BeamScheme Documentation

Release 1.01

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CHAPTER

ONE

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CHAPTER

TWO

INTRODUCTION

BeamScheme is an analysis tool for 2D datasets. It will assist you in extracting 1D profiles from 2D datasets and can calculate over 90 different parameters. BeamScheme can open various image and 2D array file formats such as SNC MapCheck, PTW 720, IBA Matrix and StarTrack, Eclipse, XiO, BrainLab, DICOM, jpg, etc.

Parameters include field size, field centre, penumbra, flatness and symmetry. FFF beams are supported with both maximum slope and sigmoid fit parameters available. Profiles can be taken at any angle, offset or thickness. Profiles can be exported to a text file or clipboard for further processing. Results can be exported to PDF.

BeamScheme v1.00 is virtually a complete rewrite of BeamScheme featuring a new parameter calculation engine. The code has been extensively modularised making it easy to add new parameters. New algorithms have been implemented with individual parameter calculation. Extensive unit testing has been implemented. The GUI has been updated. The expression parser has been dropped and all parameters are calculated in the code. Efficiency is achieved by only calculating needed parameters.

BeamScheme is not intended to replace the commercial software available with 2D arrays, but to complement it.

This manual assumes that you are familiar with using your operating system. If you are not then please consult the appropriate documentation and on-line help. BeamScheme can run on a variety of operating systems and while a thorough knowledge of your specific system is not necessary some basic knowledge such as running files will be an advantage.

CHAPTER

THREE

CONVENTIONS IN THIS MANUAL

Various typefaces and punctuation symbols are used to indicate actions that the user must perform. Here is a list of these actions and their meanings.

- Words in a courier font indicate letters that must be typed in on the keyboard. These will usually be data that should be typed into a field.
- Words between single quotes, e.g. 'Start', usually indicate the name of a menu option, field or button.
- Words between angular brackets, e.g. <Enter>, indicate a key that should be pressed. A combination of keys is indicated by a dash '-', for example <Alt-F> means you should press the <Alt> key and the <F> key together. Keys following each other are indicated by a comma ',', for example <Alt-F,S> means that you should press the <Alt> key together with the <F> key, release them and then press the <S> key.
- An icon like this  indicates important information about which you should be aware.
- A hint or short cut is shown like this  .

It should be mentioned here that when this manual uses the word 'field' it is referring to a place in the program window where data is entered and not a radiation treatment field unless it is specifically stated.

CHAPTER

FOUR

SYSTEM REQUIREMENTS

BeamScheme can run on a variety of platforms and operating systems. Currently EPS is compiled for:

- Windows 7 or higher
- Fedora 34 running KDE 5 with Qt 5.6

The program needs approximately 10 MB of disk space to install. A 19” monitor or larger is not essential but will make viewing easier. BeamScheme should not be viewed at a resolution of less than 1280x1024. Other linux versions such as GTK or Apple Mac based may be available on request.

CHAPTER

FIVE

INSTALLATION

Installing the Beam Scheme is simple, but if you are concerned that you cannot do it ask your System Administrator or Physicist to do it for you.

5.1 Uninstalling previous versions

BeamScheme V1.00 is not compatible with previous versions of BeamScheme so it is necessary to uninstall previous versions before installing the new version. If you wish to retain protocol definition files please back these up manually. Please note that the installation utility will not backup any image or 2D array files in the directory. You will need to do this yourself. To uninstall the program please follow the instructions below:

5.1.1 Under Windows

In Windows open the 'Control Panel' from the main menu, double click 'Programs and Features', (previously known as 'Add Programs') and click on the 'BeamScheme' entry. Select 'Uninstall' or 'Remove'. When BeamScheme has been removed close 'Programs and Features' and close the 'Control Panel'. Any user files such as protocol definition files may need to be removed manually.

5.1.2 Under Linux

Delete the files in the installation directory. If you have any desktop shortcuts or menu links delete those as well. Also delete the directory ~/.config/BeamScheme and any files in it.

 The protocol definition files from previous version of BeamScheme are not compatible with version 1.00 and will give errors.

5.2 Installing a new version under Windows

Insert your media containing the installation files. Using Windows Explorer navigate to the drive that you inserted. Select the folder containing the files for your site. Double click on the 'BSSetup' program and follow the on screen instructions. It is best to simply accept the default installation values. The protocol definition files from version 0.5X are not compatible with this version and will be deleted.

 Any previous data in the program installation directory and the program configuration directory will be deleted.

5.3 Installing a new version under Linux

Insert the media containing the installation files and mount it. Copy the tar file to the directory where you want to install it. Extract it to this directory. Make sure that the executable has execute permissions. If necessary create a link to the executable and place it in your path. The protocol definition files from version 0.5X are not compatible with this version. Do not retain previous protocol definition files.

5.4 USB Drive Install

From version 1.01 BeamScheme can be run from a single directory such as a USB drive without installation. Unzip the file BSSetupUSB-1.xx.zip into the required directory.

CHAPTER

SIX

RUNNING BEAMSCHEME

Contents:

6.1 Running BeamScheme under Windows

Double click the 'BeamScheme' icon  on the desktop. Alternatively select 'Start, All Programs, BeamScheme, BeamScheme' on the Start Menu.

If a USB drive install was done then using file explorer navigate to the directory that BeamScheme was installed in and double click the BeamScheme.exe file.

6.2 Running BeamScheme under Linux

Open a terminal window. Change to the directory where you installed BeamScheme. At the prompt enter:

./beamscheme &<enter>

Alternatively you can create a link to the application and place it on your desktop. Refer to your system documentation for details.

CHAPTER

SEVEN

USING BEAMSCHEME

Using BeamScheme is simple. There are two profiles, a horizontal or X profile and a vertical or Y profile. The X profile is displayed in the top right quadrant or pane of the screen. The Y profile is displayed in the bottom left quadrant. The results are displayed in the bottom right quadrant. The opened image, fluence or 2D array file is displayed in the top left quadrant. The status bar at the bottom of the screen communicates error messages and warnings. Profiles and results are calculated automatically when a profile is changed or a file is opened.

7.1 The Menu Bar

The menu bar allows you to open datasets, export profiles, edit protocols and print results. Some functions are duplicated on the toolbar in *The Image Pane*. Menu options can also be invoked using shortcut keys by press <alt> and the underlined character. Available menu items are:

7.1.1 The File Menu

The file menu options are:

File, Open

Opens a dialogue box to select an image, dose map or 2D array file to load. See *Supported File Formats*

This function can also be accessed using the Open File button  on *The Image Pane* toolbar.

 If you do not see the file you want make sure you have selected the correct file type.

Print PDF

From version 0.51 BeamScheme prints the displayed form directly to a pdf. This gives much more flexibility in printing. Selecting the option opens a file dialog for the file name.

If a hard copy is needed the pdf can be printed by any pdf reader.

Settings

Selecting “Settings” under the *File Menu* or clicking the “Edit Settings” button  on the *tool bar* will open the Settings window.

BeamScheme has a highly extendible settings module. Here default behavior for the algorithms is configured. The settings consist of key, value pairs with definable values. The values can be changed by selecting the box next to the key and either entering a value or selecting a value from the drop down list. If a setting is changed it must be saved by

pressing the "Save Settings" button  . The Settings module can be closed by pressing the "Exit Settings" button  . Available settings are:

Default Resolution

If BeamScheme cannot determine the detector resolution it will default to this value. Values are in dots per inch (dpi). This is useful for film scans where the resolution is not included in the file header such as bmp, jpg and png files. Common resolutions are 75 (Gafchromic) 76 (Xomat), 150 (fax quality) and 300 (normal commercial scanners). This is a numeric field.

 The resolution affects the distances displayed in the profile panes and the calculation of certain results.

IFA Type

Select the *In Field Area* (IFA) type in the box next to this key. BeamScheme will use this IFA definition in the calculation of parameters that use the IFA. This is a drop down selection field. Possible IFA Types are:

Proportional In Field Area

The simplest way of defining the In Field Area (IFA) is as a proportion of the field size as defined by the FWHM. The default is 80% of the FWHM. This corresponds to most definitions for standard fields such as 10x10 and 20x20, but may overestimate the in field area for small fields (< 5cm) and underestimate the in field area for large fields (> 30cm).

To set a proportional IFA under "Settings" select the "IFA Type" as "Proportional" and the "IFA Factor" as a proportion where 1.0 will include the entire field and 0 will include nothing.

 For offset fields the proportional IFA will also be offset.

Circular In Field Area

A circular In Field Area can be defined in 'Settings' with a fixed radius. Under "Settings" select the IFA type as "Circular" and enter the radius of the circle as the "IFA Factor". The position of the IFA depends on the "Centre definition" setting. If the Centre definition is "Peak" the IFA is symmetric around the peak of the distribution. If the Centre definition is "Detector" it is symmetric around the geometric centre of the detector.

 The radius of the IFA is fixed and independent of the actual field size.

Square In Field Area

A square In Field Area can be defined in 'Settings' with a fixed length. Under "Settings" select the IFA type as "Square" and enter the length of the sides of the square as the "IFA Factor". The position of the IFA depends on the "Centre definition" setting. If the Centre definition is "Peak" the IFA is symmetric around the peak of the distribution. If the Centre definition is "Detector" it is symmetric around the geometric centre of the detector.

 The length of the IFA is fixed and independent of the actual field size.

 The In Field Area affects the calculation of some parameters.

IFA Factor

Enter the *In Field Area* (IFA) Factor in the box next to this key. This defines the size of the IFA. If the IFA Type is "Proportional" the IFA Factor is a proportion between 0 and 1 where 0 includes nothing and 1 includes the entire field. This is a numeric value. If the IFA Type is "Circular" the IFA Factor is the absolute radius of the circle. If the IFA Type is square the IFA Factor is the length of the sides of the square.

 The size of the IFA is affected by the resolution for the "Circular" and "Square" IFA types.

Precision

Enter the number of decimal places the results should be displayed to next to the "Precision" key. This is a numeric field.

Centre Definition

This determines how BeamScheme locates the centre of the distribution for the calculation of results. "Peak" locates the centre between the left and right edges of the distribution. "Detector" locates the centre at the geometric centre of the detector. Where there is an even number of detectors or pixels and these straddle the centre the average of the two detectors or pixels is taken. This is a drop down selection field.

 Selection of the centre affects the calculation of parameters

Top Radius

The top radius determines the central area over which the *Top* parameter is calculated. Units are cm.

 The top radius can affect the calculation of the *peak slope*.

 If you change a setting remember to save it before exiting the settings module. Exiting without saving will discard the changed setting.

File, Exit

Exits the program

 No profiles, data or results are saved.

7.1.2 The View Menu

The file menu options are:

Invert

Inverts the grey scale values using the formula:

$$NZ = max - Z + min$$

Where *max* and *min* are the image maximum and minimum respectively. *Z* is the current pixel value and *NZ* is the new pixel value.

 If you don't want an image background level normalise the image first before inverting.

Show Parameters

Enables or disables an overlay on the image and profiles showing the parameters below:

- *In Field Area* (IFA)

Show profile points

Enables and disables the display of the profile points. Accessed from the right click context menu in the *Profile Panes* or from the *View Menu*.

7.1.3 The Export Menu

The export menu allows you to export the X and Y profiles in text form.

Export X Profile

The X profile can be exported to the clipboard or to a file. The profile is exported as a series of ordered pairs (position, value), with each pair on a new line. If the *Show Parameters* button  is enabled the *In Field Area* values will also be exported.

Export X profile to file

Opens a dialogue box to select the location and name of the text file to save the profile to. The profile is saved as a series of ordered pairs (position, value), with each pair on a new line. The file can be imported into a spreadsheet using the CSV format or opened in a text editor.

Export X profile to clipboard

Exports the profile to the clipboard in text format. The profile is saved as a series of ordered pairs (position, value), with each pair on a new line. The data can be pasted into a spreadsheet using the CSV format or opened in a text editor.

Export Y Profile

The Y profile can be exported to the clipboard or to a file. The profile is exported as a series of ordered pairs (position, value), with each pair on a new line.

Export Y profile to file

Opens a dialogue box to select the location and name of the text file to save the profile to. The profile is saved as a series of ordered pairs (position, value), with each pair on a new line. The file can be imported into a spreadsheet using the CSV format or opened in a text editor.

Export Y profile to clipboard

Exports the profile to the clipboard in text format. The profile is saved as a series of ordered pairs (position, value), with each pair on a new line. The data can be pasted into a spreadsheet using the CSV format or opened in a text editor.

7.1.4 The Protocol Menu

The protocol menu allows you to edit protocols and to save them:

Editing Protocols

Selecting "Protocol, Edit" in the menubar allows existing protocols to be edited and new protocols created. *The Results Pane* changes to the Edit Protocol window. The parameters are displayed in a grid with the left hand column giving the parameter display name and the right hand column giving the *parameter invocation* name. Click in the appropriate block to edit. You can also use <ctrl-c> and <ctrl-v> to copy and paste.

To create a parameter section heading leave the equation area blank. Parameter display names may be indented by putting spaces in front.

BeamScheme V1.00 no longer uses definable equations in the protocol list. Only parameter invocation names may be entered. Protocols from previous versions of BeamScheme are not compatible with version 1.00.

Functions available are:

- *Save protocol*
- *Add line*
- *Delete line*
- *Exit editing*

Save protocol

In *protocol editing* mode this menu command opens the save dialog to save the protocol. The "Save Protocol" button will also open the save dialog. It is highly recommended that you do not save over existing protocols. Instead give the changed protocol a unique name. Protocols saved in other directories will not be identified by the program. If you cancel the dialog you will return to the editing mode.

Do not save over a predefined protocol.

Do not save the protocol in any other directory.

Add line

Inserts a blank line into the parameter list. Click on the line above which you wish to add the new parameter. Click "Add line" . Edit the parameter name and equation.

Delete line

Deletes a line in the parameter list. Click on the line you wish to delete. Click "Delete line" .

Exit editing

Aborts editing leaving the parameter set unchanged.

Editing predefined protocols is not recommended. Rather save the protocol under a new name and then edit it.

7.1.5 The Window Menu

The Window menu allows you to maximise and/or restore the individual panes as follows:

- Image : Maximise the Image pane
- X Profile : Maximise the X Profile pane
- Y Profile : Maximise the Y profile pane

- Results : Maximise the Results pane
- Restore : Restore all panes to their default configuration

7.1.6 The Help Menu

Access this documentation. You may also view an "About" box with a description of BeamScheme, the Licence and a list of credits.

7.2 The Tool Bar

The tool bar provides some shortcuts to the *Menu Bar* functions as well as additional functions. Shortcuts to the Menu bar are:

For the *File Menu* the available buttons are:

-  *File, Open*
-  *Print PDF*
-  *Settings*
-  *Exit*

For the *View Menu* the available buttons are:

-  *Invert*
-  *Show Parameters*

Other functions available from the Tool Bar are:

-  *Normalise to CAX*
-  *Normalise to MAX*
-  *Centre Field*

"Normalise to CAX" and "Normalise to MAX" are radio buttons as only one normalisation mode can be in effect at any time.

7.2.1 Normalise to CAX

Clicking the "Normalise to CAX" button  normalises the image so that the central axis (CAX) value of the image is 100 and the minimum is zero using the formula:

$$NZ = \frac{(Z - min) * 100}{cax - min}$$

Where *cax* and *min* are the image central axis value and minimum respectively. *Z* is the current pixel value and *NZ* is the new pixel value. Clicking the button again will remove the normalisation.

7.2.2 Normalise to MAX

Clicking the "Normalise to MAX" button  normalises the image so that the maximum of the image is 100 and the minimum is zero using the formula:

$$NZ = \frac{(Z - min) * 100}{max - min}$$

Where *max* and *min* are the image maximum and minimum respectively. *Z* is the current pixel value and *NZ* is the new pixel value. Clicking the button again will remove the normalisation.

7.2.3 Centre Field

Shifts the image by the value of the X and Y field centres. The pixel value at the new index is determined using bi-linear interpolation from the four nearest neighbour pixels from the original image. Image wrap around is not used. Pixels on the leading edge of the image are lost and pixels on the trailing edge are duplicated. This function is intended for fine field adjustments only.

 This function changes the original image data.

7.3 The Profile Panes

The profile pane displays the pixel, dose, fluence or detector values under the corresponding profile on the image pane. The profile pane can be maximised in the application window by clicking the maximise button  . Individual profile values can be read by hovering the mouse cursor over the section of profile in question. The profile pane can be returned to its original state by clicking the minimise button  .

The profiles are altered by the Offset, Width and Angle spin boxes.

7.3.1 Offset

Moves the profile away from the centre of the detector or image. Values can be negative or positive. Values can be incremented or decremented via the up and down arrows in the spin box. Values can be entered manually via keyboard.

 Hint: You can change the offset quickly by clicking with the mouse on the image.

7.3.2 Width

Widens the profile symmetrically around the profile centre. Values can be increased or decreased by using the up and down arrows respectively in the spin box. Values can be entered by keyboard. Default value is 1. This means the value will always be odd and will increment by 2. Only positive values are allowed. If an even value is entered via the keyboard the profile width will be the next lowest odd value.

7.3.3 Angle

Increments or decrements the profile angle. Values can be increased or decreased by using the up and down arrows respectively in the spin box. Values can be entered by keyboard. The zero angle is in the middle of the image left hand size. The X profile starts at angle 0 and the Y profile at angle 90. The X profile can have values between -44 and 45 degrees. The Y profile can have values between 46 and 135 degrees.

Profiles can be exported from *The Export Menu* or by right clicking with the mouse and selecting from the context menu. Context menu option are:

7.3.4 Copy profile to clipboard

Exports the profile to the clipboard in text format. The profile is saved as a series of ordered pairs (position, value), with each pair on a new line. The data can be pasted into a spreadsheet using the CSV format or opened in a text editor.

7.3.5 Copy Profile to File

Opens a dialogue box to select the location and name of the text file to save the profile to. The profile is saved as a series of ordered pairs (position, value), with each pair on a new line. The file can be imported into a spreadsheet using the CSV format or opened in a text editor.

7.4 The Image Pane

The image pane displays the image, 2D array values, dose or fluence map. The image pane can be maximised in the application window by clicking the maximise button  . The image pane can be returned to its original state by clicking the minimise button  . You can quickly move the profiles to an appropriate point on the image by clicking on this point with the mouse.

The image can be windowed using the slider on the right hand side of the image. Windowing affects the displayed maximum and minimum values and can result in the profile being cut off. Windowing is useful if the image contains dead pixels or burn markers that are distorting the displayed image.

 Windowing affects the profile values.

7.5 The Results Pane

Results may be viewed in the Results pane. For a description of the various parameters calculated please see *Parameters*.

Parameters are grouped into *Protocols*. The drop down list box allows you to select a predefined protocol and display the results.

If some parameters are not visible the scroll bar on the right hand side of the pane can be used to scroll down or up to the results.

When the protocol edit mode is selected the Results pane changes to the *Edit Protocol* pane.

CHAPTER

EIGHT

SUPPORTED FILE FORMATS

Source	File Extension	Description
DICOM	*.dcm	Dicom CT or RT image files uncompressed
MapCheck	*.txt	MapCheck text files
PTW	*.mcc	PTW 729 array files only at this stage
IBA	*.opg	IBA Matrix and StarTrack opg files
Image	*.bmp	Windows bitmap
	.tif,.tiff	Tagged Image format files.
	.jpg,.jpeg	Joint Photographic Expert Group files
HIS	*.his	Raw unstructured data
XiO	None	Elekta XiO dose plane export text file
iPlan	None	BrainLab iPlan dose plane text file
RAW	*.txt	Structured text file

As the 2D array files have all been reverse engineered there is absolutely no guarantee of BeamScheme operating correctly on them. If you have a file that is causing BeamScheme to crash or is giving strange results please forward the file along with a description of the problem to alanphys@yenzakahle.co.za.

8.1 DICOM

Beamscheme will read most uncompressed DICOM image formats including CT and RI (electronic portal image device). Compressed DICOM files must first be uncompressed using a PACS such as Conquest.

8.2 MapCheck

Beamscheme will read SNC MapCheck I and II text files with or without dose calibration.

8.3 PTW

Beamscheme will read single plane acquisition PTW 729 array files. 1500 array is not supported at this time.

8.4 IBA

Beamscheme will read single plane acquisition IBA StarTrack and Matrixx array files. Multiple frames are summed and averaged

8.5 Image

Beamscheme will various 2D image formats such as Windows bitmap (BMP), Tagged Image Format files (TIFF) and Joint Photographic Expert Group (JPEG) files. For colour images only the red channel is imported. It is recommended that only monochromatic images are used for analysis. Colour images can be converted to monochrome using tools such as GIMP or ImageJ.

8.6 HIS

Very little information exists on the HIS file format. It seems to have been used by Perkin-Elmer to export X-ray images. Elekta provide it as an image export format. It appears to consist of a 100 byte header (50 16 bit integers) followed by 16 bit integers giving the image data in rows. Integers 9 and 10 appear to give the number of rows and columes respectively.

8.7 XiO

The Elekta XiO or Monaco dose plane export is a text file with a 16 line header followed by dose or fluence values. The file is not associated with any particular extension and is identified by the first line value. If dose values were exported in Gy these are converted into cGy on import.

 Care should be taken opening XiO files on Windows computers as the CR/LF combination can cause problems.

8.8 iPlan

The BrainLab iPlan dose plane export is a text file with a header followed by a separator line followed by one or more dose planes. The dose planes are prefixed by the orientation. The file is identified by the first 8 characters of the first line. If dose values were exported in Gy these are converted into cGy on import.

 The dose plane orientation is from left to right and may be mirrored from what is displayed on the iPlan depending on the patient orientation.

8.9 RAW

A RAW text file consists of sequential rows of values. Values are separated by spaces. The number of values in a row determines the X dimension. All rows must have the same number of values. The number of rows determines the Y dimension. No resolution or detector spacing is included in the file and the default resolution will be used.

CHAPTER

NINE

ALGORITHMS

There is an amazing amount of difference in the calculation of supposedly standard parameters between the different vendors. Not only do the definitions of parameters differ but factors such as whether values are interpolated or not or whether field centering is applied have a significant affect on the calculation of the parameters. It is important that the user understand how BeamScheme calculates the various parameters as this will be the first stop in an investigation into any discrepancy between values calculated by BeamScheme and values calculated by vendor supplied software.

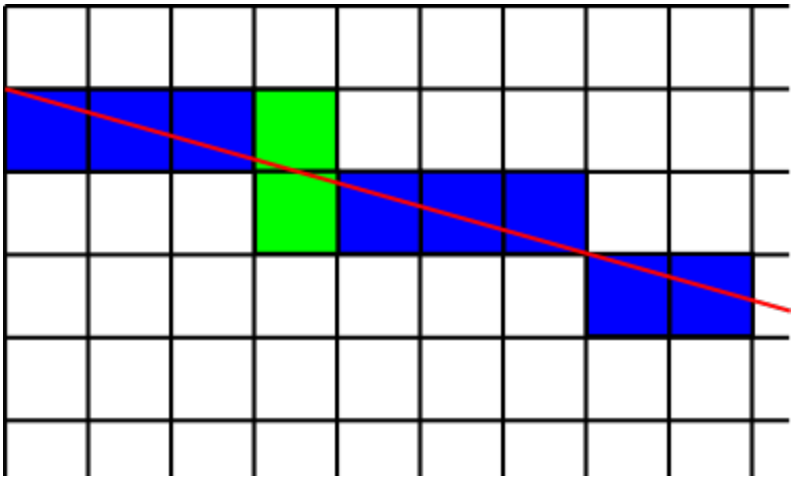
BeamScheme makes absolutely no assumptions about the data in contrast to some commercial products which require parameters such as the field size or SSD to be set. It does not perform any beam centering, and no SSD correction is made. No background correction is assumed. The profile or detector centre is defined as half the profile or detector height or width.

The profile is taken from the windowed data. This can have a serious impact on parameters such as field size and penumbra depending on how the window is chosen. The upshot is that defects in the image such as dead pixels or detectors can be reduced by appropriate windowing.

Calculation of the profiles and parameters are discussed in the following sections.

9.1 Diagonal/Skew Profiles

Diagonal or skew profiles introduce a number of inaccuracies, which is probably why none of the major vendors offer them. However, if these inaccuracies are understood then skew profiles may yield a lot of useful information. The problem is simple. Consider the following situation.



The squares represent pixels or detectors from a 2D dataset. The red line is an ideal skew profile. If the profile completely bisects a square or detector that value is added to the actual profile (blue square). The problem occurs where the ideal profile partially bisects a square or adjacent squares (green squares). There are a number of possible schemes to solve this such as selecting the nearest pixel or interpolating between adjacent pixels. BeamScheme calculates the

length of the profile and then increments an index sequentially along this length. The index is separated into its x and y components which are rounded off to give the pixel indexes along the profile. While the potential does exist for pixels to be skipped or selected twice this is a more robust method and less open to interpretation.

The situation is made worse by the introduction of wide profiles. A wide profile is a profile more than one pixel wide. BeamScheme uses a similar algorithm to that above in that for each index along the profile the normal to the profile is calculated and a second index is sequentially incremented and separated into its x and y components to give the correct pixel. The pixel values are summed. This is done symmetrically on either side of the ideal profile. Thus, the width of the profile will always be odd. This is because an even width will introduce asymmetry in the profile which can lead to further problems.

Skew wide profiles are clipped at the edge of the detector area. This means that the start and finish of wide profiles should be treated with caution and may not be a reflection of reality. The array/image edge will tend to be blurred depending on how skew the profile is.

A similar problem occurs where the profile crosses field edges. If the wide profile is not perpendicular to the field edge this will blur the field edge and increase the penumbra.

9.2 FFF algorithms

For FFF beams the standard interpolated or dose level parameters do not give good results. FFF fields are sharply peaked and the FWHM (50% dose level) is not a good indicator of the collimator field size. For FFF beams the inflection point (the point where the slope of the penumbra is greatest) of the penumbra has been proposed to represent the field edge.

While the maximum slope of the penumbra can be calculated directly by *differentiation* this can be quite inaccurate for low resolution detectors such as 2D arrays and the recommended method is to fit a sigmoid or Hill function to the penumbra data and determine the inflection point of the function.

This is described under *Inflection Point Parameters*

9.3 In Field Area

The In Field Area (IFA) refers to the flattened area of WFF beams. A number of varying definitions exist depending on the protocol. Practically these are very difficult to implement as they are usually only defined for certain profile angles and field sizes. An additional problem is that the IFA is often defined on the nominal field width in commercial systems which may be widely different from the actual field width.

BeamScheme has a sophisticated and extendible IFA algorithm. The IFA is implemented as a overlay or mask on the data. Data within the mask is processed. Data outside the mask is ignored. Current IFA types are

The field statistics, flatness and symmetry values are all calculated from the IFA. For any discrepancies between values calculated by BeamScheme and other software first examine the defined in field area.

 To view the IFA click or enable the *Show Parameters* button 

9.4 Normalisation

Normalisation is the scaling of data to defined limits, usually between 0 and 100. Normalisation in BeamScheme is visual and non-destructive, i.e. the underlying data is not changed. However, the normalisation affects the profile values and thus the parameters calculated from them. The normalisation is over the image and thus the profile maximum and minimum will not necessarily be 100 or 0 respectively. By default no normalisation is applied as it is assumed that the detector has been zeroed and calibrated.

Possible normalisation modes are:

 The normalisation mode may affect parameter calculations

9.5 Parameters

BeamScheme v1.00+ features a completely rewritten parameter calculation engine. Previously a linear search algorithm was used to calculate a series of base parameters from which the other parameters were derived. This was very efficient for single processors but encountered problems with non-linear parameters such as sigmoid fitting and could not be multithreaded for modern multiprocessor computers.

BeamScheme now calculates each parameter separately. This creates a very modular design and makes it easy to add new parameters. Where parameters calculations rely on other parameters the previous results are stored so parameters are only calculated once. Efficiencies are achieved by only calculating the parameters required by a *protocol*.

Calculation of 2D parameters is now possible. The same modular approach is used.

The calculation of parameters is affected by:

- *In Field Area*
- *Normalisation*
- *Centre Definition*

The following parameters are available for use in *protocols*. The protocol invocation name is the string by which the parameter is recognised in the protocol:

9.5.1 2D Parameters

BeamScheme can now calculate 2D parameters across the image. This is useful in disciplines such as Nuclear Medicine and Diagnostic Radiology as well as newer radiation beam metrics.

Available 2D beam parameters listed by their protocol invocation names are:

Image Statistics

Image statistics contain basic information about the image.

Available Image statistics are:

2D CAX Value

Returns the geometric centre value of the image. If the number of points in the image are even the average of the two or four centre values is returned. If *Normalise to CAX* is enabled it will return 100%.

Protocol invocation name: 2D CAX Value

 Normalisation affects this result.

2D Max Value

Returns the maximum value of the image. If *Normalise to MAX* is enabled it will return 100%

Protocol invocation name: 2D Max Value

 Normalisation affects this result.

2D Min Value

Returns the minimum value of the image. If *Normalisation* is enabled it will return 0.

Protocol invocation name: 2D Min Value

 Normalisation affects this result.

2D Ave Value

Returns the average value of the image.

Protocol invocation name: 2D Ave Value

 Normalisation affects this result.

2D Min IFA

Returns the minimum value of the *In Field Area* of the image.

Protocol invocation name: 2D Min IFA

2D CoM Value

Returns the Centre of Mass (CoM) of the image as (row, column).

Protocol invocation name: 2D CoM Value

2D CoM Scaled

Returns the Centre of Mass (CoM) of the image as (x, y).

Protocol invocation name: 2D CoM Scaled

2D X Res

Returns the X resolution of the image.

Protocol invocation name: 2D X Res

2D Y Res

Returns the Y resolution of the image.

Protocol invocation name: 2D Y Res

2D X Pixels

Returns the number of pixels/detectors of the image in the X direction.

Protocol invocation name: 2D X Pixels

2D Y Pixels

Returns the number of pixels/detectors of the image in the Y direction.

Protocol invocation name: 2D Y Pixels

2D X Size

Returns the size of the image in the X direction.

Protocol invocation name: 2D X Size

2D Y Size

Returns the size of the image in the Y direction.

Protocol invocation name: 2D Y Size

2D Flatness and Unifomity Parameters

These metrics express the degree of unflatness or nonuniformity in the image.

Available flatness and uniformity paremeters are:

2D Uniformity NCS-70

Returns the maximum difference between the max and CAX value and the min and CAX value of the IFA normalised to CAX according to NCS-70 eq 3-5.

$$maximum\left[max - cax, min - cax\right] \cdot \frac{100}{cax}$$

Where *max*, *min* and *cax* are the profile maximum, minimum and central axis values respectively.

Protocol invocation name: 2D Uniformity NCS-70

 The *max*, *min* and *cax* are affected by the set window levels.

2D Uniformity ICRU 72

Returns the maximum difference between the max and the min of the *In Field Area* normalised to the average of the IFA according to ICRU 72 eq 3.2.

$$(max - min) \cdot \frac{100}{ave}$$

Where *max* and *min* are the IFA maximum and minimum respectively and *ave* is the average value of the IFA.

Protocol invocation name: 2D Uniformity ICRU 72

 The *max* and *min* may be affected by the set window levels.

2D Uniformity Integral

Returns the maximum difference between the max and the min of the *In Field Area* normalised to the sum of the min and max according to IAEA pub 1394 section 2.3.3 eq 2.

$$\frac{(max - min)}{(max + min)} \cdot 100$$

Where *max* and *min* are the IFA maximum and minimum respectively and *ave* is the average value of the IFA.

Protocol invocation name: 2D Uniformity Integral

 The *max* and *min* may be affected by the set window levels. No smoothing or pixel summation is done.

2D Uniformity Differential

Returns the maximum difference between the max and the min of the *In Field Area* for any five contiguous pixels normalised to the sum of the min and max according to IAEA pub 1394 section 2.3.3 eq 3.

$$\frac{(max - min)}{(max + min)} \cdot 100$$

Where *max* and *min* are the IFA maximum and minimum respectively and *ave* is the average value of the IFA.

Protocol invocation name: 2D Uniformity Differential

 The *max* and *min* may be affected by the set window levels. No smoothing or pixel summation is done.

2D Symmetry Parameters

These metrics express the symmetry in an image. Available symmetry parameters are:

2D Symmetry NCS-70

Returns the maximum difference between the IFA and the IFA rotated 180 degrees, normalised to the average of the IFA according to NCS-70 eq 3-6.

$$maximum\left[abs(D(x,y) - D(-x,-y))\right] \cdot \frac{100}{ave}$$

Where D(x,y) is the pixel value at x,y and *ave* is the average value of the IFA.

Protocol invocation name: 2D Symmetry NCS-70

9.5.2 1D Parameters

BeamScheme has a comprehensive 1D parameter list and new parameters are added on a regular basis. The file param1dfuncs.pas should be consulted for the latest parameters

Available 1D beam parameters listed by their protocol invocation names are:

1D Profile Statistics

These parameters provide basic statistics on the profile.

Available statistics are:

1D CAX Value

Dose in the profile centre as defined by the image or 2D array.

Protocol invocation name: 1D CAX Value

 The dose value may be affected by the *Normalisation* or windowing.

1D Max Value

Maximum dose in the profile.

Protocol invocation name: 1D Max Value

 The dose value may be affected by the *Normalisation* or windowing.

1D Max Pos

Position of the maximum dose in the profile.

Protocol invocation name: 1D Max Pos

1D Min Value

Minimum dose in the profile.

Protocol invocation name: 1D Min Value

 The dose value may be affected by the *Normalisation* or windowing.

1D Min IFA

Minimum dose in the profile *in field area*.

Protocol invocation name: 1D Min IFA

 The dose value may be affected by the *Normalisation* or windowing.

1D Average IFA

Average dose in the profile *in field area*.

Protocol invocation name: 1D Min IFA

 The dose value may be affected by the *Normalisation* or windowing.

1D Interpolated Parameters

Linear interpolation is performed between nearest neighbour data points to determine the relevant parameter. These are the traditional beam parameters

Available interpolated parameters are:

1D Field Edge Left 50

Linear distance from the central axis as defined by the array or imaging modality to the point on the left side of the displayed profile where the dose profile drops below 50% of the central axis dose. If this point lies between two measured values the distance is linearly interpolated. This is the traditional field edge for flattened beams.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Field Edge Left 50

 Noisy data can lead to a reduced field edge value being reported.

1D Field Edge Right 50

Linear distance from the central axis as defined by the array or imaging modality to the point on the right side of the displayed profile where the dose profile drops below 50% of the central axis dose. If this point lies between two measured values the distance is linearly interpolated. This is the traditional field edge for flattened beams.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Field Edge Right 50

 Noisy data can lead to a reduced field edge value being reported.

1D Field Centre 50

The field centre (*FC*) is defined as the distance in cm from the centre of the detector to the centre of the field and is calculated as the half the difference between the distance from the profile centre to the *right* and *left* field edge:

$$FC = \frac{d(RE) + d(LE)}{2}$$

Where *d(RE)* and *d(LE)* are the linear distances from the profile centre to the right and left field edges respectively.

Protocol invocation name: 1D Field Centre 50

1D Field Size 50

The field size (*FS*) is defined as the distance from the *left field edge* to the *right field edge*:

$$FS = d(RE) - d(LE)$$

Where *d(RE)* and *d(LE)* are the linear distances from the profile centre to the right and left field edges respectively.

Protocol invocation name: 1D Field Size 50

 Noisy data can lead to a inaccurate field size being reported.

 The right and left field edges are affected by the set window levels.

1D Penumbra 8020 Left

The left 80%-20% penumbra is defined as the distance from the first point on the profile at 80% of the CAX value to the first point that reaches 20% of the CAX value on the left side of the profile:

$$Penumbra(80-20) = |d(P_{20\%}) - d(P_{80\%})|$$

$$P_{20\%} = CAX * 0.2$$

$$P_{80\%} = CAX * 0.8$$

Where d($P_{20\%}$) and d($P_{80\%}$) are the linear distances to the 20% and 80% profile values respectively as defined above.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Penumbra 8020 Left

 Profiles are no longer grounded automatically. This can lead to differences in results from previous version.

 Noisy data can lead to an inaccurate penumbra value being reported.

1D Penumbra 8020 Right

The right 80%-20% penumbra is defined as the distance from the first point on the profile at 80% of the CAX value to the first point that reaches 20% of the CAX value on the right side of the profile:

$$Penumbra(80-20) = |d(P_{20\%}) - d(P_{80\%})|$$

$$P_{20\%} = CAX * 0.2$$

$$P_{80\%} = CAX * 0.8$$

Where d($P_{20\%}$) and d($P_{80\%}$) are the linear distances to the 20% and 80% profile values respectively as defined above.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Penumbra 8020 Right

 Profiles are no longer grounded automatically. This can lead to differences in results from previous version.

 Noisy data can lead to an inaccurate penumbra value being reported.

1D Penumbra 9010 Left

The left 90%-10% penumbra is defined as the distance from the first point on the profile at 90% of the CAX value to the first point that reaches 10% of the CAX value on the left side of the profile:

$$Penumbra(90-10) = |d(P_{10\%}) - d(P_{90\%})|$$

$$P_{10\%} = CAX * 0.1$$

$$P_{90\%} = CAX * 0.9$$

Where d($P_{10\%}$) and d($P_{90\%}$) are the linear distances to the 10% and 90% profile values respectively as defined above.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Penumbra 9010 Left

 Profiles are no longer grounded automatically. This can lead to differences in results from previous version.

 Noisy data can lead to an inaccurate penumbra value being reported.

1D Penumbra 9010 Right

The right 90%-10% penumbra is defined as the distance from the first point on the profile at 90% of the CAX value to the first point that reaches 10% of the CAX value on the right side of the profile:

$$Penumbra(90-10) = |d(P_{10\%}) - d(P_{90\%})|$$

$$P_{10\%} = CAX * 0.1$$

$$P_{90\%} = CAX * 0.9$$

Where d($P_{10\%}$) and d($P_{90\%}$) are the linear distances to the 10% and 90% profile values respectively as defined above.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Penumbra 9010 Right

 Profiles are no longer grounded automatically. This can lead to differences in results from previous version.

 Noisy data can lead to an inaccurate penumbra value being reported.

1D Penumbra 9050 Left

The left 90%-50% penumbra is defined as the distance from the first point on the profile at 90% of the CAX value to the first point that reaches 50% of the CAX value on the left side of the profile:

$$Penumbra(90-50) = |d(P_{50\%}) - d(P_{90\%})|$$

$$P_{50\%} = CAX * 0.5$$

$$P_{90\%} = CAX * 0.8$$

Where d($P_{50\%}$) and d($P_{90\%}$) are the linear distances to the 50% and 90% profile values respectively as defined above.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Penumbra 9050 Left

 Profiles are no longer grounded automatically. This can lead to differences in results from previous version.

 Noisy data can lead to an inaccurate penumbra value being reported.

1D Penumbra 9050 Right

The right 90%-50% penumbra is defined as the distance from the first point on the profile at 90% of the CAX value to the first point that reaches 50% of the CAX value on the right side of the profile:

$$Penumbra(90-50) = |d(P_{50\%}) - d(P_{90\%})|$$

$$P_{50\%} = CAX * 0.5$$

$$P_{90\%} = CAX * 0.9$$

Where d($P_{50\%}$) and d($P_{90\%}$) are the linear distances to the 50% and 90% profile values respectively as defined above.

Since version 0.5 BeamScheme no longer does automatic grounding of the profile, i.e. reducing the minimum to zero. This means that if you want the grounded field size you must *explicitly* normalise or window the image.

Protocol invocation name: 1D Penumbra 9050 Right

 Profiles are no longer grounded automatically. This can lead to differences in results from previous version.

 Noisy data can lead to an inaccurate penumbra value being reported.

1D Differential Parameters

The first derivative is calculated by numerical differentiation to determine the positive and negative maximum slope values. The differential parameters are calculated relative to the maximum slope. Differentiation is sensitive to noise and the method is not accurate for low resolution detectors such as 2D arrays.

Available differential parameters are:

1D Left Diff

Linear distance from the central axis as defined by the array or imaging modality to the point on the left side of the displayed profile where the profile slope is maximum. Also known as the point of maximum gradient. The maximum slope is found by calculating the first derivative and finding the maximum value. No interpolation is performed so this method is inaccurate for low resolution detectors such as 2D arrays.

Protocol invocation name: 1D Left Diff

 Noisy data can lead to a reduced field edge value being reported.

1D Right Diff

Linear distance from the central axis as defined by the array or imaging modality to the point on the right side of the displayed profile where the profile slope is minimum. Also known as the point of maximum gradient. The minimum slope is found by calculating the first derivative and finding the minimum value. No interpolation is performed so this method is inaccurate for low resolution detectors such as 2D arrays.

Protocol invocation name: 1D Right Diff

 Noisy data can lead to a reduced field edge value being reported.

1D Field Centre Diff

The field centre (*FC*) is defined as the distance in cm from the centre of the detector to the centre of the field and is calculated as the half the difference between the distance from the profile centre to the *right* and *left* differential field edges or maximum slopes:

$$FC = \frac{d(RE) + d(LE)}{2}$$

Where *d(RE)* and *d(LE)* are the linear distances from the profile centre to the right and left differential field edges respectively.

Protocol invocation name: 1D Field Centre Diff

1D Field Size Diff

The differential field size (*FS*) is defined as the distance from the differential *left field edge* to the *right field edge*:

$$FS = d(RE) - d(LE)$$

Where *d(RE)* and *d(LE)* are the linear distances from the profile centre to the differential right and left field edges respectively.

Protocol invocation name: 1D Field Size Diff

 Noisy data can lead to an inaccurate field size being reported.

 The right and left field edges are affected by the set window levels.

1D Dose 20% Diff Left

Returns the dose at 20% of the *maximum gradient* field size on the profile left.

Protocol invocation name: 1D Dose 20% Diff Left

1D Dose 20% Diff Right

Returns the dose at 20% of the *maximum gradient* field size on the profile right

Protocol invocation name: 1D Dose 20% Diff Right

1D Dose 50% Diff Left

Returns the dose at 50% of the *maximum gradient* field size on the profile left.

Protocol invocation name: 1D Dose 50% Diff Left

1D Dose 50% Diff Right

Returns the dose at 50% of the *maximum gradient* field size on the profile right.

Protocol invocation name: 1D Dose 50% Diff Right

1D Dose 60% Diff Left

Returns the dose at 60% of the *maximum gradient* field size on the profile left.

Protocol invocation name: 1D Dose 60% Diff Left

1D Dose 60% Diff Right

Returns the dose at 60% of the *maximum gradient* field size on the profile right.

Protocol invocation name: 1D Dose 60% Diff Right

1D Dose 80% Diff Left

Returns the dose at 80% of the *maximum gradient* field size on the profile left.

Protocol invocation name: 1D Dose 80% Diff Left

1D Dose 80% Diff Right

Returns the dose at 80% of the *maximum gradient* field size on the profile right.

Protocol invocation name: 1D Dose 80% Diff Right

Inflection Point Parameters

For FFF beams the standard interpolated or dose level parameters do not give good results. The field edge of FFF beams is defined at the inflection point of the penumbra. For low resolution measuring devices like 2D arrays this can be quite inaccurate. Therefore a sigmoid model is fitted to the penumbra using a Hill function:

$$f(x) = A + \frac{B - A}{1 + \left(\frac{C}{x}\right)^D}$$

where:

- A: sigmoid low level
- B: sigmoid high level
- C: approximate inflection point
- D: slope of the sigmoid

The inflection point is determined from:

$$x = C \cdot \left(\frac{D-1}{D+1}\right)^{\frac{1}{D}}$$

Once the regression parameters have been determined the inverse Hill function can be used to determine other parameters around the inflection point:

$$x = C \cdot \left(\frac{f(x)-A}{B-f(x)}\right)^{\frac{1}{D}}$$

The algorithm selects 20 points around the maximum slope in the penumbra. For high resolution detectors these points may be within the penumbra, but for low resolution detectors there may not be enough points to fulfil this requirement and the selected points will extend from the start (or end) of the profile to the middle.

 If the penumbra is not well formed the non-linear regression will fail and the results returned will be 0.

1D Left Infl

This is the inflection point on the left side of the profile as determined by non-linear regression on a Hill function. See *Inflection Point Parameters* for the calculation of the inflection point.

Protocol invocation name: 1D Left Infl

1D Right Infl

This is the inflection point on the right side of the profile as determined by non-linear regression on a Hill function: See *Inflection Point Parameters* for the calculation of the inflection point.

Protocol invocation name: 1D Right Infl

1D Field Centre Infl

The field centre (*FC*) is defined as the distance in cm from the centre of the detector to the centre of the field and is calculated as the half the difference between the distance from the profile centre to the *right* and *left* inflection points:

$$FC = \frac{d(RE) + d(LE)}{2}$$

Where *d(RE)* and *d(LE)* are the linear distances from the profile centre to the right and left inflection points respectively.

Protocol invocation name: 1D Field Centre Infl

1D Field Size Infl

The differential field size (*FS*) is defined as the distance from the *left inflection point* to the *right inflection point*:

$$FS = d(RE) - d(LE)$$

Where *d(RE)* and *d(LE)* are the linear distances from the profile centre to the right and left inflection points respectively.

Protocol invocation name: 1D Field Size Infl

 Noisy data can lead to an inaccurate field size being reported.

 The right and left inflection points are affected by the set window levels.

1D Penumbra Infl Left

The tradional parameters for defining the penumbra do not work for FFF beams. The similar 80%-20% penumbra based on the inflection point is calculated as the distance between 1.6 times the inflection point value to 0.4 times the inflection point value for the left penumbra.

$$PenWidthINFL = |d(P_{0.4}) - d(P_{1.6})|$$

$$P_{0.4} = Y_{infl} \cdot 0.4$$

$$P_{1.6} = Y_{infl} \cdot 1.6$$

Where d(P $_{0.4}$) and d(P $_{1.6}$)) are the linear distances to 0.4 and 1.6 times the inflection point value respectively as defined above.

Protocol invocation name: 1D Penumbra Infl Left

 The profile must be centered on the origin as defined by the array or imaging modality for best results.

1D Penumbra Infl Right

The tradional parameters for defining the penumbra do not work for FFF beams. The similar 80%-20% penumbra based on the inflection point is calculated as the distance between 1.6 times the inflection point value to 0.4 times the inflection point value for the right penumbra.

$$PenWidthINFL = |d(P_{0.4}) - d(P_{1.6})|$$

$$P_{0.4} = Y_{infl} \cdot 0.4$$

$$P_{1.6} = Y_{infl} \cdot 1.6$$

Where d(P $_{0.4}$) and d(P $_{1.6}$)) are the linear distances to 0.4 and 1.6 times the inflection point value respectively as defined above.

Protocol invocation name: 1D Penumbra Infl Right

 The profile must be centered on the origin as defined by the array or imaging modality for best results.

1D Top Infl

The top or peak position of a FFF field is estimated by fitting a parabola (2nd order polynomial):

$$y = ax^2 + bx + c$$

over the central *Top Radius* of the profile peak. The peak position is determined where the tangent to the parabola is zero.

$$x = -\frac{b}{2a}$$

Protocol invocation name: 1D Top Infl

1D Dose 20% Infl Left

Returns the dose at 20% of the *inflection point* field size on the profile left.

Protocol invocation name: 1D Dose 20% Infl Left

1D Dose 20% Infl Right

Returns the dose at 20% of the *inflection point* field size on the profile right

Protocol invocation name: 1D Dose 20% Infl Right

1D Dose 50% Infl Left

Returns the dose at 50% of the *inflection point* field size on the profile left.

Protocol invocation name: 1D Dose 50% Infl Left

1D Dose 50% Infl Right

Returns the dose at 50% of the *inflection point* field size on the profile right.

Protocol invocation name: 1D Dose 50% Infl Right

1D Dose 60% Infl Left

Returns the dose at 60% of the *inflection point* field size on the profile left.

Protocol invocation name: 1D Dose 60% Infl Left

1D Dose 60% Infl Right

Returns the dose at 60% of the *inflection point* field size on the profile right.

Protocol invocation name: 1D Dose 60% Infl Right

1D Dose 80% Infl Left

Returns the dose at 80% of the *inflection point* field size on the profile left.

Protocol invocation name: 1D Dose 80% Infl Left

1D Dose 80% Infl Right

Returns the dose at 80% of the *inflection point* field size on the profile right.

Protocol invocation name: 1D Dose 80% Infl Right

1D Flatness and Uniformity

These metrics express the degree of unflatness or nonuniformity in the profile.

Available flatness and uniformity parameters are:

1D Flatness Ave

The average value dose parameter is the normalised average between the maximum and minimum profile values taken over the *in field area*:

$$\frac{100}{cax} \cdot \frac{max + min}{2}$$

Where *max* and *min* are the profile maximum and minimum respectively and *cax* is the profile centre value.

Protocol invocation name: 1D Flatness Ave

 The *max*, *min* and *cax* may be affected by *normalisation* or windowing.

1D Flatness Diff

The flatness dose difference parameter is the normalised difference between the maximum and minimum profile values taken over the *in field area*:

$$100 \cdot \frac{max - min}{max + min}$$

Where *max* and *min* are the profile maximum and minimum respectively.

Protocol invocation name: 1D Flatness Diff

 The *max* and *min* may be affected by *normalisation* or windowing.

1D Flatness Ratio

Dose ratio flatness is the ratio of the maximum profile value to the minimum profile value expressed as a percent taken over the *in field area*:

$$100 \cdot \frac{max}{min}$$

Where *max* and *min* are the profile maximum and minimum respectively.

Protocol invocation name: 1D Flatness Ratio

 The *max* and *min* may be affected by *normalisation* or windowing.

1D Flatness CAX

This is the average between the maximum and minimum profile values taken over the *in field area* normalised to CAX:

$$\frac{100}{cax} \cdot \frac{max - min}{2}$$

Where *max* and *min* are the profile maximum and minimum respectively and *cax* is the profile centre value.

Protocol invocation name: 1D Flatness CAX

 The *max*, *min* and *cax* may be affected by *normalisation* or windowing.

1D Uniformity ICRU

This is the normalised average between the maximum and minimum profile values taken over the *in field area* (IFA) normalised to the average of the IFA as defined by ICRU 72 eq 3.2:

$$100 \cdot \frac{max - min}{ave}$$

Where *max* and *min* are the profile maximum and minimum respectively and *ave* is the average of the profile values in the IFA.

Protocol invocation name: 1D Uniformity ICRU

 The *max*, *min* and *ave* may be affected by *normalisation* or windowing.

1D Uniformity NCS

This is the maximum variation in the ratio of the absorbed dose at any point in the flattened area to that of the central axis expressed as a percentage difference between the lowest and highest value of this ratio according to NCS 70 eq 3-5.

$$\frac{100}{cax} \cdot maximum\left[|max - cax|, |min - cax|\right]$$

Where *max*, *min* and *cax* are the profile maximum, minimum and central axis values respectively.

Protocol invocation name: 1D Uniformity NCS

 The *max*, *min* and *cax* are affected by *normalisation* or windowing.

1D Flatness 9050

Returns the ratio of the length of the 90% isodose over the length of the 50% isodose, with the dose normalized at 100% at beam center.:

$$100 \cdot \frac{FW_{90\%}}{FW_{50\%}}$$

where ($FW_{90\%}$) and ($FW_{50\%}$) are the distances between the 90% and 50% isodose lines respectively.

Protocol invocation name: 1D Flatness 9050

1D Peak Slope Left

The slope as determined by linear regression of the left hand side of the profile from the radius of the *Top* area to the outer edge of the *In Field Area*.

Protocol invocation name: 1D Peak Slope Left

 The peak slope may be affected by the selection of the *In Field Area* and the *Top Radius*.

1D Peak Slope Right

The slope as determined by linear regression of the right hand side of the profile from the radius of the *Top* area to the outer edge of the *In Field Area*.

Protocol invocation name: 1D Peak Slope Right

 The peak slope may be affected by the selection of the *In Field Area* and the *Top Radius*.

1D Peak Slope Ratio

The ratio of the *left peak slope* to the *right peak slope*

$$100 \cdot \frac{left}{right}$$

Protocol invocation name: 1D Peak Slope Ratio

 The peak slope ratio may be affected by the selection of the *In Field Area*.

1D Symmetry

These metrics express the degree of asymmetry in the left and right sides of the profile.

Available symmetry parameters are:

1D Symmetry Ratio

The maximum dose ratio symmetry (also called the point difference quotient) is the maximum ratio between the left and right profile values at the same distance from the profile or detector centre taken over the *in field area*:

$$100 \cdot maximum \left[\frac{P(dL)}{P(dR)}, \frac{P(dR)}{P(dL)} \right]$$

for *dR* = *-dL* from the origin as defined by the array or imaging modality to the end of the in field area.

Protocol invocation name: 1D Symmetry Ratio

 The ratio symmetry is affected by the field or detector centre. If the field is slightly offset you can use the Centre field tool  to correct any offset.

1D Symmetry Diff

The point difference (also called maximum variation) is the maximum absolute difference between the left and right profile values at the same distance from the profile or detector centre taken over the *in field area*:

$$100 \cdot \frac{|P(dL) - P(dR)|}{cax}$$

for *dR* = -*dL* from 0 to the the edge of the *in field area*.

Protocol invocation name: 1D Symmetry Diff

The point difference symmetry may be affected by the field or detector centre. If the field is slightly offset you can use the Centre field tool  to correct any offset.

1D Symmetry Ave

The point difference (also called maximum variation) is the maximum absolute difference between the left and right profile values at the same distance from the profile or detector centre taken over the *in field area* (IFA) normalised to the average of the IFA:

$$100 \cdot \frac{|P(dL) - P(dR)|}{ave}$$

for *dR* = -*dL* from 0 to the the edge of the *in field area*.

Protocol invocation name: 1D Symmetry Ave

The point difference symmetry may be affected by the field or detector centre. If the field is slightly offset you can use the Centre field tool  to correct any offset.

1D Symmetry Area

The area symmetry is the normalised difference between the right and left areas under the profile up to the *right* and *left* field edges:

$$100 \cdot \frac{RA - LA}{RA + LA}$$

Where *RA* and *LA* are the areas under the profile from the field centre to the *right* and *left* field edge respectively.

Protocol invocation name: 1D Symmetry Area

In contrast with other symmetry calculations the area symmetry is not affected by the detector centre.

Some commercial programs use a mulitplicative factor of 200.

1D Deviation

Deviation parameters generally apply only to WFF beams and express the amount of deviation from the CAX value over the *in field area*.

Available deviation parameters are:

1D Deviation Ratio

MAX/CAX deviation is the ratio of the CAX profile value to the maximum profile value expressed as a percent taken over the *in field area*:

$$100 \cdot \frac{max}{cax}$$

Where *max* and *cax* are the profile maximum and central axis values respectively.

Protocol invocation name: 1D Deviation Ratio

 The *max* and *cax* are affected by *normalisation* or windowing.

1D Deviation CAX

This is the maximum variation in the absorbed dose over the *in field area* normalised to the central axis.

$$100 \cdot \frac{max - min}{cax}$$

Where *max*, *min* and *cax* are the profile maximum, minimum and central axis values respectively.

Protocol invocation name: 1D Deviation CAX

 The *max*, *min* and *cax* are affected by *normalisation* or windowing.

CHAPTER

TEN

PROTOCOLS

Protocols are groups of *parameters*. From version 0.5 BeamScheme supports definable protocol and parameter sets. A library of standard protocols is supplied. These may be edited and renamed or new protocols defined.

10.1 Selecting a protocol

Use the drop down list in *The Results Pane* to select the desired protocol. The parameters and results are displayed in the grid below.

10.2 Defined protocols

BeamScheme has a library of standard protocol sets. Do not alter these protocols. Instead copy them and create your own sets if you wish to make changes. There is considerable variation in the implementation of the protocols by different vendors. BeamScheme attempts to provide the consensus implementation, but there is no guarantee that this will match a particular vendor.

The available predefined protocols are:

10.2.1 Default

The "Default" protocol is automatically loaded when BeamScheme starts. On first install this will be a copy of the *All* protocol. To make another protocol default perform the following steps:

1. Select the protocol you want using the list box in the results window.
2. Enter editing mode using the "Protocol, Edit" menu entry.
3. Select the name "Default" in the list box in the results window.
4. Click the save button or select the "Protocol, Save" menu entry

Make sure you do not accidentally save over another protocol.

10.2.2 All

The predefined protocol All contains every parameter implemented in BeamScheme. As this is a very long list users are encouraged to create their own parameter lists from this protocol by deleting what is not needed. This protocol should not be used regularly, but is included here for reference. The defined parameters are:

- **2D Image Stats**
  - *CAX value*
  - *Max value*

        - *Min value*
        - *Average*
        - *Min IFA*
        - *CoM (rowcol)*
        - *CoM (XY)*
        - **Resolution**
            - *X*
            - *Y*
        - **Detectors/Pixels**
            - *X*
            - *Y*
        - **Size**
            - *X*
            - *Y*
- **2D Uniformity**
    - *Uniformity NCS*
    - *Uniformity ICRU*
- **2D Symmetry**
    - *Symmetry*
- **Profile stats**
    - *CAX value*
    - *Max value*
    - *Max pos*
    - *Min value*
    - *Min IFA*
    - *Average IFA*
- **Interpolated params**
    - *Left edge*
    - *Right edge*
    - *Centre*
    - *Size*
    - **Penumbra**
        - **80-20%**
            - *Left*
            - *Right*
        - **90-10%**

            - *Left*
            - *Right*
        * **90-50%**
            - *Left*
            - *Right*

- **Differential params**
    - *Left edge*
    - *Right edge*
    - *Centre*
    - *Size*
    - *Dose 20% left*
    - *Dose 20% right*
    - *Dose 50% left*
    - *Dose 50% right*
    - *Dose 60% left*
    - *Dose 60% right*
    - *Dose 80% left*
    - *Dose 80% right*
- **Inflection params**
    - *Left edge*
    - *Right edge*
    - *Centre*
    - *Size*
    - **Penumbra**
        * *Left*
        * *Right*
    - *Dose 20% left*
    - *Dose 20% right*
    - *Dose 50% left*
    - *Dose 50% right*
    - *Dose 60% left*
    - *Dose 60% right*
    - *Dose 80% left*
    - *Dose 80% right*
- **Flatness**
    - *Average*

  - *Difference*
  - *Ratio*
  - *CAX*
  - *ICRU 72*
  - *NCS-70*
  - *90/50*
  - *Peak Slope Left*
  - *Peak Slope Right*
  - *Peak Slope Ratio*
- **Symmetry**
  - *Ratio*
  - *Difference*
  - *NCS-70*
  - *Area*
- **Deviation**
  - *Ratio*
  - *MAX/CAX*

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.3 AFFSAPS-JORF

Photon Profile Parameters

The defined photon parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*
- *Mean Value*
- *MAX/CAX*

Electron Profile Parameters

The defined electron parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*

- *Flatness L90/L50*
- *Maximum Variation*

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.4 DIN

Photon Profile Parameters

The defined photon parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*
- *Dose Ratio*

Electron Profile Parameters

The electron profile parameters are the same as the photon profile parameters.

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.5 IEC 60976

Photon Profile Parameters

The defined photon parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*
- *Mean Value*
- *Maximum Variation*

Electron Profile Parameters

The defined electron parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*
- *Flatness L90/L50*

- *Maximum Variation*

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.6 Elekta

Photon Profile Parameters

The defined photon parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*
- *Mean Value*
- *Maximum Variation*

Electron Profile Parameters

The defined electron parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Maximum Dose Ratio*
- *Flatness L90/L50*
- *Maximum Variation*

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.7 Siemens

Photon Profile Parameters

The defined photon parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Area Symmetry*
- *Dose Difference*
- *MAX/CAX*

Electron Profile Parameters

The electron parameters are the same as the photon parameters

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.8 Varian

Photon Profile Parameters

The defined photon parameters are:

- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Right*
- *Point Difference*
- *Dose Difference*

Electron Profile Parameters

The electron parameters are the same as the photon parameters

Flattened field

The flattend field is defined by the *In Field Area*.

10.2.9 FFF-LoRes

This protocol is recommended for low resolution devices such as 2D arrays.

Photon Profile Parameters

FFF parameters only apply to photon beams:

- *Field Edge Left*
- *Field Edge Right*
- *Field Centre*
- *Field Size*
- *Penumbra 80%-20% Left*
- *Penumbra 80%-20% Left*
- *Top position*
- *Area Symmetry*
- *Peak Slope Left*
- *Peak Slope Right*
- *Peak Slope Ratio*

Flattened field

FFF beams use the concept of *In Field Area* which is primarily used for the *Area Symmetry* and *Peak Slope* calculations.

10.2.10 FFF-HiRes

This protocol is recommended for high resolution devices such as EPID images.

Photon Profile Parameters

FFF parameters only apply to photon beams:

- *Field Edge Left*
- *Field Edge Right*
- *Field Centre*
- *Field Size*
- *Top position*
- *Area Symmetry*
- *Peak Slope Left*
- *Peak Slope Right*
- *Peak Slope Ratio*

Flattened field

FFF beams use the concept of *In Field Area* which is primarily used for the *Area Symmetry* and *Peak Slope* calculations.

 The protocol definition files from previous version of BeamScheme are not compatible with version 1.00 and will give errors.

CHAPTER

ELEVEN

ERRORS AND TROUBLE SHOOTING

BeamScheme has sophisticated error checking and detection. Error messages and warnings are displayed in the Status Bar. During the operation of the program you may encounter a variety of warning and error messages. There are three types of messages.

1) Informational: These give details of the program's working. These messages have a green background. No action is required they are for information only. For example the startup message "BeamScheme initialised correctly'.
2) Actional: The program is requiring some kind of response from you. These messages have a yellow background. For example "Click Point A"
3) Error: The program has detected an error condition. These messages are displayed with a red background. Some errors will not allow you to continue until the error has been corrected. In this case the area or areas with the error will be highlighted in red.

Some common error messages and their causes are discussed below:

11.1 File Import Errors

If BeamScheme does not recognise a file or encounters a problem during the import of the file an error will be thrown. BeamScheme firstly examines the file extension to determine the type of file and then the file header. If BeamScheme can not read the file or find the data in the body of the file that it is looking for it will throw one of the following errors.

11.1.1 Text file not recognised!

BeamScheme does not recognise this type of text file. Please check that the file is in the list of *Supported File Formats*. Also check that the file does not contain compression or encryption.

11.1.2 Not a recognised MapCheck text file!

BeamScheme identified this as a Sun Nuclear *MapCheck* text file, but encountered an error opening it. Try opening the file in the Sun Nuclear software to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.3 Not a recognised IBA opg file!

BeamScheme identified this as a *IBA* MyQA text file, but encountered an error opening it. Try opening the file in the IBA MyQA software to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.4 Not a recognised PTW mcc file!

BeamScheme identified this as a *PTW* Mephysto text file, but encountered an error opening it. Try opening the file in the PTW Mephysto software to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.5 Not a recognised XIO text file!

BeamScheme identified this as an Elekta *XiO* or Monaco text file, but encountered an error opening it. Try opening the file in a text editor to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.6 Not a recognised BrainLab iPlan file!

BeamScheme identified this as a BrainLab *iPlan* dose plane file but encountered an error opening it. Try opening the file in a text editor to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.7 Could not read RAW text file!

BeamScheme identified this as an *RAW* file but encountered an error opening it. Try opening the file in text editor to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.8 Not a recognised HIS file!

BeamScheme identified this as an *HIS* file but encountered an error opening it. Try opening the file in another image editor to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.9 Not a recognised Windows bitmap file!

This error applies to raster image files such as Windows Bitmap (BMP), Tagged Image Format (TIF) and Joint Photographic Expert Group (JPEG) files. BeamScheme identified this as an *Image* file but encountered an error opening it. Try opening the file in another image editor to check that the file is valid. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.10 This software can not read compressed or 24-bit color files

The DICOM image is compressed or contains a colour image. Decompress the image using a PACS system such as CONQUEST or convert the colour image to monochrome using an editor such as the GIMP.

11.1.11 Unable to load DICOM header segment. Is this really a DICOM compliant file?

The file extension is ".dcm" but BeamScheme cannot find valid DICOM header tags. Try and open the file in another DICOM reader to determine if it is a valid DICOM file. If you feel that BeamScheme should be able to open this file please raise an issue on https://github.com/alanphys/BeamSchemeV1/issues with a description of the problem and upload a copy of the file.

11.1.12 This file does not have enough data for the image size

The DICOM file size is less than the image dimensions multiplied by the pixel depth. Check that the file is not corrupted or compressed.

11.1.13 DICOM file error, no data found!

The file contained a valid DICOM header but no data.Try and open it with another DICOM reader. If this works and you feel BeamScheme should be able to read this file please contact *Technical Assistance*.

11.1.14 DICOM file error, corrupt file

A fatal error occurred while trying to read the file. Try and open it with another DICOM reader. If this works and you feel BeamScheme should be able to read this file please contact *Technical Assistance*.

11.2 Settings Errors

Invalid values in the settings may cause errors. Some of the errors are:

11.2.1 Error, could not set key

One of the values in the setting key, value pairs is invalid. Check that there are no characters in the number fields.

11.3 Protocol Errors

Errors associated with the *Protocols* are:

11.3.1 Could not save protocol

An error occured while saving a protocol. Check that you have write access to the directory in which the protocols are stored and that you are not trying to overwrite a predefined protocol.

11.3.2 No protocol definition files found. Please create a file.

BeamScheme on startup looks for protocol definition files in the default program data directory. Under Window this is "C:Program Data" and under Linux it is "~/.config/BeamScheme". If no files are found there it will look in the directory where the executable is. If you see this error you probably copied the BeamScheme executable over directly. The recommended method for installation is to use the *installer*. You can also either copy over some protocol definition files or *create* your own.

11.3.3 Could not load protocol file

An error occurred while trying to read the protocol definition file. Try viewing the file in a text editor or spreadsheet to verify that it is all right. Make sure you have read permissions on the directory where the protocol definition files are stored.

11.3.4 No file open!

You have tried to perform an operation such as *normalisation* or *inversion* without an open image. Open an image or 2D array file and repeat the operation.

11.3.5 Could not evaluate parameter

An error has occurred in the parameter calculation engine. This is most likely due to a malformed profile. Check that the image does not have burn markers, dead pixels or other artifacts. BeamScheme expects a single peak centered in the detector.

11.3.6 Illegal parameter name

The parameter name does not begin with the correct prefix. This is usually caused by trying to load a parameter definition file from a previous version of BeamScheme.

11.3.7 No edge

This message appears in *The Results Pane* and occurs when the parameter calculation engine cannot detect the edge of the profile. It is usually caused by a cutoff profile, that is the measured linac field size is too large for the detector and the profile does not tend to zero at the ends. Remeasure the profile using a smaller field size, or use a larger detector array.

11.3.8 Parameter not found

This message appears in *The Results Pane*. The parameter invocation name in the protocol does not correspond with the internal list of *parameters*. This is usually encountered setting up your own protocols manually. Check the spelling of the parameter invocation name.

Other errors may from time to time be generated by the operating system or math subsystem. These will generally be in the form of a dialogue box requiring acknowledgement. Please refer to the appropriate documentation and/or contact *Technical Assistance*.

CHAPTER

TWELVE

TECHNICAL ASSISTANCE

There are, of course, no bugs in the software. However, it may happen that the software does not behave in a manner you expect or generates results that you think are wrong. If so, we would like to know about it. Likewise, if you feel BeamScheme should be doing something that it isn't, please tell us at:

https://github.com/alanphys/BeamSchemeV1/issues

or contact the authors on alanphys@yenzakahle.co.za.

CHAPTER

THIRTEEN

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