ECFA-DESY Workshop, Saint Malo, 13 April, 2002

Project `CalcPHEP`: Calculus for Precision High Energy Physics

D. Bardin

Laboratory of Nuclear Problems,

Joint Institute for Nuclear Research

OUTLINE

1. CalcPHEP group, roots of the project
2. Basic notions
3. Present status of the project
4. Concluding remarks

1. CalcPHEP group:

D. Bardin, L. Kalinovskaya, P. Christova,

A. Andonov, G. Nanava – LNP, JINR;

S. Bondarenko – BTL, JINR;

G. Passarino – Torino University, consultant.

In collaboration with:

S. Jadach, Z. Was – INF Krakow and

B.F.L. Ward – Knoksville University on MC issues.

`CalcPHEP` site – **`brg.jinr.ru`**

development in two strategic directions:

1. creation of a software product, capable to compute pseudo- and realistic observables with one-loop precision, for more and more complicated processes of elementary particle interactions, using the principle of knowledge storing: $1 \to 2$, $1 \to 3$, $2 \to 2$, $1 \to 4$, $2 \to 3$.

   Application: LHC, Linacs;

2. works towards two-loop precision level control of HEP observables for simple processes: $1 \to 2$, $1 \to 3$ ...

   Application: GigaZ option of LC.

Two roots of `CalcPHEP`:

1. Codes aimed at a theoretical support of HEP experiments:
   - **1975 – 1986:** Together with A. Akhundov and N. Shumeiko — BCDMS, EMC and NMC, program **`TERAD`**.
   - Together with V. Dokuchaeva — CHARM-I, CDHSW and CHARM-II — **`NUDIS2, INVMUD, NUFITTER`**.
   - **1983 – 1989:** The DZRCG – 'Dubna–Zeuthen Radiative Correction Group', DB, P. Christova, T. Riemann, S. Riemann, M. Sachwitz, H. Vogt — EW-library **`DIZET`**; together with M. Bilenky, A. Chizhov and A. Sazonov — **`ZBIZON`** — fore-runner of **`ZFITTER`**
   - **1989 – 1997:** Together with A. Akhundov, A. Arbuzov, C. Burdik, J. Blümlein, P. Christova, L. Kalinovskaya, T. Riemann — experiments at HERA — **`HECTOR`**.
   - Together with L. Kalinovskaya — SMC — μ**e***la*.
   - **1989 – 2001:** Theoretical support of experiments at LEP, SLC (DZRCG — **`ZFITTER`** and **`GENTLE`**).
2. Book with G. Passarino: *The Standard Model in the Making*, OUP 1999; book-supporting **`form`**-codes ($\sim n \cdot 100$).

Like `ZFITTER`, `CalcPHEP` is meant to be a tool for precision calculations of pseudo- and realistic observables.

2. Basics: The Lagrangian in R_ξ gauge, Feynman Rules

$$\mathcal{L} = \mathcal{L}(\text{IPS of 25 parameters, fields, } \xi_A,\ \xi_Z,\ \xi)$$

the propagator of a fermion, f:

f $\qquad \dfrac{-i\not{p} + m_f}{p^2 + m_f^2}$

vector boson propagators:

A  $\qquad \dfrac{1}{p^2}\left\{\delta_{\mu\nu} + \left(\xi_A^2 - 1\right)\dfrac{p_\mu p_\nu}{p^2}\right\}$

Z  $\qquad \dfrac{1}{p^2 + M_Z^2}\left\{\delta_{\mu\nu} + \left(\xi_Z^2 - 1\right)\dfrac{p_\mu p_\nu}{p^2 + \xi_Z^2 M_Z^2}\right\}$

$W^\pm$  $\qquad \dfrac{1}{p^2 + M_W^2}\left\{\delta_{\mu\nu} + \left(\xi^2 - 1\right)\dfrac{p_\mu p_\nu}{p^2 + \xi^2 M_W^2}\right\}$

propagators of unphysical fields:

Y^A $\qquad \dfrac{\xi_A}{p^2}$

ϕ^0 $\qquad \dfrac{1}{p^2 + \xi_Z^2 M_Z^2}\,,$

Y^Z $\qquad \dfrac{\xi_Z}{p^2 + \xi_Z^2 M_Z^2}$

$\phi^\pm$ $\qquad \dfrac{1}{p^2 + \xi^2 M_W^2}\,,$

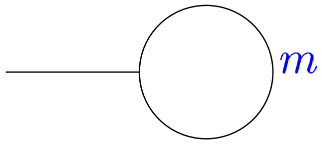
$X^\pm$ $\qquad \dfrac{\xi}{p^2 + \xi^2 M_W^2}$

propagator of the physical scalar field, H-boson:

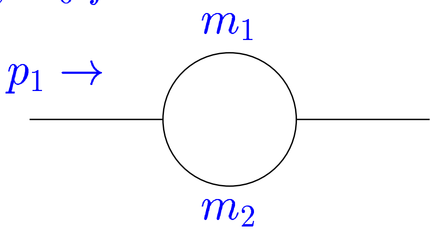
H $\qquad \dfrac{1}{p^2 + M_H^2}$

Basics: Passarino–Veltman functions and reduction

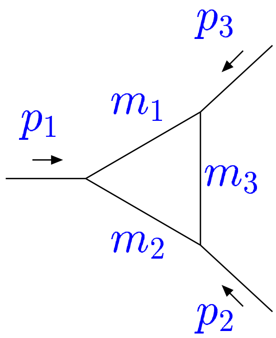
One-point integrals, A_0-functions



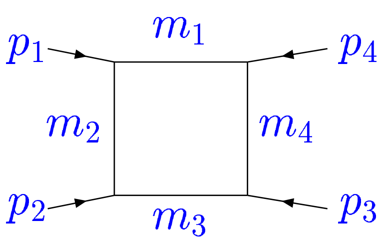
Two-point integrals, B_0-functions



Three-point integrals, C_0-functions



Four-point integrals, D_0-functions



Presently, **`CalcPHEP`** knows ALL up to third rank tensorial reduction of up to four-point PV functions and the so-called *special* PV functions: a_0, b_0, c_0 and d_0, which are due to particular form of photonic propagator in R_ξ gauge.

A **`fortran`** *library for numerical calculation of these functions is created and thoroughly tested by means of comparison with the other codes.*

3. Present Status of the project

Basic information about `CalcPHEP`

- **Four-level computer system** for automatic calculation of pseudo- and realistic observables (decay rates, event distributions) for more and more complicated processes of elementary particle interactions, using the principle of knowledge storing. Flow chart illustrates how it works for calculation of simplest pseudo-observables: $H(Z,W) \to f_1 \bar{f}_2$ decay rates:

  1. from $\mathcal{L}_{SM}$ to the Ultra Violet free amplitudes (all in `form3`);
     - calculation of Scalar Form Factors, **SFF**;
     - analytic calculation of the **Soft** and **Hard** contributions to decay rates;
     - calculation of Helicity Amplitudes, **HA**;
  2. an **s2n.f** software generates automatically the `fortran` codes, here for $\Gamma^{(1)} = \Gamma^{\rm Born} + \Gamma^{\rm Virt} + \Gamma^{\rm Soft} + \Gamma^{\rm Hard}$;
  3. HAs are generated for an accompanying Bremsstrahlung process, **HA-Br**, here $H(Z,W) \to f_1 \bar{f}_2 \gamma$ (`form3`);
  4. the latter are used in a Monte Carlo event generator to produce distributions ('manually written' `fortran` code for the time being).

- **Internet based**
- **Database based,** i.e. a storage of source codes written in several languages, which talk to each other, placed into a homogeneous environment written in JAVA (linker).
- **Principle of intermediate access,** full chain 'from the Lagrangian to realistic distribution' should work out in real time, **in principle**, however, it has several 'entries', e.g. after each level, or just for accessing its final product.
- **Supported by:**
  - INTAS – with Universities of Karlsruhe (W.Hollik) and Torino (G. Passarino);
  - NATO – with Knoxville–Krakow collaboration (S. Jadach, Z Was and B. Ward);
  - Collaboration with theorists of INR and IHEP is foreseen.
- **Present status:**
  - **v0.01, March 2001** – realizes a part of analytic calculations of Level-1 (the SFF) for decays $H(Z,W) \to f_1\bar{f}_2$ (demostration of reliability);
  - several versions **v0.02c/d** – towards realization of levels 1–4 for decays $H(Z,W) \to f_1\bar{f}_2$ (test versions);

– **v0.03** – realizes the full chain of calculations, returns numbers and distributions for the decay widths at one-loop level (as shown today) to be demonstrated by the end of June at ACAT'2002 in Moscow;

– **v0.10** – one has very many almost finished 'preparations' for processes $2 \to 2$ and decays $1 \to 3$ (levels 1–2), *eett* – just one example.

Publications:

[1] D. Bardin, L. Kalinovskaya and G. Nanava, 'An electroweak library for the calculation of EWRC to $e^+e^- \to f\bar{f}$ within the `CalcPHEP` project', `hep-ph/0012080`, revised version, November 2001, CERN-TH/2001-308.

[2] D. Bardin, L. Kalinovskaya and F. Tkachov, 'New algebraic–numeric methods for loop integrals: Some 1-loop experience', `hep-ph/0012209`, published in Tver'2000 Proceedings.

[3] Dmitri Bardin, '12 years of precision calculations for LEP. What's next?', `hep-ph/0101295`, published in Sirlin's Symposium Proceedings.

[4] D. Bardin, P. Christova, L. Kalinovskaya and G. Passarino, 'Atomic Parity Violation and Precision Physics', `hep-ph/0102233`, EPJC.

[5] A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya and G. Nanava, 'Project `CalcPHEP`: Calculus for Precision High Energy Physics', `hep-ph/0202004`, published in CAAP'2001 Proceedings.

[6] A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya and G. Nanava, 'Further study of the $e^+e^- \to f\bar{f}$ process with the aid of the `CalcPHEP` system', `hep-ph/0202112`, February 2002, CERN-TH/2002-068, together with [1] to be published in *Particles and Nuclei.*

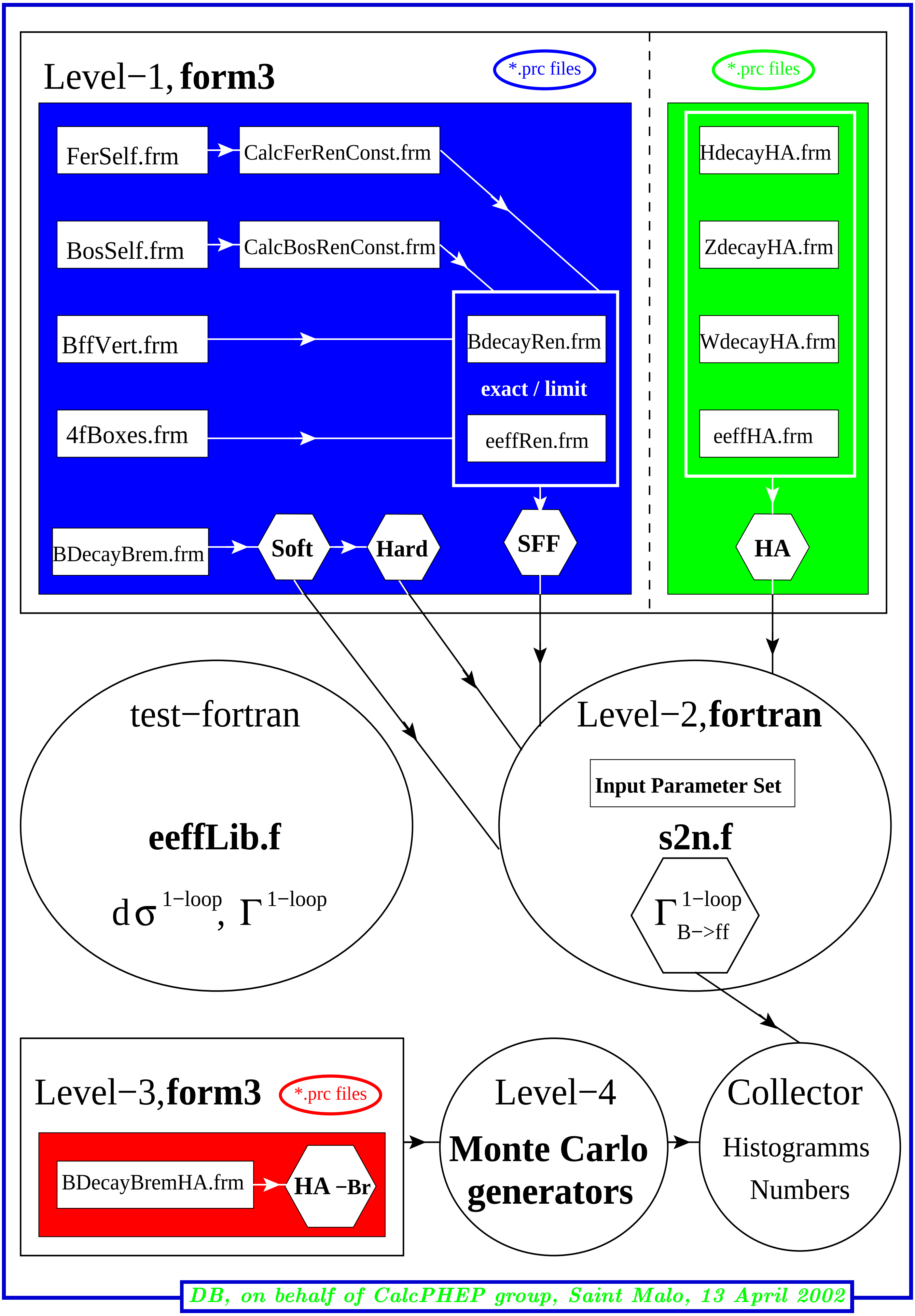
Some technical data about `CalcPHEP`

- address *http://brg.jinr.ru/*
- for realization of the site one used:
  - Apache web server under Linux;
  - **`form3`** compiler (because the 'book heritage' was in form);
  - mySQL server for relational databases (because of simplicity of syntaxes, reliability and high speed);
- In the version 0.01, user-interface was realized with the use of PHP (hypertext preprocessor);
- Nowadays, everything is rewritten in JAVA in order to reach better 'interactivity' and to use reach possibilities of already written in this language libraries.

  Main goal of this rewriting was to create a homogeneous environment both for accessing our codes from the database and for offering a possibility for simultaneous work of several members of the group and external users.

Basic unsolved problems

- Automatic generation of Feynman Rules from a Lagrangian;
- Automatic generation of topologies of Feynman diagrams;
- User support (help, graphical representation of results).



Level−1, form3
*.prc files
*.prc files
FerSelf.frm
CalcFerRenConst.frm
BosSelf.frm
CalcBosRenConst.frm
BffVert.frm
BdecayRen.frm
exact / limit
4fBoxes.frm
eeffRen.frm
BDecayBrem.frm
Soft
Hard
SFF
HdecayHA.frm
ZdecayHA.frm
WdecayHA.frm
eeffHA.frm
HA
test−fortran
eeffLib.f
$d\sigma^{1-loop}$, Γ^{1-loop}
Level−2,fortran
Input Parameter Set
s2n.f
$\Gamma^{1-loop}_{B->ff}$
Level−3,form3
*.prc files
BDecayBremHA.frm
HA −Br
Level−4
Monte Carlo generators
Collector
Histogramms
Numbers
DB, on behalf of CalcPHEP group, Saint Malo, 13 April 2002

FerSelf.frm

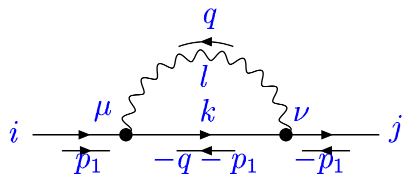


Figure 1: Two Point Fermionic Diagrams.

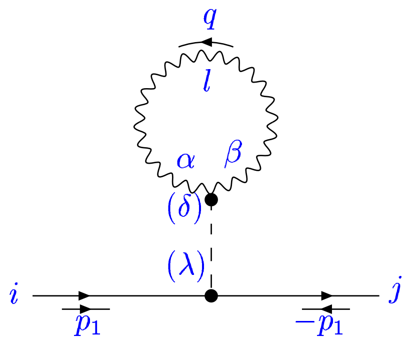


Figure 2: Tadpoles. Bosonic part.

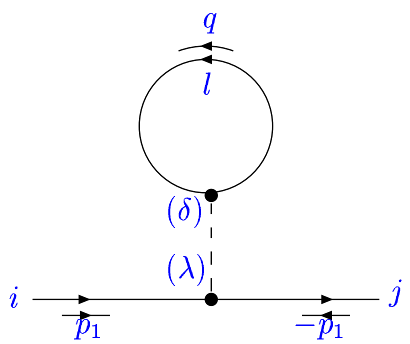


Figure 3: Tadpoles. Fermionic part.

DB, on behalf of CalcPHEP group, Saint Malo, 13 April 2002

BosSelf.frm

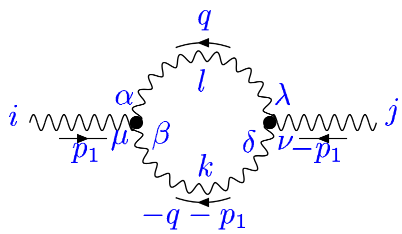


Figure 4: Self energy. Two point bosonic diagrams.

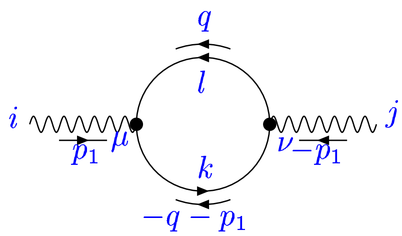


Figure 5: Self energy. Two point bosonic diagrams, fermionic component.

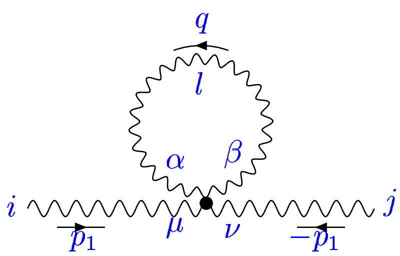


Figure 6: Self energy. One point bosonic diagrams.

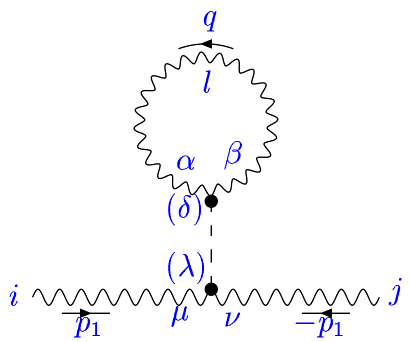


Figure 7: Tadpoles. Bosonic part.

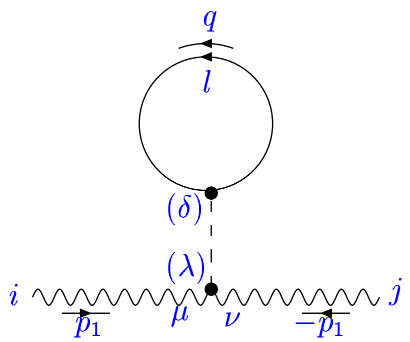


Figure 8: Tadpoles. Fermionic part.

BffVert.frm

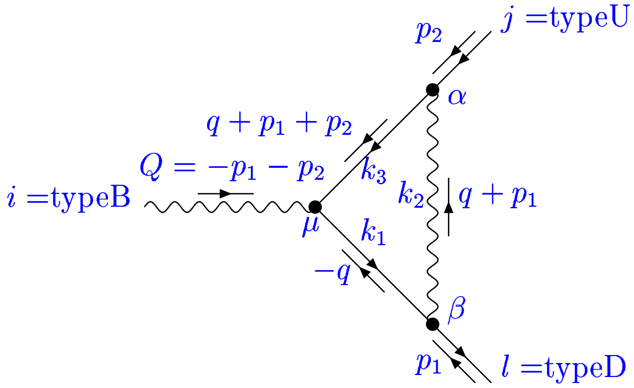


Figure 9: Vertex, FBF-topology.

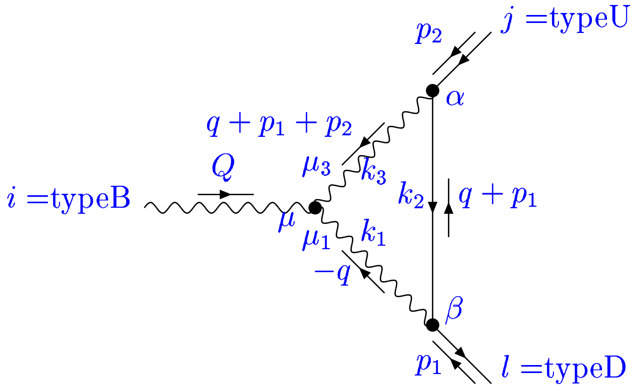


Figure 10: Vertex, BFB-topology.

4. Concluding remarks

A new frontier is at the horizon: most likely it is goodbye to the one man show. Running a new Radiative Correction project will be a little like running an experiment.

Giampiero Passarino,

"Precision Physics Near LEP Shutdown and Evolutionary Developments"

Talk presented at

50 Years of Electroweak Physics

A symposium in honor of Professor

Alberto Sirlin's 70th Birthday

October 27-28, 2000

CalcPHEP – ***apparently a long term project***

First phase of the project should be completed by June'2002 with eventual release of an official **version 0.03**.
Upon completion of **the second phase** of the project with duration of about three years we hope to have a complete software product, accessible via an Internet-based environment, and realizing the chain of calculations 'from the Lagrangian to the realistic distributions' at the one-loop level precision including processes $2 \to 3$ and decays $1 \to 4$. Plans for this period assume $R\&D$ for **the third phase** of the project, which goals are not yet defined.
To add to the site more processes as soon as possible!