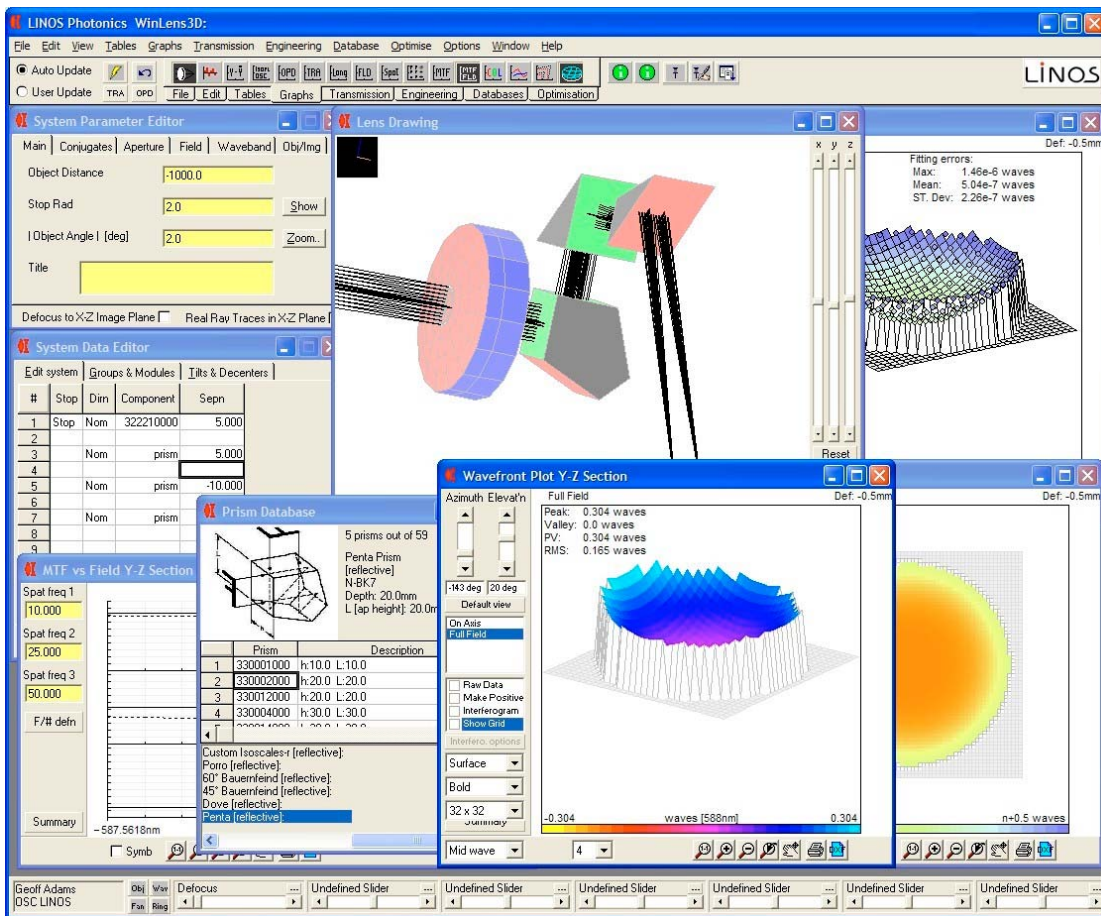


# WinLens 3D

## Optical Design Software

## Tilts & Decenters



A Product of

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## Summary

WinLens 3D is a very significant enhancement to WinLens Plus. For the first time, WinLens can model systems with one or even no planes of symmetry.

Individual surfaces can be tilted and decentered [T&D] in any/all of the three axes. Mirror surfaces, if defined as 'fold', will rotate the mechanical reference axis by twice the tilt angle - whether simple or compound. The tilt center can be offset along the local reference axis direction.

Entire components and groups of components can also be tilted and decentered. By default, component/group T&D does not change the global location of 'following' elements. This means that is now very easy to set-up and model scanners and their movements, and to assess the impact of manufacturing errors.

Co-ordinate breaks can be used to change the direction of the reference axis in cases where fold mirrors are not used.

A new 'prism' object has been added. The prism can be one of a whole range of types. Prisms can be quite complex to model, so a wizard collects key parameters for the chosen type, and then creates the necessary surfaces.

LINOS prisms are displayed in a new prism database window, and can be used in full designs - referenced by their part number.

Adjusters can now be set-up to alter T&D on surface, component, group or module.

To assess the new systems we have also made a number of enhancements to the various analysis tools:

- the lens drawing now shows 3D systems in wire-frame or solid model - with real-time rotation controlled via sliders.
- graphs make no assumptions about symmetry
- there is a new global co-ordinate table
- there is a new 3D wavefront plot - with real time rotation and many useful display options

In this manual we aim to provide a coherent guide to working with T&D in WinLens. This can be conceptually difficult, especially when dealing with the changes in reference axis and the impact on component location/orientation so it really is a good idea to Read the Manual.

The manual includes a number of commented examples which will help show how to set-up various systems.

Finally, the new and the enhanced analysis tools will be discussed at the end of the manual.

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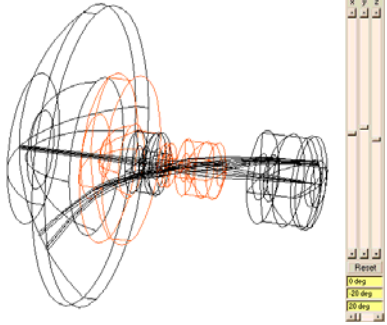
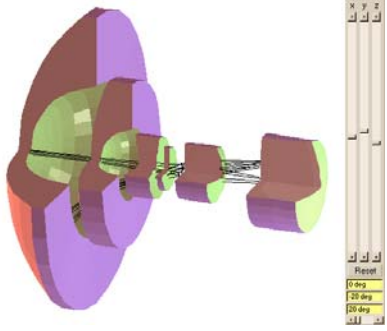
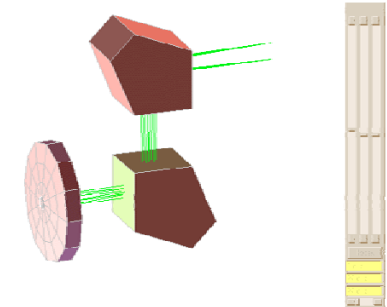
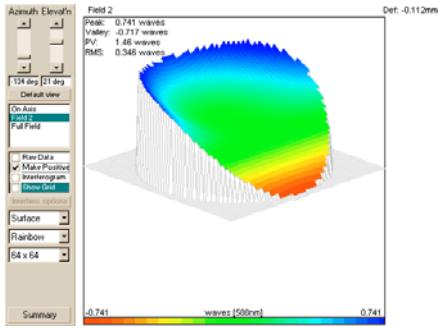
18<sup>th</sup> May 2009

Author: Dr Geoff Adams [Optical Software]

## 1. Introduction

Tilts and decenters [T & Ds] are new in WinLens [2009]. Until T & Ds were added, WinLens could only model systems with rotation symmetry or two orthogonal planes of symmetry [e.g. crossed cylinders].

Before diving into the technical side, lets see some of the new features and tools.

	<p>Wire-frame drawings of system</p> <p>Sliders to rotate point of view</p>
	<p>Solid model drawings of systems</p> <p>User selectable:</p> <ul style="list-style-type: none"> <li>• cross sections</li> <li>• colours &amp; light sources</li> <li>• mesh size</li> </ul>
	<p>Solid model showing prisms</p> <p>WinLens has a prism wizard so that modelling a variety prisms is now very easy</p> <p>The LINOS prisms are in the component database and can be accessed via part number</p>
	<p>Wavefront plot</p> <p>Sliders to rotate view point</p> <p>Interferogram option</p> <p>User selectable:</p> <ul style="list-style-type: none"> <li>• Grid size</li> <li>• Colour schemes</li> </ul>

We have worked hard to make T & D flexible and easy to use. For example, all prisms require some T & D, and most prisms are non trivial to set-up correctly. Therefore we have created a prism wizard which will set-up the prism you want given the minimum necessary information.

In general, T & Ds [simple or compound] can be applied to:

- Individual surfaces
- Individual components
- Groups [of components]
- Modules [a group of groups]

via the 'T & D' tab in the system data editor. Individual surface T&D's can also be edited in surface data table.

The following general rules describe how T&D's work in WinLens:

***T&D on surface X does not alter the global position of any following surface UNLESS surface X is a fold mirror surface.***

***Fold mirrors [either stand-alone or inside prisms], by default, rotate the reference axis by 2x the angle of tilt.***

***Tilting a component, group or module does not alter the global position of any following components - unless you choose otherwise.***

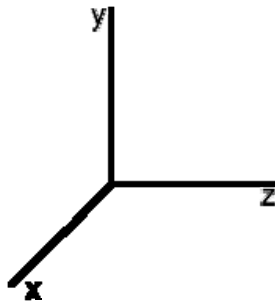
***Tilting a component, group or module does not alter the tilts on individual surfaces within that item.***

***Co-ordinate Breaks can be used to manually redefine the reference axis direction for all following components.***

In this manual, we will be looking at modelling systems with T & D's, and how to think about using these new features. We will also discuss some new features to help analyse these systems.

## 1.1 Co-ordinate systems

In this program we use a left handed axis system.



Looking at the screen, the x-axis is coming out toward you. For a system with no tilts, the z-axis is the optical axis.

Tilts are defined about the reference axes of the same 'name', thus tilt-x is a tilt about the x-axis, i.e. a lens undergoing tilt-x is rotated in the y-z plane. A positive tilt is defined in an anti-clockwise direction.

Fold mirrors do not reflect the reference axis, but rotate it by twice the angle of incidence. This means that the co-ordinate system stays left-handed.

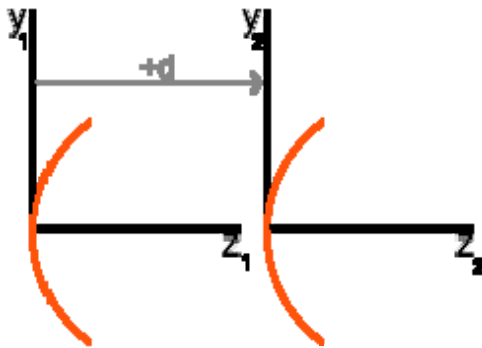
## 2. No tilts – just mirrors.

*A reminder about distance conventions...*

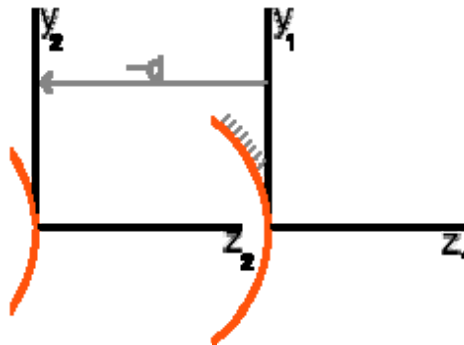
This chapter is a quick refresher - we will start with simple centered systems – i.e. **no tilts**. At each surface there is a local reference axis.



Normally these are simply displaced by some positive z value [the separation] from the next surface.



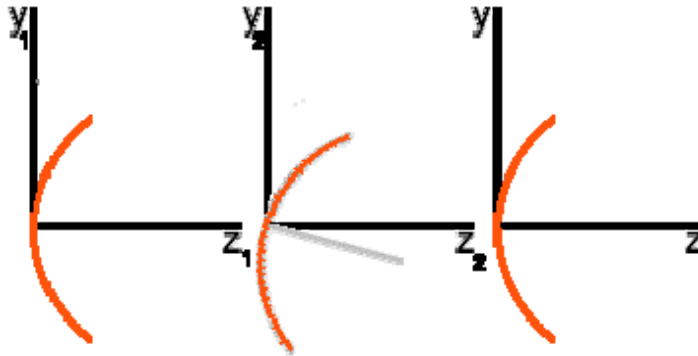
If there is a single mirror in the system, the following surfaces will be at a **negative** distance. In general the distance after a mirror will be of opposite sign to the distance before a mirror [at least inside the 'glass ware']



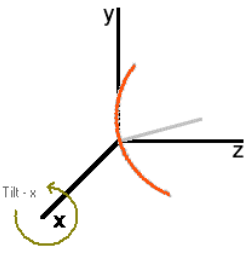
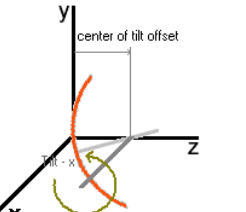
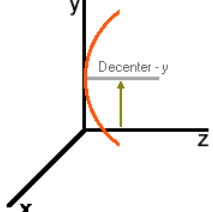
This is implemented in all versions of WLP and is also true in Zemax and Optalix.

### 3. Surface tilts and decenters

Individual surfaces can be tilted and decentered relative to their own axis.



Here we have tilted a surface in the y-z plane. This can also be thought of as 'a tilt around the x-axis' - hence we call this a 'tilt-x'.

	<p style="text-align: center;"><b>Tilts</b></p> <p>Since we live in a 3D space, there are 3 possible tilts: tilt-x, tilt-y and tilt-z<sup>1</sup>.</p> <p>The global reference axis is <b>NOT</b> tilted or decentered.</p> <p>Therefore a surface tilt does <b>NOT</b> change the position of any following surfaces - <b>unless it is a fold mirror</b> [see chapter 7]</p> <p>You can apply compound tilts to a surface e.g. tilt-x AND tilt-y simultaneously. Compound tilts are applied in alphabetical order - x, y then z.</p>
	<p style="text-align: center;"><b>Tilt center offsets</b></p> <p>By default, a tilt is about the origin of the local axis. But you can also apply an offset to the center of tilt, so that it is displaced along the reference axis in the x, y or z directions.</p> <p>These offset is displayed/edited in the columns headed 'Tilt Center Shift X' [or Y or Z as appropriate].</p> <p>Compound offsets can be extremely useful in modelling reflective polygon scanners [section 10.4]</p>
	<p style="text-align: center;"><b>Decenter</b></p> <p>Decenter<sup>2</sup> is a sideways displacement of a surface parallel to one of the axes.</p> <p>Dec-x is a decenter in the x-direction [in/out of the screen/page].</p> <p>Dec-y is a decenter along the y-axis [up and down].</p> <p>Dec-z is a decenter along the z-axis.</p>

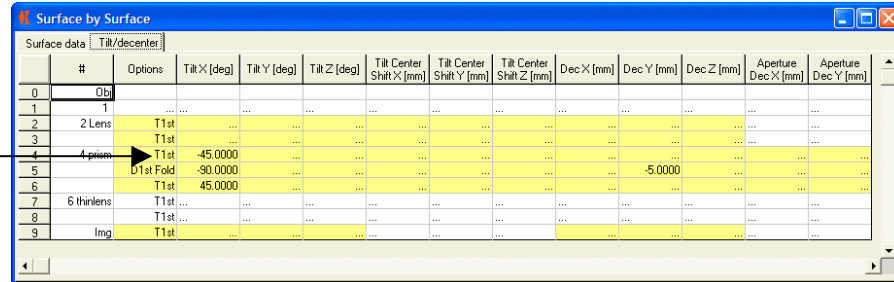
<sup>1</sup> If the surface is a surface of revolution, for example a sphere or a paraboloid, applying a tilt-z makes no difference at all.

<sup>2</sup> For a spherical surface a small **Tilt X** is equivalent to a **Dec Y** [where magnitude of the decenter equals tilt (in rad) \* radius of curvature]. By similar logic, a small **Tilt Y** is equivalent to a **Dec X**.

Surface tilts and decenters can be edited in two places:

- System data editor in the new tilt/decenter tab ['surfs' option]
- Surface data' table, in the new tilt/decenter tab [shown below]

Both look/function the same - but it is sometimes helpful to display surface tilts in the surface data editor and component level tilts in the system data editor



#	Options	Tilt X [deg]	Tilt Y [deg]	Tilt Z [deg]	Tilt Center Shift X [mm]	Tilt Center Shift Y [mm]	Tilt Center Shift Z [mm]	Dec X [mm]	Dec Y [mm]	Dec Z [mm]	Aperture Dec X [mm]	Aperture Dec Y [mm]
0	Obj	...	...	...	...	...	...	...	...	...	...	...
1	1	...	...	...	...	...	...	...	...	...	...	...
2	2 Lens	T1st	...	...	...	...	...	...	...	...	...	...
3	3	T1st	...	...	...	...	...	...	...	...	...	...
4	4 prism	T1st	-45.0000	...	...	...	...	...	...	...	...	...
5	5	D1st Fold	-90.0000	...	...	...	...	...	5.0000	...	...	...
6	6	T1st	45.0000	...	...	...	...	...	...	...	...	...
7	7 6 thinlens	T1st	...	...	...	...	...	...	...	...	...	...
8	8	T1st	...	...	...	...	...	...	...	...	...	...
9	9 Img	T1st	...	...	...	...	...	...	...	...	...	...

**LINOS components:** you cannot tilt or decenter individual surfaces in a LINOS database component – by definition they are of course perfect ☺. If you need to do this, then use the 'convert' button in the system data editor to convert the components to a user defined item.

**Aperture decenters:** at present, aperture decenters are confined to prisms.

### 3.1 Surface T&D options

Compound T&D's are applied in the order [*T1st*]:  
tilt-x, tilt-y, tilt-z, dec-x, dec-y, dec-z

You can also order the T&D's as [*D1st*]:  
dec-x, dec-y, dec-z, tilt-x, tilt-y, tilt-z.

To change the T&D order for a surface, simply click on the relevant cell in the 'Options' column, and WinLens will display the 'tilt options' dialog.

By default, mirrors are defined as 'fold' mirrors, i.e. they will tilt the reference axis. If you do not want this behaviour to apply to a specific mirror, then you can also change it in the same 'tilt options' dialog.

### 3.2 Tilt units

By default tilt values are specified in degrees. However, you may choose to specify tilts in radians, milli-radians or minutes. Simply:

- Go to the System data editor
- click on the 'Tilts & Decenters' tab
- click on the 'Units' button at bottom left
- select chosen unit.

This is a global choice and applies to all tilts, whether surface, component, group or module.

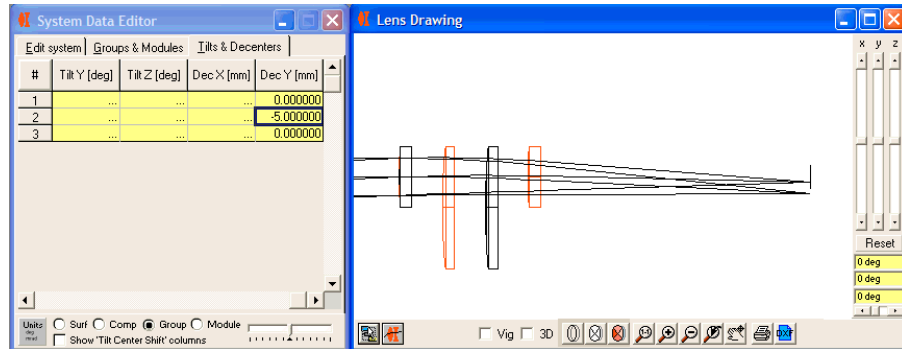


## 4. Tilted components, groups and modules

You may easily tilt whole<sup>3</sup> components, groups of components or modules [a group of groups of components] using the tilt tab on the system data editor.

By default - tilting or decentering any component, group or module will NOT alter the global position of any 'following' components.

In the screen-dump below, the 2<sup>nd</sup> and 3<sup>rd</sup> components have been grouped. This group is then decentered by -5 mm in the y direction. Note that just a single value is needed to shift the whole group. Also note that the 4<sup>th</sup> lens is unmoved.



### 4.1 Tilt options

As stated above, WinLens carefully re-aligns the reference axis at the end of each tilted component/group or module, so that 'following' elements are neither tilted nor decentered.

However you can change this option for any component, group or module by clicking the relevant cell in the 'Options' column. NB the non-default option is exactly equivalent to inserting a co-ordinate break at the start of the item.

#	Comps in Group	Options	Tilt
1	1-1	T1st	
2	3-5	T1st	
3	7-7	T1st	

You can also change the order of application of tilts and decenters.

### 4.2 Rotated system

It is possible to rotate [about the z axis] the entire 'glass works', using the slider in the toolbar at the bottom of the system data editor.



At present all object points lie along the y-axis, so by rotating the optics, you can probe or sample a different azimuth very easily.

If the design is not just a folded version of a centered system, then you will see differences in the various analysis graphs and tables.

This can easily be seen if you set up a lens followed by a wedge prism. Look, for example, at the TRA<sup>4</sup> plot or the spot diagrams and then use the slider to rotate the optics. Don't forget to define a non zero field and aperture! The TRA variations are more impressive if you analyse the system at 3 or 5 wavelengths.

<sup>3</sup> Rather than trying to tilt and decenter all the individual surfaces within a grouping, we use hidden co-ordinate breaks before and after to do the work.

<sup>4</sup> You will see clear axial coma - a classic effect of tilts, and this will rotate nicely as the slider is used.

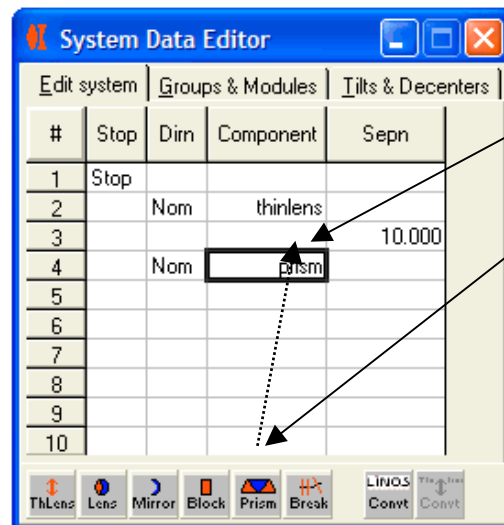
## 5. Prisms

In earlier versions of WinLens, you could model systems using lenses [thick or thin], blocks and mirrors. One of the main reasons for going to 3D is to model prisms. Therefore we have added a 'prism' object to WinLens 3D.

A prism can be dispersive or reflective, and can be one of a number of sub types.

The limitation on current prism modelling is that they must be defined and traced sequentially. To model, for example, roof prisms would require non-sequential tracing, and is therefore not possible.

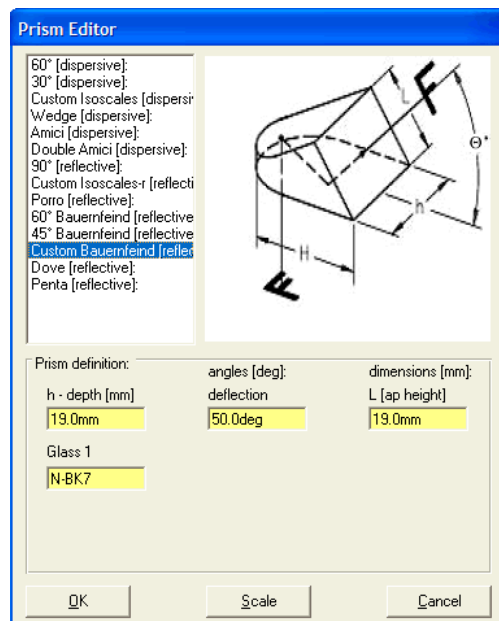
Prisms, especially the more complex prisms can be quite tricky to set up correctly, so we have created a wizard to help do the work.



This wizard appears when you first type 'prism' in the 'Component' column of the main tab in the System Data Editor.

Alternatively, drag and drop the prism icon in the toolbar to the 'Component' column

When the wizard is loaded, all you have to do is select the desired type, supply the 'key parameter values' and click OK.



There are between 3 and 6 key parameters, including 1 or 2 for materials, needed to describe a prism. You will only see those that are relevant to the selected type.

Amazingly some prisms that appear most complex actually require fewest parameters!

Once you have clicked OK, WinLens 3D will generate the prism, with surfaces with necessary tilts, decenters, separations etc. You will see the new prism in the drawing.

You can re-edit the prism parameters, by recalling the wizard. In order to recall the wizard, simply double click on relevant prism in the component

column of the system data editor.

Obviously you can see the surface by surface prescription in the Surface Data Table - the tilts and decenters can be viewed in the 'Tilt/Decenter' tab on that form. However, we suggest that you don't edit the prism data here - it is all too easy to make a real mess. Use the wizard instead!

## 5.1 Prism types

At present WinLens 3D supports the following prism types:

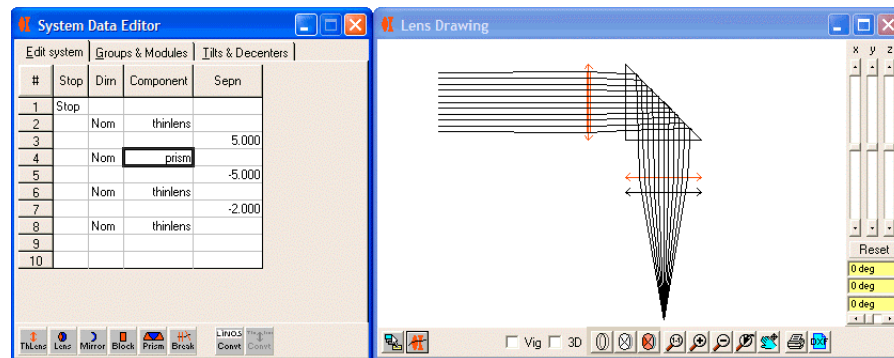
No fold mirrors [dispersive]	1 fold mirror	2 fold mirrors
60° [equilateral]	90° – reflective	Porro
30° [isoscales]	Dove	Bauernfeind 60°
Custom [isoscales]		Bauernfeind 45°
Wedge		Bauernfeind Custom
Amici		Penta
Double Amici		

Some of the prisms use decentered apertures, e.g. Amici, Bauernfeind. At present decentered apertures are limited to prisms.

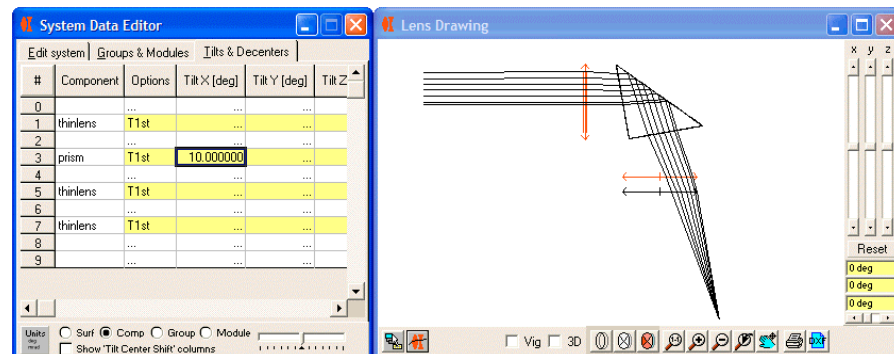
## 5.2 Reflective prisms and the reference axis

All reflective prisms use one or more internal fold mirrors. Fold mirrors, and their impact on the reference axis, are discussed in chapter 7.

However, in brief, the mirror folds the reference axis. Thus if the fold mirror is at 45° to the incoming axis, then the emergent axis will be rotated by 90°. So following components will automatically lie along the 'natural' line, and don't need to be tilted or decentered by you.



By contrast, component level tilts do not move the reference axis [by default]. This means that you can see impact of tilting the prism as a whole without shifting following components!



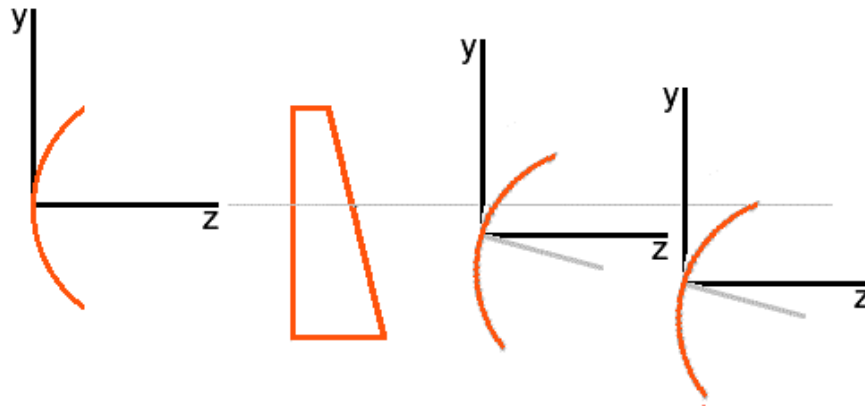
## 6. Co-ordinate breaks

Sometimes optical systems have distinct bends or kinks which are not caused by fold mirrors - an obvious example is a prism spectrograph. If every component in the spectrograph had to be defined relative to a single axis, then you would need to work out tilts and decenters for each individual component - a non trivial task!

### Important

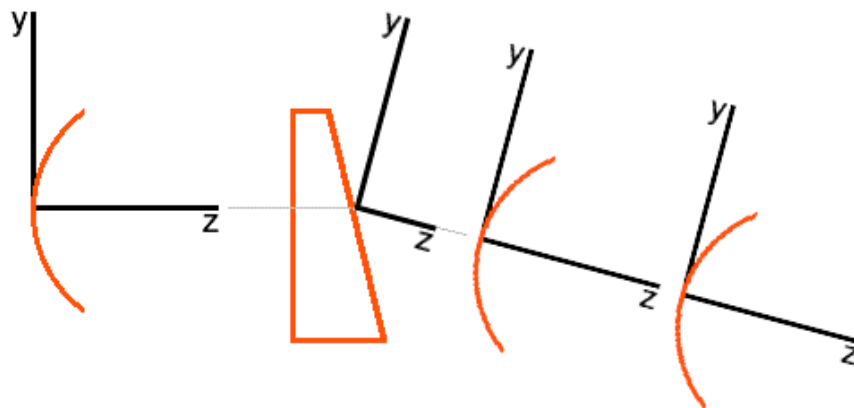
The global reference axis is not always the same as the optical axis.

In a dispersive prism for example, the optical axis will vary with wavelength - something that clearly cannot apply to the opto-mechanics!



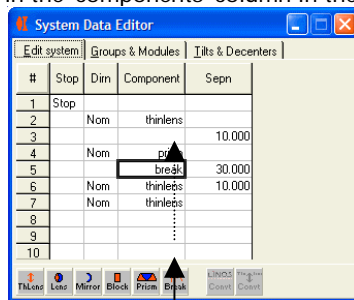
This example may not look too complex, but imagine the computations you would have to do and re-do if the system requires compound tilts to model it properly.

However, in WinLens, you can permanently alter the direction of the reference axis, using a 'co-ordinate break' surface. All items after the break will be defined relative to the new axis direction, and so don't need tilts and decenters.



Clearly, now it is much easier to set-up the system, requiring no extra computations on your side.

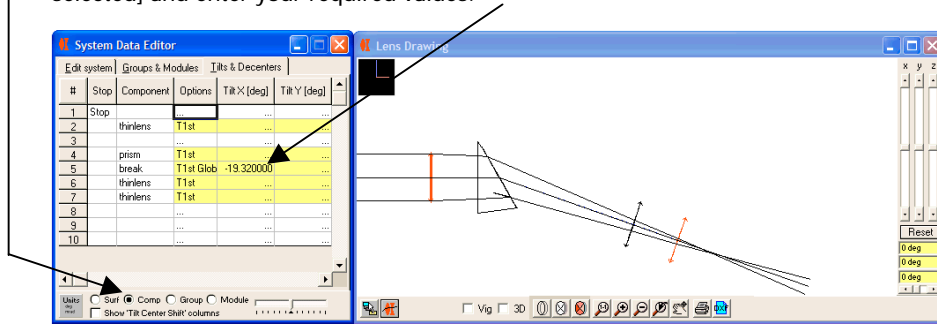
To insert a co-ordinate break, simply type the word 'break' into the appropriate cell in the 'components' column in the 'System' tab in the system data editor.



Alternatively drag and drop from the 'Break' icon in the toolbar into the same cell.

Alternatively drag and drop from the 'Break' icon in the toolbar into the same cell.

To define the tilt/decenter values, just go to the 'Tilts & Decenters' tab [with 'comp' selected] and enter your required values.



This screen-dump shows a co-ordinate break with a simple tilt-x, but you may apply decenters and even compound T&D's with a co-ordinate break.

You can also edit the T&D values in the surface data table - but these are kept synchronised with the values shown in the system data table, so it is just an editing convenience.

Note that the co-ordinate break effect applies right through to the image surface - unless you apply another co-ordinate break!

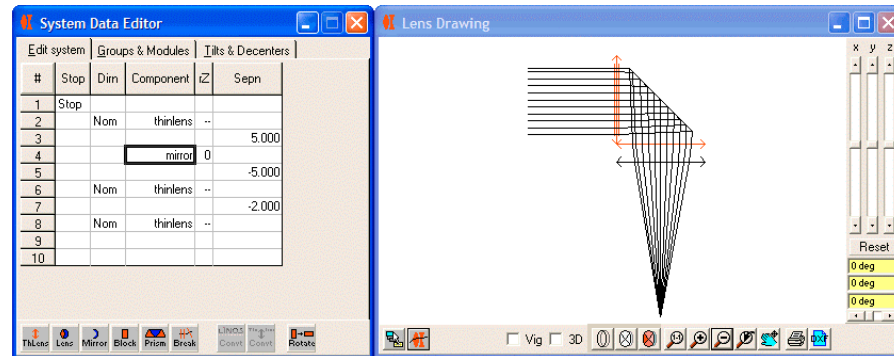
Note also that the co-ordinate break is not shown in the lens drawing, though you can see a odd looking ray segment travelling from the prism exit face to the invisible co-ordinate break.

## 7. Fold Mirrors

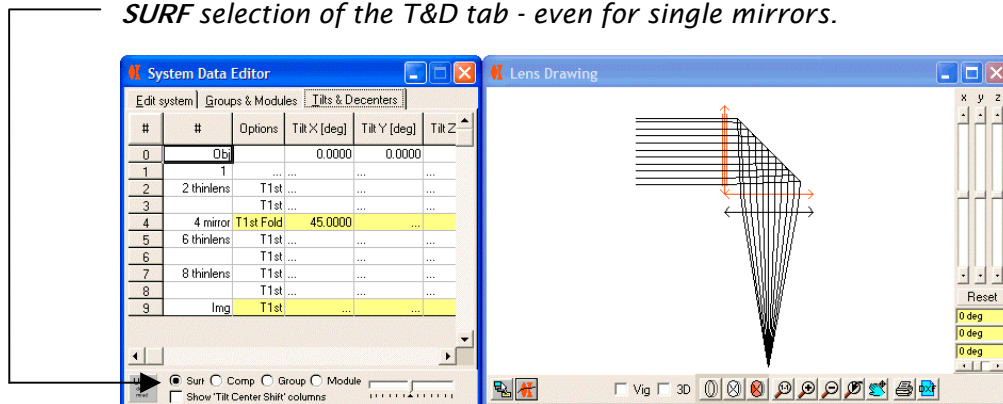
In many optical systems, the optical train is 'folded' by a single mirror or by mirror surfaces inside a prism.

These can easily be modelled in WinLens by defining a mirror surface as a 'fold mirror' [in fact, by default, mirrors are set as 'fold']

A fold mirror surface will tilt the exit reference axis by twice the 'fold angle' - the angle between the entrance reference angle and the mirror. All reflective prisms use fold mirror surfaces. All following elements will lie along the new axis.

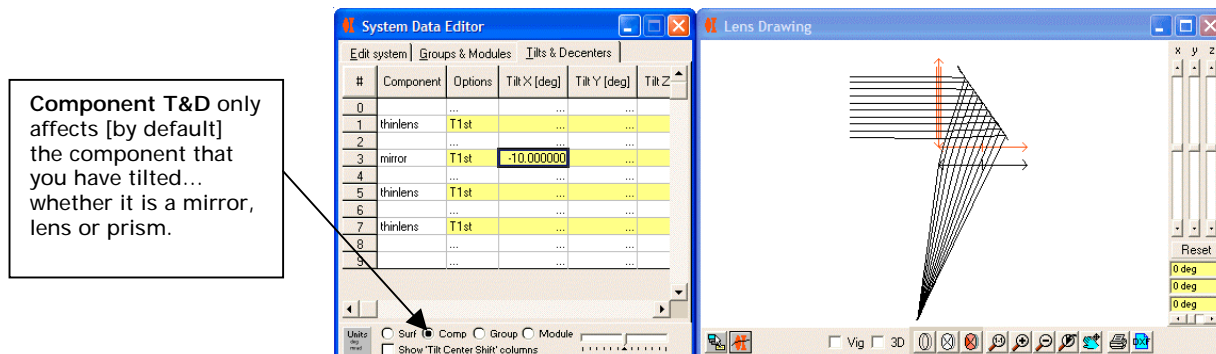


**IMPORTANT:** the fold angle of a fold mirror surface is set in the **SURF** selection of the **T&D** tab - even for single mirrors.



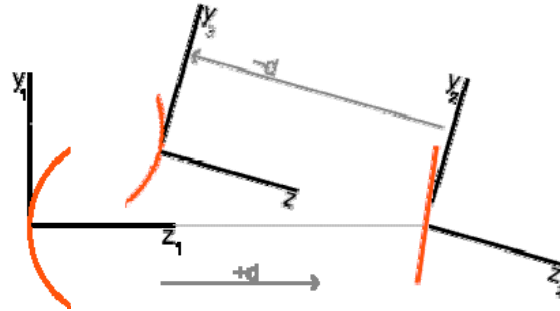
A surface tilt applied to the mirror is NOT the same as applying a component T&D to the mirror, i.e. for a mirror, there both is a surface T&D and there is a component T&D.

This may seem complex, but it is actually incredibly useful - when modelling scanners [chapter 10] for example. You can use the mirror surface T&D to nicely fold the system into its nominal 'shape', and then apply the component T&D to a mirror to scan it without disturbing the location of the rest of the system.



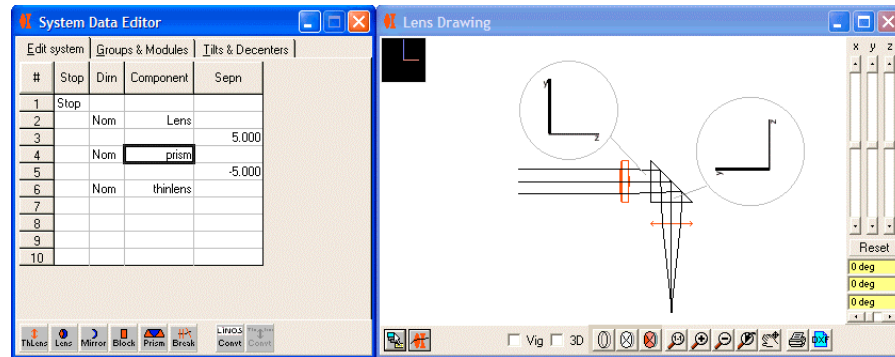
Component T&D only affects [by default] the component that you have tilted... whether it is a mirror, lens or prism.

### 7.1 Fold Mirrors: impact on separations



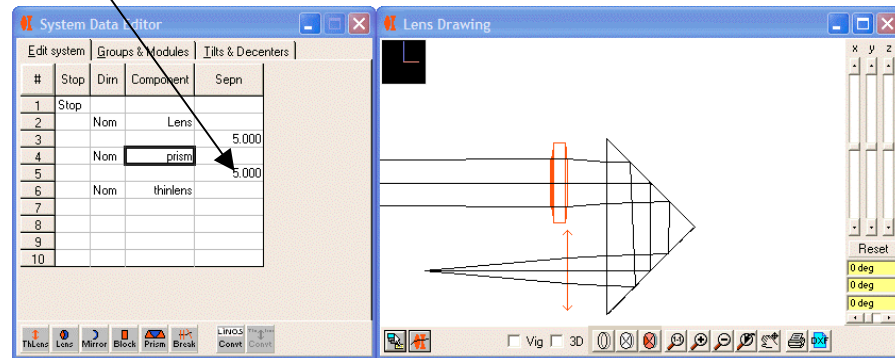
It is very important to note that the reference axis is NOT reflected, merely tilted.

This means that distances to the next surface will normally be of opposite sign to a distance before the mirror. Thus if we have a centered mirror system, the mirror can be a fold mirror or not. It will not make any difference to the sign of the distance. So in spaces after an **odd number** of mirrors, light travels in the opposite direction to the reference z axis, so distances will usually be negative.



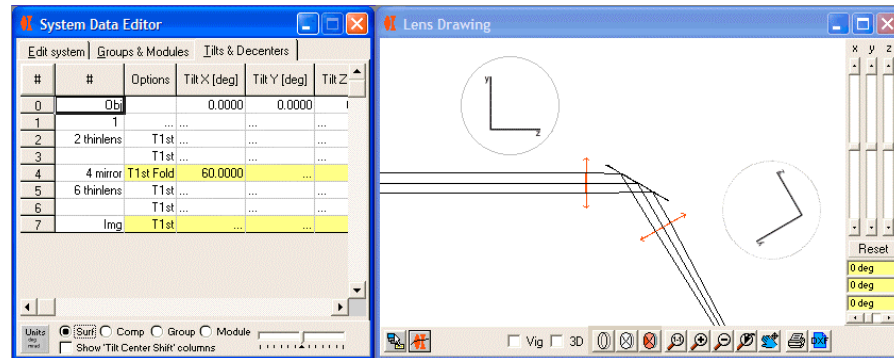
Here we see a 90° reflective prism. The middle surface [at 45 °] is automatically created as a fold mirror by the WinLens prism wizard. Note that the distance to the lens after the prism is **negative**.

By contrast, a porro prism has two fold mirrors so the distance to the following thin lens is **positive**.



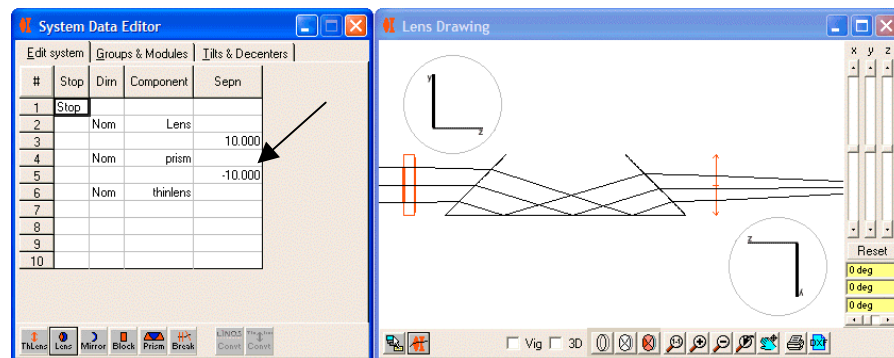
## 7.2 High incidence angle fold mirrors

Sometimes a fold mirror needs to be tilted at angles greater [sometimes much greater] than  $45^\circ$ .

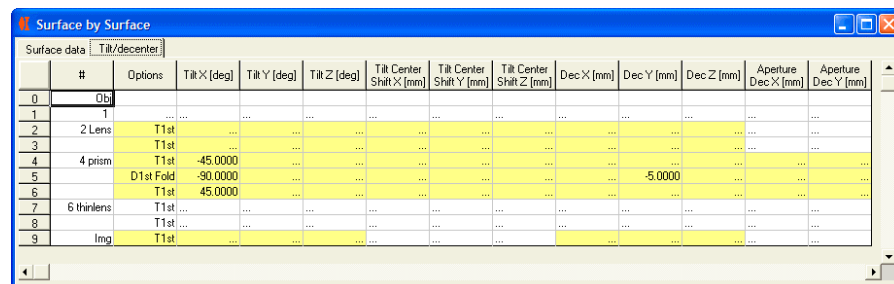


Exactly the same considerations apply, i.e. the reference axis is tilted by twice the mirror tilt angle. And therefore, as before, distances after the fold mirror will normally be of opposite sign to distances before the mirror.

One extreme example is the Dove prism where the mirror surface is titled at  $90^\circ$ . As a result, the reference axis is rotated by  $180^\circ$ . This then has the odd effect that the thin lens following the dove, at the **right** of the prism, has a negative distance. Not something that is instantly obvious!



**Note that decentering a fold mirror does NOT alter the reference axis**, so that we do not need a re-decenter on the final surface. This is clearly shown if we look at the tilts in the surface data editor.

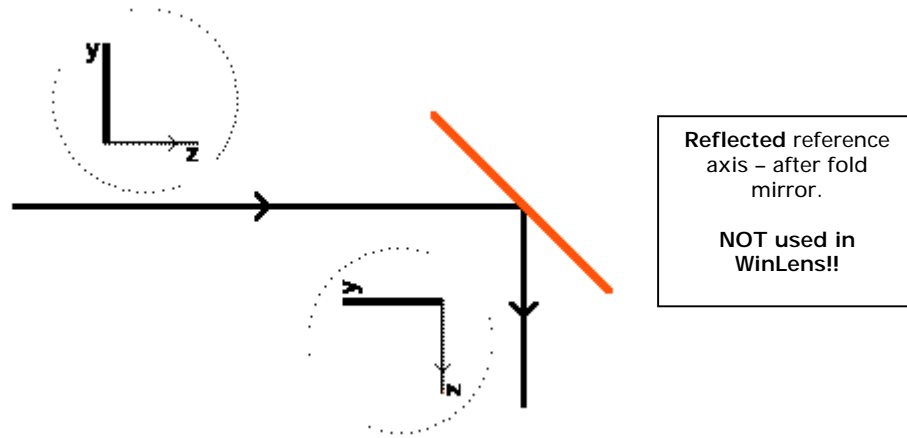




### 7.3 Fold mirrors: impact on tilts and decenters

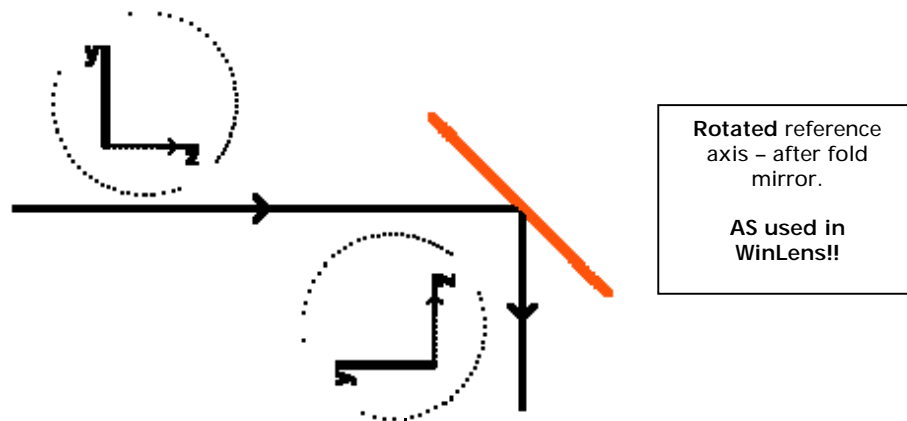
When dealing with the impact of a fold mirror, it is crucial to understand how the reference axis alters orientation. From this we will show how WinLens handles following tilted or decentered surfaces.

As we have mentioned before, a fold mirror **DOES NOT REFLECT** the reference axis



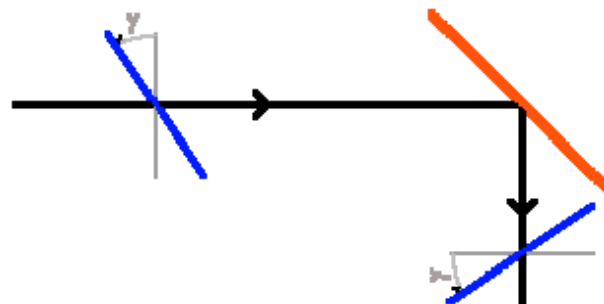
[shown here]

Instead a fold mirror rotates the reference axis by  $2x$  the angle between the original axis and the mirror.



Note that in the illustration above, in the space after the fold mirror, the light is now travelling in the opposite direction to the z axis.

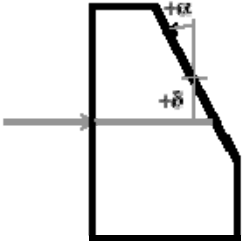
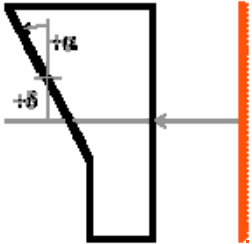
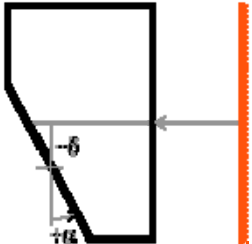
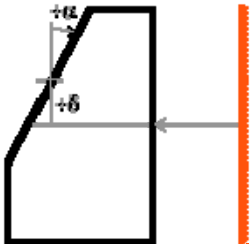
One vital consequence of this is that a **positive tilt** of a surface after the mirror will still be **anticlockwise** in the global co-ordinate system:



## 8. Prisms after previous mirrors.

In the previous section we saw the impact of a fold mirror upon tilt definitions relative to a global reference axis.

Lets see how WinLens deals with a prism, when it is placed after a single mirror. We will start with a simple dispersive prism *[this chapter is for information sake]*.

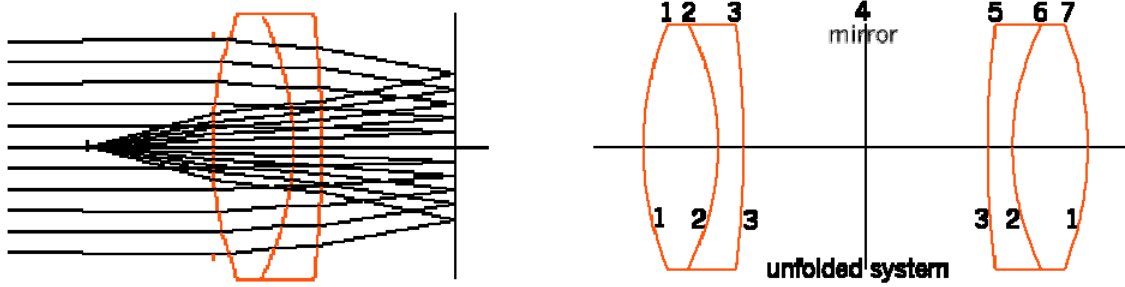
	<p>Here is the prism in normal space. The second surface has:</p> <ul style="list-style-type: none"> <li>• a positive tilt, <math>\alpha</math></li> <li>• a positive decenter, <math>\delta</math></li> </ul>
	<p>If we insert a mirror 'before' the prism, the obvious option is to keep a positive tilt and a positive decenter.</p> <p>However the prism shape will change!!</p> <p>We could leave this for the user to correct manually, but for more complex prisms, such as the Bauernfeind, the task is non-trivial.</p>
	<p>Another option is for WinLens to <b>automatically</b> reverse the signs of the decenters.</p> <p>The shape of the prism is now correct, but it is upside down [flipped].</p> <p>Of course you could apply a 180° revolution about the z axis, but that seems a bit clumsy.</p>
	<p>Our chosen option is for WinLens to <b>automatically</b> reverse the signs of the tilts, and keep the decenter signs as before.</p> <p>The prism shape is correct and it is not flipped.</p>

So, for components placed after an odd number of fold mirrors:

- Sign of tilts are automatically inverted
- Signs of decenters [including apertures] are left unchanged

## 9. How to: setup Prism Mirror Prism combo's

When modelling catadioptric systems [systems with mirrors & lenses], the light will often pass two or more times [in opposite directions], through the same lens.



In sequential raytrace programs, such as WinLens, each occurrence of a surface that the ray passes through has to be defined, even if, physically speaking, some are the same.

Therefore, in setting up such a catadioptric system we will need to have the element defined before and after the mirror. Of course, after the mirror, the surface order is reversed. This is illustrated above in the diagram of the unfolded achromat/mirror/achromat system.

Since we want the surface order to be reversed, we have to reverse the component after the mirror. Note how this is done in the system data editor [the example uses one of the LINOS achromats]. We have made a slight difference in the distance to the copy after the mirror so it shows up in the drawing.

Reversed component

#	Stop	Dirn	Component	Seprn
1	Stop			
2		Nom	322201000	5.000
3				
4			mirror	-4.800
5				
6				
7		Rev	322201000	
8				
9				
10				

When dealing with prisms we obviously wish to achieve a similar result. In WinLens this is quite simple. The exact process depends upon the number of internal mirrors within the prism.

### 9.1 Prisms with 0 or 2 internal mirrors

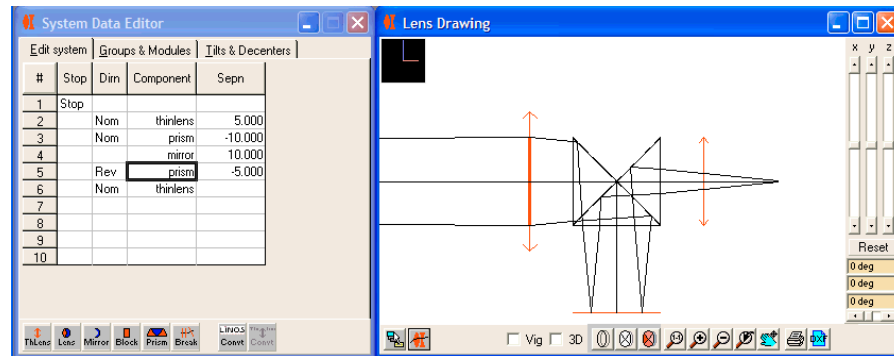
For prisms with 0 or 2 internal mirrors, proceed exactly as for the example above.

#	Stop	Dirn	Component	Seprn
1	Stop			
2		Nom	thinlens	
3				5.000
4		Nom	prism	
5				5.000
6			mirror	
7				-5.000
8				
9		Rev	prism	
10				

In this example, we use thin lenses [before and after] to give a finite image.

## 9.2 Prisms with 1 internal mirror

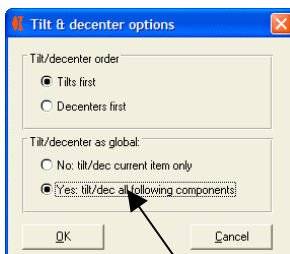
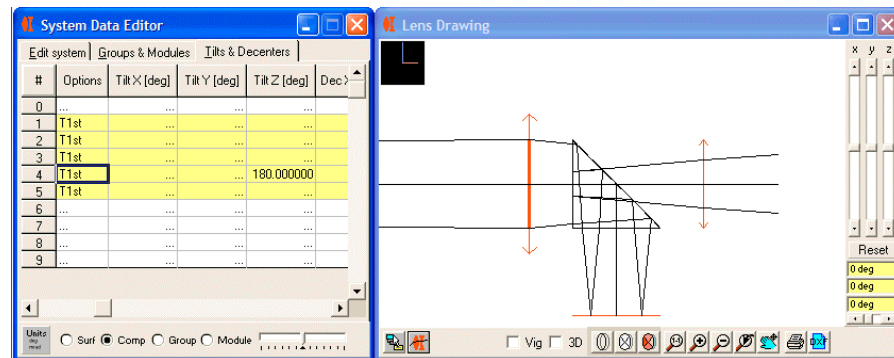
For prisms with 1 internal mirror [e.g. a Dove prism or a 90° prism], this is not yet enough to get a true overlay.



**Distances:** Because the first prism has an internal mirror, the distance after the first prism is negative. The mirror component is now the second fold mirror, so the distance after that becomes positive. The second prism contains the third fold mirror in the system, so the distance after that is positive

**Overlay problem:** Looking at the drawing, the second prism does not overlay the first, but is 'back to front'. If we had used a Dove prism, then the second Dove would appear to be upside down at this stage. This is because the first Dove has rotated the reference axis by 180°.

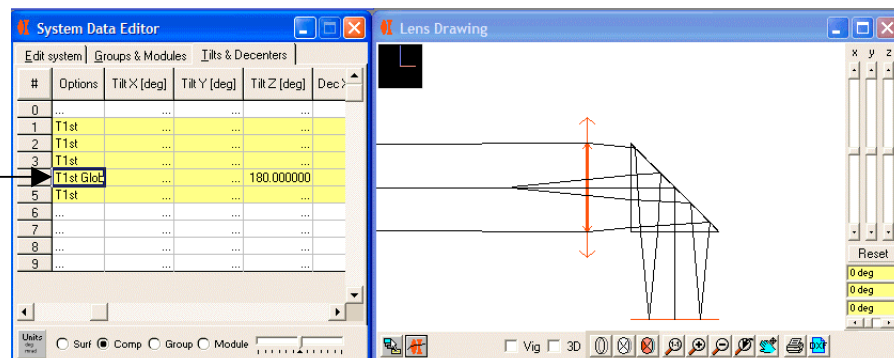
**Solution:** First apply a tilt Z of 180° to the second prism.



Click to change Prism tilt options

However if you just change the tilt-z value, then the prisms will overlap correctly, but the image plane will appear to be virtual - as shown above.

This happens because, by default, component level T&D will only apply to this prism. But we actually do want to rotate the reference axis as well, so we need to change the T&D option for the prism to global.



Now the catadioptric prism system is set-up properly.

**Alternative solution:** we could have inserted a co-ordinate break before the second prism, and applied a tilt-z of 180°.

## 10. How to: set-up scanners

Conventionally, scanners are quite tricky to set-up, especially those which 'bend' in several directions. Modelling motions of the mirrors [design or manufacturing error] can be even harder.

Designers would insert numbers of carefully placed co-ordinate breaks, in order to fold the system - and indeed you can do that in WinLens if you are so inclined.

However, by using 'fold mirror surface' tilts [section 3] and 'component tilts' [section 4], and tilt center offsets, we will show you a really simple method which will handle both the basic layout and simulation of mirror movement.

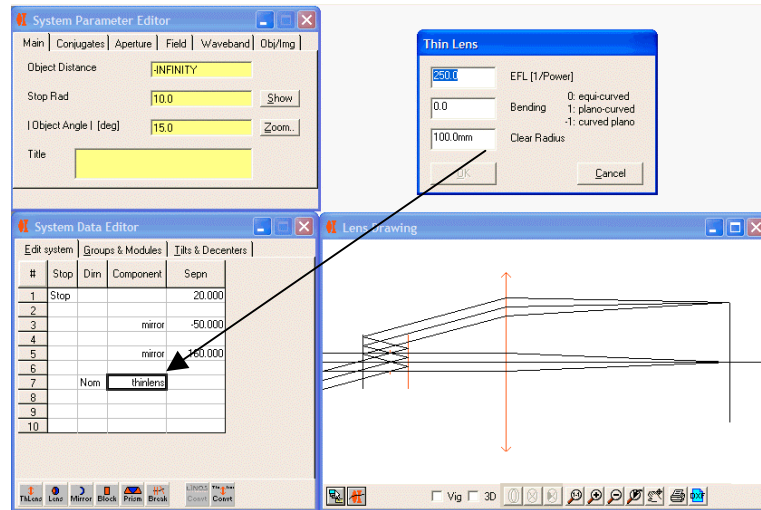
### 10.1 Simple mirror scanner

We will set up a simple 2-mirror scanner which is left-right symmetric. For simplicity sake, we will use a thin lens. We suggest that you use the following three step procedure:

1. Setup components and separations
2. Apply fold surface tilts to get nominal layout
3. Apply component tilts to simulate mirror movements

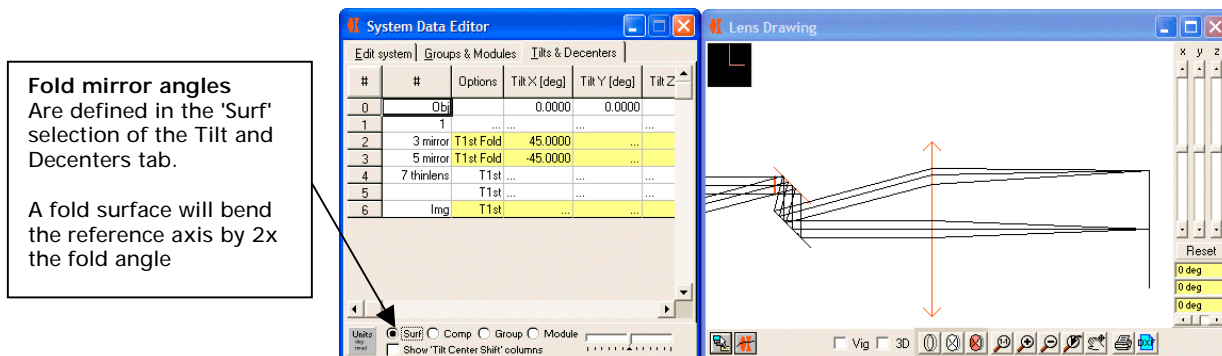
#### 10.1.1 Setup components and separations:

Enter the components and separations as shown below - the mirrors are plane.



#### 10.1.2 Apply fold surface tilts to get nominal layout

Now we define the fold angles - it is critical that you apply these to the surfaces. Being a simple scanner, both tilts are in the same azimuth [tilt-x in this case]

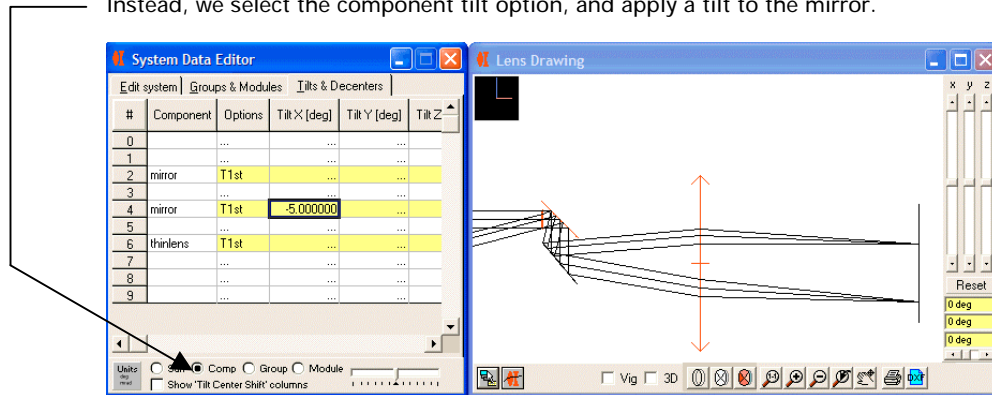


These fold angles are essential to 'bending' the system into the correct layout.

### 10.1.3 Apply component tilts to simulate mirror movements

Now if we wish to alter the tilts without altering the positions of any following components, we DO NOT alter the fold angles.

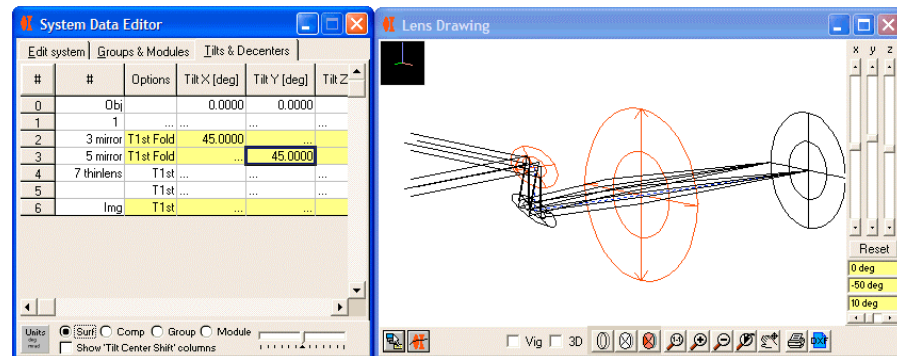
Instead, we select the component tilt option, and apply a tilt to the mirror.



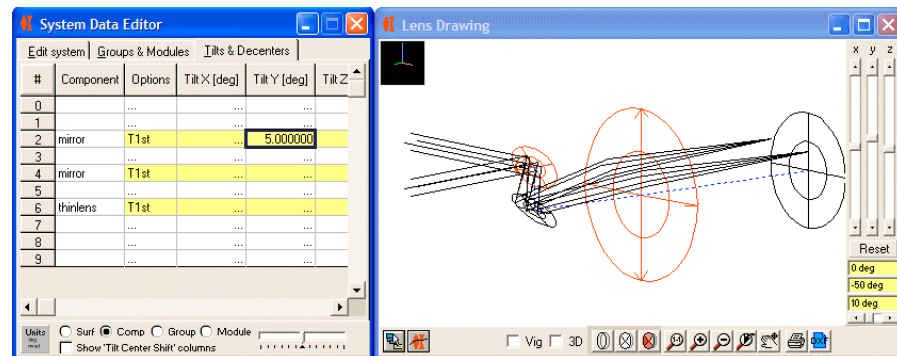
If you look at the drawing and/or the global co-ordinates table, then you will see that, without any pain on your behalf, the second mirror has been tilted, without making any movement to the other components.

### 10.2 X-XY mirror scanner

Here the tilt plane of the second mirror is orthogonal to that of the first, i.e. if the first mirror has a fold tilt-x, then the second mirror has a fold tilt-y. Notice we have used the drawing sliders to rotate the drawing to make the layout more obvious. Try looking at the solid model.



and here we can see the effects of applying a **component tilt-y** to the first mirror [the dark blue dotted line shows the mechanical reference axis - this is optional]. Note how the following lens and image plane are unmoved.

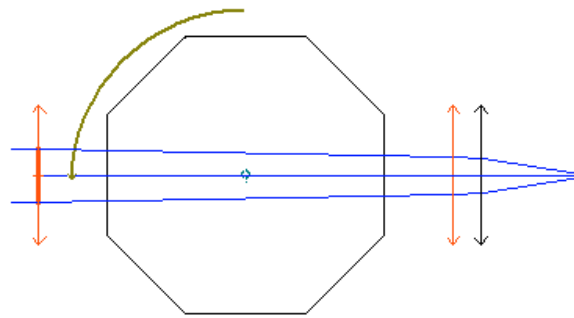


Now clear the component tilt-y, and enter a 5° tilt-x for the first mirror - easy!

Finally, try defining an adjuster, so that you can vary a surface tilt or component tilt with a slider.

### 10.3 Transmissive polygon scanner

In some high speed film cameras a rotating cylinder, with a regular polygon cross section, is used to scan the object. Here we see an octagonal cylinder, but typically many more edges are used.



We cannot exactly reproduce a polygon in WinLens, but we can setup the optical path and then model the rotation about its center. Indeed, this is so simple, that the only point is to show the use of 'Tilt Center Offsets'.

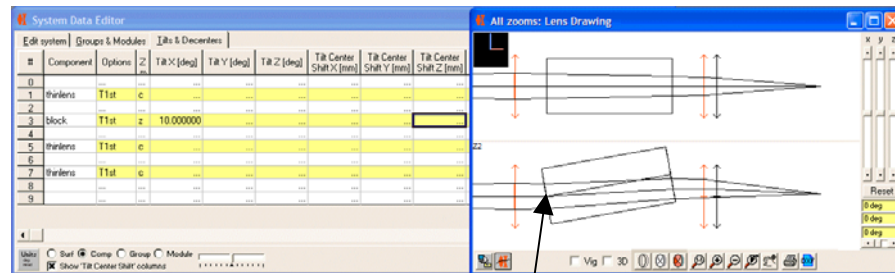
First we setup the optical path through the polygon as a simple block<sup>5</sup>, just taking the two opposite surfaces.

Then we apply the component tilt-x. By default, this does not affect the position of following elements - thus allowing you to model the rotation.

This example is set up as a zoom system:  
 Zoom 1 - untilted block  
 Zoom 2 - tilted block

The drawing shows the two zoom positions at the same time.

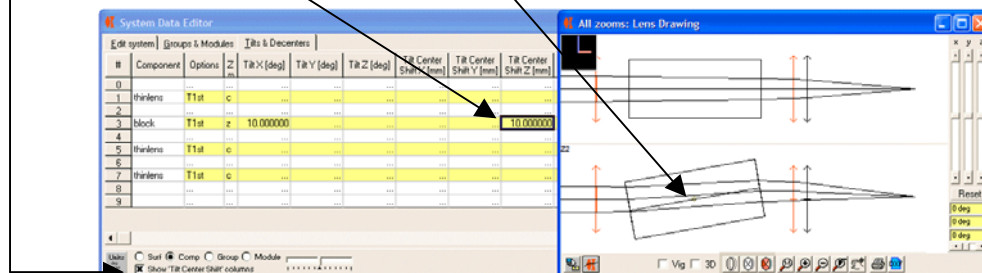
You don't need to do this!



However, at this point the block is rotating about the center of the front face. We need to rotate about the block center, which is along the z direction.

To shift the tilt center, we need to show the relevant columns. These are normally hidden to declutter the table. To show them, simply check the box 'Show Tilt Center Shift' columns.

Now we offset the center of tilt by half the block width, by entering this value in the 'Center of Tilt Z' column.



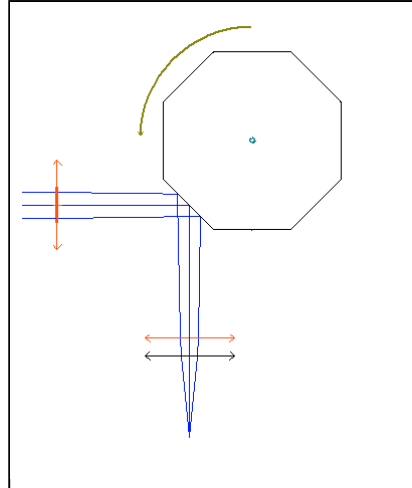
and that's it!

<sup>5</sup> If the cylinder half width is r, and there are n faces, then the block clear aperture radius, a<sub>r</sub>, will be given by: a<sub>r</sub> = r.tan(180/n).

Don't forget to make the block rectangular in cross section.

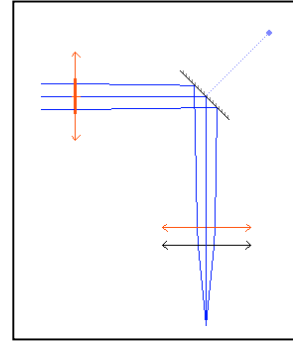
### 10.4 Reflective polygon scanner

An alternative is to use a reflective polygon. The light does not pass through the polygon, but is reflected off the outer surfaces:



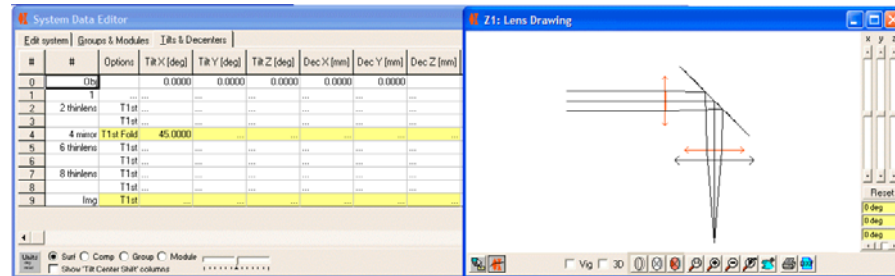
Again, we exactly cannot model a reflective polygon cylinder, but we can strip it down to its optical essentials.

We will model the polygon as a simple fold mirror, and use component tilt center shifts to specify the center of rotation.



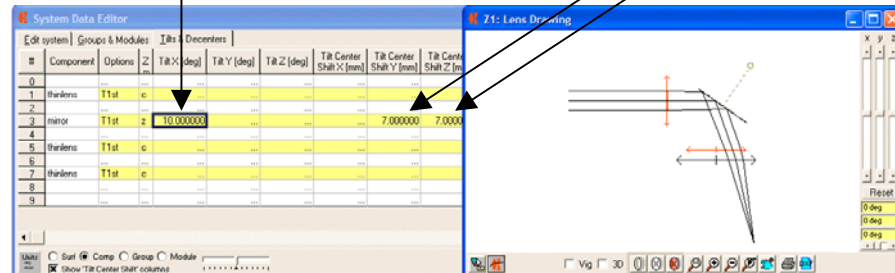
Follow the standard three stage process:

- 1) Setup the system without tilts [don't forget negative separations after the mirror!
- 2) Fold the system using a simple **surface tilt-x** on the mirror [by default this will be a fold mirror].



- 3) Model the polygon rotation using a **component tilt** whose center is offset to where the center of the polygon would be. Make sure that the Tilt Center Shift columns are visible.

Enter the rotation angle and also an equal shift in both y & z directions



The component center of rotation is shown by the little circle and dotted line.

If you want to model a different rotation angle, all you have to do is change the value in the component tilt-x.



## 11. 3D Analysis Tools

3D system modelling [even with easy setup tools] would be of little advantage if the results cannot be properly analysed and displayed. Therefore we have added a number of new features – these are:

- 3D drawing [wire-frame or solid model]
- 3D wavefront plot [with interferogram and other options]
- Global co-ordinates table [surface vertex]
- Graph enhancements [no symmetry assumptions]
- Single ray table – global co-ordinates option

Don't forget, you can use the system rotator [see section 4.2] to analyse the system at any azimuth.

### 11.1 3D Drawing

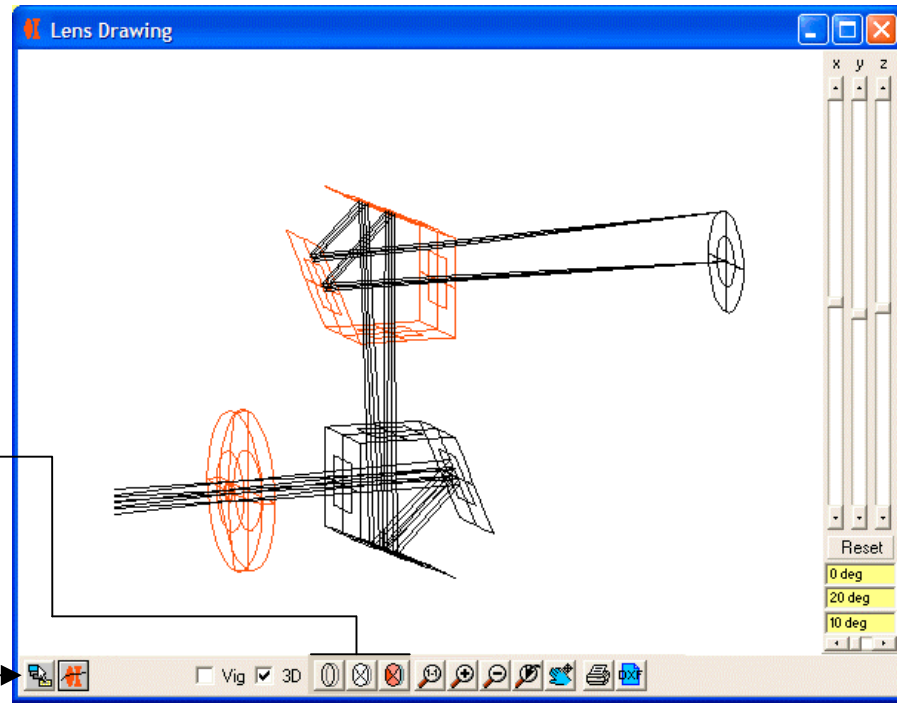
[accessed via the 'graphics' menu item: 'lens drawing']



The standard lens drawing [accessed via the graphics menu] has been enhanced to display 3D systems using 3D graphics. Different styles of 3D graphics are available ranging from a simple wire-frame through to a coloured solid model

#### 11.1.1 Wireframe

By default, 3D drawings are shown in simple wire-frames format:



**Lens drawing modes:**

- Wireframe
- Solid model – simple
- Solid model – full

**Lens drawing options**  
rays, scaling & surfaces  
plus  
solid model options:  
geometry, colouring,  
light sources and user  
defined/recalable  
default settings

You can rotate the drawing using the sliders at the right hand side of the window, or by entering values in the text boxes under the sliders. 'Reset' returns all to zero degrees [the same view point as the 2D layout]

The lens is always drawn in 3D if the system has any tilts, and is an option otherwise.

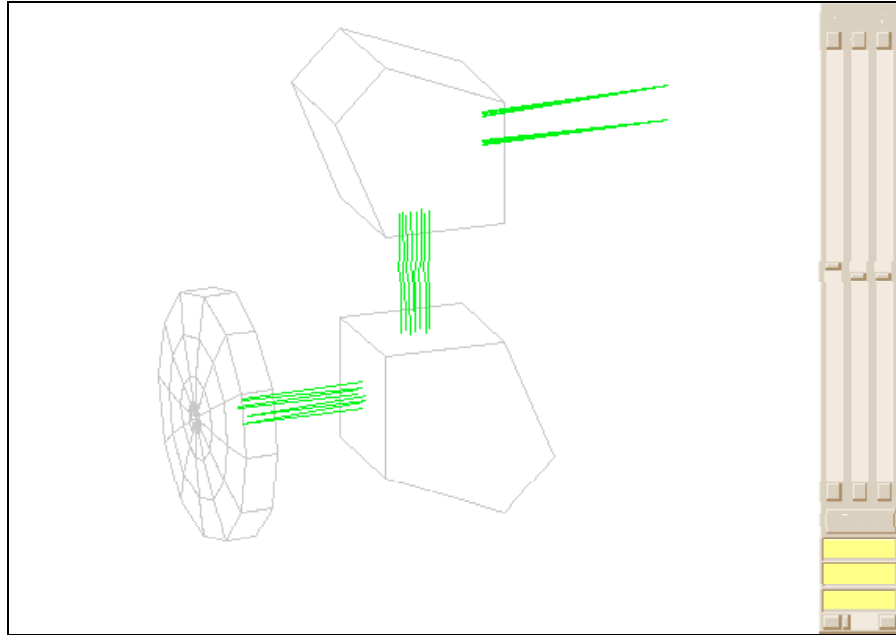
You may zoom in to the 3D drawing, just as with the 2D version.

*For users into computer graphics, we use a parallel projection by default. This means that you do lose depth cues [i.e a distant object appears same size as a near object with same dimensions] but on the other hand we avoid disconcerting distortions or even missing elements if the view point is poorly selected.*

### 11.1.2 Solid model – simple

Clearly the wireframe mode – though quick and simple to generate suffers from one major disadvantage – all surfaces are transparent, so it is very easy to get lost in the detail or confused by the apparent perspective.

The intermediate mode is a simple solid model. In solid models the lenses are represented by a series of polygons, rather than a set of lines.

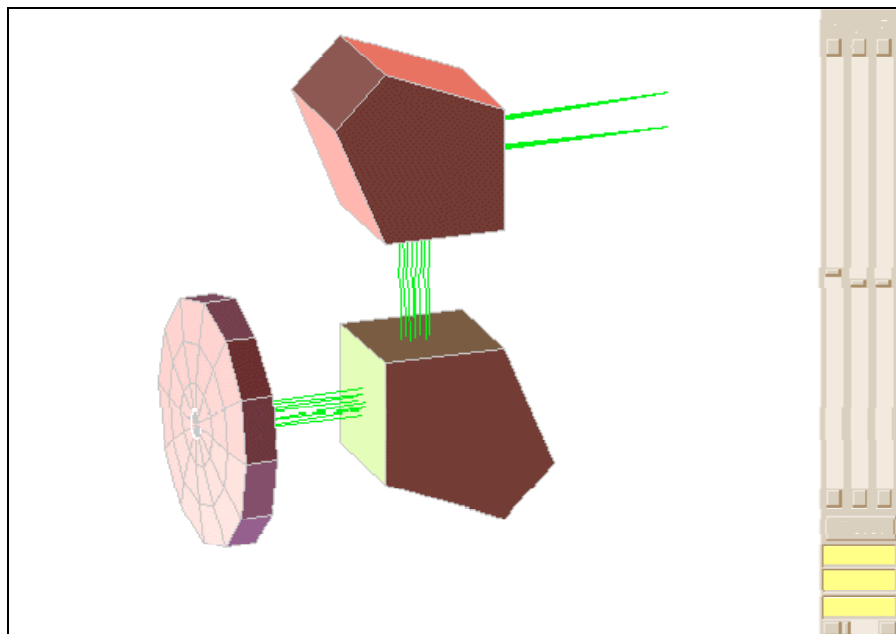


In the simple model we just hide any polygons whose 'outside' face is facing away from your current view point [technically known as hidden face removal].

All visible polygons are just drawn as simple outlines. The overall effect is much less cluttered the wireframe, but some polygons which ought to be obscured show through [as for example the rays entering the second penta prism].

### 11.1.3 Solid Model – rendered

The final mode is the full solid model.



The full solid model requires true hidden surface removal – which can be slow.

The prism system above was drawn without a significant pause, but with more complex systems the delay can be noticeable. If the drawing preparation time is above 1 second, then a progress bar will appear to give you an indication of the time remaining.

During hidden surface removal, each polygon is compared with all others and placed in correct depth order [most distant first]. When sorting is finished, the polygons are all drawn, in that order, so the closest polygon to the view-point is drawn last and will overlay any behind it.

The sort process is key to the speed of the solid modelling process. In fact, the speed is in inverse proportion to the (number of polygons)<sup>2</sup>.

Therefore while using the sliders it is probably wise to use a coarse polygon mesh [see next section] with a modest number of rays. Then when the desired view point is achieved, revert to a fine mesh and as many rays as desired.

Naturally, what is acceptable will vary from user to user, so you must experiment using the lens drawing options dialog.

### 11.1.4 Solid Model options

What you see in the final drawing is determined by:

- Level of detail [number of polygons/surface]
- Cross section type
- Colour given to each polygon – which is based upon:
  - base surface colouring
  - ambient [background] light
  - light source[s] colour and direction

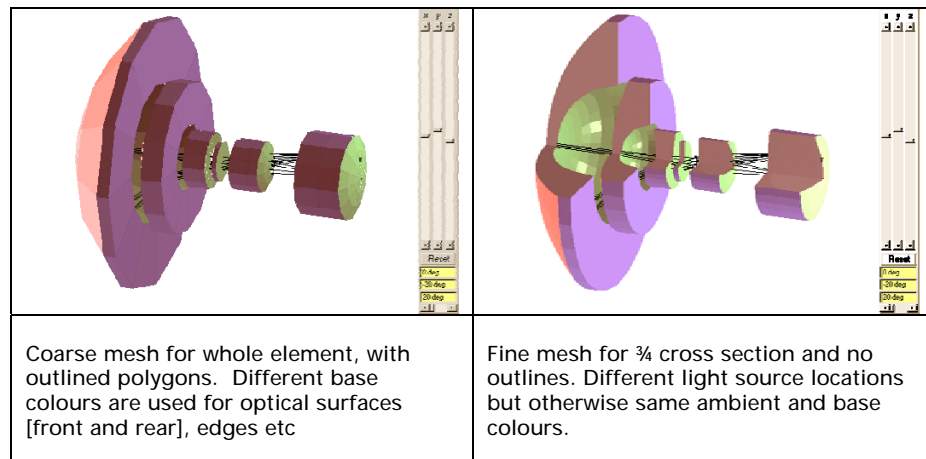
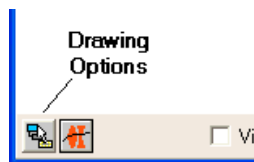
These parameters, and others, can be altered in the lens drawing options dialog. Here we show the same retrofocus lens drawn with different options:

#### Load lens drawing options dialog

1) Right click drawing and select 'options for this drawing'

or

2) Click the leftmost icon on the drawing toolbar panel

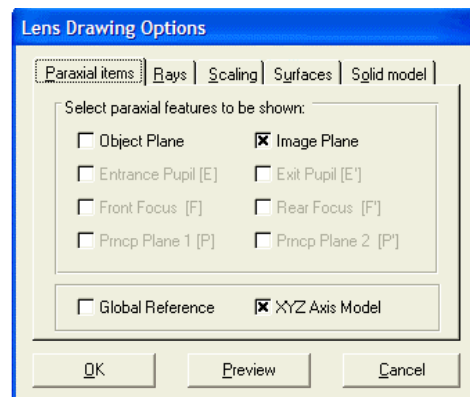


Most of the tabs ['paraxial items', 'rays', 'scaling' & 'surfaces'] are relevant to both 2D and 3D drawings, so won't be discussed here.

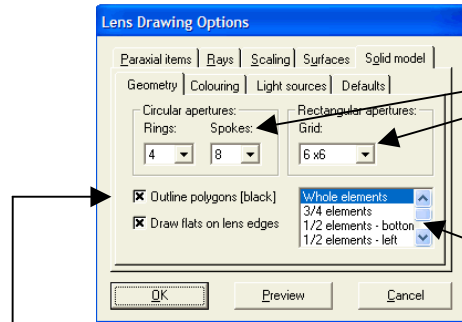
We are mostly concerned with the right most tab 'Solid model'. There are a lot of options, so these have been arranged in 4 sub tabs. We will discuss these in turn overleaf.

On the 'paraxial items' tab you can choose to show/hide

- Global reference axis [blue dotted line]
- XYZ axis model [top left of drawing]



### 11.1.4.1 Solid Model Options: Geometry



This tab determines the details shown in the solid model drawing. Working from the top, we see the mesh control options:

- Circular apertures
- Rectangle apertures

Selecting from the drop-down lists, you can increase or reduce the fineness of the mesh used to model each surface.

The list at bottom right tells WinLens whether to draw whole lenses or a particular cross section.

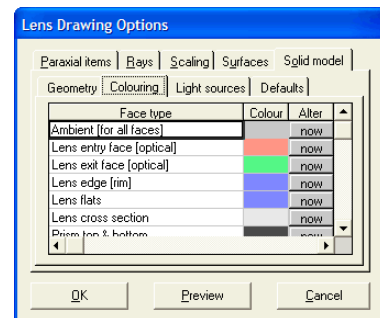
Finally, you can determine, via check boxes

at bottom left whether:

- polygons are outlined
- concave surfaces are drawn with flats or not

Note that rays are not drawn inside material spaces.

### 11.1.4.2 Solid Model Options: Colouring



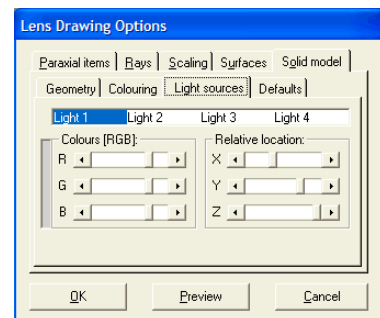
This tab controls the colour of:

- the ambient [background] light
- the base colours for different parts of lenses, mirrors and prisms

The different parts available are named in the list along with the base colour. To alter a colour simply click on the appropriate 'now' button in the 'Alter' column of the spreadsheet. A standard colour dialog will allow you to choose a new colour for that face type.

Don't forget that you can use the 'Preview' button to see the results straight away.

### 11.1.4.3 Solid Model Options: Light Sources



Besides having a background light [which is assumed to fall on all polygons equally], you can also have up to 4 discrete light sources shining from particular locations.

Simply click on the light list to select one of these 'lights'.

You then can use sliders to control

- Colour [Red, Green, Blue]
- Location [relative X, Y & Z]

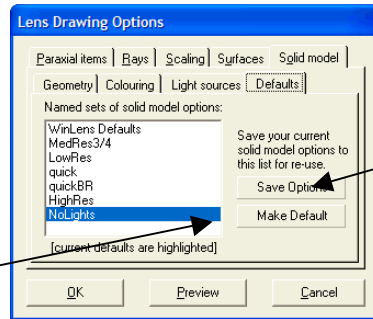
When you adjust one of the sliders the drawing is updated instantly [colouring does

not require re-sorting]

Note that the calculations of final light levels are unphysical in that they do **not** take into account shading of one surface by another.

Thus, in the fine drawing of the retrofocus lens above, one light source was moved to shine back along the z axis, in order to illuminate the concave surfaces of the front elements. Obviously in real life the light would have been almost entirely prevented from reaching the cavities!

### 11.1.4.4 Solid Model Options: Defaults



It can take a little while to obtain a set of solid model options that you like. It would be frustrating to have to continually re-create the settings.

Therefore to time and labour, you can save the current values as a named set. You will be asked for a name:

- If you elect to use the current name, the values in the current named set will be overwritten [unless it is the 'WinLens defaults'].
- If you supply a new name it will be added to the list.

To recall the values in a named set, simply click on the list and those values will be applied to the current drawing

You can then make any named set to be the default that will apply to any new drawing and that that will apply on program load.

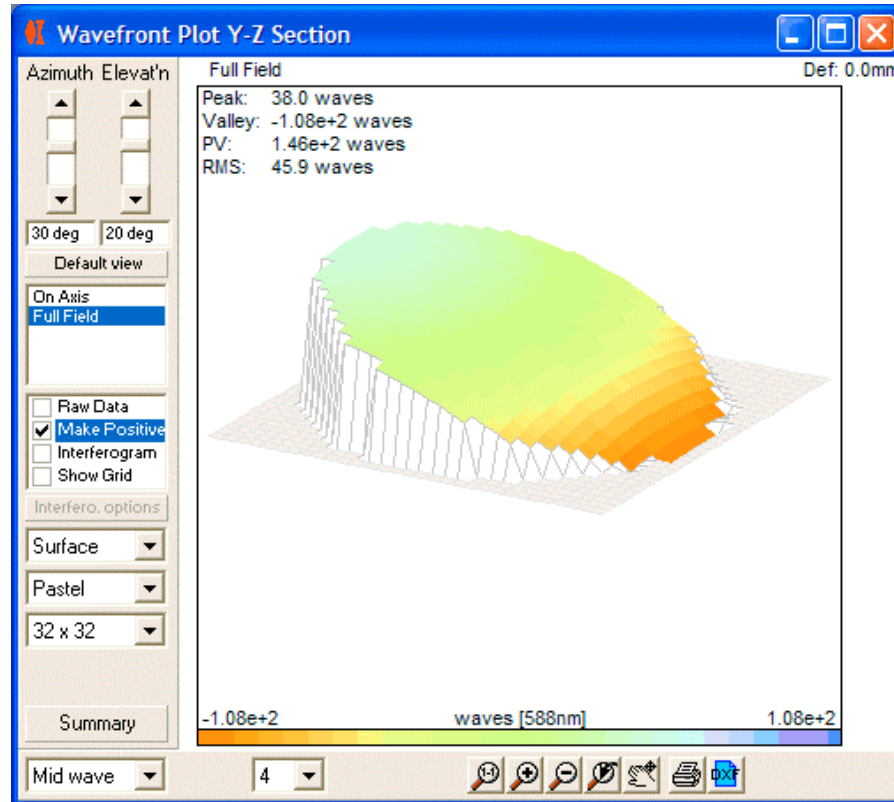
NB this only applies to solid model options



## 11.2 3D Wavefront plot

[accessed via the 'graphics' menu item: 'wavefront 3D']

In previous versions of WinLens the wavefront from any object was only displayed in two orthogonal azimuths in the OPD plot. We can now display the entire wavefront in a 3D surface plot [straight or as in interferogram].



The graphic, at any one time, shows the data for one field point at one wavelength. In detail we will see:

- Numerical data
- 3D Surface
- Colour gradient

The data is obtained from the rings of rays traced for spot diagram/MTF calculations. Unfortunately surface fitting routines require a exactly regular grid of values in x,y. Therefore the raw data is fitted to polynomials. These polynomials are then used to create the necessary grid of values, with which we plot the surface itself.

There are a lot of options available in the left hand side bar, including changing colours etc. Working from top to bottom:

**View Angles:** sliders to rotate graphic

**Field Position:** list of field points used to analyse this system [click to select]

**Data display options:** this list of independent checkboxes enables some quite important options:

- 'Raw Data' - displays the raw datapoints using small circles.
- 'Make Positive' - adds a positive offset to all raw datapoints, so that they are positive. This sometimes help display features of the wavefront
- 'Interferogram' - forces the data to be shown in interferogram form. Only worthwhile if the PV is less that a few wavelengths.
- 'Show Grid' - edge each cell with a black border

**Interferogram options:** if you have chosen to display the wavefront as an interferogram, this button will access some further options. You can make the interferogram single or double pass. You can tilt the interferogram in x or y direction.

**Display Type:** you may display the data as the default surface plot, as a wireframe [no colouring] or as transparent [only bother with this if you are displaying raw data].

**Colouring Schemes:** we offer a whole range of colouring schemes – choose one that you like, or displays the data to best advantage.

**Grid size:** You can choose to fit the data to more or less coarse grids. Obviously a coarser grid will be quicker to display and update, but will give rougher looking results [particularly for the interferogram where we may see rapid colour oscillations over a short distance].

**Summary button:** shows the polynomial coefficients.

### 11.3 Global co-ordinates table

[accessed via the 'table' menu item: 'Global coordinates']

This table provides global co-ordinates and surface direction cosines for each surface vertex. The global co-ordinate origin is the origin of the first surface [assuming it has no tilts or decenters].

GLOBAL  
COORDS

#	Srf	X	Y	Z	L	M	N
1	*	0.0000	0.0000	0.0000	0.000000	0.000000	1.000000
2	2 Lens	0.0000	0.0000	0.0000	0.000000	0.000000	1.000000
3		0.0000	0.0000	2.0000	0.000000	0.000000	1.000000
4	4 prism	0.0000	0.0000	12.0000	0.000000	-0.642788	0.766044
5	M	0.0000	-3.6736	27.3787	0.000000	-0.996195	0.087156
6		0.0000	2.6147	41.8858	0.000000	-0.766044	-0.642788
7	6 thinlens	0.0000	0.0000	52.0000	0.000000	0.000000	-1.000000
8		0.0000	0.0000	52.0000	0.000000	0.000000	-1.000000
9	Img	0.0000	0.0000	93.5439	0.000000	0.000000	-1.000000

### 11.4 Single Ray Table

[accessed via the 'table' menu item: 'Single Ray']

Previously single rays were traced from objects along the y-axis. Now you may trace from an object anywhere in the x,y plane.

#	Srf	Z	X	Y	L	M	N	SinU
0	Obj	0.00000	12017.740519	30044.350850	-0.11433565	-0.28583913	0.9514323	0.30785817
1	S	0.05599	0.519491	1.298727	-0.08111364	-0.20278410	0.9758582	0.21840517
2	S	2.94887	0.279034	0.697584	-0.08203284	-0.20508209	0.9753010	0.22088017
3	S	3.90767	0.198389	0.495971	-0.12516220	-0.31290548	0.9415012	0.33700952
4	2 *S	5.40000	0.000000	0.000000	-0.12516220	-0.31290548	0.9415012	0.33700952
5	S	6.88890	-0.197933	-0.494832	-0.08780567	-0.21951417	0.9716500	0.23642399
6	S	8.01754	-0.299925	-0.749813	-0.08147730	-0.20369324	0.9756385	0.21938433
7	S	9.74981	-0.444590	-1.111475	-0.11230261	-0.28075653	0.9531862	0.30238404
8	Img	106.30394	-11.749726	-29.374315	-0.11230261	-0.28075653	0.9531862	0.30238404

Field X: horizontal [0.2]    Field Y: vertical [0.5]    Apt X: [0.0]    Apt Y: [0.0]     Global Coords    Mid wave

Remember, these rays are specified as fractions of:

- the object [field] size
- the paraxial aperture

This also has a checkbox option to display local [default] or global co-ordinates for the ray being traced.

## 11.5 Graph enhancements

In previous version of WinLens, all systems had at least 2 orthogonal planes of symmetry – most would have had rotational symmetry. For such systems, off-axis object would have wavefronts that are left right symmetric in the aperture.

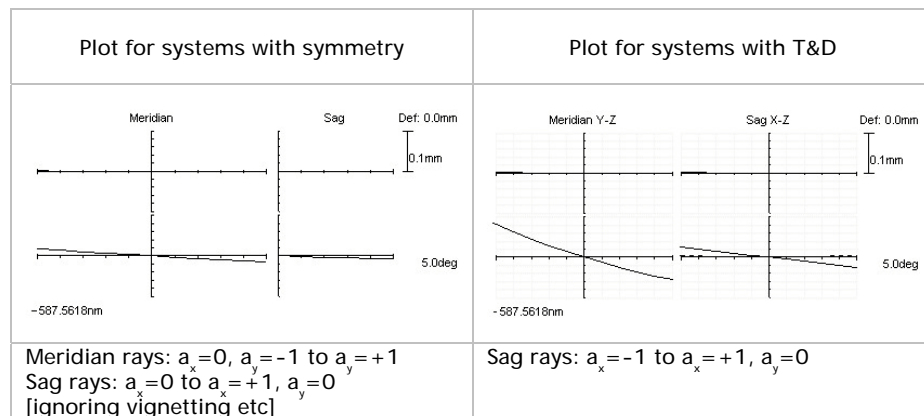
Also the ray trace data from a ray coming from some point above the axis will be identical to its mirror image ray below the axis.

Neither assumption apply to systems with T&D [in general]. We have therefore modified various graphs to provide a more thorough analysis. These are described below.

*Don't forget if you want to quickly analyse the performance along other object field azimuths, use the system rotator [chapter 4.2]. This rotates the glassware, but not the object points, about the z axis.*

### 11.5.1 Aperture aberration plots

These plots shows TRA, OPD & Longitudinal aberrations which vary across the aperture [and are also field dependant].



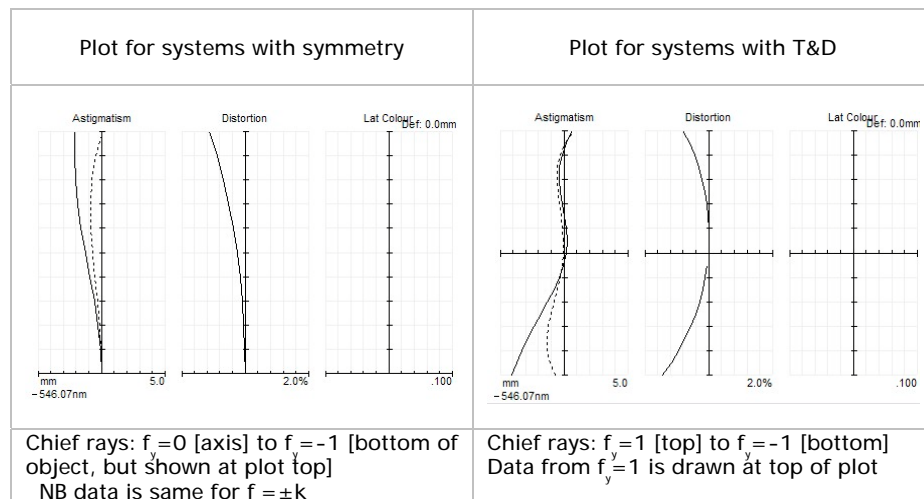
Note 1: the ray fans used to generate these plots are those shown in the lens drawing. They are traced from objects placed along the y-axis & cover the field fraction range  $f_y=0$  [axis] to  $f_y=-1$  [bottom of object].

Note 2: The reason for using objects with  $f_y < 0$ , rather than  $f_y > 0$ , is historic - it meant that the 2D lens drawing usually shows a positive image.

### 11.5.2 Field Aberrations plot

This plot shows astigmatism, distortion and lateral colour

Previously this was plotted for chief rays traced from  $f_y=0$  to  $f_y=-1$





Note 1: Distortion calculation - we subtract the bore sight error [axial chief ray coords] from the chief ray coords, before calculating distortion.

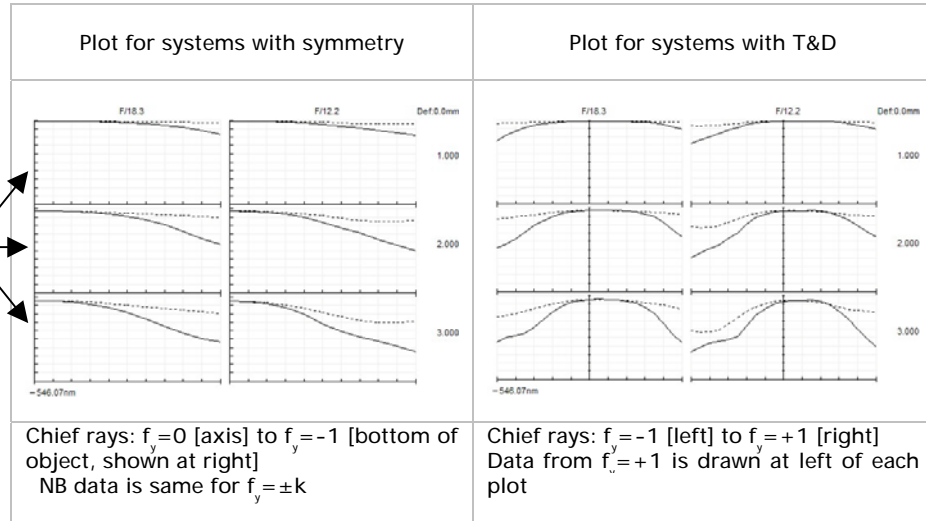
Note 1: Distortion calculation is somewhat problematical in systems with T&D as it depends upon comparing the real & paraxial ray heights. The paraxial analysis takes no account of T&D. However, you may now see the raw data in the summary table should you wish to use some other definition.

Note 2: Distortion calculations 'blow up' at the origin. For systems with no T&D, distortion is set to zero; for systems with T&D the axial value is not plotted.

### 11.5.3 MTF v Field, relative illumination

In these plots, the system performance is analysed for the same objects used in the field aberration plot. However the results are arranged with field values shown horizontally instead of vertically.

MTF v Field for three different spatial frequencies [user selected]



### 11.5.4 Full field spot and full field distortion

These show the spot patterns and distortion from a user defined rectangular grid of objects points [regular in object height].

