Towards automated use of DIANA

- Progress Report and Applications -

Tord Riemann, DESY Zeuthen

Contributed to Session III: "Simulations and Computations in Theoretical Physics and Phenomenology" of "IX Int. Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT03)."

Research in collab. with J. Gluza and A. Lorca; thanks also to J. Fleischer and M. Tentyukov

- Introduction
- $2f \rightarrow 2f$ at 1-loops - aTALC and some results
- $e^+e^- \rightarrow e^+e^-$ at 2-loops with DIANA

Summary

Tord Riemann

ACAT, KEK, Japan, Dec 1-5, 2003
Introduction

Some time ago, we were seeking a tool for the automatization of loop calculations, allowing us a (relatively) independent research, without the need to go very deep into dedicated programming.

We think with `qgraph+DIANA` we found what we were searching for.

It is very important for us to have a close connection to the authors because `qgraph+DIANA` is very powerful if one knows it sufficiently well enough.

We use it for two related, but independent projects. Here we give a short report on the status and on some results.
Study of $e^+e^- \rightarrow 2f(\gamma)$ in the ew. Standard Model

We are interested in this class of reactions mainly because of applications at the planned Linear $e^+e^-$ Collider.

First we (= J.Fleischer, A.Leike, T.R., A.Werthenbach) performed high-precision one-loop calculations for

$$e^+e^- \rightarrow t\bar{t}(\gamma)$$  \hspace{1cm} (1)

and then we (= A.Lorca, T.R.) looked also at

$$e^+e^- \rightarrow b\bar{b}(\gamma), \ e^+e^- (\gamma), \ldots$$ \hspace{1cm} (2)

After earlier comparisons with T.Hahn's Feyncalc/LoopTools and the grace group's grace we understood that we are not automated enough and aiTALC was triggered and created by A. Lorca:

$$\text{aiTALC} = \text{an Integrated Tool for Automatic Loop Calculations}$$
Thanks to ...

M. Tentyukov and J. Fleischer for **DIANA**:
http://www.physik.uni-bielefeld.de/~tentukov/diana.html

P. Nogueira for **QGRAF**:
ftp://gtae2.ist.utl.pt/pub/qgraf/

J. Vermaseren for **FORM**:
http://www.nikhef.nl/~form/

T. Hahn and G. J. van Oldenborgh for **LoopTools and FF**:
http://www.feynarts.de/looptools
http://www.xs4all.nl/~gjvo/FF.html

**Free Software Fundation and GNU-project for Make and g77**
http://www.gnu.org
What do we ask? DRIVER FILE

```latex
\begin{verbatim}
SET _processname = Bhabha
SET _TOPOLOGYEDITORNAME = "tedi"

\Begin(model,EWSM.model)
\End(model)
\Begin(process)
  ingoing le(;p1),Le(;p4);
  outgoing le(;p2),Le(;p3);
  loops = 1;
\End(process)

options = onshell,notadp;
*\excluderetvertex(Le,le,H)

SET MakeEps = "!"
\setpropline(Wm,arrowWavy, 5, 3)
...
\include(fermioncurrentanalysis.prg)
\end{verbatim}
```

What does Diana answer?

\[
\begin{align*}
G \text{ Amplitude} = \\
(-1)*F(1,1,1,0,0)*(-1.)*e/2/sw&\times Mle/MW\times F(2,2,1,1,0)* \\
(-1.)*e/2/sqrt2/sw&\times Mle/MW\times \frac{1}{2}\times (3,2,+q,Mue)\times 1.* \\
F(3,2,mu1,1,1,1,1,1)* (+1.)*e/2/sqrt2/sw&\times SS(4,0)*1.* \\
SS(1,2)*1.*VV(2, mu2, mu1, q-k2, 2)*1.* \\
V(4, mu2, p1, p2&-q+k1, 1)*(-1.)*e/2/sw;
\end{align*}
\]

#define COUNTER "626"
#define LINE "4"
#define LOOPTYPE "c"
#define PROTOTYPE "WmnH"
...
#define FERMIONCHANNEL "T"
Model files for DIANA

The user has to supply the set of Feynman rules to be used for his/her problem, the model file. We have at the moment:

- QED
- Standard Model ('basic')
- Standard Model with exact treatment of masses
- Standard Model with counter terms needed for $e^+e^- \rightarrow 2f$

I would like to remark that a realization of the XML-project, presented some time ago by A.Demichev, A.Kryukov, A.Rodionov, would be welcome.

Need of support by interfacing from tools like DIANA, of course.
XML-Based Formulation of Field Theoretical Models †

A Proposal for a Future Standard and Data Base for Model Storage, Exchange and Cross-checking of Results ‡

A.Demichev, A.Kryukov and A.Rodionov

Skobeltsyn Institute of Nuclear Physics,
Moscow State University, 119992 Moscow, Russia

Abstract

We propose an XML-based standard for formulation of field theoretical models. The goal of creation of such a standard is to provide a way for an unambiguous exchange and cross-checking of results of computer calculations in high energy physics. At the moment, the suggested standard implies that models under consideration are of the SM or MSSM type (i.e., they are just SM or MSSM, their submodels, smooth modifications or straightforward generalizations).

‡Work is partially supported by CERN-INTAS 99-377, INTAS 00-0679 and RFBR 01-02-16209 grants.
tools: Diagram analytical output

Diagram No. 626


#-

EhabhaD626 =

+ ident(1) + ident(2) + den(t, NW2) * im * Miv2 + e4 * siv4 * p121 * (   
  - 1/512 * Mde2   
  + 1/256 * C01(cc1, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  - 1/128 * C01(cc2, Me2, t, Me2, Mn2, MW2, NW2) * t * Mde2   
  + 1/256 * C01(cc2, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  + 1/64 * C01(cc00, Me2, t, Me2, Mn2, NW2, NW2) * Mde2   
  + 1/256 * C01(cc11, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  - 1/256 * C01(cc12, Me2, t, Me2, Mn2, MW2, NW2) * t * Mde2   
  + 1/128 * C01(cc12, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  + 1/256 * C01(cc22, Me2, t, Me2, Mn2, NW2, NW2) * Mde4
) 

+ ident(1) * Gamma5(2) * den(t, NW2) * im * Miv2 + e4 * siv4 * p121 * (   
  + 1/512 * Mde2   
  - 3/256 * C01(cc1, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  + 1/128 * C01(cc2, Me2, t, Me2, Mn2, MW2, NW2) * t * Mde2   
  - 5/256 * C01(cc2, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  - 1/64 * C01(cc00, Me2, t, Me2, Mn2, NW2, NW2) * Mde2   
  - 1/256 * C01(cc11, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  + 1/256 * C01(cc12, Me2, t, Me2, Mn2, MW2, NW2) * t * Mde2   
  - 1/128 * C01(cc12, Me2, t, Me2, Mn2, MW2, NW2) * Mde4   
  - 1/256 * C01(cc22, Me2, t, Me2, Mn2, NW2, NW2) * Mde4
);
$O(\alpha)$ corrections: Photon emission

- Real detectors cannot observe soft photons
- Photon emission mixes incoherently with pure Bhabha
- Remove IR singularities from ext. s.e., vertices and boxes in 1-loop

**Initial State Radiation**

**Final State Radiation**

\[
\frac{d\sigma}{d\Phi_3} \propto |A_\gamma^{\text{ini}} + A_\gamma^{\text{fin}}|^2
\]

\[
\frac{d\sigma}{d\cos\theta} \bigg|_{\text{Soft}} = \text{Soft}_\gamma\text{Factor} \times \frac{d\sigma}{d\cos\theta} \bigg|_{\text{Born}}
\]

with $\Phi_3 = \text{Phase-Space 3 part...}$
**Results: Numerical comparison**

$e^- e^+ \rightarrow e^- e^+ (\gamma)$ at LC: $\sqrt{s} = 500$ GeV, $E_{\text{max}} (\gamma_{\text{soft}}) = \frac{\sqrt{s}}{10}$

<table>
<thead>
<tr>
<th>$\cos \theta$</th>
<th>$\frac{d\sigma}{d\cos \theta}$</th>
<th>(pb)</th>
<th>$\frac{d\sigma}{d\cos \theta}$</th>
<th>$\sigma (\alpha^3) = \text{Born+QED+weak+soft}$</th>
<th>Group</th>
</tr>
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<tbody>
<tr>
<td>-0.9</td>
<td>0.21699 88288 10920</td>
<td>5</td>
<td>0.19344 50785 26863</td>
<td>6</td>
<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
</tr>
<tr>
<td>-0.9</td>
<td>0.21699 88288 10920</td>
<td>0</td>
<td>0.19344 50785 26862</td>
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<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
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<td>9</td>
<td>$m_e = 0$</td>
</tr>
<tr>
<td>-0.5</td>
<td>0.26136 04305 85323</td>
<td>6</td>
<td>0.23870 66977 23338</td>
<td>2</td>
<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
</tr>
<tr>
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<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
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<tr>
<td>0.0</td>
<td>0.59814 23072 50330</td>
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<td>0.54667 71794 69423</td>
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<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
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<tr>
<td>0.5</td>
<td>0.42127 29493 91625 6 $\times 10^1$</td>
<td></td>
<td>0.38130 07881 78966 1 $\times 10^1$</td>
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<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
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<td></td>
<td>0.38130 07881 78953 9 $\times 10^1$</td>
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<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
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<td></td>
<td>0.38130 07881 81327 0 $\times 10^1$</td>
<td>1</td>
<td>$m_e = 0$</td>
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<tr>
<td>0.9</td>
<td>0.18916 03223 32270 6 $\times 10^3$</td>
<td></td>
<td>0.17292 83490 66507 2 $\times 10^3$</td>
<td>6</td>
<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
</tr>
<tr>
<td>0.9</td>
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<td></td>
<td>0.17292 83490 66508 0 $\times 10^3$</td>
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<td>$a^4$TALC FA + FC + LT $m_e = 0$</td>
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<tr>
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<td>0.18916 03223 31848 5 $\times 10^3$</td>
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<td>0.17292 83490 61347 4 $\times 10^3$</td>
<td>4</td>
<td>$m_e = 0$</td>
</tr>
</tbody>
</table>

Extremely good agreement: 14 digits : limit in double precision

Previous agreement with FA+FC+LT: 11 digits hep-ph/0307132, SANC: 10 digits hep-ph/0207156

Thanks to T. Hahn, numbers supplied with *FeynArts + FormCalc + LoopTools*
Table 2:
The differential Bhabha cross section in nbarn as function of the scattering angle and 
the cms-energy.
$M_Z = 91.16 \text{ GeV}$, $m_t = 150 \text{ GeV}$, $M_H = 100 \text{ GeV}$.
Upper rows: DZ, lower rows: H.
$\delta_m$: largest relative deviation in per mille.

<table>
<thead>
<tr>
<th>$\sqrt{s}$ (GeV)</th>
<th>60</th>
<th>89</th>
<th>91.16</th>
<th>93</th>
<th>200</th>
</tr>
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<tbody>
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<td>$\theta$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>15°</td>
<td>129.6</td>
<td>65.11</td>
<td>57.93</td>
<td>49.00</td>
<td>11.82</td>
</tr>
<tr>
<td></td>
<td>129.6</td>
<td>65.11</td>
<td>57.93</td>
<td>49.00</td>
<td>11.82</td>
</tr>
<tr>
<td>45°</td>
<td>1.451</td>
<td>1.376</td>
<td>1.755</td>
<td>.4833</td>
<td>11.67</td>
</tr>
<tr>
<td></td>
<td>1.451</td>
<td>1.377</td>
<td>1.756</td>
<td>.4837</td>
<td>11.68</td>
</tr>
<tr>
<td>60°</td>
<td>.4303</td>
<td>.6124</td>
<td>1.125</td>
<td>.2697</td>
<td>.03075</td>
</tr>
<tr>
<td></td>
<td>.4306</td>
<td>.6129</td>
<td>1.126</td>
<td>.2699</td>
<td>.03077</td>
</tr>
<tr>
<td>75°</td>
<td>.1717</td>
<td>.3627</td>
<td>.8718</td>
<td>.2233</td>
<td>.01072</td>
</tr>
<tr>
<td></td>
<td>.1718</td>
<td>.3630</td>
<td>.8720</td>
<td>.2233</td>
<td>.01072</td>
</tr>
<tr>
<td>90°</td>
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<td>.2768</td>
<td>.7790</td>
<td>.2088</td>
<td>.004862</td>
</tr>
<tr>
<td></td>
<td>.08876</td>
<td>.2769</td>
<td>.7787</td>
<td>.2087</td>
<td>.004855</td>
</tr>
<tr>
<td>105°</td>
<td>.05917</td>
<td>.2090</td>
<td>.8082</td>
<td>.2157</td>
<td>.002858</td>
</tr>
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<td></td>
<td>.05918</td>
<td>.2090</td>
<td>.8074</td>
<td>.2157</td>
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<td>120°</td>
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<td>.3053</td>
<td>.9223</td>
<td>.2429</td>
<td>.002077</td>
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<td>.3051</td>
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<td>.002074</td>
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<tr>
<td>135°</td>
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<td>.001742</td>
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<td>.04839</td>
<td>.4635</td>
<td>1.422</td>
<td>.3584</td>
<td>.001540</td>
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<tr>
<td>$\delta_m$</td>
<td>0.6</td>
<td>0.8</td>
<td>1.8</td>
<td>2.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>
QED corrections to $A_{FB}^{(0,b)}$ at TESLA and LEP1

The experimental determination of

$$A_{FB}^{(0,b)} = \frac{\sigma_{F-B}^{(0,b)}}{\sigma_{tot}^{(0,b)}}$$

(3)

at LEP1 has a large pull of order 1 per mil compared to the Standard Model prediction.

Remember how initial state radiation is treated in e.g. zfitter:

$$\sigma_{F-B} = \int \frac{ds'}{s} \sigma_{F-B}^{(0)}(s', m) \rho_{FB} \left( \frac{s'}{s}, m = 0 \right)$$

(4)

Is this approximation good enough?

We first had a look with our code topfit at LC energies, and then at LEP1.
Some Numerical Results
for $A_{F-B}^b$ at LC energies

At TESLA energies:

\[
\begin{align*}
\sqrt{s} &= 500. \\
m_f &= 4. \\
Q_f &= -0.333333333 \\
AFB_{num} &= 0.150759697 \\
AFB_{flx} &= 0.151470125 \\
diff AFB &= num-flx = -0.000710428057 = -0.7 \times 10^{-3}
\end{align*}
\]
## Summer 2003

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Measurement</th>
<th>Fit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta \alpha^{(5)}_{\text{had}}(m_Z))</td>
<td>0.02761 ± 0.00036</td>
<td>0.02767</td>
</tr>
<tr>
<td>(m_Z) [GeV]</td>
<td>91.1875 ± 0.0021</td>
<td>91.1875</td>
</tr>
<tr>
<td>(\Gamma_Z) [GeV]</td>
<td>2.4952 ± 0.0023</td>
<td>2.4960</td>
</tr>
<tr>
<td>(\sigma^0_{\text{had}}) [nb]</td>
<td>41.540 ± 0.037</td>
<td>41.478</td>
</tr>
<tr>
<td>(R_l)</td>
<td>20.767 ± 0.025</td>
<td>20.742</td>
</tr>
<tr>
<td>(A^{0,1}_{tb})</td>
<td>0.01714 ± 0.00095</td>
<td>0.01636</td>
</tr>
<tr>
<td>(A_{l}(P,T))</td>
<td>0.1465 ± 0.0032</td>
<td>0.1477</td>
</tr>
<tr>
<td>(R_{b})</td>
<td>0.21638 ± 0.00066</td>
<td>0.21579</td>
</tr>
<tr>
<td>(R_{c})</td>
<td>0.1720 ± 0.0030</td>
<td>0.1723</td>
</tr>
<tr>
<td>(A^{0,0}_{tb})</td>
<td>0.0997 ± 0.0016</td>
<td>0.1036</td>
</tr>
<tr>
<td>(A^{0,1}_{tb})</td>
<td>0.0706 ± 0.0035</td>
<td>0.0740</td>
</tr>
<tr>
<td>(A_{b})</td>
<td>0.925 ± 0.020</td>
<td>0.935</td>
</tr>
<tr>
<td>(A_{c})</td>
<td>0.670 ± 0.026</td>
<td>0.668</td>
</tr>
<tr>
<td>(A_{l}(\text{SLD}))</td>
<td>0.1513 ± 0.0021</td>
<td>0.1477</td>
</tr>
<tr>
<td>(\sin^2\theta_{\text{eff}}(Q_{tb}))</td>
<td>0.2324 ± 0.0012</td>
<td>0.2314</td>
</tr>
<tr>
<td>(m_W) [GeV]</td>
<td>80.426 ± 0.034</td>
<td>80.385</td>
</tr>
<tr>
<td>(\Gamma_W) [GeV]</td>
<td>2.139 ± 0.069</td>
<td>2.093</td>
</tr>
<tr>
<td>(m_t) [GeV]</td>
<td>174.3 ± 5.1</td>
<td>174.3</td>
</tr>
<tr>
<td>(\sin^2\theta_W(\nu N))</td>
<td>0.2277 ± 0.0016</td>
<td>0.2229</td>
</tr>
<tr>
<td>(Q_W(\text{Cs}))</td>
<td>-72.84 ± 0.46</td>
<td>-72.90</td>
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</tbody>
</table>

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Tord Riemann

ACAT, KEK, Japan, Dec 1-5, 2003
Some Numerical Results

for $A_{F-B}^b$ at LEP 1

At LEP 1 energies we get:

$sqrt(s)$ = 91.1812166

$m_f$ = 2.8

$Q_f$ = -0.333333333

$AFB_{num}$ = 0.152658028

$AFB_{flx}$ = 0.152661305

$diff AFB$ = num-flx = -3.2767968E-06 = -0.003 x 10 E-3
We determined the complete $\mathcal{O}(\alpha)$ corrections to massive Bhabha

Building block for 2-loop project

Exact treatment of $m_e$ brings no more physics (in Standard Model part), but is good check

✓ Well known calculation method. Following
   Böhm, Spiesberger and Hollik. Fortschr. Phys. 34 (1986) 11

In A.16 in De93 - counter terms for $ffH, ff\chi$ couplings - have typos

👍 14 digits agreement! Fully satisfied, good cross-check for codes

♦ Collected some experience with a\textsc{talc} on automatization towards

Further testing and launch as public available the 2 to 2 fermion version
Apply method on realistic physical studies.
Why study 2-loop Bhabha scattering now?

- Prominent luminosity-monitoring reaction for $e^+e^-$ colliders
- 2loop Bhabha: Experimental accuracy points to 0.1%
- New Physics reach: $e^+e^-e^+e^-$ four fermion operators
  small angles: t-channel dominates
- Relatively simple in the low-angle case: QED is by far dominating;
  Only one mass: $m_e$
  At TESLA also $Z$ exchange will play a role there
Using DIANA beyond 1-loop

Here, we need DIANA not only as a tool for the preparation of calculations, but also as a tool for the analysis of the Feynman diagrams.

- Express the Feynman diagrams (or their interference with Born amplitudes) by scalar functions to be calculated
- Without using eyes – determine the relevant topologies and the derived topologies by shrinking lines and prototypes

Tord Riemann

ACAT, KEK, Japan, Dec 1-5, 2003
Diagram 109 topology u39_ (unique u39_) momentaset 1 (of 1)
Is it s-channel or t-channel?

\[ (-1, 2) \]
\[ (2, 4) \]
\[ (4, -3) \]

\( \Rightarrow \) t-channel diagram
Diagram number

Expression to be calculated

Vertices

Topological information
*This file is automatically generated by DIANA 2.34.

---#[ n109:

#define Vert1 "V1(M2,m1)"
#define Vert2 "V2(M3,m1)"
#define Vert3 "V3(M4,m5)"
#define Vert4 "V4(M7,m6)"
#define Vert5 "V5(M4,M2,m6)"
#define Vert6 "V6(M3,M7,m5)"

#define LINE "7"
#define FERMIONLINE "2"

---#] n109:

---#[ d109:

*vx(1,Le(2),le(-1),A(1))
*vx(2,Le(-2),le(3),A(1))
*vx(3,Le(-3),le(4),A(5))
*vx(4,Le(-7),le(-4),A(6))
*vx(5,Le(4),le(-2),A(6))
*vx(6,Le(3),le(7),A(5))
\begin{align*}
V_1(a_1, \ldots, a_6, m_1, \ldots, m_6, Q_1, \ldots, Q_4) \\
\text{external momenta: } Q_1, \ldots, Q_4 \\
V_2(a_1, \ldots, a_6, m_1, \ldots, m_6, Q_1, Q_2, Q_3) \\
\text{external momenta: } Q_1, Q_2, Q_3 \\
V_3(a_1, \ldots, a_6, m_1, \ldots, m_6, Q_1, \ldots, Q_4) \\
\text{external momenta: } Q_1, \ldots, Q_4 \\
V_4(a_1, \ldots, a_6, m_1, \ldots, m_6, Q_1, Q_2) \\
\text{external momenta: } Q_1, Q_2 \\
V_5(a_1, \ldots, a_6, m_1, \ldots, m_6, Q_1, Q_3) \\
\text{external momenta: } Q_1, Q_3
\end{align*}
B1  B2
B3  B4
B5  B6

Bhabha 2boxes prototypes

(70 2box diagrams)
Bkaba 2 boxes, 1 line shrunked
BY1

BY2

BY3

BY4

BY5

BY6

BY7

8habha

2 boxes, 2 lines shrinkaed
Summary

- The 1-loop topics we were interested in for LC applications are basically done. An application will be the use as a weak library in the MC-code eett6f of K. Kolodziej and A. Biernacki.

- In the 2-loop Bhabha project we hope for some less preparatory results until April 2004 ("Loops and Legs in Gauge Theories" in Zinnowitz).

- WE want to make the packages, especially the aiTALC, publicly available.