FCNC Penguin Processes in Models Beyond the SM

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Motivation for this task

LHCb data analysis as indirect search for physics beyond SM

- Measures Flavor Changing Neutral Current processes (suppressed in SM)
- Search deviations or any inconsistency in CKM matrix to observe new physics
  - CKM analysis may prove that something beyond the standard model exists

BSM models are available a lot

- Need for comparison of different models
- Need for check contribution from any new model proposed

Talks by Sajan Easo and Nigel Watson

http://feynrules.irmp.ucl.ac.be/wiki/ModelDatabaseMainPage

FeynRules model database by the authors Claude Duhr, Neil Christensen, Benjamin Fuks and others …

The Standard Model (The SM)	Simple extensions of the SM	Supersymmetric models	Extra-dimensional models	Strongly coupled and effective field theories

The Standard Model: Standard Model of Particle Physics

Simple extensions of the SM: Several models based on the SM that include one or more additional particles, like a 4th generation, a second Higgs doublet or additional colored scalars

Supersymmetric Models: Various supersymmetric extensions of the SM, including the MSSM, the NMSSM and many more

Extra-dimensional Models: Extensions of the SM including KK excitations of the SM particles

Strongly coupled and effective field theories: Including Technicolor, Little Higgs, as well as SM higher-dimensional operators, vector-like quarks

Buras A. J. Weak Hamiltonian, CP Violation and Rare Decays hep-ph/9806471v1

Base of the work

Model dependence of Wilson Coefficients and Operators in effective hamiltonian

$$H_{eff} = \frac{G_F}{\sqrt{2}} \sum_i V_{CKM}^i C_i(\mu) Q_i$$

A more fundamental theory → Effective theory

New Physics may
modify $C_i(\mu)$
add Q_i

Wilson Coefficients

- Calculation of full amplitude
- Calculation of Matrix elements
- Extraction of C_i

The main of the package

Input data

On this step, the FeynArts takes place

Creates ‘topologies’ --> ‘generic’ --> ‘classes’ --> ‘particle level’

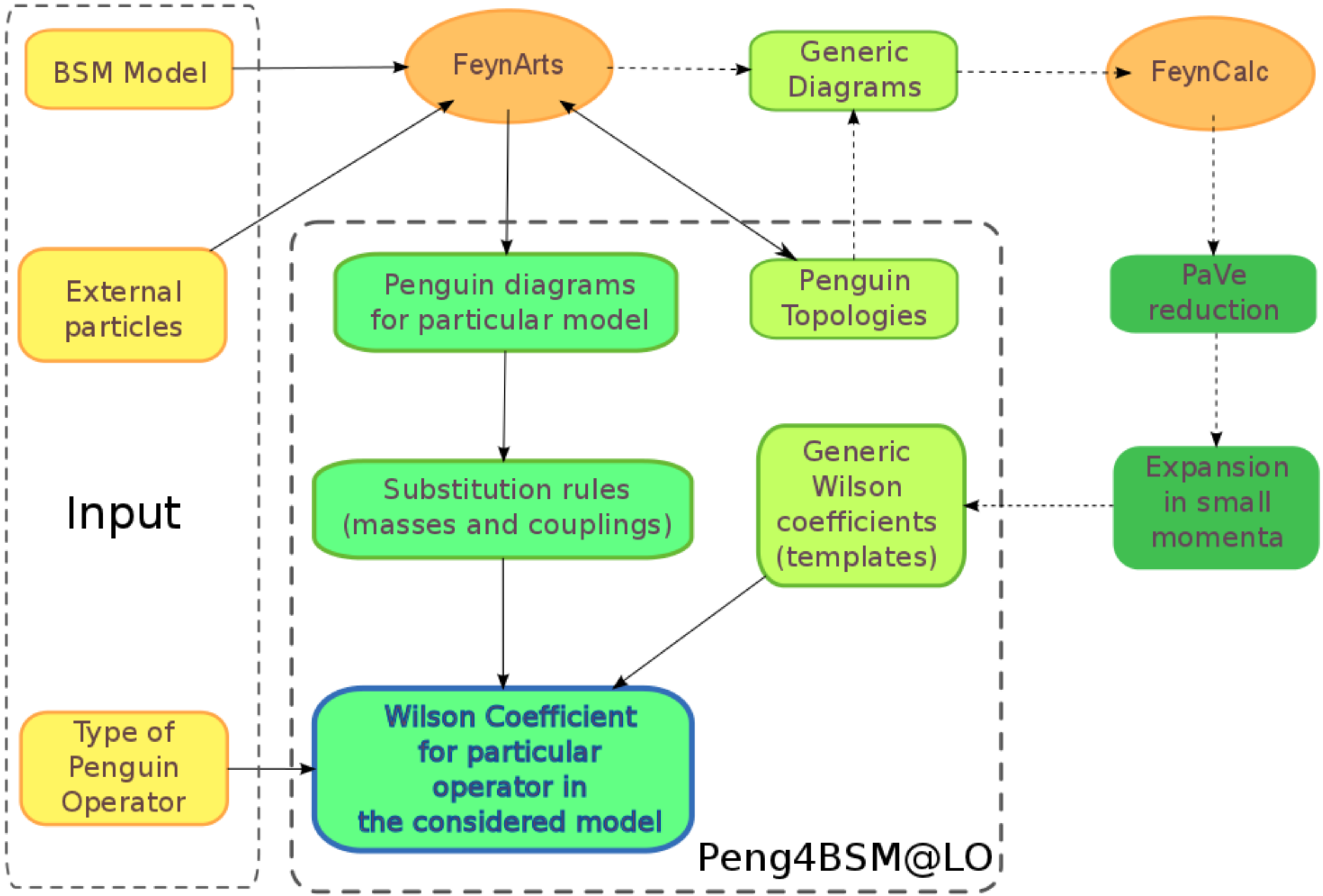
Creates ‘amplitudes’

from generic
from classes
or from the particle level

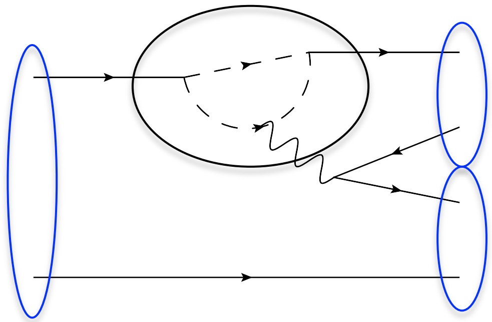
FeynCalc reformulate the amplitudes in terms of functions of Passarino-Veltman reduction

The package files include information how it should separate Q_i and respectively C_i

Separated form of amplitude transfarred to the main ‘package’


BSM Model
FeynArts
Generic Diagrams
FeynCalc
External particles
Penguin diagrams for particular model
Penguin Topologies
PaVe reduction
Substitution rules (masses and couplings)
Generic Wilson coefficients (templates)
Expansion in small momenta
Input
Type of Penguin Operator
Wilson Coefficient for particular operator in the considered model
Peng4BSM@LO

Quark level transition



Electromagnetic-monopole terms

$$\left(\overline{\psi}'_a \gamma^{\mu} P_{L,R} \psi_b V_{\mu}^{c}\right)\left(E_{a,b}^{0,c}\right)_{L,R}$$

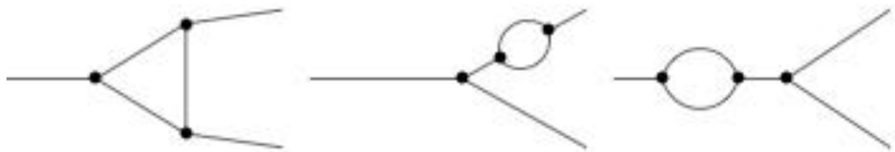
$$\left(\overline{\psi}'_a \gamma^{\mu} P_{L,R} \psi_b V_{\mu}^{c}\right)\left(g^{\mu\nu} q^2 - q^{\mu} q^{\nu}\right) V_{\nu}^{c}\left(E_{a,b}^{2,c}\right)_{L,R}$$

Electromagnetic-dipole terms

$$\left(\overline{\psi}'_a \sigma^{\mu\nu} P_{L,R} \psi_b q_{\mu} V_{\nu}^{c}\right)\left(M_{a,b}^{c}\right)_{L,R}$$

Topology

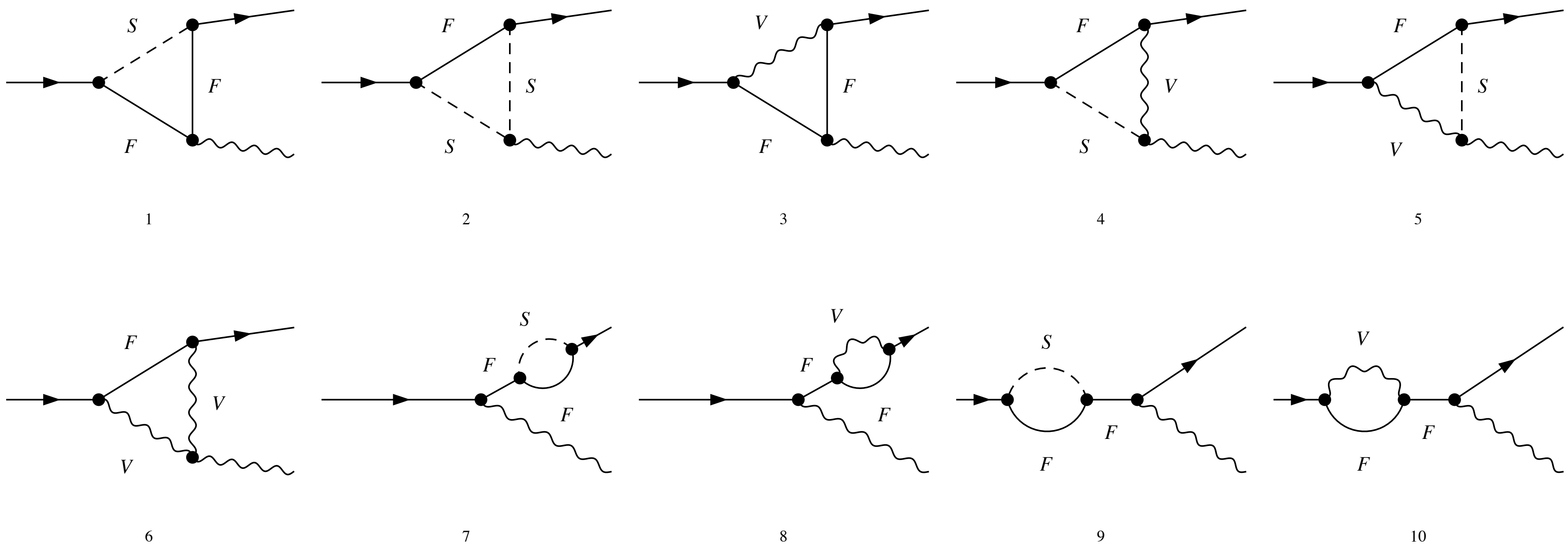
1 → 2



T1 T2 T3

Generic level

$F \rightarrow F' \; V$



Basic functions in Passarino-Veltman reduction

$$A(m_0) = \frac{(2\pi\mu)^{2\varepsilon}}{i\pi^2}\int \frac{d^n k}{N_1} = m_0\left(\Delta - Log\frac{m_0^2}{\mu^2} + 1\right)$$

$$n = 4 - 2\varepsilon$$

$$\left[B_0, B^\mu, B^{\mu\nu}\right] = \frac{(2\pi\mu)^{2\varepsilon}}{i\pi^2}\int \frac{d^n k\left[1, k^\mu, k^{\mu\nu}\right]}{N_1 N_2}$$

$$\Delta = \frac{1}{\varepsilon} - \gamma_E + Log(4\pi)$$

$$\left[C_0, C^\mu, C^{\mu\nu}, C^{\mu\nu\rho}\right] = \frac{(2\pi\mu)^{2\varepsilon}}{i\pi^2}\int \frac{d^n k\left[1, k^\mu, k^{\mu\nu}, k^{\mu\nu\rho}\right]}{N_1 N_2 N_3}$$

$$\left[D_0, D^\mu, D^{\mu\nu}, D^{\mu\nu\rho}\right] = \frac{(2\pi\mu)^{2\varepsilon}}{i\pi^2}\int \frac{d^n k\left[1, k^\mu, k^{\mu\nu}, k^{\mu\nu\rho}, k^{\mu\nu\rho\sigma}\right]}{N_1 N_2 N_3 N_4}$$

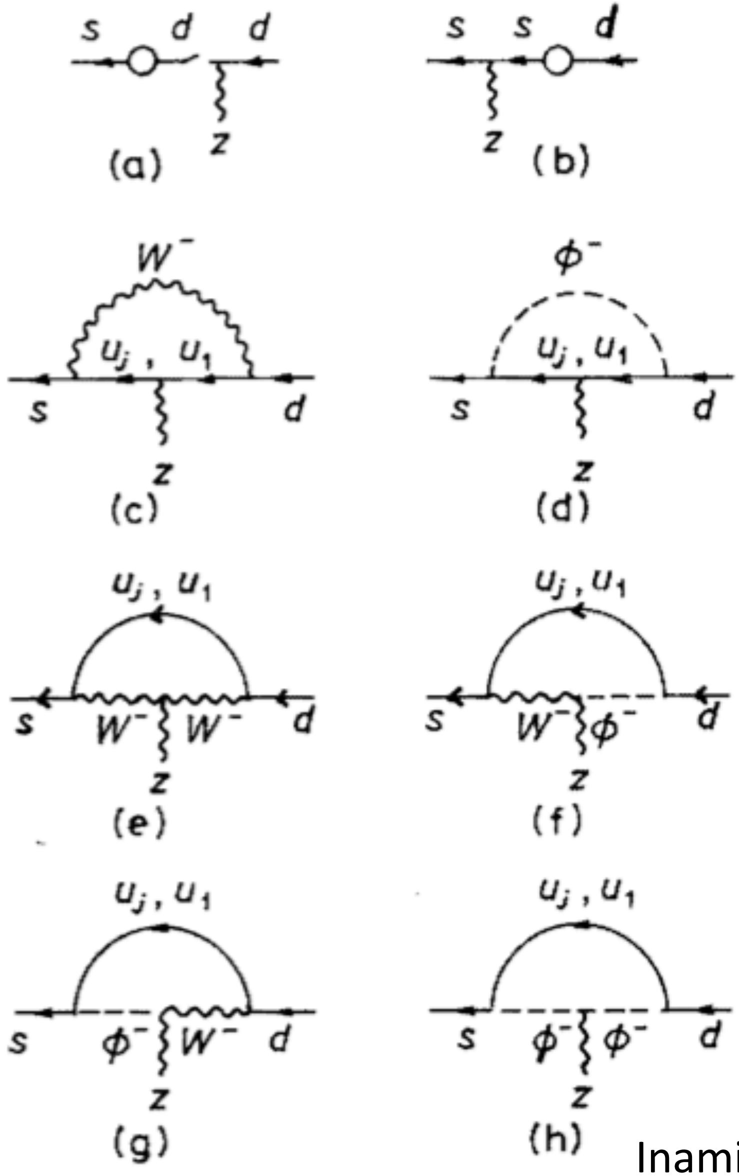
$$N_1 = k^2 - m_0^2 + i\varepsilon$$

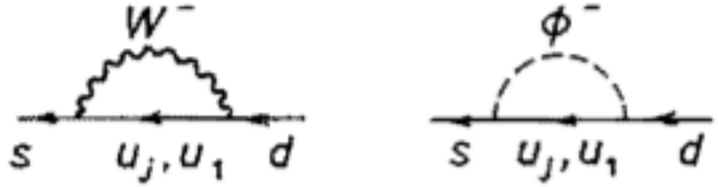
$$N_2 = (k + p_1)^2 - m_1^2 + i\varepsilon$$

$$N_3 = (k + p_1 + p_2)^2 - m_2^2 + i\varepsilon$$

$$N_3 = (k + p_1 + p_2 + p_3)^2 - m_3^2 + i\varepsilon$$

Test of package in low energy weak processes





InF = F[4,{1,o}]; d
OutF = F[4,{2,o}]; s
OutV = V[2]; Z

Inami and Lim, Prog. of Theor. Phys. Vol: 65, p. 297 (1981)

$$\Gamma_{Z\mu}^{(i)} = \frac{1}{(4\pi)^2} \frac{g^3}{Cos\theta_W} V_{js}^* V_{jd} \bar{s}_L \gamma_\mu d_L \Gamma^{(i)}$$

Checking:

EL

- no UV divergence in the end

ER

- no UV divergency in the end
- no contribution to ER

Coefficient to the EL operator at LO

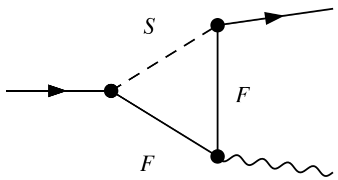
$$\frac{1}{256\pi^2\, CW\, SW^3 \left(x(1)^2-1\right)^2 \left(x(2)^2-1\right)^2} EL^3\, CKM(2,1)\, CKM(2,2)^* \Big(4x(1)^2\left(x(2)^2-1\right)^2\left(6\left(2\,SW^2+2\left(1-SW^2\right)-1\right)x(1)^2+4\right)\log(x(1)) - \left(x(1)^2-1\right) \Big(\left(x(1)^2-x(2)^2\right)\left(x(2)^2-1\right)\Big(SW^2\left(3\left(x(2)^2-1\right)x(1)^2-3x(2)^2-23\right)+\left(1-SW^2\right)\left(3\left(x(2)^2-1\right)x(1)^2-3x(2)^2-23\right)+ 7x(1)^2-7x(1)^2x(2)^2+7x(2)^2-1\Big)+4\left(x(1)^2-1\right)x(2)^2\left(6\left(2\,SW^2+2\left(1-SW^2\right)-1\right)x(2)^2+4\right)\log(x(2))\Big)\Big)$$

$$\mathrm{IndexDelta}(c1,\,c2) + \frac{1}{256\pi^2\, CW\, SW^3 \left(x(1)^2-1\right)^2 \left(x(3)^2-1\right)^2} EL^3\, CKM(3,1)\, CKM(3,2)^* \Big(4x(1)^2\left(x(3)^2-1\right)^2\left(6\left(2\,SW^2+2\left(1-SW^2\right)-1\right)x(1)^2+4\right)\log(x(1)) - \left(x(1)^2-1\right)\Big(\left(x(1)^2-x(3)^2\right)\left(x(3)^2-1\right)\Big(SW^2\left(3\left(x(3)^2-1\right)x(1)^2-3x(3)^2-23\right)+ \left(1-SW^2\right)\left(3\left(x(3)^2-1\right)x(1)^2-3x(3)^2-23\right)+7x(1)^2-7x(1)^2x(3)^2+7x(3)^2-1\Big)+ 4\left(x(1)^2-1\right)x(3)^2\left(6\left(2\,SW^2+2\left(1-SW^2\right)-1\right)x(3)^2+4\right)\log(x(3))\Big)\Big)\,\mathrm{IndexDelta}(c1,\,c2)$$

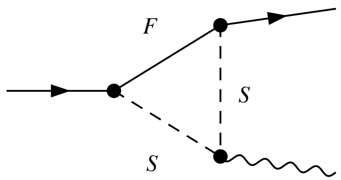
$$x(i)=\frac{m_i}{M_W}$$

Generic level

$F \quad \rightarrow \quad F' \quad V$



1



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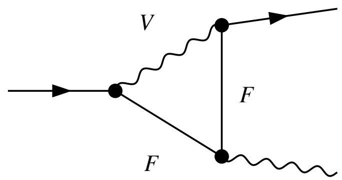

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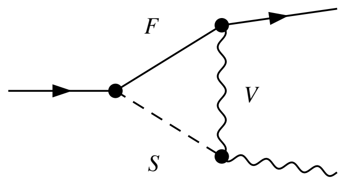

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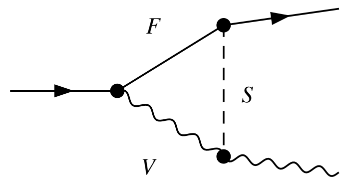

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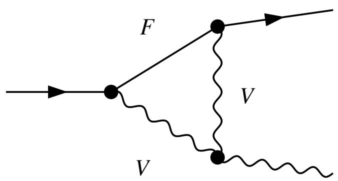

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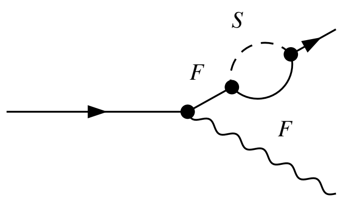

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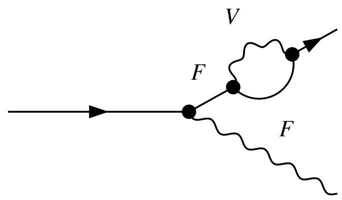

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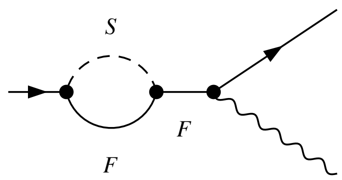

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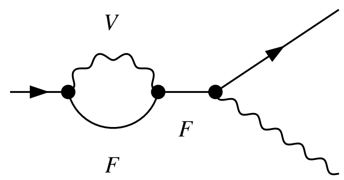

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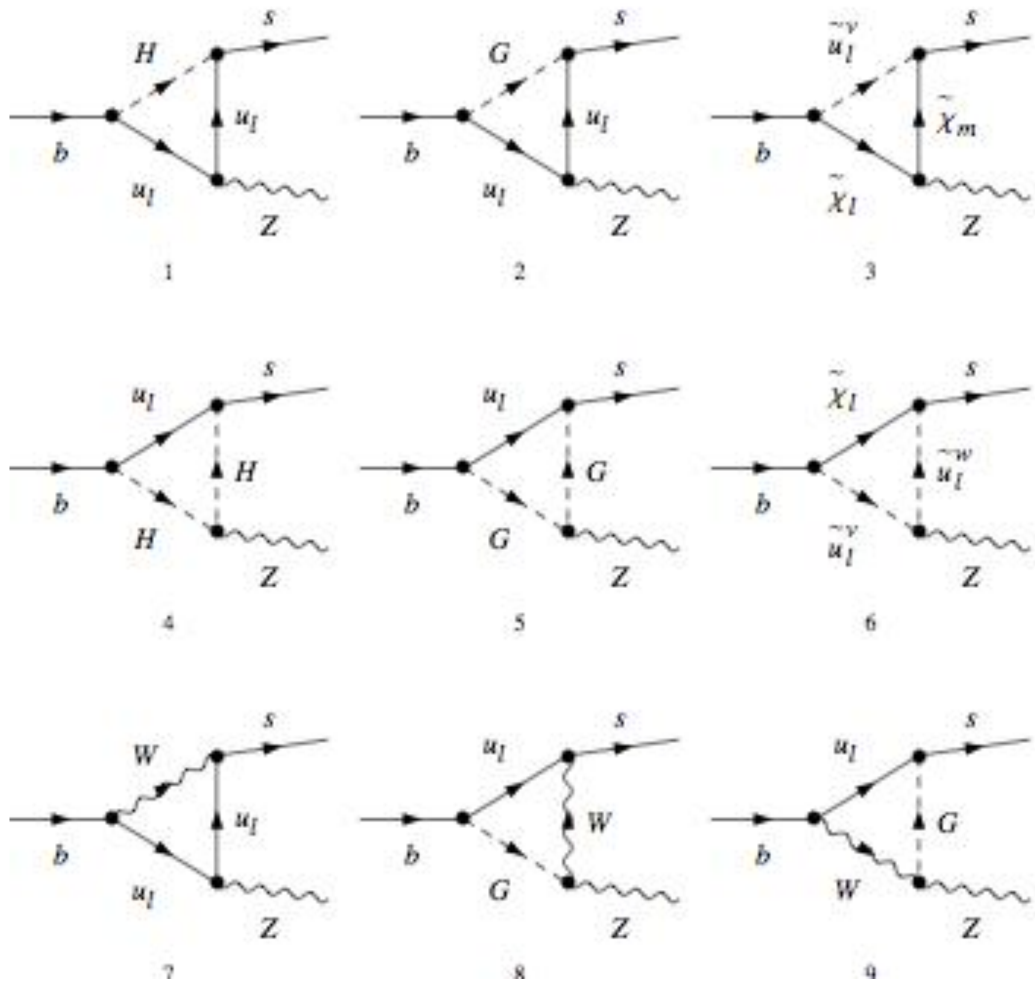
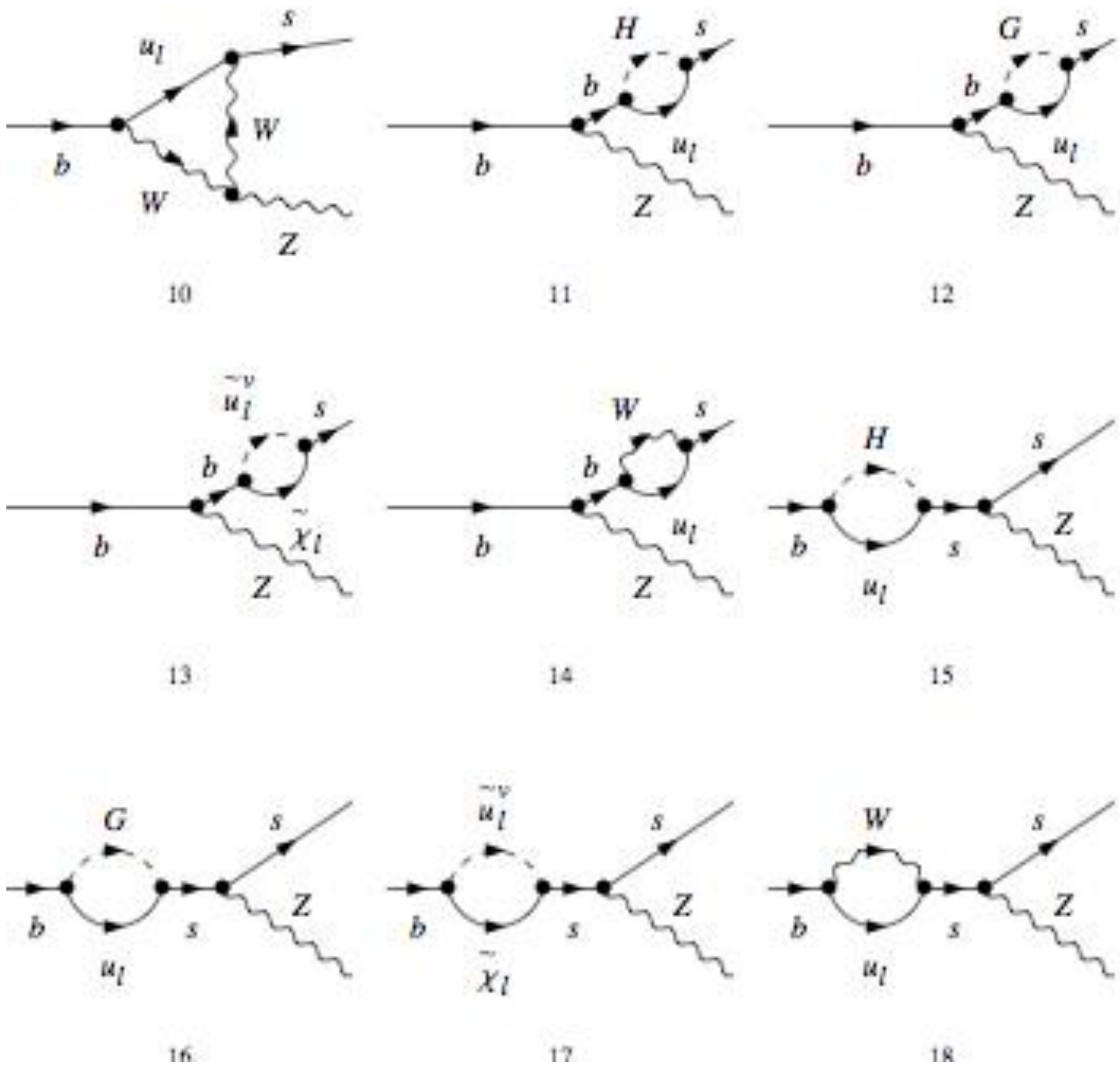
Classes

$b \rightarrow s \; Z$



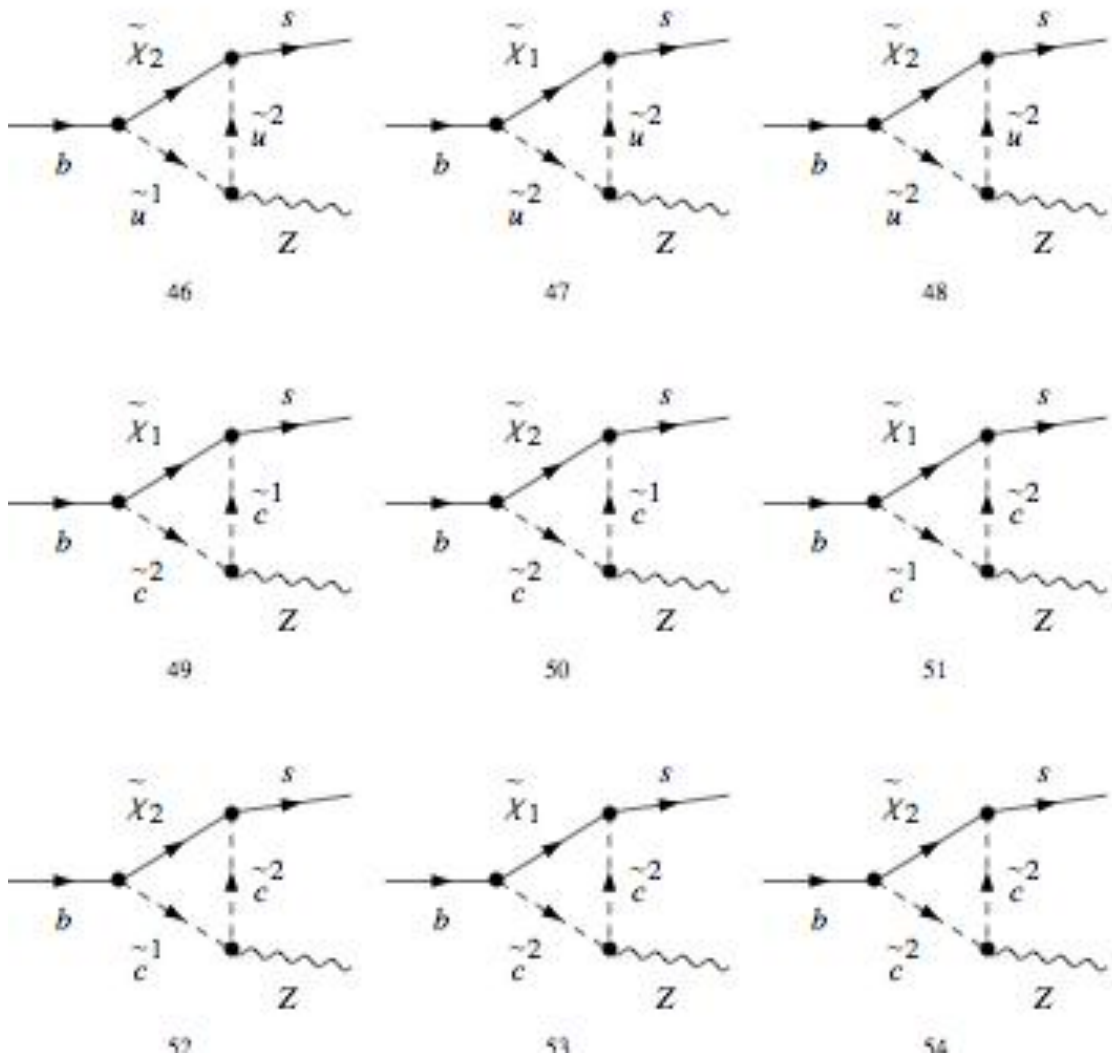
$$b \rightarrow s \quad Z$$



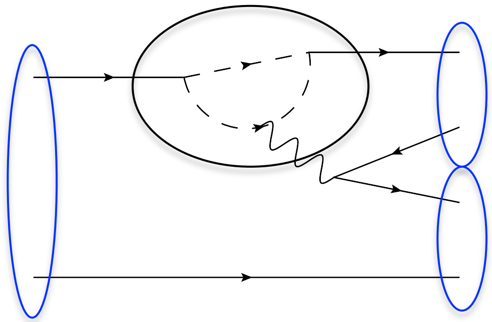
Particles' level

$b \rightarrow s \; Z$

InF = F[4, {3, c1}]; b
OutF = F[4, {2, c2}]; s
OutV = V[2]; Z



Quark level transition



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Electromagnetic-dipole terms

$$\left(\overline{\psi}_a' \sigma^{\mu\nu} P_{L,R} \psi_b q_\mu V_\nu^c\right)\left(M_{a,b}^c\right)_{L,R}$$

Next steps:

To provide ability to calculate box diagrams

To provide ability to calculate in any order

To provide ability to control more parameters on the input level of package

Use this package for the theoretical work which requires the analysis of H_{eff}

Interface with spectrum calculators, Flavour Les Houches Accord, export numerical routines …

The work in collaboration with Dr. Alexander V. Bednyakov and Prof. Dmitri I. Kazakov