1.1.1 Alignment

The alignment of the calibration unit is done with the source sitting in the center of the ASM. This source is fed by a fiber routed through the ASM. As a first step the position and tilt of the unit must be measured. This is done by the following procedure:

The CalUnit is moved into the beam of the ASM on-axis source. By shifting and tilting the ASM the beam is moved onto the default position on LUCIFER. Then again by shifting and tilting the ASM the coma, as measured on the FLAO, is removed from the beam while the beam still is kept at the default position.
The final position of the ASM with respect to the default position yields the shift of the CalUnit, as this shift is exactly the shift of the ASM.
As the coma on the beam is analized the contributions to it from the ASM and the CalUnit must add up to the value measured on LUCIFER/FLAO.
This implies (as also verified in the ZEMAX design) that CalUnit and ASM have the same focus (see Figure 1. This further implies that the ratio of the tilt of the ASM over the tilt of the CalUnit is minus the ratio of the distances to the common focus., e.g. the distance of the ASM to the prime focus is 1063 mm and that of the Calunit 32 mm., so if the ASM is tilted by 0.01 degrees the CalUnit is tilted by – 0.33 degrees.
Now the CalUnit is moved out of the beam and given the right shift and tilt within the achievable accuracy that must be 1mm in x-y-shift and 1’ in tilt.
This procedure is repeated until the CalUnit shift and tilt are within the specified values.

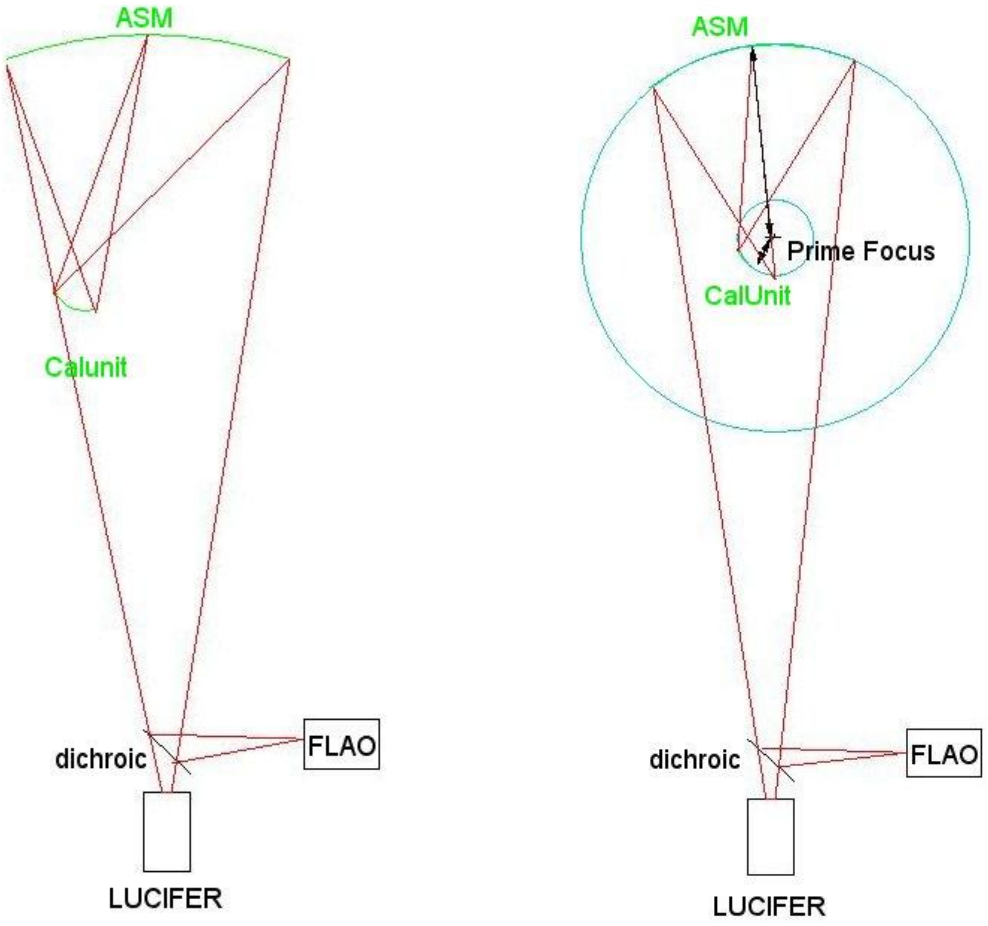

Figure 1 Left: The telescope, LUCIFER, and FLAO are aligned, the CalUnit is moved into the beam. Right: After removing the coma from the beam and centering the spot on LUCIFER the CalUnit and the ASM sit on circles around the prime focus with distances of 32.4 mm and 1063.15 mm. The ASM sits exactly above the CalUnit so the tilts of the two elements can be calculated from the focal distances.

The actual position and tilt of the CalUnit is now known.
To further align the system the ASM is shifted such that it is centered over the CalUnit. Then M3 is rotated and given a piston until the beam is back on the default position. The exact values can be calculated from the tilt of the CalUnit. Now the optical axis downstream M3 is the same as on-sky. Afterwards the off axis sources are swiched on and the position on the wavefront sensor is checked regarding a rotation around the optical axis with respect to the WFS. This rotation is removed by rotating the CalUnit around its optical axis. Finally the focus is checked in the ARGOS WFS. The WFS should already be internally focussed to the right value.
There are a few issues still to be discussed:

- The fiber in the ASM can be displaced by a fraction of a milli meter
- The measurement of the aberrations is not perfect
- The measurement of the spot position on LUCIFER is not perfect.

These three issues can be solved as follows:
The alignement is done as described above. Afterwards the off-axis sources in the CalUnit are used and the aberrations measured with the ARGOS WFS. Any discrepancy of the default values (which are

known) will show the remaining misalignment of the CalUnit. From the ZEMAX design one knows what the discrepancy means, e.g. the sign of the difference between the measured values and the default values yields the direction of a wrong tilt/shift.
So with a few iterations the CalUnit should be well aligned.
After this procedure the residual tilt of the CalUnit yields 0.2 radian aberrations with respect to the default aberrations.
This value is well below the specification of $\lambda/10$.
As the tilt of the CalUnit should be very stable and only the position might change with temperature.
Any new alignment is fast as it contains only a measurement of the position by shifting and tilting the ASM, and then retilting the ASM, rotating and pistoning M3 and refocusing of the WFS.