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Project CalcPHEP: Calculus for Precision High Energy Physics

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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.

In collaboration on MC issues with:
S. Jadach, Z. Was – INF Krakow and B.F.L. Ward – Knoxville University.

`CalcPHEP` – 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: $1 \to 2$, $1 \to 3$, $2 \to 2$, $1 \to 4$, $2 \to 3$... Application: LHC, Linacs;
2. works towards two-loop precision level control of HEP observables for simple processes: $1 \to 2$... Application: GigaZ option of LC.

Two roots of `CalcPHEP`:

1. Codes aimed at a theoretical support of HEP experiments:

   1983 – 1989: BCDMS – **`TERAD`**; CHARM-I(II), CDHSW – **`NUDIS1(2), INVMUD, NUFITTER`**;

   1989 – 1997: HERA – **`HECTOR`**; SMC – μela;

   1989 – 2001: Theoretical support of experiments at LEP, SLC – **`ZFITTER`** and **`GENTLE`**.

2. Book DB and 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 : $\dfrac{-i\not{p} + m_f}{p^2 + m_f^2}$

vector boson propagators:

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

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

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

propagators of unphysical fields:

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

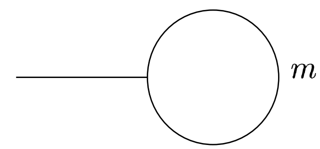
ϕ^0 : $\dfrac{1}{p^2 + \xi_Z^2 M_Z^2}$, Y^Z : $\dfrac{\xi_Z}{p^2 + \xi_Z^2 M_Z^2}$

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

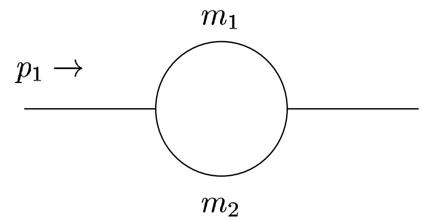
propagator of the physical H field: H : $\dfrac{1}{p^2 + M_H^2}$

2. Basics: Passarino–Veltman functions and reduction

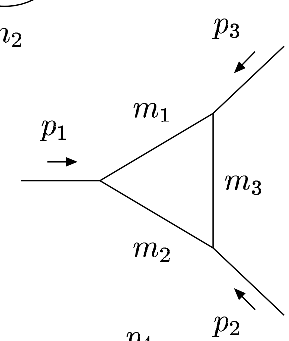
One-point integrals, A_0-functions



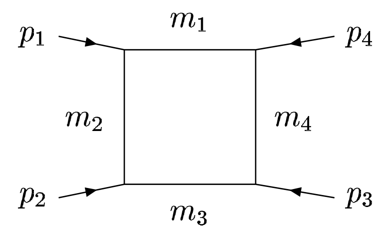
Two-point integrals, B_0-functions



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.*

2. Basics: Amplitude's basis, Scalar Form Factors (SFF), Helicity Amplitudes (HA)

Decays B(Q)$\to f(p_1)\overline{f}(p_2)$

$H \to f\overline{f}$ decay – $\mathcal{A} \propto I\mathcal{F}_S$
1 structure (**I–basis**), **1 SFF**, **1 HA**

$Z \to f\overline{f}$ decay – $\mathcal{A} \propto i\gamma_\mu\gamma_6\mathcal{F}_{\mathbf{L}} + i\gamma_\mu\mathcal{F}_{\mathbf{Q}} + m_f\,(p_1-p_2)_\mu\,\mathcal{F}_{\mathbf{D}}$
3 structures (**L,Q,D–basis**), **3 SFFs**, **3 HAs**

$W \to u\overline{d}$ decay – $\mathcal{A} \propto i\gamma_\mu\gamma_6\mathcal{F}_{\mathbf{L}} + i\gamma_\mu\gamma_7\mathcal{F}_{\mathbf{R}} + m_u\,(p_1-p_2)_\mu\,\gamma_6\mathcal{F}_{\mathbf{LD}} + m_d\,(p_1-p_2)_\mu\,\gamma_7\mathcal{F}_{\mathbf{RD}}$
4 structures (**L,R,LD,RD–basis**), **4 SFFs**, **4 HAs**

The **3 HAs** depend on kinematical factors, coupling constants and **3 SFFs**,

$$\mathbf{A}^{\mathbf{Z}}_{\mathbf{0}++} = \mathbf{A}^{\mathbf{Z}}_{\mathbf{0}--} = \frac{g m_f}{c_W}\left[a_f\mathcal{F}_{\mathbf{L}} + \delta_f\mathcal{F}_{\mathbf{Q}} + \frac{1}{2}a_f\beta_f^2 M_Z^2\mathcal{F}_{\mathbf{D}}\right]$$

$$\mathbf{A}^{\mathbf{Z}}_{++-} = \frac{g M_Z}{\sqrt{2}c_W}\left[a_f(1-\beta_f)\mathcal{F}_{\mathbf{L}} + \delta_f\mathcal{F}_{\mathbf{Q}}\right]$$

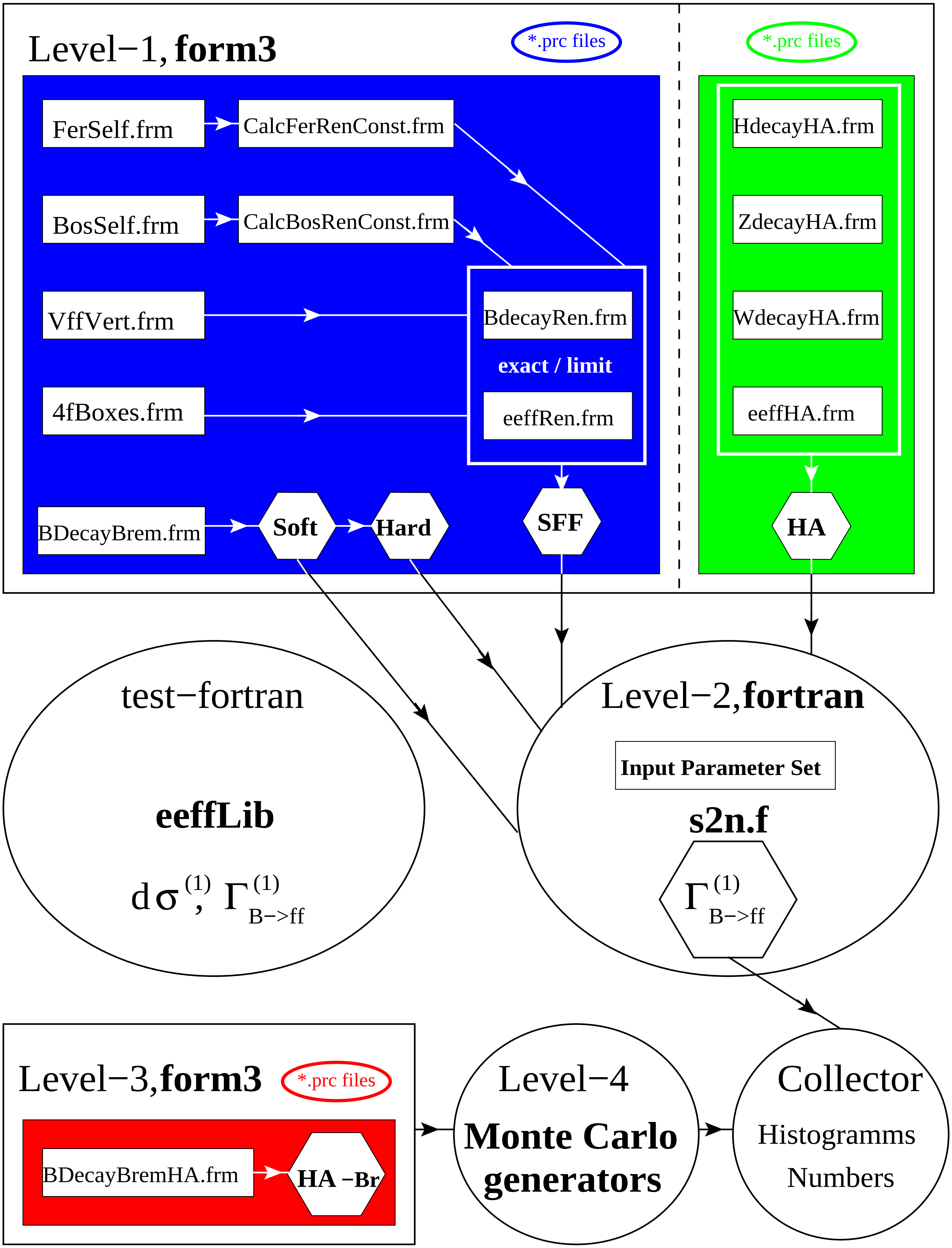
$$\mathbf{A}^{\mathbf{Z}}_{--+} = \frac{g M_Z}{\sqrt{2}c_W}\left[a_f(1+\beta_f)\mathcal{F}_{\mathbf{L}} + \delta_f\mathcal{F}_{\mathbf{Q}}\right]$$

$$\beta_f^2 = 1 - 4\frac{m_f^2}{M_Z^2}, \qquad \delta_f = v_f - a_f = -2Q_f s_W^2, \qquad a_f = I_f^{(3)}.$$

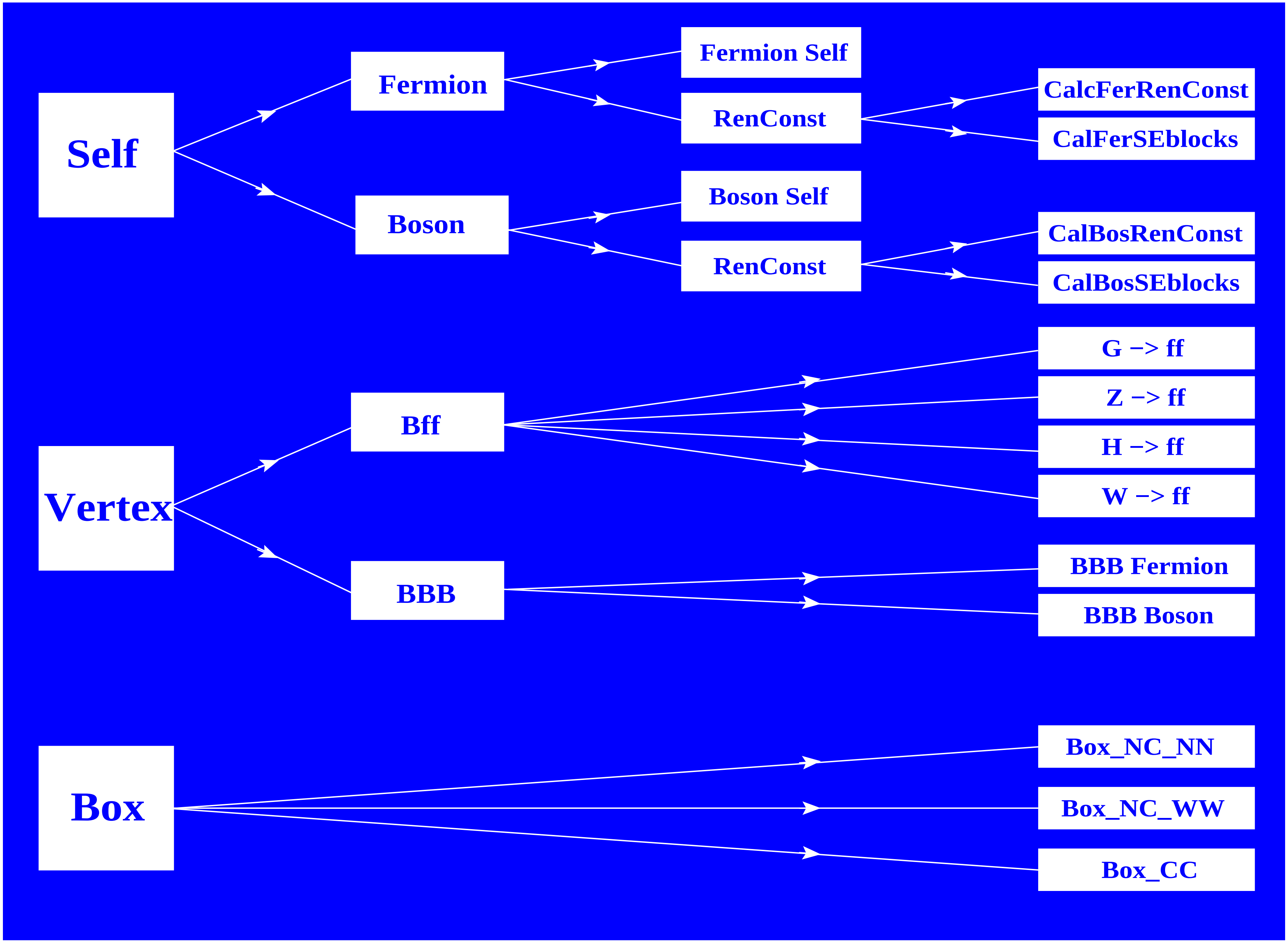
3. Present Status of the project

Basic information about `CalcPHEP`

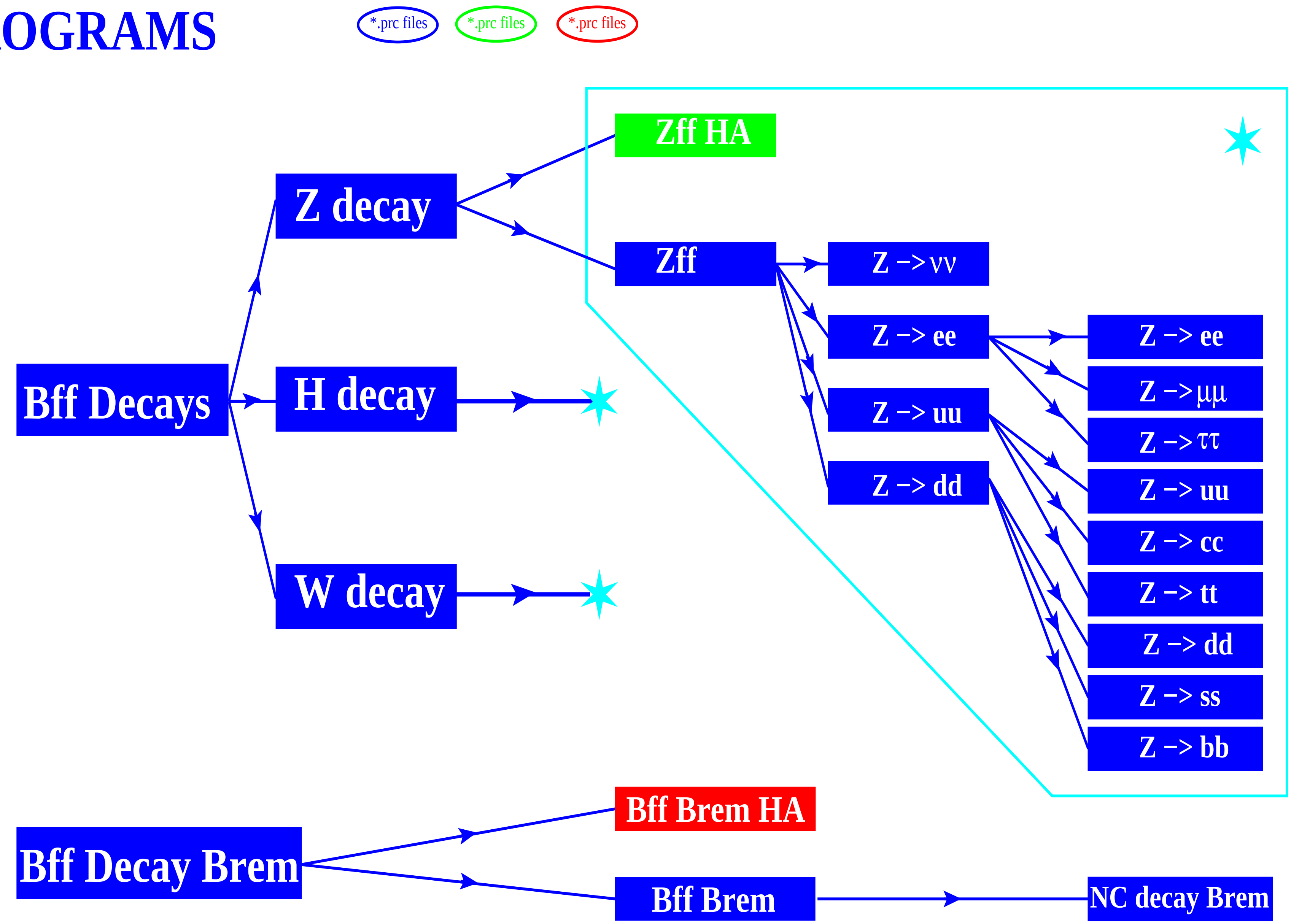
- **Four-level computer system** for automatic calculation of pseudo- and realistic observables (decay rates, event distributions) for more and more complicated processes of elementary particle interactions, using the principle of knowledge storing. *Flow chart* illustrates how it works for calculation 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** photons contributions to the decay rates;
     - calculation of Helicity Amplitudes, **HA**;
  2. an **s2n.f** software generates the `fortran` codes for $\Gamma^{(1)} = \Gamma^{\rm Born} + \Gamma^{\rm Virt} + \Gamma^{\rm Soft} + \Gamma^{\rm Hard}$;
  3. **HAs** are generated for an accompanying Bremsstrahlung, **HA-Br**, $H(Z,W) \to f_1 \bar{f}_2 \gamma$;
  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 being 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.


Level−1, form3
*.prc files
*.prc files
FerSelf.frm
CalcFerRenConst.frm
BosSelf.frm
CalcBosRenConst.frm
VffVert.frm
BdecayRen.frm
exact / limit
4fBoxes.frm
eeffRen.frm
HdecayHA.frm
ZdecayHA.frm
WdecayHA.frm
eeffHA.frm
BDecayBrem.frm
Soft
Hard
SFF
HA
test−fortran
eeffLib
dσ^(1), Γ^(1)_B−>ff
Level−2, fortran
Input Parameter Set
s2n.f
Γ^(1)_B−>ff
Level−3, form3
*.prc files
BDecayBremHA.frm
HA −Br
Level−4
Monte Carlo generators
Collector
Histogramms
Numbers

*.prc files


Self
Fermion
Fermion Self
RenConst
CalcFerRenConst
CalFerSEblocks
Boson
Boson Self
RenConst
CalBosRenConst
CalBosSEblocks
Vertex
Bff
G -> ff
Z -> ff
H -> ff
W -> ff
BBB
BBB Fermion
BBB Boson
Box
Box_NC_NN
Box_NC_WW
Box_CC

PROGRAMS


*.prc files
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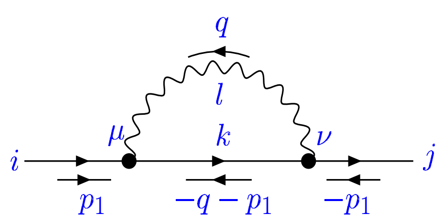
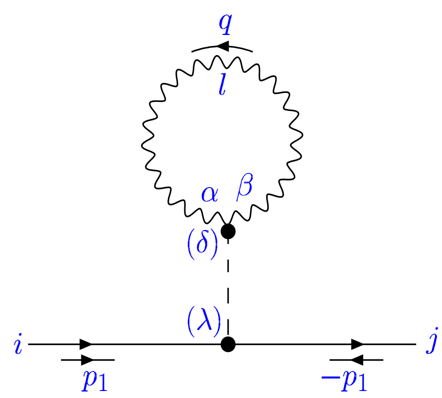
Zff HA
Z decay
Zff
Z −> νν
Z −> ee
Z −> uu
Z −> dd
Z −> ee
Z −> μμ
Z −> ττ
Z −> uu
Z −> cc
Z −> tt
Z −> dd
Z −> ss
Z −> bb
Bff Decays
H decay
W decay
Bff Decay Brem
Bff Brem HA
Bff Brem
NC decay Brem

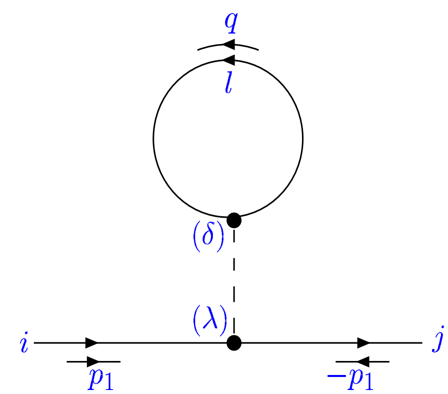
Chain: Self → Fermion → Fermion Self



Two point fermionic diagrams.

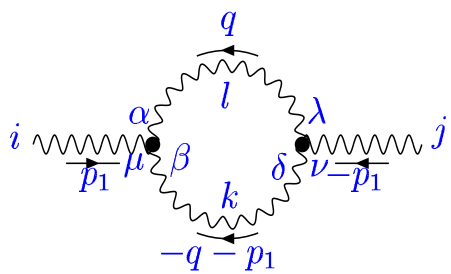


Tadpoles: bosonic part,

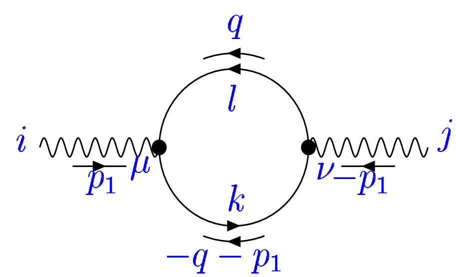


fermionic part

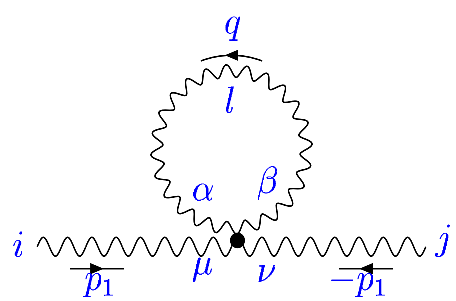
Chain: Self → Boson → Boson Self



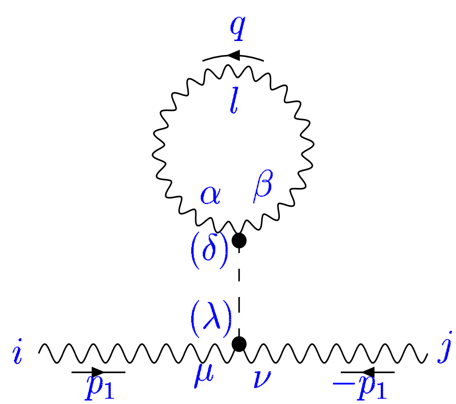
Two point bosonic diagrams,



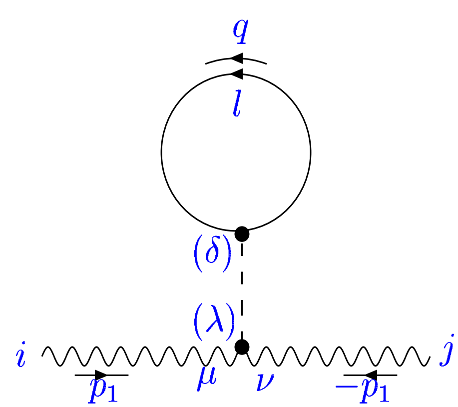
fermionic component



One point bosonic diagrams.

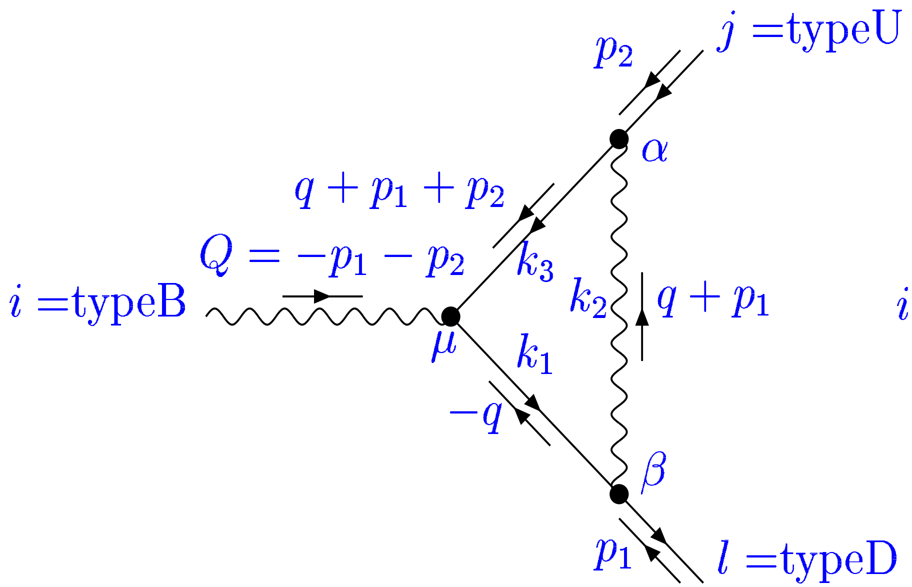


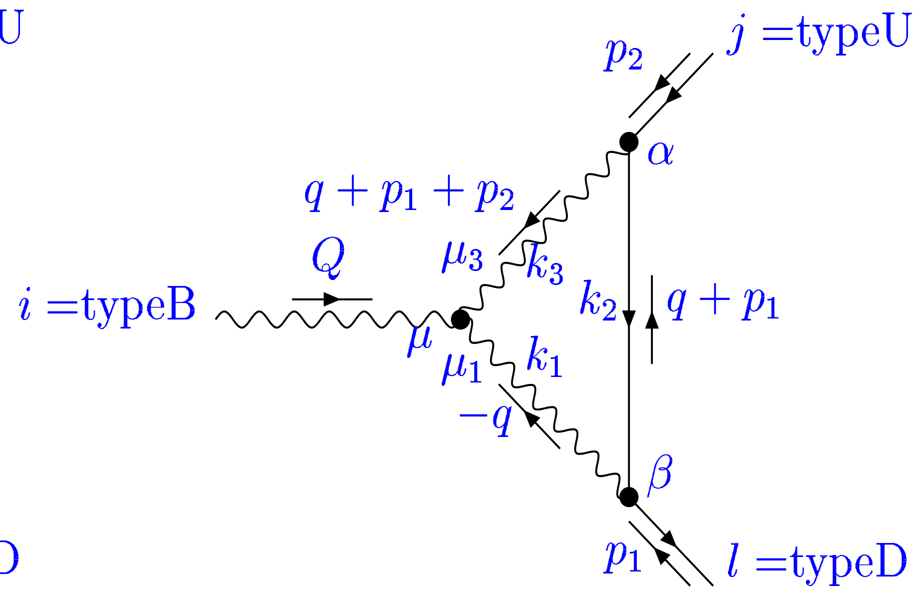
Tadpoles: bosonic part,



fermionic part

Chain: Vertex → Bff → B→ff





Vertices: FBF-topology, BFB-topology.

3. Present Status of the project (cont.)

- **Present status:**
  - **v0.01, March 2001** – realizes a part of analytic calculations of Level-1 (SFFs) for the 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 $H(Z,W) \to f_1\bar{f}_2$;
  - **v0.03, Summer 2002** – realizes the full chain of calculations, returns numbers and distributions for the decay widths at one-loop level (we intended to demonstrate it here...);
  - **v0.10, near future** – one has very many almost finished 'preparations' for processes $2 \to 2$ and decays $1 \to 3$ (levels 1–2), see poster by L. Kalinovskaya.

- **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`, Tver'2000 Proceedings, Moscow 2001.

[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`, EPJ, **C22** (2001) 99.

[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`, CAAP-2001 Proceedings, Dubna 2001.

[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.

[7] A. Andonov, D. Bardin, S. Bondarenko, P. Christova, L. Kalinovskaya and G. Nanava, 'Update of one-loop corrections for $e^+e^- \to f\bar{f}$, first run of `CalcPHEP` system', *to appear in Particles and Nuclei.*

3. Present Status of the project (cont.)

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 **`form2`**);
  - mySQL server for relational databases (simplicity of syntaxes, reliability and high speed);
  - **`s2n`** software is written in **`PERL`**;
- In the version 0.01, user-interface was realized with the use of PHP (hypertext preprocessor);
- Nowadays, the user-interface is rewritten in JAVA (web server is being rewritten in JAVA) in order to reach better 'interactivity' and to use reach possibilities of already written JAVA libraries. **Main goal of this rewriting – to create a homogeneous environment 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).

4. Concluding remarks

CalcPHEP – *apparently a long term project*

First phase should be completed by fall'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.

Program and milestones for the first year of the second phase

There are intentions to realize in 2003–2005 an important phase of CalcPHEP project: oriented toward a merger of analytic results to be produced by Dubna team with MC event generators developed by Knoxville–Krakow collaboration [a].

Milestones of first year of the second phase:

1. completion of implementation of $2f \to 2f$ processes;
2. realization of the level 1 for the radiative Z decay, $Z \to f\bar{f}\gamma$, work which is already under way;
3. completion of levels 2–4 for the radiative Z decay.

[a] In this connection it is necessary to emphasize that any future code aimed at a comparison of experimental data with theory predictions should be a MC generator, since the processes at very high energies will have multi-particle final states that make impossible a semi-analytic approach used at LEP within ZFITTER project.