GRACE

Y. Kurihara
(KEK)

MC4CEPC
@CFHEP, Beijing, China,
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Outline

- Introduction
  - ✓ What is GRACE?
- Structure of GRACE
- Recent results from GRACE
  - ✓ Recent results
    - ELWK correction for LHC
    - e^+e^- coll. w/ pol.
    - SUSY Loop effect
  - ✓ Other results
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Introduction

What is GRACE ?

GRACE:
The GRACE system is a utility to calculate cross sections and decay widths automatically in the standard model (SM) and minimal SUSY standard model (MSSM). What can be calculated by the current GRACE system is summarized below:

SM (Full electro-weak)		MSSM	
Tree	Up to 4 body easily, up to 6-body possible	Tree	Up to 6-body possible
1-Loop	Up to 3 body easily, 4-body possible	1-Loop	Up to 2-body

What is GRACE ?

GRACE:
After numerical integrations of the matrix elements, the GRACE can efficiently generate unit-weight events, which can be used for the simulation study. Beam polarization can be included in calculations except a MSSM/1-Loop case.

Structure of GRACE

GRACE Structure

Model/Process

GRACE Structure

Model/P

```
Particle=Z["Z0"];     Antiparticle=Particle;
   Gname={"Z^0"};
   PType=Vector; Charge=0; Color=1; Mass=amz; Width=agz;
   PCode=4; KFCode=23; Gauge="zb";
Pend;
%
Particle=gluon["g"]; Antiparticle=Particle;
   Gname={"g"};
   PType=Vector; Charge=0; Color=8; Mass=amg; Width=0;
   PCode=8; Massless; KFCode=21;
   Gauge="gl"; PSelect="gluon";
Pend;
Particle=electron["e-"]; Antiparticle=positron["e+"];
   PType=Fermion; Charge=-1; Color=1; Mass=amlp(1/3); Width=0;
   PCode=55; KFCode=11;
Pend;
Particle=nu-e["nue"]; Antiparticle=nu-e-bar["anue"];
   PType=Fermion; Charge=0; Color=1; Mass=amnu(1/3); Width=0;
   PCode=51; Massless; KFCode=12;
Pend;
%-----------------------------------------------------------------
% 3.10.1 FFV (FFW : without quark mixing) From Kaneko-san
%-----------------------------------------------------------------
Vertex={positron,  nu-e,     W-minus}; ELWK=1; FName=cwln(2,1/3);
      FType="V-A"; Vend;
Vertex={anti-muon, nu-mu,    W-minus}; ELWK=1; FName=cwln(2,2/3);
      FType="V-A"; Vend;
```

GRACE Structure

Model/Process

in.prc

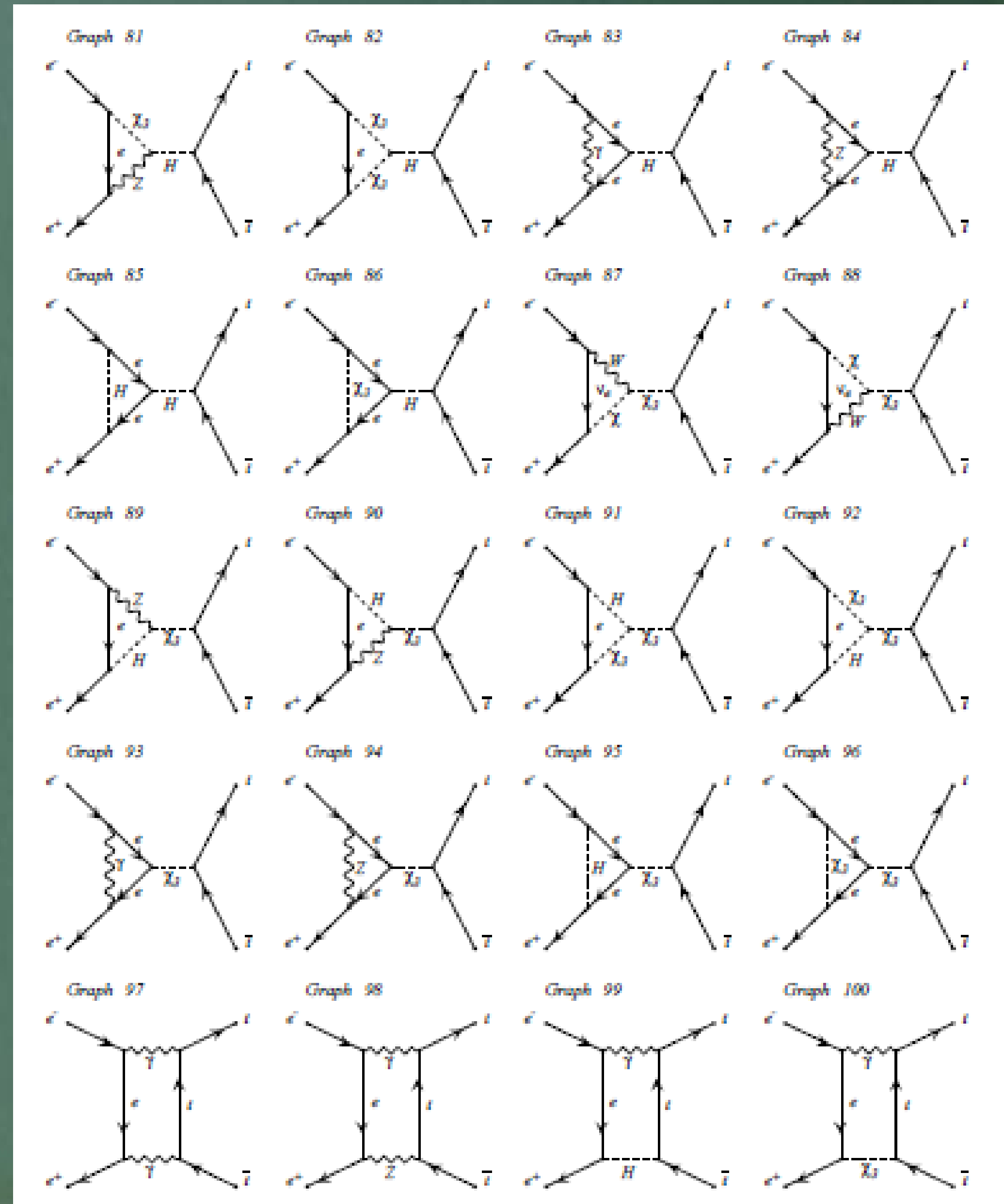
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Model="nlg2301_FF.mdl";
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Process;
  ELWK={4,2};
  Initial={electron, positron};
  Final  ={t, t-bar};
  Kinem="2201";
Pend;
```

GRACE Structure

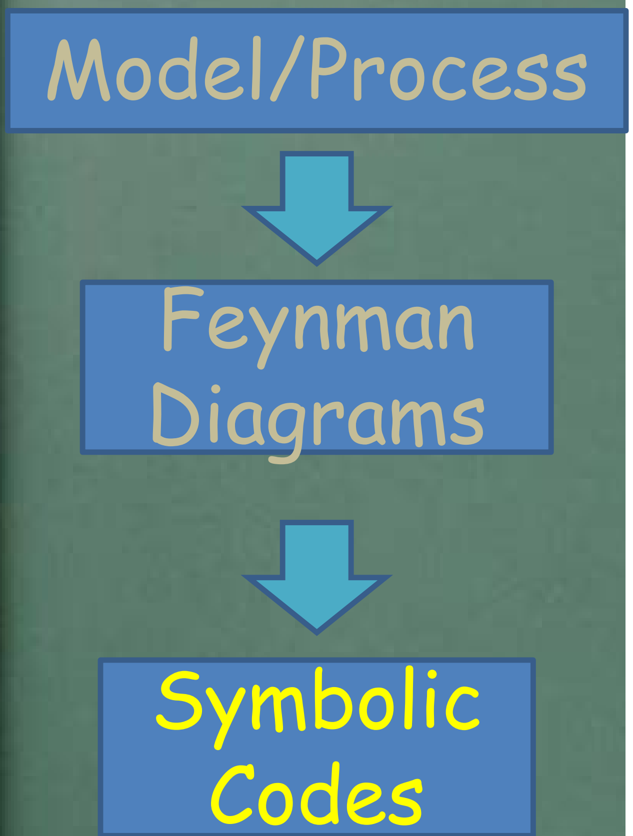
Model/Process

↓

Feynman Diagrams



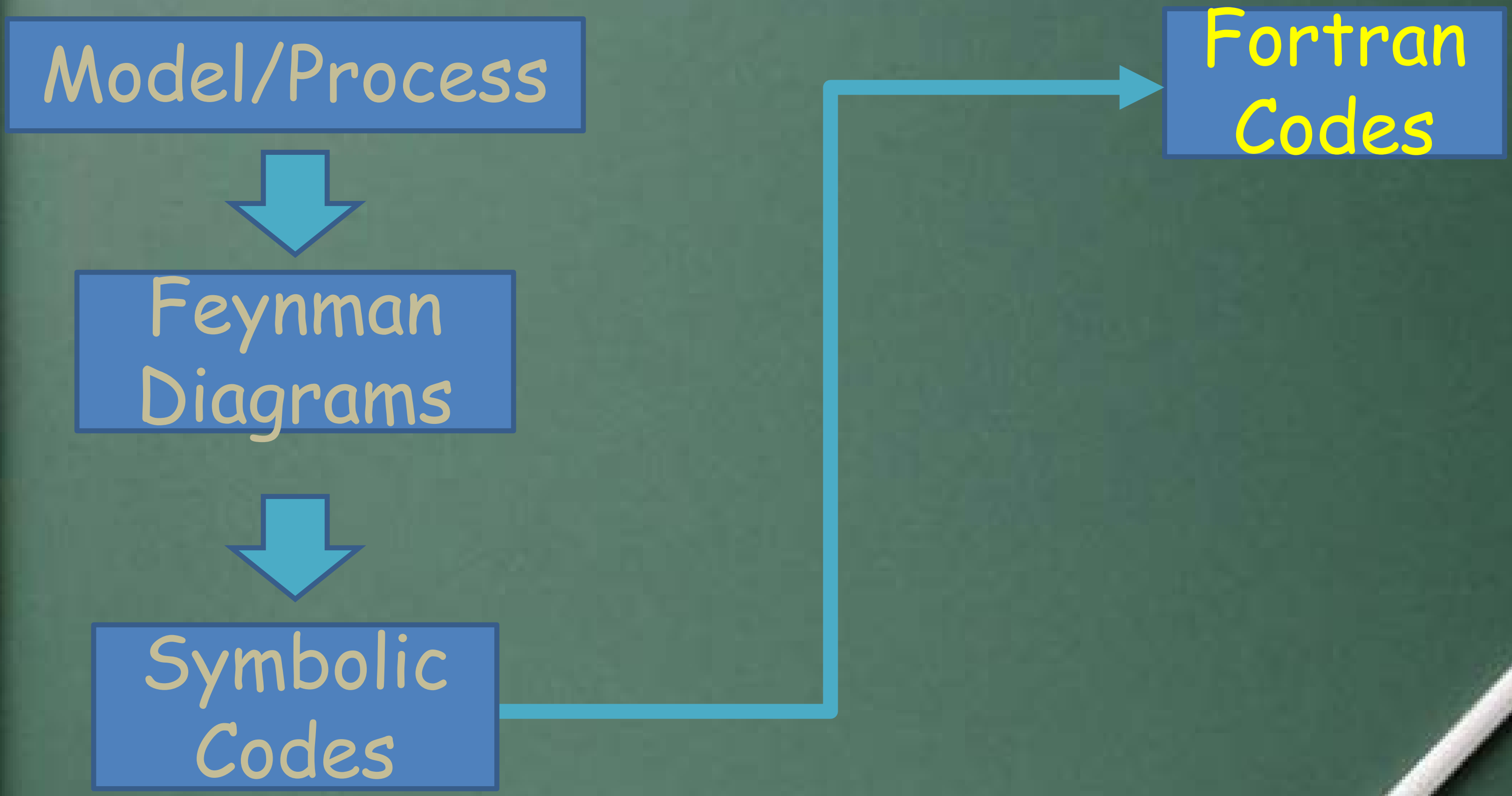
GRACE Structure



Form Source code

```
#write <'name'.f> "*"
#write <'name'.f> "      ztd = cc1"
#write <'name'.f> "      CALL snprpdn(pphase,ztd,vn7,ama**2,ama*aga)"
#write <'name'.f> "      CALL snprpdc(pphase,ztd,vn7,ama**2,ama*aga)"
#if ( 'CCCC' == 0 )
#write <'name'.f> "      ztd = 'XCP'1/ztd"
#else
#write <'name'.f> "      ztd = cc1/ztd"
#endif
#write <'name'.f> "*"
#endprocedure
*--#] Specifics :
*
*       Amplitude
*
L       Sigma = + 3
        *ufp(fl0,p1,'amel')
        *ffvc('dael1','dael2',fl0,p1,p2,q13,n8c)
        *vfp(fl0,p2,'amel')
        *ffvn('cael1','cael2',fl0,p2,p1,q5,n4c)
        *ufp(fl1,p3,'amtq')
        *ffvn('cwbq1','cwbq2',fl1,-p3,-l8,l6,m6c)
        *sfn(fl1,-l8,'ambq')
        *ffvn('cwtq1','cwtq2',fl1,l8,-p4,-k7,m7c)
        *vfp(fl1,p4,'amtq')
        *ffvc('datq1','datq2',fl1,-p4,-p3,-q13,n9c)
        *nlawwn('caww',-q5,n5a,-l6,m5b,k7,m5c)
        *dvn(n5a,n4c,q5,'ama')
        *dvn(m5b,m6c,l6,'amw')
        *dvn(m7c,m5c,k7,'amw')
        *dvc(n9c,n8c,q13,'ama');
#call grcform(1)
.clear:'NAME';
```

GRACE Structure



GRACE Structure

Fortran Source code

Fortran Codes

```
*
      ztd = cc1
      CALL snprpdn(pphase,ztd,vn7,ama**2,ama*aga)
      CALL snprpdc(pphase,ztd,vn7,ama**2,ama*aga)
      ztd = xcp1/ztd
*
      ztd = ztd*(cc6)
*
      xre=+xb(1)*xu(2)*xz(9)+xz(4)*xy(12)-xz(5)*xy(17)+xy(8)
      xre=xre*(+cc2*(1))
      g1e0(0,0)=g1e0(0,0)+ztd*xre
      xre=-xb(1)*xz(9)-xz(4)*xy(9)+xz(5)*xy(1)-xy(6)
      g1e1(0,0)=g1e1(0,0)+ztd*xre
      xre=+cc16*(xb(7)*xz(9))
      xre=xre+cc8*(xb(1)*xz(4)*xz(5)+xz(3)*xy(14)-xz(5)*xy(2)-xy(10)+(2
     &     +xnla)*(xz(10)))
      xre=xre+cc4*(xz(4)*xy(11)+xz(14)*xy(5)+(5+3*xnla)*(xz(8)))
      g0e0(0,0)=g0e0(0,0)+ztd*xre
      xre=+cc16*(-xb(7)*xz(9))
      xre=xre+cc8*(-xb(1)*xz(4)*xz(5)-xb(2)*xz(4)*e2e1-xb(3)*xu(3)*xz(
     &     13)+xu(5)*xz(4)*xz(14)*amtq2-xz(3)*xy(14)+xz(5)*xy(2)-xz(14)*
     &     xy(4)-xz(16)*xy(13)+xy(10)-(1+2*xnla)*(xz(10))-(1+3*xnla)*(
     &     xz(8)))
      xre=xre+cc4*(xb(9)*xz(7)+xb(10)*xz(12)-xz(10)*xy(16)-xz(11)*xy(3)
     &     -xz(15)*xy(7)-(3+xnla)*(xz(4)*xz(10)))
      g0e0(0,1)=g0e0(0,1)+ztd*xre
      xre=+cc12*(-xu(1)*xz(8))
      xre=xre+cc8*(xb(3)*xu(3)*xz(13)+xz(4)*xz(10)+xz(16)*xy(13))
      xre=xre+cc4*(-xb(9)*xz(7)-xb(10)*xz(12)+xu(1)*xz(4)*xz(14)*amtq2-
     &     xu(1)*xz(14)*amtq2-xz(10)*xy(15)+xz(11)*xy(3)+xz(15)*xy(7))
      g0e0(0,2)=g0e0(0,2)+ztd*xre
      xre=+cc8*(-xz(17))
      g0e0(1,0)=g0e0(1,0)+ztd*xre
      xre=+cc8*(xz(17))
      g0e0(1,1)=g0e0(1,1)+ztd*xre
      xre=+cc8*(xz(17))
      g0e0(2,0)=g0e0(2,0)+ztd*xre
      RETURN
      END
```

GRACE Structure

Model/Process

Feynman

Fortran Codes

Numerical Calculation

- Reduction: GRACE
- Scalar Integration:
  - LoopTooLs/FF/GRACE
- Numerical Integration:
  - BASES

G. Belanger, F. Boudjema, J. Fujimoto, T. Ishikawa, T. Kaneko, K. Kato and Y. Shimizu, Phys. Rept. **430**, 117 (2006) [hep-ph/0308080].

GRACE Structure

Model/Process

Feynman

Numerical Check

Fortran Codes

Numerical Calculation

- Reduction: GRACE
- Scalar Integration:
  - LoopTooLs/FF/GRACE
- Numerical Integration:
  - BASES

G. Belanger, F. Boudjema, J. Fujimoto, T. Ishikawa, T. Kaneko, K. Kato and Y. Shimizu, Phys. Rept. **430**, 117 (2006) [hep-ph/0308080].

GRACE Structure

Numerical check

$C_{UV}=1/\varepsilon-\gamma_E+\ln 4\pi$

- The renormalization has been carried out with the on-shell renormalization condition of the Kyoto scheme[2].
- The non-linear gauge fixing Lagrangian condition[3]

$$\mathcal{L}_{GF} = -\frac{1}{\xi_W}|(\partial_\mu - ie\tilde{\alpha}A_\mu - igc_W\tilde{\beta}Z_\mu)W^{\mu+} + \xi_W\frac{g}{2}(v+\tilde{\delta}H+i\tilde{\kappa}\chi_3)\chi^+|^2 - \frac{1}{2\xi_Z}(\partial.Z+\xi_Z\frac{g}{2c_W}(v+\tilde{\varepsilon}H)\chi_3)^2 - \frac{1}{2\xi_A}(\partial.A)^2 .$$

- $\xi_W=\xi_Z=\xi_A=1$: propagators are the same as in the linear 'tHooft-Feynman gauge, loop tensor structure is simples

$$\frac{1}{k^2-M_W^2}\left[g_{\mu\nu}-(1-\xi_W)\frac{k^\mu k^\nu}{k^2-\xi_W^2 M_W^2}\right]$$

GRACE Structure

Numerical check

Nmerical Check (non pol) w=500GeV, kc=10^−3 GeV			Sum
	Cuv	0	−2.574700372998826429857313203204018E−2
		100	−2.574700372998826429857313203204014E−2
		10000	−2.574700372998826429857313203204028E−2
	λ GeV	10^ −21	−2.574700372998826429883309145117605E−2
		10^ −25	−2.574700372998826429857313203204018E−2
		10^ −29	−2.574700372998826429857310603609845E−2
	NLG	0,0,0,0,0	−2.574700372998826429857313203204018E−2
		10,20,30,40,50	−2.574700372998826429857313203204021E−2
		100,200,300,400,500	−2.574700372998826429857313203204016E−2

22 digits

32 digits

Photon mass for IR

GRACE Structure

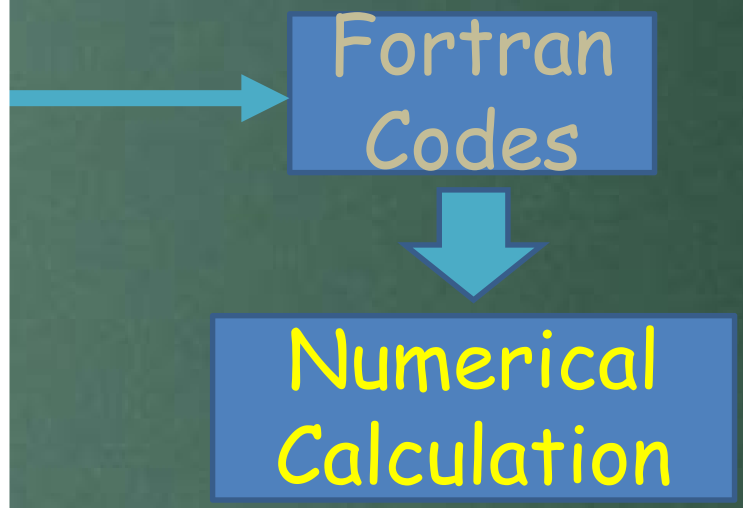
Numerical check

Soft/Hard photon separation(K_c) check

e+e- ->t t-bar w=500 GeV						
e-	e+		Tree	Loop+Soft	Hard	Total
R	L	kc=10^-3	6.1294E-01	-8.1541E-01	8.9924E-01	6.9677E-01
		kc=10^-5		-1.1783E+00	1.2615E+00	6.9617E-01
		check		-8.1541E-01	8.9924E-01	6.9677E-01
L	R	kc=10^-3	1.4285E+00	-2.0934E+00	2.0960E+00	1.4310E+00
		kc=10^-5		-2.9357E+00	2.9353E+00	1.4280E+00

GRACE Structure

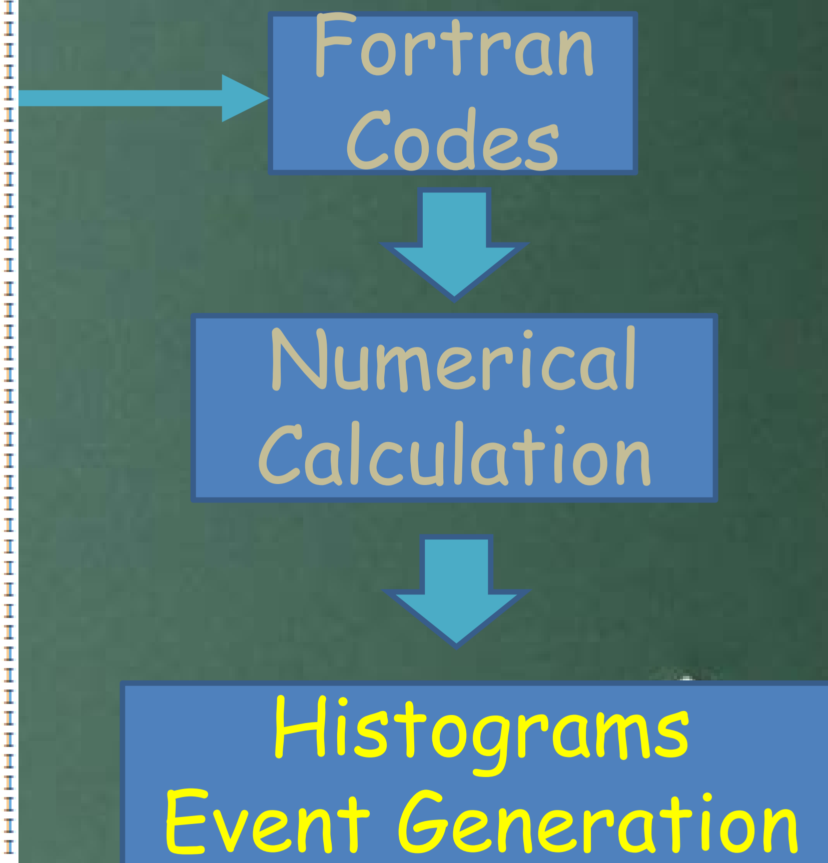
```
                                                               Date: 14/ 3/ 6   13:35
        **********************************************************
        *                                                        *
        *     BBBBBBB     AAAA     SSSSSS   EEEEEE   SSSSSS      *
        *     BB    BB   AA  AA   SS    SS  EE      SS    SS     *
        *     BB    BB  AA    AA  SS        EE      SS           *
        *     BBBBBBB   AAAAAAAA   SSSSSS   EEEEEE   SSSSSS      *
        *     BB    BB  AA    AA        SS  EE            SS     *
        *     BB    BB  AA    AA  SS    SS  EE      SS    SS     *
        *     BBBB BB   AA    AA   SSSSSS   EEEEEE   SSSSSS      *
        *                                                        *
        *                  BASES Version 5.1                     *
        *           coded by S.Kawabata KEK, March 1994          *
        **********************************************************

     <<   Parameters for BASES    >>

      (1) Dimensions of integration etc.
          # of dimensions :    Ndim    =        2   ( 50 at max.)
          # of Wilds      :    Nwild   =        1   ( 15 at max.)
          # of sample points : Ncall   =     5000(real)     5000(given)
          # of subregions    : Ng      =       50 / variable
          # of regions       : Nregion =       25 / variable
          # of Hypercubes    : Ncube   =       25

      (2) About the integration variables
          ------+---------------+---------------+-------+-------
              i       XL(i)           XU(i)       IG(i)   Wild
          ------+---------------+---------------+-------+-------
              1    0.000000E+00    1.000000E+00      1      yes
              2    0.000000E+00    1.000000E+00      0       no
          ------+---------------+---------------+-------+-------

      (3) Parameters for the grid optimization step
          Max.# of iterations: ITMX1 =          5
          Expected accuracy  : Acc1  =     0.2000 %

      (4) Parameters for the integration step
          Max.# of iterations: ITMX2 =          5
          Expected accuracy  : Acc2  =     0.0100 %


     <<   Computing Time Information    >>

              (1) For BASES                   H: M:  Sec
                  Overhead              :     0: 0: 0.00
                  Grid Optim. Step      :     0: 0: 0.01
                  Integration Step      :     0: 0: 0.02
                  Go time for all       :     0: 0: 0.03

              (2) Expected event generation time
                  Expected time for 1000 events :        0.0(
```



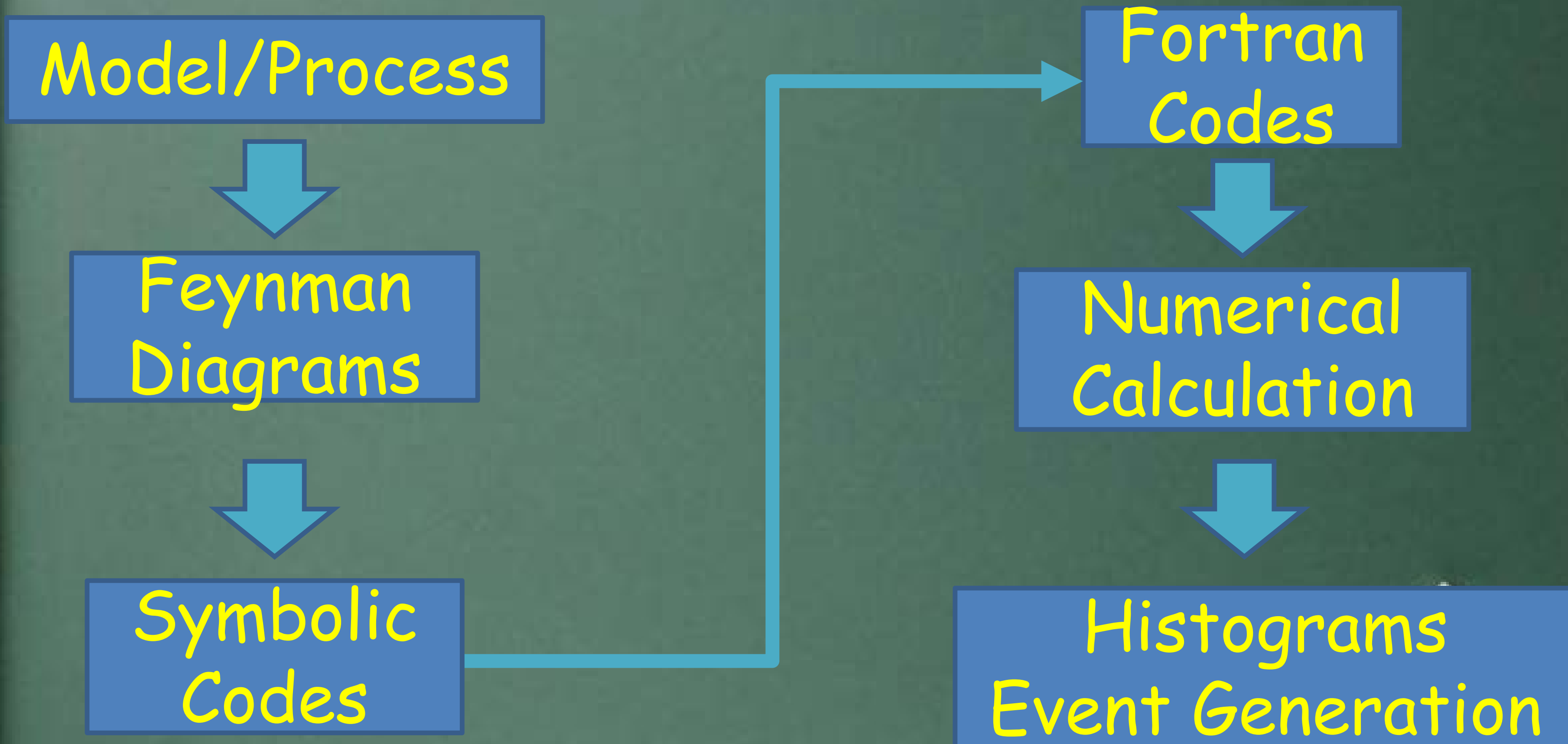

```
                                                                 Date: 14/ 3/ 6   13:35
                 Convergency Behavior for the Grid Optimization Step
 ------------------------------------------------------------------------------
 <- Result of  each iteration ->  <-     Cumulative Result         -> < CPU  time >
  IT Eff R_Neg   Estimate  Acc %  Estimate(+- Error )order   Acc %  ( H: M: Sec )
 ------------------------------------------------------------------------------
   1 100   0.00  1.151E-01  0.024  1.151194(+-0.000273)E-01  0.024    0: 0: 0.01
 ------------------------------------------------------------------------------

                                                                 Date: 14/ 3/ 6   13:35
                 Convergency Behavior for the Integration Step
 ------------------------------------------------------------------------------
 <- Result of  each iteration ->  <-     Cumulative Result         -> < CPU  time >
  IT Eff R_Neg   Estimate  Acc %  Estimate(+- Error )order   Acc %  ( H: M: Sec )
 ------------------------------------------------------------------------------
   1 100   0.00  1.151E-01  0.013  1.151255(+-0.000145)E-01  0.013    0: 0: 0.02
   2 100   0.00  1.151E-01  0.013  1.151370(+-0.000103)E-01  0.009    0: 0: 0.03
 ------------------------------------------------------------------------------
```

GRACE Structure

```
Histogram (ID =  5 ) for cos_the of Particle 3

                                  Linear Scale indicated by "*"
    x        d(Sigma)/dx        0.0E+00        2.5E-02        5.0E-02        7.5E-02
+-------+-------------------+------------------+------------+-------------+-----------+
I   E  0 I 0.000          E   0I                                                      I
I-1.000 I 8.327+-0.005 E -2I*******************************************00000           I
I-0.960 I 7.440+-0.004 E -2I**************************************000000               I
I-0.920 I 7.340+-0.003 E -2I**************************************0000000              I
I-0.880 I 7.258+-0.005 E -2I**************************************0000000              I
I-0.840 I 6.944+-0.004 E -2I************************************00000000               I
I-0.800 I 6.323+-0.003 E -2I*********************************000000000                 I
I-0.760 I 7.191+-0.003 E -2I*************************************0000000               I
I-0.720 I 6.126+-0.003 E -2I********************************000000000                  I
I-0.680 I 5.778+-0.002 E -2I******************************0000000000                   I
I-0.640 I 6.095+-0.002 E -2I********************************000000000                  I
I-0.600 I 6.296+-0.002 E -2I*********************************00000000                  I
I-0.560 I 5.363+-0.002 E -2I****************************0000000000                     I
I-0.520 I 5.407+-0.002 E -2I*****************************000000000                     I
I-0.480 I 5.352+-0.002 E -2I****************************0000000000                     I
I-0.440 I 5.331+-0.002 E -2I****************************0000000000                     I
I-0.400 I 4.778+-0.002 E -2I*************************0000000000                        I
I-0.360 I 5.066+-0.002 E -2I***************************0000000000                      I
I-0.320 I 5.069+-0.002 E -2I***************************0000000000                      I
I-0.280 I 4.625+-0.001 E -2I*************************0000000000                        I
I-0.240 I 4.619+-0.002 E -2I*************************0000000000                        I
I-0.200 I 4.983+-0.001 E -2I**************************0000000000                       I
I-0.160 I 4.117+-0.000 E -2I*********************0000000000                            I
I-0.120 I 4.690+-0.001 E -2I*************************0000000000                        I
I-0.080 I 4.950+-0.000 E -2I**************************0000000000                       I
I-0.040 I 4.092+-0.000 E -2I*********************0000000000                            I
I 0.000 I 4.937+-0.000 E -2I**************************0000000000                       I
I 0.040 I 4.193+-0.001 E -2I*********************00000000000                           I
I 0.080 I 5.020+-0.001 E -2I***************************0000000000                      I
I 0.120 I 4.494+-0.001 E -2I************************0000000000                         I
I 0.160 I 4.739+-0.001 E -2I*************************0000000000                        I
I 0.200 I 4.893+-0.001 E -2I**************************0000000000                       I
I 0.240 I 4.624+-0.002 E -2I*************************0000000000                        I
I 0.280 I 4.852+-0.002 E -2I**************************0000000000                       I
I 0.320 I 5.194+-0.002 E -2I**************************0000000000                       I
I 0.360 I 4.942+-0.003 E -2I**************************0000000000                       I
I 0.400 I 5.620+-0.002 E -2I******************************000000000                    I
I 0.440 I 4.884+-0.002 E -2I**************************0000000000                       I
I 0.480 I 5.447+-0.002 E -2I*****************************000000000                     I
I 0.520 I 5.633+-0.002 E -2I******************************000000000                    I
I 0.560 I 5.739+-0.003 E -2I******************************000000000                    I
I 0.600 I 5.990+-0.002 E -2I*******************************000000000                   I
I 0.640 I 6.477+-0.002 E -2I**********************************00000000                 I
I 0.680 I 5.942+-0.003 E -2I*******************************000000000                   I
I 0.720 I 6.814+-0.003 E -2I************************************0000000                I
I 0.760 I 6.473+-0.003 E -2I**********************************00000000                 I
I 0.800 I 6.902+-0.004 E -2I************************************0000000                I
I 0.840 I 7.261+-0.003 E -2I**************************************0000000              I
I 0.880 I 7.461+-0.003 E -2I***************************************000000              I
I 0.920 I 7.853+-0.003 E -2I*****************************************00000             I
I 0.960 I 7.902+-0.004 E -2I*****************************************00000             I
I   E  0 I 0.000          E   0I                                                      I
+-------+-------------------+-----------------------------------------------------------+
    x        d(Sigma)/dx        1.0E-02
                                  Logarithmic Scale indicated by "O"
```



GRACE Structure



Recent results from GRACE

- Recent results from GRACE
  - ✓ ELWK correction for LHC

Recent Results : SM/Loop/PP

Full $\mathcal{O}(\alpha)$ electroweak radiative corrections to the process $pp \to W^+W^- + 1$ jet at LHC with GRACE-Loop

P.H. Khiem(SOKENDAI Univ. and KEK.)

In collaboration with

Y. Kurihara, T. Kaneko (KEK); K. Kato (Kogakuin Univ.), J.A.M. Vermaseren (NIKHEF), and T. Ueda (KIT).

国立大学法人 総合研究大学院大学 The Graduate University for Advanced Studies [SOKENDAI]

KEK HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

Program No. : 28aSB-3

Recent Results : SM/Loop/PP

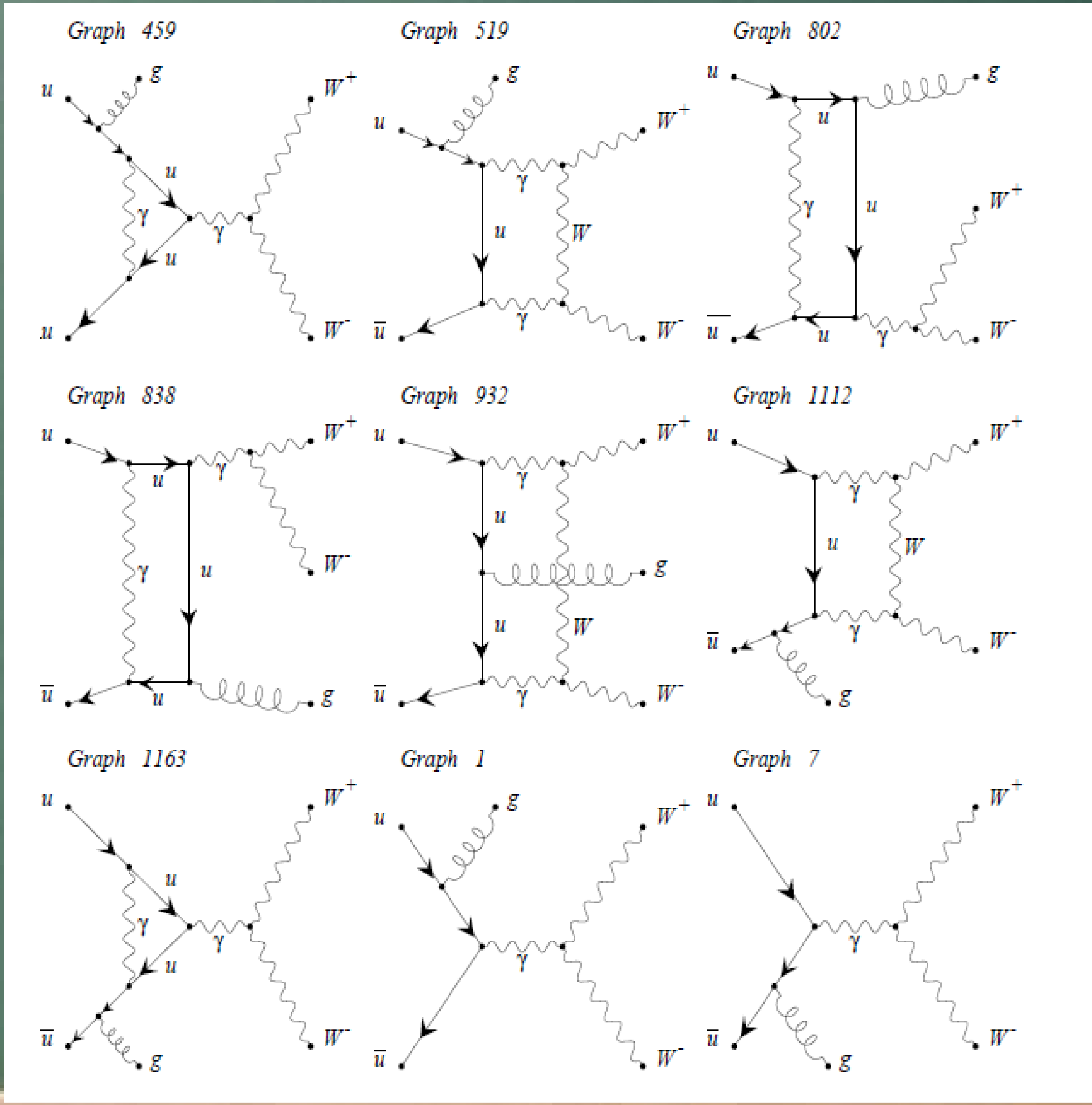
$q\bar{q} \to W^+W^- + 1$ jet at LHC@14

type	processes	$N_{\text{Tree diagrams}}$	$N_{\text{Loop diagrams}}$
$q_u\bar{q}_u \to W^+W^-g$	$u\bar{u} \to W^+W^-g$	9	1361
	$c\bar{c} \to W^+W^-g$	9	1361
$q_d\bar{q}_d \to W^+W^-g$	$dd \to W^+W^-g$	9	1361
	$s\bar{s} \to W^+W^-g$	9	1361
	$b\bar{b} \to W^+W^-g$	9	1361
$q_ug \to W^+W^-q_u$	$ug \to W^+W^-u$	9	1361
	$cg \to W^+W^-c$	9	1361
$q_dg \to W^+W^-q_d$	$dg \to W^+W^-d$	9	1361
	$sg \to W^+W^-s$	9	1361
	$bg \to W^+W^-b$	9	1361

K.H. Phan

Recent Results : SM/Loop/PP

$q\bar{q} \rightarrow W^+W^- + 1$ jet at LHC@14



K.H. Phan

Recent Results : SM/Loop/PP

$q\bar{q} \to W^+W^- + 1$ jet at LHC@14

The input parameters

- $\sqrt{s} = 14$ TeV,
- $p_T^{jet} \geq 20$ GeV, $|\eta_{jet}| \leq 3.0$,
- Particle masses

$M_W = 80.3759$ GeV	$M_H = 125$ GeV	$M_Z = 91.187$ GeV
$m_\tau = 1776.82$ MeV	$m_\mu = 105.6583$ MeV	$m_u = 1.7$ MeV
$m_d = 4.1$ MeV	$m_c = 1.27$ GeV	$m_s = 101$ MeV
$m_b = 4.19$ GeV	$m_t = 172.0$ GeV	$m_e = 0.51099$ MeV
$\alpha = 1/137.0359895$	$G_\mu = 1.16639 \cdot 10^{-5}$ GeV^{-2}	

- PDF: CTEQ6L

K.H. Phan

Recent Results : SM/Loop/PP

$q\bar{q} \to W^+W^- + 1$ jet at LHC@14

$\sqrt{s} = 14$ TeV	$p_{T,W}^{\text{cut}}$ [GeV]	$\sigma_{\text{Tree}}^{G_\mu-\text{scheme}}$ [pb]	$\delta_{EW}^{G_\mu-\text{scheme}}$ [%]
This work	100	5.377	-7.1
Ref [77]	$\lvert Y_W \rvert \leq 2.5$	5.379	-7.0
This work	250	$35.305 \cdot 10^{-2}$	-18.88
Ref [77]	$\lvert Y_W \rvert \leq 2.5$	$35.310 \cdot 10^{-2}$	-18.80
This work	500	$23.036 \cdot 10^{-3}$	-34.07
Ref [77]	$\lvert Y_W \rvert \leq 2.5$	$23.050 \cdot 10^{-3}$	-33.70

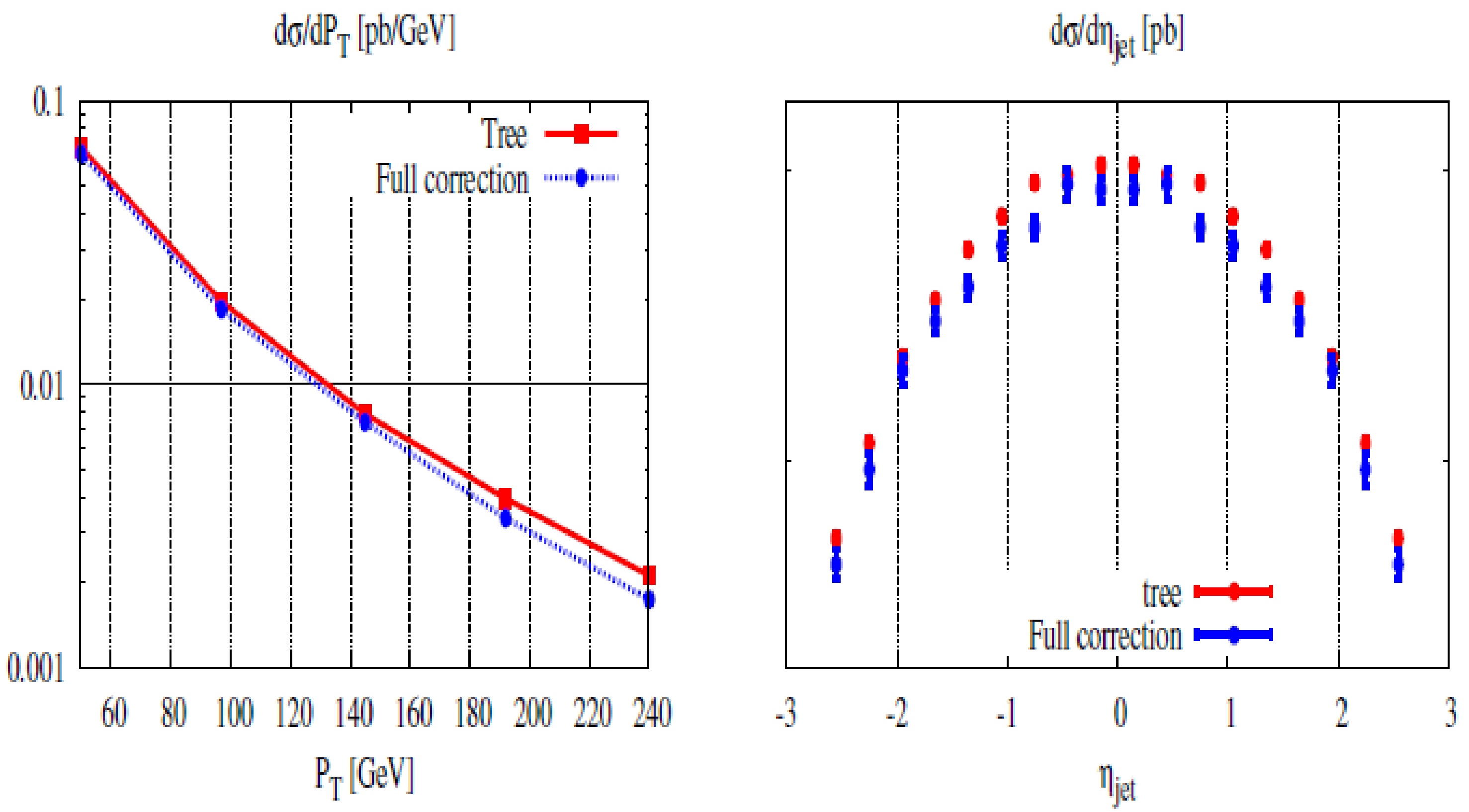
Table 3.6: Cross-check the result in this calculation to the paper [77] by varying the $p_{T,W}^{\text{cut}}$ of W boson at 14 TeV of the LHC.

[77] A. Bierweiler, T. Kasprzik, J. H. Kühn and S. Uccirati, JHEP **1211** (2012) 093 [arXiv:1208.3147 [hep-ph]].

Recent Results : SM/Loop/PP

$q\bar{q} \to W^+W^- + 1$ jet at LHC@14

$\sqrt{s}$	σ_T[pb]	σ_{tot} [pb]	$\delta_{EW}^{\alpha\text{-scheme}}$ [%]	$\delta_{EW}^{G_\mu\text{-scheme}}$ [%]
14 TeV	14.75	14.23	−3.53	−8.63



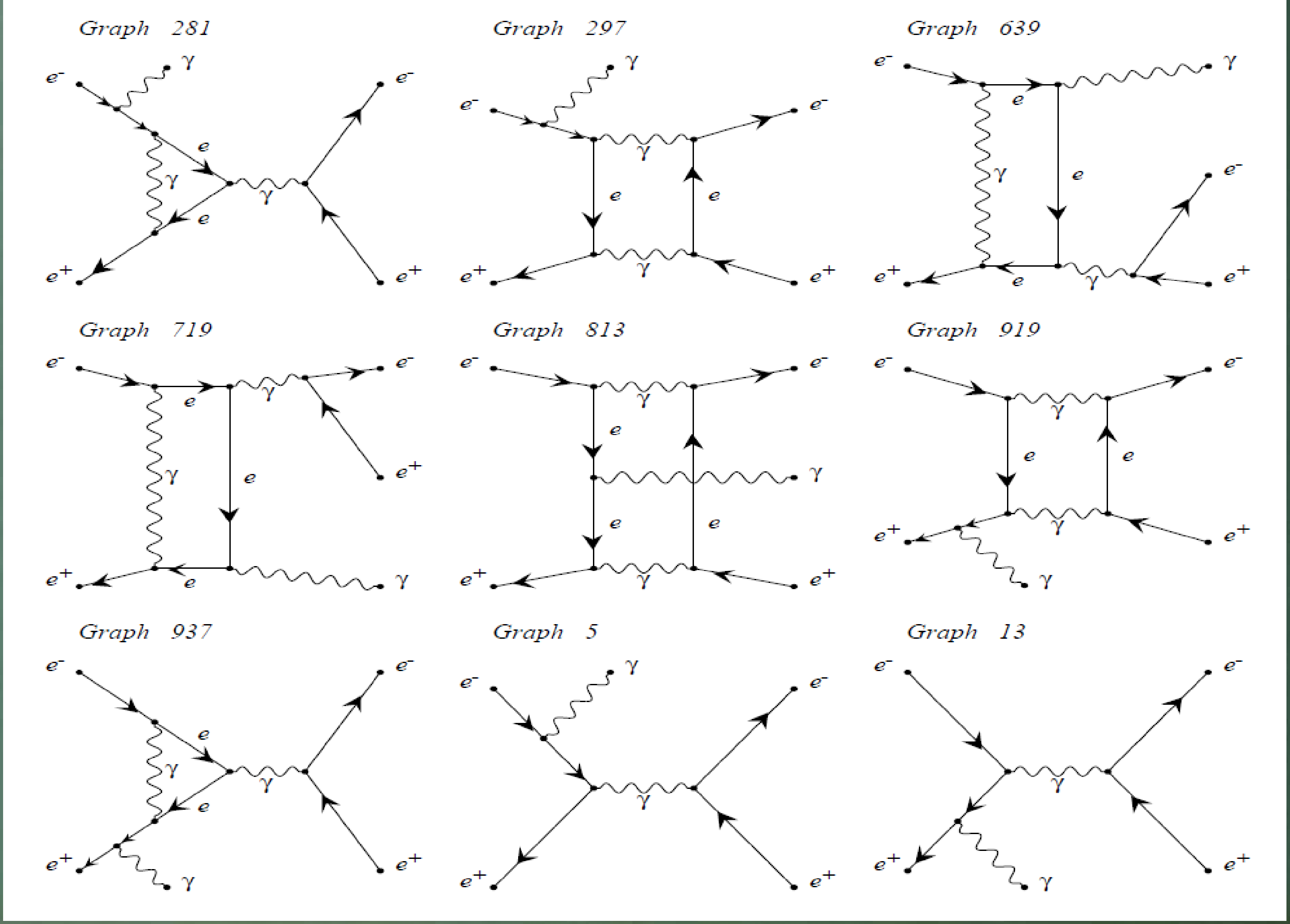
K.H. Phan

- Recent results from GRACE
  - ✓ $e^+e^-/t\bar{t}(+\gamma)$ production at e^+e^- coll.

Recent Results : SM/Loop/e^+e^-

$$e^+e^- \to e^+e^-\gamma$$

Phys. Lett. **B740**, 192 (2014)



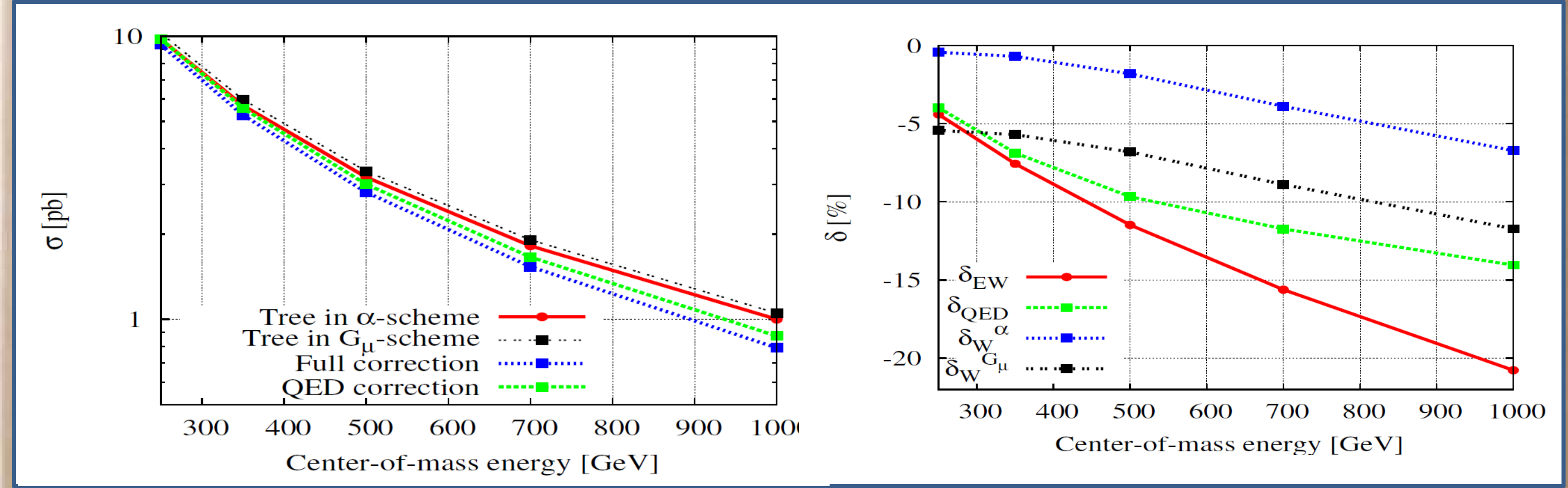
K.H. Phan

Recent Results : SM/Loop/e^+e^-

$$e^+e^- \to e^+e^-\gamma$$

Phys. Lett. **B740**, 192 (2014)

$$E_\gamma^{\mathrm{cut}} \geq 10\ \mathrm{GeV} \qquad 10^\circ \leq \theta_\gamma^{\mathrm{cut}} \leq 170^\circ$$



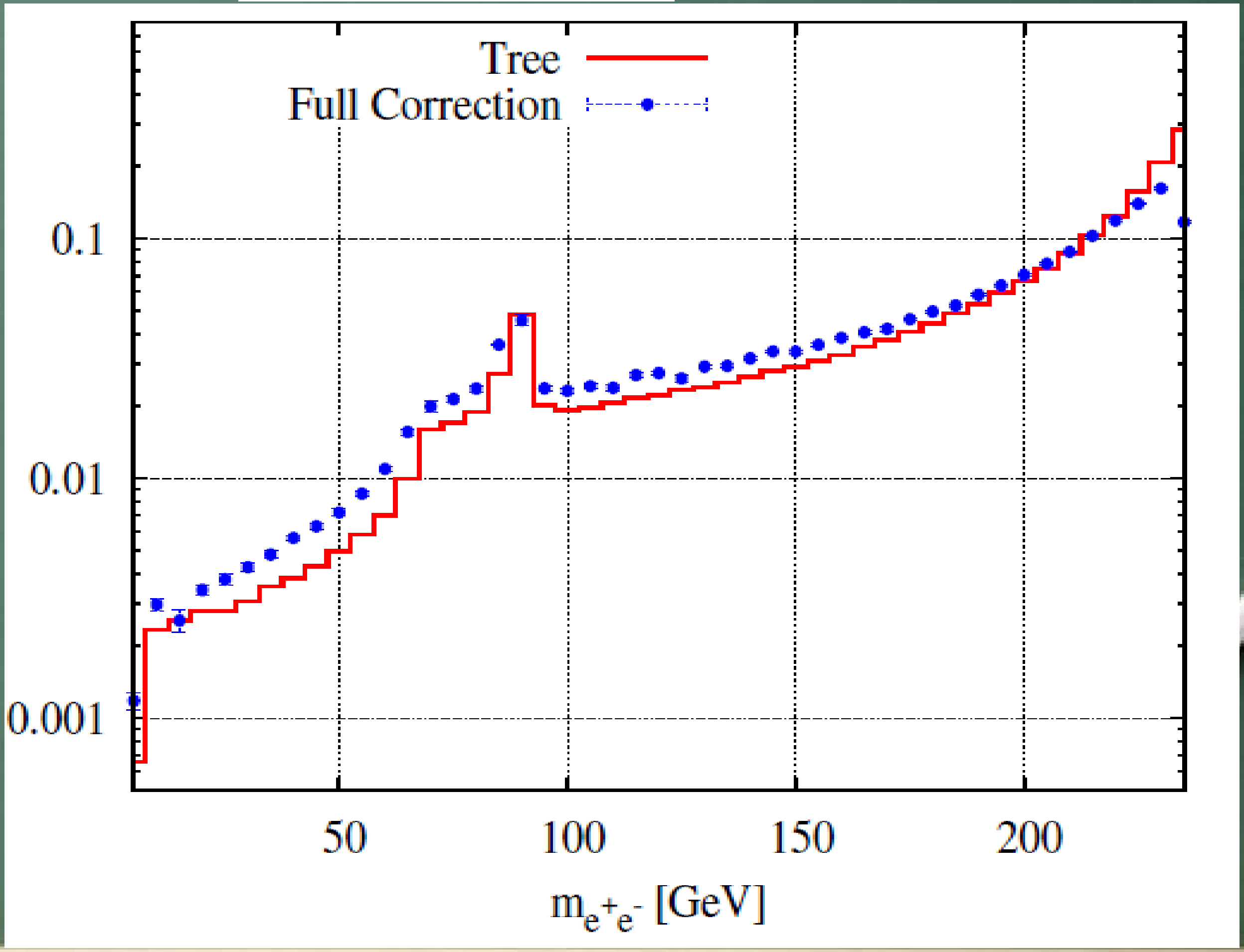
K.H. Phan

Recent Results : SM/Loop/e^+e^-

$$e^+e^- \to e^+e^-\gamma$$

Phys. Lett. **B740**, 192 (2014)

$E_\gamma^{cut} \geq 10$ GeV $10° \leq \theta_\gamma^{cut} \leq 170°$

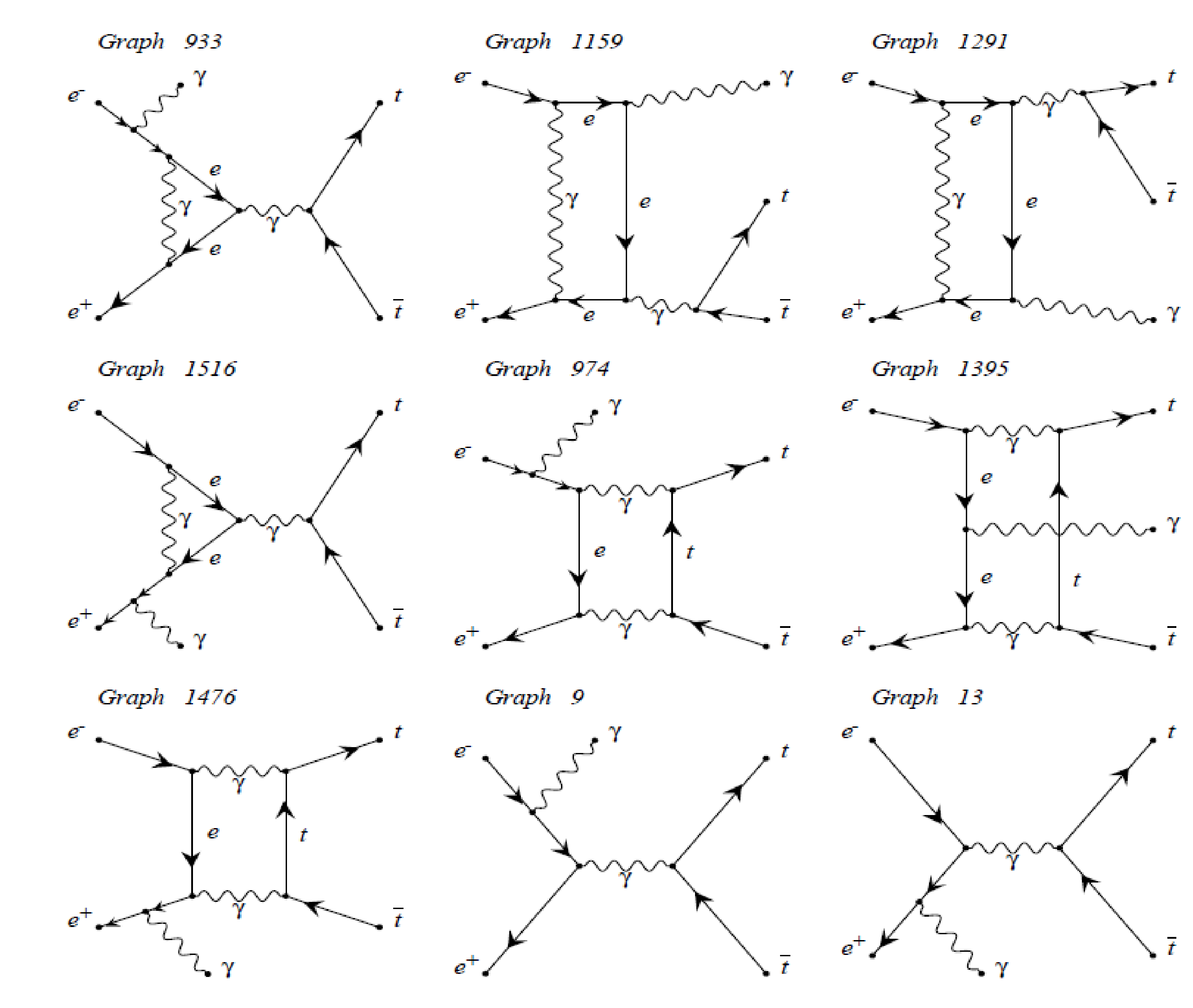


K.H. Phan

Recent Results : SM/Loop/e^+e^-

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

Eur. Phys. J. C **73**, 2400 (2013)



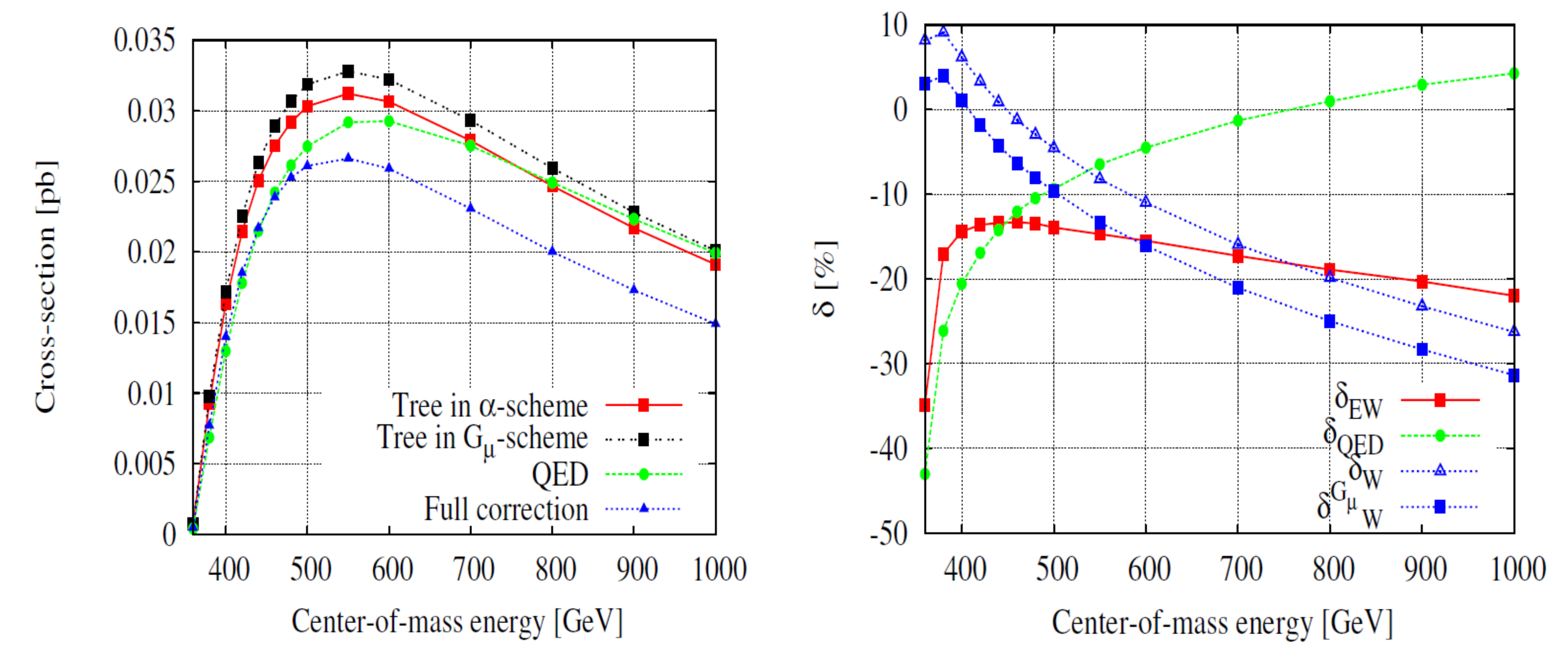
K.H. Phan

Recent Results : SM/Loop/e^+e^-

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

Eur. Phys. J. *C* **73**, 2400 (2013)

$$E_\gamma^{\rm cut} \geq 10 \text{ GeV} \qquad 10^\circ \leq \theta_\gamma^{\rm cut} \leq 170^\circ$$

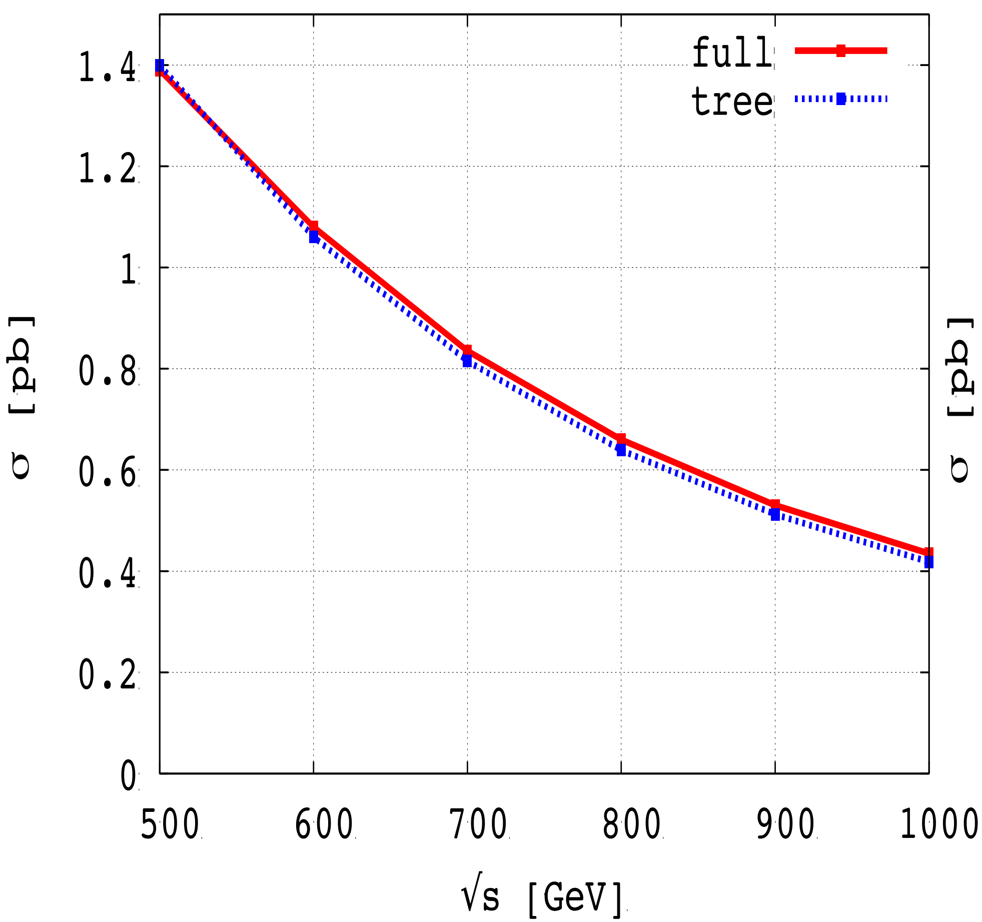


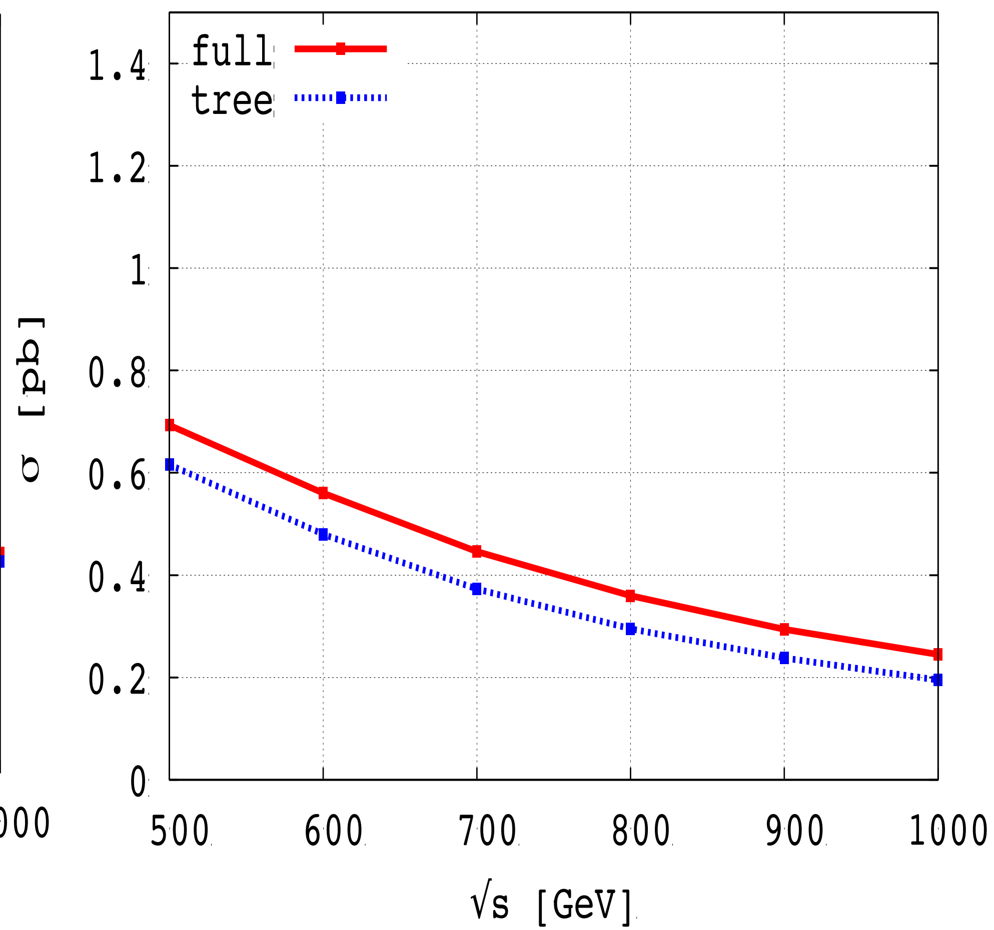
K.H. Phan

Recent Results : SM/Loop/e^+e^-/Pol.

100% POLARIZATION

$e^-_L e^+_R \rightarrow \bar{t}t$ $e^-_R e^+_L \rightarrow \bar{t}t$

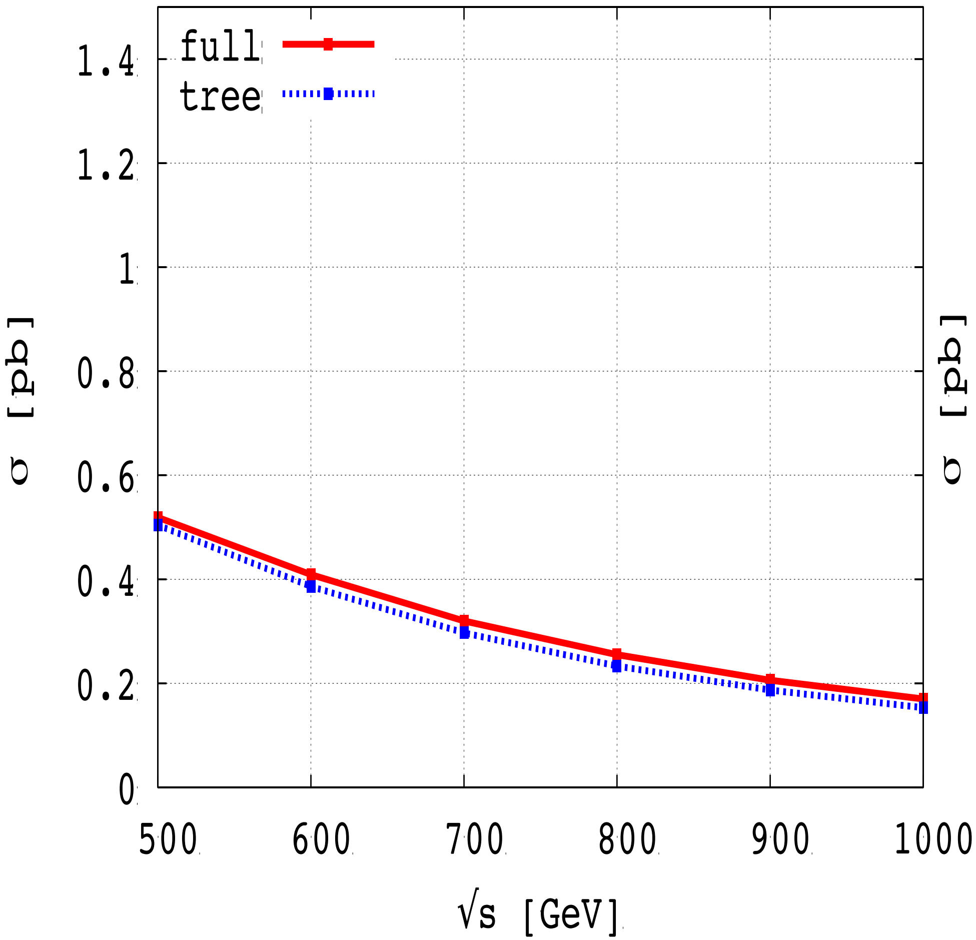




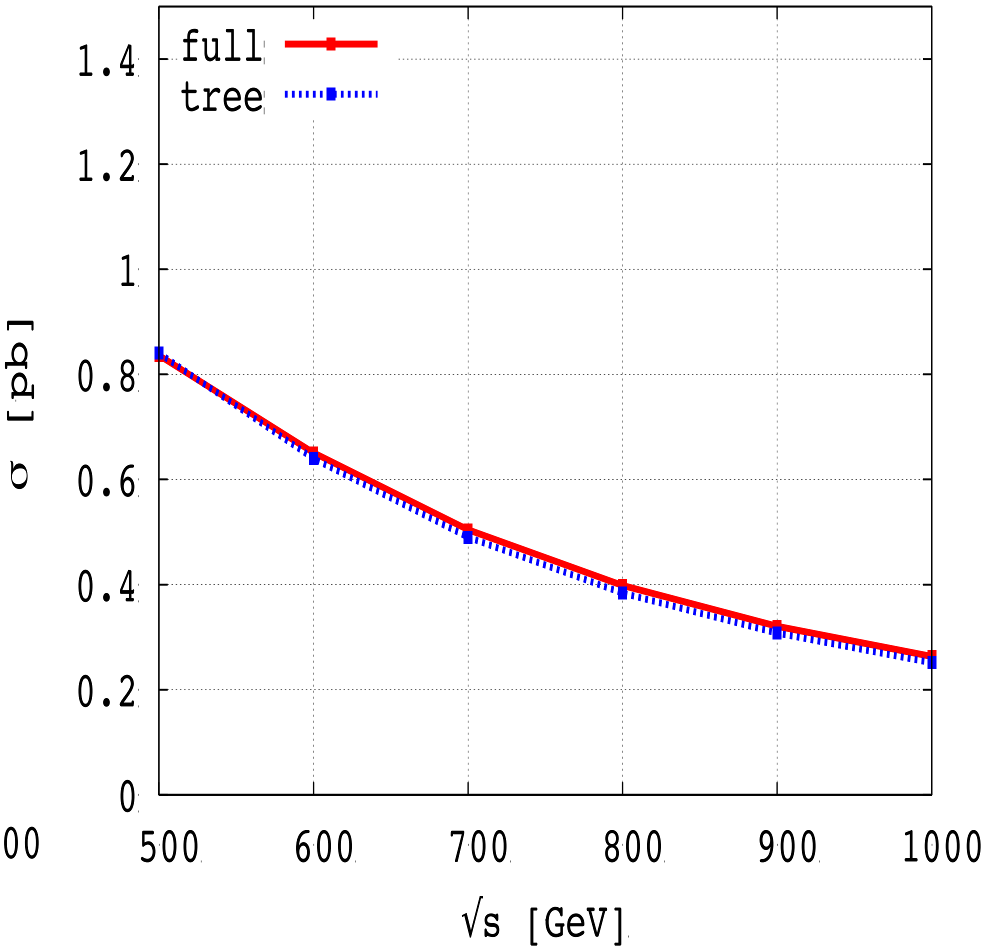
N.M.U. Quach

Recent Results : SM/Loop/e^+e^-/Pol.

Non Polarization

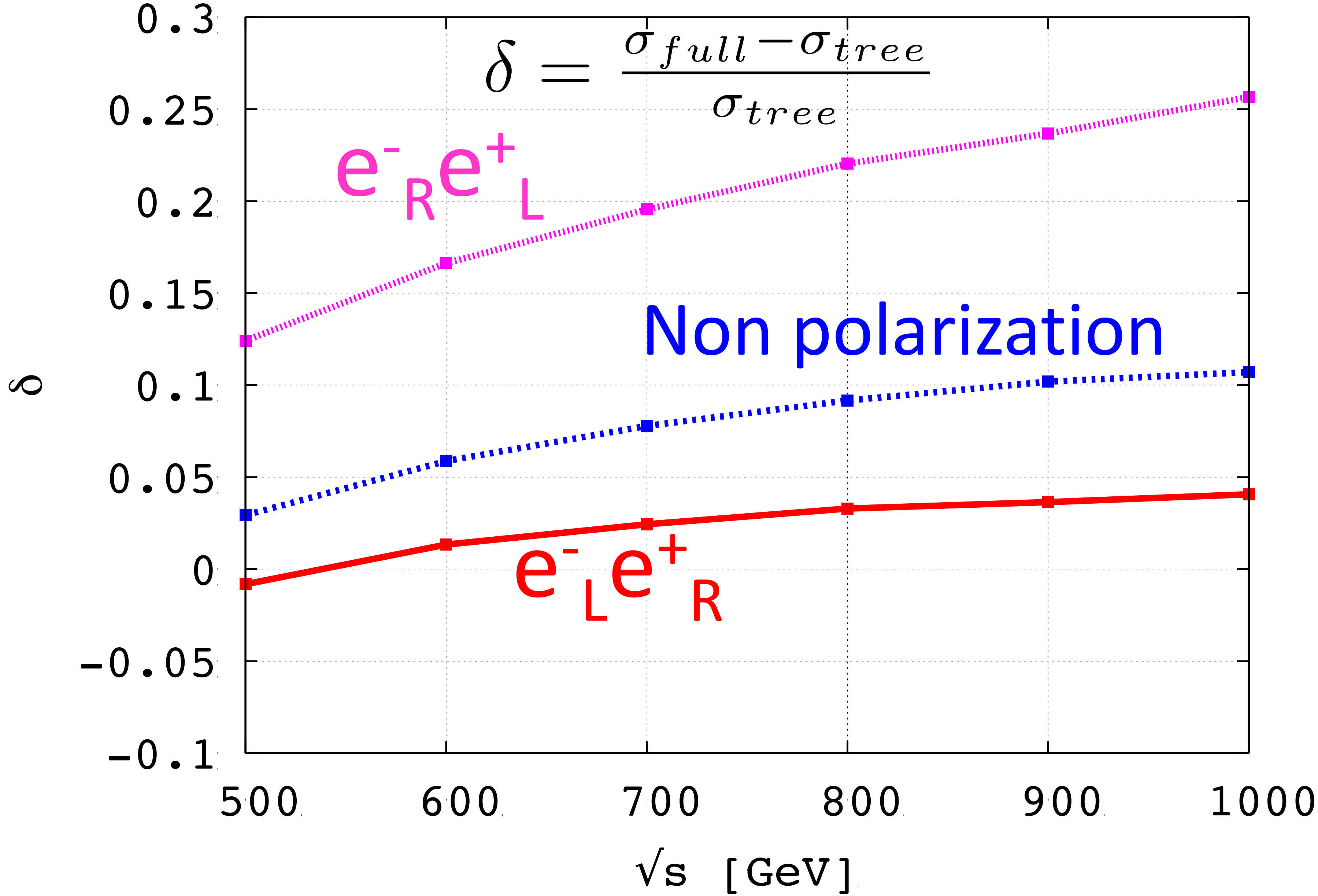


e^- 80%, e^+ 30%



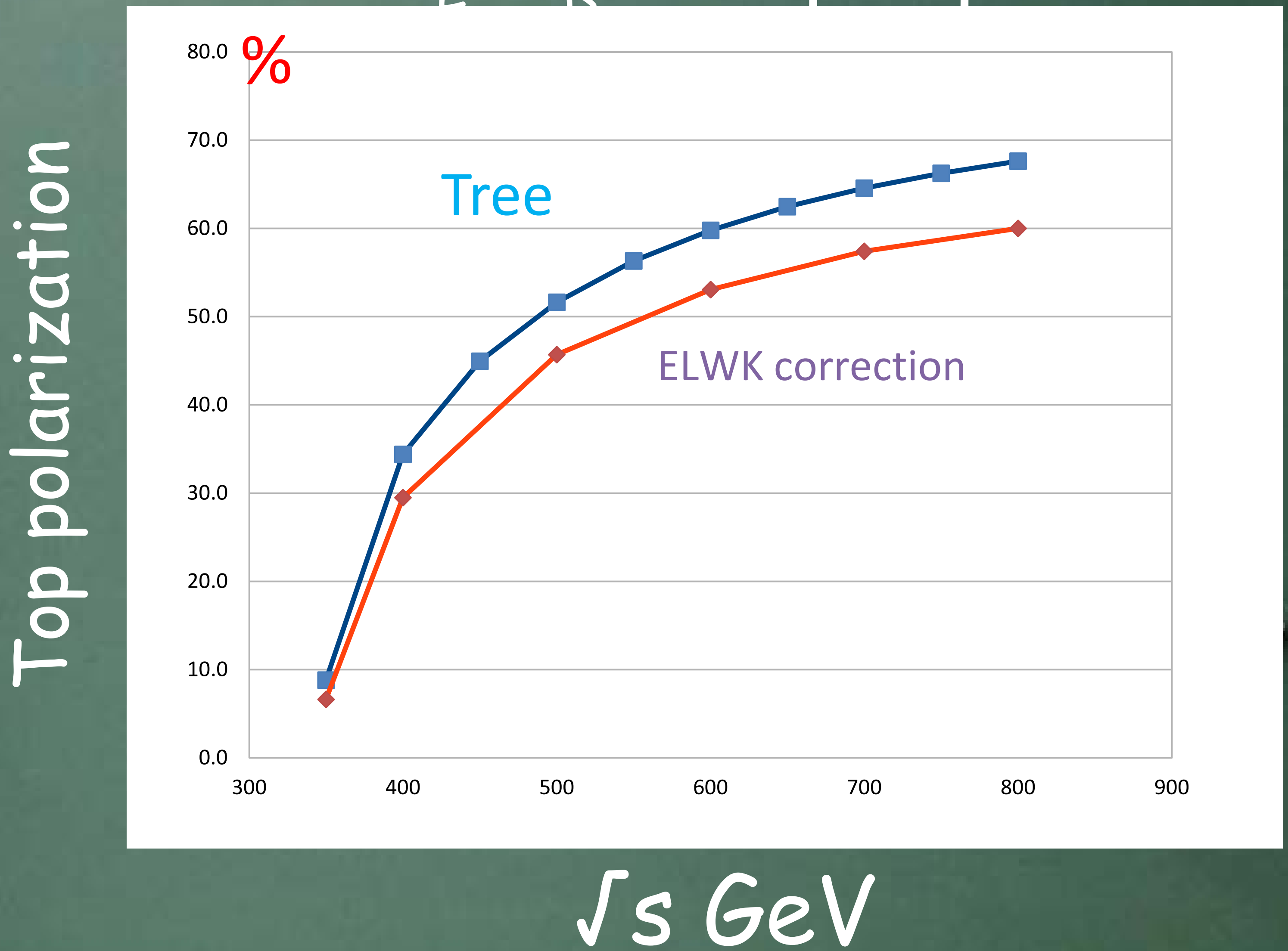
N.M.U. Quach

Recent Results : SM/Loop/e^+e^-/Pol.



Recent Results : SM/Loop/e^+e^-/Pol.

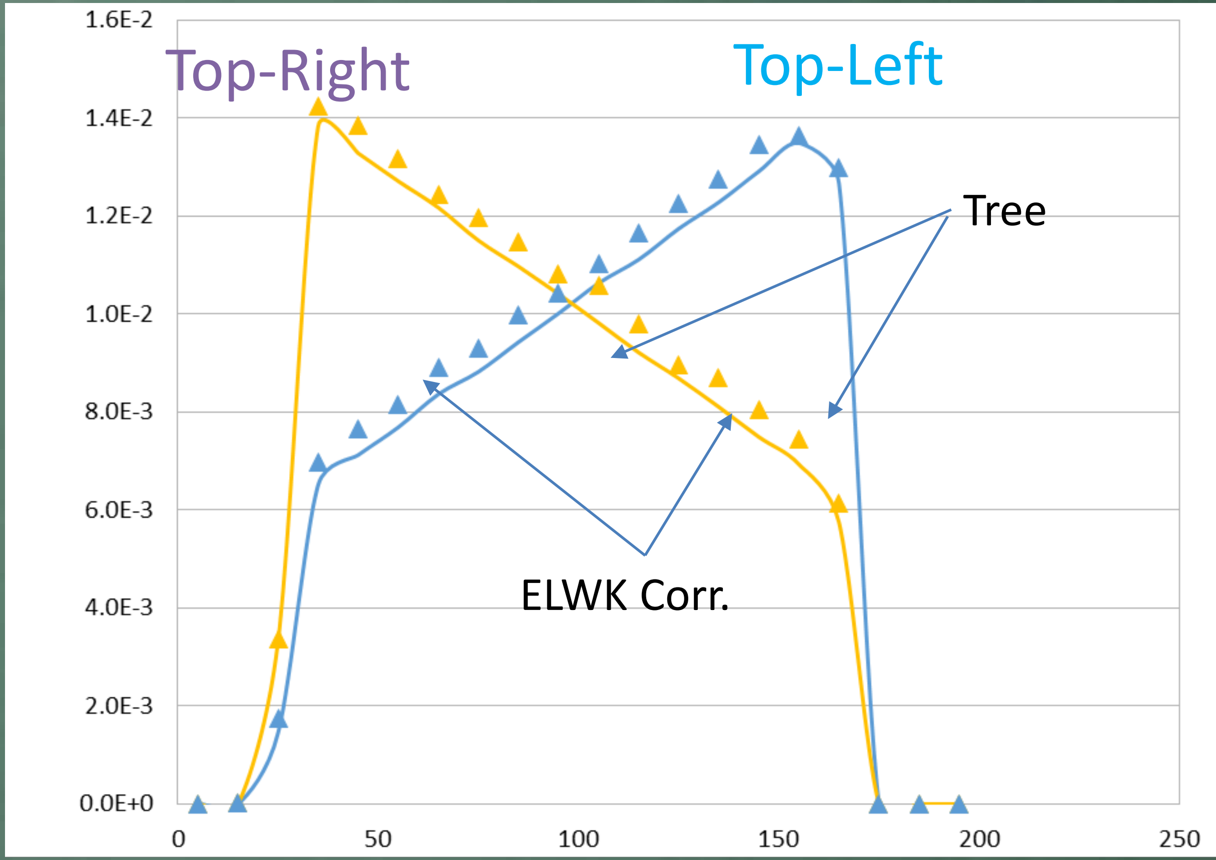
$e^-_L e^+_R \to$ top top



N.M.U. Quach

Recent Results : SM/Loop/e^+e^-/Pol.

$\sqrt{s}$=500GeV top Decay



E_b (Lab.) GeV

N.M.U. Quach

- Recent results from GRACE
  - ✓ SUSY Loop effects

One-loop effects of MSSM scenarios in 3rd generation fermion pair production at ILC with GRACE/SUSY

Y. Kouda, K. Fujiwara, T. Kon, M. Jimbo [a], T. Ishikawa [b], Y. Kurihara [b], K. Kato [c] and M. Kuroda [d]
Seikei University
[a] Chiba University of Commerce
[b] KEK
[c] Kogakuin University
[d] Meiji Gakuin University

Y. Kouda, ALCW2015, Apr. 20~24, 2015, @ KEK, Japan

Parameters consistent with muon g-2

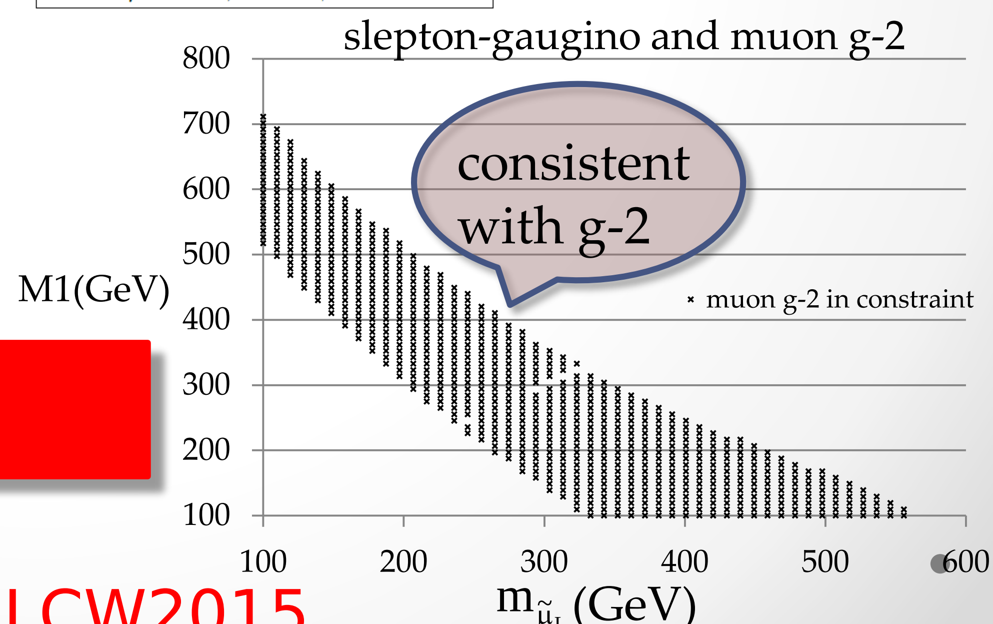
scenario 1 [GeV]			
$\tilde{\chi}_1^+$	$\tilde{\chi}_2^+$		
368.9	616.8		
$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
149.0	369.0	604.0	616.1
$\tilde{\ell}_1$	$\tilde{\ell}_2$	$\tilde{\nu}_\ell$	
362.5	367.9	359.6	
$\tilde{\tau}_1$	$\tilde{\tau}_2$	$\tilde{\nu}_\tau$	
161.1	296.1	228.2	
$\tilde{u}_1$	$\tilde{u}_2$	$\tilde{d}_1$	$\tilde{d}_2$
1720	1739	1740	1741
$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	$\tilde{b}_2$
317.0	2078	800.0	2061
θ_τ	θ_b	θ_t	
0.8071	1.557	1.456	
M_1	M_2	M_3	
150.0	380.0	1500	
μ=600, $\tan\beta$=30			

scenario 2 [GeV]			
$\tilde{\chi}_1^+$	$\tilde{\chi}_2^+$		
508.1	636.8		
$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
277.9	508.5	603.4	637.1
$\tilde{\ell}_1$	$\tilde{\ell}_2$	$\tilde{\nu}_\ell$	
317.8	323.3	313.8	
$\tilde{\tau}_1$	$\tilde{\tau}_2$	$\tilde{\nu}_\tau$	
283.9	377.1	327.4	
$\tilde{u}_1$	$\tilde{u}_2$	$\tilde{d}_1$	$\tilde{d}_2$
1720	1739	1740	1741
$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	$\tilde{b}_2$
1802	2244	1998	2063
θ_τ	θ_b	θ_t	
0.8150	1.376	0.8533	
M_1	M_2	M_3	
280.0	540.0	1500	
μ=600, $\tan\beta$=30			

scenario 3 [GeV]			
$\tilde{\chi}_1^+$	$\tilde{\chi}_2^+$		
467.5	626.7		
$\tilde{\chi}_1^0$	$\tilde{\chi}_2^0$	$\tilde{\chi}_3^0$	$\tilde{\chi}_4^0$
242.8	467.6	603.6	626.7
$\tilde{\ell}_1$	$\tilde{\ell}_2$	$\tilde{\nu}_\ell$	
322.8	328.3	318.9	
$\tilde{\tau}_1$	$\tilde{\tau}_2$	$\tilde{\nu}_\tau$	
320.1	405.3	359.6	
$\tilde{u}_1$	$\tilde{u}_2$	$\tilde{d}_1$	$\tilde{d}_2$
1720	1739	1740	1741
$\tilde{t}_1$	$\tilde{t}_2$	$\tilde{b}_1$	$\tilde{b}_2$
279.6	2078	800.0	2061
θ_τ	θ_b	θ_t	
0.8175	1.557	1.456	
M_1	M_2	M_3	
244.5	489.0	2000	
μ=600, $\tan\beta$=30			

light or heavy stop

SuSpect2 (A.Djouadi, J.Kneur and G.Moultaka hep-ph/0211331)



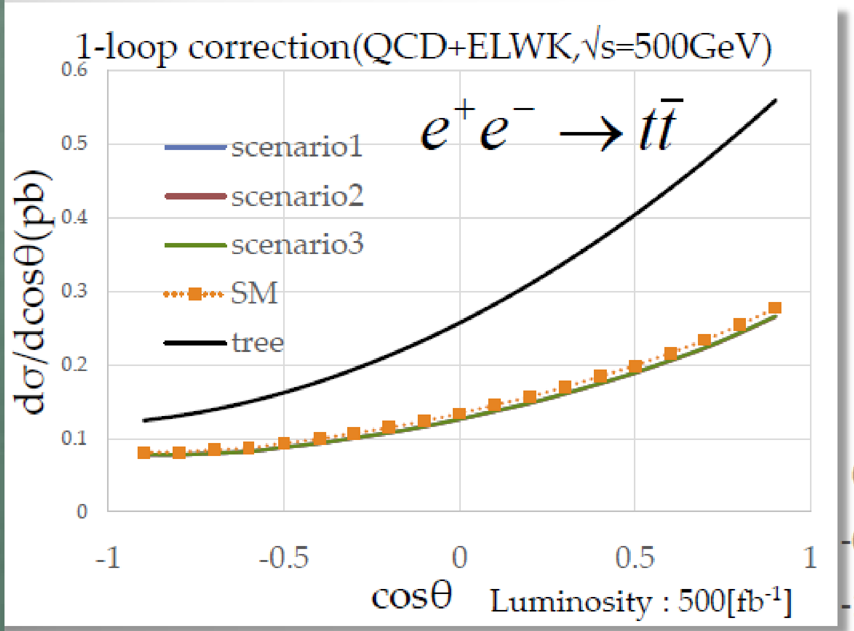
muon g-2 constrain
slepton ,gaugino
under hundreds GeV

neutralino1 LSP

Y. Kouda, ALCW2015

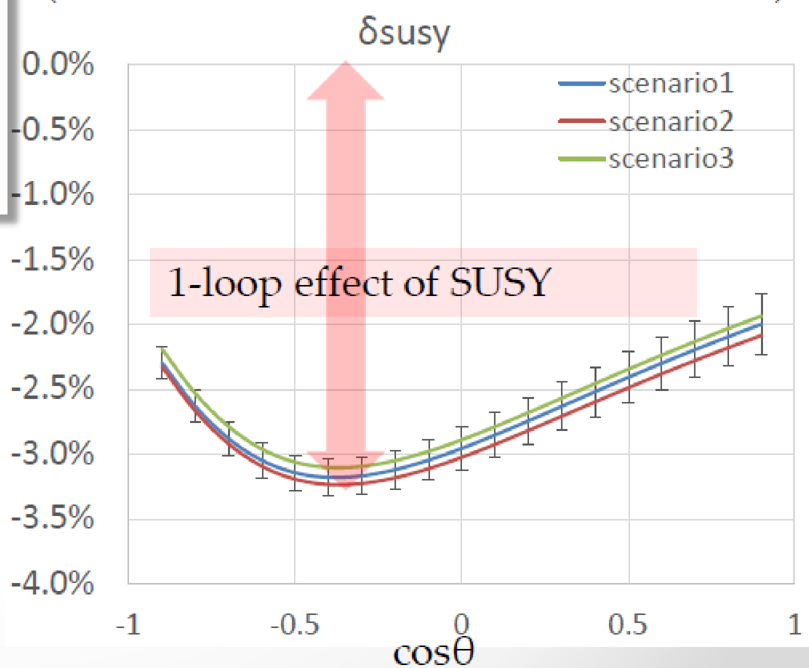
Recent Results : MSSM/Loop/e^+e^-

Top quark pair production



$$\delta_{SUSY} = \frac{\frac{d\sigma_{SUSY,1loop}}{d\cos\theta} - \frac{d\sigma_{SM,1loop}}{d\cos\theta}}{\frac{d\sigma_{tree}}{d\cos\theta}}$$

(error bar is statistic error based on SM event)



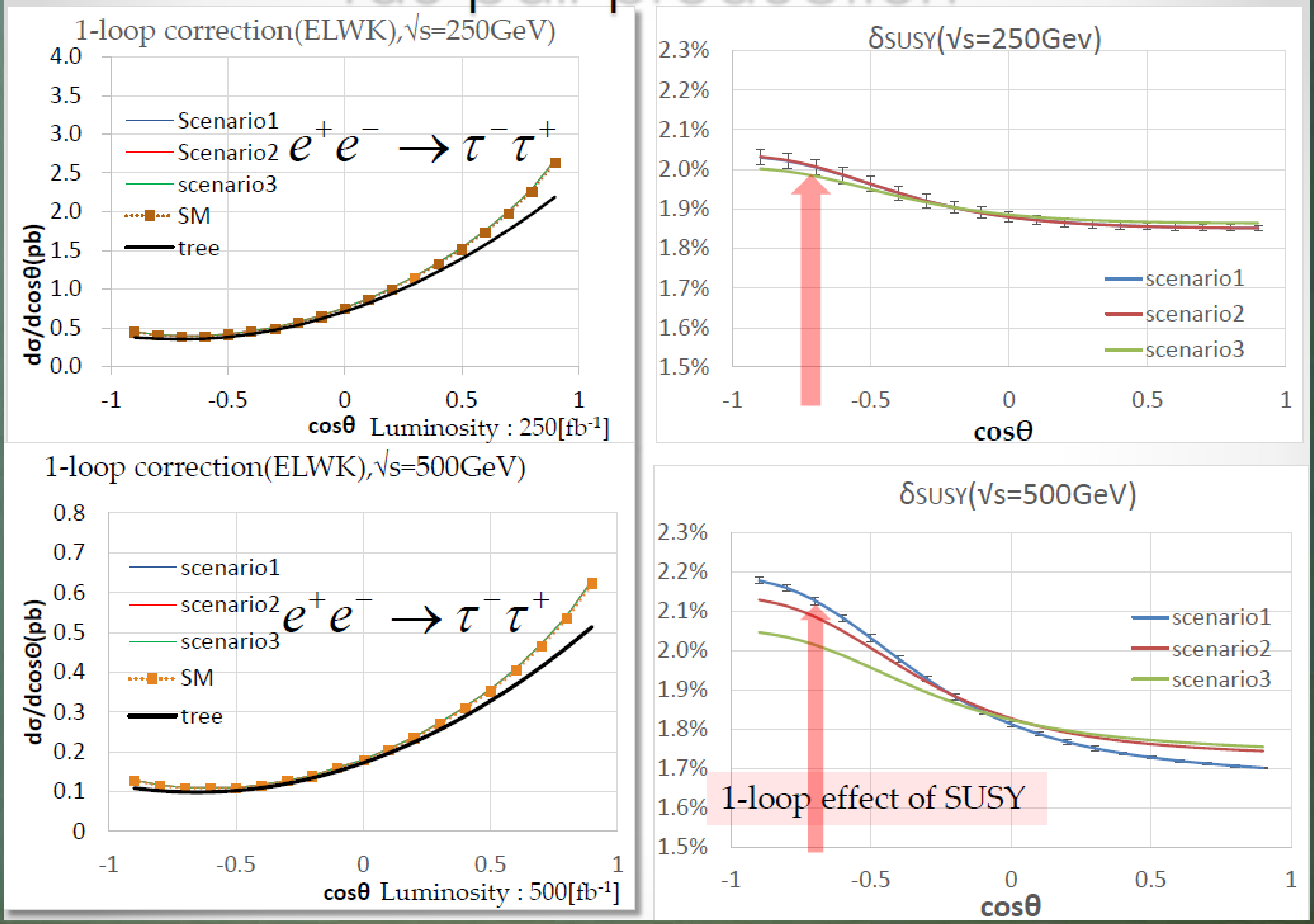
Contribution of hard photon, gluon calculated with finite top decay width

Physical quantity "δSUSY" is defined. That does not depend on the theoretical systematic error which is included in the contribution of hard calculation.

Y. Kouda, ALCW2015

Recent Results : MSSM/Loop/e^+e^-

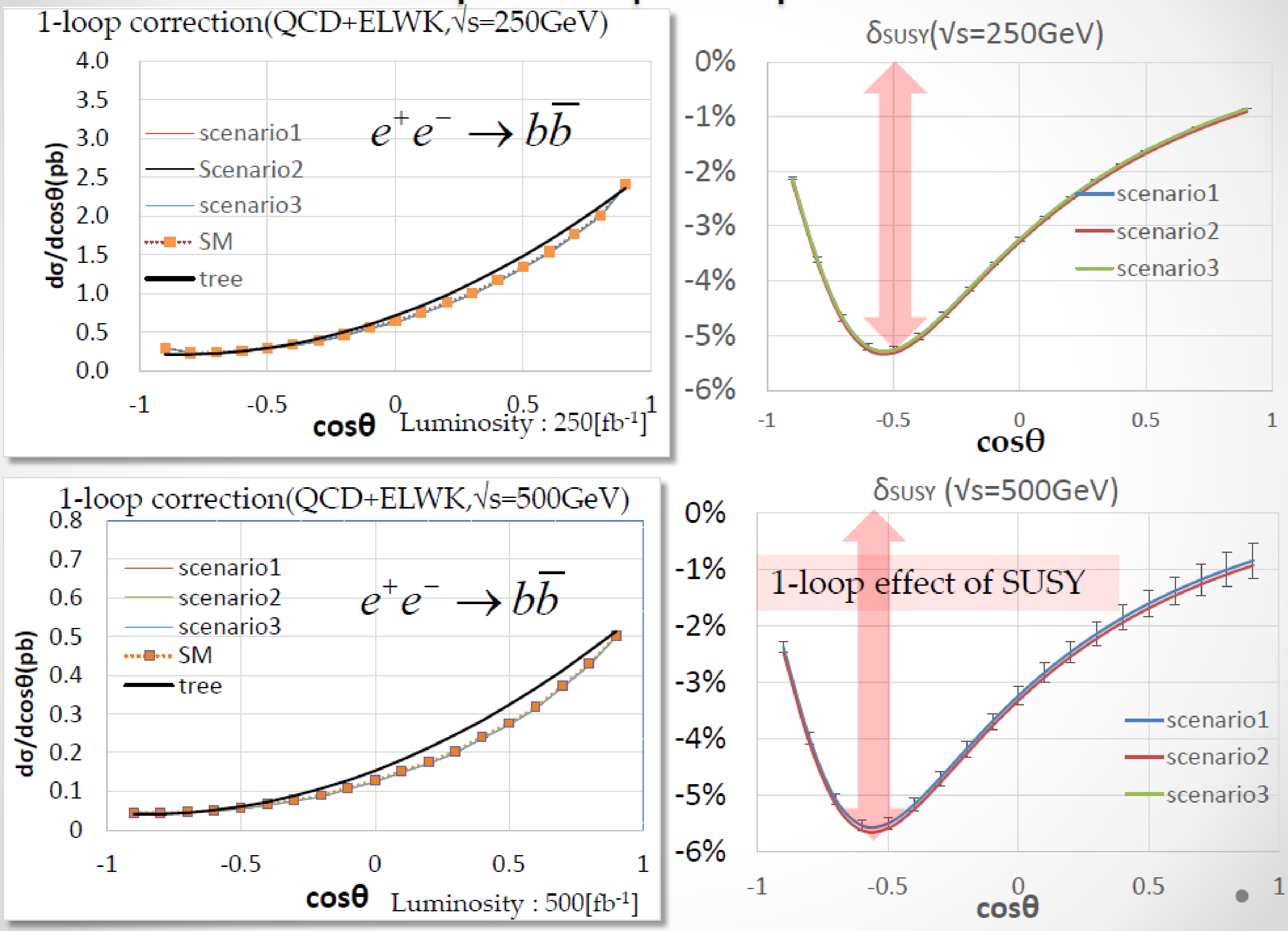
Tau pair production



Y. Kouda, ALCW2015

Recent Results : MSSM/Loop/e^+e^-

Bottom quark pair production



Y. Kouda, ALCW2015

Conclusion

- We set MSSM scenarios which are consistent with the observation values of Higgs mass 125GeV, Dark Matter density and muon g-2.
- We calculated angular distributions of top, tau and bottom pair productions.
- Combined results of t, tau and bottom pair productions indicate, even if any SUSY particle of those scenarios won't be found directly at ILC in the sub-TeV region, there is a possibility that SUSY can be inspected, without increasing the energy up to TeV scale.
- In particular, in ILC, at $\sqrt{s}$=250GeV, difference between MSSM and SM in bottom pair production is about 5 %.

Y. Kouda, ALCW2015

Other examples

List of Results

SM/Tree/PP

GR@PPA 2.8: Initial-state jet matching for weak-boson production processes at hadron collisions ☆

Shigeru Odaka *, Yoshimasa Kurihara

High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Computer Physics Communications 183 (2012) 1014–1028

List of Results

SM/Tree/PP

GR@PPA2.8

Event generator
for pp/$\bar{p}$p collision

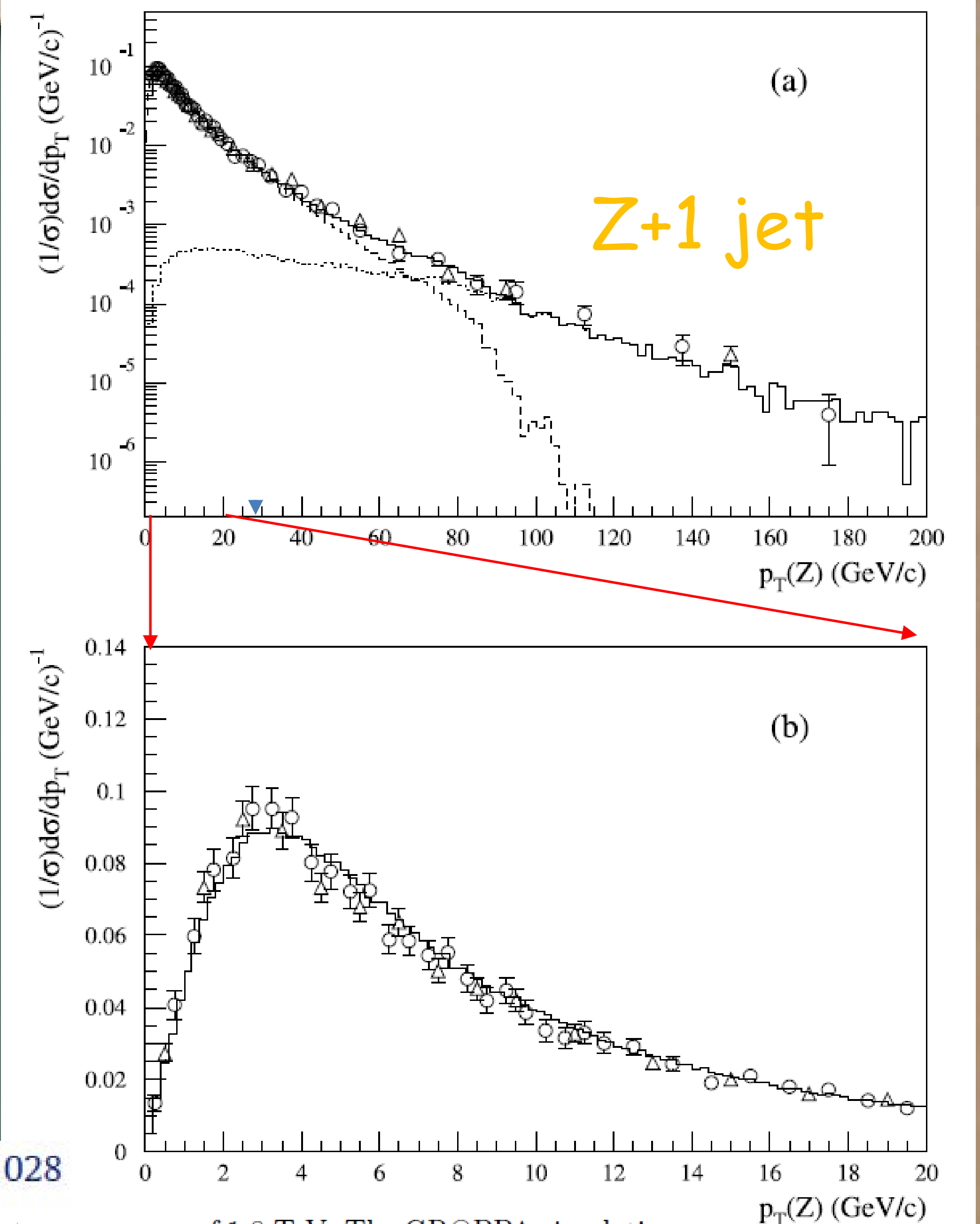
IGSUB	Coupling order	Command parameter	Process description
100	α_{em}^2	w0j	$pp(\bar{p}) \to W(2f) + 0$ jet $(+X)$
101	$\alpha_{em}^2\alpha_s$	w1j	$pp(\bar{p}) \to W(2f) + 1$ jet $(+X)$
102	$\alpha_{em}^2\alpha_s^2$	w2j	$pp(\bar{p}) \to W(2f) + 2$ jets $(+X)$
103	$\alpha_{em}^2\alpha_s^3$	w3j	$pp(\bar{p}) \to W(2f) + 3$ jets $(+X)$
104	$\alpha_{em}^2\alpha_s^4$	w4j	$pp(\bar{p}) \to W(2f) + 4$ jets $(+X)$
110	α_{em}^2	z0j	$pp(\bar{p}) \to Z/\gamma^*(2f) + 0$ jet $(+X)$
111	$\alpha_{em}^2\alpha_s$	z1j	$pp(\bar{p}) \to Z/\gamma^*(2f) + 1$ jet $(+X)$
112	$\alpha_{em}^2\alpha_s^2$	z2j	$pp(\bar{p}) \to Z/\gamma^*(2f) + 2$ jets $(+X)$
113	$\alpha_{em}^2\alpha_s^3$	z3j	$pp(\bar{p}) \to Z/\gamma^*(2f) + 3$ jets $(+X)$
114	$\alpha_{em}^2\alpha_s^4$	z4j	$pp(\bar{p}) \to Z/\gamma^*(2f) + 4$ jets $(+X)$
120	α_{em}^4	ww0j	$pp(\bar{p}) \to W^+(2f)W^-(2f') + 0$ jet $(+X)$
121	$\alpha_{em}^4\alpha_s$	ww1j	$pp(\bar{p}) \to W^+(2f)W^-(2f') + 1$ jet $(+X)$
122	$\alpha_{em}^4\alpha_s^2$	ww2j	$pp(\bar{p}) \to W^+(2f)W^-(2f') + 2$ jets $(+X)$
130	α_{em}^4	zw0j	$pp(\bar{p}) \to Z/\gamma^*(2f)W(2f') + 0$ jet $(+X)$
131	$\alpha_{em}^4\alpha_s$	zw1j	$pp(\bar{p}) \to Z/\gamma^*(2f)W(2f') + 1$ jet $(+X)$
132	$\alpha_{em}^4\alpha_s^2$	zw2j	$pp(\bar{p}) \to Z/\gamma^*(2f)W(2f') + 2$ jets $(+X)$
140	α_{em}^4	zz0j	$pp(\bar{p}) \to Z/\gamma^*(2f)Z/\gamma^*(2f') + 0$ jet $(+X)$
141	$\alpha_{em}^4\alpha_s$	zz1j	$pp(\bar{p}) \to Z/\gamma^*(2f)Z/\gamma^*(2f') + 1$ jet $(+X)$
142	$\alpha_{em}^4\alpha_s^2$	zz2j	$pp(\bar{p}) \to Z/\gamma^*(2f)Z/\gamma^*(2f') + 2$ jets $(+X)$
160	$Y_b^2\alpha_s^2$	b4hbb	$pp(\bar{p}) \to h_0(b\bar{b}) + b\bar{b}\ (+X)$
161	$\alpha_{em}^2\alpha_s^2$	b4zbb	$pp(\bar{p}) \to Z/\gamma^*(b\bar{b}) + b\bar{b}\ (+X)$
162	α_s^4	b4qcd	$pp(\bar{p}) \to b\bar{b}b\bar{b}\ (+X)$
163	$Y_b^2\alpha_{em}^2$	b4hz	$pp(\bar{p}) \to h_0(b\bar{b}) + Z/\gamma^*(b\bar{b})\ (+X)$
164	α_{em}^4	b4zz	$pp(\bar{p}) \to Z/\gamma^*(b\bar{b}) + Z/\gamma^*(b\bar{b})\ (+X)$
170	$\alpha_{em}^4\alpha_s^2$	tt6bdy	$pp(\bar{p}) \to t\bar{t} \to 6f\ (+X)$
171	$\alpha_{em}^4\alpha_s^3$	ttj7bdy	$pp(\bar{p}) \to t\bar{t} + 1$ jet $\to 6f + 1$ jet $(+X)$
182	α_s^2	qcd2j	$pp(\bar{p}) \to 2$ jets $(+X)$
183	α_s^3	qcd3j	$pp(\bar{p}) \to 3$ jets $(+X)$
184	α_s^4	qcd4j	$pp(\bar{p}) \to 4$ jets $(+X)$

Computer Physics Communications 183 (2012) 1014–1028

List of Results
SM/Tree/PP

GR@PPA2.8

Comparison
with CDF/D0 data



Computer Physics Communications 183 (2012) 1014–1028

Figure 2: p_T spectrum of Z bosons at Tevatron Run 1, $p\bar{p}$ collisions at a cm energy of 1.8 TeV. The GR@PPA simulation (histograms) is compared with the measurements by CDF [34] (circles) and D0 [35] (triangles). Together with a result covering the p_T range up to 200 GeV/c (a), a result to cover the range up to 20 GeV/c (b) is presented to show the low-p_T behavior. In addition to the summed spectrum (solid), the spectra of events from the Z + 0-jet (dashed) and Z + 1-jet (dotted) processes are separately shown for the GR@PPA simulation in (a).

List of Results

MSSM/Tree/e^+e^-

$$\left.\begin{aligned} e^+e^- &\to \gamma\tilde{\chi}_1^0\tilde{\chi}_1^0 \\ &\to Z\tilde{\chi}_1^0\tilde{\chi}_1^0 \\ &\to h\tilde{\chi}_1^0\tilde{\chi}_1^0 \end{aligned}\right\}$$

K. Fujiwara (Seikei Univ.)

List of Results

MSSM/Tree/e^+e^-

Scenario1（α） $e^+e^- \to \gamma \tilde{\chi}_1^0 \tilde{\chi}_1^0$

SUSY : $e^+e^- \to \gamma \widetilde{X_1^0} \widetilde{X_1^0}$
SM : $e^+e^- \to \gamma \nu \bar{\nu}$
Luminosity : $500 fb^{-1}$
δ_{sys} : 0.5%

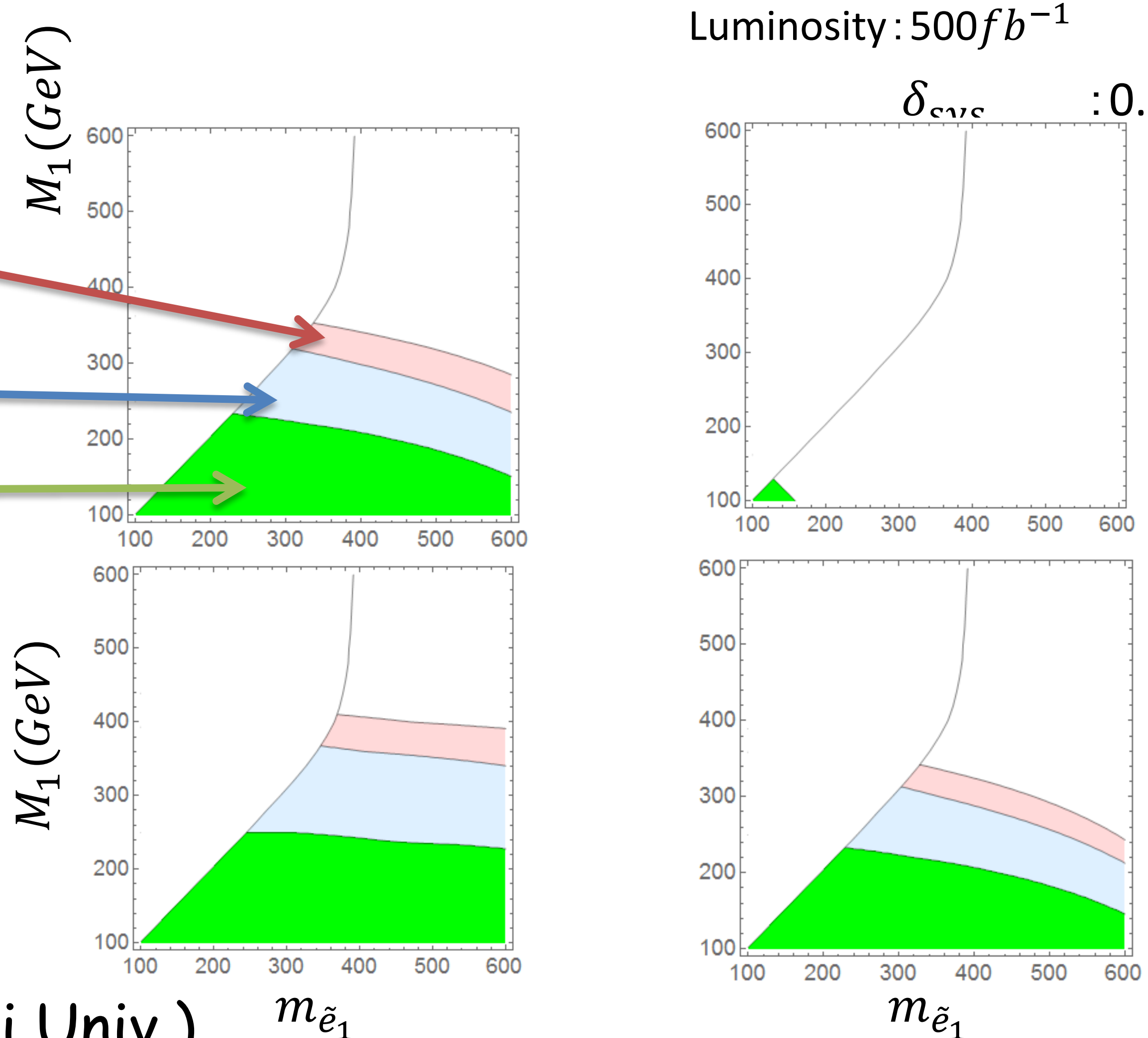
Non-Polarization

$\sqrt{s} = 1000\text{GeV}$

$\sqrt{s} = 750\text{GeV}$

$\sqrt{s} = 500\text{GeV}$

Polarization
(e+,e-)=(-30%, 80%)



K. Fujiwara (Seikei Univ.)

List of Results

BSM/Tree/e^+e^-

PHYSICAL REVIEW D **89**, 035001 (2014)

Higgs boson signal at complete tree level in the SM extension by dimension-six operators

E. Boos,[1] V. Bunichev,[1] M. Dubinin,[1] and Y. Kurihara[2]

[1]*Skobeltsyn Institute of Nuclear Physics, Moscow State University, 119991 Moscow, Russia*

[2]*High Energy Accelerators Research Organization (KEK), Tsukuba, Ibaraki-ken 305-0801, Japan*

(Received 31 October 2013; published 4 February 2014)

Expectations for probing the Higgs–fermion and the Higgs–vector boson couplings at the ILC

E. Boos [a], V. Bunichev [a,*], M. Dubinin [a,b], Y. Kurihara [b]

[a] *Skobeltsyn Institute of Nuclear Physics, Moscow State University, 119991, Moscow, Russia*

[b] *High Energy Accelerators Research Organization (KEK), Tsukuba, 305-0801 Ibaraki, Japan*

Physics Letters B 739 (2014) 410–415

List of Results

BSM/Loop/e^+e^-

TABLE I. Effective triple vertices in the Buchmueller-Wyler operator basis. The anomalous couplings C (Wilson coefficients) are multiplicative factors in front of O.

Effective operators	Triple vertices	Feynman rules
$O_{t\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(-\lambda_t)(\bar{Q}_L\Phi^c t_R)$	$\bar{t}$ t H	$-M_t \cdot \frac{v}{\Lambda^2} \cdot C_{t\Phi}$
$O_{b\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(-\lambda_b)(\bar{Q}_L\Phi b_R)$	$\bar{b}$ b H	$-M_b \cdot \frac{v}{\Lambda^2} \cdot C_{b\Phi}$
$O_{\tau\Phi} = (\Phi^\dagger\Phi - \frac{v^2}{2})(-\lambda_\tau)(\bar{L}_L\Phi\tau_R)$	$\bar{\tau}$ τ H	$-M_\tau \cdot \frac{v}{\Lambda^2} \cdot C_{\tau\Phi}$
$O_{\Phi G} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})G^a_{\mu\nu}G^{a\mu\nu}$	G_μ G_ν H	$-2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi G} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
$O_{\Phi B} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})B_{\mu\nu}B^{\mu\nu}$	A_μ A_ν H	$-2 \cdot c_w^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi B} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
	A_μ Z_ν H	$+2 \cdot c_w \cdot s_w \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi B} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
	Z_μ Z_ν H	$-2 \cdot s_w^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi B} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
$O_{\Phi W} = \frac{1}{2}(\Phi^\dagger\Phi - \frac{v^2}{2})W^i_{\mu\nu}W^{i\mu\nu}$	A_μ A_ν H	$-2 \cdot s_w^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
	A_μ Z_ν H	$-2 \cdot c_w \cdot s_w \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
	Z_μ Z_ν H	$-2 \cdot c_w^2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
	W^+_μ W^-_ν H	$-2 \cdot \frac{v}{\Lambda^2} \cdot C_{\Phi W} \cdot (g^{\mu\nu} p_1 p_2 - p_1^\nu p_2^\mu)$
$O^{(1)}_\Phi = (\Phi^\dagger\Phi - \frac{v^2}{2})D_\mu\Phi^\dagger D^\mu\Phi$	W^+_μ W^-_ν H	$M_W^2 \cdot \frac{v}{\Lambda^2} \cdot C^{(1)}_\Phi \cdot g^{\mu\nu}$
	Z_μ Z_ν H	$M_Z^2 \cdot \frac{v}{\Lambda^2} \cdot C^{(1)}_\Phi \cdot g^{\mu\nu}$

List of Results

BSM/Tree/e^+e^-

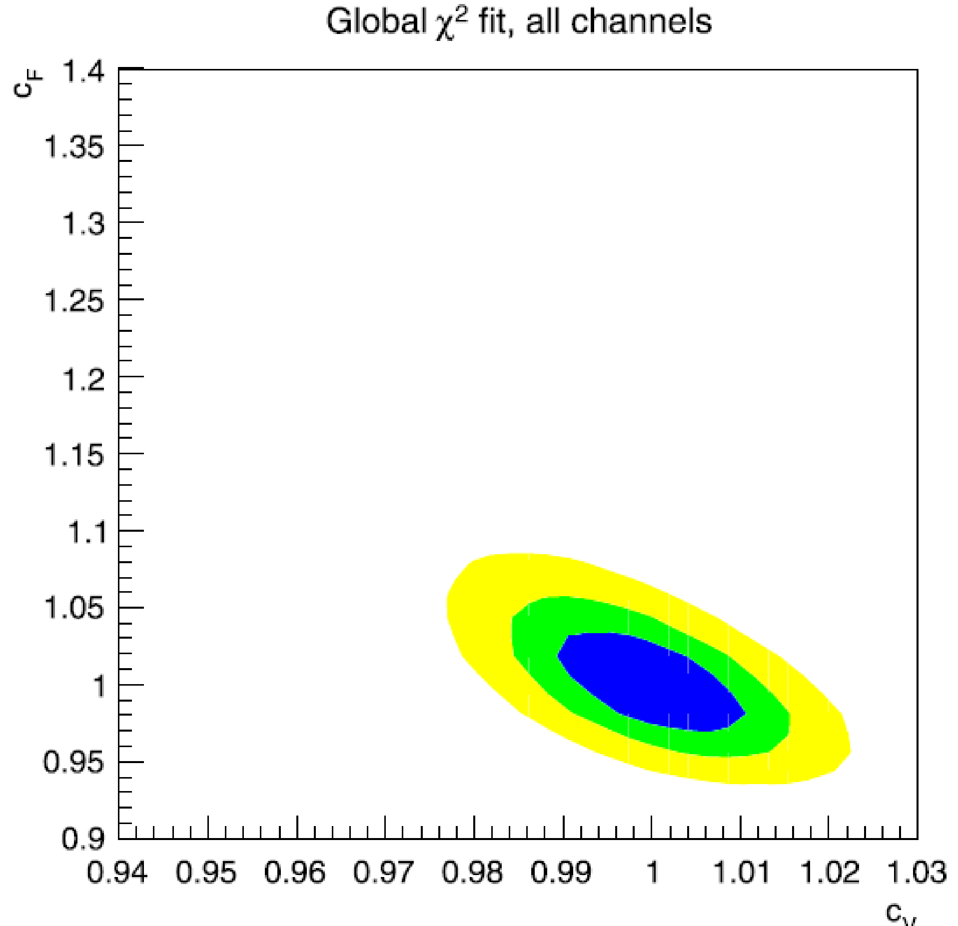
Expected accuracies $\Delta(\sigma \cdot Br)/(\sigma \cdot Br)$ for the Higgs boson production channels at the ILC

Channel	$\sqrt{s}$ and $\mathcal{L}$ (P_{e^-}, P_{e^+})	
	250 fb^{-1} at 250 GeV $(-0.8, +0.3)$	
	ZH	$\nu\bar{\nu}H$
$H \to b\bar{b}$	1.1%	10.5%
$H \to c\bar{c}$	7.4%	–
$H \to gg$	9.1%	–
$H \to WW^*$	6.4%	–
$H \to \tau^+\tau^-$	4.2%	–
$H \to ZZ^*$	19.0%	–
$H \to \gamma\gamma$	29–38%	–
$H \to \mu^+\mu^-$	100%	–

$$c_F = 1 + C_{t\Phi} \cdot \frac{v^2}{\Lambda^2}$$

$$c_V = 1 + \frac{v^2}{2\Lambda^2} \cdot C_{\Phi}^{(1)}$$

Physics Letters B 739 (2014) 410–415



(a)

Summary

Summary

- GRACE can cover physics of:
  - SM/MSSM/BSM
  - Tree/Loop
  - e^+e^-/PP

On going projects

- Top physics at ILC
- ELWK collections for LHC processes
- Development for SUSY/Loop