Practical introduction into CalcHEP

Alexander Belyaev

Southampton University & Rutherford Appleton LAB

Dartmouth-TRIUMF-University of Washington High-Energy Physics/Cosmology Tools Bootcamp
23-27 October 2017
To test theory we need
theory $\leftrightarrow$ data link
which is actually a non-trivial story
theory ↔ data requires observables to be compared with data
theory ↔ data requires observables to be compared with data and we need TOOLS to do this!

THEORY → OBSERVABLES → TOOLS! → DATA → TOOLS!
Tools for theory → observables link
Tools for **theory → observables** link

**BSM Model** → **Feynman Rules** → **Matrix Element** → **Events** → **Detector**

- **LanHEP**
- **FeynRules**
- **SARAH**
- **CalcHEP**, **CompHEP**
- **FormCalc**, **MadGraph**, **MCFM**, **MC@NLO**, **Sherpa**, **WHizard**
- **PYTHIA**
- **HERWIG**
- **ISAJET**
- **Sherpa**
- **FAST/FULL Detector Simulation**
- **PGS**, **Delphes**
- **/CMSSW**, **ATHENA**

**CalcHEP**

- **Relic Density**
- **DM Direct Detection**
- **DM Indirect Detection**

- **micrOMEGAs**

- **MadDM**

**Analysis to find/exclude/modify theory:**
- Plots, **PAW/Root**, **Fortran/C++ codes**, **Private codes**, **GAMBIT**, **MasterCode**, **CHECKMATE**, **MadAnalysis**, **HEPMDB**
• **Do ask** questions *during* the lecture

• *There are* exercises *(ex#)* for you which will be able to do during this course
Lecture I:

Introduction into CalcHEP

- system requirements & linux primer
- installation
- models and symbolic session
Lecture II:

Introduction into CalcHEP

- numerical session and kinematical distributions
- event generation
- CalcHEP Batch Interface
Lecture III:
- LanHEP
- HEPMDB
- PhenoData
- advanced topics
Web page & contacts

- **The WEB page of CalcHEP**
  
  http://theory.npi.msu.su/~pukhov/calchep.html
  
  arXiv:1207.6082

- **e-mails**
  
  calchep@googlegroups.com
  
a.belyaev@soton.ac.uk
Prerequisites

- **basic knowledge of Linux/UNIX**
  - See Linux primer – linux_primer.pdf (thanks to Elena Vataga)

### Getting Started with Linux

#### Navigating the Linux Filesystem

The Linux filesystem is a tree-like hierarchy of directories and files.

1. When you first login to a Linux machine, you find yourself in your home directory.
2. A path is a way you need to follow in the tree structure to reach a given file. An absolute path name is one beginning with the "/" character. A relative path is a path relative to your working directory.

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>pwd</code></td>
<td>&quot;Print Working Directory&quot;. Shows the current location in the directory tree</td>
</tr>
<tr>
<td><code>cd dir</code></td>
<td>Change the current directory to <code>dir</code></td>
</tr>
<tr>
<td><code>cd ..</code></td>
<td>Move one directory up</td>
</tr>
<tr>
<td><code>cd -</code></td>
<td>Return to previous directory</td>
</tr>
<tr>
<td><code>cd</code></td>
<td>Return to your home directory</td>
</tr>
<tr>
<td><code>ls</code></td>
<td>List all files in the current directory</td>
</tr>
</tbody>
</table>

#### Working with Files and Directories

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>mkdir</code></td>
<td>Make directory</td>
</tr>
<tr>
<td><code>rmdir</code></td>
<td>Remove an empty directory</td>
</tr>
<tr>
<td><code>cp source dest</code></td>
<td>Copy a file</td>
</tr>
<tr>
<td><code>cp -p ...</code></td>
<td>Copy a file, preserving its attributes like mode, ownership, timestamps</td>
</tr>
<tr>
<td><code>mv source dest</code></td>
<td>Move a file to a new location or rename it.</td>
</tr>
<tr>
<td><code>rm</code></td>
<td>Delete a file</td>
</tr>
<tr>
<td><code>rm -r</code></td>
<td>Remove directories and their contents recursively</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Command</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>less</code></td>
<td>More sophisticated version of more (can scroll backwards and has many more options)</td>
</tr>
<tr>
<td><code>dos2unix</code></td>
<td>The program that converts plain text files in DOS/MAC format to UNIX format</td>
</tr>
</tbody>
</table>

#### Getting Help

1. Help on most Linux commands is built into the commands themselves:
   ```shell
   $ ls --help
   ```
2. The best source of information for most commands is the online manual pages, known as "man pages" for short:
   ```shell
   $ man ls
   ```
3. Sometimes you might not remember the name of Linux command and you need to search for

- **gcc compiler**
- **gfortran compiler**

---

Alexander Belyaev

“Practical introduction into CalcHEP”
CalcHEP
was born as a CompHEP in 1989: MGU-89-63/140

**Author(s)**
- Alexander Pukhov, AB, Neil Christensen
  (AB and Neil Christensen have joined the project in 2009)
  http://theory.npi.msu.su/~pukhov/calchep.html

**Idea**
- The effective study of HEP phenomenology passing at high level of automation from your favorite model to physical observables such as decay width, branching ratios, cross sections, kinematic distributions, parton-level events, ...

**Analogous packages** (matrix element generators)
http://www.ippp.dur.ac.uk/montecarlo/BSM/
- CompHEP (Boos et al)
- MadGraph/MadEvent (Maltoni, Stelzer et al)
- Grace/Helas (Fujimoto et al)
- FeynArts/FeynCalc/FormCalc (Hahn et al)
- WHIZARD,O'mega (Moretti, Ohl, Reuter)
- Sherpa (Krauss et al)
Features/Limitations of CalcHEP

- Can evaluate any decay and scattering processes within any (user defined) model!
Features/Limitations of CalcHEP

- Can evaluate any decay and scattering processes within any (user defined) model!
- Tree-level processes
**Features/Limitations of CalcHEP**

- Can evaluate any decay and scattering processes within any (user defined) model!
- Tree-level processes
- Squared Matrix Element calculation
  - no spin information for outgoing particles – spin averaged amplitude
Features/Limitations of CalcHEP

- Can evaluate any decay and scattering processes within any (user defined) model!

- Tree-level processes
- Squared Matrix Element calculation
  - no spin information for outgoing particles – spin averaged amplitude
- Limit on number of external legs (involved particles) and number of diagrams
  - official limit – 8 , unofficial – none
  - limit is set from the practical point of view:
    - $2 \rightarrow 6 \ (1 \rightarrow 7)$ set the essential time/memory limit
    - number of diagrams ~ 500 set the disk space and the time limit
CalcHEP - a package for calculation of Feynman diagrams and integration over multi-particle phase space.

Authors - Alexander Pukhov, Alexander Belyaev, Neil Christensen

The main idea of CalcHEP is to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with a high level of automation. The package can be compiled on any Unix platform.

General information
- Main features
- Acknowledgments
- News&Bugs
- Publications&Lectures
- Contributions

Manual
- calchep_man_3.3.6.pdf (manual for version 3.3.6, July 19, 2012)
- HEP computer tools (Lecture by Alexander Belyaev)

See also: Dan Green, High Pt physics at hadron colliders (Cambridge University Press)

Code download.
- Licence
- Installation
- New Options
- Archive

Models:
- MSSM_10.14 (15.10.2014)
- NMSSM_8.15 (25.08.2015)
- CPVMSSM_10.14 (16.10.2014)
- 5DSM
- 6DSM
- SUSY models by A. Semenov
- LeptoQuarks
- Model database
- HEPMD

Related packages on Web:
- Packages for model generation: LanHEP, FeynRules, SARAH, CPsuperH, NMSSMTools
- RGE and spectrum calculation: SuSpect, Isajet, SoftSUSY, SPheNo
- Particle widths in MSSM: SUSY-HIT, HDECAY
- Parton showers: PYTHIA

Contacts
- Email: calchep@googlegroups.com
- Launchpad service: Ask a question, File a bug
**CalcHEP** - a package for calculation of Feynman diagrams and integration over multi-particle phase space.

**Authors** - Alexander Pukhov, Alexander Belyaev, Neil Christensen

The main idea of CalcHEP is to enable one to go directly from the Lagrangian to the cross sections and distributions effectively, with a high level of automation. The package can be compiled on any Unix platform.

**General information**
- Main features
- Acknowledgments
- News&Bugs
- Publications&Lectures
- Contributions

**Manual**
- calcchep\_man\_3.3.6.pdf (manual for version 3.3.6, July 19, 2012)
- HEP computer tools (Lecture by Alexander Belyaev)

See also: Dan Green, High Pt physics at hadron colliders (Cambridge University Press)

**Code download.**
- Licence
- Installation
- New Options

**Models:**
- MSSM\_10.14(15.10.2014)
- NMSSM\_8.15(25.08.2015)
- CPVMSSM\_10.14(16.10.2014)
- 5DSM
- 6DSM
- SUSY models by A.
- HEPMD

**Related packages on Web:**
- Packages for model generation: LanHEP, FeynRules, SARAH
- RGE and spectrum calculation: SuSpect, Isajet, SoftSUSY, SPheNo, CPsuperH, NMSSMTools
- Particle widths in MSSM: SUSY-HIT, HDECAY
- Parton showers: PYTHIA

**Contacts**
- Email: calcchep@goglegroups.com
- Launchpad service: Ask a question, File a bug

**Connected to launchpad system**
Quick start with CalcHEP: practical notes on the installation

- *Download code, read manual and compile*
  
  [http://theory.npi.msu.su/~pukhov/calchep.html](http://theory.npi.msu.su/~pukhov/calchep.html)
  - `tar -zxvf calchep_3.x.x.tgz`
  - `cd calchep_3.x.x`
  - `make`

  the current version is 3.x.x = 3.6.30

- **Create work directory**
  - From `calchep_3.x.x` directory (e.g. `../calc_work`)
    - `./mkWORKdir ../calc_work`

- **Supported operating system**
  - Linux, IRIX, IRIX64, HP-UX, OSF1, SunOS, Darwin, CYGWIN

  (see `getFlags` file)

**ex#1:** Install CalcHEP
Compilation, potential problem and its solution

- To compile the CalcHEP source code you need: C compiler, the X11 graphics library and the X11 include files

"CalcHEP is compiled successfully and can be started " is a good sign
Compilation, potential problem and its solution

- To compile the CalcHEP source code you need: C compiler, the X11 graphics library and the X11 include files
- "CalcHEP is compiled successfully and can be started " is a good sign

- Compilation for High Precision Calculations
  - Intel C compiler has a _Quad type, -D QUAD has to be added to FlagsForSh as
  - CFLAGS="-D_QUAD_ -fPIC -fsigned-char -Qoption,cpp,--extended_float_type"
Compilation, potential problem and its solution

To compile the CalcHEP source code you need:
C compiler, the X11 graphics library and the X11 include files
"CalcHEP is compiled successfully and can be started "
is a good sign

Compilation for High Precision Calculations
- Intel C compiler has a _Quad type, -D QUAD has to be added to FlagsForSh as
  CFLAGS="-D_QUAD_ -fPIC -fsigned-char -Qoption,cpp,--extended_float_type"

Potential problem in compilation
- The most frequent compilation problem is due to the absence of the X11 include files; CalcHEP still compiles, however, it only runs in non-interactive mode
  ./calchep will give
  Error: You have launched the interactive session for a version
  of CalcHEP that has been compiled without the X11 library.
  Presumably, the X11 development package is not installed on
  your computer.

- the following additional package should be install to run CalcHEP in GUI mode
  - libX11-devel for Fedora/Scientific, Darwin(MAC)
  - libX11-dev for Ubuntu/Debian
  - xorg-x11-devel for SUSE
Starting CalcHEP

- `cd ..:/calc_work`

- **Files:**
  
  bin -> ........ /calchep_3.x.x/bin
  calchep
  calchep_batch
  calchep.ini
  models/
  results/
  tmp/

- **Start:**
  
  ./calchep
Starting CalcHEP

CalcHEP – a package for Calculation in High Energy Physics
Version 3.6.30: Last correction September 21, 2017

Authors: Alexander Pukhov(Skobeltsyn Institute of Nuclear Physics, Moscow)
Alexander Belyaev(University of Southampton)
Neil Christensen (University of Pittsburgh)

For contacts:  email: <calchept@googlegroups.com>
Questions: https://answers.launchpad.net/calchept
Bugs: https://bugs.launchpad.net/calchept

The BS M s for CalcHEP were developed in collaboration with:
G.Belanger,F.Boudjema,A.Semenov

The package contains codes written by:
M.Donckt,V.Edmeral,V.Ilyin,D.Kovalenko,A.Kryukov,G.Lepage,A.Semenov

Press F9 or click the box below to get

References, Contributions, Acknowledgments

This information is available during the session by means of the F9 key
Principle KEYS for CalcHEPs GUI

Enter menu selection (forward)

Exit menu selection (back)

Help!
Starting CalcHEP

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.
Questions: https://answers.launchpad.net/calchep
Bugs: https://bugs.launchpad.net/calchep

F1- Help  F2- Man  F5- Switches  F6- Results  F9- Ref  F10- Quit
CalcHEP menu structure: symbolic part

- **SELECT MODEL**
  - Import models
  - Enter process
  - Force Unit gauge = OFF
  - Edit model
  - Numerical evaluations
  - Delete model

- **Parameters**
  - Constraints
  - Particles
  - Libraries
  - RENAME
  - CHECK MODEL

- **C-code (for num calc)**
  - C-compiler
  - Edit linker
  - REDUCE code
  - MATHEMATICA code
  - FORM code
  - Enter new process

- **View squared diagrams**
  - Symbolic calculation
  - Make & Launch n_calcheP
  - REDUCE program

- **View diagrams**
  - Square diagrams
  - Write down processes

- **Enter processes:** p, p -> W+, $2^x$
  - Composite p consists of: u, U, d, D
  - Exclude diagrams with: A
  - Exclude X-particles: G

- **Menu structure:**
  - Menu 1
  - Menu 2
  - Menu 3
  - Menu 4
  - Menu 5
  - Menu 6
  - Menu 7
  - Menu 8
  - Menu 9
CalcHEP menu structure: symbolic part

Choose of the gauge

Enter processes: $p,p \rightarrow W^+, 2 \times x$

composite $p$ consists of: $u, U, d, D$

Exclude diagrams with: $A$

Exclude X-particles: $G$
Initial Menu after the model choice

Choose your gauge  Enter Process
Edit Model       Numerical Evaluation

Model: Standard Model

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Questions: https://answers.launchpad.net/calcheep
Bugs: https://bugs.launchpad.net/calcheep
The Model Structure

Parameters
Particles

Constraints
Vertices

Model: Standard Model

Abstract

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.
Questions: https://answers.launchpad.net/calchep
Bugs: https://bugs.launchpad.net/calchep
### Particles: prtclxx.mdl (spins 0, 1/2, 1, 3/2, 2)

<table>
<thead>
<tr>
<th>Full name</th>
<th>A</th>
<th>A</th>
<th>PDG</th>
<th>2*spin</th>
<th>mass</th>
<th>width</th>
<th>color</th>
<th>aux</th>
<th>LaTeX(A)</th>
<th>LaTeX</th>
<th>La</th>
</tr>
</thead>
<tbody>
<tr>
<td>gluon</td>
<td>G</td>
<td>G</td>
<td>21</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>G</td>
<td>g</td>
<td>g</td>
<td>g</td>
</tr>
<tr>
<td>photon</td>
<td>A</td>
<td>A</td>
<td>22</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>G</td>
<td>\gamma</td>
<td>\gamma</td>
<td>ga</td>
</tr>
<tr>
<td>Z-boson</td>
<td>Z</td>
<td>Z</td>
<td>23</td>
<td>2</td>
<td>MZ</td>
<td>!wZ</td>
<td>1</td>
<td>G</td>
<td>Z</td>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>W-boson</td>
<td>W+</td>
<td>W-</td>
<td>24</td>
<td>2</td>
<td>MW</td>
<td>!wW</td>
<td>1</td>
<td>G</td>
<td>W^+</td>
<td>W^-</td>
<td>W^-</td>
</tr>
<tr>
<td>Higgs</td>
<td>h</td>
<td>h</td>
<td>25</td>
<td>0</td>
<td>Mh</td>
<td>!wh</td>
<td>1</td>
<td>h</td>
<td>h</td>
<td>h</td>
<td>h</td>
</tr>
<tr>
<td>electron</td>
<td>e</td>
<td>E</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>e^-</td>
<td>e^-</td>
<td>e^+</td>
<td>e^+</td>
</tr>
<tr>
<td>e-neutrino</td>
<td>ne</td>
<td>Ne</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>\nu_e</td>
<td>\nu_e</td>
<td>\nu_e</td>
</tr>
<tr>
<td>muon</td>
<td>m</td>
<td>M</td>
<td>13</td>
<td>1</td>
<td>Mm</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>\mu^-</td>
<td>\mu^-</td>
<td>\mu^-</td>
</tr>
<tr>
<td>m-neutrino</td>
<td>nm</td>
<td>Nm</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>\nu_-\mu</td>
<td>\nu_-\mu</td>
<td>\nu_-\mu</td>
</tr>
<tr>
<td>tau-lepton</td>
<td>l</td>
<td>L</td>
<td>15</td>
<td>1</td>
<td>Ml</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>\tau^-</td>
<td>\tau^-</td>
<td>\tau^-</td>
</tr>
<tr>
<td>t-neutrino</td>
<td>nl</td>
<td>Nl</td>
<td>16</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>\nu_-\tau</td>
<td>\nu_-\tau</td>
<td>\nu_-\tau</td>
</tr>
<tr>
<td>d-quark</td>
<td>d</td>
<td>D</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>d</td>
<td>d</td>
<td>d</td>
<td>d</td>
</tr>
<tr>
<td>u-quark</td>
<td>u</td>
<td>U</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>u</td>
<td>u</td>
<td>u</td>
<td>u</td>
</tr>
<tr>
<td>s-quark</td>
<td>s</td>
<td>S</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>s</td>
<td>s</td>
<td>s</td>
<td>s</td>
</tr>
<tr>
<td>c-quark</td>
<td>c</td>
<td>C</td>
<td>4</td>
<td>1</td>
<td>Mc</td>
<td>0</td>
<td>3</td>
<td>c</td>
<td>c</td>
<td>c</td>
<td>c</td>
</tr>
<tr>
<td>b-quark</td>
<td>b</td>
<td>B</td>
<td>5</td>
<td>1</td>
<td>Mb</td>
<td>0</td>
<td>3</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>t-quark</td>
<td>t</td>
<td>T</td>
<td>6</td>
<td>1</td>
<td>Mt</td>
<td>!wt</td>
<td>3</td>
<td>t</td>
<td>t</td>
<td>t</td>
<td>t</td>
</tr>
</tbody>
</table>
### Particles: *prtclxx.mdl*

<table>
<thead>
<tr>
<th>Name</th>
<th>A</th>
<th>A</th>
<th>PDG</th>
<th>2*spin</th>
<th>Mass</th>
<th>Width</th>
<th>Color</th>
<th>Aux</th>
<th>LaTeX(A)</th>
<th>LaTeX((A))</th>
<th>Latex(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gluon</td>
<td>G</td>
<td>G</td>
<td>21</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>G</td>
<td>g</td>
<td>g</td>
<td>g</td>
</tr>
<tr>
<td>photon</td>
<td>A</td>
<td>A</td>
<td>22</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>G</td>
<td>(\gamma)</td>
<td>(\gamma)</td>
<td>(\gamma)</td>
</tr>
<tr>
<td>Z-boson</td>
<td>Z</td>
<td>Z</td>
<td>23</td>
<td>2</td>
<td>MZ</td>
<td>(wZ)</td>
<td>1</td>
<td>G</td>
<td>Z</td>
<td>Z</td>
<td>Z</td>
</tr>
<tr>
<td>W-boson</td>
<td>W+</td>
<td>W-</td>
<td>24</td>
<td>2</td>
<td>MW</td>
<td>(wW)</td>
<td>1</td>
<td>G</td>
<td>W^+</td>
<td>W^-</td>
<td>W^-</td>
</tr>
<tr>
<td>Higgs</td>
<td>h</td>
<td>h</td>
<td>25</td>
<td>0</td>
<td>Mh</td>
<td></td>
<td>1</td>
<td>h</td>
<td>h</td>
<td>h</td>
<td>h</td>
</tr>
<tr>
<td>electron</td>
<td>e</td>
<td>E</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>e</td>
<td>^-</td>
<td>e^+</td>
<td>e^+</td>
</tr>
<tr>
<td>e-neutrino</td>
<td>ne</td>
<td>Ne</td>
<td>12</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>(\nu_e)</td>
<td>(\nu_e)</td>
<td>(\nu_e)</td>
</tr>
<tr>
<td>muon</td>
<td>m</td>
<td>M</td>
<td>13</td>
<td>1</td>
<td>Mm</td>
<td>0</td>
<td>1</td>
<td>(\mu^-)</td>
<td>(\mu^-)</td>
<td>(\mu^-)</td>
<td></td>
</tr>
<tr>
<td>m-neutrino</td>
<td>nm</td>
<td>Nm</td>
<td>14</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>(\nu_{\mu})</td>
<td>(\nu_{\mu})</td>
<td>(\nu_{\mu})</td>
</tr>
<tr>
<td>tau-lepton</td>
<td>l</td>
<td>L</td>
<td>15</td>
<td>1</td>
<td>Ml</td>
<td>0</td>
<td>1</td>
<td>(\tau^-)</td>
<td>(\tau^-)</td>
<td>(\tau^-)</td>
<td></td>
</tr>
<tr>
<td>t-neutrino</td>
<td>nl</td>
<td>Nl</td>
<td>16</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>L</td>
<td>(\nu_{\tau})</td>
<td>(\nu_{\tau})</td>
<td>(\nu_{\tau})</td>
</tr>
<tr>
<td>d-quark</td>
<td>d</td>
<td>D</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>u-quark</td>
<td>u</td>
<td>U</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>u</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s-quark</td>
<td>s</td>
<td>S</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c-quark</td>
<td>c</td>
<td>C</td>
<td>4</td>
<td>1</td>
<td>Mc</td>
<td>0</td>
<td>3</td>
<td>c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b-quark</td>
<td>b</td>
<td>B</td>
<td>5</td>
<td>1</td>
<td>Mb</td>
<td>0</td>
<td>3</td>
<td>b</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-quark</td>
<td>t</td>
<td>T</td>
<td>6</td>
<td>1</td>
<td>Mt</td>
<td>(wt)</td>
<td>3</td>
<td>t</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Higgs boson width will be calculated `on the fly`**
### Independent parameters: `varsxx.mdl`

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE</td>
<td>0.31343</td>
<td>electromagnetic constant</td>
</tr>
<tr>
<td>alfSMZ</td>
<td>0.1184</td>
<td>Strong alpha(MZ) for running mass calculation</td>
</tr>
<tr>
<td>Q</td>
<td>100</td>
<td>scale for running mass calculation</td>
</tr>
<tr>
<td>s12</td>
<td>0.221</td>
<td>Parameter of C-K-M matrix (PDG96)</td>
</tr>
<tr>
<td>s23</td>
<td>0.041</td>
<td>Parameter of C-K-M matrix (PDG96)</td>
</tr>
<tr>
<td>s13</td>
<td>0.0035</td>
<td>Parameter of C-K-M matrix (PDG96)</td>
</tr>
<tr>
<td>Mm</td>
<td>0.1057</td>
<td>muon mass</td>
</tr>
<tr>
<td>Ml</td>
<td>1.777</td>
<td>tau-lepton mass</td>
</tr>
<tr>
<td>McMc</td>
<td>1.2</td>
<td>Mc(Mc)</td>
</tr>
<tr>
<td>MbMb</td>
<td>4.25</td>
<td>Mb(Mb)</td>
</tr>
<tr>
<td>Mtp</td>
<td>173.07</td>
<td>t-quark pole mass</td>
</tr>
<tr>
<td>MZ</td>
<td>91.189</td>
<td>Z-boson mass</td>
</tr>
<tr>
<td>MW</td>
<td>80.385</td>
<td>W-boson mass</td>
</tr>
<tr>
<td>Mh</td>
<td>125</td>
<td>higgs mass</td>
</tr>
</tbody>
</table>
### Dependent parameters (constraints): `funcxx.mdl`

<table>
<thead>
<tr>
<th>Name</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>MW/MZ</td>
</tr>
<tr>
<td></td>
<td>% on-shell cos of the Weinberg angle</td>
</tr>
<tr>
<td>SW</td>
<td>sqrt(1-CW^2)</td>
</tr>
<tr>
<td></td>
<td>% sin of the Weinberg angle</td>
</tr>
<tr>
<td>GF</td>
<td>EE^2/(2<em>SW</em>MW)^2/Sqrt2</td>
</tr>
<tr>
<td></td>
<td>% Fermi constant (not used below)</td>
</tr>
<tr>
<td>LamQCD</td>
<td>initQCD5(alfSMZ,McMc,MbMb,Mtp)</td>
</tr>
<tr>
<td>Mb</td>
<td>MbEff(Q)</td>
</tr>
<tr>
<td>Mt</td>
<td>MtEff(Q)</td>
</tr>
<tr>
<td>Mc</td>
<td>McEff(Q)</td>
</tr>
<tr>
<td>c12</td>
<td>sqrt(1-s12^2)</td>
</tr>
<tr>
<td></td>
<td>% parameter of C-K-M matrix</td>
</tr>
<tr>
<td>c23</td>
<td>sqrt(1-s23^2)</td>
</tr>
<tr>
<td></td>
<td>% parameter of C-K-M matrix</td>
</tr>
<tr>
<td>c13</td>
<td>sqrt(1-s13^2)</td>
</tr>
<tr>
<td></td>
<td>% parameter of C-K-M matrix</td>
</tr>
<tr>
<td>Vud</td>
<td>c12*c13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vus</td>
<td>s12*c13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vub</td>
<td>s13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vcd</td>
<td>-s12<em>c23-c12</em>s23*s13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vcs</td>
<td>c12<em>c23-s12</em>s23*s13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vcb</td>
<td>s23*c13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vtd</td>
<td>s12<em>s23-c12</em>c23*s13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vts</td>
<td>-c12<em>s23-s12</em>c23*s13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
<tr>
<td>Vtb</td>
<td>c23*c13</td>
</tr>
<tr>
<td></td>
<td>% C-K-M matrix element</td>
</tr>
</tbody>
</table>
### Feynman rules: lgrngxx.mdl

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>Factor</th>
<th>Lorentz part</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>l</td>
<td>A</td>
<td></td>
<td>-EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>Ne</td>
<td>e</td>
<td>W+</td>
<td></td>
<td>EE/(2<em>Sqrt2</em>SW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>Nm</td>
<td>m</td>
<td>W+</td>
<td></td>
<td>EE/(2<em>Sqrt2</em>SW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>Nl</td>
<td>l</td>
<td>W+</td>
<td></td>
<td>EE/(2<em>Sqrt2</em>SW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>E</td>
<td>ne</td>
<td>W-</td>
<td></td>
<td>EE/(2<em>Sqrt2</em>SW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>M</td>
<td>nm</td>
<td>W-</td>
<td></td>
<td>EE/(2<em>Sqrt2</em>SW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>L</td>
<td>nl</td>
<td>W-</td>
<td></td>
<td>EE/(2<em>Sqrt2</em>SW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>E</td>
<td>e</td>
<td>Z</td>
<td></td>
<td>-EE/(4<em>SW</em>CW)</td>
<td>G(m3)<em>(1-G5)-4</em>(SW^2)</td>
</tr>
<tr>
<td>M</td>
<td>m</td>
<td>Z</td>
<td></td>
<td>-EE/(4<em>SW</em>CW)</td>
<td>G(m3)<em>(1-G5)-4</em>(SW^2)</td>
</tr>
<tr>
<td>L</td>
<td>l</td>
<td>Z</td>
<td></td>
<td>-EE/(4<em>SW</em>CW)</td>
<td>G(m3)<em>(1-G5)-4</em>(SW^2)</td>
</tr>
<tr>
<td>Ne</td>
<td>ne</td>
<td>Z</td>
<td></td>
<td>EE/(4<em>SW</em>CW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>Nm</td>
<td>nm</td>
<td>Z</td>
<td></td>
<td>EE/(4<em>SW</em>CW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>Nl</td>
<td>nl</td>
<td>Z</td>
<td></td>
<td>EE/(4<em>SW</em>CW)</td>
<td>G(m3)*(1-G5)</td>
</tr>
<tr>
<td>U</td>
<td>u</td>
<td>A</td>
<td></td>
<td>(2/3)*EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>D</td>
<td>d</td>
<td>A</td>
<td></td>
<td>(-1/3)*EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>C</td>
<td>c</td>
<td>A</td>
<td></td>
<td>(2/3)*EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>S</td>
<td>s</td>
<td>A</td>
<td></td>
<td>(-1/3)*EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>B</td>
<td>b</td>
<td>A</td>
<td></td>
<td>(-1/3)*EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>T</td>
<td>t</td>
<td>A</td>
<td></td>
<td>(2/3)*EE</td>
<td>G(m3)</td>
</tr>
<tr>
<td>U</td>
<td>u</td>
<td>Z</td>
<td></td>
<td>-EE/(12<em>SW</em>CW)</td>
<td>-3<em>G(m3)</em>(1-G5)+8*(SW^2)</td>
</tr>
<tr>
<td>D</td>
<td>d</td>
<td>Z</td>
<td></td>
<td>-EE/(12<em>SW</em>CW)</td>
<td>+3<em>G(m3)</em>(1-G5)-4*(SW^2)</td>
</tr>
</tbody>
</table>
External Libraries: extlibxx.mdl

Typically is empty for simple models but can be used for any library which helps to build complicated model. E.g. mass spectra calculator for SUSY (involving RGE solutions etc)

```
External libraries

/home/belyaev/calchep/work/models/MSSM/mLib.a

% 1. Default code for spectrum calculation and RGE solution
% attached to the model is SuSpect:
% http://www.lpta.univ-montp2.fr/users/kneur/Suspect/
%\bibitem{Djouadi:2002ze}
% A.~Djouadi, J.~L.~Kneur and G.~Moultaka,
% \"SuSpect: A Fortran code for the supersymmetric and Higgs particle
% spectrum in the MSSM,\"'
%
% 2. The realization in terms of CalcHEP was done by
%\bibitem{Belanger:2004yn}
% G.~Belanger, F.~Boudjema, A.~Pukhov and A.~Semenov,
% \`MicrOMEGAs: Version 1.3,\''
```
Numerical evaluation of masses & branchings

CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

Questions: https://answers.launchpad.net/calchep

Bugs: https://bugs.launchpad.net/calchep

See results in file 'decaySLHA2.txt' Press any key
Numerical evaluation of masses & branchings

**Abstract**
CalChEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalChEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.

Use F2 key to get information about interface facilities and F1 - as online help.

**Questions**: [https://answers.launchpad.net/calchep](https://answers.launchpad.net/calchep)

**Bugs**: [https://bugs.launchpad.net/calchep](https://bugs.launchpad.net/calchep)

**Numerical Evaluation**

**Parameters**
- All Constraints
- Masses, Widths, Branch.

---

**ex#2**: Find the SM particles spectrum and Br ratios
Details of symbolic session

- the input syntax: \( P1[,P2] \rightarrow P3,P4 [,..,,[N*x]] \)

- hadron/composite particle scattering
  'p,p->W+,b,B'
  unknown particle are assumed to be composite:
  'p' consists of u,U,d,D,s,S,c,C,b,B,G

- wild cards/names for outgoing particles
  'H -> 2*x'

- intermediate particles can be non-trivially excluded
  'W+ > 2, A>1, Z>3'

ex#3: Evaluate SM Higgs total widths and Br ratios as a function of its mass in the 100-500 GeV range
### Symbolic session (1)

**Model:** Standard Model

**List of particles (antiparticles)**

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>G(G)</td>
<td>gluon</td>
</tr>
<tr>
<td>A</td>
<td>A(A)</td>
<td>photon</td>
</tr>
<tr>
<td>Z</td>
<td>Z(Z)</td>
<td>Z-boson</td>
</tr>
<tr>
<td>W±</td>
<td>W±(W-)</td>
<td>W-boson</td>
</tr>
<tr>
<td>h</td>
<td>h(h)</td>
<td>Higgs</td>
</tr>
<tr>
<td>e</td>
<td>e(E)</td>
<td>electron</td>
</tr>
<tr>
<td>n</td>
<td>n(N)</td>
<td>e-neutrino</td>
</tr>
<tr>
<td>m</td>
<td>m(M)</td>
<td>muon</td>
</tr>
<tr>
<td>n</td>
<td>n(N)</td>
<td>m-neutrino</td>
</tr>
<tr>
<td>l</td>
<td>l(L)</td>
<td>tau-lepton</td>
</tr>
<tr>
<td>n</td>
<td>n(N)</td>
<td>t-neutrino</td>
</tr>
<tr>
<td>u</td>
<td>u(U)</td>
<td>u-quark</td>
</tr>
<tr>
<td>s</td>
<td>s(S)</td>
<td>s-quark</td>
</tr>
<tr>
<td>c</td>
<td>c(C)</td>
<td>c-quark</td>
</tr>
<tr>
<td>b</td>
<td>b(B)</td>
<td>b-quark</td>
</tr>
<tr>
<td>t</td>
<td>t(T)</td>
<td>t-quark</td>
</tr>
</tbody>
</table>

Enter process: `p,p->W,b,B`

Composite 'p' consists of: `u,U,d,D,s,S,c,C,b,B,G`

Composite 'W' consists of: `W+,W-`

Exclude diagrams with: _
Symbolic session (2)

Model: Standard Model

Process: p, p \rightarrow W, b, B

Feynman diagrams

464 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
**Symbolic session (3)**

**Model:** Standard Model

**Process:** \( p, p \rightarrow W, b, B \)

*Feynman diagrams*

464 diagrams in 24 subprocesses are constructed. 0 diagrams are deleted.

<table>
<thead>
<tr>
<th>NN</th>
<th>Subprocess</th>
<th>Del</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( u, D \rightarrow W^+, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>( u, S \rightarrow W^+, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>( u, B \rightarrow W^+, b, B )</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>4</td>
<td>( U, d \rightarrow W^-, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>( U, s \rightarrow W^-, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>( U, b \rightarrow W^-, b, B )</td>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>7</td>
<td>( d, U \rightarrow W^-, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>( d, C \rightarrow W^-, b, B )</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>9</td>
<td>( D, u \rightarrow W^+, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>( D, c \rightarrow W^+, b, B )</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>( s, U \rightarrow W^-, b, B )</td>
<td>0</td>
<td>15</td>
</tr>
</tbody>
</table>
Symbolic session (4)
Symbolic session (5)

Model: Standard Model

Process: \( p,p \rightarrow W,b,B \)

Feynman diagrams
464 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.

Squared diagrams
5076 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
0 diagrams are calculated.
Symbolic session (6)
Symbolic session (7)

Model: Standard Model

Process: p,p→W,b,B

**Feynman diagrams**
464 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.

**Squared diagrams**
5076 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
5076 diagrams are calculated.

F1-Help F2-Man F3-Model F4-Diagrams F5-Switches F6-Results F9-Ref F10-Quit
Symbolic session (8)

Model: Standard Model

Process: $p, p \rightarrow W, b, B$

Feynman diagrams
464 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.

Squared diagrams
5076 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
5076 diagrams are calculated.

C code
C-compiler
Edit Linker
REDUCE code
MATHEMATICA code
FORM code
Enter new process

F1-Help F2-Man F3-Model F4-Diagrams F5-Switches F6-Results F9-Ref F10-Quit
Symbolic session (9)

Model: Standard Model

Process: p,p→W,b,B

Feynman diagrams
464 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.

Squared diagrams
5076 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
5076 diagrams are calculated.

C Source Codes
Process........... p,p→W,b,B
Total diagrams... 4372
Processed......... 43 (%)
Current.......... 1894
Press Esc to stop
Numerical part of CalcHEP

(sub)Process: u, D -> W+, b, B
Monte Carlo session: 1

#IT Cross section[pb] Error[%] nCall Eff. chi^2

F1-Help F2-Man F5-Options F6-Results F8-Calc F9-Ref F10-Quit

Alexander Belyaev

“Practical introduction into CalcHEP”
Lecture II:

Introduction into CalcHEP

- numerical session and kinematical distributions
- event generation
- CalcHEP Batch Interface