Measurement of $\sigma(e^+e^- \to HZ) \times Br(H \to ZZ^*)$ at the 250 GeV ILC

published in Phys Rev D. DOI: 10.1103/PhysRevD.104.093007

E. Antonov (LPI/MEPhI) on behalf of the ILD Collaboration

Introduction

Width of the Higgs boson *is difficult to measure at LHC in a model-independent approach* (the uncertainty is expected to be ~20% after LHC luminosity upgrade) [DOI: 10.1093/ptep/ptaa104].

We propose to use the process $e^+e^- \to HZ$ with the subsequent decay $H \to ZZ^*$ to measure **in ILC**:

$$\sigma(e^+e^- \to HZ) \times Br(H \to ZZ^\star) = C \cdot g_Z^4/\Gamma_H$$

Constant, Error < 1% expected arXiv:1403.7734

Coupling HZZ Error < 0.5% expected arXiv:1903.01629

Higgs boson width

Full Geant-4-based detector simulation

One of secondary Z bosons (from Higgs boson decay) is reconstructed from two quarks:

$$Z_1 \to jj \text{ or } \nu\nu,\ Z \to jj \text{ or } ll,\ Z^\star \to ll \text{ or } jj$$

On-shell Off-shell

Channel 1: $e^+e^- \to Z_1(j_1j_2)\,H, \quad H \to Z(j_3j_4)Z^\star(\ell_1\ell_2)$

Channel 2: $e^+e^- \to Z_1(j_1j_2)\,H, \quad H \to Z(\ell_1\ell_2)Z^\star(j_3j_4)$

Channel 3: $e^+e^- \to Z_1(\nu\bar{\nu})\,H, \quad H \to Z(j_1j_2)Z^\star(\ell_1\ell_2)$

Channel 4: $e^+e^- \to Z_1(\nu\bar{\nu})\,H, \quad H \to Z(\ell_1\ell_2)Z^\star(j_1j_2)$

Analysis steps

Channels	$\mathcal{P}_{e^-e^+}$	MC events	Lepton tagging, events	Weight factors	Weighted number of events
$Z_1(jj)$, $Z(jj)$, $Z^*(\ell\ell)$	eLpR eRpL	23989 23845	16088 16027	$2.1 \cdot 10^{-2}$ $1.3 \cdot 10^{-3}$	338 21
$Z_1(jj)$, $Z(\ell\ell)$, $Z^*(jj)$	eLpR eRpL	23261 23132	20879 20664	$2.1 \cdot 10^{-2}$ $1.3 \cdot 10^{-3}$	439 27
$Z_1(\nu_e\bar{\nu}_e)$, $Z(jj)$, $Z^\star(\ell\ell)$	eLpR eRpL	24044 23910	17429 17259	$3.7 \cdot 10^{-3}$ $7.9 \cdot 10^{-5}$	65 1.4
$Z_1(\nu_e\bar{\nu}_e)$, $Z(\ell\ell)$, $Z^\star(jj)$	eLpR eRpL	23059 23096	21108 21149	$3.7 \cdot 10^{-3}$ $7.9 \cdot 10^{-5}$	79 1.7
$Z_1(\nu_{\mu,\tau}\bar{\nu}_{\mu,\tau})$, $Z(jj)$, $Z^\star(\ell\ell)$	eLpR eRpL	23840 23862	17103 17168	$4.1 \cdot 10^{-3}$ $1.6 \cdot 10^{-4}$	71 2.7
$Z_1(\nu_{\mu,\tau}\bar{\nu}_{\mu,\tau})$, $Z(\ell\ell)$, $Z^\star(jj)$	eLpR eRpL	23189 23225	21168 21246	$4.1 \cdot 10^{-3}$ $1.6 \cdot 10^{-4}$	88 3.3

1. For detailed background studies we extract specific processes on generator level.
2. We identify two isolated lepton candidates.
3. ISR identification and removing procedure. DOI: 10.1140/epjc/s10052-020-08729-7
4. Jet reconstruction using clustering tools.
5. Applying weight factors to each event to get expected number of signal or background events.

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

$\mathcal{L}$ - the sample integrated luminosities

Valencia algorithm is used to force the remaining particles into 2 or 4 jets.

Optimized Valencia algorithm parameters chosen for the jet reconstruction in different channels:

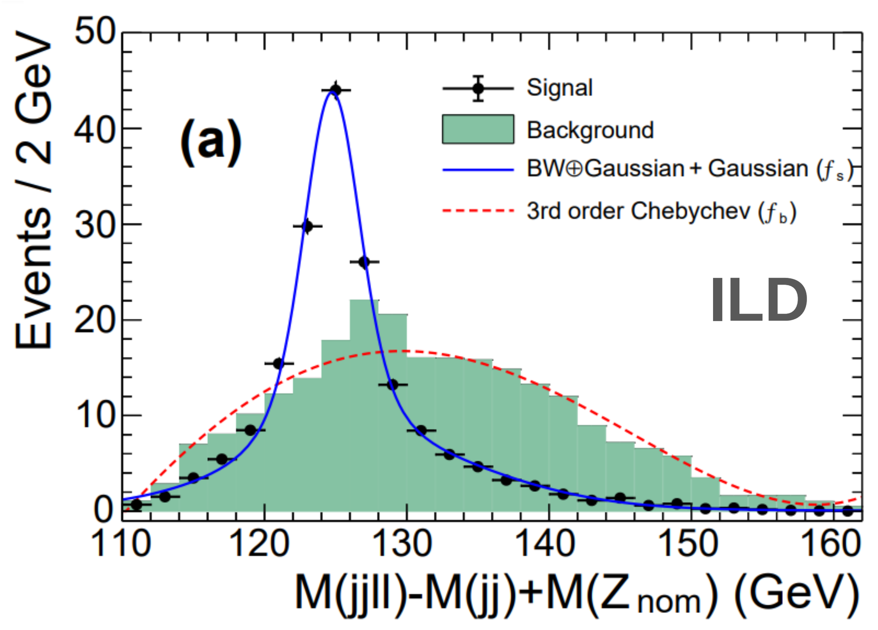
Valencia parameters	$Z_1(jj)$, $Z(jj)$, $Z^*(\ell\ell)$	$Z_1(jj)$, $Z(\ell\ell)$, $Z^*(jj)$	$Z_1(\nu\bar{\nu})$, $Z(jj)$, $Z^*(\ell\ell)$	$Z_1(\nu\bar{\nu})$, $Z(\ell\ell)$, $Z^*(jj)$
β	1.0	1.0	1.0	1.0
γ	0.4	0.4	0.6	0.3
R	1.6	0.7	1.4	1.4

To cancel jet reconstruction uncertainties:

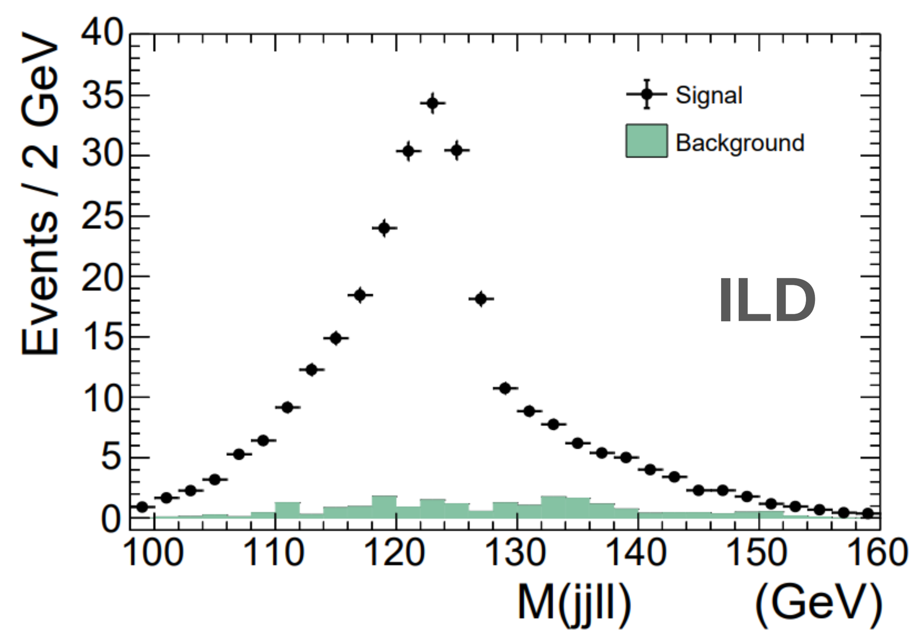
$$M_\Delta = M(jj\ell\ell) - M(jj) + M(Z_{nom})$$

Analysis results for four channels

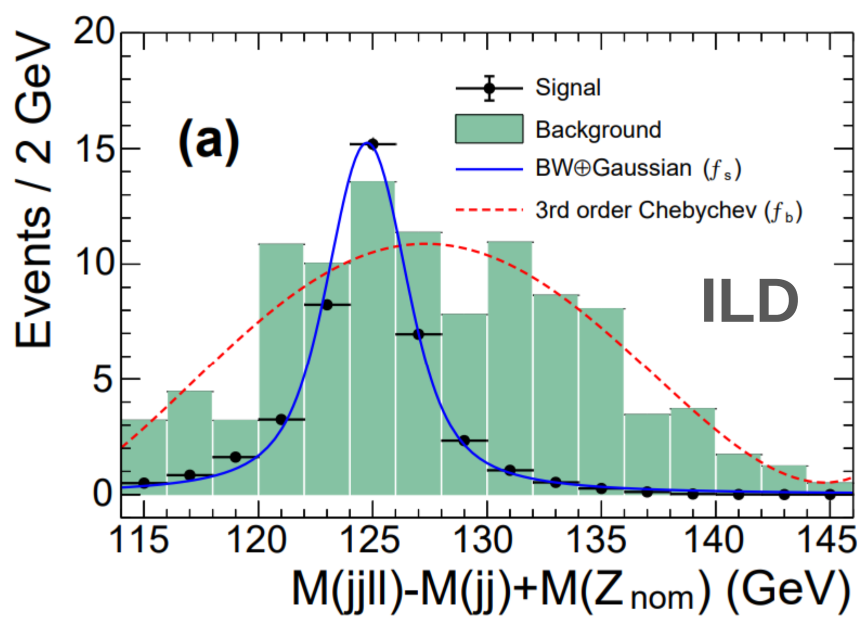
Channel 1:



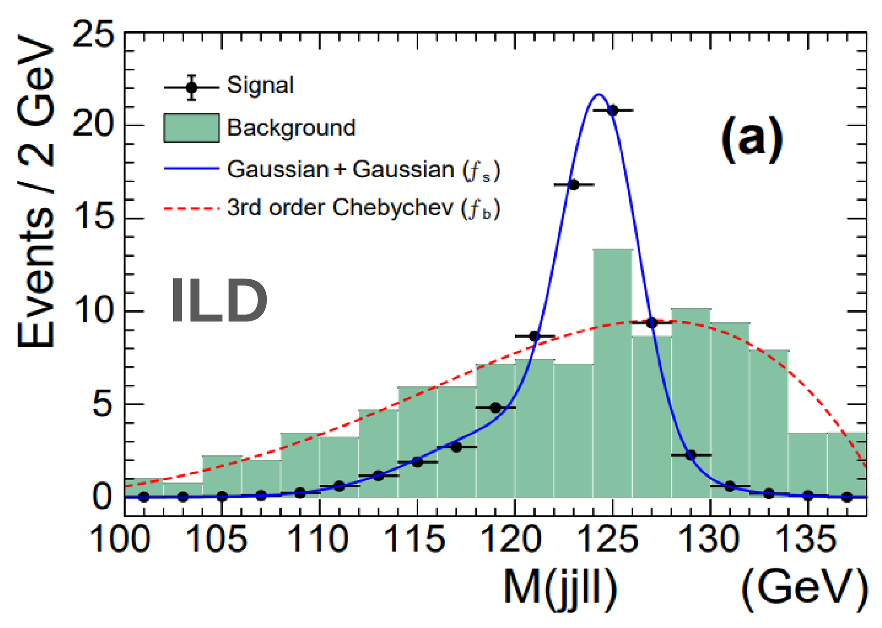
Channel 2:

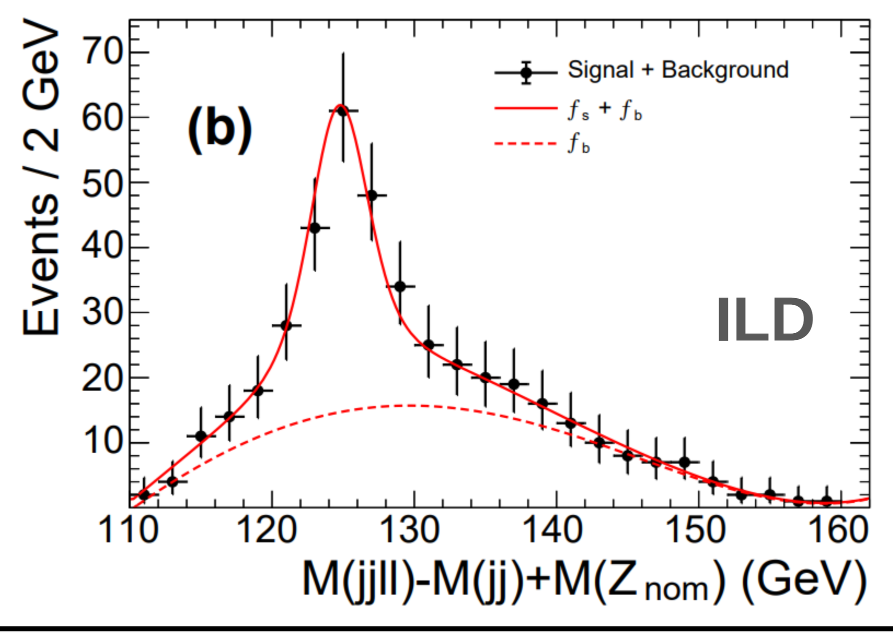


Channel 3:



Channel 4:





f_s – *fraction of signal*

f_b – *fraction of background*

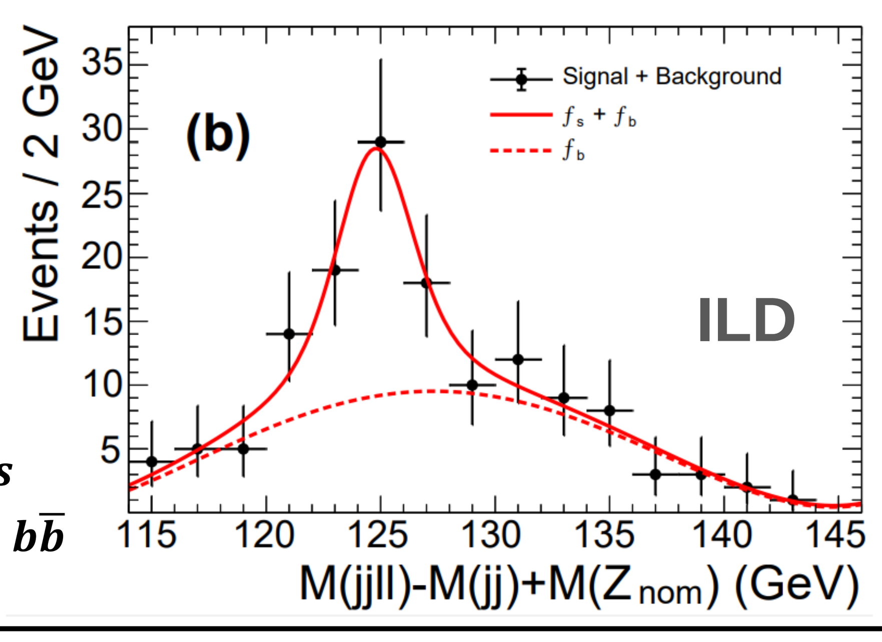
Dominant backgrounds:

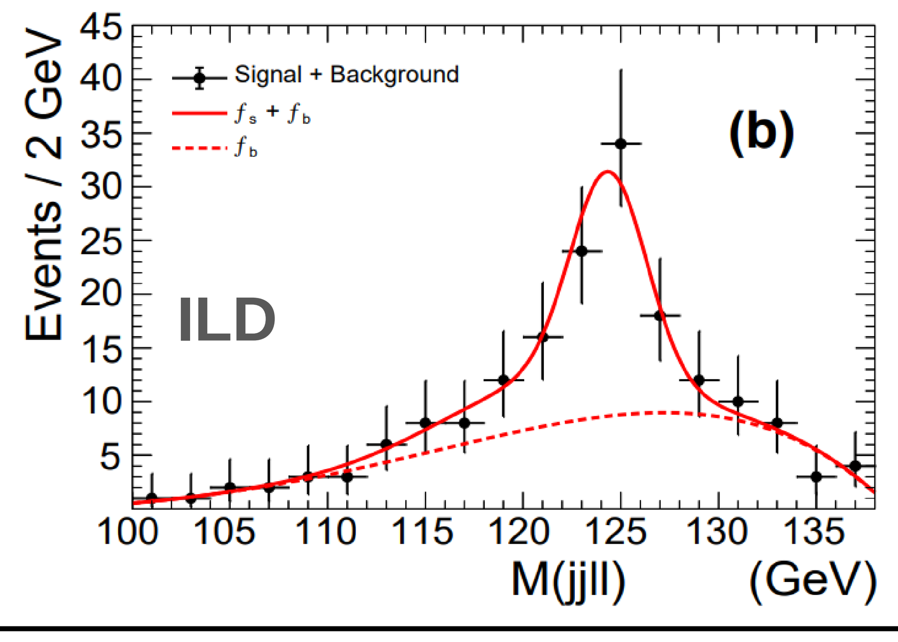
Ch 1: $W^+W^-\gamma^*$ *and* $ZZ\gamma^*$, *where* $\gamma^* \to ll$

Ch 2: *No significant background*

Ch 3: $Z(2j)Z(2\tau)$ *with* τ *leptonic decays,* $W(2j)W(lv)$, $b\bar{b}$ *semileptonic decays*

Ch 4: *Similar to the channel 3 except the* $b\bar{b}$





Combined signal significance estimate

We calculate the combined statistical uncertainty from statistical significance of individual channels:

$$S_{\text{comb}} = 1/\sqrt{\sum_{i=1}^{4} S_i^{-2}}$$

These results indicate that the Higgs width can be measured at ILC with an accuracy of about (5-6)% in the model-independent approach.

Number of signal events and uncertainties for each channel

	$Z_1(jj)$, $Z(jj)$, $Z^*(\ell\ell)$	$Z_1(jj)$, $Z(\ell\ell)$, $Z^*(jj)$	$Z_1(\nu\bar{\nu})$, $Z(jj)$, $Z^*(\ell\ell)$	$Z_1(\nu\bar{\nu})$, $Z(\ell\ell)$, $Z^\star(jj)$	Sum
		2 ab^{-1} eLpR			
Number of events	192.4 $\pm$24.9	275.3 $\pm$17.2	51.9 $\pm$13.0	73.3 $\pm$14.2	- -
Statistical uncertainty	12.9%	6.3%	25.1%	19.3%	5.29%
		0.9 ab^{-1} eLpR + 0.9 ab^{-1} eRpL			
Number of events	135.2 $\pm$20.4	202.2 $\pm$14.7	30.9 $\pm$10.7	67.3 $\pm$14.3	- -
Statistical uncertainty	15.1%	7.3%	34.6%	21.2%	6.15%

Conclusions

At 250 GeV the accuracy of this method is similar to one obtained in arXiv:1310.0763, arXiv:1403.7734 using the combination of four channels measurements. The results of both methods can be combined to further improve the accuracy.

Our measurement can be used to test the Higgs width value obtained within the SM, as well as within the EFT approach. The theoretical accuracy of the Higgs width is expected to be about 2% [DOI: 10.1103/PhysRevD.97.053003].

The Higgs boson width can be measured in ILC experimentally *in a model-independent approach with accuracy is about (5-6)%*.

30th International Symposium on Lepton Photon Interactions at High Energies
Jan 10-14, 2022