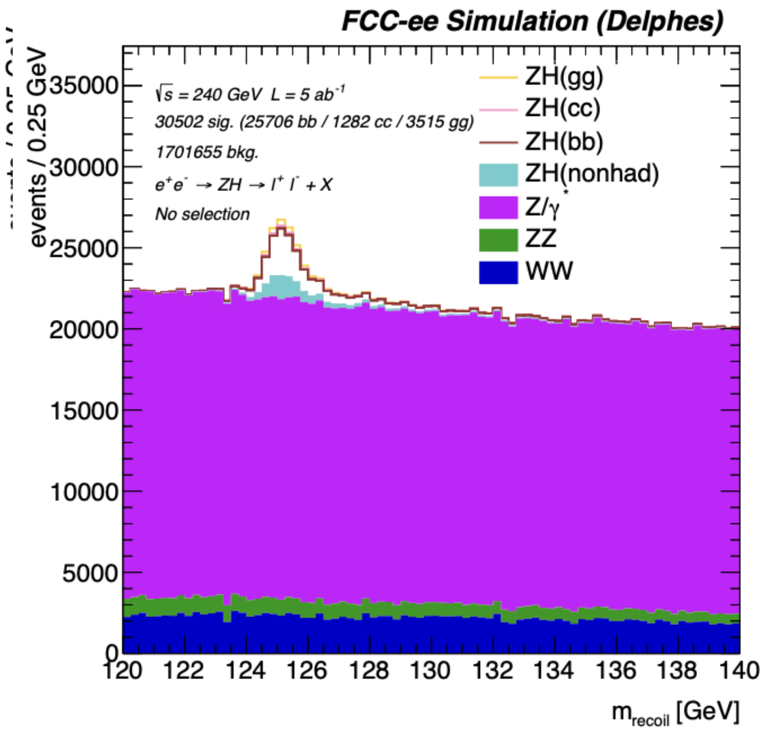
Double sided crystal ball

$$CB(m_{\gamma\gamma}) = N \times \begin{cases} e^{-t^2/2}, & \text{if } -\alpha_{\text{low}} \leq t \leq \alpha_{\text{high}} \\ e^{-\frac{1}{2}\alpha_{\text{low}}^2}\left[\frac{1}{R_{\text{low}}}\left(R_{\text{low}} - \alpha_{\text{low}} - t\right)\right]^{-n_{\text{low}}}, & \text{if } t < -\alpha_{\text{low}} \\ e^{-\frac{1}{2}\alpha_{\text{high}}^2}\left[\frac{1}{R_{\text{high}}}\left(R_{\text{high}} - \alpha_{\text{high}} - t\right)\right]^{-n_{\text{high}}}, & \text{if } t > \alpha_{\text{high}} \end{cases}$$

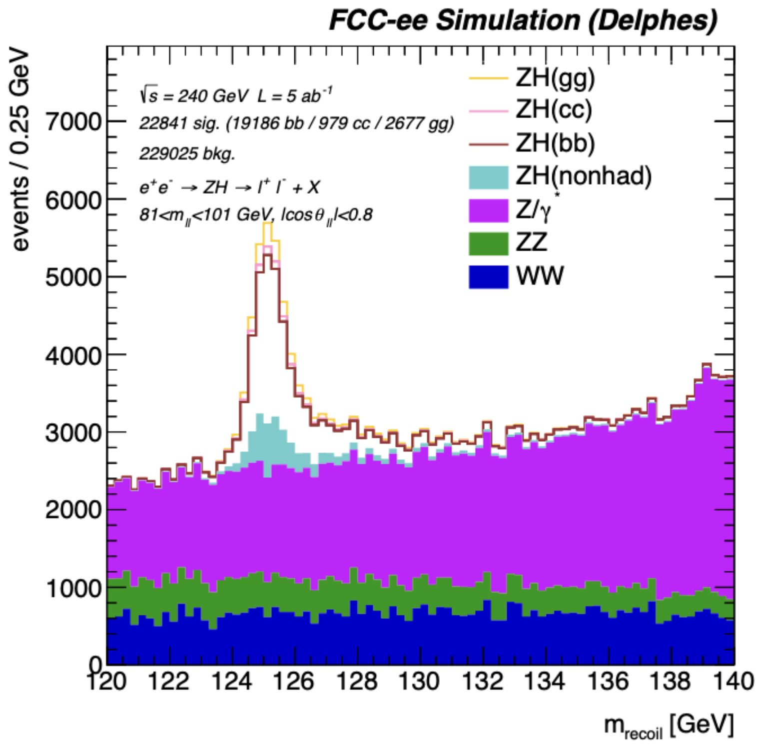


Selection with Zgamma

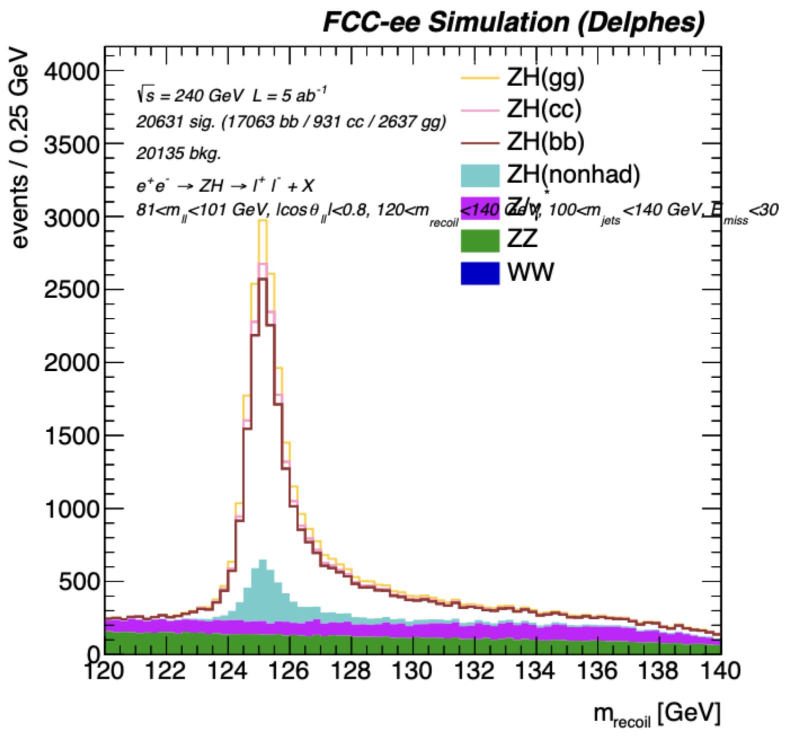
After reconstruction



After Z selection



After recoil, jets, Emiss selection



Cutflow

Cut	ZHbb Yield	ZHbb Sig	ZHcc Yield	ZHcc Sig	ZHgg Yield	ZHgg Sig	ZHnonhad Yield	ZZ Yield	WW Yield
No cuts	40750	4	2023	0	5730	1	21470	6794950	82192500
2e or 2mu	27045	15	1357	1	3724	2	12375	871502	2130832
No extra lep	26739	15	1356	1	3718	2	9573	831747	2128490
p(lep) 25-80 GeV	26124	24	1328	1	3646	3	9001	426207	700864
q(ll)=0	26122	24	1328	1	3646	3	8785	425439	700683
m(ll) 80-100 GeV	24463	34	1244	2	3417	5	8049	295892	170319
|cos(theta_ll)|<0.8	19950	34	1017	2	2787	5	6593	187765	128845
m(recoil) 120-140 GeV	19186	57	979	3	2677	8	6318	31090	53376
100<m(jets)<140 GeV	17103	93	932	5	2637	14	3804	9397	0
Emiss < 30 GeV	17063	93	931	5	2637	14	3796	9283	0

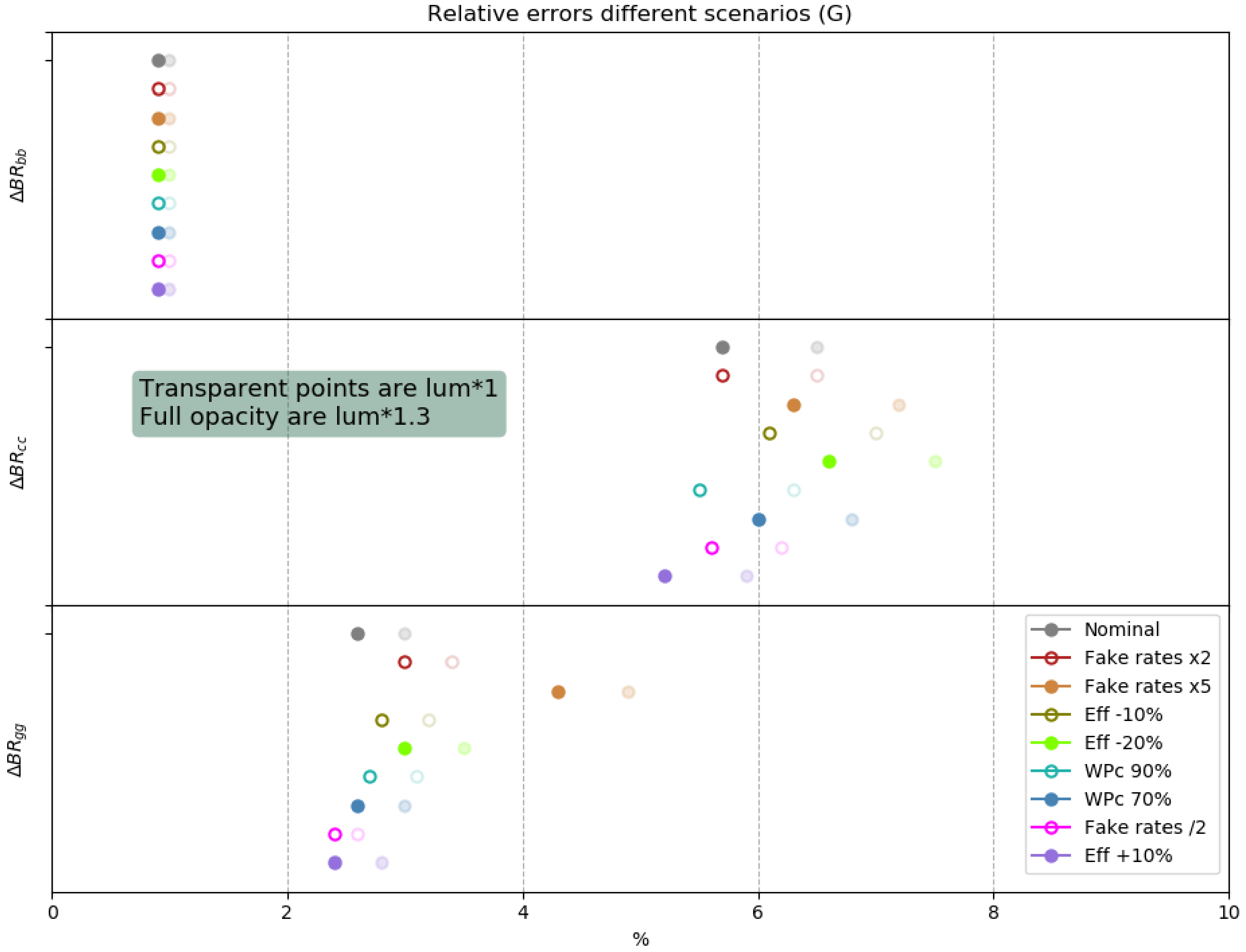
Efficiency (%)	ZHbb	ZHcc	ZHgg	ZHnonhad	WW	ZZ
	41.87	46.01	46.01	17.68	0.00	0.14

Significance : $S = \frac{N_{signal}}{\sqrt{N_{signal}+N_{background}}}$

- Results for CEPC at $\sqrt{s} = 240$ GeV and $L = 5$ ab-1

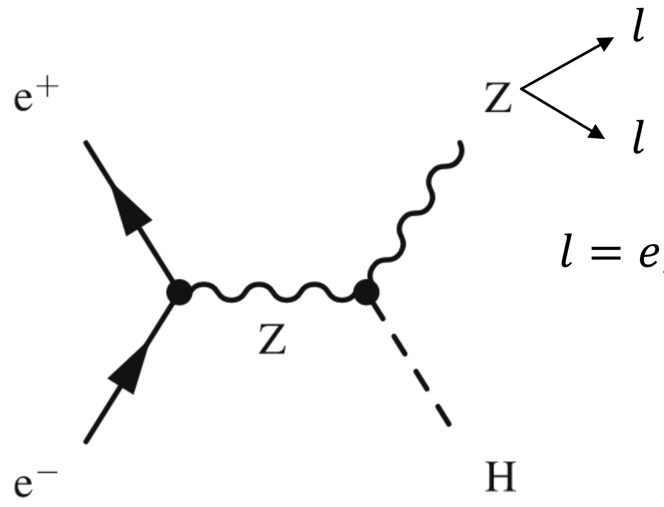
Channel	Expected error
$H \rightarrow b\bar{b}$	0.9%
$H \rightarrow c\bar{c}$	8.3%
$H \rightarrow gg$	4.7%

Luminosity comparison



Model independance

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



$l = e, \mu$

- **Without looking at the Higgs decay:**

$$\sigma(ee \rightarrow ZH) \Rightarrow g^2_{HZZ}$$

- **Reconstructing H→ZZ:**

$$\sigma(ee \rightarrow ZH)BR(H \rightarrow ZZ) \propto \frac{g^4_{HZZ}}{\Gamma} \Rightarrow \Gamma$$

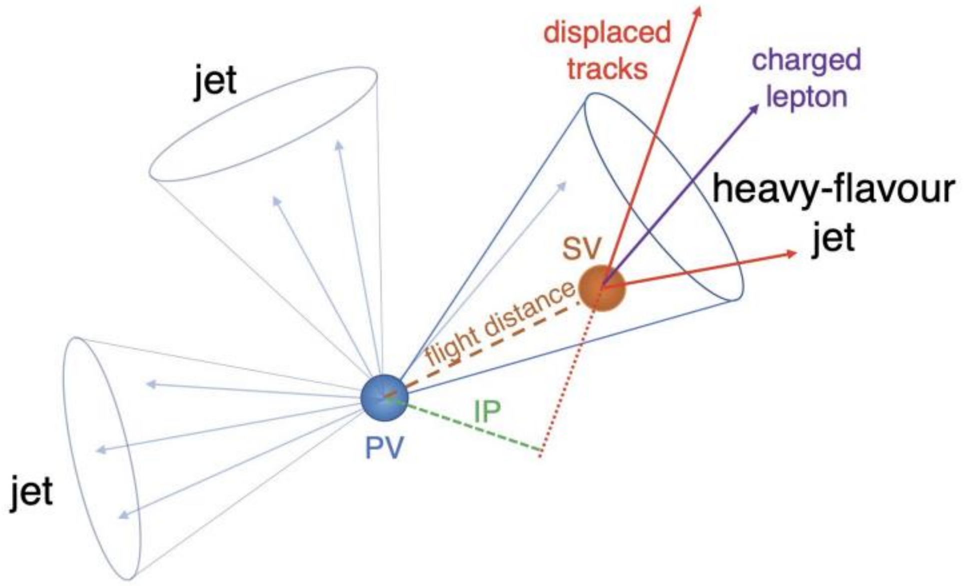
- **Reconstructing other Higgs Boson decays H→XX:**

$$\sigma(ee \rightarrow ZH)BR(H \rightarrow XX) \propto \frac{g^2_{HZZ} g^2_{HXX}}{\Gamma} \Rightarrow g^2_{HXX}$$

- **Looking at “invisible” Higgs decays (large missing energy) ⇒ BR(H→invisible)**

Flavour tagging

- Large lifetime
  - b (c) decay length: ~5 (2-3) mm for ~50 GeV boost
- Large track multiplicity
  - ~5 (~2) charged tracks/decay
- Non-isolated e/μ
  - ~20 (10)% in B (C) decays



ZnunuHqq cutflow

Cut	ZHbb Yield	ZHbb Sig	ZHcc Yield	ZHcc Sig	ZHgg Yield	ZHgg Sig	ZHnonhad Yield	ZZ Yield	WW Yield	Zqq Yield	nuenueZ Yield
No sel	134360	7	6695	0	18930	1	70870	6794950	82192500	263269500	166370
Njets = 2	134360	7	6695	0	18930	1	65296	6450313	79261507	262049957	126029
m(recoil) 80-130 GeV	119238	22	6085	1	17614	3	36880	1612130	5863005	21943329	64044
m(dijets) 100-140 GeV	111609	49	5906	3	17420	8	29107	225336	3106219	1698852	2120
p(jet) 20-95 GeV	111229	49	5885	3	17406	8	29096	223004	3048618	1659230	2111
e(jet) 20-105 GeV	111172	50	5880	3	17371	8	28869	221602	2999541	1646988	2100
Npart: (jet1)>10/(jet2)>6	109069	61	5611	3	17264	10	25506	167887	1486213	1409492	1627
e(miss) 20-60 GeV	103463	72	5379	4	16564	12	24247	91067	948452	859127	1161
|cos(theta)|<0.9	73686	82	3833	4	11788	13	17308	50171	585737	64448	717
|cos()|<0.9 & n_GenKt	54104	83	2812	4	6409	10	7054	25761	276816	46625	401
Jet(d23)<500	61107	113	3150	6	7556	14	3755	23000	142012	52733	361
Jet(d23)<500 & n_GenKt	47680	104	2460	5	4685	10	2056	16009	96847	40254	247
tighter cuts	43159	131	1777	5	6612	20	2771	9315	33444	11321	116
tighter cuts & n_GenKt	33050	121	1341	5	4074	15	1437	6164	20499	8109	75

Efficiency (%)	ZHbb	ZHcc	ZHgg	ZHnonhad	nuenueZ	Zqq	WW	ZZ
	77.00	80.35	87.50	34.21	0.70	0.33	1.15	1.34