Section 9
Tilted and Decentered Systems

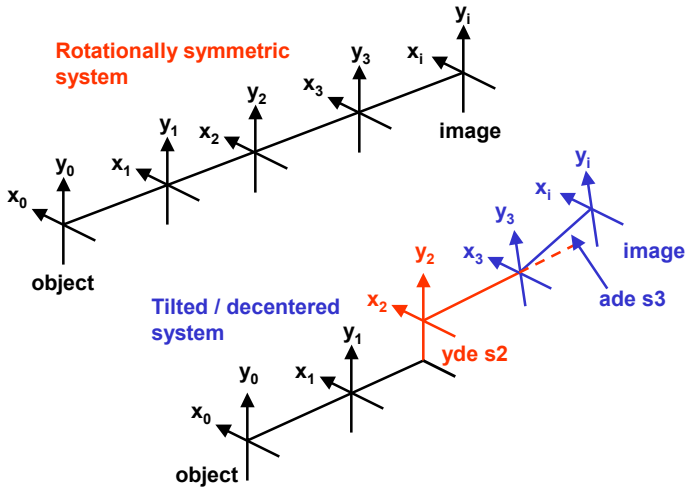
OPTICAL RESEARCH ASSOCIATES
3280 East Foothill Boulevard
Pasadena, California 91107 USA
(626) 795-9101 Fax (626) 795-0184
e-mail: service@opticalres.com
World Wide Web: http://www.opticalres.com

Decentered Systems - Philosophy

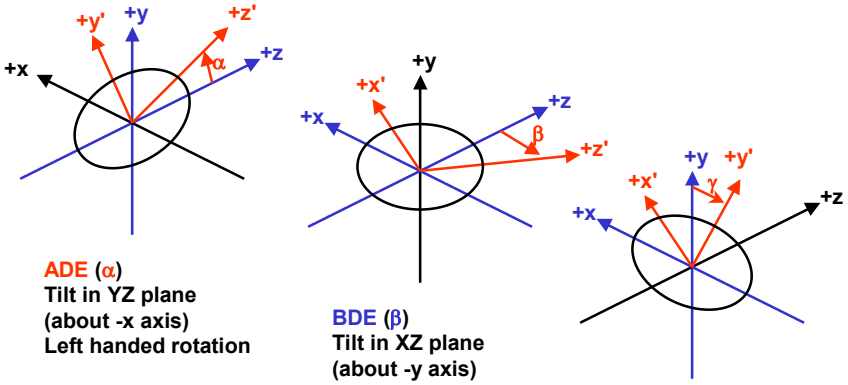
- Surfaces in CODE V are always centered on their local coordinate system
- When we "tilt or decenter a surface" we are actually tilting or decentering the local coordinate system in which the surface is defined
- The coordinate systems for surfaces following the tilted/decentered surface are aligned to the tilted/decentered system until changed
  - Thus, multiple tilts and decenters are cumulative
- Thus, the z-axis defines a "mechanical reference axis" which is not necessarily the optical axis

Decentered Systems

- Each surface has its own local coordinate system



Tilt Sign Conventions



ADE (α)
Tilt in YZ plane
(about -x axis)
Left handed rotation

BDE (β)
Tilt in XZ plane
(about -y axis)
Left handed rotation

CDE (γ)
Tilt in XY plane
(about +z axis)
Right handed rotation

Order of Operations

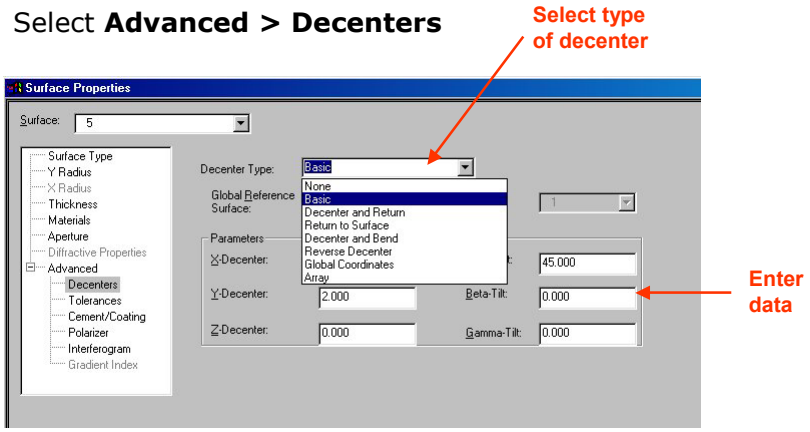
- For normal type decenter
  - Translate from previous surface (by **THI**)
  - Decenter by **XDE**, **YDE**, **ZDE** (order does not matter)
  - Tilt by **ADE** (alpha) in coordinate system defined above steps
  - Tilt by **BDE** (beta) in coordinate system defined above steps
  - Tilt by **CDE** (gamma) in coordinate system defined above steps
  - Refract, reflect, or diffract the ray
  - Translate to next surface (**THI**) along z-axis defined by above steps
- If **Decenter and bend** type decenter **(BEN),** repeat **ADE**, **BDE**, **CDE** tilts before translating to next surface
- If **Decenter and return** type decenter (**DAR**), return to starting coordinate system before translating to next surface
- To alter the order of the above operations, you may need to use multiple dummy surfaces with one operation per surface

Types of Decenters

- **Basic type** (**DDA**)
  - New axis defined for current and succeeding surfaces
- **Decenter and Return** (**DAR**)
  - New axis defined for current surface only
- **Return** (**RET**)
  - Returns coordinate system to those of a previous surface
- **Decenter and Bend** (**BEN**)
  - Adds another set of tilts after the current surface
  - Only used on fold mirrors
- **Reverse** (**REV**)
  - Defines new axis for succeeding surfaces, but NOT for the current surface
- **Global** (**GLB**)
  - Surfaces are oriented globally relative to some specified surface

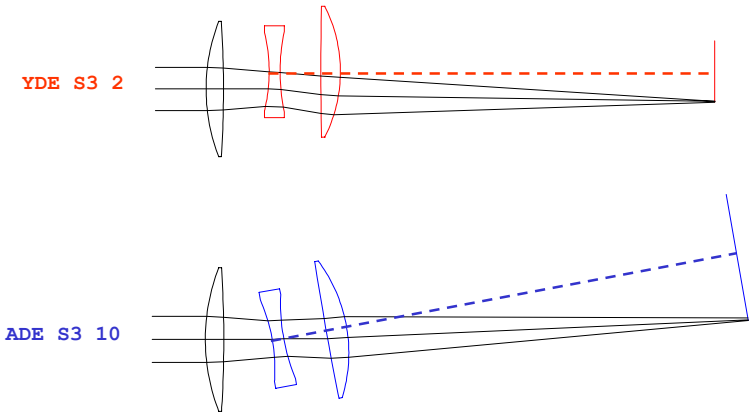
Entering Tilts and Decenters

- Open **Surface Properties** dialog box (**Lens > Surface Properties** or right click on LDM spreadsheet cell)
- Select **Advanced > Decenters**



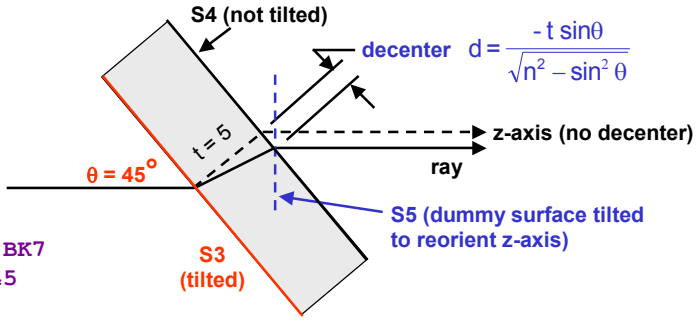
Basic Decenter and Tilt

- A new axis is defined for current and succeeding surfaces



Example - Tilted Plate

- On-axis chief ray does not follow z-axis
  - Requires decenter to align z-axis with ray

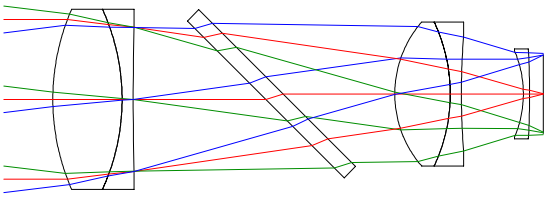


Input:

```
S3 0 5 BK7
  ADE 45
S4 0 0
S5 0 (thi)
  YDE -2.625
  ADE -45
```


Workshop 11 - Tilted Plate

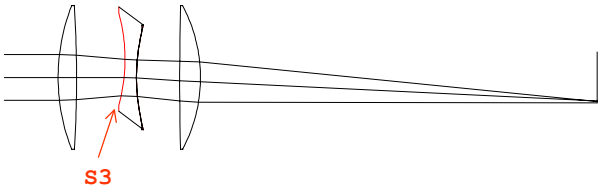
1. Restore the CODE V standard Petzval lens (**File > New** and in the New Lens Wizard start with **CODE V Sample Lens** and choose **cv_lens:petzval.len**). Change the field specification to 0°, -7°, 7°.
2. Insert a 5 mm thick BK7 beamsplitter at 45° approximately halfway in the middle airspace. Make a picture to be sure you have inserted it correctly.
3. Freeze all the variables. Make the decenter on the back side of the tilted plate a variable and use **Optimization > Automatic Design** to compute the decenter necessary so the on-axis chief ray is centered on the rear set of lenses. Trace the on-axis chief ray to verify the ray is centered.



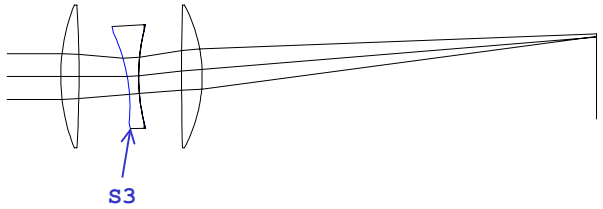
Decenter and Return (DAR)

- Only the current surface is tilted and/or decentered
  - Acts as a temporary tilt for just one surface

```
YDE S3 2
DAR
```

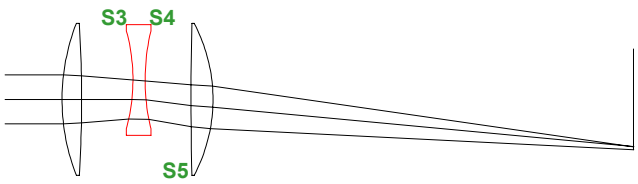



```
ADE S3 10
DAR
```



Usually More Than One Way to Tilt and Decenter

- Only middle element decentered up by 2.0



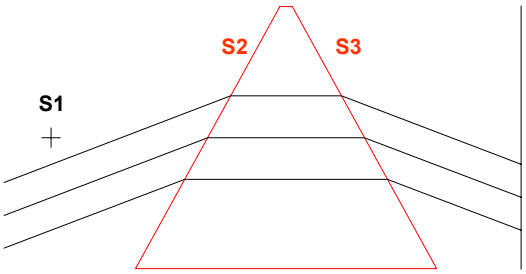
- Two ways:

```
YDE S3 +2
YDE S5 -2
```

or

```
YDE S3 2
DAR
YDE S4 2
DAR
```

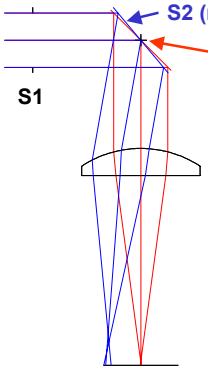
DAR Example - Prism




```
LENS
EPD 2
DIM M
YAN 20
WL 587
S1 0 5
S2 0 5 LLF6
  STOP
  !Tilt & return
  ADE -30
  DAR
  !Add rectangular
   aperture
  REX 4; REY 4
S3 0 5
  !Tilt & return
  ADE 30
  DAR
  !Add rectangular
   aperture
  REX 4; REY 4
GO
```


DAR Example - Scanning Mirror

- A scanning mirror changes its orientation while the surrounding optics remain fixed in position
  - Results in a scanning of the input beam (fixed output ray direction) or scanning of the output beam (fixed input ray direction - shown below)



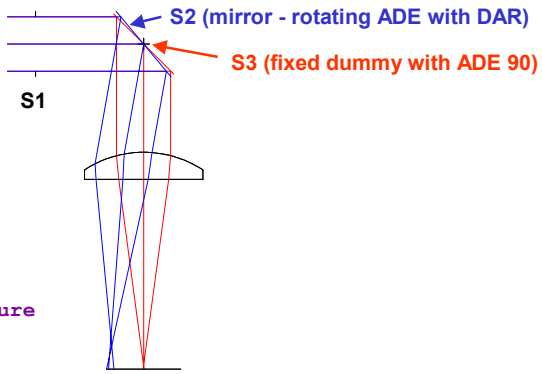
Lens Data Manager

Surface #	Y Radius	Thickness	Glass	Refract Mode	Y Semi-Aperture	Non-Centered Data
Object	Infinity	Infinity		Refract		
Stop	Infinity	20.000		Refract	5.000	
2	Infinity	0.000		Reflect	7.071	Decenter & Return
3	Infinity	-20.000		Refract	5.000	Basic Decenter
4	-20.000	5.000	BK7_SCHOT	Refract	10.000	
5	Infinity	-35.071 S		Refract	4.617	
Image	Infinity	0.000		Refract	0.094	

End Of Data

DAR Example – Commands

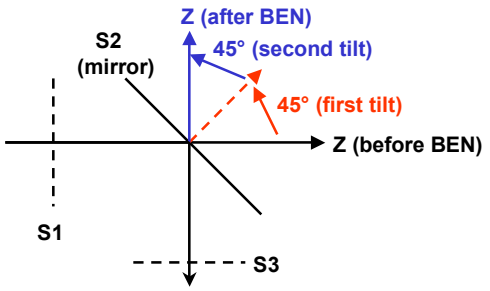
```
LENS
EPD 10; WL 500
S1 0 20
  STOP
S2 0 0 REFL
  ADE 45; DAR
S3 0 -20
  ADE 90
S4 -20 -5 BK7
  CIR 10 !Circular aperture
S5 0 0
  PIM
GO
```



Decenter and Bend (BEN)

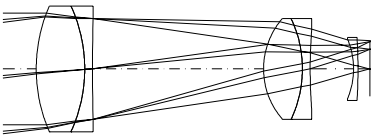
- Used for convenience in entering fold mirrors
  - Eliminates the necessity for an extra dummy surface to follow the light
  - Do NOT use on scanning mirrors (will not keep following optics fixed)
- Adds an additional, equal tilt after reflection

```
S1 0  10
S2 0 -10 REFL
  ADE 45
  BEN
S3 etc.
```



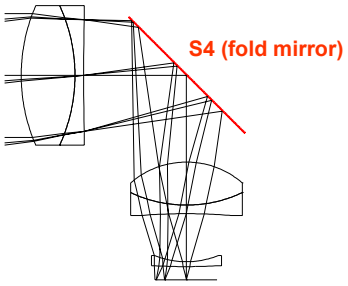
BEN Example - Fold Mirror

- Start with Petzval lens (**File > New > CODE V Sample Lens > cv_lens:petzval.len**)



- Insert a fold mirror inside center thickness

```
TIN S3 -35
INS S4 0 35 REFL
SCA FAC S4..I -1
ADE S4 45
BEN
```



BEN with Compound Tilts

- When both an **ADE** and **BDE** are applied to a **BEN** surface, there is a rotation of the XY plane after the bend
- CODE V automatically adds a **CDE** to keep the orientation of the XY plane

$$\cos(CDE) = \frac{\cos(ADE) + \cos(BDE)}{1 + \cos(ADE)\cos(BDE)}$$

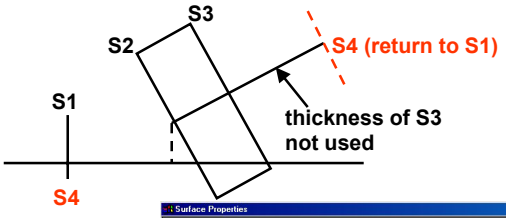
$$\sin(CDE) = \frac{-\sin(ADE)\sin(BDE)}{1 + \cos(ADE)\cos(BDE)}$$

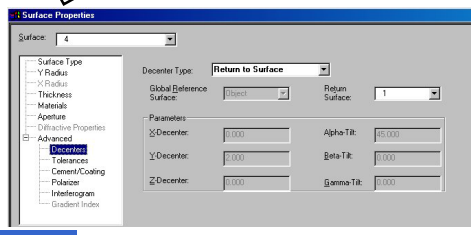
- The effect is to rotate the system following the **BEN** surface so a meridional ray remains a meridional ray in the following surfaces
- If this is not wanted (e.g., the following surfaces are not rotationally symmetric), then do not use a **BEN** and use a dummy surface to apply the second set of tilts

Return Surface (RET)

- Returns a surface to the coordinate system of a previous surface
  - Normally applied to a dummy surface, but can be a real surface
  - Automatically undoes all intervening decenters and tilts and thicknesses

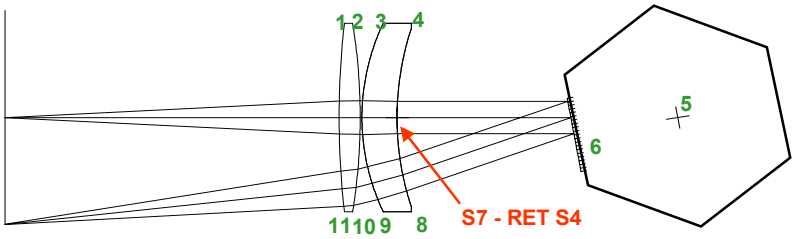
```
S1  0  10
S2  0  5  BK7
  YDE  3
  ADE  30
S3  0  10
S4  0  (thi)
  RET  S1
```





RET Example - Double Pass Scanner

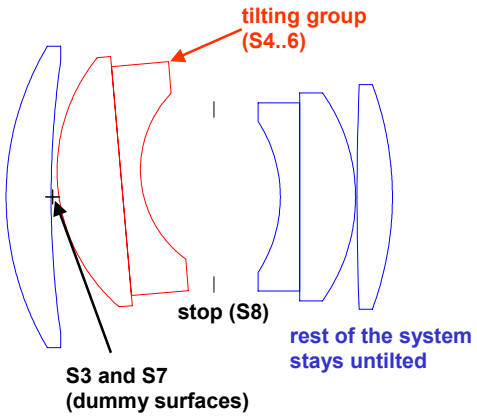
- Surfaces S8..11 are physically the same as surfaces S1..4
- Surface S7 is a dummy, returned to S4



RET Example - Displacement Analysis

- Needs a dummy surface at the start (for the reference) and another after (for the **RET** surface)
- Example - displace and tilt surfaces S3..5

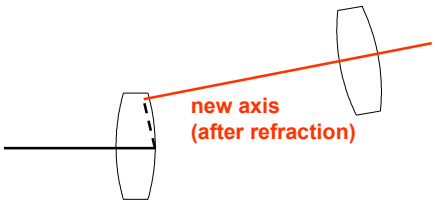
```
INS S3
INS S7
THI S7 (OAL S3..7)
RET S7 S3

XDE S4 Δx
YDE S4 Δy
ZDE S4 Δz
ADE S4 Δα
BDE S4 Δβ
CDE S4 Δγ
```



Reverse Decenter (REV)

- New axis is defined AFTER refraction, reflection, or diffraction at the current surface
  - New axis affects succeeding surfaces, but not the current surface
- Order of operations is reversed, and opposite signs are used
  - Tilt by **-CDE**, then by **-BDE**, then by **-ADE**, then decenter by **-XDE**, **-YDE**, and **-ZDE**
  - Designed to allow undoing of a specific normal decenter and tilt
    - **RET** surface can often be used for same operation

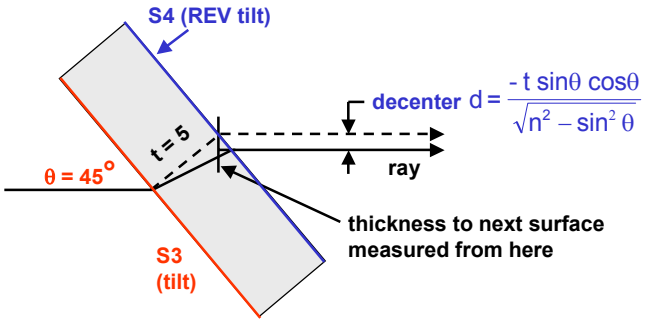
```
YDE S2 -20
ADE S2 -10
REV
```



REV Example - Tilted Plate

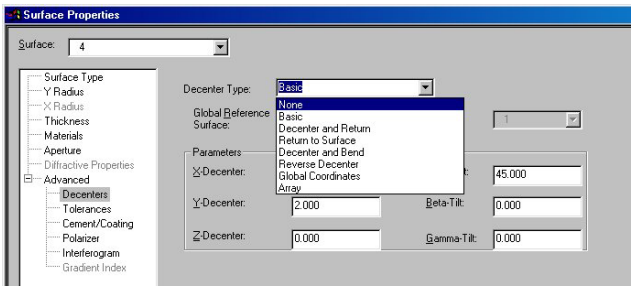
- A tilted plate can be modeled without the need of an extra dummy surface
  - Care needs to be made in understanding vertex locations and thicknesses

```
S3  0  5
  ADE  45
S4  0  (thi)
  YDE  1.856
  ADE  45
  REV
```



Deleting Decenter Data

- Setting decenter data to 0 does not delete the decenter itself. CODE V still treats this as a decentered surface
- In **Surface Properties** dialog box, change **Decenter Type** to **None**



- In command mode, use `DEL DDA Sk|Si..j` (delete decenter data)
  - Can also delete special decenter type
  - `DEL DAR`, `DEL BEN`, `DEL REV`, `DEL GLB`

Tips for Decentered Systems

- **Display > View Lens** option is extremely helpful in verifying correct setup
- Use only **YDE** and **ADE** if possible
  - Symmetry is maintained in X direction (faster analysis and optimization)
  - VIEW will show full effects of tilts/decenters
- Global coordinates of each surface can be listed relative to a given origin
  - Select **Display > List Lens Data > Global Coordinates**
  - Command is `GSC`
- Ray trace output can be local or global
  - Select **Analysis > Diagnostics > Real Ray Trace**, click on **Global Coordinates** tab
  - Command is `GLO Sk`
- Use **RET** surface to restore coordinate system to known coordinates
  - Useful in scanning systems
  - Useful after compound tilts or decenters

Workshop 12 - Right Angle Prism

1. Restore the CODE V standard Petzval lens again. Change the field specification to 0°, -7°, 7°. Save this lens as "petzval2.len"
2. Insert a right angle prism reflecting downward between the two lens groups. The prism should have a face width of 50 mm and be made of BK7 glass. Hint: scale the part of the lens after the prism by a factor of -1 to account for the sign change after reflection.
3. Adjust the air spacings on either side of the prism to be equal and to account for the optical thickness of the prism (the prism will occupy an equivalent air thickness of 50/n, where n is the index of the prism, 1.516798). This will maintain the focal length at its original value.
4. Set appropriate edge apertures (**REX EDG** and **REY EDG**) on the prism faces and prism hypotenuse to get a "nice" picture. It should look like the Figure on the next page.
5. The CODE V supplied macro, **RTANG.SEQ** , can also be used to accomplish steps 2 through 4 more efficiently. Restore petzval2 and choose **Tools > Macro** and click the browse button (**...**). This should open in the C:\CODEV900\macro folder; if not, navigate to this folder, open **RTANG.SEQ** and **Run**. (Or at command prompt enter `in cv_macro:rtang`.) Enter "4" for the surface number, enter "50" for the face length, and click **OK**.

Workshop 12 - Right Angle Prism (cont.)