Towards automated use of DIANA
– Progress Report and Applications –

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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
- $2f \to 2f$ at 1-loops – aiTALC and some results
- $e^+e^- \to e^+e^-$ at 2-loops with DIANA
- Summary

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 $e^+e^- \to 2f(\gamma)$ 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

$$e^+e^- \to t\bar{t}(\gamma) \tag{1}$$

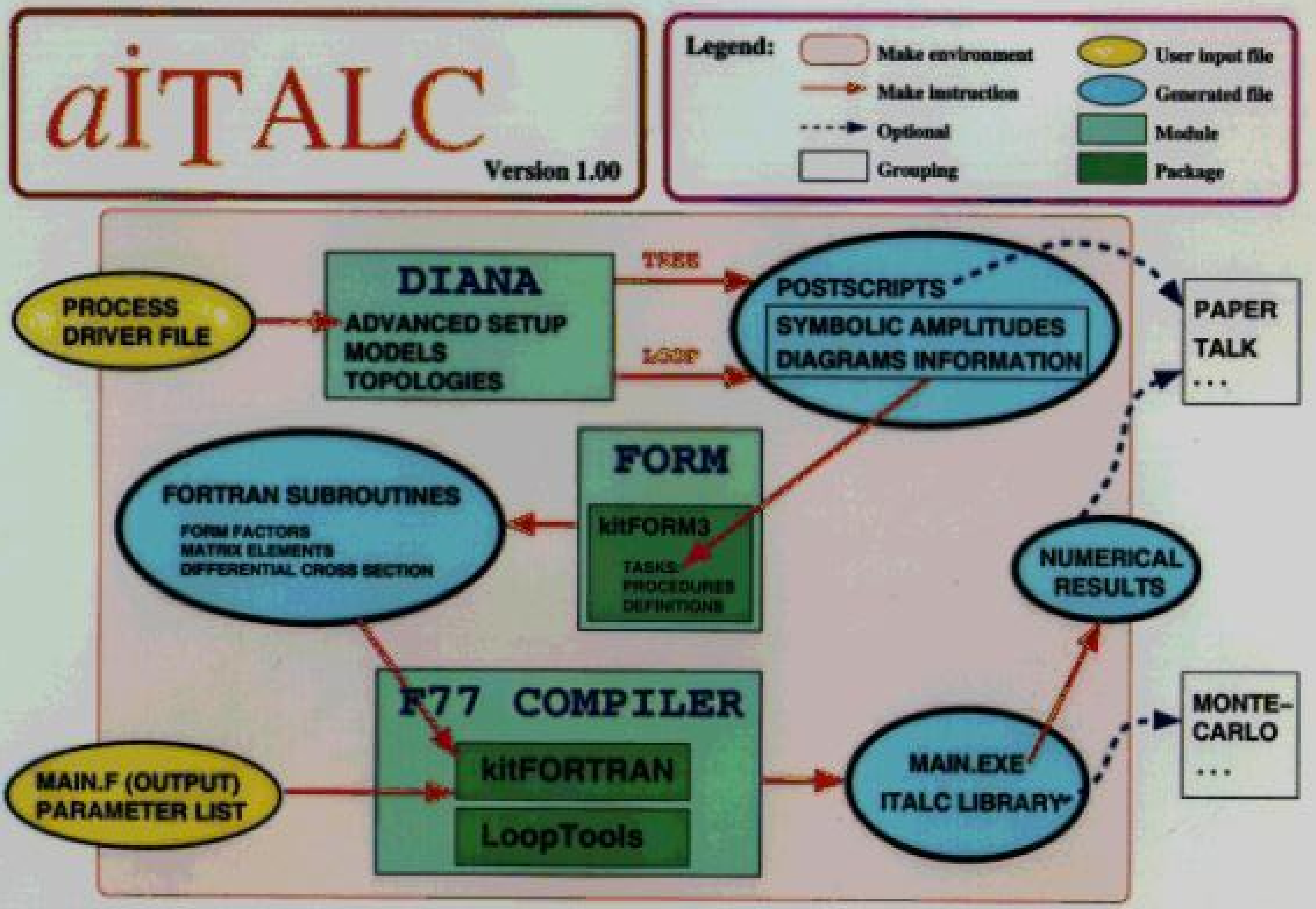
and then we (= A.Lorca, T.R.) looked also at

$$e^+e^- \to b\bar{b}(\gamma),\ ,e^+e^-(\gamma),\ldots \tag{2}$$

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:

aiTALC = an Integrated Tool for Automatic Loop Calculations

Structure of *ai*TALC: Flowchart



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`

Modules in aiTALC: DIANA

What do we ask? DRIVER FILE

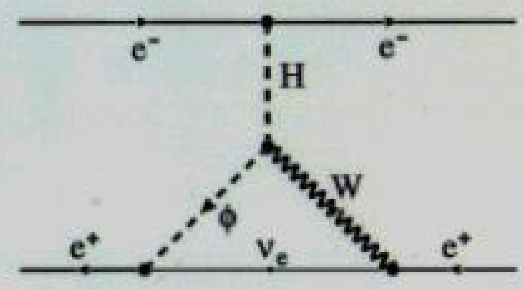
```
SET _processname = Bhabha
SET _TOPOLOGYEDITORNAME = "tedi"
```

```
\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;
*\excludevertex(Le,le,H)
```

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

What does Diana answer?




```
G Amplitude =
(-1)*F(1,1,1,0,0)*(-i_)*e/2/sw*Mle/MW*F(2,2,1,-1,0)*
(-i_)*e/2/sqrt2/sw*Mle/MW*FF(3,2,+q,Mne)*i_*
F(3,2,mu1,1,-1,1)*(+i_)*e/2/sqrt2/sw*SS(4,0)*i_*
SS(1,2)*i_*VV(2,mu2,mu1,-q-k2,2)*i_*
V(4,mu2,+p1+p2-(+q+k1),1)*(-i_)*e/2/sw;
```

```
#define COUNTER "626"
#define LINE "4"
#define LOOPTYPE "c"
#define PROTOTYPE "WWnH"
...
#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 $e^+e^- \to 2f$

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

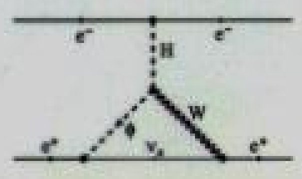
We propose an XML-based standard for formulation of field theoretical models. The goal of creation of such a standard is to provide a way for an unambiguous exchange and cross-checking of results of computer calculations in high energy physics. At the moment, the suggested standard implies that models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

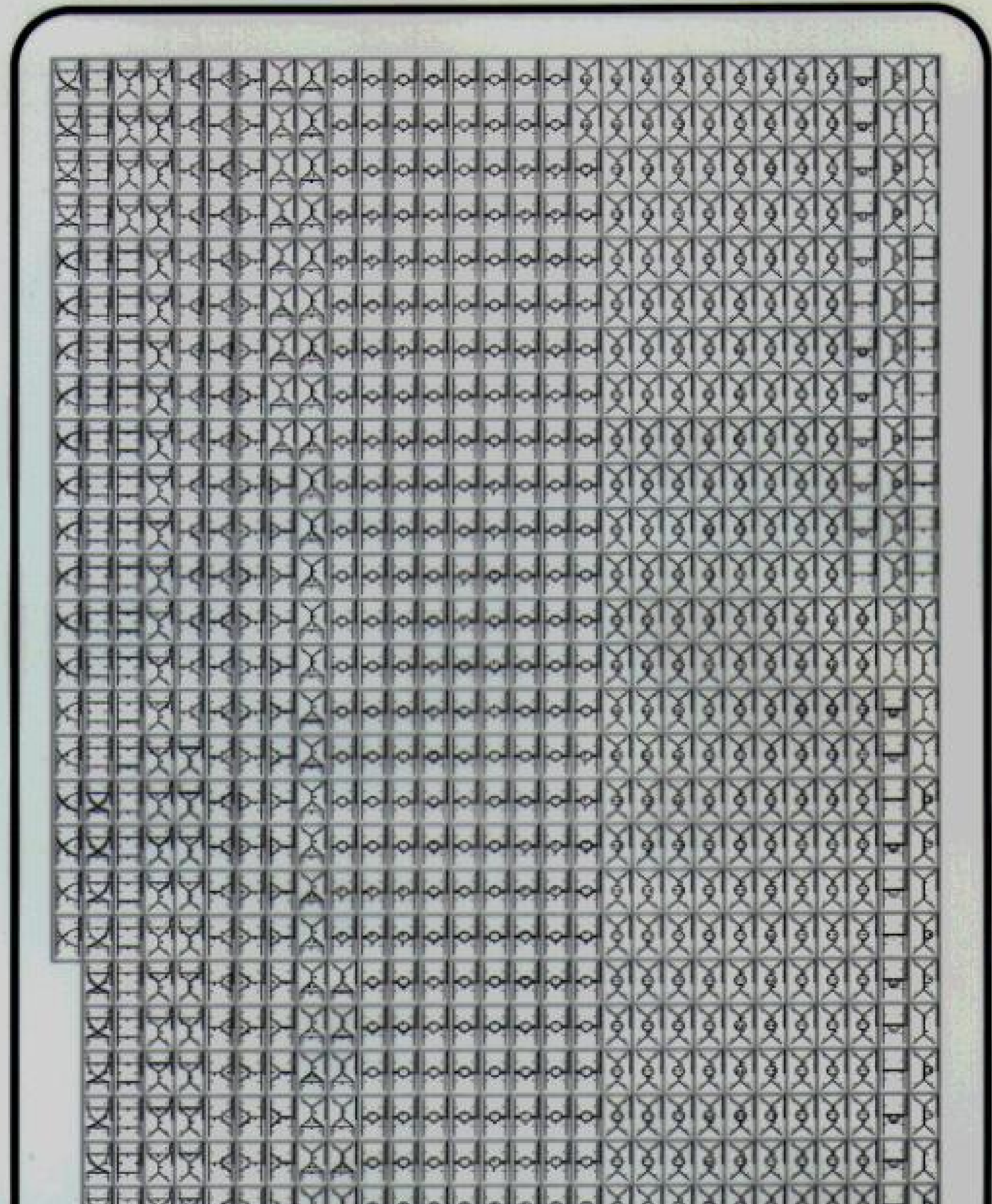
[†]Talk presented by A.Kryukov at the International Workshop "Automatic Calculation for Future Colliders" (CPP2001), November 28-30, 2001, Tokyo, Japan.

[‡]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\\
FORM by J.Vermaseren,version 3.1(Jan 24 2003) Run at: Tue Nov 11 19:32:33 2003\\
   #-

  BhabhaD626 =

      + ident(1)*ident(2)*den(t,MH2)*im*Miw2*e4*siw4*pi2i * (
         - 1/512*Mde2
         + 1/256*C0i(cc1,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         - 1/128*C0i(cc2,Me2,t,Me2,Mn2,MW2,MW2)*t*Mde2
         + 1/256*C0i(cc2,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         + 1/64*C0i(cc00,Me2,t,Me2,Mn2,MW2,MW2)*Mde2
         + 1/256*C0i(cc11,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         - 1/256*C0i(cc12,Me2,t,Me2,Mn2,MW2,MW2)*t*Mde2
         + 1/128*C0i(cc12,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         + 1/256*C0i(cc22,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         )

      + ident(1)*gamma5(2)*den(t,MH2)*im*Miw2*e4*siw4*pi2i * (
         + 1/512*Mde2
         - 3/256*C0i(cc1,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         + 1/128*C0i(cc2,Me2,t,Me2,Mn2,MW2,MW2)*t*Mde2
         - 5/256*C0i(cc2,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         - 1/64*C0i(cc00,Me2,t,Me2,Mn2,MW2,MW2)*Mde2
         - 1/256*C0i(cc11,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         + 1/256*C0i(cc12,Me2,t,Me2,Mn2,MW2,MW2)*t*Mde2
         - 1/128*C0i(cc12,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         - 1/256*C0i(cc22,Me2,t,Me2,Mn2,MW2,MW2)*Mde4
         );
```

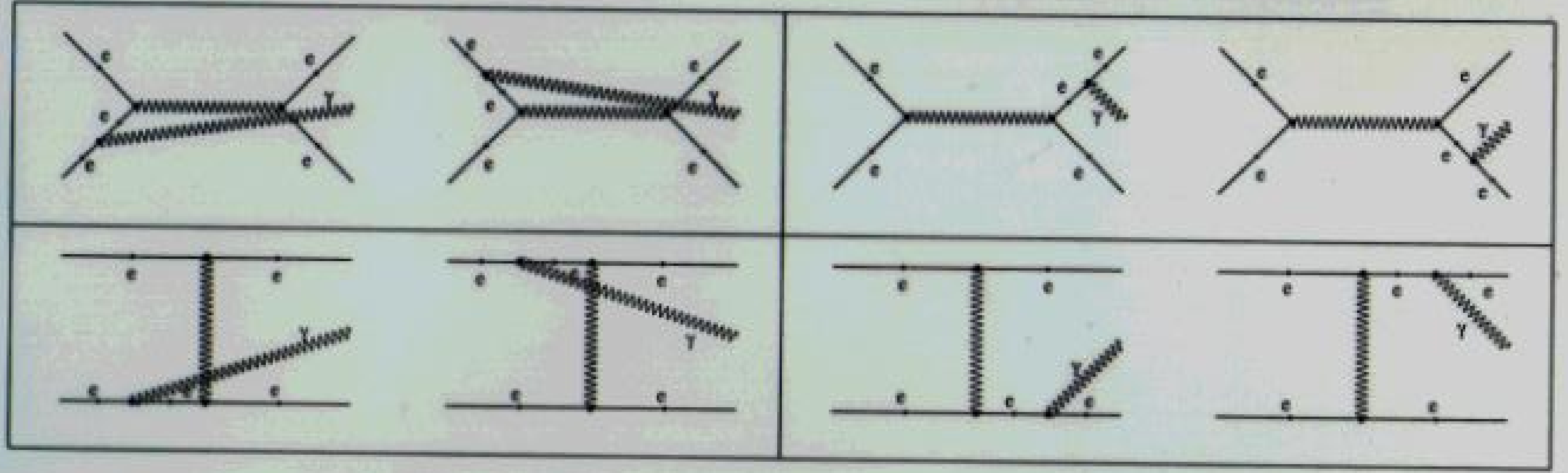




$\mathcal{O}(\alpha)$ corrections: **Photon emission**

- ✗ **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**



$$\frac{d\sigma}{d\Phi_3} \propto |\mathcal{A}_\gamma^{\text{ini}} + \mathcal{A}_\gamma^{\text{fin}}|^2$$

with Φ_3 = Phase-Space 3 part…

$$\frac{d\sigma}{d\cos\theta}\Big|_{\text{Soft}} = \text{Soft}_\gamma\text{Factor} \times \frac{d\sigma}{d\cos\theta}\Big|_{\text{Born}}$$

Results: Numerical comparison

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

$\cos\theta$	$\left[\frac{d\sigma}{d\cos\theta}\right]_{\text{Born}}$ (pb)	$\left[\frac{d\sigma}{d\cos\theta}\right]_{\mathcal{O}(\alpha^3)=\text{Born+QED+weak+soft}}$	Group
−0.9	0.21699 88288 10920 5	0.19344 50785 26863 6	aITALC
−0.9	0.21699 88288 10920 0	0.19344 50785 26862 2	$FA+FC+LT$
−0.9	0.21699 88288 41513 1	0.19344 50785 62637 9	$m_e = 0$
−0.5	0.26136 04305 85323 6	0.23870 66977 23338 2	aITALC
−0.5	0.26136 04305 85323 4	0.23870 66977 23344 6	$FA+FC+LT$
−0.5	0.26136 04306 17585 0	0.23870 66977 50854 7	$m_e = 0$
0.0	0.59814 23072 50330 3	0.54667 71794 69423 1	aITALC
0.0	0.59814 23072 50329 4	0.54667 71794 69421 8	$FA+FC+LT$
0.0	0.59814 23072 88584 4	0.54667 71794 99961 4	$m_e = 0$
0.5	$0.42127\ 29493\ 91625\ 6 \cdot 10^1$	$0.38130\ 07881\ 78966\ 1 \cdot 10^1$	aITALC
0.5	$0.42127\ 29493\ 91625\ 1 \cdot 10^1$	$0.38130\ 07881\ 78953\ 9 \cdot 10^1$	$FA+FC+LT$
0.5	$0.42127\ 29493\ 96691\ 5 \cdot 10^1$	$0.38130\ 07881\ 81327\ 0 \cdot 10^1$	$m_e = 0$
0.9	$0.18916\ 03223\ 32270\ 6 \cdot 10^3$	$0.17292\ 83490\ 66507\ 2 \cdot 10^3$	aITALC
0.9	$0.18916\ 03223\ 32270\ 6 \cdot 10^3$	$0.17292\ 83490\ 66508\ 0 \cdot 10^3$	$FA+FC+LT$
0.9	$0.18916\ 03223\ 31848\ 5 \cdot 10^3$	$0.17292\ 83490\ 61347\ 4 \cdot 10^3$	$m_e = 0$

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*

Bardin, Hollik, T.R., Z. Physik C49 (1991) 485

Table 2:
The differential Bhabha cross section in nbarn as function of the scattering angle and the cms-energy.
$M_Z = 91.16$ *GeV*, $m_t = 150$ *GeV*, $M_H = 100$ *GeV*.
Upper rows: DZ, lower rows: H.
δ_m*: largest relative deviation in per mille.*

$\sqrt{s}$ (GeV) / θ	60	89	91.16	93	200
15°	129.6 129.6	65.11 65.11	57.93 57.93	49.00 49.00	11.82 11.82
45°	1.451 1.451	1.376 1.377	1.755 1.756	.4833 .4837	11.67 11.68
60°	.4303 .4305	.6124 .6129	1.125 1.126	.2697 .2699	.03075 .03077
75°	.1717 .1718	.3627 .3630	.8718 .8720	.2232 .2233	.01072 .01072
90°	.08873 .08876	.2768 .2769	.7790 .7787	.2088 .2087	.004862 .004855
105°	.05917 .05918	.2690 .2690	.8082 .8074	.2157 .2157	.002858 .002853
120°	.04906 .04906	.3053 .3051	.9323 .9309	.2429 .2426	.002077 .002074
135°	.04671 .04672	.3626 .3624	1.111 1.109	.2838 .2833	.001743 .001742
165°	.04839 .04839	.4638 .4635	1.425 1.422	.3590 .3584	.001539 .001540
δ_m	0.6	0.8	1.8	2.0	1.7

QED corrections to $A_{FB}^{(0,b)}$ at TESLA and LEP1

The experimental determination of

$$A_{FB}^{(0,b)} = \frac{\sigma_{F-B}^{(0,b)}}{\sigma_{tot}^{(0,b)}} \tag{3}$$

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:

$$\sigma_{F-B} = \int \frac{ds'}{s} \, \sigma_{F-B}^{(0)}(s',m) \, \rho_{FB}\left(\frac{s'}{s}, m=0\right) \tag{4}$$

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^b_{F-B} at LC energies

At TESLA energies:

```
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 x 10 E-3
```

LEPEWWG-plots-summer03-s03_show_pull.eps

Summer 2003

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4960
σ^0_{had} [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.742
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01636
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1477
R_b	0.21638 ± 0.00066	0.21579
R_c	0.1720 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0997 ± 0.0016	0.1036
$A^{0,c}_{fb}$	0.0706 ± 0.0035	0.0740
A_b	0.925 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1477
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.426 ± 0.034	80.385
Γ_W [GeV]	2.139 ± 0.069	2.093
m_t [GeV]	174.3 ± 5.1	174.3
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	0.2229
Q_W(Cs)	-72.84 ± 0.46	-72.90

Some Numerical Results

for A^b_{F-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
```

Summary (I)

- **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

  A. Denner. Fortschr. Phys. 41 (1993) 4

  In A.16 in De93 - counter terms for $\bar{f} f H$, $\bar{f} f \chi$ couplings - have typos
- **14 digits agreement! Fully satisfied, good cross-check for codes**
- **Collected some experience with aiTALC 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

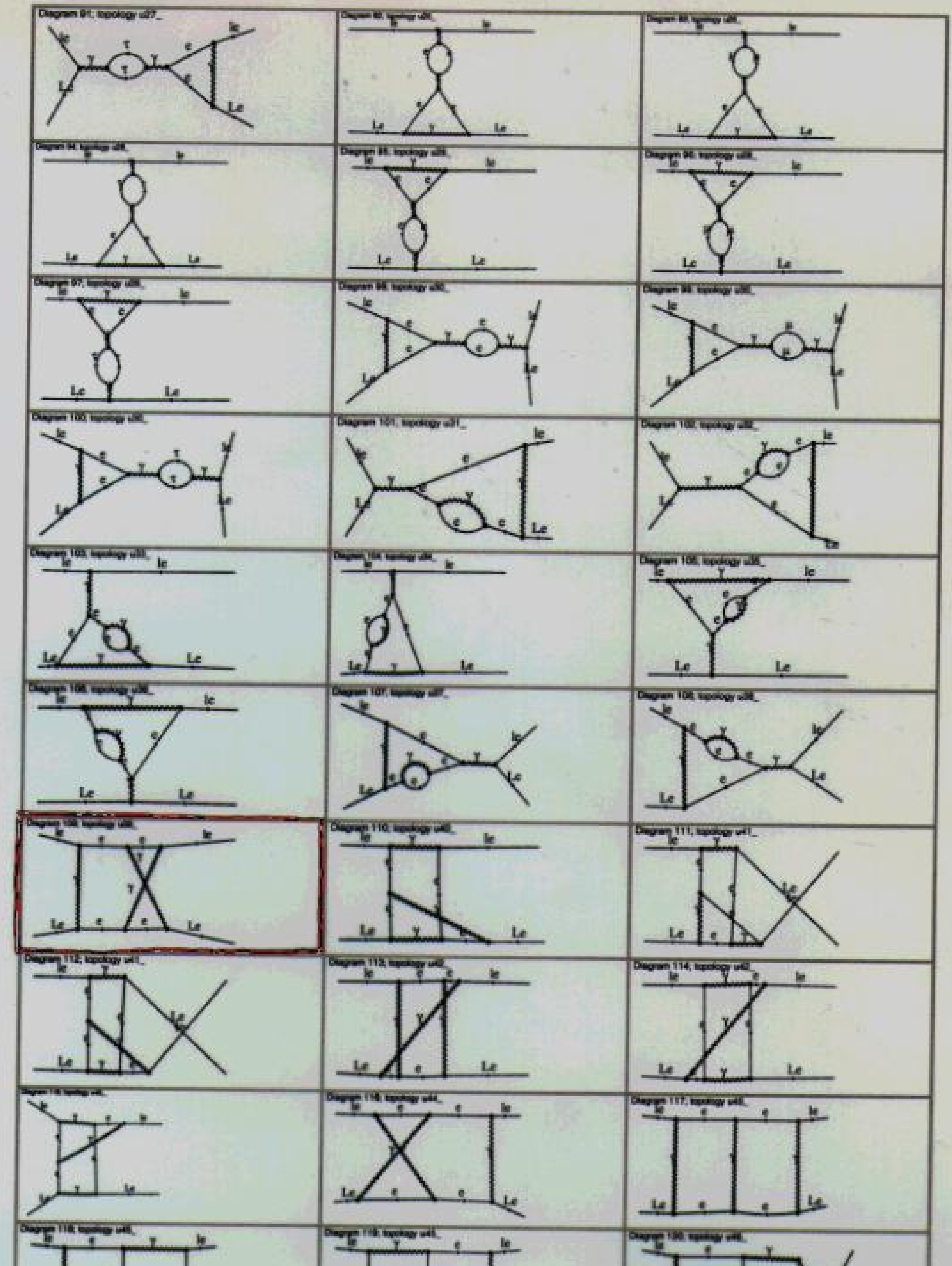
Using DIANA beyond 1-loop

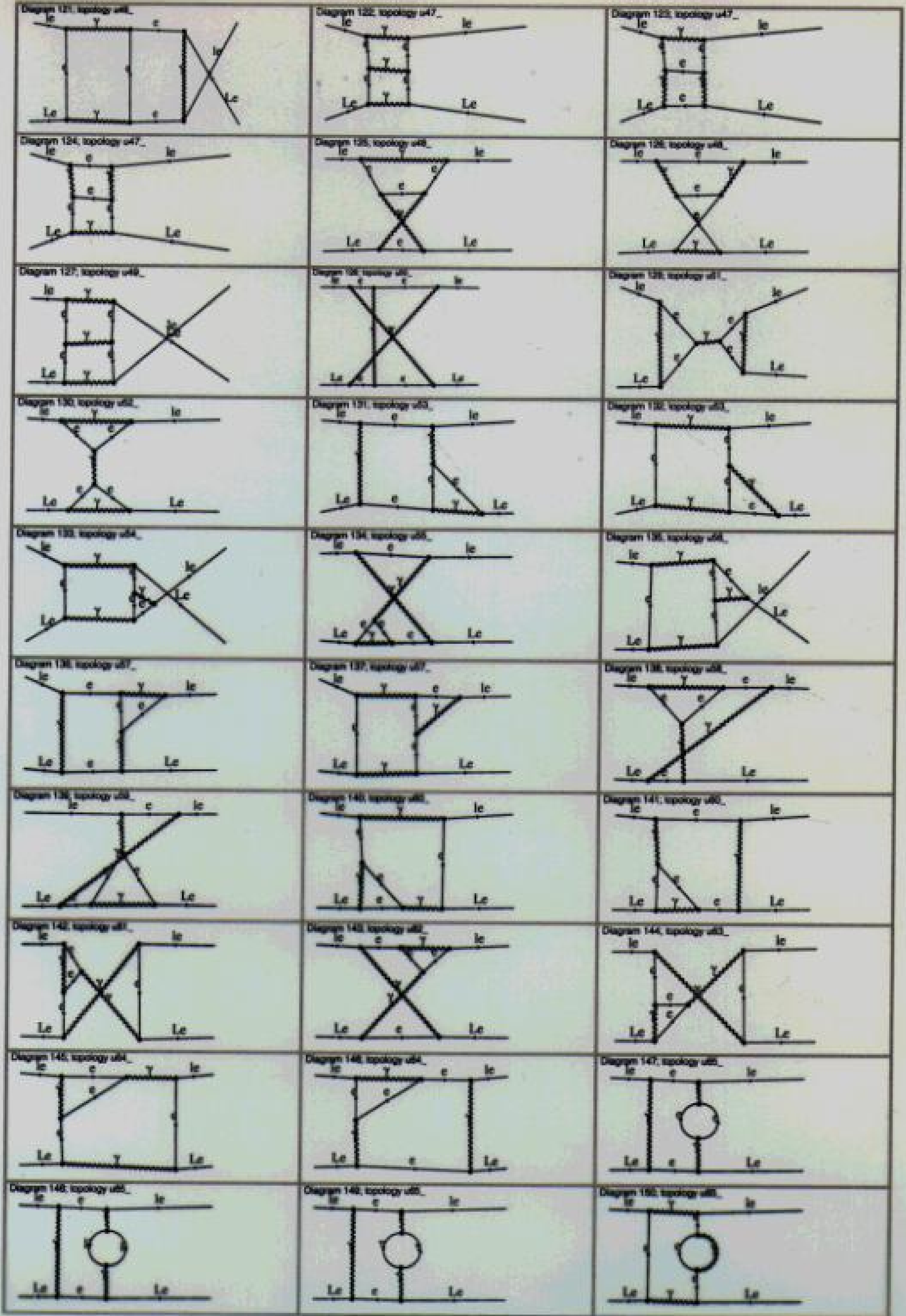
Here, we need DIANA not only as a tool for the preparation of calculations, but also as a tool for the analysis of the Feynman diagrams.

- 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

topology : ignore diff. particles
prototype : do not





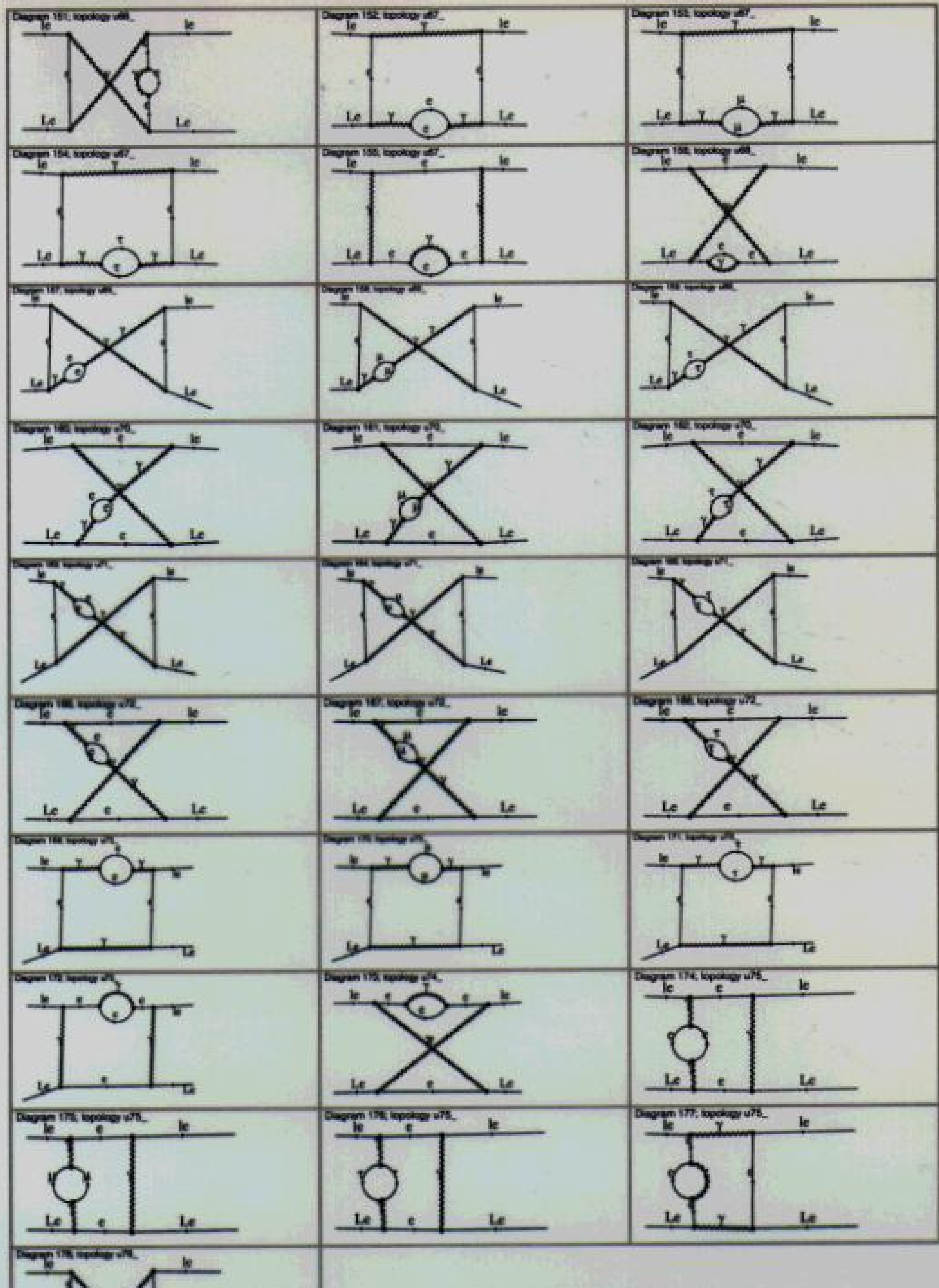


Diagram 174; topology u75_
Diagram 175; topology u75_
Diagram 176; topology u75_
Diagram 177; topology u75_
Diagram 178; topology u76_

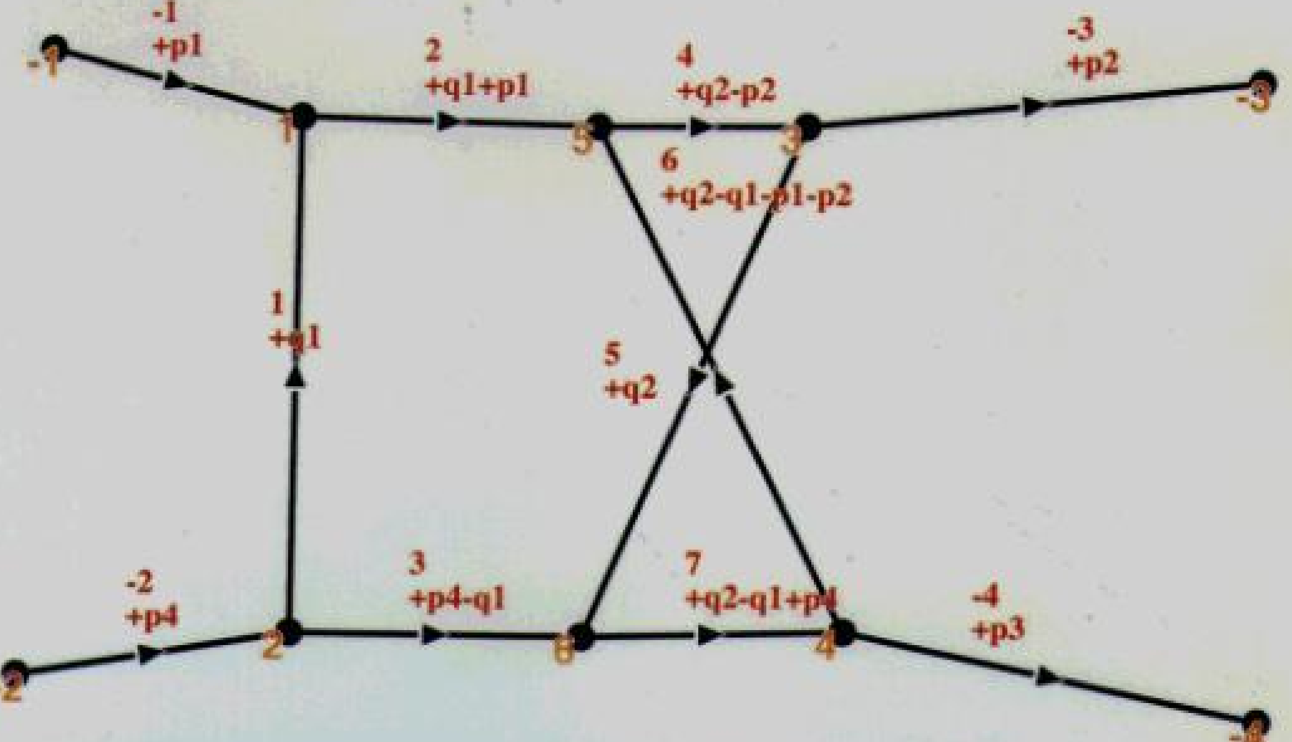
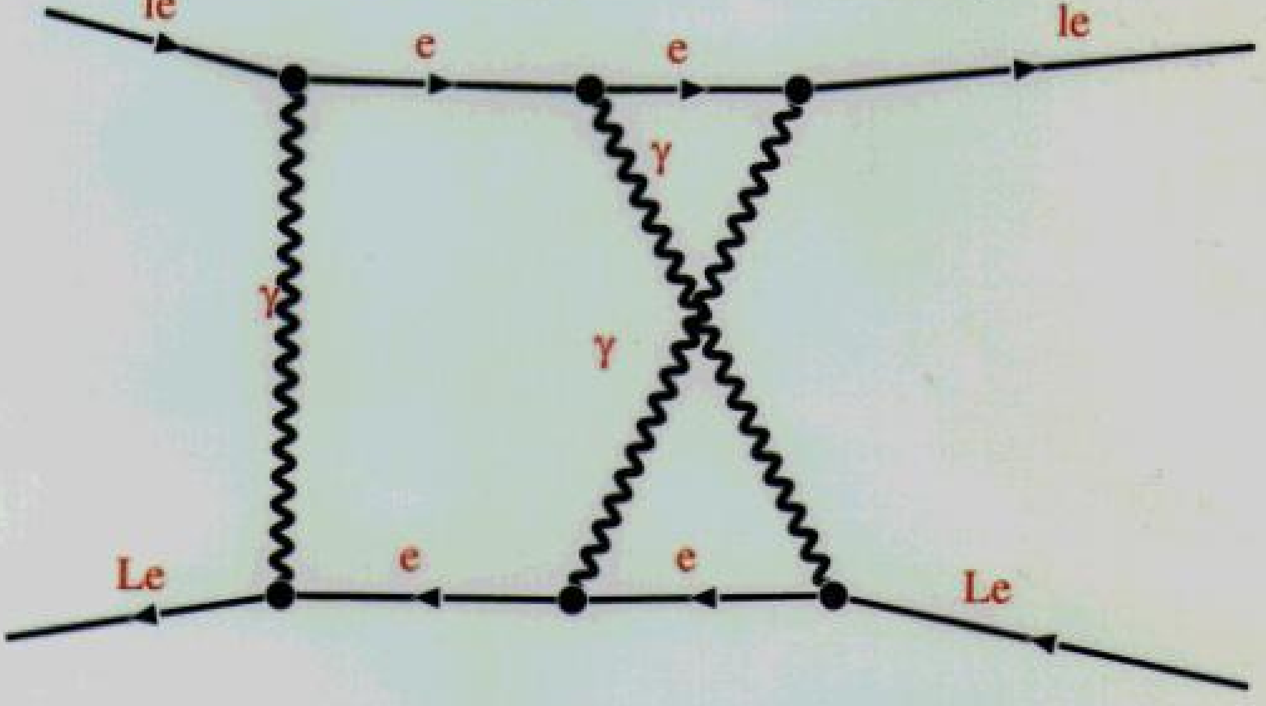
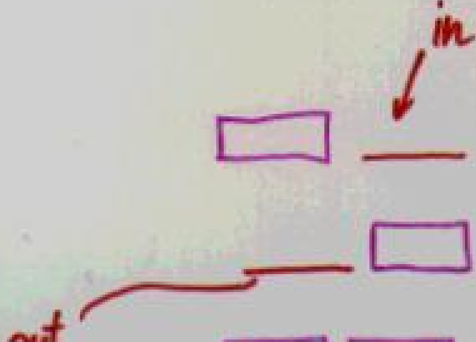


Diagram 109 topology u39_ (unique u39_) momentaset 1 (of 1)



Is it s-channel or t-channel ?



((−1), 2)
↓
(2, 4)
↓
(4, (−3)) ⇒ t-channel diagram

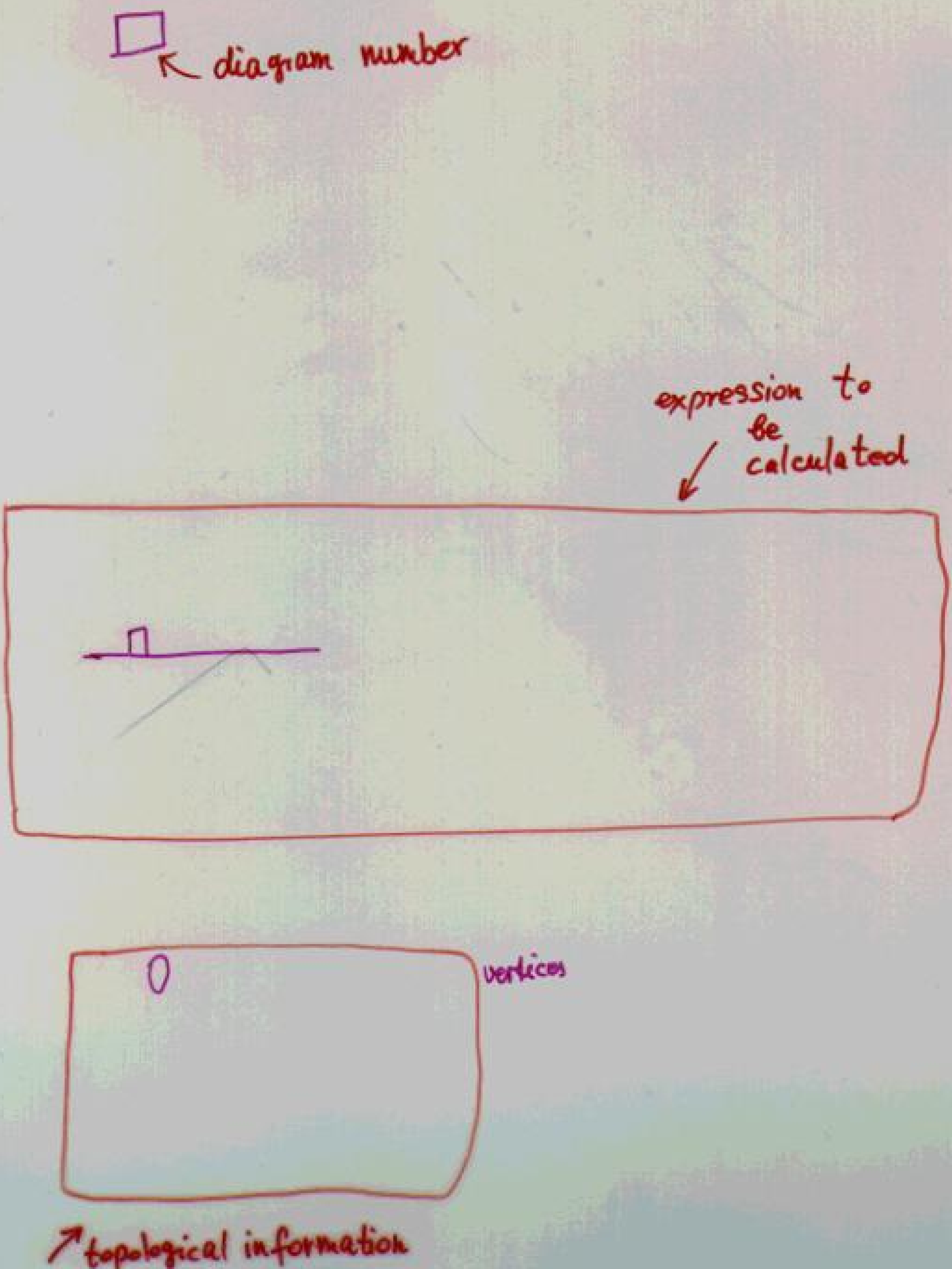
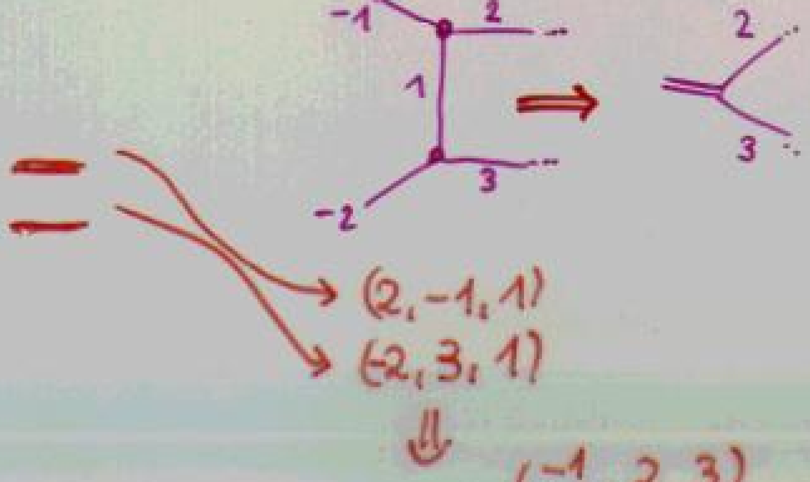


diagram number
expression to be calculated
vertices
topological information

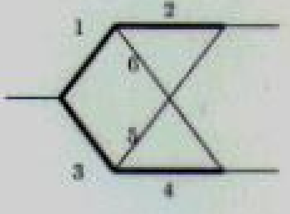
```
*This file is automatically generated by DIANA 2.34.

*--#[ 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"
*---------------------------------------
g Rq =
     (-1)*F(3,1,mu3,1,0,1)*(-i_)*e*Ql*FF(4,1,+q2-p2,mle)*i_*
     F(5,1,mu6,1,0,1)*(-i_)*e*Ql*FF(2,1,+q1+p1,mle)*i_*
     F(1,1,mu1,1,0,1)*(-i_)*e*Ql*F(2,2,mu2,1,0,1)*(-i_)*e*Ql*
     FF(3,2,-p4+q1,mle)*i_*F(6,2,mu4,1,0,1)*(-i_)*e*Ql*
     FF(7,2,-q2+q1-p4,mle)*i_*F(4,2,mu5,1,0,1)*(-i_)*e*Ql*
     VV(1,mu1,mu2,-q1,0)*i_*VV(5,mu3,mu4,+q2,0)*i_*
     VV(6,mu5,mu6,+q2-q1-p1-p2,0)*i_;
*--#] 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))
                                        ...
```


-1
2
1
3
-2
2
3
(2, -1, 1)
(-2, 3, 1)
(-1/-2, 2, 3)

1

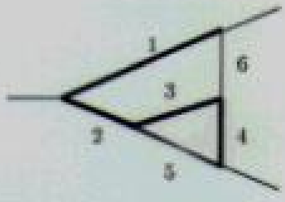
/afs/ifh.de/group/theorie/tord/bhabha/gluza/BHABHA_QED/TOPOLOGIES

V1



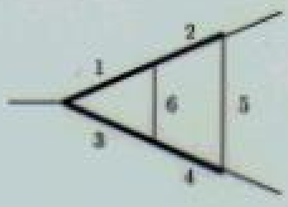
V1($\alpha_1, ..., \alpha_6, m_1, ..., m_6, Q_1, ..., Q_4$)
external momenta: $Q_1, ..., Q_4$

V2



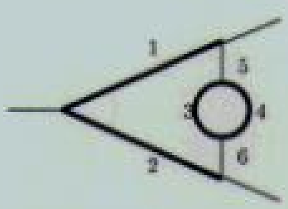
V2($\alpha_1, ..., \alpha_6, m_1, ..., m_6, Q_1, Q_2, Q_3$)
external momenta: Q_1, Q_2, Q_3

V3



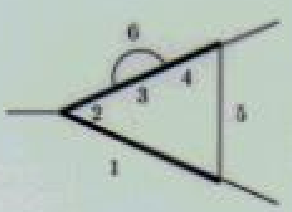
V3($\alpha_1, ..., \alpha_6, m_1, ..., m_6, Q_1, ..., Q_4$)
external momenta: $Q_1, ..., Q_4$

V4

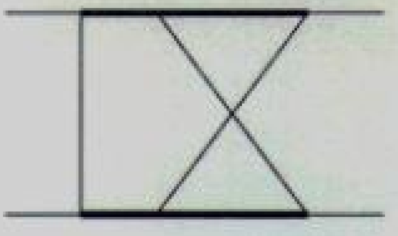


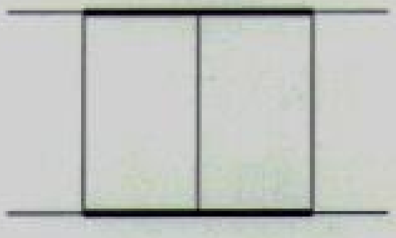
V4($\alpha_1, ..., \alpha_6, m_1, ..., m_6, Q_1, Q_3$)
external momenta: Q_1, Q_3

V5



V5($\alpha_1, ..., \alpha_6, m_1, ..., m_6, Q_1, Q_3$)
external momenta: Q_1, Q_3

B1


B2


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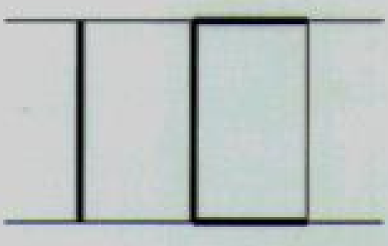

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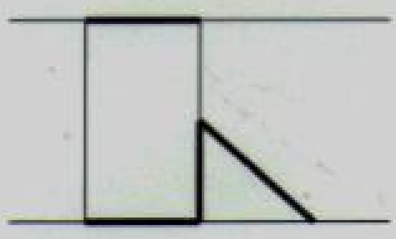
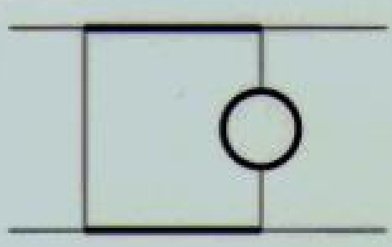
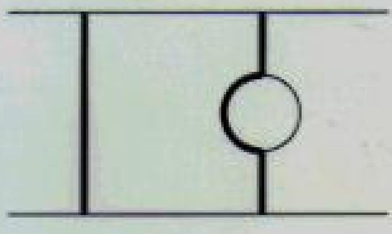


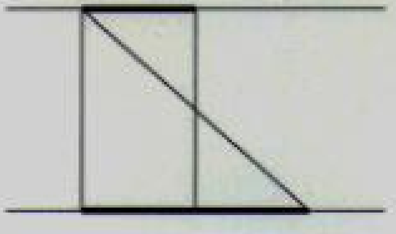
B5


B6


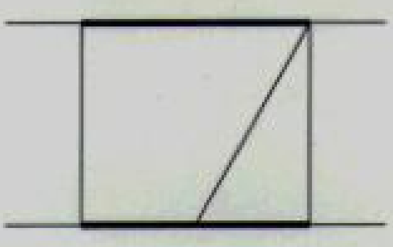
Bhabha 2boxes prototypes

(70 2box diagrams)

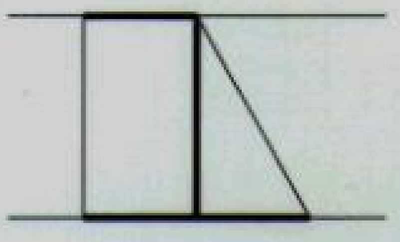
BX1



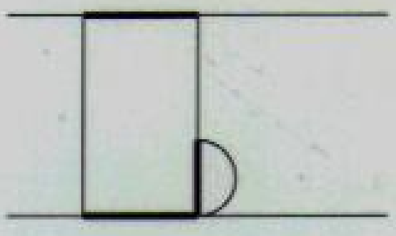
BX2



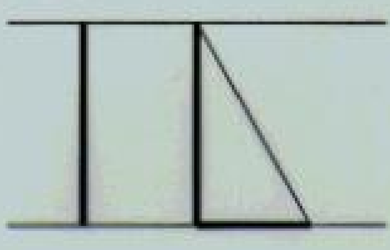
BX3



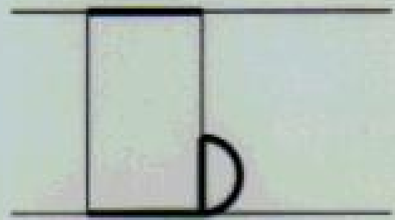
BX4



BX5

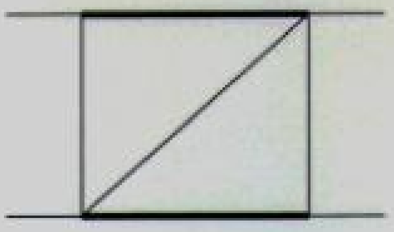


BX6

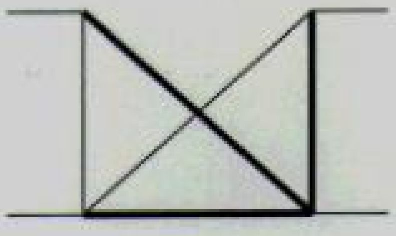


Blaba 2 boxes, 1 line shrinked

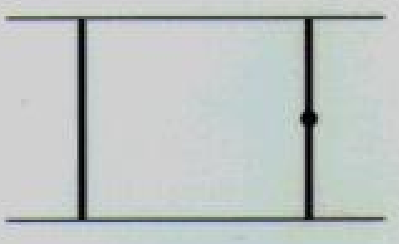
BY1



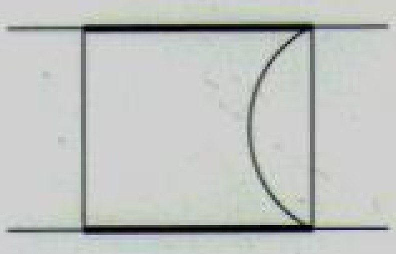
BY2



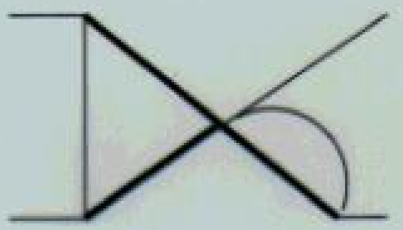
BY3



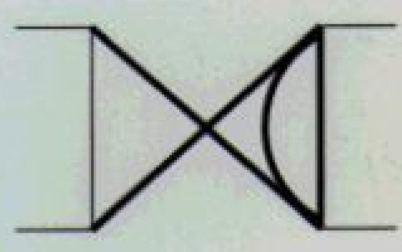
BY4



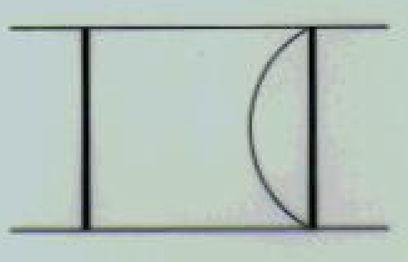
BY5



BY6



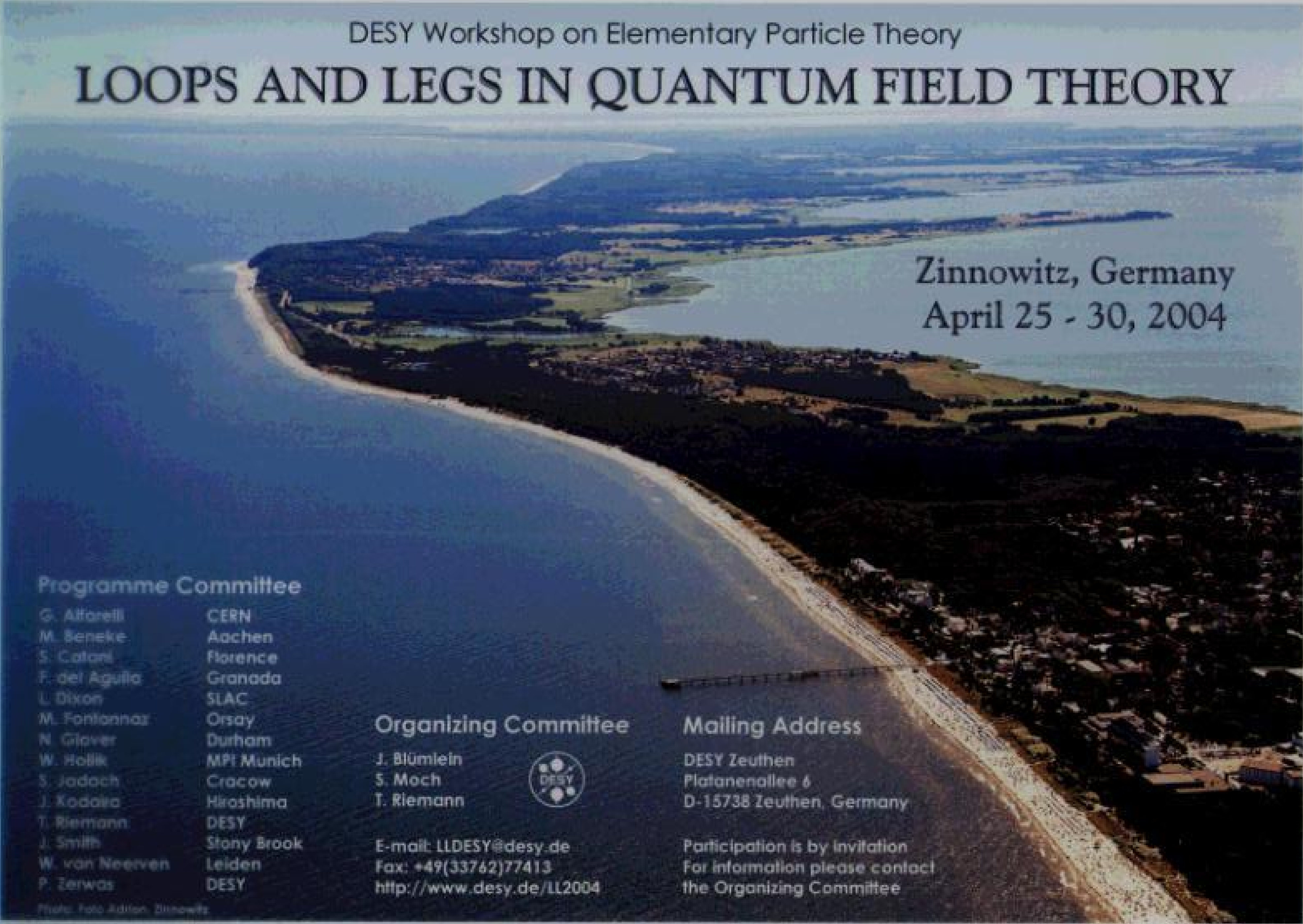
BY7



Bhabha 2 boxes, 2 lines shrinked

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.Biernacik.
- In the 2-loop Bhabha project we hope for some less preparatory results until April 2004 ("Loops and and Legs in Gauge Theories" in Zinnowitz).
- WE want to make the packages, especially the aiTALC, publicly available.


DESY Workshop on Elementary Particle Theory
LOOPS AND LEGS IN QUANTUM FIELD THEORY
Zinnowitz, Germany
April 25 - 30, 2004
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