

# FoCa Startup Guide



**Version 1.7b ALPHA**

**April 5<sup>th</sup>, 2016**

**Daniel Sánchez Parcerisa**  
[dsparcerisa@ucm.es](mailto:dsparcerisa@ucm.es)

**Alejandro Carabe**  
[a.carabe@uphs.upenn.edu](mailto:a.carabe@uphs.upenn.edu)

**Hospital of the University of Pennsylvania**  
**Department of Radiation Oncology**

## Introduction

FoCa is an in-house modular treatment planning system, developed entirely in MATLAB, which includes forward dose and LET calculation of proton radiotherapy plans in both active and passive modalities as well as a generic optimization suite for inverse treatment planning. The software has a dual education and research purpose. From the educational point of view, it can be an invaluable teaching tool for educating medical physicists, showing the insights of a treatment planning system from a well-known and widely accessible software platform. From the research point of view, its current and potential uses range from the fast calculation of any physical, radiobiological or clinical quantity in a patient CT geometry, to the development of new treatment modalities not yet available in commercial treatment planning systems.

## Disclaimer

FoCa has been developed as an incremental research tool, rather than as a complete software. For this reason, there are a number of features that have not been implemented. In particular, the current version of the system is not able to **not able to process DS plans that use a patient-specific range compensator**. Similarly, **machines including range shifters in PBS have not been created**. These limitations can be overcome by extending FoCa to match the user's needs.

The software is provided 'as is'. Although it has gone through thorough commissioning and testing, bugs are expected. Please report any found bugs and proposed solutions.

**Partial or total redistribution** of the code without written approval by the copyright owners is not permitted.

Version 1.7b does **not** include LET calculation capabilities. If interested in full LET calculation please contact Alejandro Carabe at [a.carabe@uphs.upenn.edu](mailto:a.carabe@uphs.upenn.edu).

## About this User Manual

This User Manual, along with the example script provided in the example\_data folder, should lead potential users through their first steps with FoCa. For more advanced uses, including DVH and LET-VH analysis of plans, using individual classes, interfacing with other codes, or code compilation, please refer to the actual MATLAB classes, either by inspecting the M-files or by using the help command within the MATLAB window.

# Installation

## Requisites

FoCa has been developed with MATLAB (R2014a) and observed to work with all later versions of MATLAB up to R2015a.

## External libraries

There are a number of external functions libraries used in MATLAB coding, with varying licensing schemes. The files are located under the /libs folder of the FoCa data path. For more information:

- matGeom library (<http://matgeom.sourceforge.net/wiki/index.php/MatGeom>).
- ini2struct function (<http://www.mathworks.com/matlabcentral/fileexchange/17177-ini2struct>). Provided with FoCa standard repository under the folder /libs, no need to reinstall from external sources.

## Installation procedure

FoCa files must be copied to a local directory and added to the MATLAB path. In summary, what must be added to the MATLAB path is:

- FoCa folder
- FoCa folder/libs
- /matgeom folder with all subfolders

Additionally, the FoCa data path is specified in the MATLAB environment variable FOCA\_DATA\_PATH. Within this folder, the following items must exist

- beamdata/ folder, including all machines, with each folder corresponding to either a PBS or a DS machine.
- aux\_files/ folder.

The command **testPWD** returns the FoCa installation directory, making the first line of all FoCa scripts to be:

```
setenv('FOCA_DATA_PATH',testPWD)
```

As a final step, FoCa installation can be verified by running the following command

```
verifyFoCaInstallation
```

## Running FoCa via GUI

Running FoCa via GUI presents the user with the following interface:

To begin, the user would choose the desired CT folder, structure set, and plan in the section shown below:

Following this, the user will be allowed to specify the origin and cropping parameters.

User Origin:	X	<input type="text" value="0"/>	Y	<input type="text" value="0"/>	Z	<input type="text" value="0"/>
Cropping MIN:	X	<input type="text" value="0"/>	Y	<input type="text" value="0"/>	Z	<input type="text" value="0"/>
Cropping MAX:	X	<input type="text" value="0"/>	Y	<input type="text" value="0"/>	Z	<input type="text" value="0"/>

The user will need to specify the machine type, calculation method, and target and body structures. The machine type is dependent on the whether the loaded structure set is for Pencil Beam Scanning (PBS) or Double Scattering (DS).

Machine	<input type="text" value="DS5"/>	Calculation method	<input type="text" value="Robust"/>
Body structure	<input type="text" value="[Load RS File]"/>	Interpolation Method	<input type="text" value="MATLABNative"/>
Target structure	<input type="text" value="[Load RS File]"/>	<input checked="" type="checkbox"/> Calculate LET	

Users may specify HU corrections for Bolus or Artifacts, and may additionally choose to crop all points outside the body structure. When a user attempts to add a correction for a preexisting structure, the new HU will overwrite the old value. The corrections interface is shown below:

Artifact/bolus corrections		Structure	HU	
Add Bolus/Artifact Corrections				
Structure name	<input type="text" value="None"/>		<input type="text" value="0"/>	<input type="button" value="Add"/>
<input type="checkbox"/> Make HU=-1000 for points outside body structure				<input type="button" value="Remove"/>

After setting corrections, the user can choose to output model DICOM files for Dose and LET, then finally calculate using the set parameters using the following interface:

Output Model DICOM Files	
<input type="checkbox"/> Save DICOM Files (requires model files)	
Dose File <input type="text"/> Mode <input type="text"/> <input type="button" value="Choose"/>	LET File name <input type="text"/> Mode <input type="text"/> <input type="button" value="Choose"/>
Save as MATLAB file <input type="checkbox"/> Save as MATLAB file <input type="text"/>	
<input type="button" value="Calculate"/>	

Currently, the GUI does not have a feature for evaluating results implemented at this moment. In order to evaluate results, the user will need to operate FoCa by text.

## Running FoCa via MATLAB Script

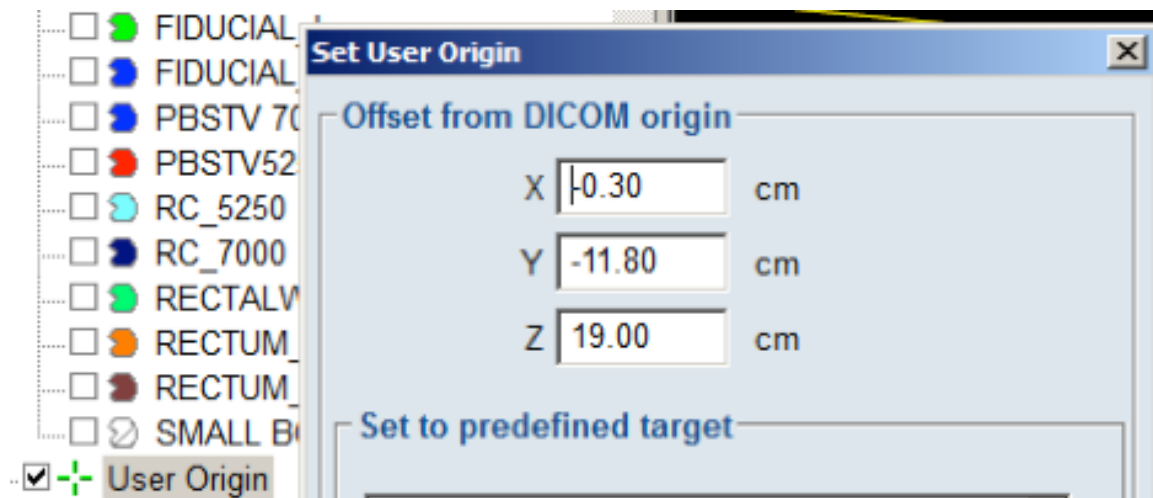
Make sure the current version of FoCa is in the current active folder, or has been added to the MATLAB path (to do that, go to File -> Set Path...). Additionally, the FOCA\_DATA\_PATH

environment variable must be set:

```
setenv('FOCA_DATA_PATH',testPWD)
```

For each plan, it is necessary to specify various things:

- Plan DICOM file (RN) (both for DS and PBS).
- Folder containing CT slices.
- Path to structure set (RS) Dicom file.
- Names of BODY and TARGET structures.
- Name of machine used for the calculation. Currently implemented machines are: 'PBS1', 'PBS2', 'PBS2MC' (tuned to reproduce data from Geant4), 'PBS3' and 'DS5'.
- Name of physics model; use 'Standard' by default.
- User Origin position (from Eclipse, can be found here).



Additionally, a cropping can be specified (will speed up the interpolation step). If the calculation is performed in a water box (i.e. no CT is used), this cropping is used to define the dimensions of the box.

Then, the first lines of the MATLAB file have to be similar to:

```
userOrigin = [-0.30 -11.8 19];
planPath='RN.dcm';
CTPath = 'CT/';
bodyName = 'BODY';
targetName = 'TARGET';
machineName = 'PBS3';
physicsModel = 'Standard';
```

The next step is to define the configuration. This is done by instantiating the FoCaConfiguration class and, if required, change some of the parameters (see comments in FoCaConfiguration.m file).

```
FC = FoCaConfiguration;  
FC.dz = 0.1; % Example
```

Then, the calculation class FoCaManager is created with the following syntax

```
FM = FoCaManager(FC, userOrigin, RNPPath, CTPath, RSPPath, bodyName, targetName, [],  
true, machineName, physicsModel);
```

If artifacts have to be overridden (in the example, the ROI named 'ARTIFACT' is overridden with 0 HU), use the following syntax:

```
FM.overrideArtifact('ARTIFACT', 0, 'HU');
```

Finally, the program is asked to perform the calculation. This will take a while.

```
FM.process();
```

## Evaluate results

The class FoCaManager has some basic processing functions to view the result of the calculation. These are

plotDoseSlice(axis, value). Plots a dose slice over the CT. Example

```
FM.plotDoseSlice('Y', 0)
```

plotLETSSlice(axis, value). Plots a LET slice over the CT.

```
FM.plotLETSSlice('Y', 0)
```

For further analysis, the object FM.FullResultsGrid contains all the calculated data and implements more analysis functions. See file ResultGrids.m and DVHAnalysis.m for details.

## Load DICOM dose files (RD)

The class ExternalDose provides functionality to load dose distributions in DICOM format (RD files). To create an ExternalDose object (FoCa representation of a RD file), use the following constructor:

```
ED = ExternalDose(RDpath, userOrigin)
```

where RDpath is the path to the RD file, and UserOrigin is the registration origin as defined before.

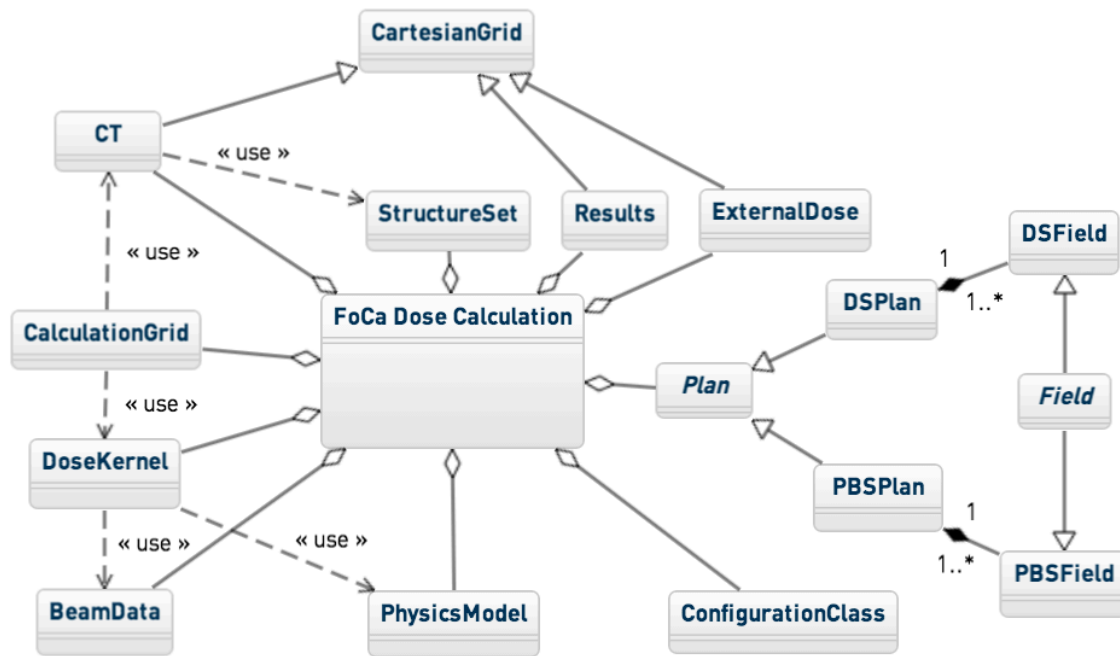
See the file ExternalDose.m for full details on the analysis tools provided for RD files, such as Gamma index calculation of dose distributions.

## Export FoCa dose and LET calculation through DICOM files into Eclipse

1. Create a new plan in Eclipse as a copy of the plan being calculated in FoCa and call it FOCA\_IMPORT. If you want to calculate LET, repeat this process and call it FOCA\_IMP\_LET.
2. Export both plans from Eclipse (right click -> Export wizard). For dose, make sure you select "Total plan dose" in the radio button panel and "Relative values (1.0=100%)". For LET, make sure you select "Total plan dose" and "Absolute values". If the radio button for "Absolute values" is greyed out, make sure you specify a prescription dose in the plan configuration. Click "Clear" in the next page to avoid errors with DVH exporting, then click Next. Select "PCAM\_Mapcheck" as export filter, check the checkbox at the bottom of the page and hit "Next". You should have two files for each plan, the RD dose distribution and the RN plan. Give your files a meaningful name and hit 'Finish'. Repeat the process for LET. In our example, we have produced the files: RD\_MODEL\_DOSE.dcm, RN\_MODEL\_DOSE.dcm, RD\_MODEL\_LET.dcm and RN\_MODEL\_LET.dcm.
3. In FoCa execute command `FM.saveToDicom('RD_DOSE.dcm', 'RD_MODEL_DOSE.dcm', 'RD_LET.dcm', 'RD_MODEL_LET.dcm')`, being FM the name of your FoCaManager object and RD\_DOSE.dcm and RD\_LET.dcm the desired output file names.
4. Back in Eclipse, delete the plans FOCA\_IMPORT and FOCA\_IMP\_LET from the course and save the data.
5. In Eclipse, select 'Import Wizard' and import 4 files: RN\_MODEL\_DOSE.dcm (unchanged) RN\_MODEL\_LET.dcm (unchanged) RD\_DOSE.dcm (generated from FoCa) RD\_LET.dcm (generated from FoCa)
6. If everything went right, FOCA\_IMPORT plan should now display the FoCa calculated dose. Keep in mind that it is relative dose and will be scaled by the prescribed dose set in your plan. FOCA\_IMP\_LET plan should now display the FoCa calculated LET. To see its value, set the dose display in Eclipse to Absolute Dose. 1Gy in Eclipse equals 1keV/um when displaying LET from FoCa.



## Advanced uses of FoCa



Each of the FoCa classes can be instantiated separately from any piece of MATLAB code. Despite the object oriented (OO) paradigm, we have decided to make all properties of public access, to facilitate experimental programming. Do take time to explore the classes and find solutions that suit your needs. This is a **non-comprehensive** list of the available functionalities:

### Through FoCaManager class

- Perform dose (and LET) calculations of PBS and DS plans on patient geometries.
- Perform any type of dose or dose+LET calculations on water-phantoms, created with a given size at given coordinates.
- Perform a cropping of a CT in order to do the calculations taking into account only a certain volume.
- Normalize the dose calculated by FoCa on the Result grid using several algorithm.
- Plot a 2D dose or LET distribution at any given plane (parallel to the axes) superimposed to the CT.
- Save dose or dose+LET to DICOM files. Requires voxel size in X and Z to be the same and requires a model ED DICOM file.
- Crop everything outside body: Makes every voxel outside the Body contour have the density of air.
- Override artifacts defined in the structure set either based on a given water-equivalent density or on a based HU number.
- Plot dose/LET slice with structures over CT.

- Calculate Gamma Index and Distance To Agreement matrices.

### **Through StructureSet Class**

- Find the ROI number of a structure given its name.
- Plot a 2D contour plot a given slice of a structure.
- Determine if a given point belongs to a ROI or not.
- Create a binary mask with information of the structures to which a point belongs (or for the complete DG).
- Calculate the geometrical distance between the edge of the BODY contour and the field isocentre.
- Calculate the geometrical range for a given BODY and TARGET structures, for a given gantry/couch position.

### **Through CT class**

- Apply a HU-to-WET conversion to a given CT.
- Extract or plot a 2D slice of the CT at an arbitrary plane parallel to the axes.
- Calculate the water-equivalent path length between two points in the CT.

### **Through PrecalculatedPhysData and PrecalculatedPhysData\_LET classes**

- Calculate dose and LET kernels of a given size for given machine and beam conditions.

### **Through DivergentGrid and DivergentGrid\_LET classes**

- Plot the calculation grid in 3D including fluence, dose and LET information.
- Plot the polygon defined by a given MLC position over a heatmap of the fluence matrix in BEV coordinates.

### **Through ExternalDose class**

- Load a DICOM RD file containing a dose matrix.
- Extract or plot a 2D slice of the external dose matrix or an arbitrary plane parallel to the axes.
- Create a 1D plot of the external dose distribution containing any given point, in a direction parallel to any of the axes.

### **Through DSPlan, DSField, PBSPlan and PBSField classes**

- Load a DICOM file containing a proton plan.
- Print plan information.
- Extract the projection of the MLC shape into the isocentre as a polygon.
- Display a heatmap of the spot of a given layer of a PBS field.

**Through DVHAnalysis class**

- Create dose-volume histograms and LET-volume histograms of FoCa-calculated plans.
- Create dose-volume histograms and LET-volume histograms of external dose files.

## References

- D Sánchez-Parcerisa, M Kondrila, A Shaindlin and A Carabe: FoCa: A modular treatment planning system for proton radiotherapy with research and educational purposes. *Phys. Med. Biol.* 59, 7341.
- Ainsley C et al (2013). Optimization of the modelling of longitudinal dose distributions for double-scattered proton beams in a commercially-available treatment planning system. *Phys. Med. Biol.* 58, 11
- Clasie B et al (2012). Golden beam data for proton pencil-beam scanning. *Phys. Med. Biol.* 57, 1147–1158.
- Fraass B et al (1998) American Association of Physicists in Medicine Radiation Therapy Committee Task Group 53: Quality assurance for clinical radiotherapy treatment planning. *Med. Phys.*, 25, 1773-1829
- Ingber, L. (1996). Adaptive simulated annealing (ASA): Lessons learned. *Control and cybernetics*.
- Jäkel O et al (2001) Treatment planning for heavy ion radiotherapy: clinical implementation and application. *Phys. Med. Biol.* 46 , 1101
- Krämer M et al (2000) Treatment planning for heavy-ion radiotherapy: physical beam model and dose optimization. *Phys. Med. Biol.* 45, 3299
- Low, D. A., Harms, W. B., Mutic, S., & Purdy, J. A. (1998). A technique for the quantitative evaluation of dose distributions. *Med. Phys.*, 25(5), 656-661.
- NEMA PS3 (2011), Digital Imaging and Communications in Medicine (DICOM) Standard, Part 3: Information Object Definitions. National Electrical Manufacturers Association, Rosslyn, VA, USA (available free at <http://medical.nema.org/>)
- Sánchez Parcerisa D et al (2014) Fast range switching of passively scattered proton beams using a modulation wheel and dynamic beam current modulation. *Phys. Med. Biol.* 59, N19
- Schaffner, B, Pedroni, E., & Lomax, a. (1999). Dose calculation models for proton treatment planning using a dynamic beam delivery system: an attempt to include density heterogeneity effects in the analytical dose calculation. *Phys. Med. Biol.* 44(1), 27–41.
- Schaffner, Barbara. (2008). Proton dose calculation based on in-air fluence measurements. *Physics in medicine and biology*, 53(6), 1545–62. doi:10.1088/0031-9155/53/6/003
- Spezi E, Lewis DG, Smith CW (2002). A DICOM-RT-based toolbox for the evaluation and verification of radiotherapy plans. *Phys. Med. Biol.* 47, 4223
- Ulmer, W. (2007) Theoretical aspects of energy-range relations, stopping power and energy straggling of protons. *Rad. Phys. Chem.* 76 1089–107

- Ulmer W & Schaffner B, (2011). Foundation of an analytical proton beamlet model for inclusion in a general proton dose calculation system, *Radiation physics and chemistry*, 80(3), 378.
- Ulmer, W., & Matsinos, E. (2010). Theoretical methods for the calculation of Bragg curves and 3D distributions of proton beams. *The European Physical Journal Special Topics*, 190(1), 1–81.
- Wilkens, J. J., & Oelfke, U. (2003). Analytical linear energy transfer calculations for proton therapy. *Med. Phys.*, 30(5), 806.
- Wilkens, J. J., & Oelfke, U. (2004). Three-dimensional LET calculations for treatment planning of proton therapy. *Zeitschrift für medizinische Physik*, 14(1), 41–6.