Basics of the lidar instrument: optics

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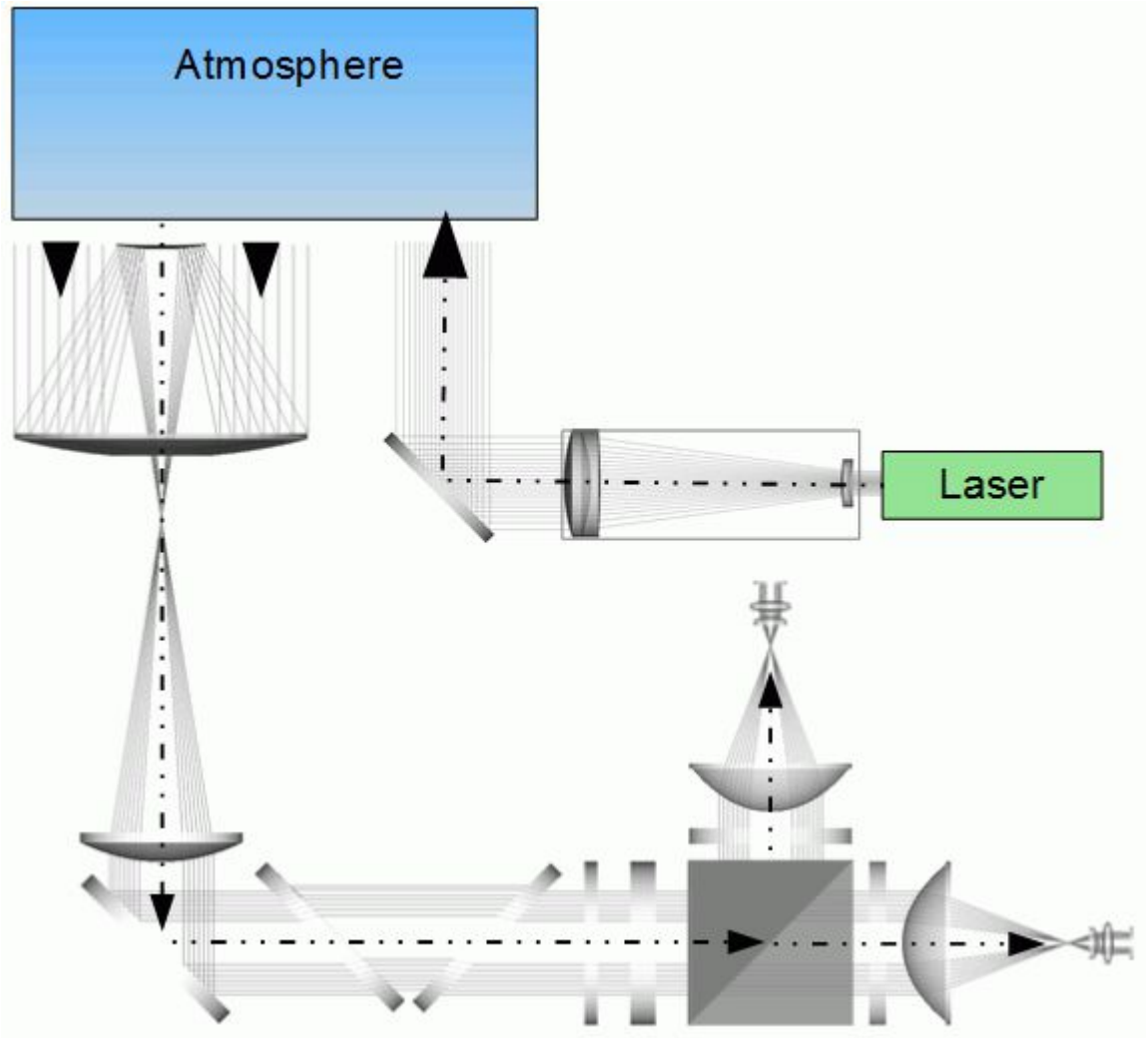
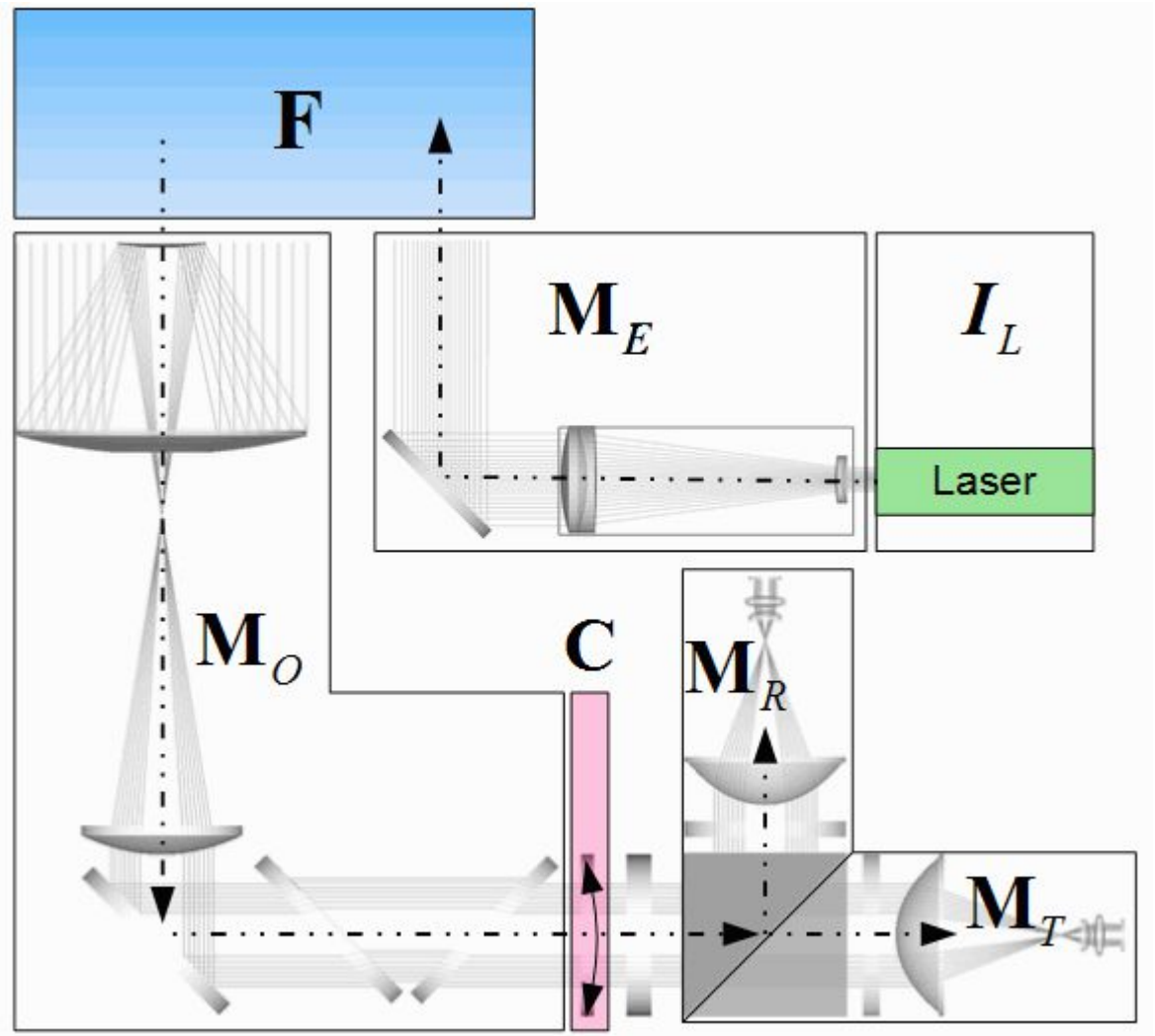
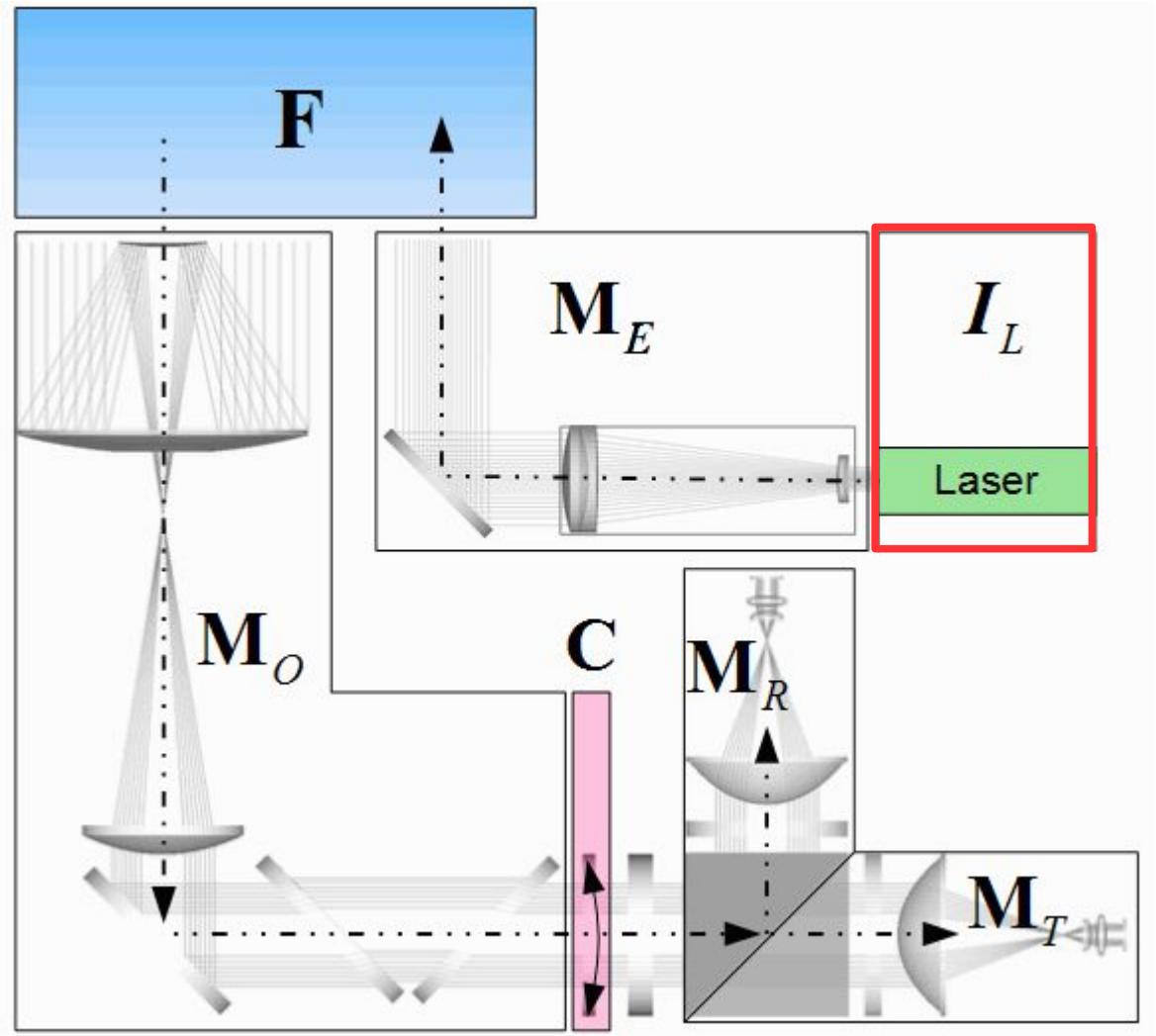
Typical lidar setup



Typical lidar setup – modules / blocks





laser

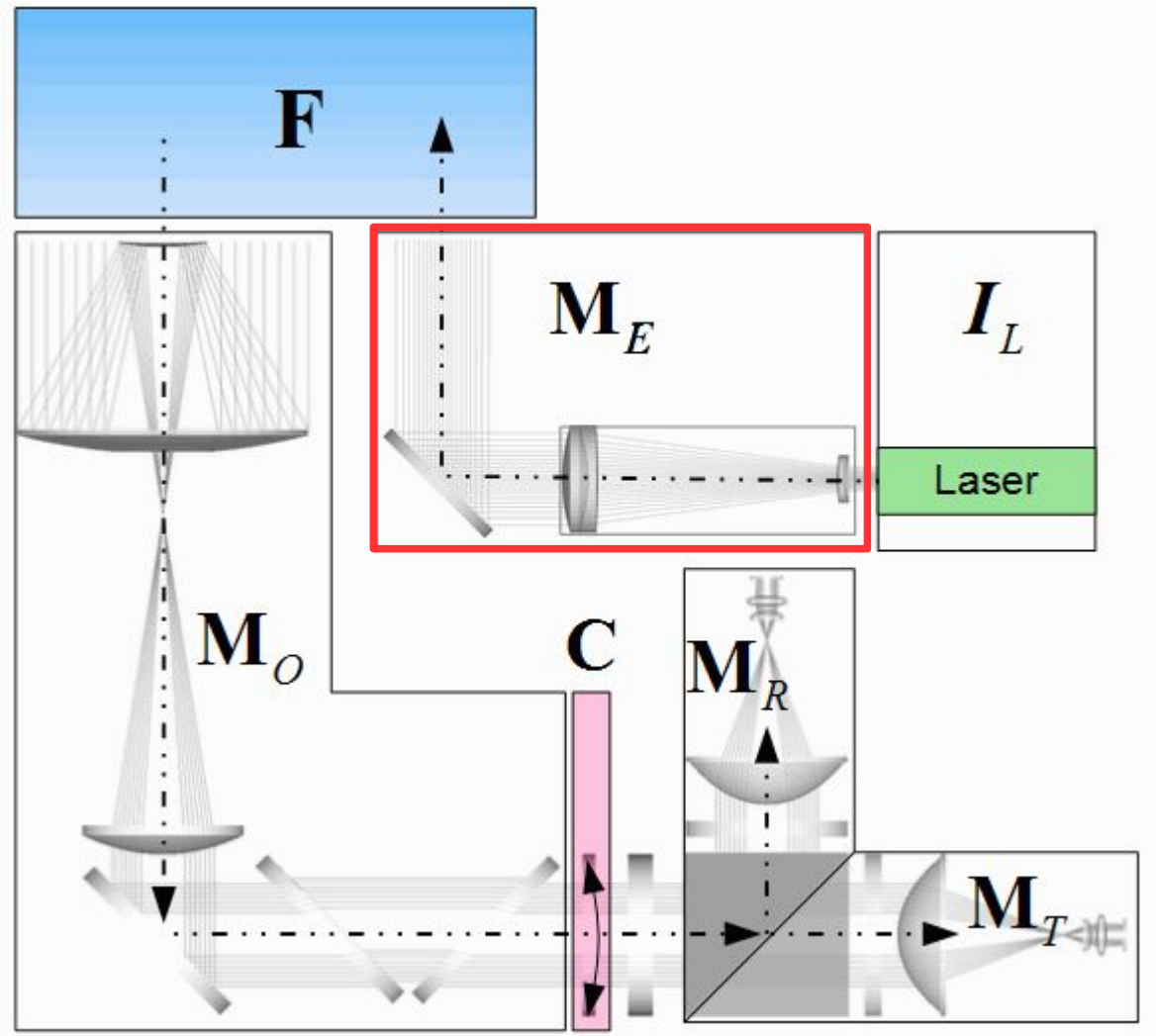
divergence

pointing / jitter

wavelength

polarisation
- purity
- orientation

temporal / thermal stability

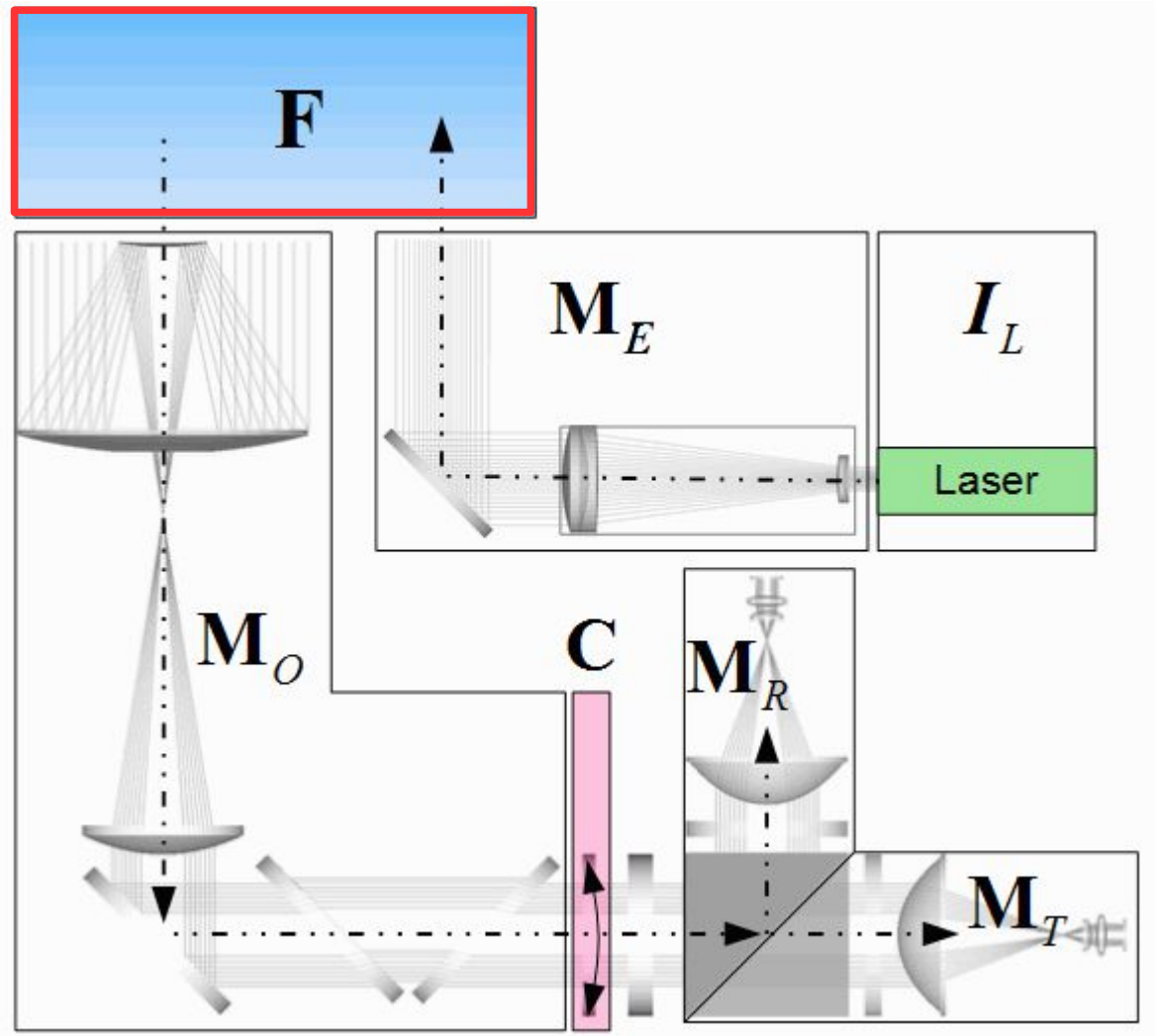


emitter and steering optics

wavelength dependent
- focus
- transmission
- polarisation
- birefringence

alignment
- accuracy
- stability
- alignment control

polarisation
- orientation
- flatness

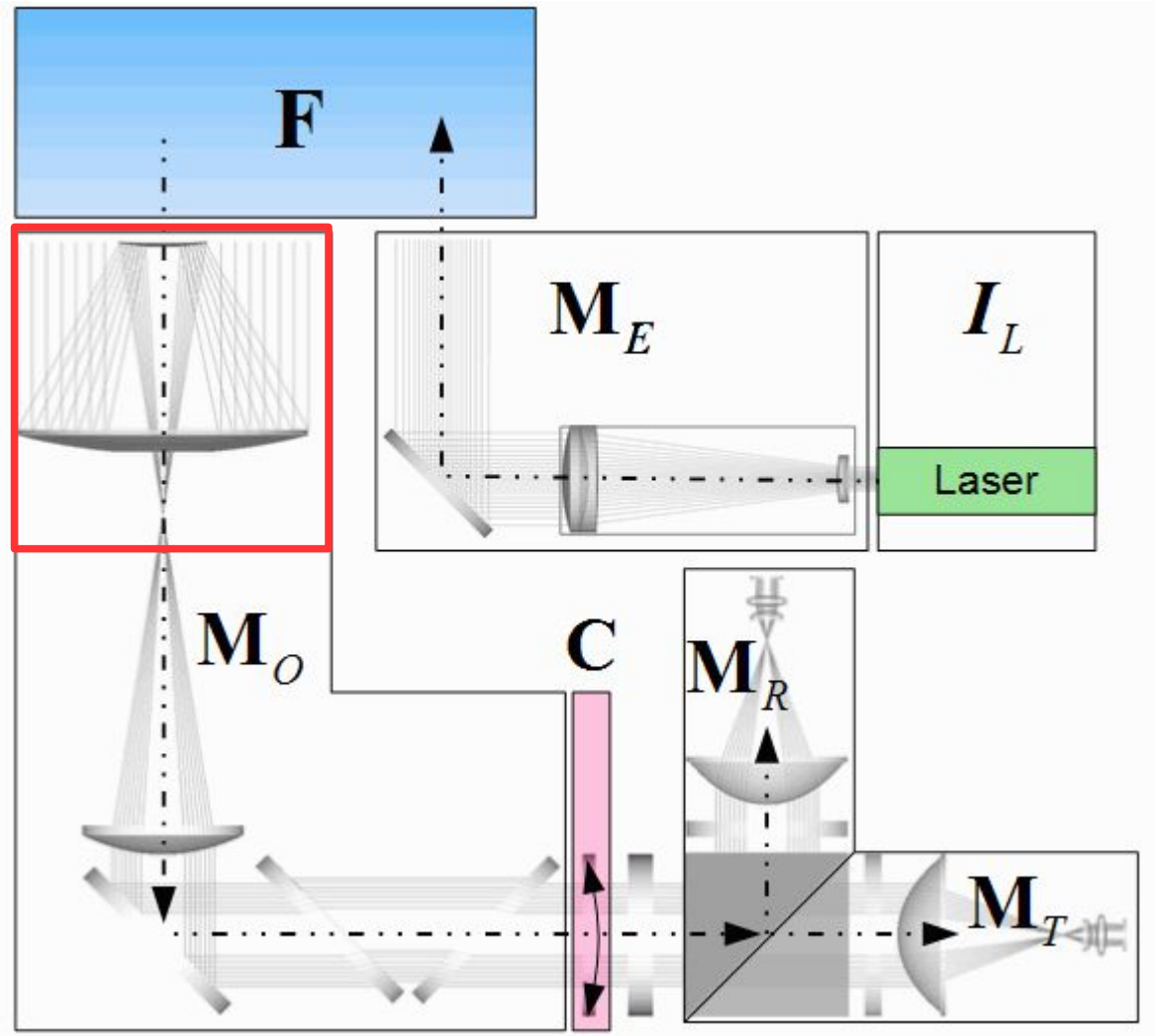


atmosphere

Rayleigh calibration

Rayleigh
- backscatter coefficients
- depolarisation ratios
- Raman lines in IFF bw

radiosonde data



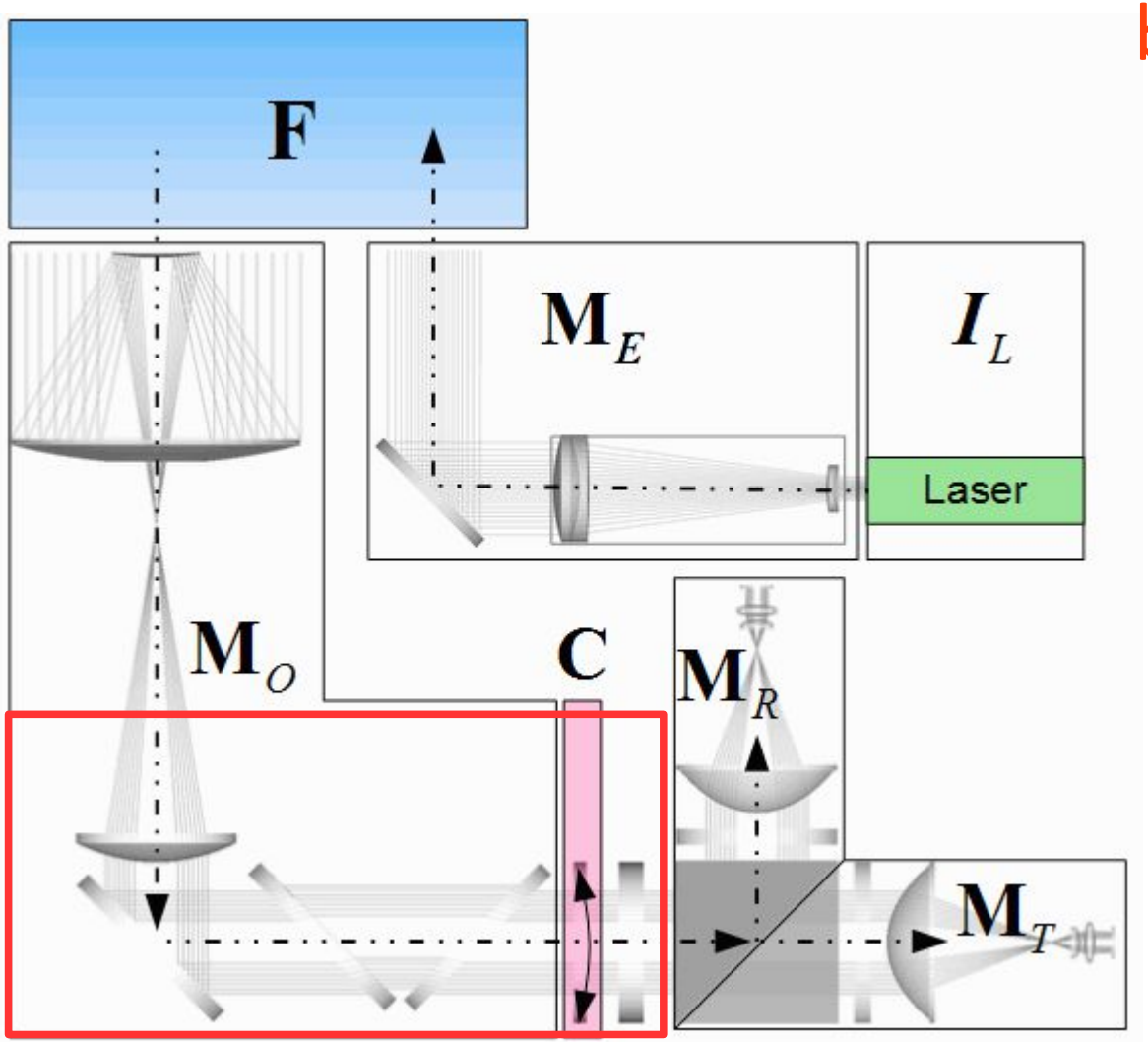
receiving optics telescope

focal length, diameter

alignment stability

Newton telescope
90° mirror depolarisation

field of view



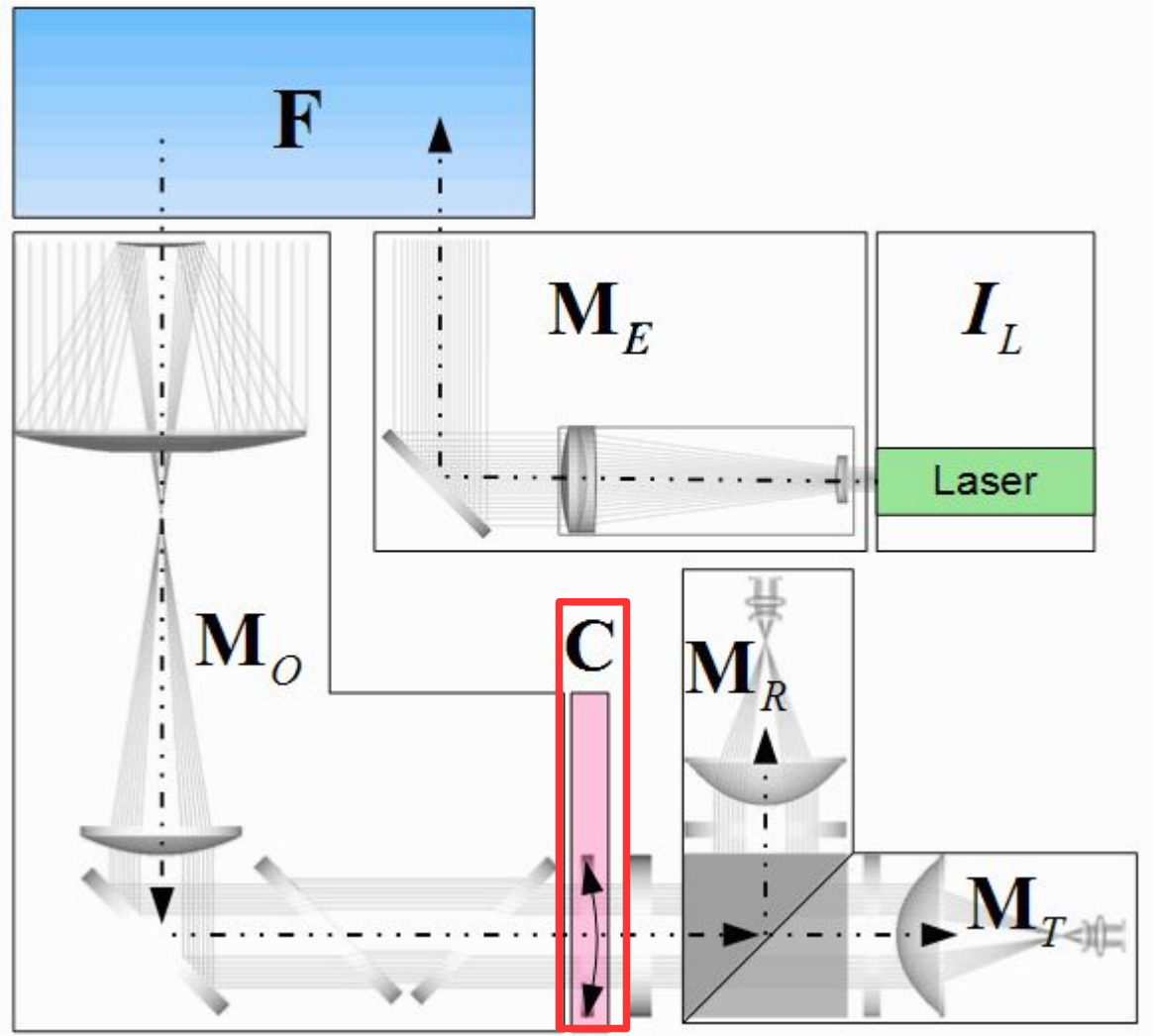
receiving optics
beamsplitters and filters

focal length of collimator
- => beam divergence
- => beam diameter

accpetance angles of
- beamsplitters and
- interference filters

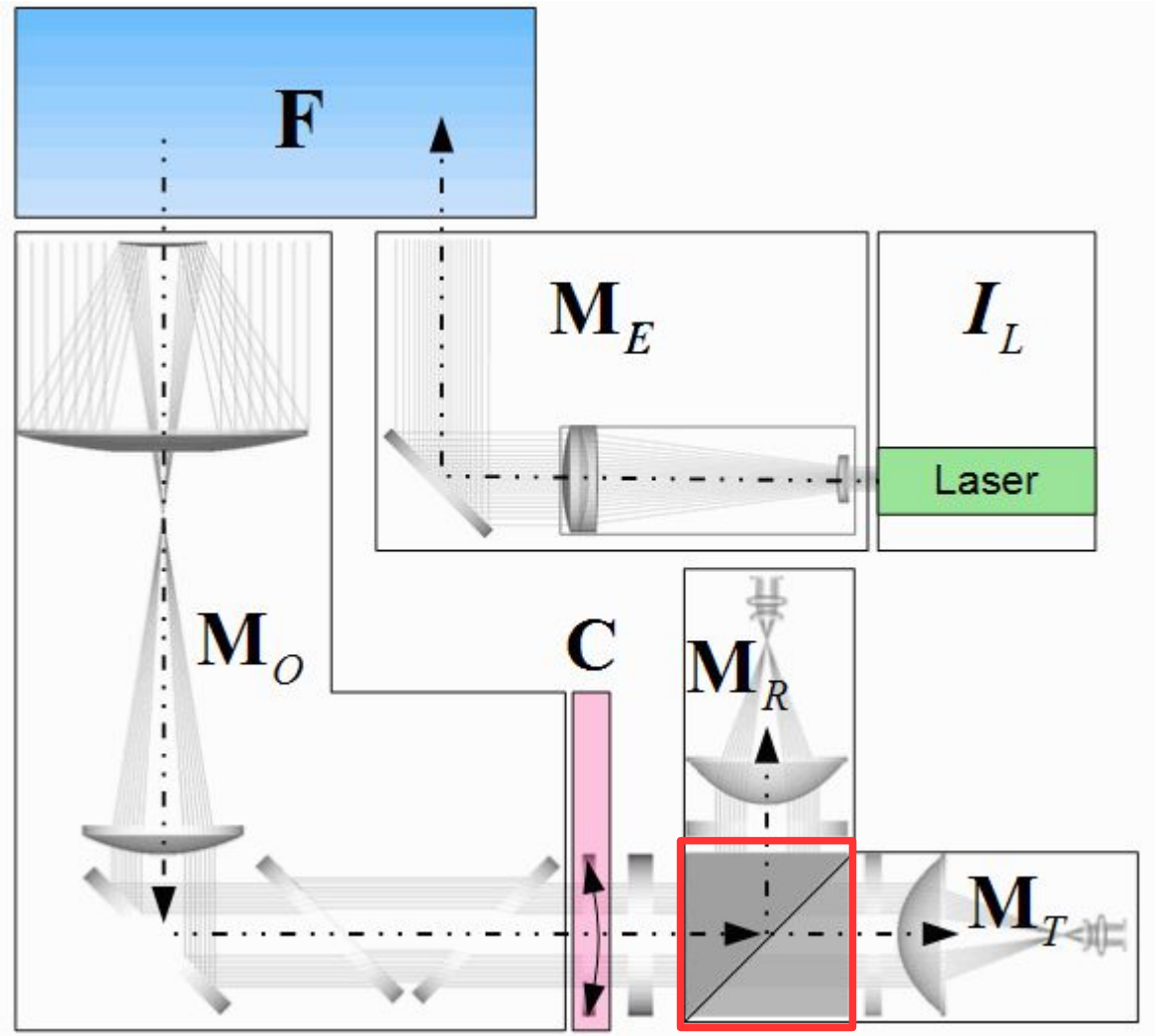
polarisation problemes
- diattenuation
- retardance

polarisation calibrator



location

type

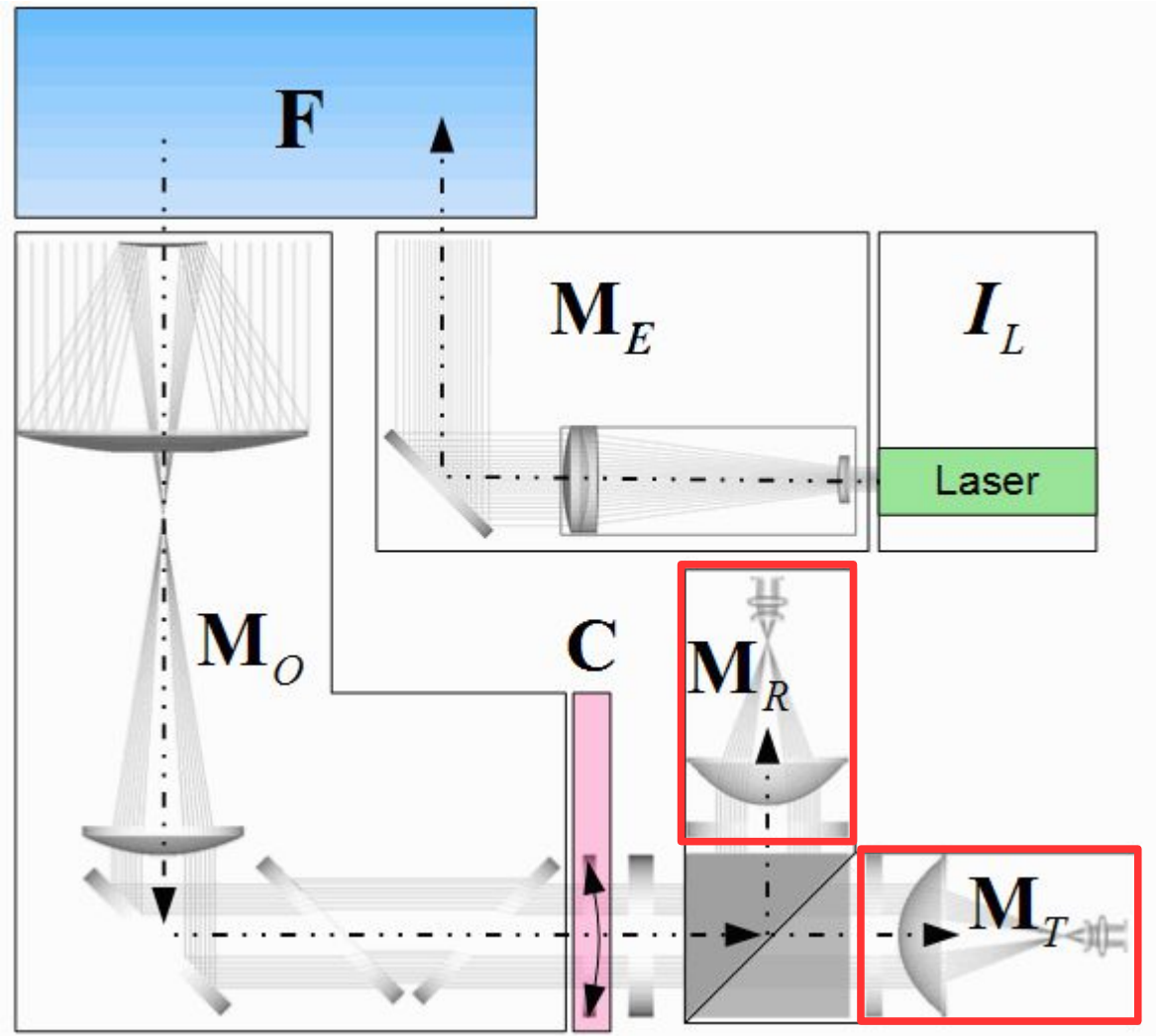


polarising
beam splitter

acceptance angles

extinction ratio

cleaning



detectors and optics

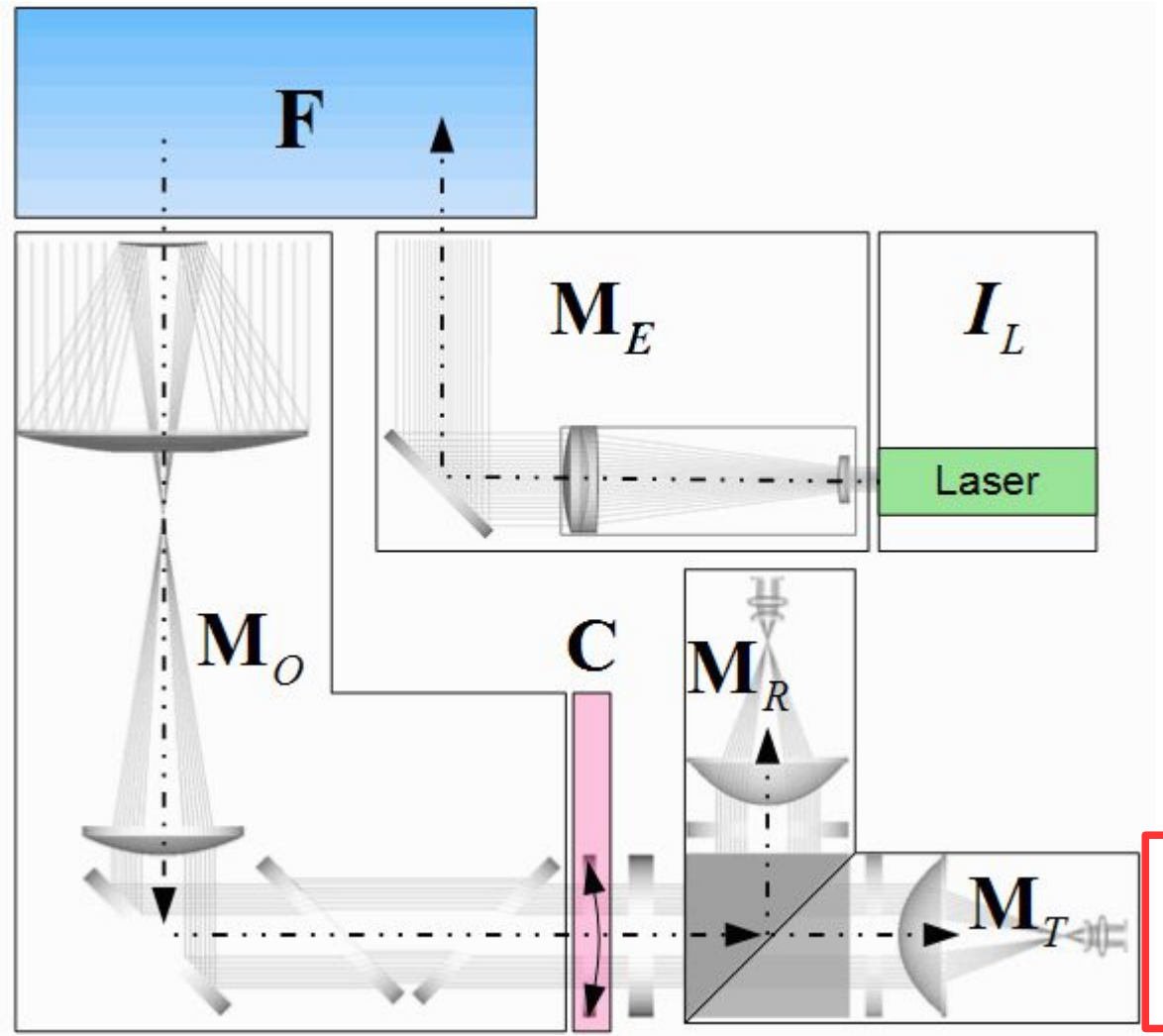
PMT
- homogeneity of the sensitivity

APD
- small diameter

eyepiece
- => telescope imaging

neutral density filters
- => adjust signal level (LICEL)

data acquisition

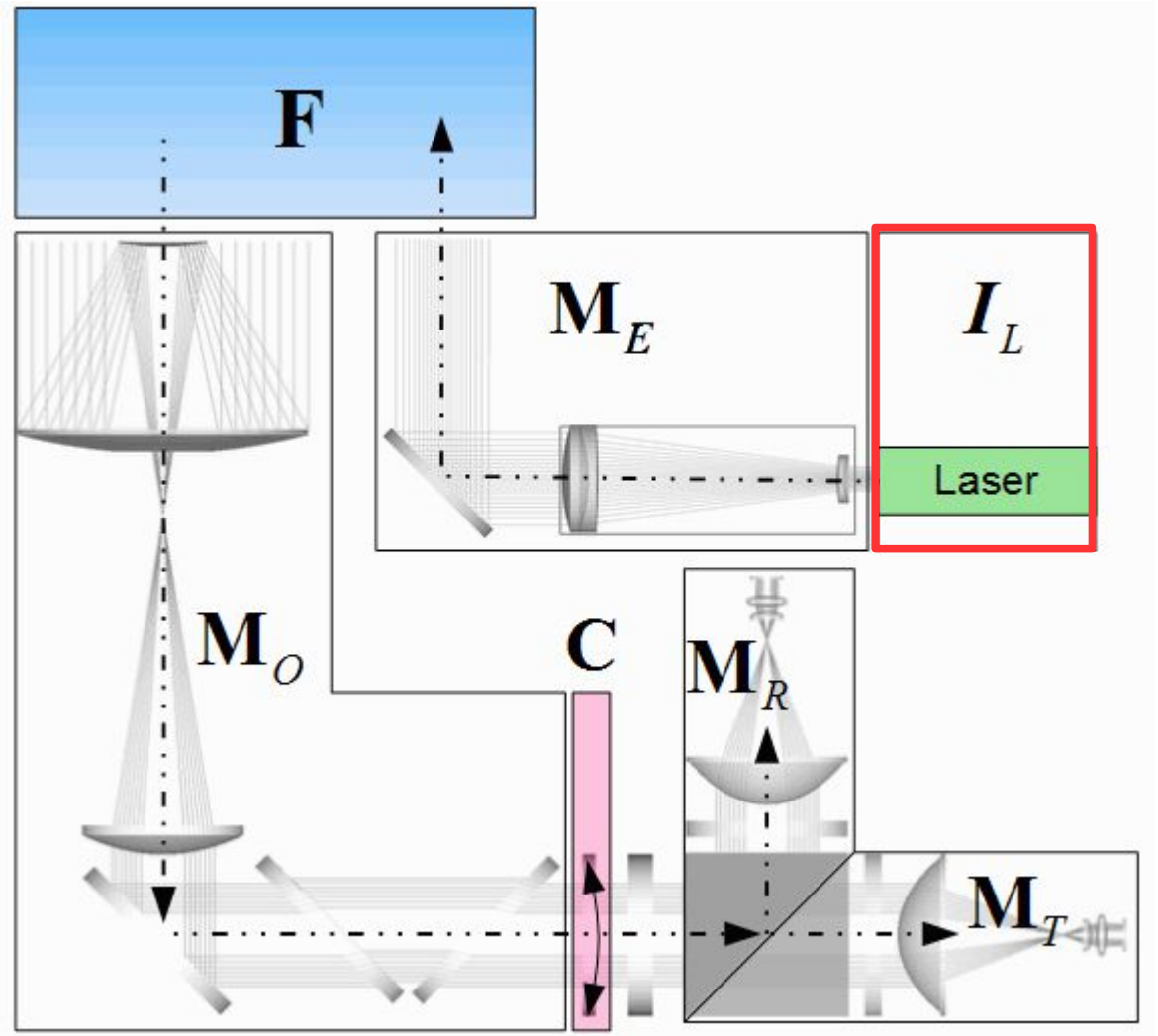


trigger delay

analogue
max. upper level

photon counting
max. background

DAQ



laser

divergence

pointing / jitter

wavelength

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- purity
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temporal / thermal stability

Brilliant b Specifications

Repetition rate (Hz)		**10**	**10 SLM***	**20**	
Energy per pulse (mJ)	**1064 nm**	**850**	**700**	**700**	**Measured with a calibrated wattmeter**
	532 nm	**400**	**290**	**300**	
	355 nm	**185/225**	**135**	**120/140**	**Regular/High energy UV option**
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Polarization ratio (%)	**1064 nm**	**>80**	**>70**	**>70**	**Horizontal polarization**

source: http://www.quantel-laser.com

1D Gaußverteilung

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{1}{2}\frac{(x-a)^2}{\sigma^2}\right)$$

2D symmetrische Gaußverteilung

Für $\rho = 0$ und $\sigma_1 = \sigma_2$

$$f(x_1, x_2) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{(x_1-a_1)^2 + (x_2-a_2)^2}{2\sigma^2}\right)$$

$$r = \sqrt{x_1^2 + x_2^2} \Rightarrow f(r) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right)$$

$$\int_0^b 2\pi r \cdot f(r)\, dr = \int_0^b \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right) dr$$ nicht analytisch lösbar.

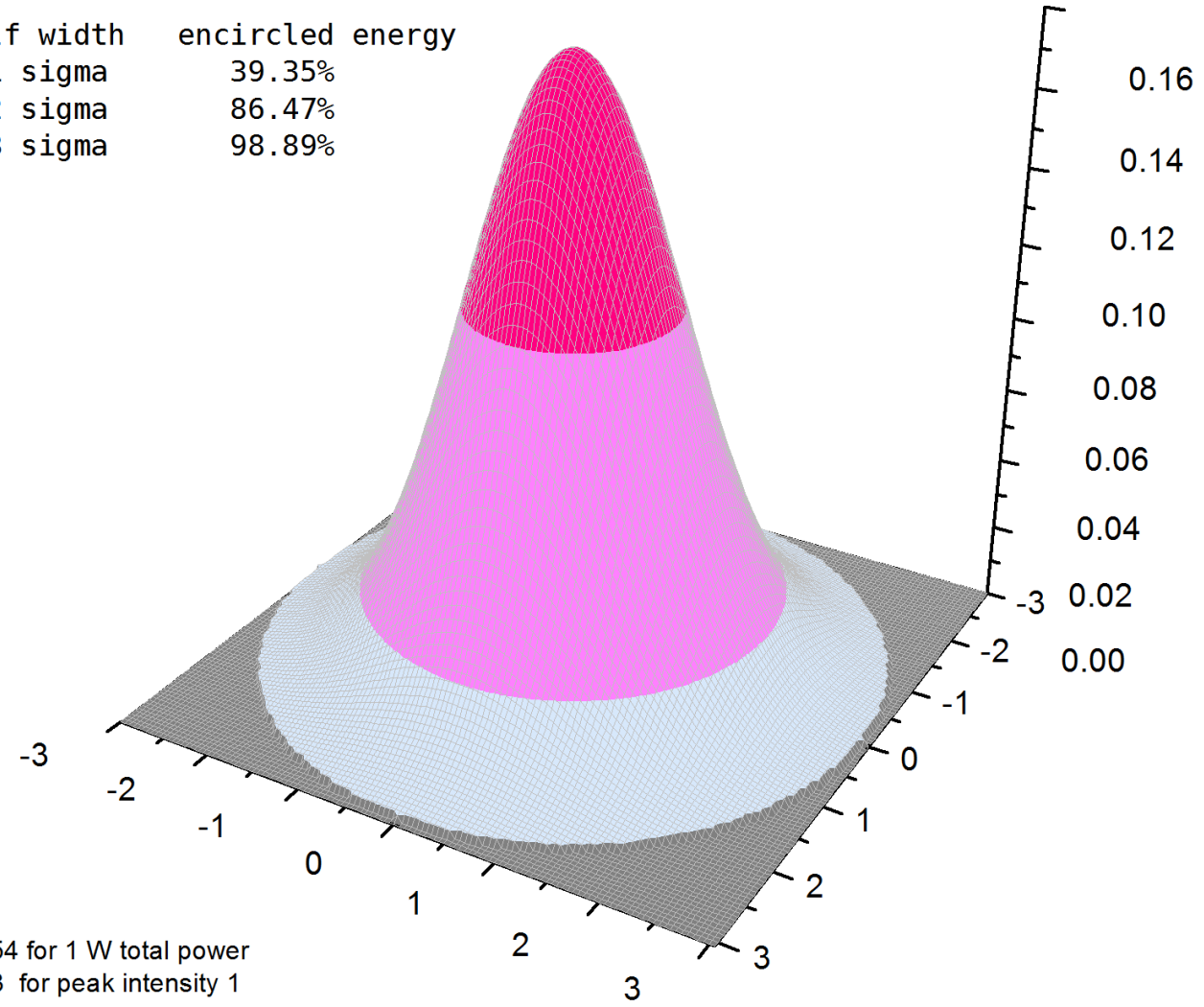
$$f(r)/f(0) = 0.5 \Rightarrow r_{1/2} = \sqrt{2\ln 2}\cdot\sigma \Rightarrow fwhm = 2r_{1/2} = 2.35482\sigma$$

Gaussian beam waist

$$I(r,0) = \exp\left(-\frac{r^2}{2\sigma^2}\right) \Rightarrow \sigma = \frac{w}{2}$$

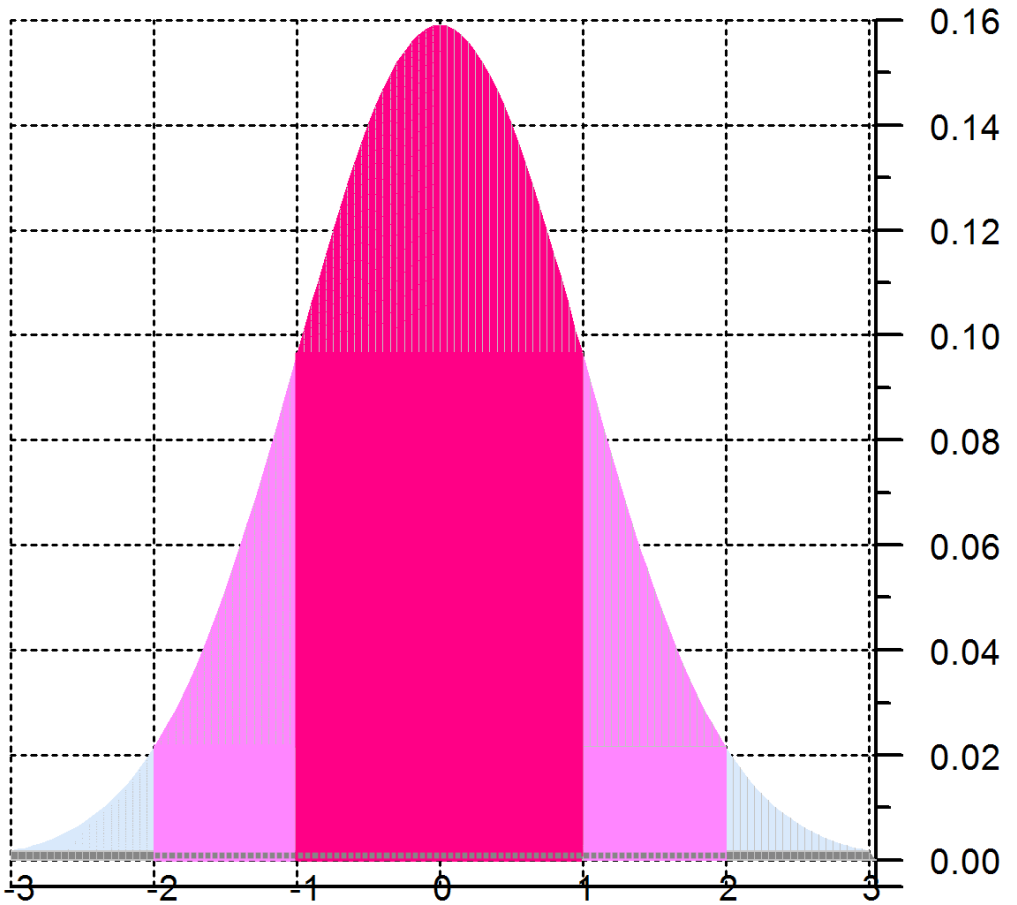
Laser – divergence - Gauß

	half width	encircled energy
red	1 sigma	39.35%
magenta:	2 sigma	86.47%
lt. blue:	3 sigma	98.89%



At 2 Sigma ring:
intensity = 0.02154 for 1 W total power
intensity = 0.1353 for peak intensity 1

Laser – divergence - Gauß



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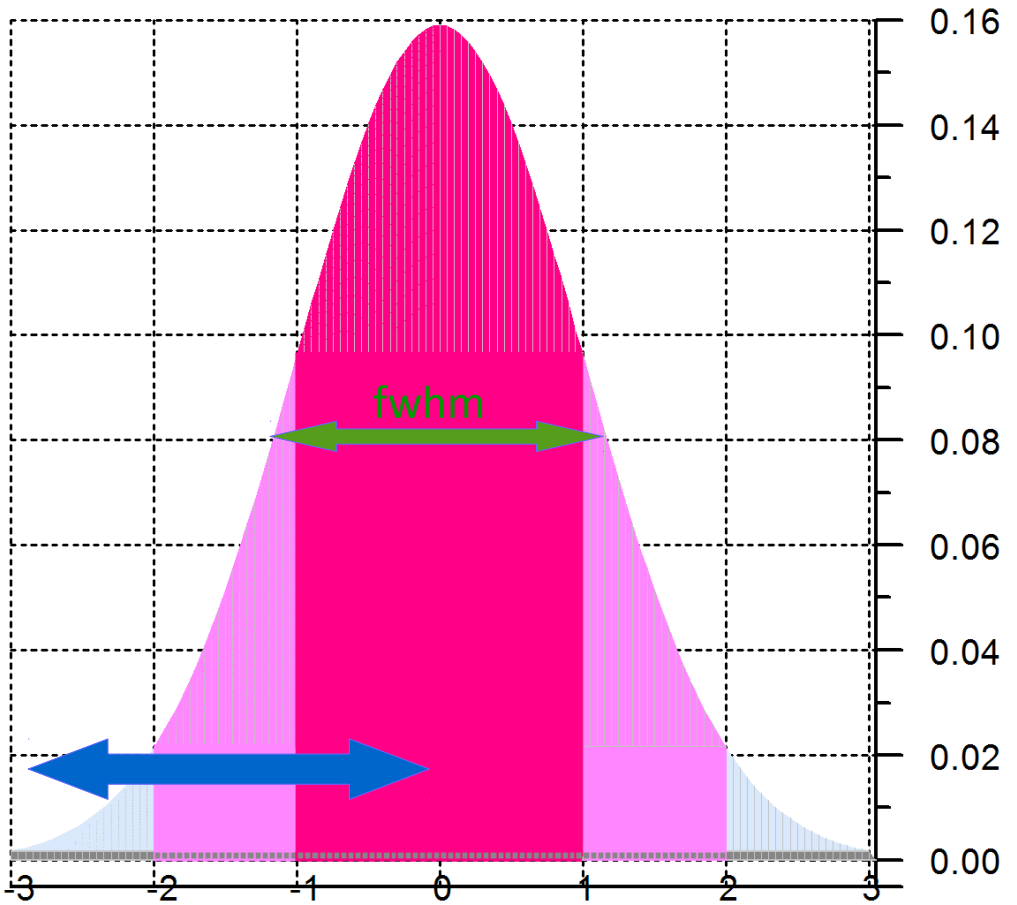

we need 3 sigma hw !

At 2 Sigma ring:
intensity = 0.02154 for 1 W total power
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	half width	encircled energy
red	1 sigma	39.35%
magenta:	2 sigma	86.47%
lt. blue	3 sigma	98.89%
	hwhm	50.00 %

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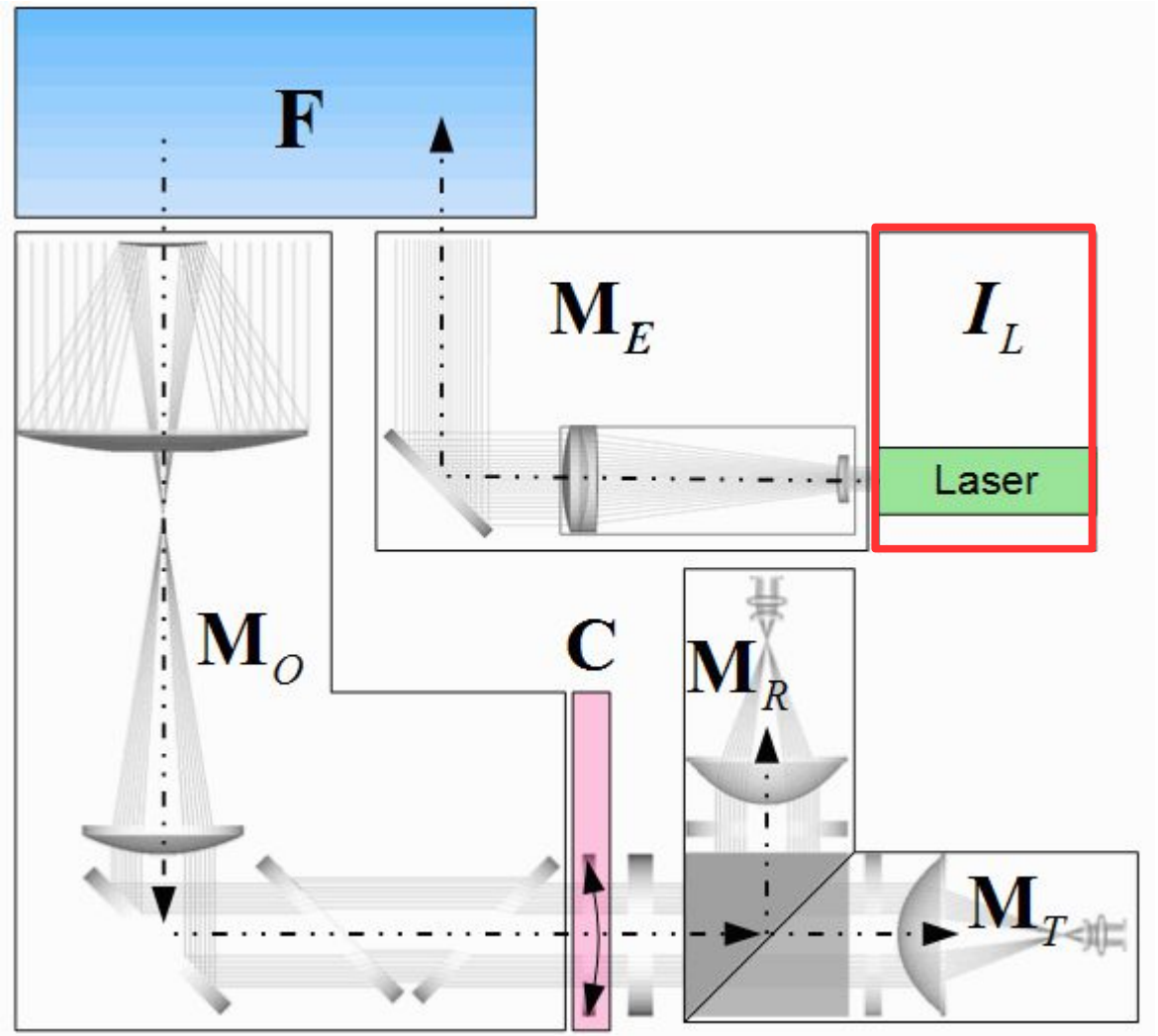
Polarization ratio (%)	**1064 nm**	**>80**	**>70**	**>70**	**Horizontal polarization**

3 sigma = 0.75 mrad
pointing stability = 0.05 mrad (± ?)
---
beam fw = 0.85 mrad

source: http://www.quantel-laser.com



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Question: can we use an interference filter with 0.5 nm bandwidth ? (=> fwhm ?)

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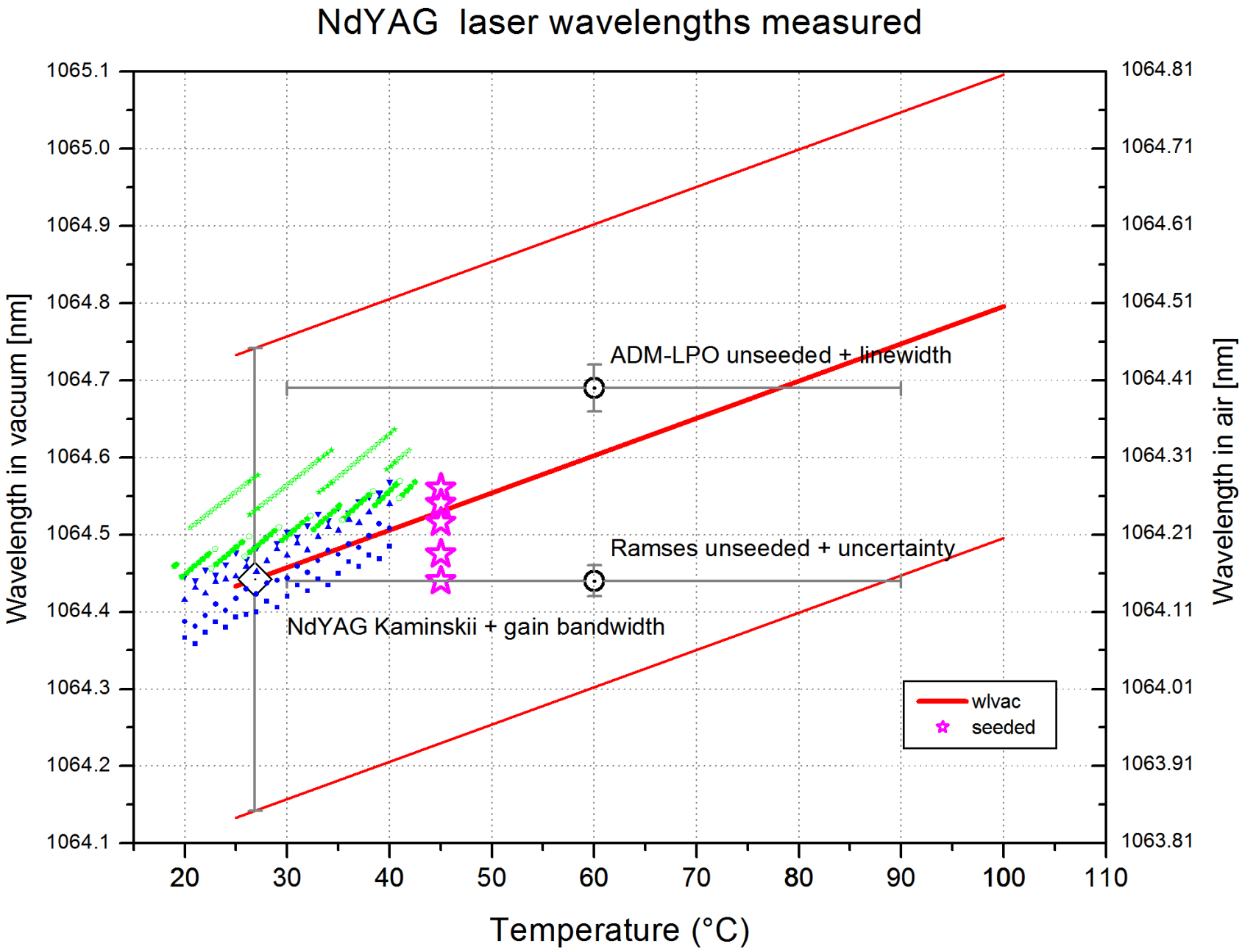


source: http://www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/Rayleigh_scattering/Rayleigh_coefficients.pdf

Temperature and its distribution inside the NdYAG rod
- => laser design
- => environmental temperature
- => cooling stability

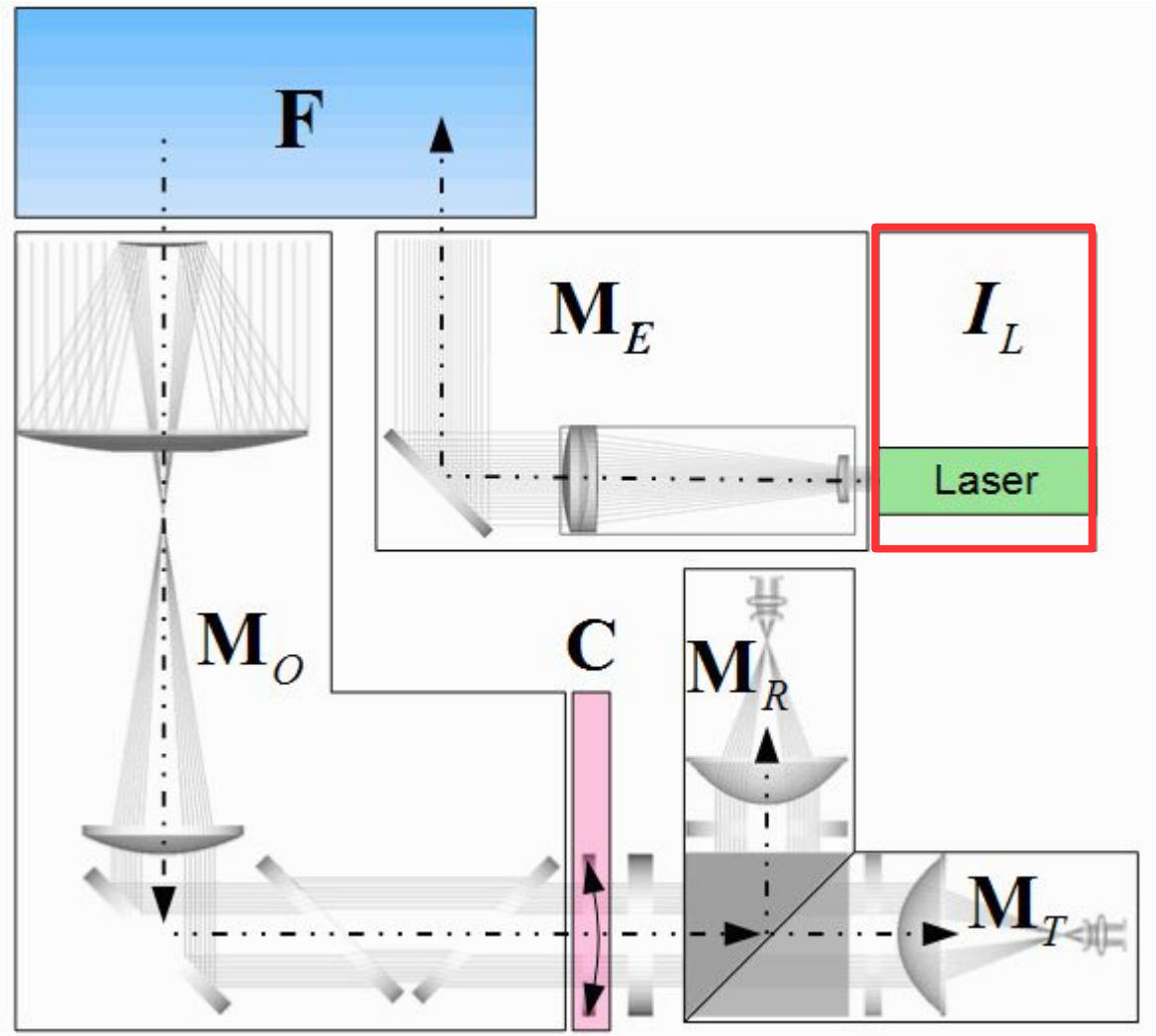
Laser gain bandwidth

Two laser lines

Theoretical and measurement uncertainties

The usual lidar laser is not of best quality (high price)
=> consider the worst case, unless verfied else.

Literature and references in =>
Rayleigh_coefficients_ver1.4g.pdf
http://www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/Rayleigh_scattering/Rayleigh_coefficients.pdf



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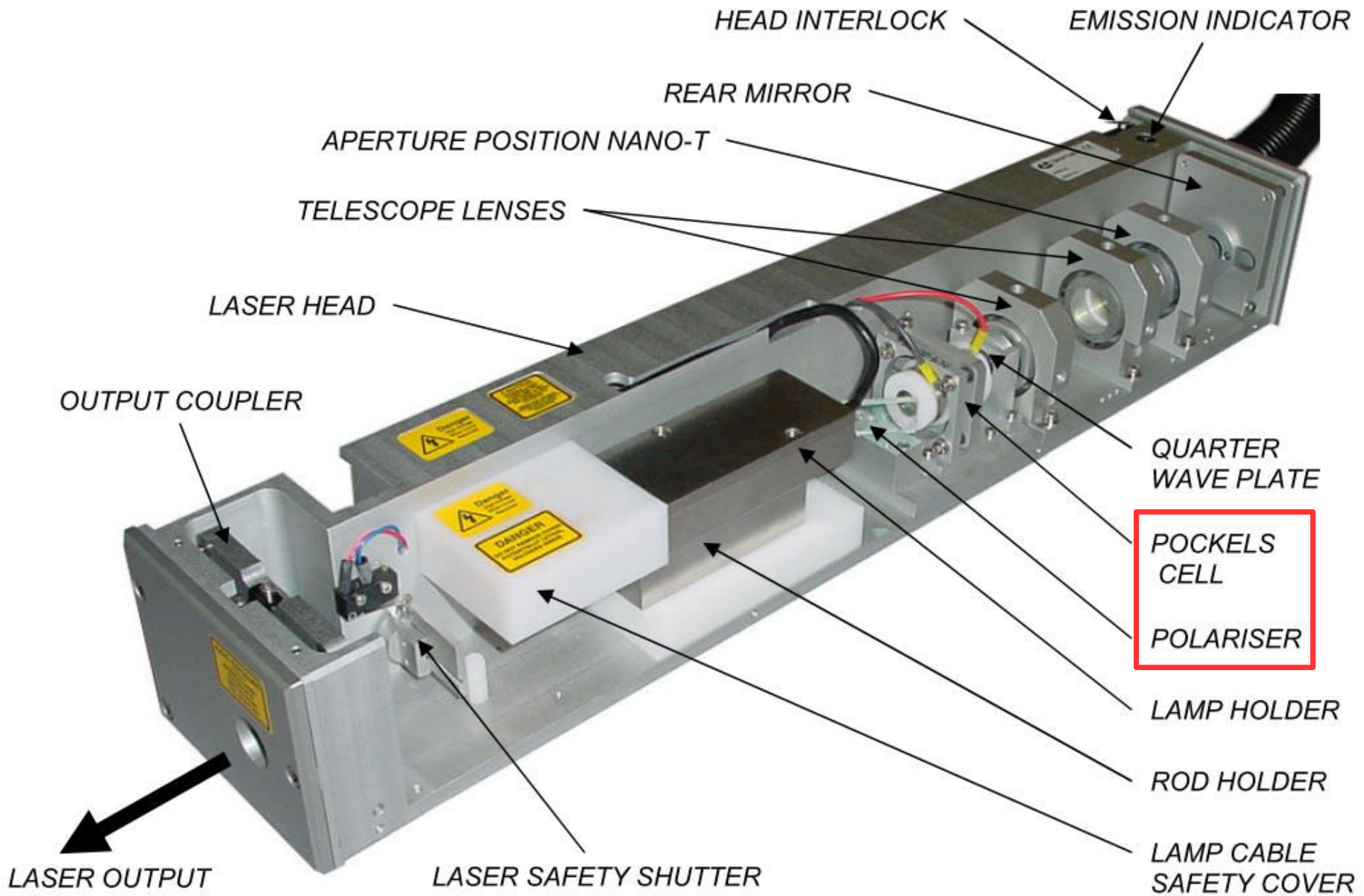
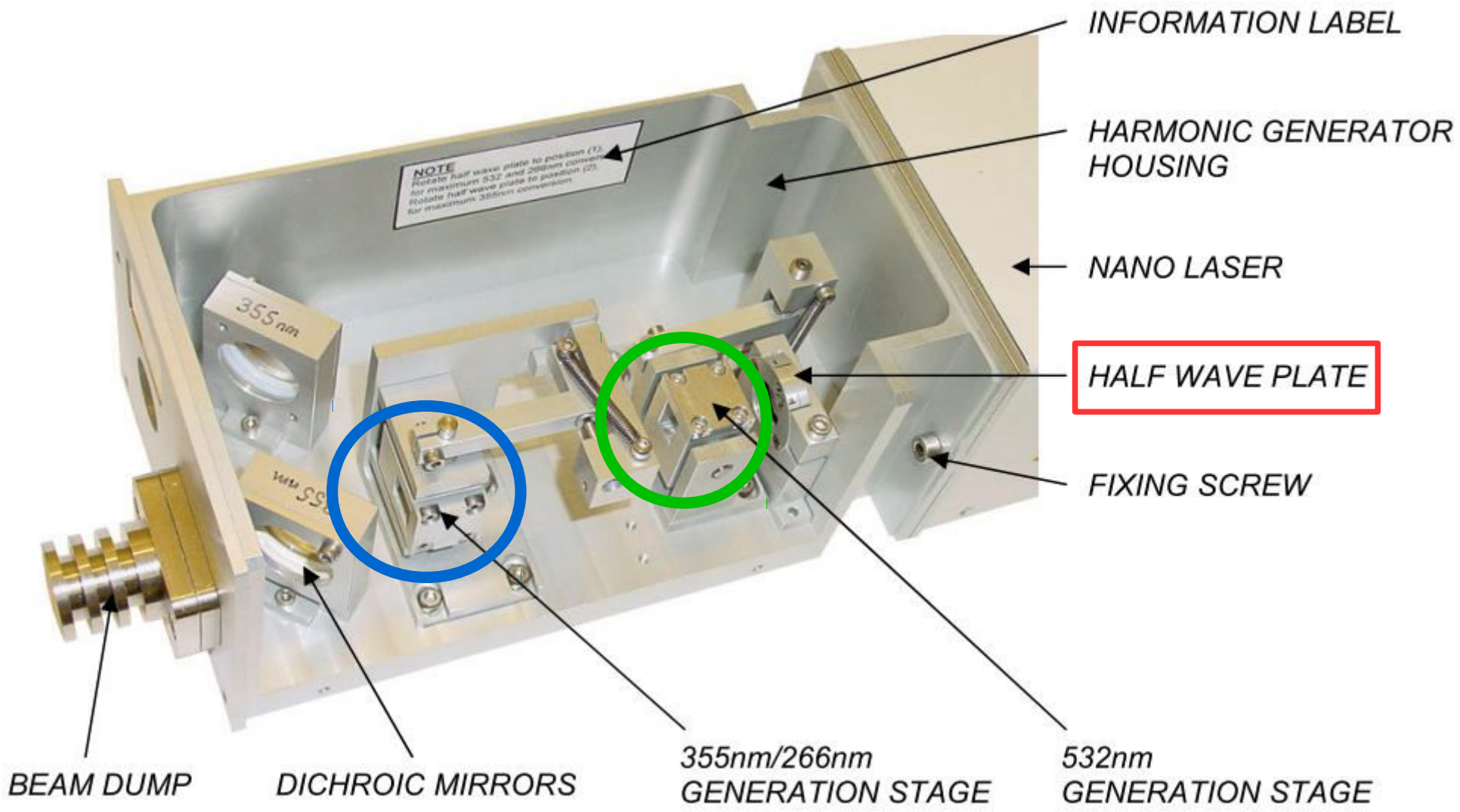
source: http://www.quantel-laser.com

Laser - polarisation



source: http://www.litronlasers.com/pages/nano_series.html



source: http://www.litronlasers.com/pages/nano_series.html

Linear polariser in the resonator should clean the 1064 polarisation,

- but NdYAG rod birefringence can decrease
  the DOLP (Degree Of Linear Polarisation) of 1064 nm

- SHG and THG only convert light in certain polarisation planes
  => DOLP of 355 should be very clean
  => DOLP of 532 could be decreased by THG
  => DOLP of the residual 1064 less than original

- Harmonic beam separators can decrease the DOLP

see also: https://en.wikipedia.org/wiki/Second-harmonic_generation
https://www.rp-photonics.com/frequency_doubling.html

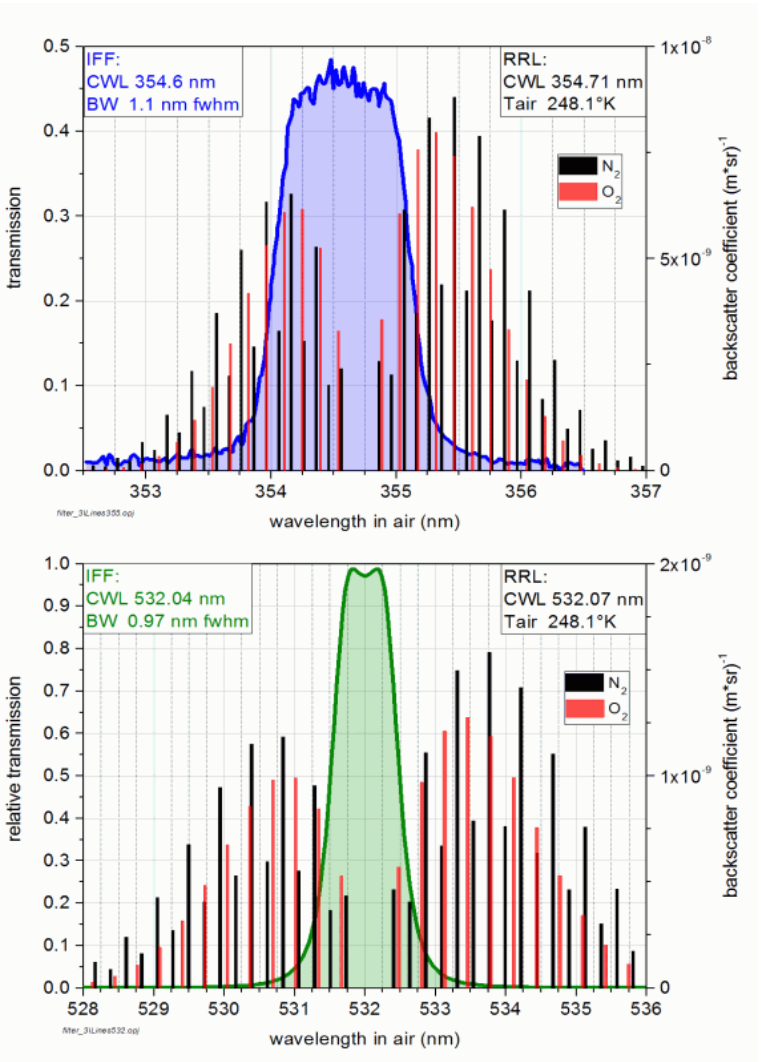
Giuseppe d'Amico 2006:

I send the measurement results from Continuum USA.

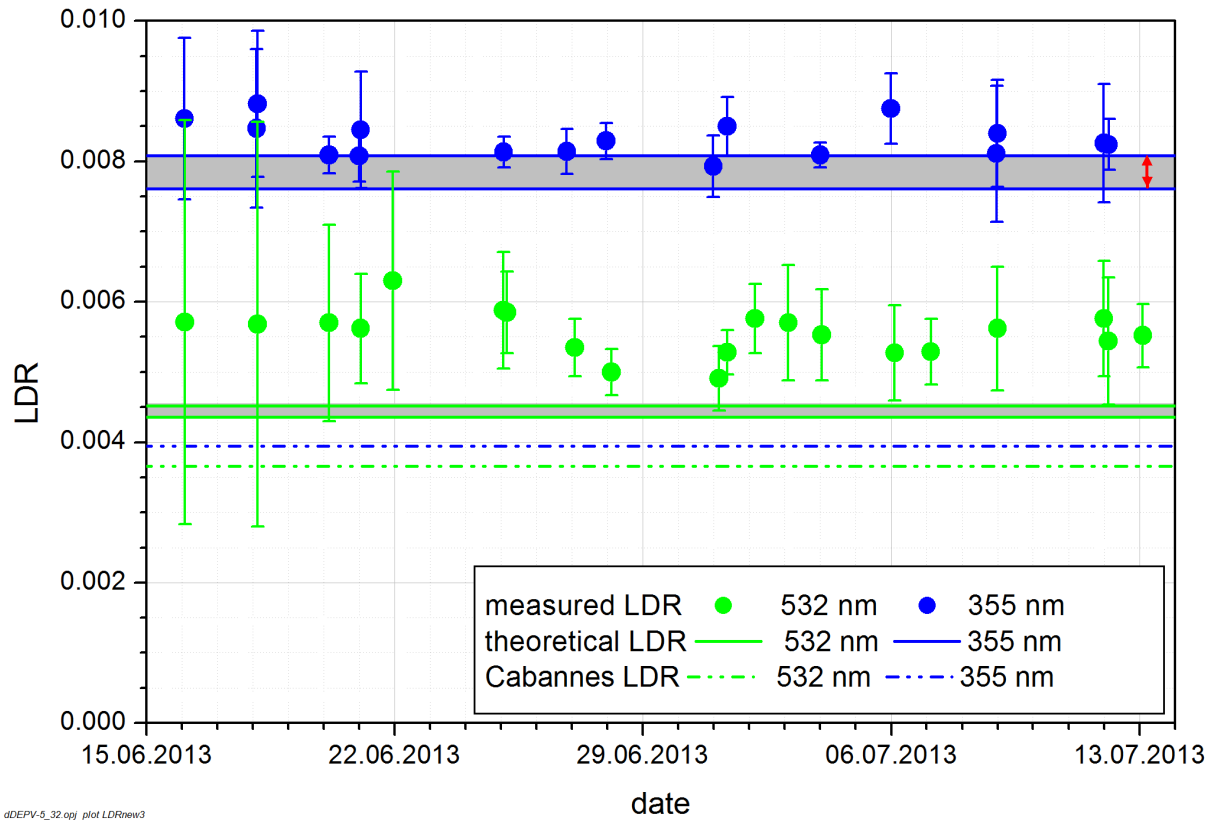
The measurements were done using a laser Surelite II - 10Hz with a SHG crystal of Type I and II. (so at 532 nm; Giuseppe)

Using both crystals, the energy of the vertical component of polarization was 3 Watts and the energy of the horizontal component was 2 mWatts corresponding to ***polarization purity of about 99.93%****.*

=> LDR = 0.002 / 3 = 0.00067

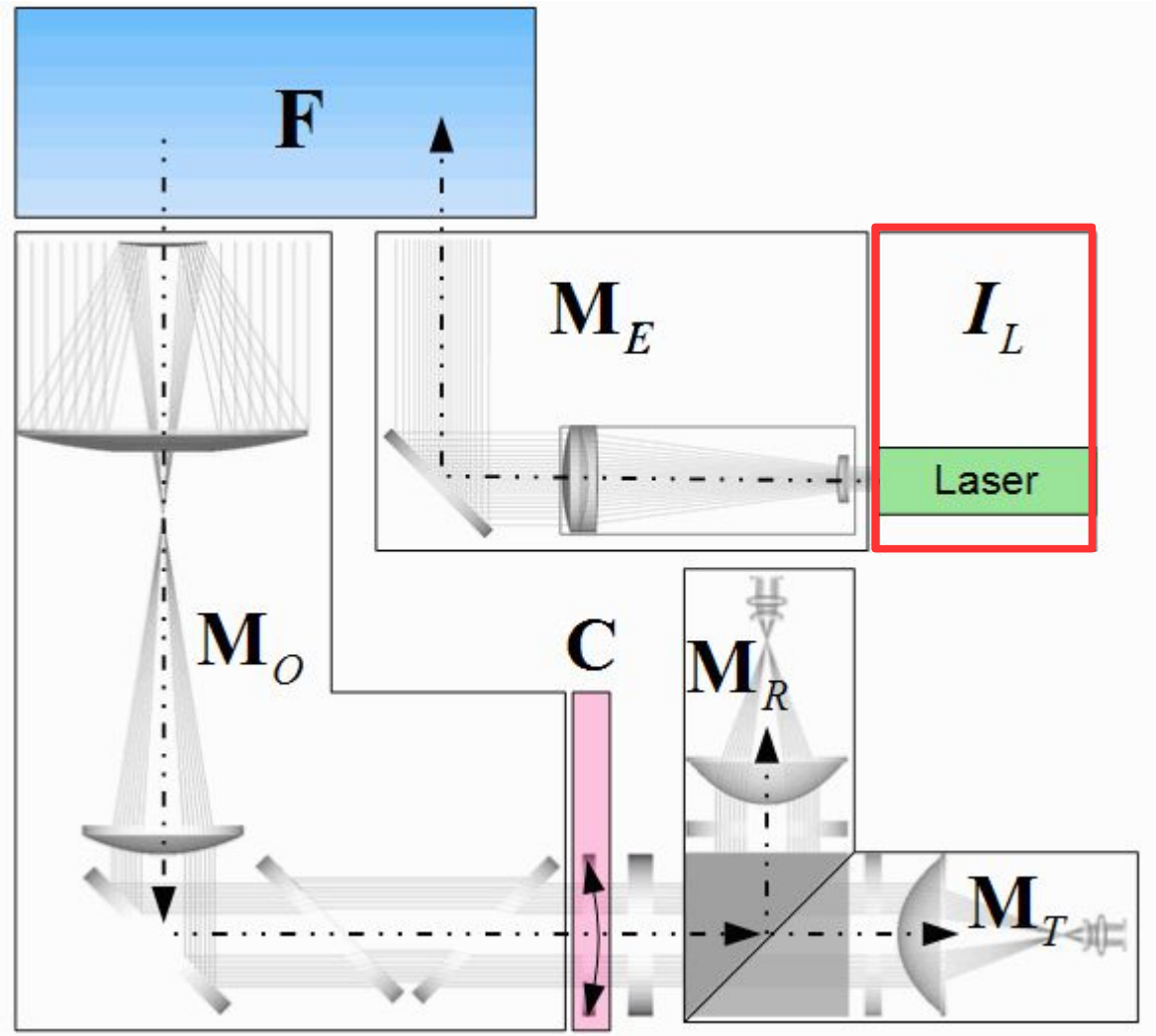


uncertain theoretical LDR due to uncertainties in
- laser wavelength
- Rot. Raman Lines in interference filter bandwidth



Laser polarisation must be cleaner than deviation of measurements from theory

source: Freudenthaler et al., 27th ILRC 2015, Accuracy of linear depolaristion ratios in clear air ranges measured with POLIS-6 at 355 and 532 nm. https://epub.ub.uni-muenchen.de/24942/index.html



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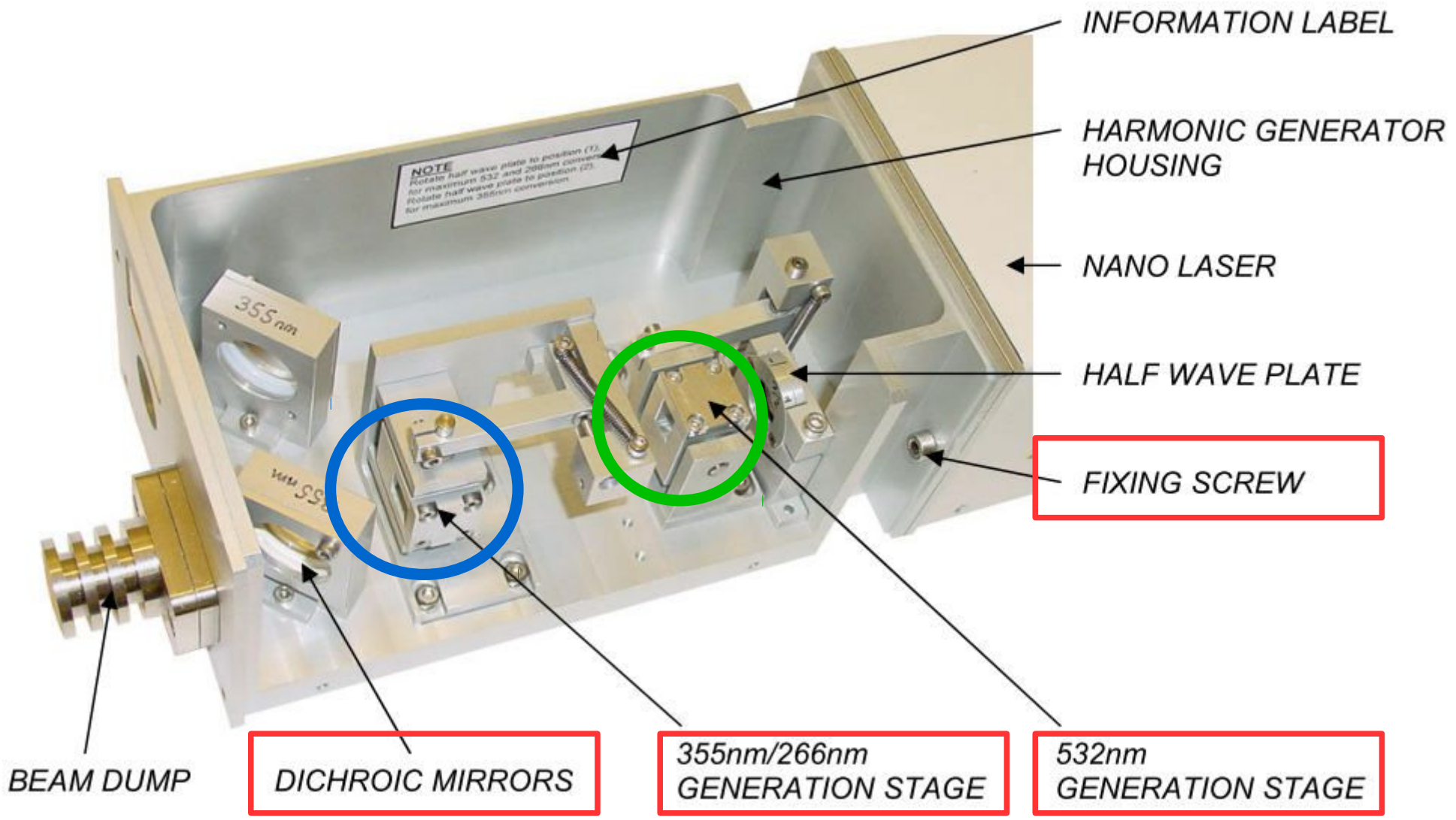
Laser – polarisation – orientation



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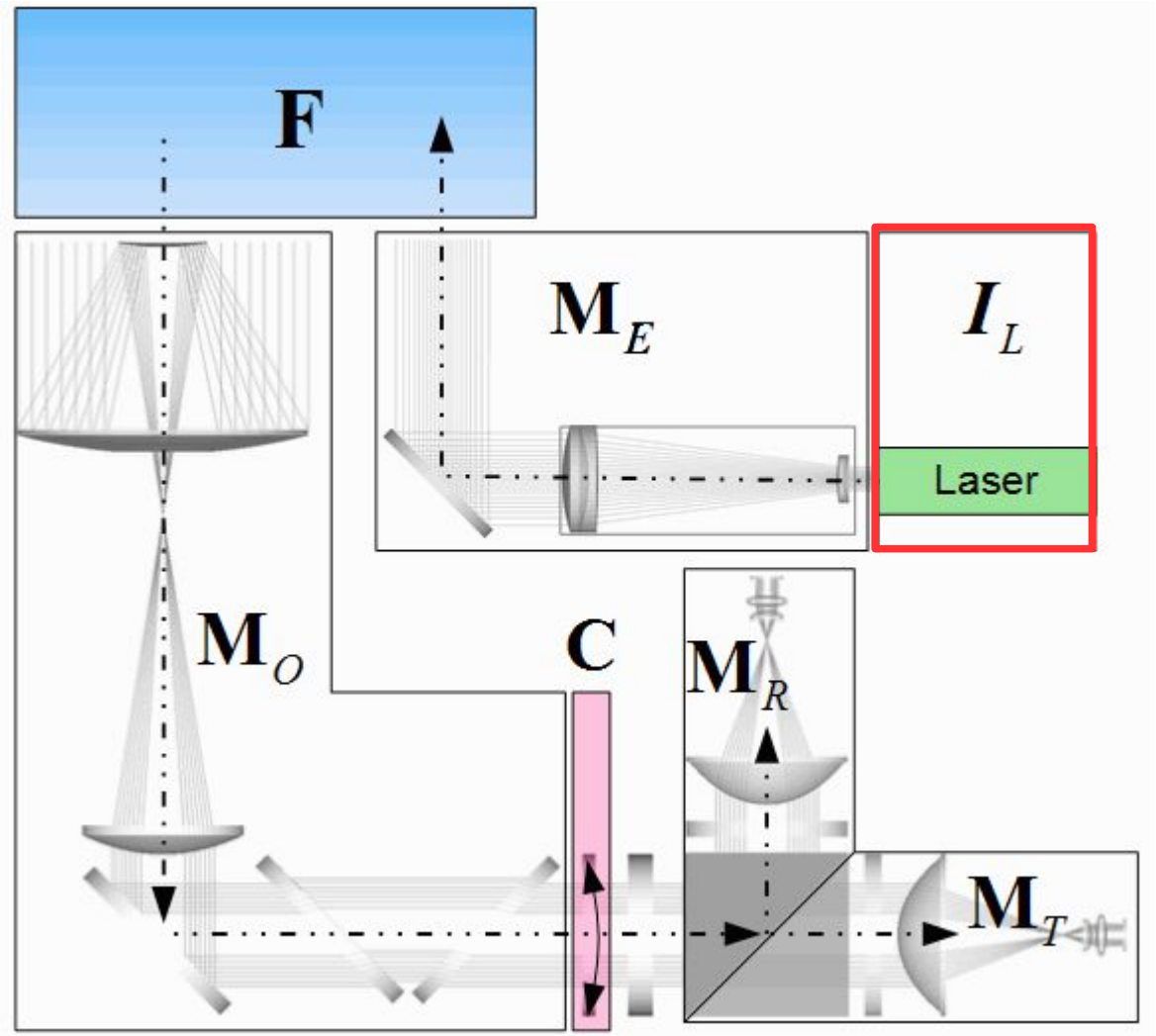

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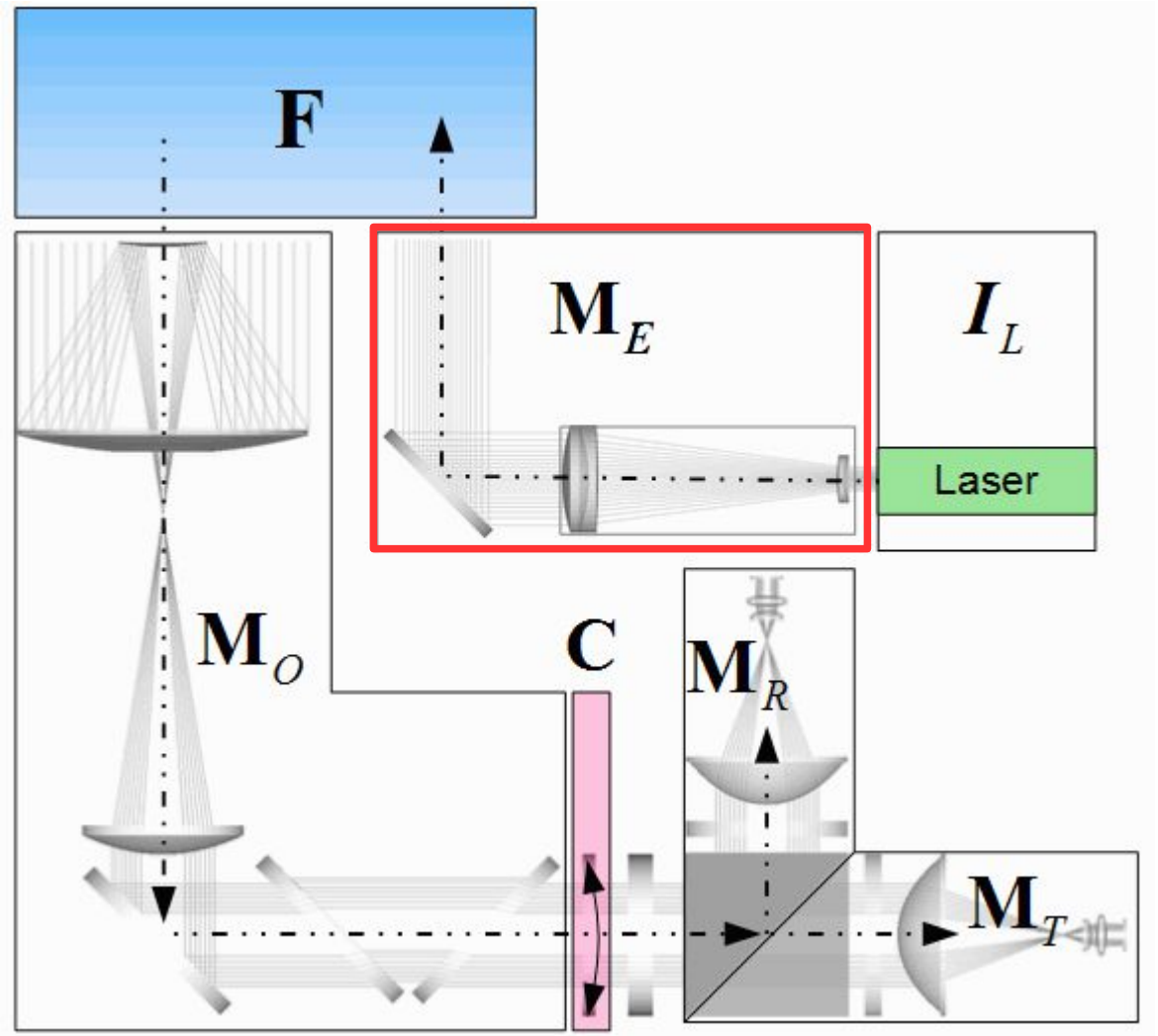

emitter and steering optics

wavelength dependence
- focal length => divergence
- transmission
- polarisation
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alignment
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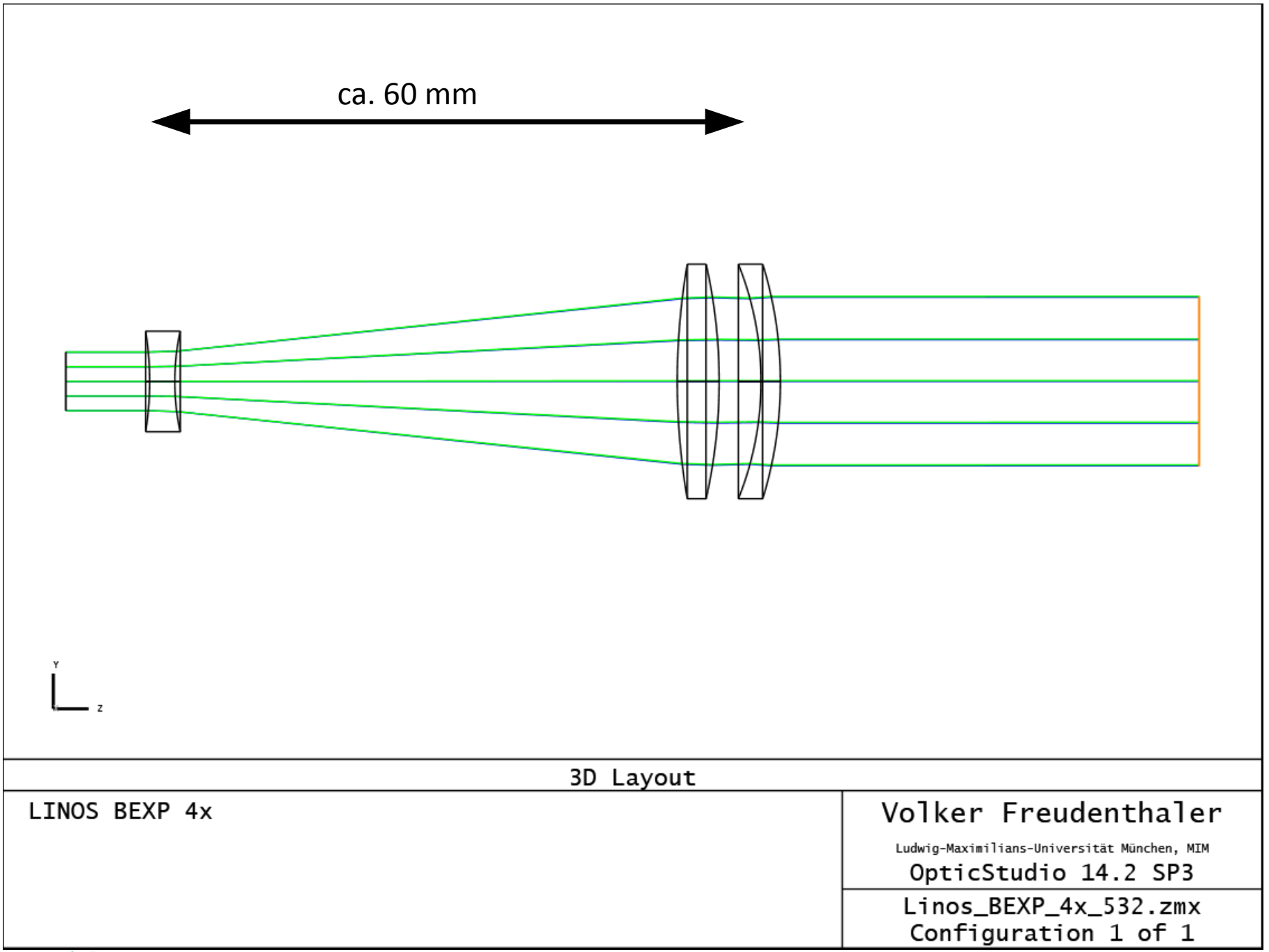
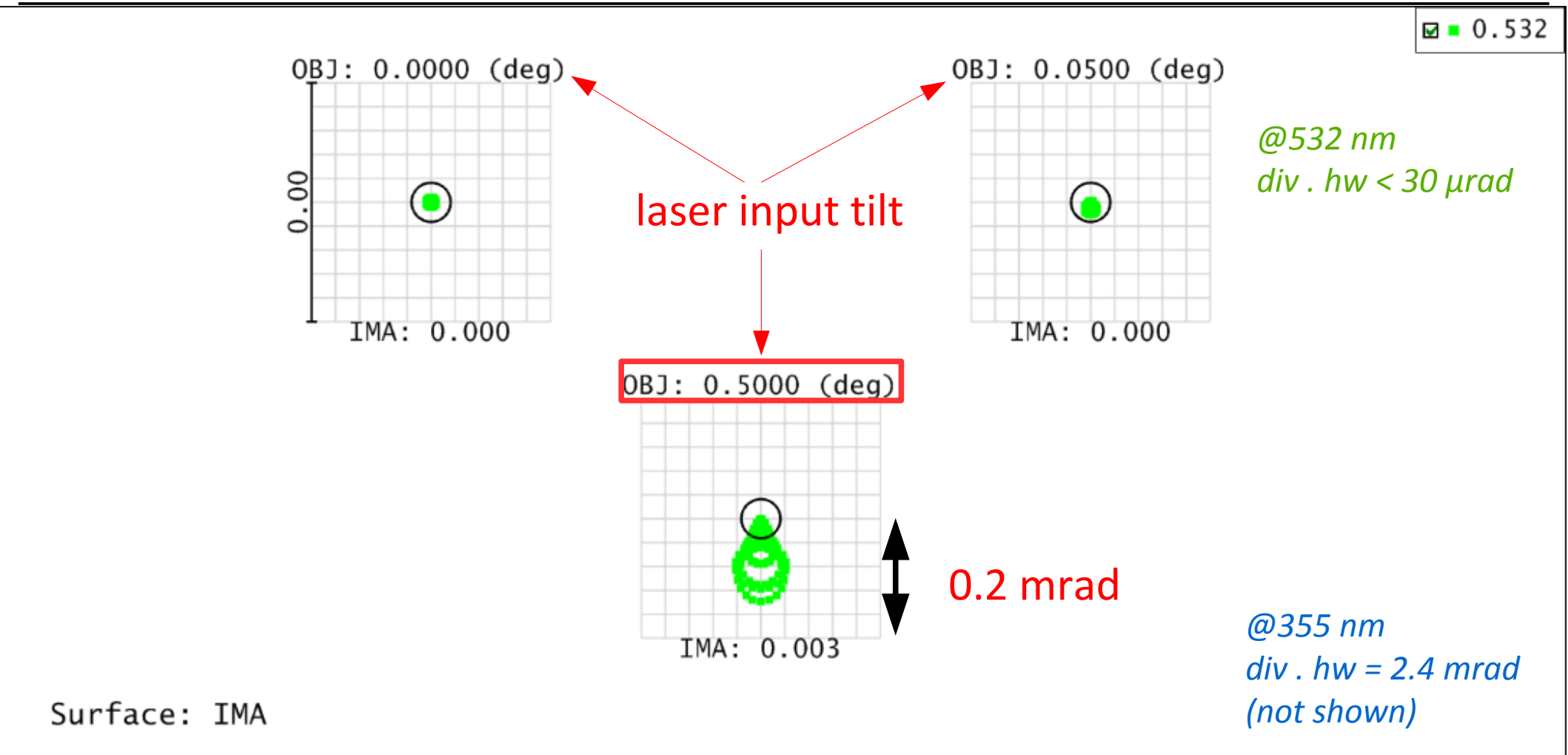
Emitter optics – LINOS 4x beam expander simulation (silica lenses)



Emitter optics - LINOS 4x beam expander parallel input => output angle distribution



Spot Diagram: Cosine Space

LINOS BEXP 4x

Units are direction cosines. Airy Radius: 3.275e-005

Field	:	1	2	3
RMS radius	:	0.0000047	0.0000080	0.0000662
GEO radius	:	0.0000080	0.0000207	0.0001384

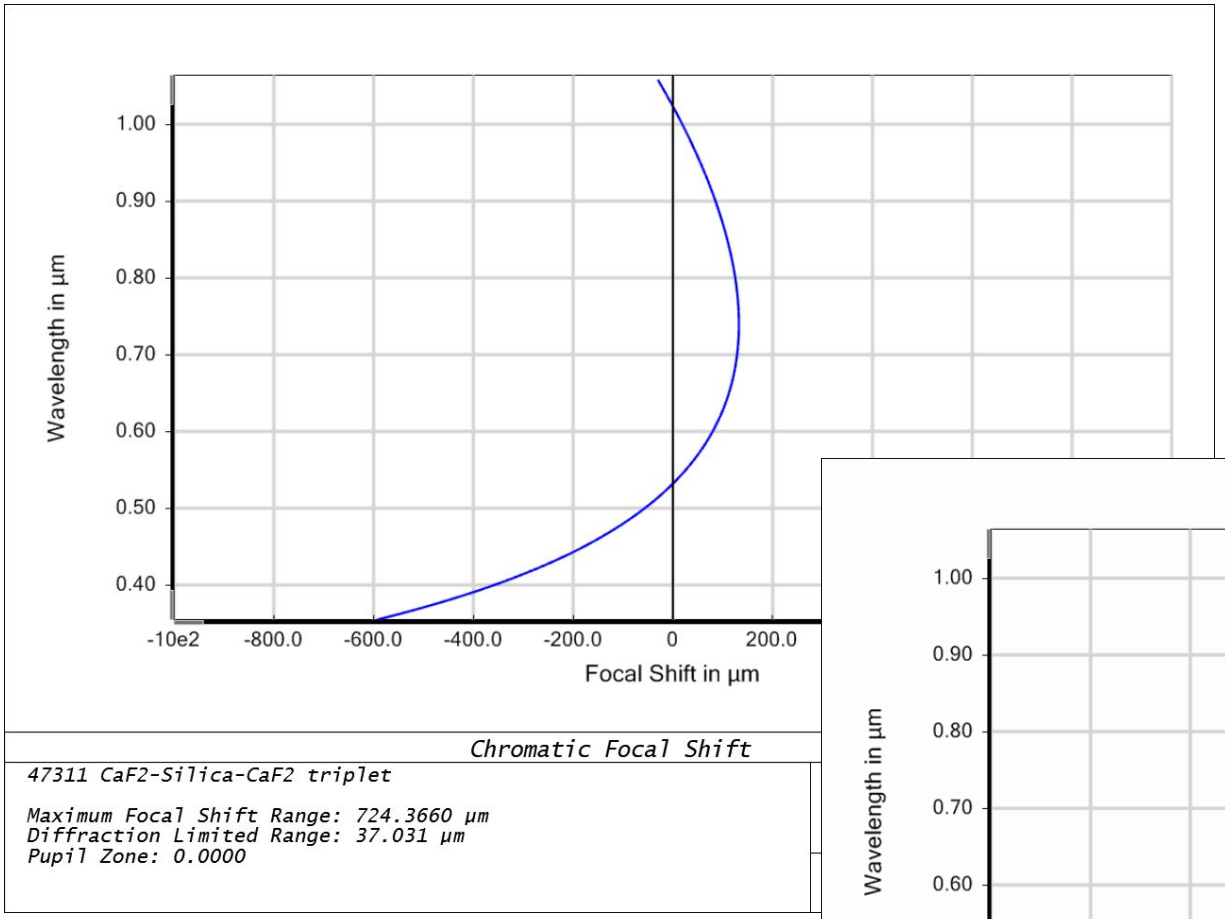
Scale bar : 0.0004 Reference : Chief Ray

Volker Freudenthaler
Ludwig-Maximilians-Universität München, MIM
OpticStudio 14.2 SP3

Linos_BEXP_4x_532.zmx
Configuration 1 of 1

Angular spot diagrams for 0°, 0.05°, and 0.5° tilted input, showing a performance better than the diffraction limit (black circle).
At laser input tilt of 0.5° (lower plot) already 0.14 mrad distortions (hw).

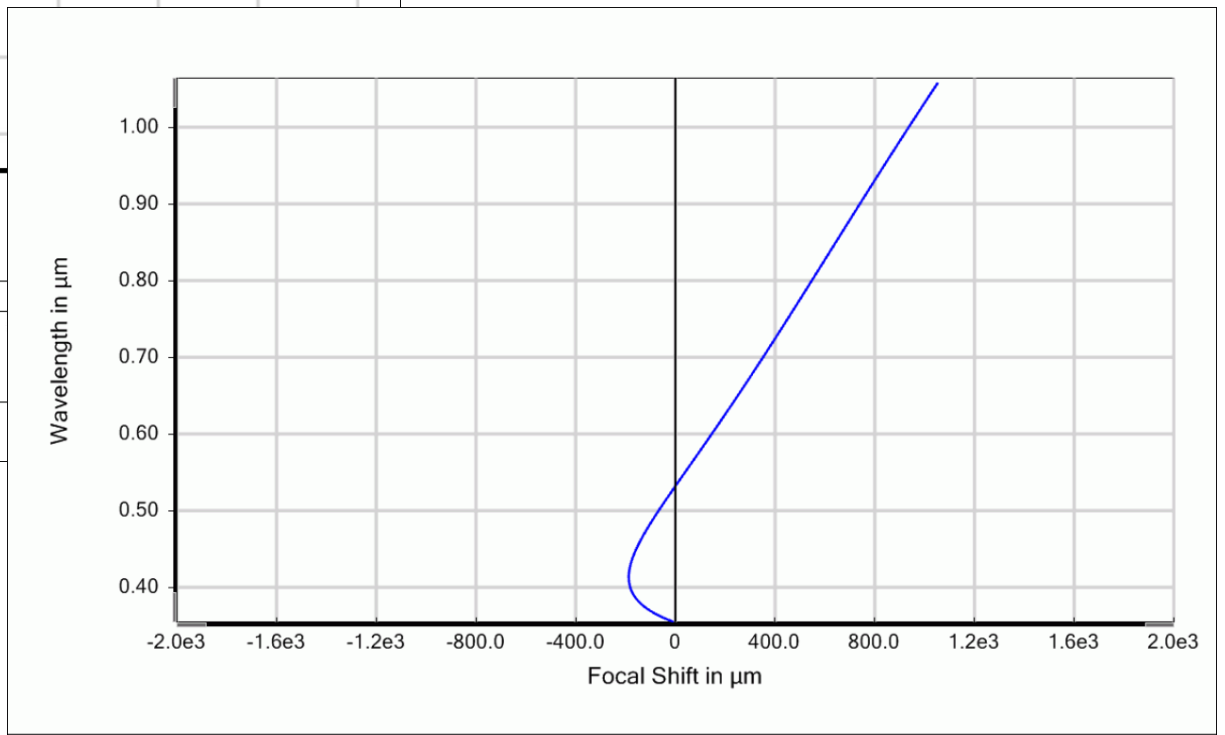
Emitter optics – beam expander with achromats



Chromatic Focal Shift

47311 CaF2-Silica-CaF2 triplet

Maximum Focal Shift Range: 724.3660 µm
Diffraction Limited Range: 37.031 µm
Pupil Zone: 0.0000



Chromatic Focal Shift

85878 Near UV Achromat Lens focal length 100 mm

Maximum Focal Shift Range: 1252.7830 µm
Diffraction Limited Range: 7.974 µm
Pupil Zone: 0.0000

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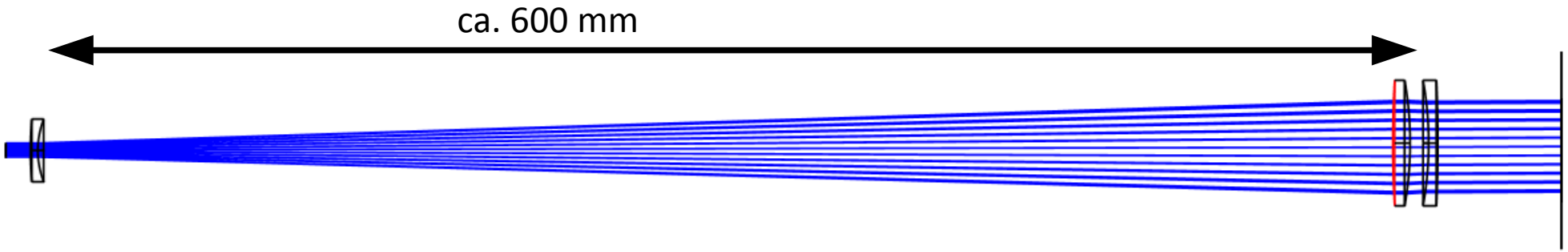
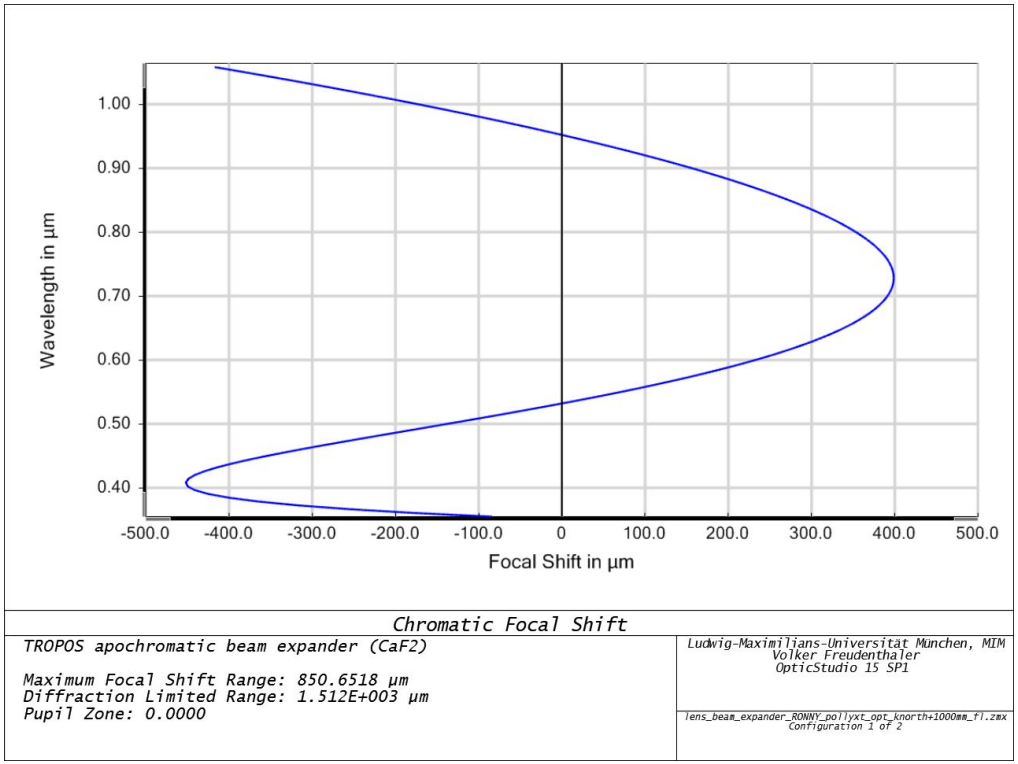
Volker Freudenthaler
OpticStudio 15 SP1

zmax_85878.zmx
Configuration 1 of 1

Emitter optics – TROPOS beam expander 6.5x (with CaF2 lens) apochromat

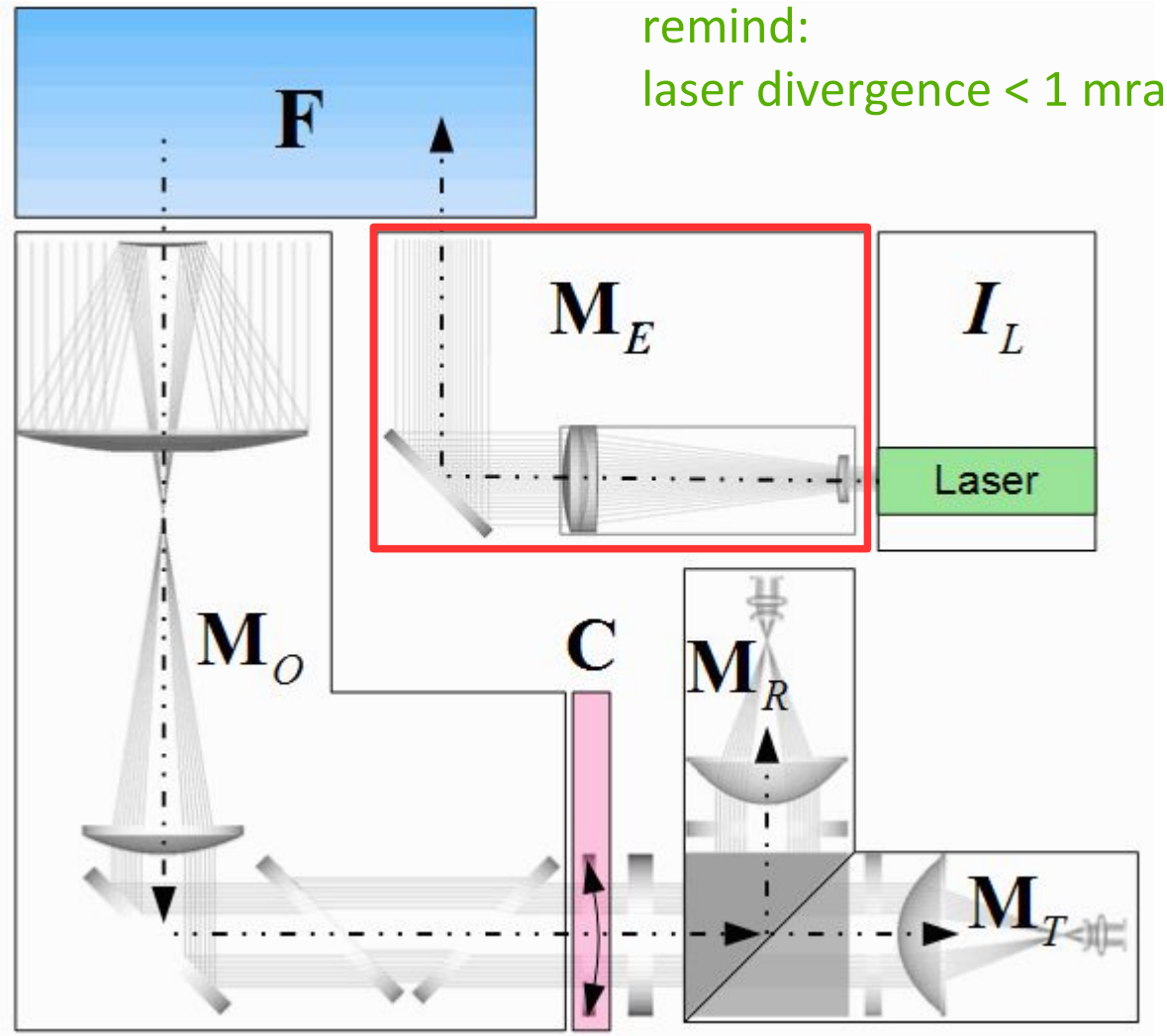


Engelmann, R., et al., The Automated Multiwavelength Raman, Polarization, and Water-Vapor Lidar Polly XT : The NeXT Generation, AMT, 2016. http://www.atmos-meas-tech.net/9/1767/2016/amt-9-1767-2016.html



Big problem:
CaF2 and MgF2 lenses are birefringent

Other problems:
- residual wavelength dependence
- 3 lambda AR-coating
- glass solarisation



remind:
laser divergence < 1 mrad

emitter and steering optics

wavelength dependence
- focal length => divergence
- transmission
- polarisation
- birefringence

alignment
- accuracy
- stability
- alignment control

polarisation
- orientation
- flatness

Kinematic Mirror Mounts Adjustment Accuracy

remind:
laser divergence < 1 mrad

0.5" Resolution: 13 mrad (0.75°) per Rev

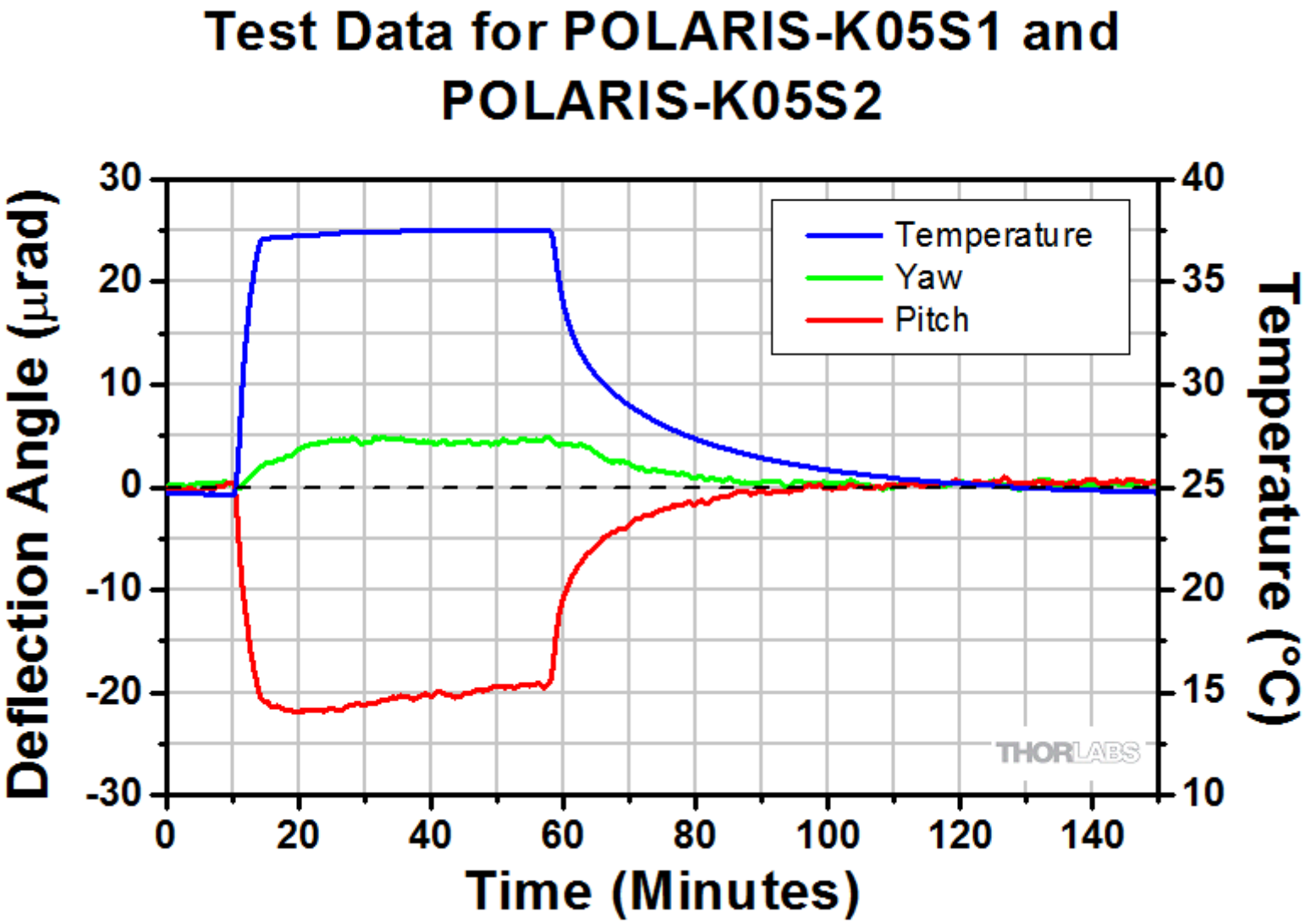
1" Resolution: 8 mrad (0.5°) per Rev

2" Resolution: 5 mrad (0.3°) per Rev

source: http://www.thorlabs.de/search/thorsearch.cfm?search=Kinematic%20Mount

Low Drift Ø0.5" Kinematic Mirror Mount – Deflection over Temperature

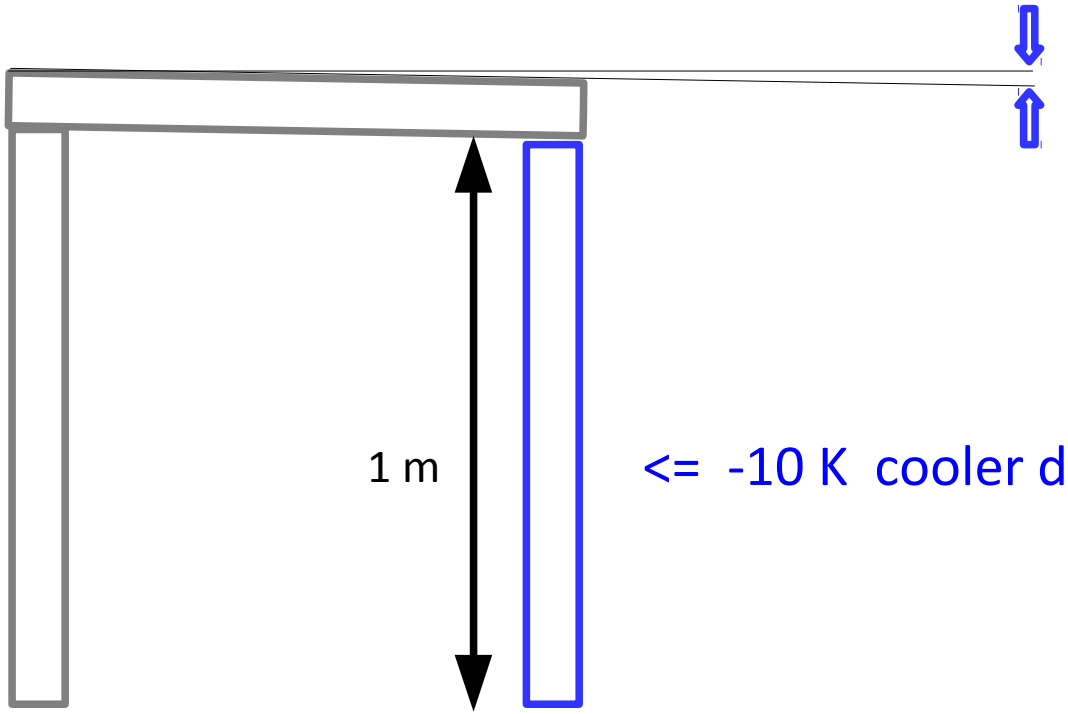
source: http://www.thorlabs.de/newgrouppage9.cfm?objectgroup_id=3912



remind:
laser divergence < 1 mrad

aluminium $23.1 * 10^{-6} / K$

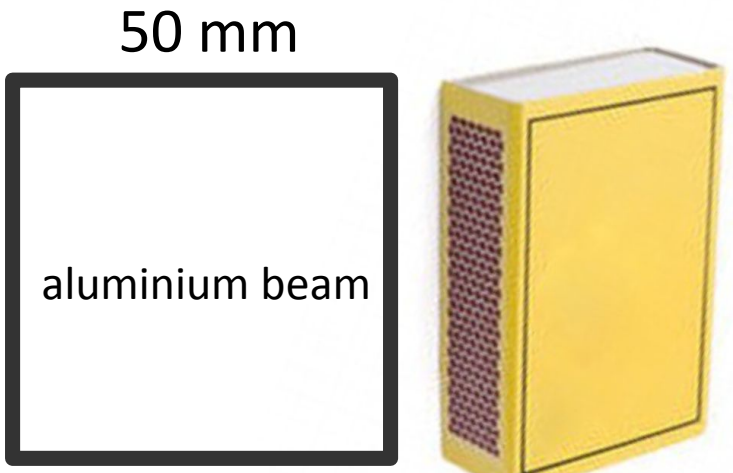
$\Delta T = 10\ K$
$L = 1\ m$
$\Rightarrow \Delta L = 0.231\ mm$

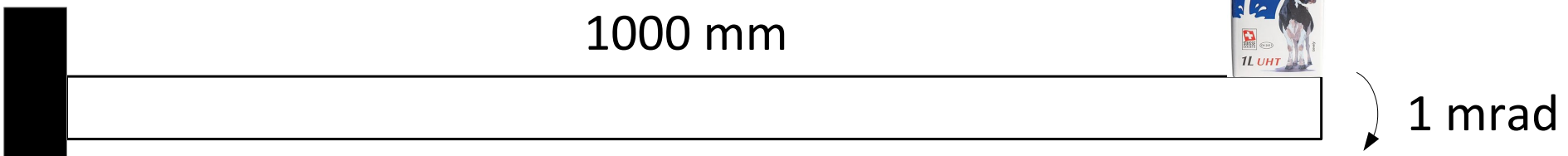


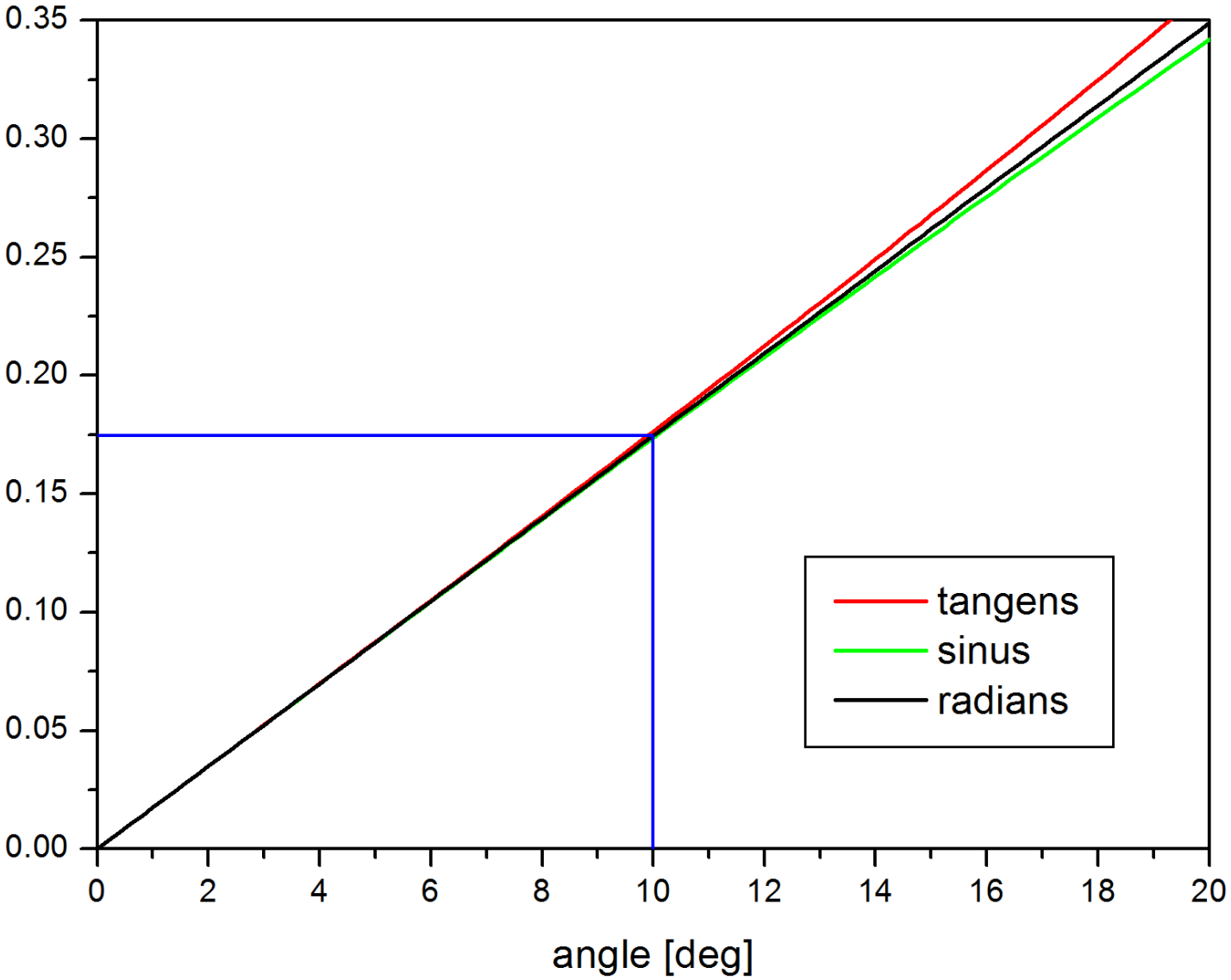
=> - 0.231 mrad

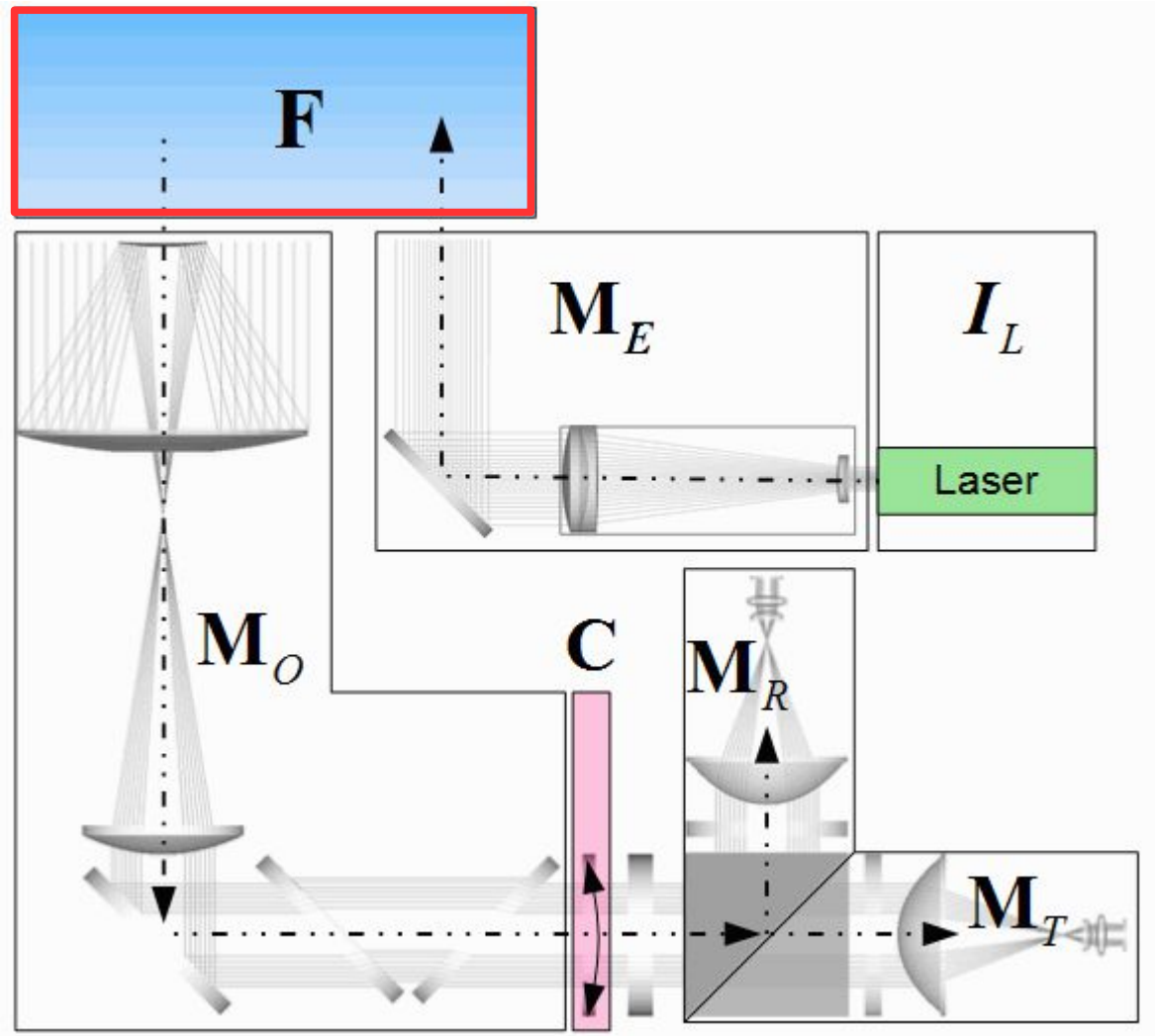
<= -10 K cooler due to air conditioning

Bending of a square, hollow aluminium beam with 50 mm side and 2 mm walls






0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
12
14
16
18
20
angle [deg]
tangens
sinus
radians



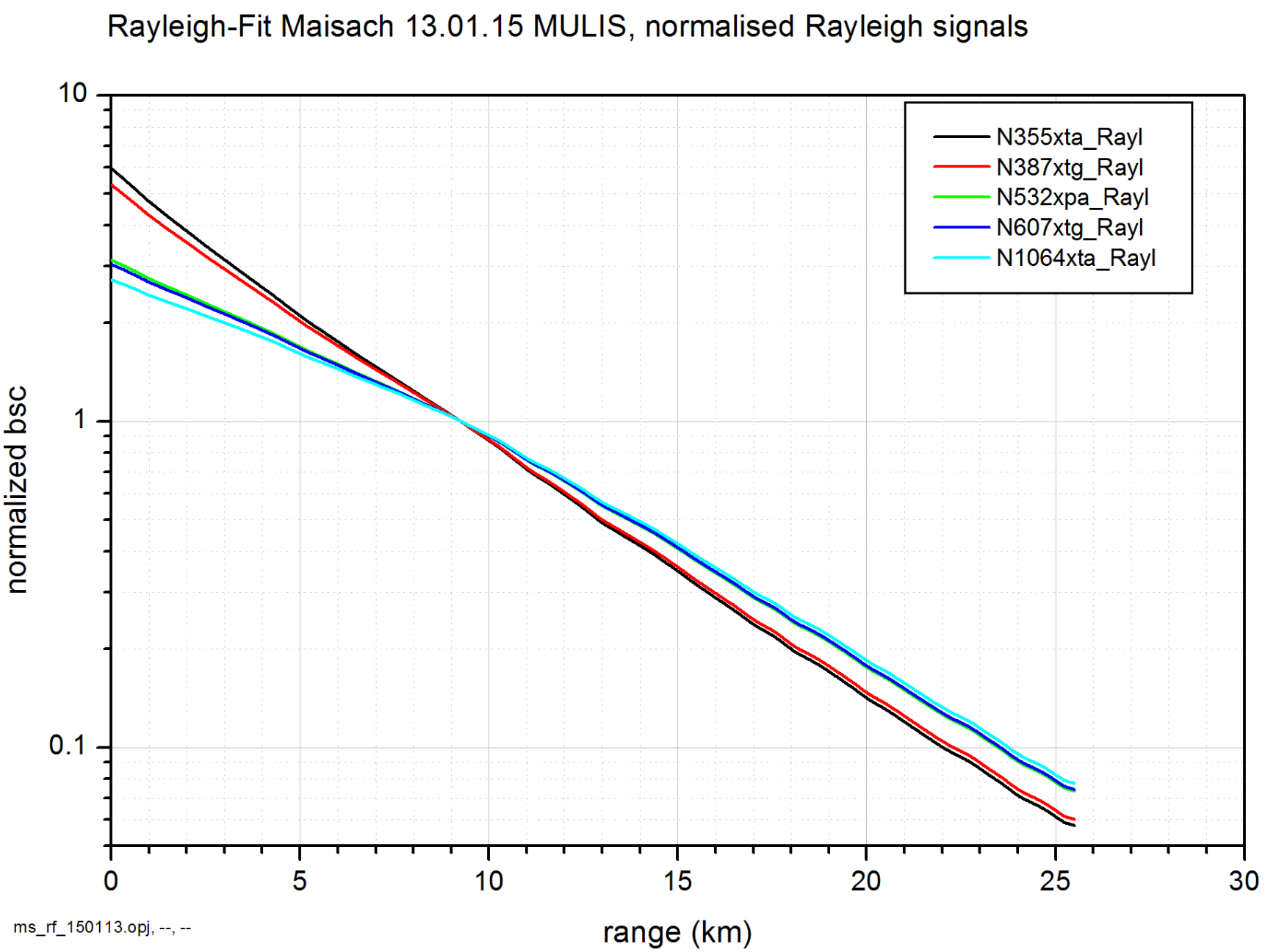
atmosphere

Rayleigh calibration

Rayleigh
- backscatter coefficients
- depolarisation ratios
- Raman lines in IFF bw

radiosonde data

Rayleigh calibration: absolute backscatter coefficient and extinction (slope)



Rayleigh scattering (extinction) cross section

$$\sigma_m(z,\lambda) = C_s(\lambda)\frac{p(z)}{T(z)}$$

and backscatter coefficients
for the Cabannes line (^{C}) and total (^{T}) Rayleigh scattering

$$\beta_m^{C,T}(z,\lambda) = B_s^{C,T}(\lambda)\frac{p(z)}{T(z)}$$

from atmospheric pressure p and temperature T depending on height z.

http://www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/Rayleigh_scattering/Rayleigh_coefficients.pdf

Rayleigh calibration: absolute backscatter coefficient and extinction (slope)

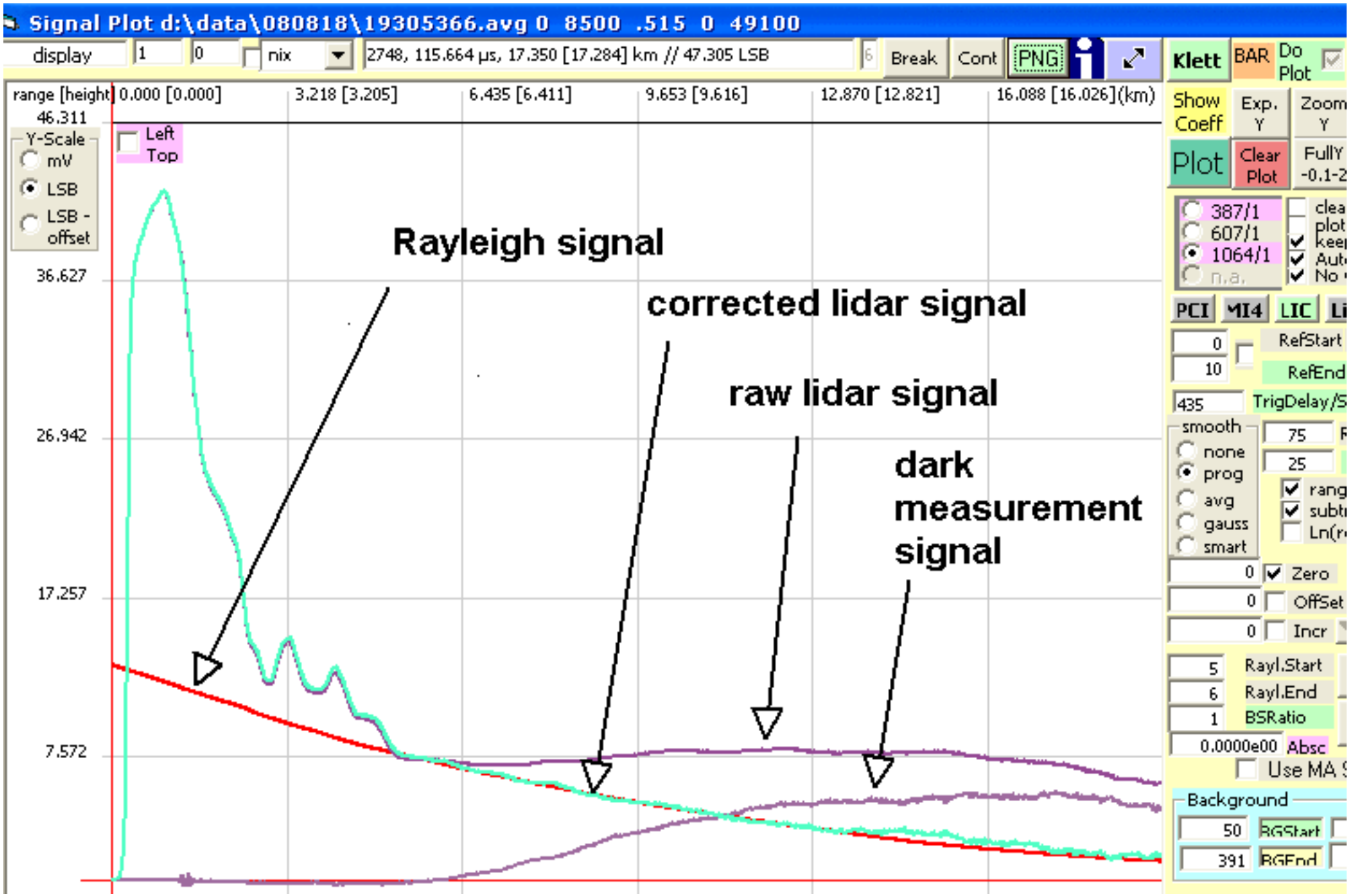
Table of scattering conversion factors and related values (ver. 1.4f)

wave-length	$(n_s - 1)$	King factor F_k	C_s	B_s^T	B_s^C	k_{bw}^T	k_{bw}^C	σ_m	β_m^T	β_m^C	δ_m^T	δ_m^C
(air/vacuum)			(17)(14)(10)	(18)	(18)	(20)	(22)	(17)	(18)	(18)	(15)	(16)
[nm]	[*1e-8]		[K/hPa/m]	[K/hPa/(m*sr)]	[K/hPa/(m*sr)]			[1/m]	[1/(m*sr)]	[1/(m*sr)]	[*1e-2]	[*1e-2]
	STD air	STD air						STD air	STD air	STD air	STD air	STD air
308 / 308.089	29046.6	1.05574	3.6506e-5	4.2886E-6	4.1678E-6	1.01610	1.04554	1.2837E-4	1.5080E-5	1.4656E-5	0.01636	0.004158
351 / 351.100	28602.7	1.05307	2.0934e-5	2.4610E-6	2.3949E-6	1.01535	1.04338	7.3611E-5	8.6539E-6	8.4214E-6	0.01559	0.003959
354.717 / 354.818	28572.4	1.05290	2.0024E-5	2.3542E-6	2.2912E-6	1.01530	1.04324	7.0414E-5	8.2783E-6	8.0566E-6	0.01554	0.003946
355 / 355.101	28570.2	1.05288	1.9957E-5	2.3463E-6	2.2835E-6	1.01530	1.04323	7.0177E-5	8.2506E-6	8.0393E-6	0.01554	0.003946
386.890 / 387.000	28350.2	1.05166	1.3942e-5					4.8925E-5				
400 / 400.113	28275.2	1.05125	1.2109E-5	1.4242E-6	1.3872E-6	1.01484	1.04191	4.2579E-5	5.00810E-6	4.8780E-6	0.01507	0.003825
407.558 / 407.673	28235.1	1.05105	1.1202e-5					3.9389E-5				
510.6 / 510.742	27869.4	1.04922	4.4221E-6	5.2042E-7	5.0742E-7	1.01427	1.04026	1.5550E-5	1.8300E-6	1.7843E-6	0.01448	0.003673
532 / 532.148	27819.9	1.04899	3.7382E-6	4.3997E-7	4.2903E-7	1.01421	1.04007	1.3145E-5	1.5471E-6	1.5086E-6	0.01441	0.003656
532.075 / 532.223	27819.4	1.04899	3.7361E-6	4.3971E-7	4.2878E-7	1.01421	1.04007	1.3138E-5	1.5462E-6	1.5078E-6	0.01441	0.003656
607.435 / 607.603	27686.3	1.04839	2.1772e-6					7.6559E-6				
710 / 710.196	27570.4	1.04790	1.1561E-6	1.3611E-7	1.3280E-7	1.01390	1.03919	4.0655E-6	4.7863E-7	4.66698E-7	0.01410	0.003575
800 / 800.220	27503.8	1.04763	7.1364E-7	8.4022E-8	8.1989E-8	1.01383	1.03897	2.5094E-6	2.9546E-7	2.8831E-7	0.01402	0.003555
1064 / 1064.292	27397.5	1.04721	2.2622E-7	2.6638E-8	2.5999E-8	1.01371	1.03863	7.95949E-7	9.3670E-8	9.1423E-8	0.01390	0.003524
1064.150 / 1064.442	27397.4	1.04721	2.2609E-7	2.6623E-8	2.5984E-8	1.01371	1.03863	7.9504E-7	9.3617E-8	9.1371E-8	0.01390	0.003524

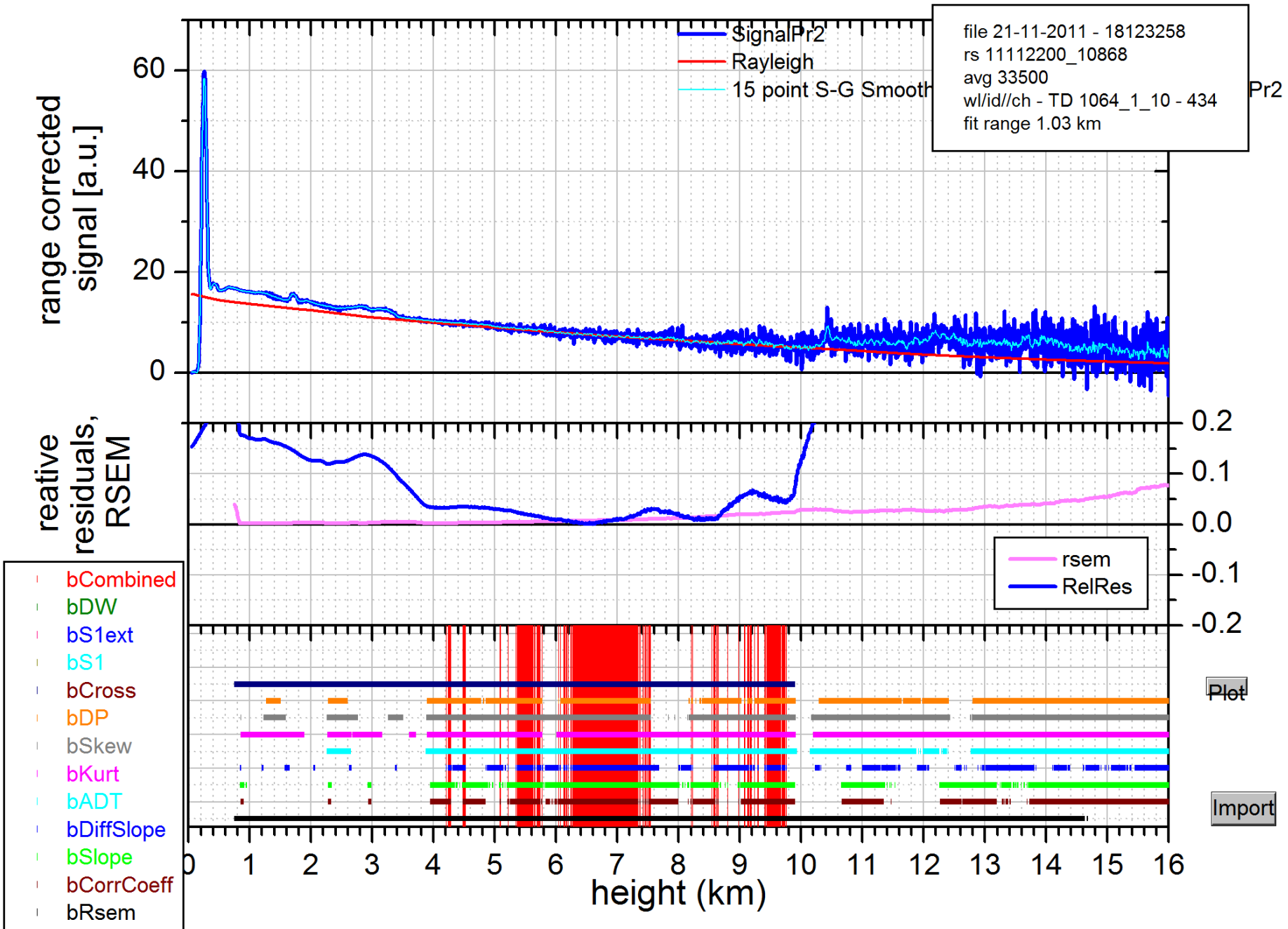
***Table 1**: Refractive index (n_s), King factor (F_k), extinction coefficients (σ_m), Cabannes (β_m^C) and total Rayleigh (β_m^T) backscatter coefficients, proportionality factors (see text above), and Cabannes (δ_m^C) and total Rayleigh (δ_m^T) linear depolarisation ratios caclulated with the equations in row two, for STD air conditions where mentioned (STD air: p_s = 1013.25 hPa, T_s = 288.15 K). The refractive indices and the King factors are calculated according to Tomasi et al. (2005) and Ciddor (2002) with 385 ppmv CO_2 and 0% RH. Please note that the values in the table of the Tomasi paper were caclulated for slightly different conditions. NdYAG elastic and Raman wavelenghts (underlined) are for vacuum, calculated from the fundamental air wavelength 1064.15 nm (1064.442 nm in vacuum) at 300 K rod temperature according to Kaminskii. (RAMAN3G.ods, Laserlinien.ods, Rayleigh1.vbs) (This tabel is version 1.4f from Feb. 2013: some "exact" wavelengths added to version 1.1 and corrected from ver. 1.3; 1.4f: wavelengths in air and vacuum). In order to enable the comparison of the accuracy of the calculatuions by the readers, more decimal digits are shown than certified by the accuracy of the model and the assumtions.*

http://www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/Rayleigh_scattering/Rayleigh_coefficients.pdf

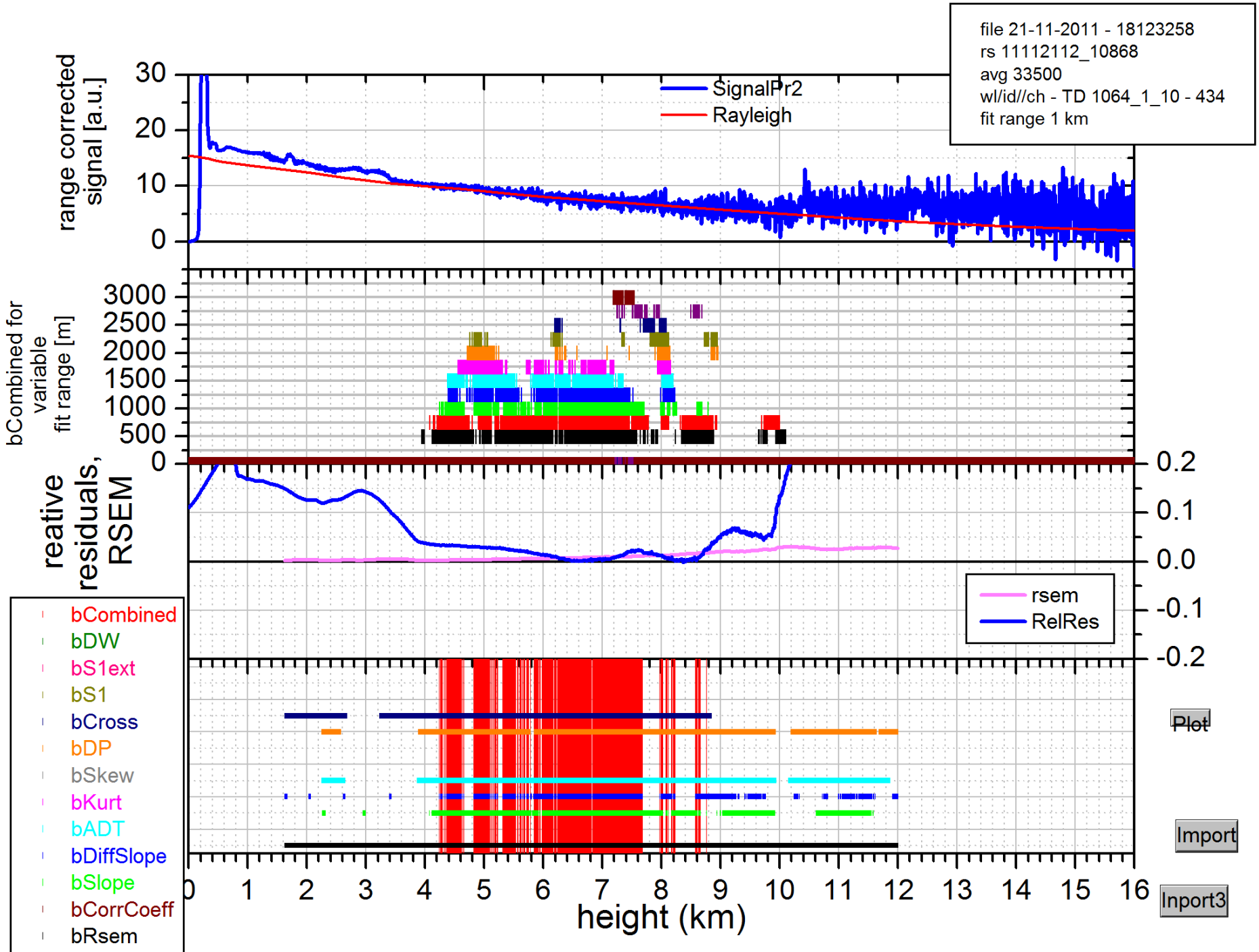
Rayleigh calibration: absolute backscatter coefficient and extinction (slope)



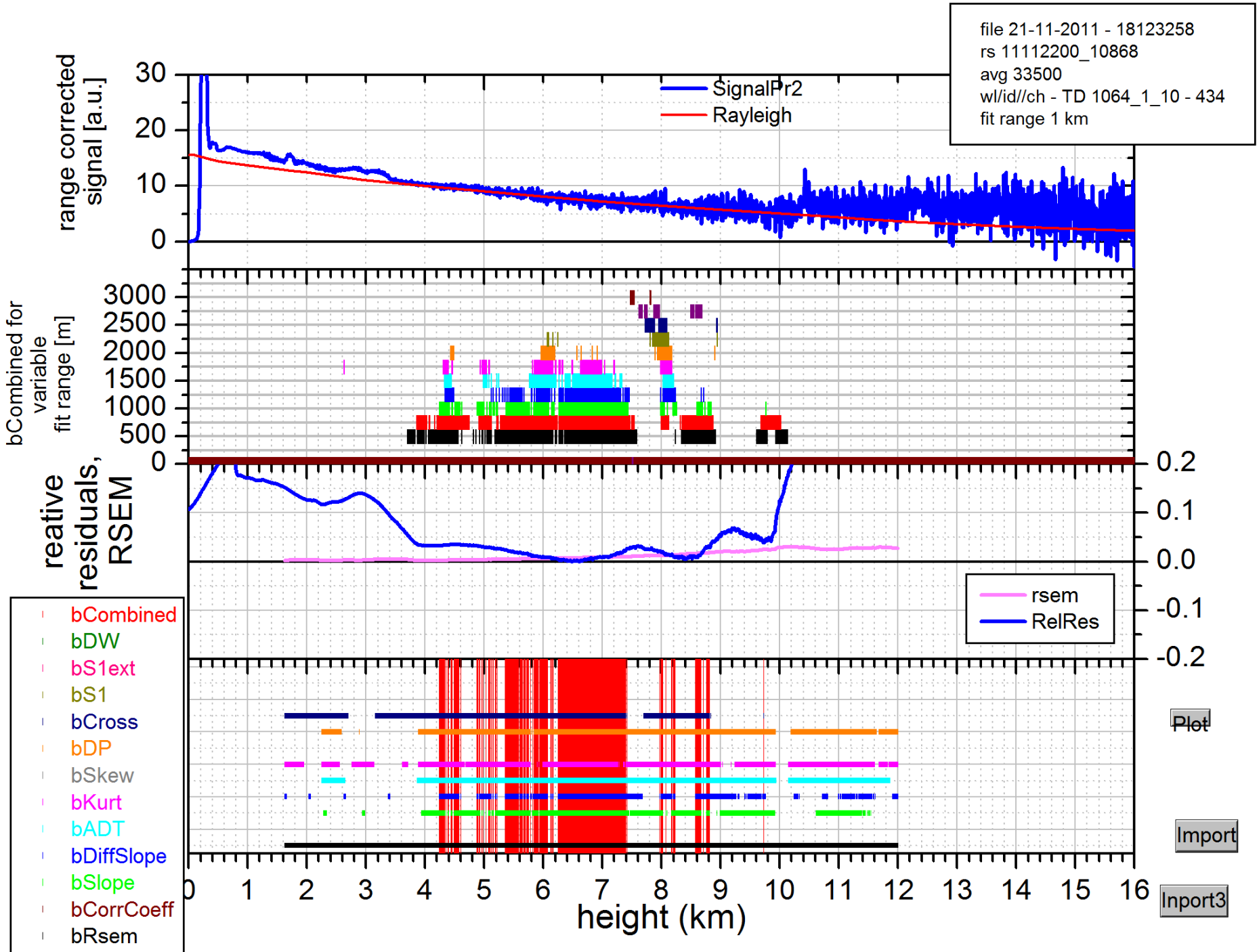
Rayleigh calibration: quality checks

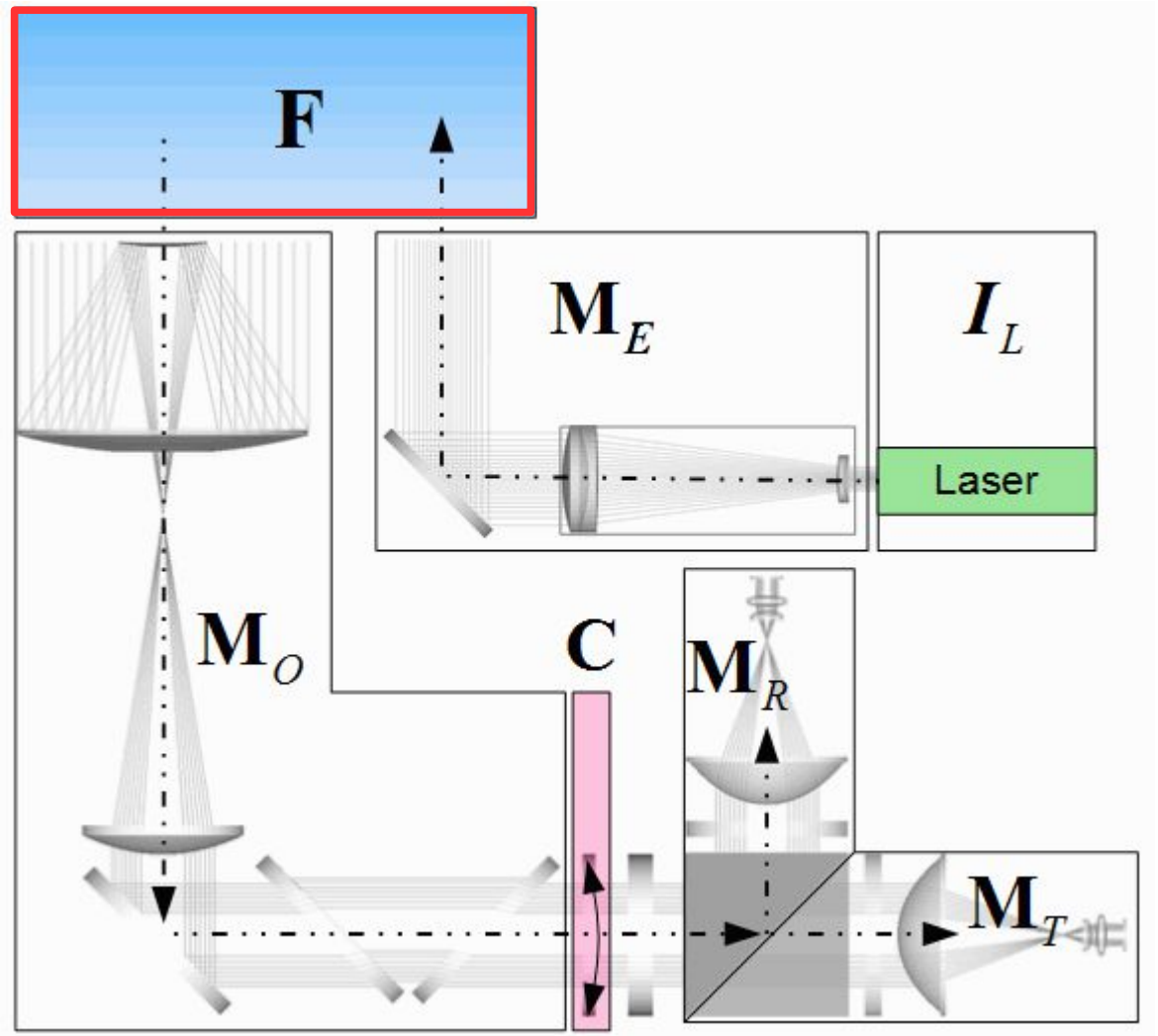


Rayleigh calibration: quality checks



Rayleigh calibration: quality checks



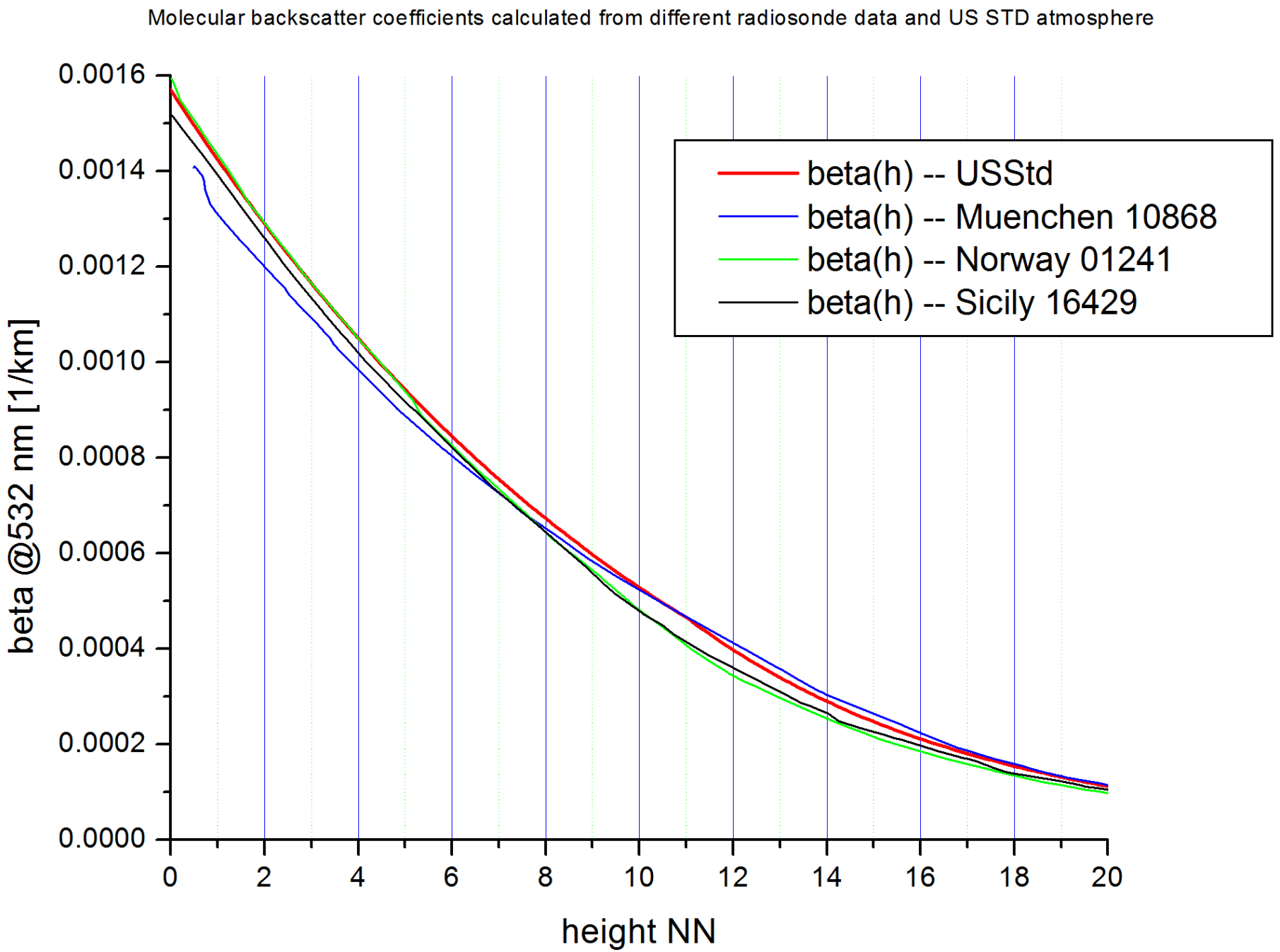


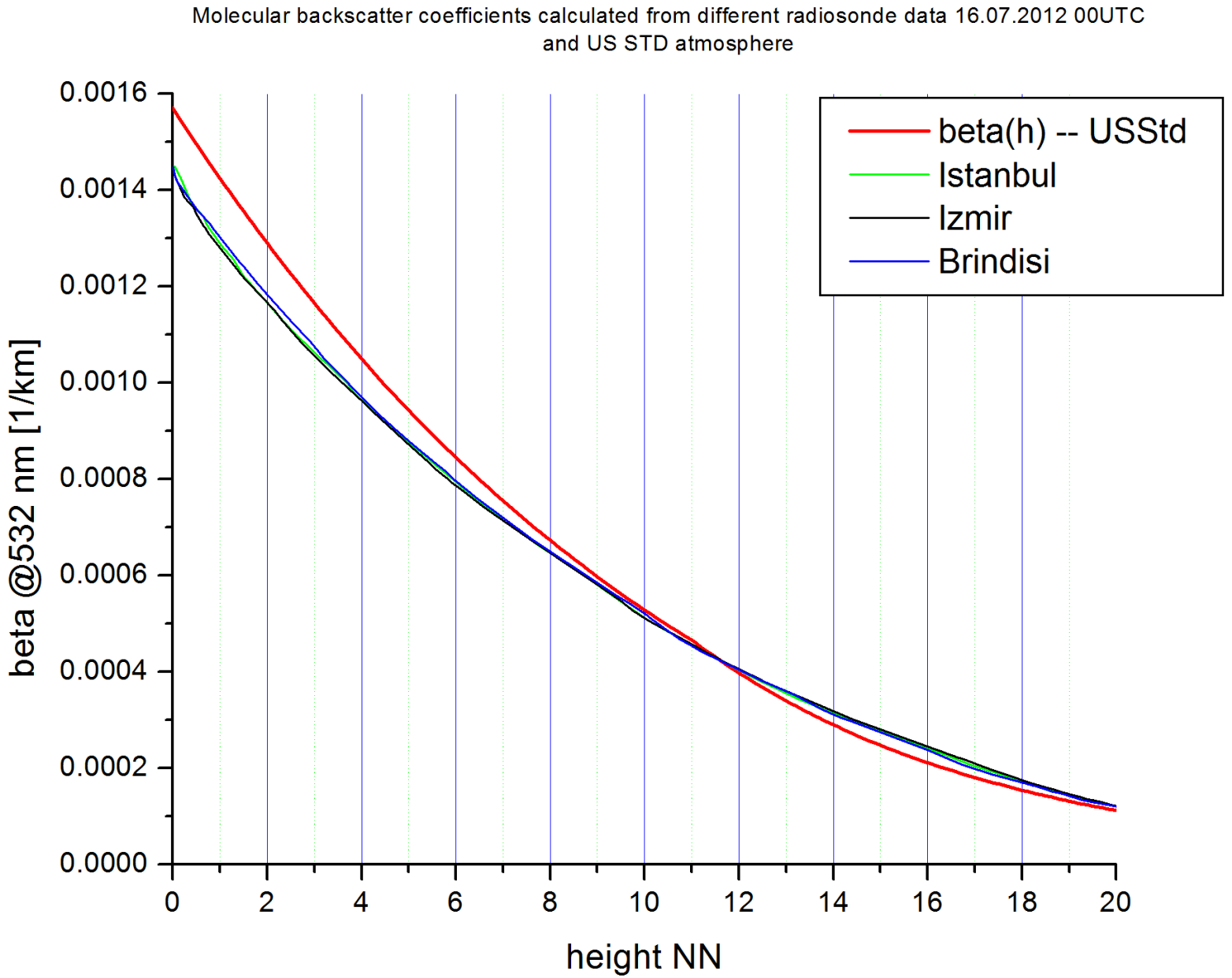
atmosphere

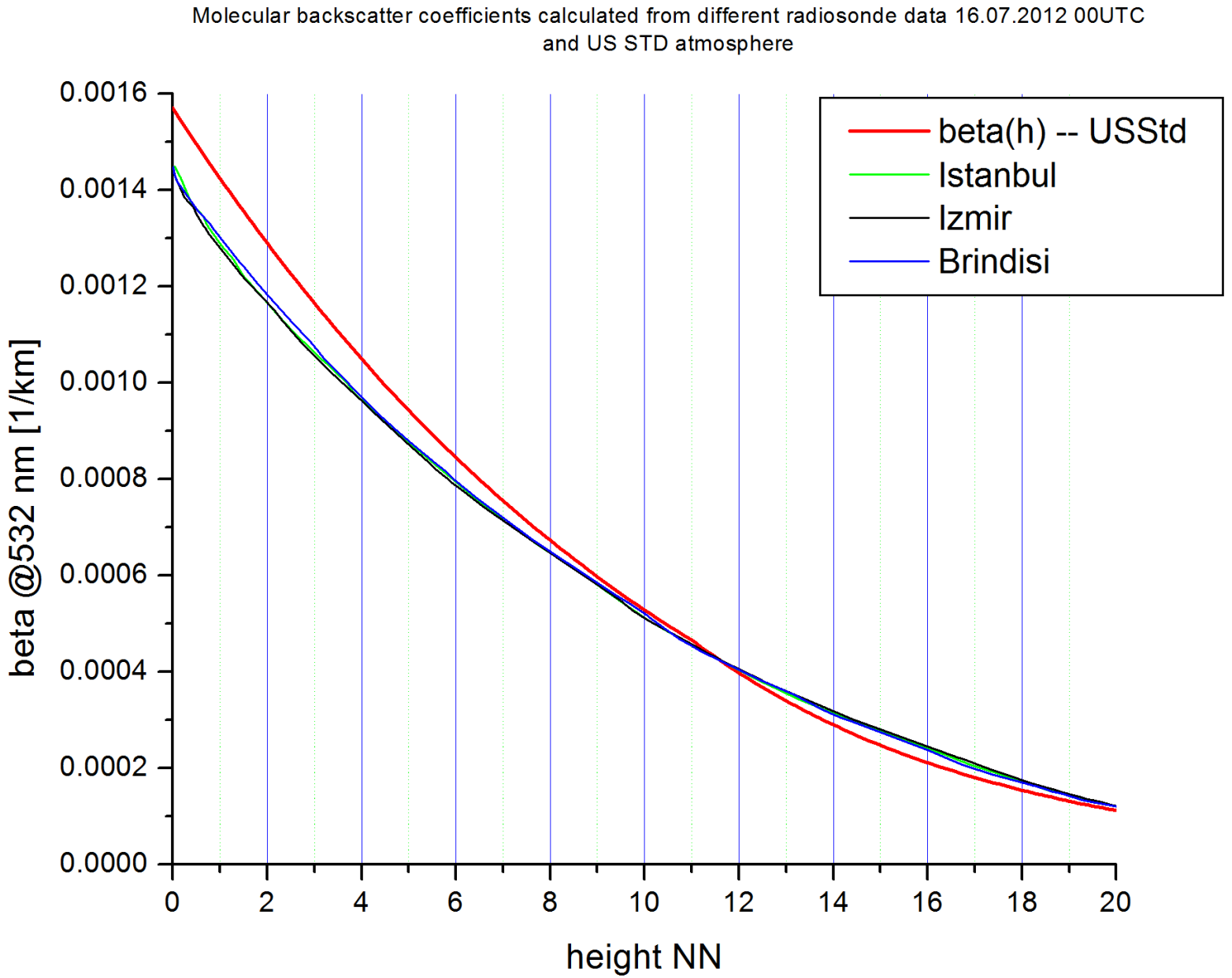
Rayleigh calibration

Rayleigh
- backscatter coefficients
- depolarisation ratios
- Raman lines in IFF bw

radiosonde data


Molecular backscatter coefficients calculated from different radiosonde data and US STD atmosphere
beta @532 nm [1/km]
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0
2
4
6
8
10
12
14
16
18
20
height NN
beta(h) -- USStd
beta(h) -- Muenchen 10868
beta(h) -- Norway 01241
beta(h) -- Sicily 16429


Molecular backscatter coefficients calculated from different radiosonde data 16.07.2012 00UTC
and US STD atmosphere
beta(h) -- USStd
Istanbul
Izmir
Brindisi
beta @532 nm [1/km]
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0
2
4
6
8
10
12
14
16
18
20
height NN


Molecular backscatter coefficients calculated from different radiosonde data 16.07.2012 00UTC
and US STD atmosphere
beta(h) -- USStd
Istanbul
Izmir
Brindisi
beta @532 nm [1/km]
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0
2
4
6
8
10
12
14
16
18
20
height NN

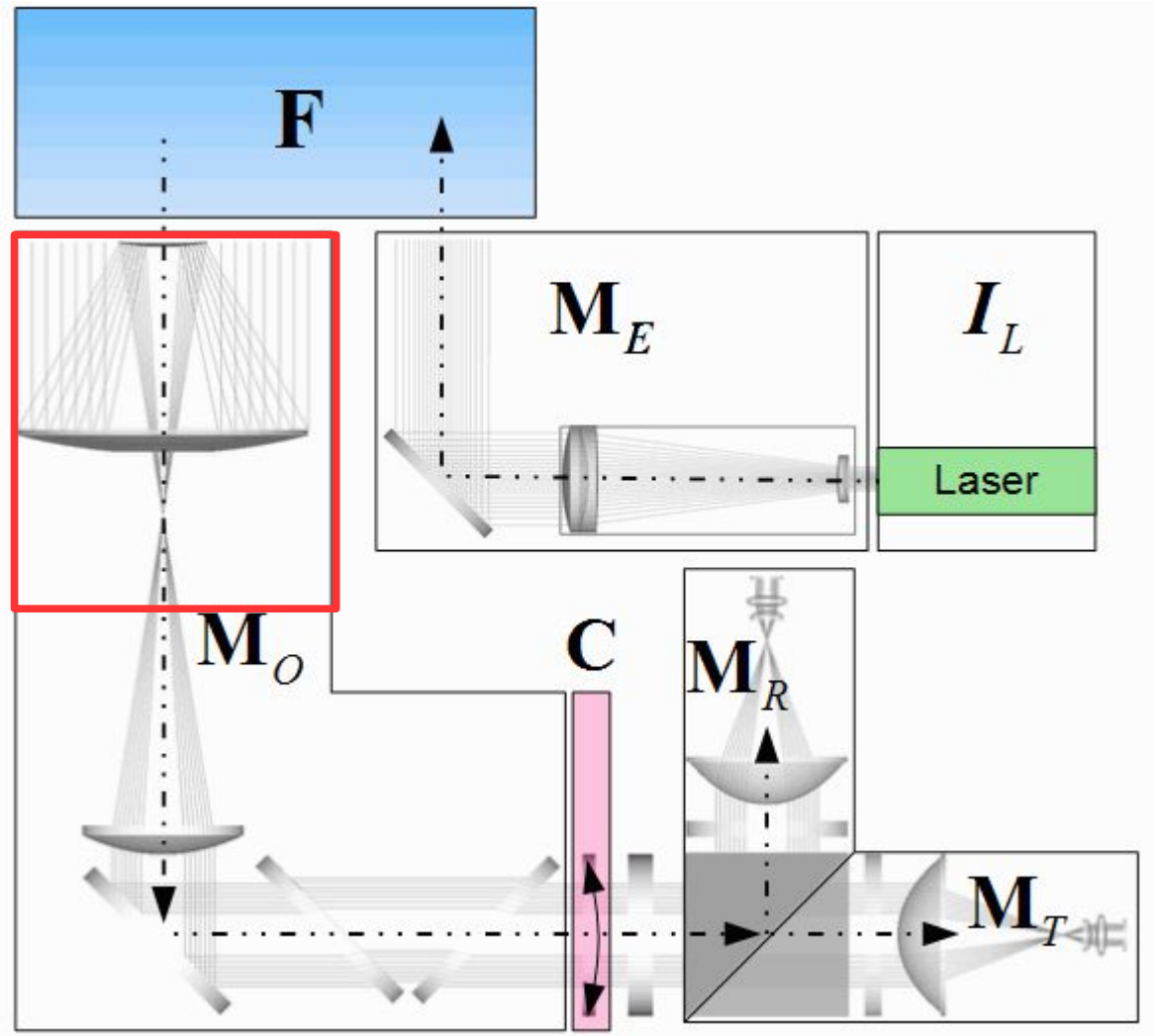
Atmosphere – radiosonde – how to get?

Radiosonde data:
http://weather.uwyo.edu/upperair/sounding.html

Modell data:
http://rucsoundings.noaa.gov/

EARLINET forum: earlinetforum.imaa.cnr.it
=> topic: QA Rayleigh-fit and radiosonde

http://www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/Rayleigh_scattering/EA-radiosondes.html
=> Generate soundings from model analysis and forecast
=> Generate soundings from archived model data
=> Archived soundings from radio sondes



receiving optics telescope

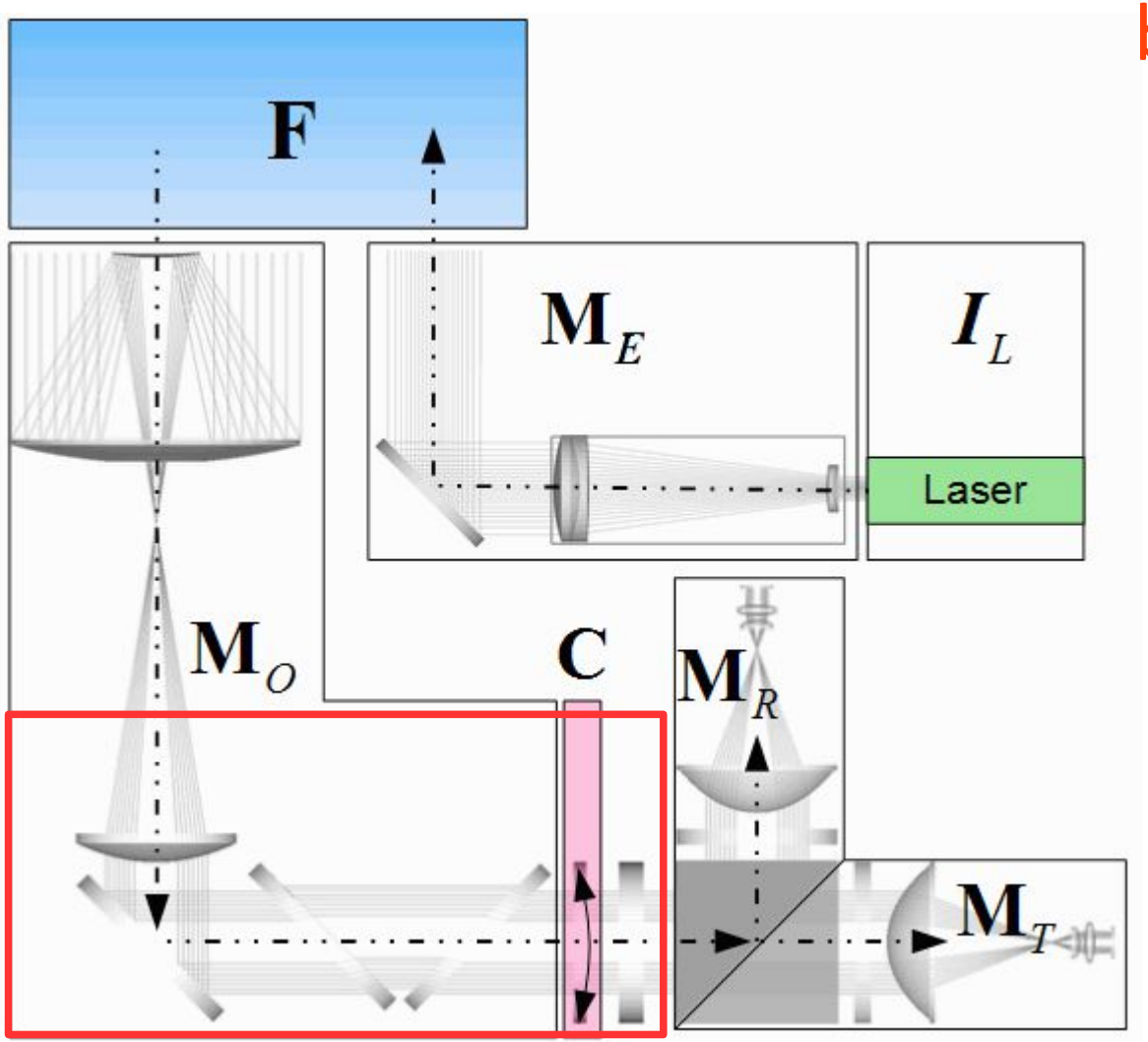
focal length, diameter

alignment stability

Newton telescope
90° mirror depolarisation

field of view

distance of full overlap



receiving optics
beamsplitters and filters

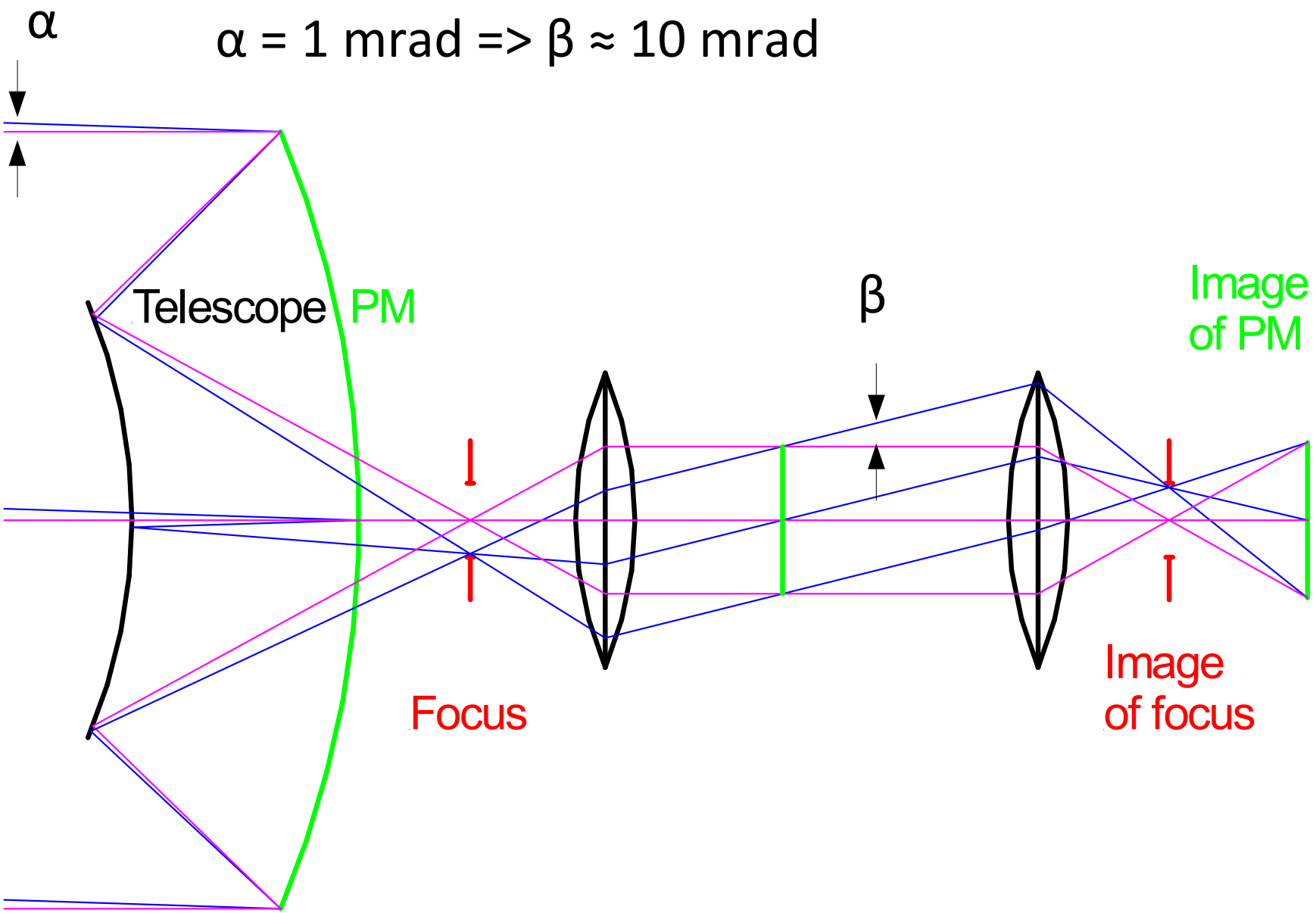
focal length of collimator
=> optics beam divergence
=> optics beam diameter

accpetance angles of
beamsplitters and
interference filters

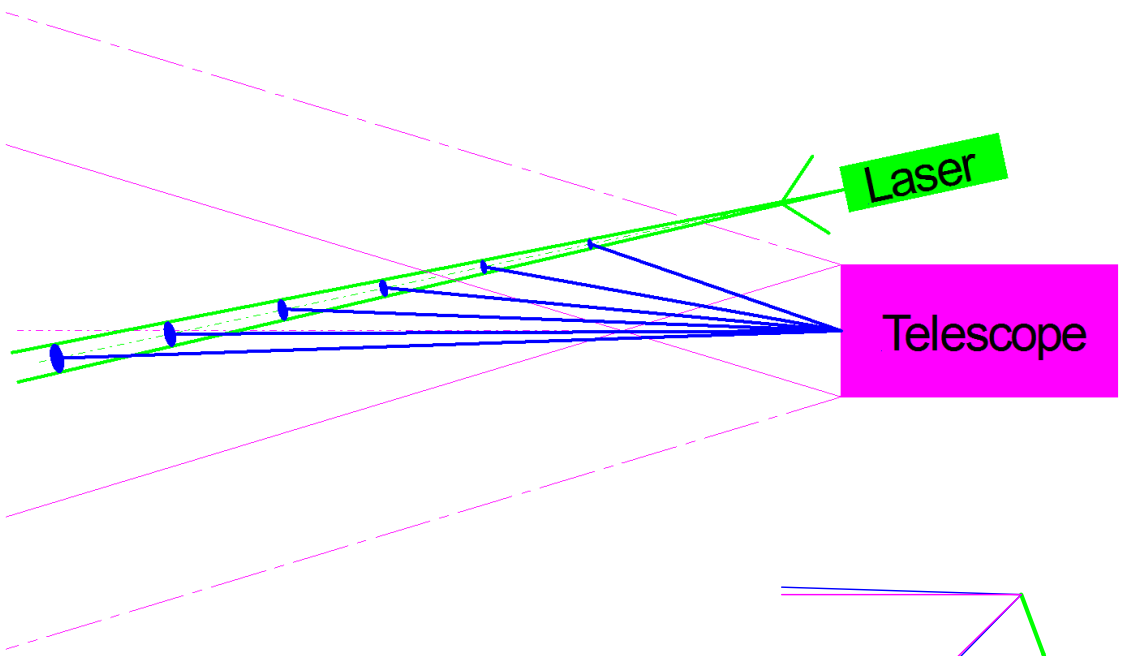
polarisation problemes
diattenuation
retardance

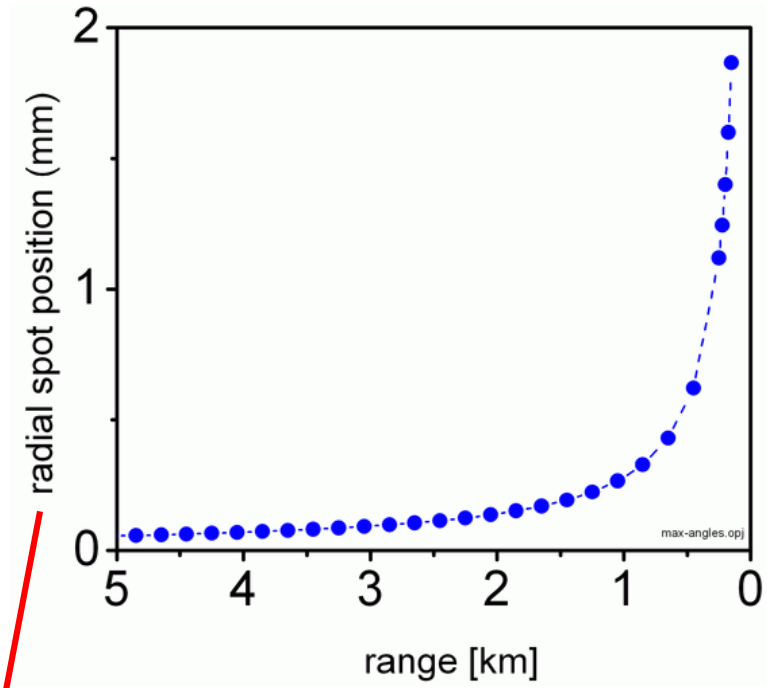
$$\alpha/\beta \approx \tan\alpha / \tan\beta = f_{coll} / f_{tele} \approx 100 / 1000 = 0.1$$

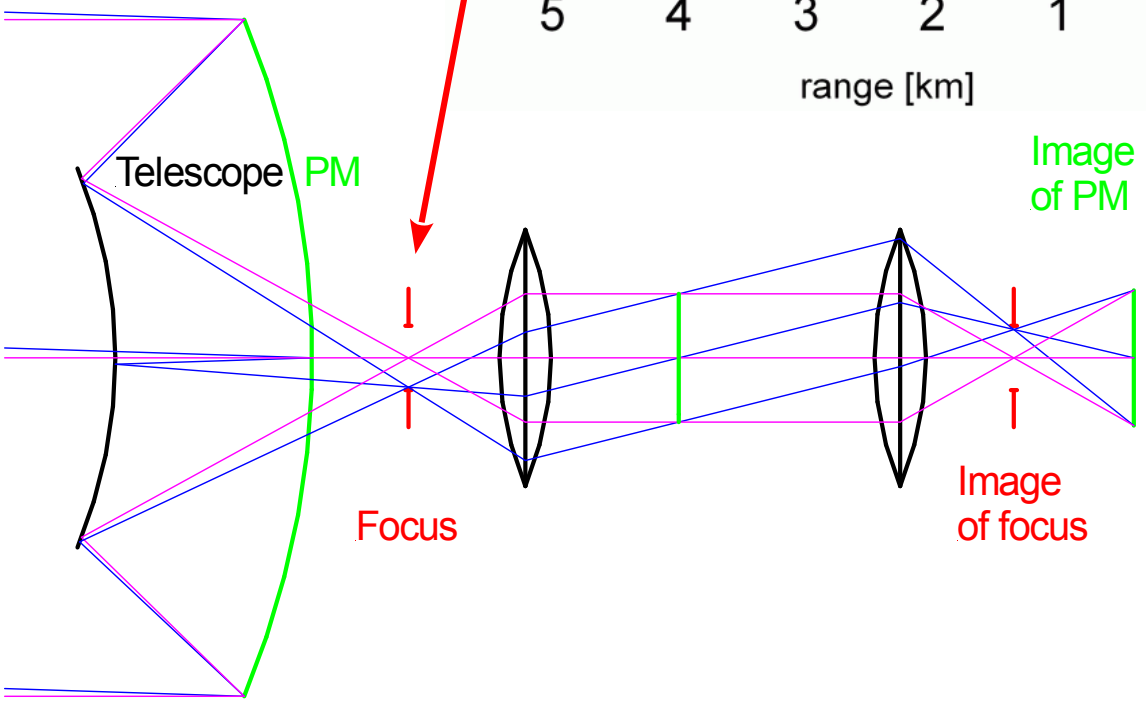
$$\alpha = 1 \text{ mrad} \Rightarrow \beta \approx 10 \text{ mrad}$$



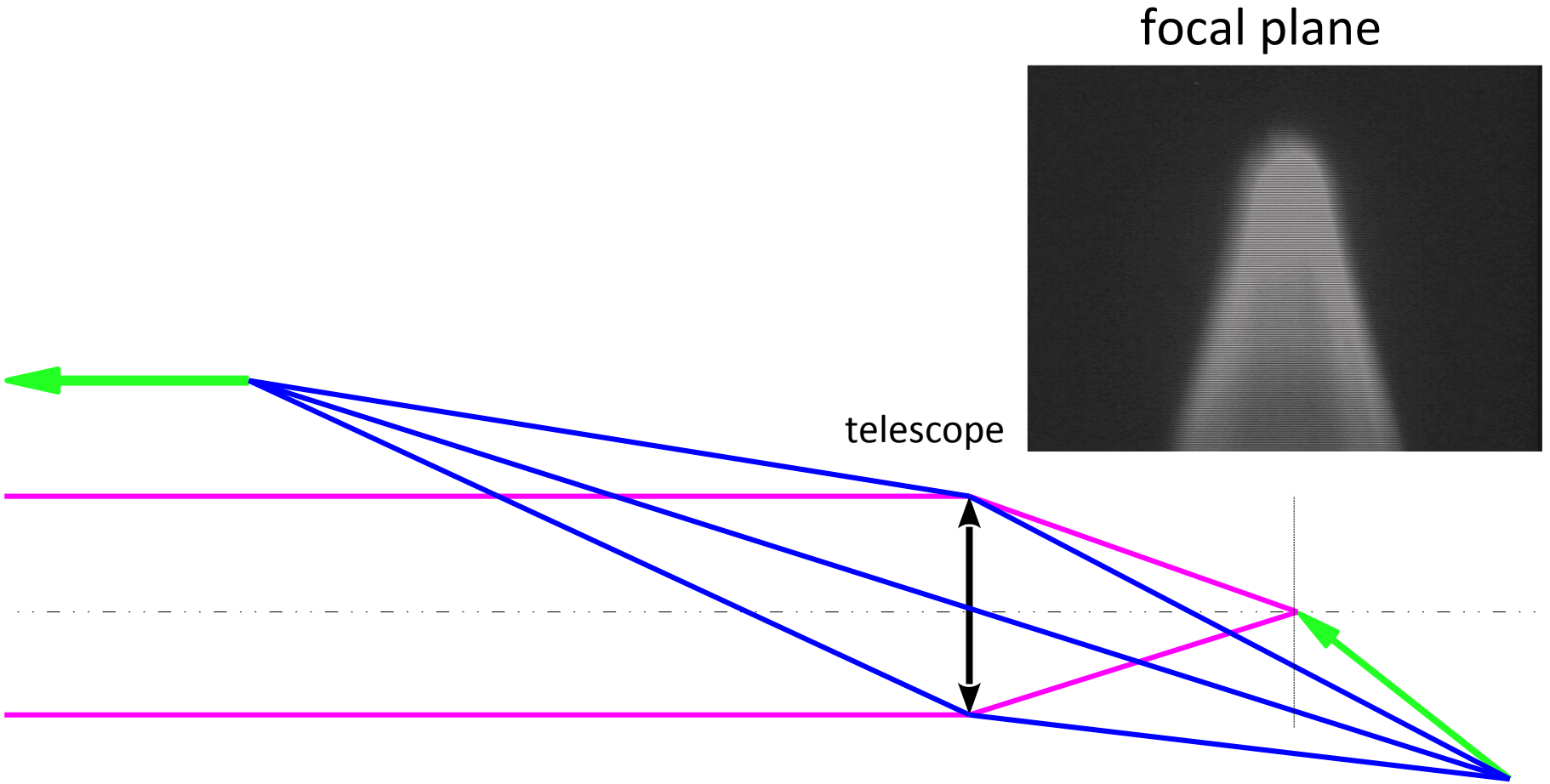
Overlap function, focal spot radial position (∞ incident angle) - change with range



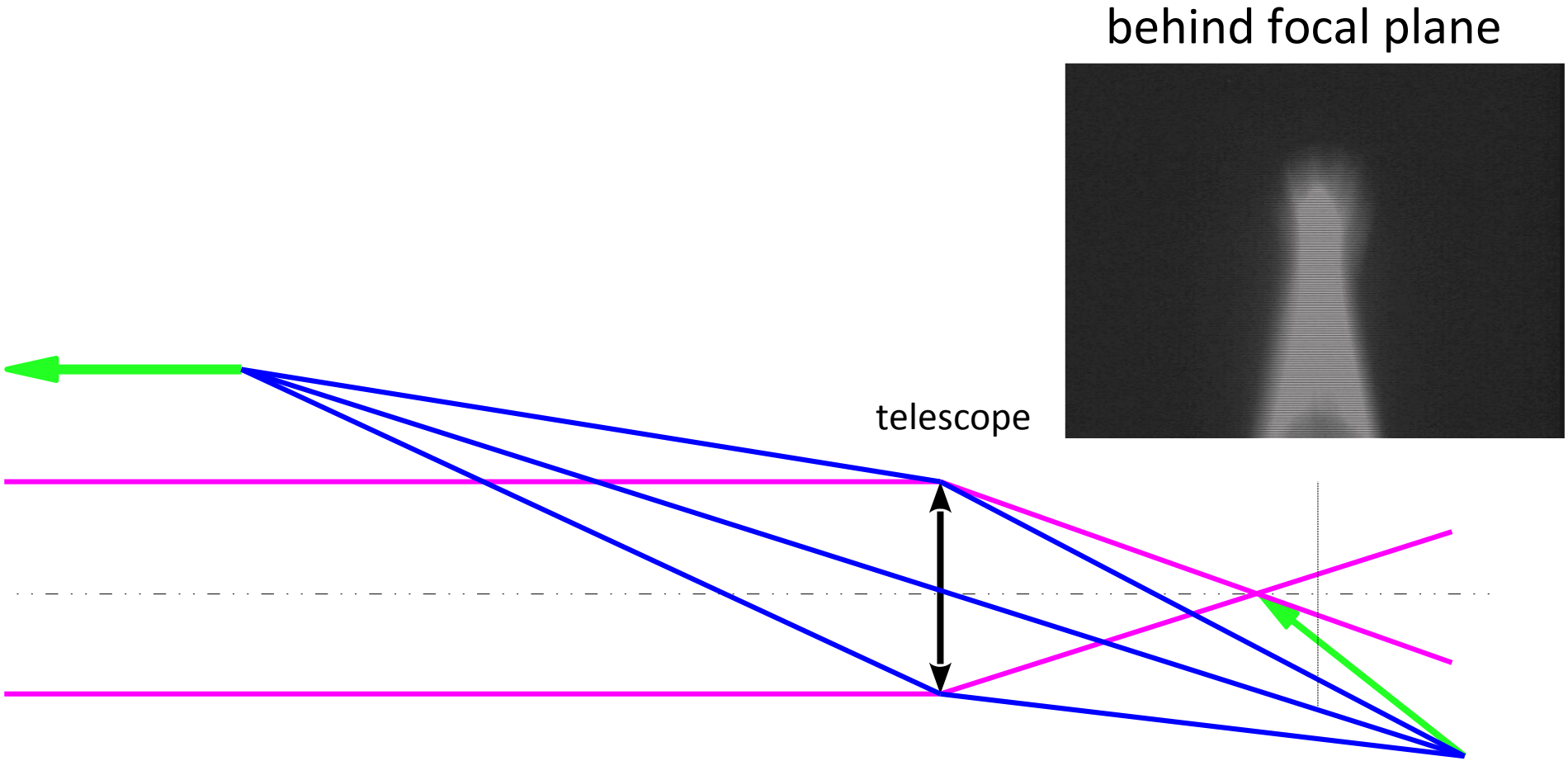




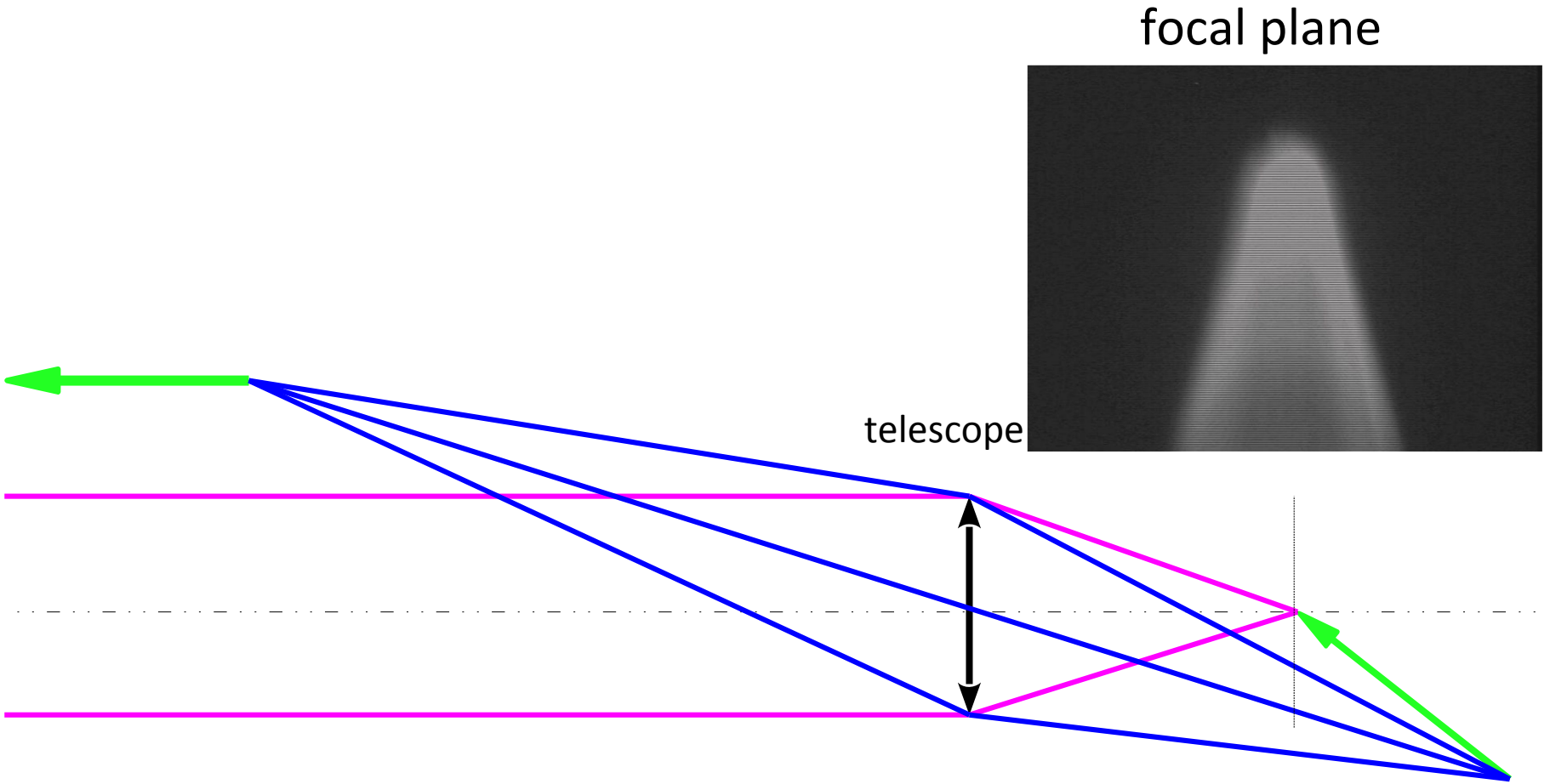
Focal spot radial/axial position - change with range



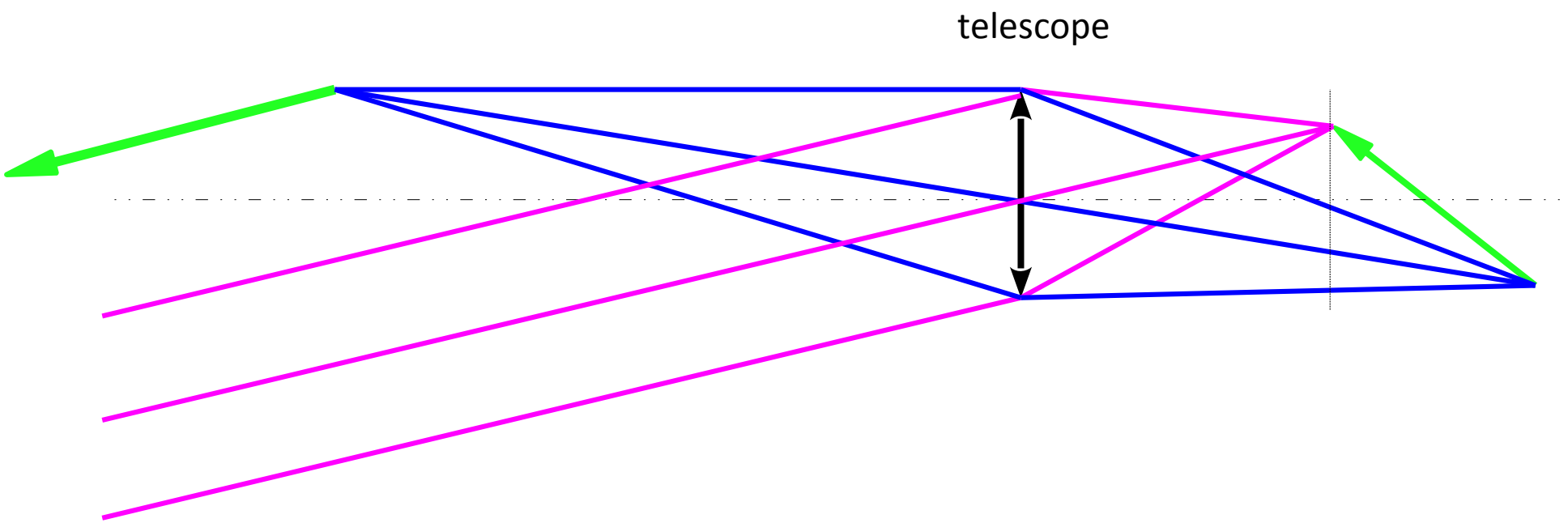
Focal spot radial/axial position - change with range



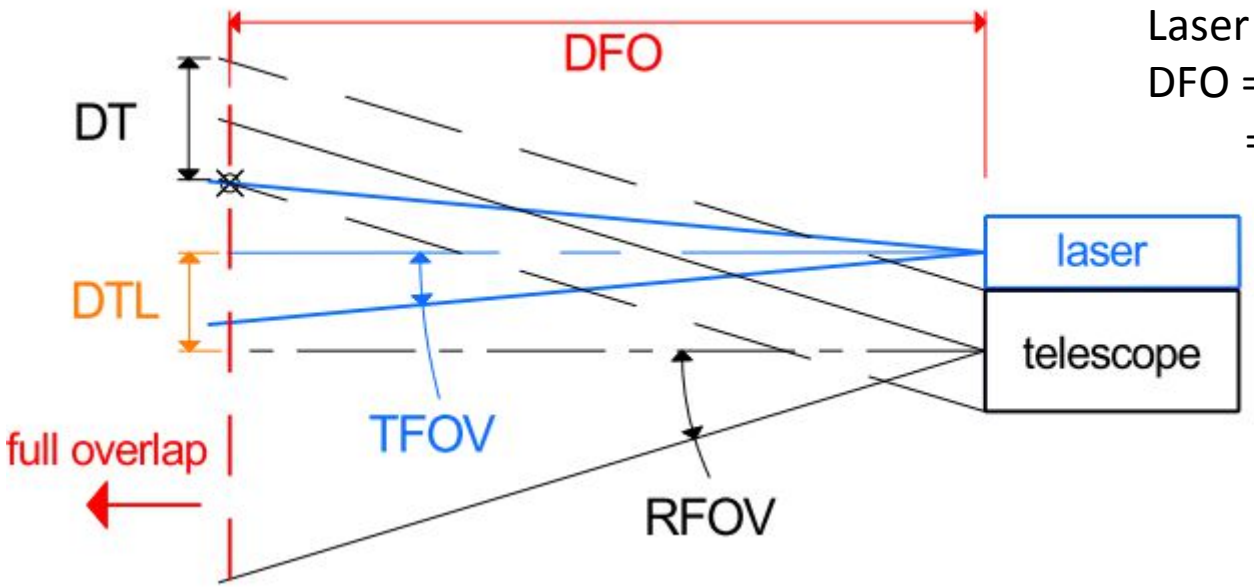
Focal spot radial/axial position - change with range



Focal spot radial/axial position - change with range – tilted laser beam



Overlap function – distance of full overlap with and w/o laser tilt

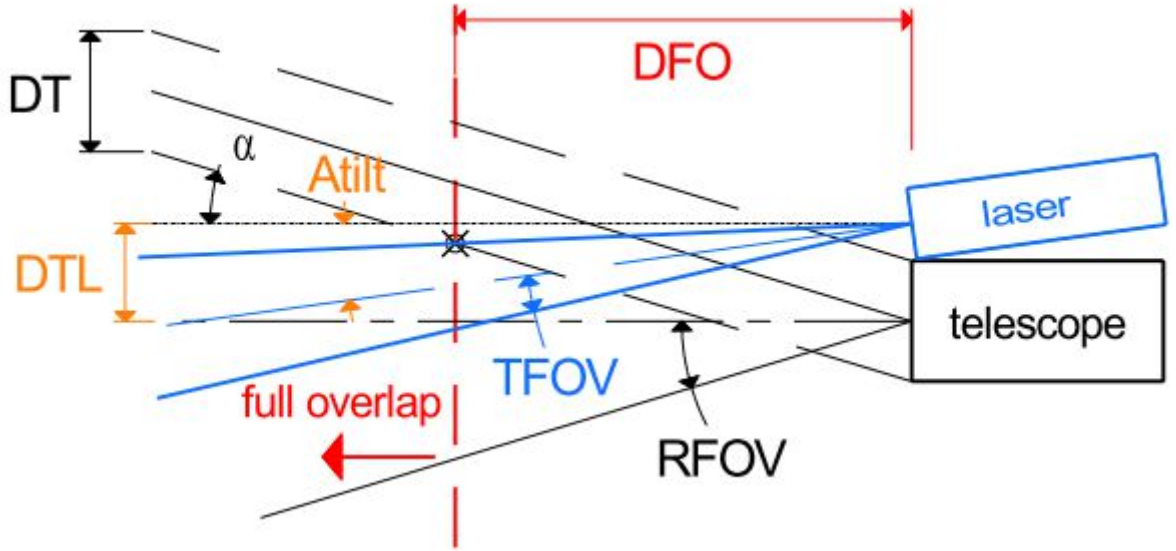


Laser axis parallel to telescope axis

DFO = (2*DTL + DT) / 2 / (RFOV - TFOV) =

= (2*0.2 m + 0.2 m) / 2 / (0.001 - 0.0005)

DFO = 600 m



With optimal laser tilt

Atilt = RFOV – TFOV

DFO = (2*DTL + DT) / (4 * Atilt) =

= (2*0.2 m + 0.2 m) / (4 * 0.0005)

DFO = 300 m

V. Freudenthaler, "Optimized background suppression in near field lidar telescopes", 6th ISTP Int. Symposium on Tropospheric Profiling, 14. - 20. Sept. 2003, Leipzig, Germany, (2003). URN urn:nbn:de:bvb:19-epub-12957-5 , available online: http://epub.ub.uni-muenchen.de/12957/

Explanations:

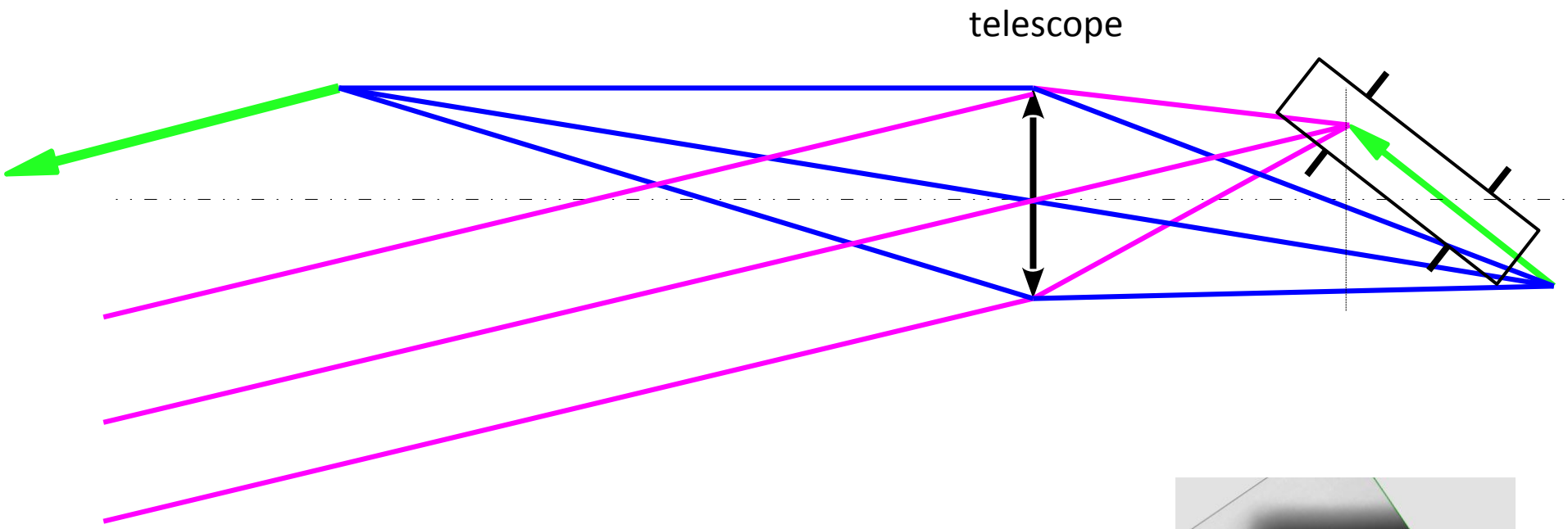
www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/raytracing/Basic_design/basic_lidar_design.html

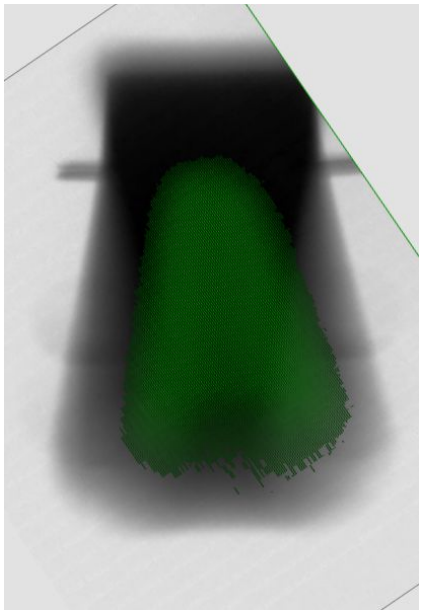
EXCEL spreadsheet (basic_lidar_design_ver_1.0.xls, Panos Kokkalis)

www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/raytracing/Basic_design/basic_lidar_design_ver_1.0.xls

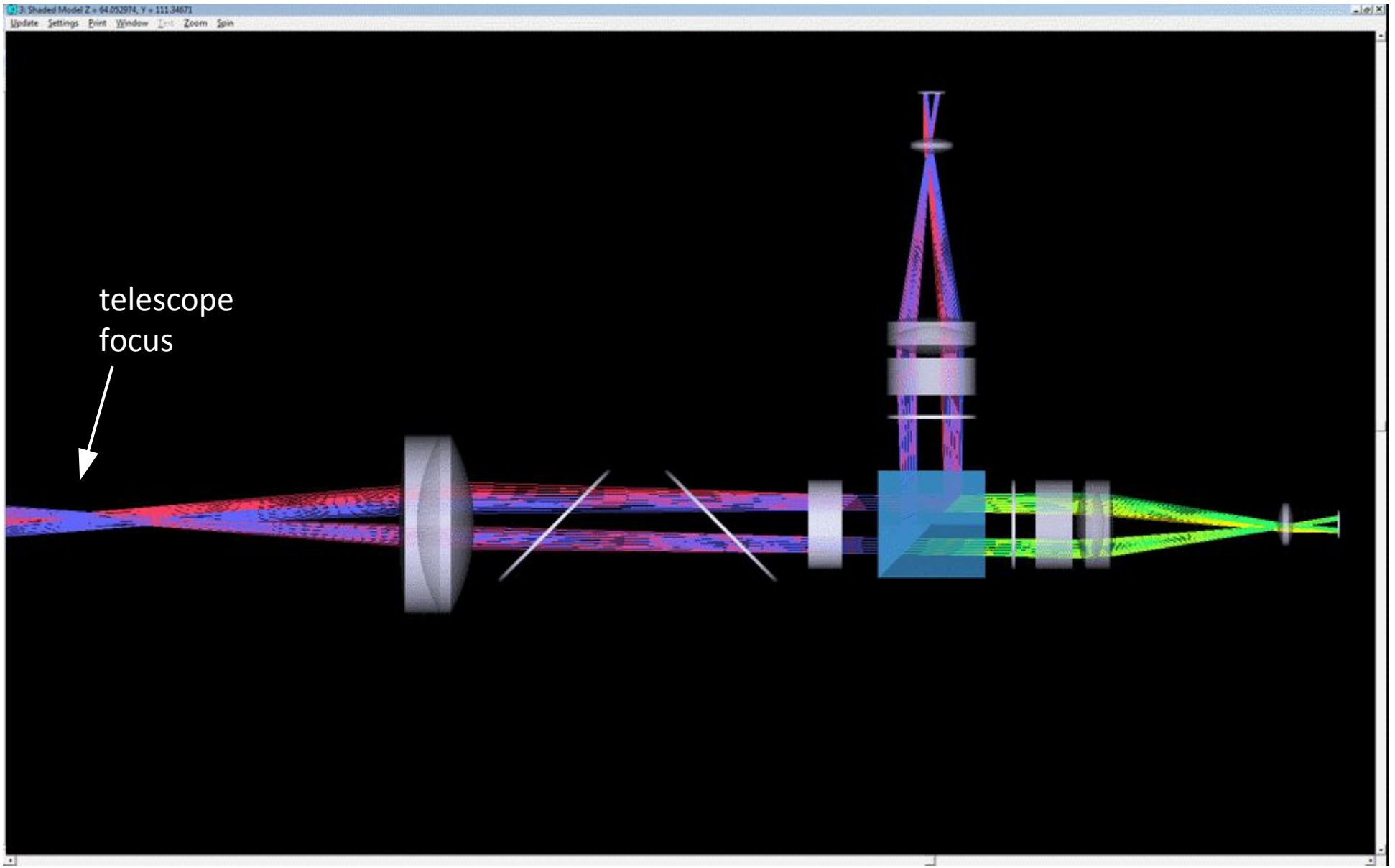
INPUTS		OUTPUTS	
Laser		**Depending only on laser and telescope**	
Atilt (mrad)	0.50	Atilt max (mrad)	0.560
TFOV nominal (mrad)	0.60	DFOmin (m) @ Atilt max	405.36
Dlaser (mm)	8.00	DFO (m)	428.30
GaussSizeFactor	3.00		
Beam Expander x	1.00		
TFOV expanded (mrad)	0.900		
Dlaser expanded (mm)	8.00		
Telescope		***CURRENT SYSTEM***	
DTL (mm)	300.00	FCOL (mm)	50.00
FT (mm)	1200.00	DCOL (mm)	16.15
DT (mm)	300.00	A (deg)	2.008
DFieldstop (mm)	3.00	Zll (mm)	52.08
RFOV (mrad)	1.50	Dll (mm)	12.50
RFOV tolerance (mrad)	0.04	Z1 (mm)	444.49
effective RFOV (mrad)	1.460	ZOBJ (mm)	392.41
Behind the Diaphragm (FOVD)		DOBJ (mm)	40.000
FCOL (mm)	50.000	FOBJ (mm)	80.00
		FEYE (mm)	32.00
DOBJ (mm)	40.000	DEYE (mm)	1.849
FOBJ / DOBJ	2.00	Z2 (mm)	112.00
DPMT (mm)	5.00	Z3 (mm)	-17.985

Tilted laser beam with tilted slit fov diaphragm

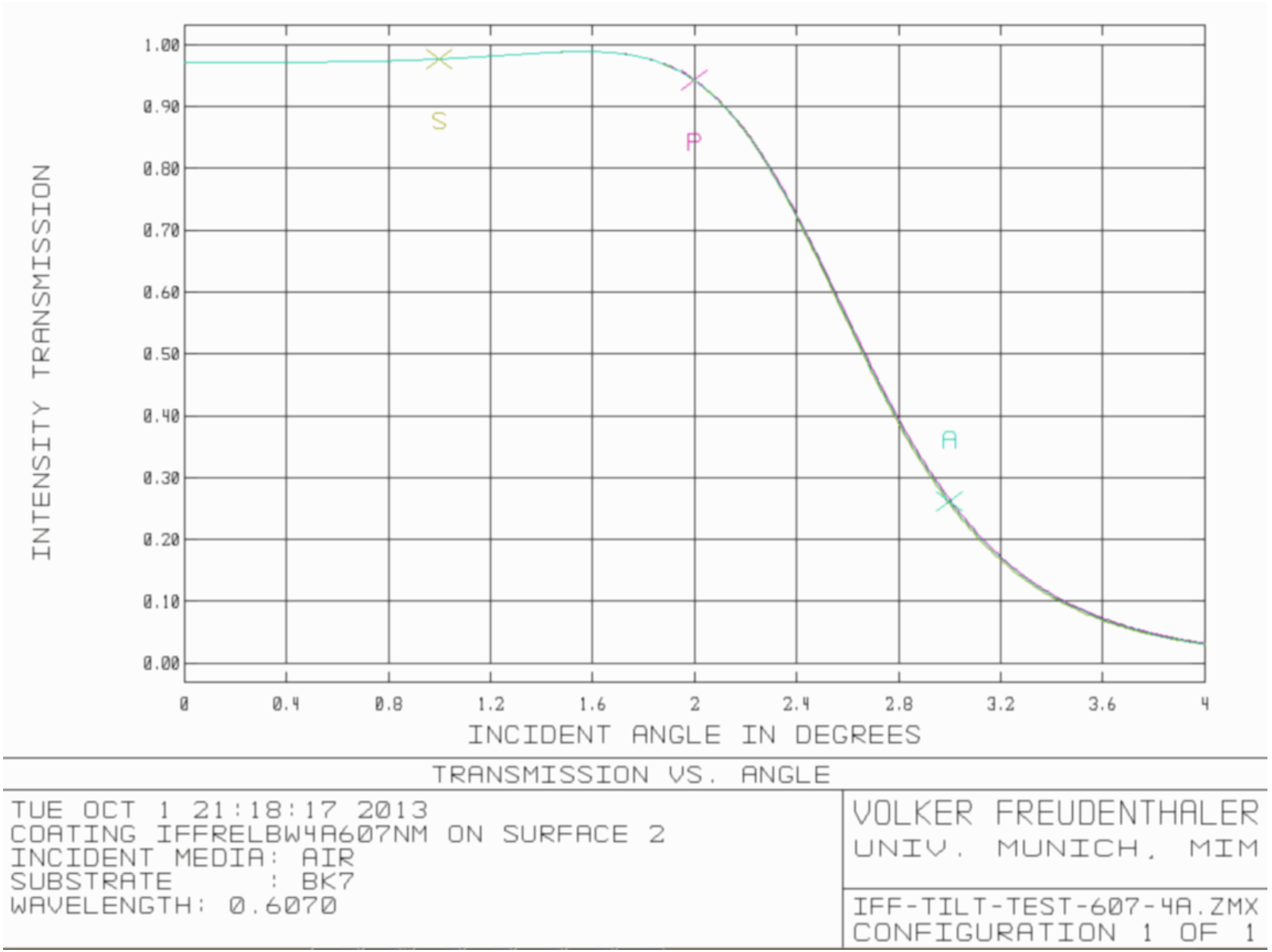




Spatial and angular beam truncation by apertures and coatings



Transmission of an interference filter depending on incidence angle

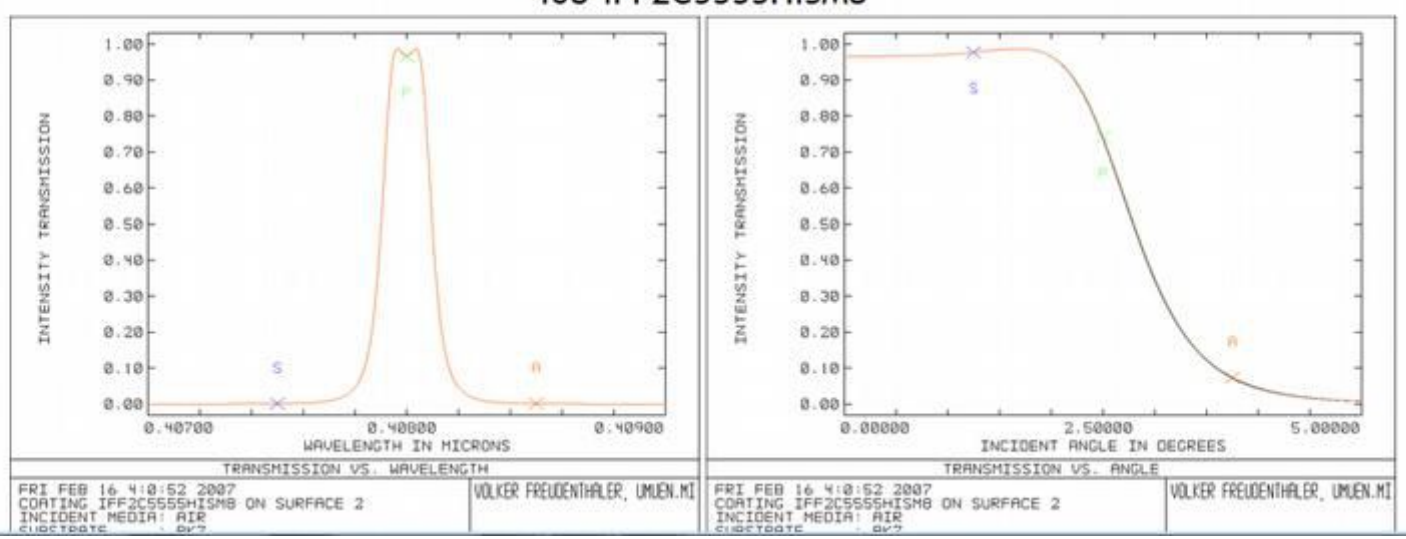


Introduction, explanations, database

www.meteo.physik.uni-muenchen.de/~stlidar/earlinet_asos/raytracing/IFF/EA-IFFilters.html

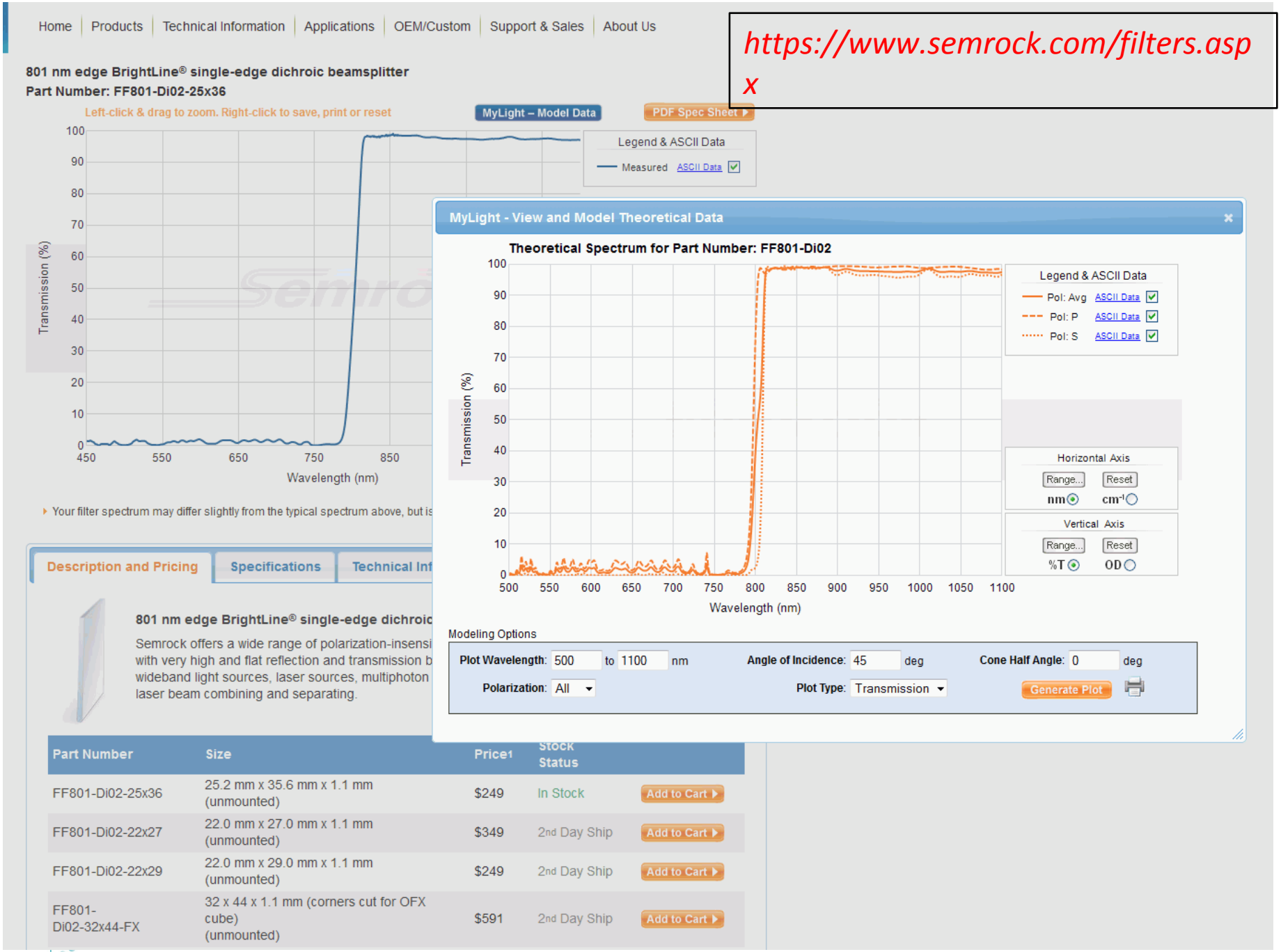
Centre wl [nm]	355	BW	neff	φ	387	BW	neff	φ	400	408	BW	neff	φ	511	532	BW	neff	φ
IFF BW (nm)																		
0.14															IFF2C5555SCLISM2	0.14	1.48	1.4
															IFF2C4444SCHISM4	0.14	2.04	1.6
0.2	IFF2C5555HISM3	0.22	2.01	2.5	IFF2C5555HISM5	0.22	1.97	2.45		IFF2C5555HISM8	0.2	2	2.2		IFF2C5555HISM20	0.19	2.01	1.8
	IFF2C4444HISM10	0.2	2.17	2.7											IFF2C5555HISM22	0.18	2.01	1.7
															IFF2C4444SCHISM3	0.18	1.99	1.7
0.3	IFF2C4444HISM6	0.31	2.1	3.2														
0.35									1						1			
0.42										1								
0.5	IFF2C3333HISM9	0.52	2.12	4.2	IFF2C4444HISM5	0.48	1.97	3.7		IFF2C4444HISM7	0.48	1.99	3.4	1	IFF2C4444HISM15	0.5	1.99	2.9
										IFF2C3333HISM16	0.52	2.05	3.7					
1	IFF2C3333HISM4	0.98	2.05	6.8						IFF2C3333HISM8	0.94	2	4.8		IFF2C3333HISM16	0.99	1.99	4
1.5															1			
3	1				1					1					IFF2C2222HISM10	3.0	1.96	8.8

Centre wl [nm]	607	BW	neff	φ	660	710	800	1064	BW	neff	φ
IFF BW (nm)											
0.14											

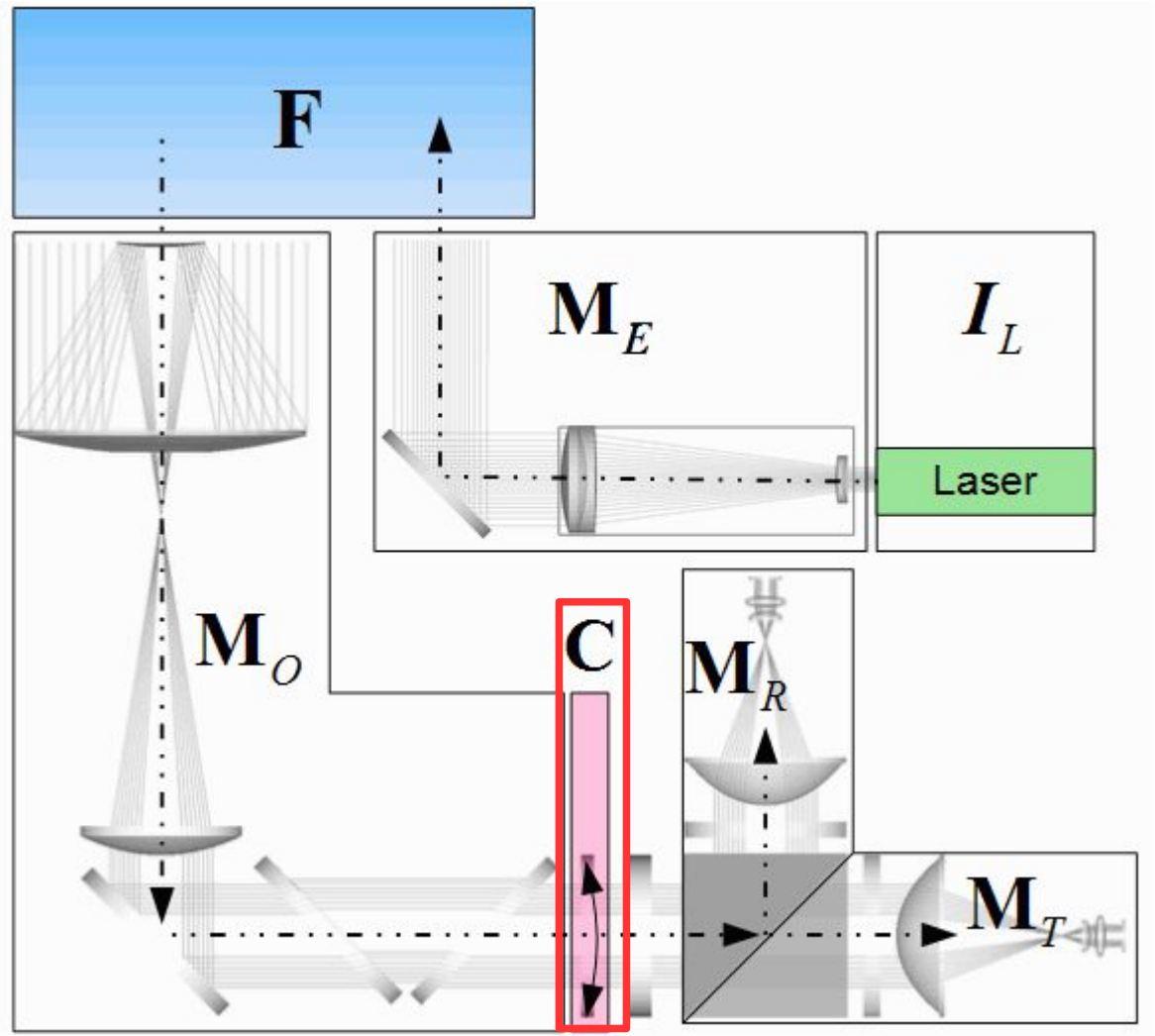


SEMROCK filter simulator

https://www.semrock.com/filters.aspx



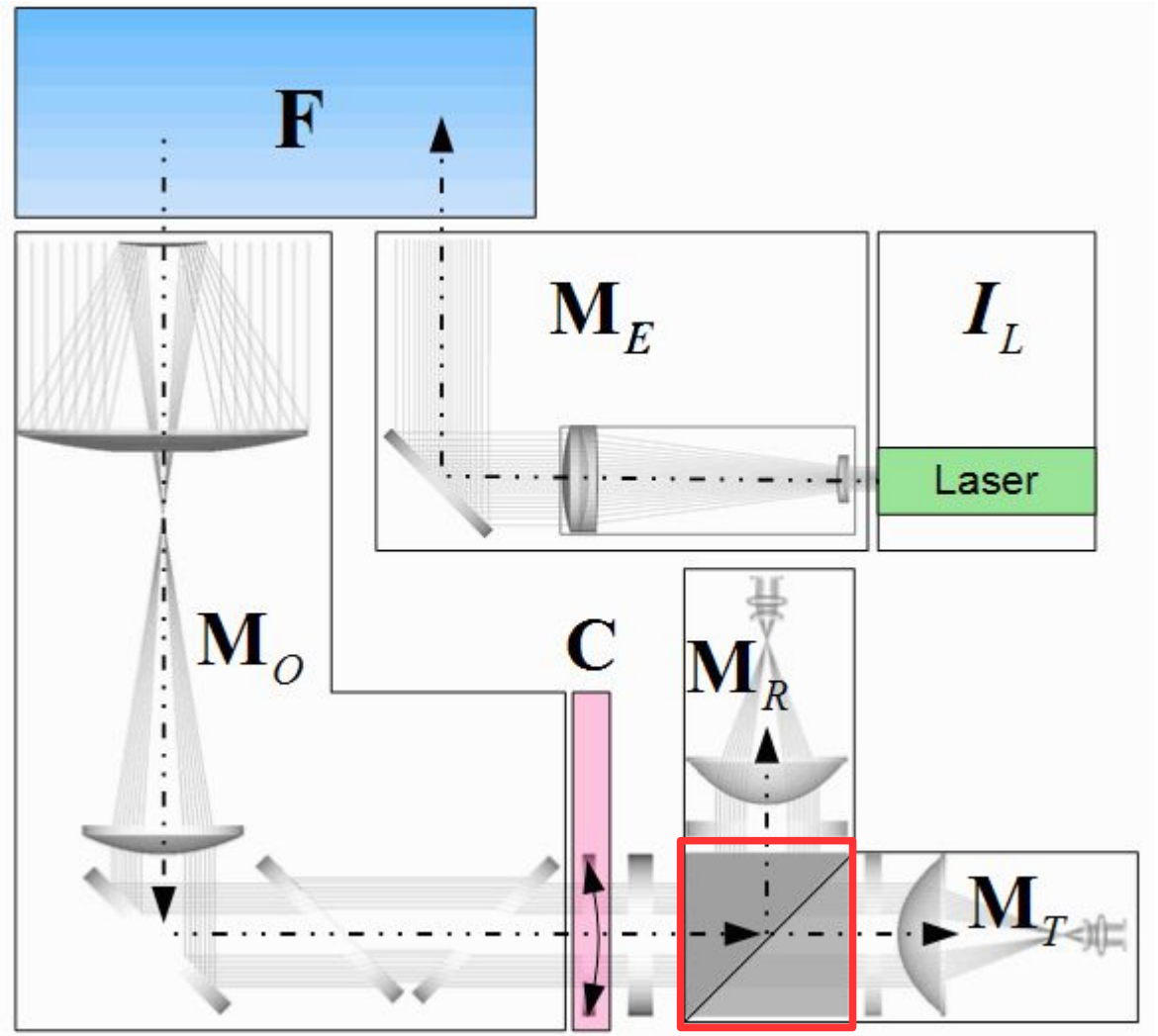
polarisation calibrator



location

type

parameters to determine

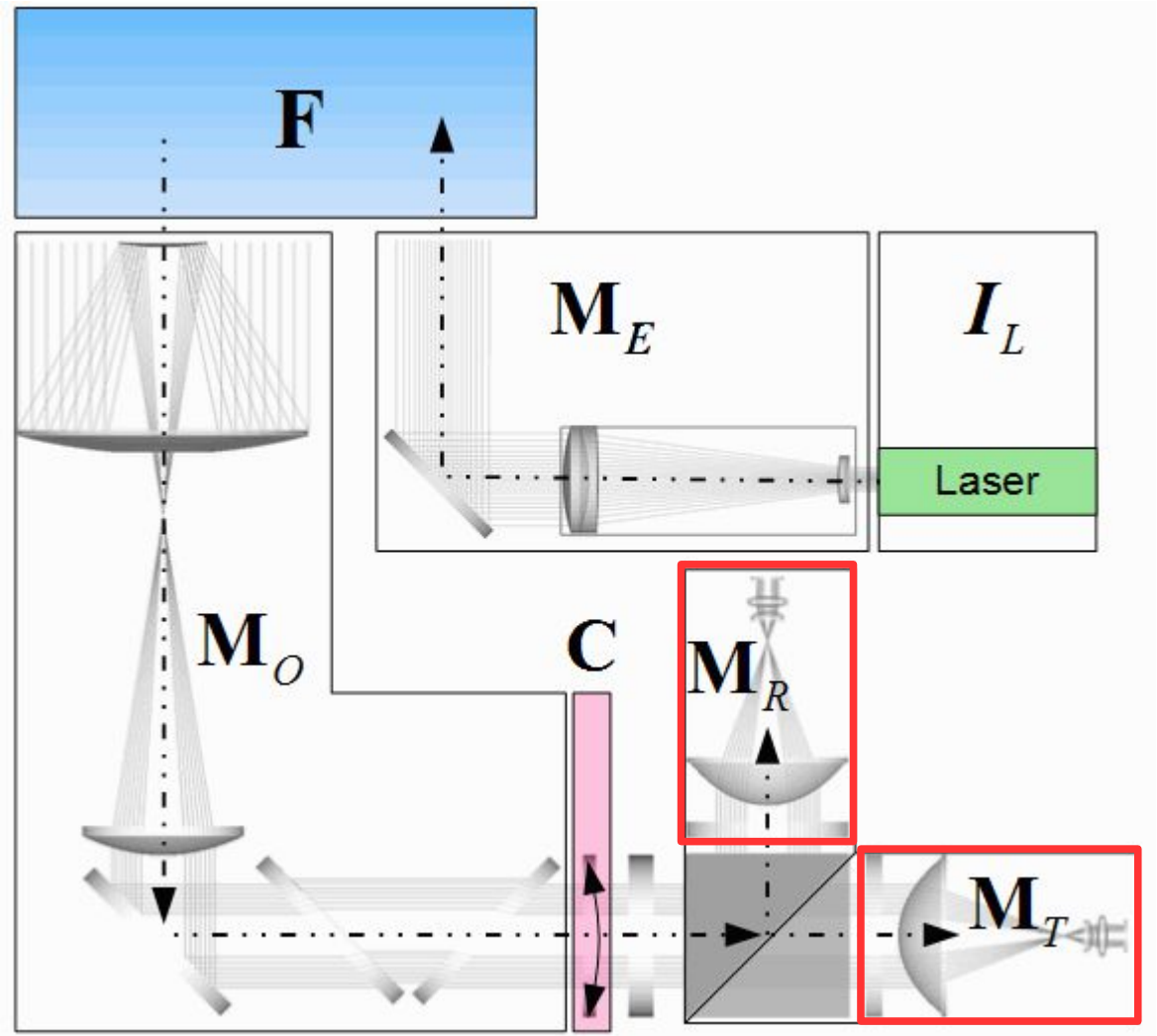


polarising
beam splitter

acceptance angles

extinction ratio

cleaning



detectors and optics

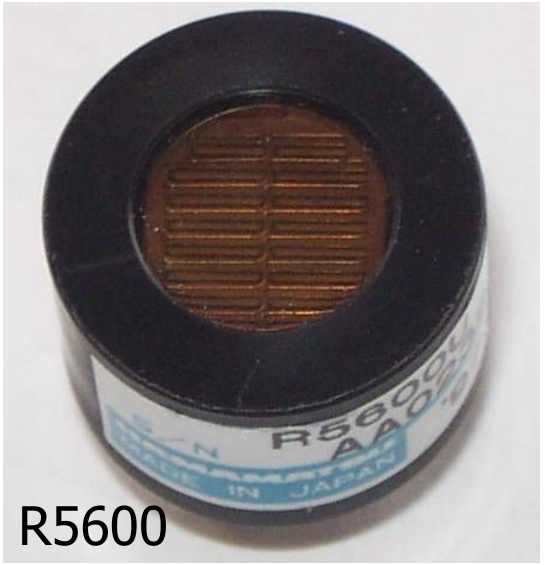
PMT
- homogeneity of the sensitivity

APD
- small diameter

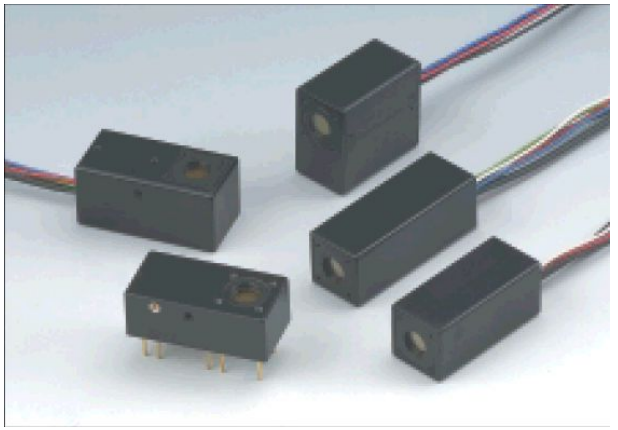
eyepiece
- => telescope imaging

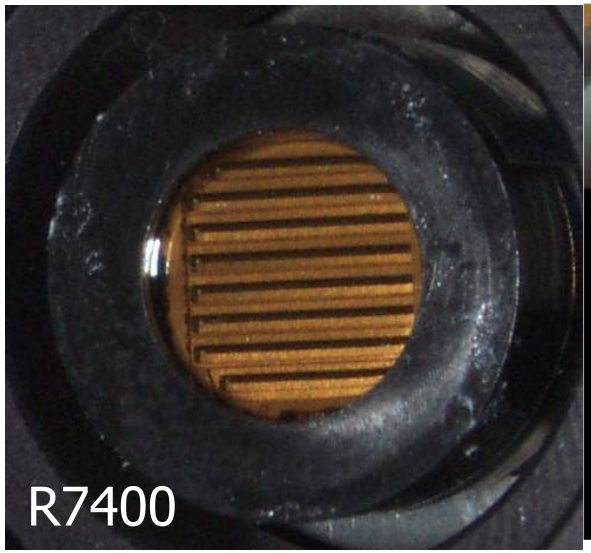
neutral density filters
- => adjust signal level (LICEL)

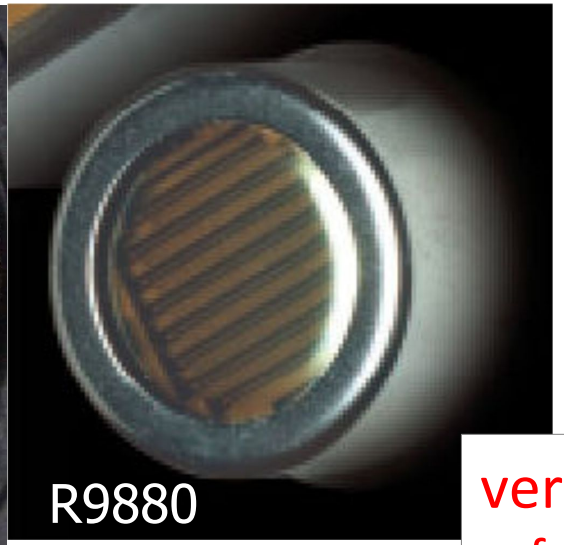
Detectors: Hamamatsu photomultiplier R5600, R7400, R9880 (LICEL)



assembled in many Hamamatsu photosensor and photocounting modules like



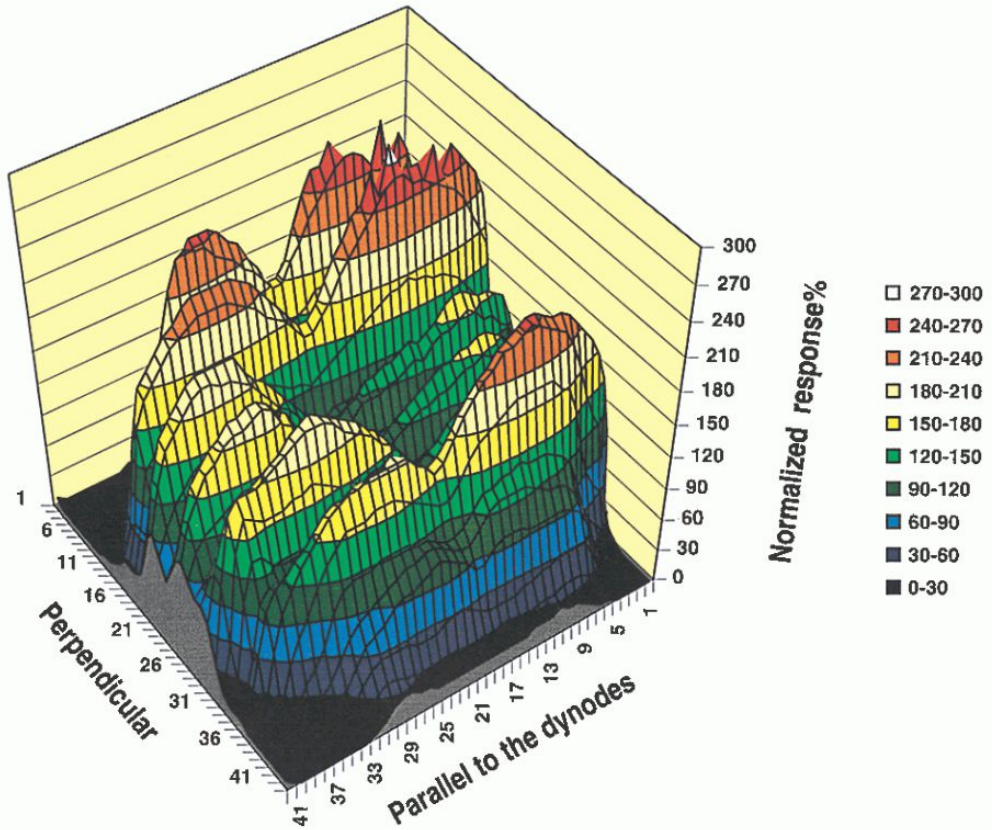




source:
http://www.hamamatsu.com/us/en/product/category/index.html

very small size =>
fastest rise time =>
highest count rate and dynamic range
+ relatively insensitive to magnetic fields
used also in LICEL lidar data aquisition

Detectors: Hamamatsu photomultiplier R5600, R7400, R9880 (LICEL)



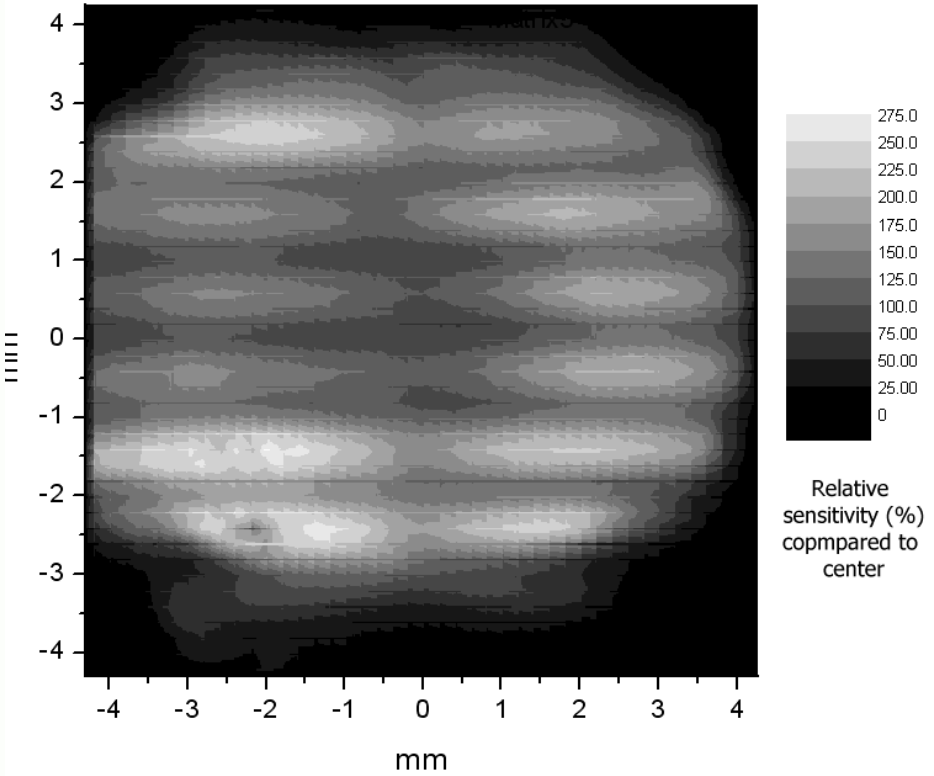
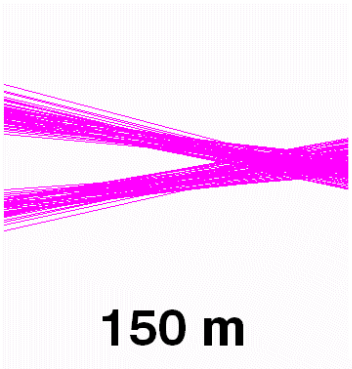
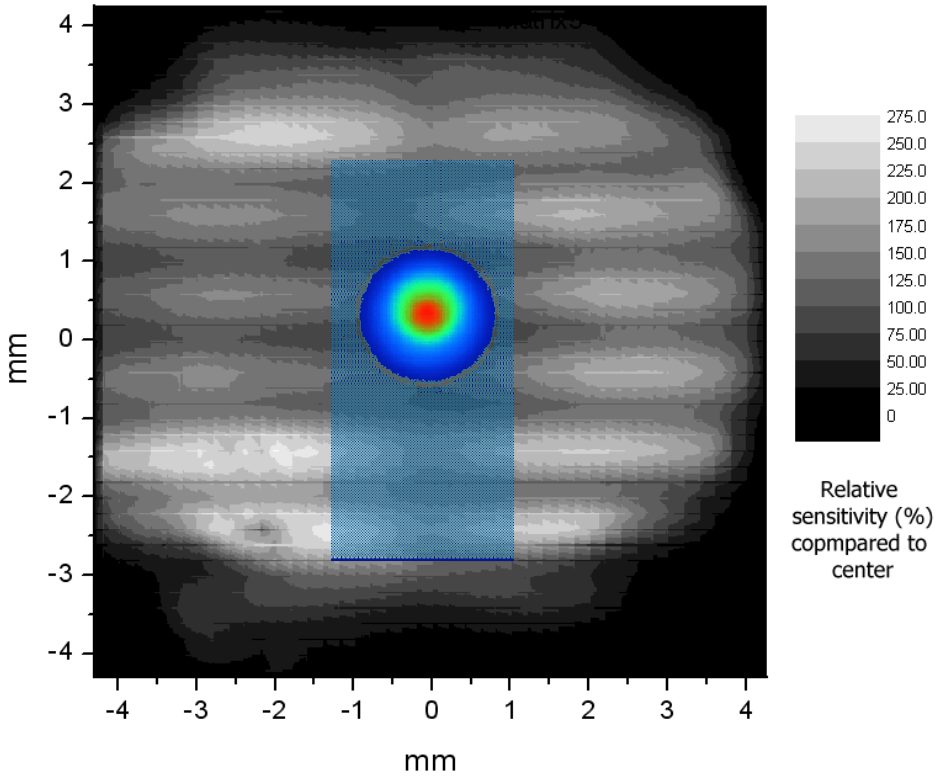


Fig. 1. Anode spatial uniformity of the Hamamatsu H5783-06 photosensor module measured with a resolution of 200 μm. The values were normalized to the average of the central part of the photocathode (2 × 2 mm).

source: V. Simeonov et al., Influence of the Photomultiplier Tube Spatial Uniformity on Lidar Signals, Appl. Opt. **38**, 5186-5190 August 1999.

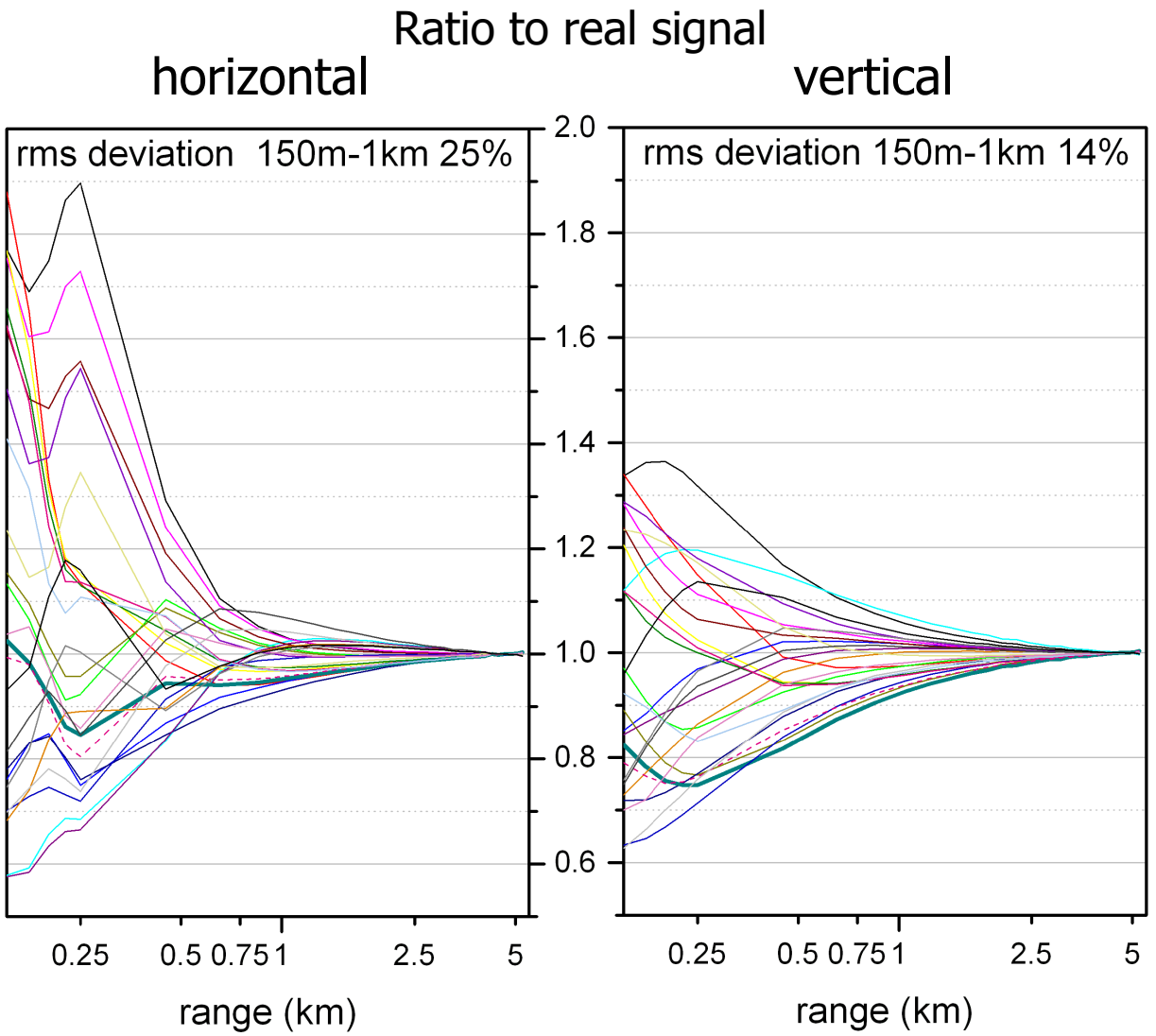
Detectors: Hamamatsu PMTs R5600 spatial sensitivity – detector in a focal plane

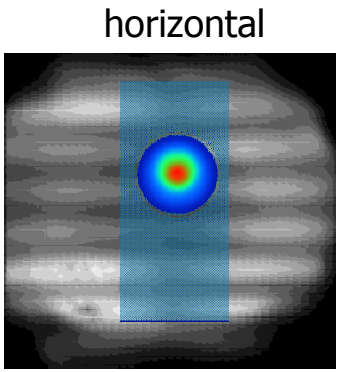


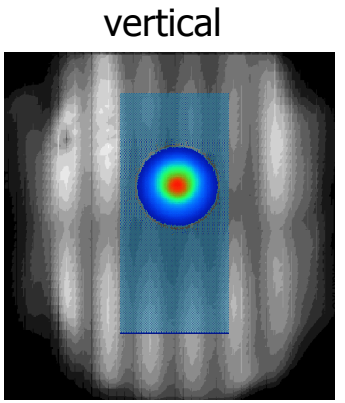


source: V. Freudenthaler, Effects of spatially inhomogeneous photomultiplier sensitivity on lidar signals and remedies, ILRC22, 2004
http://www.meteo.physik.uni-muenchen.de/~st212fre/ILRC22/index.html

Detectors: Hamamatsu PMTs R5600 spatial sensitivity – detector in a focal plane

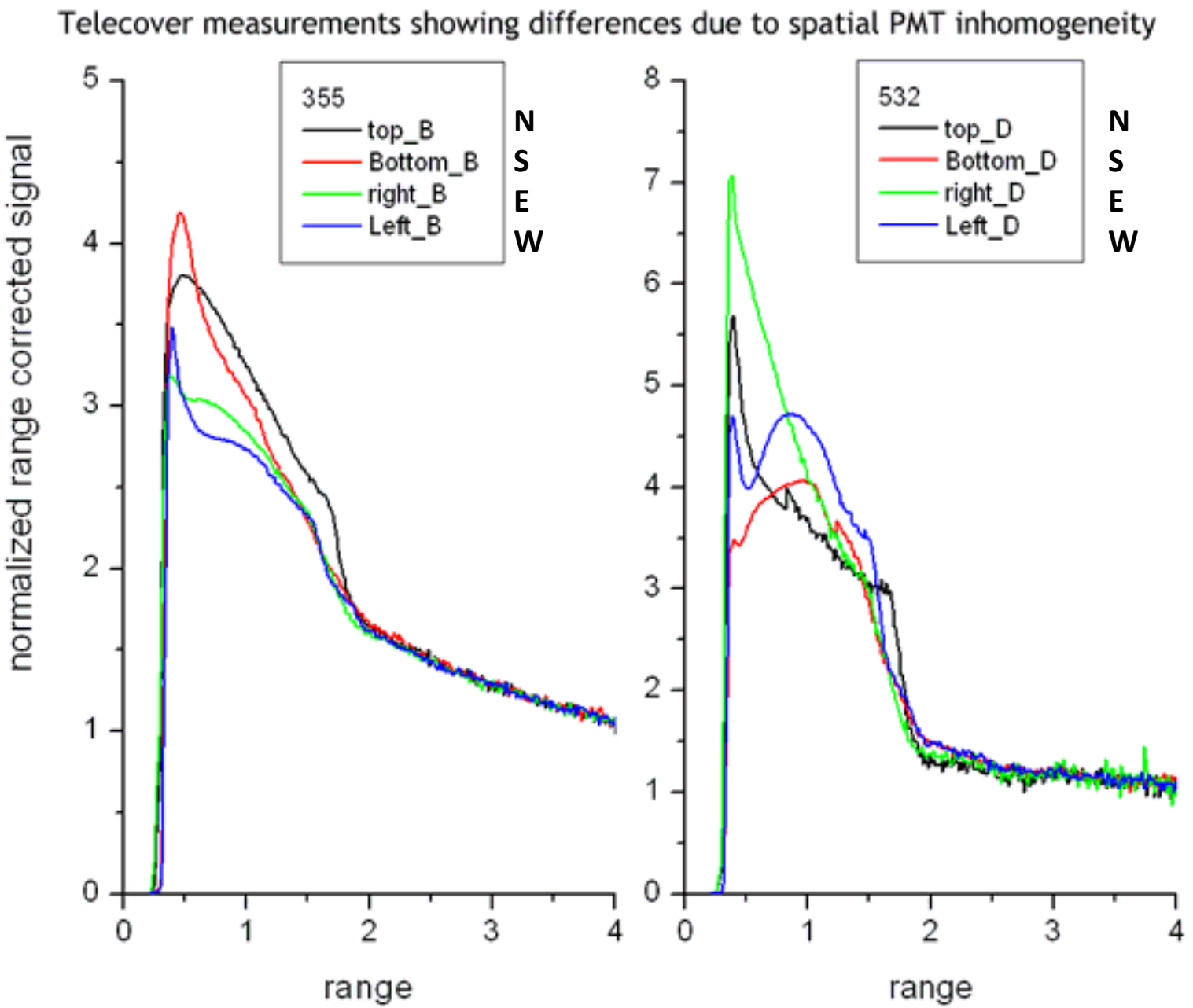




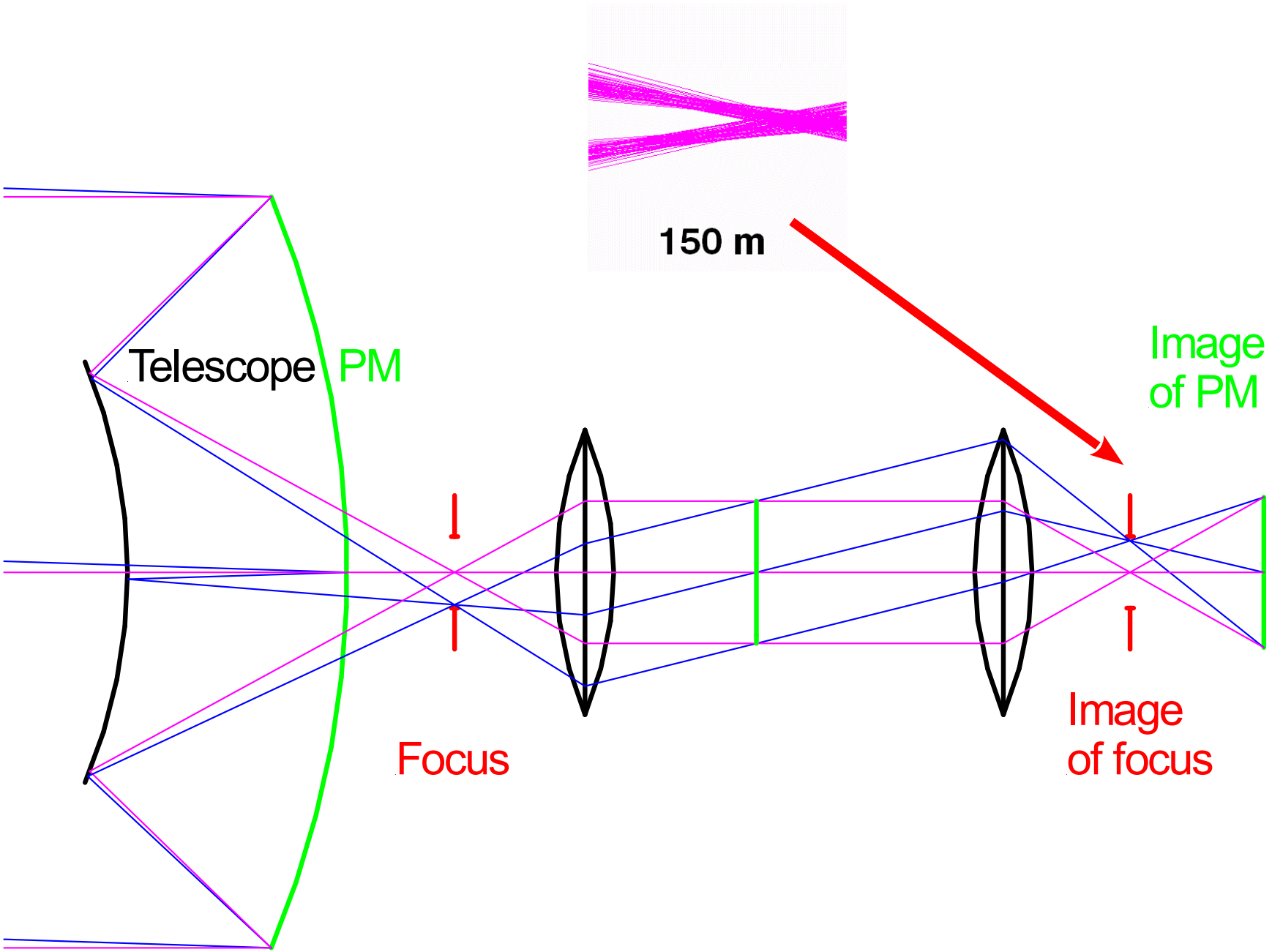


source: V. Freudenthaler, Effects of spatially inhomogeneous photomultiplier sensitivity on lidar signals and remedies, ILRC22, 2004
http://www.meteo.physik.uni-muenchen.de/~st212fre/ILRC22/index.html

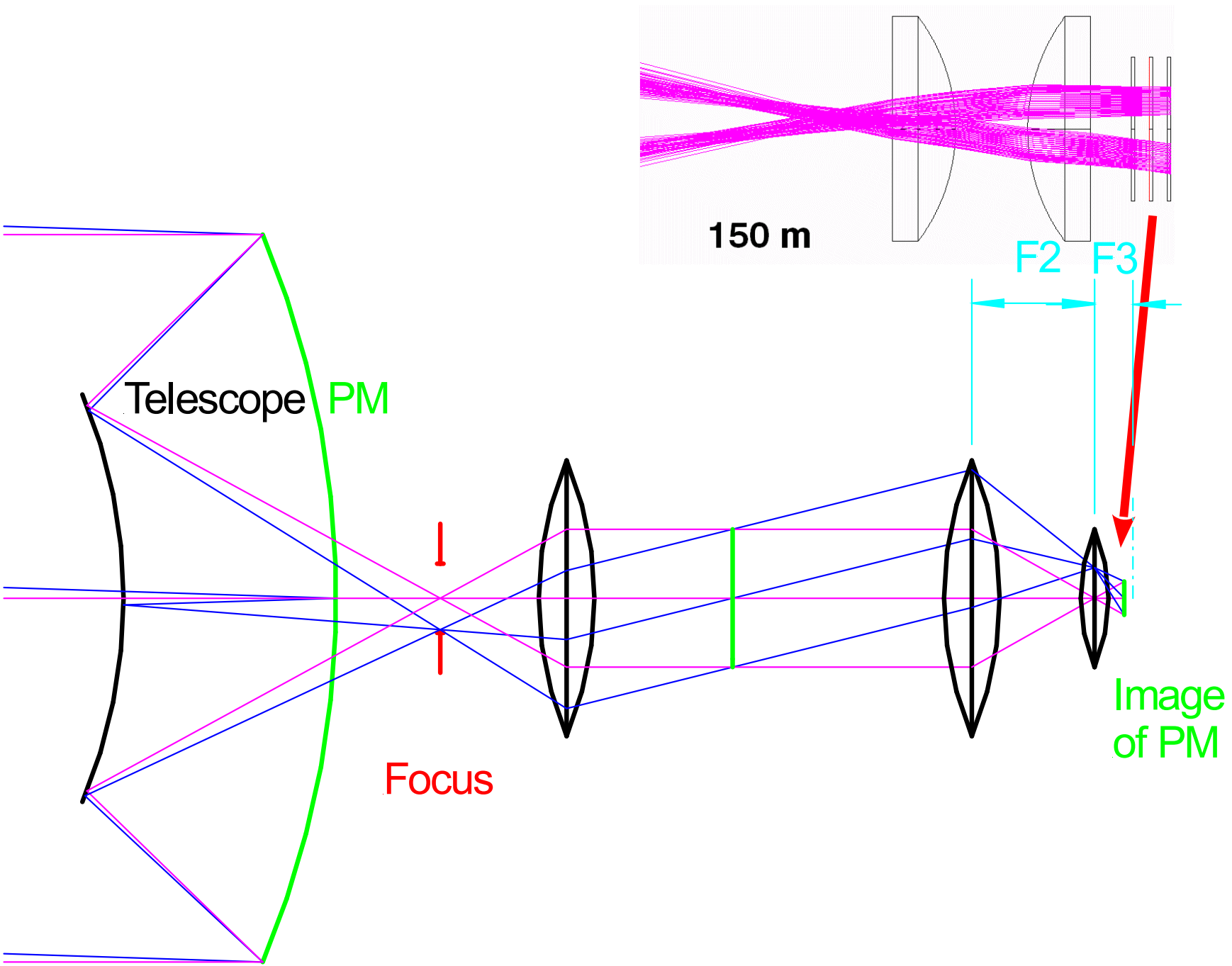
Detectors: Hamamatsu PMTs R5600 spatial sensitivity – detector in a focal plane



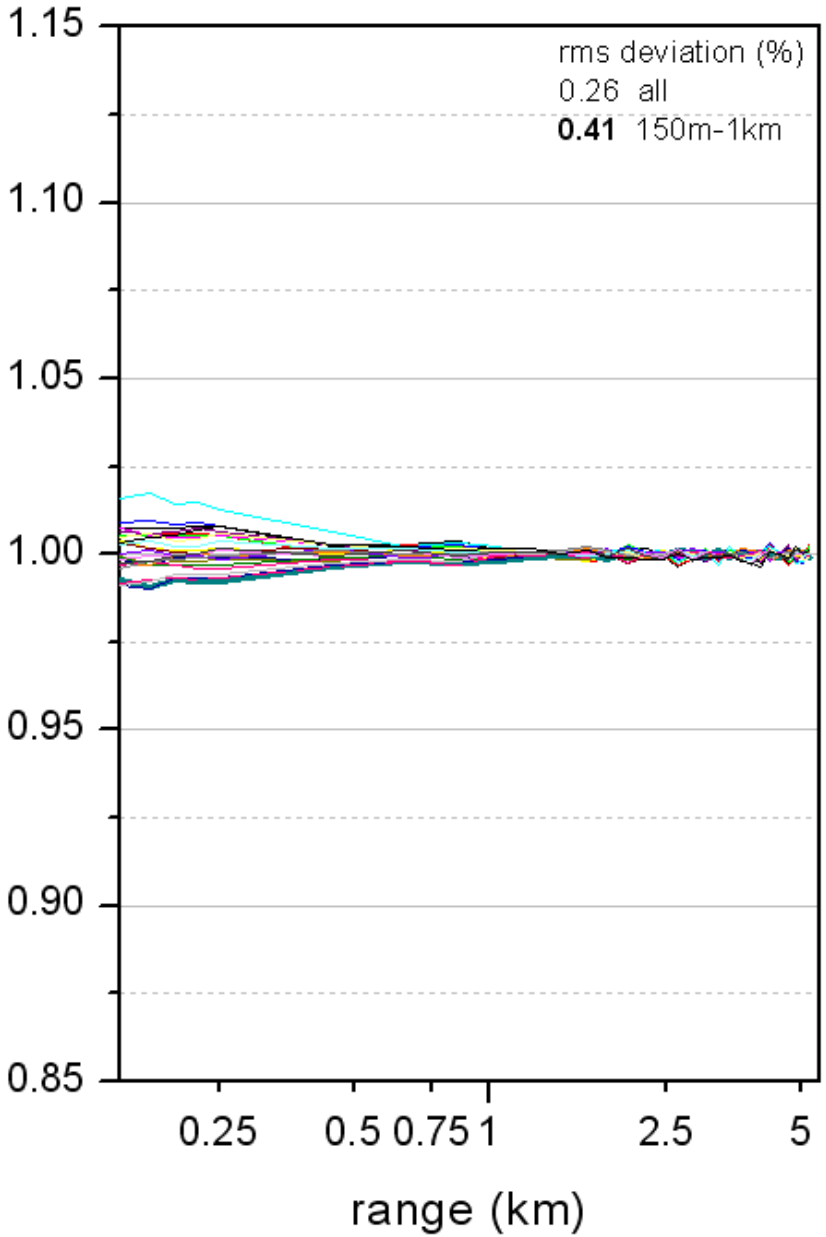
Transmission function, focal spot position on detector - change with lidar range

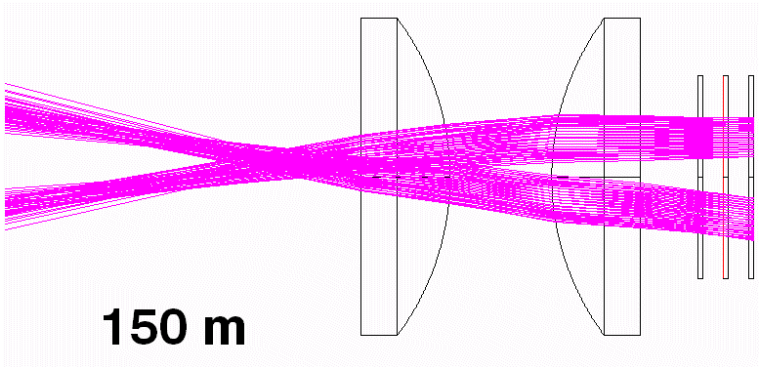


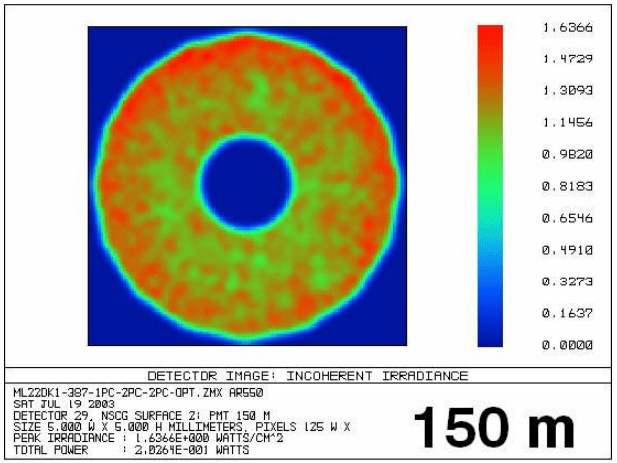
Transmission function, primary mirror image on detector - change with lidar range



Hamamatsu PMTs R5600 spatial sensitivity – relative signal deviations



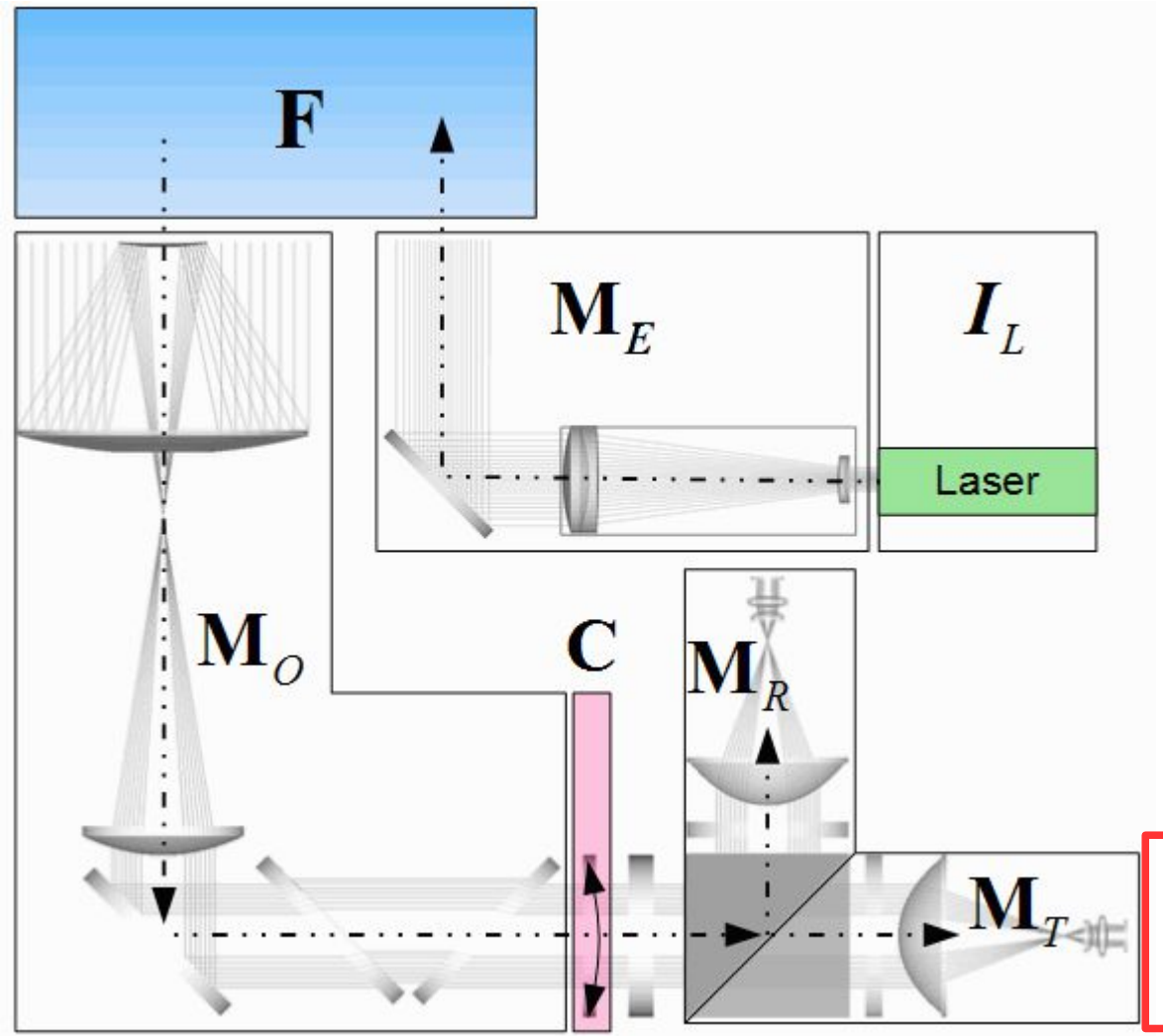




+ Spot does not move
– change of intensity distribution

source: V. Freudenthaler, Effects of spatially inhomogeneous photomultiplier sensitivity on lidar signals and remedies, ILRC22, 2004
http://www.meteo.physik.uni-muenchen.de/~st212fre/ILRC22/index.html

data acquisition



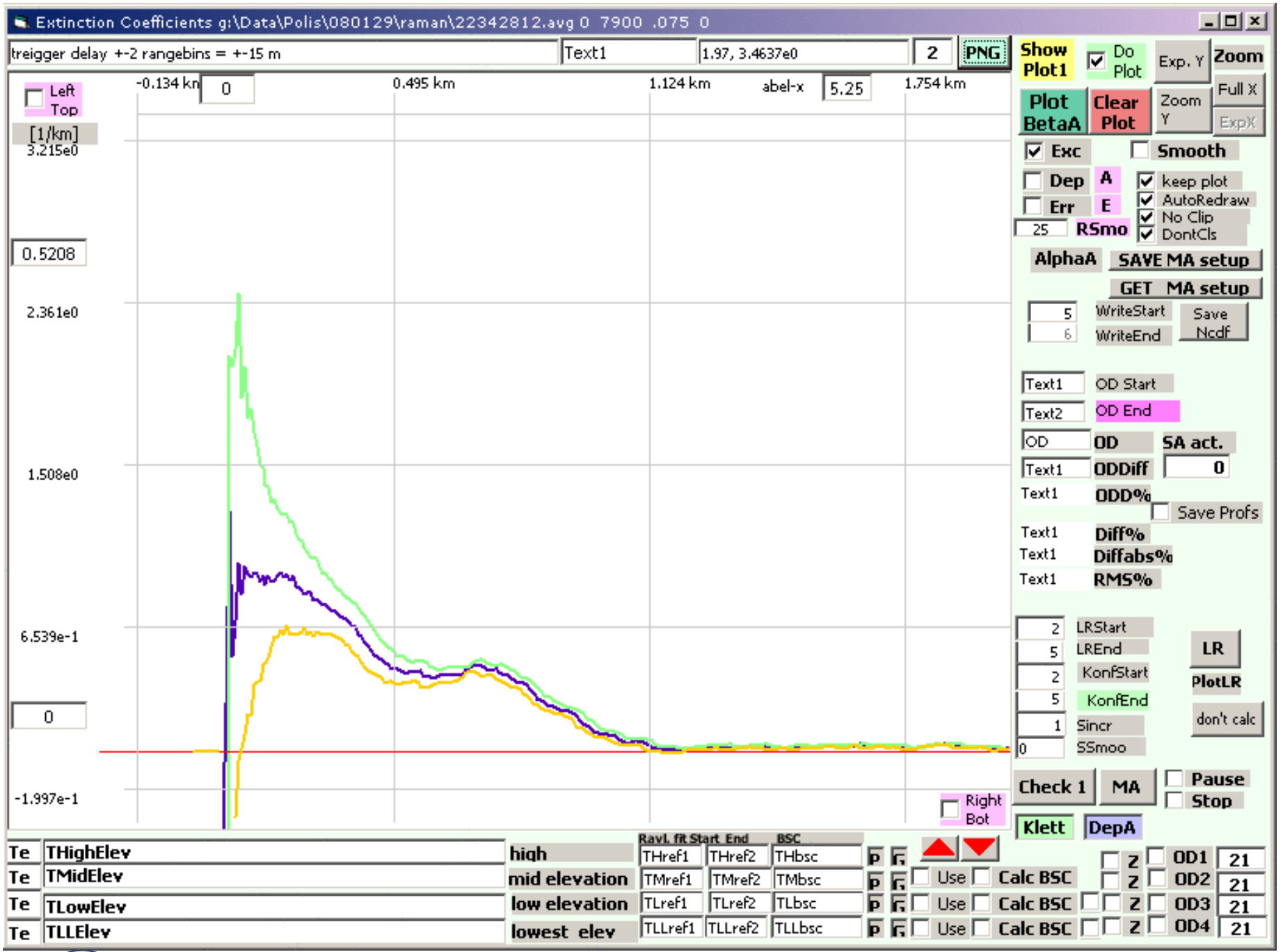
trigger delay

analogue
max. upper level

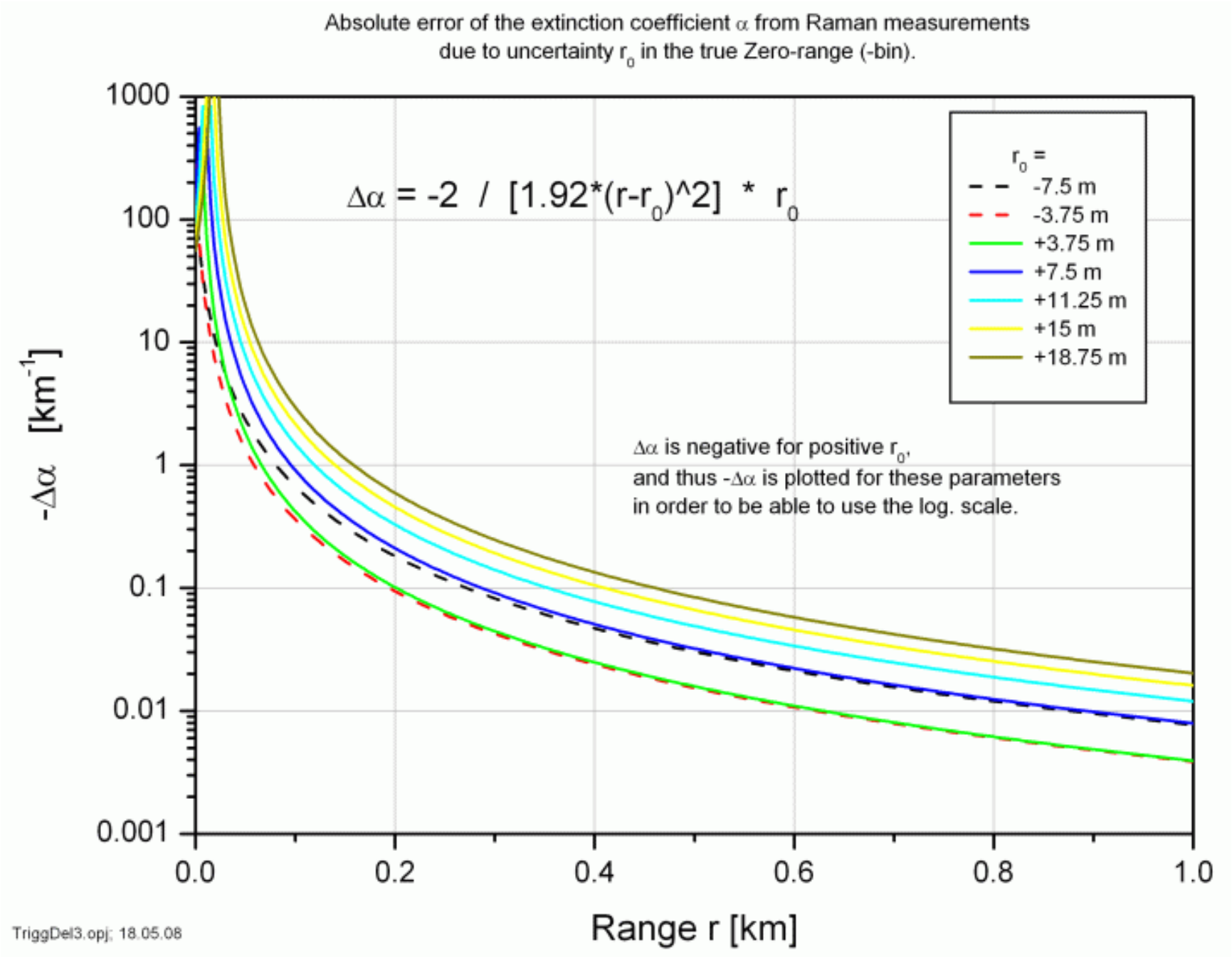
photon counting
max. background

DAQ

Trigger delay

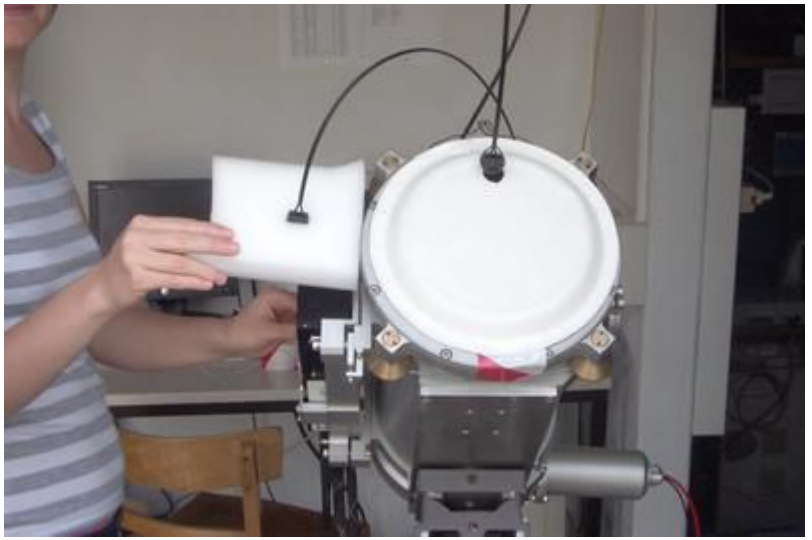


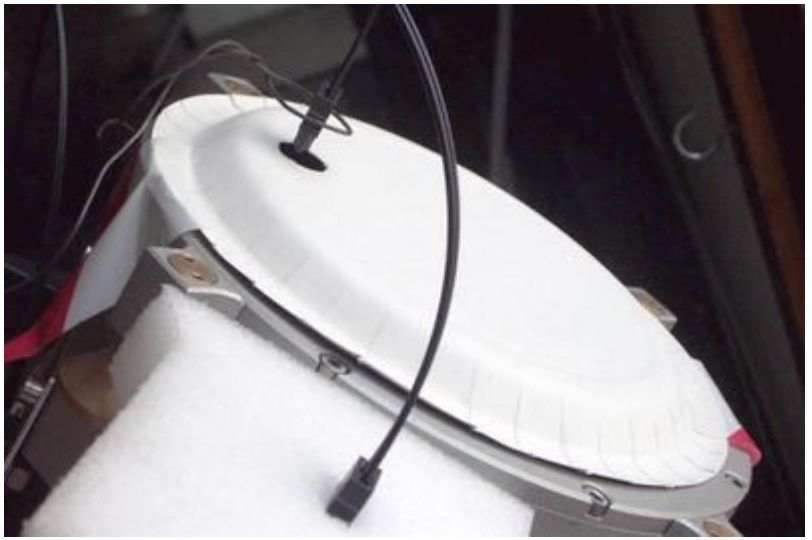
Trigger delay

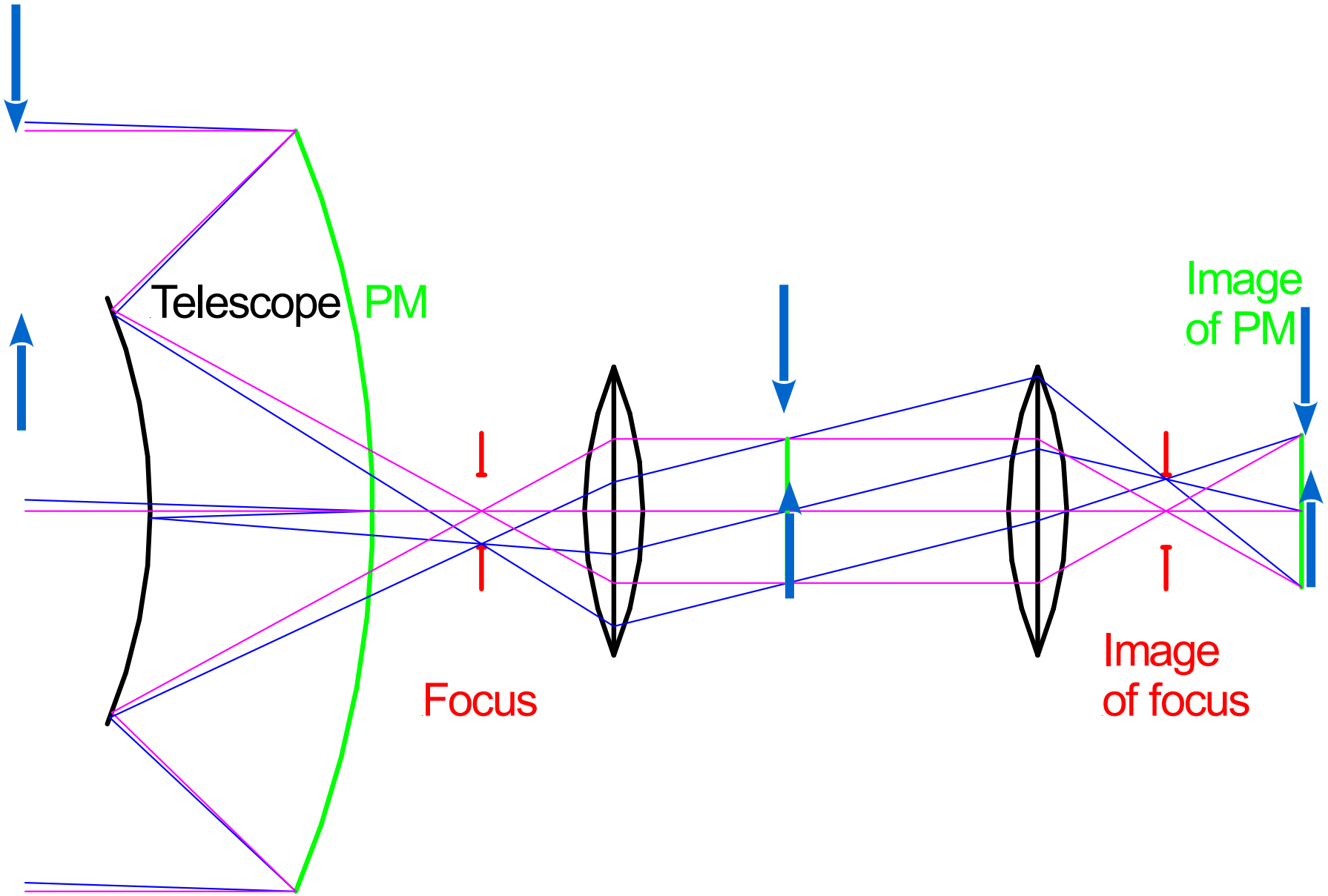


Trigger delay measurement

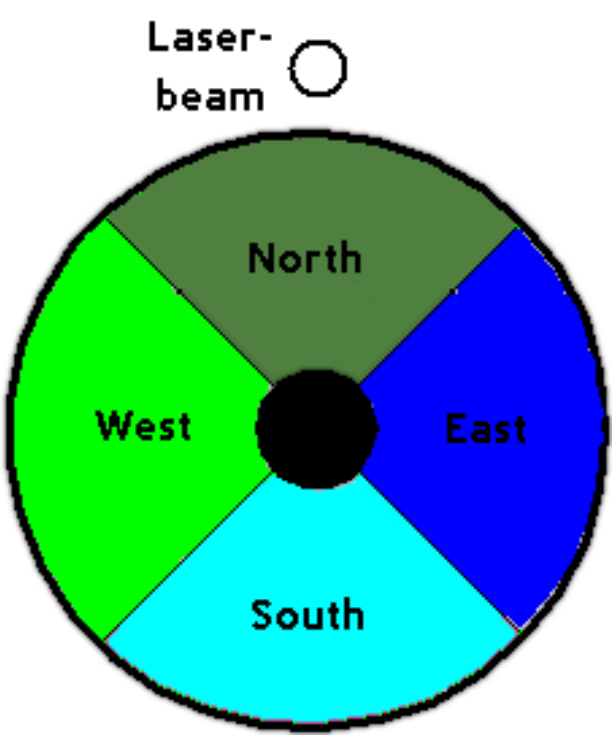
Trigger delay measurement

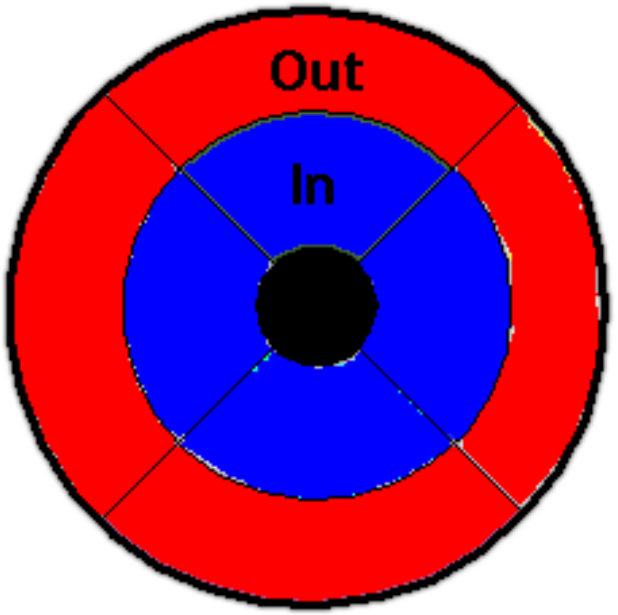


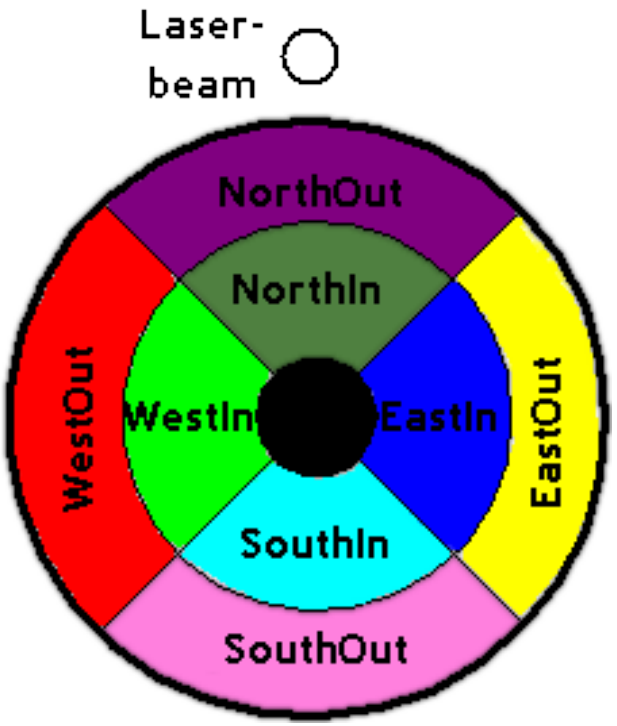



Telescope
PM
Image
of PM
Focus
Image
of focus

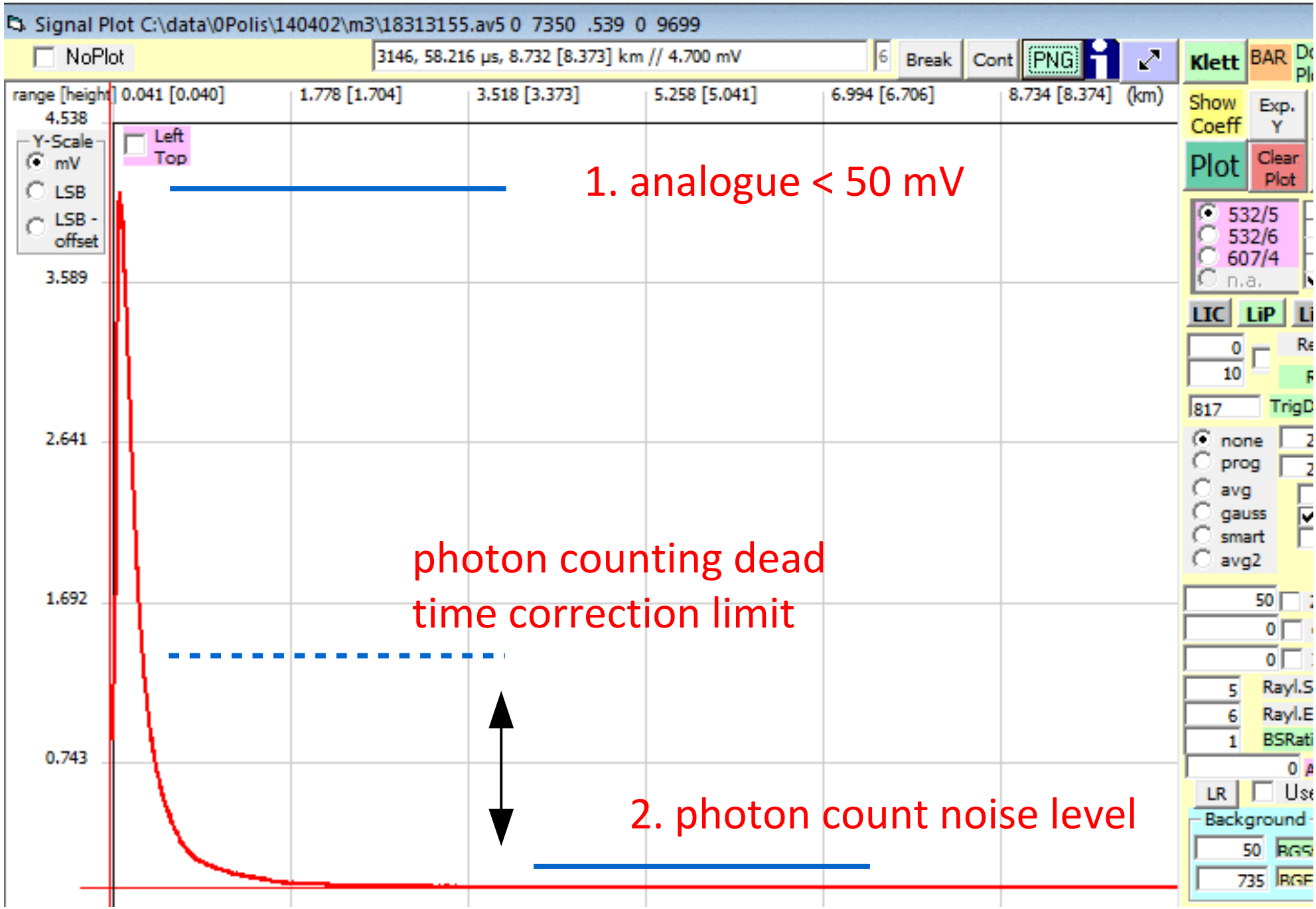
Telecover measurements







Signal limits



CONTROLLING STRESS IN BONDED OPTICS

Andrew Bachmann, Dr. John Arnold and Nicole Langer
DYMAX Corporation, Torrington, Connecticut
October 1, 2001

delamination, birefringence can lead to optical failure. Figure 4, below shows a photograph of birefringence caused by the adhesive at three stress points. The birefringence radiates out from the stress points from a positioning adhesive as seen through a polarizer . Figure 5 shows adhesive-caused stress in a doublet boned over the entire lens surface.

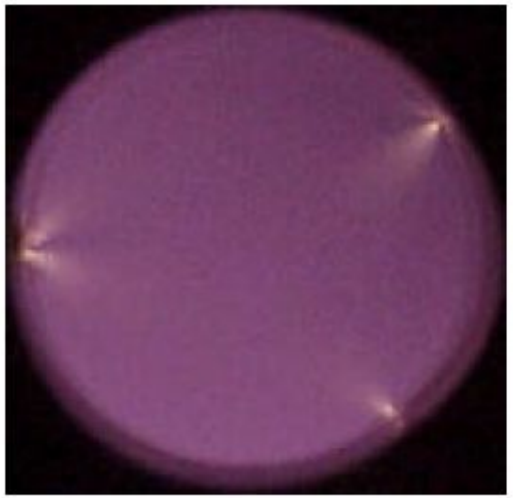


Figure 4. Birefringence as seen through a polariscope at each of a 3-point bond for a 1 inch diameter optic

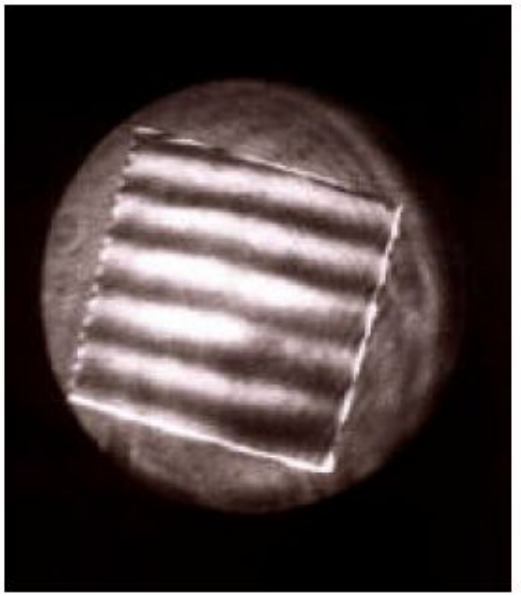


Figure 5. Lens, as seen through a polarized film