LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY

-LIGO-

CALIFORNIA INSTITUTE OF TECHNOLOGY

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aLIGO Optical Lever Telescope Assembly Procedure

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Introduction

In this report we describe the telescopes which launch a fiber fed, single mode (670 nm CW) fixed common source beam into free space. Each telescope is designed to focus this fiber- end beam to a waist at the position of its intended photo-detector (after having reflected off the center of its monitored component). This entire focal distance (“throw”: see table 1) varies from ~4m to ~66m depending on the optic (or HAM table) being monitored. A single telescope structure has been designed to encompass this range, with the variation of focal distances being accommodated by the adjustment of its two lens positions and the incorporation of three different focal length (100, 200 and 300mm) objective lenses. The overall description and assembly concept for this family of telescopes is shown in Fig. 1 (LIGO-D0901362-v2). Full advantage has been taken of standard commercial (Thor-Labs) mounting components (see drawing parts list) from which each telescope is entirely constructed.

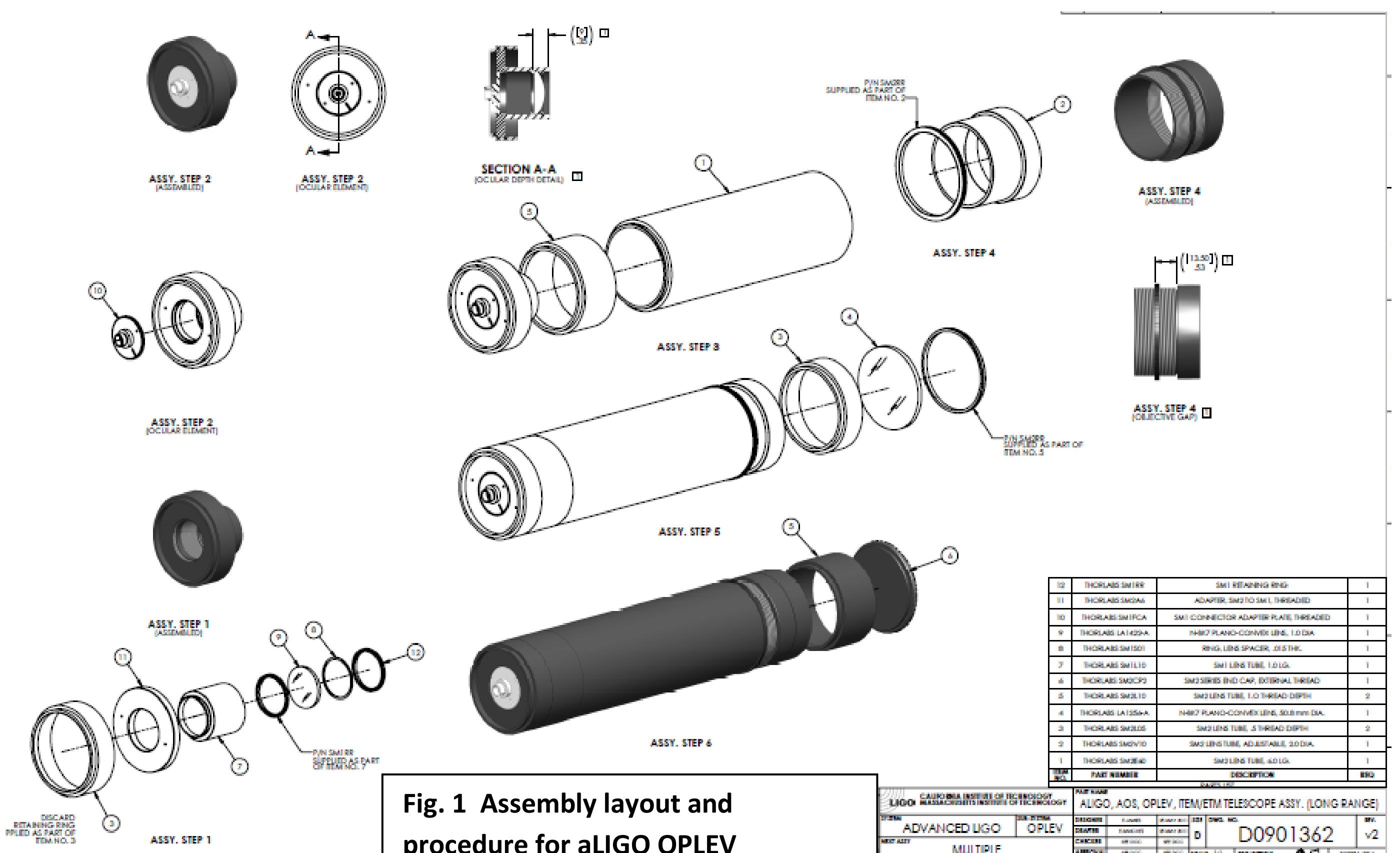


Fig. 1 Assembly layout and procedure for aLIGO OPLEV telescopes (specifically Long version

Optical design

The requirements for the optical design of the lever subsystem (including these telescopes) is presented in LIGO-T1000219 v2. This specifies that the launched beams come to an approximate waist of ϕ 2mm (Gaussian *w*) at the front surface of the sensing element (Q PD). The basic design of a telescope to propagate to such a waist starting from the beam exiting a single mode laser power distribution fiber was developed assuming Gaussian beam propagation throughout. These calculations result in the table of telescope lens focal lengths and spacings of LIGO-E1300254-v5/6. Figure 2 illustrates the associated physical design (note the specified "Ocular depth" and "Objective gap" lengths called out in the drawing and table).

A two lens ("Ocular" plus "Objective") telescope design was found to suffice for all monitoring configurations. In all telescopes the "Ocular" lens is a 40 mm focal length, ϕ 1" plano-convex fused silica element. Depending on monitoring distance, the "Objective" lenses are 100, 200, or 300 mm focal length (ϕ 1,2 " depending on mounting, see below) plano-convex fused silica elements. With these element choices all Gaussian beam focal distances are accommodated with simple threaded tube sectional adjustment of the telescope shell. Setting the "Ocular depth" (see figure 2 and table 1) adjusts the distance between the fiber end and the ocular lens plano surface. Since this lens is recessed within the fiber capture sub-assembly (Assy. Step 2; section A-A of D0901362-v2) this setting is achieved with the aid of a special recessed lock-ring adjustment tool (see fig. 3).

Setting the "Objective gap" adjusts the spacing between the two telescope lenses. This is achieved by means of the threaded outer shell pieces, and fixed with the associated lock-ring (see Fig. 4). This threaded adjustment does not provide sufficient range for all telescopes. Therefore there are two versions: "Long Range" (as specifically shown in D0901362-v2, and as indicated in table 1); and "Short Range" (same as D0901362-v2 except that tube component #1, Assy. Step 3 is 3.0" long). Since this outer shell "Objective" gap is far easier to adjust, it has been found adequate for fine tuning, in-situ, the completed telescope for any necessary correction to its throw (compensating for inaccuracies in setting the "Ocular depth").

For the BS optic levers a mechanical mounting interference issue precluded this ϕ 2" tube telescope design. Therefore a special third telescope shell design (LIGO-D1201110-v1) was developed for just the BS situation, using the same ocular lens but a smaller diameter objective. For this too the components are all standard Thor-Labs. units.

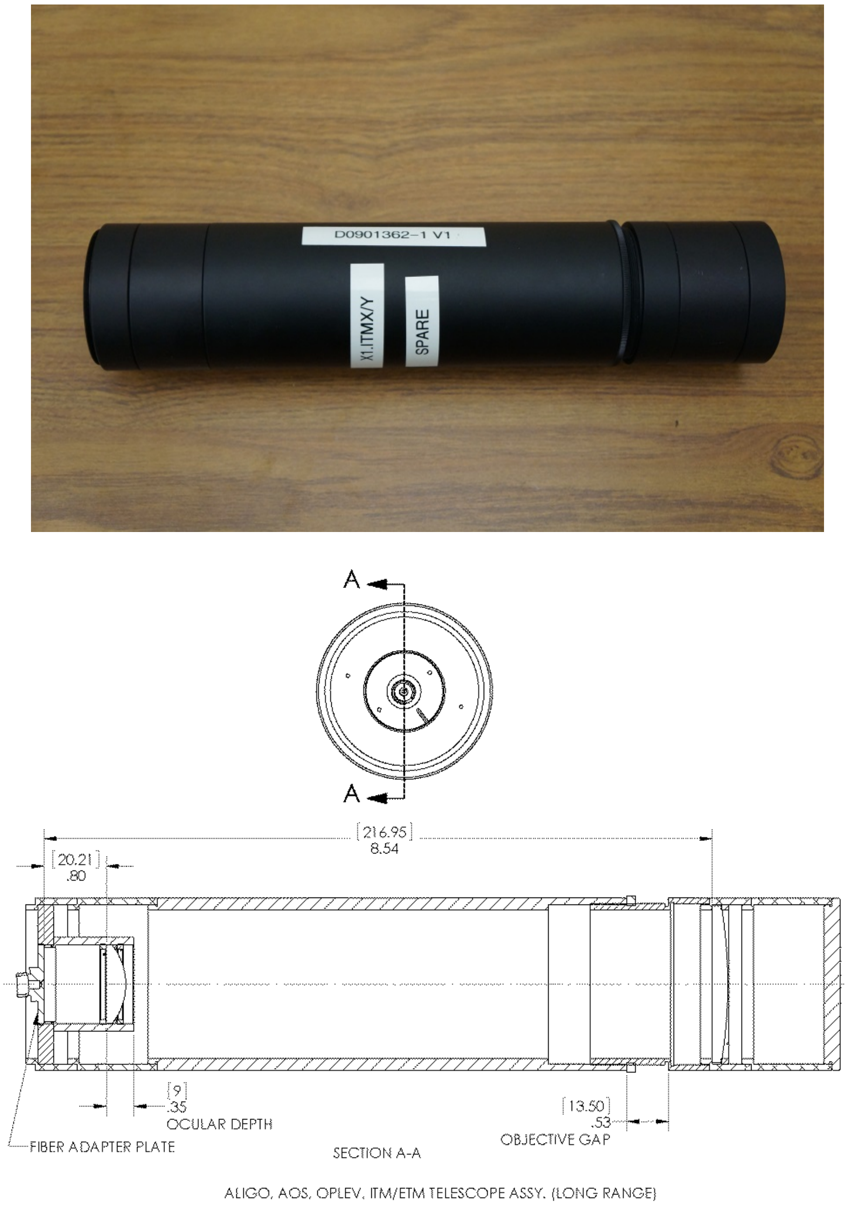


Fig. 2 A photo of the typical telescope assembly with internal optical layout.

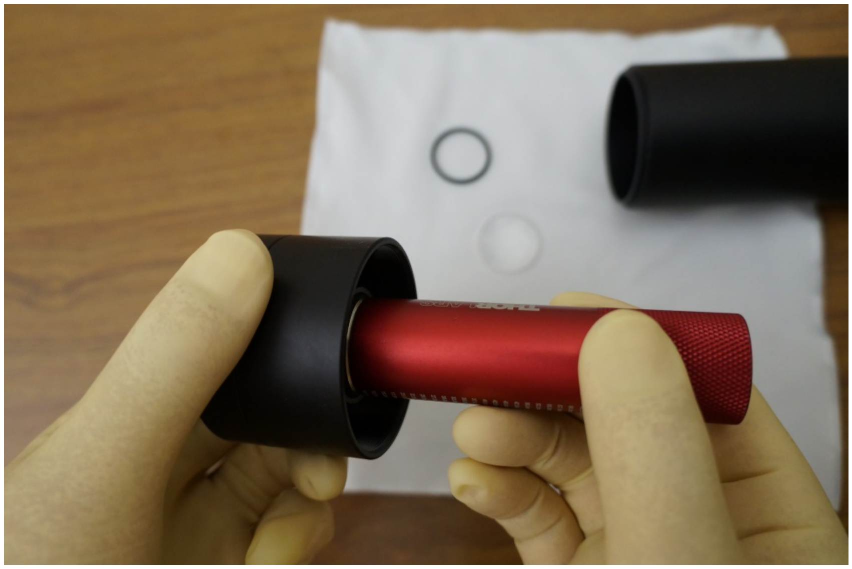


Fig. 3 Adjustment of the ocular depth. The ocular lens is fixed between two rings inside its mounting tube. To adjust the outer ring and lens must first be removed. The inner ring, which defines the “ocular depth”, may then be screwed in/out(0.635 mm/turn) using the special tool.

Fig. 4 Adjustment of the objective gap. The adjustment of the objective gap is straight forward by releasing the lock ring which holds the 2” objective mount tube fixed, then turning it (0.635 mm/turn).

Assembly of Telescope Components

Each telescope is basically a sectioned, continuous mounting tube consisting of pre-fabricated cylindrical sections designed to screw and lock together. This is entirely described in the assembly views detailed in LIGO-D0901362-v2 (Fig. 1). The most convenient order of assembling these parts is indicated also in this drawing. Figure 2 is a cross section view of a complete assembled “Long Range” unit. A preliminary drawing of the special BS telescope mounting is given in LIGO-D1201110-v1 (less the fiber mounting sub-assembly, which is identical to that in the other units). Its assembly proceeds similarly.

drawing no.		serial no.	destination	throw	ocular depth	objective focal length	objective gap	ICS entry
D0901362-1 v1		001						ASSY-D0901362-1-001
		002	I1.ETMY	11.2m				
		003	I1.ETMX	11.2m				
		004						
	short	005	L1.ETMX	11.2m	8.5mm	200mm	14mm	
	short	006	L1.ETMY	11.2m	8.5mm	200mm	11.5mm	
		007						
		008						
		009						
		010						
		011	I1.HAM3	26.6m				
		012	L1.HAM4	26.6m				
		013	L1.HAM5	26.8m				
	short	014	H1.HAM2	26.6m	9.0mm	200mm	15mm	
	short	015	H1.HAM3	26.6m	9.0mm	200mm	15mm	
	short	016	H1.HAM4	26.6m	9.0mm	200mm	14mm	
	short	017	H1.HAM5	26.8m	9.0mm	200mm	14mm	
	short	018	I1.HAM2	26.6m	9.0mm	200mm	14mm	
	BS	019	H1.BS - obsolete	4.0m	9.0mm	100mm	8mm	
	BS	020	L1.BS - obsolete	4.0m	9.0mm	100mm	8mm	
	BS	021	I1.BS - obsolete	4.0m	9.0mm	100mm	8mm	
	short	022	I1.HAM4	26.6m	9.0mm	200mm	15mm	sent to LLO, 10/14/2013
	short	023	L1.PR3	27.7m	9.0mm	200mm	15mm	
	long	024	L1.ITMX	66.1m	shallow	300mm	11.5mm	
	long	025	L1.ITMY	66.1m	3.0 mm	300mm	21.0mm	sent to LLO, 10/14/2013
	long	026	H1.ITMX	66.1m	3.0 mm		19.0 mm	sent to LHO, 10/14/2013
	long	027	I1.ITMX	66.1m				sent to LLO, 10/14/2013
	short	028	H1.ETMX	11.2m	8.5mm	200mm	9.7mm	sent to LHO, 10/14/2013
	short	029	H1.SR3	27.5m	9.0mm	200mm	12.7mm	sent to LHO, 10/14/2013
	short	030	I1.HAM5	26.8m	9.0mm	200mm	15.0mm	sent to LLO, 10/14/2013
	short	031	I1.PR3	27.7m	9.0mm	200mm	13.8mm	sent to LLO, 10/14/2013
	short	032	I1.SR3	27.5m	9.0mm	200mm	13.5mm	
	short	033	L1.SR3	27.5m	9.0mm	200mm	12.7mm	sent to LLO, 10/14/2013
D1201110-1	small BS	001	L1.BS	4.0m				D1201110-1-00-0001
	small BS	002	H1.BS	4.0m				D1201110-1-00-0002
	small BS	003	I1.BS	4.0m				D1201110-1-00-0003

Table 1. Optical adjustment and deployment table for all fabricated telescope assemblies. Highlighted in color are those telescopes assembled at Caltech. Of these 025, 026, 029, and 033 were individually adjusted for actually measured throw and spot size. Others are nominal adjustments prescribed by “ABCD” matrix propagation of nominal fiber exit beam. Note: “obsolete” BS telescopes are replaced by “small BS” re-design. This table is an as measured update of LIGO-E1300254-v5.

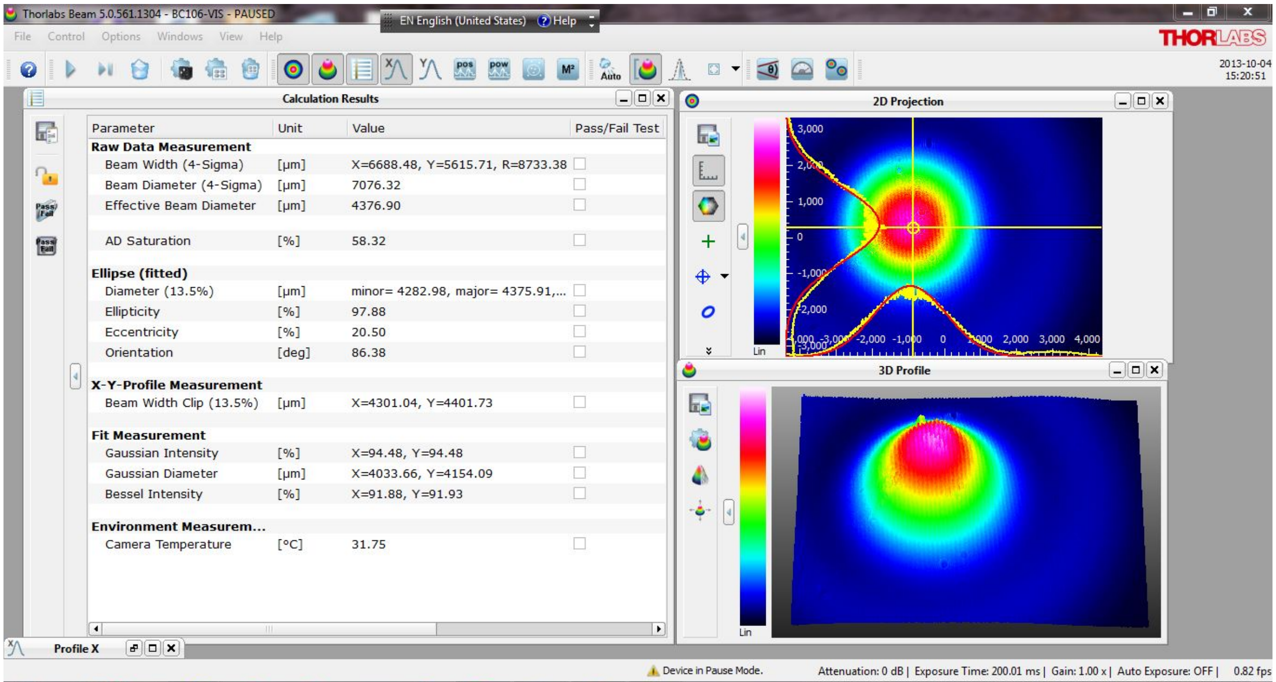
Adjustment for spurious intensity ring (Long Range)

In performing laboratory throw/spot size measurements (see table 1) it was found that the focal spots for the longest throw telescopes deviated significantly from Gaussian with a second intensity peak appearing as a ring at ~2 w_0. This is believed to be due to the limited apertures involved in the practical structure (fiber, lens apertures). An empirical prescription was developed for reducing this ring intensity with little degradation of core spot diameter at the throw distance. This corrective adjustment was applied to telescopes # 024-027 of table 1.

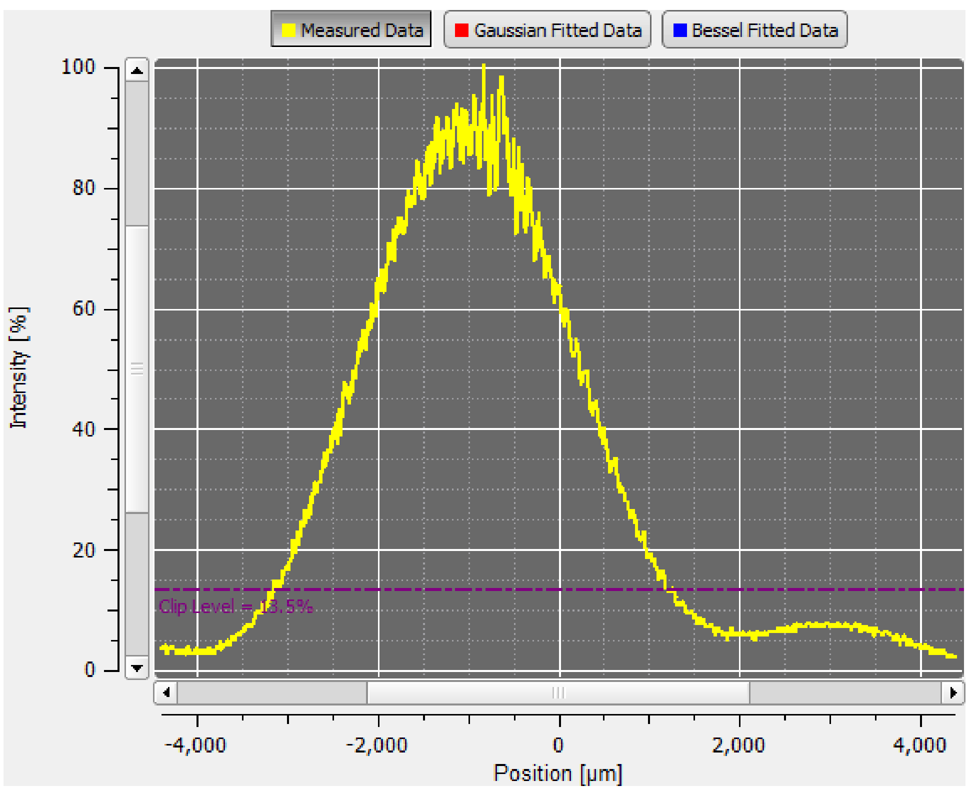
The figures 5,6 and 7 show measurement results with the default ocular depth, increasing by 0.6 mm (one thread) and 1.8 mm (3 threads) respectively. The measurement was done with a Thorlabs CCD camera profiler (BC-106-VIS). In each measurement, the objective gap was adjusted correspondingly to keep 66.1 m in the downstream and the beam size (w) there being around 2 mm. As summarized in the table below, increasing the ocular depth by 0.6 mm can decrease the relative ring intensity as that of Gaussian peak from about 8% to 3% while keeping the objective gap within its adjustment range of 25 mm. Further suppressing the ring intensity to ~1% needs to exchange the assembling order of the objective lens with the 1" tube (D0901362-v2), which needs an approval of engineering change request.

Test	Ocular depth (mm)	Objective gap (mm)	Beam size at 66.1 m (w, mm)	Relative ring intensity (%)	Measurement
1	2	11	2.1	8	Fig.5
2	2.6	17	2.1	3	Fig.6
3	3.8	48*	2.1	1	Fig.7

*The objective lens tube (part-3 in D0901362-v2) is exchanged with the 1" long tube (part-5 in D0901362-v2).

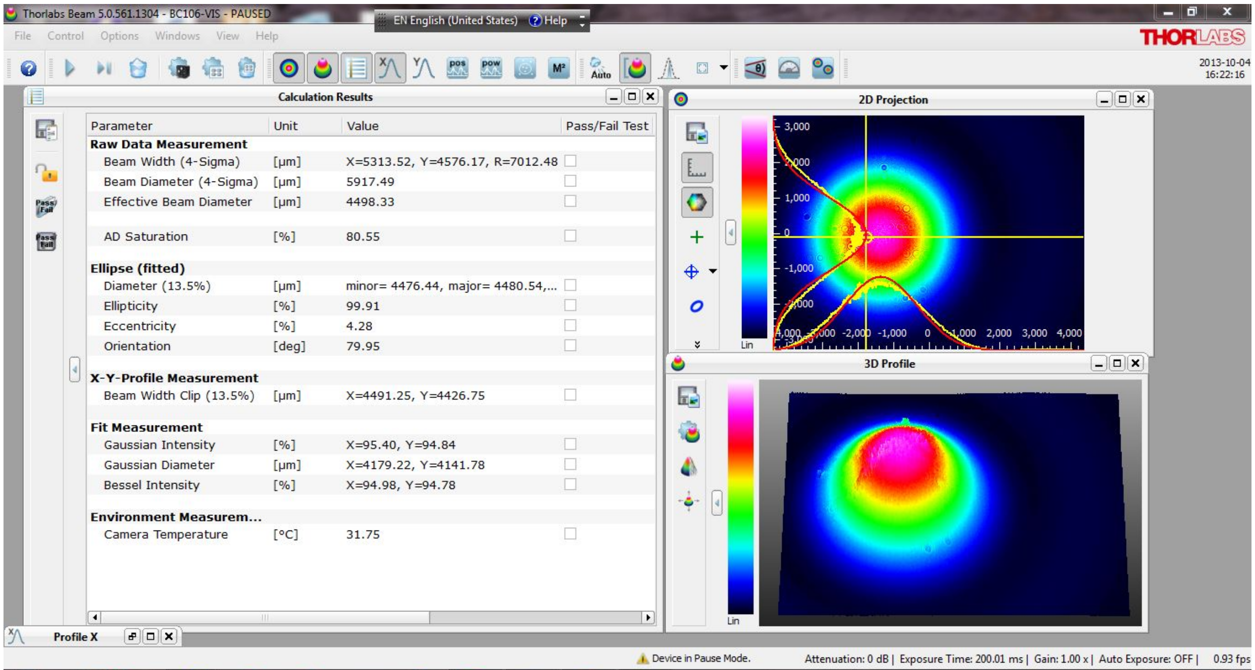


Thorlabs Beam 5.0.561.1304 - BC106-VIS - PAUSED
EN English (United States)
Help
File
Control
Options
Windows
View
Help
THORLABS
2013-10-04
15:20:51
Calculation Results
Parameter
Unit
Value
Pass/Fail Test
Raw Data Measurement
Beam Width (4-Sigma) [µm] X=6688.48, Y=5615.71, R=8733.38
Beam Diameter (4-Sigma) [µm] 7076.32
Effective Beam Diameter [µm] 4376.90
AD Saturation [%] 58.32
Ellipse (fitted)
Diameter (13.5%) [µm] minor= 4282.98, major= 4375.91,...
Ellipticity [%] 97.88
Eccentricity [%] 20.50
Orientation [deg] 86.38
X-Y-Profile Measurement
Beam Width Clip (13.5%) [µm] X=4301.04, Y=4401.73
Fit Measurement
Gaussian Intensity [%] X=94.48, Y=94.48
Gaussian Diameter [µm] X=4033.66, Y=4154.09
Bessel Intensity [%] X=91.88, Y=91.93
Environment Measurem...
Camera Temperature [°C] 31.75
2D Projection
3D Profile
Lin
Profile X
Device in Pause Mode.
Attenuation: 0 dB | Exposure Time: 200.01 ms | Gain: 1.00 x | Auto Exposure: OFF | 0.82 fps



Measured Data
Gaussian Fitted Data
Bessel Fitted Data
Intensity [%]
100
80
60
40
20
0
Clip Level = 13.5%
-4,000
-2,000
0
2,000
4,000
Position [µm]

Fig. 5 The measurement result (above) and power distribution along X (below) with the ocular depth of 2 mm and objective gap of 11 mm.



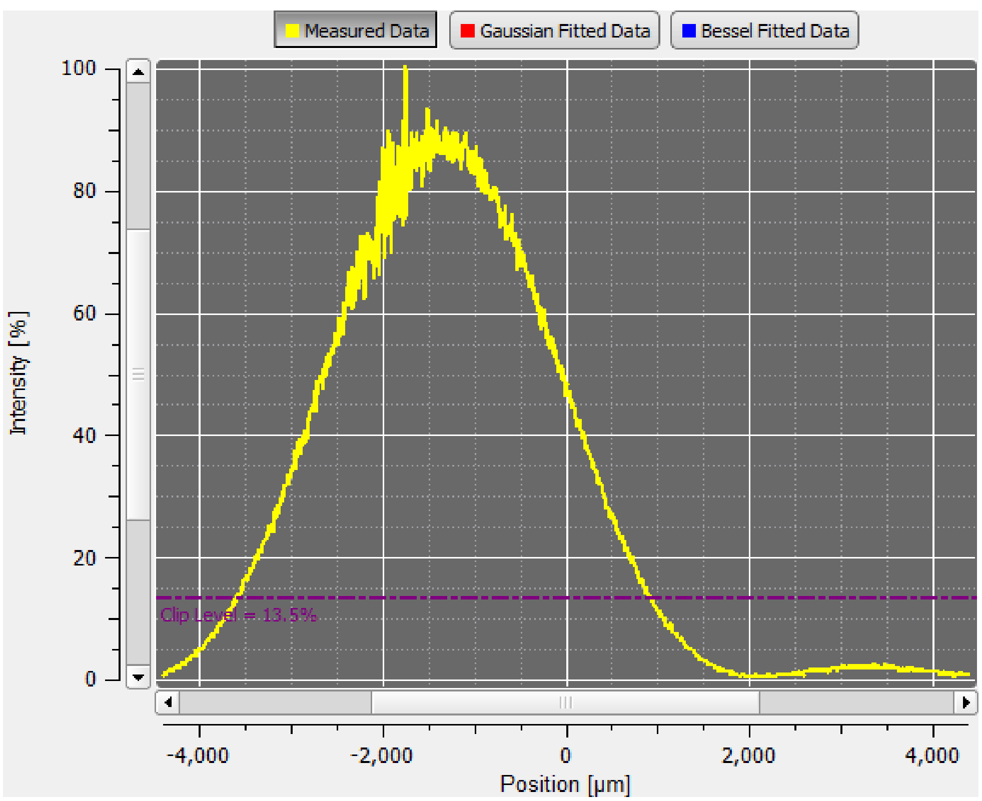


Fig. 6 The measurement result (above) and power distribution along X (below) with the ocular depth of 2.6 mm and objective gap of 17 mm.

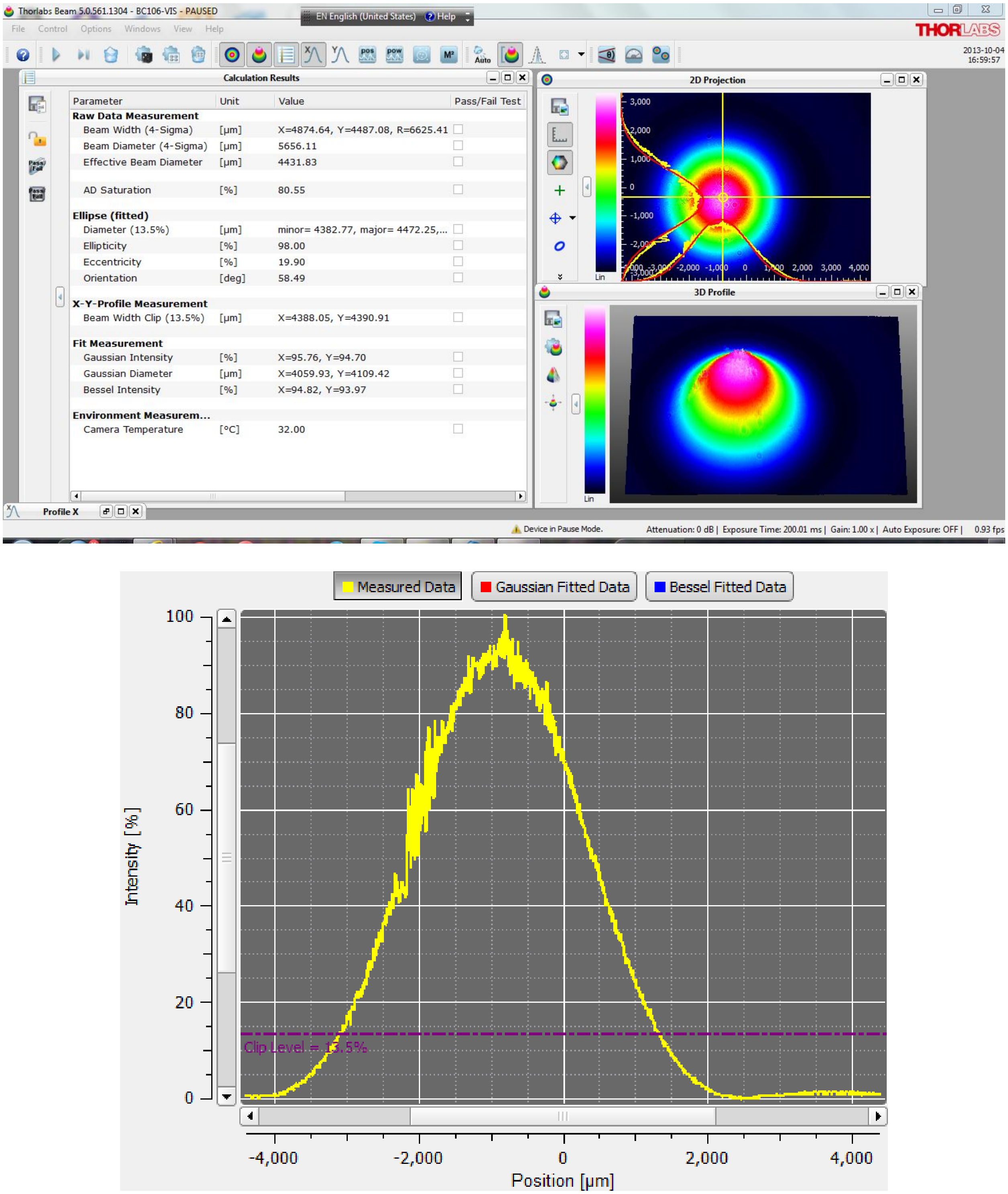


Fig. 7 The measurement result (above) and power distribution along X (below) with the ocular depth of 3.8 mm and objective gap of 48 mm.