Full one-loop electroweak radiative corrections for LC

LAPTH-Minamitateya Collaboration

LoopFest III

2004.4.1-3, KITP UCSB

presented by K.Kato(Kogakuin U.)

Introduction

LHC→LC(NLC, Tesla, GLC, …)

Higgs, SUSY,…

Discovery is not the goal

→ Detailed SM study

→ Find *something* beyond SM

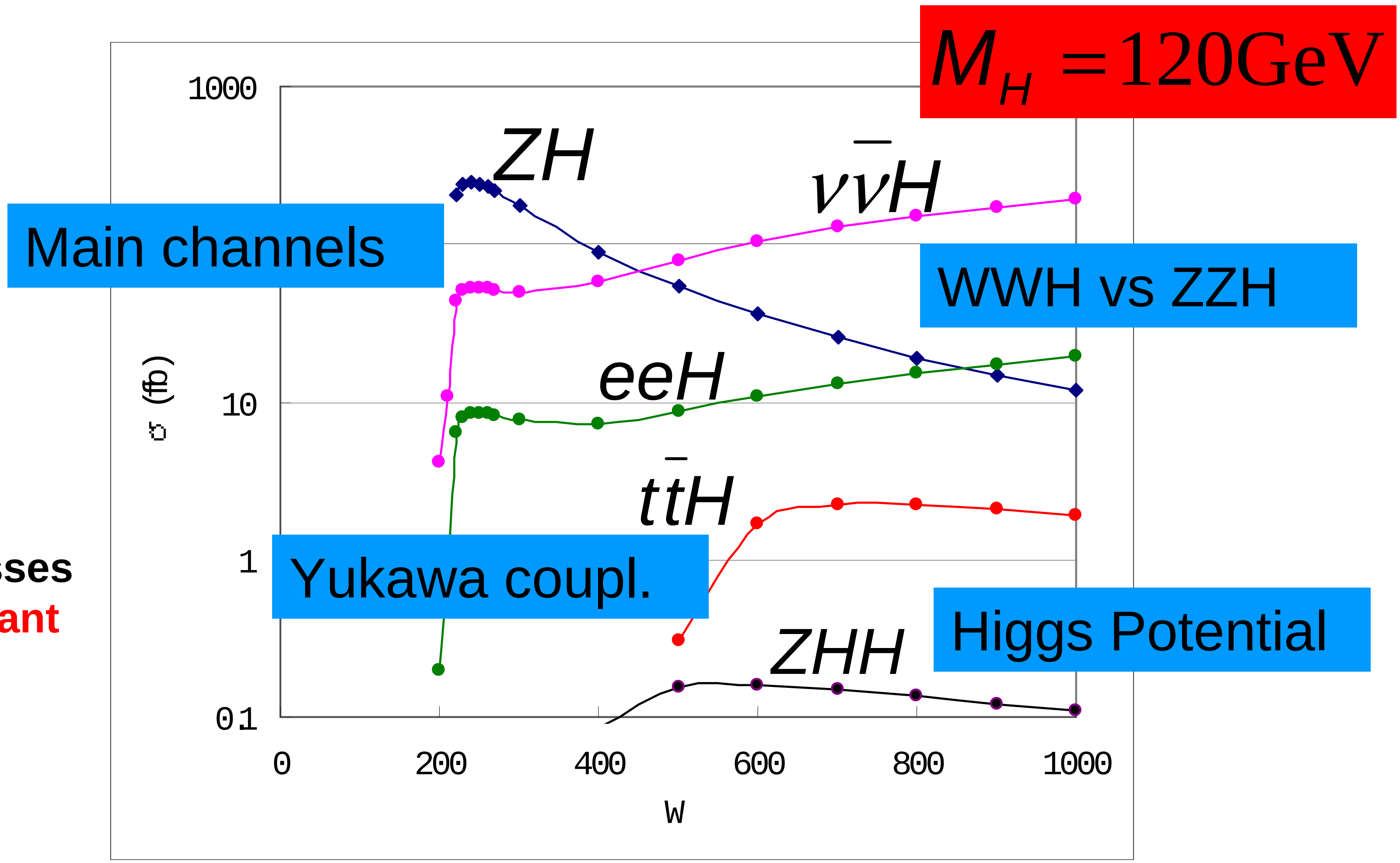
Good accelerator & detectors

High statistics

Requires accurate theoretical values → R.C.

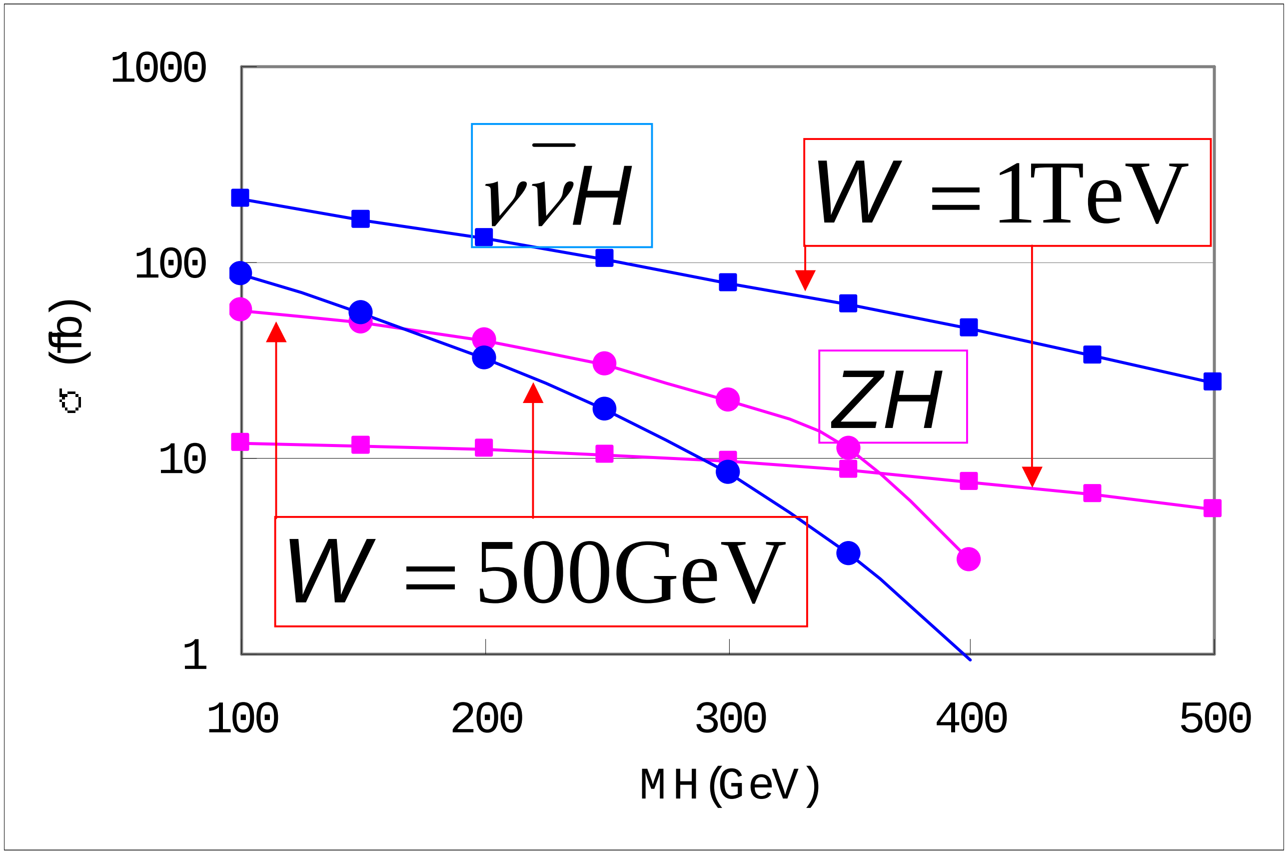
2→3, 4 channels important

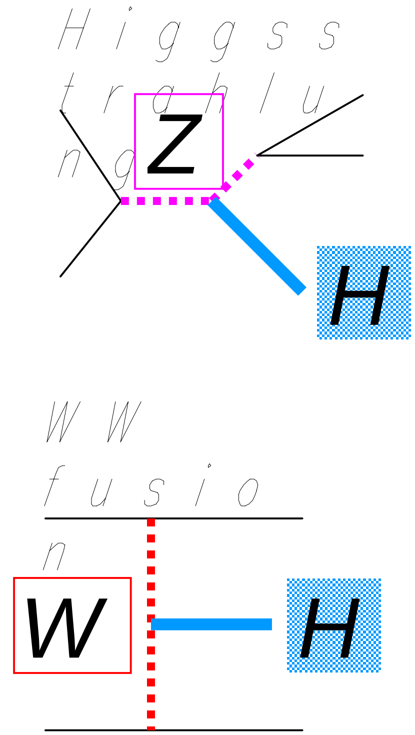
Higgs@LC:tree cross sections



2→3 processes
important

tree cross sections





Interference

➔ Full calculation

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 years required to develop 2→3 tools

with(without) e-scalar couplings

Now…Full 1-loop RC available

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

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

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

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

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

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

New results

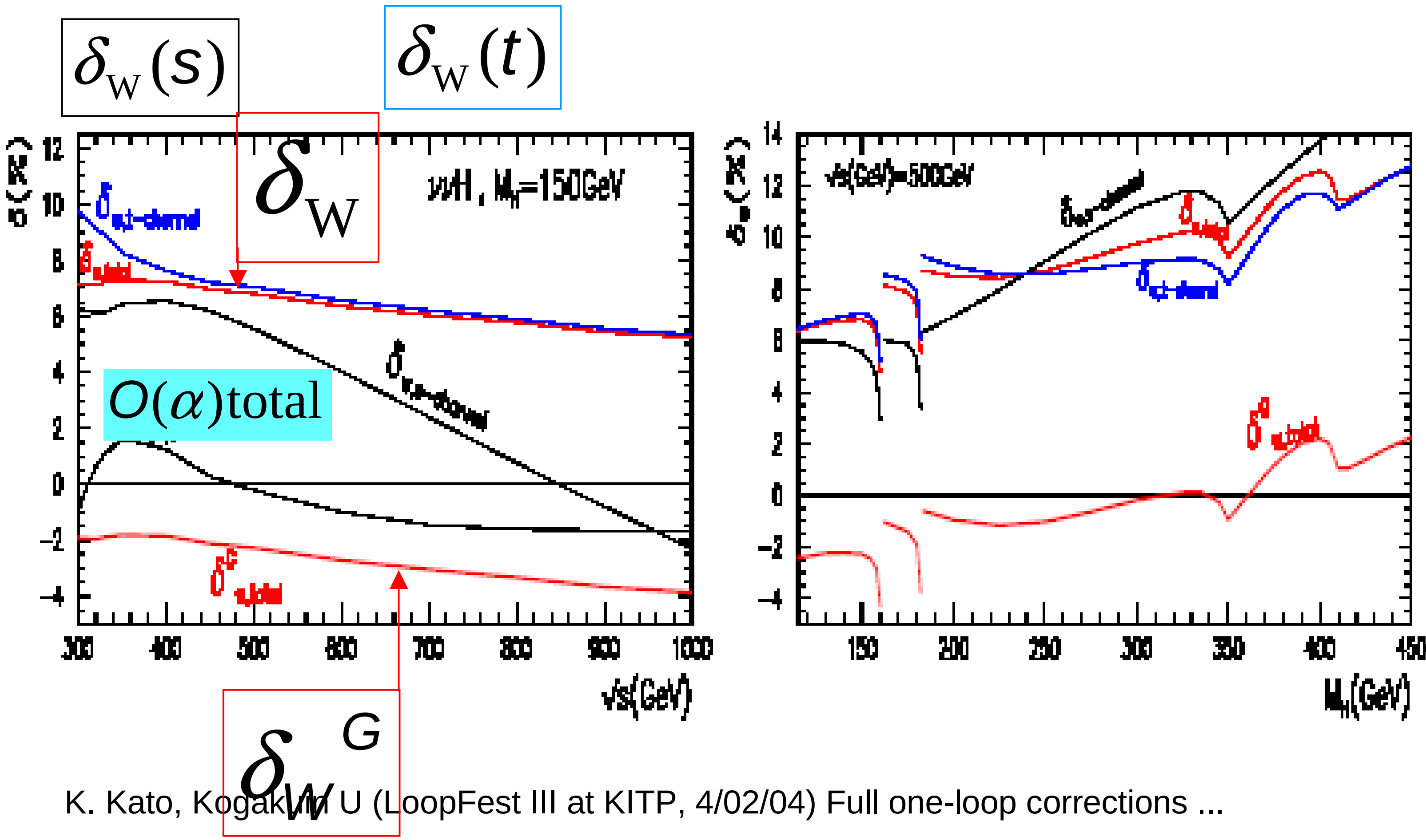
$$e^+e^- \rightarrow e^+e^-H \qquad e^+e^- \rightarrow \nu\bar{\nu}\gamma$$

$$\nu = \nu_\mu, \nu_e$$

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

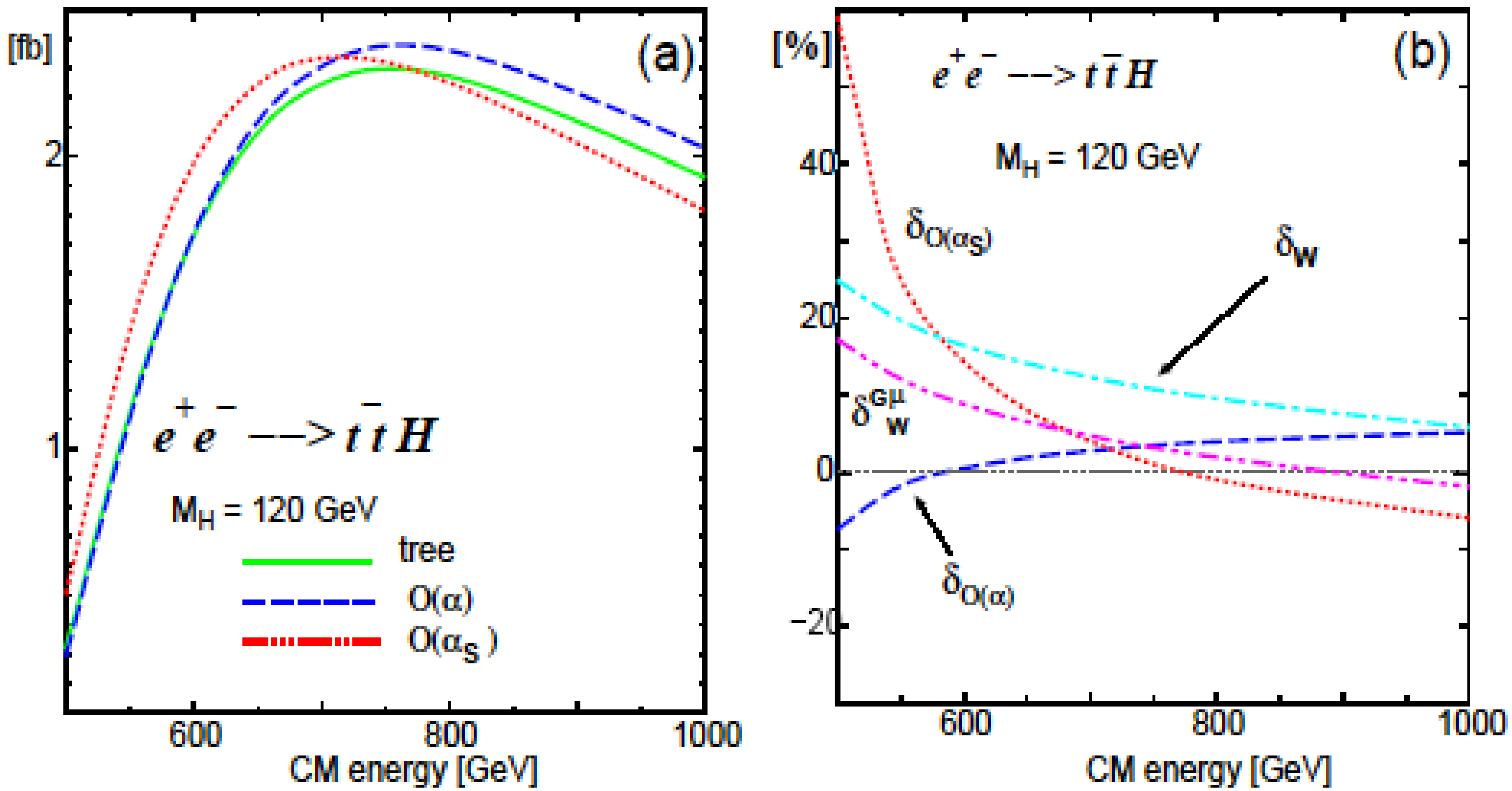
hep-ph/0212261
Phys.Lett.B 559(2003) 252.

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



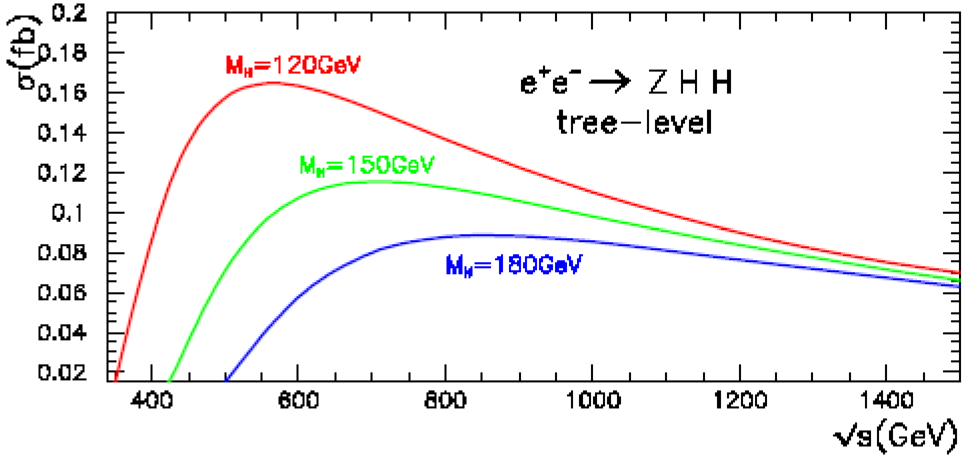
$$e^+e^- \to t\bar{t}H$$

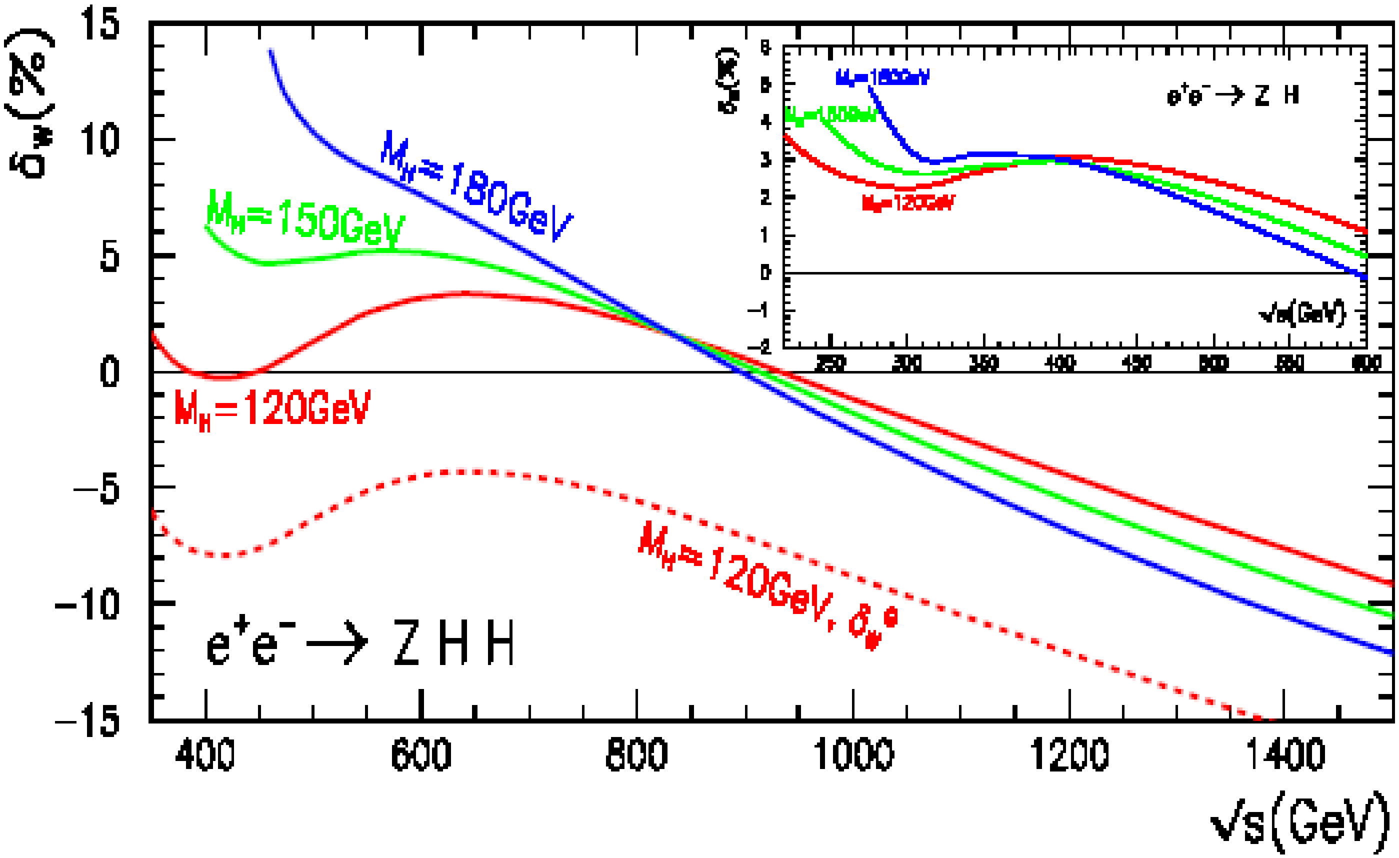
hep-ph/0307029
Phys.Lett.B 571(2003) 163.



$e^+e^- \rightarrow ZHH$

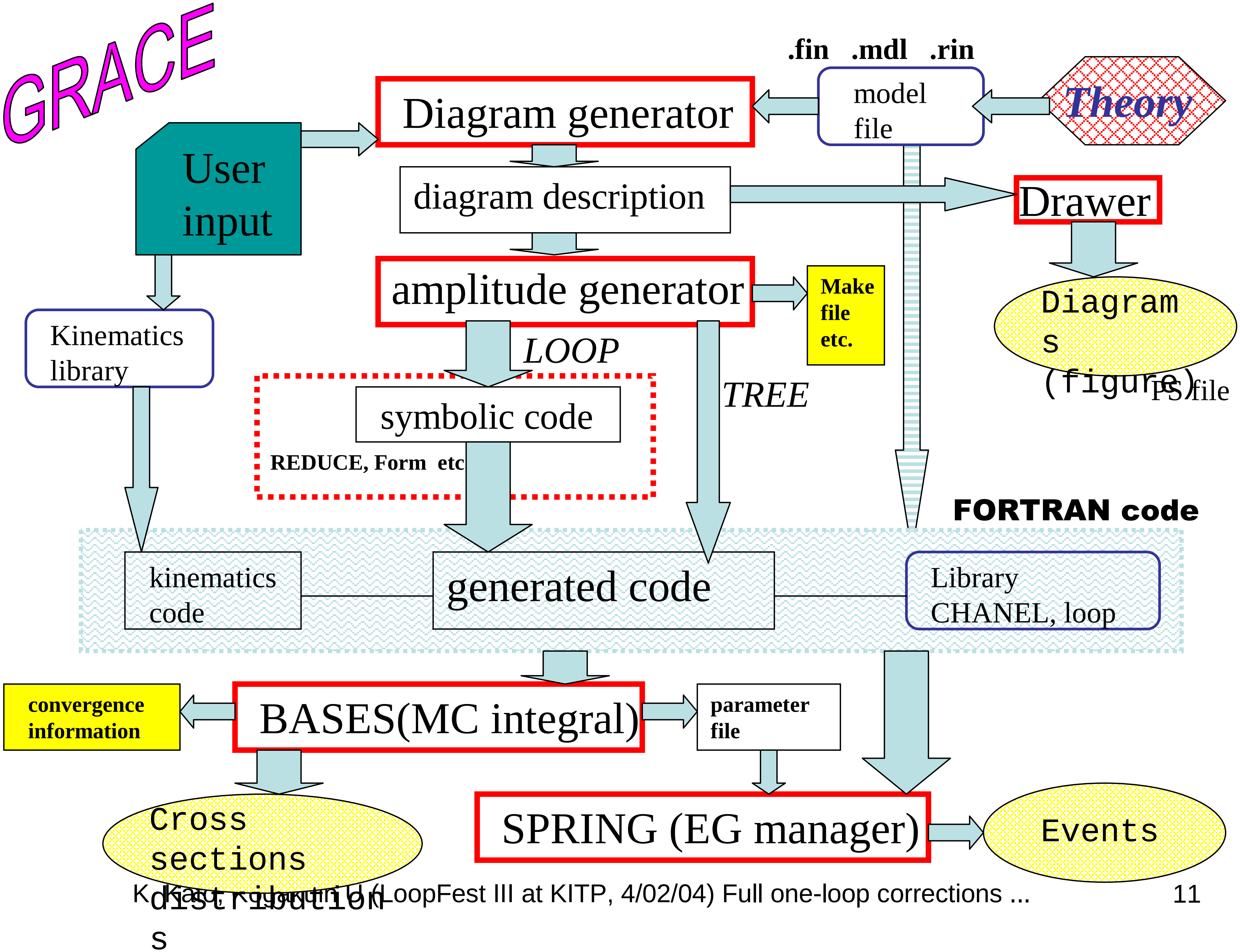
hep-ph/030910
Phys.Lett.B 576(2003)152.





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.


GRACE
.fin .mdl .rin
model file
Theory
Diagram generator
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

5-point functions

N rank M

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

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

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

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

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

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

scalar 5-pnt

BOX

BOX rank M-1

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

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

How to check?

- Diagnostic step is highly important

  (example) Denner et al. : evaluate σ in 2 (or more) independent ways and observe numerical agreement

- GRACE
  UV independence
  IR stability
  Gauge invariance → Non-linear gauge

Non-linear gauge fixing terms

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

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

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

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

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

Gauge invariance check

- full set (all diagrams) quadruple precision
  at a few phase-space points
  compute values of ME for a several sets of
  gauge parameters

If check is OK

- production set (kill e-scalar couplings)
  double precision
  integrate in phase-space

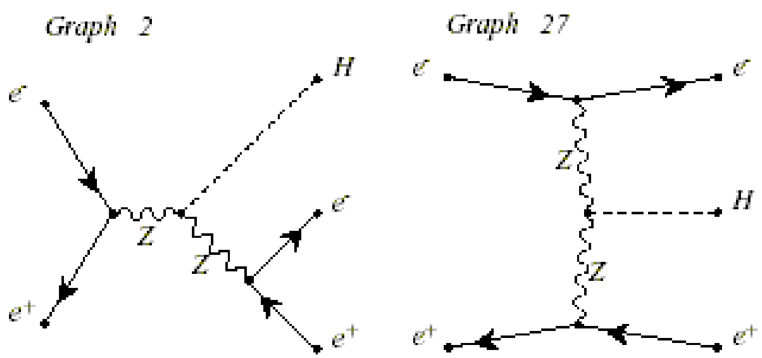
ee→eeH

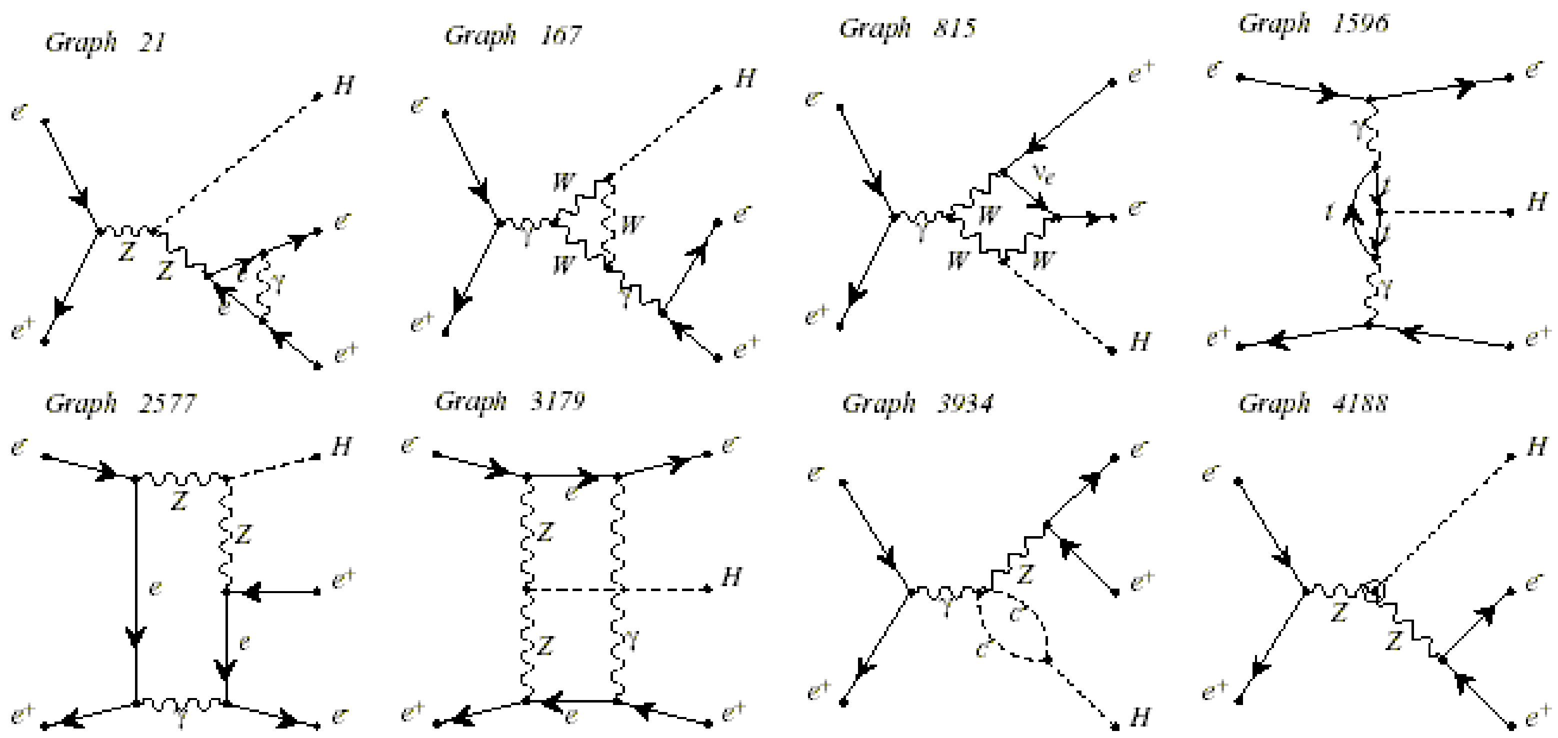
- diagrams
  full set (for NLG check) tree 42, 1-loop 4470 (inc. C.T.)
  production set (for integration) tree 2, 1-loop 510 (inc. C.T.)

- M_Z= 91.1876 GeV Γ_Z= 2.4952 GeV (appear at resonant poles only)
  m_t = 174GeV, G_μ=1.16639 × 10^{-5}GeV^{-2}
  E_{CM}= 200 ～ 1000 GeV, kcut=E*0.05

  M_H= 120GeV → M_W= 80.3766 GeV, Δr= 2.55%
  M_H= 150GeV → M_W= 80.3611 GeV, Δr= 2.63%
  M_H= 180GeV → M_W= 80.3477 GeV, Δr= 2.70%
  (by Z.Hioki's formulas, Δr in 1-loop)

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


Graph 2
Graph 27


Graph 21
Graph 167
Graph 815
Graph 1596
Graph 2577
Graph 3179
Graph 3934
Graph 4188

check by NLG (ee→eeH)

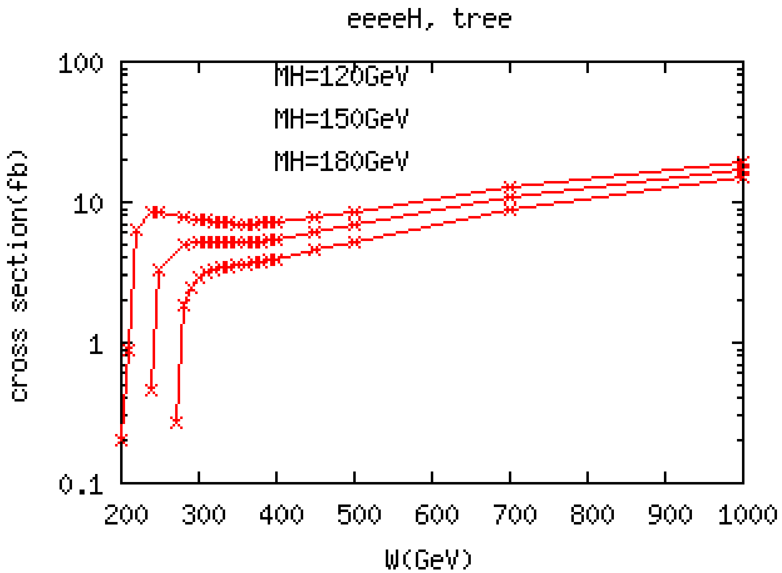
compute for several ξ, at a point in PS

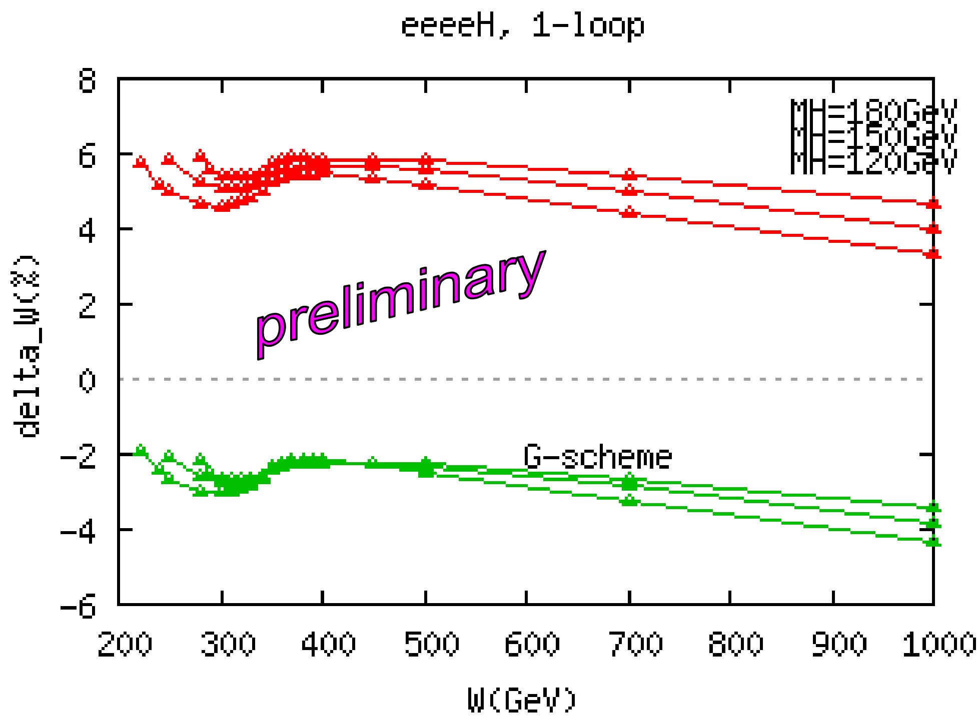
$$f = \sum_{k=0}^{4} a_k \xi^k \quad (\xi = \tilde{\alpha}, \tilde{\beta}, \tilde{\delta}, \tilde{\varepsilon}, \tilde{\kappa})$$

$\tilde{\alpha}$

```
        |       a^4        |       a^3        |       a^2        |       a^1        |
a^0
  -------------------------------------------------------------------------------
---------------
    166 @                                          |    .2626107E-05 |  -.5842526E-05
|    .3216419E-05
    167 @                                          |  -.1247760E-04 |    .1306251E-04 |   -
.2558662E-04
    168                                                             |    .1083887E-05 |   -
.1083887E-05
    169 @                                          |    .3625232E-06 |  -.7250464E-06
|    .3625232E-06
    170 @                                          |    .2626107E-05 |  -.5842526E-05
|    .3216419E-05
    171 @                                          |  -.1247760E-04 |    .1306251E-04 |   -
.2558662E-04
    172                                                             |    .1083887E-05 |   -
.1083887E-05
    173 @                                          |    .3625232E-06 |  -.7250464E-06
|    .3625232E-06
      :                                                  :                 :
        :
```

ee→eeH

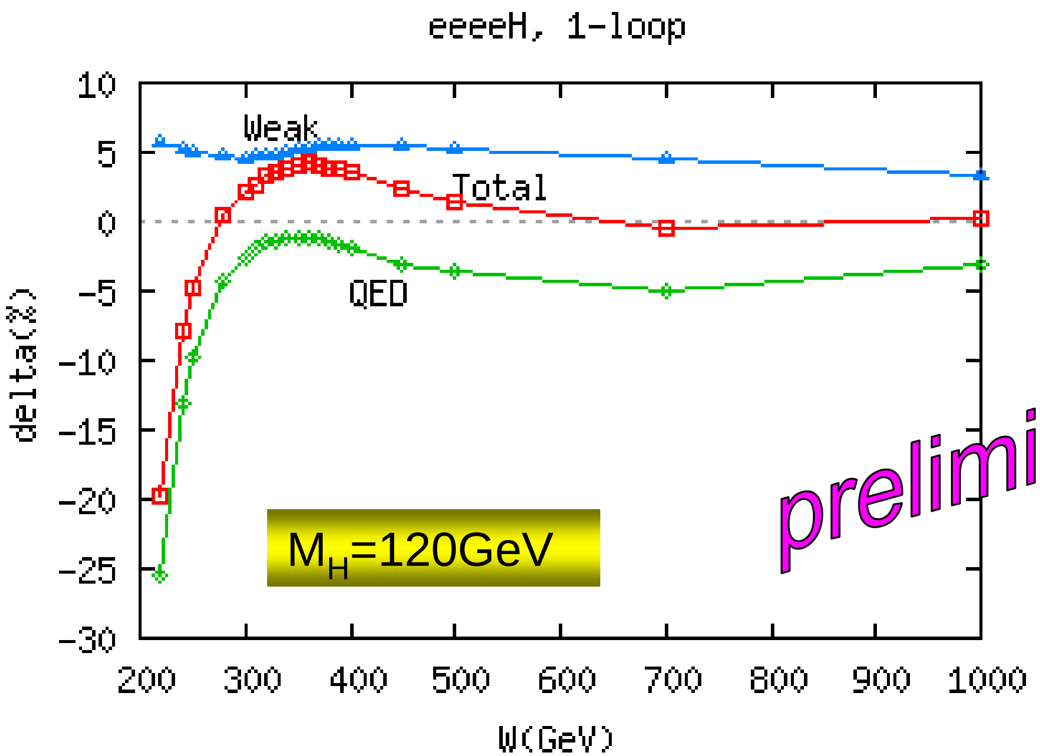


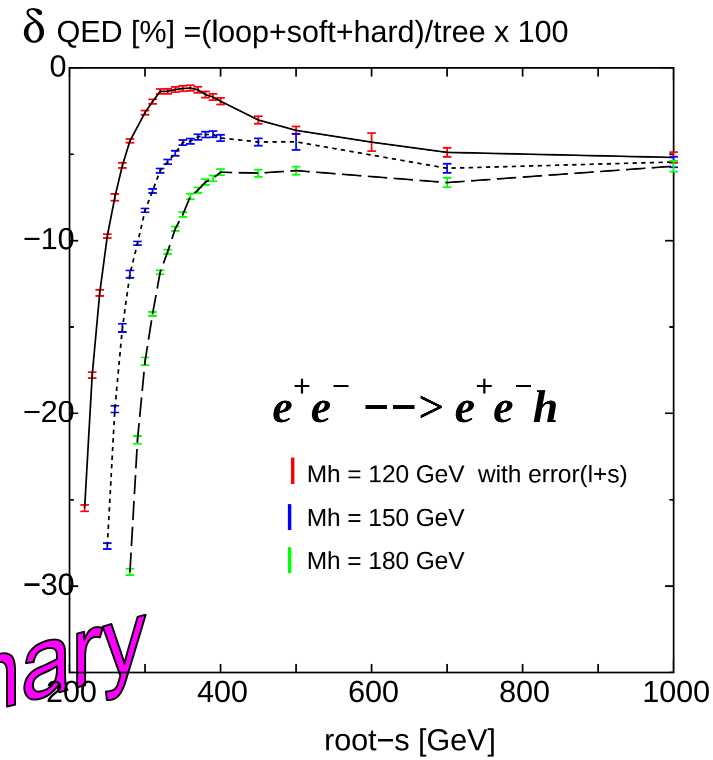


G-scheme absorbs MH-dep, correction is -2 to -4%

ee→eeH

results look similar to ee→nunuH case …





preliminary

another progress $e^+e^- \to \nu\bar{\nu}\gamma$

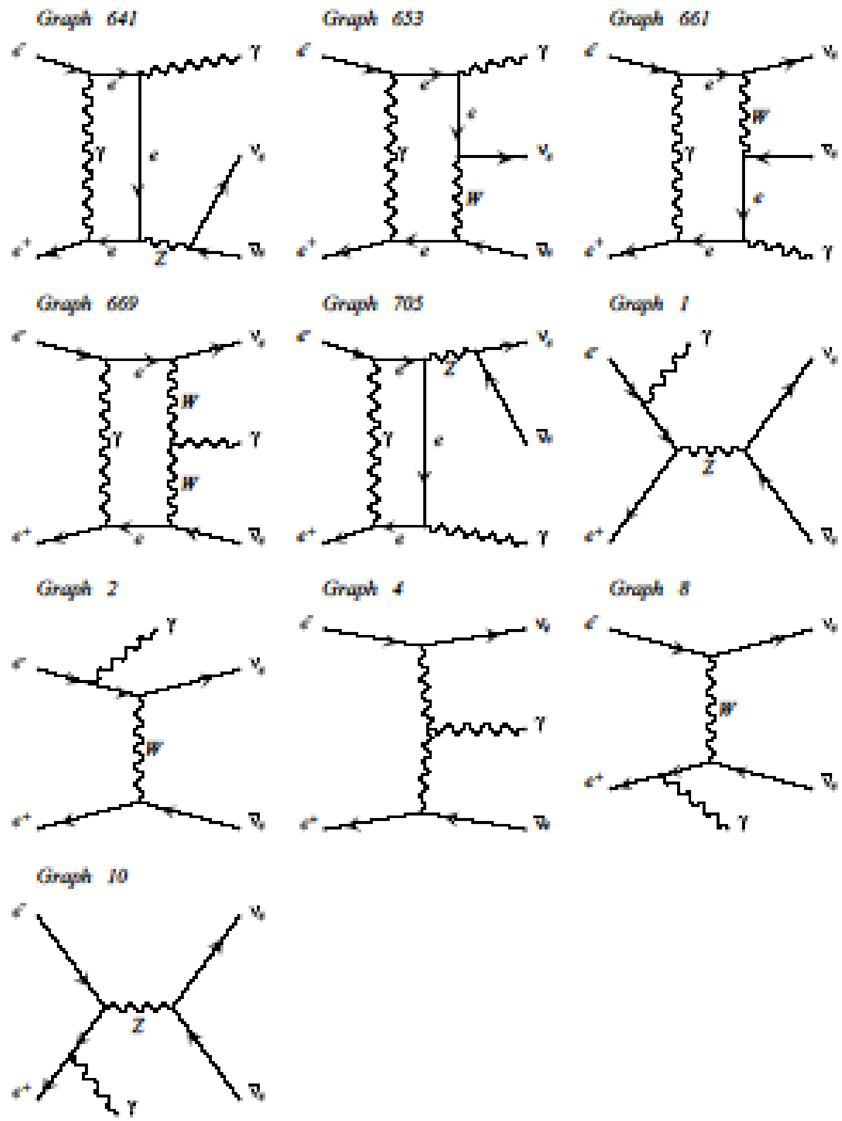
for SUSY

- diagrams
  full set (for NLG check)
  tree 10, 1-loop 1099 (inc. C.T.)
  production set (for integration)
  tree 5, 1-loop 331 (inc. C.T.)
- M_W= 80.3766 GeV , M_Z= 91.1876 GeV
  Γ_Z= 2.4956 GeV
  M_H= 120GeV, m_t = 174GeV
  E_{CM}= 200 $\sim$ 3000 GeV
  OPAL cut: $(\gamma) p_T > 0.05 E_B$, $15^\circ < \theta < 165^\circ$

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

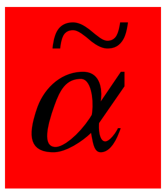
IR diagrams

tree diagrams



check by NLG (ee→nunuA)

	a^4	a^3	a^2	a^1	a^0
1V				-.5252278E-03	.7952048E-03
2V				.1872623E-14	-.1872623E-14
6V				.1872623E-14	-.1872623E-14
□					
18V			.4986017E-11	.7865753E-10	-.8364354E-10
19V			.3779384E-10	.1104061E-09	-.1482000E-09
20V			.1208277E-10	-.2416554E-10	.1208277E-10
22V				.6561564E-10	-.6561564E-10
23V				-.4995059E-42	.4995059E-42
24V			.4797596E-09	-.9595192E-09	.4797596E-09
26V				-.6561564E-10	.6561564E-10
27V				.4995059E-42	-.4995059E-42
28V			-.4797596E-09	.9595192E-09	-.4797596E-09
29V-	-.4773915E-37	.2482467E-36	.5633036E-36	-.7638111E-36	-.1405948E-07
30V-	-.7346840E-39	.4897893E-39	.3673420E-38	-.3428525E-38	.5827357E-08
31V-	-.1040802E-37	.9896805E-37	.1900383E-36	-.2785983E-36	-.1405949E-07
□					
854P				-.1180226E-14	.1180226E-14
855B			.7634114E-04	-.3060816E-03	.8768512E-03
sum1	.14148E-30	-.40640E-30	-.86324E-25	.17416E-23	.51997
max	.12998E-30	.32070E-04	.96820E-04	.59183E-01	.15505
cnt	15	25	70	381	

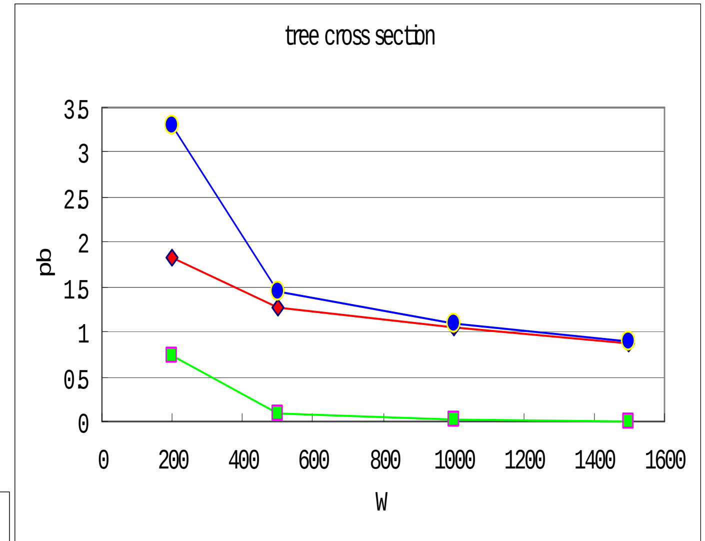


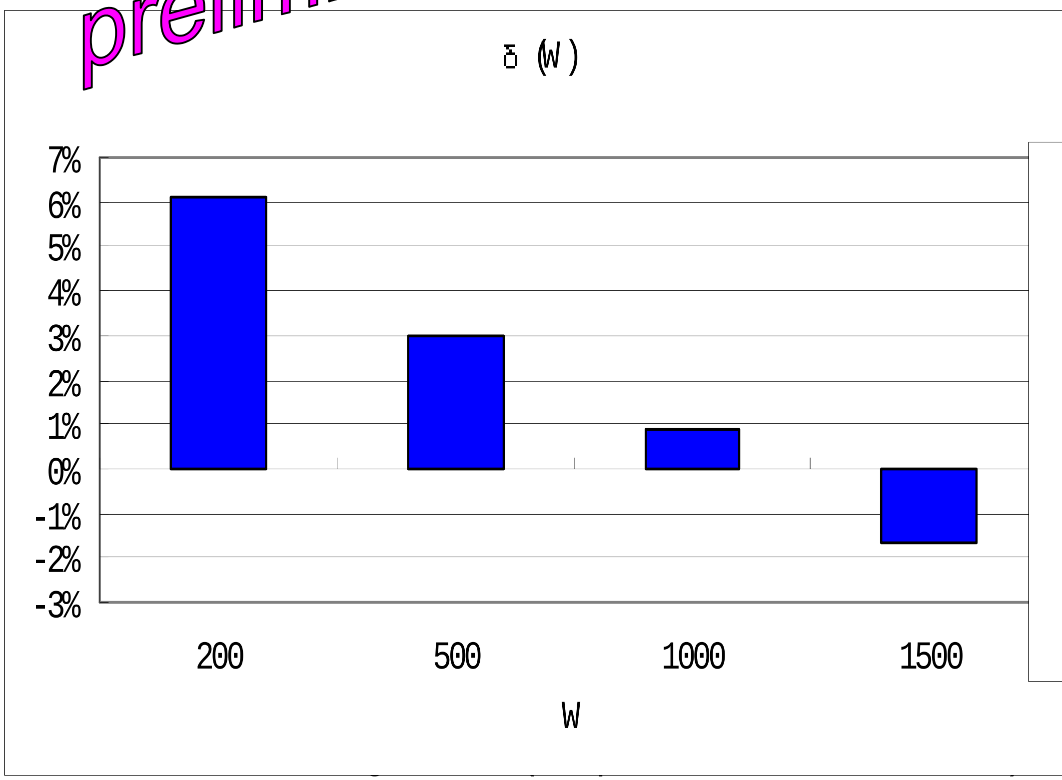
$$e^+e^- \to \nu\bar{\nu}\gamma$$

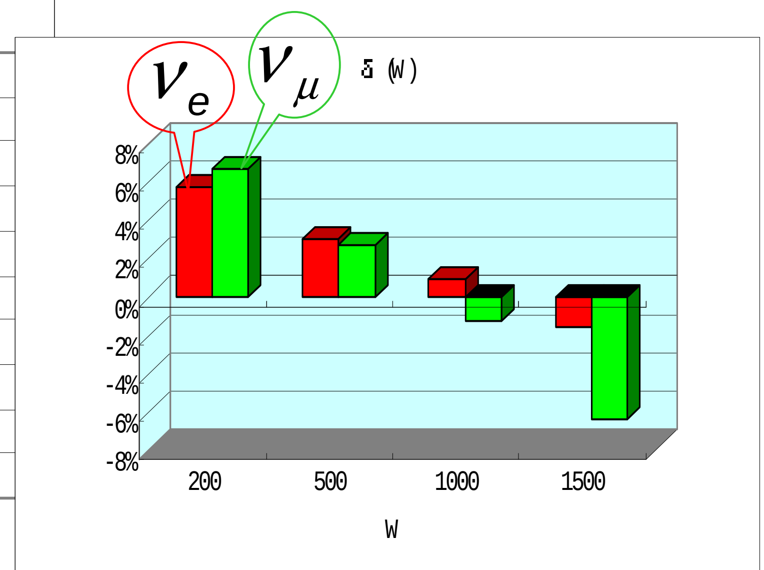
photon distribution … in progress

preliminary

M_H=120GeV







$\Delta r = 2.55\%$

ll one-loop corrections ...

conclusion

- Technology is established to handle full-EW RC for 2→3 processes.
- Gauge parameter independence in NLG is powerful to confirm the results.
- $e^+e^- \to e^+e^-H$ calculated, size and behavior is similar to $e^+e^- \to \nu\bar{\nu}H$
- study of $e^+e^- \to \nu\bar{\nu}\gamma$ in progress