Status reports from the GRACE Group

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KEK Minamitateya collaboration

GRACE/FORM

Collaboration with J.Vermaseren (NIKHEF)

- new version of GRACE/LOOP with FORM
  - EW one-loop 2 to 2, 2 to 3 is now working
    - hh→hh zz→hh ww→ww ee→tth etc.etc.
- successfully optimized
  - ww→ww source size
    - reduce version 212Mb form version 79Mb
      - two or tree times faster than reduce version!!
  - ee→ee γ ⇔ uncontrollable with reduce

GRACE/SUSY

M.Kuroda et.al.

- MSSM at 1-loop
  - up to 2→2 and 1→3 amplitudes
- On-shell renormalization scheme
  - On-shell conditions by Kuroda
    - Gauge bosons,Fermions, Scalar fermions
    - (A^0,H^0) $(\chi_1^0,\chi_1^+,\chi_2^+)$

3-body chargino decays

parameter sets

$\tan\beta$	μ	M_1	M_2	M_3	M_{A^0}
10.00	399.15	100.13	157.53	610	431

$m_{\tilde{u}_1}$	$m_{\tilde{u}_2}$	$m_{\tilde{d}_1}$	$m_{\tilde{d}_2}$	$m_{\tilde{e}_1}$	$m_{\tilde{e}_2}$	$m_{\tilde{\nu}_e}$	$\cos\theta_u$	$\cos\theta_d$	$\cos\theta_e$
506.48	524.14	506.07	530.14	163.22	187.37	169.64	9.4×10^{-5}	8.5×10^{-4}	9.1×10^{-5}
$m_{\tilde{c}_1}$	$m_{\tilde{c}_2}$	$m_{\tilde{s}_1}$	$m_{\tilde{s}_2}$	$m_{\tilde{\mu}_1}$	$m_{\tilde{\mu}_2}$	$m_{\tilde{\nu}_\mu}$	$\cos\theta_c$	$\cos\theta_s$	$\cos\theta_\mu$
506.47	524.16	506.07	530.14	163.19	187.38	169.64	0.033	1.6×10^{-5}	0.019
$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$	$m_{\tilde{b}_1}$	$m_{\tilde{b}_2}$	$m_{\tilde{\tau}_1}$	$m_{\tilde{\tau}_2}$	$m_{\tilde{\nu}_\tau}$	$\cos\theta_t$	$\cos\theta_b$	$\cos\theta_\tau$
345.37	556.78	469.43	507.15	150.07	190.39	170.02	0.5567	0.9266	0.271

➔2 body decays of χ_1^+ are kinematically forbidden

	Γ_0 (GeV)	Γ (GeV)	$\delta\Gamma/\Gamma_0$	Br
$\tilde{\chi}_1^+ \to e^+\nu_e\tilde{\chi}_1^0$	4.42×10^{-6}	4.48×10^{-6}	+9.4%	20.18%
$\tilde{\chi}_1^+ \to \mu^+\nu_\mu\tilde{\chi}_1^0$	4.42×10^{-6}	4.48×10^{-6}	+9.4%	20.18%
$\tilde{\chi}_1^+ \to \tau^+\nu_\tau\tilde{\chi}_1^0$	6.46×10^{-6}	7.22×10^{-6}	+11.8%	30.09%
$\tilde{\chi}_1^+ \to u\bar{d}\tilde{\chi}_1^0$	3.35×10^{-6}	3.55×10^{-6}	−0.2%(ELWK) +6.3%(QCD)	14.81%
$\tilde{\chi}_1^+ \to c\bar{s}\tilde{\chi}_1^0$	3.33×10^{-6}	3.54×10^{-6}	−0.2%(ELWK) +6.3%(QCD)	14.74%

LHC/QCD etc.

- LHC NLO project
  - New Collaboration between France & Japan
    - LAPP ATLAS group & ATLAS Japan
  - Diphox system
    - target process $H \rightarrow \gamma\gamma$

➢ Talk in Les Houches by Kurihara

- 11-29 June 2007

Loop Calculations

- GOAL of GRACE system
  - Automatic computation system of multi-loop integrals
- How to deal with loop integrals
  - analytic treatments are required
    - Infrared singularity -> *log(λ), 1/ε*
    - two-loop and higher calculations
  - We would like to treat loop integrals in a fully numerical way!!

Overview of Numerical approach

- Early works on two loop cal.
  - 1988-92 J.Fujimoto et.al,
  - 1991 D.Kreimer et.al,
- Sector Decomposition
  - 2000 T.Binoth et.al,
- Bernsterin-Tkachov algorithm
  - 2001 G.Passarino et.al,
- Hypergeometric function
  - 2005 Y.Kurihara et.al,
    - And More and More!!

Numerical Extrapolation Method

Collaboration with E. de Doncker (WMU)

- Put $i\varepsilon$ in the denominator of Feynman integrals
  - to prevent the integral from diverging

$$I = \int \frac{d^4 l}{(2\pi)^4 i} \frac{1}{(l^2 - m_1{}^2 + i\varepsilon)((l+p_1)^2 - m_2{}^2 + i\varepsilon)\cdots((l+\sum_{j=1}^{n-1} p_j)^2 - m_n{}^2 + i\varepsilon)}$$

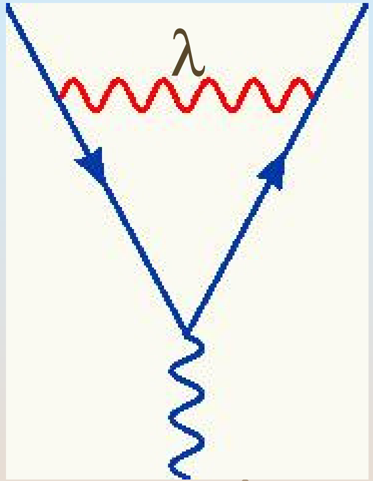
- Numerical extrapolation into ε → 0
  - Adapt the epsilon-algorithm to an asymptotic expansion of $I(\varepsilon_j)$ introduced by Wynn

One-loop IR vertex

$$I(s)=\int_0^1 dx\int_0^{1-x} dy\,\frac{1}{-xys+(x+y)^2m^2+(1-x-y)\lambda^2}$$

$$\sqrt{s}=500\mathrm{GeV}\qquad m=m_e=0.5\times10^{-3}\mathrm{GeV}$$

$$\lambda=10^n\,\mathrm{GeV}\ \ \text{A fictitious photon mass}$$



- HMLIB with P-precision
  - based on IEEE754 FP
    - 1bit :sign,15bit:exponent
    - 32*P-16:Mantissa
- P=4 ⇔ Mantissa=112bit
  - Quadruple-precision is not enough
    - →Octuple-precision!!

n	Av. Lost bit	Max. Lost bit
-20	88	92
-21	98	102
-22	108	112

Numerical vs. Analytical

Real Part of the One-loop IR vertex

$\lambda=10^n$ photon mass, P- precision

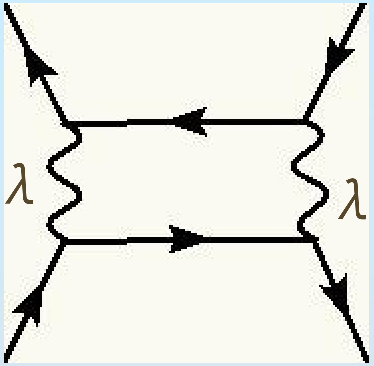
n	Numerical Results	P	Analytic Results	P
-30	-0.15089928698007D-01 ±0.771D-26	8	-0.15089928698004D-01	4
-80	-0.405390396284D-01 ±0.580D-15	16	-0.4053903962834D-01	4
-150	-0.761677949309D-01 ±0.931D-15	32	-0.761677949307D-01	4
-160	-0.812576177D-01 ±0.548D-10	32	-0.812576188D-01	4

Numerical vs. Analytical

Imag. Part of the One-loop IR vertex

$\lambda=10^n$ photon mass, P- precision

n	Numerical Results	P	Analytic Results	P
-30	-0.1892298396158D-02 ±0.124D-25	8	-0.18922983961555D-02	4
-80	-0.47858121612D-02 ±0.401D-12	16	-0.47858121611D-02	4
-150	-0.88367314318D-02 ±0.260D-13	32	-0.88367314320D-02	4
-160	-0.941543410D-01 ±0.109D-11	32	-0.941543433D-01	4



One-loop IR box

Real Part

$\lambda = 10^n$ photon mass, P- precision

n	Numerical Results	P	Analytic Results	P
-15	-0.192786110D-06 ±0.314D-14	4	-0.192786112D-06	4
-20	-0.2472486348D-06 ±0.586D-15	4	-0.247248635D-06	4
-25	-0.30171112D-06 ±0.111D-13	4	-0.30171115D-06	4
-30	-0.35810D-06 ±0.440D-9	4	-0.35617D-06	4

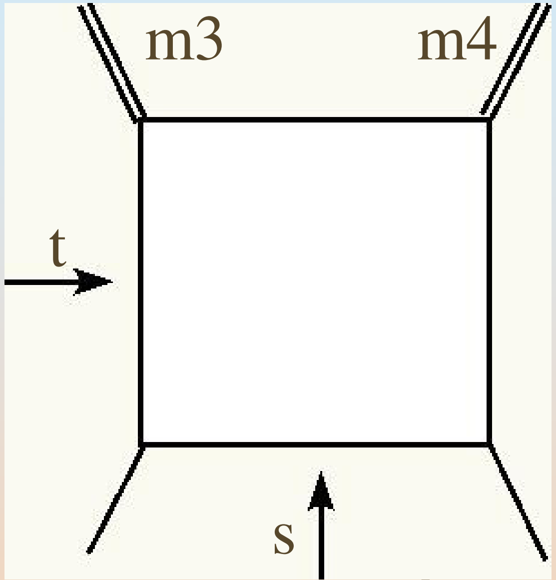
5.1 days with Opteron 2.2GHz

$$m_e = 0.5\times10^{-3}\,GeV,\ \ m_f = 150\,GeV,\ \sqrt{s} = 500\,GeV,\ t = -150^2\,GeV^2$$

Sector Decomposition Method

Ueda et.al.

- form code to perform the Sector Decomposition automatically
- Ex. IR box
  - Dim regularization ($D=4+2\varepsilon$)
  - Adapt extrapolation method to the numerical integrations



Numerical vs. Analytical

$$I_4 = \int_{i=1}^{4} dx_i \frac{\delta(1-\sum x_i)}{(-sx_1x_3 - tx_2x_4 - m_3{}^2 x_3x_4 - m_4{}^4 x_1x_4)^{2-\varepsilon}}$$
$$= \sum_{n=-2,-1,0,\cdots} C_n \times \varepsilon^n$$

Real part of C_n with double-precision

n	Numerical Results	Analytic Results(*)
-2	-0.40650406505E-04	-0.40650406504E-04
-1	-0.34156307031E-03	-0.34156306995E-03
0	-0.14929502492E-02	-0.14929502456E-02

$s = 123$, $t = -200$, $m_3{}^2 = 50$, $m_4{}^2 = 60$

(*)Kurihara, Duplancic et.al

Summary

- GRACE projects
  - GRACE/FORM check for 2→2, 3 in 1-loop
  - GRACE/SUSY 1→3 2→2 in 1-loop
  - LHC/QCD new collaboration with LAPP group
- New attempt
  - Numerical Integration
    - extrapolation method with epsilon-algorithm
    - sector decomposition
  - Super High precision control with HMLIB
    - Octuple and higher precision