New functionality of CompHEP 4.6 package

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in collaboration with

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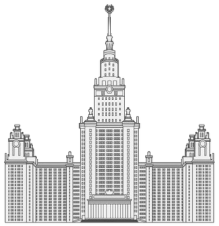
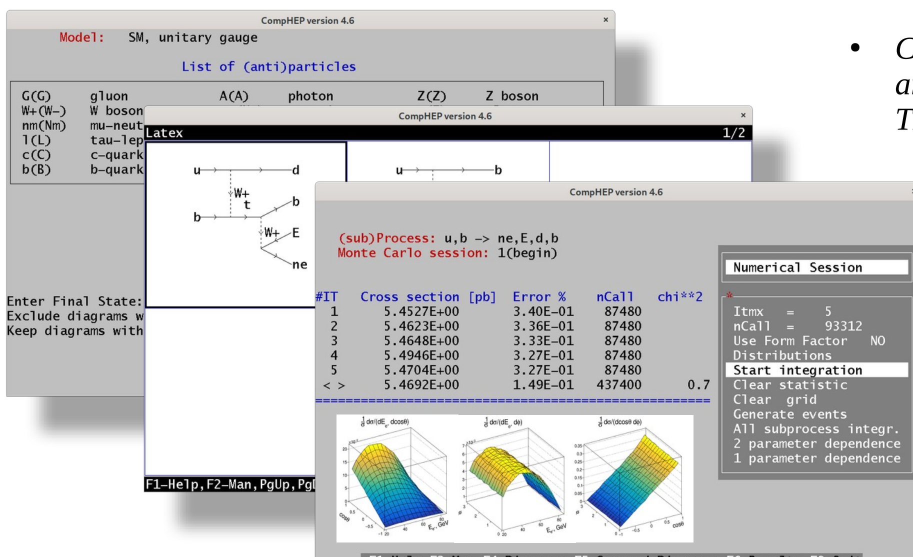
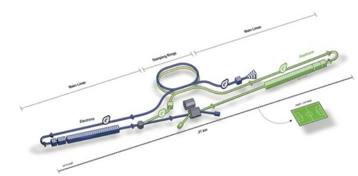
CompHEP is a program for calculating the characteristics and modeling the processes of production and decay of elementary particles at colliders

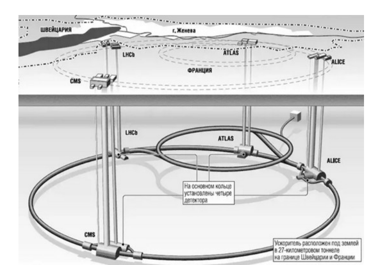


CompHEP was created in 1998 by scientists of the SINP MSU.
A. Pukhov, V. Ilyin, E. Boos, V. Edneral, A. Kryukov, M. Dubinin, V. Savrin, A. Semenov, D. Kovalenko, S. Shichanin.

- *User-friendly graphical interface and high level of automation*
- *Teaching Quantum Field Theory to MSU students*
- *Creation of Monte Carlo generators for hadron and electron-positron colliders NICA, LHC, TEVATRON, FCC, HERA, LEP, , ILC etc.*
- *Calculation of processes characteristics in symbolic and numerical form, construction of kinematic distributions*







$$\frac{d\sigma_{SM}(\hat{s})_{ub\to db\nu e^+}}{d\epsilon\cdot d\cos\theta\cdot d\phi} = \frac{\alpha^2\cdot V_{ud}^2\cdot V_{tb}^2}{8\cdot 3\cdot\sin^4\Theta_W\cdot m_W^2\cdot(1-r^2)^2(1+2r^2)}\cdot\frac{(\hat{s}-m_t^2)^2}{\hat{s}(\hat{s}-m_t^2+m_W^2)}\cdot(1-\epsilon)\cdot\epsilon\cdot(1+\cos\theta)$$

Modern requirements for the CompHEP package

- Due to the increased accuracy of modern collider experiments, there is a request for performing calculations of characteristics and modeling with a higher level of theoretical confidence in the next-to-leading order of perturbation theory with complicated form factors at the interaction vertices.

- Modern models of new physics have many new parameters whose values are not defined. Usually it is necessary to sort through the entire multidimensional set of such values, perform calculations with each of the defined sets of values and compare the results of calculations based on them with experimental data. The listed chain of actions is extremely resource-intensive and is associated with the risk of making errors. There is a need to automate this process.

- For a correct and theoretically justified comparison of simulation results with experimental data, it is necessary to apply modern statistical analysis methods to build confidence regions in the model parameter space and identify the most reliable values of these parameters.

- To improve the capabilities of theoretical analysis and search for the most sensitive characteristics, it is necessary to present the simulation results in a convenient graphical format in the form of one-dimensional, two-dimensional and three-dimensional graphs, which can be used for further analysis in the ROOT package.

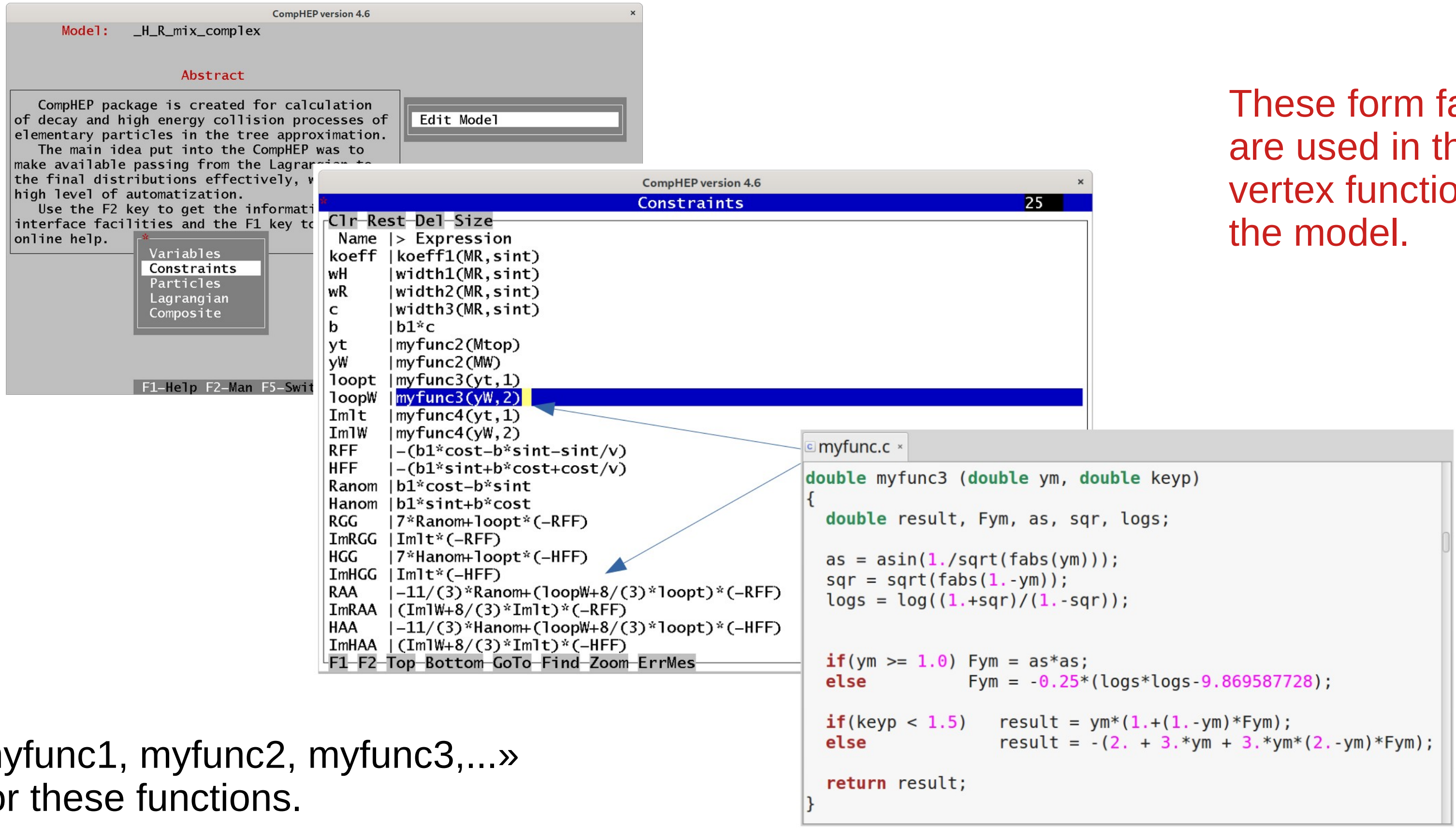
Calculations with complicated form factors. Option 1

The model vertices use complcated form factors that depend on the momenta of the incoming particles, which arise from calculations in the next-to-leading order of perturbation theory.

$$F_W = -(2 + 3y_W + 3y_W(2 - y_W)f(y_W)),$$
$$F_t = y_t(1 + (1 - y_t)f(y_t)),\ y_i = 4m_i^2/(2p_1 \cdot p_2),$$

$$f(z) = \begin{cases} \left[\sin^{-1}\left(\frac{1}{\sqrt{z}}\right)\right]^2, & z \geq 1 \\ -\frac{1}{4}\left[\log\frac{1+\sqrt{1-z}}{1-\sqrt{1-z}} - i\pi\right]^2, & z < 1. \end{cases}$$

First possibility: Call the user-defined form factor function in a CompHEP **symbolic session**, in the model's list of functional expressions.

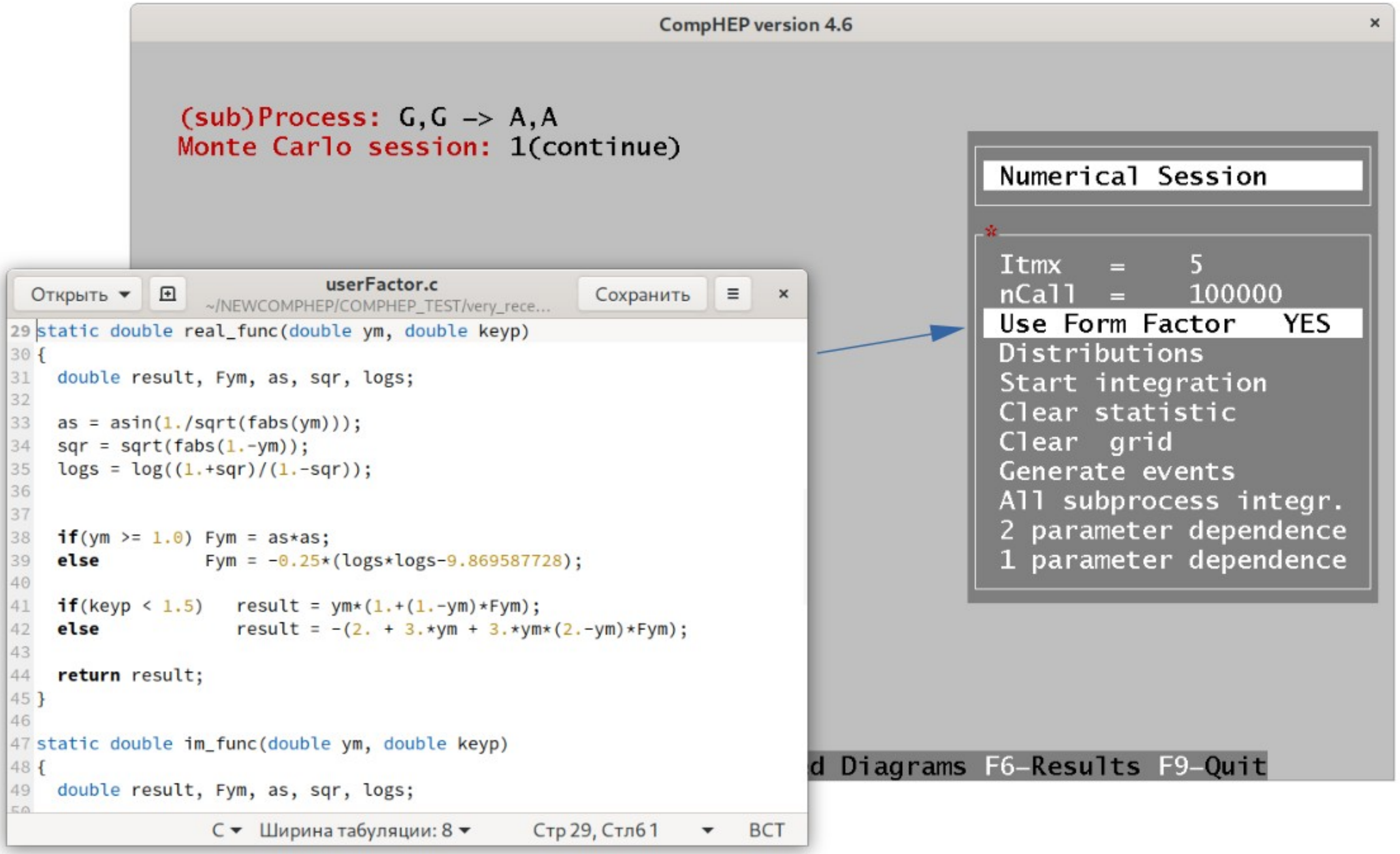


These form factors are used in the vertex functions of the model.

The names «myfunc1, myfunc2, myfunc3,...» are reserved for these functions.

Calculations with complicated form factors. Option 2

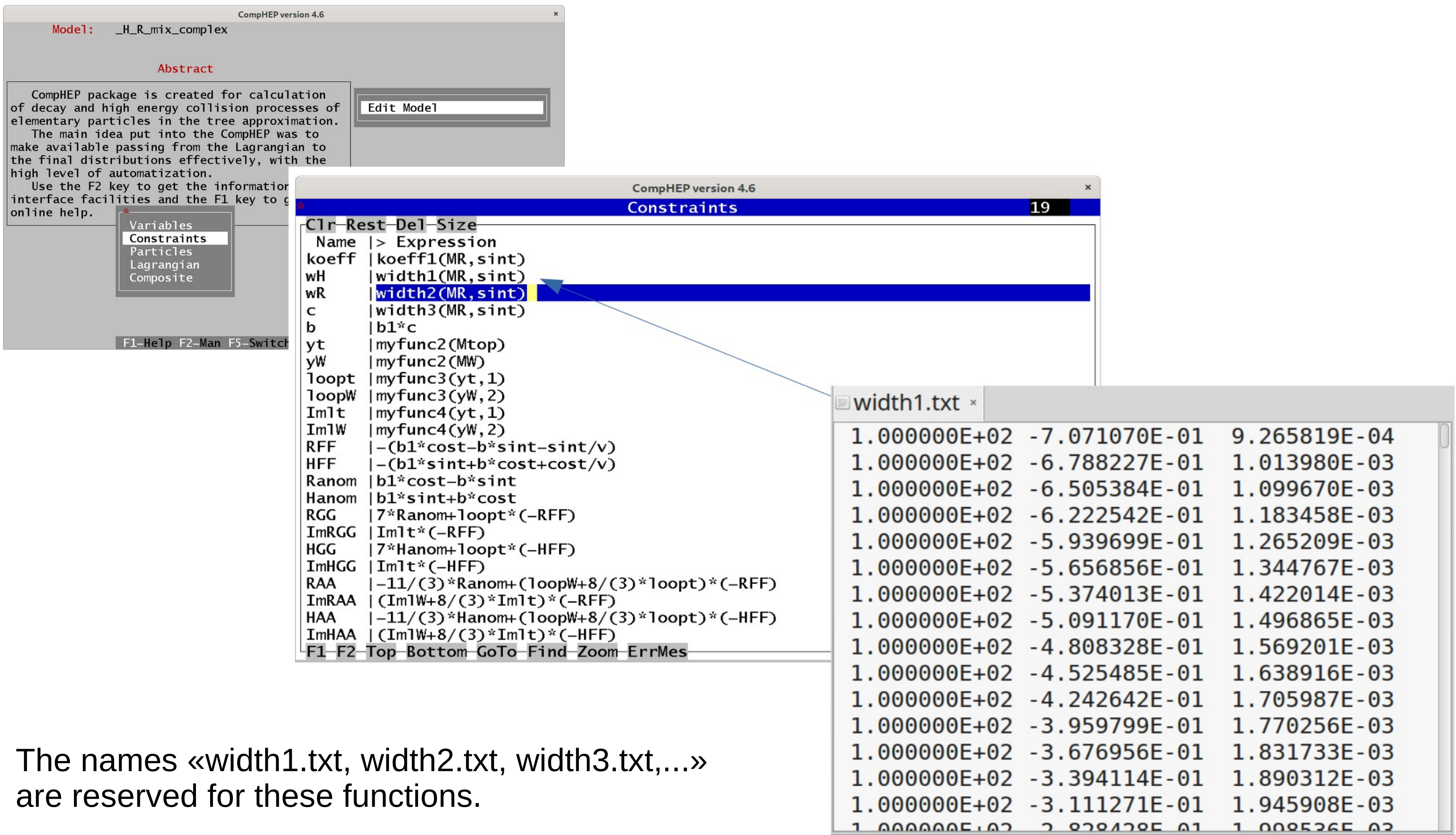
Second possibility Call a user-defined form factor function in a CompHEP **numerical session** in the list of numerical procedures.



This form factor is used as a common multiplier of the full process matrix element.

Using table-defined functions in model parameter expressions. Option 1

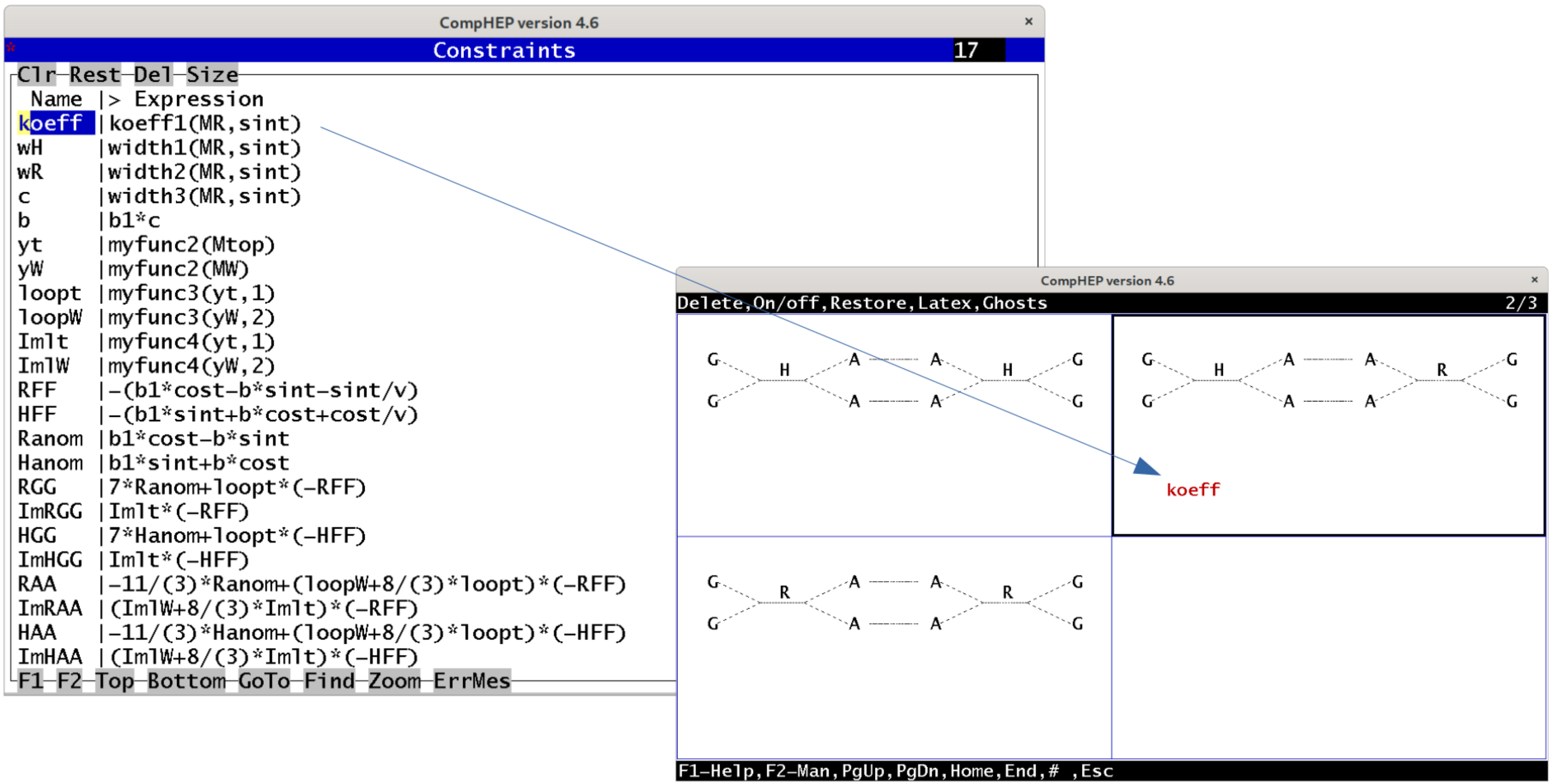
Call the user-defined function specified as a table of values and defined in the file "width1.txt" in the CompHEP **numerical session** in the list of functional expressions of the model.



The names «width1.txt, width2.txt, width3.txt,...» are reserved for these functions.

Using table-defined functionsin model parameter expressions. Option 2

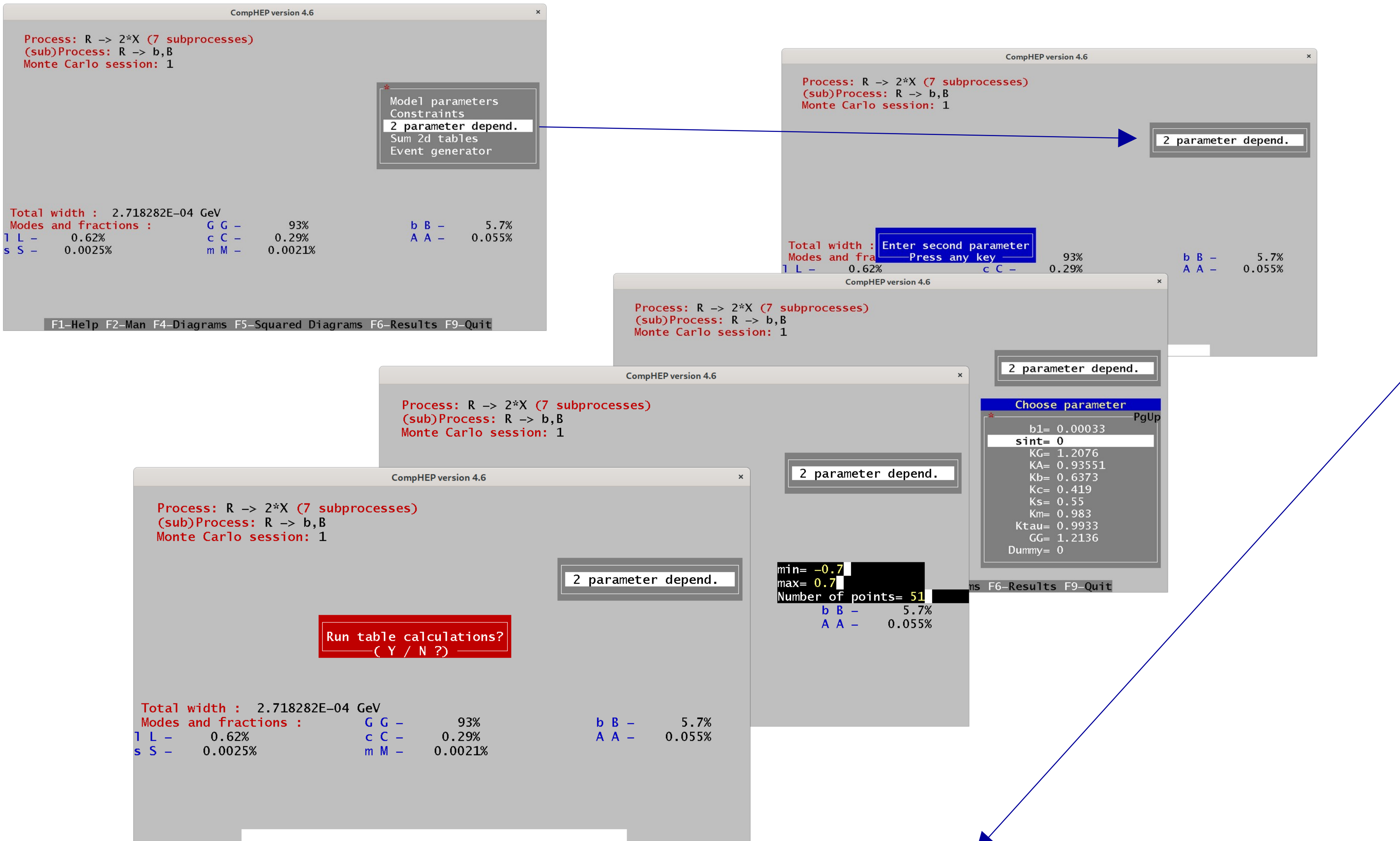
Multiplication of any part of the square of the amplitude modulus by a function specified as a table of values and defined in the file "koeff1.txt" in the CompHEP **symbolic session** in the list of functional expressions of the model.



The names «koeff1.txt, koeff2.txt, koeff3.txt,...» are reserved for these functions.

Calculating an array of decay width values depending on multidimensional array of model parameter values

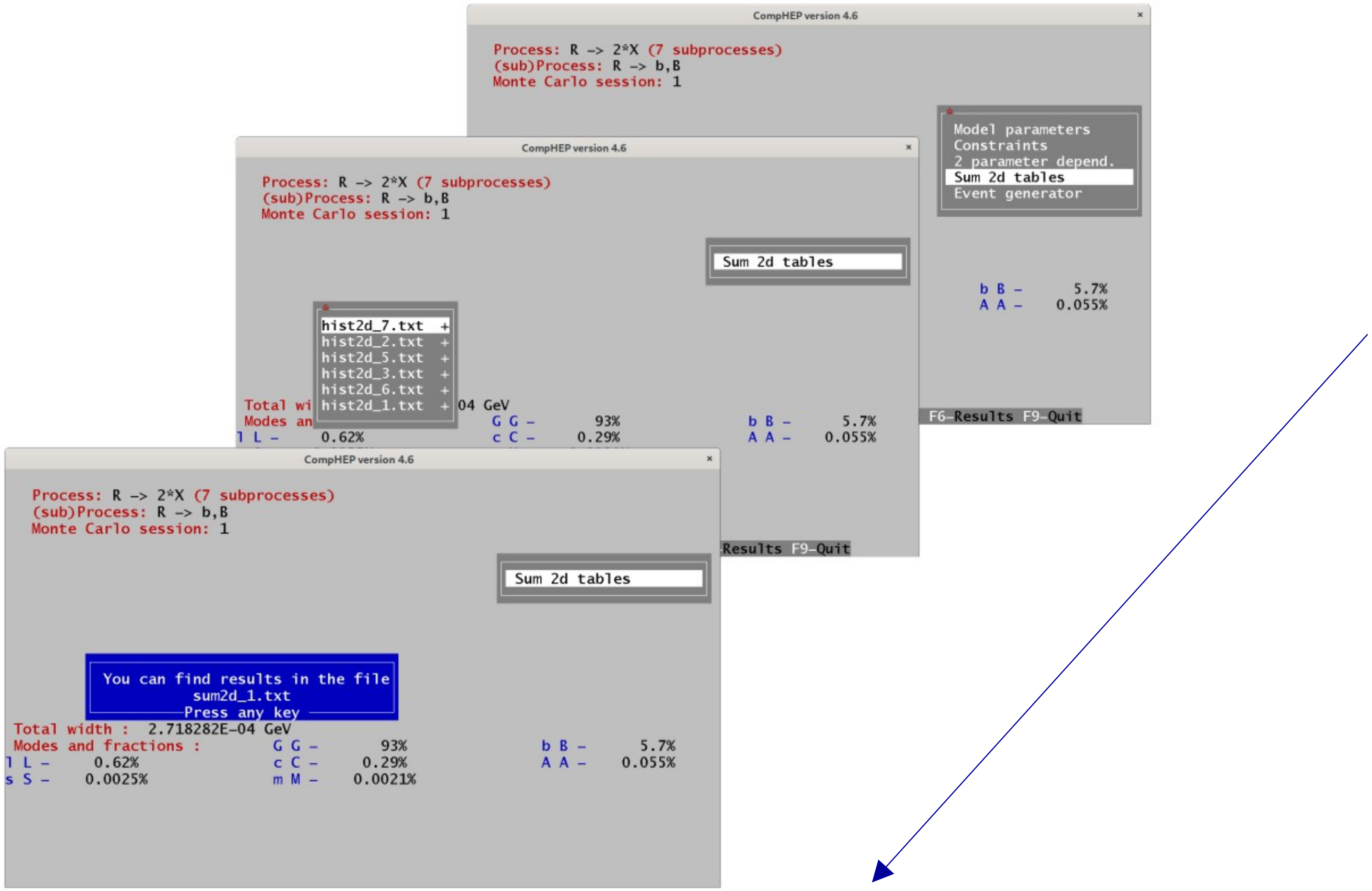
In the decay width calculation menu in the CompHEP **numerical session.**



The table of width values is written to the file "width_N.txt".

Summation of arrays of partial decay width values

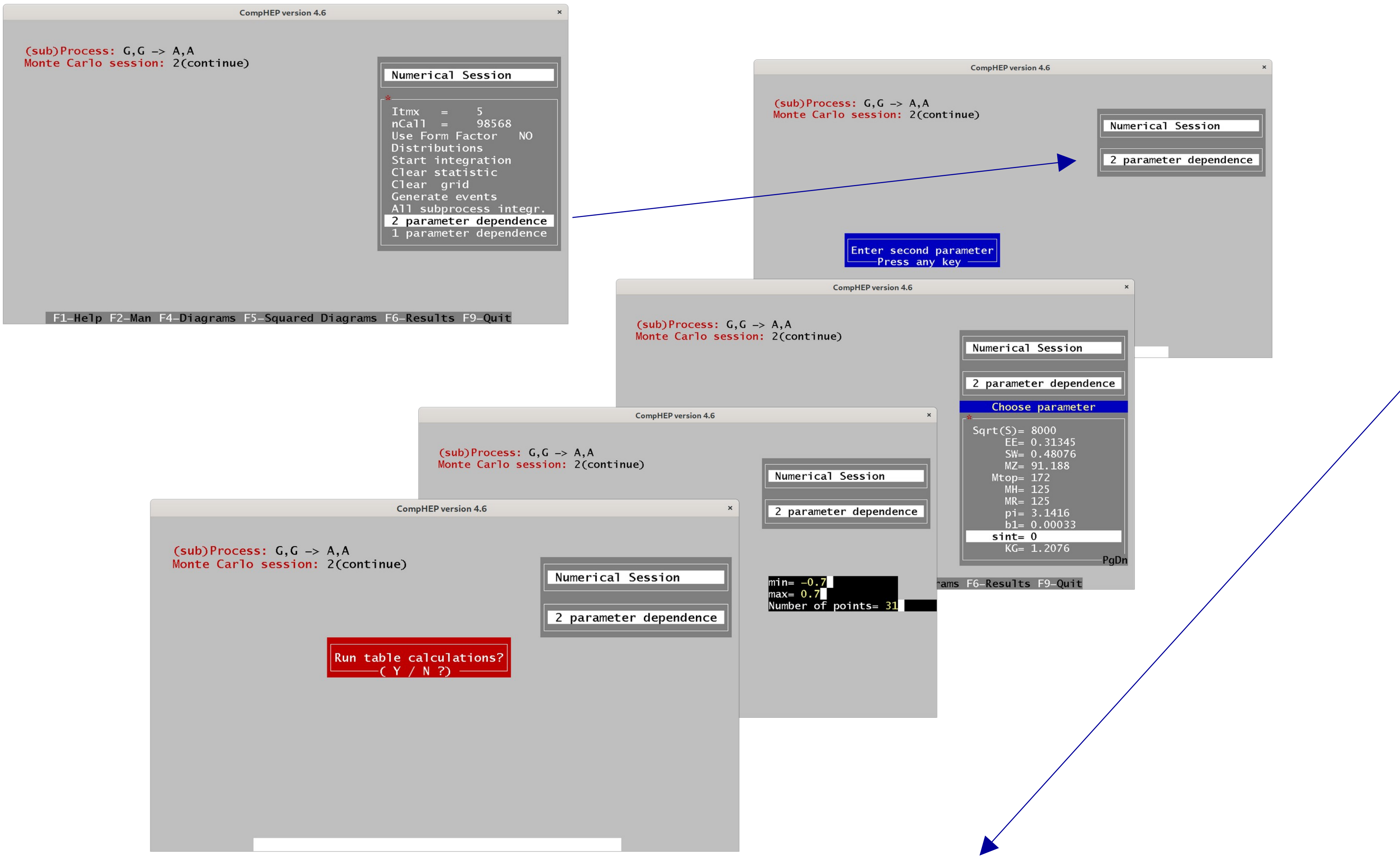
In the decay width calculation menu in the CompHEP **numerical session**.



The table of summed partial width values is written to the file "sum2d_N .txt".
This file can be renamed to "width_N.txt" and used as a table-defined function in the model.

Calculating an array of scattering cross-section values depending on multidimensional arrays of model parameter values (Interactive mode)

In the scattering cross-section calculation menu in the CompHEP **numerical session**.



The table of scattering cross-section values is written to the file "table2d_1.txt".

Calculating an array of scattering cross-section values depending on multidimensional arrays of model parameter values (Batch mode)

In command mode, edit the file "tablecalc.dat":

```
subprocnum=   1
count1=   9
count2=  37
dummyflag1= 0
param1num= 6
minprm1= 1.000000e+02
maxprm1= 1.500000e+02
npoints1= 51
dummyflag2= 0
param2num= 9
minprm2= -7.000000e-01
maxprm2= 7.000000e-01
npoints2= 51
```

- subprocnum — Subprocess number
- count1 — Current step of 1st parameter
- count2 — Current step of 2nd parameter
- dummyflag1 — 1st dummy parameter indicator
- param1num — Number of the 1st parameter in the list
- minprm1 — Minimum value of 1st parameter
- maxprm1 — Maximum value of 1st parameter
- npoints1 — Number of steps for 1st parameter
- dummyflag2 — 2nd dummy parameter indicator
- param2num — Number of the 2nd parameter in the list
- minprm2 — Minimum value of the 2nd parameter
- maxprm2 — Maximum value of the 2nd parameter
- npoints2 — Number of steps for the 2nd parameter

In command mode, run the command "./table_batch".

Statistical processing of results and construction of confidence regions in the space of model parameters

Confidence regions of parameters are determined by searching for the minimum of the function χ^2 :

$$\chi^2(\mu_i) = \sum_i^{N_{ch}} \frac{(\mu_i - \hat{\mu}_i)^2}{\sigma_i^2}$$

- where ***ch*** - is the number of channels for the production of a new particle, $\boldsymbol{\mu_i}$ - theoretical (fitting) value of signal strength for a given channel, $\boldsymbol{\mu_i}$ˆ - experimental value of signal strength for a given channel, $\boldsymbol{\sigma}_i$-ошибка измерения экспериментальной силы сигнала для даного канала.

- The fitted value of the signal strength $\boldsymbol{\mu_i}$ is defined as the value of the process cross-section predicted by the new model divided by the value of the cross-section predicted by the Standard Model: $\mu_i = \sigma_{bsm,i}/\sigma_{sm,i.}$

- The experimental value of signal strength is calculated as: $$\hat{\mu}_i = \frac{N_{obs,i} - N_{backgr,i}}{N^{SM}_{signal,i}}$$

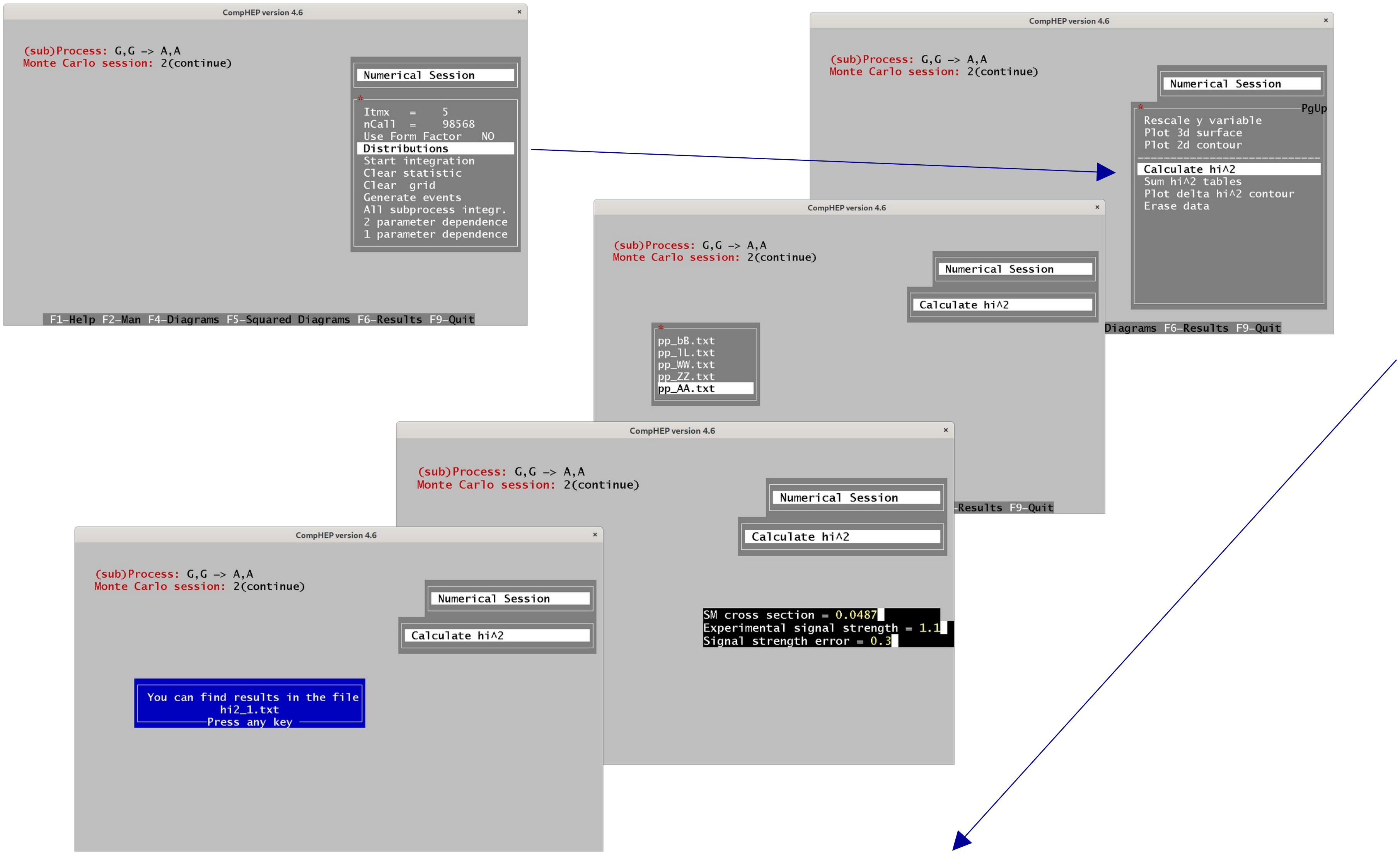
- where $\boldsymbol{N_{obs,i}}$ - total observed number of events, $\boldsymbol{N_{obs,i}}$ - number of background events, $\boldsymbol{N_{obs,i}}$ - the number of events predicted by the Standard Model.

- Finding the minimum of the function χ^2 allows us to determine $\mathbf{1}\boldsymbol{\sigma}$, $\mathbf{2}\boldsymbol{\sigma}$, $\mathbf{3}\boldsymbol{\sigma}$ *- confidence regions of the parameters using the formula:* $\chi^2 = \chi^2_{min} + \Delta\chi^2$

- where $\boldsymbol{\Delta\chi^2}$ - is a quantile and is determined by the cumulative distribution function.

Calculating an array of χ^2 function values depending on multidimensional arrays of model parameter values

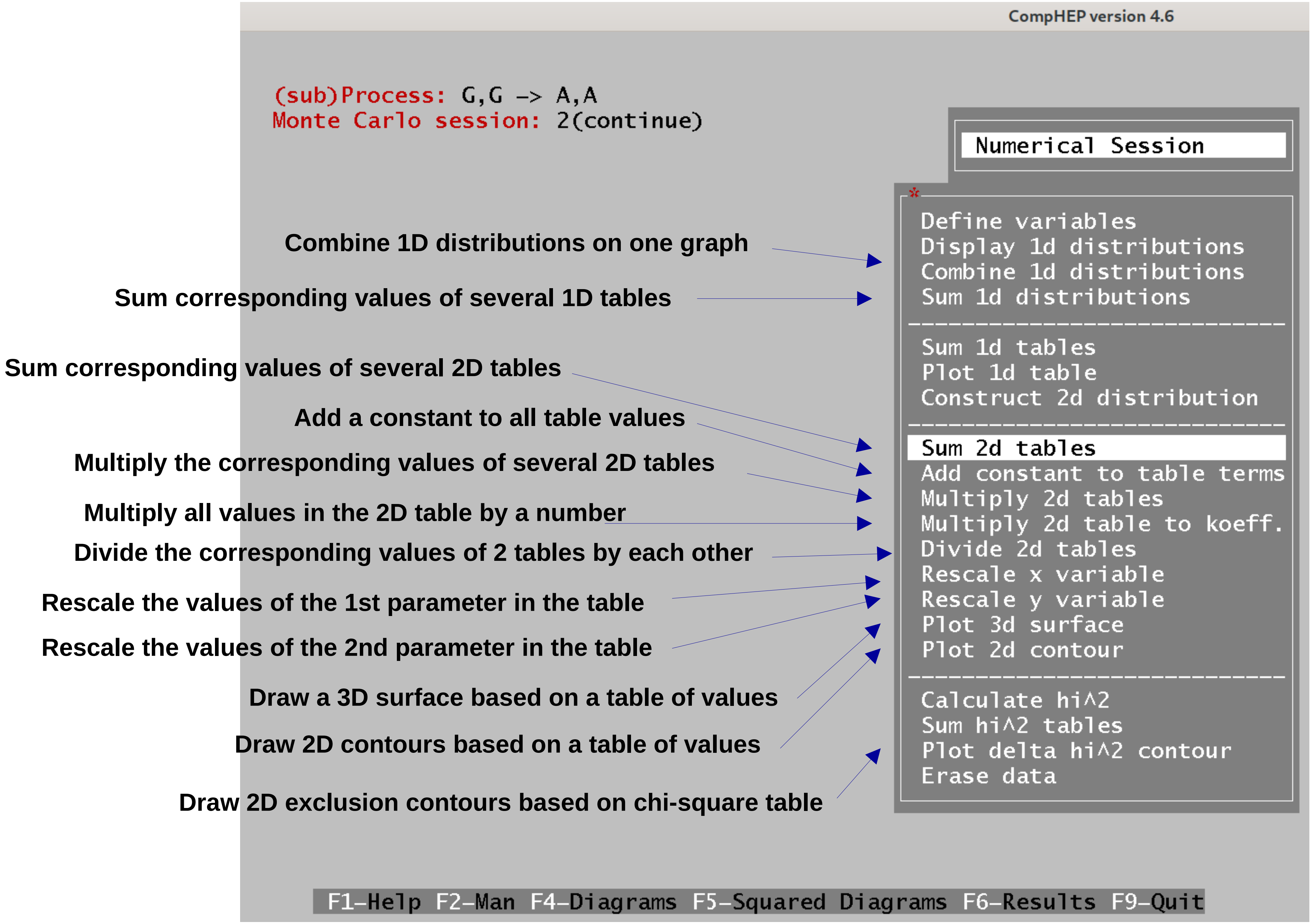
In the distribution construction menu in the CompHEP **numerical session**.



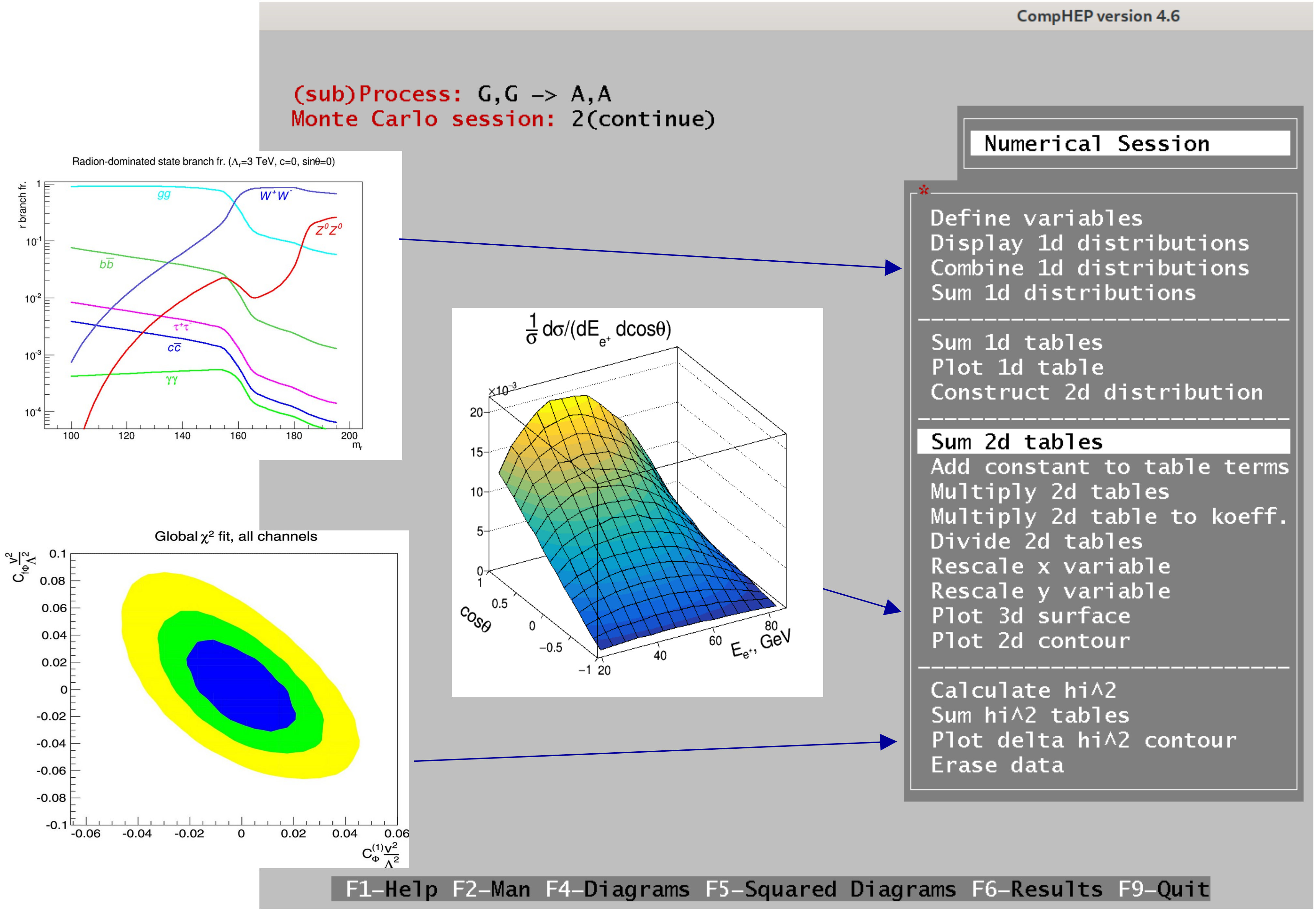
The table of scattering cross-section values is written to the file “hi2_1.txt”.

New CompHEP functions for data processing and graphical presentation of results

In the distribution construction menu in the CompHEP **numerical session**.



Examples of the new CompHEP functions for graphical presentation of results



The functionality of the CompHEP software package has been extended:

- The CompHEP package has been extended to handle complicated form factors, allowing the calculation of decay widths and scattering cross sections in next-to-leading order of perturbation theory.
- A module of the CompHEP package has been developed for automatic sequential calculations of arrays of decay width and scattering cross-section values depending on multidimensional arrays of model parameter values.
- A module of the CompHEP package has been developed for statistical processing of results and construction of confidence regions in the space of model parameters.
- A module of the CompHEP package has been developed for extended graphical presentation of results: construction of one-dimensional, two-dimensional and three-dimensional graphs in the ROOT package format.

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