Electroweak Correction for the Study of Higgs Potential in LC

LAPTH-Minamitateya Collaboration

LCWS05

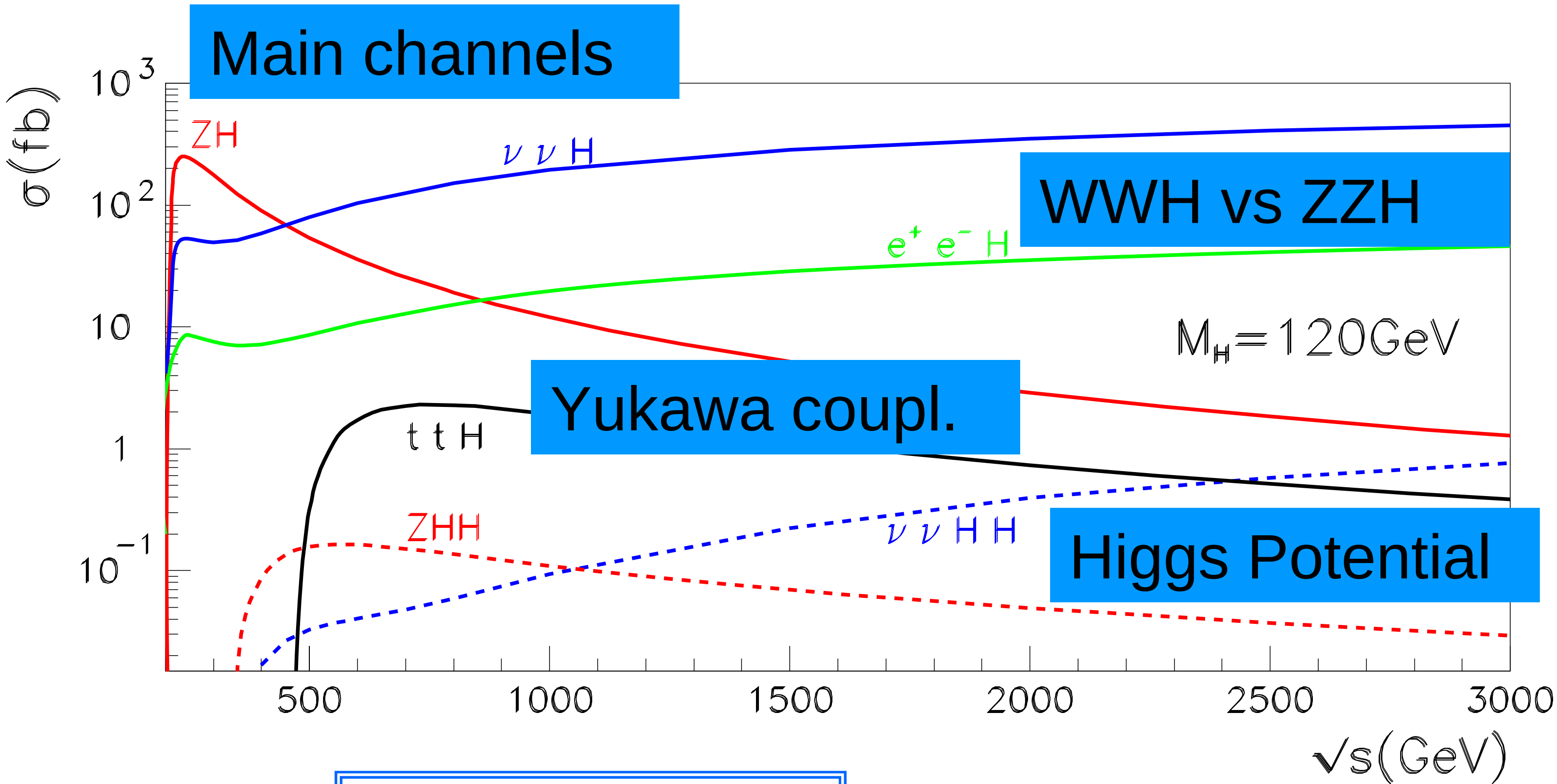
2005.3.19, Stanford U.

presented by K.Kato(Kogakuin U.)

Introduction

- LC : high-precision experiments
  → Requires the same level theoretical prediction = Needs higher order calculation
- Higgs study : Central target
  → Interesting channels = multi-body final states
- 1-loop correction to $e^+e^- \to$ 3, 4-bodies : Great Progress since Sept. 2002

Higgs@LC:tree cross sections



2→3,4 processes
important

number of diagrams (GRACE:NLG model)

A.Denner, J.Kublbeck,
R.Mertig, M.Bohm,
Z.Phys.C56(1992) 261;
B.A.Kniehl,
Z.Phys.C55(1992) 605.

$e^+e^- \to$	tree	1-loop
ZH	4(1)	341(119)

10 yea
required to
develop 2→3
tools
Automated
Systems

with(without) e-scalar couplings

Full 1-loop RC available

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

GRACE, PLB559(2003)252
Denner et al., NPB660(2003)289

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

GRACE, PLB571(2003)163
You et al., PLB571(2003)85
Denner et al., PLB575(2003)290

$$e^+e^- \to ZHH$$

GRACE, PLB576(2003)152
Zhang et al., PLB578(2004)349

$$e^+e^- \to e^+e^-H$$

GRACE, PLB600(2004)65

$$e^+e^- \to \nu\bar{\nu}\gamma \quad \nu = \nu_\mu, \nu_e$$

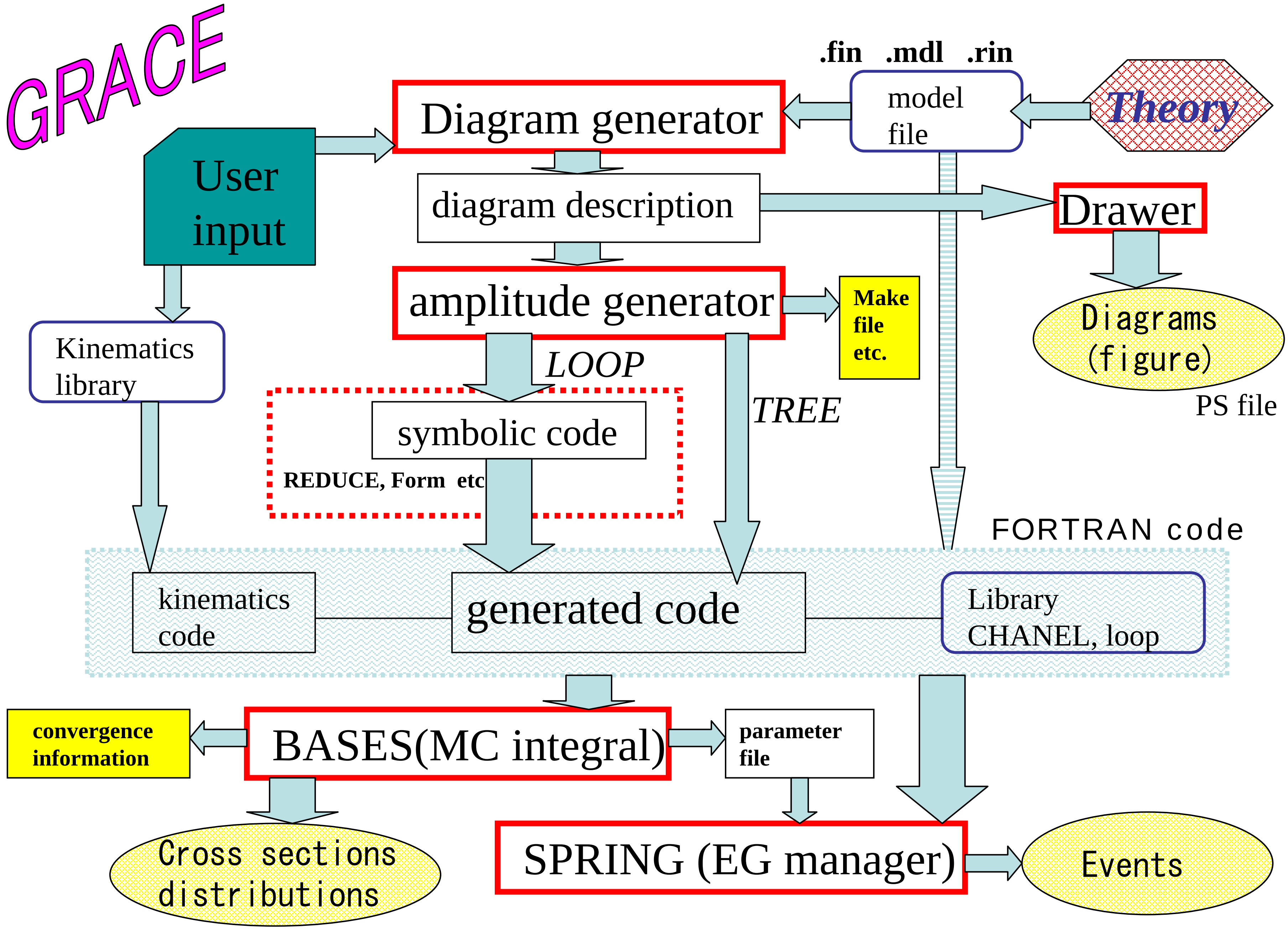
GRACE, NIM A534(2004)334

$$e^+e^- \to \nu\bar{\nu}HH$$

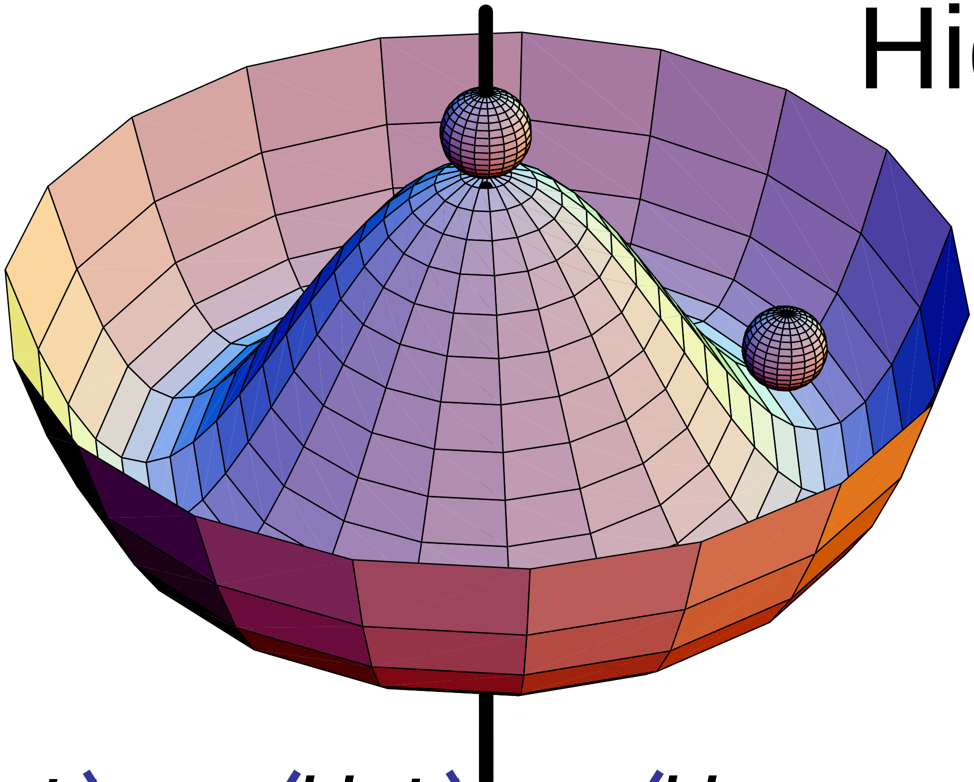
GRACE, Talk by Y.Yasui at Durham(Sep.2004)

$$e^+e^- \to \nu_\tau\tau^+\mu^-\bar{\nu}_\mu,\ u\bar{d}s\bar{c}$$

Denner etal., hep-ph/0502063

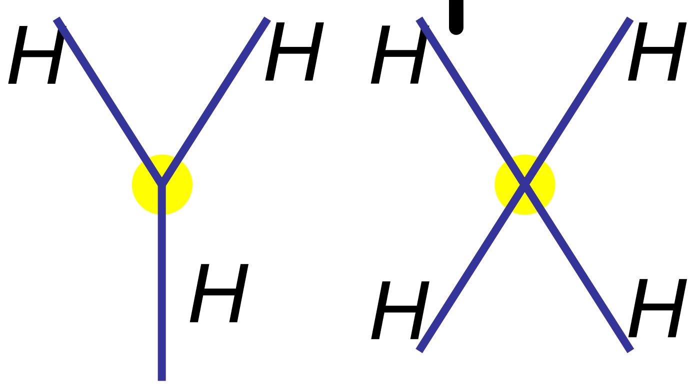

GRACE
.fin .mdl .rin
Diagram generator
model file
Theory
User input
diagram description
Drawer
amplitude generator
Make file etc.
Diagrams (figure)
PS file
Kinematics library
LOOP
TREE
symbolic code
REDUCE, Form etc
FORTRAN code
kinematics code
generated code
Library CHANEL, loop
convergence information
BASES(MC integral)
parameter file
Cross sections distributions
SPRING (EG manager)
Events

Higgs Potential



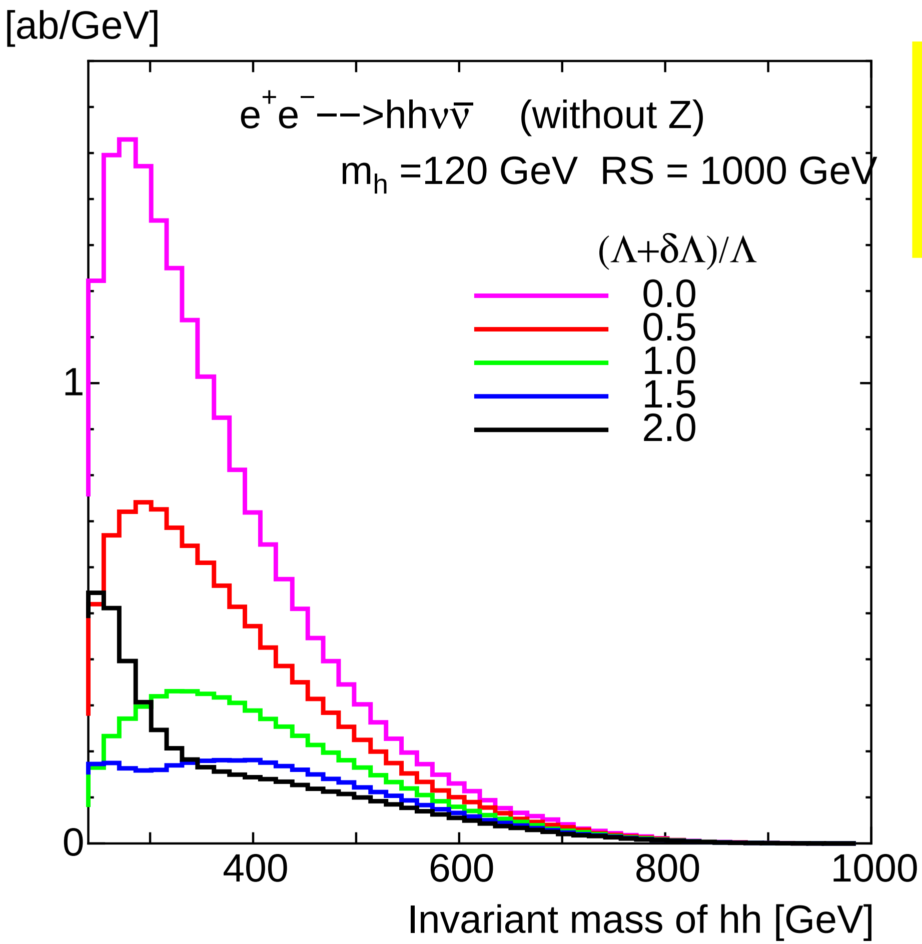
Something required to provide mass
Key for the structure of standard model

Window to New Physics



Double (triple) Higgs production Process

$e^+e^- \rightarrow \nu\ \nu\ HH$

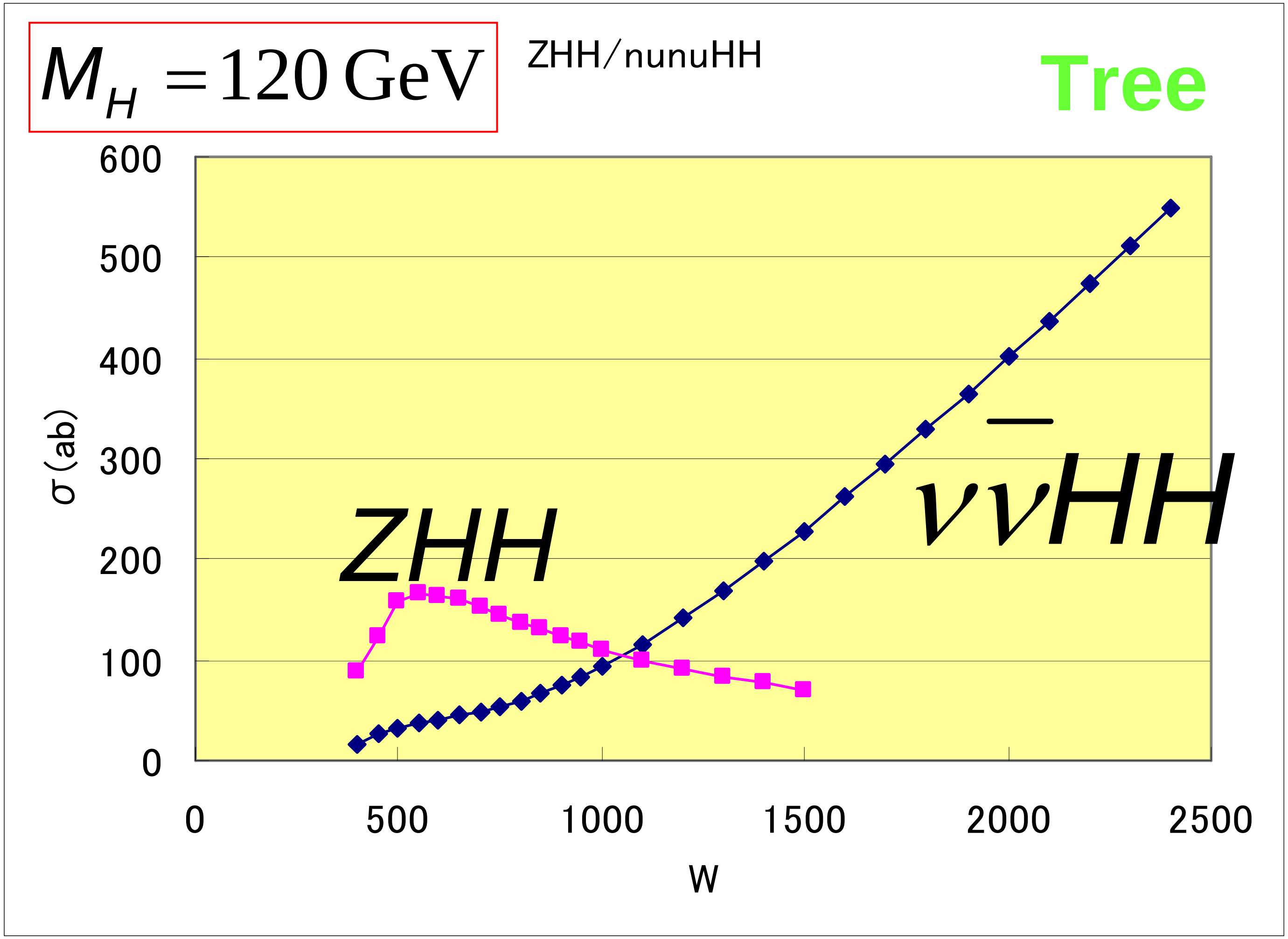


HHH coupling dependence
SM: $\delta\Lambda = 0$

tree

old parameter set

ν ν HH vs ZHH



$$e^+e^- \rightarrow ZHH$$

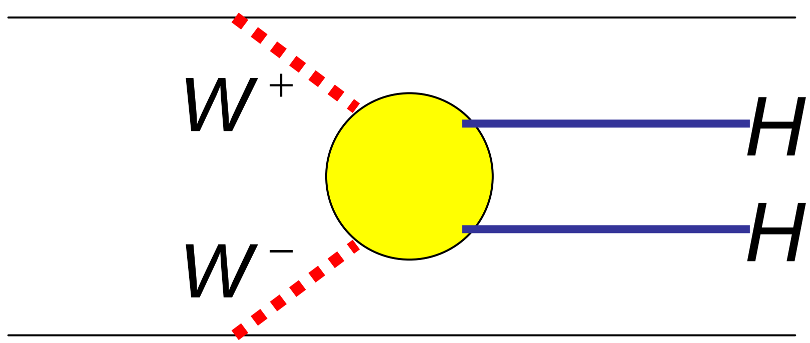
Low W

FULL calculation

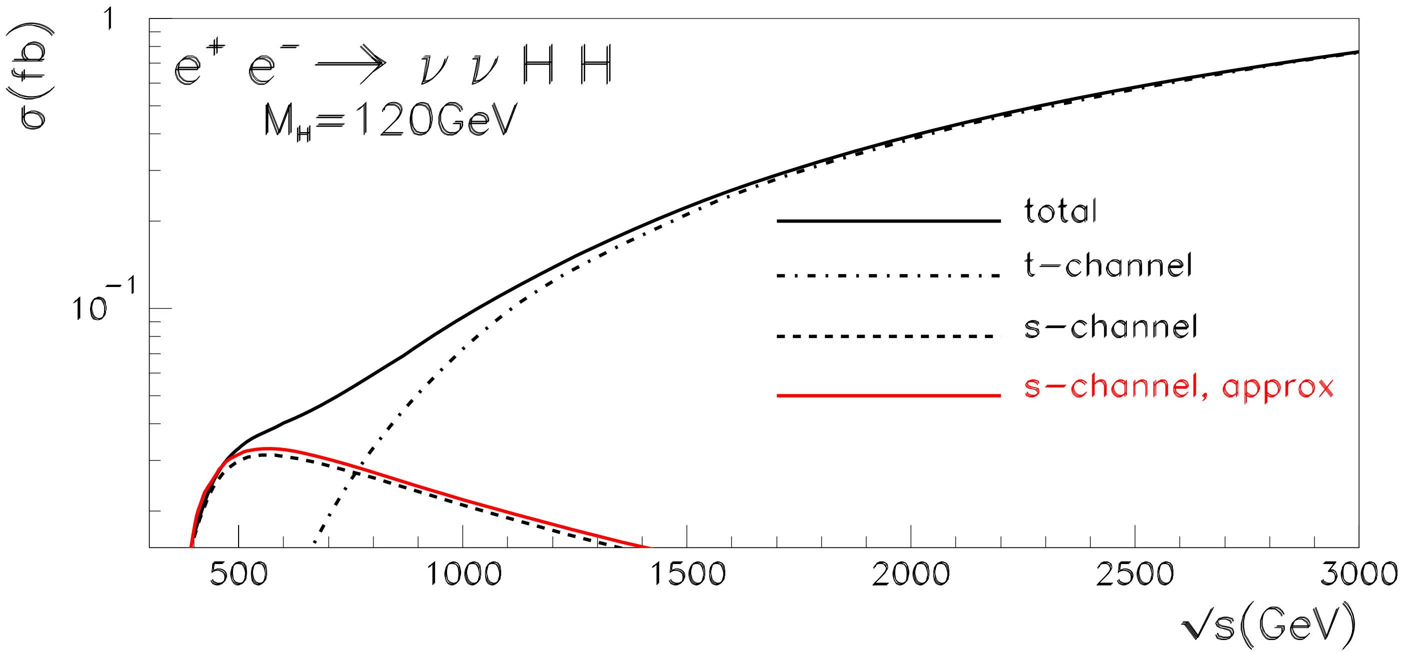
$$e^+e^- \rightarrow \nu\bar{\nu}HH$$

High W

dominant mechanism (approximation)

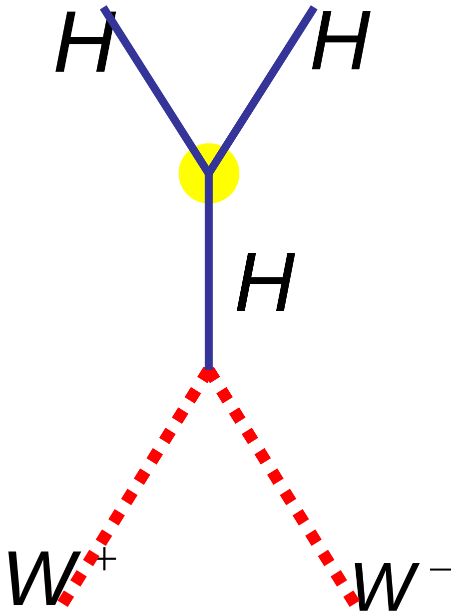


$e^+e^- \rightarrow \nu\ \nu$ HH

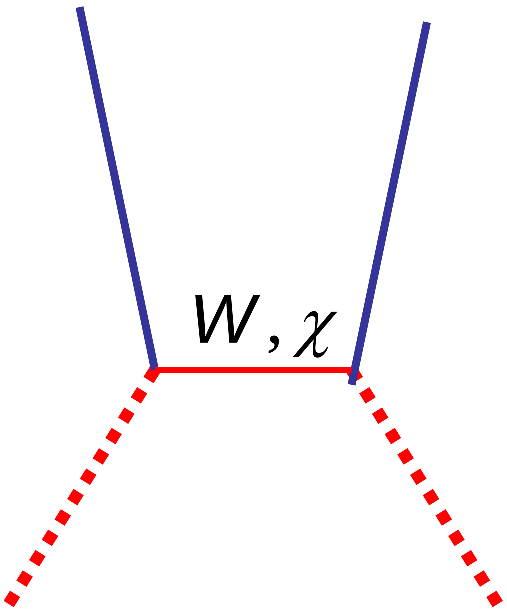


$W^+W^- \rightarrow HH$

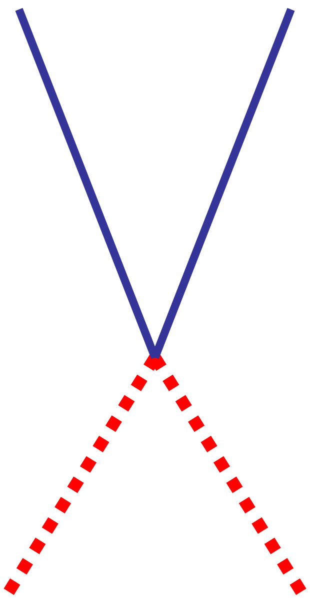
Annihilation



Boson Exchange



Contact Interaction



$W^+W^- \rightarrow HH$

- tree … 6 diagrams

  Annihilation, **B**oson exch., **C**ontact int.

  B ←→ **A**, **C** … opposite sign

- 1-loop … 827 diagrams

  → 13 groups

  A : vertex corr .HHH, WWH, AWW, ZWW

  B : vertex corr. WWH, W χ H

  C : Box

Check : Cuv independence

	Cuv=0	Cuv=100	Cuv=10000
$M_1^{(1)}$	-2.43803300748454E-02	-2.43803300748515E-02	-2.43803300745575E-02
$M_2^{(1)}$	6.36129553455079E-03	6.36129553455044E-03	6.36129553460606E-03
$M_3^{(1)}$	7.23087719852241E-03	7.23087719852186E-03	7.23087719846840E-03
$M_4^{(1)}$	6.36129553455080E-03	6.36129553455055E-03	6.36129553462738E-03
$M_5^{(1)}$	7.23087719852242E-03	7.23087719852180E-03	7.23087719845419E-03
$M_6^{(1)}$	3.06287858179164E-02	3.06287858179168E-02	3.06287858180306E-02
$M_7^{(1)}$	0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00
$M_8^{(1)}$	0.00000000000000E+00	0.00000000000000E+00	0.00000000000000E+00
$M_9^{(1)}$	3.27505572723379E-02	3.27505572723362E-02	3.27505572717802E-02
$M_{10}^{(1)}$	3.00769736052286E-02	3.00769736052207E-02	3.00769736047325E-02
$M_{11}^{(1)}$	3.27505572723379E-02	3.27505572723362E-02	3.27505572717802E-02
$M_{12}^{(1)}$	3.00769736052286E-02	3.00769736052209E-02	3.00769736047325E-02
$M_{13}^{(1)}$	-1.87904957771869E-01	-1.87904957771862E-01	-1.87904957771593E-01
$M_A^{(1)}$	6.24845574307105E-03	6.24845574306529E-03	6.24845574347307E-03
$M_B^{(1)}$	1.52839407221279E-01	1.52839407221259E-01	1.52839407219181E-01
$M_C^{(1)}$	-1.87904957771869E-01	-1.87904957771862E-01	-1.87904957771593E-01
Total	-2.88170948075182E-02	-2.88170948075379E-02	-2.88170948089388E-02

Linear Gauge vs Non-Linear Gauge

NLG	Cuv=0	Cuv=100
$M_1^{(1)}$	-5.88235946700174E-02	-5.88235946700178E-02
$M_2^{(1)}$	-3.07618745586793E-02	3.45210584160196E-01
$M_3^{(1)}$	-3.28642239568896E-02	3.47696096879355E-01
$M_4^{(1)}$	-3.07618745586793E-02	3.45210584160196E-01
$M_5^{(1)}$	-3.28642239568896E-02	3.47696096879354E-01
$M_6^{(1)}$	2.36103152312794E-02	2.36103152312744E-02
$M_7^{(1)}$	0.00000000000000E+00	-6.93889390390723E-18
$M_8^{(1)}$	0.00000000000000E+00	0.00000000000000E+00
$M_9^{(1)}$	1.84494128486571E-02	-3.57523045870251E-01
$M_{10}^{(1)}$	2.10500413941455E-02	-3.59510279442103E-01
$M_{11}^{(1)}$	1.84494128486572E-02	-3.57523045870251E-01
$M_{12}^{(1)}$	2.10500413941454E-02	-3.59510279442102E-01
$M_{13}^{(1)}$	5.46494731767579E-02	5.46494731769278E-02
$M_A^{(1)}$	-3.52132794387380E-02	-3.52132794387434E-02
$M_B^{(1)}$	-4.82532885455325E-02	-4.82532885456059E-02
$M_C^{(1)}$	5.46494731767579E-02	5.46494731769278E-02
Total	-2.88170948075125E-02	-2.88170948074217E-02

LG	Cuv=0
$M_1^{(1)}$	-2.43803300748454E-02
$M_2^{(1)}$	6.36129553455079E-03
$M_3^{(1)}$	7.23087719852241E-03
$M_4^{(1)}$	6.36129553455080E-03
$M_5^{(1)}$	7.23087719852242E-03
$M_6^{(1)}$	3.06287858179164E-02
$M_7^{(1)}$	0.00000000000000E+00
$M_8^{(1)}$	0.00000000000000E+00
$M_9^{(1)}$	3.27505572723379E-02
$M_{10}^{(1)}$	3.00769736052286E-02
$M_{11}^{(1)}$	3.27505572723379E-02
$M_{12}^{(1)}$	3.00769736052286E-02
$M_{13}^{(1)}$	-1.87904957771869E-01
$M_A^{(1)}$	6.24845574307105E-03
$M_B^{(1)}$	1.52839407221279E-01
$M_C^{(1)}$	-1.87904957771869E-01
Total	-2.88170948075182E-02

leading m_t formulas

A: $C_H + C_W$

B: $2C_W$

C: C_4

M_W=80.4163
M_Z=91.1876
M_H=120
m_t=180
α=1/137.0359895

$$C_H = -\frac{\alpha}{3\pi s_w^2} N_C \frac{m_t^4}{M_W^2 M_H^2}$$

−0.11779616

$$C_W = -\frac{\alpha}{8\pi s_w^2} N_C \frac{m_t^2}{M_W^2} \frac{2s_W^2 + 3}{12 s_w^2}$$

−0.02535196

$$C_4 = -\frac{\alpha}{8\pi s_w^2} N_C \frac{m_t^2}{M_W^2} \frac{8s_W^2 + 3}{6 s_w^2}$$

−0.07033663

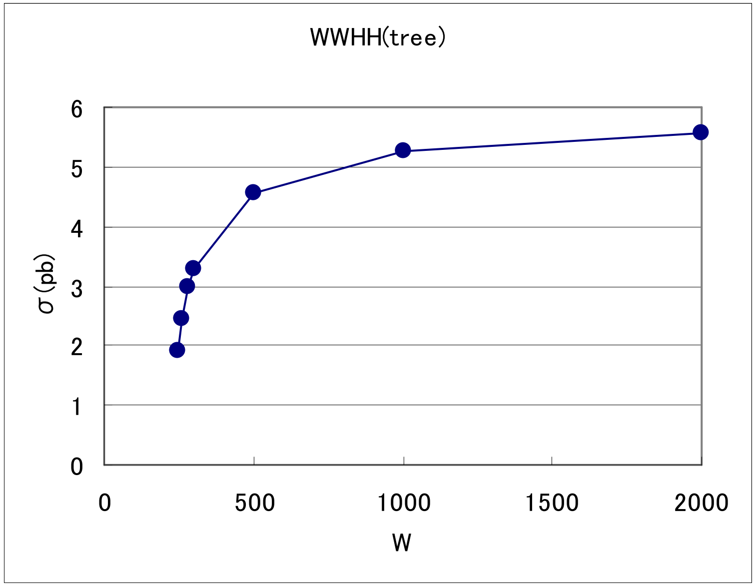
$$m_t = 180 \times 10^{(n-1)} \text{ GeV } (n = 1,2,3,4,5)$$

real world : NOT m_t >> W, M_H, M_Z,…

	$m_t = 180$	$m_t = 180 \times 10^1$	$m_t = 180 \times 10^2$	$m_t = 180 \times 10^3$	$m_t = 180 \times 10^4$
R_1	-3.95661868E-02	-1.16590883E+03	-1.17784063E+07	-1.17796040E+11	-1.17796160E+15
R_2	1.08836690E-01	-2.41343274E+00	-2.53407370E+02	-2.53518663E+04	-2.53519683E+06
R_3	1.09491467E-01	-2.41224707E+00	-2.53406171E+02	-2.53518651E+04	-2.53519683E+06
R_4	1.08836690E-01	-2.41343274E+00	-2.53407370E+02	-2.53518663E+04	-2.53519683E+06
R_5	1.09491467E-01	-2.41224707E+00	-2.53406171E+02	-2.53518651E+04	-2.53519683E+06
R_6	1.39129674E-01	-2.38545988E+00	-2.53379444E+02	-2.53518384E+04	-2.53519680E+06
R_9	4.49015626E-02	-2.47168199E+00	-2.53465487E+02	-2.53519244E+04	-2.53519689E+06
R_{10}	4.49636773E-02	-2.47197693E+00	-2.53465796E+02	-2.53519247E+04	-2.53519689E+06
R_{11}	4.49015626E-02	-2.47168199E+00	-2.53465487E+02	-2.53519244E+04	-2.53519689E+06
R_{12}	4.49636773E-02	-2.47197693E+00	-2.53465796E+02	-2.53519247E+04	-2.53519689E+06
R_{13}	1.03054258E-01	-6.88133668E+00	-7.03232676E+02	-7.03365171E+04	-7.03359795E+06

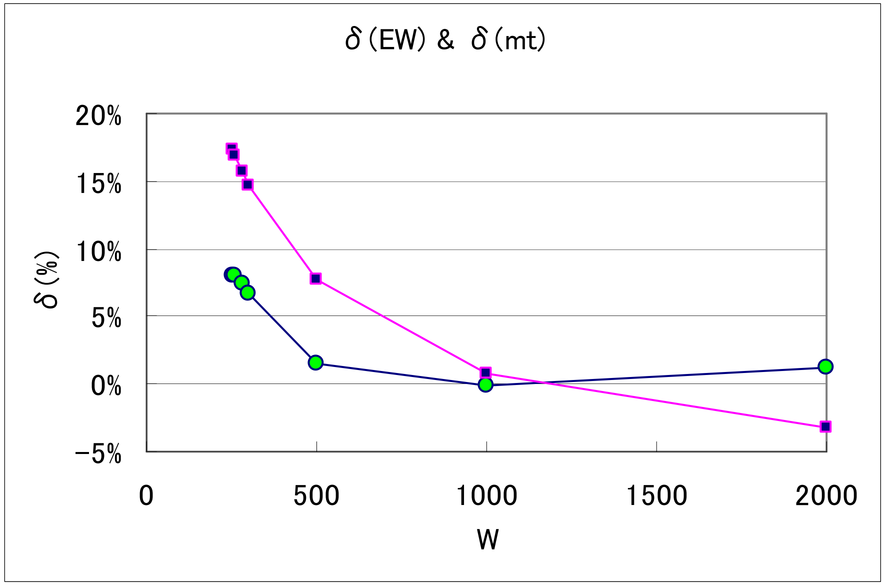
OK

proof of the formulas and
the performance of GRACE system

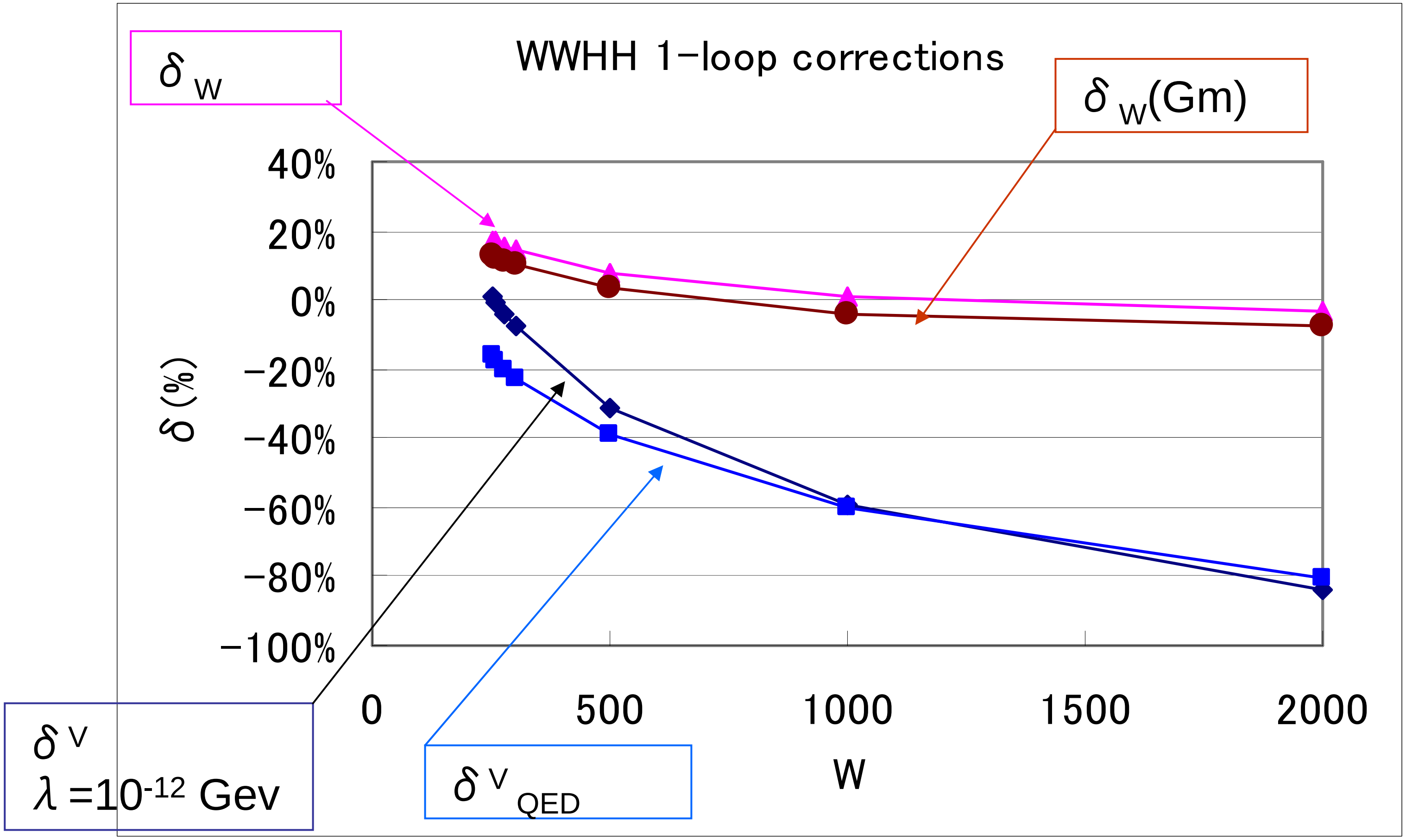


tree+leading mt correction

full EW correction (w/o QED)



$W^+W^- \rightarrow HH$



$e^+e^- \rightarrow \nu\ \nu$ H H

- number of diagrams

ν_e ... tree= 81 loop=19638

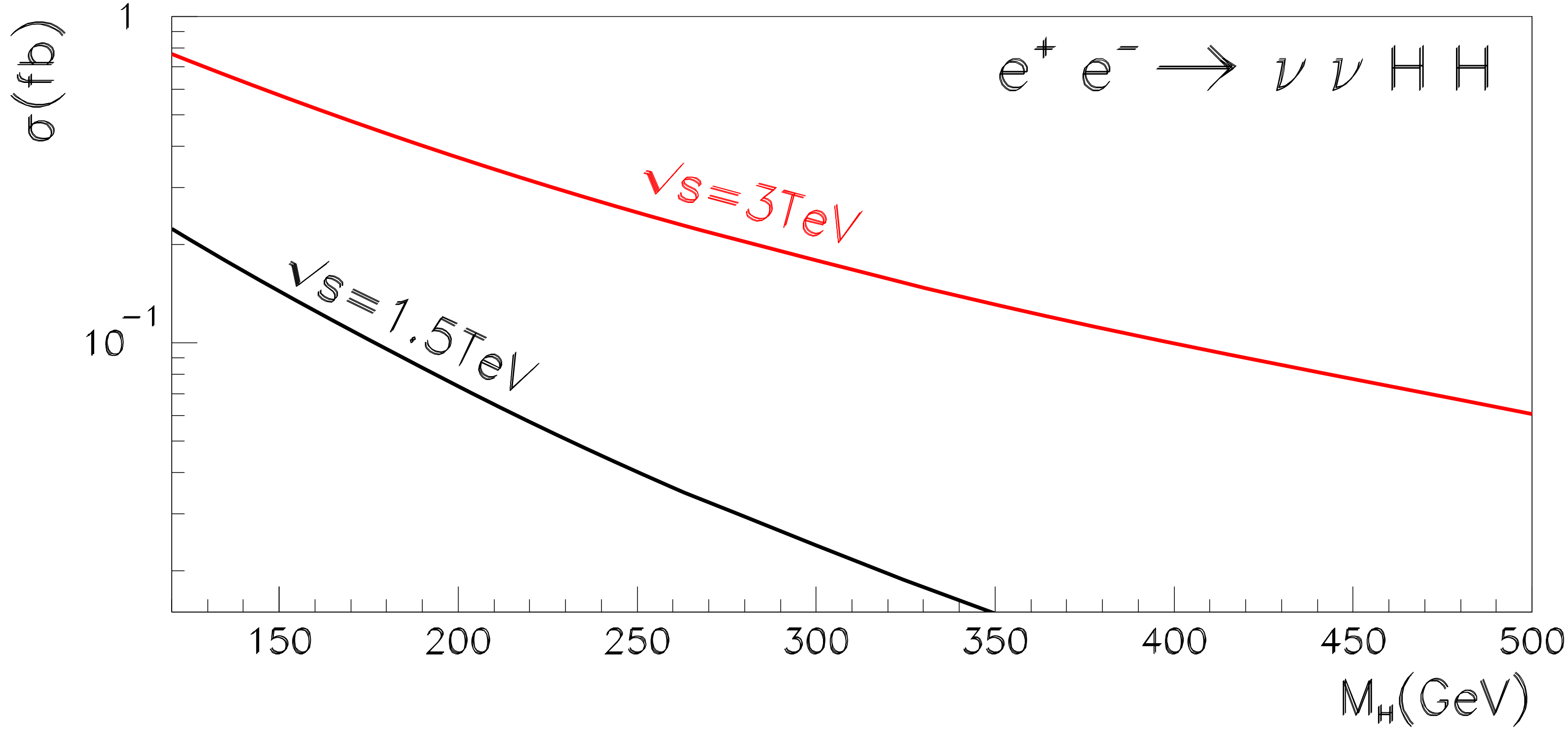
(prod. set = 12 x 3416)

50M lines of Fortran code

ν_{mu} ... tree= 27 loop=8292

(prod. set = 6 x 1754)

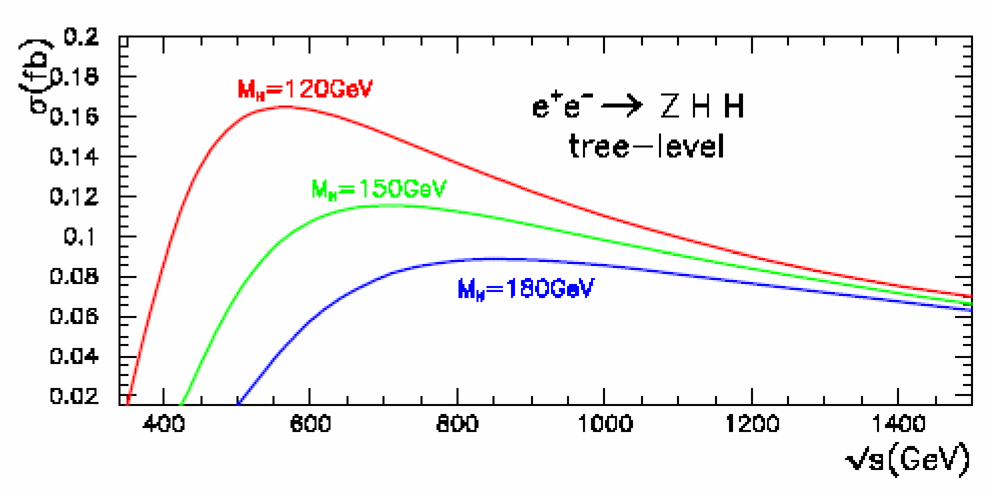
$e^+e^- \rightarrow \nu\ \nu$ HH

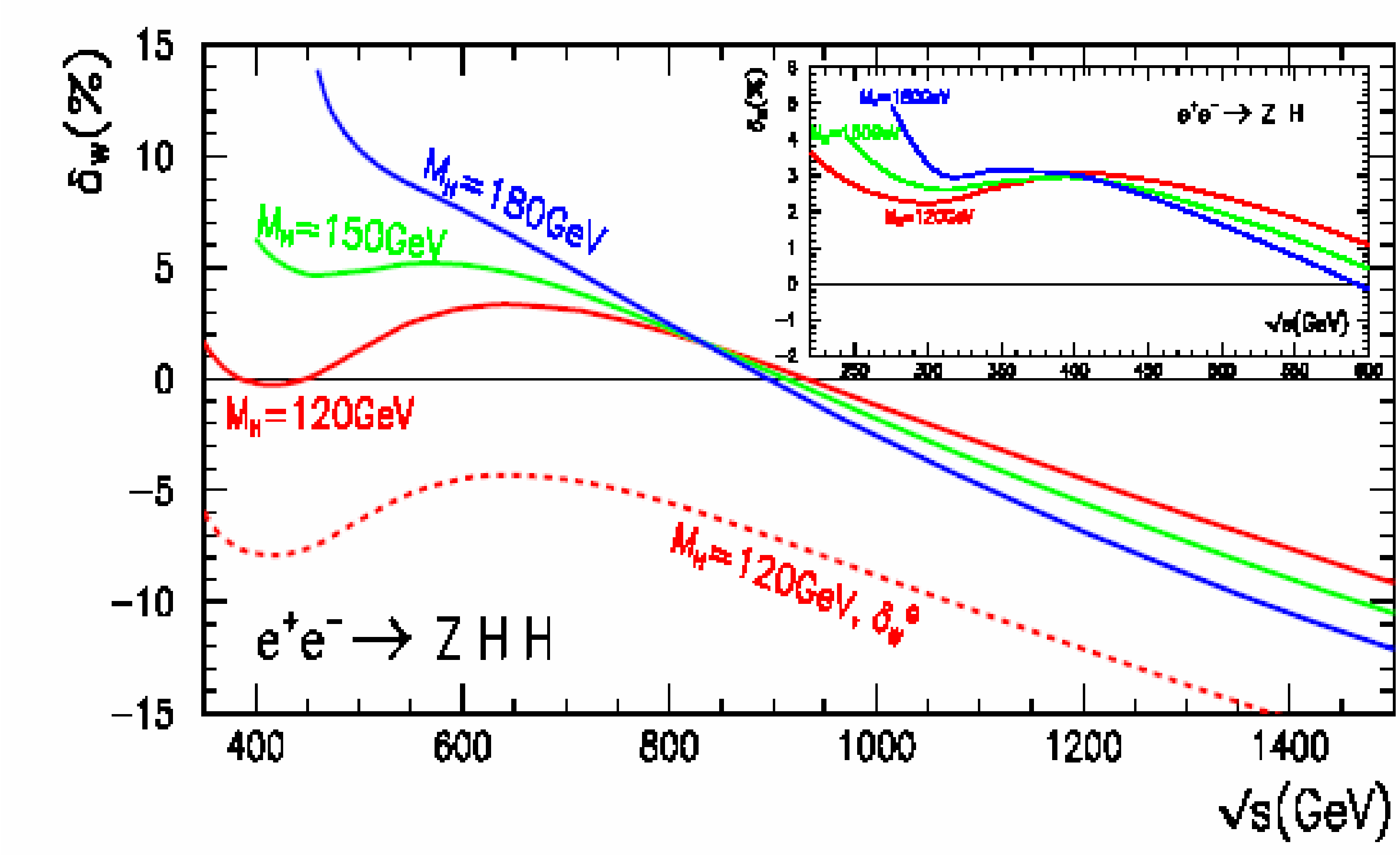


"s-channel"

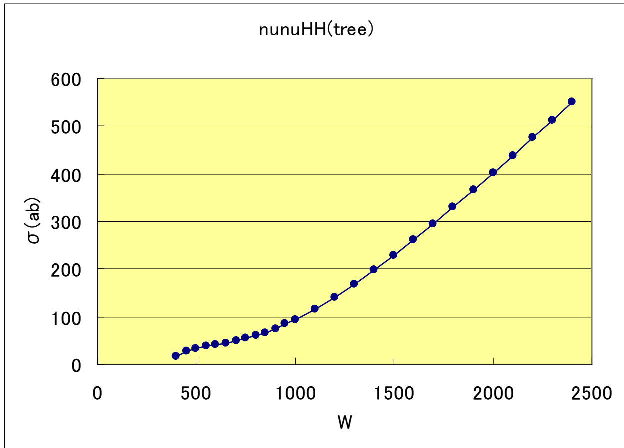
$$e^+e^- \to ZHH$$

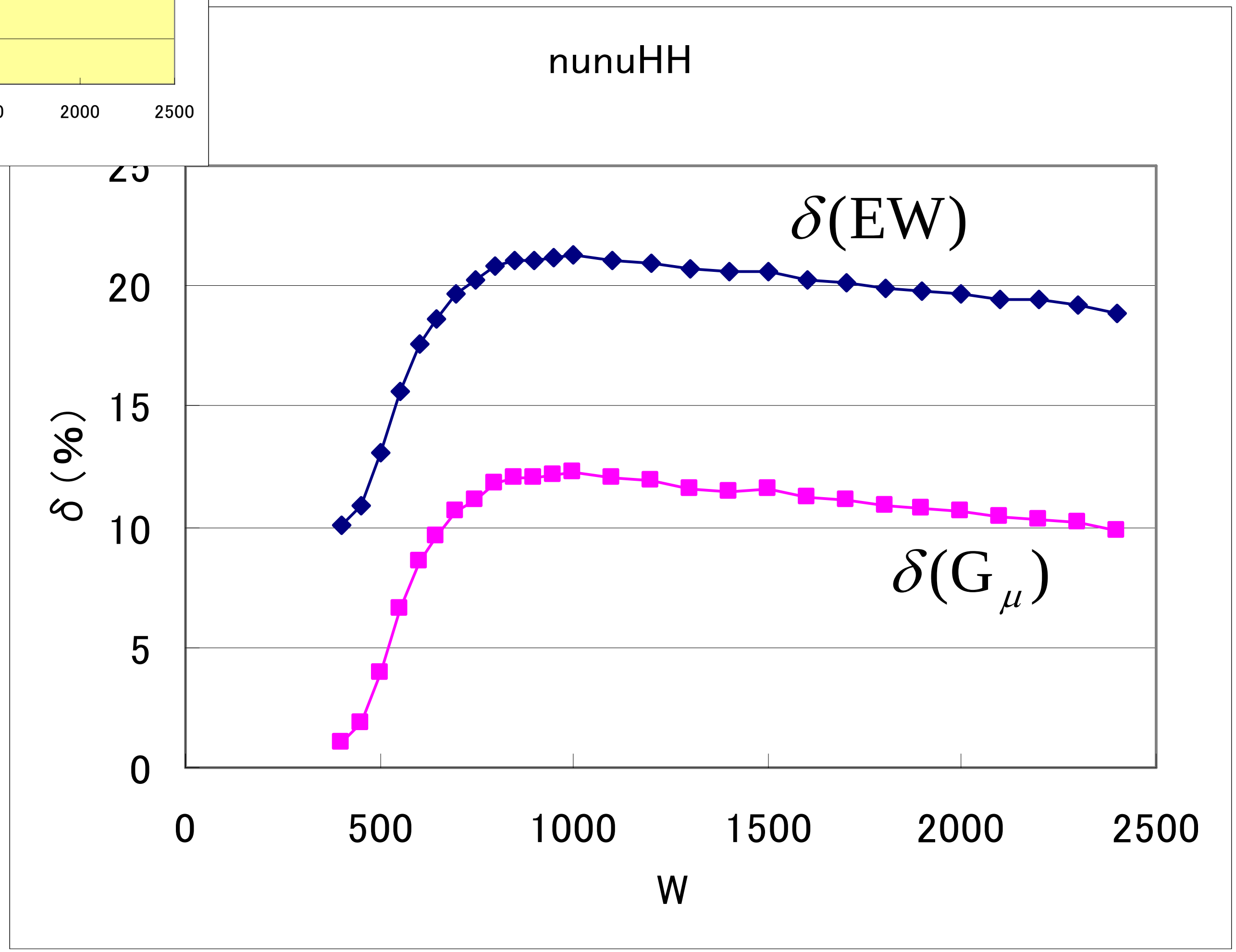
hep-ph/030910
Phys.Lett.B 576(2003)152.





$e^+e^- \rightarrow \nu\,\nu\,HH$

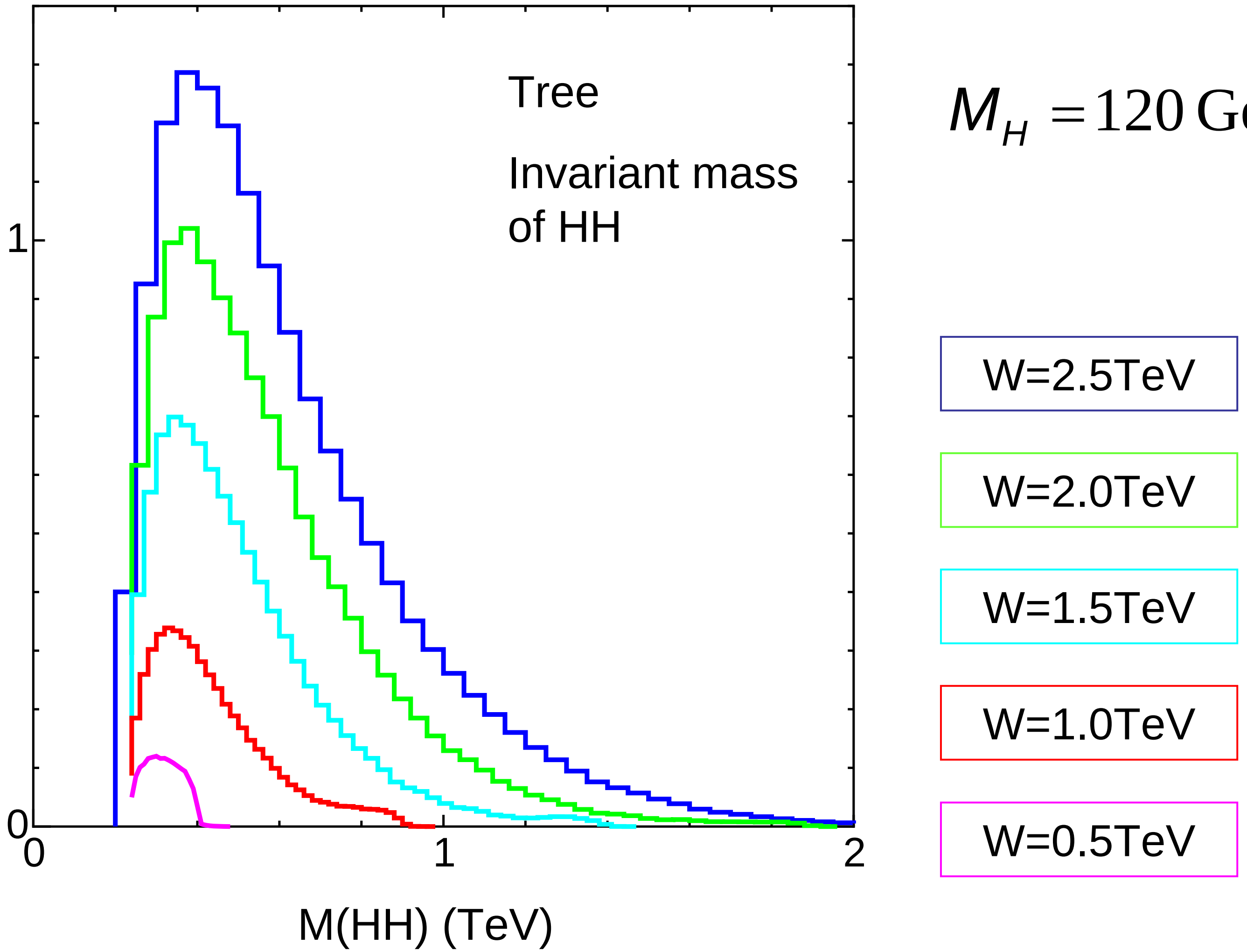




Full calculation
M_H=120GeV

$e^+e^- \rightarrow \nu\ \nu$ HH

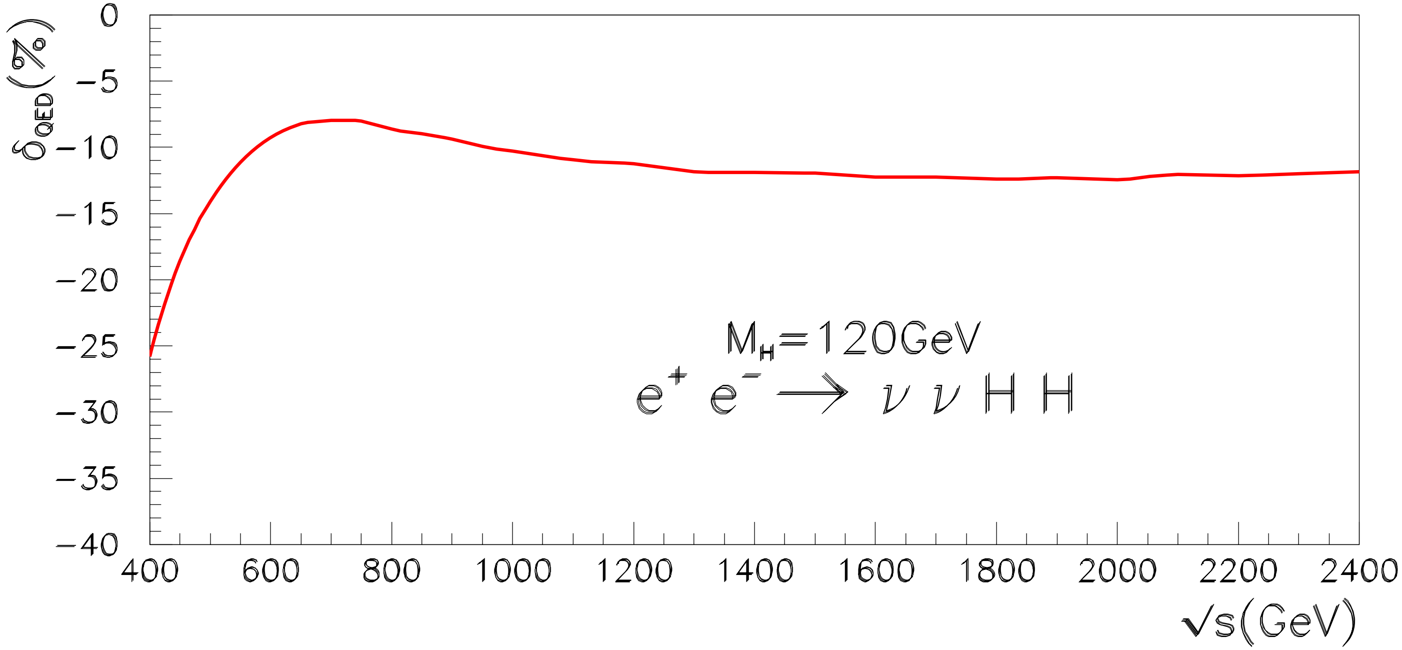
$M_H = 120\,\mathrm{GeV}$



Summary

- Higgs Potential channel ee→$\nu\nu$HH cross section and its EW correction is calculated. $\sigma = O(100\ \mathrm{ab})$ and greater than ee→ZHH in high-E LC region ($\sqrt{s} \geqq 1$TeV). δ(Gmu) is ~10% for $\sqrt{s}$>700GeV. Large diviation from ee→ZHH dominated by s-channel.
- WW→HH is studied to check the t-channel structure of ee→$\nu\nu$HH and has shown validity and limitation of the leading m_t formulas.

$e^+e^- \rightarrow \nu\,\nu\,H\,H$

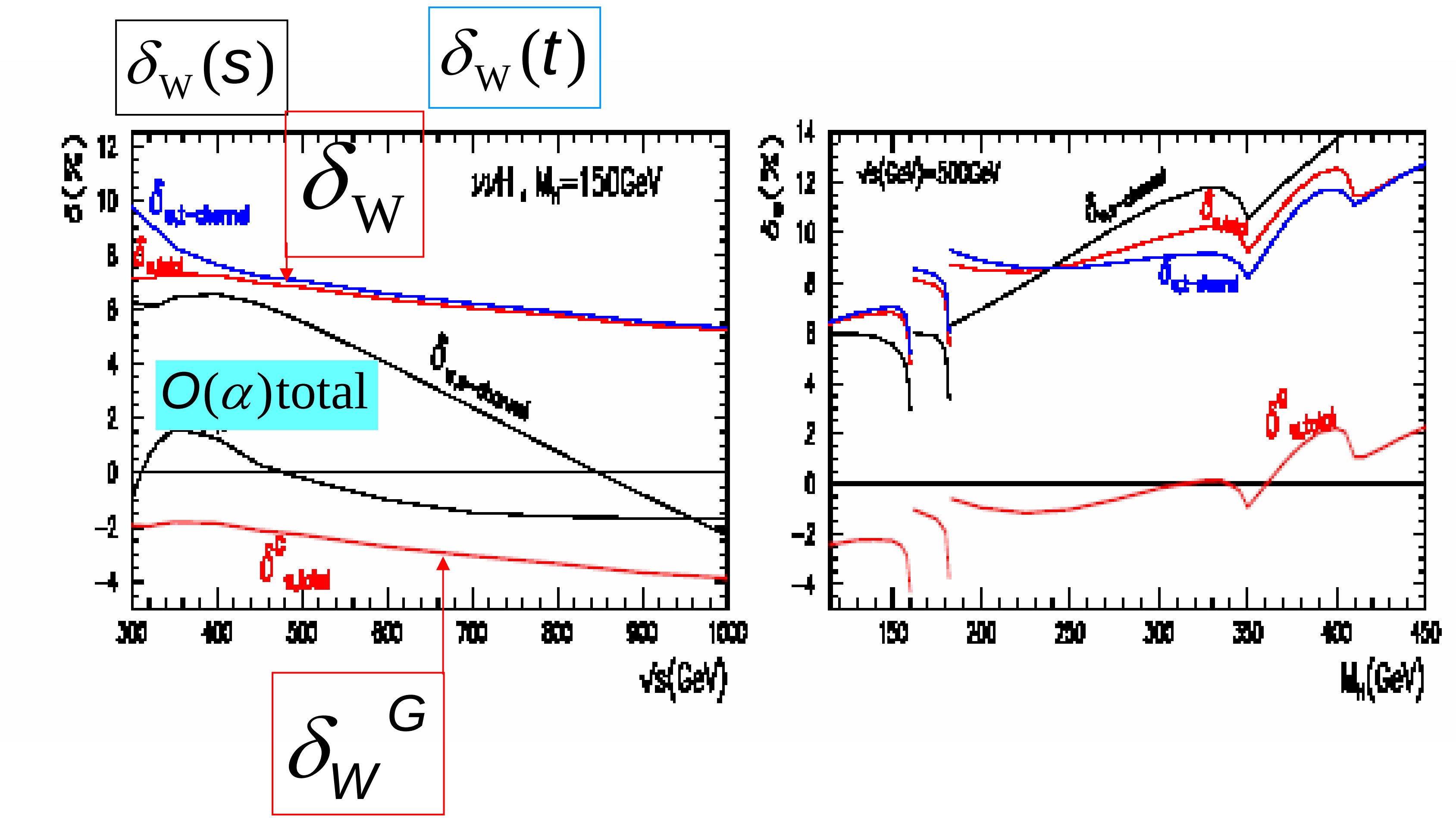


$$e^+e^- \to \nu\bar{\nu}H$$

hep-ph/0212261
Phys.Lett.B 559(2003) 252.

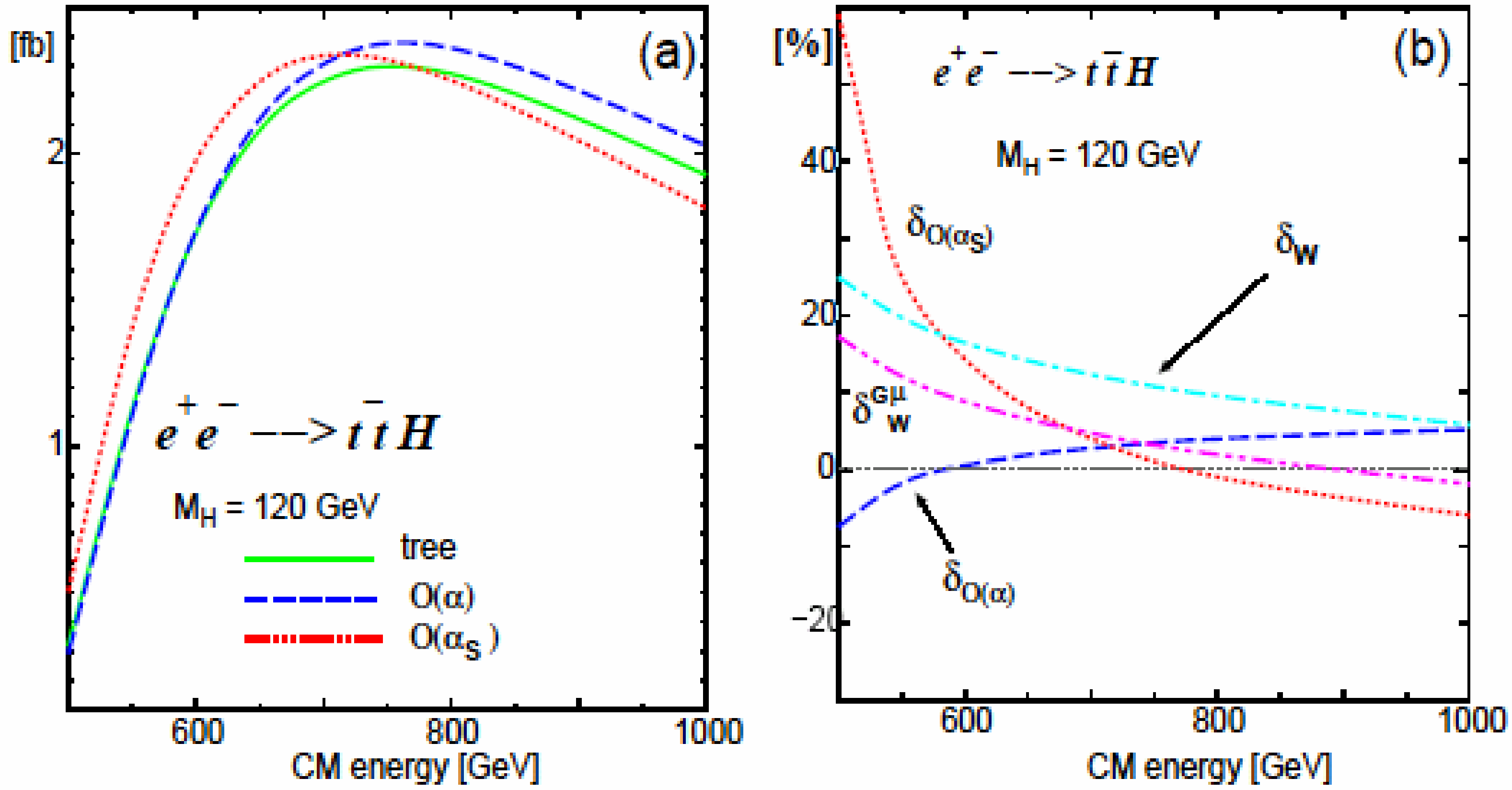
s,t channels show different behavior
genuine weak correction in G-scheme is -2～-4%

$$\delta_{\mathrm{HWW}} = -\frac{5\alpha M_t^2}{16\pi s_W^2 M_W^2} = -1.5\%$$



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

hep-ph/0307029
Phys.Lett.B 571(2003) 163.



system components

- Diagram generation for input process
- Amplitude/Matrix element generation
- Kinematics and Integration (efficiency)
- Event generation (efficiency & weight)
- Peripheral tools: rule generator, diagram selection, QED radiation, PDF, loop integral library, multi-process, color flow and interface for hadronization, etc.

5-point functions

N rank M

$$I_5 = \sum G_{\mu\nu\cdots\sigma} \int d\ell \, \frac{\ell^\mu \ell^\nu \cdots \ell^\sigma}{D_0 D_1 D_2 D_3 D_4}$$

$$D_0 = \ell^2 + X_0$$

$$D_j = \ell^2 + 2\ell \cdot r_j + X_j$$

$$A_{ij} = r_i \cdot r_j \qquad g^{\mu\nu} = r_i^\mu A_{ij}^{-1} r_j^\nu \qquad \ell^2 = D_0 - X_0$$

$$\ell^\mu = r_i^\mu A_{ij}^{-1} (r_j^\nu \ell) = \tfrac{1}{2} r_i^\mu A_{ij}^{-1} [D_j - D_0 + X_0 - X_j]$$

$$N = \sum_{\alpha=}^{4} E_\alpha(\ell) D_\alpha + F \qquad 1 = \sum_{\alpha=0}^{4} [a_\alpha + b_{\alpha j}(\ell r_j)] D_\alpha$$

scalar 5-pnt

BOX rank M-1

BOX

δ (QED), δ (EW)

$$\sigma = \sigma_0 (1 + \delta_{QED} + \delta_W)$$

δ_W non-QED virtual corrections

$$\delta_{QED} = \delta_{QED}^{V} + \delta_{QED}^{soft} + \delta_{QED}^{hard}$$

phase space subtraction f_{LL} =radiator

$$\delta_{QED} = \int \left(d\sigma_0 \delta_{QED}^{v} + d\tilde{\sigma}_0 \otimes f_{LL} \right) + \int_{hard} \left(d\sigma_{1\gamma} - d\tilde{\sigma}_0 \otimes f_{LL} \right)$$

Non-linear gauge fixing terms

$$L_{GF} = -\frac{1}{\xi_W} F^+ F^- - \frac{1}{2\xi_Z}\left(F^Z\right)^2 - \frac{1}{2\xi}\left(F^A\right)^2$$

$$F^{\pm} = \left(\partial^\mu \mp ie\tilde{\alpha} A^\mu \mp i\frac{ec_W}{s_W}\tilde{\beta} Z^\mu\right) W_\mu^{\pm} \qquad F^A = \partial^\mu A_\mu$$

$$+\xi_W\left(M_W \chi^{\pm} + \frac{e}{2s_W}\tilde{\delta} H \chi^{\pm} \pm i\frac{e}{2s_W}\tilde{\kappa}\chi_3 \chi^{\pm}\right)$$

$$F^Z = \partial^\mu Z_\mu + \xi_Z\left(M_W \chi_3 + \frac{e}{2s_W c_W}\tilde{\varepsilon} H \chi_3\right)$$

Samples of NLG Feynman rules

$$W - W - A$$

$$e[g^{\mu\nu}(p_1 - p_2)^\rho$$
$$+ (1 + \tilde{\alpha} / \xi_W)(p_3^\nu g^{\mu\rho} - p_3^\mu g^{\nu\rho})$$
$$+ (1 + \tilde{\alpha} / \xi_W)(p_2^\mu g^{\nu\rho} - p_1^\nu g^{\mu\rho})]$$

$$W - \chi - A$$

$$\mp ieM_W (1 - \tilde{\alpha}) g^{\mu\nu}$$

modified

$$\bar{c}^\mp - c^A - A - W^\pm$$

$$- e^2 \tilde{\alpha} g^{\mu\nu}$$

$$\bar{c}^\mp - c^A - \chi^\pm - H$$

$$\mp ie^2 \frac{1}{2s_W} \tilde{\delta} \xi_W$$

ghost-ghost- vector-vector / ghost-ghost-scalar-scalar

Non-linear gauge

- Numerator structure is the same as Feynman gauge
  → Loop integral library
- Vertices modified
- general values → #diagrams

$$g^{\mu\nu} \quad (\text{for } \xi = 1)$$

"old" usage
→reduce #diagram

$$\tilde{\alpha} = 1 \Rightarrow \text{no } AW\chi$$

$$\tilde{\alpha}, \tilde{\beta}, \tilde{\delta}, \tilde{\varepsilon}, \tilde{\kappa}$$

Check gauge invariance
→Independence on gauge parameters