Introduction

In particle physics, the concept of a cross section is used to express the likelihood of interaction between particles. It can therefore characterize the probability that a particular reaction will take place, or the statistical nature of scattering events. The cross section is expressed in units of area, usually in barn. The cross section of two particles (i.e. observed when the two particles are colliding with each other) is a measure of the interaction event between the two particles.

In HEP experiments the measured variable related to cross section is the number of measured events. One can measure e.g. the total number of events, or events found per unit space angle to measure the angular distributions. The number of events measured depends on the process cross section, integrated luminosity and the detector efficiency

$$N = \sigma \, L \, \epsilon$$

The branching ratio (branching fraction) is the fraction of events for a chosen particle measured to decay in a certain way. The sum of branching ratios for a particle is one. The branching ratio is defined as the partial decay width divided by the total width.

The measurements of particle properties and interactions in HEP experiments have led to a theoretical model, the so called Standard Model (SM). The measured particle production and decay give estimates for the SM coupling constants. With these coupling constants cross sections for rare reactions can be predicted, and the predictions are experimentally verified, when possible. At LHC era, when the CM energies are increased by about an order of magnitude, the SM can give predictions for the SM particle production at LHC.

In addition to the SM, there are several theoretical models which are extending the SM. One of those models is the Minimal Supersymmetric Standard Model (MSSM). The MSSM predicts a set of

new particles, their production cross sections and branching ratios. As those extensions are not experimentally verified, there are several open parameters. Since studying all the possible values for dozens or hundreds of parameters is not feasible, one usually chooses some key scenarios for the studies. To predict the particle production cross sections and decay widths one needs a theoretical model and a scenario for calculating them. To have the results available also for non-experts, theorists have in many occasions written a program or programs to make the actual calculations. The user has to set the scenario, i.e. select the input parameters.

We will not go here through every program available for calculating the cross sections or branching ratios. New programs are being written and old ones are updated. Some programs overlap each other, therefore providing a possibility to double-check results with independent calculations.

Event generators

Event generators, like PYTHIA, have built-in the theoretical models for calculating the cross sections and decay widths. In many occasions the cross sections and branching ratios are determined with adequate accuracy using the event generators. One should remember, though, that the accuracy e.g. in PYTHIA depends on the number of simulated events.

In PYTHIA the cross section is stored in a common block

COMMON/PYPARS/ MSTP(200),PARP(200),MSTI(200),PARI(200)

where PARI(1) gives the total integrated cross section, obtained as a by-product of the selection of hard-process kinematics, and PARI(2) gives the ratio of total integrated cross section and the number of events generated.

In case one is not satisfied with the cross sections and branching ratios coming from the event generators, then one has to use other methods. A

cross section can be given by theorists, based on the best knowledge available, or one can use the special programs provided for making these calculations.

HDECAY

HDECAY is a self-contained and fast program for calculating the decay widths and branching ratios of the SM Higgs boson, and the Higgs bosons of the MSSM according to the current theoretical knowledge. The motivation for the program according to the authors is:

"The search of the Higgs boson is one of the major goals of future colliders, such as LHC and LC. Once the Higgs boson is found, it will be of outmost importance to perform a detailed investigation of its fundamental properties. To this end, a very precise prediction of the production cross section and of the branching ratios for the main decay channels is mandatory."

The url for HDECAY is

http://people.web.psi.ch/spira/proglist.html

HDECAY includes

- All kinematically allowed decay channels which have branching ratios greater than 10^{-4}.
- All relevant higher-order QCD corrections.
- Double off-shell decays into massive gauge bosons
- All important below-threshold three-body decays
- Complete radiative corrections in the effective potential approach with full mixing in the stop and sbottom sectors
- Loop mediated channels including mixing

HDECAY is used via input parameter file. The basic input parameters are the fermion and gauge boson masses and their total widths, coupling constants, and in the MSSM soft SUSY breaking parameters. The full list of input parameters can be found in the program manual (hep-ph/9704448). The output is produced in several text files.

The SUSY parameters can be chosen e.g. according to selected benchmark scenarios, like presented in hep-ph/0202167. A typical scenario is the max-m_h scenario, which maximizes the h mass:

MU	=	200.D0
M2	=	200.D0
M_{SUSY}	=	1000.D0
AL	=	0.D0
AU	=	2450.D0
AD	=	2450.D0
OFF-SUSY	=	0

Here M_{SUSY} is the common mass for all input masses between MSL1 - MDR. In the scenario selection and choosing parameters, one has to be careful that no parameter is set to value which is already experimentally excluded. For example the non-observation of neutralinos and charginos at LEP limits the value of MU and M2.

FeynHiggs

FeynHiggs is a Fortran code for diagrammatic calculation of the masses and mixing angles of the Higgs bosons in the MSSM at two-loop level. FeynHiggs provides a convenient way of invoking the subroutines of the FeynHiggs library from the command line. The input parameters are read from a file and the output is displayed in a human-readable form on screen.

Url: http://www.feynhiggs.de

FeynHiggs documentation is in manual pages. Those pages are available after installing the package, or they can be found in the FeynHiggs web page.

FeynHiggs can be used via mathematica, as a FORTRAN library, or using an interactive web page. It also provides a C/C++ interface. The web page cannot do everything, but for simple usage it is an easy start (FHUCC: obtain results online).

The examples in FeynHiggs are not too well documented and easy to use. In FORTRAN usage the user should provide the main program (like example/demo.F), which calls the subroutines available in the FeynHiggs library libFH.a. The bin, library and include files can be found under iX86-linux/ directory X being e.g. 3, 4 or 5. Another possibility is to use the binary FeynHiggs with input file (like example/var.in). Linking FeynHiggs with your own code should be straightforward due to the FeynHiggs library being available.

HQQ, HIGLU etc.

In addition to HDECAY, M.Spira has written programs also for the Higgs cross section calculations. There are several programs, which calculate the production cross sections for different channels. Also PROSPINO, a code for SUSY particle production at hadron colliders is available. The programs can be found at http://people.web.psi.ch/spira/proglist.html

The program HQQ calculates the production cross section of Higgs bosons via qqbar,gg → h,H,A + ttbar/bbbar at hadron colliders at LO QCD. The program allows to calculate the total production cross sections for the neutral Higgs bosons of the SM and MSSM. The parton densities are defined in the subroutine STRUC at the end of the program and can be changed there. The default is the use of the PDFLIB. The input parameters can be chosen as in HDECAY.

The program PPHQQ calculates the production cross section of Higgs bosons via vector boson fusion WW/ZZ → h,H at hadron colliders at NLO QCD. Interference effects between W- and Z-boson fusion are neglected, since they are less than 1%. The program allows to calculate the total production cross section in the DIS as well as the MSbar scheme for the parton densities for the scalar Higgs bosons of the SM and MSSM. The MSSM Higgs sector is implemented in the approximate two-loop RGE approach. The parton densities are defined in the subroutine STRUC at

the end of the program and can be changed there. The default is the use of the PDFLIB.

HIGLU is a program for calculating the total Higgs production cross section at hadron colliders via gluon fusion in the SM and MSSM. NLO QCD corrections and contributions of virtual top and bottom loops are included. The program allows also to calculate the decay widths of Higgs bosons into gluons. Parton distributions can be attached to the program in any desirable way by adjusting the corresponding subroutine STRUC. The default PDF's the program uses are GRV sets.

MCFM

MCFM is a parton-level Monte Carlo program which gives NLO predictions for processes at hadron colliders. This program is useful for calculating the SM cross sections. MCFM allows the user to choose between a number of schemes for defining the electroweak couplings.

Part of the parameters is found in file src/User/mdata.f, part of the parameters in an input file (Bin/input.DAT). A number of parton distributions are included, and the parameters to choose the PDF set are specified in the input file. The available processes and PDF's are listed in the program documentation. The url to MCFM package is
http://mcfm.fnal.gov

PDF's

Parton distribution functions give the probability to find partons (quarks and gluons) in a hadron as a function of the fraction x of the proton's momentum carried by the parton. They are determined from experimental results on short distance scattering of the partons.

The programs which calculate the cross sections for hadron collisions, need parton distribution functions, PDF's. They are also called structure functions.

Cross section and branching ratio calculations

In the example programs above the PDF's are included in the program code, or a library like PDFLIB or LHAPDF is linked with the program. Almost all PDF's are included in the libraries, which makes the PDF selection very easy. It also possibly to download the PDF source codes, but for them there is not necessarily any easy-to-use interface available like in the libraries. If one wants to use a PDF set which is not included in the program, then it is necessary to download the PDF set in question and modify the program to include it. PDF sets available are e.g.

- MRS
- CTEQ
- GRV

In addition to selecting the PDF, one must remember to set the parameters like $\alpha_S(M_W)$ to match the values used in the PDF. One should also use the correct order for the PDF, like LO PDF for LO cross section calculations.
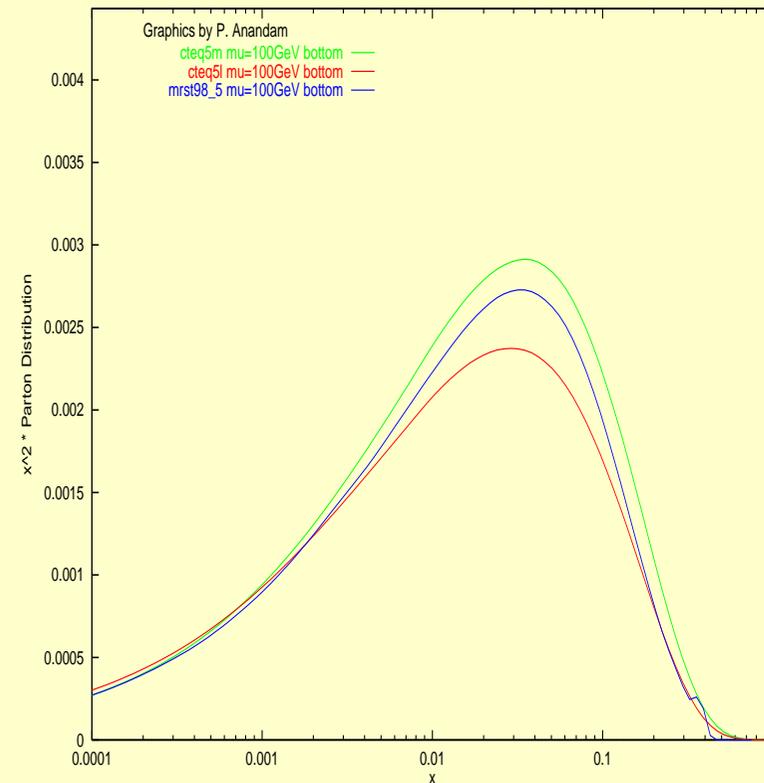

Figure 1: Parton distributions for bottom quarks with CTEQ5L, CTEQ5M and MRST98_5 structure functions. Made with http://zebu.uoregon.edu/~parton parton distribution plotter.