Total Higgs Width from WW-fusion at the ILC

Claude Fabienne Dürig

University of Bonn, Germany

December 2012

Helmholtz Alliance, 6th Annual Workshop

Contents

Contents

Introduction

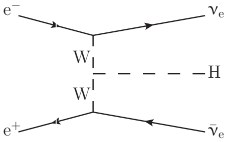
- **model-independent measurement** of Higgs decay width
- $\sqrt{s} = 250$ GeV and $\mathcal{L} = 250\ \text{fb}^{-1}$
- **aim of study**: estimate the measurement accuracies of the total decay width obtainable at the ILC
- $m_H = 120$ GeV, 126 GeV, 130 GeV, 140 GeV
- WW-fusion: $e^+e^- \longrightarrow \nu_e\bar{\nu}_e H$
- former study on the same topic for TESLA $\longrightarrow$ $\sqrt{s} = 350$ GeV/500 GeV

  Niels Meyer: Higgs-Bosons at TESLA: Studies on production in WW-fusion and total decay width (University of Hamburg, Germany, July 2000)

Contents

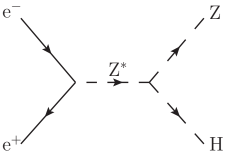
Higgs Production Processes

WW-fusion



$e^+e^- \rightarrow \nu_e\bar{\nu}_e H$

Higgs-strahlung



$e^+e^- \rightarrow Z^\star \rightarrow ZH$

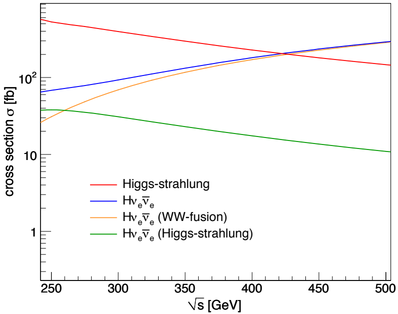


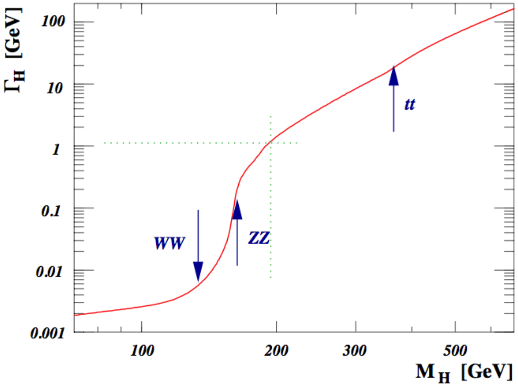
Figure: Production cross section σ as a function of $\sqrt{s}$ for $m_H = 120$ GeV

- $H\nu_e\bar{\nu}_e \rightarrow ZH$ and WW-fusion interfere

- σ(Higgs-strahlung) max.: $\sqrt{s} = m_H + m_Z$
  $\longrightarrow$ dominant at low $\sqrt{s}$

- σ(WW-fusion) dominant at high $\sqrt{s}$

Total Decay Width of the Higgs Boson



Meyer,N.: *Higgs-Boson at TESLA: Studies on Production in WW-Fusion and Total Decay Width*, University of Hamburg, Germany, 2000

- for $m_H \geq 190$ GeV:

  $\Gamma_H^{tot} \sim 1$ GeV direct determination possible

- for $m_H \leq 190$ GeV:

  detector resolution significantly larger than natural width of Higgs boson

  determination of Γ_H^{tot}

  ↓

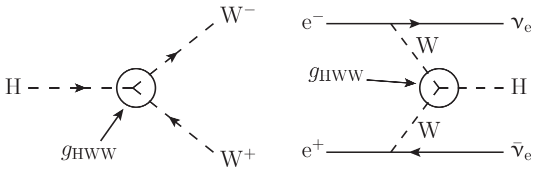
  indirect methods

  ↓

  which method?

Contents

Determination of Γ_H^{tot} by measuring the coupling g_{HWW}



Decay: $H \to WW$

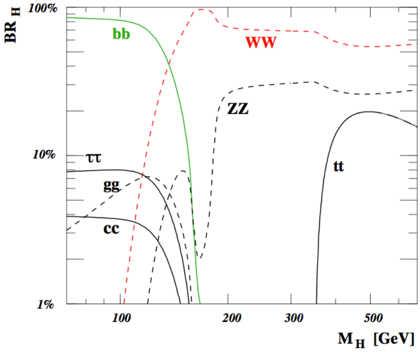
WW-fusion

coupling g_{HWW} unknown

$$\Gamma_H(H \to WW) \propto g_{HWW}^2 \propto \sigma(\text{WW-fusion})$$

$$\Gamma_H^{tot} = \frac{\Gamma_H(H \to WW)}{BR(H \to WW)} \longrightarrow \boxed{\Gamma_H^{tot} \propto \frac{\sigma(\text{WW-fusion})}{BR(H \to WW)}}$$

Determination of σ(WW-fusion)



MEYER,N.: *Higgs-Boson at TESLA: Studies on Production in WW-Fusion and Total Decay Width*, University of Hamburg, Germany, 2000

low m_H range:

$$m_H = 120\ \text{GeV} - 140\ \text{GeV}$$

dominant decay mode: $\boxed{H \rightarrow b\bar{b}}$

$$\sigma(\text{WW-fusion}) = \frac{\sigma_{fus}(H \rightarrow b\bar{b})}{BR(H \rightarrow b\bar{b})}$$

$$\text{WW-fusion} : e^+e^- \longrightarrow \nu_e\bar{\nu}_e H \longrightarrow \nu_e\bar{\nu}_e b\bar{b}$$

Signal sample

generating events: **Whizard** 1.95 $\longrightarrow$ $e^+e^- \to \nu_l\bar{\nu}_l H$ for $P_{e^+e^-} = (0.3, -0.8)$

ILC Software (version 01-11)

- Mokka (mokka-07-06-p02)
  $\longrightarrow$ detector model ILD_00
- Marlin (v01-00)
- LCTuple LCIO (v01-51-02)

number of events in each sample:

m_H[GeV]	$N(\nu_l\bar{\nu}_l H)$	$N(\nu_l\bar{\nu}_l b\bar{b})$
120	20 430	13 870
126	17 428	11 831
130	17 203	11 679
140	12 771	8 671

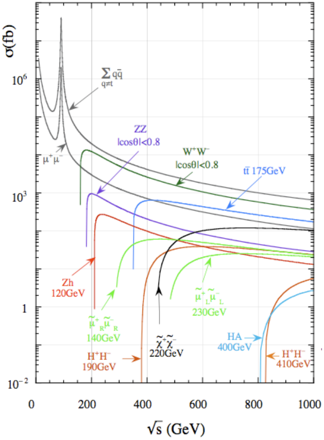
WW-fusion contribution:

m_H[GeV]	$N(\nu_e\bar{\nu}_e H)$	$N(\nu_e\bar{\nu}_e b\bar{b})$
120	4 520	3 065
126	3 426	2 325
130	3 343	2 266
140	2 398	1 626

Higgs-strahlung contribution:

m_H[GeV]	$N(\nu_l\bar{\nu}_l H)$	$N(\nu_l\bar{\nu}_l b\bar{b})$
120	16 019	10 876
126	14 002	9 506
130	13 653	9 257
140	9 345	6 344

Background Samples



http://www-zeuthen.desy.de/ILC/physics/

centre of mass energy: $\sqrt{s} = 250$ GeV

luminosity: $\mathcal{L} = 250\ \text{fb}^{-1}$

polarisation: $P_{e^+e^-} = (0.3, -0.8)$

$e^+e^- \rightarrow$	N_{bgrd}
$\nu_l\bar{\nu}_l b\bar{b}$	30 562
$\nu_l\bar{\nu}_l q\bar{q}$	119 296
$l^+l^- q\bar{q}$	299 741
$q\bar{q}l\nu_l$	1 730 574
$q\bar{q}q\bar{q}$	3 908 020
$q\bar{q}$	$26.016 \cdot 10^6$

$$N_{bgrd}^{tot} = 32.104 \cdot 10^6$$

Contents

cutflow ($m_H = 120$ GeV)	
0	no cut
1	$10 \leq N_{ctrk} \leq 40$
2	no isolated leptons
3	$m_H - 20\text{ GeV} \leq m_{vis} \leq m_H + 10\text{ GeV}$
4	$100\text{ GeV} \leq E_{vis} \leq 160\text{ GeV}$
5	$20\text{ GeV} \leq \sum p_T \leq 80\text{ GeV}$
6	$Y_{23} \leq 0.02$
7	$0.2 \leq Y_{12} \leq 0.8$
8	btag ≥ 0.85
9	$-60\text{ GeV} \leq p_z \leq 60\text{ GeV}$
10	$\lvert\cos(\theta_{jet})\rvert \leq 0.95$

$m_H = 126$ GeV:

$$105\text{ GeV} \leq E_{vis} \leq 160\text{ GeV}$$

$m_H = 130$ GeV:

$$110\text{ GeV} \leq E_{vis} \leq 160\text{ GeV}$$

$m_H = 140$ GeV:

$$125\text{ GeV} \leq E_{vis} \leq 170\text{ GeV}$$

$m_H = 120$ GeV	N_{WW}	N_{ZH}	N_{bgrd}^{tot}
no cut	4 525	16 019	$32.104 \cdot 10^6$
cut	898	2 767	534

$m_H = 126$ GeV	N_{WW}	N_{ZH}	N_{bgrd}^{tot}
no cut	3 426	14 002	$32.104 \cdot 10^6$
cut	507	2 546	449

$m_H = 130$ GeV	N_{WW}	N_{ZH}	N_{bgrd}^{tot}
no cut	3 343	13 653	$32.104 \cdot 10^6$
cut	401	2 079	366

$m_H = 140$ GeV	N_{WW}	N_{ZH}	N_{bgrd}^{tot}
no cut	2 398	9 345	$32.104 \cdot 10^6$
cut	190	759	433

WW-fusion and Higgs-strahlung can be separated by exploiting their different characteristics in the $\nu\bar{\nu}$ invariant mass

χ^2-fit on missing mass distribution

normalised MC as reference   Fit-parameter: N'_{WW}, N'^{tot}_{bgrd}, N'_{ZH}

$$\sigma(\text{WW-fusion}) = \frac{\sigma_{fus}(H \to b\bar{b})}{BR(H \to b\bar{b})} \longrightarrow \frac{N'_{WW}}{\epsilon \cdot \mathcal{L} \cdot BR(H \to b\bar{b})}$$

Measurement accuracy of σ(WW-fusion):

$$\frac{\Delta N'_{WW}}{N'_{WW}} \;\&\; \frac{\Delta BR(H \to b\bar{b})}{BR(H \to b\bar{b})}^{*} \longrightarrow \frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$$

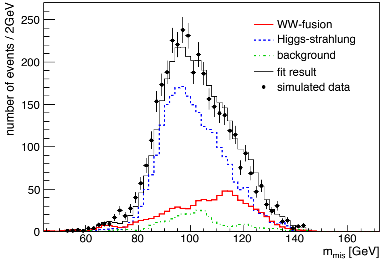
Measurement accuracy of Γ_H^{tot}:

$$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})} \;\&\; \frac{\Delta BR(H \to WW)}{BR(H \to WW)}^{**} \longrightarrow \frac{\Delta\Gamma_H^{tot}}{\Gamma_H^{tot}}$$

* H. Ono, A. Miyamoto: *Higgs Branching Fraction Study in ILC*, arXiv:1202.4955v1 [hep-ex];

** J. Tian, H. Ono: *Branching fraction analysis*, KLIC12

Results for $m_H = 120$ GeV:



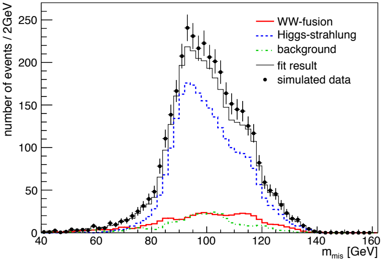
$$\frac{\Delta BR(H\to b\bar{b})}{BR(H\to b\bar{b})} = 2.7\,\%, \quad \frac{\Delta BR(H\to WW)}{BR(H\to WW)} = 8.4\,\%$$

$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
873 ± 58	$2\,666 \pm 66$

$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
6.64 %	2.48 %	7.2 %

$\longrightarrow$ $\Delta\Gamma_H^{tot}/\Gamma_H^{tot} = 11.06\,\%$

Results for $m_H = 126$ GeV:



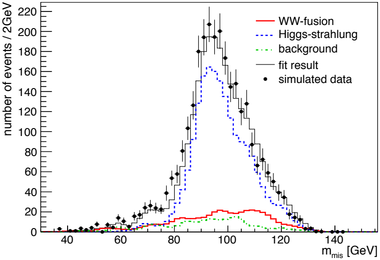
$$\frac{\Delta BR(H\to b\bar{b})}{BR(H\to b\bar{b})} = 3.0\,\%, \quad \frac{\Delta BR(H\to WW)}{BR(H\to WW)} = 7.2\,\%$$

$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
512 ± 54	$2\,497 \pm 85$

$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
10.54 %	3.4 %	10.96 %

$\longrightarrow$ $\Delta\Gamma_H^{tot}/\Gamma_H^{tot} = 13.11\,\%$

Results for $m_H = 130$ GeV:



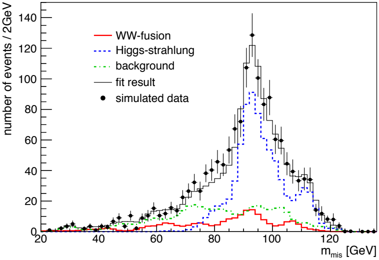
$$\frac{\Delta BR(H \to b\bar{b})}{BR(H \to b\bar{b})} = 3.5\,\%, \quad \frac{\Delta BR(H \to WW)}{BR(H \to WW)} = 5.8\,\%$$

$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
407 ± 46	$1\,978 \pm 78$

$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
11.3 %	3.89 %	11.83 %

$\longrightarrow$ $\Delta\Gamma_H^{tot}/\Gamma_H^{tot} = 13.18\,\%$

Results for $m_H = 140$ GeV:

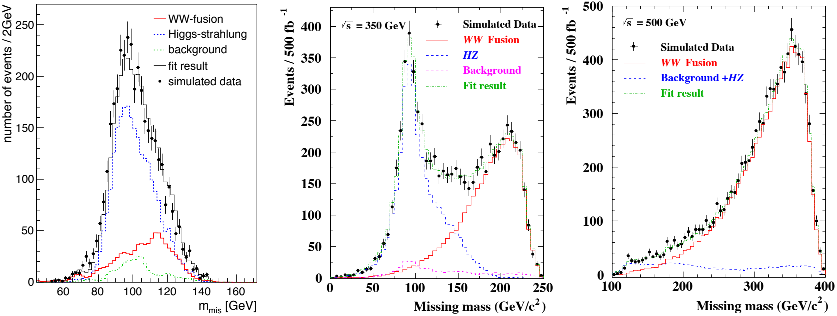


$$\frac{\Delta BR(H \to b\bar{b})}{BR(H \to b\bar{b})} = 5.1\,\%, \quad \frac{\Delta BR(H \to WW)}{BR(H \to WW)} = 4.4\,\%$$

$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
185 ± 44	737 ± 30

$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
23.78 %	4.07 %	24.32 %

$\longrightarrow$ $\Delta\Gamma_H^{tot}/\Gamma_H^{tot} = 24.71\,\%$



	$\sqrt{s} = 250$ GeV		$\sqrt{s} = 350$ GeV*		$\sqrt{s} = 500$ GeV*	
m_H[GeV]	$\Delta\sigma(WW)/\sigma(WW)$	$\Delta\Gamma_H^{tot}/\Gamma_H^{tot}$	$\Delta\sigma(WW)/\sigma(WW)$	$\Delta\Gamma_H^{tot}/\Gamma_H^{tot}$	$\Delta\sigma(WW)/\sigma(WW)$	$\Delta\Gamma_H^{tot}/\Gamma_H^{tot}$
120	7.2 %	11.06 %	3.3 %	6.3 %	2.8 %	6.1 %
126	10.96 %	13.11 %	–	–	–	–
130	11.83 %	13.18 %	3.8 %	5.1 %	3.7 %	5.0 %
140	24.32 %	24.71 %	5.1 %	5.7 %	4.2 %	4.9 %

* MEYER,N.:*Higgs-Boson at TESLA: Studies on Production in WW-Fusion and Total Decay Width*, University of Hamburg, 2000

Contents

Summary

- **model-independent** measurement of σ(WW-fusion) and Γ_H^{tot}
- WW-fusion: $e^+e^- \longrightarrow \nu_e\bar{\nu}_e H \longrightarrow \nu_e\bar{\nu}_e b\bar{b}$
- determining σ(WW-fusion) $\rightarrow$ information on g_{HWW} $\rightarrow$ Γ_H^{tot}
- challenging at $\sqrt{s} = 250$ GeV: large **background**/**Higgs-strahlung** contribution,
  small **WW-fusion** contribution
- all important background processes are taken into account
- **measurement accuracy $\Delta\sigma$(WW)/σ(WW)** between 7.2 % - 24.32 %
- **measurement accuracy $\Delta\Gamma_H^{tot}/\Gamma_H^{tot}$** between 11.06 % - 24.71 %
- much **better results** for $\Delta\Gamma_H^{tot}/\Gamma_H^{tot}$ at **high** $\sqrt{s}$ (4.9 % - 6.3 %)

BACKUP SLIDES

Background Processes

irreducible background: $b\bar{b}\nu_l\bar{\nu}_l$

other background:

W-boson pairs: $e^+e^- \longrightarrow W^+W^- \longrightarrow \nu_l l^\pm q\bar{q}$

$\longrightarrow q\bar{q}q\bar{q}$

single W-bosons: $e^+e^- \longrightarrow W^\pm e^- \nu_e \longrightarrow \nu_e e^- q\bar{q}$

Z-boson pairs: $e^+e^- \longrightarrow ZZ \longrightarrow \nu_l\bar{\nu}_l q\bar{q}$

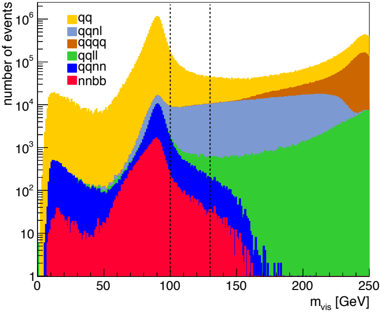
$\longrightarrow q\bar{q}q\bar{q}$

$\longrightarrow l^+l^- q\bar{q}$

$\longrightarrow q\bar{q}q\bar{q}$

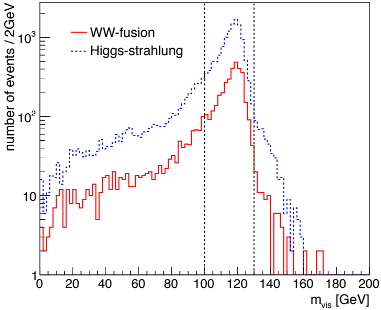
single Z-bosons: $e^+e^- \longrightarrow Ze^+e^- \longrightarrow e^+e^- q\bar{q}$

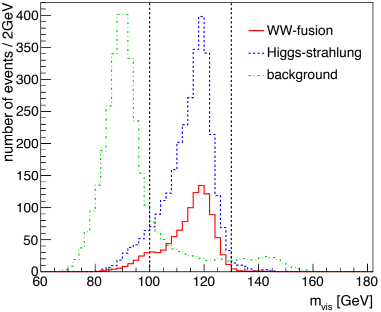
quark-antiquark pairs: $e^+e^- \longrightarrow q\bar{q}$

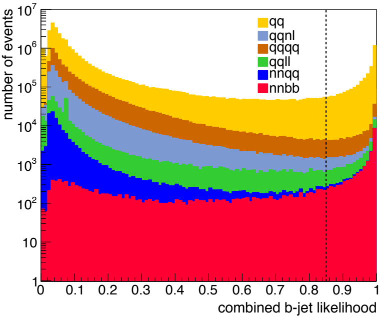


visible mass cut for $m_{\mathrm{H}} = 120$ GeV:

$$m_{\mathrm{H}} - 20 \text{ GeV} \leq m_{vis} \leq m_{\mathrm{H}} + 10 \text{ GeV}$$



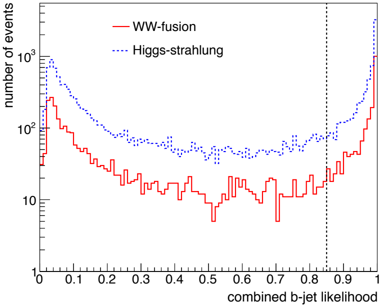




combined b-jet likelihood for

$m_H = 120$ GeV:

$btag \geq 0.85$



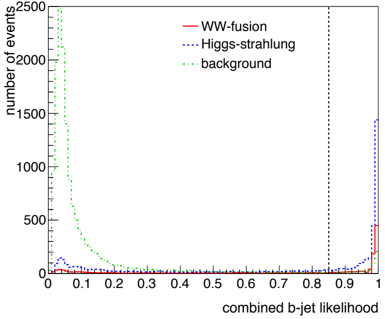


Table: Cutflow Signal

	m_H = 120 GeV		m_H = 126 GeV		m_H = 130 GeV		m_H = 140 GeV	
	N_{WW}	N_{ZH}	N_{WW}	N_{ZH}	N_{WW}	N_{ZH}	N_{WW}	N_{ZH}
no cut	4 525	16 019	3 426	14 002	3 343	13 653	2 398	9 345
N_{ctrk}	3 581	11 975	2 663	10 918	2 587	10 437	1 776	7 128
no isolated leptons	3 581	11 892	2 663	10 918	2 587	10 437	1 776	7 128
m_{vis}	2 899	8 058	2 07	8 356	1 892	7 494	1 124	4 416
E_{vis}	2 887	8 041	2 023	8 356	1 877	7 485	1 093	4 170
$\sum p_T$	2 596	7 391	1 577	7 448	1 535	6 909	897	3 669
Y_{23}	1 824	5 408	1 053	4 860	928	4 212	426	1 740
Y_{12}	1 778	5 260	965	4 594	848	3 894	377	1 431
btag	974	2 932	547	2 574	440	2 139	208	789
$\lvert \sum p_z \rvert$	920	2 837	519	2 546	405	2 130	195	786
$\lvert \cos(\theta_{jet}) \rvert$	898	2 767	507	2 546	401	2 079	190	759
number of events	898	2 767	507	2 546	401	2 079	190	759

Table: Cutflow and the number of WW-fusion and Higgs-strahlung events for the four different Higgs masses after every single cut.

Example: Cutflow Background for $m_H = 126$ GeV

	N_{bgrd}^{tot}	$\nu_l\bar{\nu}_l b\bar{b}$	$\nu_l\bar{\nu}_l q\bar{q}$	$q\bar{q}l^+l^-$	$q\bar{q}l\nu$	$q\bar{q}q\bar{q}$	$q\bar{q}$
no cut	$32.104 \cdot 10^6$	30 562	119 296	299 741	1 730 574	3 908 020	$26.016 \cdot 10^6$
$10 < N_{ctrk} < 40$	$27.474 \cdot 10^6$	28 883	110 291	229 073	1 682 652	1 603 046	$23.821 \cdot 10^6$
no isolated leptons	$19.846 \cdot 10^6$	23 012	88 998	153 540	1 156 157	1 150 993	$17.274 \cdot 10^6$
$106\text{ GeV} < m_{vis} < 136\text{ GeV}$	1 047 860	1 040	5 548	6 196	181 973	782	852 321
$105\text{ GeV} < E_{vis} < 160\text{ GeV}$	985 320	1 040	5 545	5 922	177 193	728	794 892
$20\text{ GeV} < \sum p_T < 80\text{ GeV}$	142 909	878	4 714	1 760	134 047	3	1 507
$Y_{23} < 0.02$	27 271	421	2 408	588	22 654	1	1 199
$0.2 < Y_{12} < 0.8$	24 385	390	2 271	508	20 533	0	683
btag > 0.85	1 404	224	15	65	111	0	289
$\lvert \sum p_z \rvert < 60\text{ GeV}$	465	193	9	38	73	0	152
$\lvert \cos(\theta_{jet}) \rvert < 0.95$	449	187	9	36	65	0	152
number of events	449	187	9	36	65	0	152

Table: Cutflow and number of events for every background process for $m_H = 126$ GeV. The total number of background events after every cut is listed.

Coupling g_{HWW}

$$\sigma(\text{WW-fusion}) = \frac{g_{HWW}^2 m_W^2}{32\pi^3} \int_{\kappa_H}^1 \int_x^1 \frac{\mathrm{d}x\mathrm{d}y}{[1+(y-x)/\kappa_W]^2} f(x,y)\,,$$

$$f(x,y) = \left(\frac{2x}{y^3} - \frac{1+3x}{y^2} + \frac{2+x}{y} - 1\right)\left[\frac{z}{1+z} - \log(1+z)\right] + \frac{x}{y^3}\cdot\frac{z^2(1-y)}{1+z}$$

with: $\kappa_H = m_H^2/s$, $\kappa_W = m_W^2/s$, $z = y(x-\kappa_H)/(\kappa_W x)$

g_{HWW} closely linked to g_{HZZ} through $SU(2)\times U(1)$ symmetry: $\frac{g_{HWW}}{g_{HZZ}} = \frac{1}{\cos(\theta_W)}$

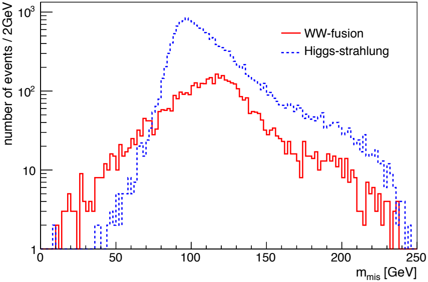
comparison between g_{HZZ} and g_{HWW} $\longrightarrow$ verify $SU(2)\times U(1)$ structure

$\downarrow$

essential to establish Higgs mechanism

coupling to gauge bosons can be probed best in measurement of production cross sections

Results for $m_H = 120$ GeV

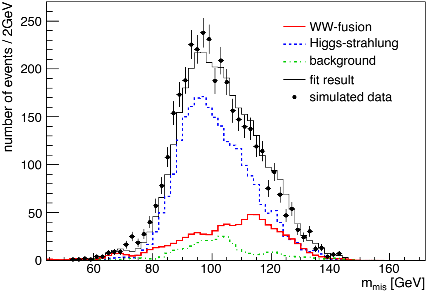


$$\frac{\Delta BR(H\to b\bar{b})}{BR(H\to b\bar{b})} = 2.7\,\%$$

$$\frac{\Delta BR(H\to WW)}{BR(H\to WW)} = 8.4\,\%$$

Fit result:

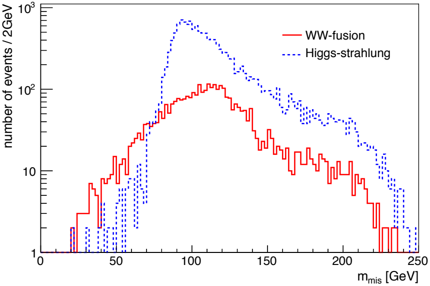
$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
873 ± 58	$2\,666 \pm 66$



$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
6.64 %	2.48 %	7.2 %

$$\longrightarrow \quad \Delta\Gamma_H^{tot}/\Gamma_H^{tot} = 11.06\,\%$$

Results for $m_H = 126$ GeV

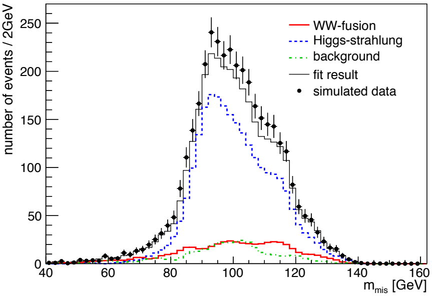


$$\frac{\Delta BR(H \to b\bar{b})}{BR(H \to b\bar{b})} = 3.0\,\%$$

$$\frac{\Delta BR(H \to WW)}{BR(H \to WW)} = 7.2\,\%$$

Fit result:

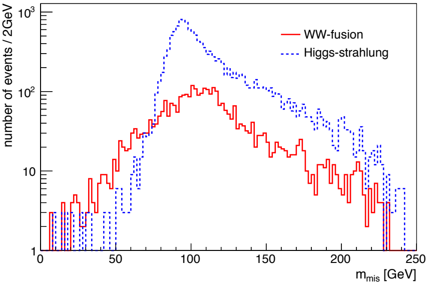
$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
512 ± 54	$2\,497 \pm 85$



$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
10.54 %	3.4 %	10.96 %

$$\longrightarrow \quad \Delta\Gamma_H^{tot} / \Gamma_H^{tot} = 13.11\,\%$$

Results for $m_H = 130$ GeV

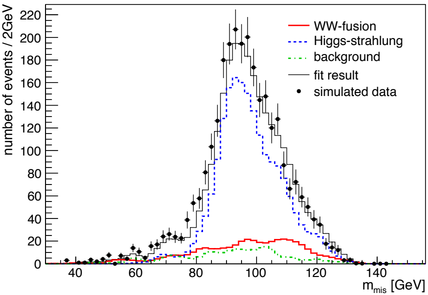


$$\frac{\Delta BR(H\to b\bar{b})}{BR(H\to b\bar{b})} = 3.5\,\%$$

$$\frac{\Delta BR(H\to WW)}{BR(H\to WW)} = 5.8\,\%$$

Fit result:

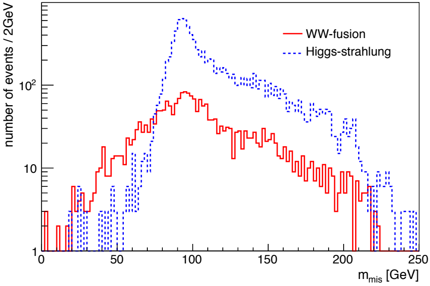
$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
407 ± 46	$1\,978 \pm 78$



$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
11.3 %	3.89 %	11.83 %

$\longrightarrow$ $\Delta\Gamma_H^{tot}/\Gamma_H^{tot} = 13.18\,\%$

Results for $m_H = 140$ GeV

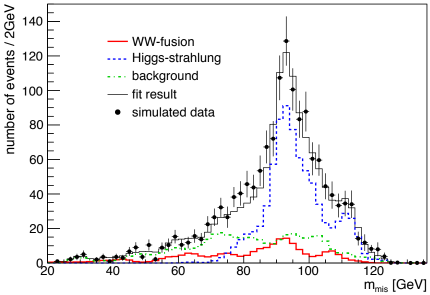


$$\frac{\Delta BR(H \to b\bar{b})}{BR(H \to b\bar{b})} = 5.1\,\%$$

$$\frac{\Delta BR(H \to WW)}{BR(H \to WW)} = 4.4\,\%$$

Fit result:

$N'_{WW} \pm \Delta N'_{WW}$	$N'_{ZH} \pm \Delta N'_{ZH}$
185 ± 44	737 ± 30



$\frac{\Delta N'_{WW}}{N'_{WW}}$	$\frac{\Delta N'_{ZH}}{N'_{ZH}}$	$\frac{\Delta\sigma(\text{WW-fusion})}{\sigma(\text{WW-fusion})}$
23.78 %	4.07 %	24.32 %

$$\longrightarrow \quad \Delta\Gamma_H^{tot} / \Gamma_H^{tot} = 24.71\,\%$$