PBO Lab™ 3.0
(Particle Beam Optics Laboratory 3.0)

User Manual Supplement:
PARMILA-2 Application Module

A PBO Lab Module Created with the OASIS Module Builder Technology

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1. Getting Started

1. Getting Started

The PARMILA-2 Module for PBO Lab is based upon the Open Architecture Software Integration System (OASIS™) Module Builder. The OASIS Module Builder is used to create Application Modules for the Particle Beam Optics Laboratory (PBO Lab™) software. This User Manual Supplement describes the use of the PARMILA-2 Module with the PBO Lab framework. Refer to the PBO Lab User Manual (Basic Package) for general information on the PBO Lab user interface.

Overview

The PARMILA-2 Module is available commercially as a PBO Lab Module. The PARMILA 2 executable physics program is included with the PBO Lab PARMILA-2 Module under the terms of a license agreement with the Los Alamos National Laboratory. This Section of the User Manual Supplement provides an introduction to the Module. The installation of the PARMILA-2 Module is described, a summary of the PARMILA-2 Module command structure is presented, and the PBO Lab Pieces supported by the PARMILA-2 Module are listed.

Section 2 of the User Manual Supplement describes the Commands submenu for the PARMILA-2 Module. Section 3 describes the PARMILA-2 Module Optics, Parameter and Command Pieces. Section 4 summarizes the Auxiliary Input, List Windows and PARMILA-2 Options available to the user. Section 5 presents an example of carrying out PARMILA-2 computations and presents some example results. The Appendix provides copies of PARMILA-2 documentation, included as part of this User Manual Supplement under the license agreement with the Los Alamos National Laboratory.


Installing the PARMILA-2 Module

The PARMILA-2 Module consists of two parts:
1. The OASIS Module Specification Document, and
2. The PARMILA 2 physics program.

The OASIS Module Specification Document is a file with extension .omod and has the name OASIS-PARMILA-2. The PARMILA 2 physics program has several executable files with .exe extension and certain other files. To install the PARMILA-2 Module these files need to be moved (or copied) to specific locations on your computer's hard drive.

1. Move (or copy) the files with extension " .omod " to the folder (directory) named "OModules" inside the folder (directory) where the PBO Lab 3.0 (or later) executable application is installed.

2. Move (or copy) the folder "PARMILA 2" to the folder (directory) where the PBO Lab 3.0 (or later) executable application is installed.

Figure 1 shows the locations for these components. Other files in the main directory are not illustrated.

You will need to have PBO Lab 3.0 (or later) in order to utilize the PARMILA-2 Module. If you do not already have PBO Lab 3.0 installed on your computer, you will need to install it first. Follow the installation instructions that accompanied your PBO Lab 3.0 software. If you already have PBO Lab 3.0 installed on your computer, you will not need to reinstall it. There will be many other files and folders (directories) appearing in the main PBO Lab directory. These are not shown in Figure 1.
To access the PARMILA-2 Module you will need to have a user license number for PBO Lab 3.0 (or later) and a CD-Key enabled for OASIS Modules. The user license number and CD-Key are included in the documentation shipped with the PBO Lab software or Module upgrade. The license number and CD-Key need to be entered into the PBO Lab Registration window after installation of the PBO Lab software. If you are installing PBO Lab for the first time, follow the instructions in the PBO Lab User Manual (Basic Package). If you are adding the PARMILA-2 Module to an existing PBO Lab installation, you will need to update your CD Key. To do this, start PBO Lab in the (default) Single Model Mode. You should see a PBO Lab Document Window like that illustrated in Figure 2. Under the Tutorial menu of the Document Window select the Register choice. A PBO Lab Registration window will open. Enter your CD Key and other data as necessary.

You will need to have PBO Lab 3.0 or later in order to utilize the OASIS PARMILA-2 Module. (OASIS will not work properly with PBO Lab 2 or earlier.)

Figure 2. The Tutorial menu of the PBO Lab Document window contains a Register selection.
The PBO Lab PARMILA-2 Module installation CD contains two folders:

- PARMILA OModules
- PARMILA 2

The PARMILA OModules folder on the CD contains the following Module files:

- PARMILA-2.omod
- PARMILA-LinGraf.omod
- PARMILA-Plots.omod
- PARMILA-T3D-File.omod

Each of these OModule supports different capabilities of the PBO Lab PARMILA 2 application. The corresponding libraries for the computation engines of each of the OModules are located in the PARMILA 2 folder on the CD, which contains the following files:

- PARMILA.EXE
- Lingraf.exe
- readdst.exe
- T3Din.dll

You may wish to install certain optional items from the PARMILA-2 installation CD. A PDF version of this user manual is contained in the Manuals folder on the CD. Drag this folder from the CD to the same directory (folder) on your hard drive where PBO Lab is installed. Some PBO Lab files for running example PARMILA-2 problems are contained in the Examples folder installed in the PBO Lab main directory. Other examples may be in a folder on the CD, but not automatically installed.

**Summary of Command Structure**

A brief summary of the PARMILA-2 command structure is presented here. Individual PARMILA-2 commands are described in more detail in the following Sections of this Supplement. Figure 3 illustrates a PBO Lab Document window with the PARMILA-2 Commands submenu selected in the PBO Lab Command Menu.

Figure 3. PBO Lab Document Window showing the PARMILA-2 Module Commands submenu.
The PBO Lab Document window illustrated in Figure 3 also shows the entries on the Commands menu for the other PARMILA Modules:

- PARMILA-Lingraf
- PARMILA-Plots
- PARMILA-T3D-file

The Command Menu shown in Figure 3 also includes six other installed PBO Lab Application Modules: TRANSPORT, TURTLE, DECAY-TURTLE, MARYLIE, TRACE 3-D, and MAD.

The PARMILA-2 Commands submenu is shown in the side-bar with the corresponding Manual Sections that describe the entries in more detail. The command structure for the PARMILA-Lingraf, PARMILA-Plots and PARMILA-T3D-file Modules are also discussed in later Manual Sections.

The Command Menu in the PBO Lab Document Window contains submenus for any installed Application Modules. The full PARMILA application has four separate Modules, and each of these has as a corresponding Commands submenu. The structure of each of these submenus is similar.

The PARMILA-2 Commands submenu is separated into six groups. The first two groups contain commands for generating I/O for the PARMILA-2 Module, and for running the computation engine. The Main Input File for the PARMILA-2 Module is named "input.LIN" and most of the commands operate via that file. These commands are described in Section 2 of this Supplement.
The next group of commands in the PARMILA-2 Commands submenu focuses on the different types of beamline elements (Pieces) that are supported by the PARMILA-2 Module. The PARMILA-2 Module utilizes each of the four Piece types listed in the menu. These Piece creation commands are discussed in Section 3 of this Supplement.

The next command group contains a submenu for PARMILA-2 Auxiliary Input. There are two items in the Auxiliary Input submenu that can be used to add additional text directly to the PARMILA-2 Main Input File (input.LIN). One is for "Header Instructions" to follow the Header Section of the Main Input File, and the other is for "Footer Instructions" to precede the Footer Section of the Main Input File. These are described in Section 4 of this Supplement.

The PARMILA-2 List Windows are used to compile results from different types of parameter and labeling searches over a beamline model. These commands are also described in Section 4 of this Supplement. Although these commands are not utilized directly by the PARMILA-2 Module, they provide information on parameters utilized by other PBO Lab Modules.

The final entry on the Commands submenu is used to open the PARMILA-2 Options window. Section 4 of this Supplement illustrates the Options window and discusses the PARMILA-2 Options.
Summary of Supported Pieces

A summary of the Pieces supported by the PARMILA-2 Module is given here. The different types of Pieces include (a) PBO Lab "Palette Bar" optics elements that are supported by PARMILA-2 and by most other PBO Lab Application Modules, as well as (b) custom Command, Parameter and Optics Pieces developed specifically for the PARMILA-2 Module. Figure 4 lists (a) all of the Palette Bar Pieces that are supported by the PARMILA-2 Module. These include certain complex Pieces (e.g. DTL, CCL) unique to PARMILA. Section 3 of this Supplement describes (b) the PARMILA-2 specific Pieces including Command Pieces, Parameter Pieces and Optics Pieces that can be used by the PARMILA-2 Application Module. These Pieces implement specific PARMILA-2 instructions and are intended for use with the PARMILA-2 Module only. (Other PBO Lab Modules ignore these Pieces.) They are described more fully in Section 3 of this Supplement.

Figure 4. PBO Lab Palette Bar Pieces supported by the PARMILA-2 Module.
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2. The PARMILA Command Menus
2. The PARMILA Command Menus

There are four Command menus associated with the PBO Lab PARMILA Module, corresponding to the four executable components of the Module:

- **PARMILA.EXE**
- **Lingraf.exe**
- **readdst.exe**
- **T3Din.dll**

Each of the Commands Menus associated with these components have a similar appearance in the PBO Lab graphic interface, but their functionality is customized to the capabilities of each executable.

**PARMILA-2 Commands Menu**

A summary of the PARMILA-2 Module command structure was given in Section 1 and illustrated in Figure 3. This Section will describe the six groups of commands in the PARMILA-2 submenu shown in the side-bar at the lower right, concentrating on the first two ("Write" & "Run") groups. Section 3 provides additional details on the four items of the third ("Pieces") group, while Section 4 discusses additional features of the last three groups (Auxiliary Input, List Windows and PARMILA-2 Options).

The first group of commands provides a general command to execute the PARMILA.EXE computation engine. The "Write and Run 'input.LIN'" item is generally the most frequently used command. When selected, the "Write and Run 'input.LIN'" command will write the PARMILA-2 Main Input File (input.LIN) for the beamline in the Document Window and then run the PARMILA.EXE executable with that input. During execution, a "cmd.exe" window will open and provide some feedback on the progress. Upon completion of the run, the "cmd.exe" window will close, and another window opens to display the PARMILA-2 results.
Figure 5 illustrates an example of the cmd.exe window that opens following a "Write and Run 'input.LIN' " command. The illustration is for the example file "SNS DTL Tank 1.pbol" that is included in the Examples/PARMILA folder located in the PBO-Lab main directory (the Examples folder is installed when PBO Lab is installed).

The "cmd.exe" update window provides brief feedback during a PARMILA.exe calculation. The current location of the dynamics calculation is displayed and is updated as each step of the calculation is completed. The window closes upon completion of the PARMILA.exe computations.

Figure 5. A PARMILA.exe ("cmd.exe") window will open, perhaps only briefly, upon execution of the Write and Run 'input.LIN' command.

The example used for the illustrations of Figures 5-6 is contained in the PBO Lab file: SNS DTL Tank 1.pbol
You may wish to open that example to see the results on your computer.

The window illustrated in Figure 5 provides some feedback on the progress of the PARMILA.exe execution, and closes immediately following the completion of the PARMILA calculations. Depending upon the speed of your computer and the size of the problem you are running, the "cmd.exe" window may open and then close very quickly. The illustration shown in Figure 5 indicates that the PARMILA calculations were taking place in DTL cell number 23 of Structure 1, in the example "SNS DTL Tank 1.pbol" when the "screen shot" was taken of the "cmd.exe" window.
After the PARMILA.exe computations are complete, a PBO Lab window will automatically open to display the results of the calculations, which are recorded in 'Parmila.out' (the PARMILA Main Output File). Figure 6 illustrates the 'Parmila.out' window after running the example file "SNS DTL Tank 1.pbol".

When selected, the "Write and Run 'input.LIN'" command will write the PARMILA-2 Main Input File (input.LIN) for the beamline in the Document Window and then run the PARMILA.EXE executable with that input. During execution, a cmd.exe window will open (Figure 5) and then close when the PARMILA calculations are completed. Upon completion of the run, the Main Output File 'Parmila.out' window will open to display the primary results of the computations.

The next item on the commands menu, PARMILA-2 Plot Specification, is used in conjunction with a particle distribution file that PARMILA can create. Discussion of that capability appears in Section 3.
The second group of items on the PARMILA-2 Commands menu may be used to examine the Main Input File 'input.LIN'.

The sequence of events that occurs with the "Write and Run 'input.LIN'" command can be divided into separate steps by utilizing the second group of commands on the PARMILA-2 Commands menu. The second group of commands in the Commands Menu provides individual commands to Write, View and Run the PARMILA-2 Main Input File. The "Write and View 'input.LIN'" command will cause a new Main Input File to be written and opened for viewing. Figure 7 illustrates the window that is automatically opened following this command for the 'input.LIN' created for the model in the file "SNS DTL Tank 1.pbol".

Use scroll bars to access different parts of the text window.

![Figure 7. The Main Input File for the beamline on the Model Space is displayed automatically after the "Write and View 'input.LIN'" command is selected.](image)
The "View 'input.LIN' " command is used to open the existing Main Input File 'input.LIN'. A window like that illustrated in Figure 7 opens when this command is executed. The existing 'input.LIN' file is not overwritten; it is simply opened for viewing.

The "Run 'input.LIN' " command is used to call the PARMILA-2 executable for the existing Main Input File 'input.LIN'. The existing 'input.LIN' file is not overwritten when the "Run 'input.LIN' " command is executed. The existing 'input.LIN' is run using the PARMILA.exe program. The "cmd.exe" window (Figure 5) will open and close (perhaps quickly), and then the Main Output File 'Parmila.out' (Figure 6) will open to display the results of the run.

**PARMILA-2 Module I/O**

Whenever the PARMILA-2 executable is run there may be additional output files generated. Which files are generated will depend upon the PARMILA-2 Command and/or Parameter Pieces used in the beamline model. Those Pieces are discussed in Section 3. Some of the files that PARMILA-2 generates are used by other parts of the PBO Lab PARMILA-2 Module: PARMILA-LinGraf, PARMILA-Plots or PARMILA-T3D-file. The next few pages describe the use of those. Table 1 summarizes the various I/O files that may be generated by a PARMILA-2 execution.

Table 1. Summary of main I/O files used by the PBO Lab PARMILA 2 Modules.

<table>
<thead>
<tr>
<th>File Name</th>
<th>Description</th>
<th>Written By</th>
<th>Used By</th>
</tr>
</thead>
<tbody>
<tr>
<td>input.LIN</td>
<td>PARMILA Main Input File</td>
<td>PBO-Lab PARMILA-2 Module</td>
<td>Parmila.exe</td>
</tr>
<tr>
<td>Parmila.out</td>
<td>PARMILA Main Output File</td>
<td>Parmila.exe</td>
<td>PBO-Lab View Menu</td>
</tr>
<tr>
<td>parmla.plt</td>
<td>LinGraf binary data file</td>
<td>Parmila.exe</td>
<td>Lingraf.exe</td>
</tr>
<tr>
<td>lgraf.lgf</td>
<td>LinGraf Main Input File</td>
<td>PBO-Lab PARMILA-LinGraf Module</td>
<td>Lingraf.exe</td>
</tr>
<tr>
<td>Lgrafout.txt</td>
<td>LinGraf Main Output File</td>
<td>Lingraf.exe</td>
<td>PBO-Lab View Menu</td>
</tr>
<tr>
<td>part_dtl.dst</td>
<td>distribution binary data file</td>
<td>Parmila.exe</td>
<td>readdst.exe</td>
</tr>
<tr>
<td>part_dtl.txt</td>
<td>distribution text data file</td>
<td>readdst.exe</td>
<td>PBO-Lab PARMILA-2 Plots</td>
</tr>
<tr>
<td>Tr3Din.3d</td>
<td>lattice description file</td>
<td>Parmila.exe</td>
<td>PBO-Lab PARMILA-T3D-file</td>
</tr>
<tr>
<td>Tr3Din.pbop</td>
<td>PBO-Lab object model file</td>
<td>PBO-Lab PARMILA-T3D-file</td>
<td>PBO-Lab Edit Menu</td>
</tr>
</tbody>
</table>
PARMILA-Lingraf Commands Menu

The layout of the PARMILA-Lingraf commands menu is similar to that of the PARMILA-2 commands menu except that several of the items are not currently used. The illustration in the sidebar to the left indicates the command entries that are used by the PARMILA-Lingraf module.

The "Write and Run 'ingraf.lgf' " command functions is used in a manner similar to that of the "Write and Run 'input.LIN' " command for the PARMILA.EXE executable. That is, when "Write and Run 'ingraf.lgf'" is selected the Main Input File ('ingraf.lgf') for Lingraf.exe is written, Lingraf.exe is called to run that input file, and then a window opens to illustrate the results. There are two principal differences:

- The output from a Lingraf.exe run can be a graphics display, a text file ('Lgrafout.txt'), or both, and
- Only PARMILA-Lingraf Command Pieces are used to prepare the Main Input File 'ingraf.lgf'.

An example will illustrate how to use the PARMILA-Lingraf part of the PBO Lab PARMILA 2 Module. The example will use the PBO Lab file "SNS DTL Tank 1.pbol" included in the /Examples/Parmila/ folder (directory) created when PBO-Lab 3.0 is installed CD.

Step 1 is to open the "SNS DTL Tank 1.pbol" file in PBO Lab and execute the PARMILA-2 "Write and Run 'input.LIN'" command. This step writes the necessary binary data file (parmila.plt) needed by Lingraf. Step 2 is to select the "PARMILA-Lingraf Command Pieces" item from the PARMILA-Lingraf commands submenu. This procedure is illustrated in Figure 8, and results in the opening of the PARMILA-Lingraf Command Pieces window illustrated in Figure 9.
Selecting the "PARMILA-Lingraf Command Pieces" item will open a window listing the available Lingraf Command Pieces. That window is illustrated in Figure 9.

When a Lingraf Command Piece is selected (from Figure 9 list) the new Command Piece will appear in the lower left region of the Work Space.

When a Lingraf Command Piece is selected, and the Create Piece button pushed, the new Piece will appear in the lower left region of the Work Space.

Select a Lingraf Command Piece to activate the Create Piece button.

Available Lingraf Command Pieces cover all of the PARMILA-2 Lingraf capabilities including non-graphic (text) output to the file 'Lgrafout.txt'.

Lingraf also supports other programs such as PARMTEQ. Only PARMILA-2 applicable Lingraf commands are in the PARMILA-Lingraf Command Pieces window (Figure 9).

One PARMILA-Lingraf Command Piece is used for requesting graphics output from Lingraf; the others produce text output to a file named 'Lgrafout.txt'.
Step 3 in initially setting up a Lingraf run involves selecting a Lingraf Command Piece from the list that appears in the PARMILA-Lingraf Command Pieces window (Figure 9). For illustrating a graphics display, select the Piece named "Lingraf Graphics Request." The "Create Piece" button appearing in the right side of the window (Figure 9) will become active. Push (mouse click on) the "Create Piece" button. A new Piece will appear on the Work Space of the Document window. The location of the newly created Piece is illustrated in Figure 10.

Figure 10. A newly created Piece will appear in the lower left part of the Work Space of a PBO Lab Document window, below (and partially covered by) the Global Parameter Pane. For convenience, the Globals hide/show toggle button may be used to hide (and later, show) the Global Parameter Pane.

Figure 10 also illustrates Step 4: Drag the new Piece to the Model Space. The location in the beamline of the "Lingraf Graphics Request" Piece is not important; the PBO Lab PARMILA-Lingraf Module will correctly assign the necessary data when preparing the Lingraf Main Input File 'ingraf.lgf'.
Step 5 is to open the Piece window for the "Lingraf Graphics Request" Piece. Double-click the "Lingraf Graphics Request" Piece that is located in the beamline on the Model Space. Figure 11 illustrates the "Lingraf Graphics Request" Piece window.

Figure 11. The "Lingraf Graphics Request" Piece window used for setting up Lingraf graphics data.

Step 6 is to enter a "1" into the "Value" field for the "Phase Space (1=Yes, 0=No)" parameter. As the parameter name indicates, the value "1" corresponds to saying "Yes" create the phase space displays. The other data may be edited as desired. For the example to be run here, no other parameter value modifications are necessary.

Step 7 is the last step: Select the "Write and Run 'ingraf.lgf'" item on the PARMILA-Lingraf Command Menu. A "cmd.exe" window (similar to that shown in Figure 5) will open and close, and then a Lingraf graphics window will open. For the "SNS DTL Tank 1.pbol" example illustrated here, the Lingraf graphics window should be similar to that shown in Figure 12.

The parameter "Phase Spread (Table V-2)" shown in Figure 11 controls the specific layout of the Lingraf graphics window. Negative and zero Value entries result in different phase plane displays. Details are described further in Section 4.
The 'LgrafOut.text' file may, or may not, have data in it, depending upon the specific parameter values set in the Lingraf Graphics Request Command Piece. The example shown in Figure 13 is for the parameters illustrated in Figure 11, using the "SNS DTL Tank 1.pbol" example.

Additional information on the Lingraf graphics window is provided in Section 4 of this user manual. When the Lingraf graphics window is closed, a window opens that displays the LgrafOut.txt file. Figure 13 illustrates an example of the LgrafOut.txt window for the "SNS DTL Tank 1.pbol" example.

Lingraf offers several options for graphics displays and the text output of calculated results. All of these use the binary data file 'parmila.plt'. The 'parmila.plt' file is written to the PBO Lab main directory whenever a PARMILA-2 command is executed with an appropriate "PrtBeam" (print beam) PARMILA-2 Command Piece included in the beamline on the Model Space.
The three commands "Write and View 'ingraf.lgf'," "View 'input.LIN'," and "Run 'input.LIN' " are used to work with PARMILA-Lingraf Main Input File ('ingraf.lgf') directly. These commands may be helpful if there is a desire to edit the 'ingraf.lgf' file directly, or to examine the details of that file prior to running the Lingraf.exe executable. For the "SNS DTL Tank 1.pbol" example, with the "Lingraf Graphics Request" Piece added, and using the parameter values of Figure 11, the "Write and View 'ingraf.lgf' " will open the 'ingraf.lgf' file window shown in Figure 14.

The 'ingraf.lgf' file maybe examined or edited directly using the 2nd command group.
Figure 14. The 'ingraf.lgf' file window that opens following the command "Write and View 'ingraf.lgf'."

This completes the introductory discussion of the PARMILA-Lingraf Commands Menu. The PBO Lab file "SNS DTL Tank 1.pbol" was utilized to illustrate an example of the use of Lingraf. Further capabilities of the PARMILA-Lingraf Module are described in Section 4. The remainder of Section 3 summarizes the Command Menus for the PARMILA-Plots and PARMILA-T3D-file parts of the PBO Lab PARMILA 2 Module.

**PARMILA-Plots Commands Menu**

The layout of the PARMILA-Plots commands menu is similar to that of the PARMILA-2 and PARMILA-Lingraf command menus. However, only two of the command items are used. The illustration in the sidebar to the left indicates the command entries that are used by the PARMILA-Plots module.

The PARMILA-Plots command a "Write and Run 'input.temp' " is used to create a text file version of the particle distribution binary data written by PARMILA-2 to the file 'part_dtl.dst'. When the command is selected, the executable "readdst.exe" opens a Windows file selection dialog. An example is illustrated in Figure 15. Select the file named 'part_dtl.dst' and then use to Open button to have that file read by "readdst.exe" executable.
Figure 15. A Windows file selection dialog opens following the selection of the PARMILA-Plots command "Write and Run 'input.temp' ". Select the file named 'part_dtl.dst' and push the "Open" button.

Once the "Open" button (Figure 15) has been selected, the executable "readdst.exe" will read the binary data in the file, and then write a text version of the data to a file named 'part_dtl.TXT'. A window will automatically open to display the 'part_dtl.TXT' file following the completion of the data conversion. Figure 16 illustrates the window for the data generated with the PBO Lab example file "SNS DTL Tank 1.pbol".

Three representative PBO Lab Plot Windows will also open following the completion of the "readdst.exe" execution. The three Plot Windows are scatter plots for the X-X', Y-Y' and Energy-Phase phase space planes. Figure 17 illustrates the transverse phase space (X-X', Y-Y') plots for the PBO Lab example file "SNS DTL Tank 1.pbol". Figure 18 shows the longitudinal phase space (Energy-Phase) plot for the same example.
Figure 16. The window displaying the 'part_dtl.TXT' file that opens following the conversion of the ‘part_dtl.dst’ file by the ‘part_dtl.dst’ program. The data in this file is used by the PARMILA-Plots module for various graphics displays.

Figure 17. Default transverse phase space plots displayed following completion of the PARMILA-Plots command "Write and Run 'input.temp'".
Figure 18. Default longitudinal phase space plot that is displayed following completion of the PARMILA-Plots command "Write and Run 'input.temp'."

Figures 17 and 18 illustrate the three default PBO Lab Plot Windows that open following the completion of the "readdst.exe" execution. Many other built-in plot options are available as part of the PARMILA-Plots and PARMILA-2 Modules. These other plot options are accessed using the "PARMILA-Plots Plot Specification" command or the "PARMILA-2 Plot Specification" command. Figure 19 illustrates the list of Plot Specifications that are available for these commands. Both the "PARMILA-Plots Plot Specification" and the "PARMILA-2 Plot Specification" commands provide similar selections. Figure 20 shows the selection of these two commands, both of which lead to a Plot Specifications list similar to the list shown in Figure 19.

The examples shown in Figures 17 and 18 have used the Pen Width selector to increase the point size of the data displayed. All other settings are default values, which include the PBO Lab Plot Window automatic scale settings to assure that all data will appear in the Figures.

The Plot Windows that open following the execution of the PARMILA-Plots command "Write and Run 'input.temp'", or with any Plot Window opened through a "PARMILA-Plots Plot Specification" or a "PARMILA-2 Plot Specification" command, support all of the interactive capabilities of the PBO Lab Plot Windows. The scales may be changed (Set Scale button), the point size adjusted (Pen Width selector), the display printed (Print button) or copied (Copy button) for use in another document, etc. See the PBO Lab Basic Package User Manual for more information.
Select a plot option to activate the "Plot Selection" button.

Use the "Plot Selection" button to display the selected plot option.

Figure 19. Plot Options available for the PARMILA-Plots (or PARMILA-2) Module using the command "PARMILA-Plots Plot Specification" (or "PARMILA-2 Plot Specification").

Figure 20. Several built-in plot options are available as part of both the PARMILA-Plots Module and the PARMILA-2 Module.

Plot Specification commands of both the PARMILA-2 and PARMILA-Plots utilize the same 'part_dtl.TXT' data file. The "readdst.exe" executable needs to be run (Write and Run 'input.temp') whenever a new binary distribution file ('part_dtl.dst') has been created by PARMILA-2.

Figure 20 illustrates the virtual equivalence of accessing the Plot Specifications from either the PARMILA-2 or PARMILA-Plots command menus. However, it needs to be remembered that the PARMILA-Plots command "Write and Run 'input.temp' " must be selected at least one time after executing a PARMILA-2 "Write and Run 'input.LIN' " command.
An example of a built-in Plot Option is shown in Figure 21. The illustration is the histogram plot displayed using the "Final Beam energy Profile" PARMILA-2 Plot Option (see Figure 19) for the PBO Lab example file "SNS DTL Tank 1.pbol".

![Figure 21. Example of an additional built-in plot display available in the PBO Lab PARMILA-2 Module.](image)

The built-in PARMILA-2 Plot Options have displays that support all of the interactive capabilities of the PBO Lab Plot Windows. The scales may be changed (Set Scale button), the point size adjusted (Pen Width selector), the display printed (Print button) or copied (Copy button) for use in another document, etc. See the PBO Lab Basic Package User Manual for more information.

In addition to the built-in plot options available as part of the PARMILA-Plots and PARMILA-2 Modules, users may create customized Plot Windows using the PBO Lab 3.0 Tools menu. The use of these tools is described in the PBO Lab Basic Package User Manual.
PARMILA-T3D-file Commands Menu

The PARMILA-T3D-file Module is used to create a basic element PBO-Lab Subline Model that is equivalent to the PARMILA-2 beamline that is on the PBO Lab Model Space. The equivalent basic element PBO-Lab Subline Model may be used to simulate the PARMILA-2 generated design using any other PBO Lab Application Module such as TRANSPORT, TURTLE, TRACE 3-D or MARYLIE.

The layout of the PARMILA-T3D-file commands menu is parallels that of other PARMILA-2 command menus. However, only one of the items is used, the "Write and Run 'Tr3Din_convert'" command. This command operates on the PARMILA 2 generated file named 'Tr3Din.t3d'. The data in the 'Tr3Din.t3d' file provides a TRACE 3-D type lattice description of the beamline. That lattice description is converted into a PBO Lab object model representation of the beamline when the "Write and Run 'Tr3Din_convert'" command is executed.

The PBO Lab model created by the PARMILA-TD-file Module is written to a file named 'Tr3Din.pbop' which can then be read by PBO Lab. If the command is successfully completed, a text file window will open and display the PBO Lab object model data in the file 'Tr3Din.pbop'. An example of this file is illustrated in Figure 22. The file is displayed for information purposes only in order to signify completion of the the "Write and Run 'Tr3Din_convert'" command.

Use the Edit menu of the Document Window to select the item "Import Pieces (.pbop)." This will open a standard Windows file selection dialog similar to that illustrated previously in Figure 15. Navigate to the file named 'Tr3Din.pbop' and select 'Open'.

PARMILA-T3D-file utilizes the one command item identified with the blue arrow (→). Selection of this command results in the creation of a PBO Lab object model file called 'Tr3Din.pbop'.

The PARMILA-T3D-file Module also utilizes the PBO Lab Edit menu to import the PBO Lab object model file called 'Tr3Din.pbop'.

Cut
Copy
Paste
Delete
Find
Select All Pieces
Also Renamed
Open Options
Preferences
Check Points
Modify Comments
Edit Section
Import Pieces (.pbop)
Figure 22. Example of a 'Tr3Din.pbop' file that opens after the completion of the "Write and Run 'Tr3Din_convert'" command. The example is for "SNS DTL Tank 1.pbol".

When the file named 'Tr3Din.pbop' has been imported a Subline will appear on the Work Space of the Document Window. This Subline Piece will appear in the lower left corner of the Work Space, similar to that illustrated previously in Figure 10. The newly created Subline can be moved to the Model Space for use with other PBO Lab Modules.

Depending upon the size of the PARMILA linac from which it was created, the Subline imported from the 'Tr3Din.pbop' file will included nested Sublines. Double-clicking the Subline will open a window similar to that shown in Figure 23, which illustrates the first level of nesting. Double-clicking on one of the interior (nested) Sublines will open a window that displays the details of that Subline. Figure 24 illustrates the details for the second Subline of Figure 23.
Figure 23. Example of a Subline created with the PARMILA-T3D-file Module. The example is for "SNS DTL Tank 1.pbol". Double-clicking the 2nd Subline in this window will open a view of the details of the 2nd Subline, as shown in Figure 24.

Figure 24. Details of the second interior Subline for the example illustrated in Figure 23. The individual Pieces comprising the first four cells of the PARMILA design for the example "SNS DTL Tank 1.pbol" drift tube linac.

Any Subline created with the PARMILA-T3D-file Module can be used with other PBO Lab Modules. Figure 25 illustrates a TRACE 3-D Module simulation of the Subline example of Figures 23 and 24. Figure 26 shows a TRANSPORT Module simulation for the same Subline.
The use of equivalent Sublines, for PARMILA-2 generated beamline designs, allows the easy comparison of results for different modeling and simulation codes.

Different simulation codes employ different physics models. Comparing results from different codes can help to identify issues that may need further study.

Figure 25. Result of using the Graph Beam Line command of the TRACE 3-D Module for the Subline illustrated in Figures 23 and 24.

Figure 26. Example of a TRANSPORT Module beam envelope simulation for the Subline illustrated in Figures 23 and 24.
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3. PARMILA-2 Supported Pieces

3. PARMILA-2 Supported Pieces

A summary of the Pieces appearing on the PBO Lab Palette Bar that are supported by the PARMILA-2 Module was presented in Section 1, Getting Started. Those Pieces include common transport elements as well as specialized Pieces used for the complex accelerator structures that PARMILA-2 can be used to design. All of the PARMILA-2 Pieces may be accessed using four items appearing on the PARMILA-2 Commands menu:

- PARMILA-2 Command Pieces
- PARMILA-2 Parameter Pieces
- PARMILA-2 Optics Pieces
- PARMILA-2 PBO-Lab Pieces

For example, selecting the menu item "PARMILA-2 PBO-Lab Pieces" opens the window illustrated in Figure 27. Pieces listed in the window can be selected and then created using the Create Piece button. The list can also be used to determine which PBO Lab Palette Pieces are supported by the PARMILA-2 Module.

Figure 27. The PARMILA-2 Pieces window lists all of the PBO Lab Palette Bar Pieces used by the PARMILA-2 Module.
Many of the PBO Lab Pieces for describing transport lines (drifts, quadrupoles, bends, etc.) are supported by the PARMILA-2 Module. The set up of transfer lines, and the selection of parameters for the individual Pieces in a transfer line, follow the standard PBO Lab procedures used for any PBO Lab Optics Application Module. A special "TRANSPORT STRUCTURE" PARMILA-2 Command Piece, described later in this manual (in the PARMILA-2 Command Piece section), is used to define the start of a transfer segment. Otherwise the set up of a transfer section is similar to that for any other PBO Lab Module.

The PARMILA-2 Module has five (5) unique Pieces that are used for both the design and simulation of linear accelerators. These Pieces include:

- DTL for Drift Tube Linac
- CCL for Coupled Cavity Linac
- CCDTL for Coupled Cavity Drift Tube Linac
- SC1 for Missing Quad Superconducting Linac
- SC2 for Grouped Quad Superconducting Linac

The accelerator structures used for these types of linacs included radiofrequency cavities for acceleration and longitudinal focusing, with magnetic quadrupole lenses for transverse focusing. These structures are "complex" when compared to individual particle optics elements such as a radiofrequency gap or one magnetic quadrupole. One of the main capabilities of PARMILA 2 is that it generates designs for these complex structures starting with a set of user-specified goals or objectives. The PBO Lab Pieces for these complex structures have been developed to aid the user in setting up these design goals.
Drift Tube Linac (DTL) Piece

The DTL Piece is used to set up the main parameters for either designing or simulating a drift tube linac. The parameters are grouped into four (4) categories:

- RF Field
- Quads
- Field Ramp
- Geometry

The Piece Window for the DTL Piece has one tab panel for each of these parameter groups. The RF Field tab panel appears in front when a DTL Piece window is opened. Figure 28 illustrates the tab panel for the RF Field parameters.

The RF Field parameters for a DTL Piece provide the top level field and output energy design objectives for one drift tube linac tank. Each tank of a multiple-tank drift tube linear accelerator is represented by separate DTL Piece. A key parameter used in designing a DLT tank is the final energy goal for the tank. This can be specified as either a "Nominal Final Energy" or a "Final Cell Number" goal. PBO Lab automatically formats the input for these two options.

Tank Output Energy Goal is a primary design objective: that goal can be specified as either: Nominal Final Energy, or Final Cell Number

The RF Field tab is used for setting the starting (Initial) values for the radiofrequency (RF) phase and amplitude: Synchronous Phase, and Axial Electric Field

Two parameters are related to the tank following this one: Distance to Next Tank, and Phase Change to Next Tank

A Maximum Power Limit goal for the tank may also be specified. If set to zero, it is ignored.

The parameters on the RF Field tab page correspond to the following parameter numbers in Table IV-4 of the Appendix: 2, 3, 4, 7, 8, 19.

The tank number (parameter 1 of Appendix Table IV-4) is automatically set by the PBO Lab PARMILA 2 Module.
If the Tank Output Energy Goal switch is set to 'Output Energy' (in the RF Field tab page, Figure 28) then PARMILA 2 will compute the number of cells for the tank needed to achieve the energy goal. If the Tank Output Energy Goal switch is set to 'Cell Number' then PARMILA 2 will compute the output energy of the tank that would be produced for the specified cell number.

Each DTL tank consists of a number of cells. Figure 29 illustrates the basic geometrical layout for two cells of a drift tube linac. Depending upon the setting of the switch "Tank Output Energy Goal" on the RF Field tab panel, the number of cells is either computed by PARMILA 2, or set as a goal for the PARMILA 2 design. In either case, PARMILA 2 will generate data for all of the cells in each DTL tank. The calculated geometry data will appear as a cell table in the file 'Parmila.out'. Figure 30 illustrates an example output.
Figure 30. Geometry cell table for a drift tube linac (DTL) in the file ‘Parmila.out’.

The Quads tab panel of the DTL Piece window is used for specifying the top level design goals for the magnetic quadrupoles used for transverse focusing in a DTL. Figure 31 illustrates the tab panel for the quadrupole parameters.

PARMILA 2 uses a formula for estimating the gradients (B’) of the magnet quadrupoles inside the drift tubes. The first 2 parameters of the Quad tab are coefficients in this formula. The Quad Formula is given on the next page.

The DTL geometry cell table (Figure 30) gives the design values for the DTL parameters illustrated in Figure 29. The Parmila.out file also provides a text description of these parameters immediately before the cell table data.
Quad Formula: \[ B' = \left[ \frac{L_c}{(2L_q)} \right] \left[ \frac{\gamma}{c(\beta)} \right] \left\{ C_0 \left( \frac{mc^2}{q\beta^2} \right) + C_1 \left( \frac{\pi E_0 T \sin \phi_s}{\lambda \beta \gamma^3} \right) \right\} \]

The Quad Formula is given in the PARMILA 2 documentation (Appendix) but is also repeated here for clarity. The values of \( C_0 \) and \( C_1 \) are the first two parameters appearing in the Quad tab panel of the DTL Piece Window. In the Quad Formula, the speed of light is given by \( c \). The particle mass \((m)\), particle charge \((q)\), and radiofrequency wavelength \((\lambda)\) are determined by the corresponding Global Parameters (see Figure 10). The other parameters in the Quad Formula \((L_c, L_q, \beta, \gamma, E_0, T, \phi_s)\) are computed by PARMILA-2 for each cell of the DTL.

The Length of Quad Magnets, \( L_q \), determines the ratio \( \left[ \frac{L_c}{(2L_q)} \right] \) where \( L_c \) is the cell length. In Figure 29, the length \( L_c = L_N \) for cell N, and the length \( L_q = 2DQ_N \) for cell N. Two primary options are available for specifying the design goals for \( L_q \): "Use Fixed Length" (in cm) or "Use Length Ratio". When the "Use Fixed Length" choice is selected, the "Effective Quad Length" parameter is utilized for entering the design goal value. The value may be entered using any of several PBO Lab choices for units, and the "Effective Quad Length" in cm will be written to the PARMILA-2 input file ('input.Lin'). The value of \( \left[ \frac{L_c}{(2L_q)} \right] \) will then be computed for each cell. When the "Use Length Ratio" choice is selected, the goal value is set in the "Ratio of Quad/Cell Length" parameter field. This choice effectively sets a fixed goal for \( \left[ \frac{L_c}{(2L_q)} \right] \) that is independent of the cell number.

The top level goals for the quadrupole lengths and gradients can be modified with the use of Change lines in the PARMILA-2 input file 'input.Lin'. Change lines are implemented using PARMILA-2 Parameter Pieces. The PARMILA-2 Parameter Pieces are described later in this section.
PARMILA-2 offers five basic options for the quadrupole lattice structure. The "Quad Sequence" parameter is used to select these options. The options are designated by the polarity sequence of the quadrupoles inside a sequential set of drift tubes. The sequence contains a combination of "F" (for focusing in the x direction) and "D" (for defocusing) quadrupole specifications, and may also contain "0" specifications for an empty drift tubes (no quadrupole inside).

For a specific "Quad Sequence" selection an additional parameter is used to specify how the sequence starts. The "Quad Sequence Start Point" parameter determines the initial quad polarity at the start of the DTL tank. Not all start point options are meaningful for every choice of quadrupole sequence. Figure 32 illustrates the "Quad Sequence Start Point" options that are appropriate for each Quad Sequence selection.

Figure 32. Meaningful options for the "Quad Sequence Start Point" are tied to the choice of "Quad Sequence".

The initial (entrance) and final (exit) quadrupole length can each be specified as either a "Half Length Quadrupole" or as a "Full Length Quadrupole". The "Half Length Quadrupole" choice is useful when only half of a quadrupole is physically located within a DTL tank. A matching half quadrupole may be included in an adjacent TRANSPORT line.
A Linear Ramp in Eo has Three Options for the Phase:

- Constant Phase
- Adjusted Phase
- Constant Longitudinal Focusing

Field-tilt Coefficient specifies the Linear Ramp in Eo

Maximum Value for Eo

Eo Ramp Starting Location

Start Cell for Phase Ramp

Start Cell for Phase Ramp

Limit to Phase Ramp

The parameters on the Field Ramp tab page correspond to the following parameter numbers in Table IV-4 of the Appendix:

- 22
- 5
- 6
- 15
- 23
- 24
- 25
- 26

Figure 33. Field Ramp tab panel for a DTL Piece.

The starting values for the axial accelerating field and synchronous phase are given by the "Initial Axial Electric Field" and "Initial Synchronous Phase" parameters on RF Field tab panel (see Figure 28). Specifying a zero "Field-tilt Coefficient" (default value) corresponds to a flat field, i.e. no ramp is used. For this "no ramp" case, the other parameters on the Field Ramp tab panel are not significant and will be ignored by PARMILA 2.

If the "Field-tilt Coefficient" is non-zero, then the DTL design goals will include a field ramp, and the other parameters on the Field Ramp tab panel will be significant. The "Linear Ramp in Eo" selection on the Field Ramp tab panel is used to specify the RampType. The first choice corresponds to a "Constant Phase", while the second choice corresponds to an "Adjusted Phase" that maintains a fixed width (in cm) of the zero-current separatrix. The third choice corresponds to "Constant Longitudinal Focusing". This also maintains a fixed width for the zero-current separatrix, but adjusts the field ramp as well (no longer linear).
When the RampType is set to "Constant Phase", the "Field-tilt Coefficient", $C_{\text{Tilt}}$, and "Initial Position for Eo Ramp", $\Delta z_E$, are used to compute the axial accelerating field at each cell location from the formula given in the PARMILA 2 documentation (Appendix):

$$E_{o,\text{cell}} = E_o [1.0 + C_{\text{Tilt}}(z_{\text{cell}} - \Delta z_E)] \text{ for } z_{\text{cell}} > \Delta z_E$$

The "Initial Axial Electric Field", $E_o$, is the value entered in the RF Field tab panel (see Figure 28). The value of $z_{\text{cell}}$ is the (approximate) location of the center of the cell (e.g. at the location between $L_N$ and $L_{N+1}$ illustrated in Figure 29). The ramp is continued to the end of the tank, unless $E_{o,\text{cell}} = E_{o,\text{max}}$ where $E_{o,\text{max}}$ is the "Maximum Axial Electric Field". The ramp is then terminated, and $E_{o,\text{cell}}$ is held constant. The phase of the RF, $\phi_s$, is held constant to the "Initial Synchronous Phase" throughout the tank.

When the RampType is set to "Adjusted Phase", a ramp similar to that for "Constant Phase" is utilized, except that the effective value of $\Delta z_E = z_{N_{\text{Start}}}$ where $N_{\text{Start}}$ is the "Starting Cell Number". The ramp is continued until $z_{\text{cell}} = z_{N_{\text{End}}}$ where $N_{\text{End}}$ is the "Ending Cell Number", unless $E_{o,\text{cell}} = E_{o,\text{max}}$. The ramp is then terminated, and $E_{o,\text{cell}}$ is held constant. The phase of the RF, $\phi_s$, is adjusted throughout the tank so that the (zero-current) separatrix is held approximately constant in length (cm). The adjustment of $\phi_s$ continues throughout the tank unless either $z_{\text{cell}} = z_{N_{\text{End}}}$ or $\phi_s = \phi_{s,\text{Max}}$ occurs, where $\phi_{s,\text{Max}}$ is the "Phase Ramp Stop Value". The phase of the RF is then held constant through the remainder of the tank.

For a RampType set to "Constant Longitudinal Focusing", both axial electric field and the synchronous phase are adjusted throughout the tank. See the PARMILA 2 documentation (Appendix) for a description of this choice.
The last tab of the DTL Piece window is the Geometry tab, illustrated in Figure 34.

![Figure 34. Geometry tab panel for a DTL Piece.](image)

The parameters on the Geometry tab correspond to the following parameter numbers in Table IV-4 of the Appendix: 16, 17, 18, 21.

The DTL parameters in the Geometry tab are used to set design goals for the bore radii (apertures) of the drift tubes, and to specify the cell length in terms of $\beta \lambda$. Two drift drift tube apertures, $R_{b1}$ and $R_{b2}$, can be set: one for the drift tubes at the beginning of the tank ("Bore Radius, Low Energy") and the other for the drift tubes near the exit of the tank ("Bore Radius, High Energy"). The transition from the "low energy" to the "high energy" bore radius occurs at cell number $N_{NBR}$ given by the "1st Cell Using Radius Rb2" parameter.

The overall length of one DTL cell ($L_N$ in Figure 29) is an integer multiple of $\beta \lambda$. The default value for this multiple is 1. The "Cell Lengths (BetaLambda)" parameter is used to set a different value for the multiple.
In addition to the data contained in the DTL Piece, other parameters are utilized by PARMILA 2 in completing the design and/or simulation of a drift tube linac tank. Important among these is the use of SuperFish data. Several PARMILA-2 Command (COMM) Pieces are available for linking in SuperFish data. These are described in the discussion of the PARMILA-2 COMM Pieces later in this Section. Figure 35 illustrates a representative PBO Lab DTL "Design Line" that includes a DLT SuperFish Data Piece labeled "DLT sfd".

Figure 35. Example of a DTL "Design Line" that includes two Change lines and SuperFish Data

Many of the goal parameters for the design of a DTL tank, setup with the DTL Piece illustrated in Figures 28, 31, 33, and 34, may be adjusted or "fine-tuned" before PARMILA 2 completes the design. This "tweaking" of the design goals is accomplished with the use of Changes. Changes are implemented using PARMILA-2 Parameter (PARAM) Pieces that are located between the DTL Piece and the SuperFish data COMM Piece. The PARMILA-2 PARAM Pieces are described later in this Section. Figure 35 illustrates an example where Change types 14 (C-14) and 16 (C-16) are to be incorporated into the design. Change types 14 and 16 specify objectives for the magnetic quadrupole gradients, overriding the magnetic gradient goals set using the DTL Piece Quad tab (Figure 31). (Other parameters on the Quad tab, such as "Quad Sequencing", are not changed by C-14 or C-16). Note that Change Pieces located after the DLT sfd Piece do not modify the design objectives, but post-modify the PARMILA 2 created design for simulations.
Several PARMILA-2 examples for a drift tube linac have been used for illustration earlier in this manual. See Figures 5, 6, 12, 13, 14, 16, 17, 18, 21, and 30.

PBO Lab can also be used to create equivalent object models of a DTL for computation with other optics codes. See Figures 25 and 26.

Figure 7 shows the first several lines the 'input.LIN' file that is written for a DTL example file ("SNS DTL Tank 1.pbol"). Illustrations from parts of the corresponding 'Parmila.out' file are shown in Figure 6 and Figure 30. Samples of Lingraf results for the same DTL example were also illustrated previously, in Figures 12, 13 and 14. The final particle distribution text file ('part_dtl.txt') that can be created after running the example file "SNS DTL Tank 1.pbol" is shown in Figure 16. Representative scatter plots of that same DTL data are illustrated in Figures 17, 18 and 21.

Examples of the creation and use of equivalent PBO Lab object models for a DTL were also illustrated previously. Figure 25 shows a PBO Lab TRACE 3-D Module calculation, and Figure 26 shows a PBO Lab TRANSPORT Module calculation, for the same "SNS DTL Tank 1.pbol" example, using an equivalent PBO Lab object model of the drift tube linac created with PARMILA-T3D-file Module.
**Coupled Cavity Linac (CCL) Piece**

The CCL Piece is used to set up parameters for designing a coupled cavity linac. Similar to the DTL Piece, the parameters for the CCL Piece are grouped into five (5) categories:

- RF Field
- Quads
- Field Ramp
- Phase Ramp
- Geometry

The Piece Window for the CCL Piece has one tab panel for each of these parameter groups. The RF Field tab panel appears in front when a CCL Piece window is opened. Figure CCL-1 illustrates the tab panel for the RF Field parameters.

![Figure CCL-1. RF Field tab panel for a CCL Piece.](image)

The RF Field parameters for a CCL Piece provide the top level field and output energy design objectives for one coupled cavity section. Each CCL Piece defines one PARMILA 2 CCL structure. Several parameters on the RF Field tab panel are used for a CCL Structure line in the PARMILA-2 Main Input File (input.LIN).

- **Nominal Final Energy**: is a primary design objective.
- **Last Cell Number**: will be the final cell actually used in CCL.
- **Frequency Harmonic for CCL**: is a multiple of the (Document Window) Global Frequency.
- **If SuperFish Data Frequency is different from the Frequency of CLL, PARMILA 2 will scale the SuperFish data.**

The parameters on the RF Field tab page correspond to the following parameter numbers in Table IV-7 of the Appendix:

- 1, 2, 3
Figure 37. Layout of a coupled cavity linac (CCL), not to scale, from Appendix Figure III-5. This example has 5 cavities per segment.

The structure number for each CCL is automatically set by the PBO Lab PARMILA 2 Module.

The number of cells per segment is same for a given CCL structure, and is set using the Geometry tab panel (see Figure 42).

The parameters on the Quads tab page correspond to the following parameter numbers in Table IV-7 of the Appendix: 6, 7, 5, 11, 12, 8, 13, 10, 9

Figure 38. Quads tab panel for a CCL Piece.
The Lattice Type parameter on the CCL Quads tab panel is used to specify whether the "Quadrupole\textsubscript{N}" gray areas illustrated in Figure 37 are to be \textit{singlet} or \textit{doublet} lenses. This parameter determines which of the following quadrupole parameters are meaningful:

- Distance Between Quads
- Sequencing for Singlet
- Polarity for Doublets
- Quad at Tank Entrance

Figure 39 shows the relationship to the choice of Lattice Type.

For a given choice of "Lattice Type" only the related parameters shown in Figure 39 will be used by PARMILA 2 for the design. The parameters related to other choice of "Lattice Type" are ignored.

Another quad parameter is available for adjustment is for the "Magnet Locations". The "Magnet Locations" parameter is applicable to \textit{both} the "Singlet Quads" and the "Doublet Quads" selection for "Lattice Type". The "Magnet Locations" parameter refers to the position within the space between adjacent segments (see Figure 39, which illustrates the "Magnet Locations" default "Start of Space").
The distance set in the Shift Location from End field is used to create a "QuadLocs" (keyword) entry in the PARMILA-2 input.LIN file. See Section IV.A.25 of the Appendix.

The parameters on the Field Ramp tab page correspond to the keywords "SetBetaRamp" and "E0Ramp" in Section IV.A.15 of the Appendix.

Field Ramp Choices

- Field Ramp selection will activate ramp parameters:
  - Acceleration Ramp Rate or Fixed Field Step Size
  - Maximum Axial Electric Field
  - Start Cell for Field Ramp
  - End Cell for Field Ramp
  - Choice for Applying Ramp

One final quad parameter that can be used for additional adjustment is "Shift Location from End". This parameter shifts the location of all CCL quadrupole magnets by a fixed distance. The distance is always taken as positive. If the "Magnet Locations" parameter is set to "Start of Space" (see previous page) a non-zero entry for the "Shift Location from End" will result in all quadrupoles being moved downstream by the entered distance. If the "Magnet Locations" parameter is set to "End of Space" then a non-zero entry for the "Shift Location from End" will result in all quadrupoles being moved upstream by the entered distance. The distance entry is ignored for the "Middle of Space" selection.

Accelerating electric field and synchronous phase ramps may be used with each CCL structure. The parameters for these ramps are set on separate tab pages of the CCL Piece window. Figure 40 shows the Field Ramp tab panel.

![Field Ramp tab panel for a CCL Piece.](image)

The default setting for the "Accelerating Field Ramp" is "No Field Ramp". However, two basic types of "Accelerating Field Ramp" can be applied to a given CCL Piece: "Change per Unit $\beta$" and "Fixed Step in Field".
The "Fixed Step in Field" selection uses the "Fixed Field Step Size" ($E_{o,\text{Step}}$) to incrementally increase the axial electric field ($E_o$). The starting value of $E_o$ is set by the axial electric field at the cell number set by "Delay Accel Ramp to Cell" parameter. This may, or may not, correspond to the "Initial Axial Electric Field" value set in the RF Field tab panel of the CCL Piece (see Figure 36), depending on whether the "Apply Field Ramp to" option is set to "Eo" or "EoT". If "EoT" is set, then a PARMILA-2 $ETFixed$ keyword is used (see sidebar).

When using the "Change per Unit $\beta$" selection, the "Acceleration Ramp Rate" $R_E$ is used to try to ramp the electric field $E_o(\beta)$, as a linear function of $\beta$ ($=v/c$):

$$E_o(\beta) = E_o + R_E (\beta - \beta_0)$$

The starting value of $E_o$ is set according to the same criteria described above for the "Fixed Step in Field" selection. The relativistic velocity corresponding to $E_o$ is $\beta_0$.

For either "Accelerating Field Ramp" option (i.e. other than "No Field Ramp") the axial electric field ramp is continued until either (a) the cell number assigned in "Stop Accel Ramp after Cell" is reached or (b) the "Maximum Axial Electric Field" value is attained. The accelerating field is then maintained at a constant value, or adjusted, according to the selection of the "Apply Field Ramp to" option ("Eo" or "EoT").

The synchronous phase of the CCL may also be ramped. Figure 41 illustrates the Phase Ramp tab panel of the CCL Piece Window. Each of the parameters appearing on the Phase Ramp tab panel (Figure 41) is similar to one of the parameters on the Field Ramp tab panel (Figure 40).
Phase Ramp Choices

Synchronous Phase Ramp selection will activate ramp parameters:

- Phase Ramp Rate
- or Fixed Phase Step Size

Limiting Phase Value

Start Cell for Phase Ramp

End Cell for Phase Ramp

The parameters on the Field Ramp tab page are used to write a "PhaseRamp" keyword line to the 'input.LIN' file for the CCL. The "PhaseRamp" keyword line is discussed in Section IV.A.15 of the Appendix.

![Phase Ramp tab panel for a CCL Piece.](image)

Figure 41. Phase Ramp tab panel for a CCL Piece.

The "Synchronous Phase Ramp" switch is used to select the type of ramp to be applied, with "No Phase Ramp" being the default. The other options are: "Change per Unit $\beta$" and "Fixed Step in Phase". If one of these options is selected, then the corresponding numerical input field becomes active: "Phase Ramp Rate" (in degrees/$\beta$) or "Fixed Phase Step Size" (in Degrees or other units choice).

For either choice of the "Synchronous Phase Ramp" (other than "No Phase Ramp") the remaining three parameters impose certain limits on the phase ramp. The phase begins at the cell number given by the "Delay Phase Ramp to Cell" entry. The phase ramp is continued until either (a) the limiting value specified for the "Phase Ramp Stop Value" is attained or (b) the cell number given by "Stop Phase Ramp after Cell" entry is reached. The synchronous phase is then held constant through the remainder of the CCL structure.

Various layout and dimensional parameters for the CCL are set using the Geometry tab panel. The Geometry tab panel of the CCL Piece Window is illustrated in Figure 42.
Figure 42. Geometry tab panel for a CCL Piece.

The aperture of the CCL entrance cavity is set by the "Bore Radius, Low Energy" parameter (Rb1). The aperture may be changed further down the structure by using the "Bore Radius, High Energy" parameter (Rb2). The change in aperture will occur at the cell number given by the "1st Cell Using Radius Rb2" entry. These parameters are not used for the CCL design, but are utilized for beam dynamics simulations.

The number of cavities for each CCL segment is set by the "Cavities per Segment (Ncav)" entry. This number is a constant for a given CCL tank (i.e. one PARMILA-2 CCL Structure). Figure 37 illustrates an example with 5 cavities per segment.

The CCL may use a graded-β design where the length of each cavity is adjusted to a computed geometric β for the cell. Each cavity thus has a different length. It may be more convenient (e.g. for easier fabrication) to use cavities of equal length. This type of CCL structure is referred to as a symmetric design. The "Use Symmetric Cavities" popup is used to select the type of design desired. The default setting "Yes" is for a symmetric design.

The 3 parameters specifying the bore radii are used to create a "Bore" keyword line in the 'input.LIN' file for the CCL structure. The "Bore" keyword line is only used in the beam dynamics simulation and is discussed in Section IV.B.18 of the Appendix.

The Yes choice of the Use Symmetric Cavities switch on the Geometry tab panel adds a "SymDesign" keyword line to the 'input.LIN' file for that CCL structure. The "SymDesign" keyword line is discussed in Section IV.A.10 of the Appendix.
When the (default) "Yes" setting for "Use Symmetric Cavities" popup switch is selected, the three remaining parameters are utilized. The "No, use graded-β" setting does not utilize the three parameters following the switch, and those parameters are all inactive for that switch setting.

Similar to the DTL, the CCL design goals may be adjusted, or fine-tuned, using Changes. Changes are implemented using PARMILA-2 Parameter (PARAM) Pieces. In addition, there are other specialized modifications related to the external quadrupoles of the CCL. These are also implemented with PARMILA-2 Parameter (PARAM) Pieces.

One important Piece for the CCL design is a SuperFish data Piece. Several PARMILA-2 Command (COMM) Pieces are available for linking in SuperFish data. These are described in the discussion of the PARMILA-2 COMM Pieces later in this Section. Figure 43 illustrates a representative PBO Lab CCL "Design Line" that includes a CCL SuperFish Data Piece labeled "CCL sfd".

Figure 43. Example of a CCL "Design Line" that includes SuperFish Data

The PBO Lab file named "SNS-CCL-1st-8-cells.pbol" provides an example of using PARMILA-2 to design a CCL and then simulate its performance. The example file is located in the Examples/Parmila directory installed with PBO Lab 3.
Figure 44 shows the first several lines of the 'input.LIN' file that is written for the CCL example file ("SNS-CCL-1st-8-cells.pbol"). This example is for an 8-cell symmetric cavity design. The example includes a Field Ramp but no Phase Ramp.

It can help to set options on a CCL Piece and then use the "Write and View 'input.LIN' " PARMILA-2 Command to see how the settings impact the 'input.LIN' file.

Figure 44. The Main Input (input.LIN) for the example "SNS-CCL-1st-8-cells.pbol" after executing the command "Write and View 'input.LIN' ".

The 'input.LIN' file illustrated in Figure 44 shows, near the bottom of the Figure, the beginning of the SuperFish Data (following the SFDATAQ entry) for this example.
The reader should note that the design for the example contains more than 8 cells. The design goal for the Last Cell Number parameter (see Figure 36) is actually set to 40 in this example.

Figure 45 shows a section of the corresponding 'Parmila.out' file for the example "SNS-CCL-1st-8-cells.pbol". The portion of the output displayed (accessed by adjusting the scroll bar on the right side of the window) shows the design details for the first few cells.

![Figure 45. The Main Output File ('Parmila.out') for the example "SNS-CCL-1st-8-cells.pbol" after executing the command "Write and Run 'input.LIN' ".](image)

A representative Lingraf plot for the same "SNS-CCL-1st-8-cells.pbol" example is shown in Figure 46. The plot runs through 40 cells.
Figure 46. Lingraf profile plots for the example "SNS-CCL-1st-8-cells.pbol." Note that this example actually has 40 cells in the design.

The final particle distribution text file ('part_dtl.txt') created for the example file "SNS-CCL-1st-8-cells.pbol" is shown in Figure 47.

Figure 47. "SNS-CCL-1st-8-cells.pbol" Particle distribution data example after running the PARMILA-Plots command "Write and Run 'input.temp'".
Representative scatter plots at the exit of the CCL, utilizing the data in the 'part_dtl.txt' file, are illustrated in Figure 48.

Figure 48. Phase space scatter plots for the example "SNS-CCL-1st-8-cells.pbol": (a) horizontal phase space (upper), (b) vertical phase space (middle), and (c) longitudinal phase space (lower).
Similar to the DTL, an equivalent PBO Lab object models for a CCDTL can be created for use with other PBO Lab Modules. The PARMILA-T3D-file Module is utilized for this purpose. The procedure is outlined in Section 2 of this manual: an equivalent basic element PBO-Lab Subline Model is created using, the "Write and Run Tr3Din_convert" command of the PARMILA-T3D-file Module.

Figure 49 shows a PBO Lab TRACE 3-D Module calculation for the "SNS-CCL-1st-8-cells.pbol" example, using the equivalent PBO Lab object model of the coupled cavity linac created with PARMILA-T3D-file Module.

The CCL Piece is unique to the PARMILA 2 Module, and is ignored by other (non-PARMILA) PBO Lab Modules. However, an equivalent PBO Lab Subline can be created with the PARMILA-T3D-file Module. The equivalent Subline can then be used with other PBO Lab Modules, such as TRACE 3-D and TRANSPORT.

Figure 49. TRACE 3-D calculation using the PBO Lab equivalent object model for the example "SNS-CCL-1st-8-cells.pbol".
Note: For a standalone CCL example such as this one, a PARMILA-T3D-file _command Write and View 'Tr3Din_convert' should be run, in order to look at the frequency appearing at the top of the file Tr3Din_convert. That frequency (in MHz) should correspond to the Frequency of CCL (see Figure 36). If it does not, then change the value in the Tr3Din_convert file, and save that file. Then use the PARMILA-T3D-file _command named Run 'Tr3Din_convert' to execute the new Tr3Din_convert file that was saved with the corrected frequency. The remaining procedures, to create the equivalent subline from the 'Tr3Din.pbop' file, are the same as described in Section 2.

The output energy (W) from the TRACE 3-D calculation (104.9174 MeV) and the TRACE 3-D beamline length (4563.14 mm) are in agreement with the corresponding data from the 'Parmila.out' file after 40 cells. The following lines, copied from further down in the 'Parmila.out' file shown in Figure 45, give the values (underlines added) needed to compare to the TRACE 3-D results:

| 40 | 104.9172 | 0.43707 | 7.6810 | 0.8934 | 0.0318 | 0.3478 | 0.0468 | 0.000 | 0.000 | 3.5059 | 3.5059 | -30.740 | -30.442 | 453.3147 |
| 40 | 104.9172 | 0.43707 | 30.8301 | 0.000 | 7.4981 | 3.000 | 454.8147 |
| 41 | 105.1422 | 0.43747 | 7.7354 | 0.8939 | 0.0317 | 0.3473 | 0.0468 | 0.000 | 0.000 | 3.8074 | 3.8074 | -31.257 | -30.442 | 491.8802 |

The first entry is the cell number (40 and 41 selected from the 'Parmila.out' file. The second entry (underlined) is the beam energy after the cell. For cell 40 this is 104.9172 MeV, in agreement with the TRACE 3-D result to within 2 parts in 10^6 (or 0.0002 %). The last number in a cell line (e.g. those that start with 40 or 41) is the distance (in cm) from the start of the CCL to the end of the corresponding cell. For cell 40 this is 453.3147 cm (underlined). Information on the quadrupoles between CCL cavities is given in abbreviated lines between cell lines. The length of the quadrupole space after cell 40 is 3.000 cm (underlined). Adding this quadrupole space to the to distance to the exit of cell 40 gives the corresponding beamline length through that quadrupole space: 456.3147 cm. This is also within 2 parts in 10^6 of the TRACE 3-D calculation.
Coupled Cavity Drift Tube Linac (CCDTL)

The CCDTL Piece is used to set up parameters for designing a coupled cavity drift tube linac. The parameters describing a CCDTL are nearly identical to those used to describe a CCL. Similar to the CCL Piece, the parameters for the CCDTL Piece are grouped into five (5) categories:

- RF Field
- Quads
- Field Ramp
- Phase Ramp
- Geometry

Similar to the CCL, the Piece Window for the CCDTL Piece has one tab panel for each of these parameter groups. The parameters have the same basic meaning as for the CCL and users may refer to CCL Figures 36 and 38-41 for additional information. The CCDTL has one more parameter than the CCL: the number of drift tubes per cavity. This parameter is set on the Geometry tab panel of the CCDTL which is illustrated in Figure 50.

![Geometry tab panel of a CCDTL Piece](image)

Figure 50. Geometry tab panel of a CCDTL Piece has 1 more parameter than the Geometry tab of a CCL Piece.

The Number of Drift Tubes per Cavity is the only extra parameter for a CCDTL that is not on a CCL Piece.

Use one CCDTL Piece for each coupled cavity structure of a multi-structure CCDTL.

The parameters on the various tab pages of the CCDTL Piece Window include all of the parameters given in Table IV-8 of the Appendix. Similar to the CCL Piece, other parameters also appear on the tab pages.

Each CCDTL Piece represents one STRUCTURE section in the PARMILA 2 input file "input.LIN".
Figure 51. Layout of a coupled cavity drift tube linac (CCDTL), not to scale, from Appendix Figure III-4. This example has 2 cavities per segment.

Figure 51, taken from the Appendix attached to this manual, shows the general layout for a coupled cavity drift tube linac. This example has two cavities per segment, and two drift tubes per cavity. The drawing indicates that singlet quadrupoles are used between each segment.

An example of with a CCDTL structure is included in the Examples/Parmila folder of the PBO Lab software installation. The file is named: "100 MeV LINAC through CCDTL.pbol"

In addition to the CCDTL, the first 20 MeV of the accelerator in this example is composed of the two DTL tanks. A DTL to CCDTL matching section is also included in the example.
**SuperConducting Linac Overview**

Superconducting (SC) linear accelerators differ in several respects from the drift tube linac (DTL), coupled cavity linac (CCL) and coupled cavity drift tube linac (CCDTL) accelerator structures. PARMILA-2 divides an SC accelerator into structures. Each SC structure of a linac corresponds to one PBO Lab SC Piece. Typically one SC structure can accelerate a beam by several hundred MeV so that only a few PBO Lab SC Pieces are needed to model the complete superconducting portion of a linac.

Each SC structure is divided into segments, which are sometimes referred to as cavities in the literature. Each segment is comprised of a fixed number of cells. The individual cells of an SC structure (i.e. all segments of the structure) all have the same length. This cell length is defined in terms of \( \beta_g \lambda / 2 \) for the structure, where \( \beta_g \) is the physical or geometric \( \beta \) for the structure and \( \lambda \) is the radiofrequency wavelength for the structure. Figure 52 illustrates a basic SC structure modeled by PARMILA-2.

![Superconducting Linac Diagram](image)

Figure 52. Superconducting (SC) layout consisting of multiple segments and \( N_{\text{Cells}} \) per segment, not to scale, from Appendix Figure III-6.
Hierarchy of PARMILA 2 objects used for modeling superconducting structures:

- **STRUCTURE**
  A STRUCTURE is composed of one or more LAYOUTS. The number of LAYOUTS is specified by the user.

- **LAYOUT**
  One LAYOUT is composed of a number of SEGMENTS. The number of SEGMENTS is computed by PARMILA 2 for each LAYOUT.

- **SEGMENT**
  Each SEGMENT contains a fixed number of CELLS. This number is the same for all of the LAYOUTS within a STRUCTURE. The number of CELLS per SEGMENT for a STRUCTURE is specified by the user.

- **CELL**
  Each CELL contains detailed information regarding RF fields and physical dimensions.

PARMILA 2 utilizes quadrupole magnets for transverse beam focusing. The quad LATTICE determines the x and y focusing properties for each STRUCTURE.

The example SC structure illustrated in Figure 52 has 4 cells per segment ($N_{\text{Cells}}=4$). The distance between each segment is denoted by $d_{\text{Seg}}$. Focussing magnets (not shown in Figure 53) are located between segments.

PARMILA 2 further divides each structure into a number of layouts. Certain details of the segments within a given layout may be specified, such as the value of $d_{\text{seg}}$, the energy gain goal for each segment, and other parameters discussed later. While some design details for each layout can be independently specified, the physical cavity structures are the same for each layout. In particular, the values of $N_{\text{Cells}}$ and $\beta_g$ are the same for all segments and layouts within a structure.

Two general classes of SC structures, referred to as SC1 and SC2, can be designed and/or modeled by the PBO Lab PARMILA-2 Module. Each of these is described in separate sections of this User Manual, but the brief overviews below may be helpful.

SC1 has singlet quadrupole magnets located within the space $d_{\text{Seg}}$. However, the primary characteristic of the SC1 structure is that the one segment in the structure does not contain a cavity. This is referred to as a missing segments superconducting linac. The linac designer (PBO Lab PARMILA-2 user) can specify which segment is missing.

The SC2 type of structure has extra space between specific segments (not illustrated in Figure 53) in order to accommodate larger focusing magnets. Either quadrupole singlets or doublets can be used within the extra space. This is referred to as a grouped segments superconducting linac. Whenever a magnet is located between two segments, the extra space introduces a region larger than $d_{\text{Seg}}$ between those segments.
**Missing Segments SuperConducting (SC1) Linac Piece**

The missing segments superconducting (SC1) linac structure of PARMILA 2 refers to a superconducting structure where there is an acceleration segment (cavity) not present (i.e. "missing") in each layout (see Figure 54). The parameters for the SC1 Piece are grouped into four (4) categories:

- RF Field
- Quads
- Segment Layouts
- Geometry

The Piece Window for the SC1 Piece has one tab panel for each of these parameter groups. The RF Field tab panel appears in front when a SC1 Piece window is opened. Figure 54 illustrates the tab panel for the RF Field parameters.

Figure 53. RF Field tab panel for a SC1 Piece.

Many of the parameters on the RF Field tab of the SC1 Piece window are the same as those appearing on the RF Field tab panel of the CCL Piece window (see Figure 36).
The Nominal Final Energy and Initial Synchronous Phase parameters on the RF Field tab page of the SC1 Piece correspond to the following parameter numbers in Table IV-9 of the Appendix: 1, 2

The RF Field parameters Last Cell Number, Frequency of SC1, and SuperFish Data Frequency of the SC1 Piece specify the corresponding data for the SC1 Structure line appearing in the PARMILA 2 input file "input.LIN".

The popup switch Energy Gain Goal on the RF Field tab of the SC1 Piece determines whether or not to use a "ConstESuper" keyword line in the PARMILA 2 input file "input.LIN". When the popup switch option is set to Constant Axial Electric Field Eo, then the "ConstESuper" keyword line is utilized, and the value for the Axial Electric Field Eo parameter specifies the data for that keyword line.

Quadrupoles are located between all general segments (cavities) of the SC1 Structure, including the so-called "missing" segments. There will actually be 2 quadrupoles, of opposite polarity, located in the special region that contains the "missing" segment. Or, equivalently, there will be (a) one quadrupole located after the segment that precedes the missing segment space and (b) another quadrupole, of opposite polarity, before the segment that follows the missing segment location.

The parameters in the SC1 Piece window, whose names are the same as those appearing on the on the CCL Piece window, may be understood to play the same basic role in the SC1 design process as the corresponding parameters of the CCL. However, the SC1 Piece does not have a parameter for specifying the initial axial electric field. The SC1 utilizes "Segment Layouts" in the design of the structure, and the axial electric field is determined by the details (primarily the "Energy Gain per Segment", see Figure 56) of the "Segment Layouts". The "Energy Gain Goal" popup switch illustrated in Figure 53 has its default setting to use those energy gains.

An "override" of the "Segment Layouts" specifications can be used to replace all axial electric fields in the entire Structure with a constant value. The "Energy Gain Goal" popup option "Constant Axial Electric Field Eo" is used to select this override. The "Axial Electric Field Eo" parameter value field is then used to input the desired constant value of the axial field.

An example illustrating one Layout of a missing segment superconducting linac (SC1) structure is shown in Figure 54. Specifying the details for individual "Segment Layouts" is described in detail further below. Note that there is one quadrupole located between every segment. For the SC1 this is a property of the entire Structure. That is, a quadrupole magnet is located between every Segment of every Layout of one SC1 Structure. The "Quads" tab panel of the SC1 Piece window is used to specify details for the quadrupole lattice. Figure 55 illustrates the SC1 Piece window "Quads" tab panel.
Figure 54. Layout for a missing segment superconducting linac (SC1), not to scale, from Appendix Figure III-7. This example has 1 missing segment every 4 segments.

Figure 55. Quads tab panel for a SC1 Piece.

The first two parameters on the "Quads" tab panel determine the quadrupole gradient and effective length for the entire SC1 Structure. The popup parameters ("Sequencing of Polarities", "Magnet Locations", "Quad at Tank Entrance") have the same choices as available for a CCL using singlet quadrupoles (see Figure 39).
Each SC1 Piece can support from 1 to 10 *Segment Layouts*. (At least one is required.) Figure 54 illustrates *one* Segment Layout, and the example layout shown has 1 missing segment, for every 4 segments. The "Segment Layouts" tab panel of the SC1 Piece window is used to set most of the other parameters illustrated in Figure 54. The SC1 "Segment Layouts" tab panel is shown in Figure 56.

PARMILA 2 superconducting structure hierarchy:

- **STRUCTURE**
  A STRUCTURE is comprised of a Number of Layouts

- **LAYOUT**
  One LAYOUT is composed of a number of SEGMENTS. The number is computed by PARMILA 2 for each LAYOUT.

- **SEGMENT**
  Each SEGMENT in a LAYOUT contains the fixed Number of Cells per Segment

Figure 56. Segment Layouts tab panel for a SC1 Piece.

The SC1 "Segment Layouts" tab panel, illustrated in Figure 56, can be conceptually separated into 2 parts. The upper part contains the two parameter input fields for "Number of Layouts" and "Number of Cells per Segment". These two parameters are the same for all Segments in each Layout. The sidebar to the left contains a summary of the superconducting structure hierarchy determined by the values of the parameters.
The "Number of Layouts" must be at least 1 (otherwise no SC1 structure exists). Similarly, the number of "Number of Cells per Segment" must also be at least 1.

The second part, of the conceptual division of the SC1 "Segment Layouts" tab panel, contains the popup switch "Individual Segment Layouts" and the remainder of the parameters on the tab. The "Individual Segment Layouts" popup switch has ten (10) positions, corresponding to the (maximum) possible "Number of Layouts". For each of the 10 switch positions, the popup switch "Use this Layout" and the five parameter input fields immediately below are individually set.

Parameters only need to be entered for the "Number of Layouts" specified. For example, if the "Number of Layouts" is set to "2", then values are only needed for the "Segment Layout 1 Parameters" and "Segment Layout 2 Parameters". (Values for "Segment Layout 3 Parameters" through "Segment Layout 10 Parameters" will not be used by the PARMILA-2 Module.) It is important that the popup switch "Use this Layout" be set to "Yes" for both Layout 1 and Layout 2. Only Layout 1 has a default of Yes", all other Layouts have "No" as their default setting. The sidebar to the right provides a summary of the PARMILA 2 superconducting structure hierarchy for the example of 2 Layouts.

Each Layout has five (5) parameters that determine the SC1 design: "Starting Velocity (v/c)", "Energy Gain per Segment", "Distance Between Segments", "Missing Segment Number m" and "Shift Missing Segment". One of these parameters, "Starting Velocity (v/c)", should be increasing from one Layout to the next. The others may, or may not, be unique to each Layout. In the SC1 basic design all Layouts will have the same singlet quadrupole focusing characteristics as specified on the Quads tab panel (Figure 55).
When setting up the design goals for a SC1 Structure, it is important to specify a "Nominal Final Energy" (see Figure 53) that is high enough to allow PARMILA 2 to determine the design beyond the "Maximum Cell Number" desired for the actual Structure. As the preceding discussion of the superconducting structure hierarchy suggests, this may not be known a priori at the beginning of the design process. Users should anticipate the need for some iteration of the design.

The last tab panel of the SC1 Piece window is the Geometry tab. The SC1 Geometry tab panel is illustrated in Figure 57.

The parameters on the Geometry tab provide the data for each SC1 "Bore" keyword line in the PARMILA 2 input file "input.LIN". Section IV.B.18 of the Appendix discusses the "Bore" keyword data.

The three parameters on the Geometry tab panel of the SC1 Piece window are used for PARMILA 2 beam simulations. The parameters play a role for each SC1 structure similar to the corresponding parameters of the DTL (Figure 34) and the CCL (Figure 44). If only one value for the bore radius is desired, set the desired value in the "Bore Radius, Low Energy" data field, and then set the integer parameter "1st Cell Using Radius Rb2" to "0" (default value). Any entry in the "Bore Radius, High Energy" data field will then be ignored.
All PARMILA 2 radiofrequency *Structures* require a block of SuperFish data in order to carry out a design or simulation. Figure 58 illustrates a PBO Lab Document Window with a representative set of Pieces used for a carrying out a SC1 design and simulation.

The PBO Lab file "SC1 MissingCavity 700 MHz.pbol" is located in the PBO Lab installation folder: Examples/Parmila

![Figure 58. PBO Lab Document Window for the "SC1 MissingCavity 700 MHz.pbol" example.](image)

The SC1 Piece and the COMM Piece immediately following it in Figure 58 comprise the SC1 "Design Line" for the example. These two Pieces represent a minimal Design Line which incorporates the required SuperFish data through the COMM Piece labeled "SC1 sfd", but has no other Pieces that effect the design of the SC1. The other Pieces are utilized for the beam dynamics simulation and specifying various design or simulation outputs.
Similar to the DTL, CCL and CCDTL structures, various options are available to override (or replace) the basic SC1 design goals with other criteria. For example, the specification of individual quadrupole parameters can be imposed upon the design and simulation of an SC1 structure. The set up of these additional conditions utilizes various PARMILA-2 Parameter (PARAM) and Command (COMM) Pieces, similar to the examples illustrated for the DTL Piece (see Figure 35). The PARMILA-2 Parameter (PARAM) and Command (COMM) Pieces are described in a later Section of this manual.

Figure 59 illustrates part of the design section of the 'Parmila.out' file for the "SC1 MissingCavity 700 MHz.pbol" example. This SC1 example has 1 Layout, 5 cells per Segment, with every 4th Segment "missing" (m=3). The quadrupole Lattice is a DFDF type, meaning that the first full-length quadrupole (located after the 1st Segment) is defocusing (D) in the horizontal, or x, direction. There is an initial half-length quadrupole at the Structure entrance (before the 1st Segment) which has the opposite polarity.
Figure 59. A portion of the 'Parmila.out' file, following completion of the menu command "Write and Run 'input.LIN'", for the example file "SC1 MissingCavity 700 MHz.pbol".
**Grouped Segments SuperConducting (SC2) Linac Piece**

The second type of superconducting structure available in PARMILA 2 is referred to as the grouped segments superconducting (SC2) linac structure. This type of superconducting structure has quadrupoles located between groups of segments and differs in several ways from the SC1 structure. For example, either singlet or doublet quadrupole lattices can be used with SC2 structures. The parameters for the SC2 Piece are grouped into four (4) categories:

- RF Field
- Quads & Segments
- Segment Layouts
- Geometry

The Piece Window for the SC2 Piece has one tab panel for each of these parameter groups. The RF Field tab panel appears in front when a SC2 Piece window is opened. Figure 60 illustrates the tab panel for the RF Field parameters, which is identical to that of the SC1.

![Figure 60. RF Field tab panel for a SC2 Piece.](image)

- Nominal Final Energy should be larger than design objective
- Last Cell Number will be the final cell actually used in SC2.
- Initial Synchronous Phase
- Frequency Harmonic for SC2 is a multiple of the (Document Window) Global Frequency, and sets Frequency of SC2
- Two options are available for the Energy Gain Goal:
  - **Energy Gain of Segment Layouts**
  - **Constant Axial Electric Field Eo**
  - The Axial Electric Field value is used if the Energy Gain Goal is Constant Axial Electric Field Eo
  - SuperFish Data Frequency may be different from the Frequency of SC2; PARMILA 2 will scale data
The Nominal Final Energy and Initial Synchronous Phase parameters on the RF Field tab page of the SC2 Piece correspond to the following parameter numbers in Table IV-10 of the Appendix: 1, 2

The parameters Last Cell Number, Frequency of SC2, SuperFish Data Frequency, and Beam Dynamics Phase Shift specify the corresponding data for the SC2 Structure line appearing in the PARMILA 2 input file “input.LIN”.

The SC2 Structure supports both doublet (Figure 61) and singlet (Figure 62) lattice configurations.

The RF Field tab panel for the SC2 Piece window is the same as the RF Field tab panel of the SC1 Piece (Figure 53). The discussion following Figure 53 is applicable to the SC2 Structure as well. A few summary items of that discussion are included in the sidebars of the next few pages, but users may wish to review the SC1 discussion in more detail.

The SC2 Structure can be designed using either a quadrupole doublet or a quadrupole singlet focusing Lattice. Figure 61 illustrates an example of one Layout for a SC2 with doublet quads after every 3 segments. Figure 62 shows a similar Layout example for a SC2 Structure that uses singlet quads after every 3 segments. The transverse quadrupole Lattice period for the singlet Lattice is generally longer than for a doublet Lattice. General properties of each SC2 Layout and Lattice are specified with parameters on the Quads & Segments tab panel, illustrated in Figure 63.

Segment N Segment N+1

Quadrupole doublet

Segment N+6

Transverse period

Figure 61. Layout for a grouped segment superconducting linac (SC2) using quadrupole doublet focusing, not to scale, from Appendix Figure III-8.
Figure 62. Layout for a grouped segment superconducting linac (SC2) using quadrupole singlet focusing, not to scale, from Appendix Figure III-9.

Figure 63 shows the Quads & Segments tab panel for the SC2 Piece window. The SC2 structure hierarchy follows the same pattern as for the SC1. A primary difference is that the quadrupole details (gradient, length) are specified for each Layout in an SC2, rather than for the whole Structure as in the case of an SC1. The Quads & Segments tab panel reflects this difference - only the top-level Structure inputs are on the Quads & Segments tab panel.

The "Lattice Type" popup switch is used to specify whether the SC2 Structure will use "Singlet Quads" or "Doublet Quads". If a doublet type lattice is selected, then the "Polarity for Doublets" popup switch assigns the polarity for the first quad in each doublet. The "Polarity for Doublets" setting is ignored if a singlet type lattice is selected. A half-length entrance quad may be included using the "Quad at Tank Entrance" popup switch.

PARMILA 2 superconducting structure hierarchy:

- **STRUCTURE**
  A STRUCTURE is comprised of a Number of Layouts.

- **LAYOUT**
  One LAYOUT is composed of a number of SEGMENTS. The number is computed by PARMILA 2 for each LAYOUT.

- **SEGMENT**
  Each SEGMENT in a LAYOUT contains the fixed Number of Cells per Segment.

- **CELLS**
  Detailed cell parameters will be computed by PARMILA 2.
Lattice Type determines quad arrangement for Structure

Polarity for Doublets only applies if Doublet Quads is selected for the Lattice Type

Quad at Tank Entrance has 2 possible choices

Number of Layouts must be at least 1 and not more than 10

All Layouts for an SC2 Piece will have the same Number of Cells per Segment

The parameters on the SC2 Quads & Segment tab page (except Polarity for Doublets) correspond to the following parameter numbers in Table IV-10 of the Appendix: 5, 6, 3, 4

The Polarity for Doublets is utilized in conjunction with parameters on the Segment Layouts tab page of the SC2 Piece window (Figure 64).

The parameters selected on the Quad & Segments tab panel will impact the use of certain parameters on the Segment Layouts tab panel.

The remaining 2 top-level SC2 Structure parameters appearing on the Quads & Segments tab panel determine the "Number of Layouts" and the "Number of Cells per Segment". These parameters are identical to the parameters with the same names that appear at the top of the SC1 Segment Layouts tab panel (Figure 56). Their functionality is also the same for SC2 Structures.

The Segment Layouts tab panel for the SC2 Piece is illustrated in Figure 64. Five of the first six parameters appearing on the SC2 Segment Layouts tab panel are the same as the parameters of the same name that also appear on the SC1 Segment Layouts tab panel (Figure 56). The first two are the popup switches: "Individual Segment Layouts" and "Use this Layout". These switches are used in the same manner as those of the SC1 Piece: Set the "Use this Layout" popup switch to "Yes" for each layout number that is to be used. For example, if the "Number of Layouts" is set to 4, then the switch needs to be set to "Yes" for "Segment Layout 1 Parameters", "Segment Layout 2 Parameters", "Segment Layout 3 Parameters" and "Segment Layout 4 Parameters".
Figure 64. Segment Layouts tab panel for SC2 Piece.

The next SC2 two parameters on the Segment Layouts tab panel, "Starting Velocity (v/c)" and "Energy Gain per Segment", are also the same as the corresponding parameters on the SC1 Segment Layouts tab panel. Values for these should be entered for each setting of the "Individual Segment Layouts" switch for a layout number that is to be used in the SC2 design. The value for the "Starting Velocity (v/c)" should be an increasing function of the layout number.

The SC2 parameter "Distance Between Segments" also has the same characteristics as the corresponding SC1 parameter, but the integer parameter "Segs Between Quad Spaces" is unique to the SC2 Piece. Figures 61 and 62 illustrate examples where the "Segs Between Quad Spaces" are equal to 3.
Individual Layout parameter: 
Sequencing for Singlet is only used for the Singlet Quad choice of the SC2 Lattice Type selection.

Individual Layout parameter: 
Distance Between Quads is only used for the Doublet Quad choice of the SC2 Lattice Type selection.

The Polarity for Doublets appearing on the SC2 Quads & Segments tab panel (Figure 63) is also utilized with the PARMILA 2 "QuadDoublet" keyword line in the input file "input.LIN".

The 'QuadSinglet' keyword line is discussed in Section IV.A.21 of the Appendix.

The 'QuadDoublet' keyword line is discussed in Section IV.A.22 of the Appendix.

The remaining five SC2 Segment Layouts tab panel parameters are associated with the magnetic quadrupole lattice to be used for a given layout. Unlike the SC1 Structure, where the quadrupole lattice in the same for all layouts, the SC2 Structure can be used for layouts in which the parameters of the lattice quadrupoles are different in each layout.

The "Space for Quadrupoles" defines the physical length of the additional space between segments within which the quadrupoles (singlets or doublets) are located. The "Space for Quadrupoles" is the distance indicated by $d_{qs}$ in Figures 61 and 62.

The SC2 Segment Layouts tab panel parameters discussed to this point all appear in the main PARMILA 2 input file "input.LIN" following the PARMILA 2 keyword "SC2". The remainder of the parameters on the SC2 Segment Layouts tab panel, which give the details of the quadrupole lattice parameters, will appear after one of two other possible keywords: "QuadSinglet" or "QuadDoublet". The PBO Lab PARMILA-2 Module keeps track of all parameter settings, and writes all necessary and sufficient data in the correct order to the PARMILA 2 input file "input.LIN".

Note that for a doublet lattice, the value for the "Space for Quadrupoles" should be greater than twice the "Effective Quad Length" plus the "Distance Between Quads". For a singlet lattice, the "Space for Quadrupoles" need only be greater than the "Effective Quad Length". The Guidance Limits for the "Space for Quadrupoles" parameters reflect these requirements.
The SC2 Geometry tab panel is the same as the corresponding SC1 Geometry tab panel (Figure 57). The three parameters on the Geometry tab panel of the SC2 Piece window are used for PARMILA 2 beam dynamics simulations. The parameters play a role for each SC2 structure similar to the corresponding parameters of the DTL (Figure 34) and the CCL (Figure 44). If only one value for the bore radius is desired, set the desired value in the "Bore Radius, Low Energy" data field, and then set the integer parameter "1st Cell Using Radius Rb2" to "0" (default value). Any entry in the "Bore Radius, High Energy" data field will then be ignored.
Specialized PARMILA-2 Optics Pieces

The PARMILA 2 code has a few specialized optics elements that are not found in most other optics codes. These include the PARMILA 2 funnel and chopper elements. These specialized, or custom, optics elements are accessed using the PARMILA-2 Optics Pieces submenu on the PARMILA-2 commands menu. Selection of the PARMILA-2 Optics Pieces menu item opens the window illustrated in Figure 67.

![Figure 67. The PARMILA-2 Optics Pieces window](image)

Figure 67. The PARMILA-2 Optics Pieces window lists all of the specialized optics elements used by the PARMILA-2 Module.

The PARMILA 2 funnel and chopper elements do not include any external fields in their physics models. They only impact the beam simulation indirectly, through affects introduced by space charge.

Note: Some or all of the specialized PARMILA-2 Optics Pieces may be incorporated into the Palette Bar in future releases of PBO Lab.
Table 2. Summary of output files created by Parmila.exe.
(to be completed)

<table>
<thead>
<tr>
<th>File Name</th>
<th>Description</th>
<th>PARMILA-2 Command</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parmila.out</td>
<td>PARMILA Main Output File</td>
<td>Write and Run 'input.LIN'</td>
<td>Always written</td>
</tr>
<tr>
<td>Design.out</td>
<td>Beam Dynamic Design Detail</td>
<td>Write and Run 'input.LIN'</td>
<td>Use LINOUT Command Piece</td>
</tr>
<tr>
<td>Beam.out</td>
<td></td>
<td>Write and Run 'input.LIN'</td>
<td>Use PrtBeam Command Piece</td>
</tr>
<tr>
<td>E0prof.out</td>
<td></td>
<td>Write and Run 'input.LIN'</td>
<td></td>
</tr>
<tr>
<td>Quad.out</td>
<td></td>
<td>Write and Run 'input.LIN'</td>
<td></td>
</tr>
<tr>
<td>QuadErrs.out</td>
<td></td>
<td>Write and Run 'input.LIN'</td>
<td></td>
</tr>
<tr>
<td>QuadPos.out</td>
<td></td>
<td>Write and Run 'input.LIN'</td>
<td></td>
</tr>
<tr>
<td>WallPwr.out</td>
<td>LinGraf binary data file</td>
<td>Write and Run 'input.LIN'</td>
<td>Use POWER Command Piece</td>
</tr>
<tr>
<td>parmila.plt</td>
<td>LinGraf binary data file</td>
<td>Write and Run 'input.LIN'</td>
<td>Use PrtBeam Command Piece</td>
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