GRACE for $t\bar{t}$ Physics @ ILC

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& GRACE Group

Outline

- What is GRACE ?
- Full $o(\alpha)$ Correction for $e^+e^- \to t\bar{t}$
  - Correction on total cross sections
  - Correction on A_{FB}
  - Initial beam-polarization effect
- SUSY effect on loop
- Summary

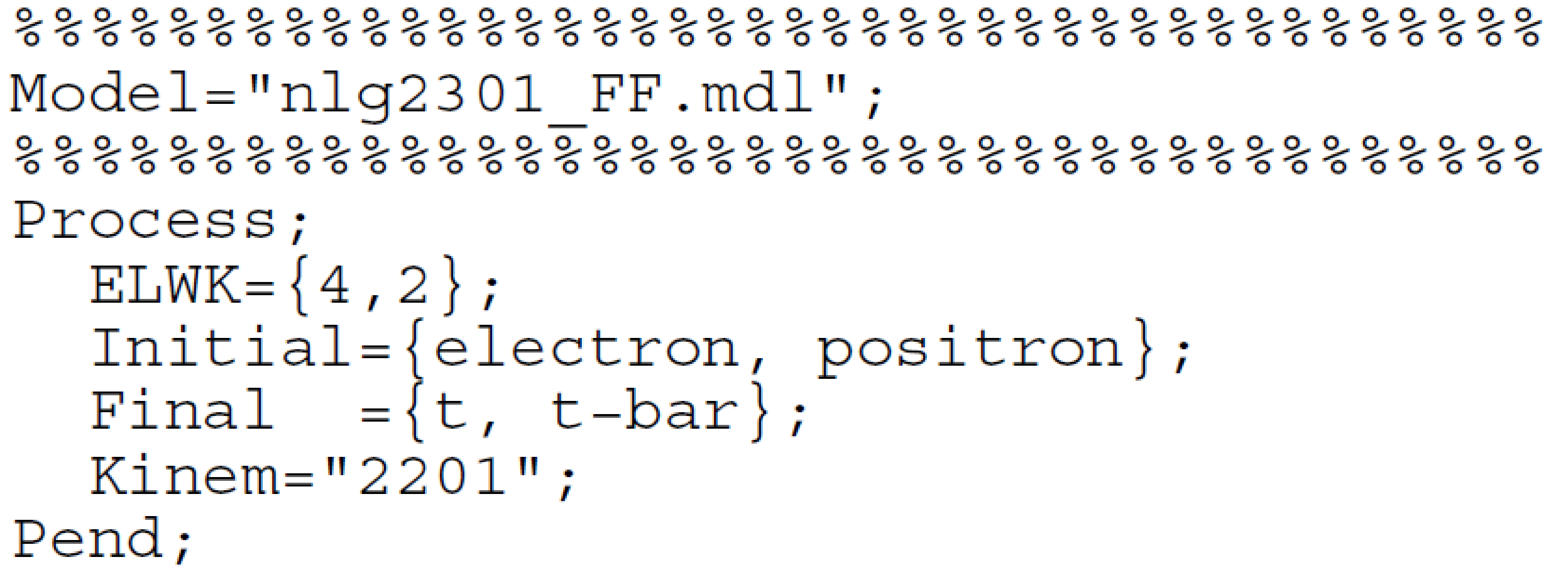
What is GRACE?

What is GRACE?

GRACE is a system to calculate tree and loop cross sections automatically based on SM and MSSM.

What is GRACE?

Model/Process



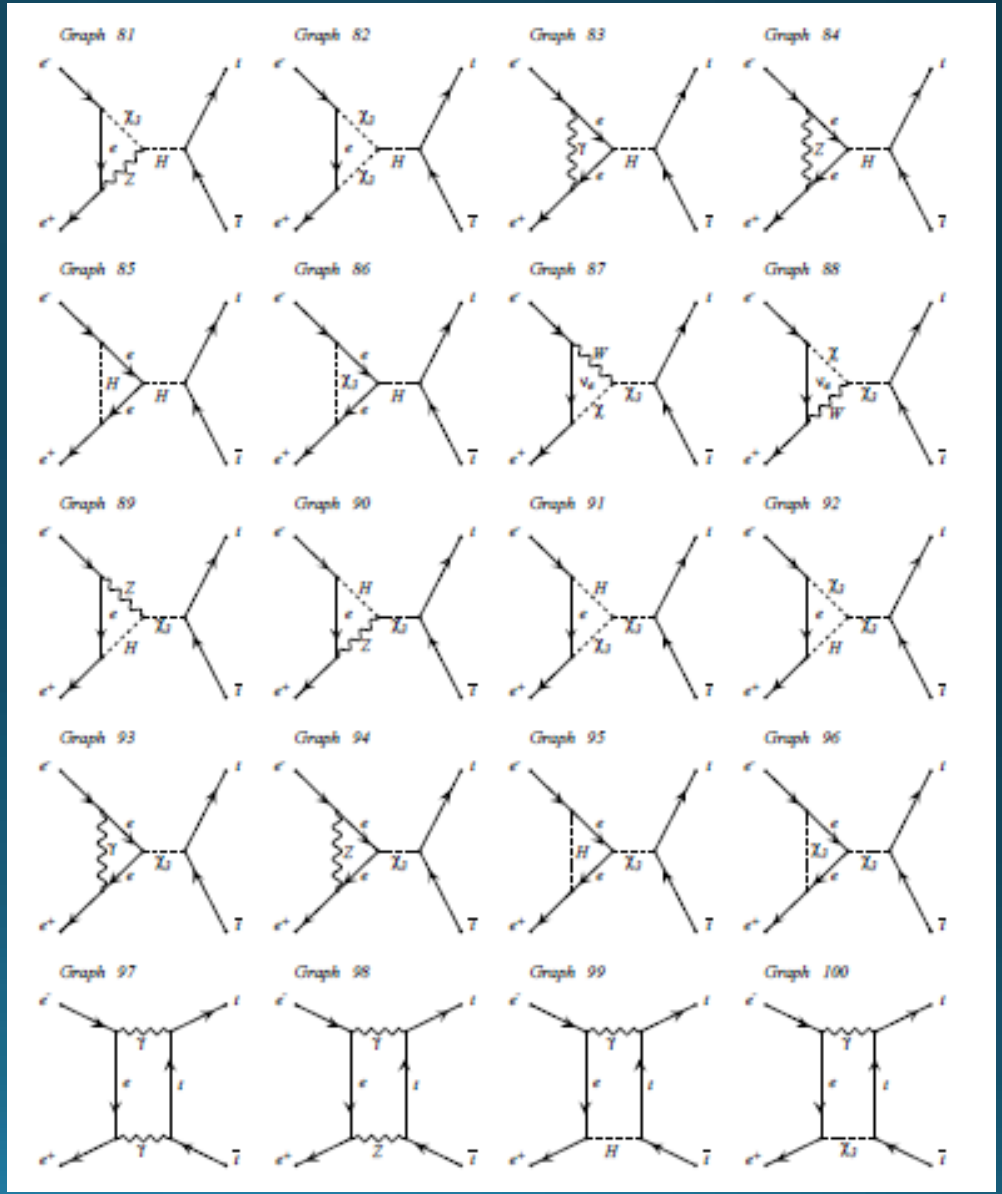
```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Model="nlg2301_FF.mdl";
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Process;
  ELWK={4,2};
  Initial={electron, positron};
  Final  ={t, t-bar};
  Kinem="2201";
Pend;
```

What is GRACE?

Model/Process

↓

Feynman Diagrams



What is GRACE?

Model/Process

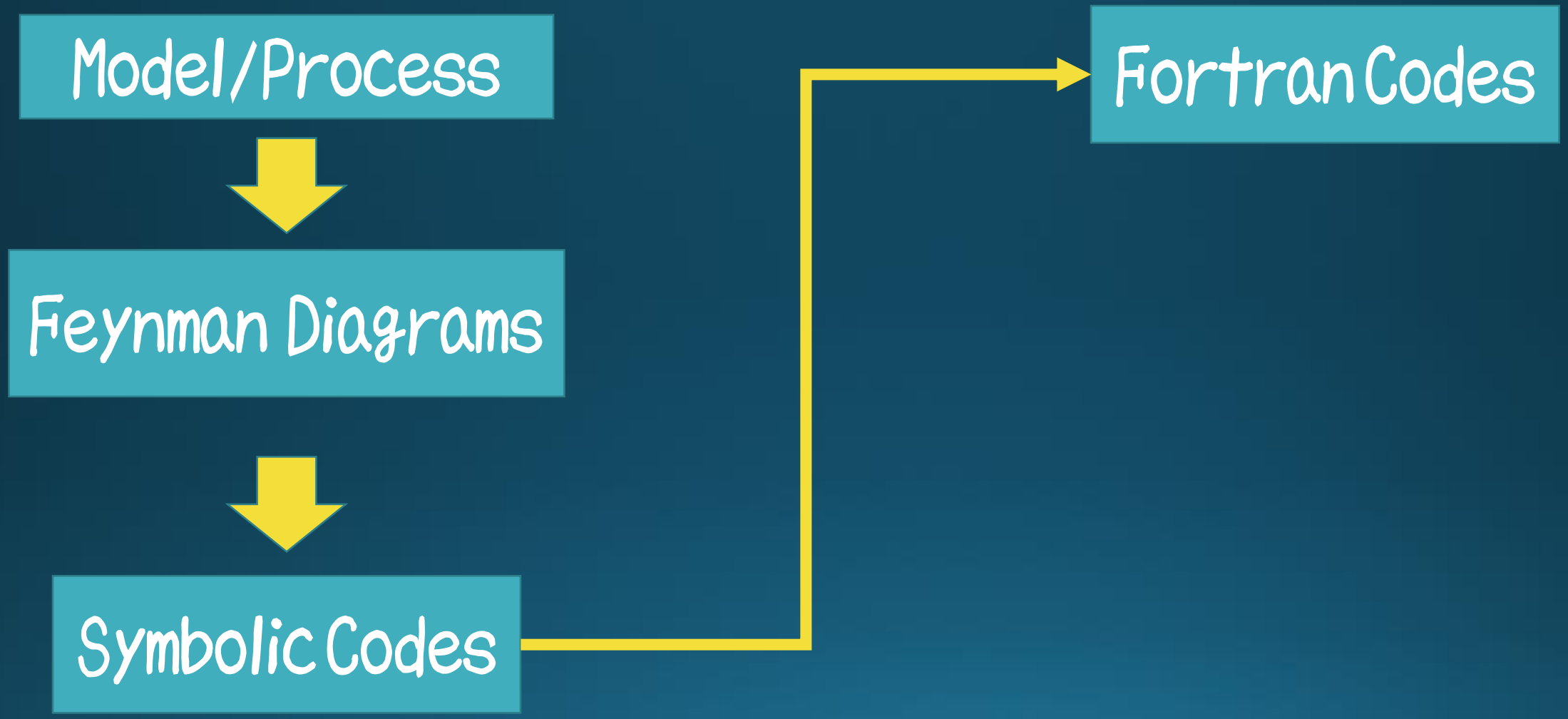
Feynman Diagrams

Symbolic Codes

```
#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';
```

FORM source

What is GRACE?

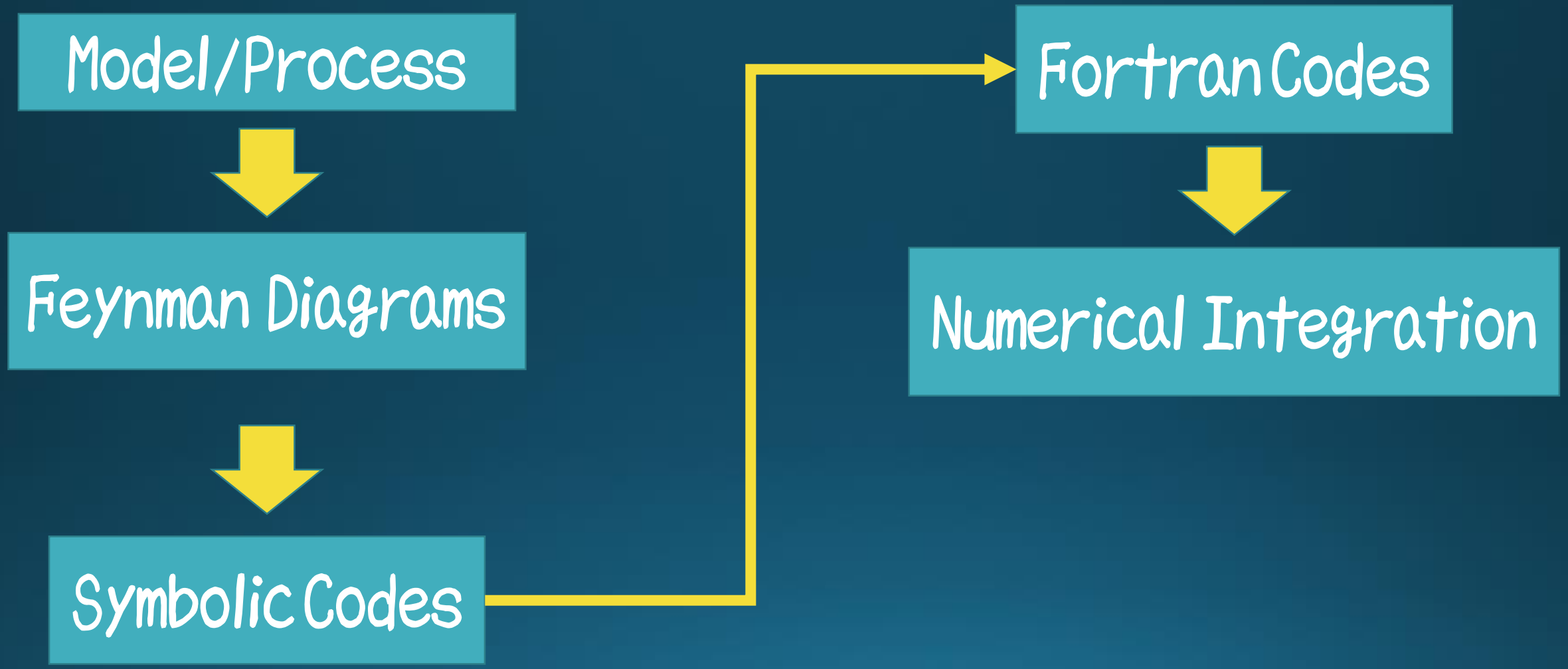


What is GRACE?

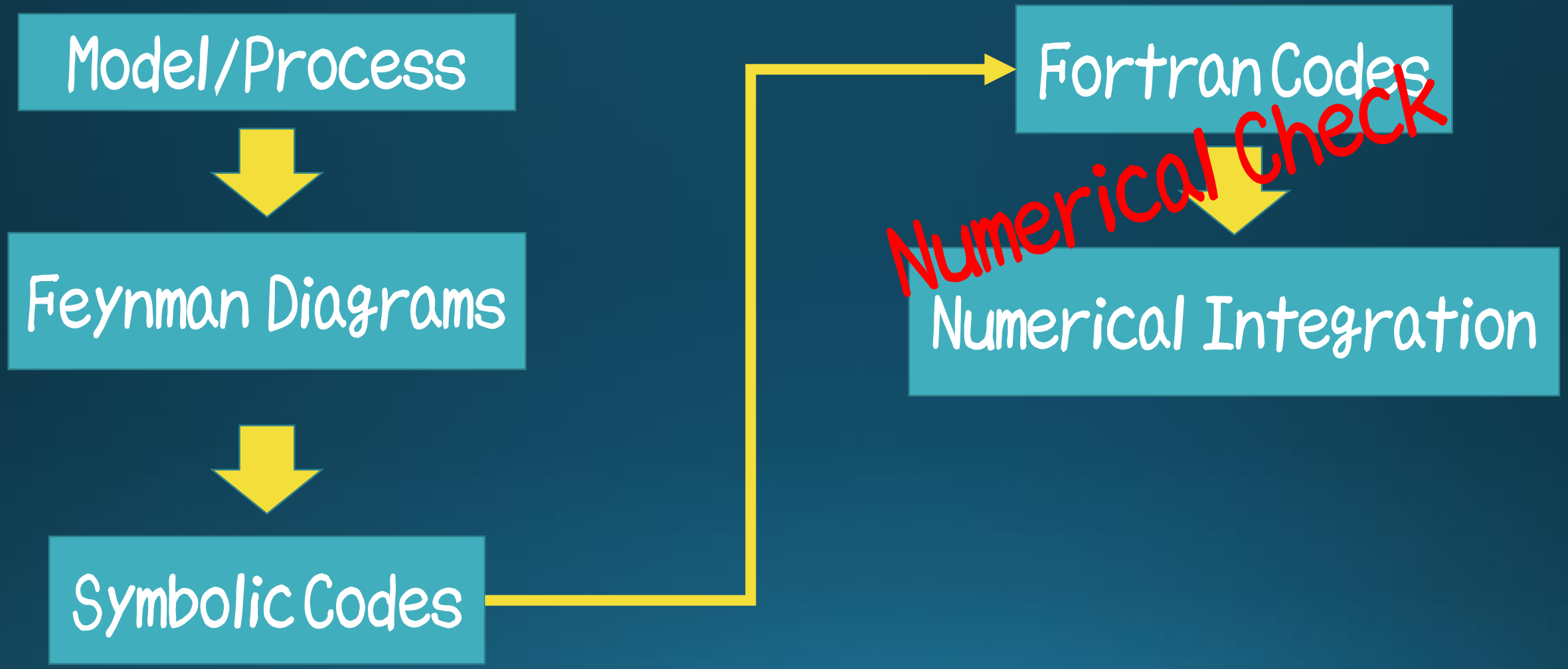
```
*
      ztd = cc1
      CALL snprpdn(pphase,ztd,vn7,ama**2,ama*aga)
      CALL snprpdc(pphase,ztd,vn7,ama**2,ama*aga)
      ztd = xcp1/ztd
*
      ztd = ztd*(cc6)
*
      xre=+xb(1)*xu(2)*xz(9)+xz(4)*xy(12)-xz(5)*xy(17)+xy(8)
      xre=xre*(+cc2*(1))
      g1e0(0,0)=g1e0(0,0)+ztd*xre
      xre=-xb(1)*xz(9)-xz(4)*xy(9)+xz(5)*xy(1)-xy(6)
      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
```

Fortran Codes

What is GRACE?



What is GRACE?



Numerical check non-pol case

			Sum
Nmerical Check (non pol) w=500GeV, kc=10^-3 GeV	Cuv	0	-2.5747003729988264298573132032040 18E-2
		100	-2.5747003729988264298573132032040 14E-2
		10000	-2.5747003729988264298573132032040 28E-2
	λ GeV	-21	-2.5747003729988264298833091451176 05E-2
		-25	-2.5747003729988264298573132032040 18E-2
		-29	-2.5747003729988264298573106036098 45E-2
	NLG	0,0,0,0,0	-2.5747003729988264298573132032040 18E-2
		10,20,30,40,50	-2.5747003729988264298573132032040 21E-2
		100,200,300,400,500	-2.5747003729988264298573132032040 16E-2

22 digits

32 digits

Numerical check non-pol case

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

What is GRACE?

```
                                                    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 :       0.00 Sec
```

Fortran Codes

Numerical Integration

```
                                                    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
-------------------------------------------------------------------------------------------
```

What is GRACE?

Fortran Codes

Numerical Integration

Histograms
Events

top-pair productions@ILC

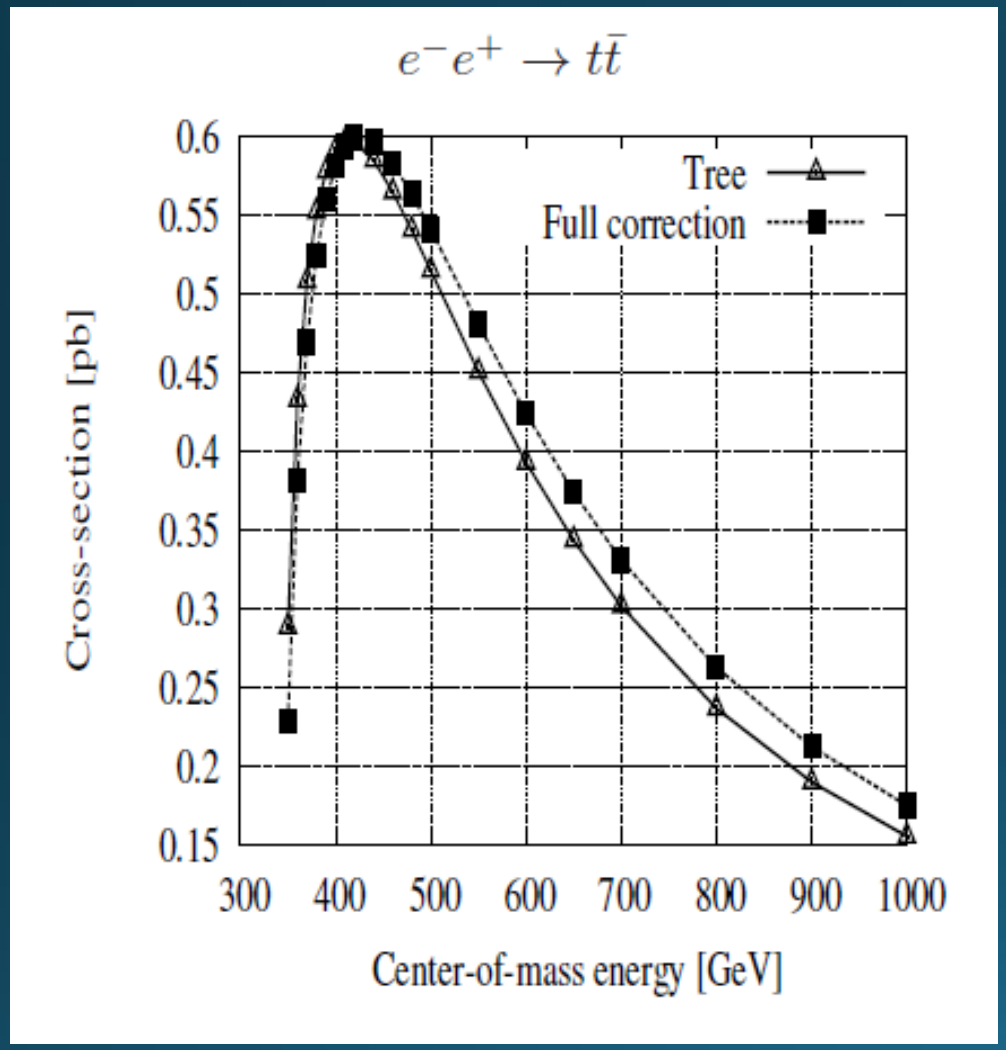
Refs

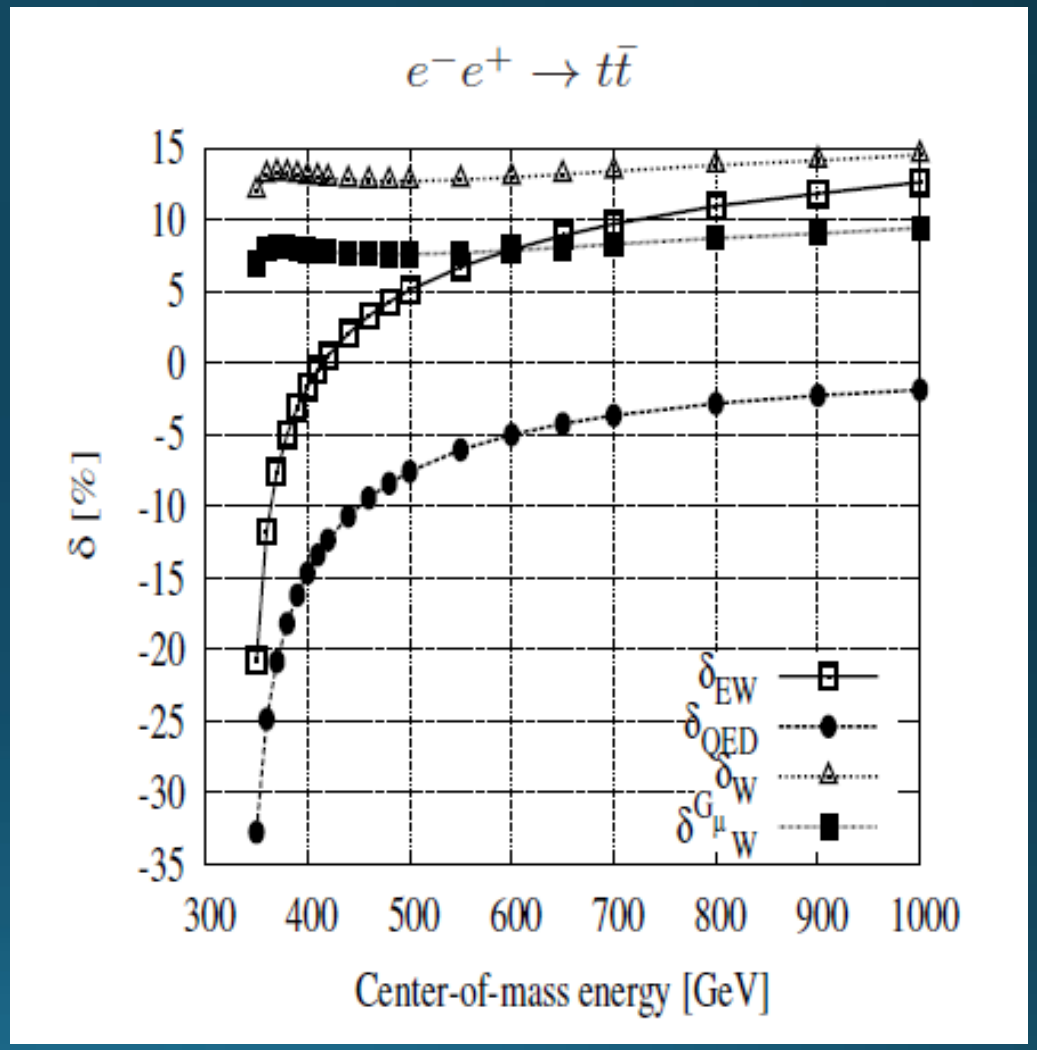
J. Fujimoto and Y. Shimizu, Mod. Phys. Lett. **3A**, 581 (1988).

J. Fleischer, T. Hahn, W. Hollik, T. Riemann, C. Schappacher and A. Werthenbach, hep-ph/0202109.

J. Fleischer, A. Leike, T. Riemann and A. Werthenbach, Eur. Phys. J. C **31**, 37 (2003) [hep-ph/0302259].

Full electroweak correction on top-pair productions@ILC

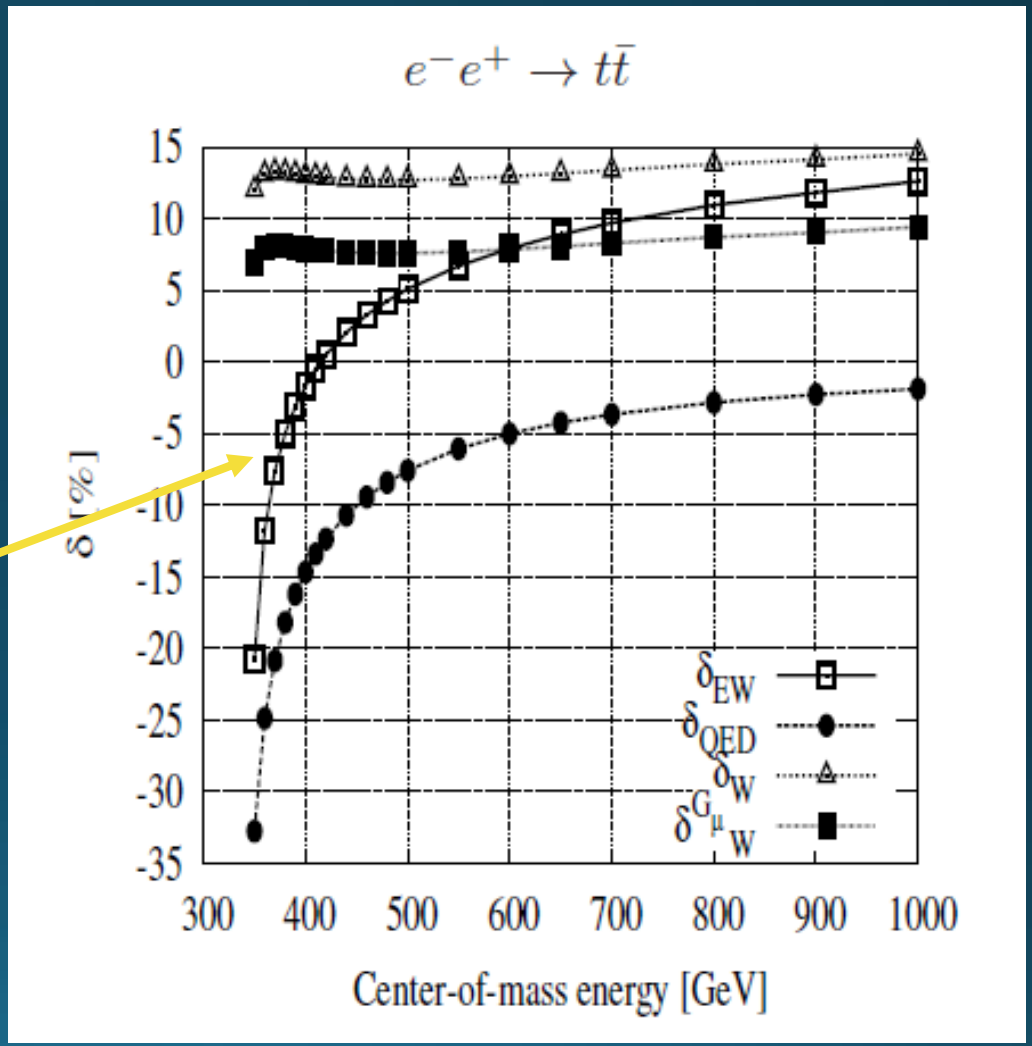




K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Full electroweak correction on top-pair productions@ILC

Full electroweak correction

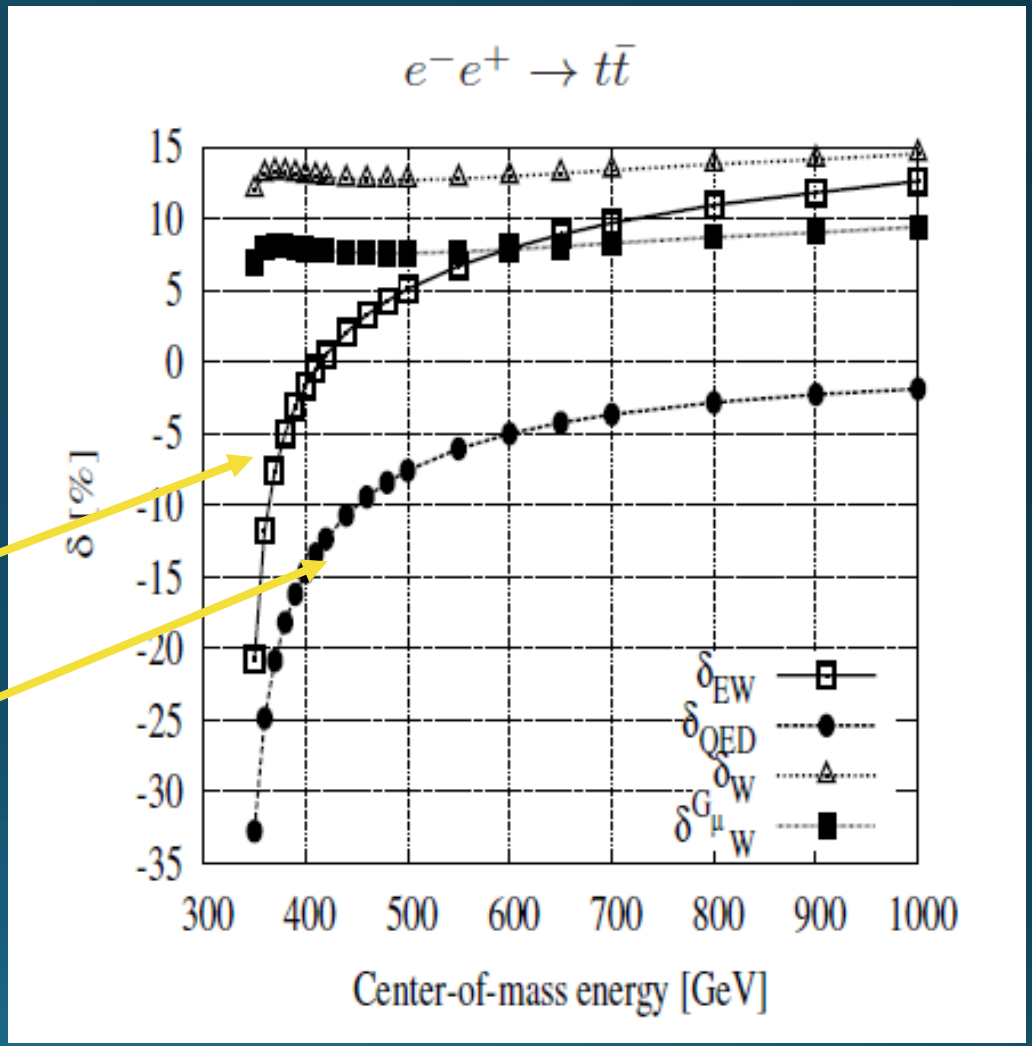


K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Full electroweak correction on top-pair productions@ILC

Full electroweak correction

QED corrections



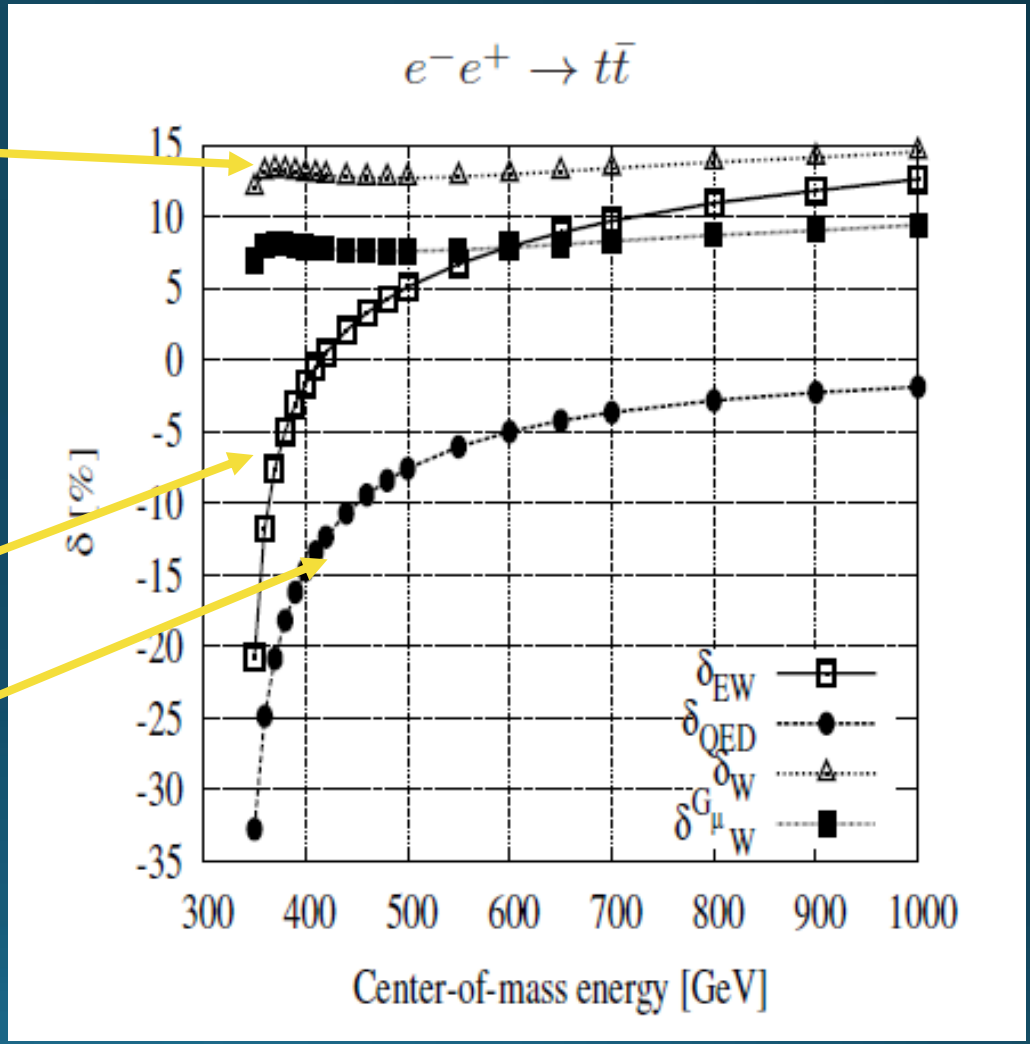
K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Full electroweak correction on top-pair productions@ILC

Full ELWK - QED

Full electroweak correction

QED corrections



K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

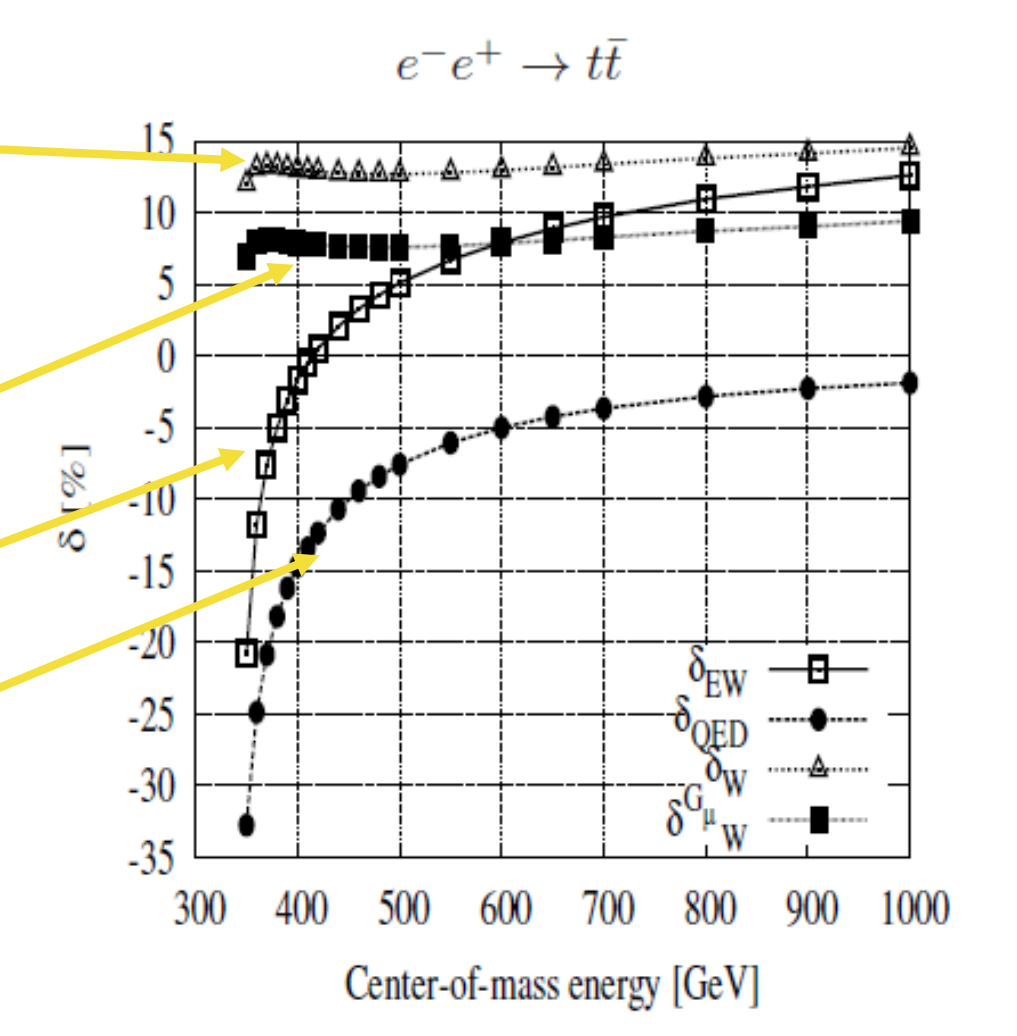
Full electroweak correction on top-pair productions@ILC

Full ELWK - QED

Full ELWK - QED
-running coupling

Full electroweak correction

QED corrections

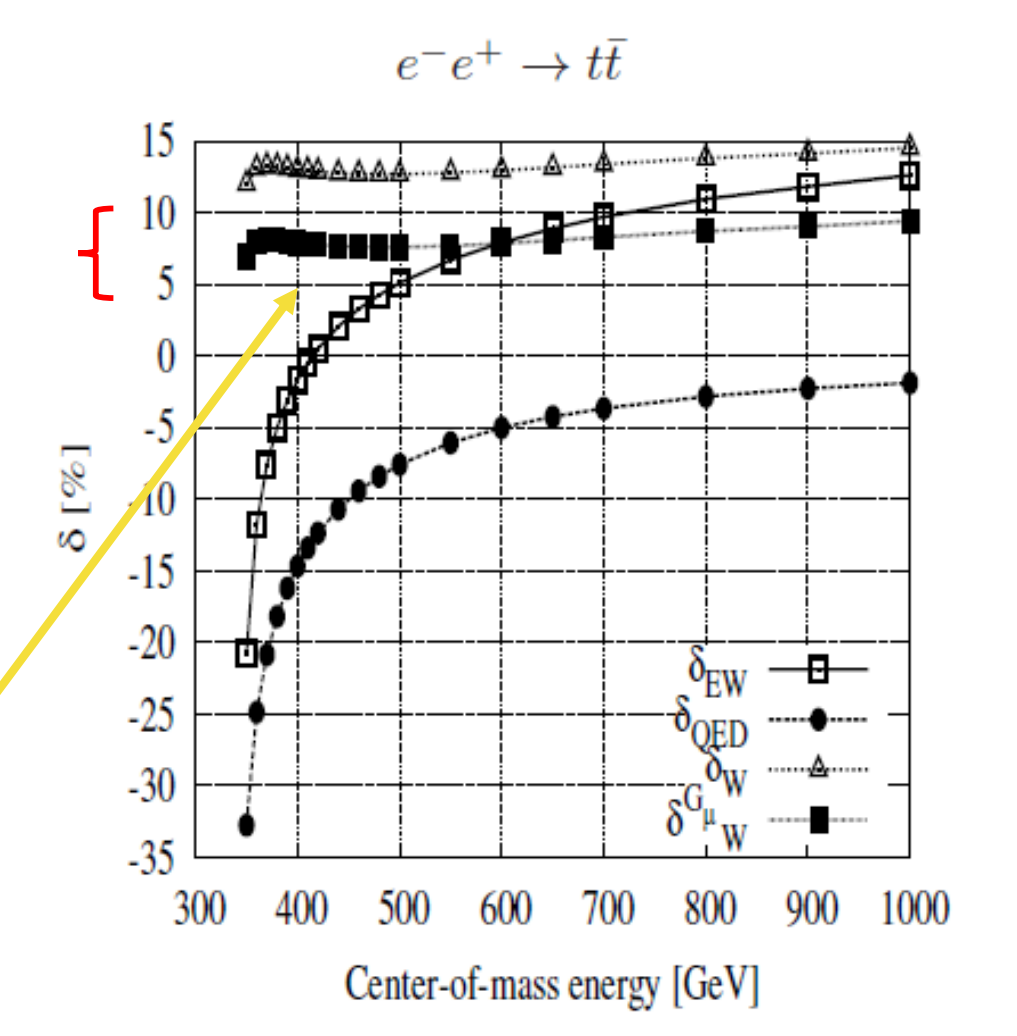


K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Full electroweak correction on top-pair productions@ILC

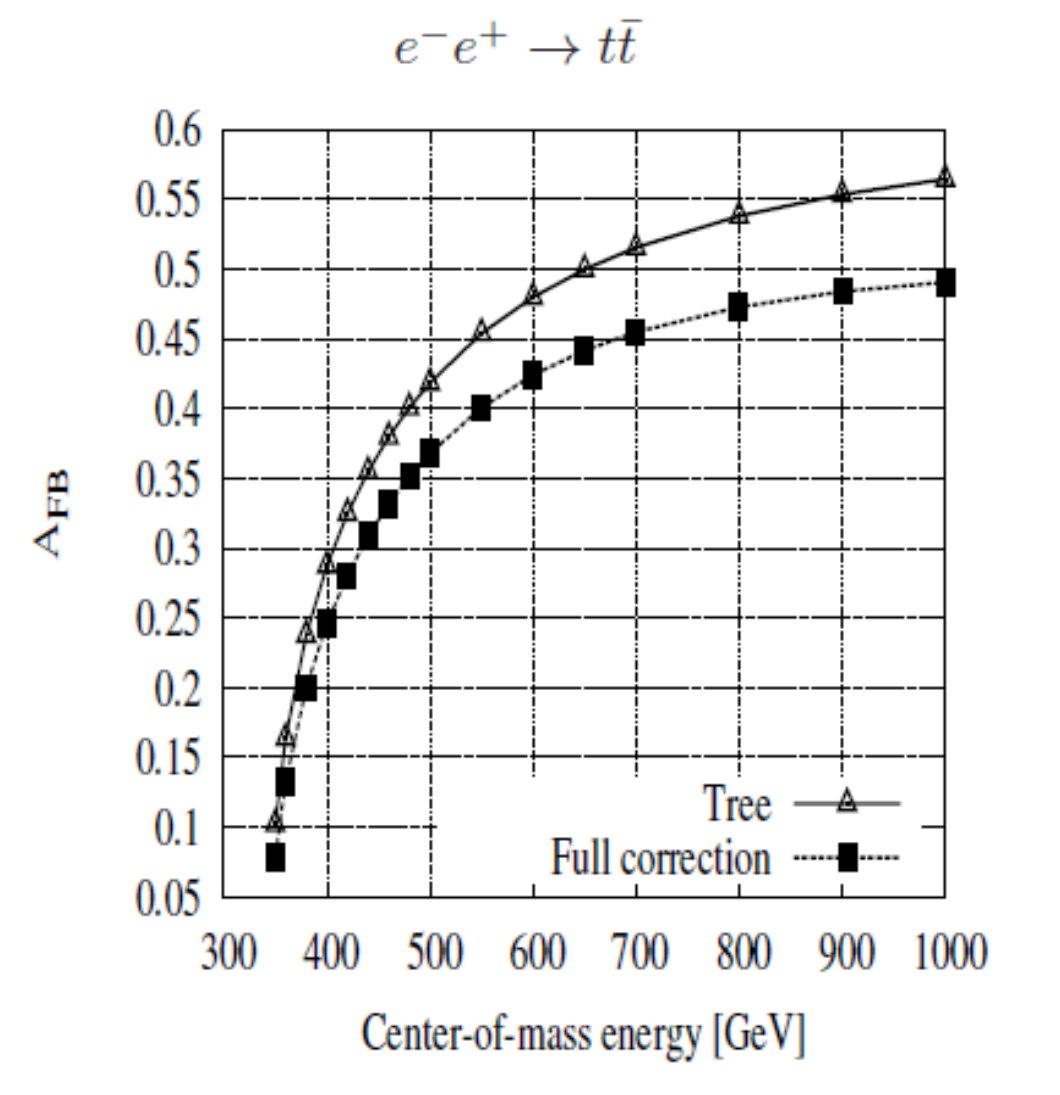
Pure weak correction : 7~10%

Full ELWK - QED
-running coupling



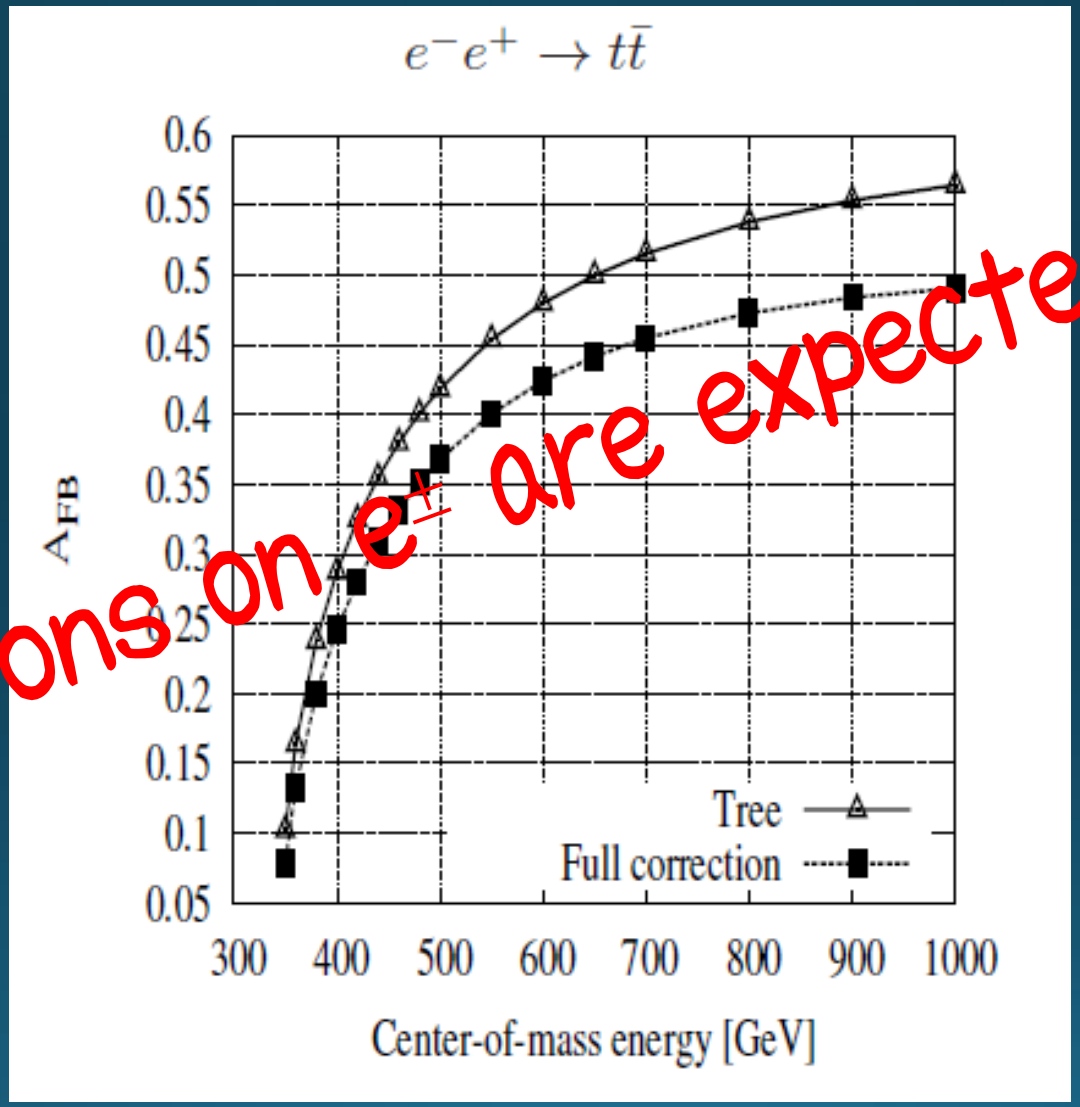
K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Full electroweak correction on top-pair productions@ILC



K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Full electroweak correction on top-pair productions@ILC



Spin polarizations on $e^{\pm}$ are expected on ILC.

e^- : ±80%
e^+ : ±30%

K.H. Pham, et al, European physical journal. C, Particles and fields 73 (4), 1-7

Polarized Cross sections

$e^+e^- \rightarrow t\,t$

		e-	
		R	L
e+	R	2.1873×10^{-10}	4.1824×10^{-1}
	L	1.9516×10^{-1}	2.1873×10^{-10}

Parameters

$\sqrt{s}$ = 1000 GeV

α = 1/137.0359895

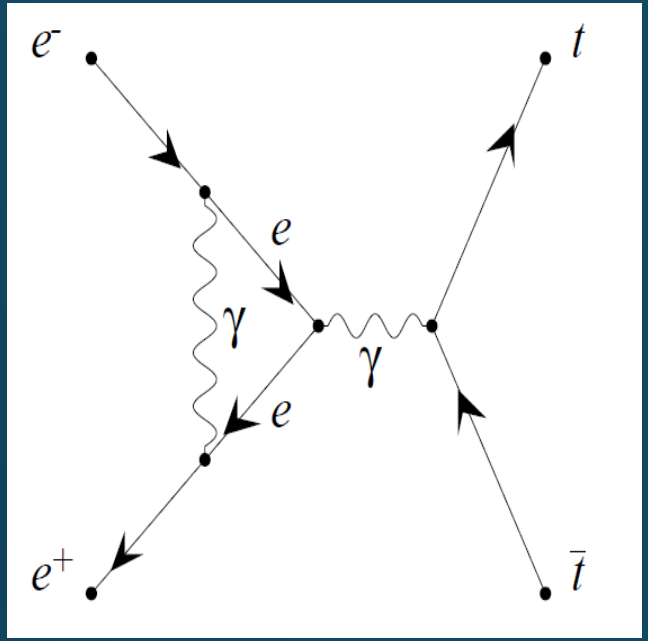
m_e = 0.51099906 MeV

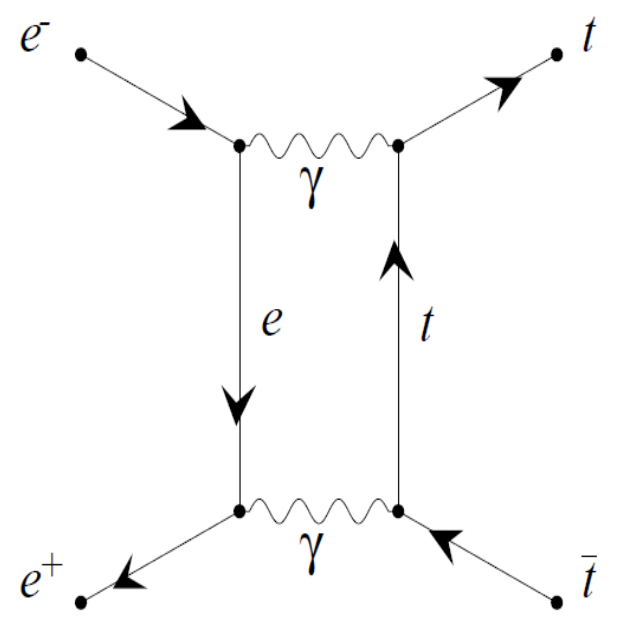
m_t = 174 GeV

m_z =91.187 GeV

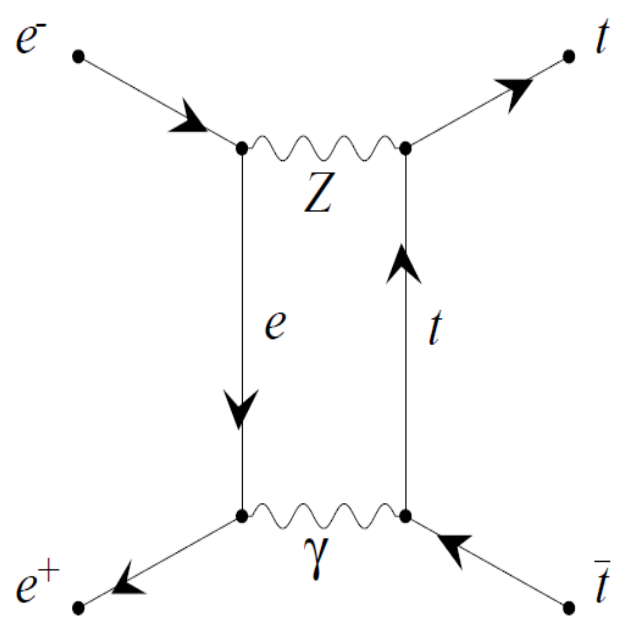
Examples of loop-diagrams

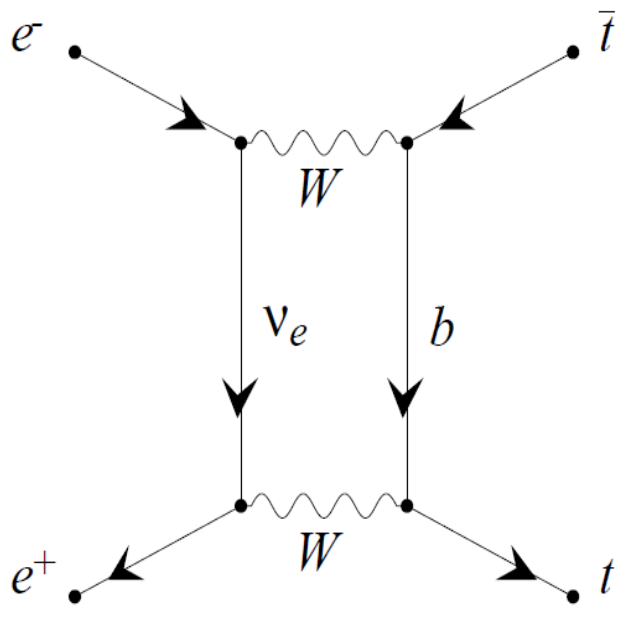
Pol. Independent

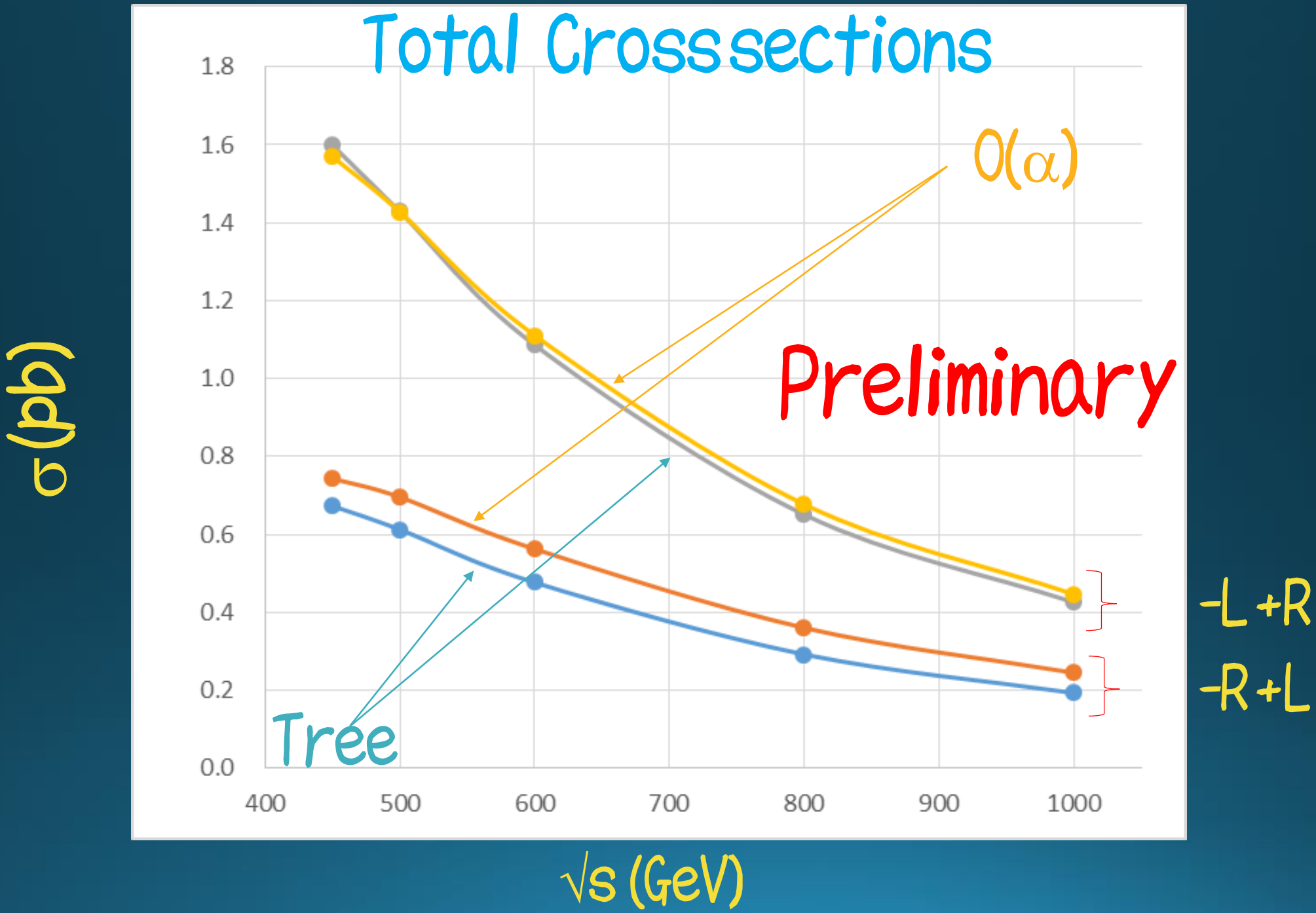


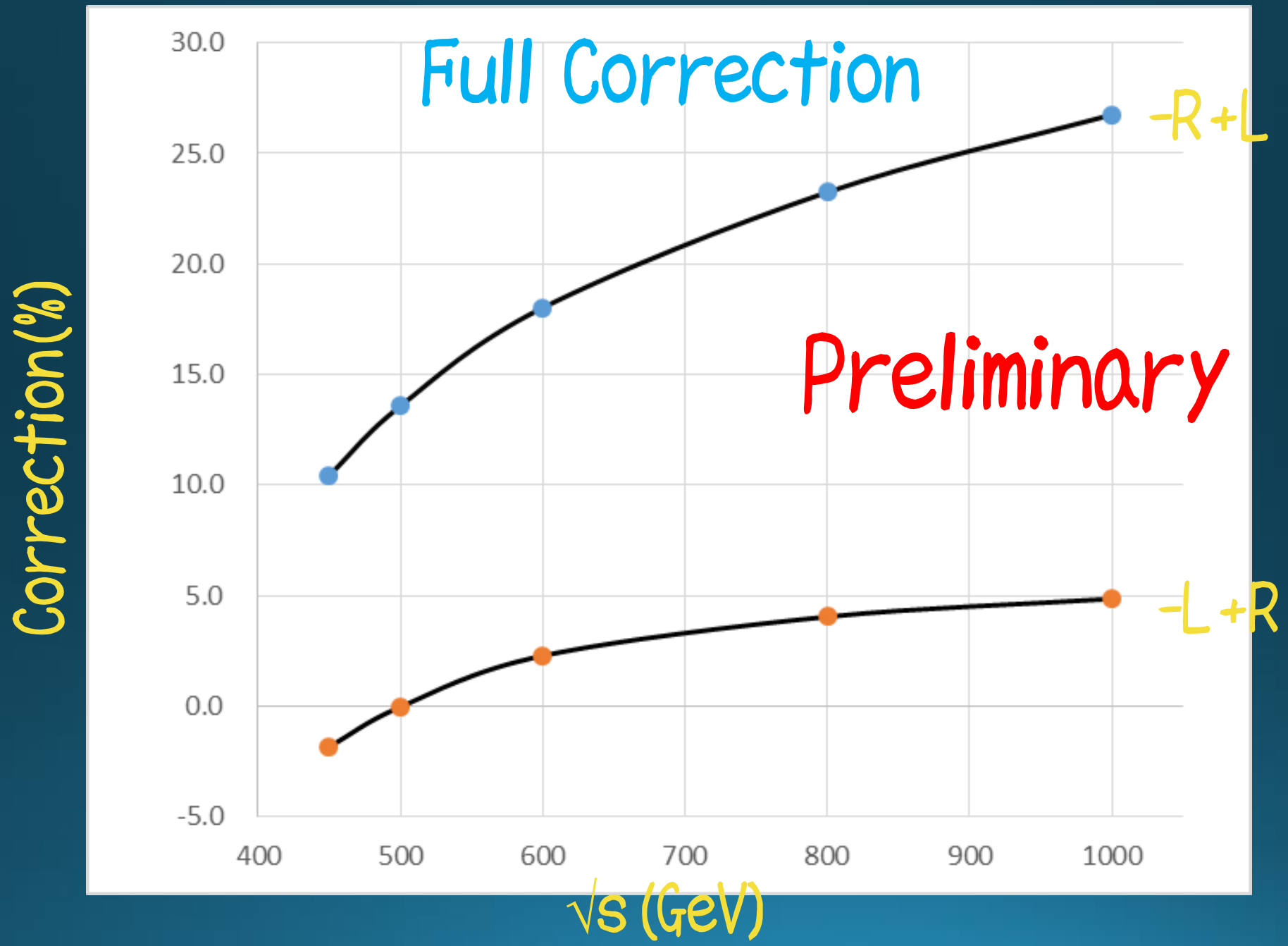


Pol. Dependent

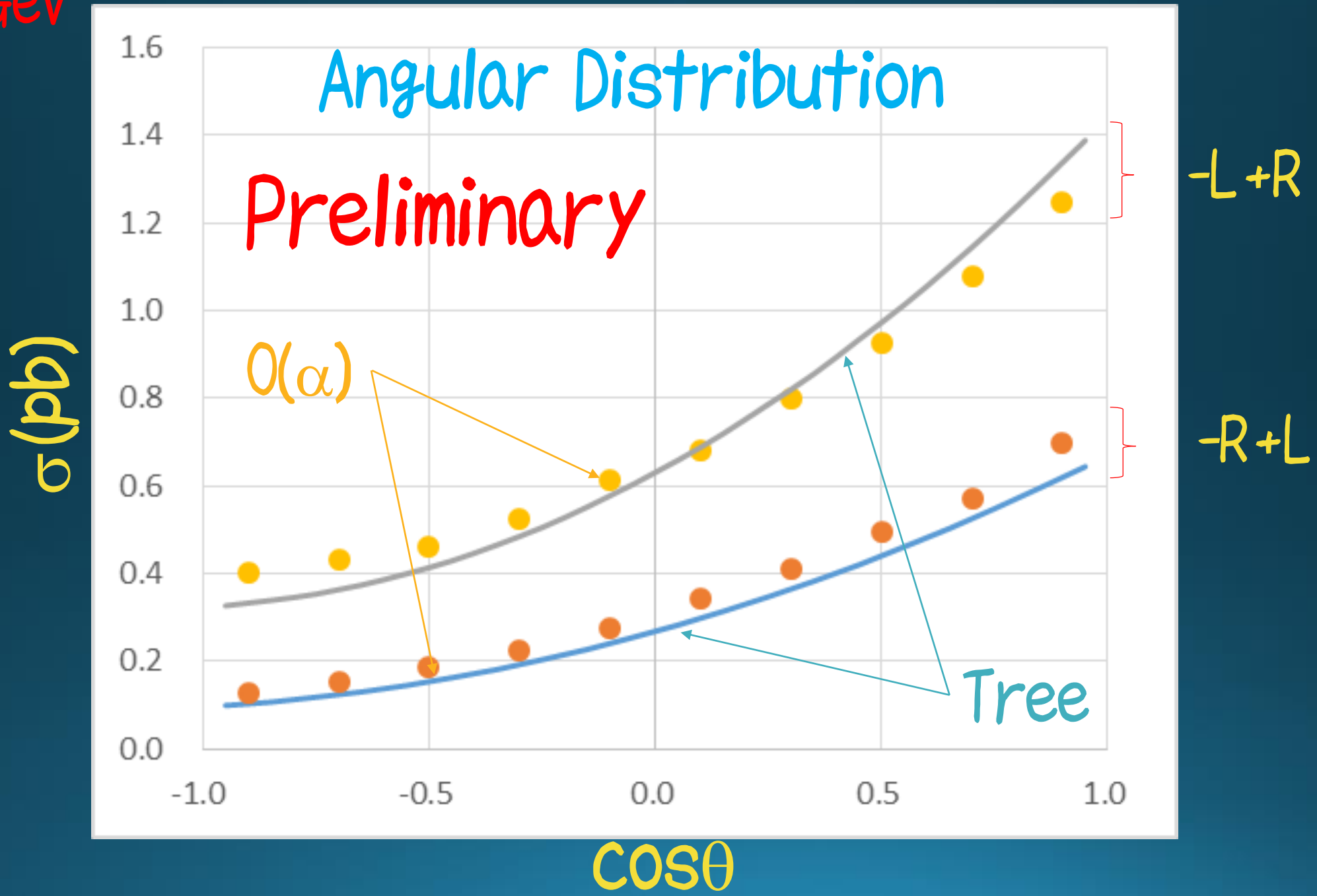





Total Crosssections
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
400
500
600
700
800
900
1000
O(α)
Preliminary
Tree
-L+R
-R+L
σ (pb)
√s (GeV)


Full Correction
Preliminary
-R+L
-L+R
Correction(%)
√s (GeV)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
400
500
600
700
800
900
1000

√s=500 GeV


Angular Distribution
Preliminary
O(α)
Tree
-L +R
-R +L
σ(pb)
cosθ
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-1.0
-0.5
0.0
0.5
1.0

SUSY Signal in Loop@ILC

Signatures at One-loop Order of Split Stops Scenarios using GRACE/SUSY

T.Kon, Y.Kouda, K.Kato, T.Ishikawa, Y.Kurihara, M.Jimbo and M.Kuroda

LCWS13
Nov 2013, Tokyo
(Revised at Feb 2014)

LCWS13
Nov 2013, Tokyo
(Revised at Feb 2014)

Simple split scenario

Scenario 0			
$\tan\beta$	30	m_h	126 GeV
μ	400 GeV		
M_2	380 GeV	$x_t/\sqrt{6}$	0.05
M_1	177 GeV		
$m_{\tilde{\chi}_1^0}$	174 GeV	$m_{\tilde{g}}$	1.5 TeV
$m_{\tilde{\chi}_1^+}$	336 GeV	$m_{\tilde{q}}$	1.6 TeV
$m_{\tilde{\ell}}$	365 GeV	$m_{\tilde{t}_1}$	1.5 TeV
$m_{\tilde{\tau}_1}$	334 GeV	$m_{\tilde{t}_2}$	1.5 TeV
$m_{\tilde{\tau}_2}$	394 GeV	$m_{\tilde{b}_1}$	1.5 TeV
m_A	1.5 TeV	$m_{\tilde{b}_2}$	1.5 TeV

Low Energy / LEP Constraints	
$\Delta\rho$	0.233×10^{-4}
$g_\mu-2$	0.251×10^{-8}
$Br(b\to s\gamma)$	0.349×10^{-3}
$Br(B_s\to\mu\mu)$	1×10^{-13}

Suspect 2.4

G.Kane et al.
hep-ph/0310042v1

Split stops scenarios

Scenario 1			
$\tan\beta$	30	m_h	126 GeV
μ	400 GeV		
M_2	380 GeV	$x_t/\sqrt{6}$	0.9
M_1	177 GeV		
$m_{\tilde{\chi}_1^0}$	174 GeV	$m_{\tilde{g}}$	1.5 TeV
$m_{\tilde{\chi}_1^+}$	337 GeV	$m_{\tilde{q}}$	1.7 TeV
$m_{\tilde{\ell}}$	365 GeV	$m_{\tilde{t}_1}$	0.33 TeV
$m_{\tilde{\tau}_1}$	336 GeV	$m_{\tilde{t}_2}$	2.1 TeV
$m_{\tilde{\tau}_2}$	393 GeV	$m_{\tilde{b}_1}$	0.8 TeV
m_A	1.5 TeV	$m_{\tilde{b}_2}$	2.1 TeV

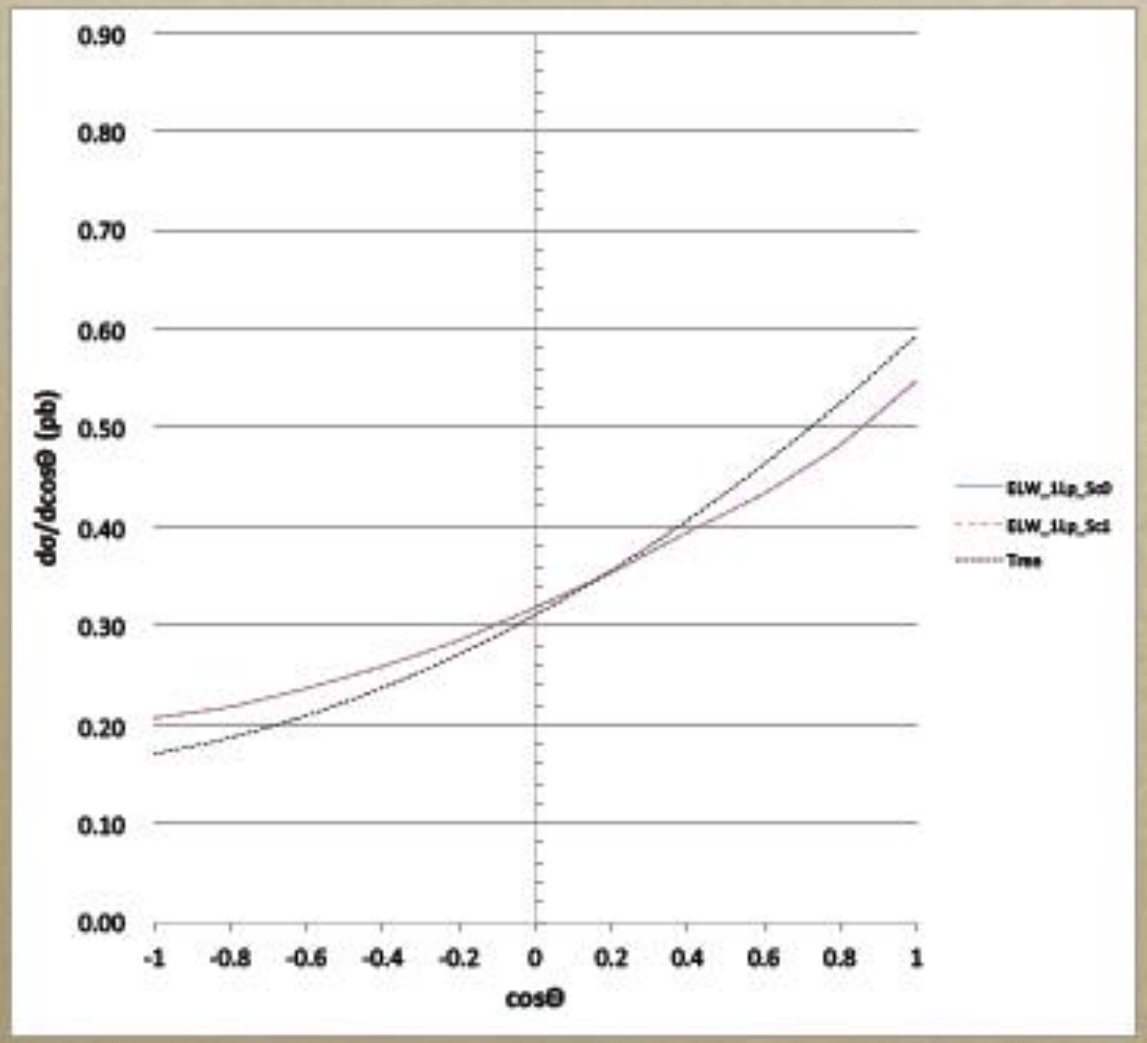
Low Energy / LEP Constraints	
$\Delta\rho$	0.898×10^{-4}
$g_\mu-2$	0.249×10^{-8}
$Br(b\to s\gamma)$	0.243×10^{-3}
$Br(B_s\to\mu\mu)$	4×10^{-11}

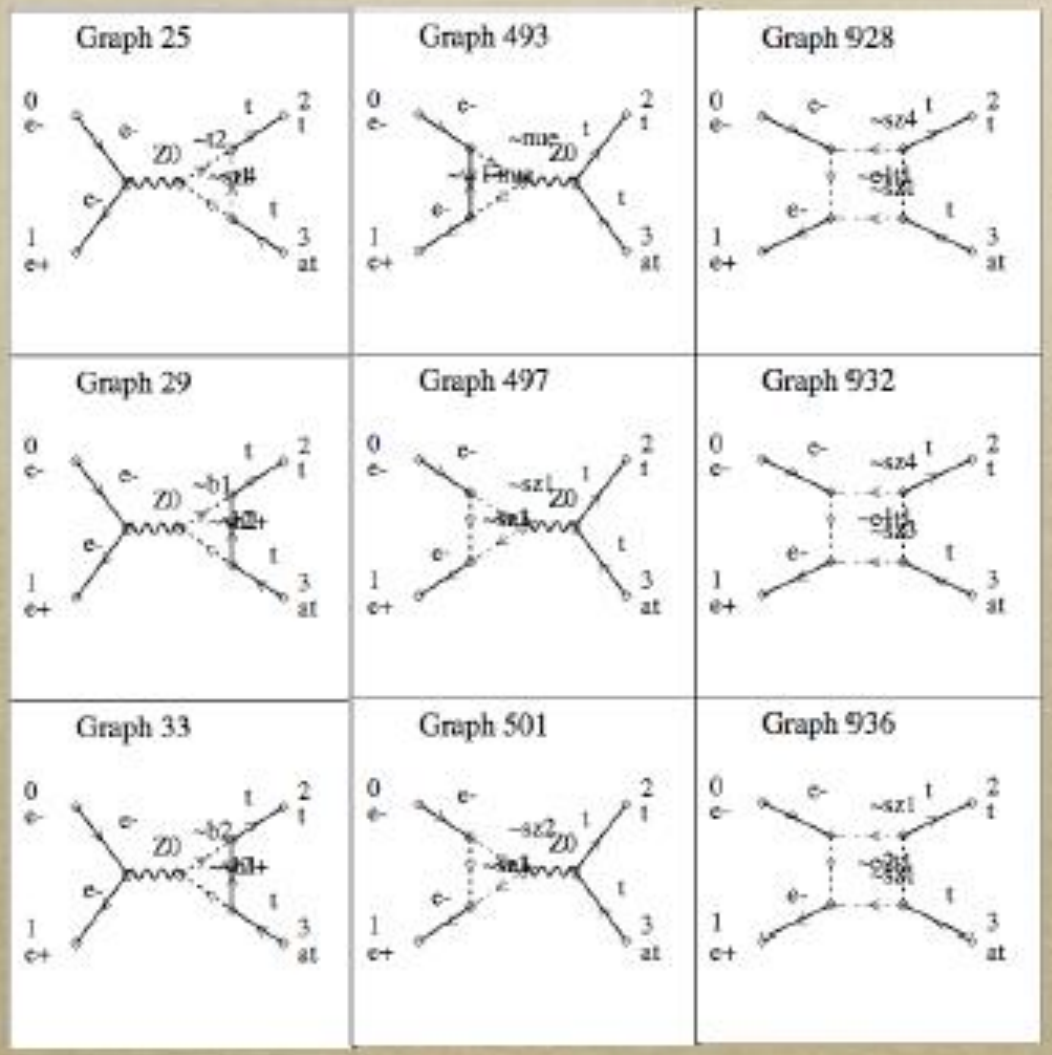
$$\tilde{t}_1\to bW^+\tilde{\chi}_1^0$$

$\sqrt{s} = 420\,GeV$

LCWS13
Nov 2013, Tokyo
(Revised at Feb 2014)

ELW correction $e^+e^- \to t\bar{t}$ *1114 diagrams*





$\sqrt{s} = 420\,GeV$

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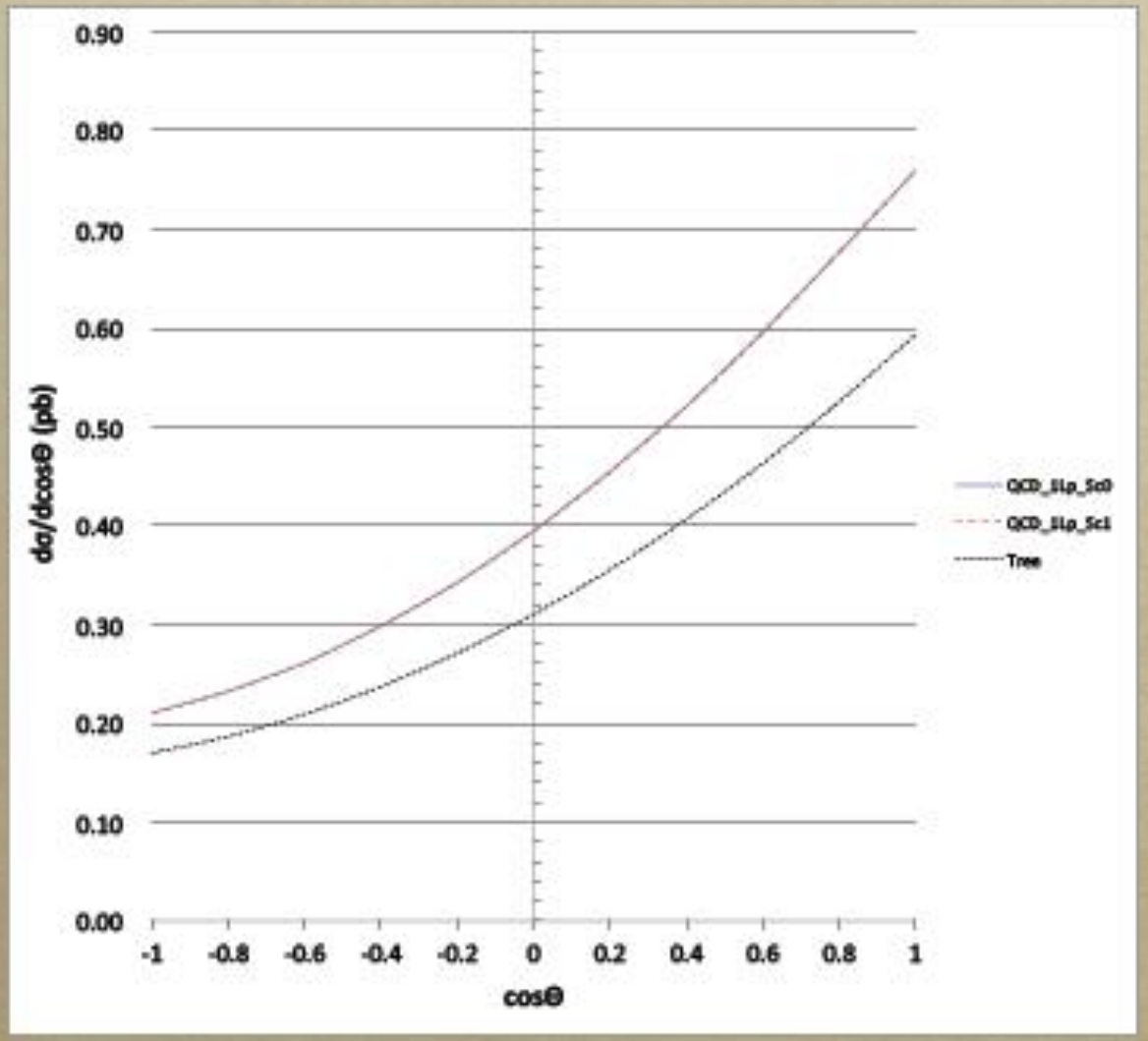
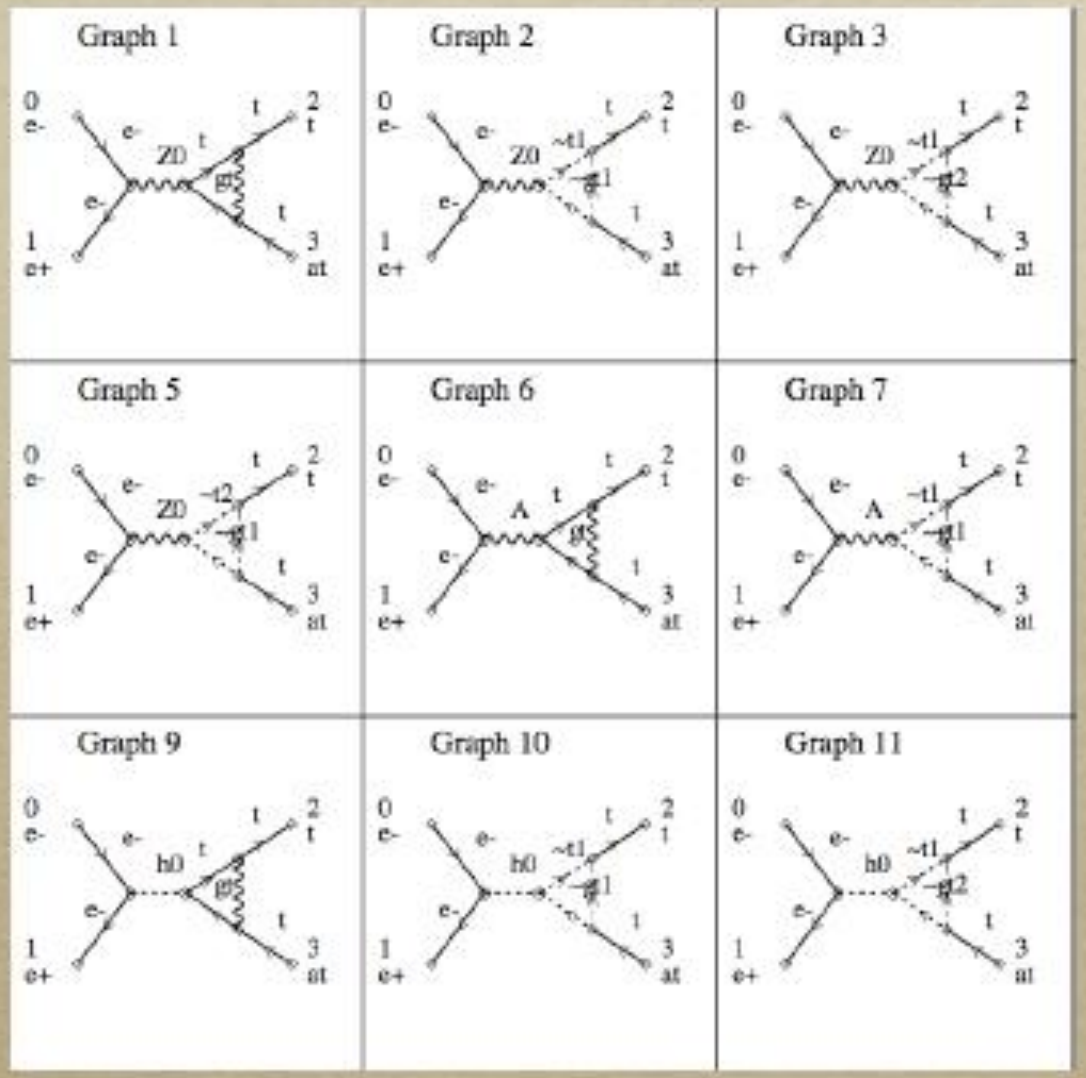
QCD correction $e^+e^- \to t\bar{t}$

30 diagrams





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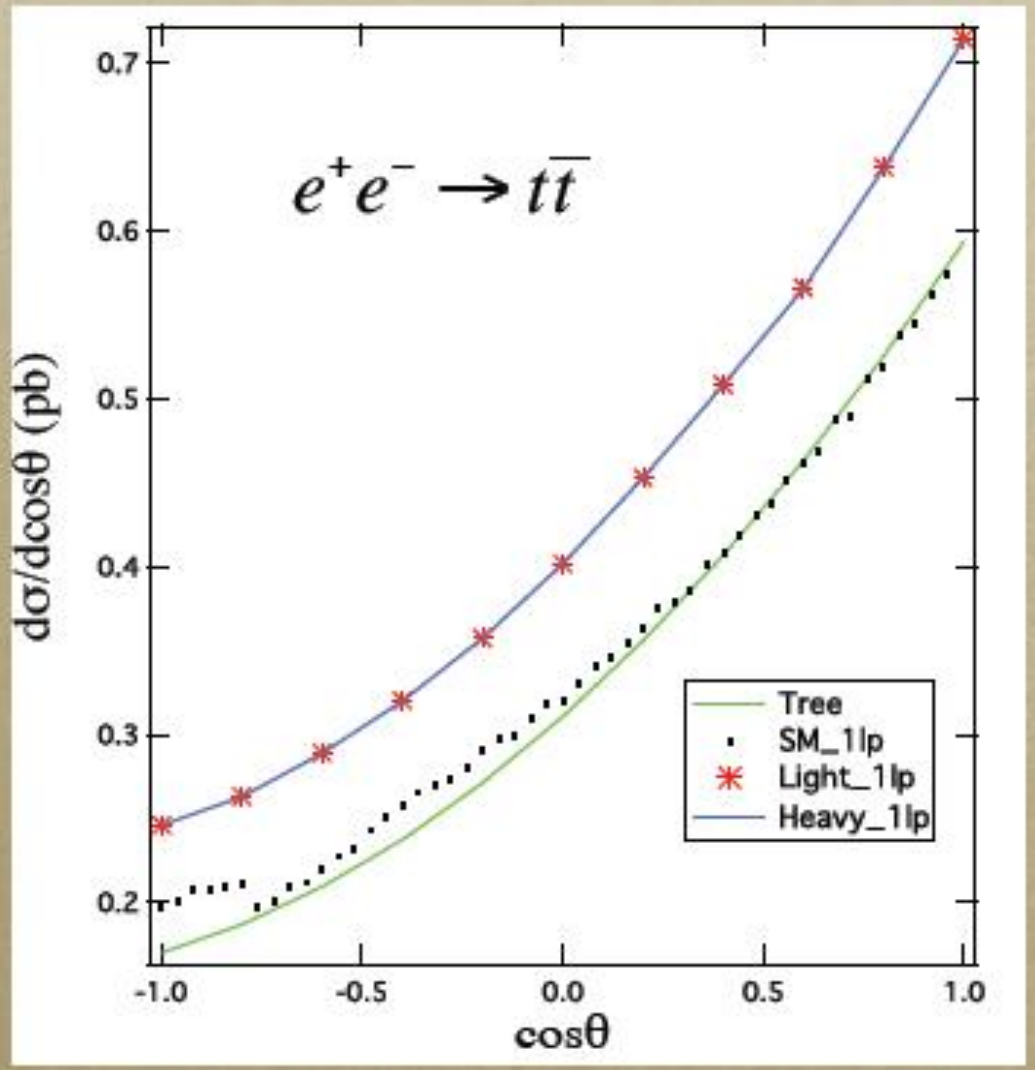
(Revised at Feb 2014)

$\sqrt{s} = 420\,GeV$

ELW & QCD correction



non-pol.

Summary

- GRACE: Automatic Full $O(\alpha)$ ELWK correction w/ SM & MSSM
- Beam polarization is implemented in GRACE-system, but Still Preliminary.
- Polarization of "$e^-_L\ e^+_R$" gives smaller $O(\alpha)$-corrections than "$e^-_R\ e^+_L$", however change A_{FB}
- SUSY signals can be seen through loop-effect.

Numerical check pol case

31 digits

			Sum
Nmerical Check (LR case) w=500GeV, kc=10^-3 GeV	Cuv	0	-2.916207534804507738009635715444534E-2
		100	-2.916207534804507738009635715444526E-2
		10000	-2.916207534804507738009635715444606E-2
	λ GeV	-21	-2.916207534752326707057241445514167E-2
		-25	-2.916207534804507738009635715444534E-2
		-29	-2.916207534856688768993031867460595E-2
	NLG	0,0,0,0,0	-2.916207534804507738009635715444534E-2
		10,20,30,40,50	-2.916207535341148199477787565285640E-2
		100,200,300,400,500	-2.916207587320318894457550601640950E-2

8~10 digits

Still not enough!

But after phase-space integration, no parameter-dependence is observed.