Training for the adjustment of parabolic mirror at ELI-NP

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Goals of the training course 1) Way of thinking for experimental research

Basic cycle for experimental research

- Define your way scientifically (i.e. make hypothesis & reference)
- Execute your way
- Evaluate your way, that is, consider why your way is correct or wrong
- Modify your way if it is imperfect
- Conclude your study
- Outlook your study for the future

Remarks

- We do not necessarily have the solution a priori or even the existence of the solution is not trivial for experimental research. So the basic cycle is important to tackle experimental research .
- The training coarse aims to experience the basic cycle in simple optical system.
- Keep “reasoning” when you take any actions.

Goals of the training course 2) Contents

- Understand the basis of the alignment of optics and handling of optomechanics.
- Make your own configuration to align the optics on optical table.
- Do alignment of the mirrors, the beam expander, and focusing by off-axis parabolic mirror.
- Measure focal spot image by CMOS Camera
- Analyze the focal spot image.
- Present your configuration, the way of methods, and your results

Schedule of training course

- Kick-off meeting for introduction of training course **(Today)**
  - Introduction of training course (basis of alignment, goals and laboratory works)
  - Explanation of equipment at LP14
- 5 days for laboratory works for each group (in three groups) at lp14
  - Start-up discussion **at 10:00 on Monday**
  - Finish lab. works **by 15:00 on Friday**
- Presentation by each group in **30 July (Wed.)**
- Back-up day in **31 July (Thu.)**

Day	Time	Contents	Remarks
4 July (Fri)	09:30 - 12:00	Introduction of training course	
	13:00 - 15:00	Introduction of laboratory	Explanation of equipment/optomechanics/tools at LP14
07 July - 11 July	-	Training at LP14 for Group A	Finish by 15:00 on the final day (Friday) for next group
14 July - 18 July	-	Training at LP14 for Group B	
21 July - 25 July	-	Training at LP14 for Group C	
30 July (Wed)	09:30 - 11:30	Presentation by Group A and B	30 minutes presentation + 20 minutes discussion
	13:00 - 14:30	Presentation by Group C	
	14:30 - 17:00	Summary and dicussion	
31 July (Thu)	09:30 - 12:00	Back-up day for further discussion	
4 Aug - 8 Aug	-	Back-up week	

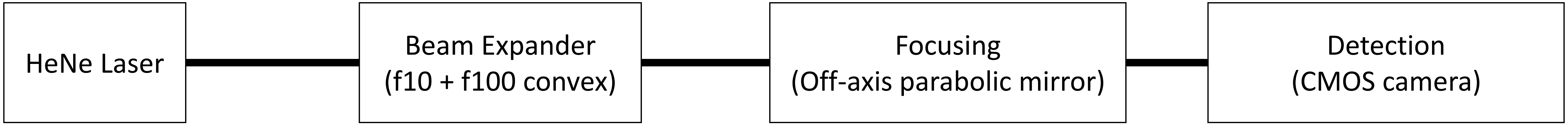
Schedule of group activity in laboratory

Group	Period of Lab activities	Name	Department
A	07 July (Mon) - 11 July (Fri)	Annemarie Cristmann	LDED
		Fattima	LSD
		Popescu Vlad	LSD
		Saidbek	LSD
B	14 July (Mon) - 18 July (Fri)	Cana Alexandra Cristina	GSD
		Claudia Jerca	LDED
		Diana Naum	LDED
		Iancu Andrei Daniel	GSD
		Ioan Paul Pârlea	GDED
		Ionut Slabu	LGED
C	21 July (Mon) - 25 July (Fri)	Cristi Alexe	LSD
		Diana Catana	LDED
		Emilia Matache	LSD
		Grigore Alexandra-Elena	LSD
		Octavian Cretu	LDED
		Patrascoiu Robert	GSD
		Sandu Denis	LSD

Remarks for 1 week laboratory works by each group

- Start-up discussion **at 10:00 on Monday**
  - Brief remarks of equipment/tools/optomechanics
  - Confirmation of safety issues
- Completion of laboratory work **at 15:00 on Friday**
  - Deconstruct the system for initialization for next group after 15:00
- You should concentrate on taking the data and collecting the information of your system on Friday, regardless of your progress.

Block diagram of the optical system in the lab.



- All the optical components are installed on the mounts and mechanics.
- The training coarse starts from to consider your optical setup and align them almost from the scratch.
  - We skipped the process of considering/designing/finding each components due to the limitation of sources. Just keep in your mind when you execute your experimental researches

Definition of terminology to adjust mirror mount

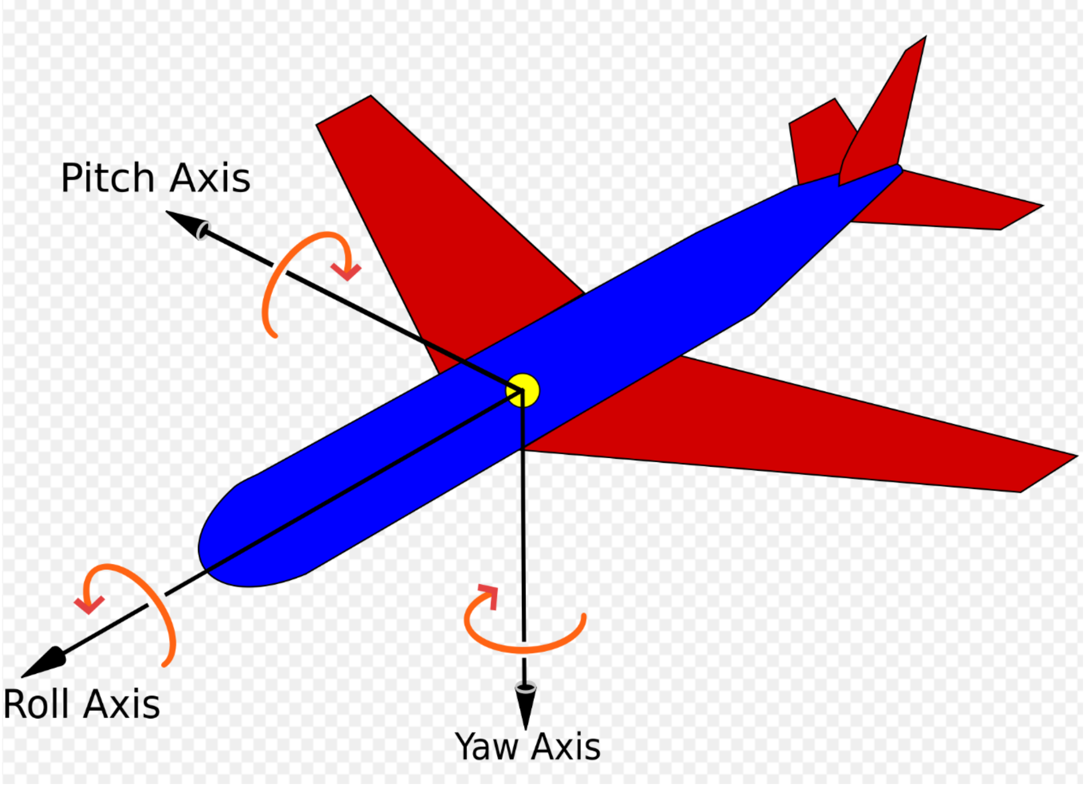
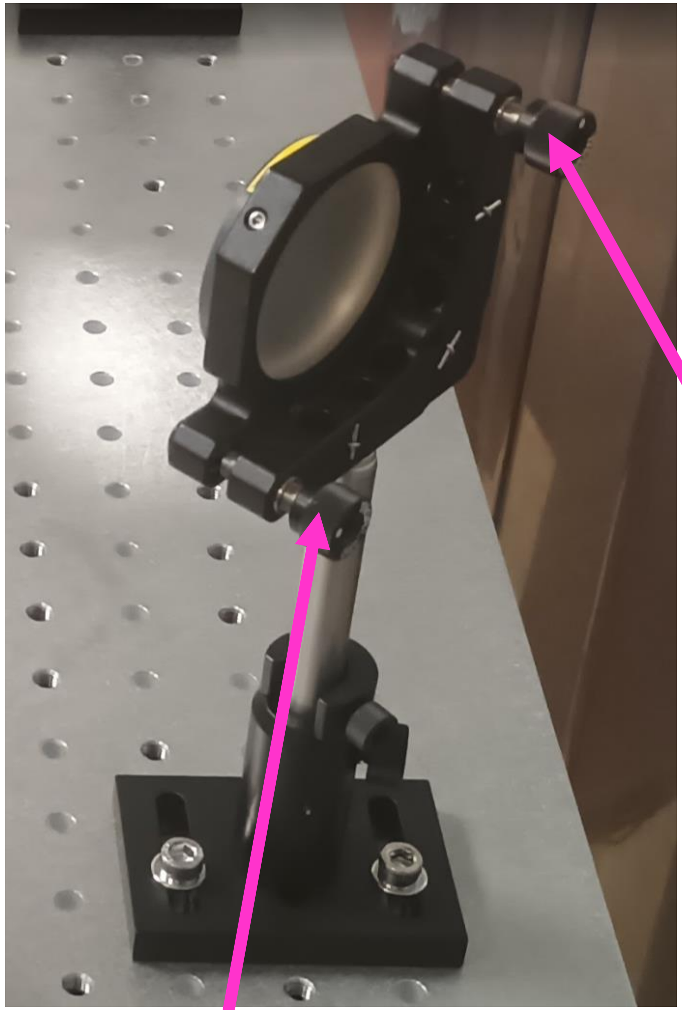


illustration is cited from Wikipedia
https://en.wikipedia.org/wiki/Aircraft_principal_axes#/media/File:Yaw_Axis_Corrected.svg



Typical kinematic mirror mount

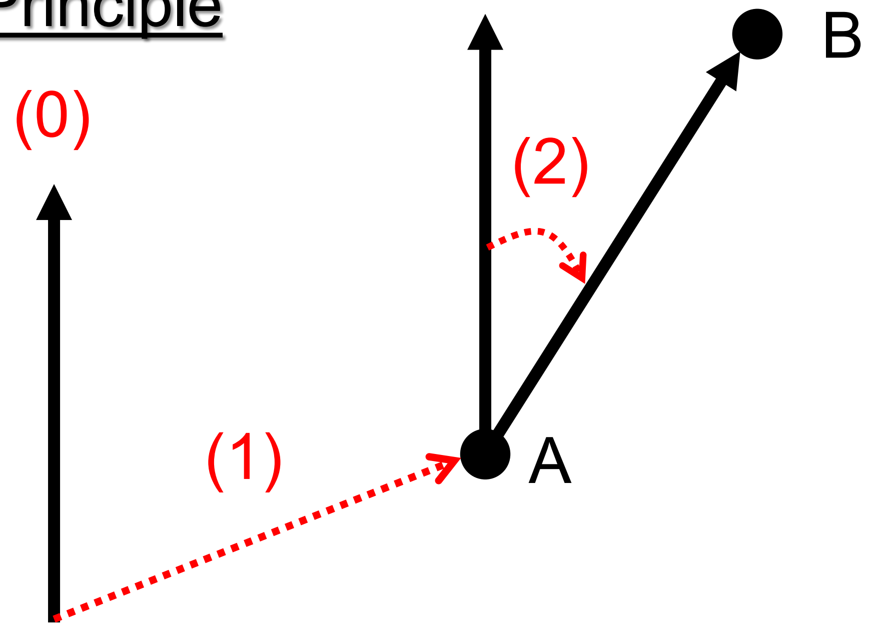
Knob for Pitch

Knob for Yaw

"Yaw" is rotation horizontally
"Pitch" is rotation vertically

Bais of alignment

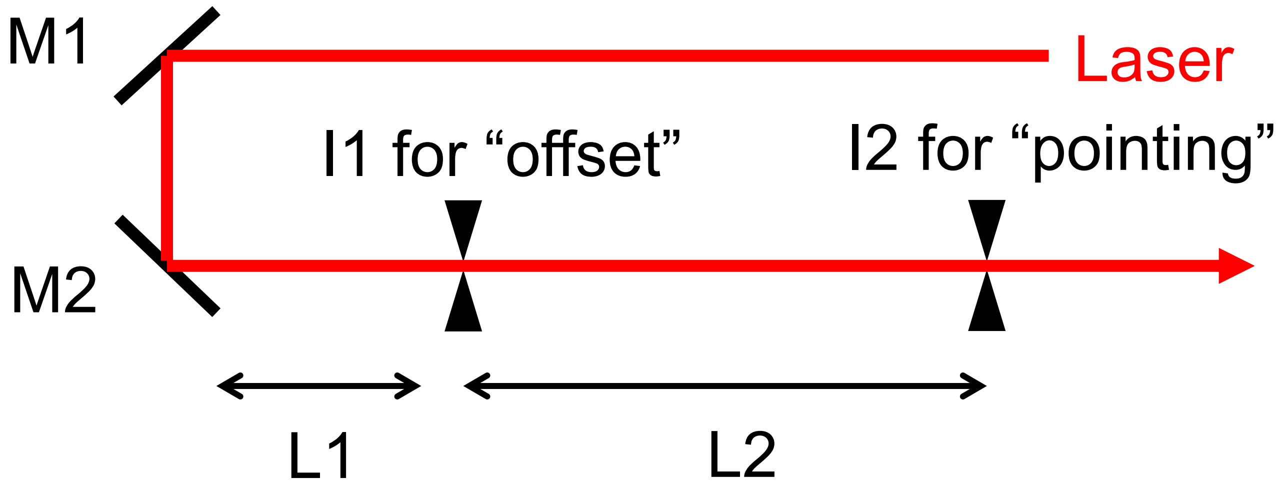
Principle



(0) Initial ray vector
(1) "Offset" alignment
(equiv. to parallel shift)
(2) "Pointing" alignment
(equiv. to angle correction)

Alignment

M=Mirror
I=Iris



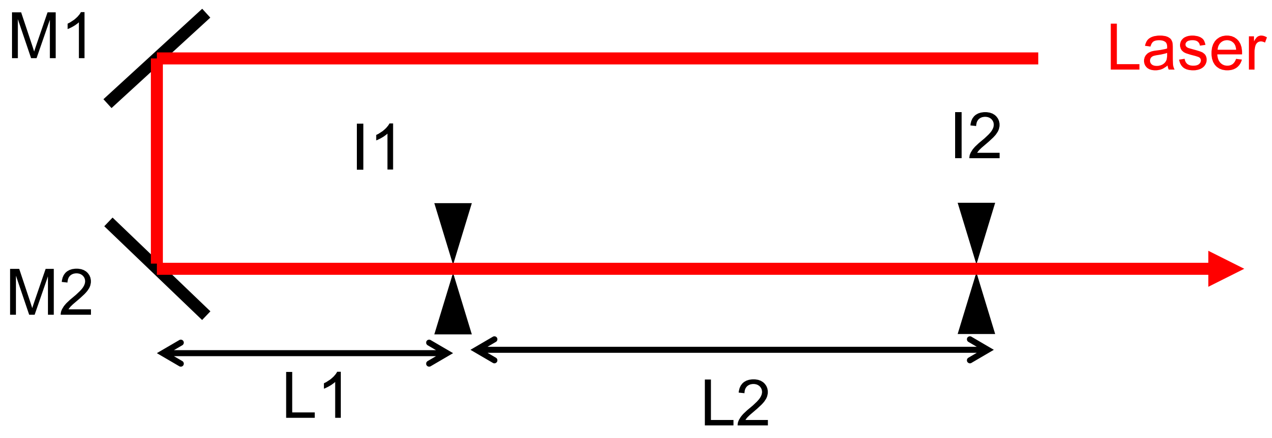
If M2 has adjustability of

- horizontal & vertical shift (by translation stage)
- yaw & pitch (by mirror mount)

+ if L1=0, L2=∞,

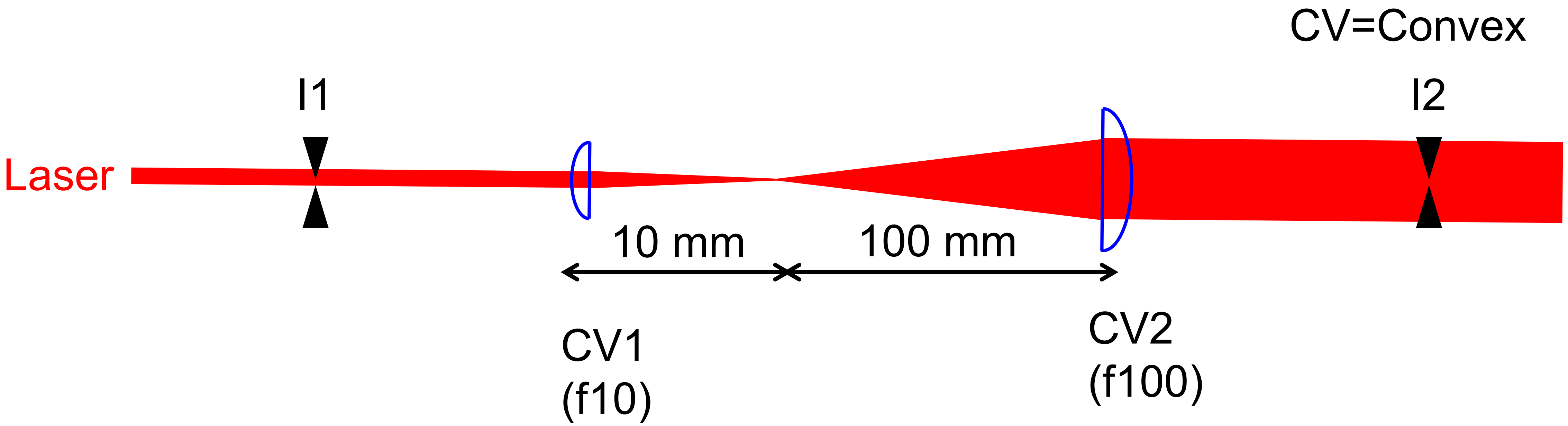
M2 adjustment works exactly as principle

Alignment of two mirrors



- Yaw and Pitch for M1 is used for “offset” alignment with I1.
- Yaw and Pitch for M2 is used for “pointing (angle)” alignment with I2
- Since L1 $\neq 0$ and L2 $\neq \infty$, we need iteration of alignment with finite precision of angle
- Since Adjustment of M1 and M2 are not independent operation, we need iteration of alignment

Alignment of beam expander



- Beam expander is made of a Keplerian telescope configuration by two convex lens.
- Install CV1 and CV2 and optimize the lens position to keep reference laser alignment
- Optimize laser divergence by adjusting the distance between CV1 and CV2
- Collimated beam is necessary as output

Property of paraboloid

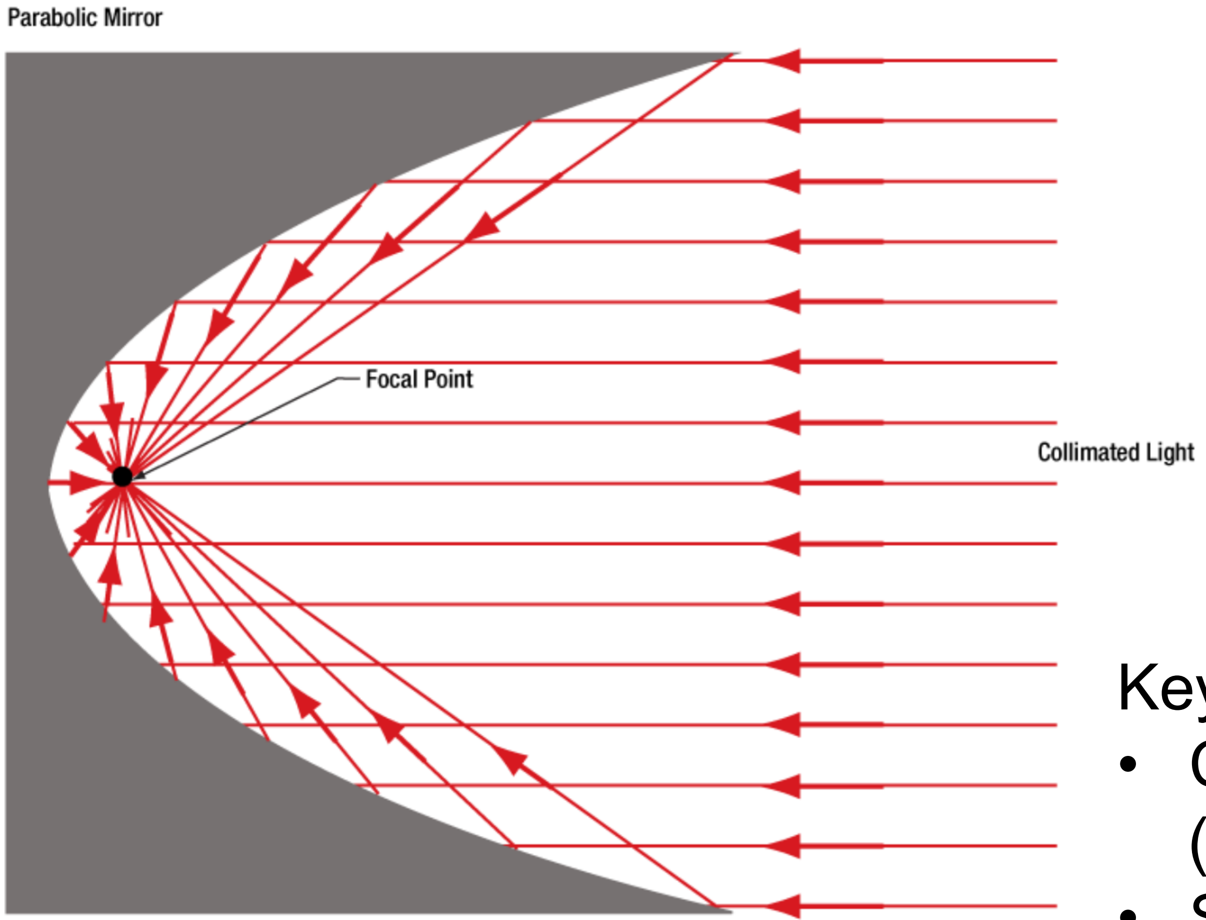
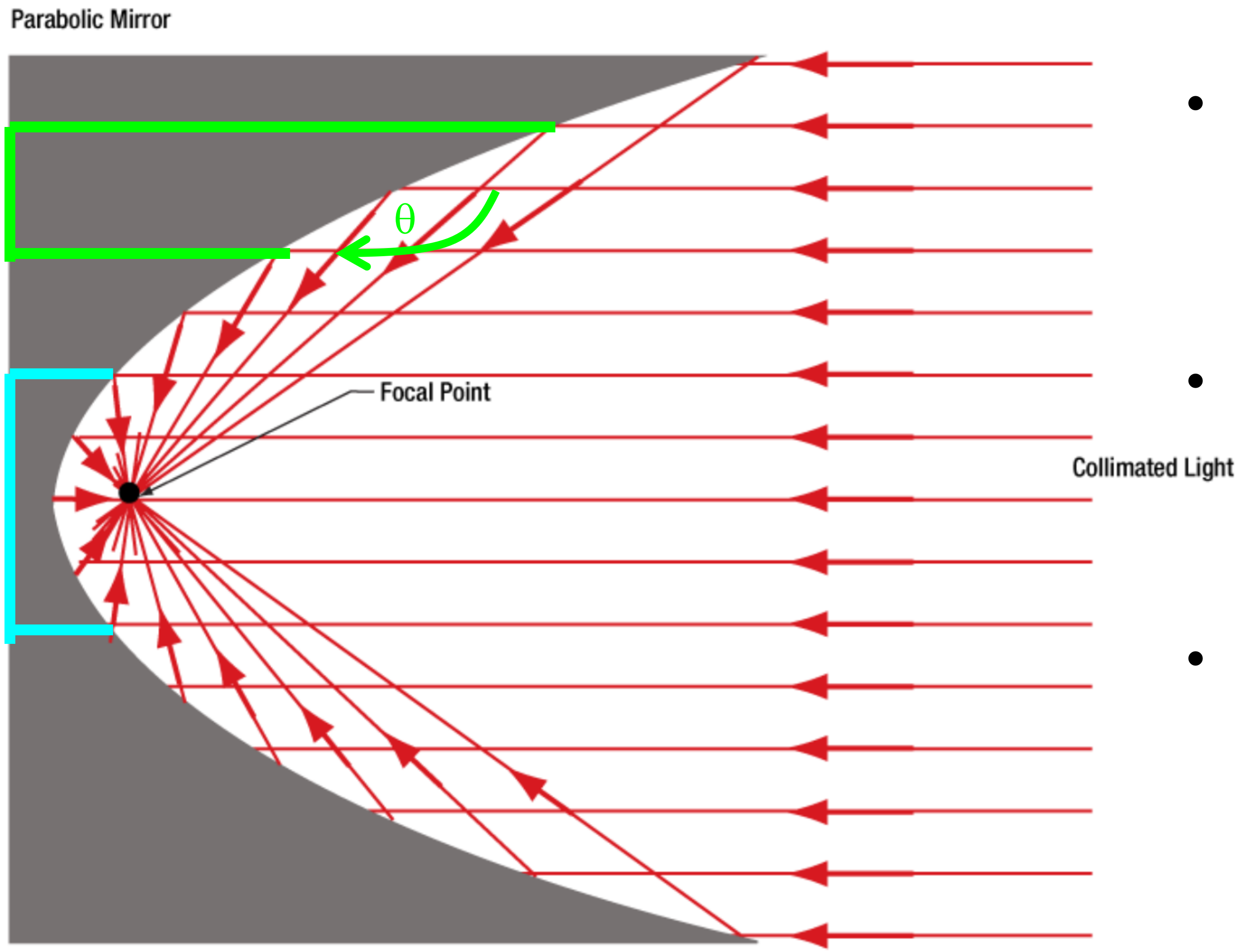


Illustration is cited from Thorlabs page: https://www.thorlabs.co.jp/newgrouppage9.cfm?objectgroup_id=14211

Key property for focusing by parabolic mirror

- Collimated incoming laser (well control of divergence)
- Sensitive to angle of incident of incoming laser (good precision of angle of incidence)
- Insensitive of offset shift of incoming laser

Off-axis parabolic mirror

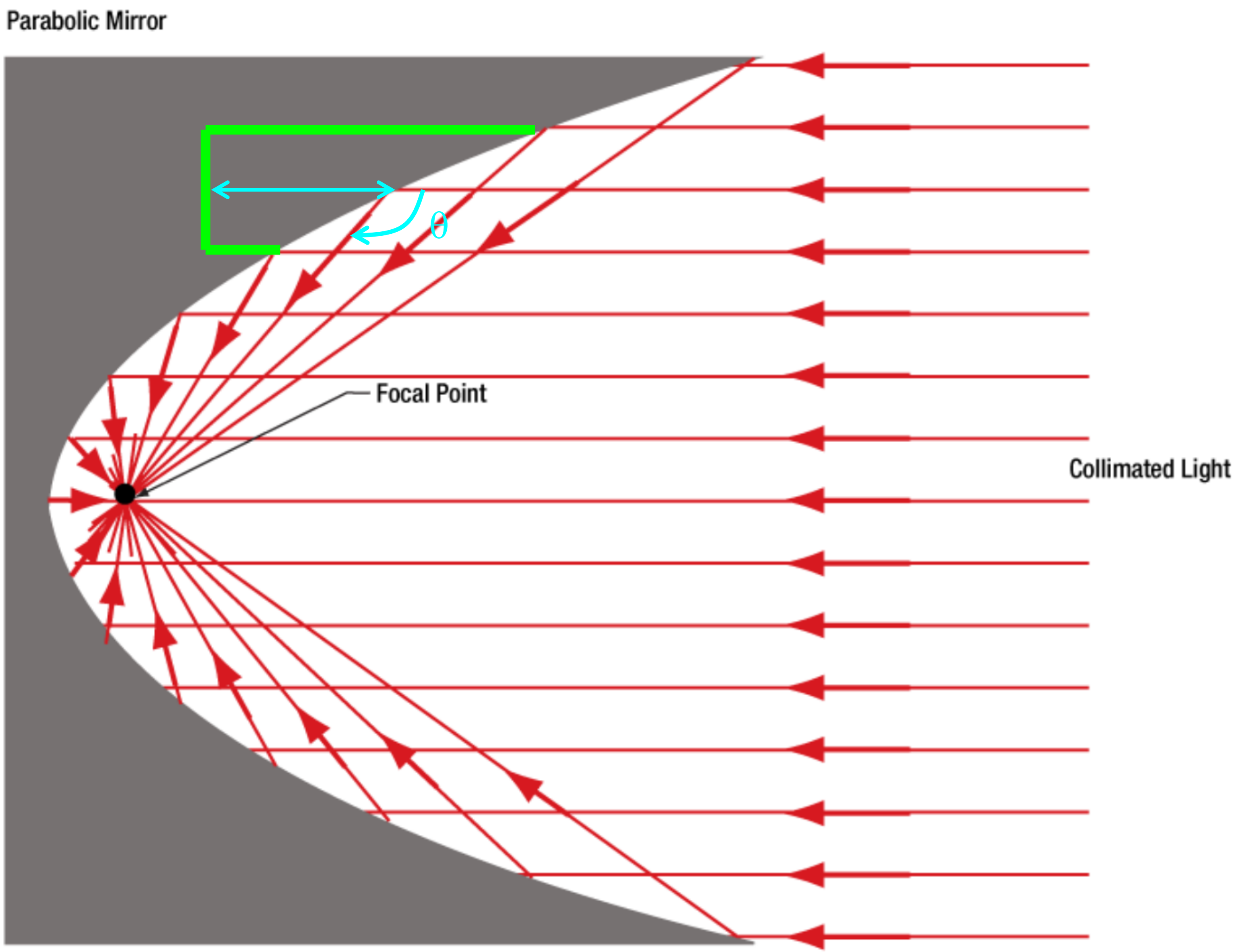


- If one cut paraboloid according to light blue line
 -> On-axis parabolic mirror

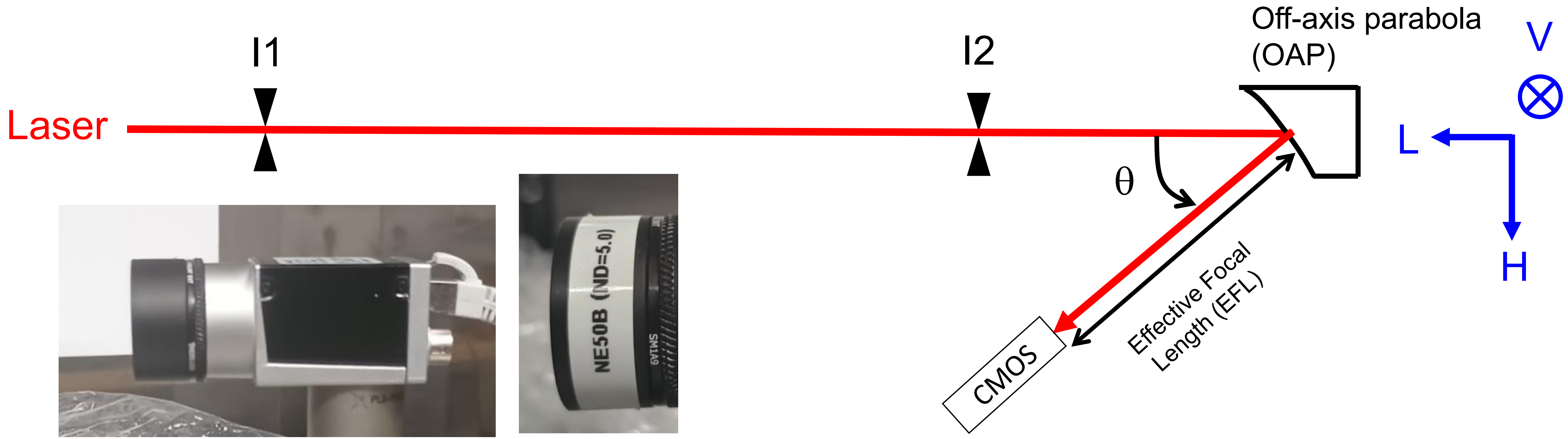
- If one cut paraboloid according to light green line
 -> Off-axis parabolic mirror

- Angle of Off-axis parabolic mirror is defined as θ (Full-angle) or $\theta/2$ (AOI, angle of incidence) in specification

Illustration is cited from Thorlabs page:
https://www.thorlabs.co.jp/newgrouppage9.cfm?objectgroup_id=14211

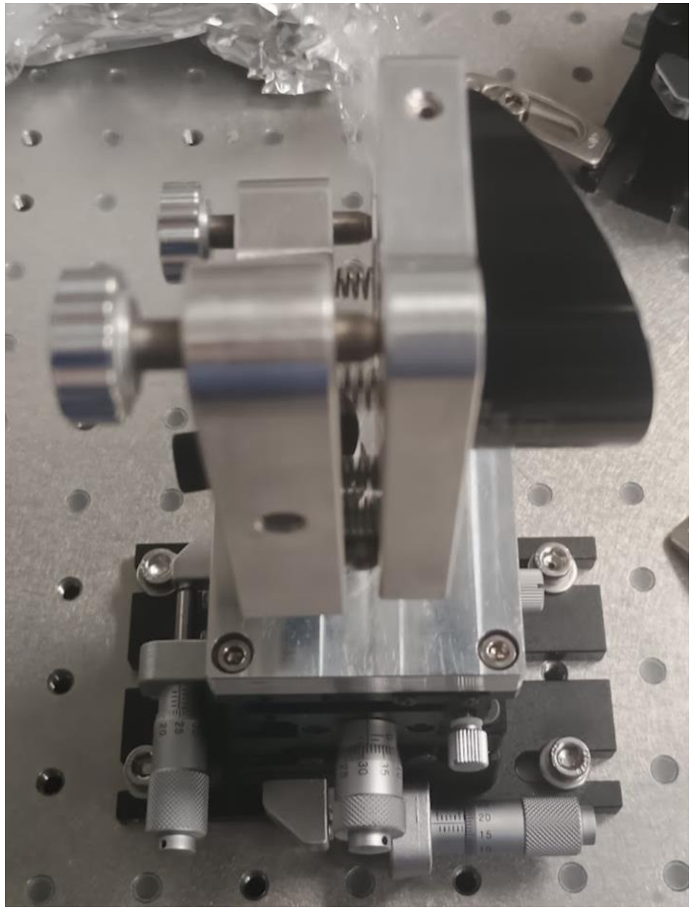

Parabolic Mirror
θ
Focal Point
Collimated Light

Coarse alignment of off-axis parabolic mirror (OAP)



- Alignment of incident angle to OAP
- Alignment of outgoing angle from OAP to set initial position to bring the laser to expected focal-spot point
- Install CMOS camera + ND5 (See photograph)
- Check the astigmatism on image

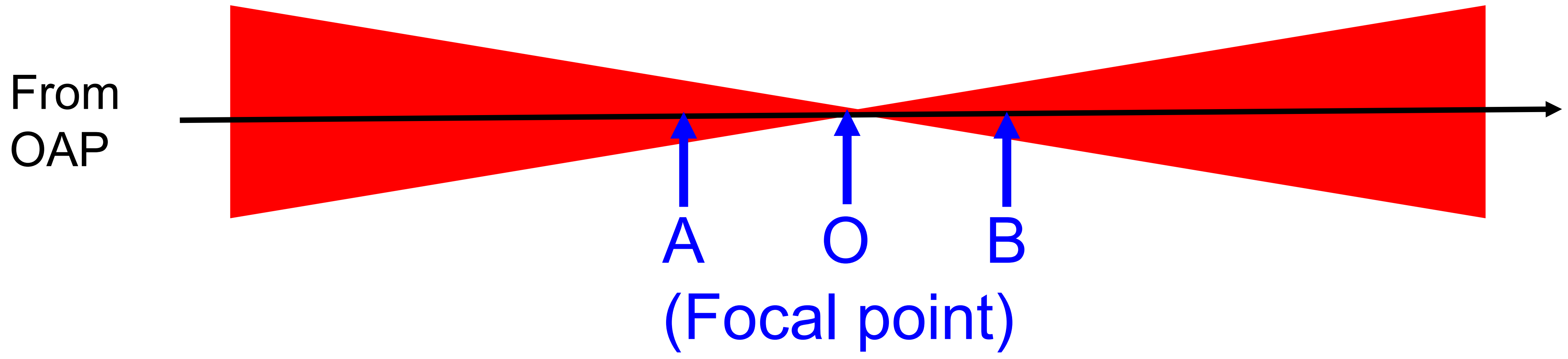
Tips: Adjustability of off-axis parabolic mirror and CMOS Camera

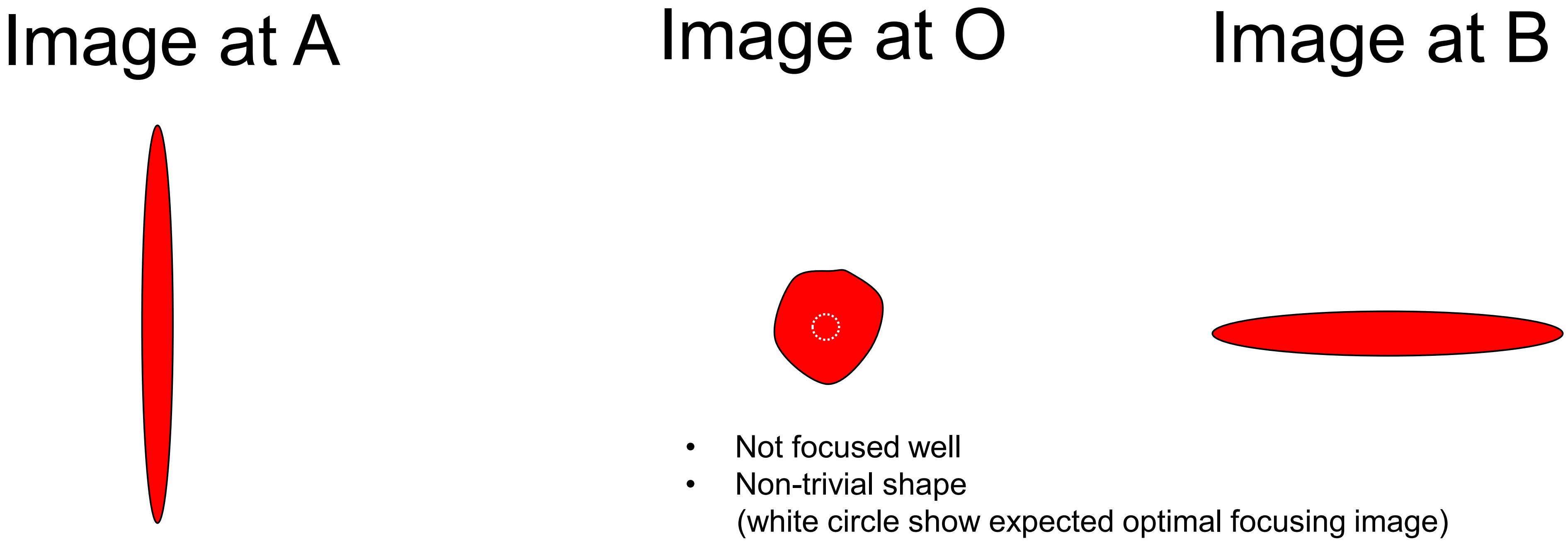


5 axes for OAP
- V (Vertical translation)
- H (Horizontal translation)
- L (Longitudinal translation)
- Pitch
- Yaw

3 axes for CMOS camera
- V (Vertical translation)
- H (Horizontal translation)
- L (Longitudinal translation)

Astigmatism by off-axis parabolic mirror

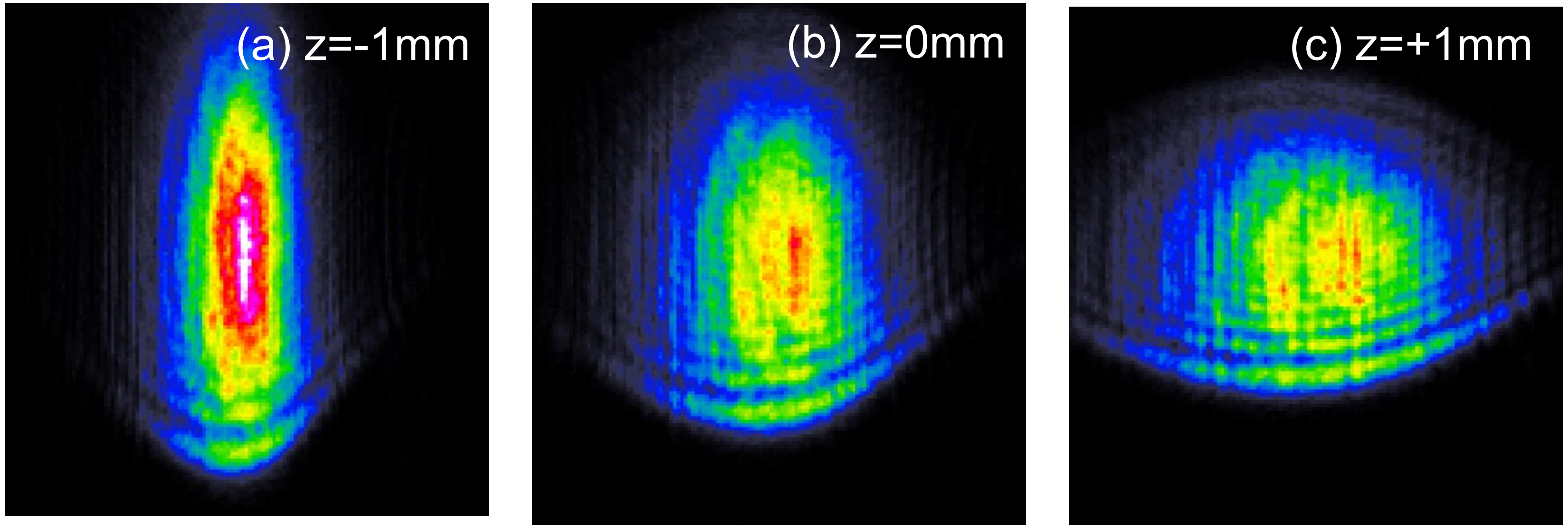




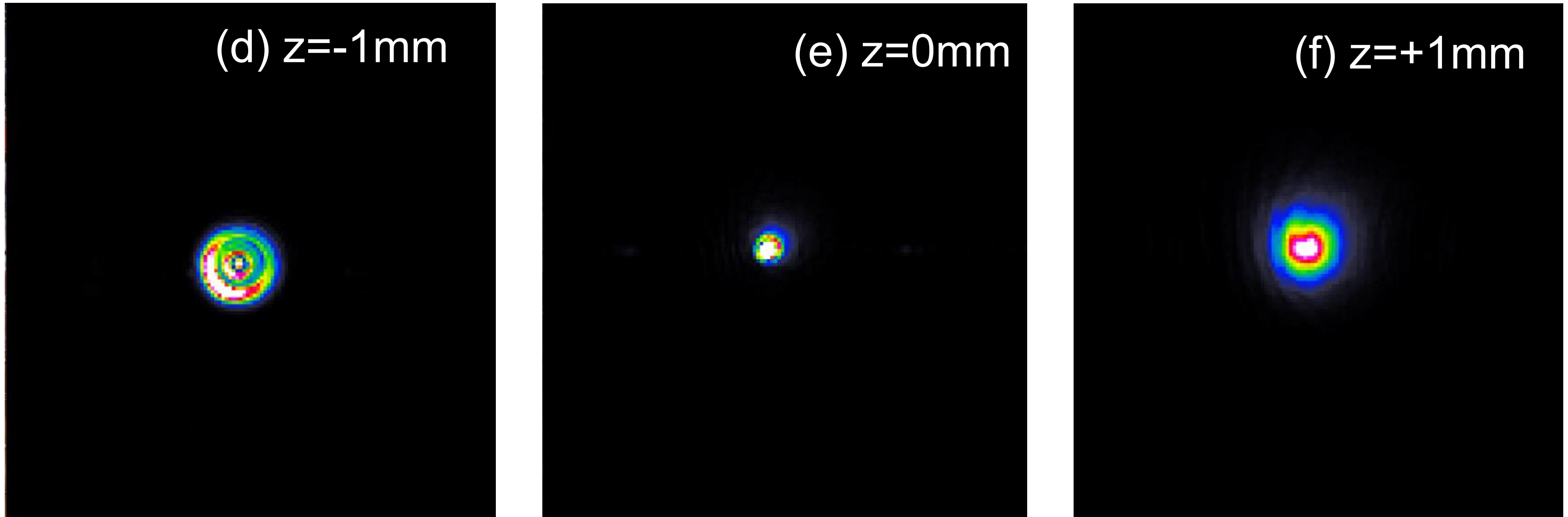
- Not focused well
- Non-trivial shape
  (white circle show expected optimal focusing image)

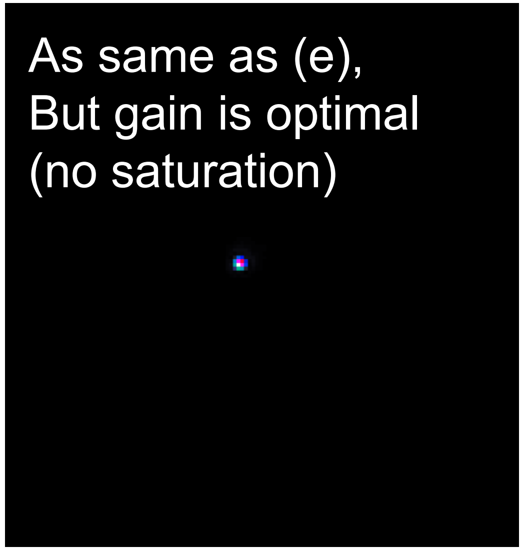
Astigmatism by off-axis parabolic mirror

Astigmatic case (misaligned at a few degrees)

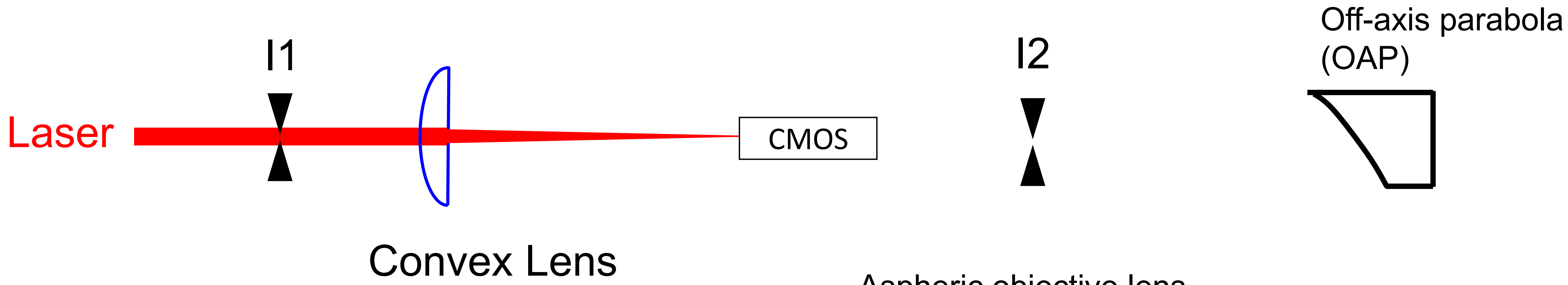


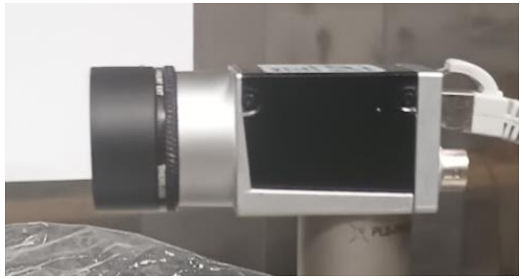
Little astigmatic case

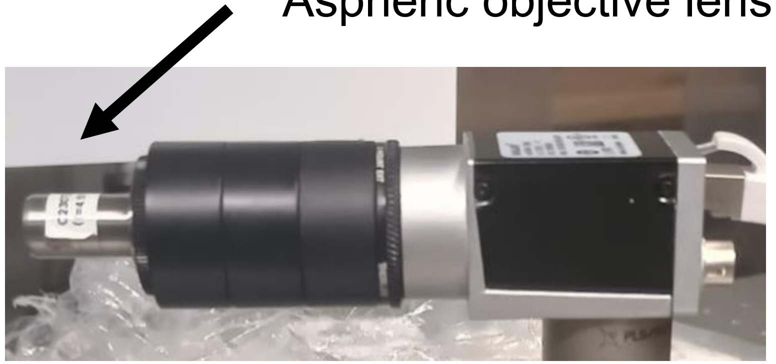




Confirmation of “input” laser quality if your beam is astigmatic





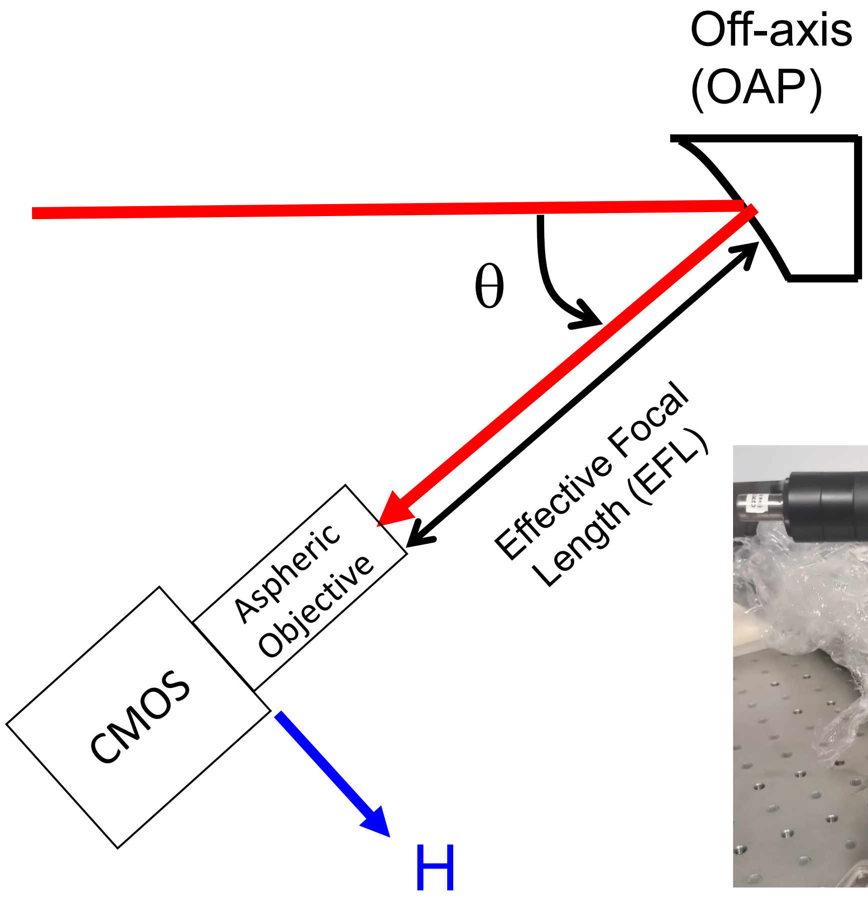


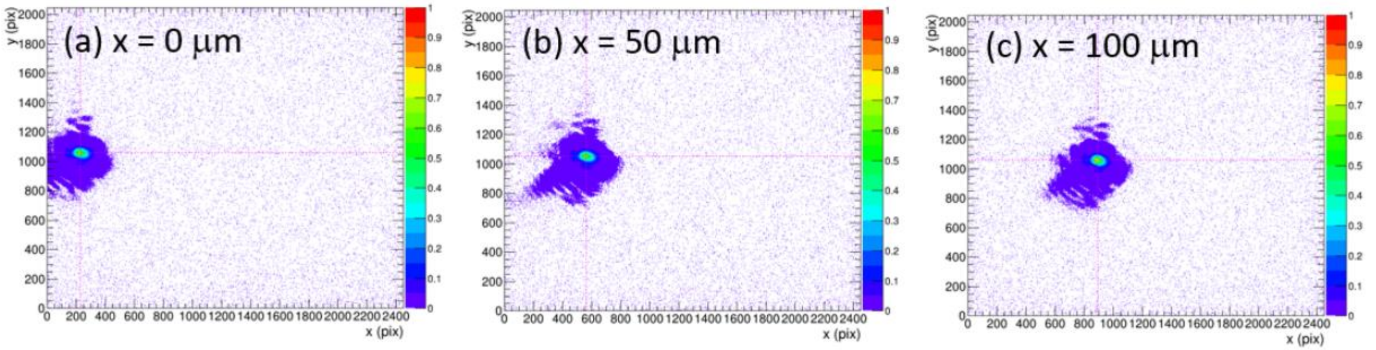
- You can check input laser beam quality by focusing lens
- You may need aspheric lens to see detailed shape for focusing due to necessity of magnification

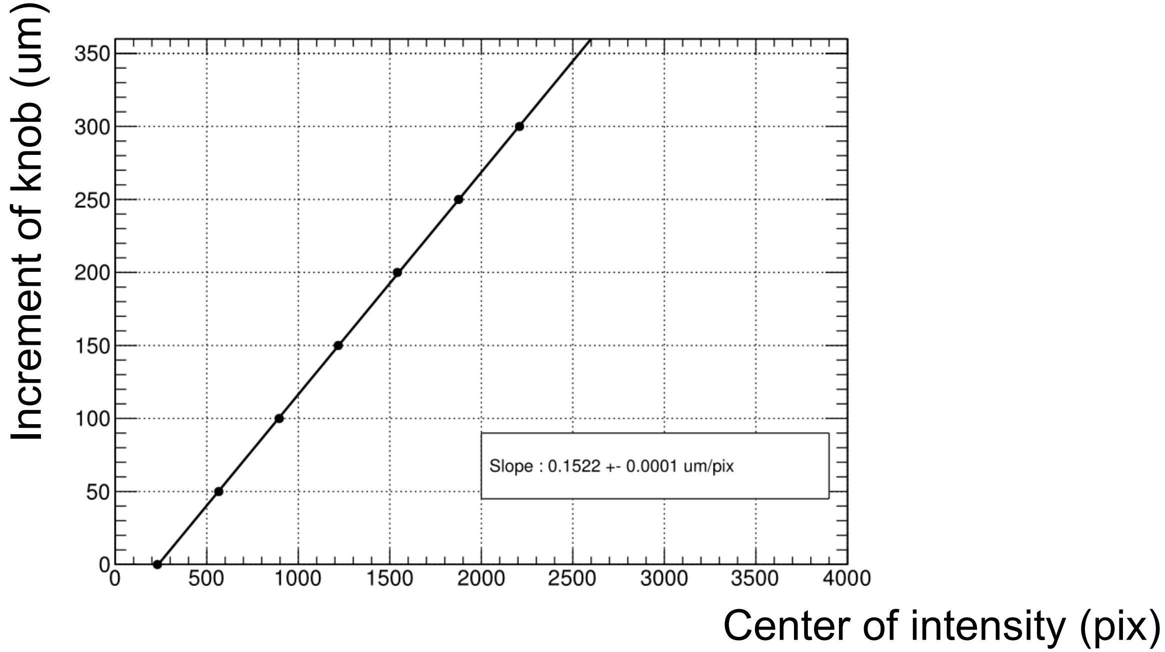
Fine adjustment of OAP for shaping focal-spot profile

- Install aspheric lens on CMOS camera to find focal point
- Adjust Yaw & H to keep the image on the camera center
  - To get the circular shape
  - To get the smallest spot size
  - To get the highest intensity spot
- (If necessarily) Adjust Pitch & V to keep the image on the camera center to get the smallest spot size as well as the highest intensity spot.

Calibration of magnification

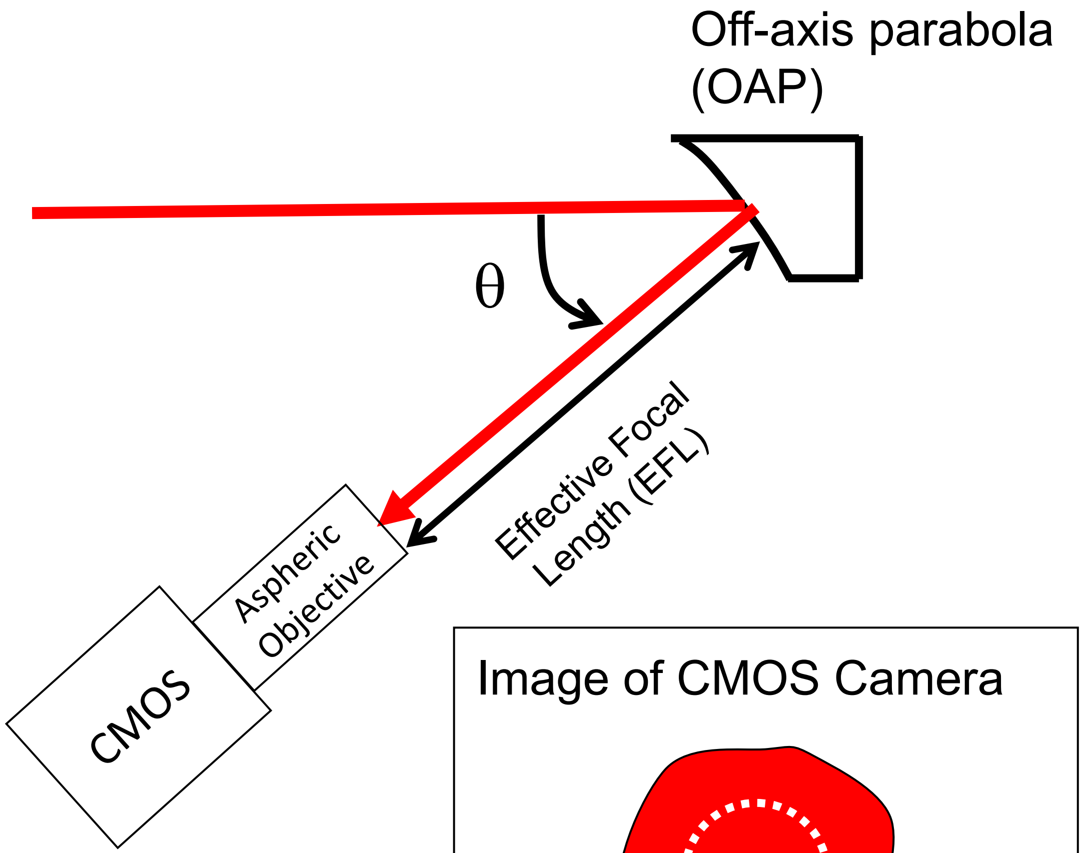


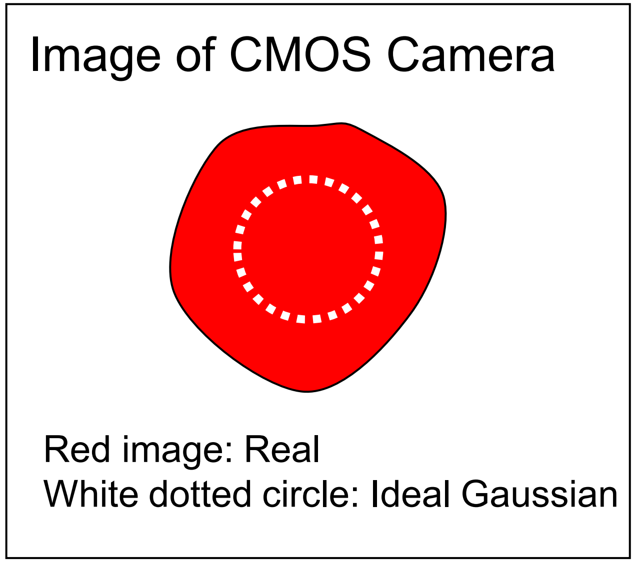




Move the camera by knob and see how much intensity centroid (pixels) moves in on sensor plane

Focal-spot measurement and evaluation





Spot radius w_0 of Gaussian laser beam

$$w_0 \sim \frac{2}{\pi} \lambda f_{num},$$

$$f_{num} = \frac{f}{\Phi},$$

λ: wavelength

f_{num} : f number

f: focal distance

Φ: laser-beam diameter before focusing

Missions of your laboratory activities

- Alignment of mirrors and beam expander
- Control of divergence of beam expander (Collimated laser beam)
- Alignment towards OAP (angle of incidence to OAP)
- Coarse alignment of OAP (angle of outgoing from OAP)
- Measure focal image without aspheric objective lens (astigmatism check)
- Alignment of CMOS camera with aspheric objective lens
- Fine alignment of OAP (optimal shaping of focal-spot profile)
- Data acquisition 1) Focal-image by focusing lens before OAP (with calibration)
- Data acquisition 2) Focal-image by OAP after OAP (with calibration)
- Offline data analysis
    - Focal-spot size with physical scale (um)
    - Evaluate how good or bad your focusing image is
- Make your presentation
- (Advanced) play further to see tendency (e.g. detune worse direction on purpose to see how astigmatism grows etc.)

Presentation by each group in **30 July (Wed.)**

The meeting for presentation of your laboratory activities.

- Presentation in **30 July (Wed.)**
- Each group should **present for 30 minutes + discussion for 20 minutes**,

Your presentation should include the following points

- Show your optical setup
- Show your way of the alignment. In particular,
  - Optimization of beam expander
  - Optimization of angle of incident to OAP
  - Optimization of angle of outgoing from OAP
- Show your measurement, analysis and result
  - Data sets
  - The way of analysis
  - Analysis results (Calibration and spot size)
- Show your opinions/insights about, for example,
  - What is the most difficult/critical part for your activities ?
  - How do you tackle and take care of the difficulties ?
  - Any strange/interesting phenomenon you noticed
- Show your Summary
  - What is your achievement ?
  - What is remaining issues and improvement ?
  - Anything else ?

Laser safety

- Never do your eye level to be the same on the laser beam
- Remove the reflective accessory (for instance, bracelet, watch etc.)
- Build the beam blocker at the termination in your alignment process, in particular, for the direction to the area where the other people access.
- Wear the safety goggles

Short discussions after the meeting

Confirm grouping and group members

Confirm equipment/optomechanics/tools

Back up

Component List

Name	Qty	Model	Manufacturer	Remarks
HeNe Laser	1	HNL050R	Thorlabs	
Adjustable ND filter	1	NDC-50C-4M-B	Thorlabs	
1 inch Ag mirror	3	PF10-03-P01	Thorlabs	
1 inch Al mirror	1	PF10-03-G01	Thorlabs	
1 inch Al mirror	1	092-3015	Eksma	
2 inch Ag mirrror	1	PF20-03-P01	Thorlabs	
2 inch Au mirror	1	20Z40ER.4	Newport	
20 mm Iris	1	IDA20/M	Thorlabs	Minimal aperture size is 1.2 mm
25 mm Iris	1	ID25SS/M	Thorlabs	Minimal aperture size is 1.4 mm
37 mm Iris	1	ID37Z/M	Thorlabs	Minimal aperture size is 0 mm
50 mm Iris	1	ID50Z/M	Thorlabs	Minimal aperture size is 0 mm
Convex f10	1	AC080-010-A-ML	Thorlabs	Achromatic
Convex f100	1	SLB-50.8-100PM	Thorlabs	Plano-convex
Convex f150	1	SLB-50.8-150PM	Thorlabs	Plano-convex
Off-axis palabolic	1	35516	Edmund	Off-set full angle 60 deg., EFL=101.6mm
Aspheric lens f4.5 mı	1	C230TMD-B	Thorlabs	Mount on CMOC camera
1 inch ND	1	NE50B	Thorlabs	Mount on CMOC camera
CMOS camera	1	acA2440-20gm	Basler	