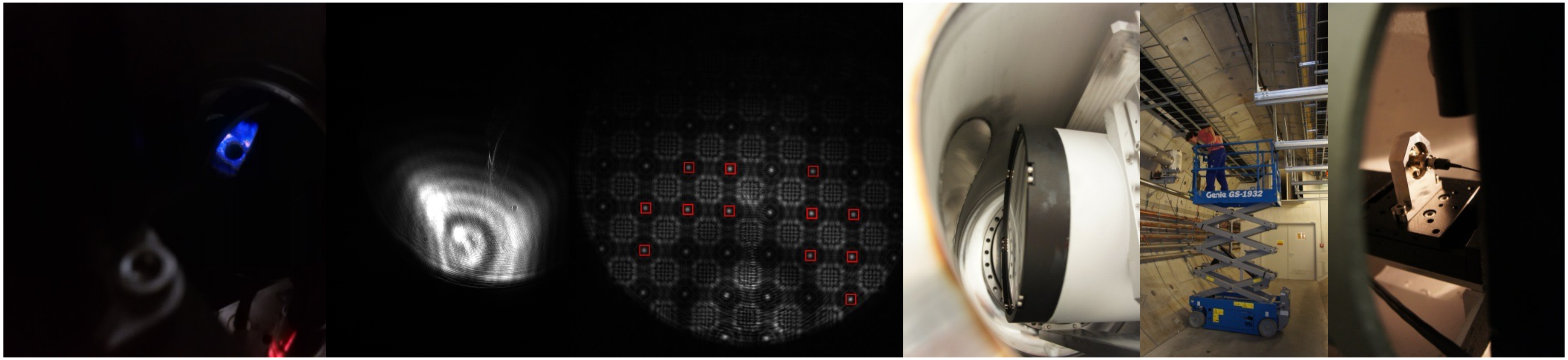
SLRS Finals

…our very last steps towards a running Straight Line Reference System



Dr. Johannes J. Prenting

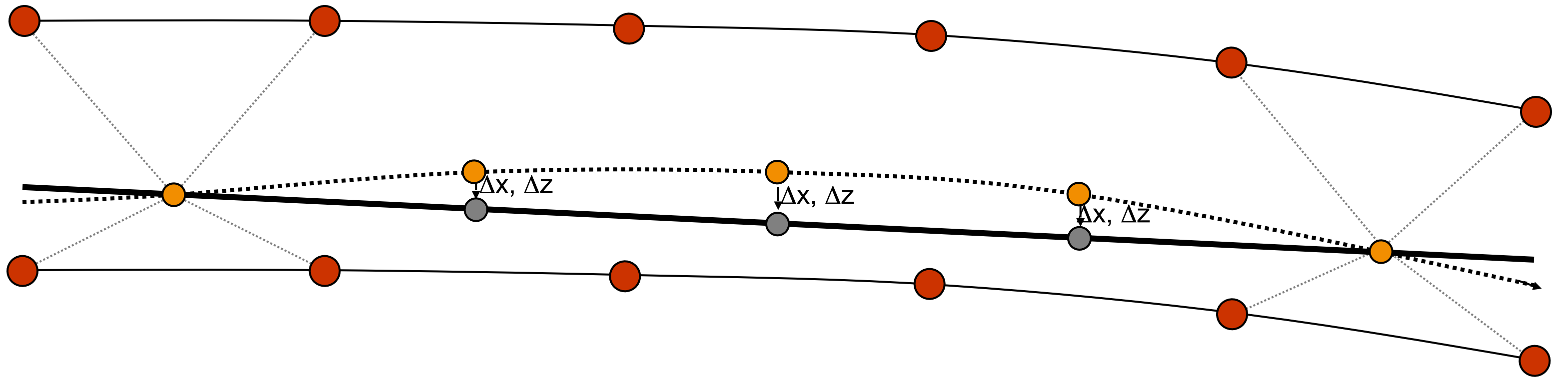
SLRS Semi Finals
Grenoble, October 2016

HELMHOLTZ ASSOCIATION

DESY

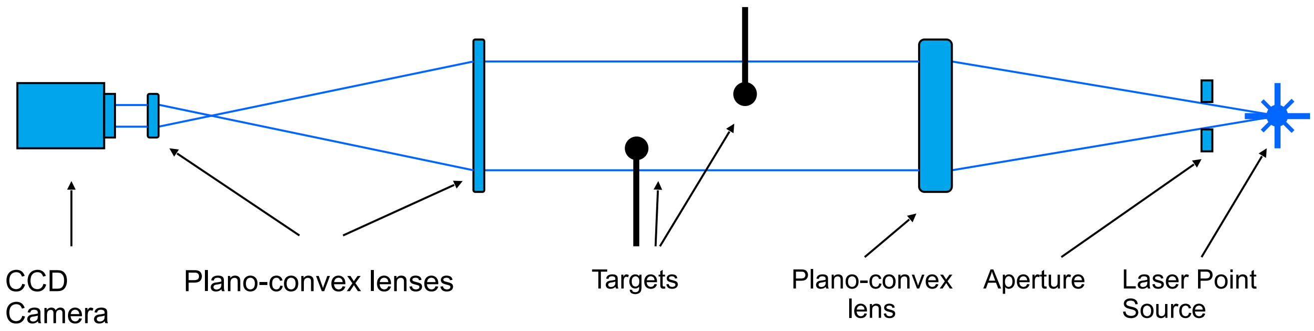
System setup

- The SLRS (Straight Line Reference Surveyor) is a refraction free alignment system
- It uses a collimated laser beam within an ISO200 vacuum tube
- SLRS is used like a ruler put into the seemingly bent (refraction) tunnel network
- There is no direct connection between the SLRS and machine components
- SLRS provides correction parameters (dx, dz) for the geodetic network
- Calibrated transfer pieces are used to connect the SLRS measuremets with the tunnel network



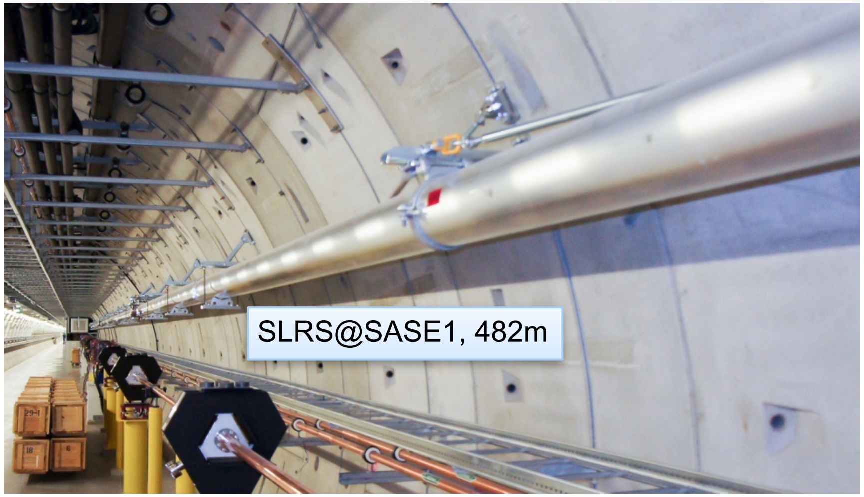
System setup

- Principle of the SLRS:
  - A laser light source emits coherent light
  - A fiber end, aperture and a plano convex lens are used to expand and collimate the beam
  - Spheres put into the beam along the measuring section originate a poisson spot behind the centre of the sphere which can be viewed with a ccd camera
  - The centre of the sphere and the centre of its poisson spot in the image generate a straight line
  - A lens system focuses the expanded beam to the dimensions of the CCD sensor
  - Correlation algorithms are used to calculate the poisson centres in the image



DESY

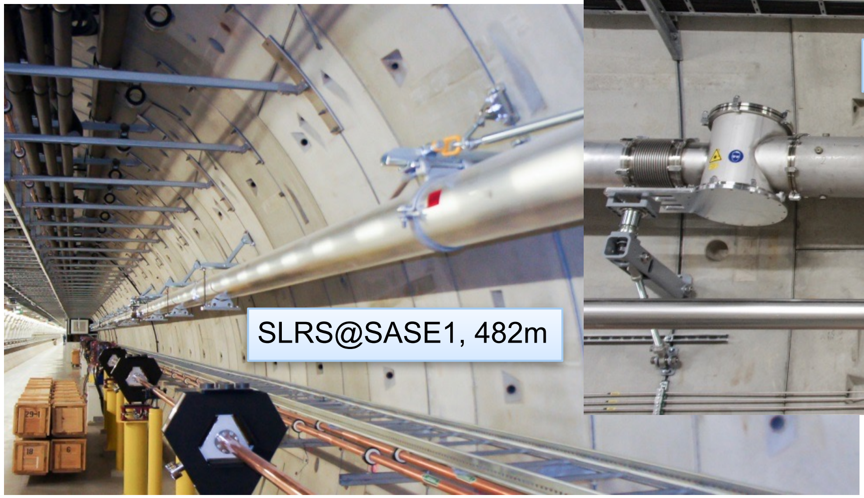
System setup

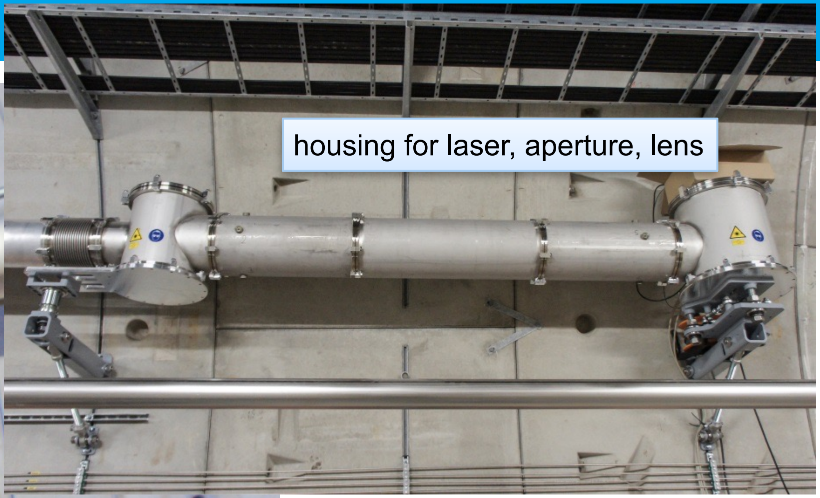


- Actual setup:
  - Aluminum pipes, 7.73m/3.87m long, 200mm diameter. Supports are placed every 3 to 4.5m with fixed point and floating point fixing.
  - special housings for (laser, aperture, lenses) and (lenses & camera)
  - Tee piece connector with bellows, every 24m, every 2nd is

    equipped with adapted measurement targets (aka target boxes)
  - blue laser (wavelength = 405nm) allows for small targets and provides fine interference patterns
  - revised plano convex lenses for minimal spherical aberration
  - GigE-Camera with 2048x2048 pix. resolution
  - Oerlikon/Leybold Trivac D 65 B Vacuum pumps

System setup





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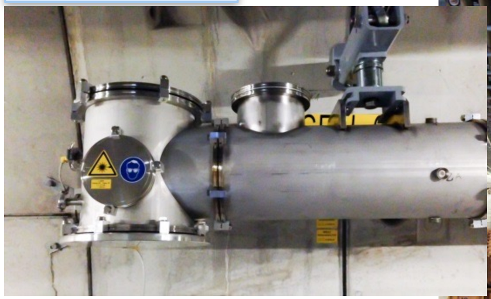
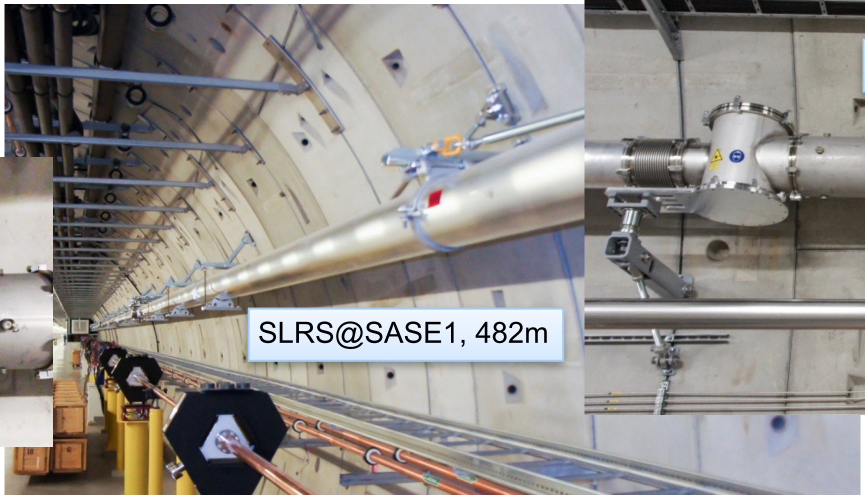
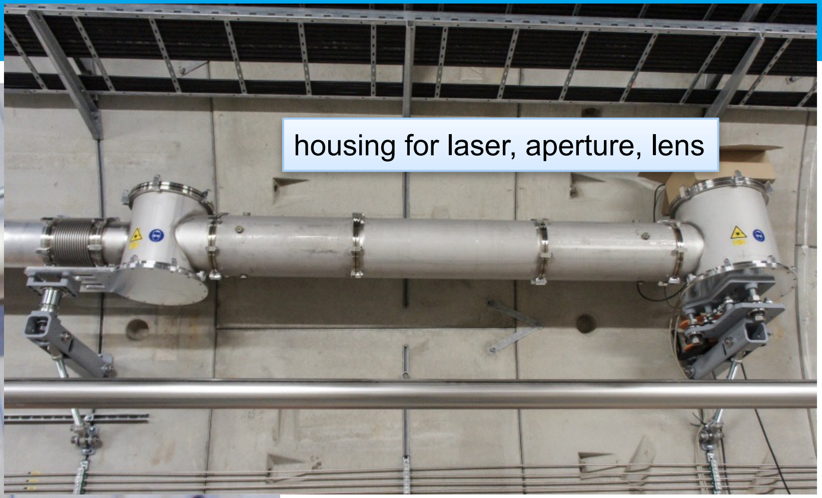
System setup

camera housing







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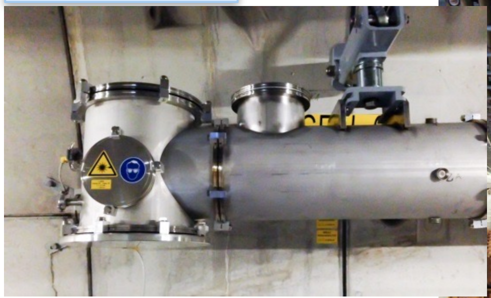

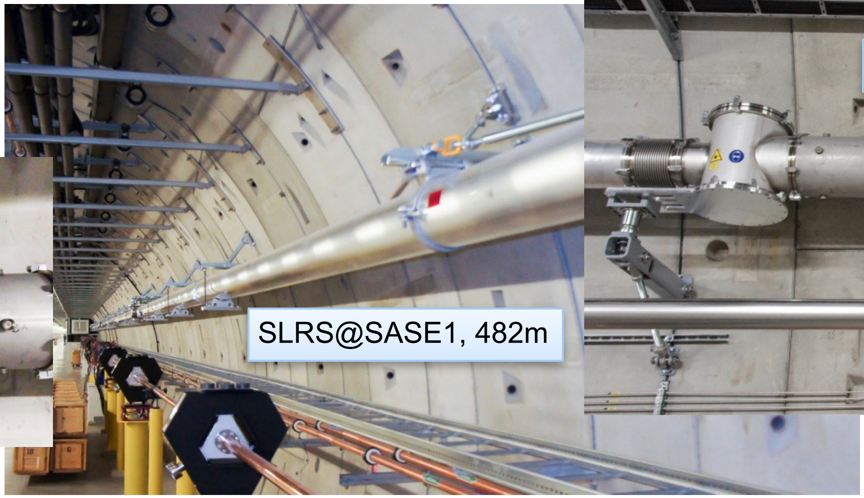

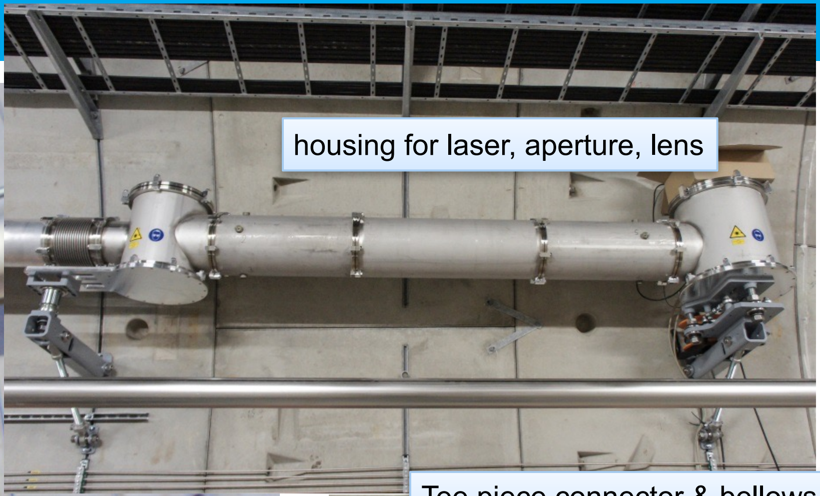

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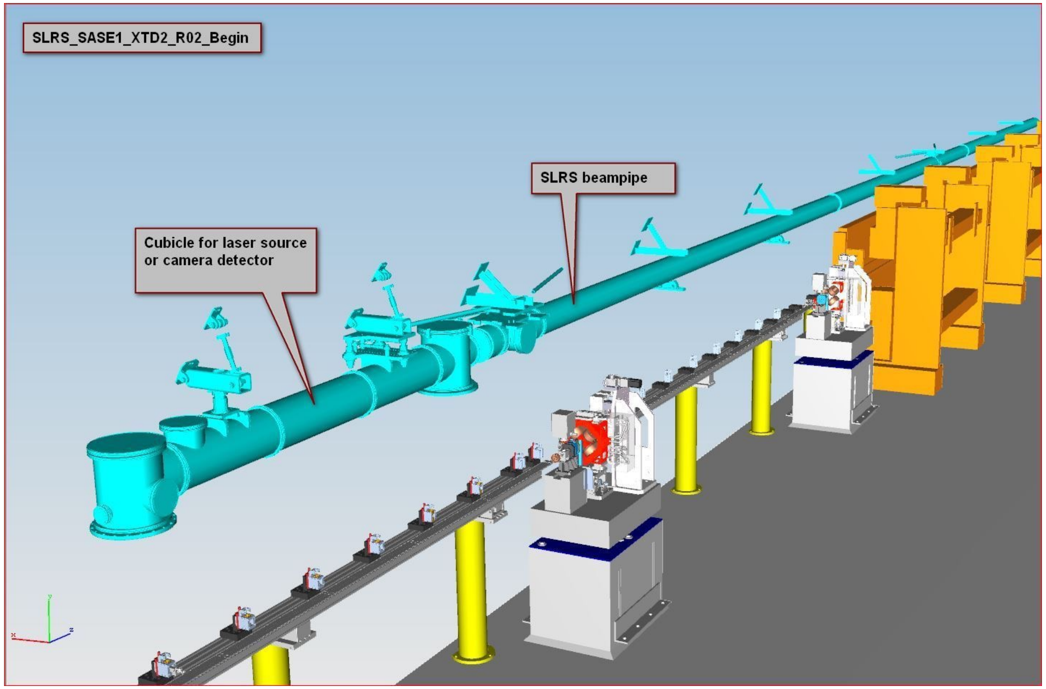
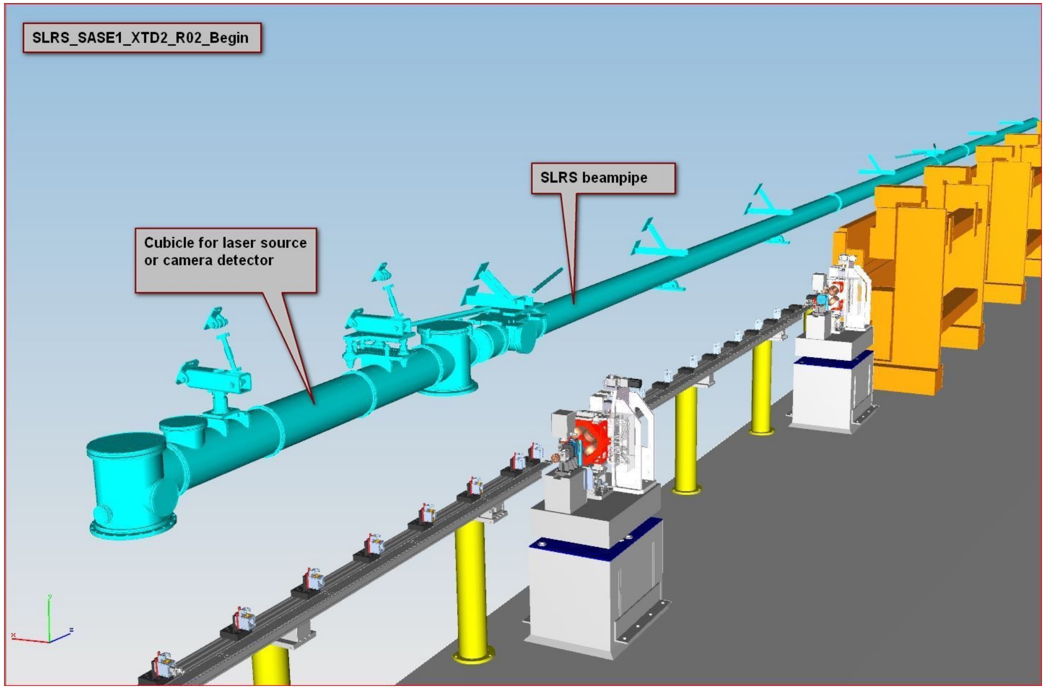
2


SLRS_SASE1_XTD2_R02_Begin
SLRS beampipe
Cubicle for laser source or camera detector

2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camera housing

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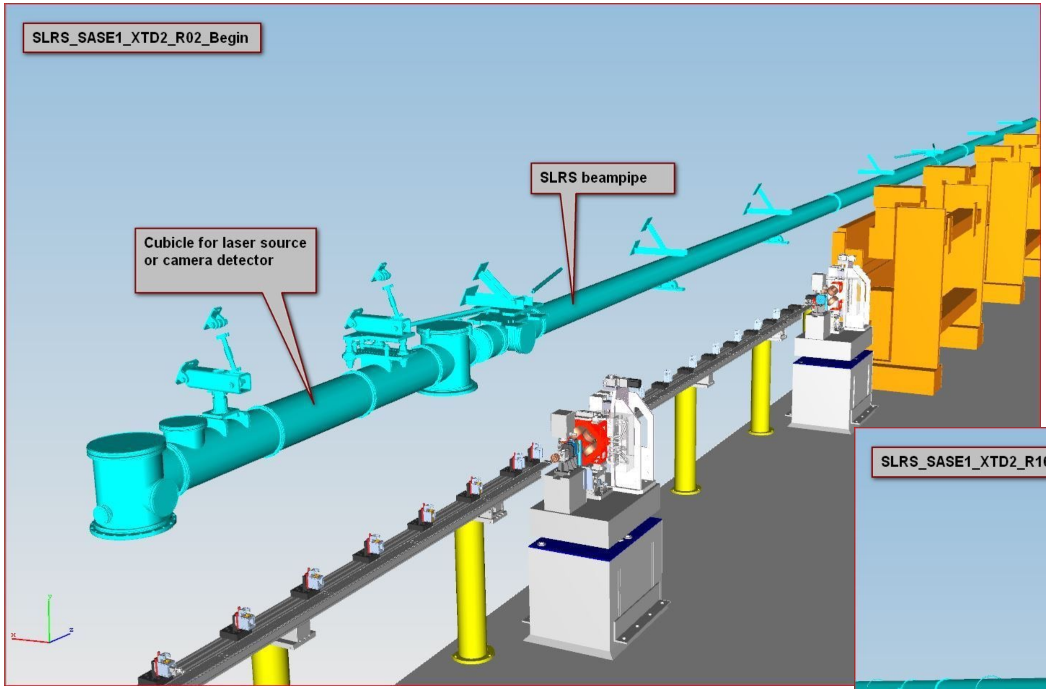
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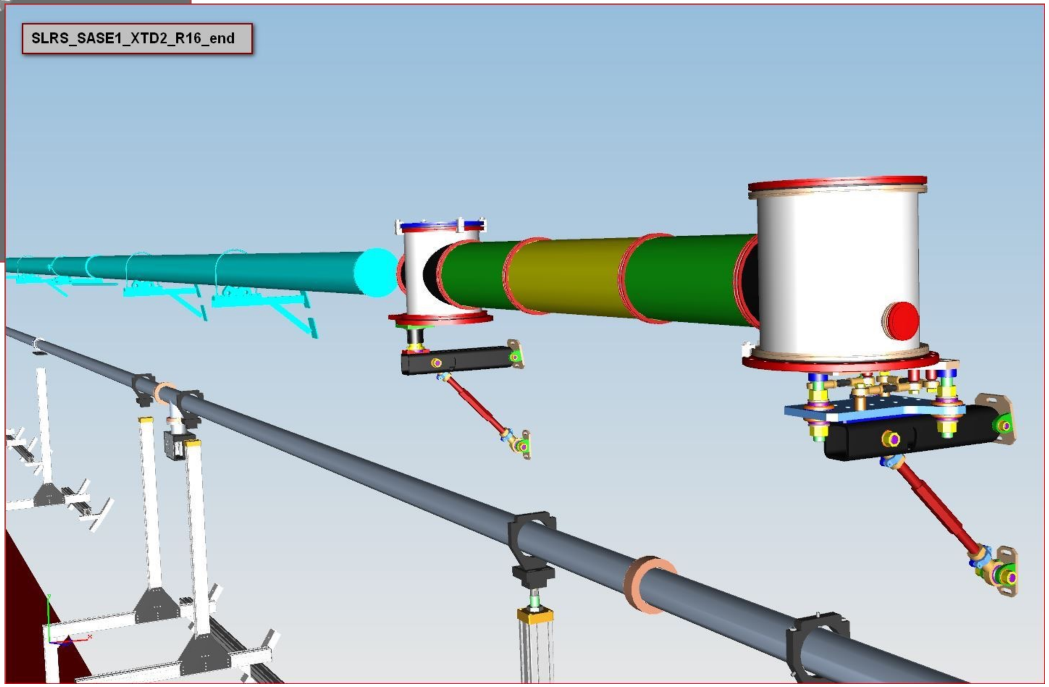
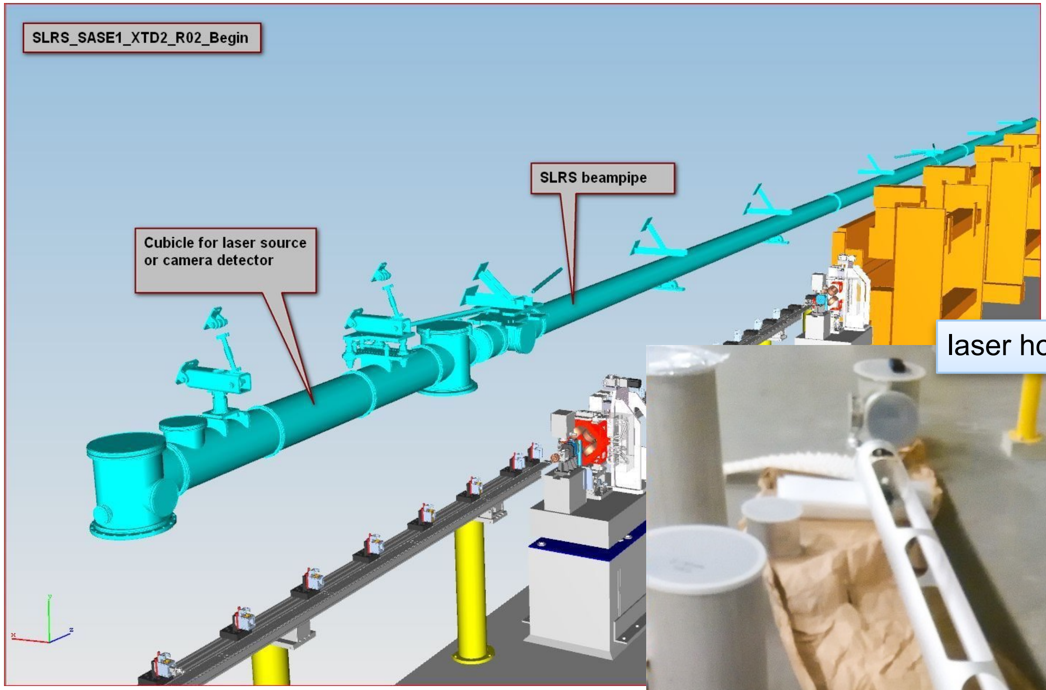

SLRS_SASE1_XTD2_R16_end

2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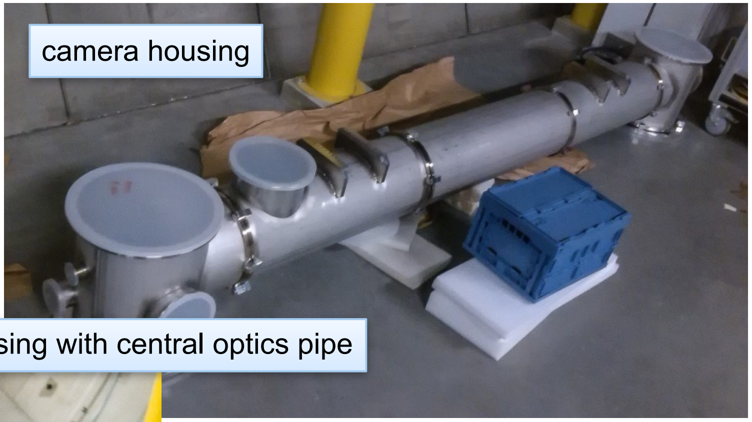
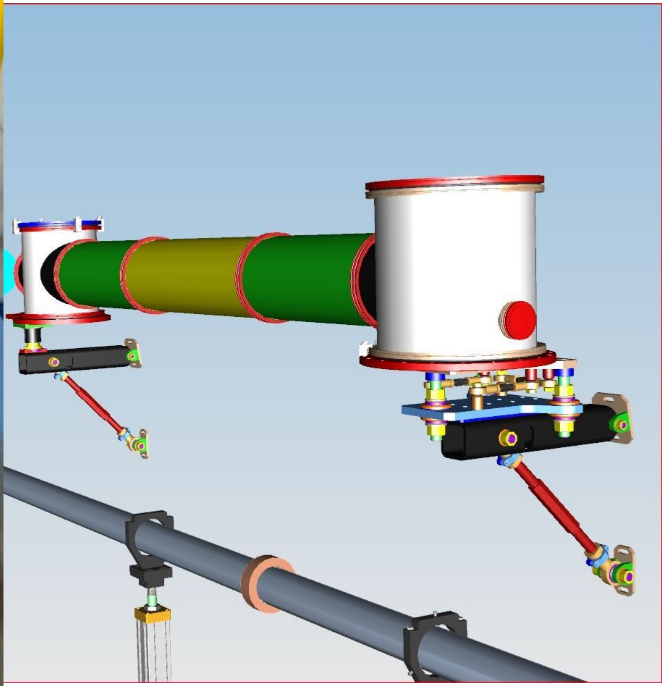

camera housing


laser housing with central optics pipe



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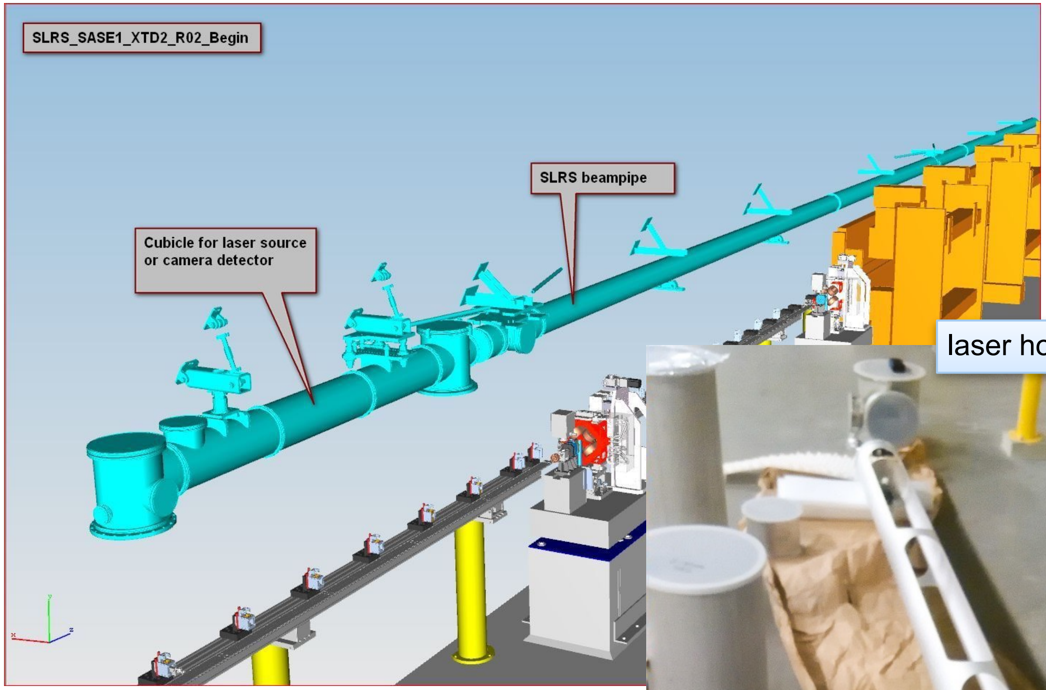
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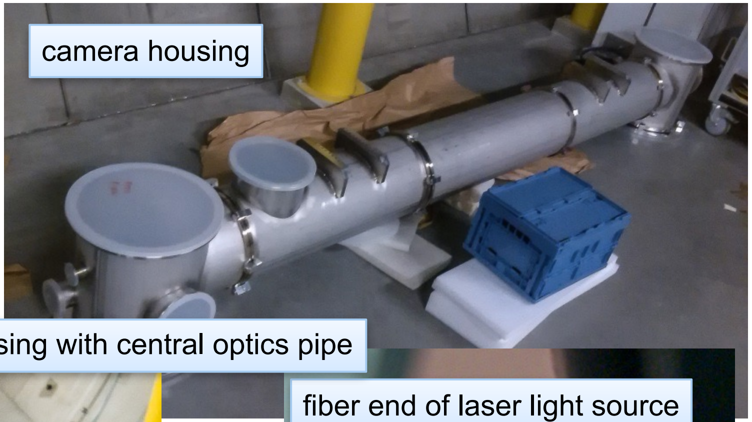
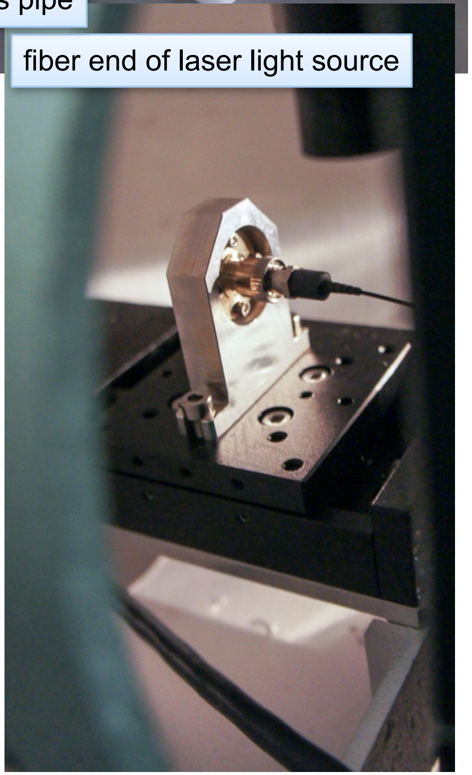
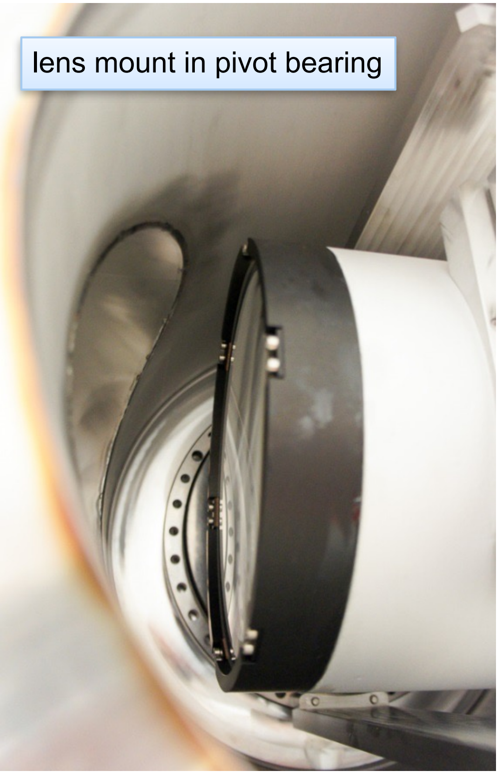

camera housing


laser housing with central optics pipe

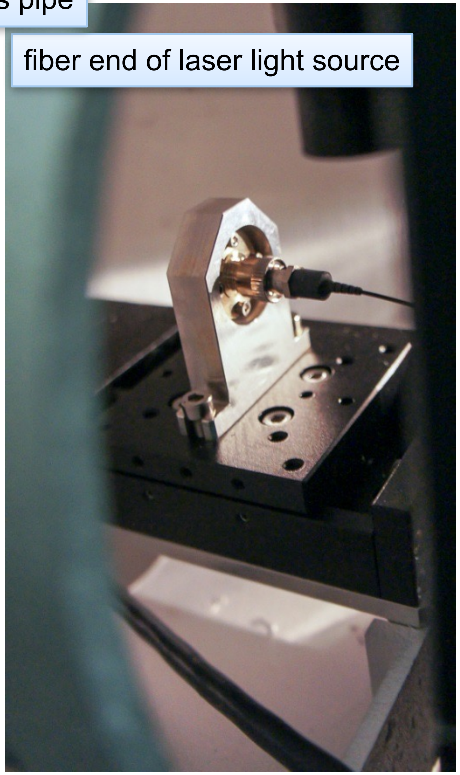

fiber end of laser light source

2



lens mount in pivot bearing

laser housing with central optics pipe



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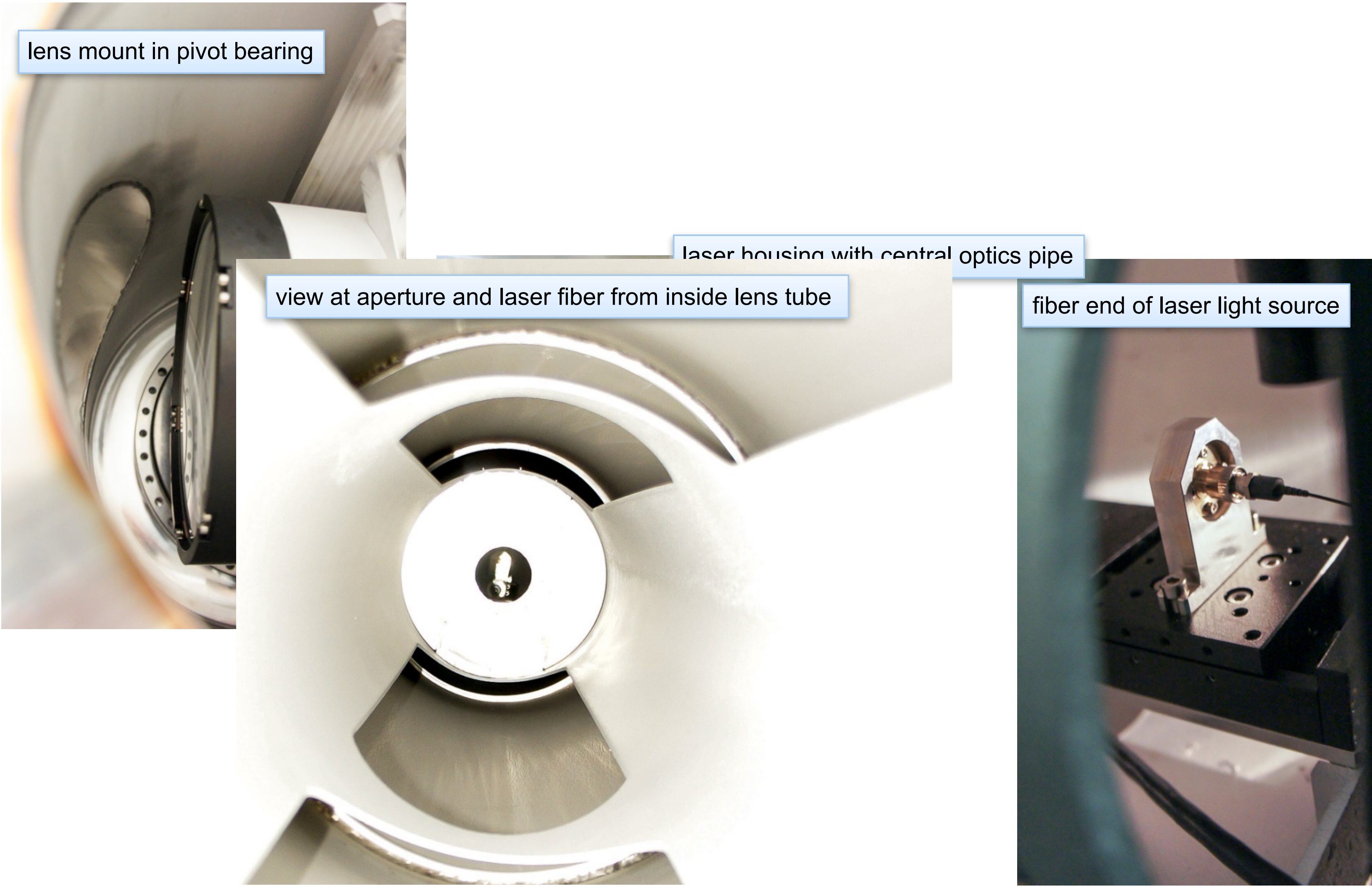
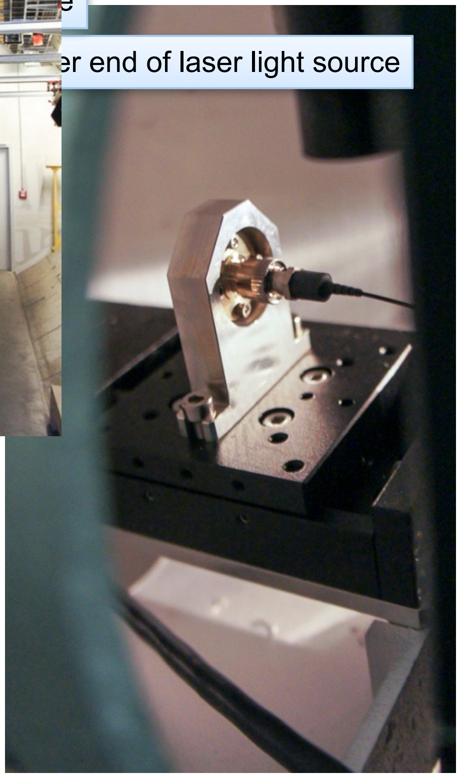

lens mount in pivot bearing
laser housing with central optics pipe
view at aperture and laser fiber from inside lens tube
fiber end of laser light source

2


lens mount in pivot bearing


view at aperture and laser fiber fror

installation of laser into laser housing


e
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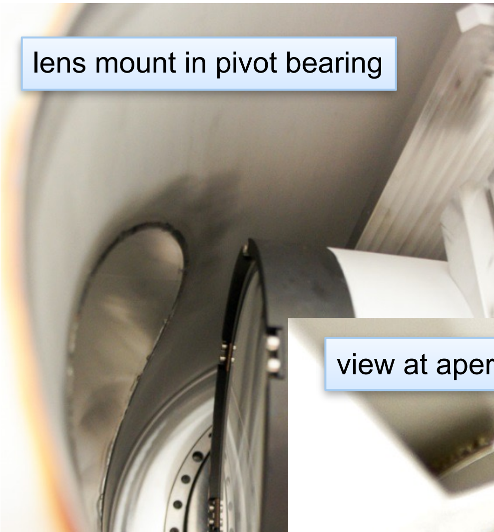

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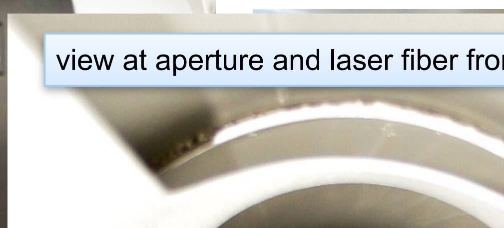

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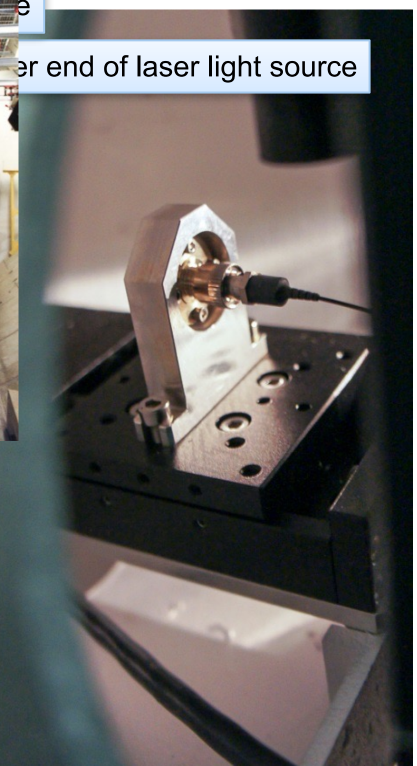

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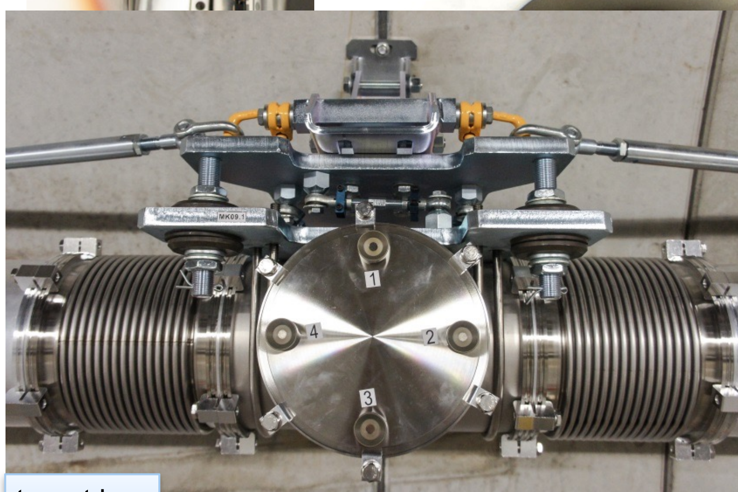
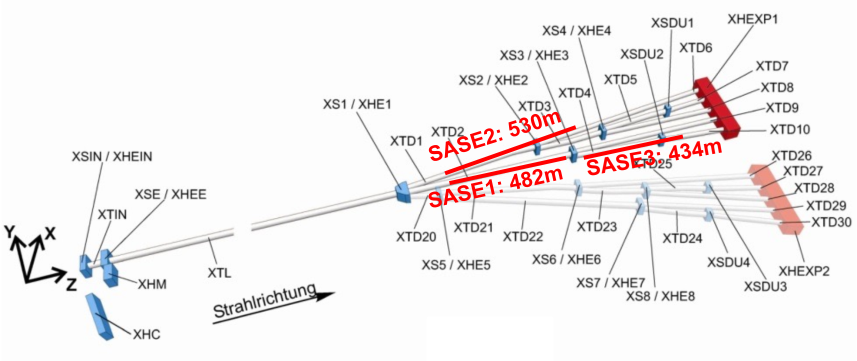


target box

System setup

- Distribution of SLR-Systems in XFEL Tunnels



- First SLRS operational @ SASE1, XTD2
- Second SLRS awaiting commissioning @ SASE3, XTD4 & XTD10
- Third SLRS under installation @ SASE2, XTD1 & XTD6

System setup

- Distribution of SLR-Systems in XFEL Tunnels

begin of SLRS @ SASE3, XTD4

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begin of SLRS @ SASE3, X

crossing the dump shaft XSDU2

System setup

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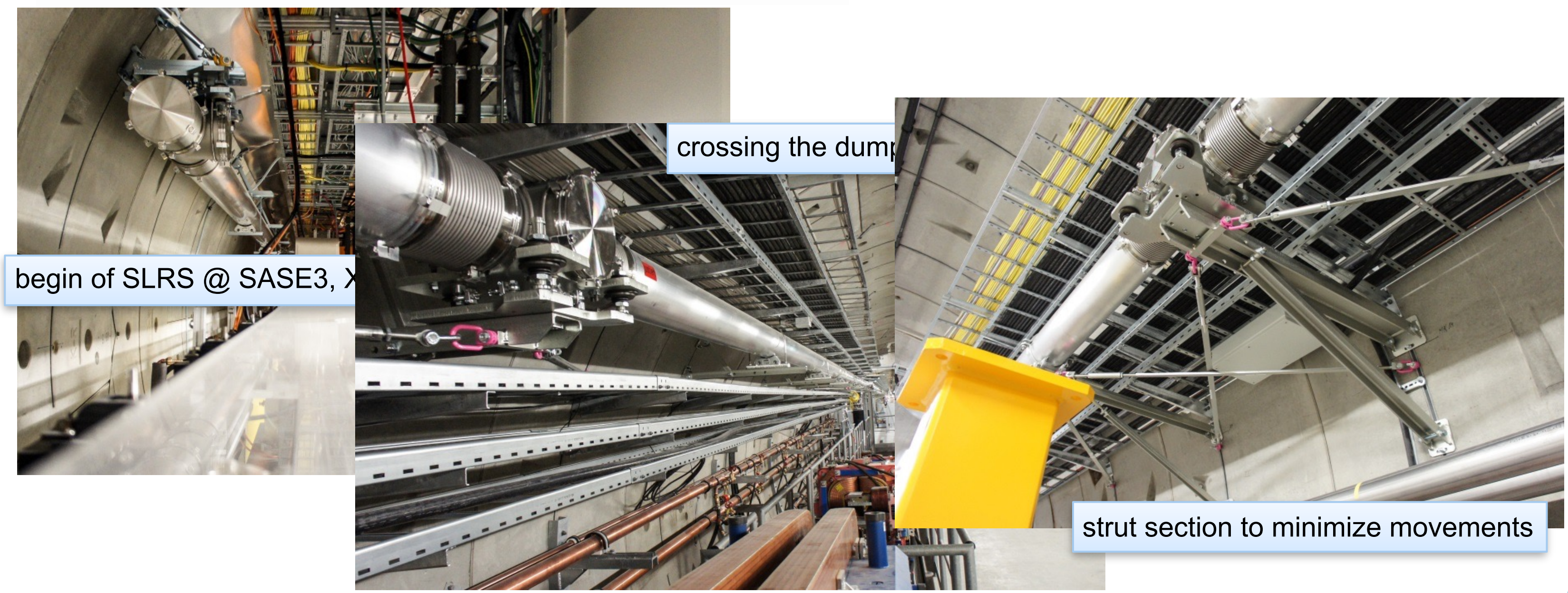

begin of SLRS @ SASE3, X

crossing the dump

strut section to minimize movements

System setup

- Distribution of SLR-Systems in XFEL Tunnels

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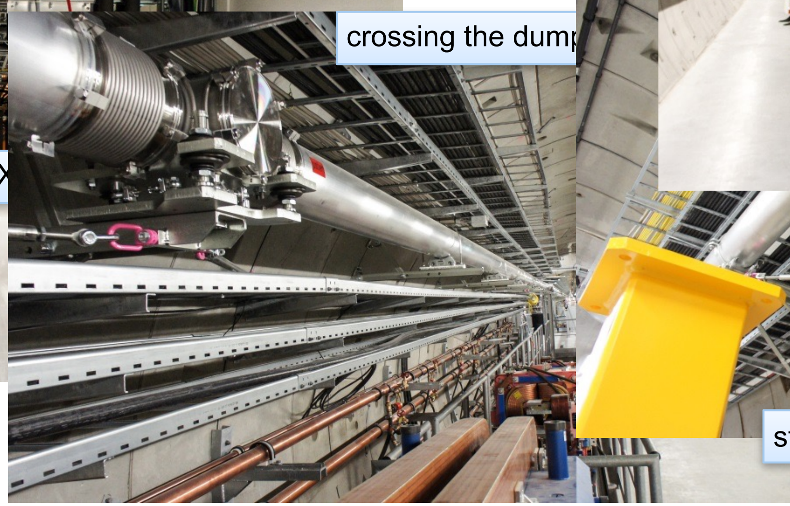
begin of SLRS @ SASE3, X



crossing the dump

end section @ XTD10

strut section to minimize movements

System setup

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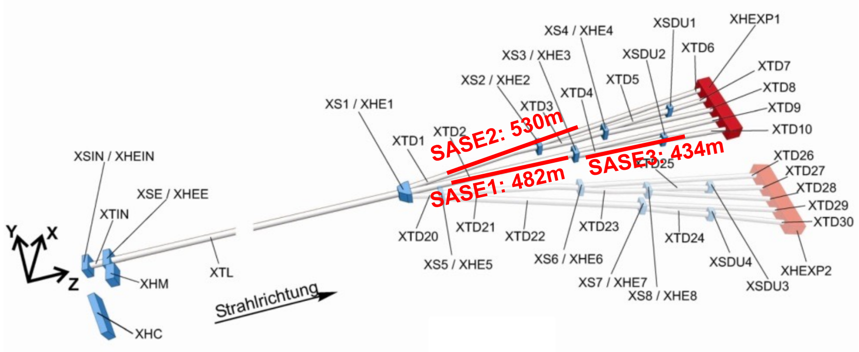

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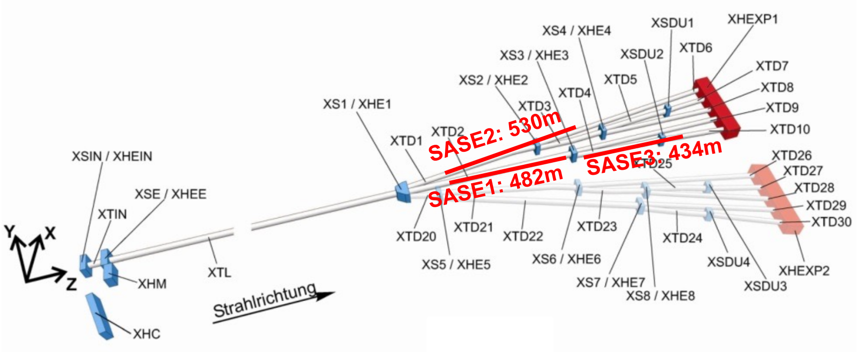
begin SLRS @ SASE2, XTD1

DESY

System setup

- Distribution of SLR-Systems in XFEL Tunnels



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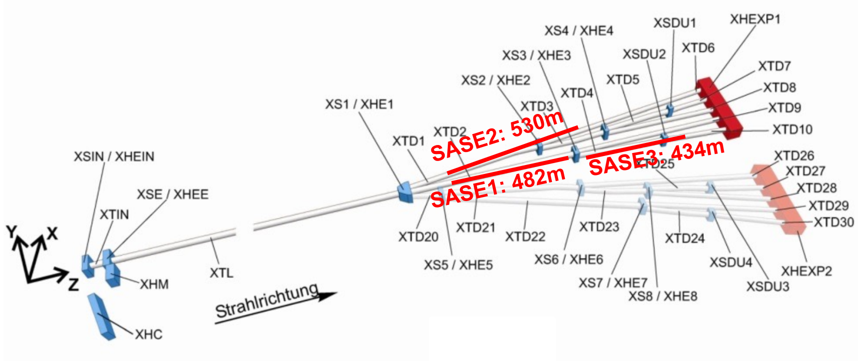
begin SLRS @ SASE2, XTD1


crossing the curved XTD1

System setup

- Distribution of SLR-Systems in XFEL Tunnels



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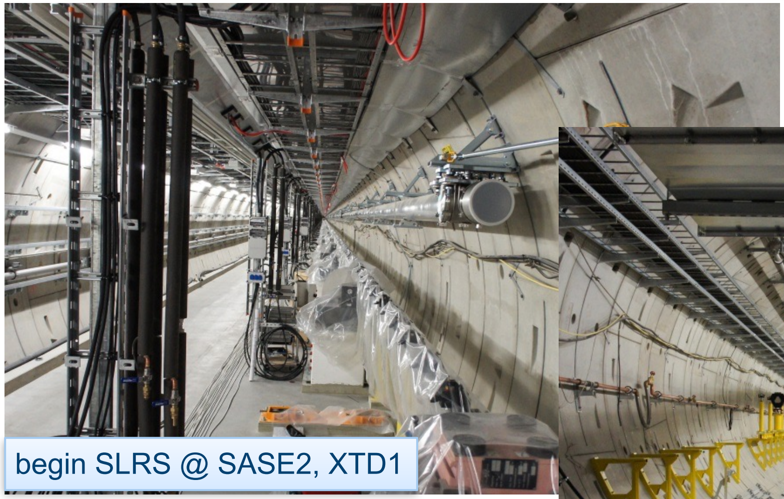
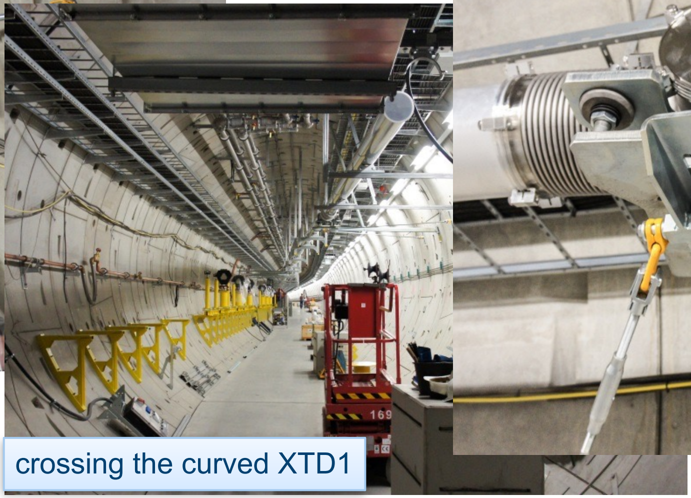
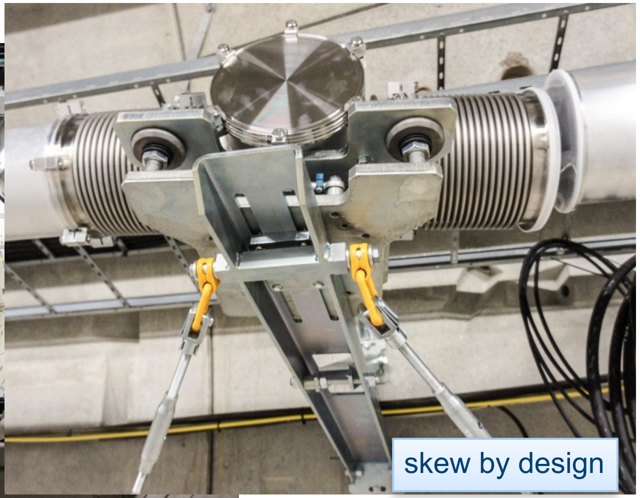

begin SLRS @ SASE2, XTD1


crossing the curved XTD1


skew by design

DESY

System setup

- Distribution of SLR-Systems in XFEL Tunnels

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end section @ XTD6

begin SLRS @ SASE2, XTD1

crossing the curved XTD1

skew by design

Optimisation of targets for various positions, simulation with „Zemax“ software.

- Standard poisson spots seemed to be too dark and had to be optimised

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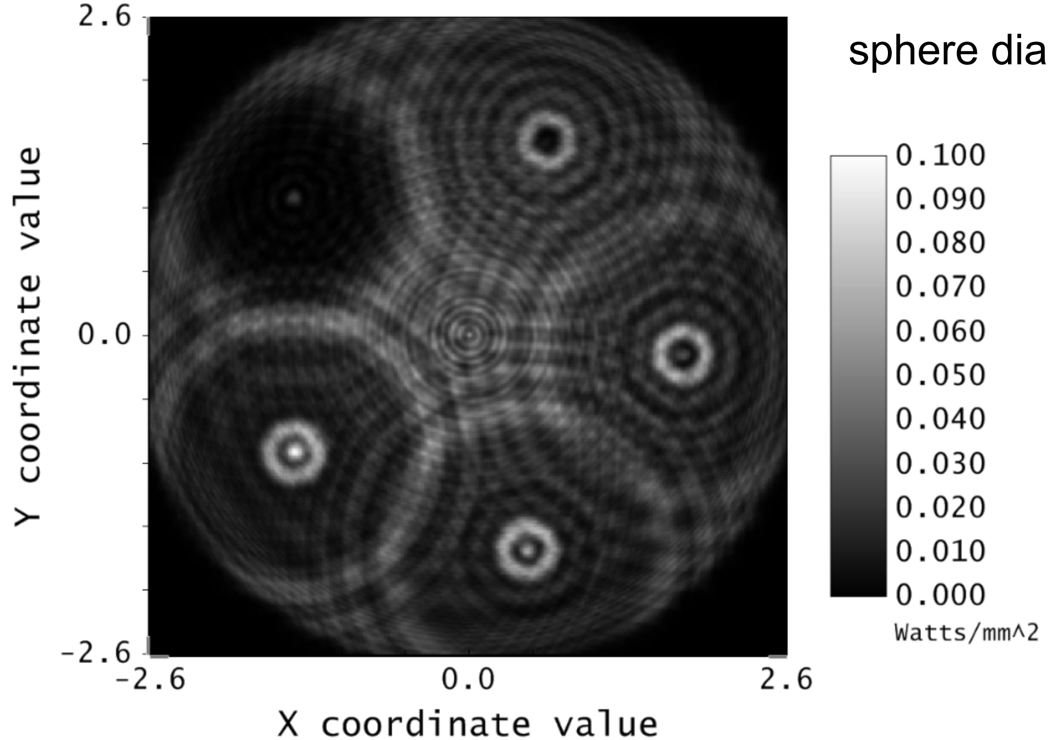

sphere diam. 45mm, ring with 2,3,4,5mm width

Total Irradiance surface 19

03.12.2014
Wavelength 0.40500 µm in index 1.00000 at 0.0000, 0.0000 (deg)
Display X Width = 5.3016E+000, Y Height = 5.3016E+000 Millimeters
Peak Irradiance = 9.9876E-002 Watts/Millimeters^2, Total Power = 4.5324E-001 Watts
Pilot: Size= 4.6207E+000, Waist= 6.3949E-002, Pos= -2.2919E+003, Rayleigh= 3.1722E+001

Optimisation of targets for various positions, simulation with „Zemax“ software.

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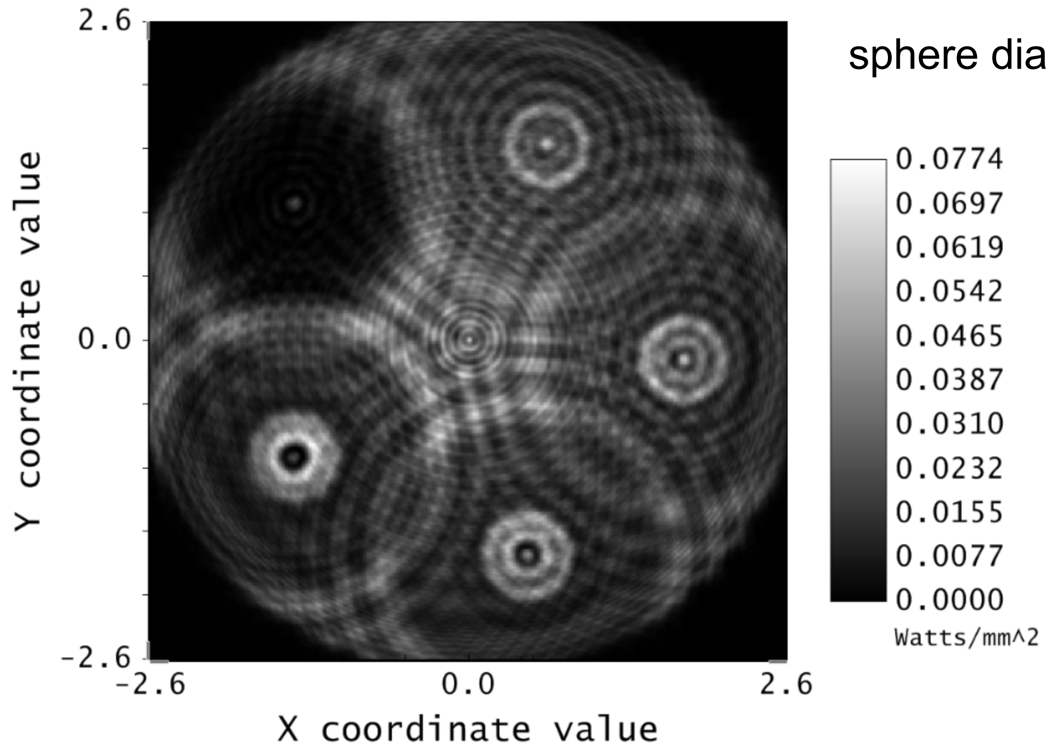
sphere diam. 50mm, ring with 2,3,4,5mm width



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Peak Irradiance = 7.7415E-002 Watts/Millimeters^2, Total Power = 4.3906E-001 Watts
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Optimisation of targets for various positions, simulation with „Zemax“ software.

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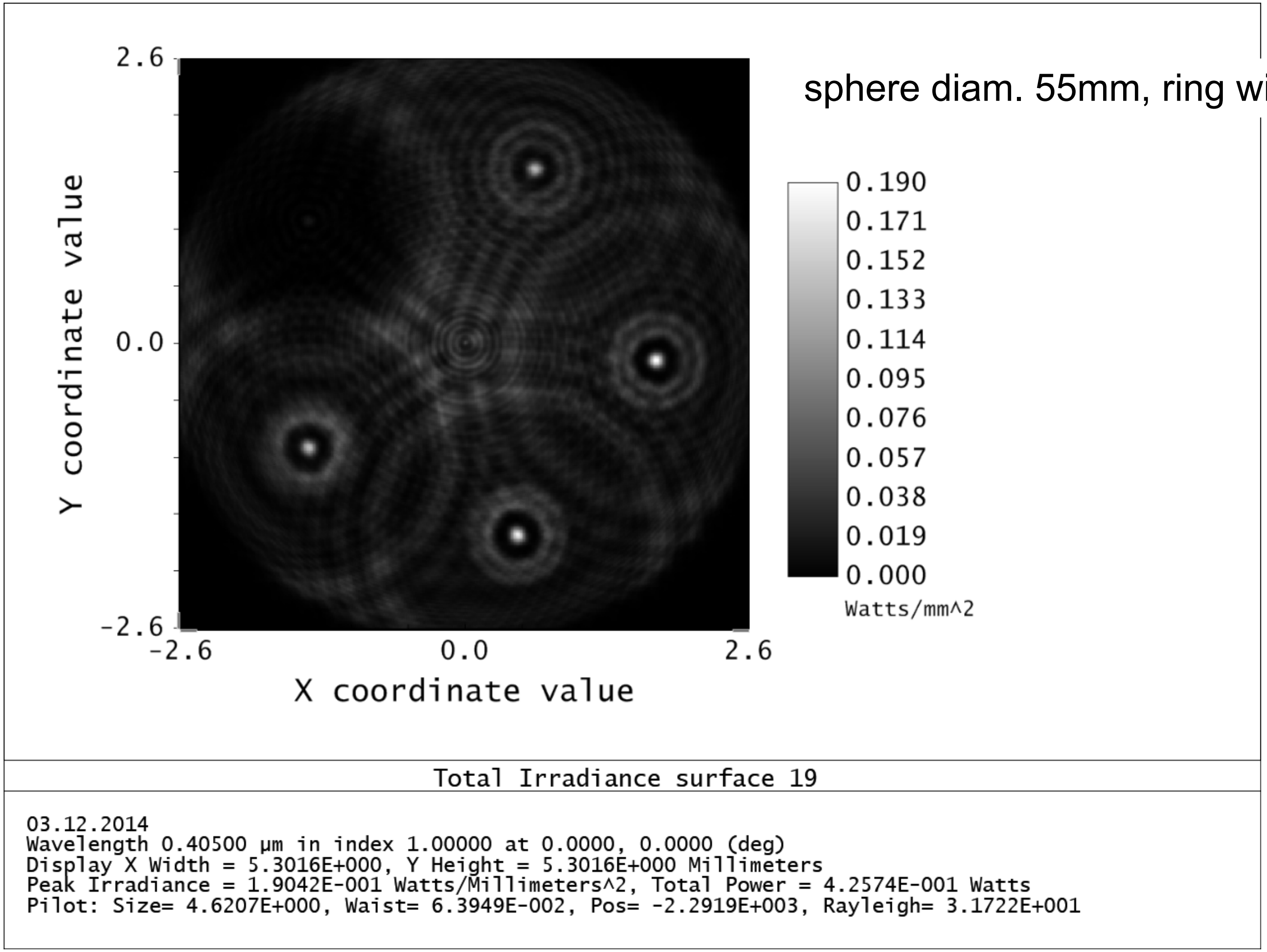
sphere diam. 55mm, ring with 2,3,4,5mm width



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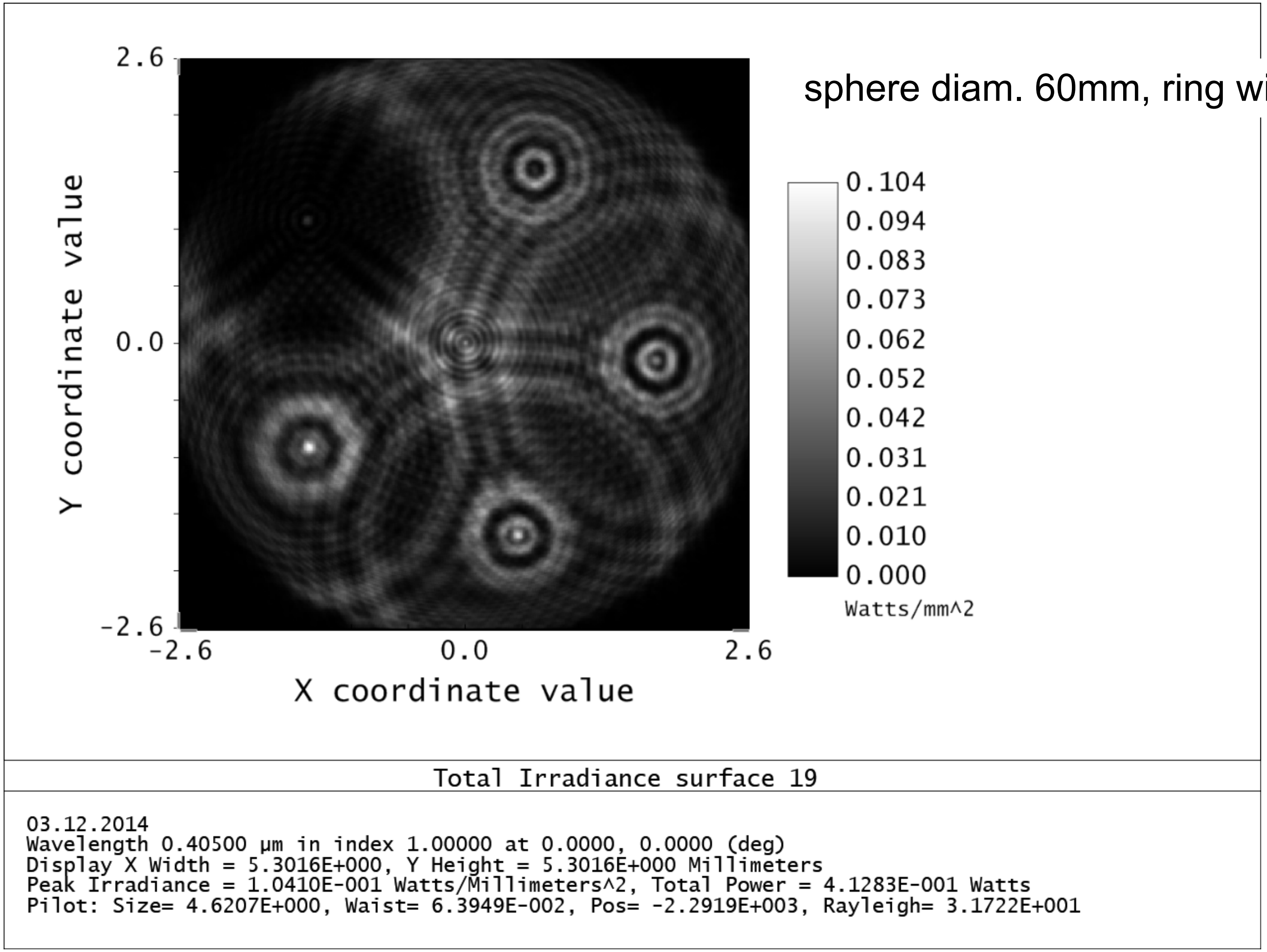
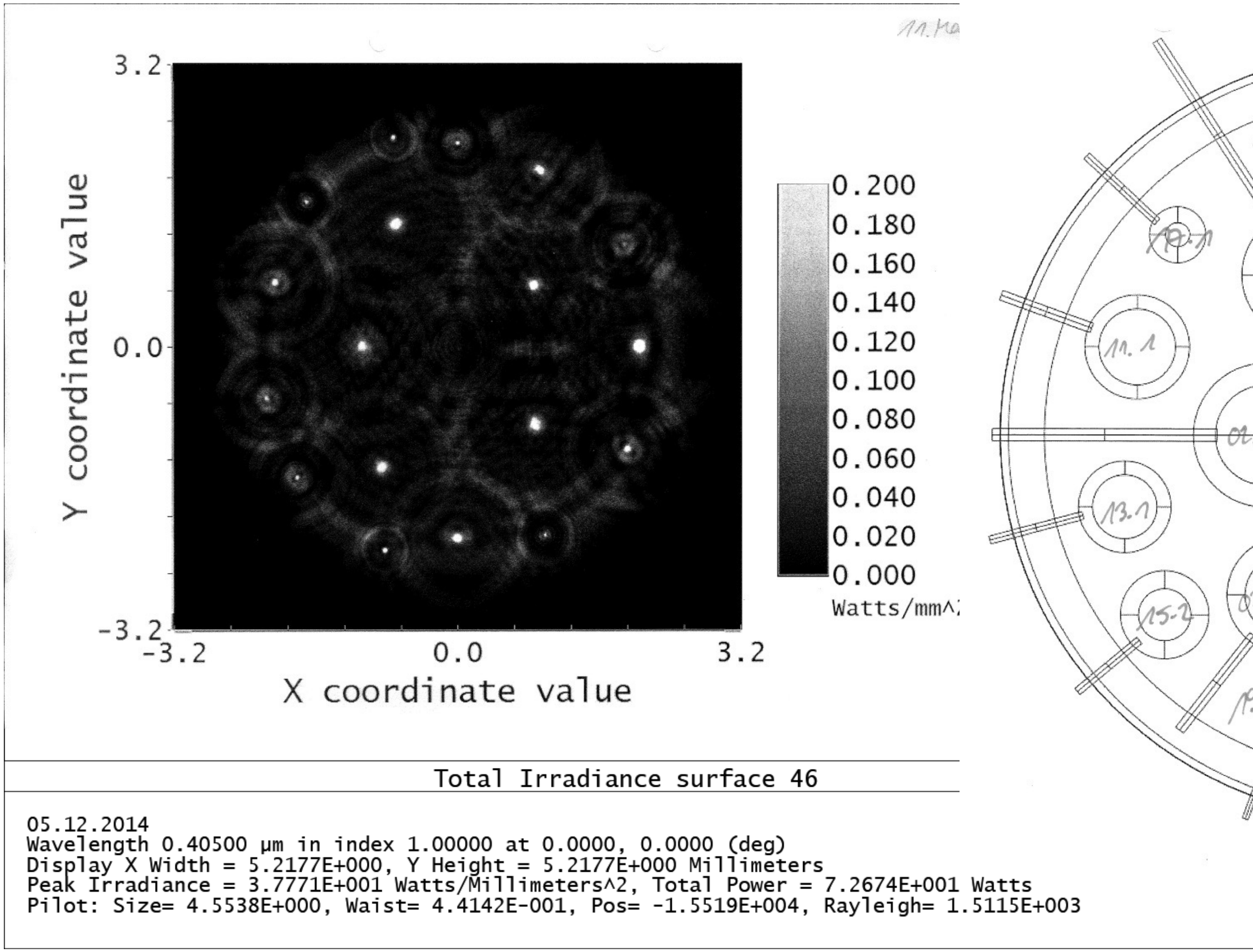
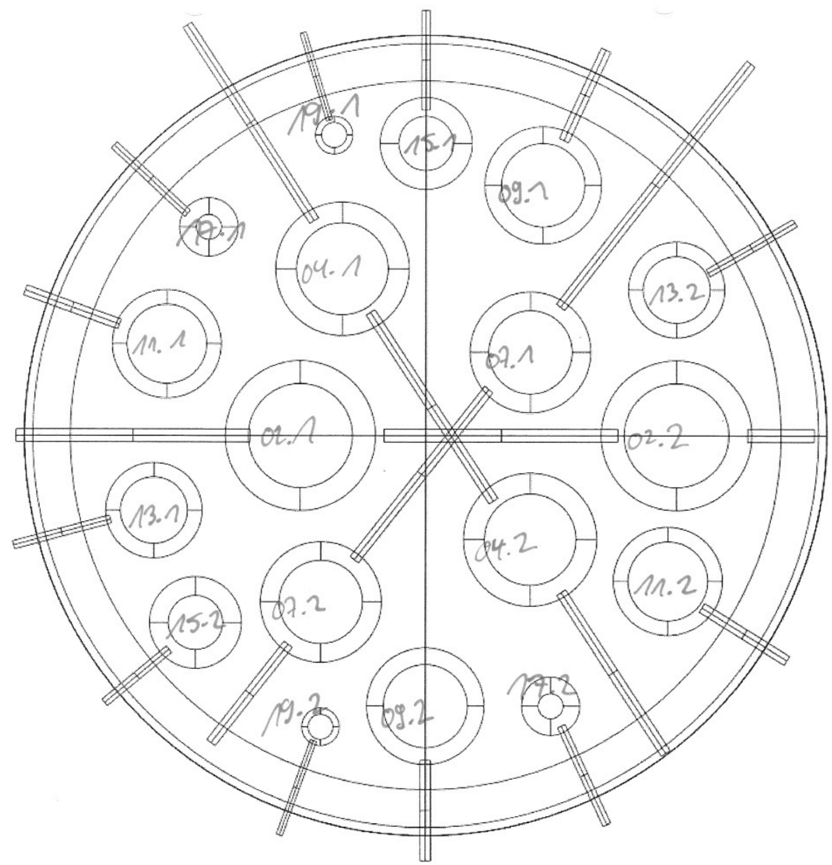


sphere diam. 60mm, ring with 2,3,4,5mm width

Distributed targets for alignment measurements

Targets were developed for each of 9 equipped stations of the SLRS. Shown below is a „Zemax“ simulation, the final design layout and the laser cut target frames. Every station is equipped with 2 targets, the target size is dependent on the longitudinal position of the respective target within the system.





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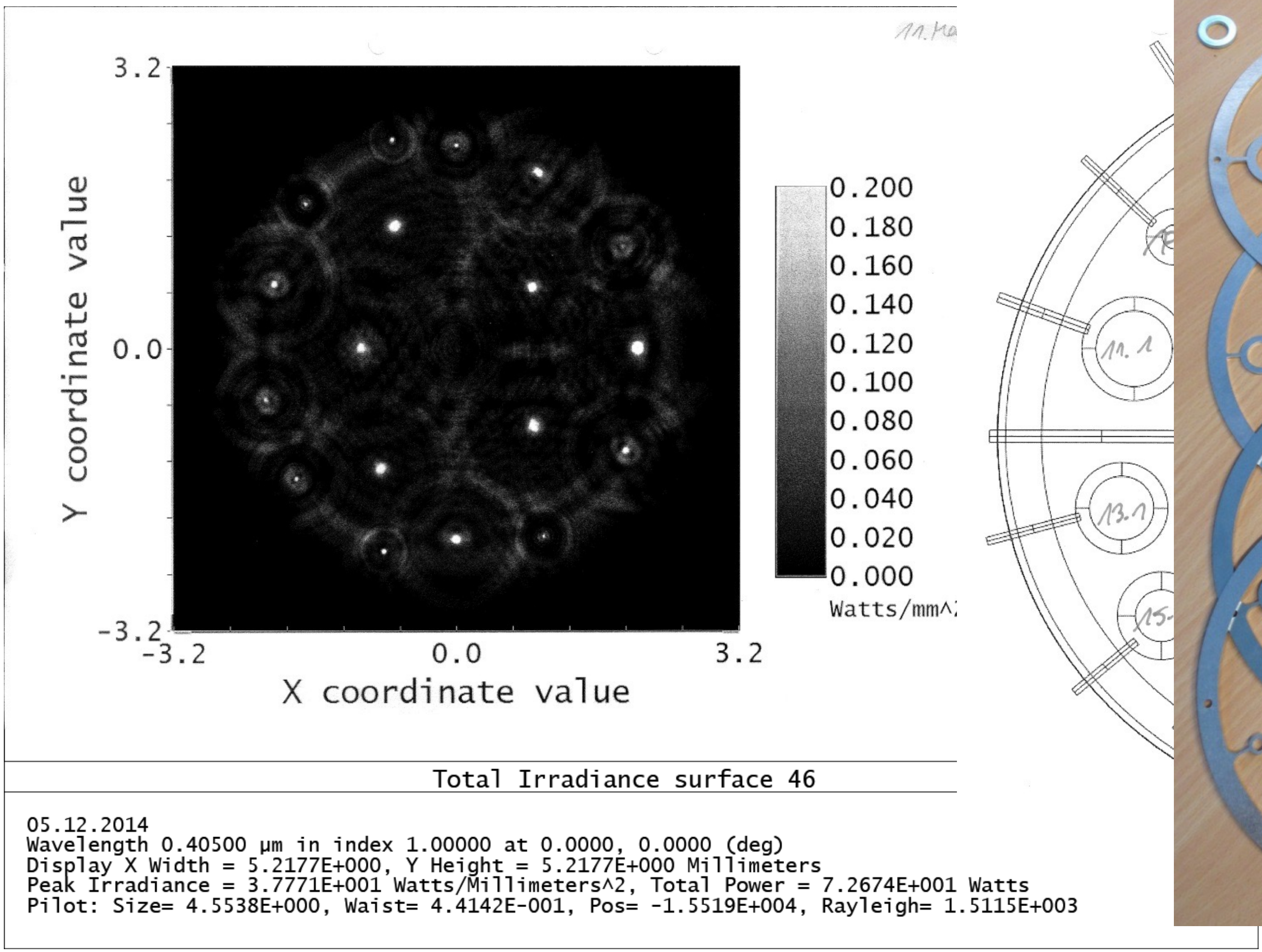
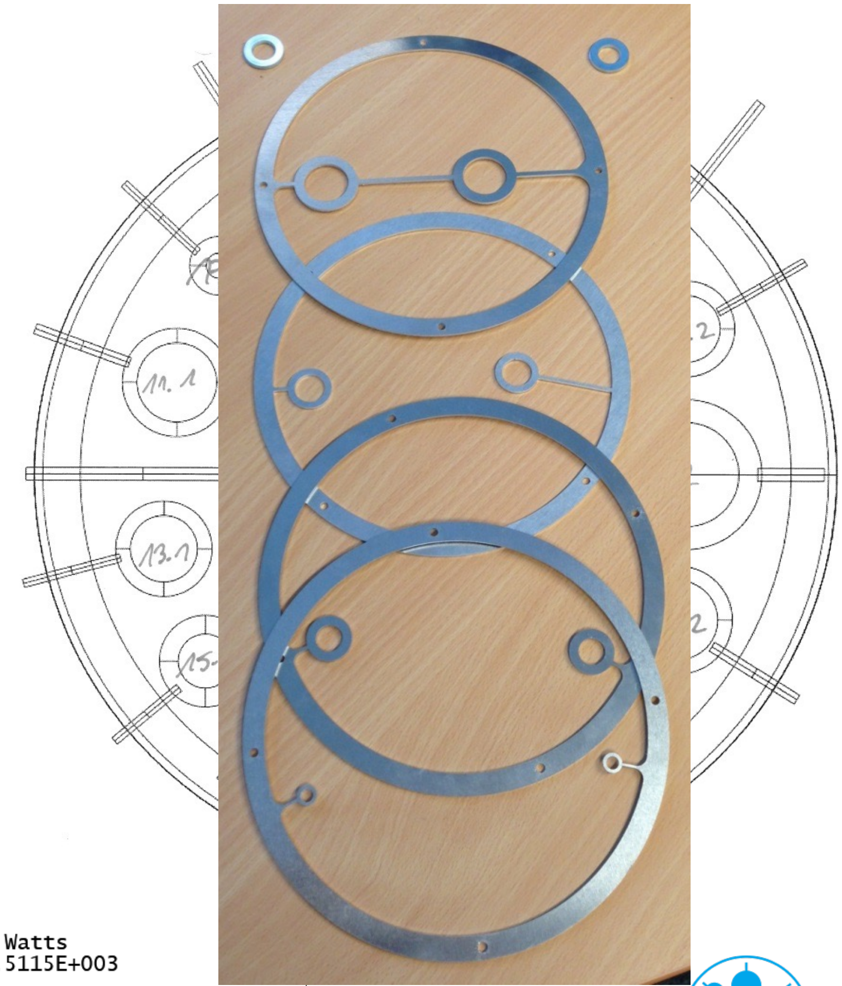
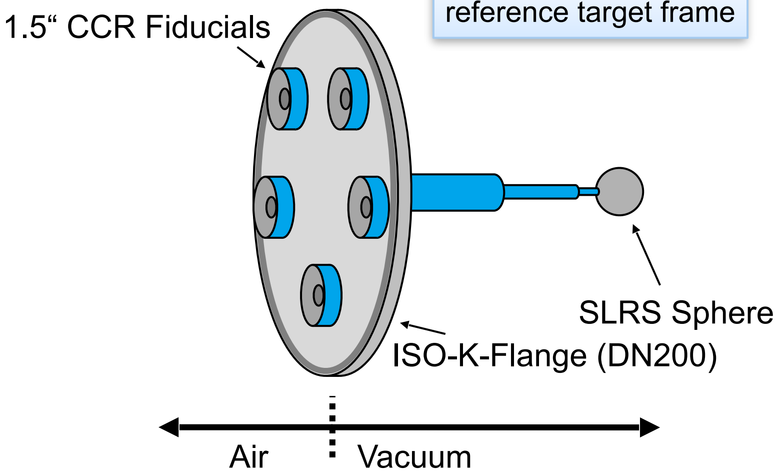




Target frames for camera calibration - fiducialisation

- Two types of target frames:
  - camera calibration, distortion
  - alignment measurements
- Fiducialisation of the reference target frames & the measurement target frames were done with a measuring arm.
- the reference nests on the outside and the reference targets on the inside were measured in one setup.
- analysis was done with spatial analyzer

reference target frame

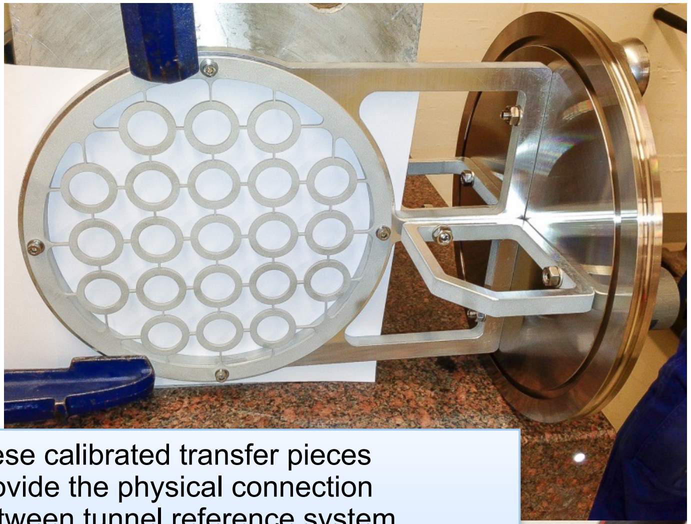


these calibrated transfer pieces provide the physical connection between tunnel reference system and the SLRS internal coordinate system

Target frames for camera calibration - fiducialisation

- Two types of target frames:
  - camera calibration, distortion
  - alignment measurements
- Fiducialisation of the reference target frames & the measurement target frames were done with a measuring arm.
- the reference nests on the outside and the reference targets on the inside were measured in one setup.
- analysis was done with spatial analyzer

reference target frame



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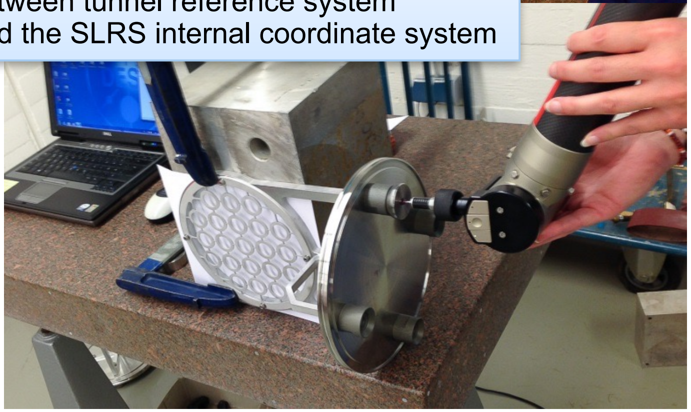

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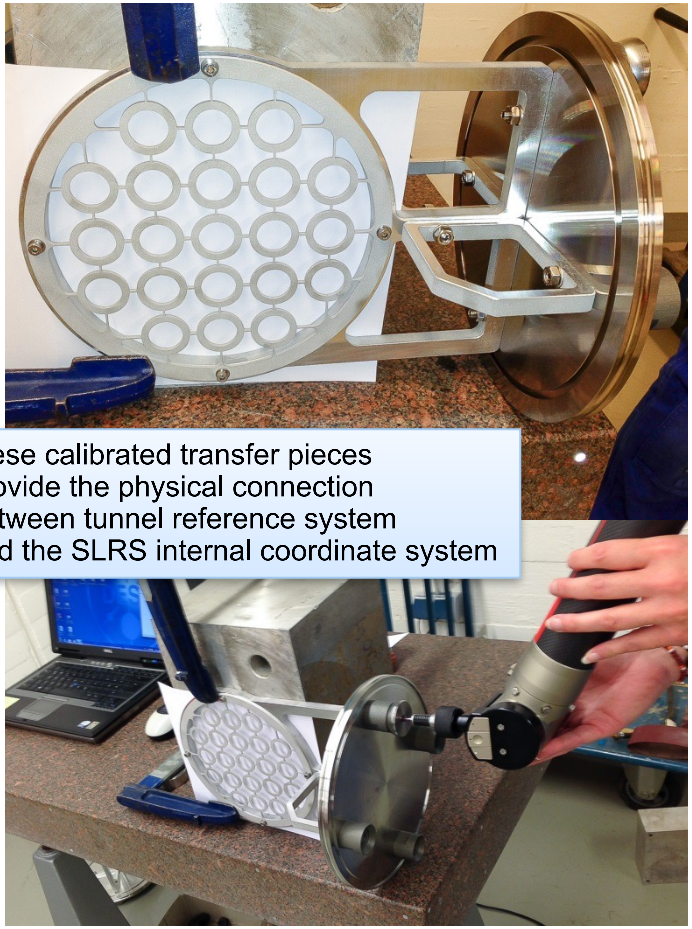

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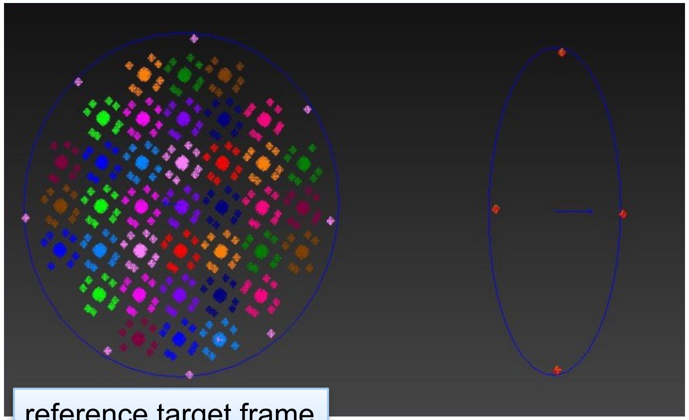

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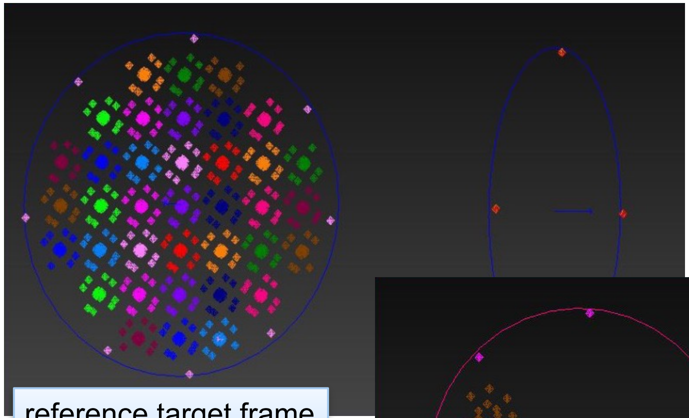
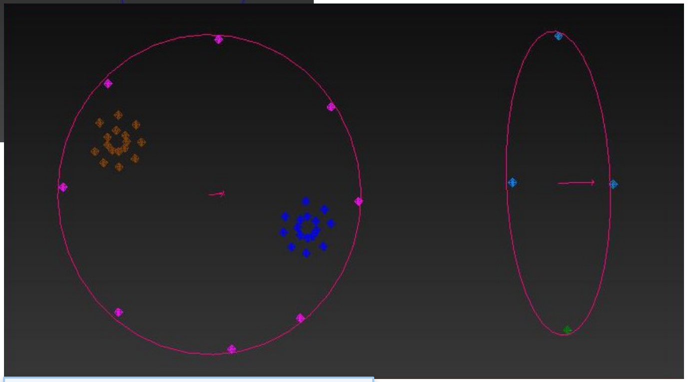
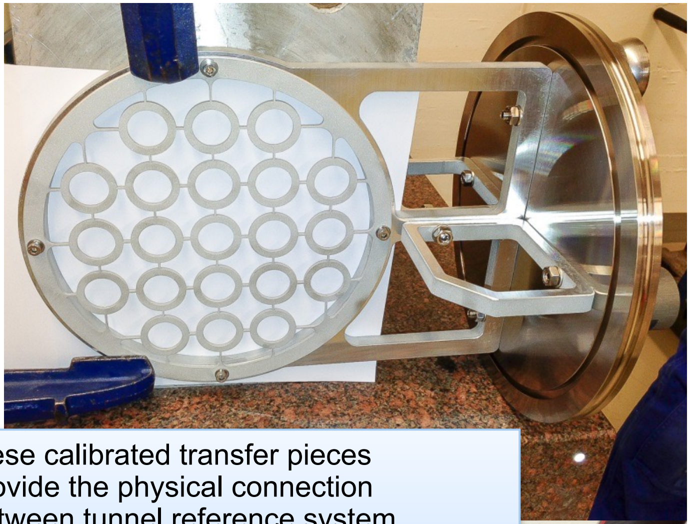


reference target frame



measurement target frame

reference target frame



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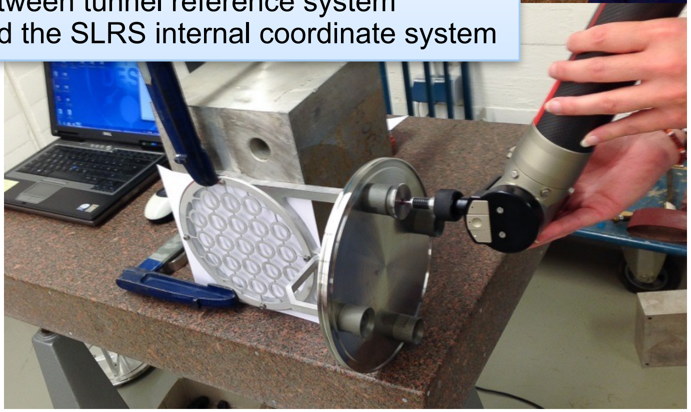
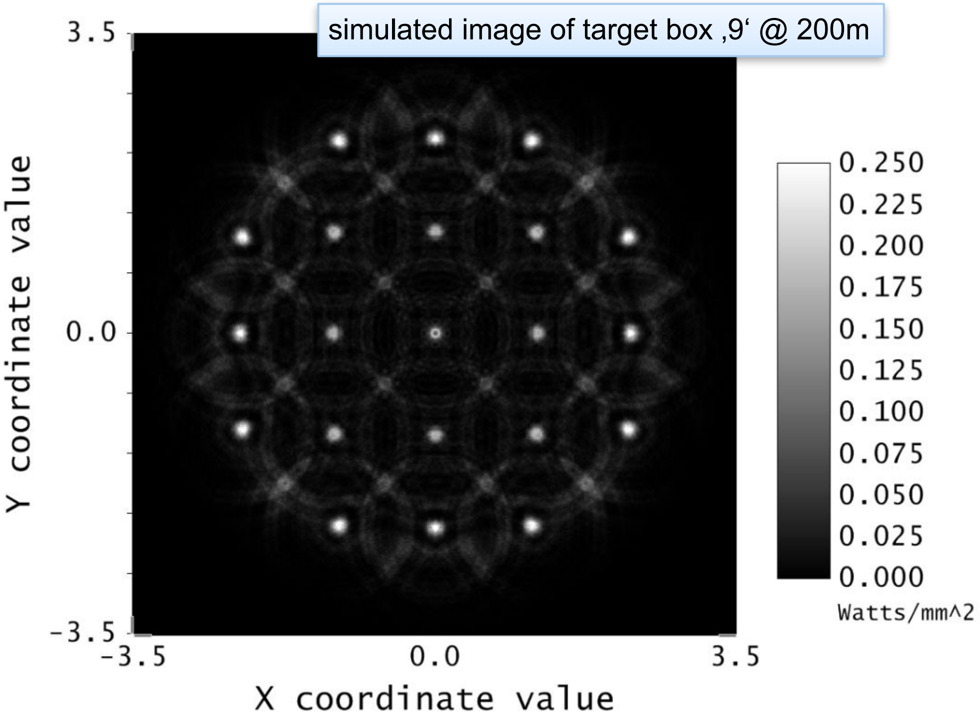


Commissioning of SLRS@SASE1:

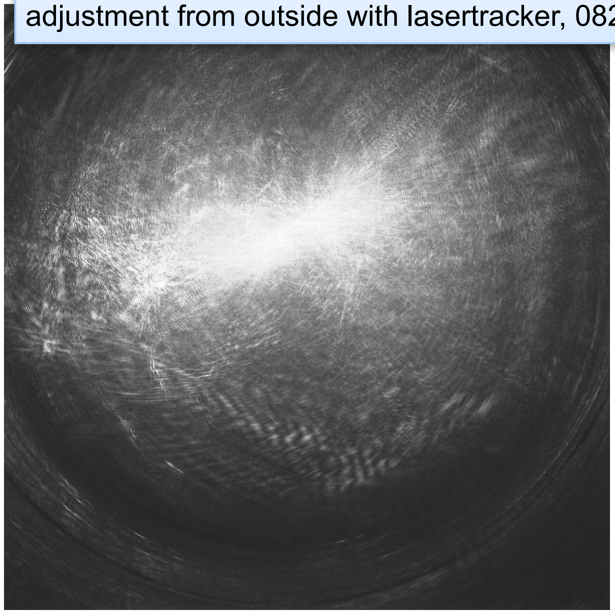
- Simulation vs. the real thing
  - or: please let there be light



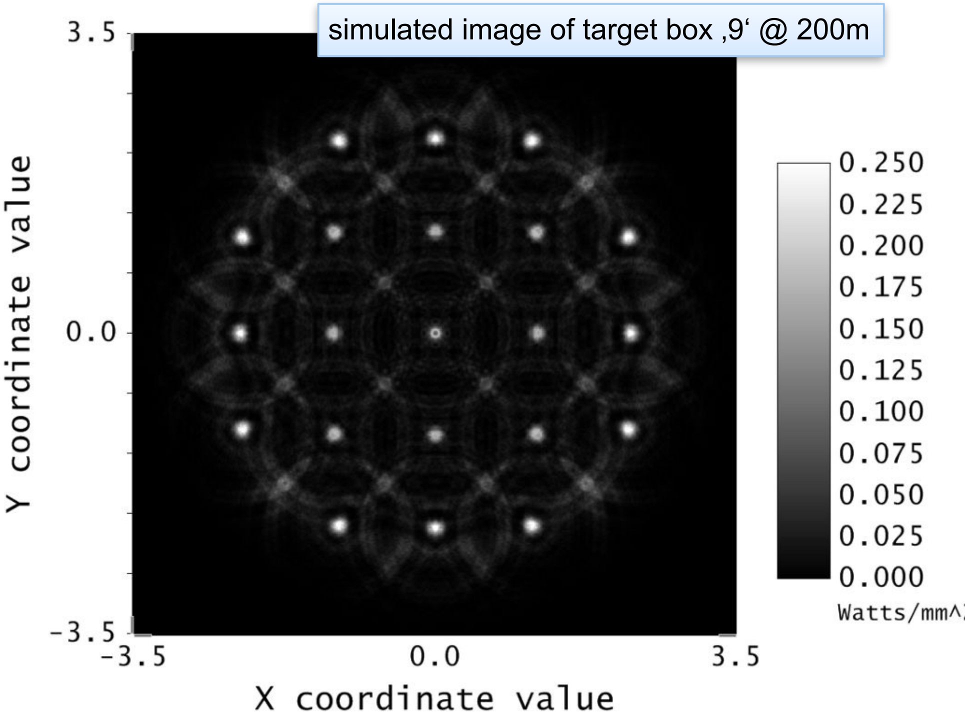
Commissioning of SLRS@SASE1:

- Simulation vs. the real thing

first image after complete installation and adjustment from outside with lasertracker, 0823



simulated image of target box ‚9‘ @ 200m

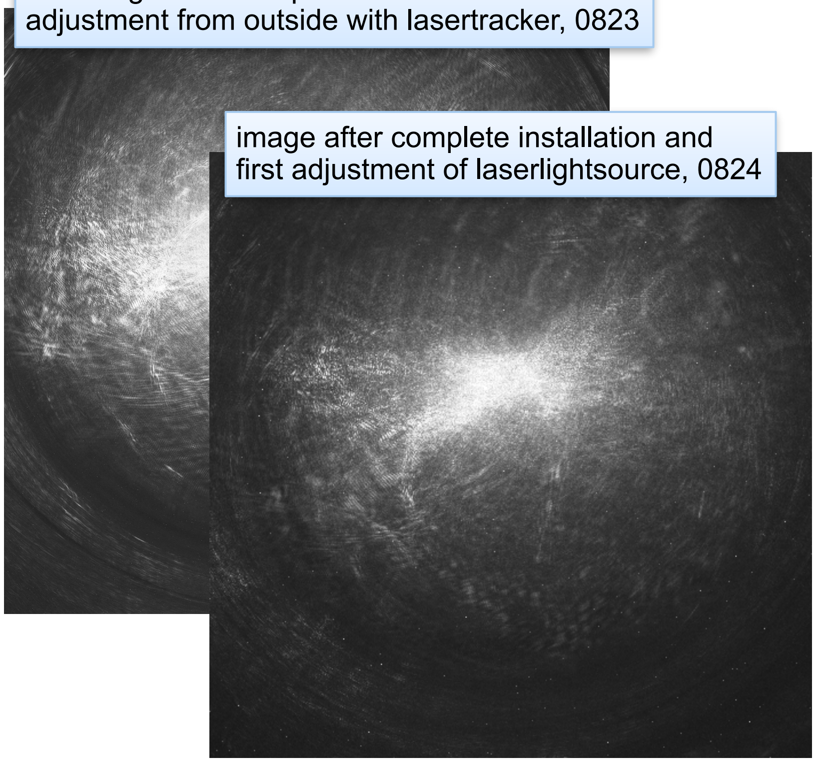


Commissioning of SLRS@SASE1:

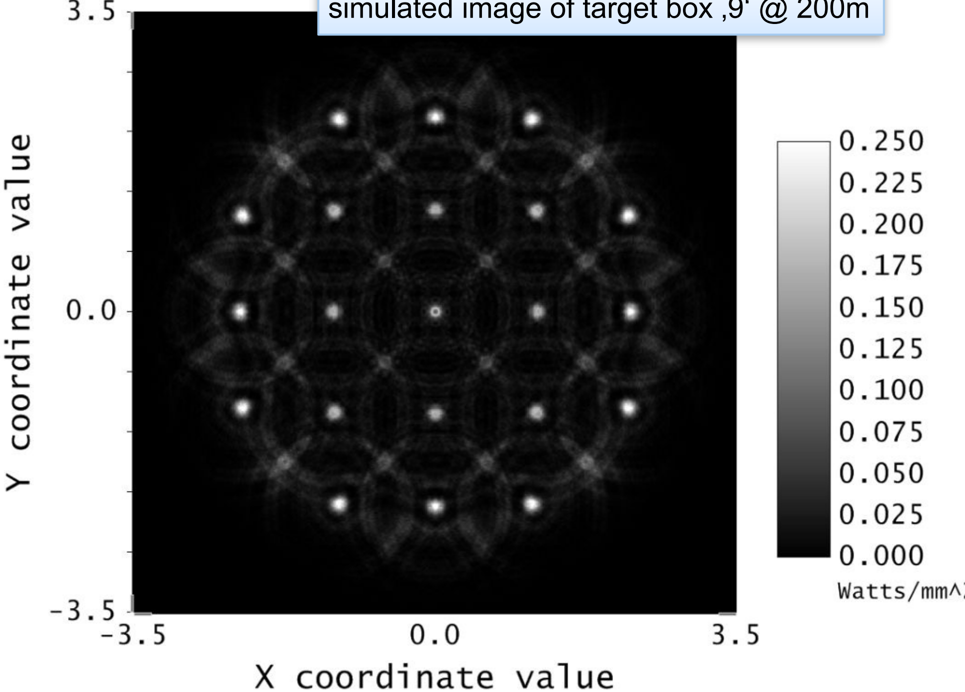
- Simulation vs. the real thing

first image after complete installation and adjustment from outside with lasertracker, 0823

image after complete installation and first adjustment of laserlightsource, 0824



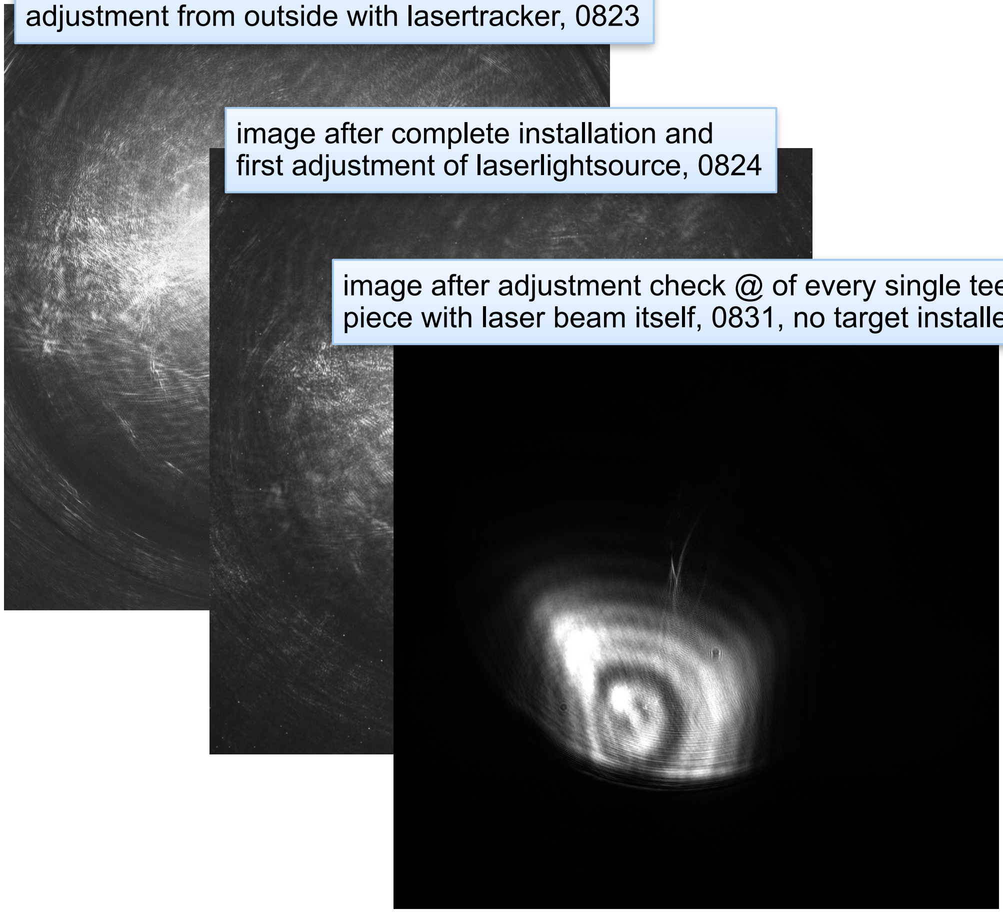
simulated image of target box ‚9‘ @ 200m



DESY

Commissioning of SLRS@SASE1:

- Simulation vs. the real thing



first image after complete installation and adjustment from outside with lasertracker, 0823

image after complete installation and first adjustment of laserlightsource, 0824

image after adjustment check @ of every single tee piece with laser beam itself, 0831, no target installed

Commissioning of SLRS@SASE1:

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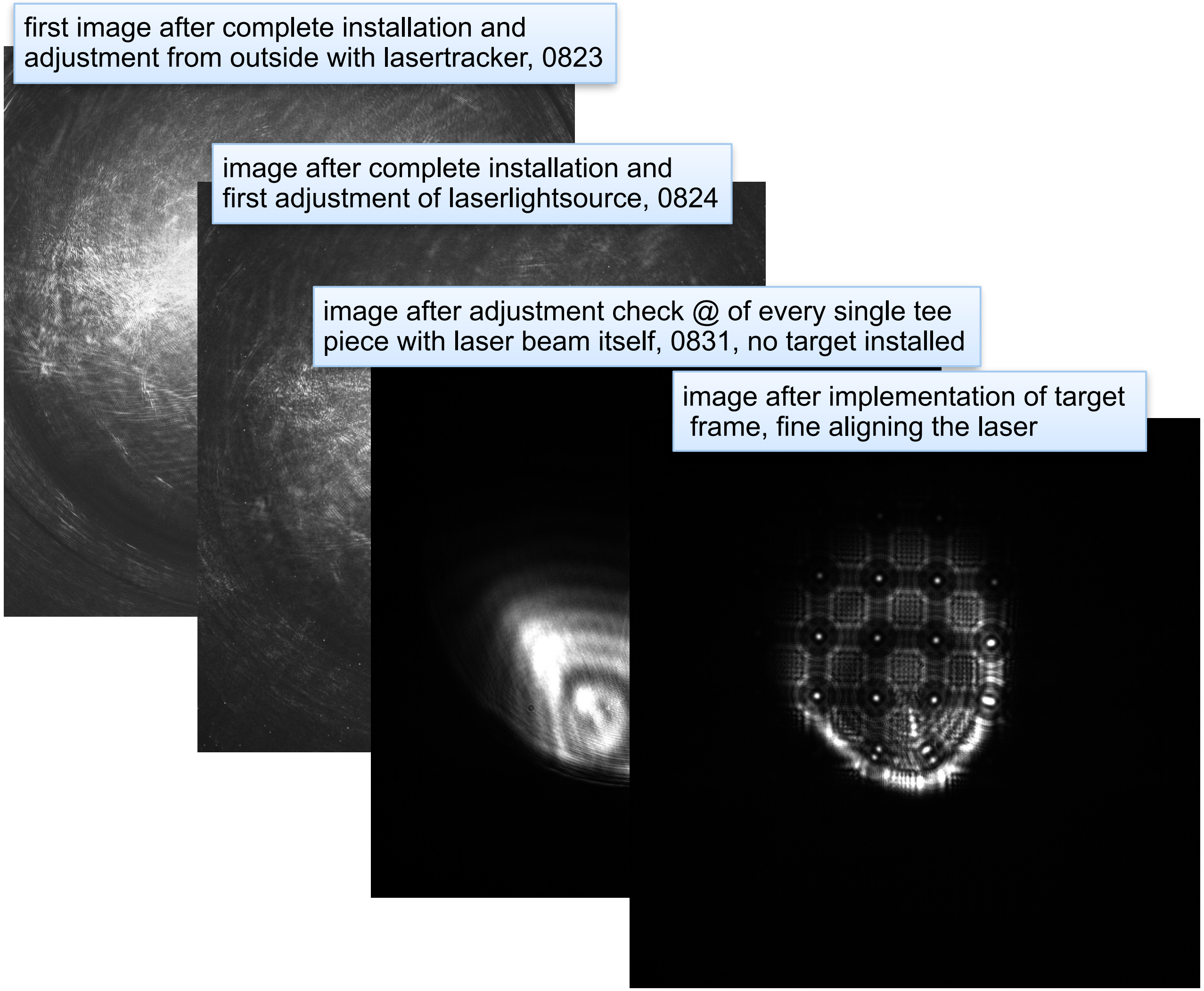
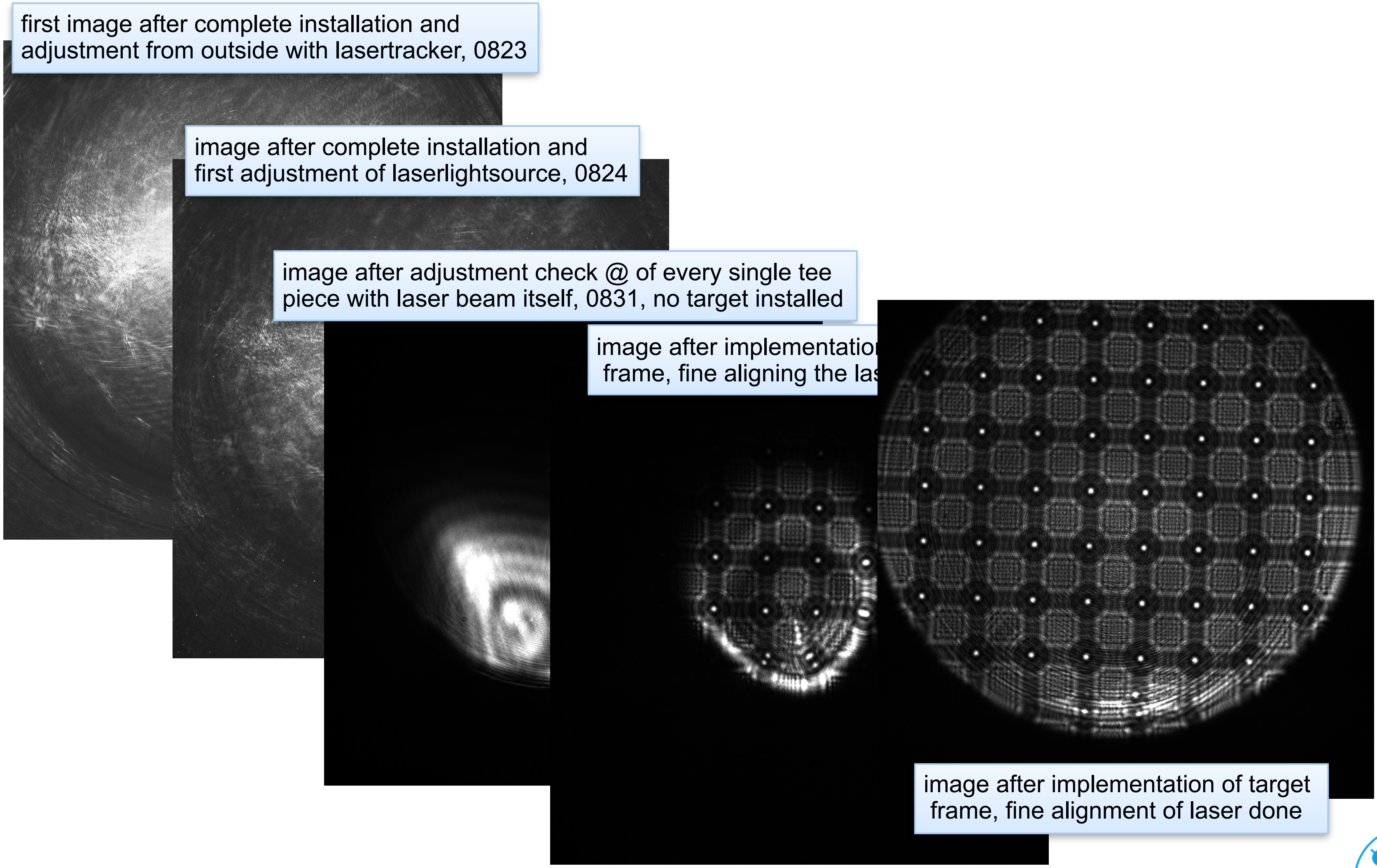


Commissioning of SLRS@SASE1:

- Simulation vs. the real thing



first image after complete installation and adjustment from outside with lasertracker, 0823

image after complete installation and first adjustment of laserlightsource, 0824

image after adjustment check @ of every single tee piece with laser beam itself, 0831, no target installed

image after implementatio frame, fine aligning the las

image after implementation of target frame, fine alignment of laser done

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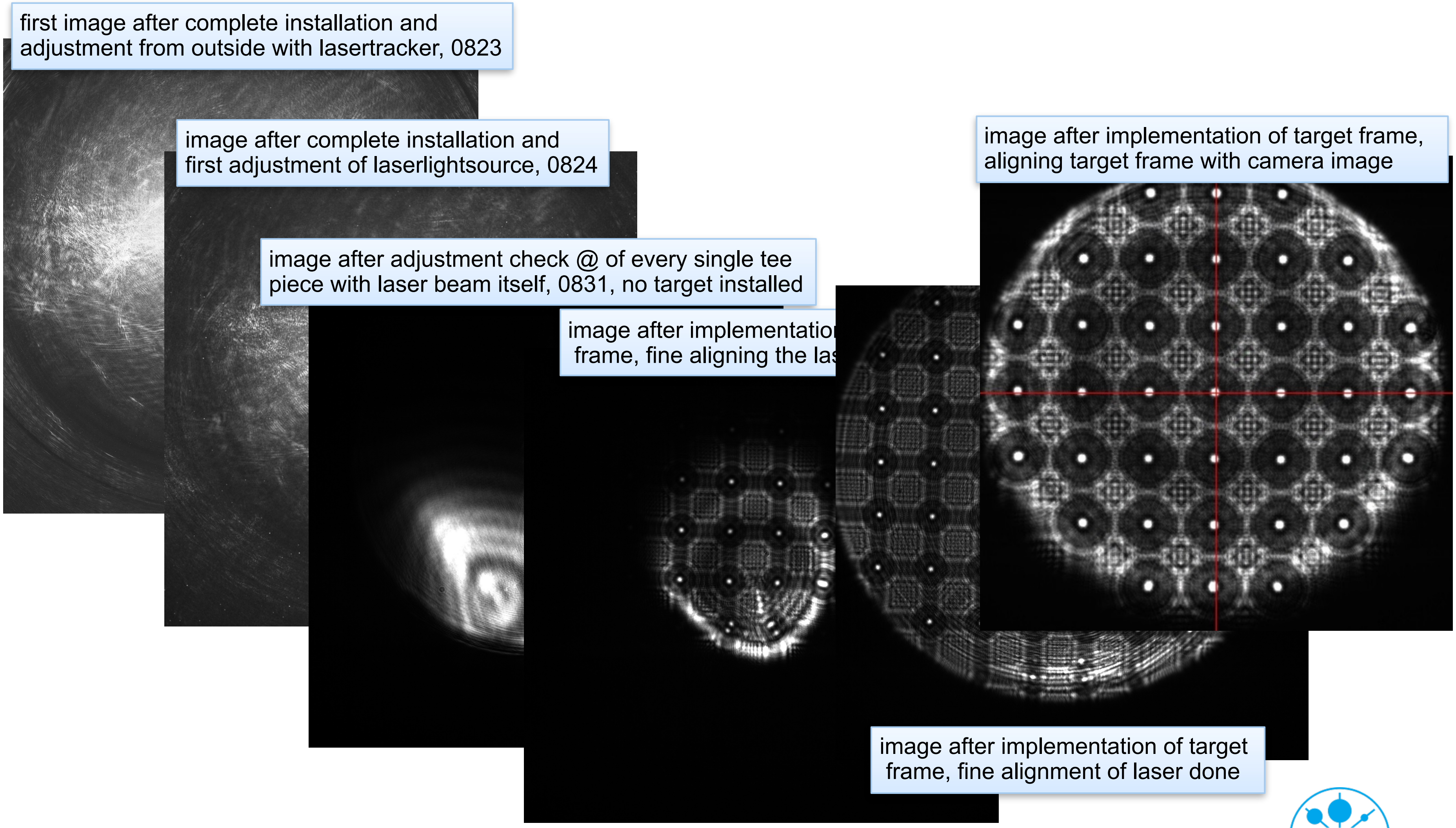

Commissioning of SLRS@SASE1:

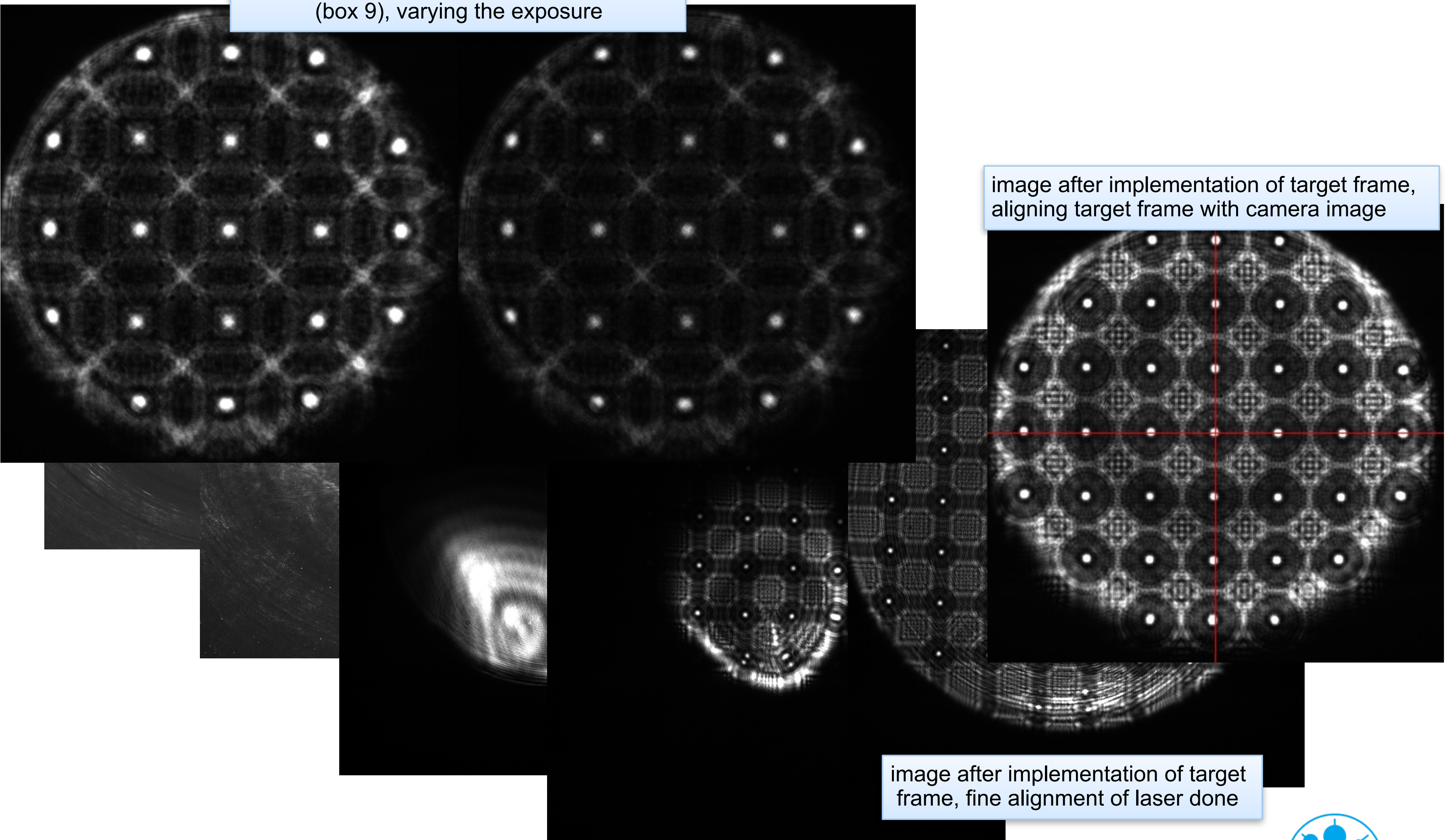

image after implementation of target frame, (box 9), varying the exposure

image after implementation of target frame, aligning target frame with camera image

image after implementation of target frame, fine alignment of laser done

Commissioning of SLRS@SASE1:

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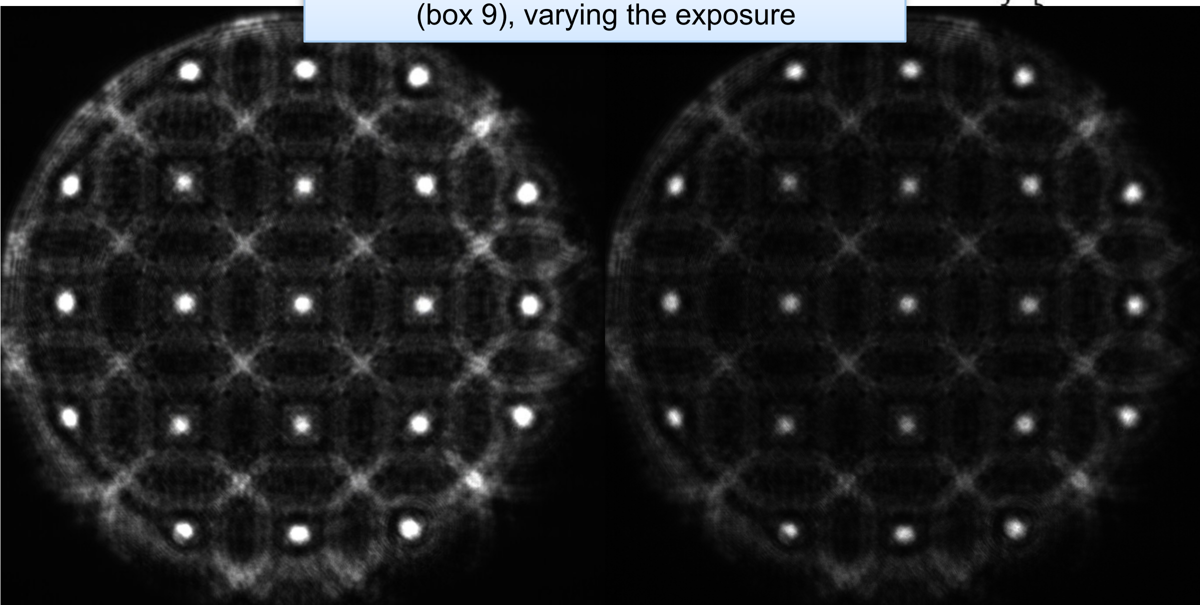
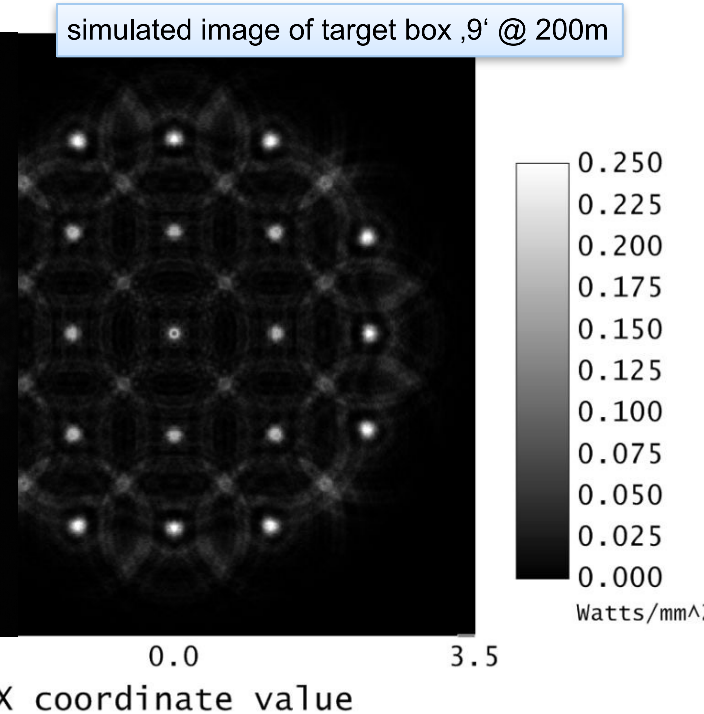


simulated image of target box ‚9‘ @ 200m



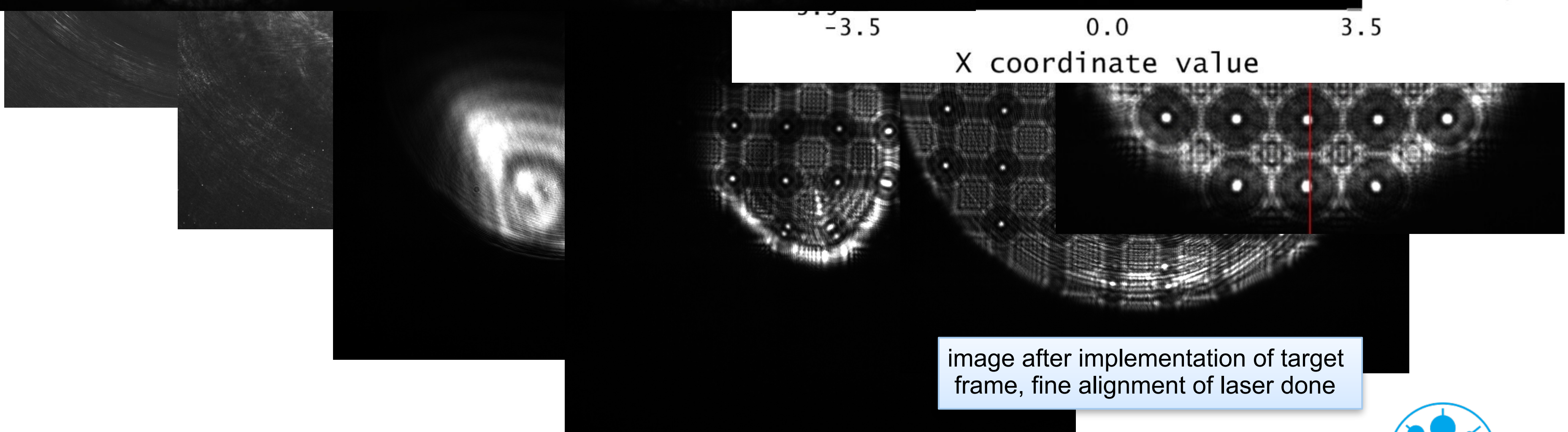
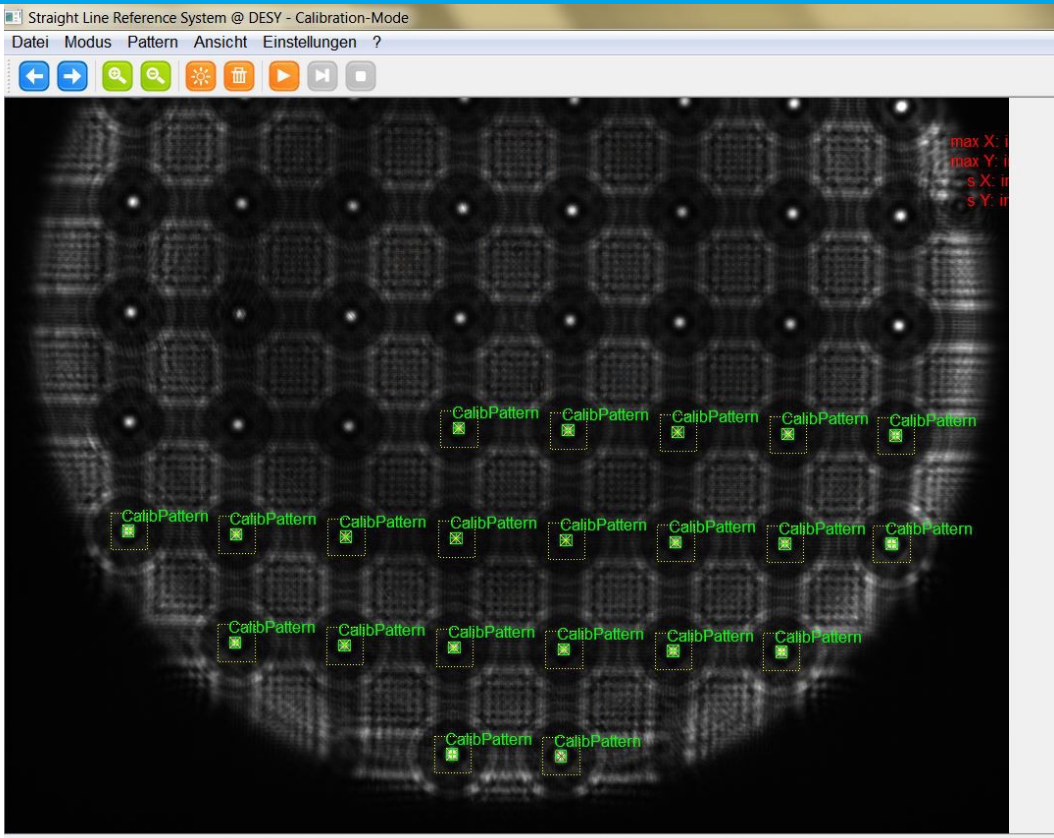
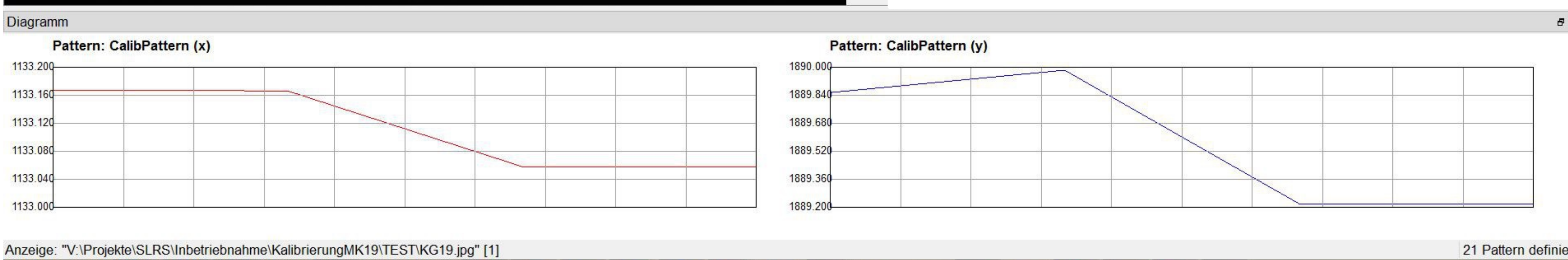


image after implementation of target frame, fine alignment of laser done

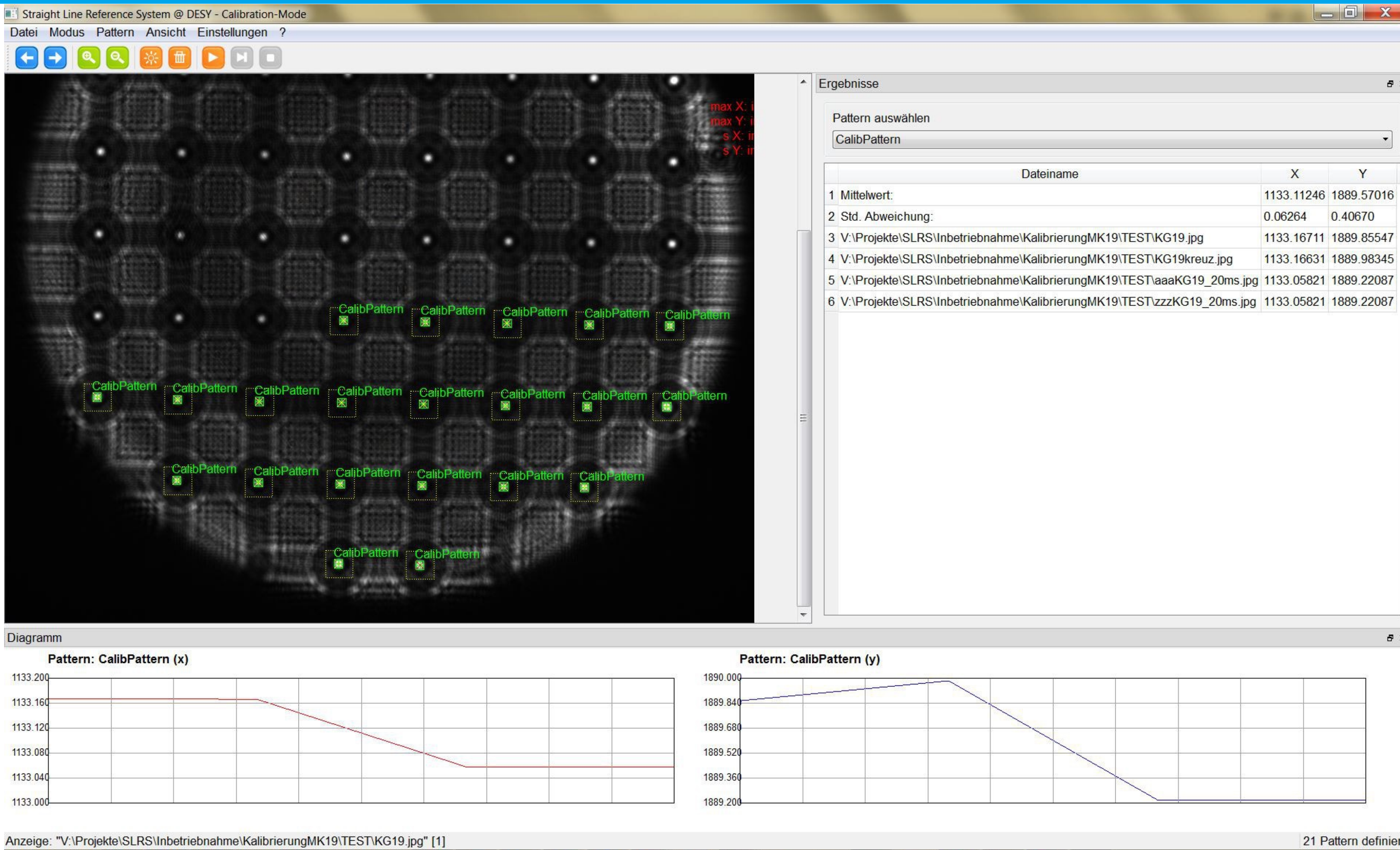
Measuring software, calibration



- evaluates images of calibrated target frames
- delivers position of each target in image coordinates within each image
  - used algorithm: cross correlation with subpixel estimation
- shows graphical trend of the target position in every image
- delivers parameters of the transformation between camera coordinate system and tunnel coordinate system, if respective fiducialisation parameters are used.
- delivers parameters for optical distortion

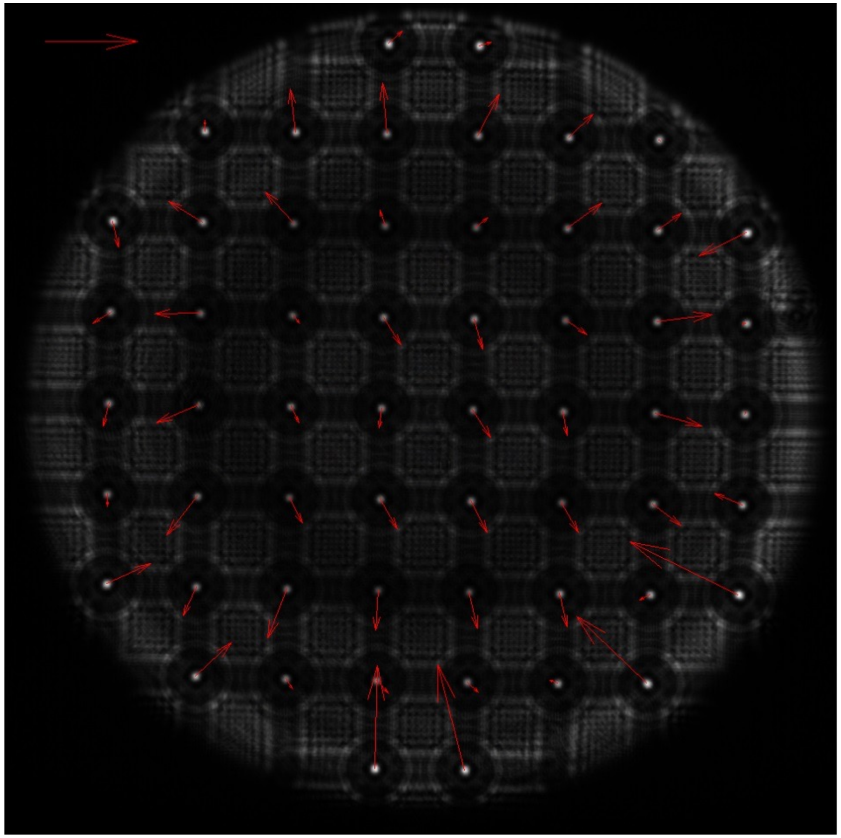


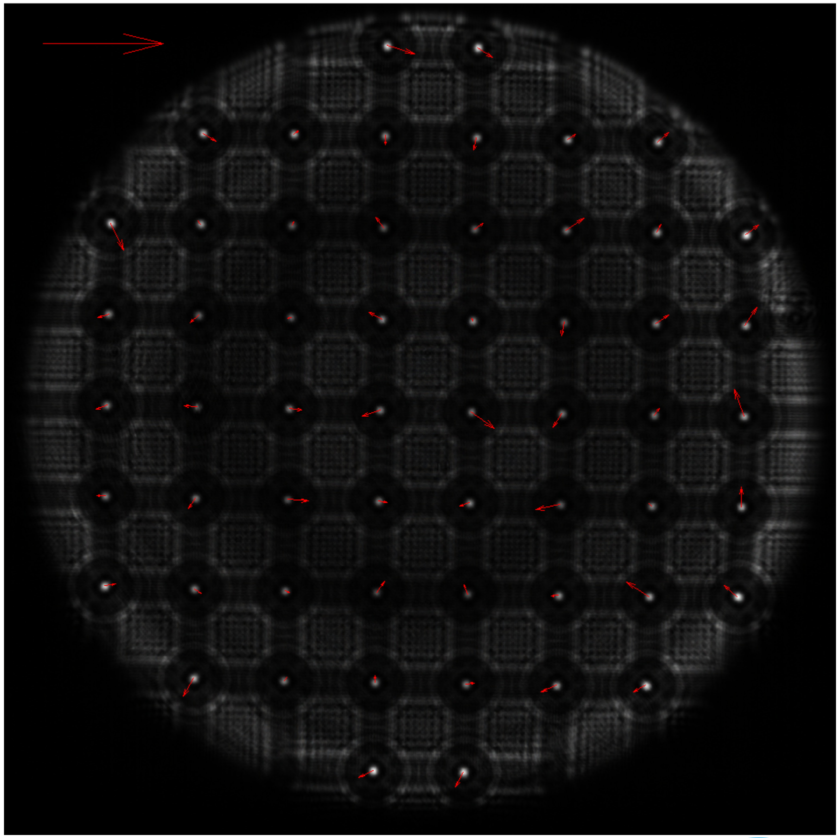
Measuring software, calibration



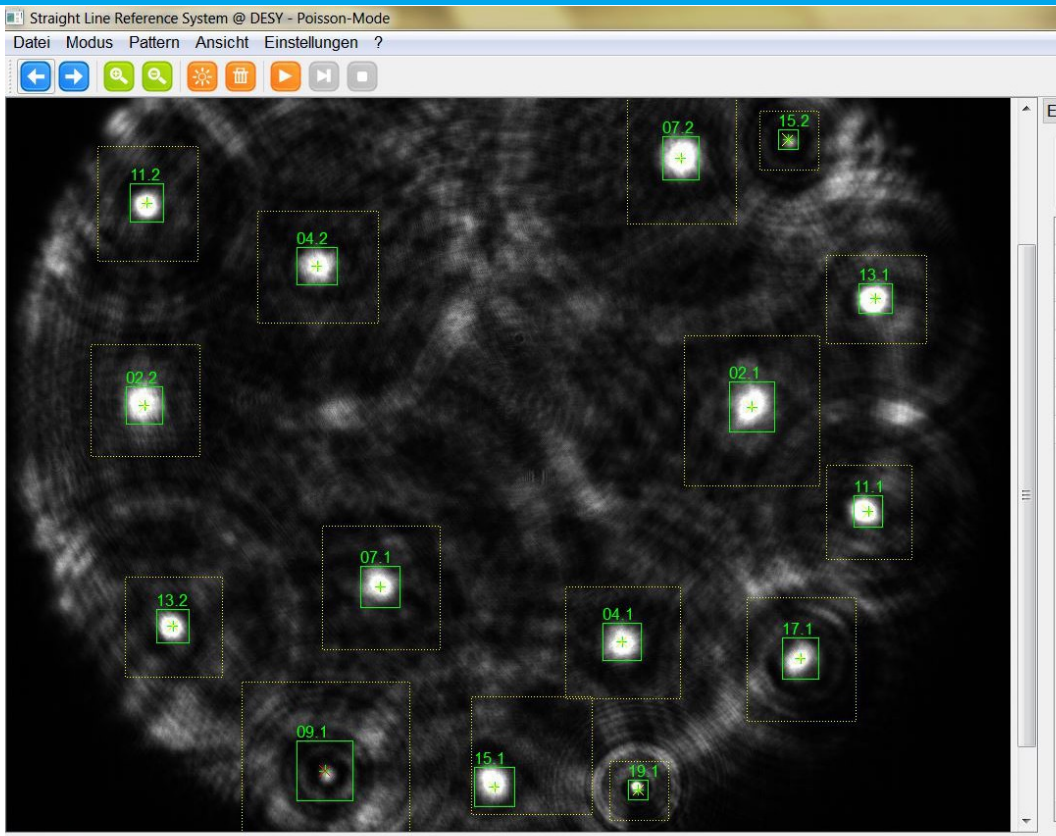
Measuring software, calibration, distortion

- Images show remaining errors (residuals) of the image transformation wrt. to nominal coordinates of the fiducialisation measurement
  - scale arrow length equals 0.5 pixel, scale differs in images.
  - left image is calculated with 5 parameters model of transformation (no distortion calculation), max. 0.5pix residuals.
  - right image is calculated with 10 parameters model of transformation, max. 0.1pix residuals.

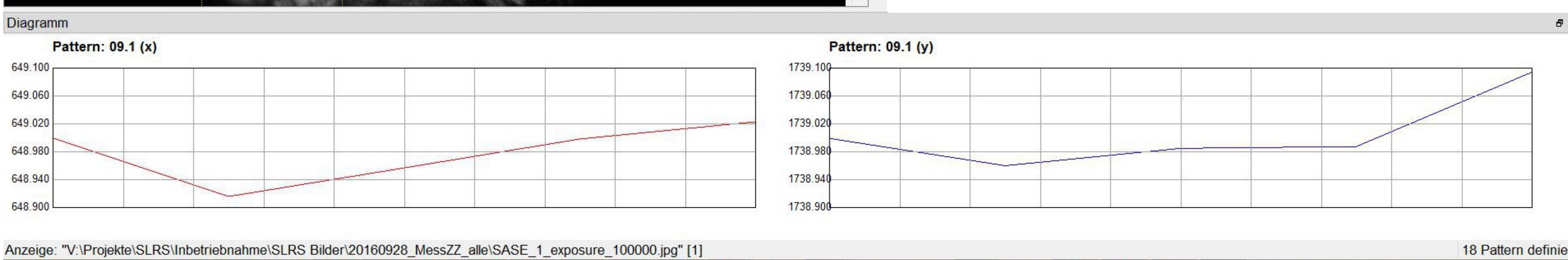




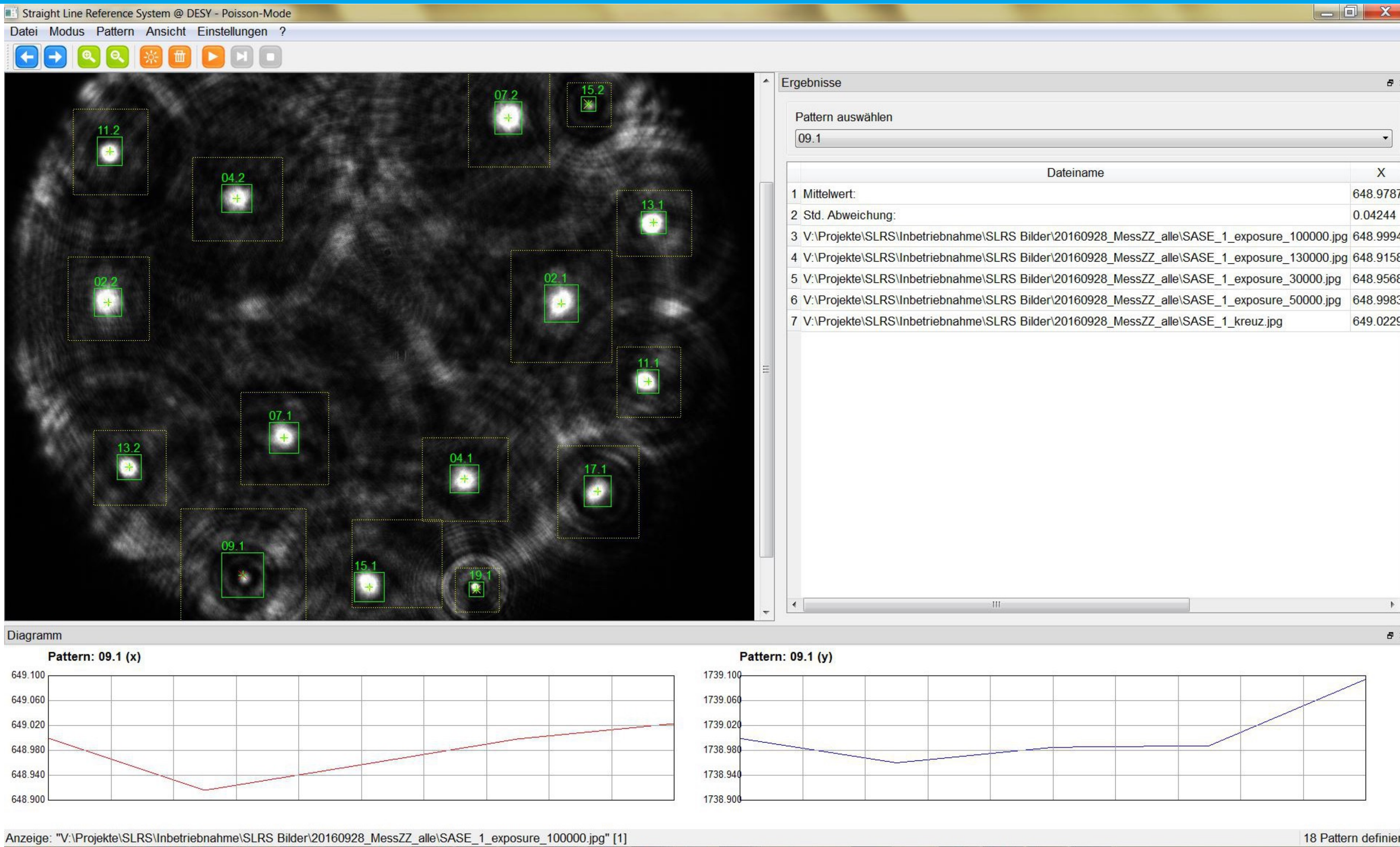
Measuring software, poisson alignment



- evaluates images of selected targets
- delivers position of each target in image coordinates within each image
  - used algorithm: cross correlation with subpixel estimation
- shows graphical trend of the target position in every image
- search patterns can be copied from image itself or generated as an artificial pattern
- search area (see yellow frame) for each target can be defined
- surface for subpixel estimation can be defined (f.e. paraboloid or gaussian fit)



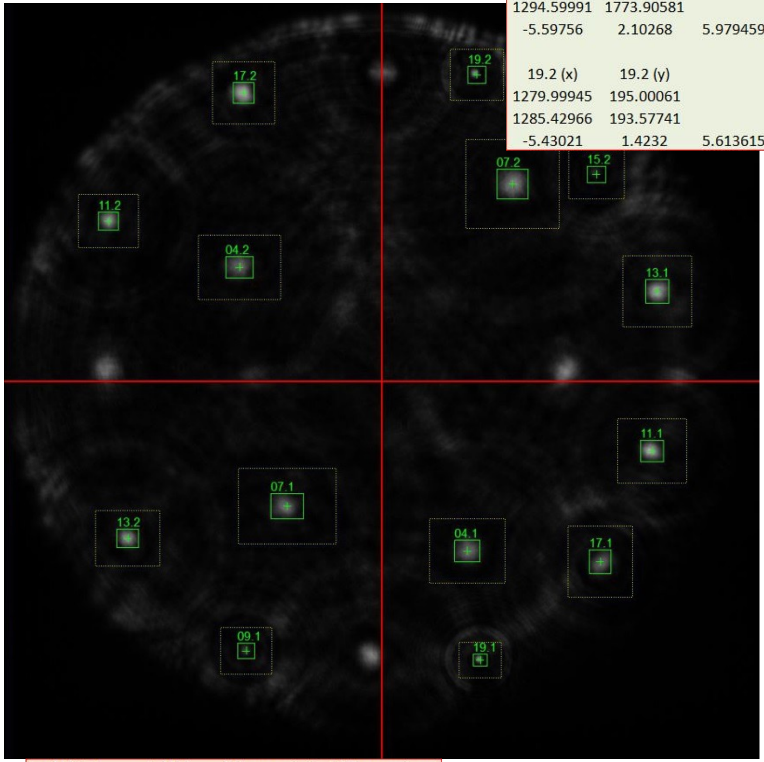
Measuring software, poisson alignment



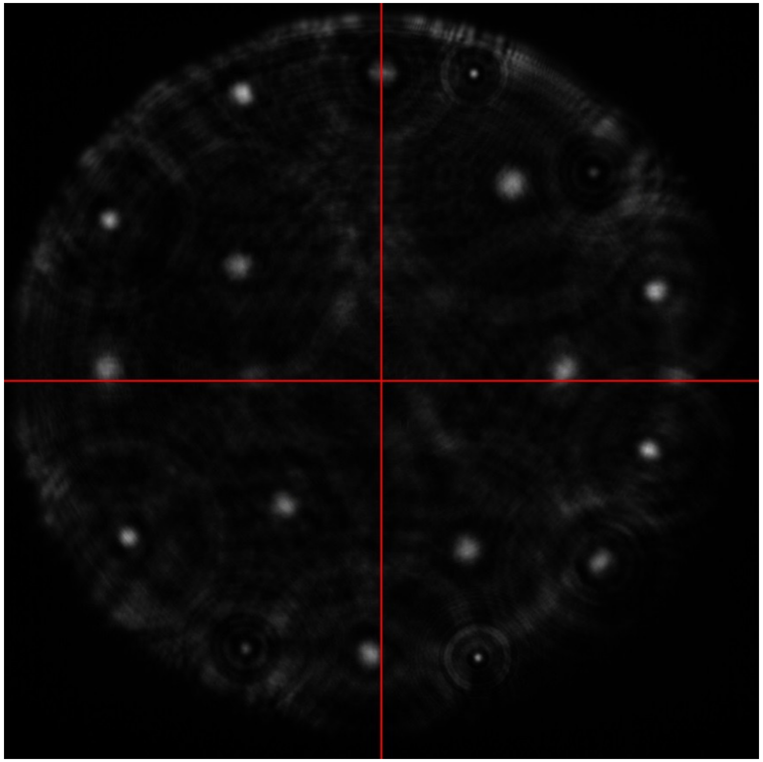
first checks

- drift check between
  - 2016-09-28 directly after pumping down
  - 2016-09-30

dx [pix]	dy [pix]	d distance [pix]	d distance [mm]
19.1 (x)	19.1 (y)		
1289.00235	1776.00849		
1294.59991	1773.90581		
-5.59756	2.10268	5.979459937	0.496341889
19.2 (x)	19.2 (y)		
1279.99945	195.00061		
1285.42966	193.57741		
-5.43021	1.4232	5.613615491	0.465973942



dx [pix]	dy [pix]	d distance [pix]	d distance [mm]
07.1 (x)	07.1 (y)		
768.00651	1360.00025		
829.66568	1337.1235		
-61.65917	22.87675	65.76624465	5.459112105
07.2 (x)	07.2 (y)		
1375.99894	489.99979		
1443.02749	462.48076		
-67.02855	27.51903	72.45773614	6.014558176



- Pixel size 5,5µm -> resolution of 8.3µm @ object size
- min value 0.46mm @ closest target (#19.2) to camera
- max. value 6mm @ target (#07.2) far from camera
- similar movements of all targets -> mainly movement of laser box

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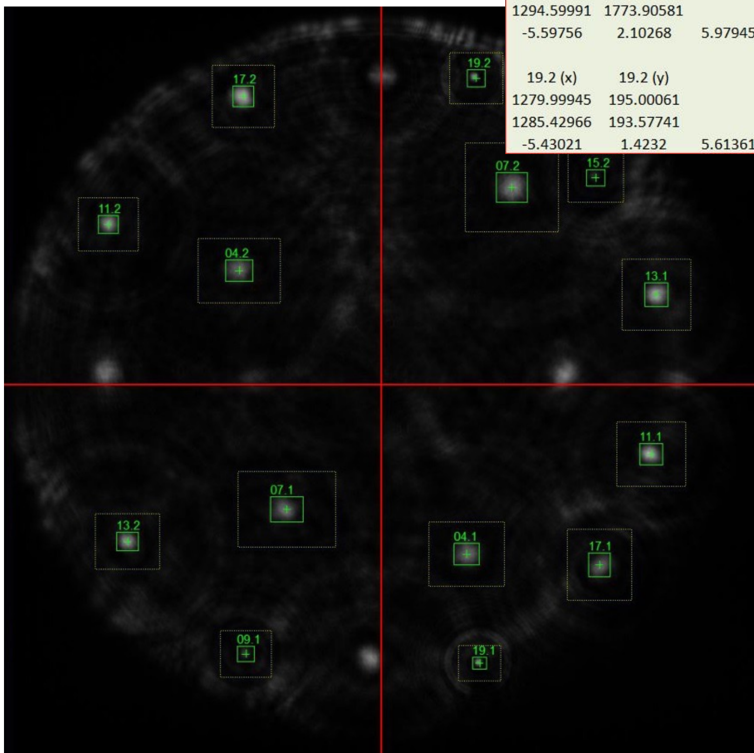

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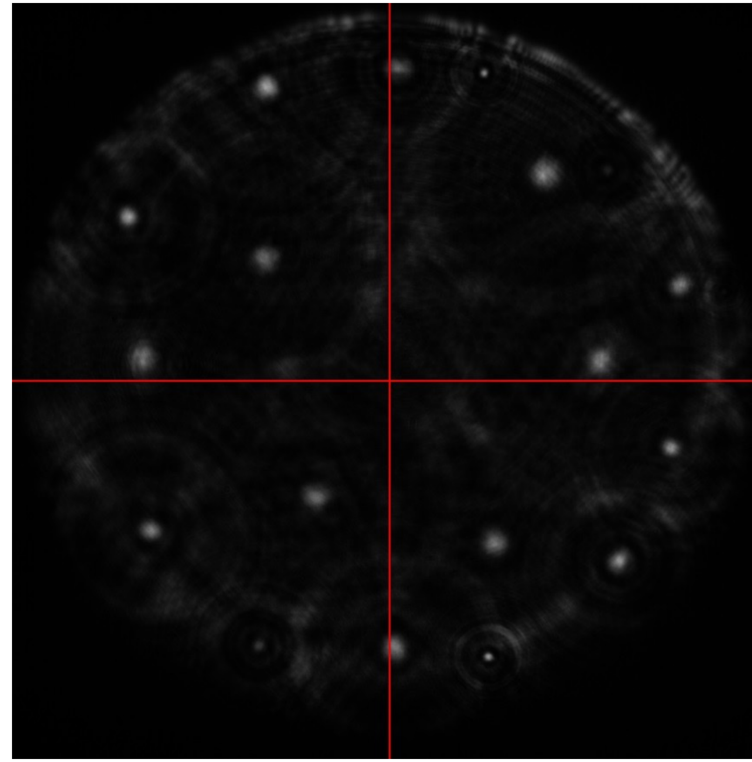

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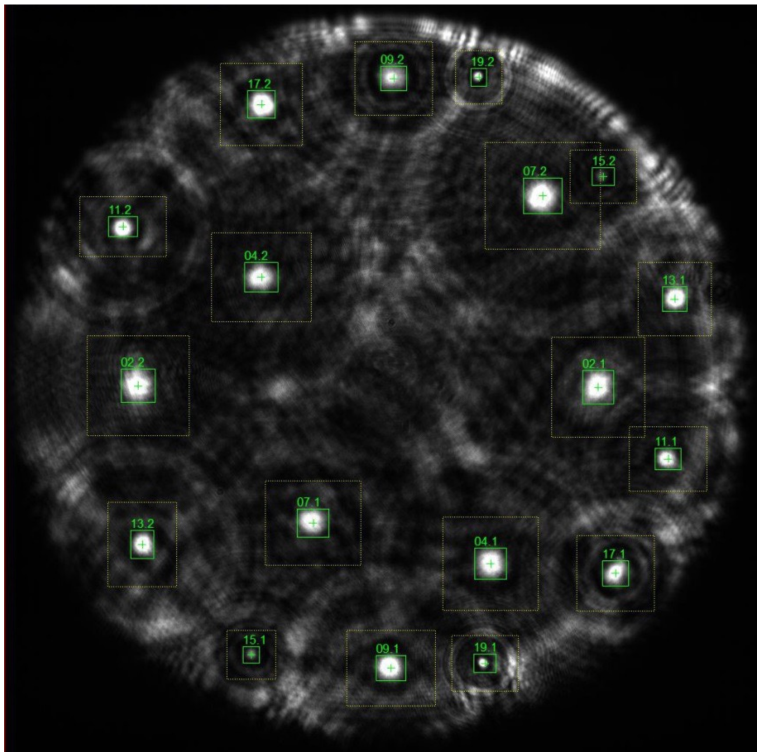
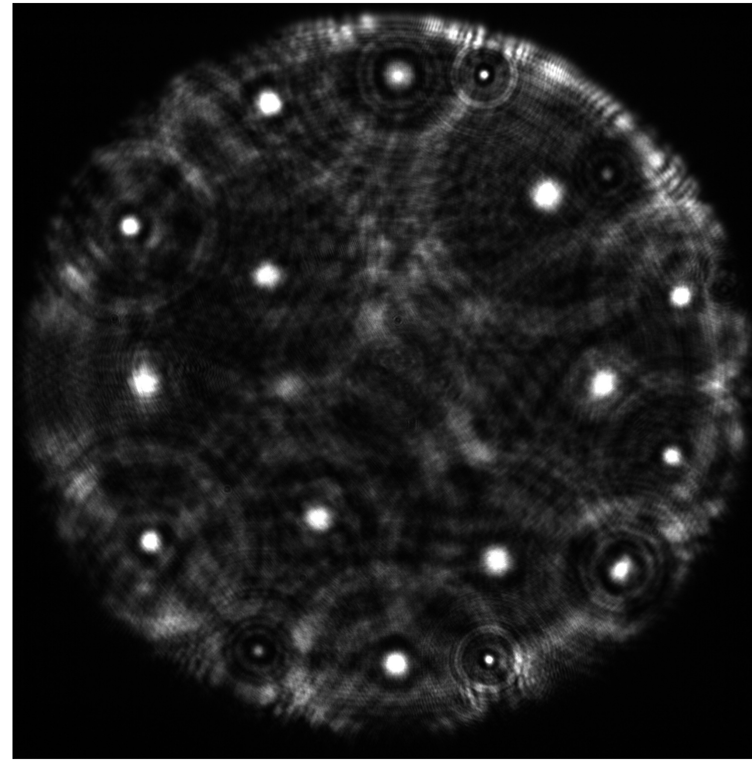
first checks

- check between
  - 4 consecutive images after new adjustement on 2016-09-30
- different exposures of 100ms, 130ms, 50ms, 30ms





13.1 (x)	13.1 (y)	dx [pix]	dy [pix]	d distance [pix]	d distance [µm]
1810.94526	795.03201	0.01433	-0.07405	0.075423812	6.260765635
1810.94009	795.04736	0.0195	-0.0894	0.091501967	7.595378136
1810.95959	794.95796	0	0	0	0
1811.09644	794.89874	-0.1369	0.05922	0.149113819	12.3776119

17.2 (x)	17.2 (y)	dx [pix]	dy [pix]	d distance [pix]	d distance [µm]
692.95155	268.95561	-0.5118	-1.0156	1.137269801	94.40227839
693.01941	269.26763	-0.5797	-1.32762	1.448647845	120.2490887
692.43975	267.94001	0	0	0	0
692.4607	267.81572	-0.0209	0.12429	0.126043273	10.46257635

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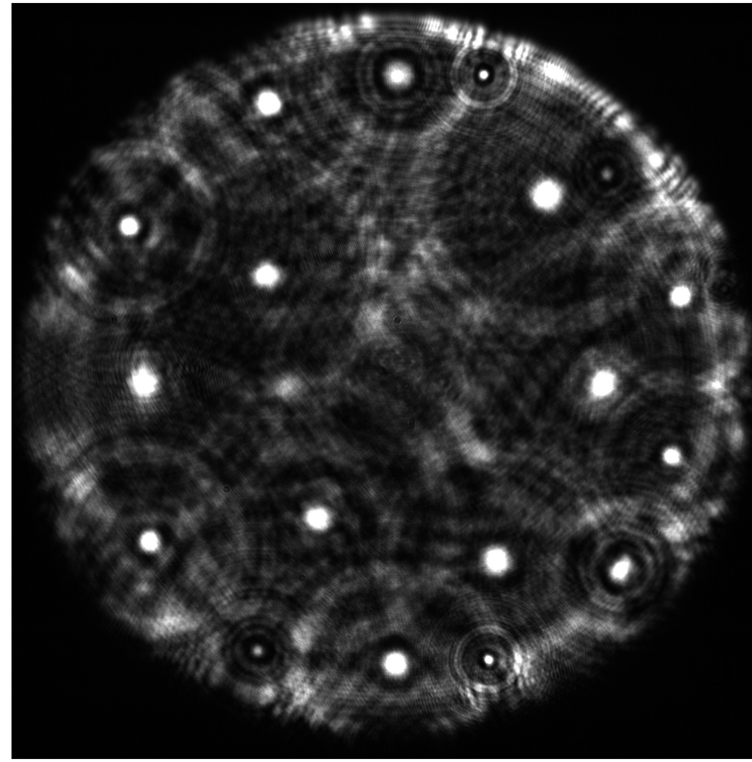

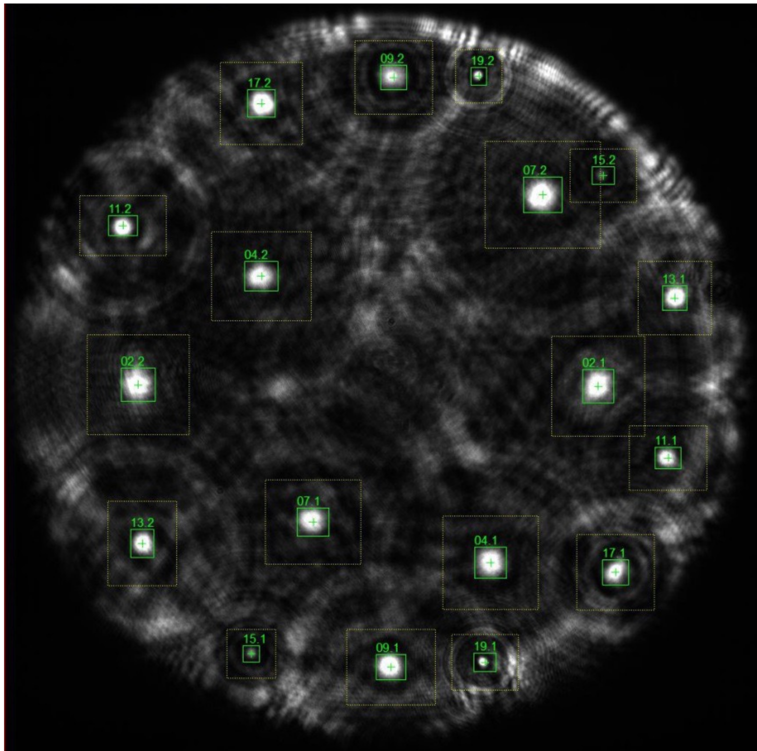

13.1 (x)	13.1 (y)	dx [pix]	dy [pix]	d distance [pix]	d distance [µm]
1810.94526	795.03201	0.01433	-0.07405	0.075423812	6.260765635
1810.94009	795.04736	0.0195	-0.0894	0.091501967	7.595378136
1810.95959	794.95796	0	0	0	0
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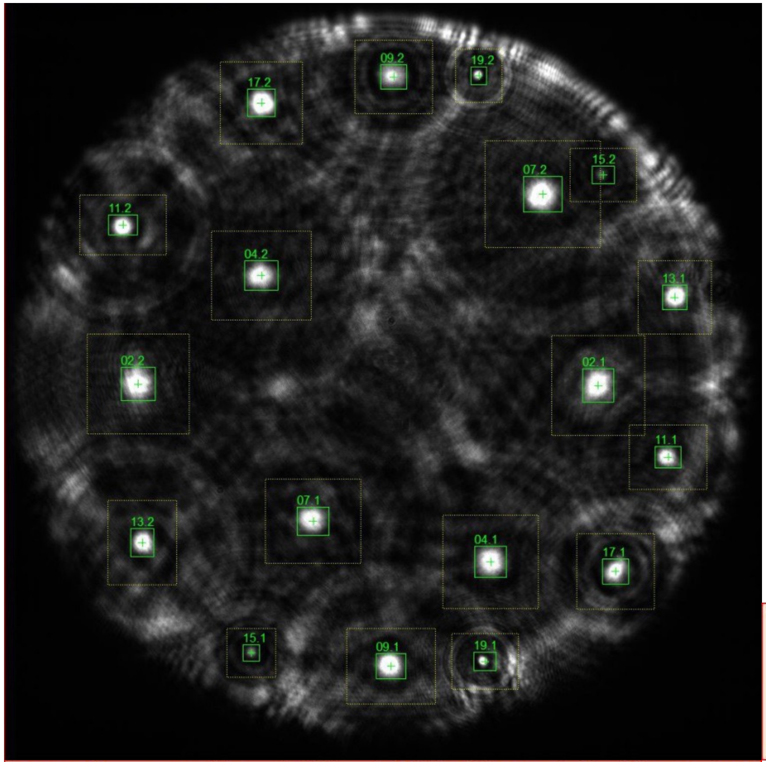
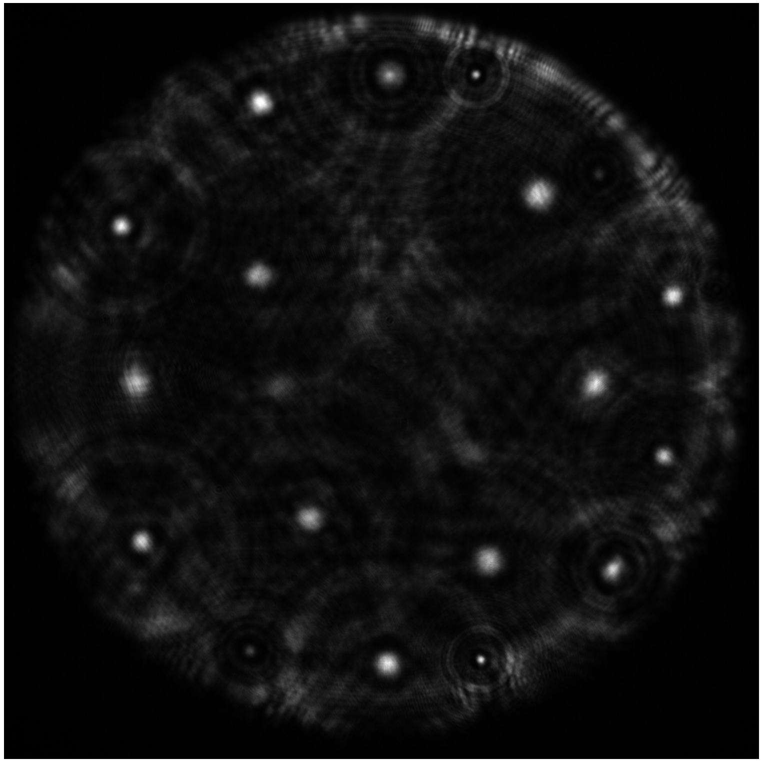


17.2 (x)	17.2 (y)	dx [pix]	dy [pix]	d distance [pix]	d distance [µm]
692.95155	268.95561	-0.5118	-1.0156	1.137269801	94.40227839
693.01941	269.26763	-0.5797	-1.32762	1.448647845	120.2490887
692.43975	267.94001	0	0	0	0
692.4607	267.81572	-0.0209	0.12429	0.126043273	10.46257635



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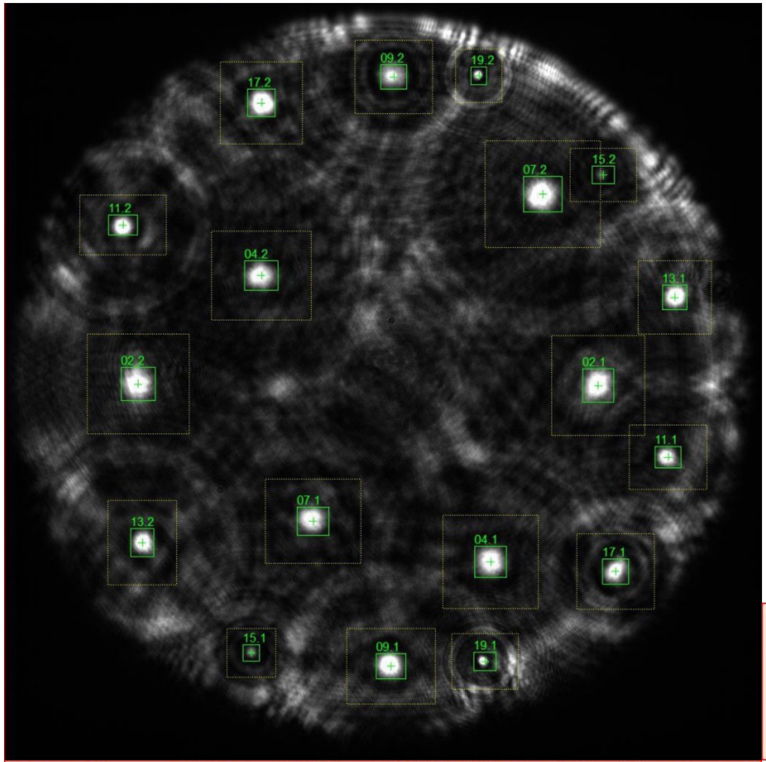

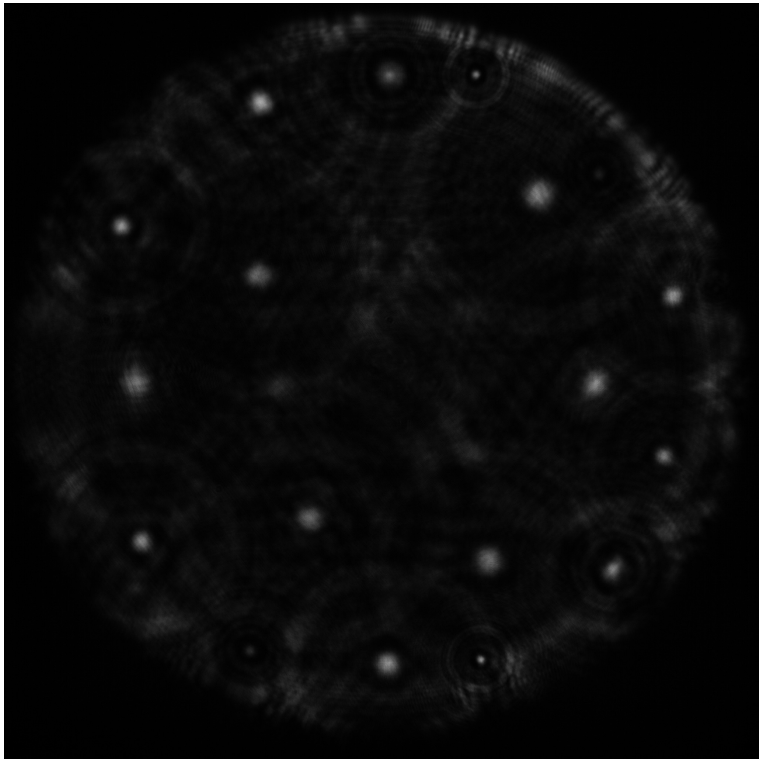

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692.4607	267.81572	-0.0209	0.12429	0.126043273	10.46257635

Conclusions

- „Zemax“ software was very helpful to design target components and optics of the real SLRS.
- Generally, the images just turned out to equal the simulations. There has been no possibility for earlier checks over the complete length.
  - From prototype (48m length) to actual system (483m - 550m length) this is a scaling of 10.

- Tests presented here are only marginal, due to the just recent completion of the SLRS.
- Reference grid measurements including the SLRS targets and corrections started on tuesday this week.

- More precise evaluations are to come in near future.
- Complete calculation process including all steps still has to be improved.
  - the fiducialisation measurements combined with reference grid & SLRS target survey result in coordinates of the inner targets in the reference grid system.
  - these are approximation values for the equalization calculation of dx&dy of reference grid values.

- A good impression of the status of the accelerator from April 2016 is available here: https://www.youtube.com/watch?v=p3G90p4gIQA
  - The SLRS in XTD2 comes into view from 3'31" until 4'16" on the left hand side 90cm above the beamline fixed to the tunnel wall.
  - View from September 2016: https://www.youtube.com/watch?v=mg5znQrDAfc

- THANK YOU FOR YOUR ATTENTION.