SLD User's Guide

R.C. Fernow
Brookhaven National Laboratory
30 March 2010

The Solenoid Lattice Designer (SLD) is a Windows program for designing solenoid lattices for ionization cooling channels. The program displays the coil configuration graphically and shows the location of the peak field and peak hoop stress in the coils. It shows the solenoid field on-axis as a function of z, shows the beta function as a function of z, and shows the beta function as a function of momentum. It can also display the force distribution inside the coils, a grid of the off-axis magnetic field, magnetic lines of force, or the Fourier components of the on-axis field. It also contains a built-in optimizer.

1. Starting the program

The program can be started from a DOS (command) window using the command

C:> sld

or

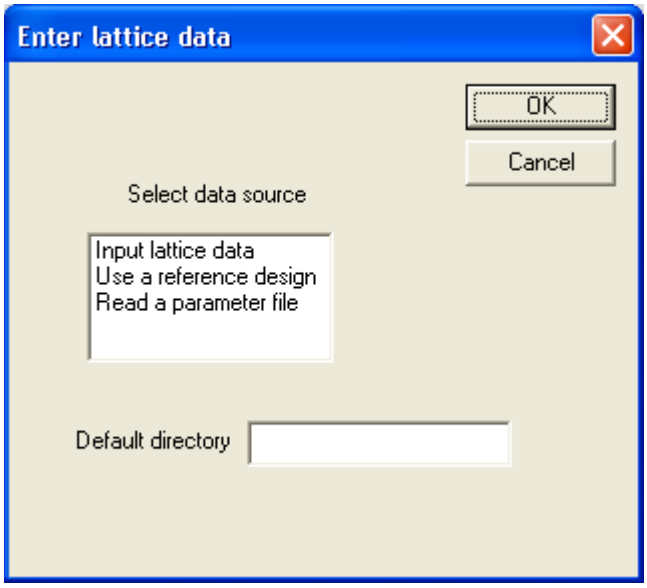
C:> sld file.prm

where *file.prm* is the name of an existing parameter file.

The program can also be started by clicking on its Windows icon.

2. Opening screens

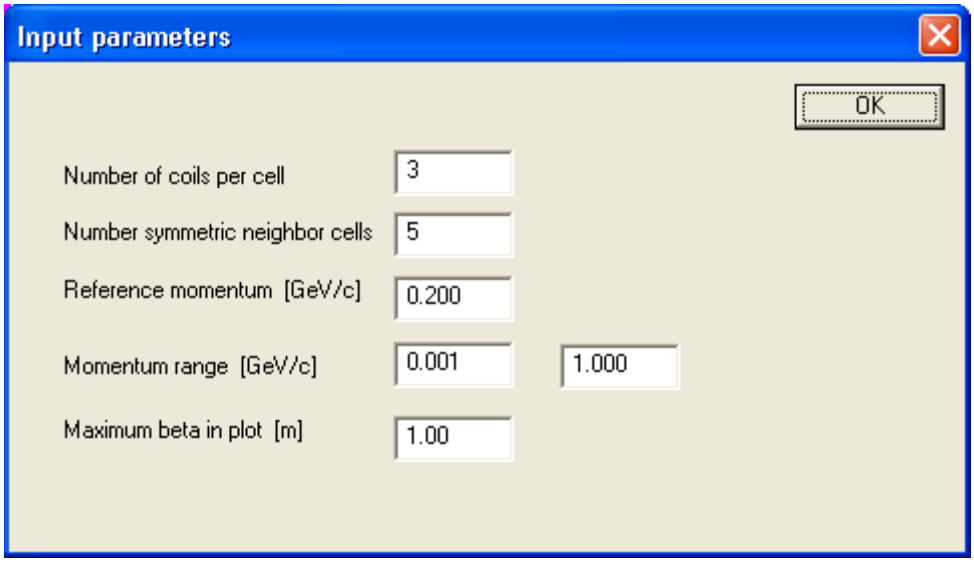
The figure shows the opening screen when the program is started without specifying a pre-existing parameter file.



The user has three choices to enter the lattice design data. The first choice allows inputting the data by filling out a set of dialog windows. The second choice brings up a list of built-in reference designs. The last choice is to read in an existing parameter file that has been previously saved or created offline. The directory for reading and writing files may also be changed here.

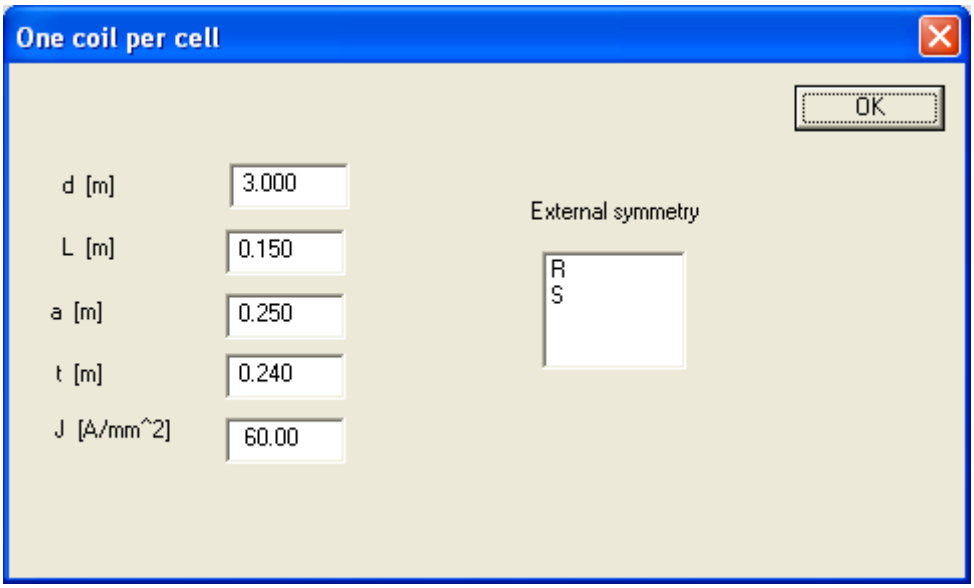
2.1 Entering data using the dialog windows

If the user chooses to input the data by hand it brings up the window



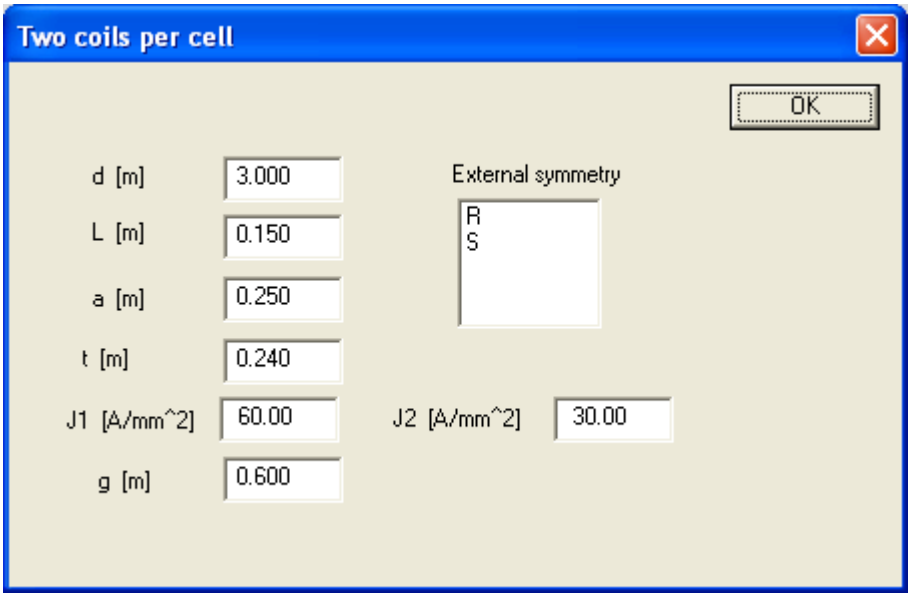
The number of coils per cell must be from one to four. The next window that comes up depends on the number of coils per cell.

For 1 coil per cell the following window comes up.



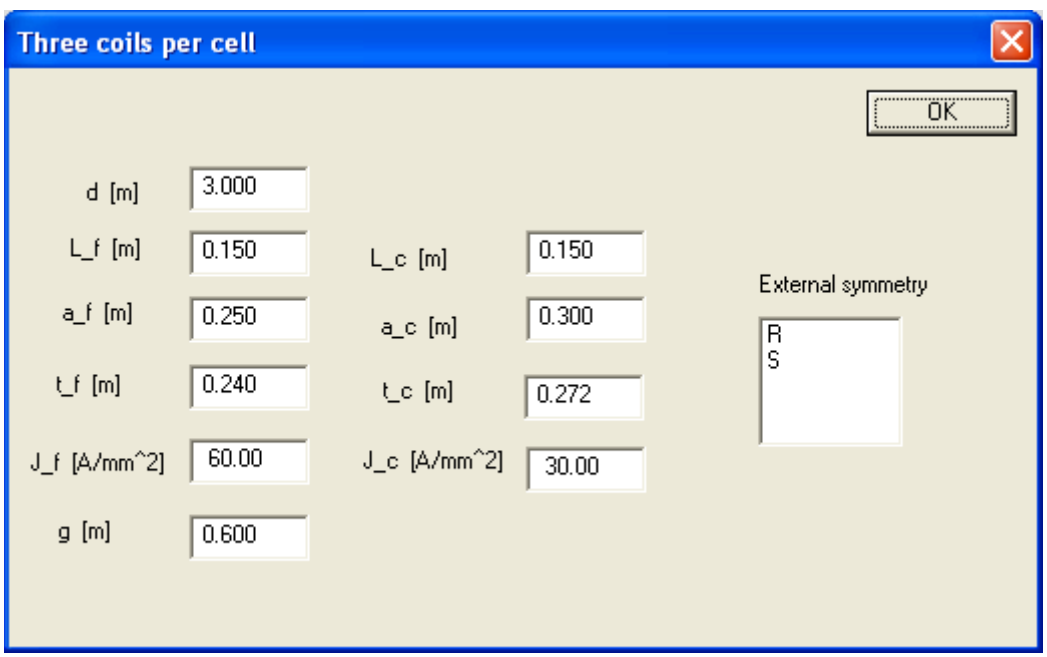
d is the cell length, **L** is the coil length, **a** is the coil inner radius, **t** is the radial thickness, and **J** is the current density. The external symmetry parameter controls the polarity of the currents in alternate cells in the lattice. **R** symmetry means the polarities are the same in every cell. **S** symmetry means the polarities of corresponding coils flip in alternate cells.

For 2 coils per cell the following window comes up.



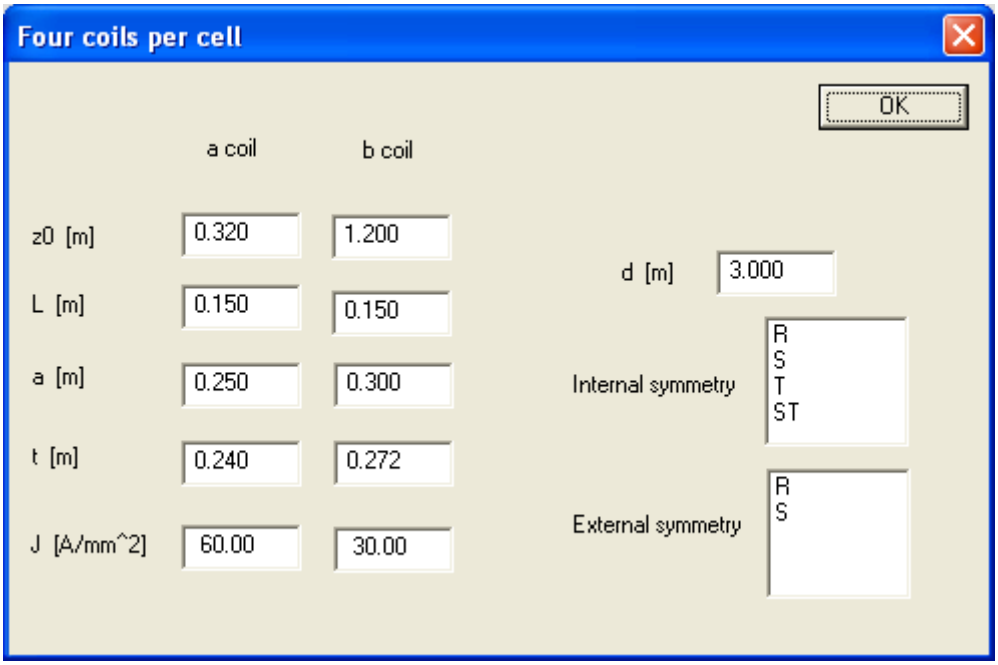
J1 and **J2** are the current densities in the two coils, and **g** is the gap between the coils at the cell boundary.

For 3 coils per cell the following window comes up.



The symmetric coils nearest the boundaries are called the *focus* coils. The other coil centered on the midplane is called the *coupling* coil.

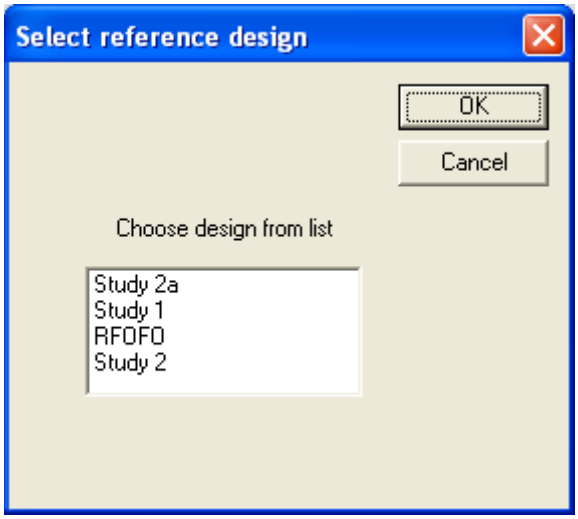
For 4 coils per cell the following window comes up.



The parameters of two of the coils (*a* and *b*) must be specified. **z0** is the distance of the left edge of the coil from the left cell boundary. The other two coils (*c* and *d*) in the cell are determined by the *internal symmetry parameter*. **R** means the geometry and polarities are the same as the corresponding specified coils. **S** means the geometry is the same, but the polarities are flipped. **T** means the geometry is reversed, but the polarity is the same, i.e. *c* has the same geometry as *b*, etc. **ST** has both the geometry and the polarity reversed. The *external symmetry parameter* controls the polarity of the coils in alternate cells along the lattice. **R** means the polarities of all coils are the same as the corresponding coils in the original cell. **S** means the polarities of all coils are opposite from the corresponding coils in the original cell.

2.2 Entering a reference design

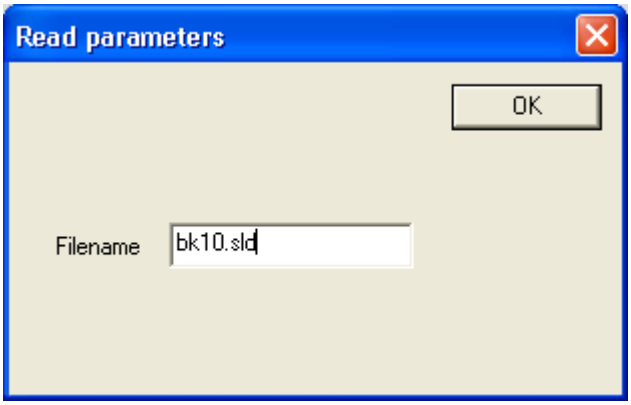
If the user chooses to enter a reference design it brings up the window



The user should click on an item in the list.

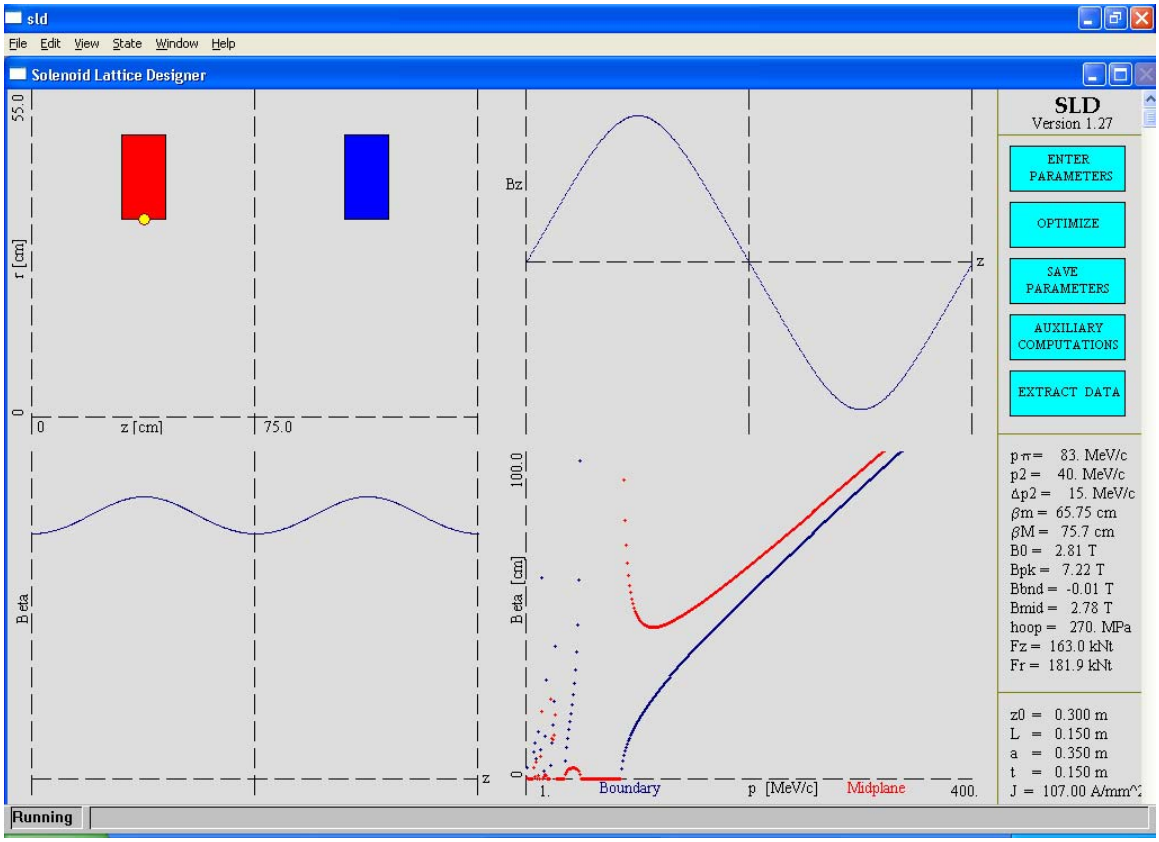
2.3 Entering a saved design

If the user chooses to enter a saved design, it brings up the following window.



3. Results screen

After a design has been entered the program displays a screen similar to the following.



The upper-left graph shows the coil geometry for two cells of the lattice. Coils with positive current are shown in red, while coils with negative current are shown in blue. The yellow circle on the coil shows the peak field location. The brown circle shows the location in the coils of the maximum hoop stress. The dashed vertical lines show the locations of cell boundaries.

The upper right graph shows the solenoidal field on-axis for two adjacent cells. The lower left graph shows the beta function as a function of z, evaluated at the reference momentum. The lower-right graph shows the beta function as a function of momentum. The beta function at the cell boundary is shown in blue, while the beta function at the cell midplane (midway between the boundaries) is shown in red.

The right hand panel is broken into four parts. The upper box indicates the version of the program that is running.

The second box contains five buttons that can be executed by clicking with the mouse. ENTER PARAMETERS brings up a series of windows for the user to enter the parameters for a new design. OPTIMIZE brings up a series of windows for the user to start an optimization study. SAVE PARAMETERS is used to save the parameters for a

design to a file. AUXILIARY COMPUTATIONS brings up additional calculations of the magnetic field grid, force distribution inside the coils, magnetic lines of force, or Fourier components of the on-axis field. EXTRACT DATA creates external ASCII files of selected information, such as the geometry, field or beta function data for a design.

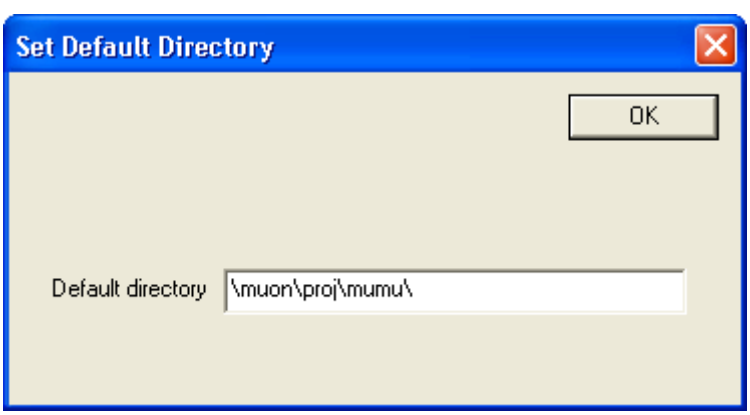
The third box is used to display numerical values for some important coil properties and lattice characteristics:

$p\pi$	upper momentum edge of π resonance stop band
p2	central momentum of second pass band
$\Delta p2$	full width of second pass band
βm	minimum value of beta function at reference momentum
βM	maximum value of beta function at reference momentum
B0	maximum solenoid field on-axis
Bpk	peak field
Bbnd	solenoid field at cell boundary
Bmid	solenoid field at cell midplane
hoop	maximum hoop stress
Fz	maximum axial force
Fr	maximum radial force

The lower box contains data about the current parameters of a selected coil. The user determines what is displayed here by moving the mouse over the drawing of the desired coil in the left-most cell of the upper-left window. The information displayed is

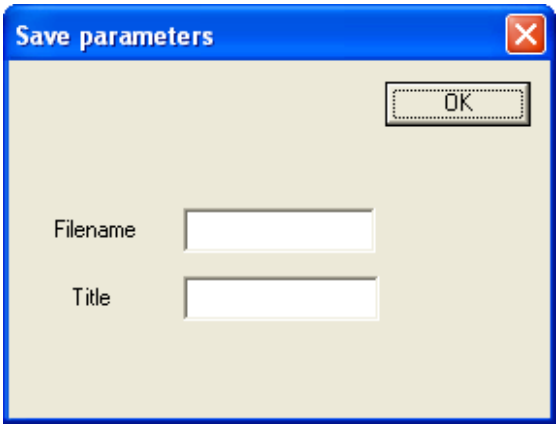
z0	axial position of left edge of coil [m]
L	axial length of coil [m]
a	inner radius of coil [m]
t	radial thickness of coil [m]
J	engineering current density [A/mm^2]

The user can set a default directory for reading and writing files by clicking on the File menu and selecting Set Default Directory. This will bring up the following dialog box.



4. Save parameters

This command is used to save the parameters for the current design.



Besides the name of the file the user can enter some descriptive information as the title.

This file can also be created offline with a text editor. The format of the file is:

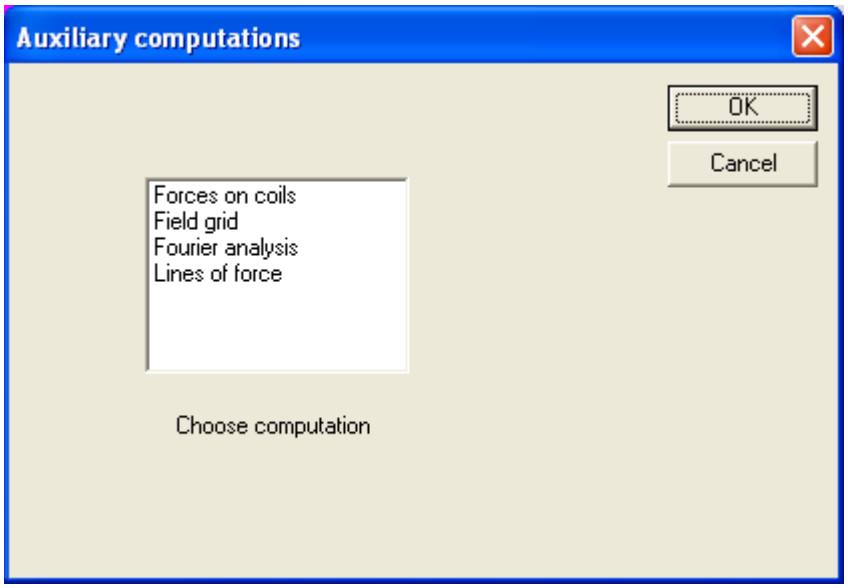
Title	(a80)
d g	(R) d:cell period [m] g: boundary gap [m]
pref pmin pmax	(R) reference, minimum, & maximum momentum [GeV/c]
btmx	(R) maximum value of beta in plot [m]
syme symi	(a3) external & internal symmetry parameters syme = {R, S} symi = {R, S, T, ST, N}
nsnc	(I) number of symmetric neighbor cells
ncpc	(I) number of coils per cell {1-50}

For i=1,ncpc
za(i) La(i) aa(i) ta(i) Ja(i) (R)
where za = axial position of left edge of coil [m]
La = axial length of coil [m]
aa = inner radius of coil [m]
ta = radial thickness of coil [m]
Ja = engineering current density [A/mm^2]

If the user is creating an external file with more than 4 coils per cell or a non-symmetric lattice with 2-4 coils per cell, then set SYMI=N. For symmetric lattices with 4 coils per cell the user should enter SYMI the appropriate symmetric code from the set {R, S, T, ST}. Externally created files must have NCPC lines of coil data.

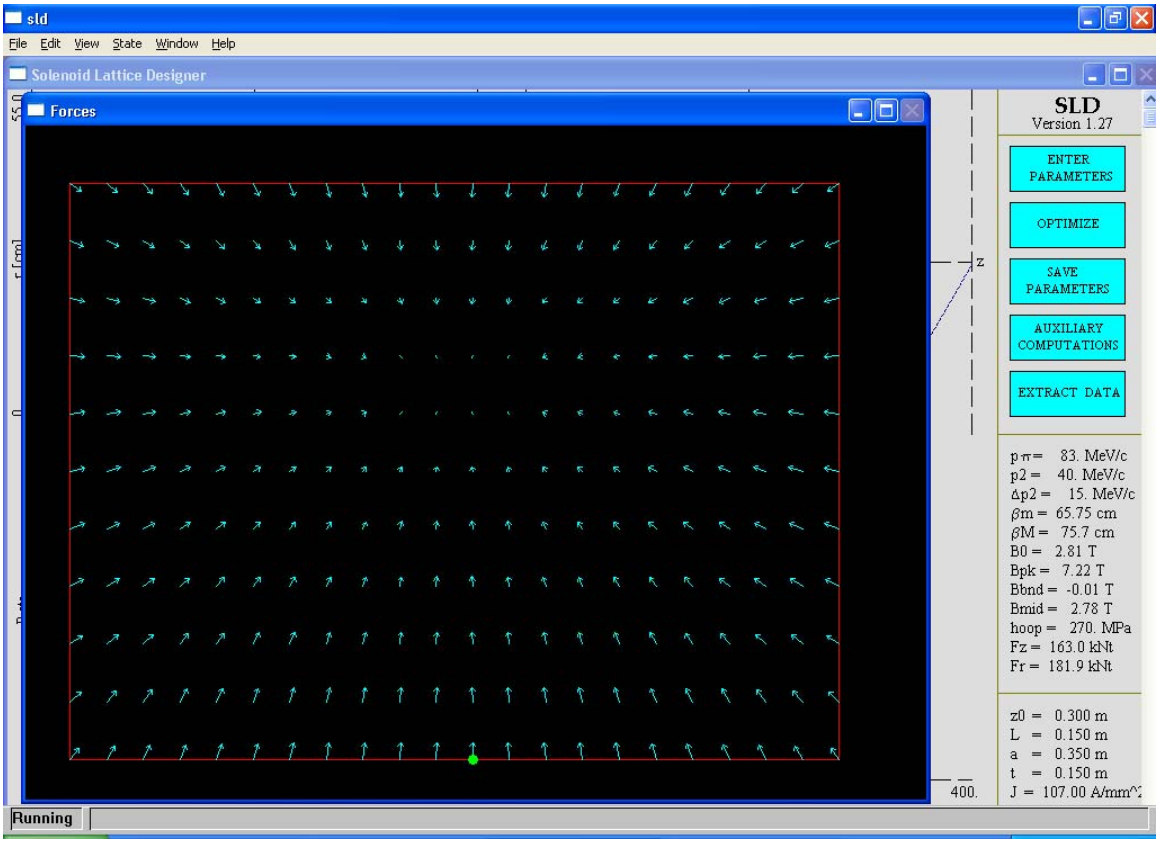
5. Auxiliary Computations

The AUXILIARY COMPUTATIONS button brings up a new window where the user may select additional calculations of the magnetic field grid, force distribution inside the coils, magnetic lines of force, or Fourier components of the on-axis field.



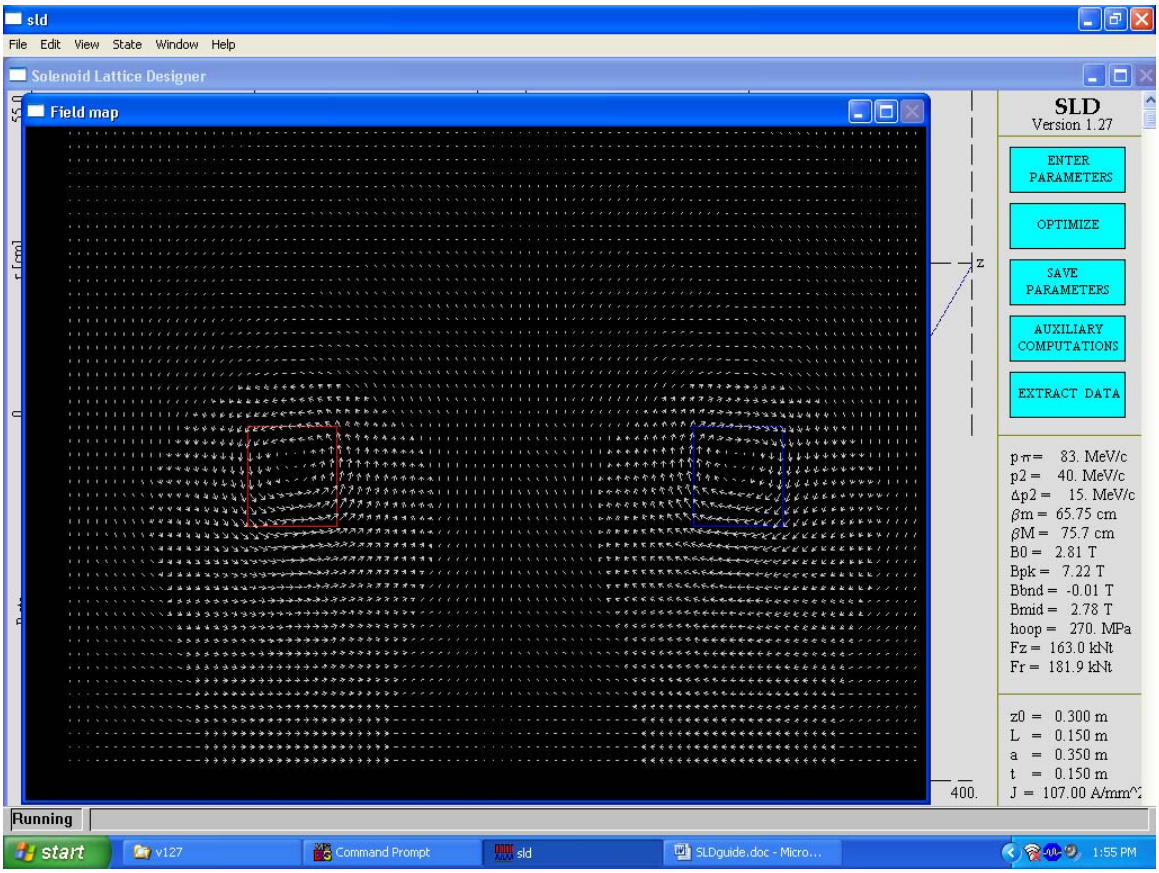
The user must select one of the items in the list and press OK.

Here is an example of forces on the coil.



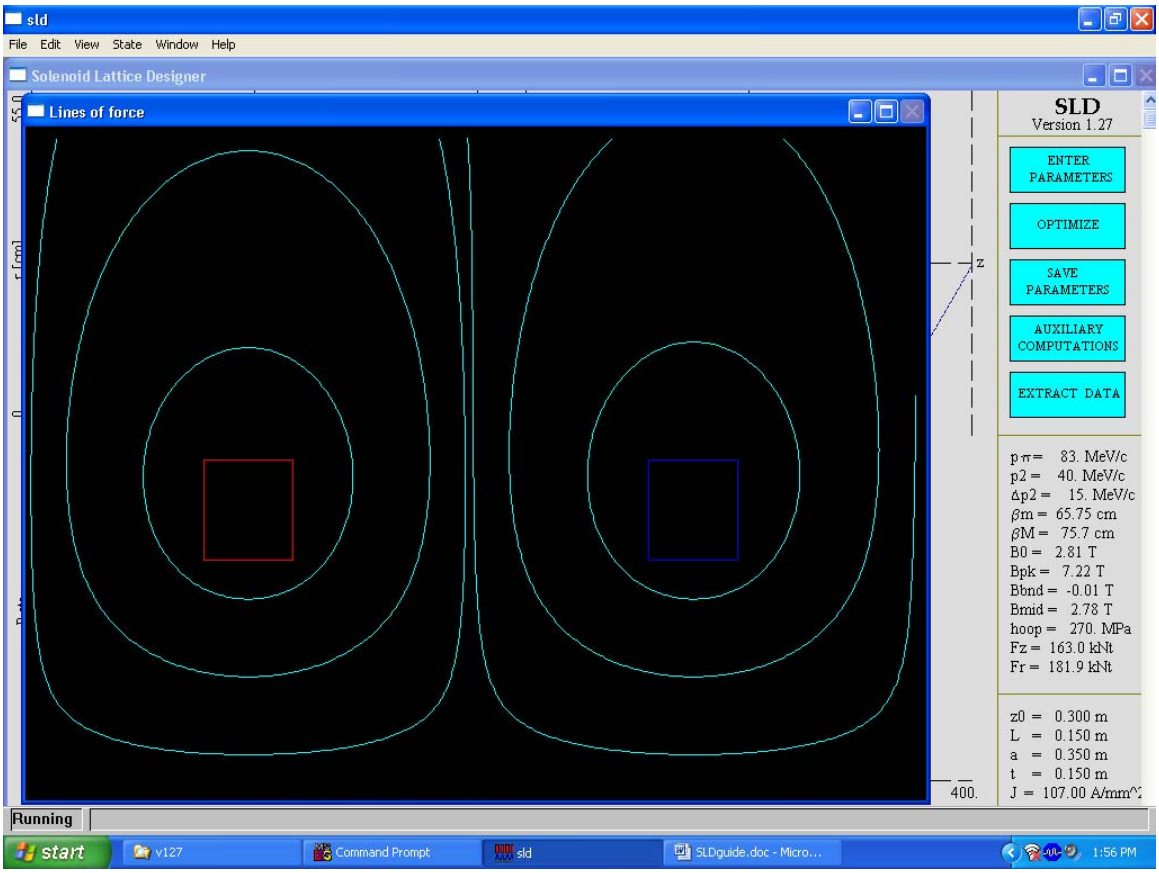
The location of the peak magnitude of the force is shown as a green circle. Symmetric coils in a lattice are not shown.

Here is an example of a magnetic field grid. There is a delay of 20-30 seconds while the grid is being calculated.

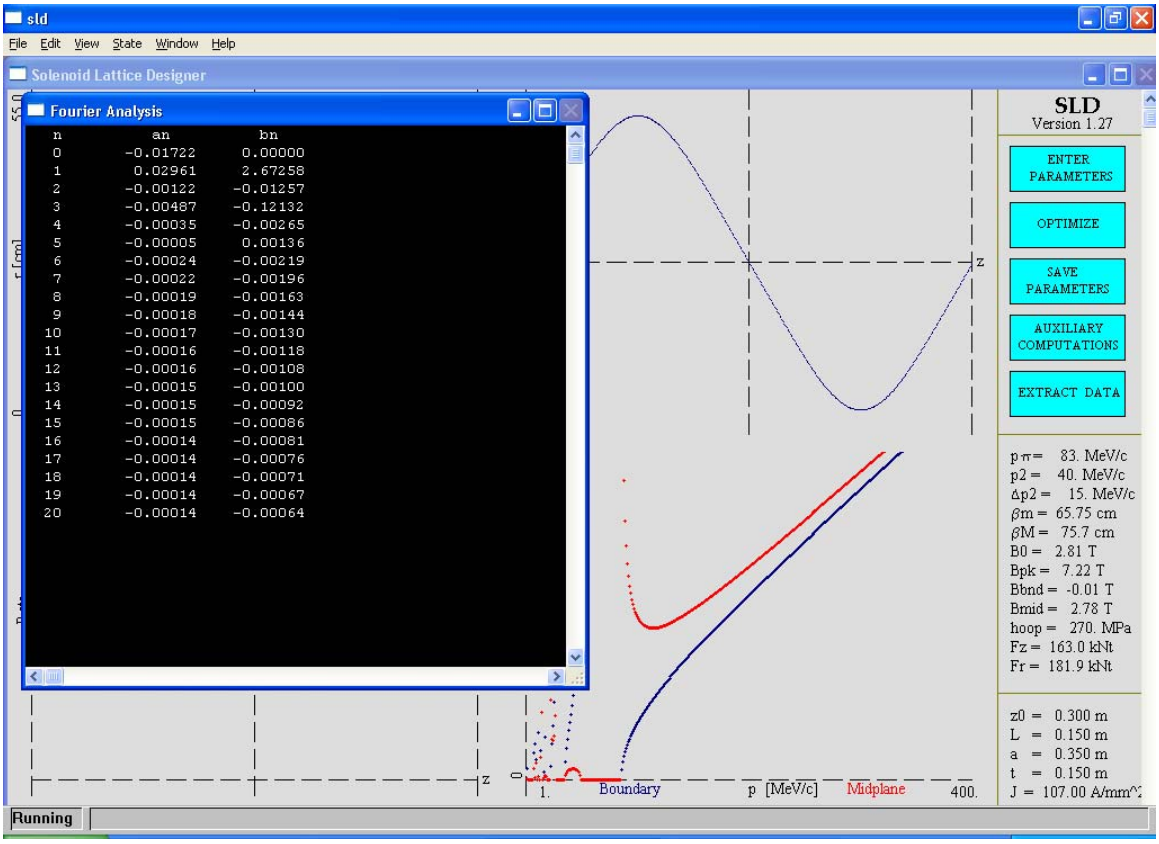


The coil positions are outlined in red and blue.

Here is an example of magnetic lines of force. There is a delay of 20-30 seconds while the grid is being calculated, unless the grid was calculated previously



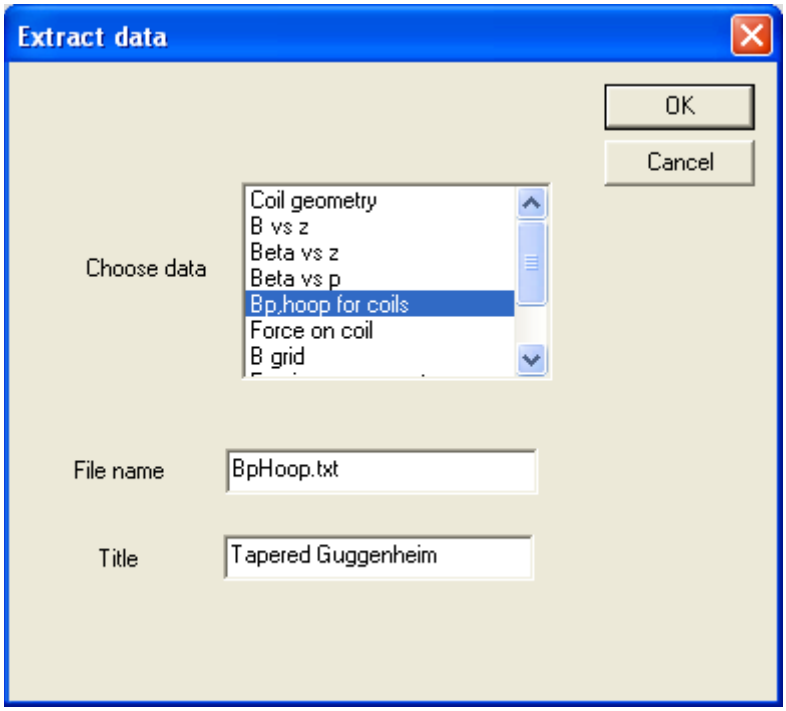
Here is an example of a Fourier analysis of the on-axis magnetic field.



The a_n coefficients are the cosine-like terms, while the b_n coefficients are the sine-like terms.

6. Extract Data

The EXTRACT DATA button can be used write selected information to an external file. This will bring up the following window.



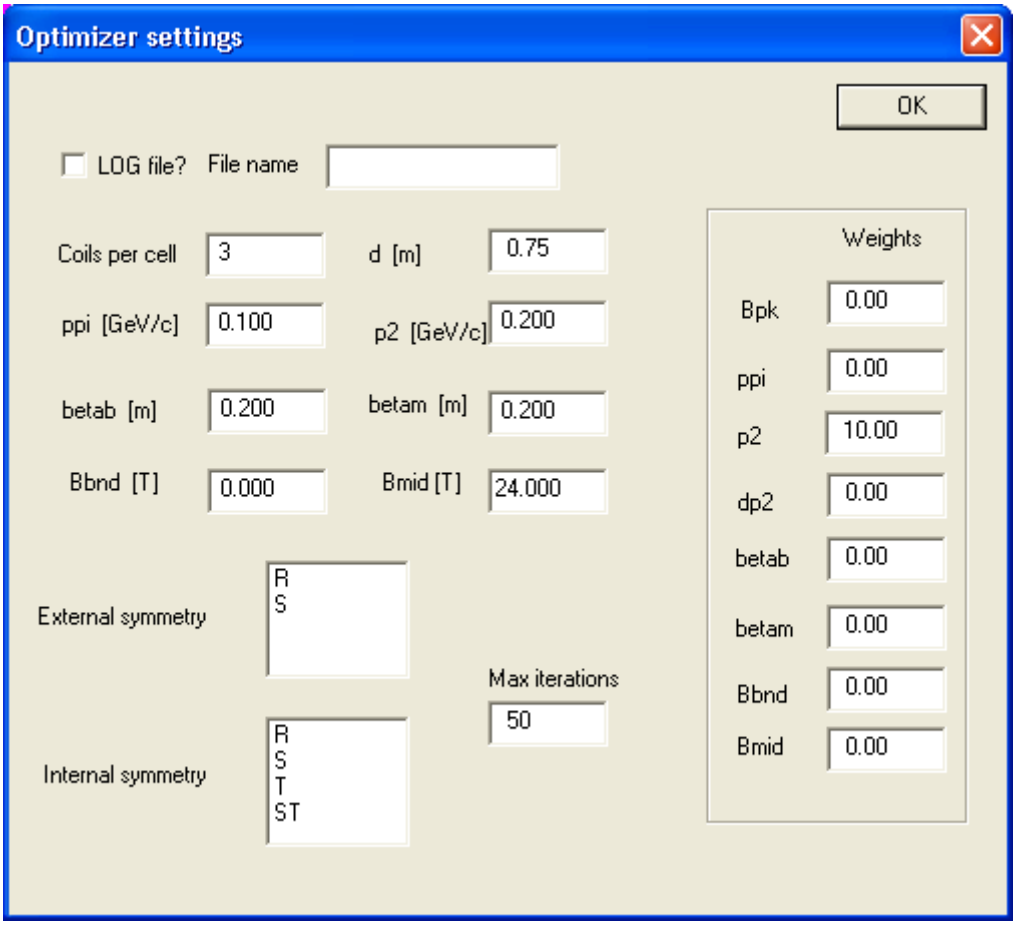
The user can specify the file name where the data is written and can specify up to 80 characters of "title" information at the head of the file. All available information can be written to a single file by choosing All Data.

The B vs z choice also lists dB/dz and d^2B/dz^2.

The Beta vs p choice also lists the phase advance.

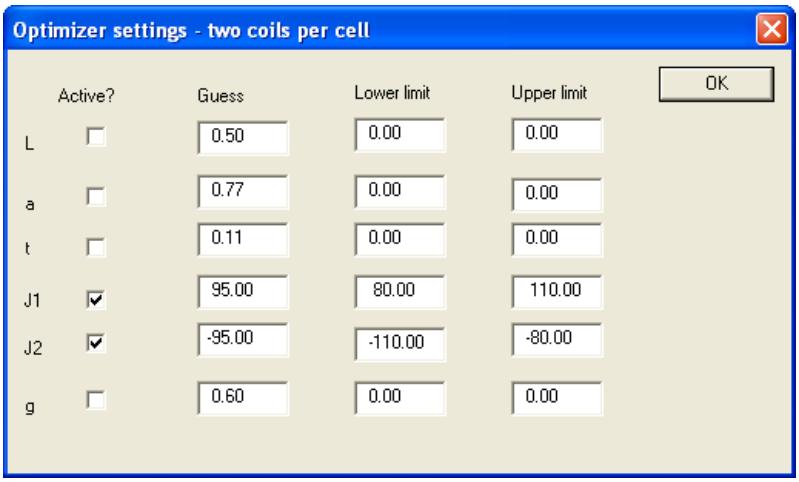
7. Optimization

The first window controls some general properties of the optimizer.



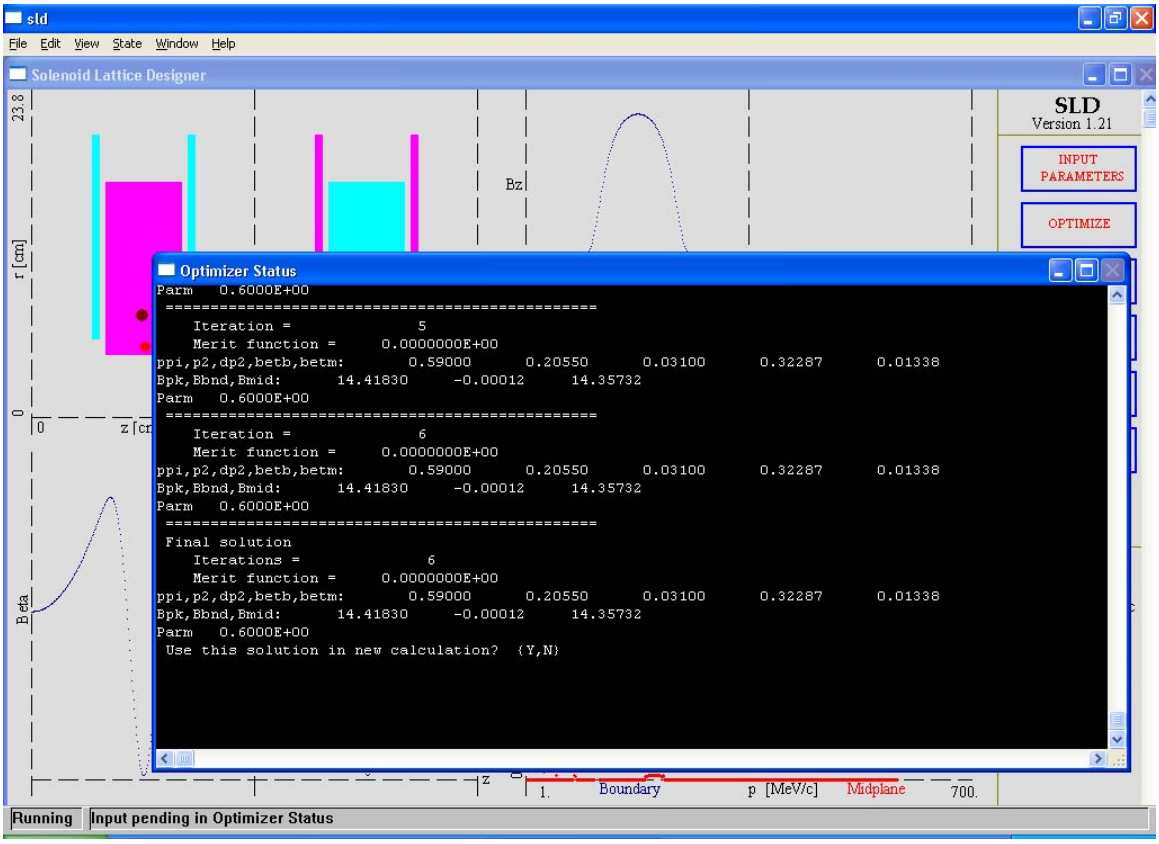
The progress of the optimization can be saved in an ascii log file. The number of coils per cell controls the content of the second optimizer window. ppi is the desired value of p_π, p2 is the desired value of p_2, betab is the desired value of β at the boundary, betam is the desired value of β at the midplane, Bbnd is the desired value of the field at the cell boundary, and Bmid is the desired value of the field at the cell midplane. The maximum number of iterations roughly controls how long the optimizer will continue. The weights determine the merit function for the optimization. At least one weight must be non-zero. There are weights for minimizing the peak field, getting the desired value for p_π , p_2 , β_b , β_m , Bbnd, or Bmid, or maximizing the width of the second pass band Δp_2.

The second optimizer window is used to enter specific information about the coils. For example, for two coils per cell



One must enter an initial guess for the values of all the parameters. The variables in the fit are selected by clicking on the desired Active buttons. Lower and upper limits must be entered for each of the active variables.

Once the optimization begins the progress is displayed in another window.



At completion one must type Y to replace the current solution with the optimizer results, or N to ignore it.