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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:
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In collaboration on MC issues with:

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:
   \(1 \rightarrow 2, 1 \rightarrow 3, 2 \rightarrow 2, 1 \rightarrow 4, 2 \rightarrow 3\)… Application: LHC, Linacs;
2. works towards two-loop precision level control of HEP observables for simple processes:
   \(1 \rightarrow 2\)… Application: GigaZ option of LC.

Two roots of CalcPHEP:

1. Codes aimed at a theoretical support of HEP experiments:
   \(1983 – 1989\): BCDMS – \textsc{terad}; CHARM-I(II), CDHSW – \textsc{nuDIS1(2)}, \textsc{invmud}, \textsc{nuFitter};
   \(1989 – 1997\): HERA – \textsc{hector}; SMC – \textsc{muela};
   \(1989 – 2001\): Theoretical support of experiments at LEP, SLC – \textsc{ZFITTER} and \textsc{gentle}.
   form-codes (\(\sim n \cdot 100\)).

\textit{Like \textsc{ZFITTER}, CalcPHEP is meant to be a tool for precision calculations of pseudo-
and realistic observables.}
2. Basics: The Lagrangian in $R_\xi$ gauge, Feynman Rules

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

the propagator of a fermion, \[ f : \quad \frac{-i\not{p} + m_f}{p^2 + m_f^2} \]

vector boson propagators:

\[ A : \quad \frac{1}{p^2} \left\{ \delta_{\mu\nu} + \left( \xi_A^2 - 1 \right) \frac{p_\mu p_\nu}{p^2} \right\} \]

\[ Z : \quad \frac{1}{p^2 + M_Z^2} \left\{ \delta_{\mu\nu} + \left( \xi_Z^2 - 1 \right) \frac{p_\mu p_\nu}{p^2 + \xi_Z^2 M_Z^2} \right\} \]

\[ W^\pm : \quad \frac{1}{p^2 + M_W^2} \left\{ \delta_{\mu\nu} + \left( \xi^2 - 1 \right) \frac{p_\mu p_\nu}{p^2 + \xi^2 M_W^2} \right\} \]

propagators of unphysical fields:

\[ Y^A : \quad \frac{\xi_A}{p^2} \]

\[ \phi^0 : \quad \frac{1}{p^2 + \xi_Z^2 M_Z^2} \]

\[ Y^Z : \quad \frac{\xi_Z}{p^2 + \xi_Z^2 M_Z^2} \]

\[ \phi^\pm : \quad \frac{1}{p^2 + \xi_Z^2 M_Z^2} \]

\[ X^\pm : \quad \frac{\xi}{p^2 + \xi^2 M_W^2} \]

propagator of the physical $H$ field:

\[ H : \quad \frac{1}{p^2 + M_H^2} \]
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 $R_\xi$ 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 $B(Q) \rightarrow f(p_1)\bar{f}(p_2)$

$H \rightarrow f\bar{f}$ decay $-$ $A \propto IF_s$
1 structure (I–basis), 1 SFF, 1 HA

$Z \rightarrow f\bar{f}$ decay $-$ $A \propto i\gamma_\mu\gamma_6F_L + i\gamma_\mu F_Q + m_f(p_1 - p_2)_\mu F_D$
3 structures (L,Q,D–basis), 3 SFFs, 3 HAs

$W \rightarrow ud$ decay $-$ $A \propto i\gamma_\mu\gamma_6F_L + i\gamma_\mu\gamma_7F_R + m_u(p_1 - p_2)_\mu \gamma_6F_{LD} + m_d(p_1 - p_2)_\mu \gamma_7F_{RD}$
4 structures (L,R,LD,RD–basis), 4 SFFs, 4 HAs

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

\[
A_{0++}^z = A_{0--}^z = \frac{gm_f}{c_w} \left[ a_f F_L + \delta_f F_Q + \frac{1}{2} a_f \beta_f^2 M_Z^2 F_D \right]
\]

\[
A_{++--}^z = \frac{gM_Z}{\sqrt{2}c_w} \left[ a_f (1 - \beta_f) F_L + \delta_f F_Q \right]
\]

\[
A_{--++}^z = \frac{gM_Z}{\sqrt{2}c_w} \left[ a_f (1 + \beta_f) F_L + \delta_f F_Q \right]
\]

\[
\beta_f^2 = 1 - 4\frac{m_f^2}{M_Z^2}, \quad \delta_f = v_f - a_f = -2Q_f s_W^2, \quad a_f = I_f^{(3)}.
\]
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: \( H(Z, W) \rightarrow f_1\bar{f}_2 \) decay rates:

1. from \( L_{SM} \) 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 \( \Gamma^{(1)} = \Gamma^{\text{Born}} + \Gamma^{\text{Virt}} + \Gamma^{\text{Soft}} + \Gamma^{\text{Hard}} \);

3. **HAs** are generated for an accompanying Bremsstrahlung, **HA-Br**, \( H(Z, W) \rightarrow f_1\bar{f}_2\gamma \);

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

FerSelf.frm → CalcFerRenConst.frm
BosSelf.frm → CalcBosRenConst.frm
VffVert.frm → BdecayRen.frm
4fBoxes.frm → eeffRen.frm
BDecayBrem.frm → Soft
CalcFerRenConst.frm → Hard
CalcBosRenConst.frm → SFF

exact / limit

HA

Level−2, fortran

Input Parameter Set

s2n.f

Γ(1)_{B->ff}

GammaLib

dσ^{(1)}_{B->ff}

Level−3, form3

BDecayBremHA.frm → HA – Br

Monte Carlo generators

Collector

Histogramms Numbers

CalcPHEP, LNP, JINR D.Bardin, ACAT’2002
PRECOMPUTATION

Self

Fermion

Boson

Fermion Self

RenConst

Boson Self

RenConst

CalcFerRenConst

CalFerSEblocks

CalBosRenConst

CalBosSEblocks

G → ff

Z → ff

H → ff

W → ff

BBB Fermion

BBB Boson

Bff

BBB

Box

Box_NC_NN

Box_NC_WW

Box_CC

*.prc files
Z decay

Bff Decays → H decay → W decay

Bff Decay Brem → Bff Brem HA → NC decay Brem

Zff HA

Z → νν
Z → ee
Z → µµ
Z → ττ
Z → uu
Z → cc
Z → tt
Z → dd
Z → ss
Z → bb

Z → tt

PROGRAMS

*.prc files
Chain: Self $\rightarrow$ Fermion $\rightarrow$ Fermion Self

Two point fermionic diagrams.

Tadpoles: bosonic part, fermionic part
Chain: Self $\rightarrow$ Boson $\rightarrow$ Boson Self

Two point bosonic diagrams, fermionic component

One point bosonic diagrams. Tadpoles: bosonic part, fermionic part
Chain: Vertex \rightarrow Bff \rightarrow B\rightarrow 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 $H(Z, W) \rightarrow f_1 f_2$ (demonstration of reliability);
  - several versions **v0.02c/d** – towards realization of levels 1–4 for decays $H(Z, W) \rightarrow f_1 f_2$;
  - **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 $2 \rightarrow 2$ and decays $1 \rightarrow 3$ (levels 1–2), see poster by L. Kalinovskaya.

- **Publications:**

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.