Measurement of $H \rightarrow Z\gamma$ decay at the 250 GeV ILC

Status report

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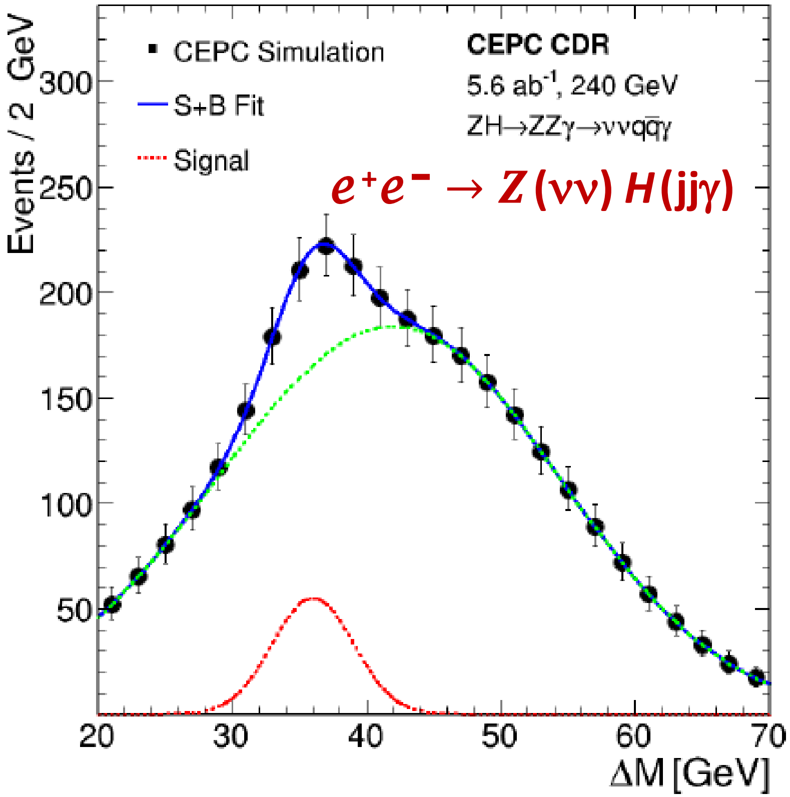
Introduction

CEPC accuracy of H→Zγ decay measurement using Z→νν and Z→*jj* modes



CEPC accuracies (in %)

Decay mode	$\sigma(ZH)\times\mathrm{BR}$	BR
$H\to b\bar{b}$	0.27%	0.56%
$H\to c\bar{c}$	3.3%	3.3%
$H\to gg$	1.3%	1.4%
$H\to WW^*$	1.0%	1.1%
$H\to ZZ^*$	5.1%	5.1%
$H\to\gamma\gamma$	6.8%	6.9%
$H\to Z\gamma$	15%	15%

Combining 2 channels, accuracy of 15% is obtained for 5.6 ab^{-1}.

arXiv:1810.09037

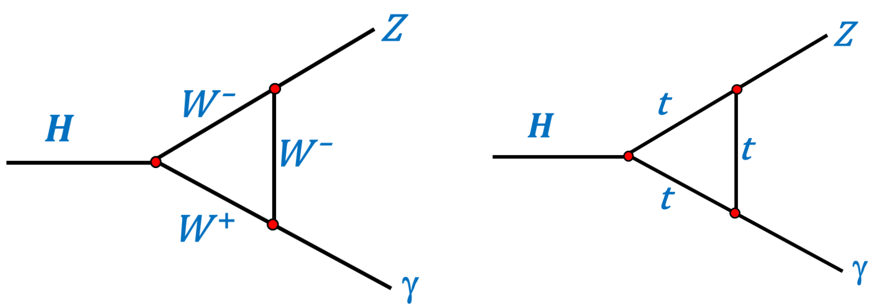
selected photon pairs for $Z\to\nu\bar{\nu}$. (b) $e^+e^-\to ZH$ production with $H\to Z\gamma$: the distribution of the mass difference between the reconstructed $Z\gamma$ and Z system including contributions from both $M(qq\gamma)-M(qq)$ and $M(\nu\bar{\nu}\gamma)-M(\nu\bar{\nu})$. The markers and their uncertainties represent expectations from a CEPC dataset of 5.6 ab^{-1}, whereas the solid blue curves are the signal-plus-background fit results. The dashed curves are the signal and background components.

Introduction

Decay **H → Zγ** go through loop diagram with charged particles inside loop.
It is sensitive to heavy charged particles contributions.

ATLAS and CMS obtained upper limits for this channel of about (3-4) × SM.
It is difficult to get 5σ at LHC even after upgrade.

Possible sensitivity to loop contributions of heavy charged BSM particles (arXiv:2205.14880). The decay branching fraction depends (not strongly) on the W boson mass (arXiv:2204.05284).



Dominant contribution **~10-15 %**

Isolated photon identification

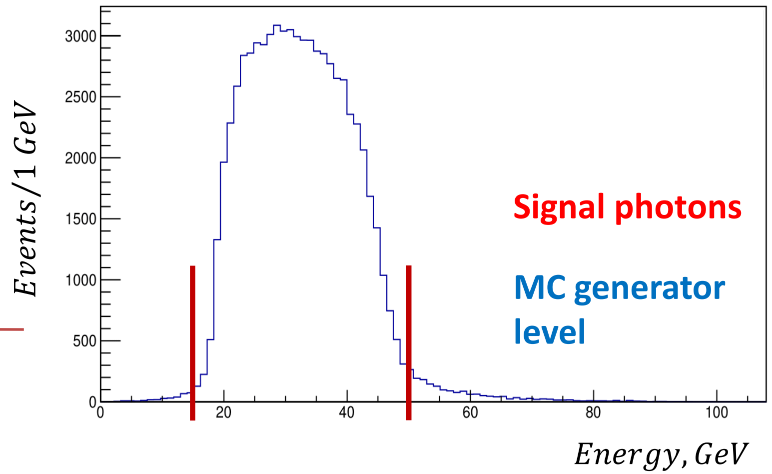
We use ***IsolatedPhotonTagging*** processor to obtain gamma with parameters:

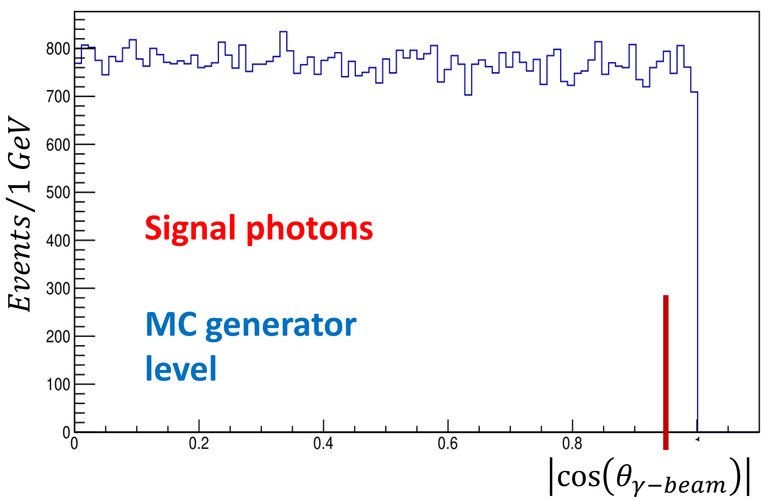
$cos(\theta_{small})$ = 0.98, $cos(\theta_{large})$ = 0.95

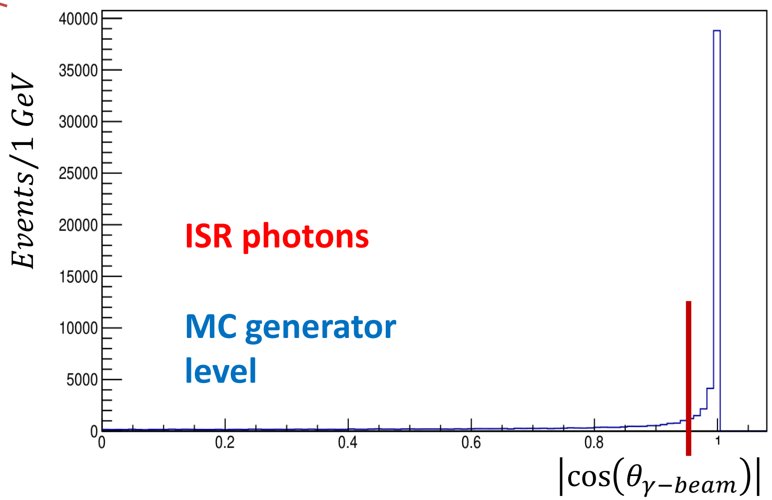
$\frac{E_{PFOs}}{E_\gamma}$ (small cone) ≤ 0.1, $\frac{E_{PFOs}}{E_\gamma}$ (large cone) ≤ 0.05

Signal photons are located in these ranges:

$$15 \leq \mathbf{E_\gamma} \leq 50 \text{ GeV}$$
$$|\cos(\theta_{\gamma-\text{beam}})| < 0.95$$



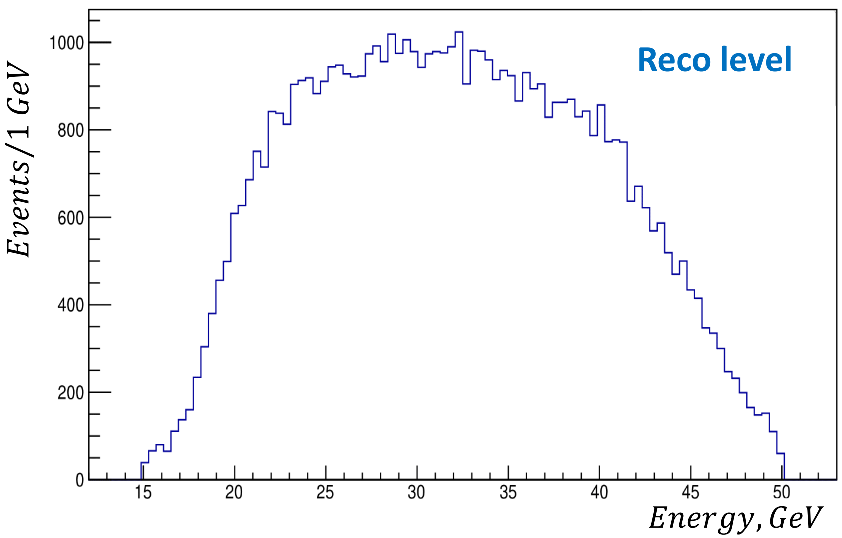




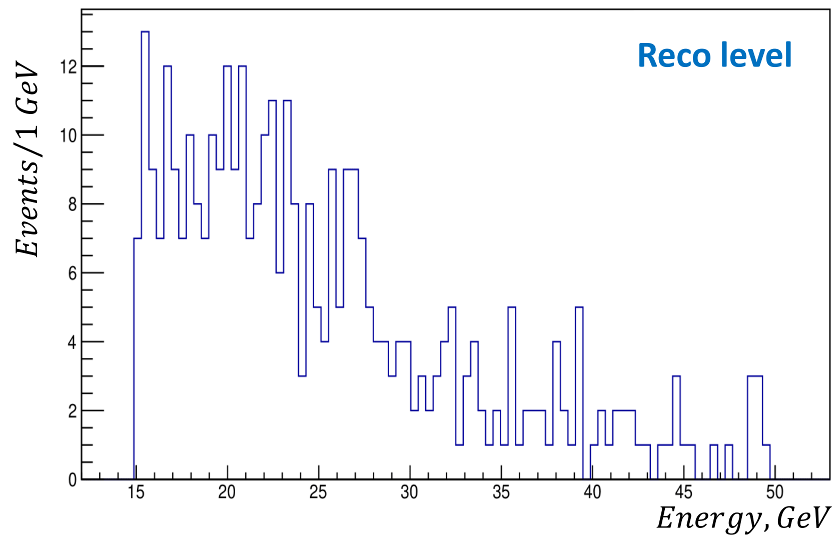
Isolated photon identification

Same cuts are applied on reconstruction level:

$$\begin{cases} 15 \leq E_{\gamma} \leq 50 \text{ GeV} \\ \left|cos(\theta_{\gamma-beam})\right| < 0.95 \end{cases}$$



Signal photons



ISR photons

Jet reconstruction procedure

We identify isolated leptons using ***IsolatedLeptonTagging*** processor with standard parameters and separate it from all PFO's before jet reconstruction.

Process $e^+e^- \to W^+W^-\gamma$ gives a strong background contribution. To suppress this background we select only events with one of **Z bosons decaying to b-jets**.

For jet reconstruction and b-tagging we use ***FastJet*** processor with the ***Valencia algorithm***.

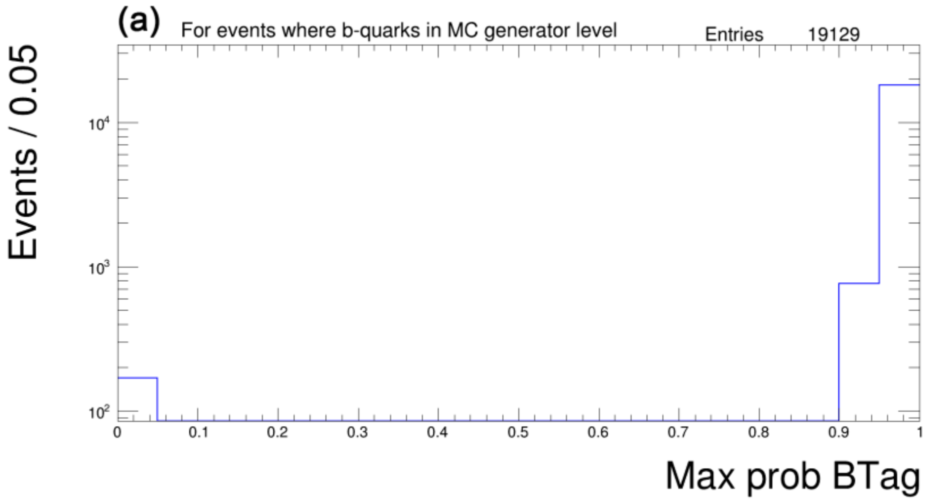
The Algorithm contains 3 parameters: R - generalized jet radius, $\boldsymbol{\gamma}$ and β -special capture parameters in beam distance.

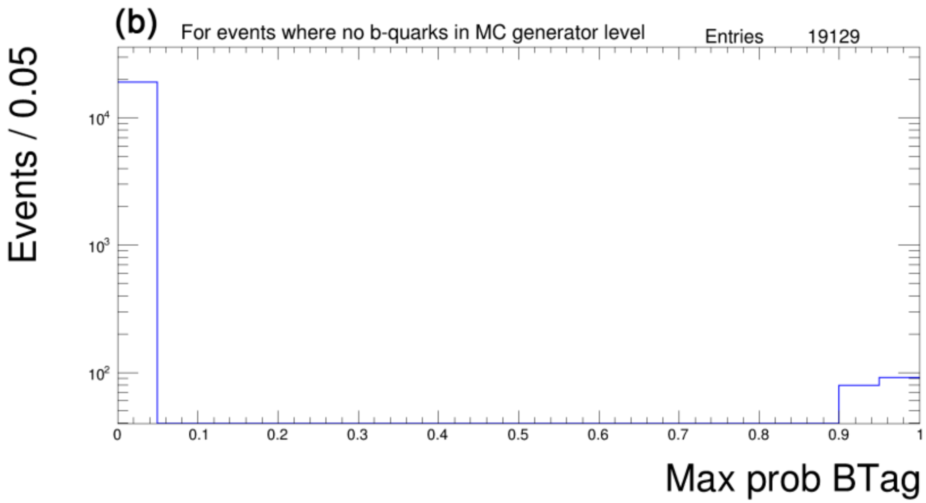
We use **β = 1, R = 1.5 and γ = 0.5**.

Jet reconstruction procedure

The selection criteria for event tagging with b-jets: at least one jet with **more than 90%** probability is identified as b-jet.

The efficiency of the b-tagging is **86%** for the signal process.





Number of misstagging events lass than **1%**.

Studied backgrounds

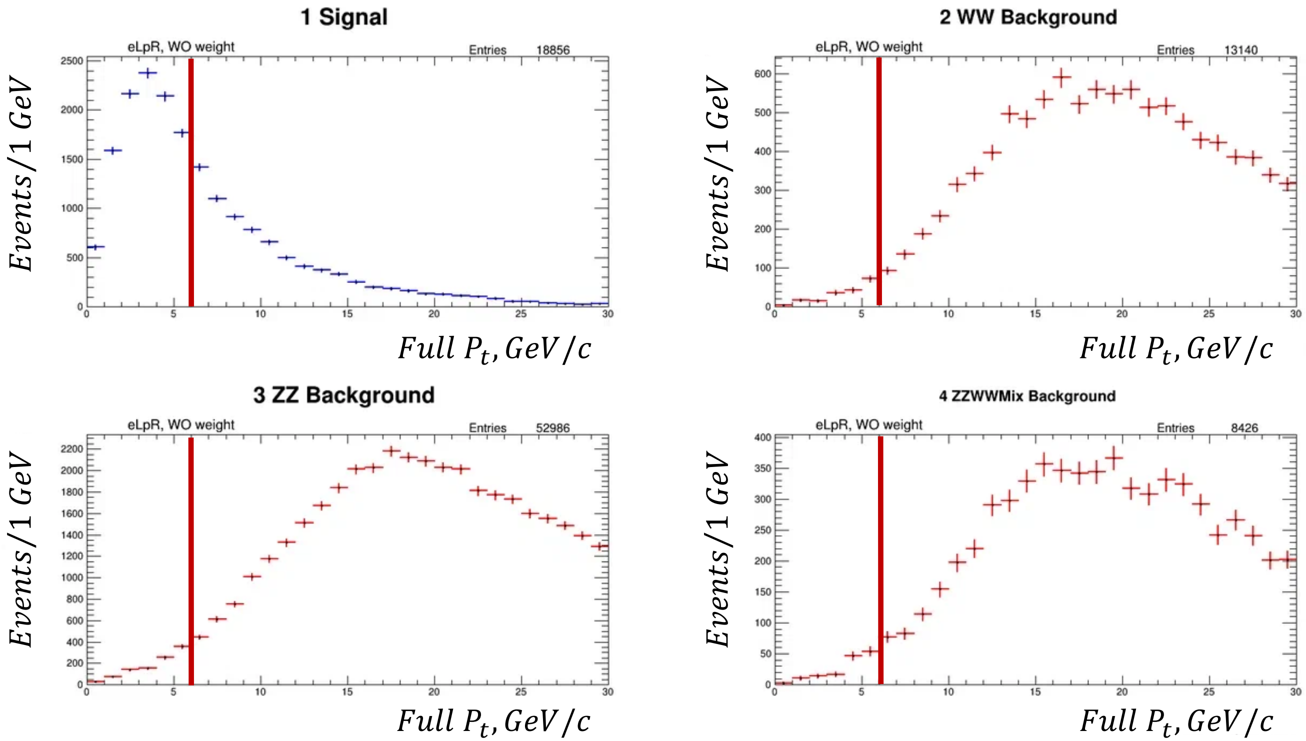
We study many background sources: 2-, 4-, 6-fermion processes, $H(jj)$ where $H \rightarrow all$ and other Higgs boson processes.

Dangerous backgrounds come from 2f_hadronic, 4f_ZZ and e3e3H samples.

Small backgrounds come from 4f_WW and qqH_e3e3 samples.

To suppress backgrounds we applied several cuts:

1) $P_T\,(jjjj\gamma) < 6\ GeV/c$



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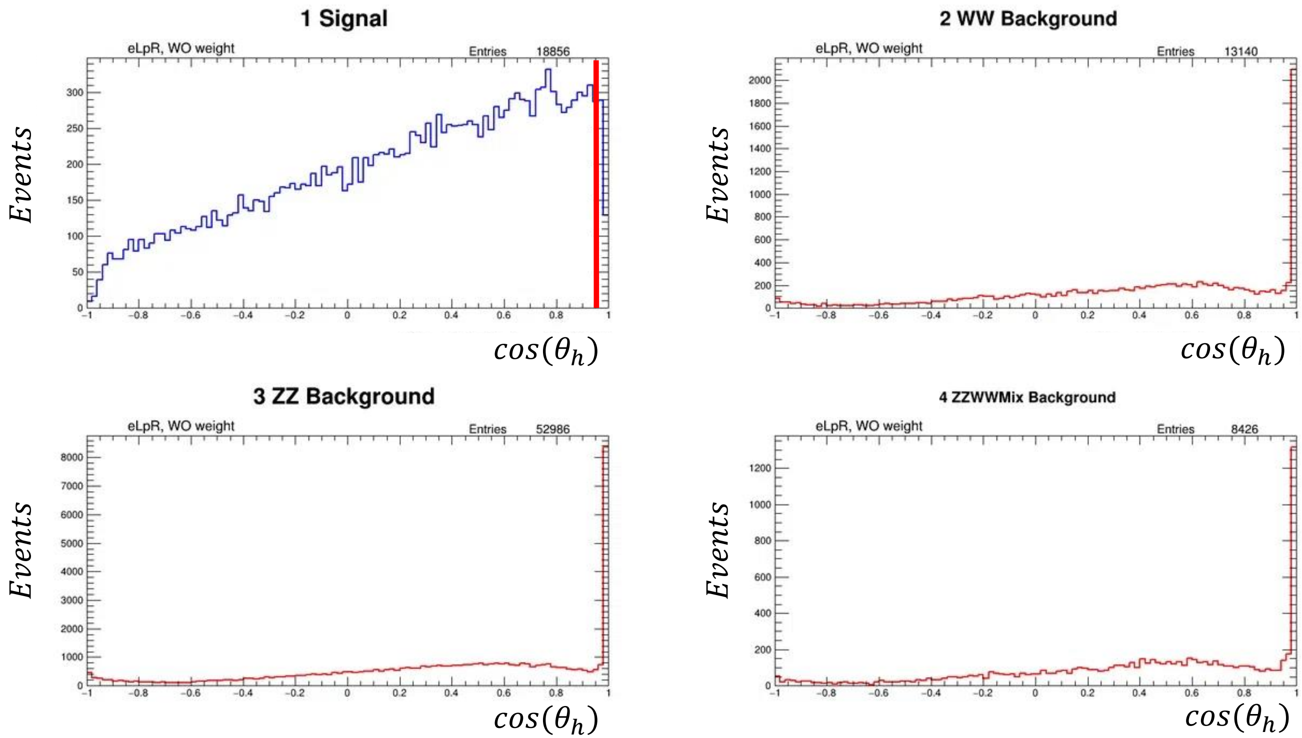
To suppress backgrounds we applied several cuts:

2) Helicity angle between Higgs and jet from Z boson $cos(\theta_h) < 0.98$:



Studied backgrounds

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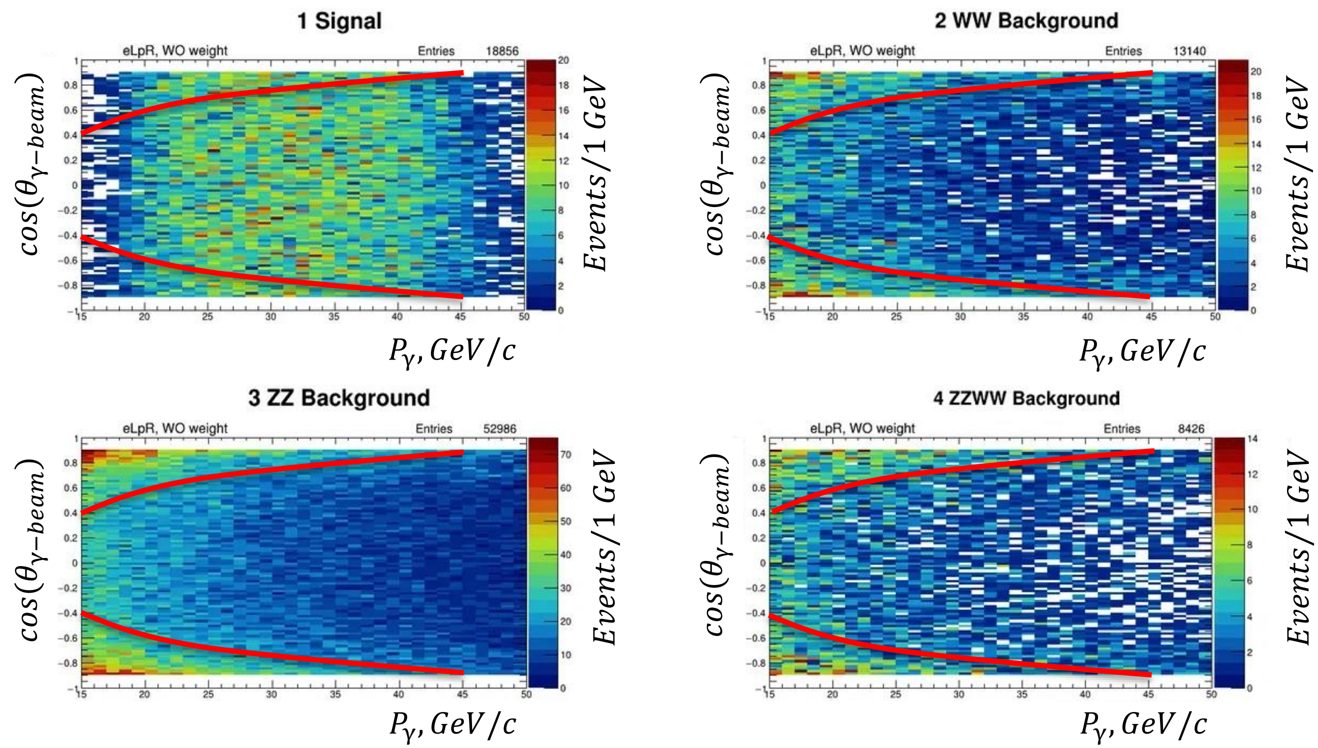
Small background comes from 4f_WW and qqH_e3e3 samples.

To suppress backgrounds we applied several cuts:

3) $|P_\gamma - 35 \cdot cos^2(\theta_{\gamma-beam})$ > 10 GeV/c| :



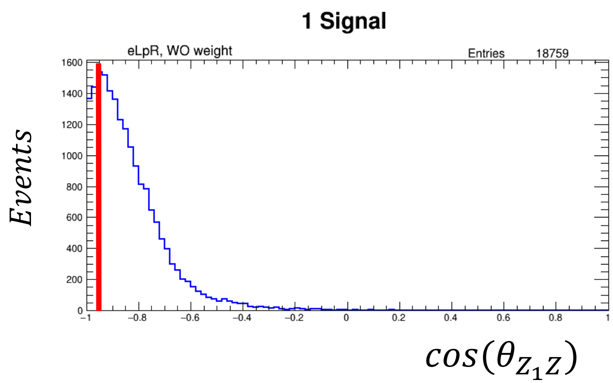
Studied backgrounds

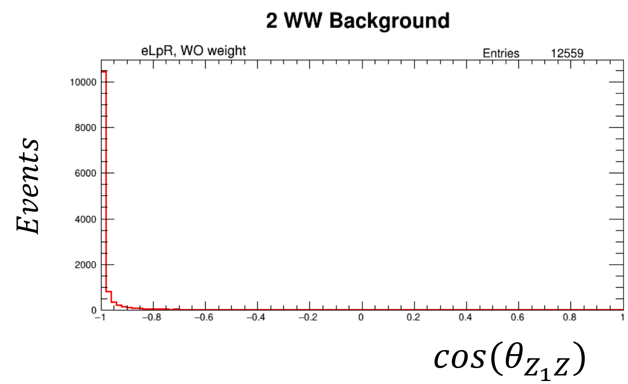
We study many background sources: **2-, 4-, 6-fermion processes**, $\boldsymbol{H(jj)}$ **where** $\boldsymbol{H \rightarrow all}$ and other Higgs boson processes.
Dangerous backgrounds come from 2f_hadronic, 4f_ZZ and e3e3H samples.
Small background comes from 4f_WW and qqH_e3e3 samples.

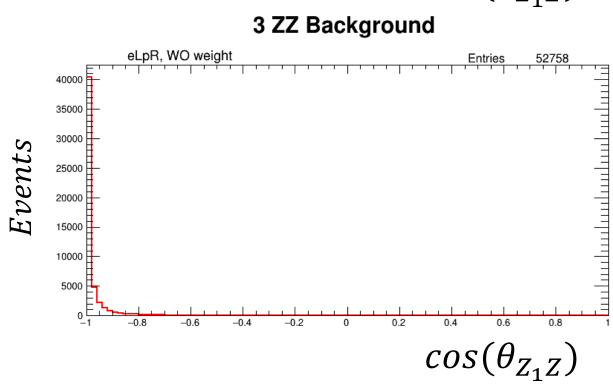
To suppress backgrounds we applied several cuts:

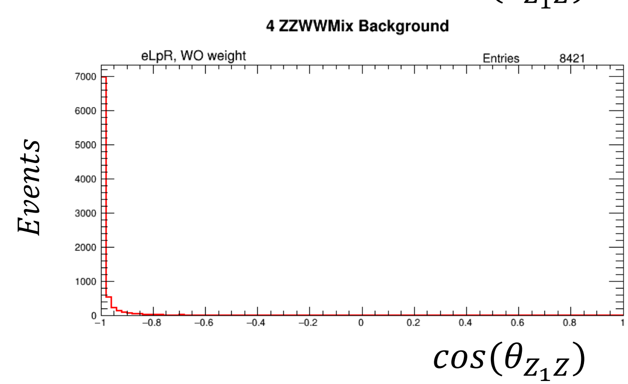
4) $\boldsymbol{cos(\theta_{Z_1 Z}) > -0.98}$ **:**

5) $\boldsymbol{N_{PFO's} > 60}$ **to suppress leptonic backgrounds.**









Technical issues

The final state of the first studied channel includes *four jets*. To form the Z_1 and Z bosons from these four jets we calculate χ^2 for six possible two-jet combinations:

$$\chi^2 = \frac{\left(M(Z_1) - M(Z_{nom})\right)^2}{\sigma^2_{M_{Z_1}}} + \frac{\left(M(Z) - M(Z_{nom})\right)^2}{\sigma^2_{M_Z}} + \frac{\left(P(Z_1) - \bar{P}(Z_1)\right)^2}{\sigma^2_{P_{Z_1}}} + \frac{\left(P(Z+\gamma) - \bar{P}(Z_1)\right)^2}{\sigma^2_{P_{Z+\gamma}}}$$

$\overline{P}(Z_1) = 60.0\ \mathrm{GeV}/c$ is the mean Z_1 momentum

$M(Z_{\mathrm{nom}}) = 91.2\ \mathrm{GeV}$

All σ parameters are the mean widths of corresponding mass or momentum distributions on the reconstruction level.

To get expected number of signal or background events we apply weight factors to each event:

$$W = \left[\frac{1 \pm 0.8}{2} \cdot \frac{1 \pm 0.3}{2}\right] \cdot \frac{2\ \mathrm{ab}^{-1}}{\mathcal{L}_{\mathrm{nom}}}$$

Mass difference is used to get a better mass resolution:

$$\boldsymbol{M_\Delta = M(jj\gamma) - M(jj) + M(Z_{nom})}$$

Results with 2 ab^{-1}

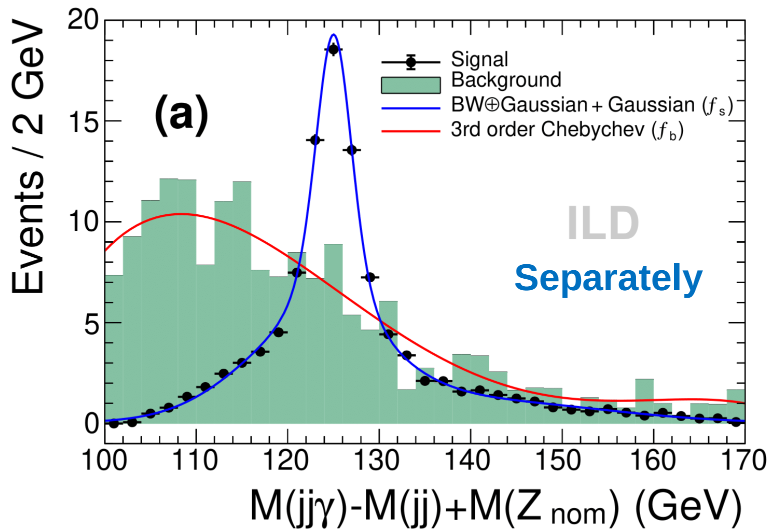
After weighting and applying all cuts the $\boldsymbol{M}_\Delta$ distributions is obtained for $\mathcal{P}_{e^-e^+} = (-0.8, +0.3)$ with $2\,ab^{-1}$ integrated luminosity.

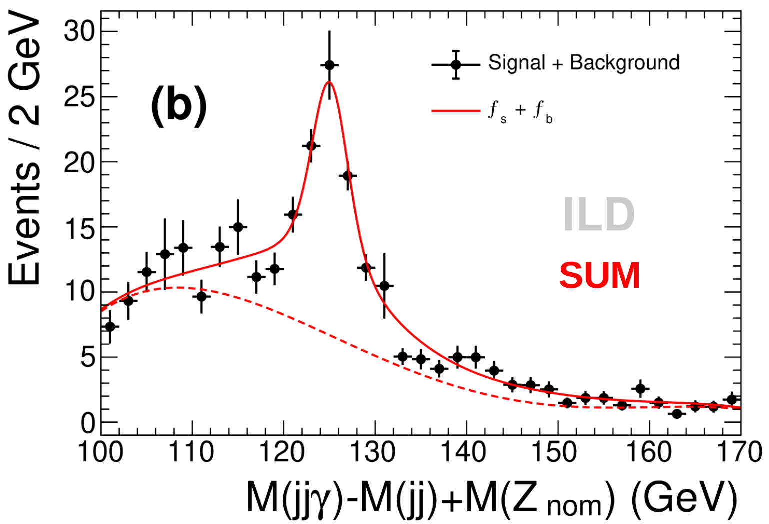
The signal distribution was described by the convolution of Breit-Wigner and Gaussian functions + additional wide Gaussian to describe left side.

The background distribution is described by 3-rd order Chebychev polynomial.

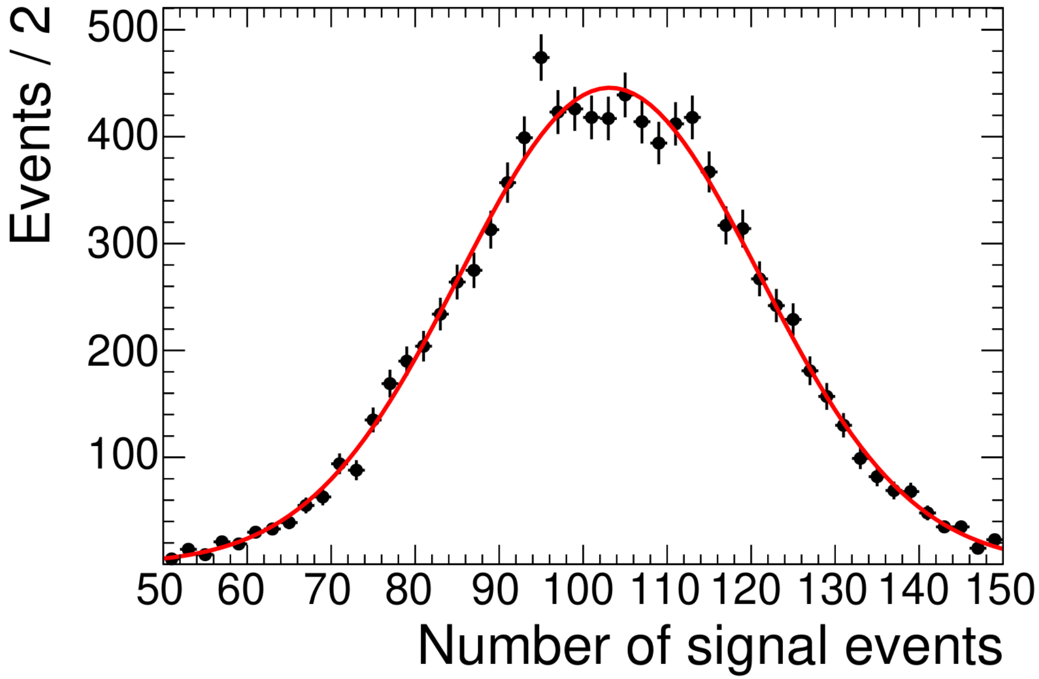
The fit yields $\mathbf{103.9 \pm 17.4}$ signal events for $\boldsymbol{2\,ab^{-1}}$ with single polarization.

This corresponds to uncertainty of 16.7%.





Toy MC results with 2 ab^{-1}



The **10000** $\boldsymbol{M_\Delta}$ mass distributions are generated using the shapes and normalizations for the sum of the signal and background distributions obtained separately.

Toy MC yields $\mathbf{103.2 \pm 17.9}$ signal events.
This corresponds to uncertainty of 17.3%.

Conclusions

We studied the $e^+e^- \to HZ$ process with the subsequent $\boldsymbol{H \to Z\gamma}$ decay.

The analysis is performed assuming the integrated luminosity $2\ \mathrm{ab}^{-1}$ collected at the e^+e^- collisions with center-of-mass energy 250 GeV and the beam polarizations $\mathcal{P}_{e^-e^+} = (-0.8, +0.3)$.

The corresponding signal and background contributions are estimated using all ILD MC simulated samples.

We obtain the statistical uncertainty of 17.3% with $2\ \mathrm{ab}^{-1}$ at 250 GeV.

List of studied background samples

2f_hadronic (eLpR, eRpL)
2f_leptonic (eLpR, eRpL)
2f_eehiq (eLpR, eRpL, eLpL, eRpR)
4f_singleW_leptonic (eLpR, eRpL, eLpL, eRpR)
4f_singleW_semileptonic (eLpR, eRpL, eLpL, eRpR)
4f_singleZee_leptonic (eLpR, eRpL, eLpL, eRpR)
4f_singleZee_semileptonic (eLpR, eRpL, eLpL, eRpR)
4f_singleZnunu_leptonic (eLpR, eRpL)
4f_singleZnunu_semileptonic (eLpR, eRpL)
4f_singleZsingleWMix_leptonic (eLpR, eRpL, eLpL, eRpR)
4f_WW_hadronic (eLpR, eRpL)
4f_WW_leptonic (eLpR, eRpL)
4f_WW_semileptonic (eLpR, eRpL)
4f_ZZ_hadronic (eLpR, eRpL)
4f_ZZ_leptonic (eLpR, eRpL)
4f_ZZ_semileptonic (eLpR, eRpL)
4f_Znunu_leptonic (eLpR, eRpL)
4f_Znunu_semileptonic (eLpR, eRpL)
4f_ZZWWMix_hadronic (eLpR, eRpL)
4f_ZZWWMix_leptonic (eLpR, eRpL)
6f_eexxxx (eLpR, eRpL, eLpL, eRpR)
6f_eexyyx (eLpR, eRpL, eLpL, eRpR)
6f_eeyyyy (eLpR, eRpL, eLpL, eRpR)
6f_llxxxx (eLpR, eRpL)
6f_llxyyx (eLpR, eRpL)
6f_llyyyy (eLpR, eRpL)
6f_vvxxxx (eLpR, eRpL)
6f_vvxyyx (eLpR, eRpL)
6f_vvyyyy (eLpR, eRpL)

e1e1H (eLpR, eRpL, eLpL, eRpR)
e2e2H (eLpR, eRpL)
e3e3H (eLpR, eRpL)
n1n1H (eLpR, eRpL)
n23n23H (eLpR, eRpL)
qqh_aa (eLpR, eRpL)
qqh_bb (eLpR, eRpL)
qqh_cc (eLpR, eRpL)
qqh_e2e2 (eLpR, eRpL)
qqh_e3e3 (eLpR, eRpL)
qqh_gg (eLpR, eRpL)
qqh_ww (eLpR, eRpL)
qqh_zz (eLpR, eRpL)

Text of the paper draft will be ready soon.