Electroweak radiative corrections to the processes $\mathrm{e}^+\mathrm{e}^- \to \nu\bar{\nu}\mathrm{H}, \mathrm{t}\bar{\mathrm{t}}\mathrm{H}$

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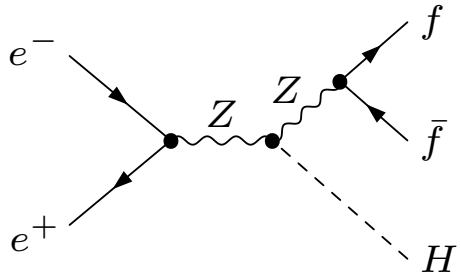
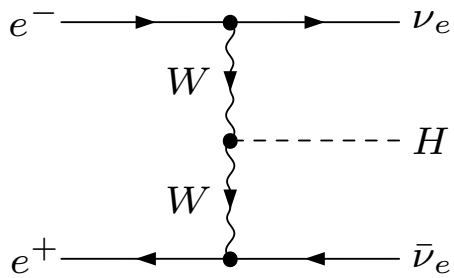
Most important Higgs-production processes in e^+e^- annihilation

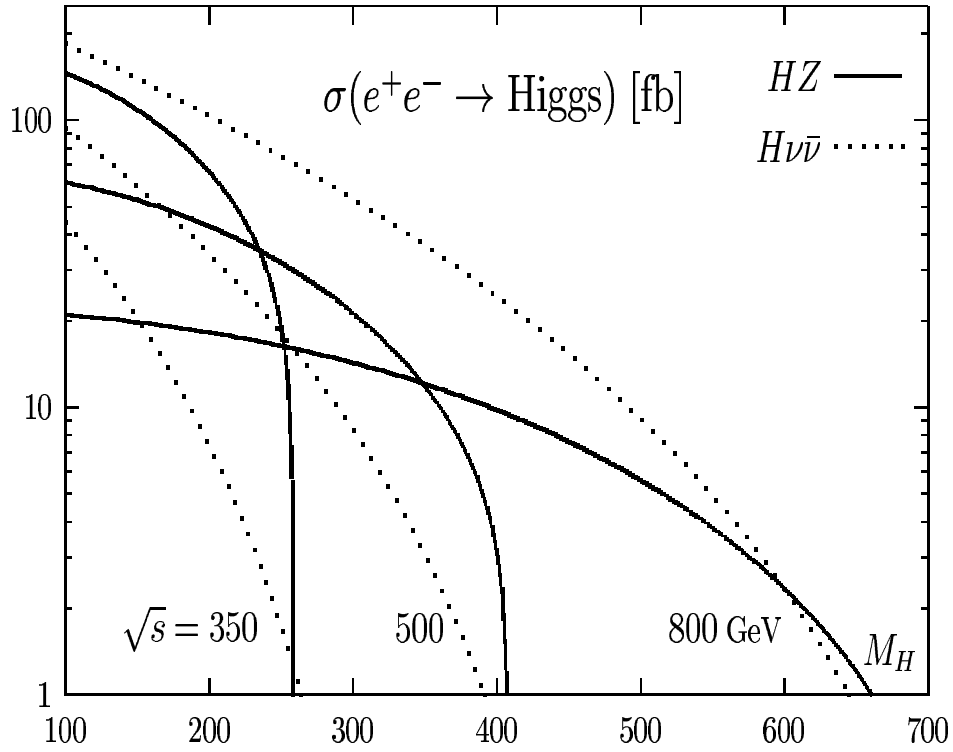
ZH production ("Higgs-strahlung")



WW fusion



TESLA-TDR '01



WW fusion dominates
at high energies ($\sqrt{s} \gg M_{\mathrm{H}}$):

$\sigma_{\mathrm{ZH}} \sim \mathrm{const} \,/\, s$

$\sigma_{\mathrm{WW}} \sim \mathrm{const} \times \ln(s/M_{\mathrm{W}}^2)$

Physics issues:

– Higgs decay rate
– quantum numbers (spin, P, CP)
– couplings
– extended Higgs sectors ?

Corrections to $\mathrm{e^+e^-} \to \mathrm{ZH}$

- $\mathcal{O}(\alpha)$ corrections for stable Z and H bosons known

Fleischer, Jegerlehner '83; Kniehl '92
Denner, Küblbeck, Mertig, Böhm '92

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

- fermion-loop corrections (+sfermion loops in MSSM)

Eberl, Majerotto, Spanos '02
Hahn, Heinemeyer, Weiglein '02

- complete $\mathcal{O}(\alpha)$ correction

Bélanger, Boudjema, Fujimoto, Ishikawa, Kaneko, Kato, Shimizu '02
Denner, S.D., Roth, Weber '03

improved by leading-log ISR beyond $\mathcal{O}(\alpha)$ Denner, S.D., Roth, Weber '03

comparison of results: ($\sqrt{s} = 500\,\mathrm{GeV}$, $\alpha(0)$-Schema)

M_H [GeV]	σ_tree [fb]	σ [fb]	$\sigma/\sigma_\mathrm{tree} - 1[\%]$	
150	61.074(7)	60.99(7)	-0.2	Bélanger et al.
	61.076(5)	60.80(2)	$-0.44(3)$	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.
350	4.6079(5)	4.184(4)	-9.1	Bélanger et al.
	4.6077(2)	4.181(1)	$-9.27(3)$	Denner et al.

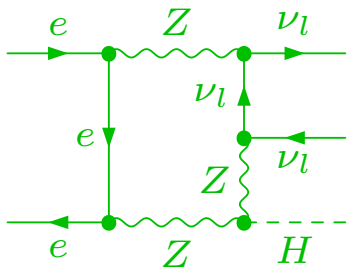
agreement within $\mathcal{O}(0.2\%)$

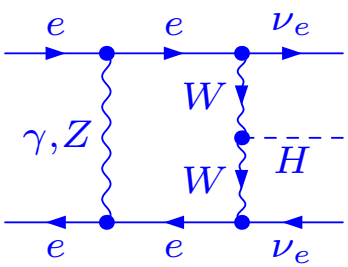
On the $\mathcal{O}(\alpha)$ correction to $\mathrm{e}^+\mathrm{e}^- \to \nu\bar{\nu}H$

Denner, S.D., Roth, Weber '03

- $\mathcal{O}(350)$ 1-loop diagrams (coherence of ZH and WW contributions)
- peculiarity: Z resonance (respect gauge invariance !)
- "consistency checks":
  - ◇ compensation of UV and IR divergences
  - ◇ different methods for combining "virtual + real" ("subtraction" vs. "slicing")
  - ◇ gauge independence: 't Hooft-Feynman vs. background-field gauge
  - ◇ two completely independent calculations of virtual + real corrections
- main complication:

  numerically stable evaluation of "pentagon diagrams"



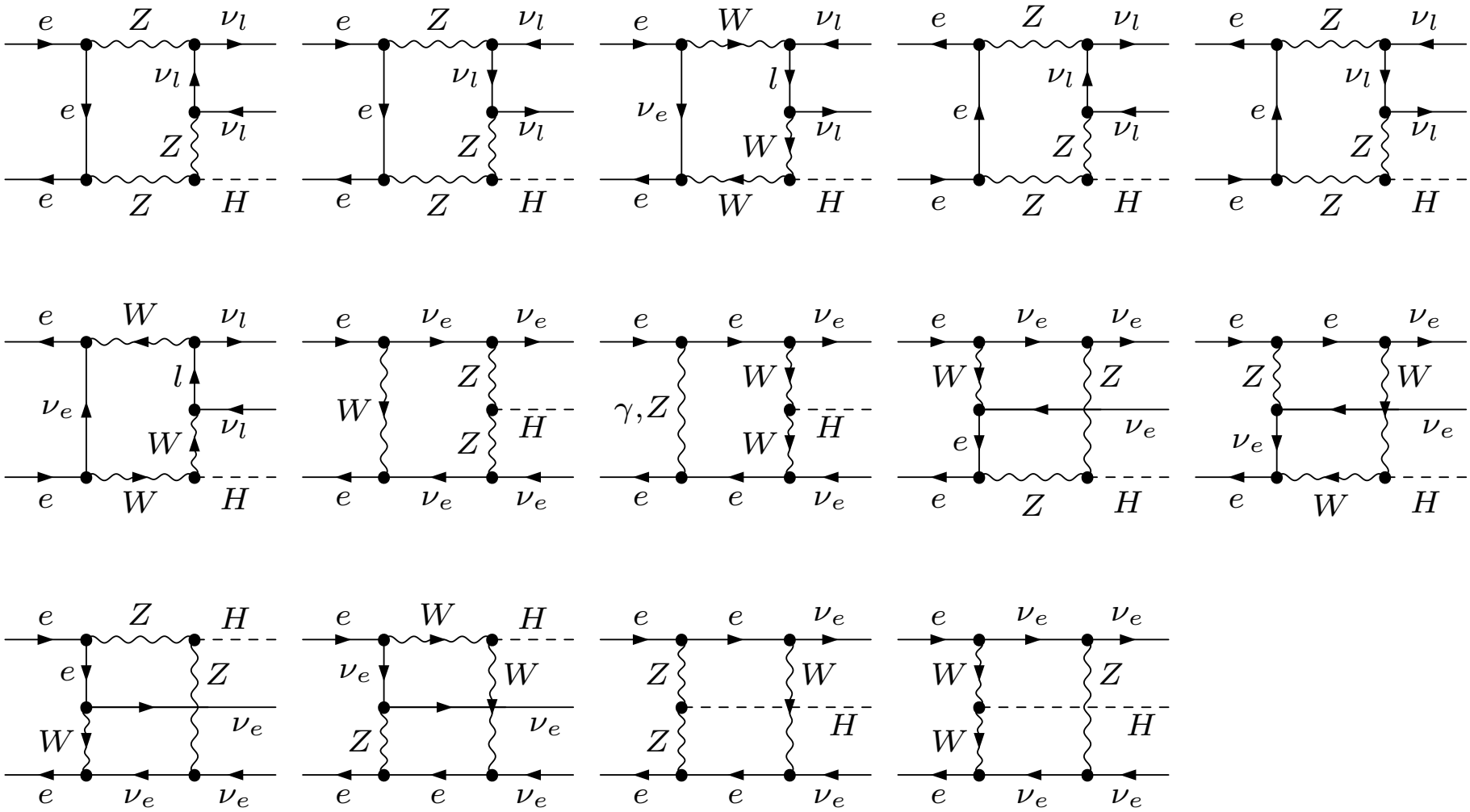


+ 13 others

direct reduction of 5-point to 4-point one-loop integrals Melrose '65

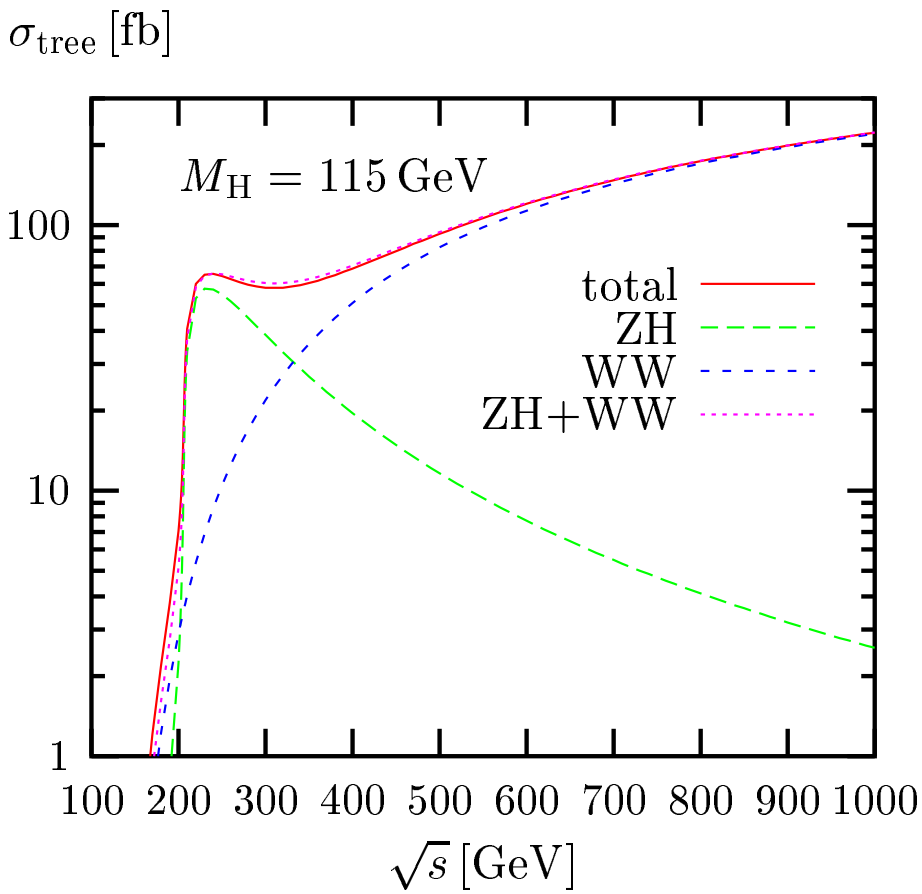
avoiding leading inverse Gram determinants in tensor reduction Denner, S.D. '02

Pentagon diagrams for $\mathrm{e}^+\mathrm{e}^- \to \nu\bar{\nu}H$

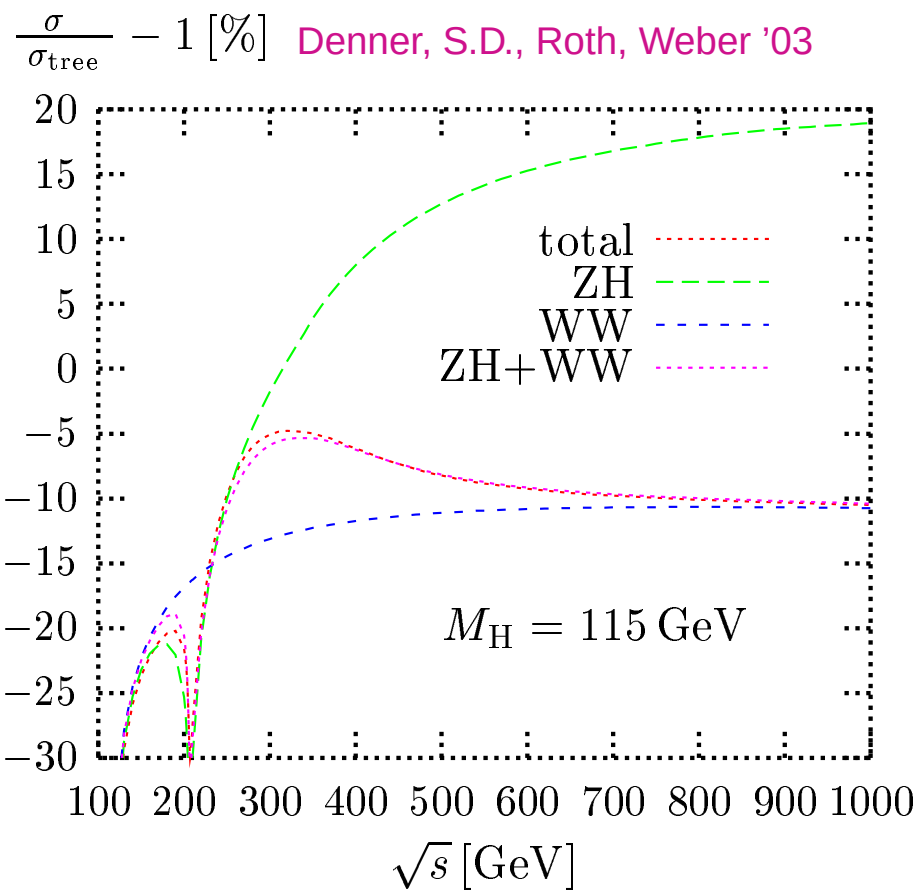


Total cross section for $e^+e^- \to \nu\bar{\nu}H$

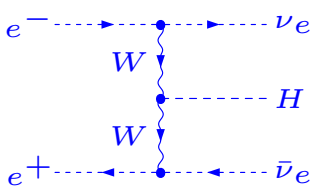
Born approximation:



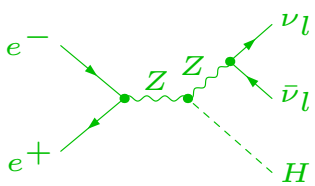
Relative corrections (G_μ-scheme):



WW:



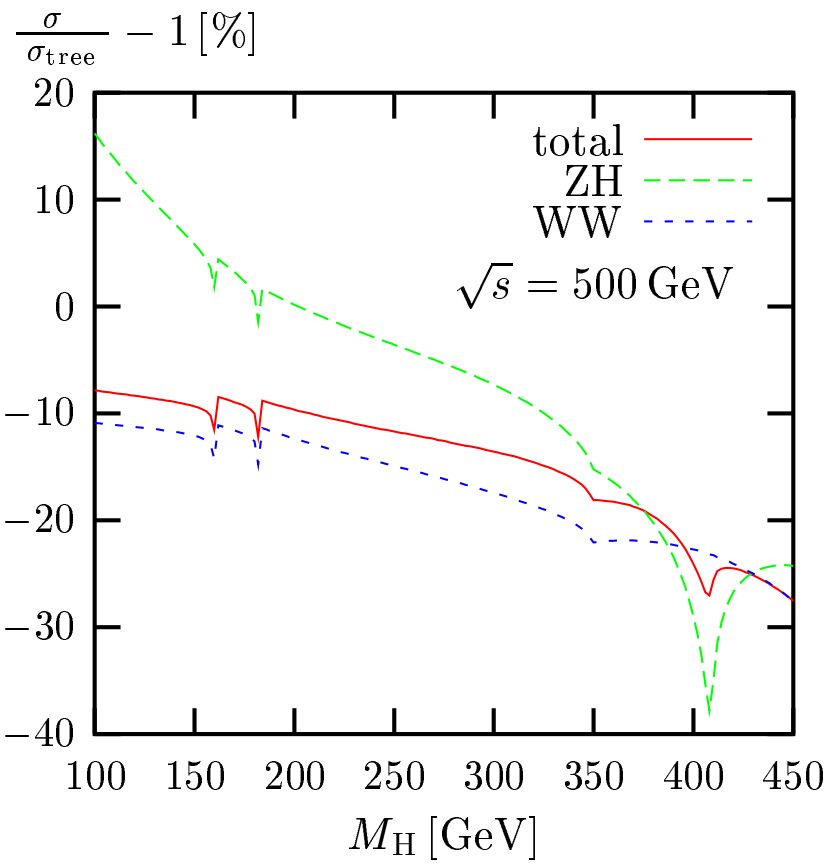
ZH:



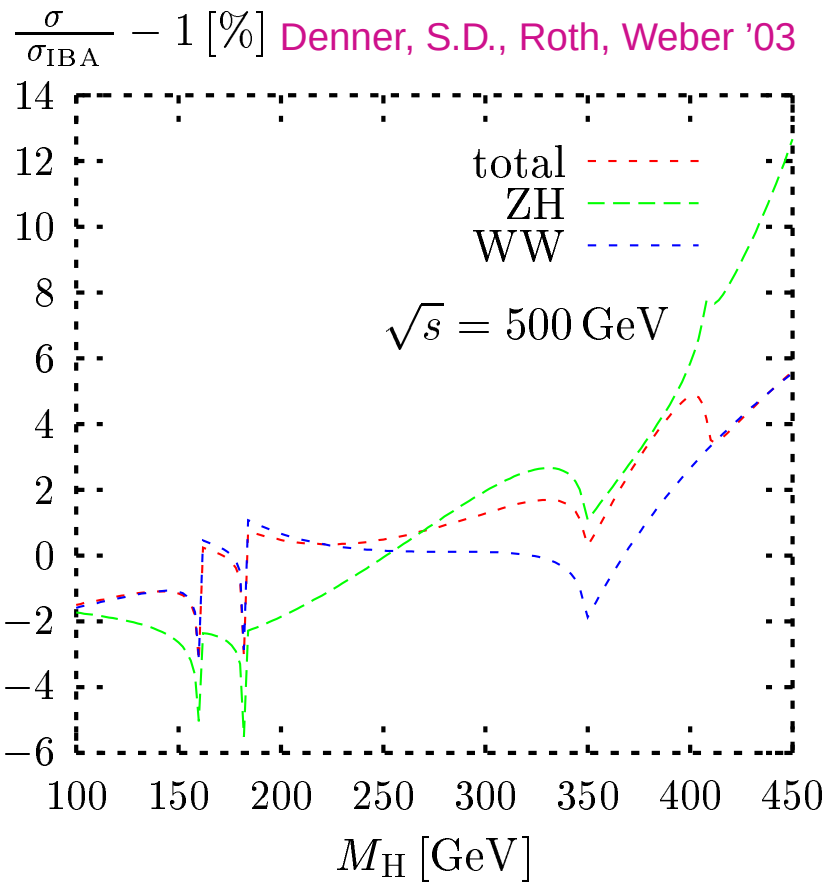
Improved Born approximation (IBA) for $e^+e^- \to \nu\bar{\nu}H$

IBA includes ISR and heavy-top corrections.

correction w.r.t. Born cs:



correction w.r.t. IBA:

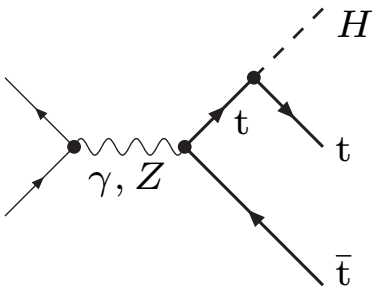


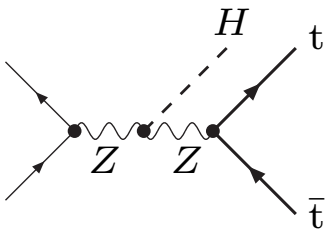
IBA only good within $\mathcal{O}(3{-}5\%)$

$\hookrightarrow$ full $\mathcal{O}(\alpha)$ calculation needed for per-cent accuracy at LC

Channel for analyzing the top-quark Yukawa coupling:

Associated Higgs production: $e^+e^- \to t\bar{t}H$



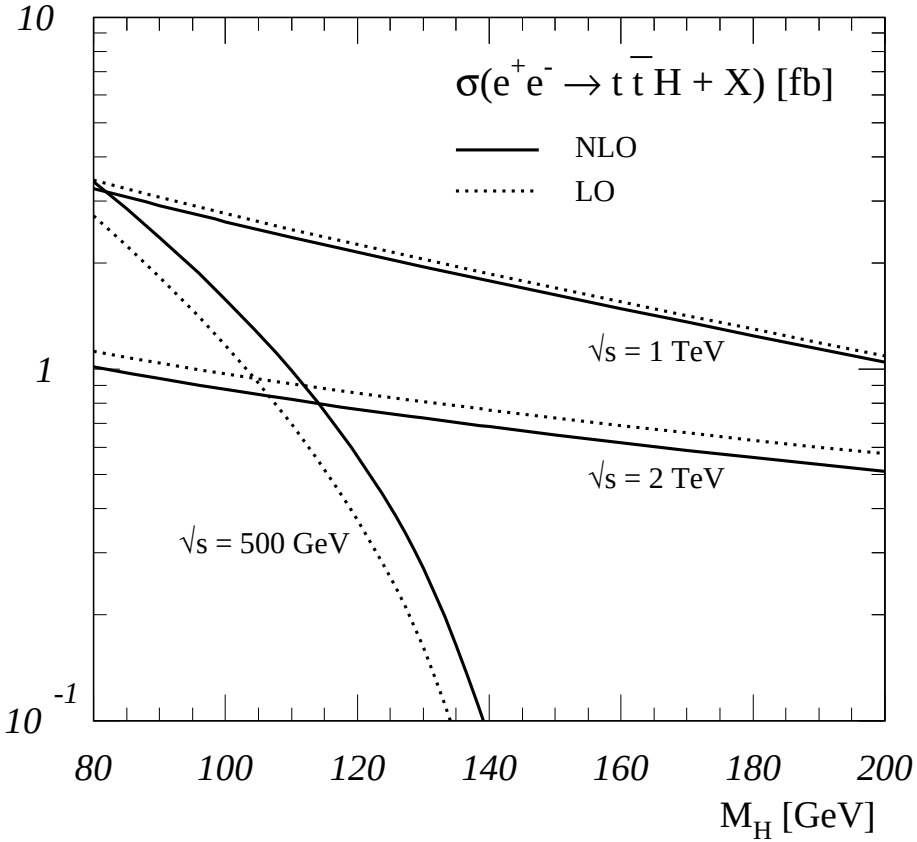


expected precision:

$\Delta g_{\mathrm{ttH}}/g_{\mathrm{ttH}} \sim 5\%$

QCD-corrected cross section:

S.D., Krämer, Liao, Spira, Zerwas '98



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

- QCD corrections in $\mathcal{O}(\alpha_s)$ — S.D., Krämer, Liao, Spira, Zerwas '98; Dawson, Reina '98
- SUSY-QCD corrections in $\mathcal{O}(\alpha_s)$ — Zhu '02
- recently: $\mathcal{O}(\alpha)$ corrections known — You, Ma, Chen, Zhang, Yan-Bin, Hou '03; Bélanger et al. '03; Denner, S.D., Roth, Weber '03

  improved by leading-log ISR beyond $\mathcal{O}(\alpha)$ — Denner, S.D., Roth, Weber '03

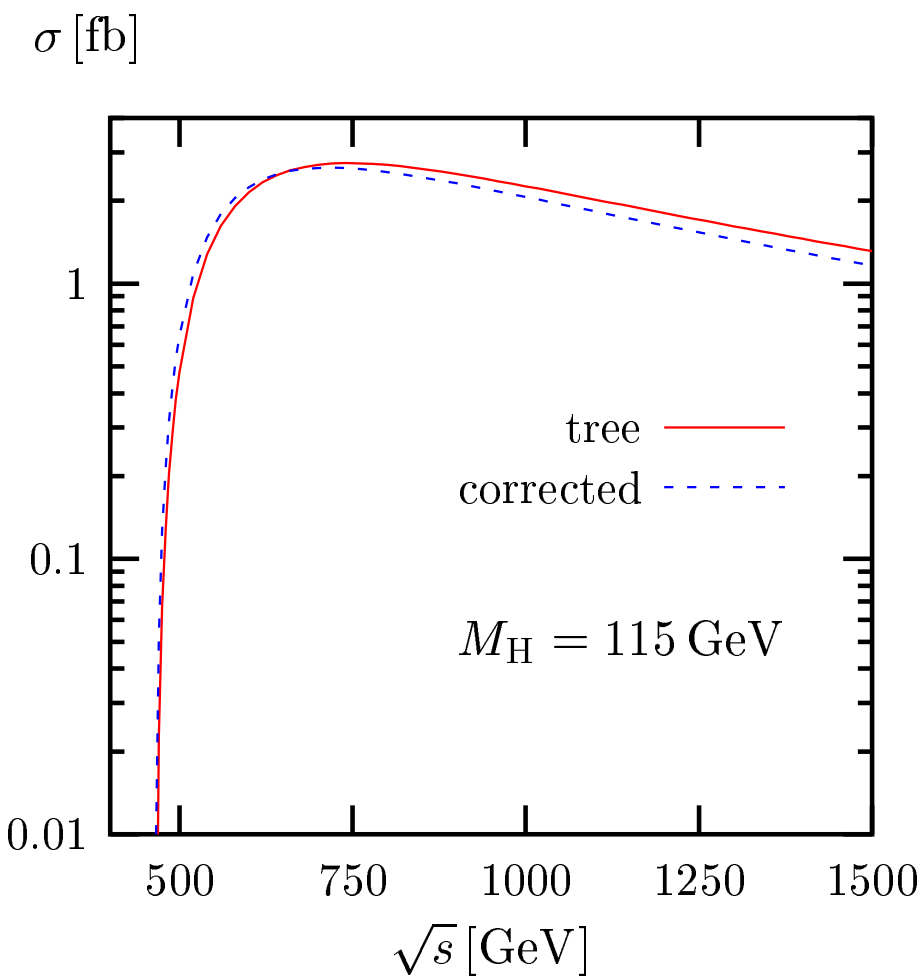
  - calculation similar to $e^+e^- \to \nu\bar{\nu}H$ but even more complex, $\mathcal{O}(700)$ 1-loop diagrams
  - comparison of results:

$\sqrt{s}$ [GeV]	$\sigma_{\rm tree}$ [fb]	σ [fb]	$\sigma/\sigma_{\rm tree} - 1[\%]$	
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.

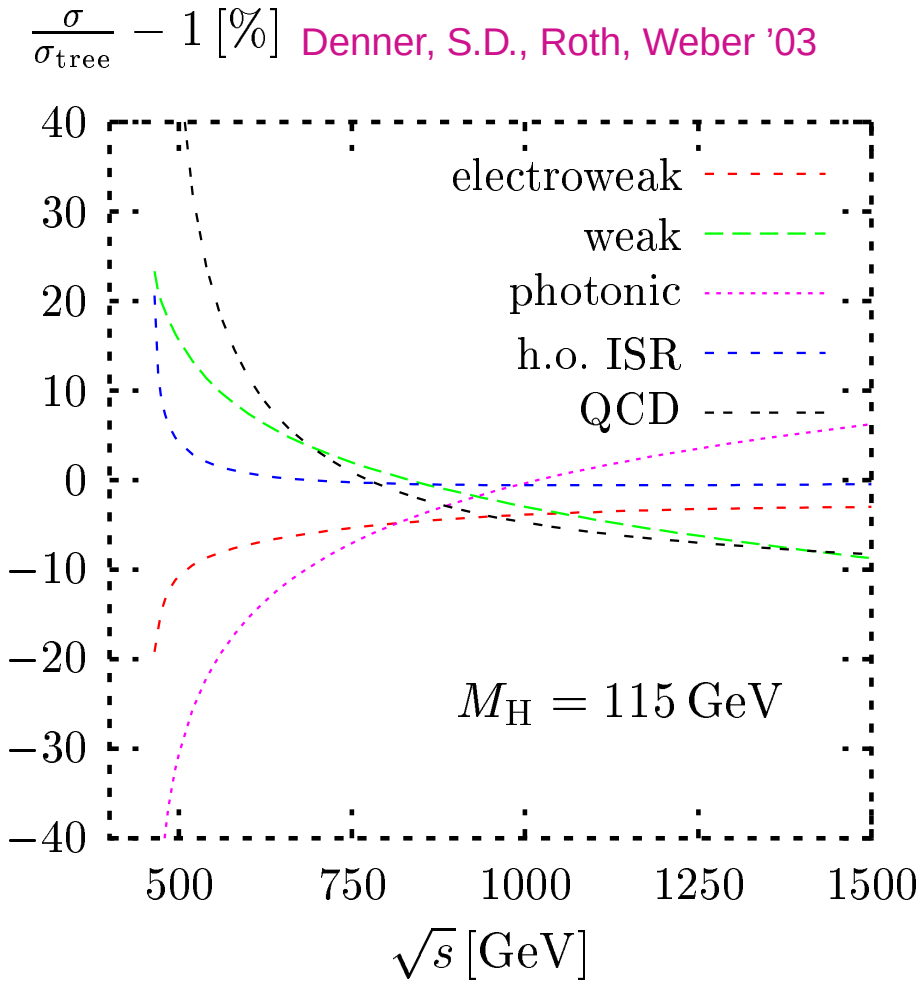
agreement between Bélanger et al. and Denner et al. within 0.1%
(differences to You et al. for large and small energies)

Total cross section for $e^+e^- \to t\bar{t}H$

Born approximation:

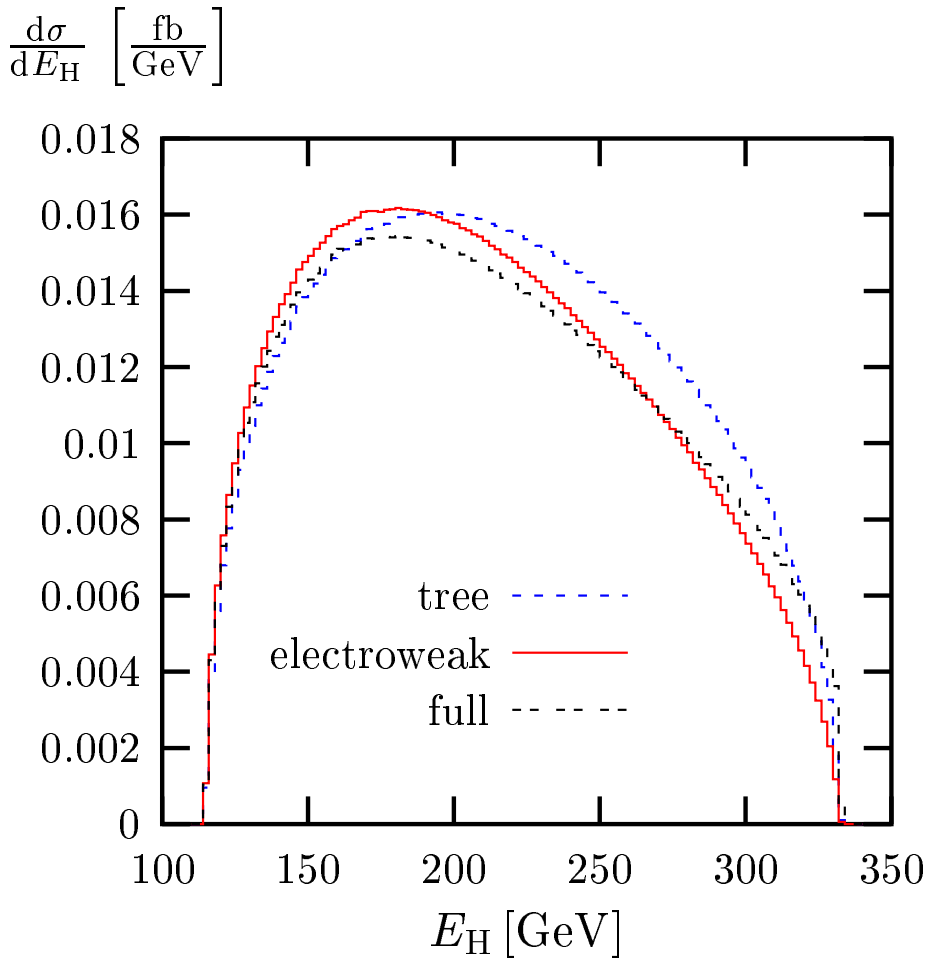


Relative corrections (G_μ-scheme):

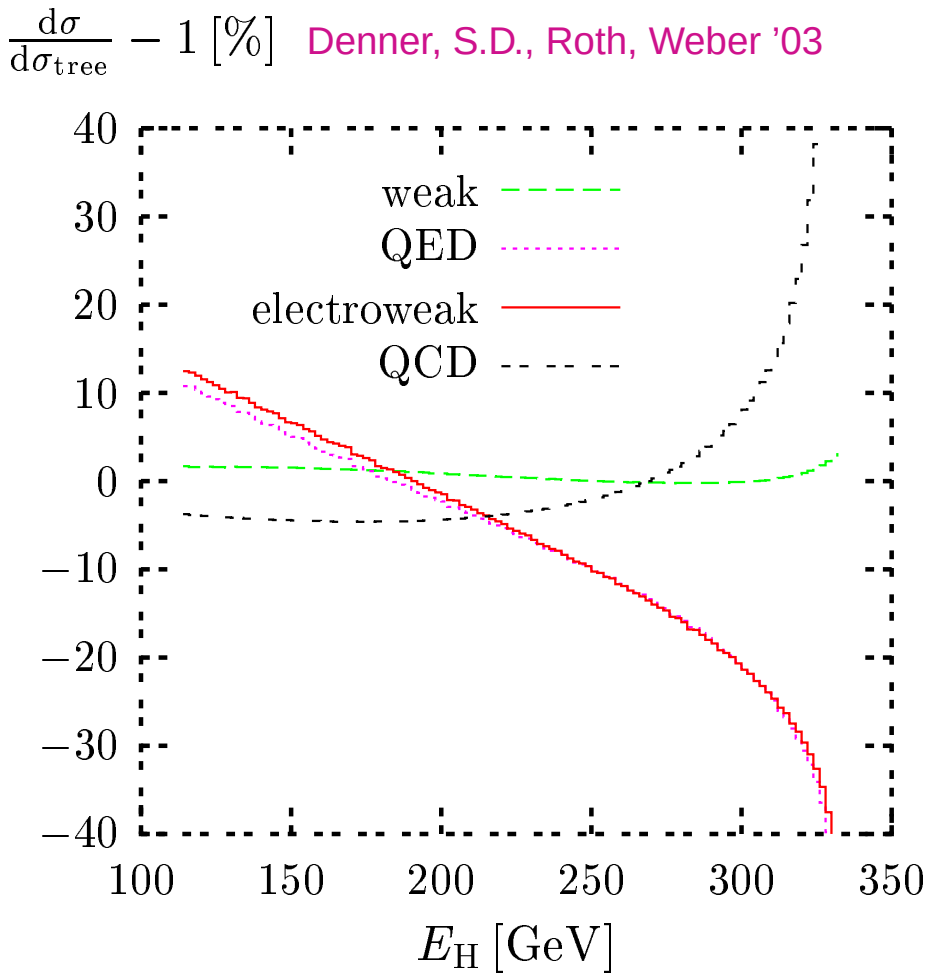


Higgs energy distribution for $e^+e^- \to t\bar{t}H$

Born approximation:



Relative corrections (G_μ-scheme):



Summary

Recent results for $\mathcal{O}(\alpha)$ corrections to Higgs-production processes

- Three competing groups:
  - ◇ Bélanger, Boudjema, Fujimoto, Ishikawa, Kaneko, Kato, Shimizu
    ↪ GRACE / 1-LOOP package
  - ◇ Denner, S.D., Roth, Weber
  - ◇ You, Ma, Chen, Zhang, Yan-Bin, Hou
- Full $\mathcal{O}(\alpha)$ corrections calculated for
  - ◇ $\mathrm{e^+e^- \to \nu\bar{\nu}H}$ — Bélanger et al. '02; Denner et al. '03
  - ◇ $\mathrm{e^+e^- \to t\bar{t}H}$ — You et al. '03; Bélanger et al. '03; Denner et al. '03
  - ◇ $\mathrm{e^+e^- \to ZHH}$ — You et al. '03; Bélanger et al. '03
  - ◇ $\mathrm{\gamma\gamma \to t\bar{t}H}$ — You et al. '03
- Total cross sections and distributions investigated
- Features of the corrections:
  - ◇ electroweak corrections typically of $\mathcal{O}(10\%)$
  - ◇ simple approximation for corrections seems unfeasible

$\Rightarrow$ Full calculations needed for LC physics