Electroweak radiative corrections to $e^+e^- \to \nu\bar{\nu}H$

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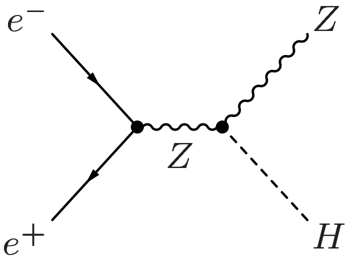
- Motivation
- Tree results
- NLO calculation
- Numerical results
- Conclusions

Denner, Dittmaier, Roth, Weber, hep-ph/0301189, hep-ph/0302198

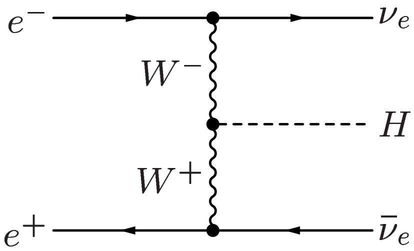
Motivation

Higgs production at e^+e^- colliders: 2 main channels

Higgs-strahlung



WW fusion



large $\sqrt{s}$ $\quad$ $\sigma \propto \frac{1}{s}$ $\quad$ $\sigma \propto \ln s$

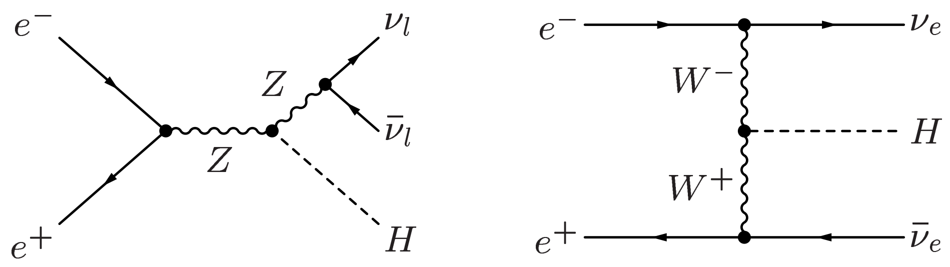
ZZ fusion: σ factor ≈ 10 smaller than WW fusion

WW fusion process $e^+e^- \to \nu\bar{\nu}H$:

- dominant channel for large $\sqrt{s}$
- measurement of W^+W^-H-coupling
- TESLA TDR: $\frac{\delta\sigma}{\sigma} \approx 3\%$
  ($m_H = 120\,\text{GeV}$, $\sqrt{s} = 500\,\text{GeV}$, $\int \mathcal{L} = 500\,\text{fb}^{-1}$)
  $\to$ full EW 1 loop corrections necessary

$e^+e^- \to \nu\bar{\nu}H$: tree results

[Kilian, Krämer, Zerwas '96]

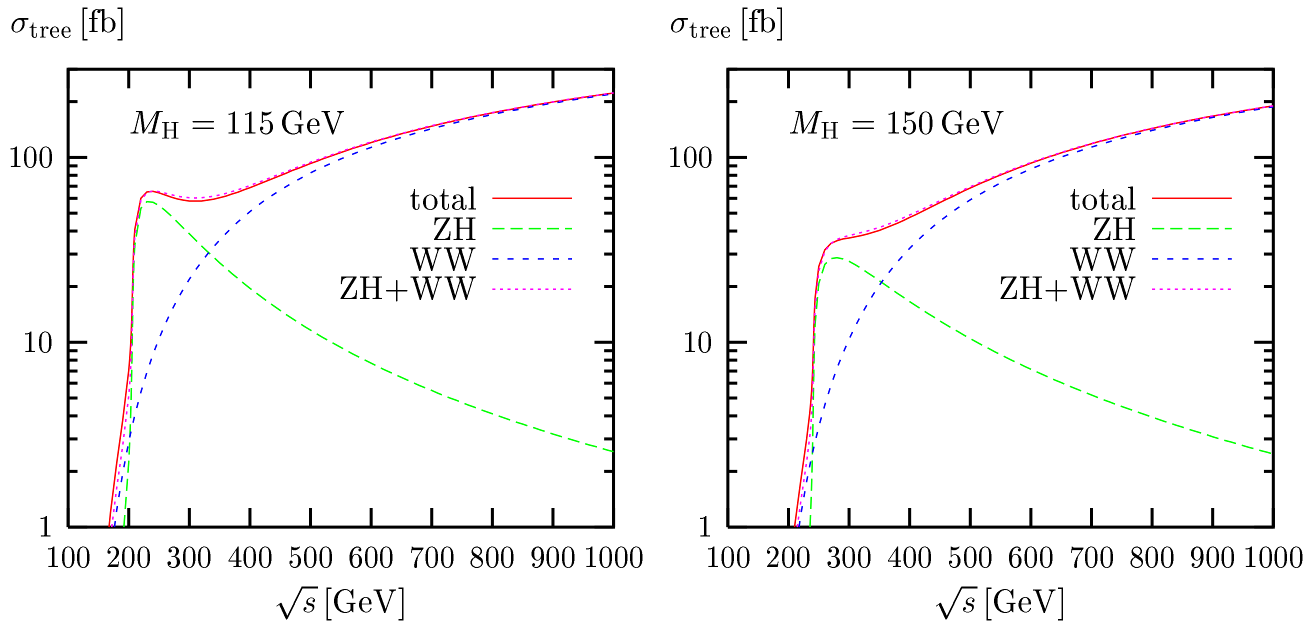


decompose amplitude into ZH and WW contributions

$$\sigma = \sigma^{ZH} + \sigma^{WW} + \sigma^{\text{int}}$$

contributions are gauge invariant

- sum over all 3 neutrino species
- fixed width for resonant Z
- derive α from Fermi constant: $\alpha_{G_\mu} = \dfrac{\sqrt{2}G_\mu m_{\mathrm{W}}^2 s_{\mathrm{W}}^2}{\pi}$



$e^+e^- \to \nu\bar{\nu}H$: NLO calculation

existing work:

- fermion and sfermion loop contributions within MSSM

  [Eberl, Majerotto, Spanos '02]

  [Hahn, Heinemeyer, Weiglein '02]

- analytical results for virtual corrections

  [Jegerlehner, Tarasov '02]

- complete $\mathcal{O}(\alpha)$ corrections in SM

  [Bélanger, Boudjema, Fujimoto, Ishikawa, Kaneko, Kato, Shimizu '02]

our calculation:

- complete $\mathcal{O}(\alpha)$ electroweak corrections to $e^+e^- \to \nu_l\bar{\nu}_l H$ for $l = e, \mu, \tau$ including hard photon radiation

- higher order ISR in structure function approach

- Monte Carlo program
  $\to$ total cross sections and distributions

virtual corrections

calculation of Feynman diagrams:

- 't Hooft-Feynman gauge

- generation by FeynArts

- evaluation using Mathematica / FormCalc
  $\rightarrow$ standard matrix elements and coefficients containing tensor loop integrals
  $\rightarrow$ translation to Fortran/C++ code

- Passarino-Veltman reduction of tensor loop integrals to scalar integrals in Fortran
  5-point: numerical problems $\rightarrow$ special techniques

- scalar integrals: evaluated with standard techniques
  dimensional regularization for UV divergences
  infinitesimal photon mass for IR divergences

- on-shell renormalization scheme

- G_μ scheme: $\alpha_{G_\mu} = \frac{\sqrt{2} G_\mu m_\mathrm{W}^2 s_\mathrm{W}^2}{\pi}$

  absorbs: – running from $Q^2 = 0$ to $Q^2 = m_\mathrm{Z}^2$
  – universal $m_\mathrm{t}^2 / m_\mathrm{W}^2$ corrections related to CC

- $\alpha(0)$ in relative radiative corrections
  $\rightarrow d\sigma^V \propto \alpha_{G_\mu}^3 \alpha(0)$

treatment of Z resonance

tree level:

- use fixed Z-boson width: $\frac{1}{s_{\nu\bar{\nu}}-m_Z^2+im_Z\Gamma_Z}$

NLO corrections:

avoid double counting:
$\rightarrow$ subtract $i\,\mathrm{Im}\,\Sigma_T^{ZZ}(m_Z^2)$ from virtual corrections

fixed width scheme:

- resonant parts: $\frac{1}{s_{\nu\bar{\nu}}-m_Z^2} \rightarrow \frac{1}{s_{\nu\bar{\nu}}-m_Z^2+im_Z\Gamma_Z}$
- non-resonant parts: unchanged
- potentially violates gauge invariance

factorization scheme:

- rescale full ZH amplitude by $\frac{s_{\nu\bar{\nu}}-m_Z^2}{s_{\nu\bar{\nu}}-m_Z^2+im_Z\Gamma_Z}$
- gauge invariant
- non-resonant ZH contributions neglected on resonance
  $\rightarrow$ error $\mathcal{O}(\alpha\Gamma_Z/m_Z) \sim \mathcal{O}(\alpha^2)$

$\Rightarrow$ numerical agreement within integration errors

pentagon diagrams

Passarino-Veltman reduction:

Gram determinants in denominator

Gram dets. vanish in phase space

$\rightarrow$ numerical instabilities

3 solutions:

- workaround:
  calculate $\mathrm{Re}\,\mathcal{M}_1^{\mathrm{pent}}\mathcal{M}_0^*$, evaluate Dirac traces
  loop momenta only in scalar products
  $\rightarrow$ cancel against propagator denominators
  $\rightarrow$ only scalar 5-point functions
  $\Rightarrow$ not general

- Passarino-Veltman and extrapolation:
  extrapolate $d\sigma$ from safe inner phase space regions
  $\Rightarrow$ computationally expensive

- new reduction of 5-point tensor coefficients:
  [Denner, Dittmaier '02]
  $\Rightarrow$ no inverse Gram determinants, completely general

$\Rightarrow$ numerical agreement of all 3 approaches

reduction of 5-point tensor coefficients

[Denner, Dittmaier '02]

4-dimensionality of spacetime
$\to$ loop mom. = linear combination of external mom.

already known: scalar 5-point $\to$ scalar 4-point

[Melrose '65; van Neerven, Vermaseren '84]

this method: extension to tensor 5-point integrals

$$E_0 = \sum_{i=0}^{4} \eta_i D_0(i)$$

$$E^\mu = \sum_{j=1}^{4} p_j^\mu E_j$$

$$E_j = -\sum_{i=1, i\neq j}^{4} \eta_i D_{j_i}(i) - \eta_0 D_j(0) + 2\sum_{i=1}^{4} \zeta_{ji}[D_{00}(i) - D_{00}(0)]$$

$D_*(i)$ omit ith propagator, $i = 0 \ldots 4$ from E_*

- no Gram determinants in denominator
- completely general
- up to tensor rank 4

real corrections

matrix elements:

- evaluated with Weyl–van der Waerden spinor technique
- checked against MadGraph

soft and collinear singularities:

- dipole formalism
- phase space slicing

$\rightarrow$ numerical agreement within 0.03%
$\rightarrow$ slicing needs much more statistics for same precision

$\Rightarrow$ dipole formalism preferable

higher order ISR: using structure function approach

checks and comparisons

checks of the calculation:

- 2 independent calculations
  $\rightarrow$ 2 computer codes for numerical evaluation
  $\rightarrow$ agreement within 12 digits for $d\sigma$

- virtual corrections:
  conventional and background field method
  $\rightarrow$ gauge independence

- soft and collinear singularities:
  dipole formalism and phase space slicing

comparison with other groups:

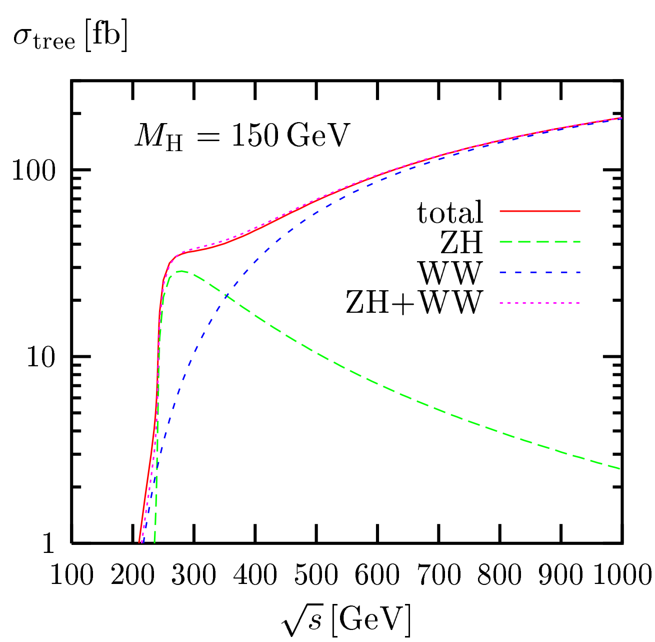
- [Eberl, Majerotto, Spanos], [Hahn, Heinemeyer, Weiglein]
  fermion loop contributions
  discrepancy between these two?
  no, just different renormalization schemes:
  Hahn et al.: G_μ scheme
  Eberl et al.: $\alpha_{\overline{MS}}(m_Z^2)$
  $\rightarrow$ shift $\approx -13\%$ from G_μ scheme
  we find: agreement with both groups

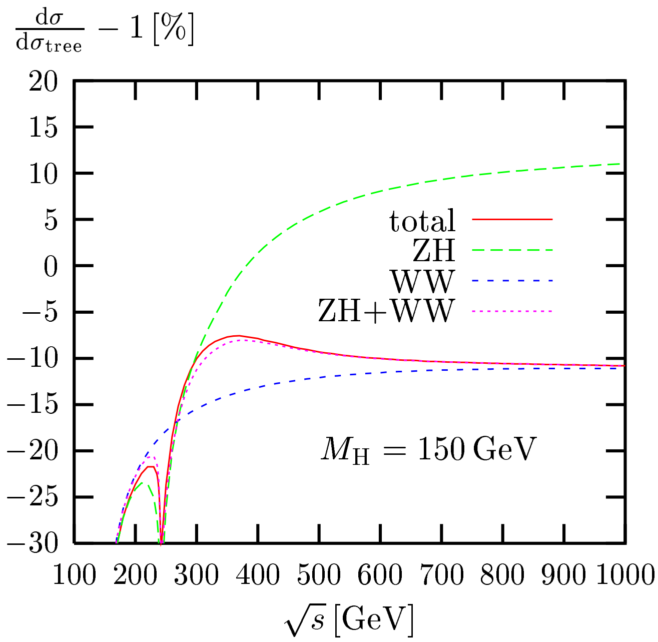
- [Bélanger, Boudjema, Fujimoto, Ishikawa, Kaneko, Kato, Shimizu]
  complete $\mathcal{O}(\alpha)$ corrections in SM
  use $\alpha(0)$ $\rightarrow$ shift $\approx +9\%$ from G_μ scheme
  agreement within 0.3% for corrected σ
  agreement for E_H and $\cos\theta_H$ distributions

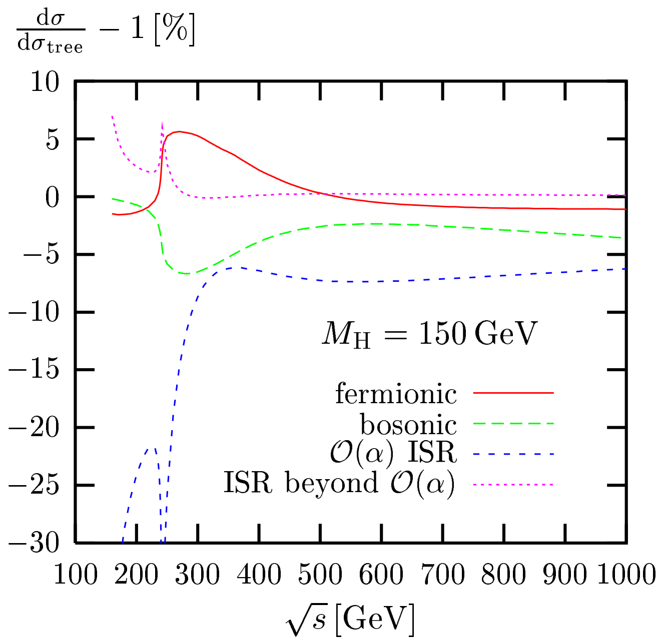
numerical results

input parameters:

PDG 2002, use $m_{\mathrm{W}}^{\mathrm{exp}}$, not m_{W} from G_μ







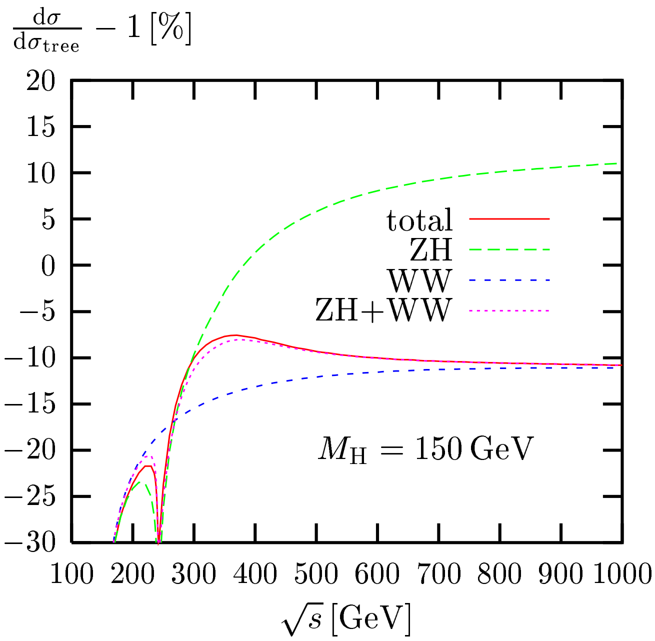
- total corrections dominated by ISR
- remaining contributions:
  $-6\% \ldots +6\%$ for $\sqrt{s} < 500$ GeV
  $1\% \ldots -4\%$ for $\sqrt{s} > 500$ GeV

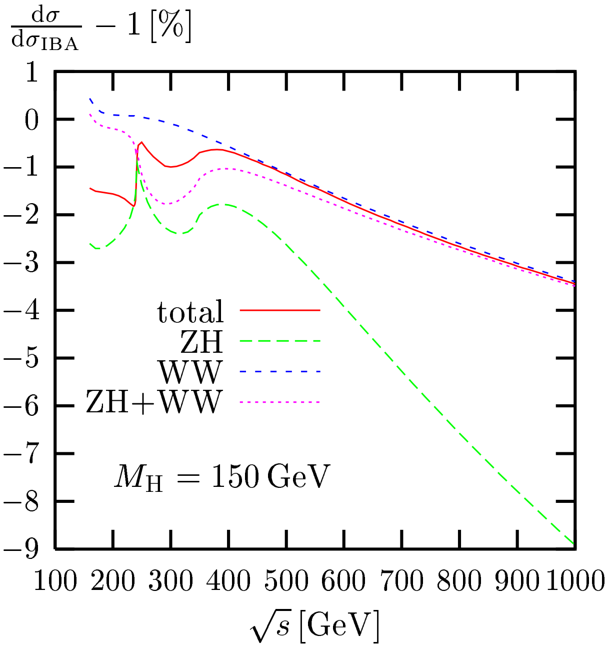
improved Born approximation (IBA)

definition of IBA:

$$d\sigma_{\text{IBA}}^{\text{non-photonic}} = d\sigma_0 - d\sigma_0^{WW} \frac{5\alpha}{16\pi s_{\mathrm{W}}^2} \frac{m_{\mathrm{t}}^2}{m_{\mathrm{W}}^2}$$

$$\sigma_{\text{IBA}} = \int \text{ISR structure functions} \otimes d\sigma_{\text{IBA}}^{\text{non-photonic}}$$

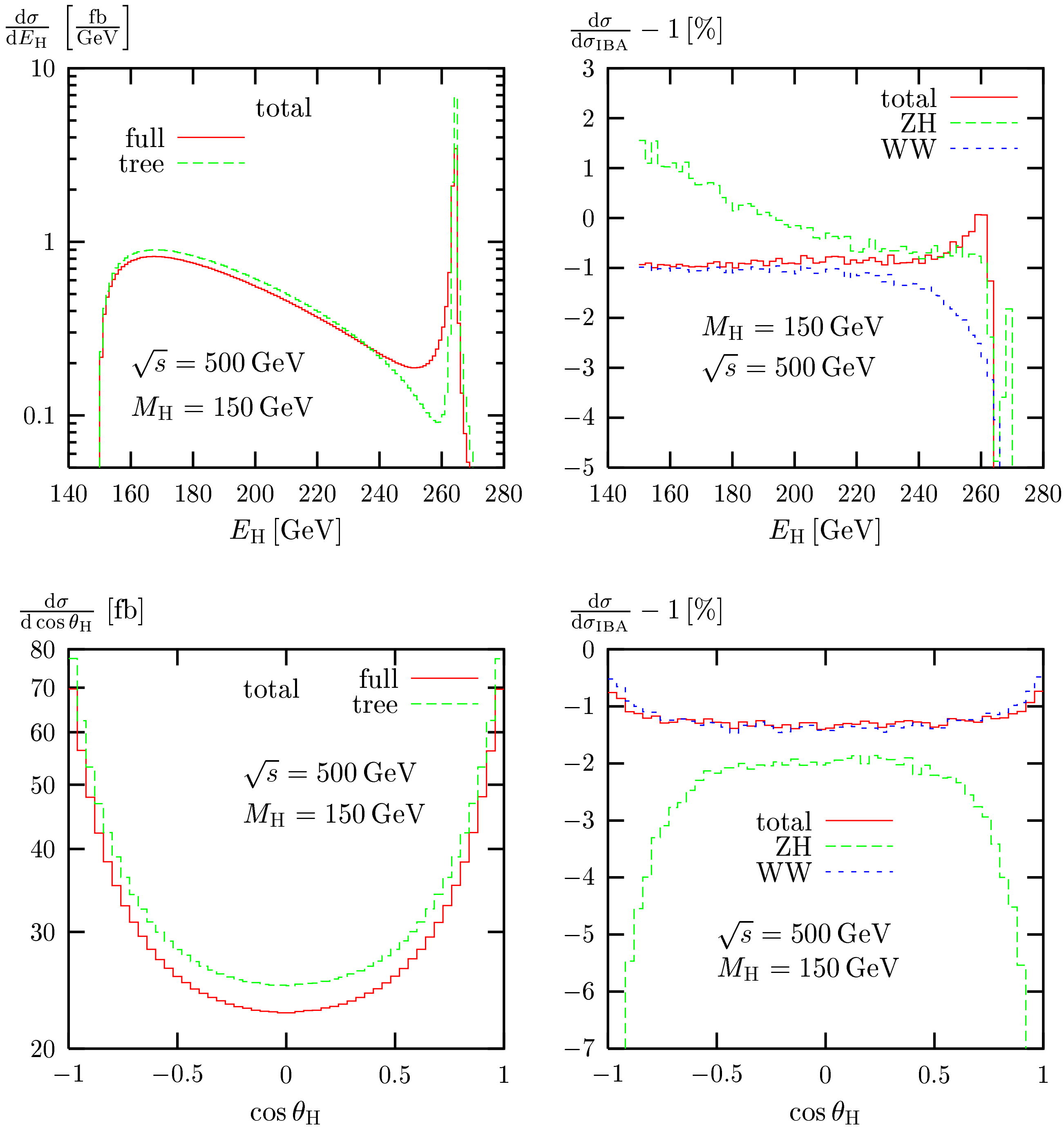




- IBA absorbs large part of corrections
- corrections relative to IBA ≈ experimental error on σ

$\Rightarrow$ full corrections necessary for precision analysis

distributions



- corrections relative to IBA: weak variation with E_H / $\cos\theta_H$ for total σ and WW part

conclusions

- $e^+e^- \to \nu\bar{\nu}H$ important process for H production
- complete calculation of electroweak $\mathcal{O}(\alpha)$ corrections
  $\to$ agreement with other groups
- total σ: corrections $\approx -10\%$ for high $\sqrt{s}$
  larger for lower energies
  bulk from ISR
- constructed IBA:
  accuracy for σ_{tot}: $1\%(3\%)$ for $\sqrt{s} < 500\,\mathrm{GeV}(1\,\mathrm{TeV})$
  $\to$ full corrections necessary for precision analysis
- distributions in E_H and $\cos\theta_H$:
  corrections relative to IBA: nearly flat for total σ and WW contribution