Electroweak Corrections to $\mathbf{e^-e^+ \to f\bar{f}H}$

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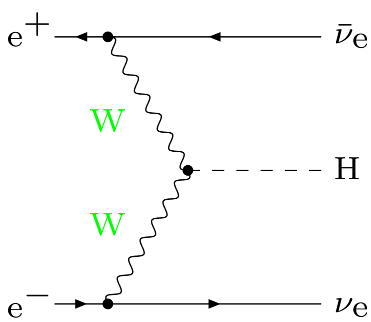
Electroweak corrections to Higgs-production processes

- $e^-e^+ \to \nu\bar{\nu}H$
- $e^-e^+ \to t\bar{t}H$

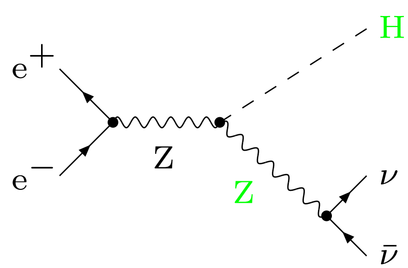
Higgs-production process $e^- e^+ \to \nu \bar{\nu} H$

Tree-level diagrams

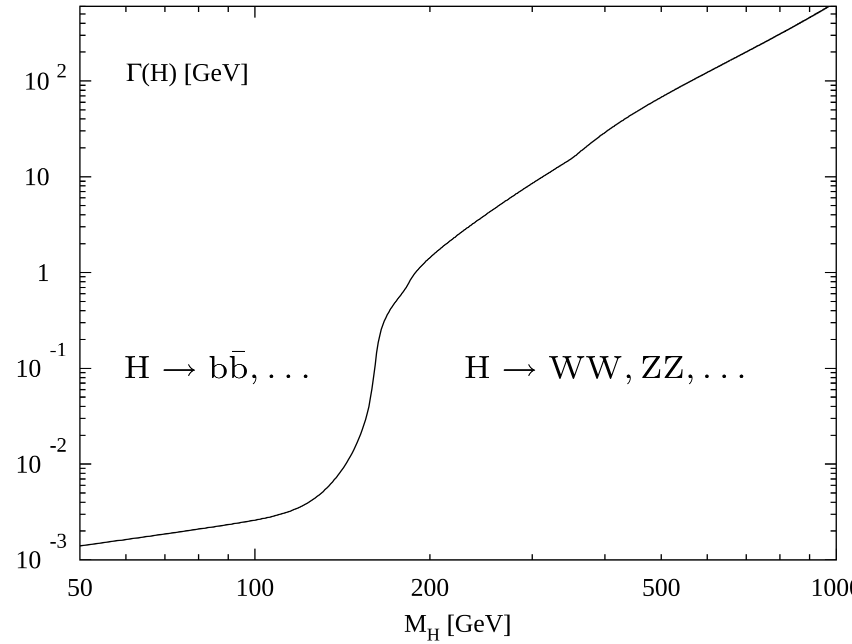
W-boson fusion (WW)



Higgs radiation (ZH)



Djouadi,Kalinowski,Spira '97



General aspects

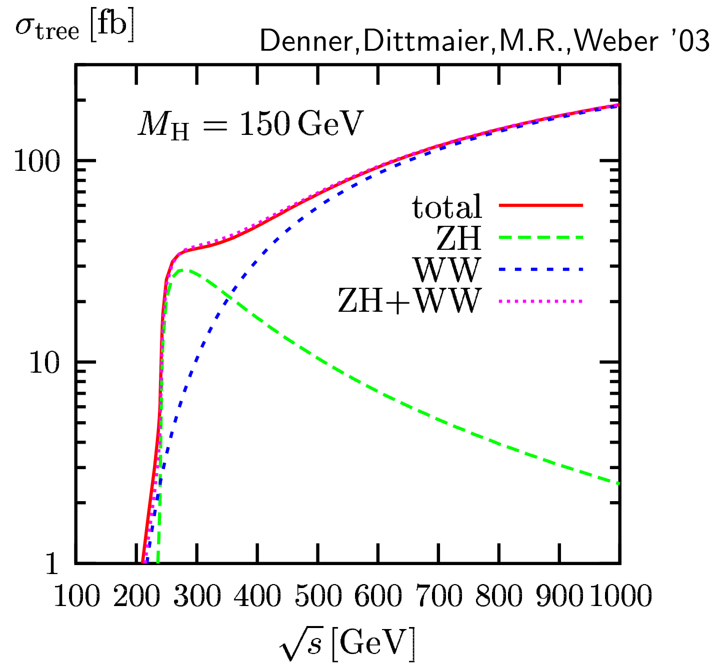
- Higgs practically stable for $M_{\mathrm{H}} \lesssim 160\,\mathrm{GeV}$ since Γ_{H} relatively small
- Neutrinos invisible

$$\left|\mathcal{M}^{e^- e^+ \to \nu\bar{\nu}H}\right|^2 = |\mathcal{M}_{\mathrm{WW}}|^2 + 3\,|\mathcal{M}_{\mathrm{ZH}}|^2 + 2\,\mathrm{Re}\,(\mathcal{M}_{\mathrm{WW}}\mathcal{M}^*_{\mathrm{ZH}})$$

High-energy behaviour:

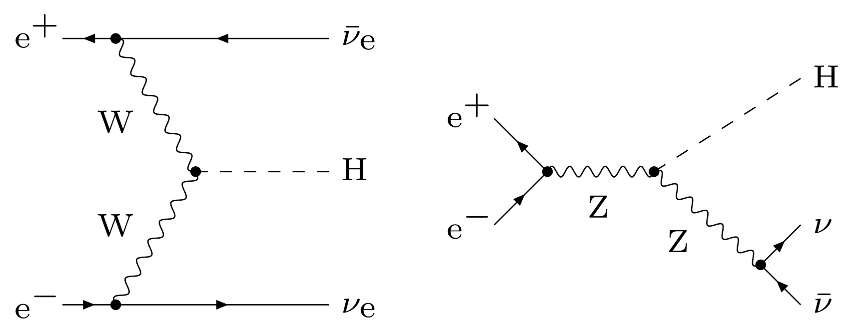
$$\sigma_{\mathrm{WW}} \sim \ln(s), \quad s \to \infty$$
$$\sigma_{\mathrm{ZH}} \sim 1/s, \quad s \to \infty$$

$\Rightarrow$ W fusion dominates for high energies!



What can we learn from $\mathrm{e}^-\mathrm{e}^+ \to \nu\bar{\nu}\mathrm{H}$?

- Direct search of a SM Higgs boson
- Measurement of M_{H} and BRs
- Information on Higgs couplings



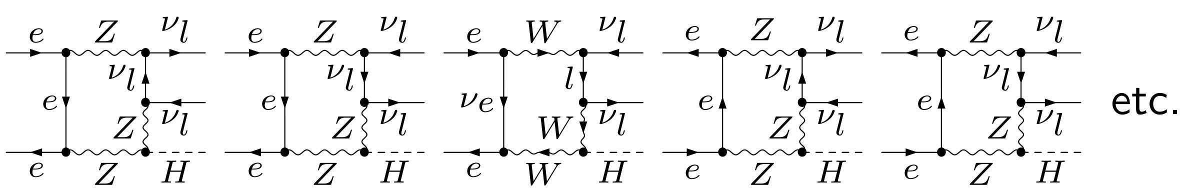
Experimental accuracy at a future LC:

$$\Delta\sigma/\sigma = \text{a few } \%$$

Complications in the calculation of $\mathrm{e}^-\mathrm{e}^+ \to \nu\bar{\nu}\mathrm{H}$

Virtual corrections

- Number of 1-loop diagrams: 100-180 (depending on the gauge)
- Appearence of pentagon diagrams:



Numerical instabilities at the phase-space boundary
due to inverse Gram determinants from Passarino-Veltman reduction

Leading inverse Gram determinants can be avoided by reducing 5-point tensor integrals directly to 4-point tensor integrals — Denner,Dittmaier '02

Real corrections

- Treatment of infrared and collinear singularities
  $\Rightarrow$ Compare results from phase-space slicing and dipole subtraction method

Status of radiative corrections

- Full $\mathcal{O}(\alpha)$ corrections to $\mathrm{e^-e^+} \to \mathrm{ZH}$:

  J. Fleischer, F. Jegerlehner '83;

  A. Denner, J, Kübelbeck, R. Mertig, M. Böhm '92;

  B. A. Kniehl '92.

- Fermionic and sfermionic loops to $\mathrm{e^-e^+} \to \nu\bar{\nu}\mathrm{H}$ in the MSSM:

  H. Eberl, W. Majerotto, V.C. Spanos '02;

  T. Hahn, S. Heinemeyer, G. Weiglein '02.

- Analytical results for virtual corrections to $\mathrm{e^-e^+} \to \nu\bar{\nu}\mathrm{H}$:

  F. Jegerlehner, O. Tarasov '02 (MAPLE output, no numerical studies)

- Full $\mathcal{O}(\alpha)$ corrections to $\mathrm{e^-e^+} \to \nu\bar{\nu}\mathrm{H}$:

  G. B. Bélanger et al. '03;

  A. Denner, S. Dittmaier, M. R., M. M. Weber '03 (including higher-order ISR).

Comparison between Bélanger et al. and Denner et al.

Process: $e^-e^+ \to \nu\bar{\nu}H$, $\alpha(0)$ scheme, $\sqrt{s} = 500\,\text{GeV}$

M_H [GeV]	σ_{tree} [fb]	σ [fb]	δ [%]	Reference
150	61.074(7)	60.99(7)	−0.2	Bélanger et al.
	61.076(5)	60.80(2)	−0.44(3)	Denner et al.
200	37.294(4)	37.16(4)	−0.4	Bélanger et al.
	37.293(3)	37.09(2)	−0.56(4)	Denner et al.
250	21.135(2)	20.63(2)	−2.5	Bélanger et al.
	21.134(1)	20.60(1)	−2.53(3)	Denner et al.
300	10.758(1)	10.30(1)	−4.2	Bélanger et al.
	10.7552(7)	10.282(4)	−4.40(3)	Denner et al.

⇒ Agreement within $\approx 0.2\%$ (=statistical error of Bélanger et al.)

Improved Born Approximation (IBA) for $\mathrm{e^-e^+} \to \nu\bar{\nu}\mathrm{H}$

Corrections included in IBA: $\Delta\sigma/\sigma$

- LL corrections from ISR via structure functions $\mathcal{O}(-10\%)$
- Universal corrections from G_μ scheme

$$\alpha(0) \to \alpha_{\mathrm{G}_\mu} = \frac{\sqrt{2}\mathrm{G}_\mu M_\mathrm{W}^2 s_\mathrm{W}^2}{\pi} \qquad \frac{\alpha_{\mathrm{G}_\mu}^3}{\alpha^3(0)} - 1 \approx 3\Delta r \approx 3\left(\Delta\alpha - \frac{c_\mathrm{W}^2}{s_\mathrm{W}^2}\Delta\rho\right)$$

  - Running of α $3\Delta\alpha = 18\%$
  - Universal corrections $\propto m_\mathrm{t}^2/M_\mathrm{W}^2$ (ρ parameter) $-3\frac{c_\mathrm{W}^2}{s_\mathrm{W}^2}\Delta\rho = -9\%$

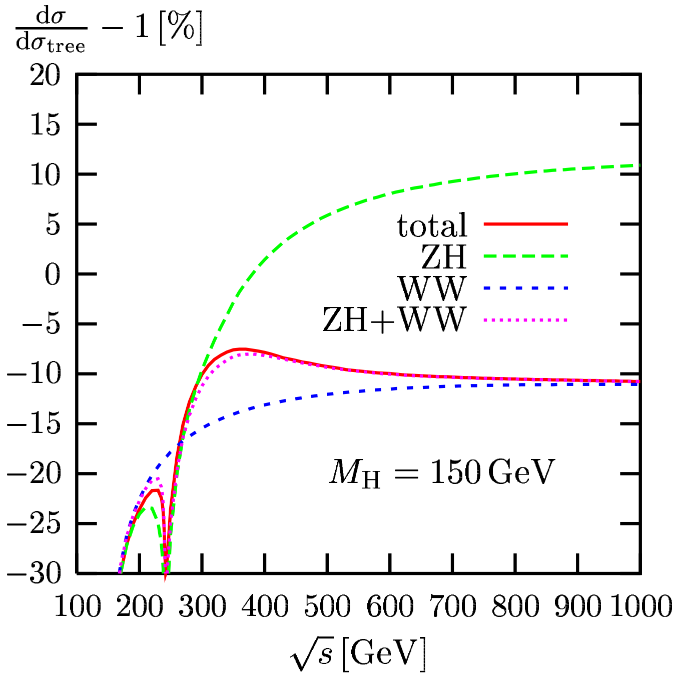
- Additional corrections $\propto m_\mathrm{t}^2/M_\mathrm{W}^2$ from WWH vertex Kniehl,Steinhauser '95

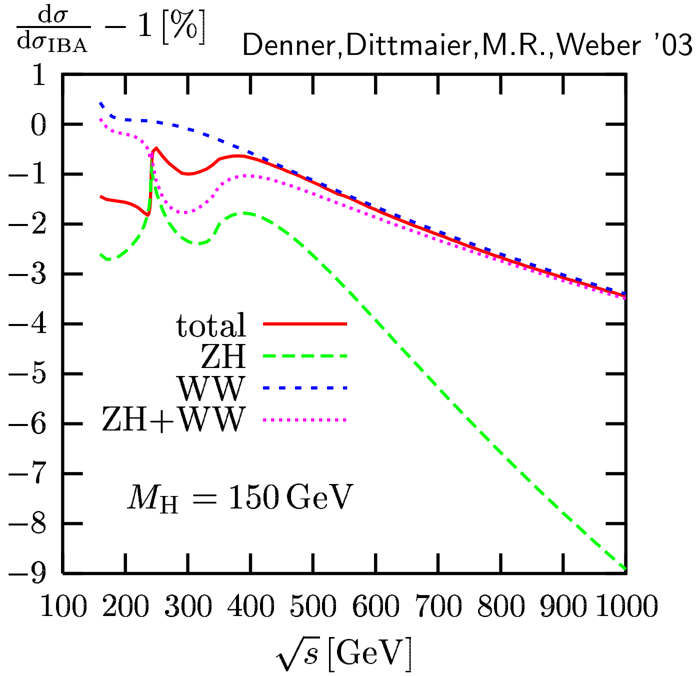
$$\mathrm{d}\sigma_\mathrm{IBA} = \mathrm{d}\sigma_\mathrm{tree} - \frac{5\alpha_{\mathrm{G}_\mu}}{16\pi s_\mathrm{W}^2}\frac{m_\mathrm{t}^2}{M_\mathrm{W}^2}\,\mathrm{d}\sigma_\mathrm{tree}^\mathrm{WW} \qquad -\frac{5\alpha_{\mathrm{G}_\mu}}{16\pi s_\mathrm{W}^2}\frac{m_\mathrm{t}^2}{M_\mathrm{W}^2} = -1.6\%$$

Approximation $m_\mathrm{t} \gg M_\mathrm{W}$ works for W fusion, but not for Higgs radiation
Good approximation for high energies since W fusion dominates in this case

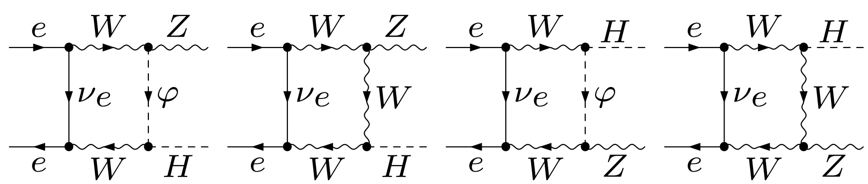
Total cross section

Prozess: $e^- e^+ \to \nu\bar{\nu}H$, G_μ scheme



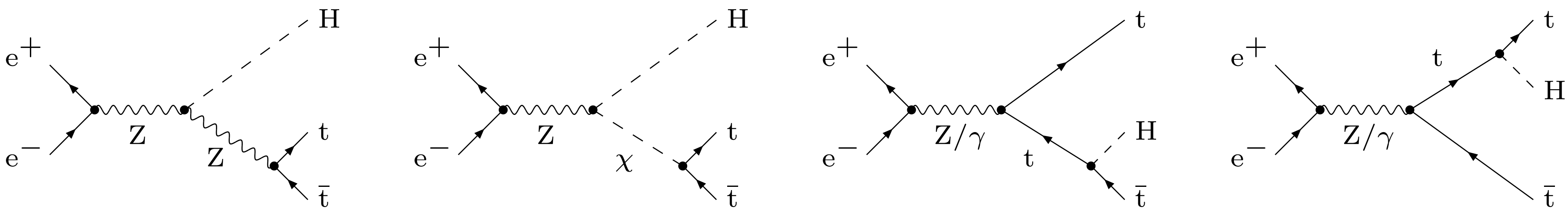


Large weak corrections from box diagrams with W exchange:



Higgs-production process $\mathrm{e^-e^+ \to t\bar{t}H}$

Tree-level diagrams



General aspects for $\mathrm{e^-e^+ \to t\bar{t}H}$

- Measurement of the $\mathrm{t\bar{t}H}$-Yukawa coupling ($\propto m_\mathrm{t}/M_\mathrm{W}$)
  Expected accuracy at a future LC: $\Delta\sigma/\sigma \approx 5\%$ TESLA TDR '01
- Calculation even more complicated than for $\mathrm{e^-e^+ \to \nu\bar{\nu}H}$
  Number of 1-loop diagrams: $\mathcal{O}(1000)$
  Same computational techniques as for $\mathrm{e^-e^+ \to \nu\bar{\nu}H}$ applicable

Status of radiative corrections

- Full $\mathcal{O}(\alpha)$ corrections to $\mathrm{e^-e^+ \to t\bar{t}H}$

  Y. Yu et al., hep-ph/0306036;
  G. Bélanger et al., hep-ph/0307029;
  A. Denner, S. Dittmaier, M. R., M. M. Weber, hep-ph/0307193.

Results of Bélanger et al. and Denner et al. in full agreement

Results of Yu et al. differ from Bélanger et al. and Denner et al. for high energies and at threshold

Comparison between Bélanger et al. and Denner et al.

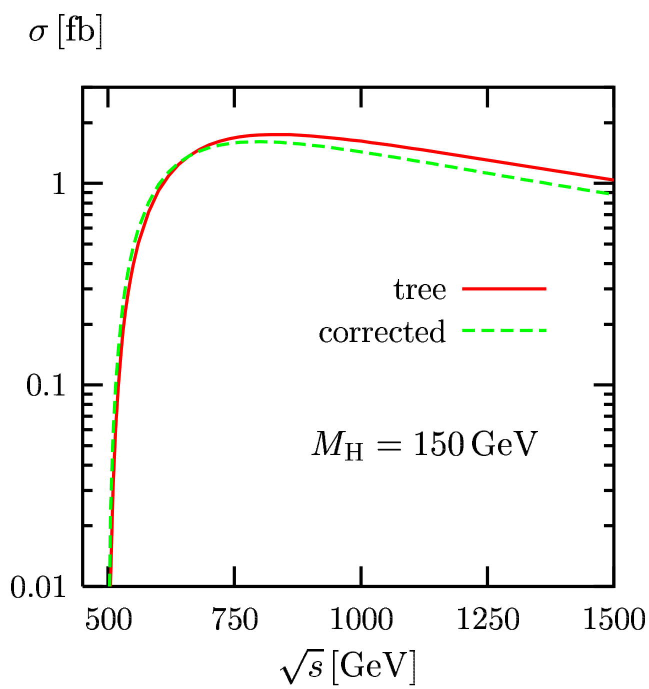
Process: $e^- e^+ \to t\bar{t}H$, $\alpha(0)$ scheme, $M_H = 120\,\mathrm{GeV}$

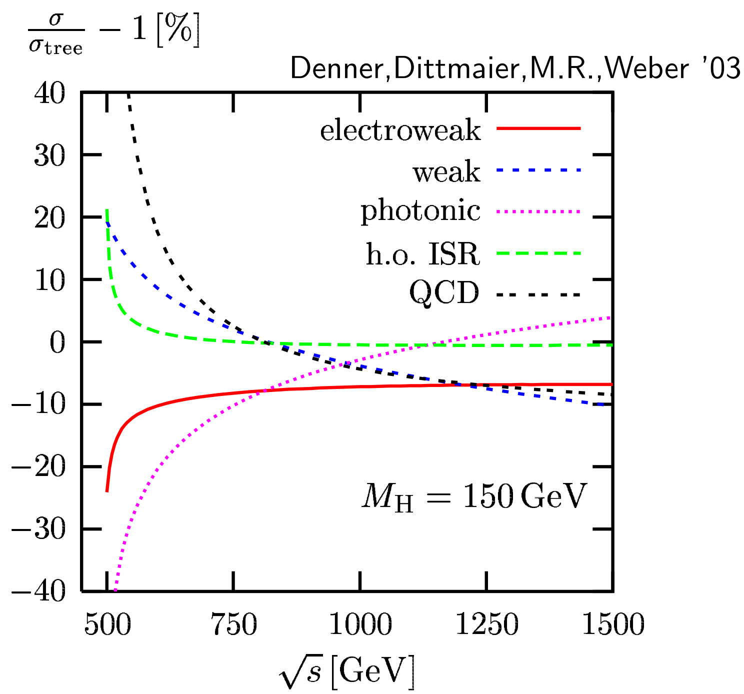
$\sqrt{s}$ [GeV]	σ_{tree} [fb]	σ [fb]	δ [%]	Reference
600	1.7293(3)	1.738(2)	0.5	Bélanger et al.
	1.7292(2)	1.7368(6)	0.44(3)	Denner et al.
800	2.2724(5)	2.362(4)	3.9	Bélanger et al.
	2.2723(3)	2.3599(6)	3.86(2)	Denner et al.
1000	1.9273(5)	2.027(4)	5.2	Bélanger et al.
	1.9271(3)	2.0252(5)	5.09(2)	Denner et al.

$\Rightarrow$ Agreement within $\approx 0.1\%$ (=statistical error of Bélanger et al.)

$\mathrm{t\bar{t}H}$ production

Process: $\mathrm{e^-e^+ \to t\bar{t}H}$, G_μ scheme





- Large QCD corrections at threshold from Coulomb singularity
- Large contributions to photonic corrections from $\mathcal{O}(\alpha)$ ISR
- Compensations between weak and photonic corrections

$\Rightarrow$ In general, radiative corrections are large!

Conclusions

Higgs physics is a very important issue of future $\mathrm{e}^+\mathrm{e}^-$ colliders

- Full $\mathcal{O}(\alpha)$ corrections now available for the processes:
  - $\mathrm{e}^-\mathrm{e}^+ \to \nu\bar{\nu}\mathrm{H}$
  - $\mathrm{e}^-\mathrm{e}^+ \to \mathrm{t}\bar{\mathrm{t}}\mathrm{H}$

  Independent calculations show agreement better than 0.2% and 0.1%
- Non-universal weak corrections are large $\mathcal{O}(10\%)$

  But: future $\mathrm{e}^+\mathrm{e}^-$ colliders reach accuracy of a few $\%$

  $\Rightarrow$ Complete $\mathcal{O}(\alpha)$ corrections are required to obtain adequate theoretical predictions for future $\mathrm{e}^+\mathrm{e}^-$ colliders

Comparison between Yu et al. and Denner et al.

Process: $e^- e^+ \to t\bar{t}H$, $\alpha(0)$ scheme, $M_H = 150\,\mathrm{GeV}$

$\sqrt{s}$ [GeV]	σ_{tree} [fb]	σ [fb]	δ [%]	Reference
500	$4.8142 \cdot 10^{-4}$	$3.401 \cdot 10^{-4}$	-29.35	Yu et al.
	$4.8140(8) \cdot 10^{-4}$	$3.168(4) \cdot 10^{-4}$	-34.19(8)	Denner et al.
800	1.58	1.63	3.60	Yu et al.
	1.5749(2)	1.6243(4)	3.14(2)	Denner et al.
1000	1.47	1.53	4.47	Yu et al.
	1.4664(2)	1.5273(4)	4.15(2)	Denner et al.
2000	0.6270	0.6297	0.43	Yu et al.
	0.6269(1)	0.6526(3)	4.11(5)	Denner et al.

Statistical error of Yu et al. below 1%