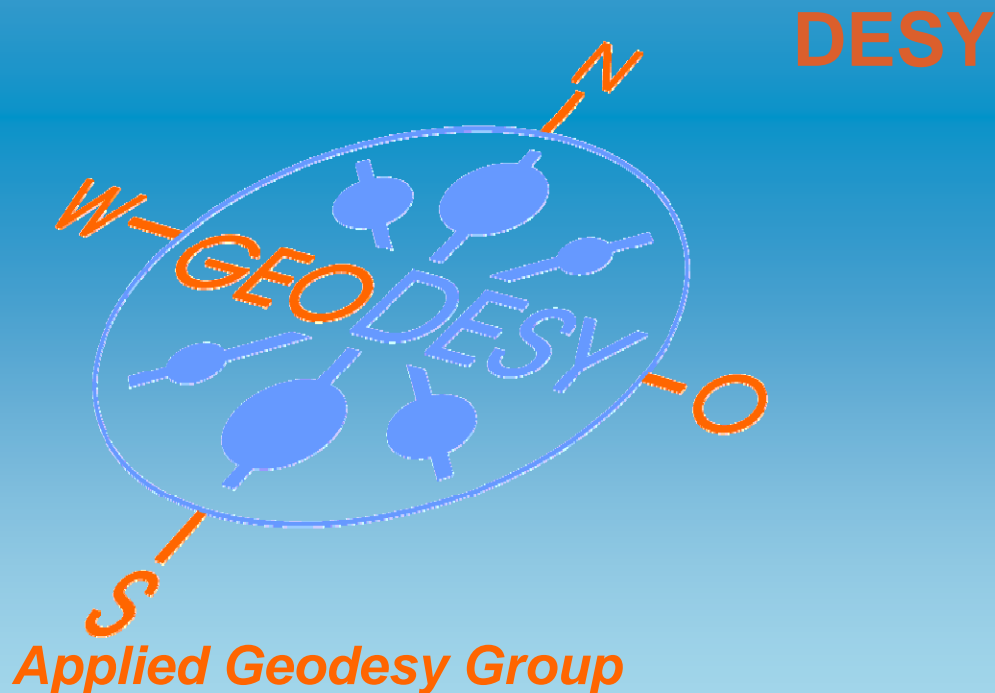


Straight Line Reference System (SLRS) for the adjustment of the X-ray free-electron Laser (XFEL) @ DESY

Daniel Kaemtner, Johannes Prenting



Straight Line Reference System (SLRS) for the adjustment of the X-ray free-electron Laser (XFEL) @ DESY

Outline of presentation:

1. Overview about new projects at **DESY**

2. **SLRS-XFEL**

3. **Poisson Alignment System:**

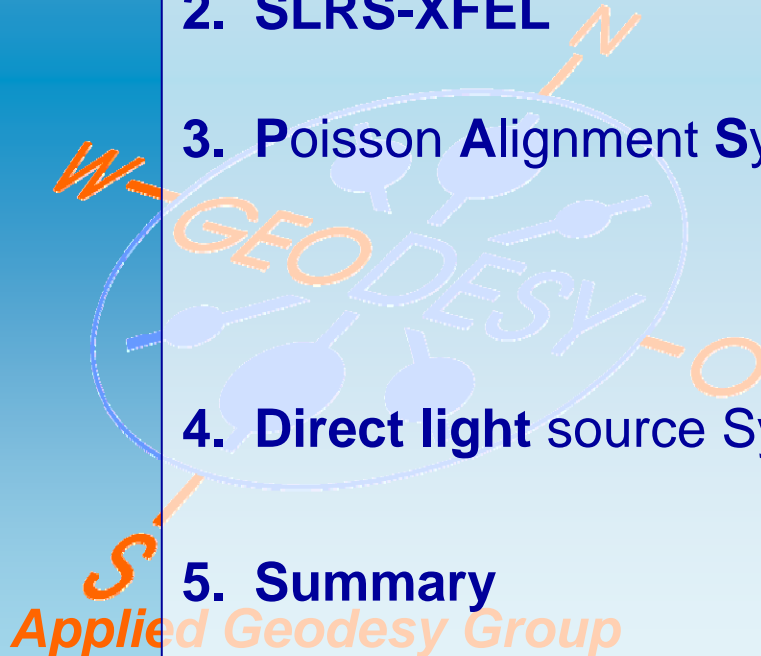
- Introduction
- Simulation
- Empirical tests

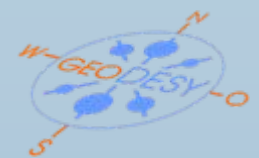
4. **Direct light source System:**

- Introduction
- Empirical tests

5. **Summary**

6. **Future developments**





SLRS for XFEL @ DESY

NEW PROJECTS

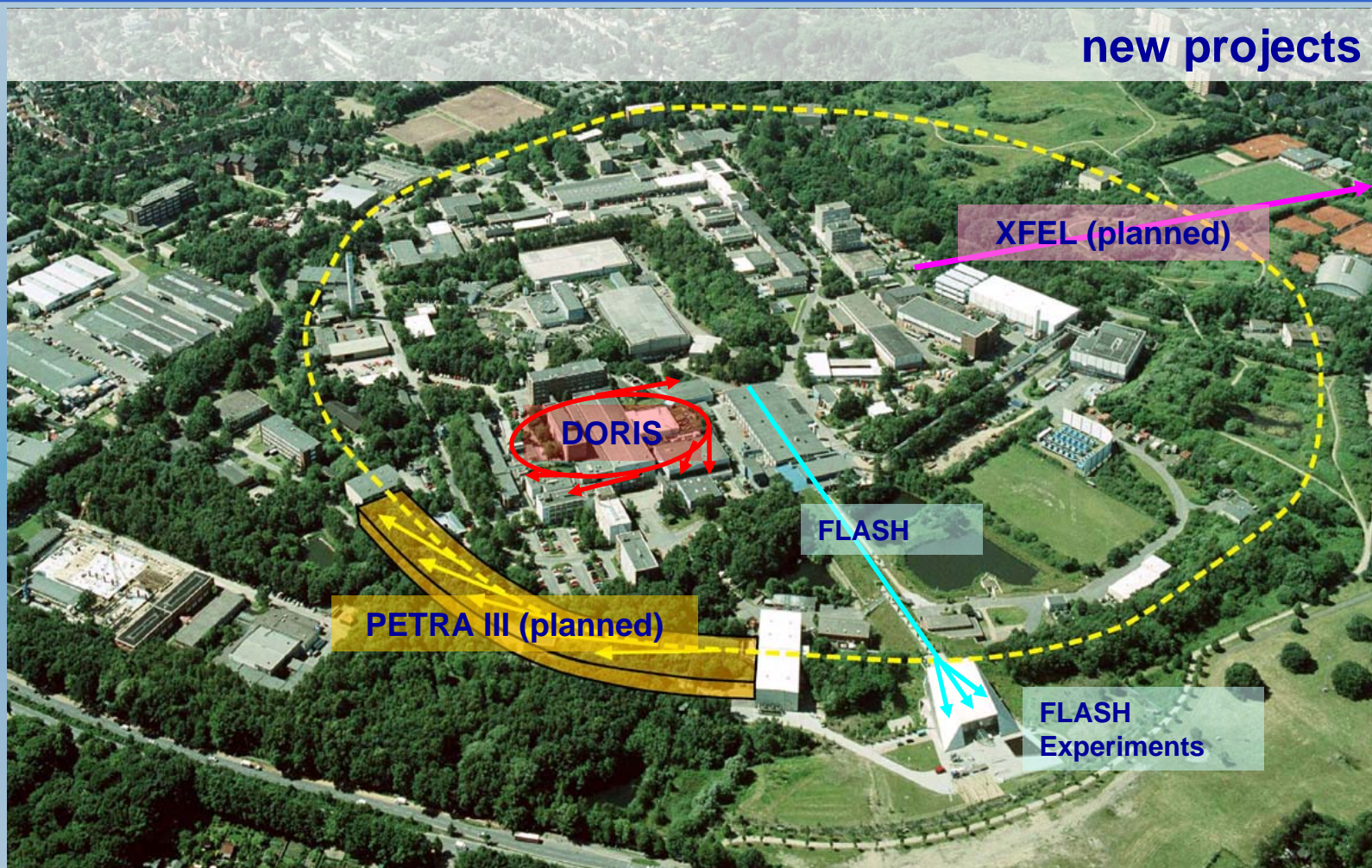
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

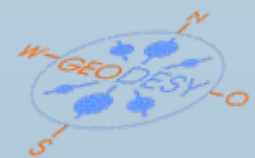
FUTURE
DEVELOPMENT



Flash : world record: 13.5nm with 10 mW, rep. rate 150x / second

PETRA III : conversion into one of the most brilliant x-ray sources worldwide

XFEL : approved statement „Planfeststellungsbeschuß“ published



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

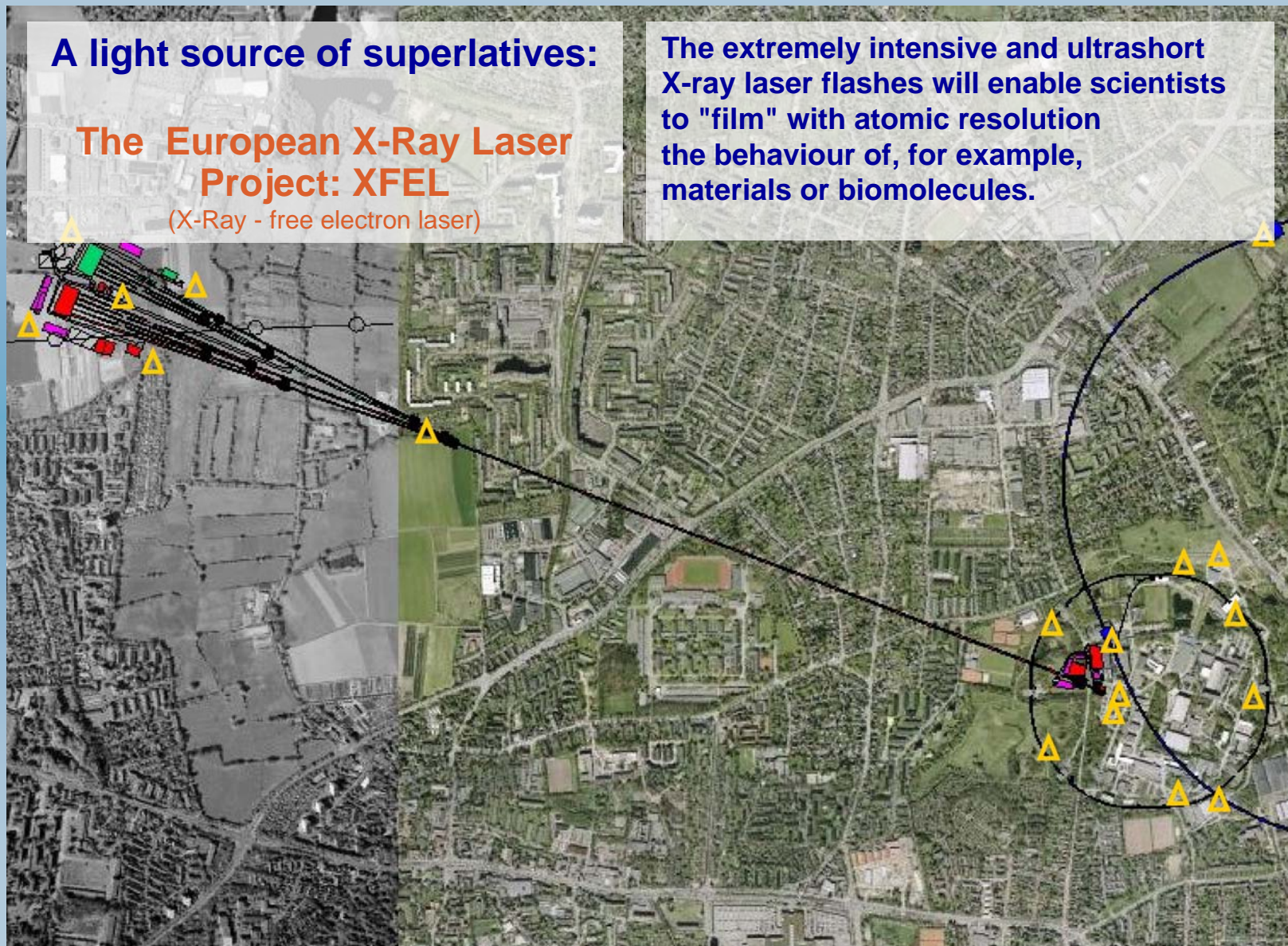
FUTURE
DEVELOPMENT

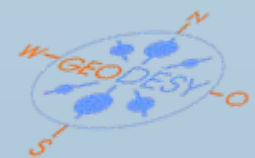
A light source of superlatives:

**The European X-Ray Laser
Project: XFEL**

(X-Ray - free electron laser)

The extremely intensive and ultrashort X-ray laser flashes will enable scientists to "film" with atomic resolution the behaviour of, for example, materials or biomolecules.





SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

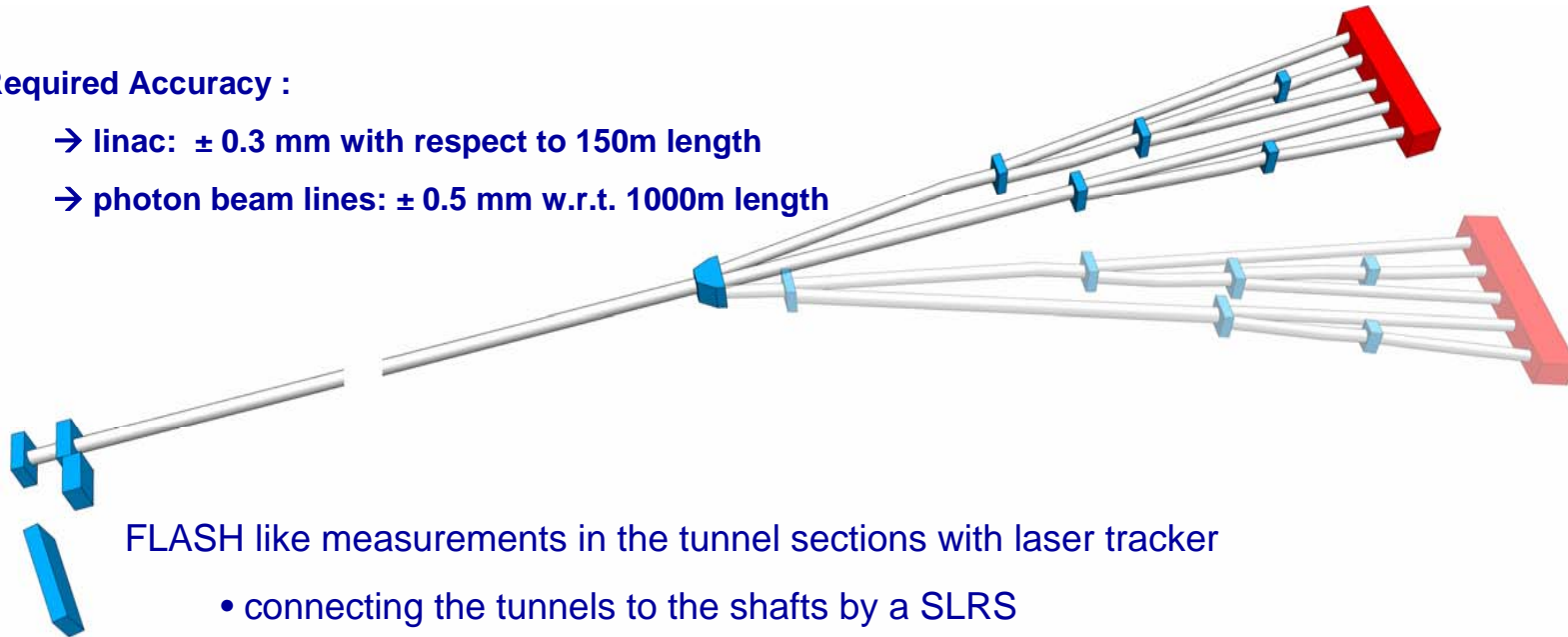
FUTURE
DEVELOPMENT

XFEL-survey concept

Required Accuracy :

→ linac: ± 0.3 mm with respect to 150m length

→ photon beam lines: ± 0.5 mm w.r.t. 1000m length



FLASH like measurements in the tunnel sections with laser tracker

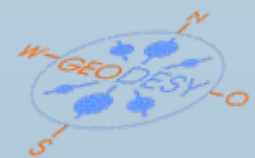
- connecting the tunnels to the shafts by a SLRS
- alternative : Wire measurement system and HLS
- SLRS for monochromators and other optical elements in each distribution tunnel

General data:

Total length of facility: approx. **3.3 km**

Wavelength of X-Ray radiation: **6 down to 0.085 nanometer**

Length of light pulses: < **100 femtoseconds**



SLRS for XFEL @ DESY

NEW PROJECTS

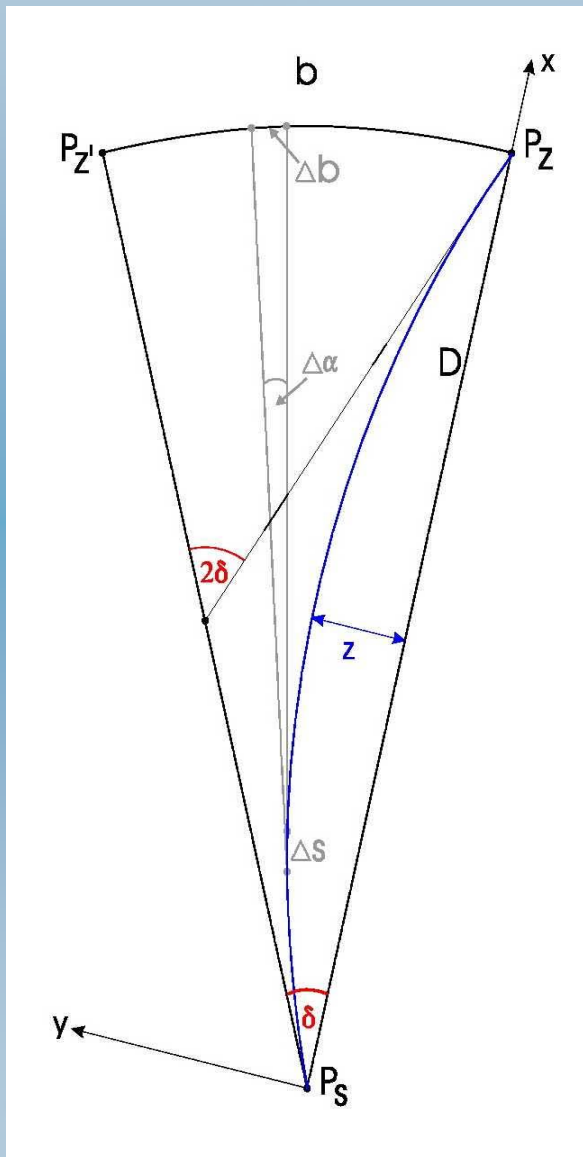
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



angle of refraction

$$\delta_{[rad]} = \frac{\kappa}{R \cdot D} \int_{P_s}^{P_z} (D - s) ds$$

- with $\frac{\delta n}{\delta y} = a = \text{constant}$

n = refractivity index of air

κ = local refractivity coefficient

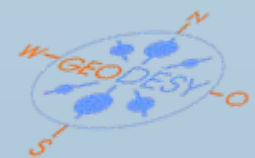
$$\kappa = f(P, T, \frac{\delta T}{\delta y} \approx f(\frac{\delta T}{\delta y})$$

- temperature gradient perpendicular to the beam

approximation equations

$$2\delta_{[rad]} = \int_{P_s}^{P_z} \frac{\delta n}{\delta y} ds = \int_0^D \frac{\delta n}{\delta y} ds$$

thus $\delta_{[rad]} = a \cdot \frac{D}{2}$ and $z = a \cdot \frac{D^2}{8}$



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
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DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

numerical examples for various $\frac{\delta T}{\delta y}$

	lateral refraction $\frac{\delta T}{\delta y} = +0,1 K/m$		Comparison with altimetry $\frac{\delta T}{\delta y} = -0,065 K/m$	
distance	angular error	lateral error	angular error	lateral error
[m]	[mgon]	[mm]	[mgon]	[mm]
50	0,16	0,031	-0,10	-0,020
100	0,32	0,125	-0,21	-0,081
150	0,48	0,281	-0,31	-0,183
200	0,64	0,500	-0,41	-0,325
250	0,80	0,781	-0,52	-0,508
300	0,95	1,125	-0,62	-0,731
600	1,91	4,500	-1,24	-2,925
1200	3,82	18,000	-2,48	-11,700

standard solution to minimize effects of refraction:
monitoring pillars alternating on either side of the tunnel.



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

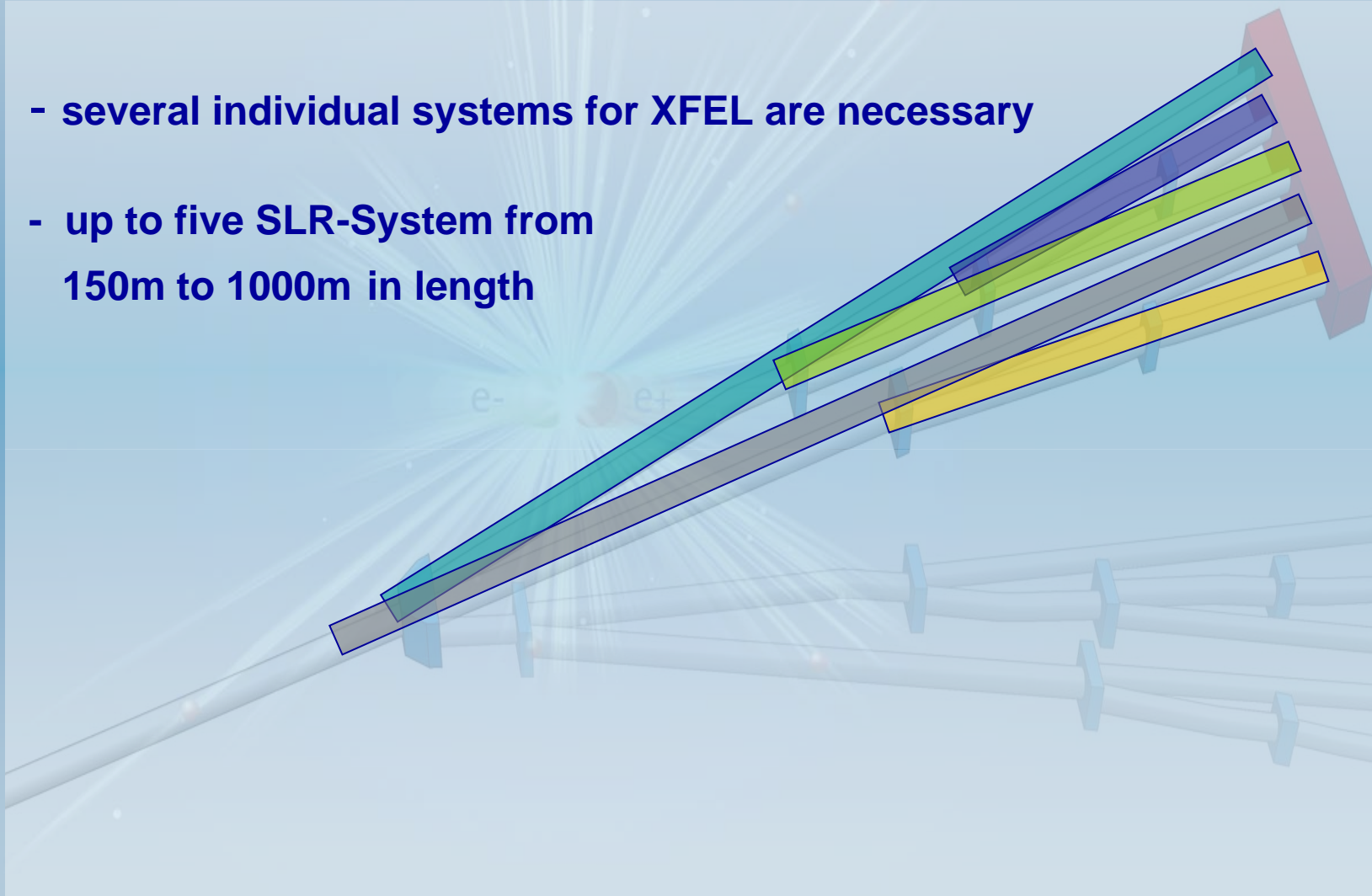
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

SLRS concept

- several individual systems for XFEL are necessary
- up to five SLR-System from 150m to 1000m in length





SLRS for XFEL @ DESY

SLRS concept

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

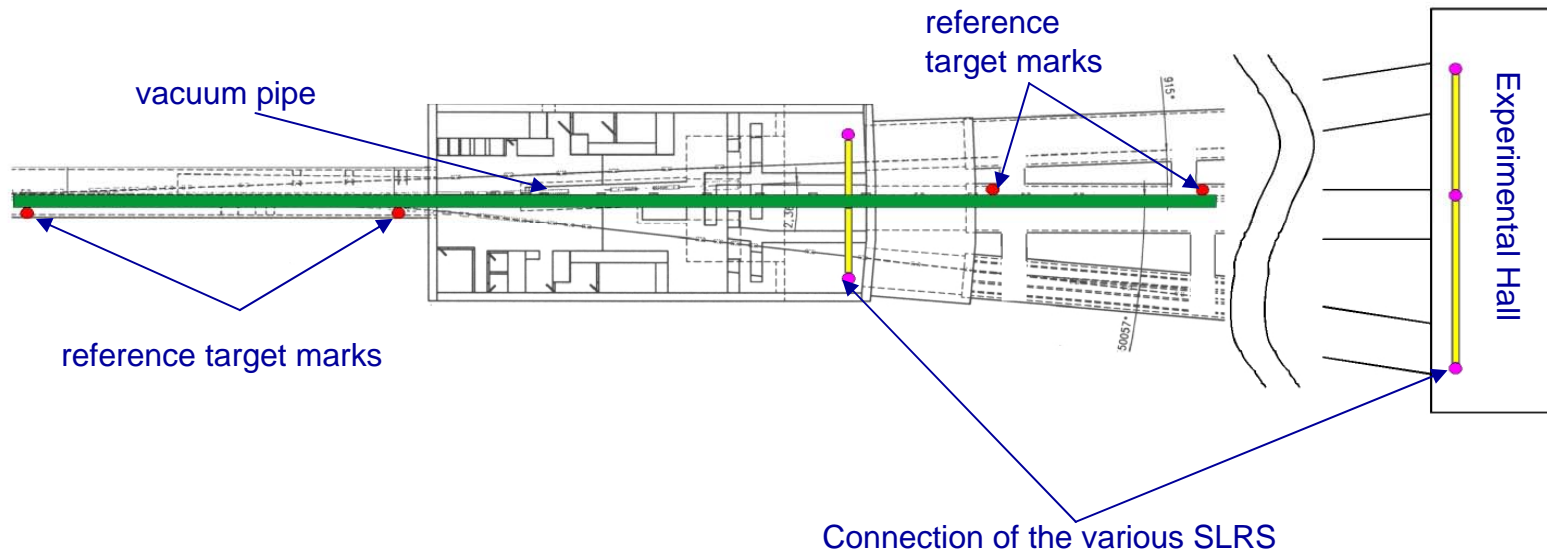
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

Principle: crossing the shafts

straightness reference for alignment, connection of the various SLRS



- reference coordinate system transported by SLRS (by conventional optical survey methods, impossible to cross the shaft)
- cross connection give relation between various SLRS



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

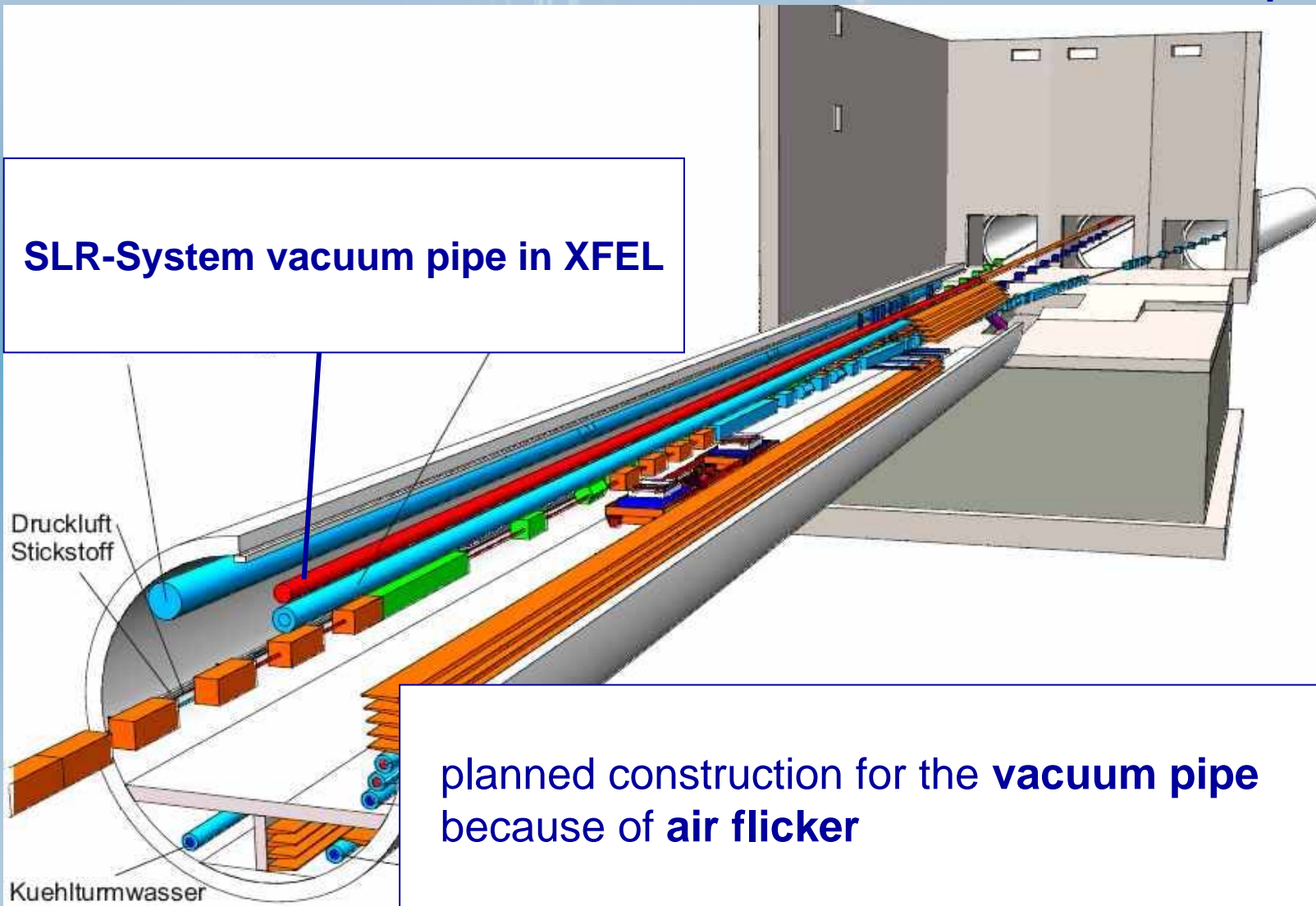
POISSON
ALIGNMENT
SYSTEM

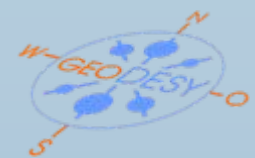
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

SLRS concept





SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

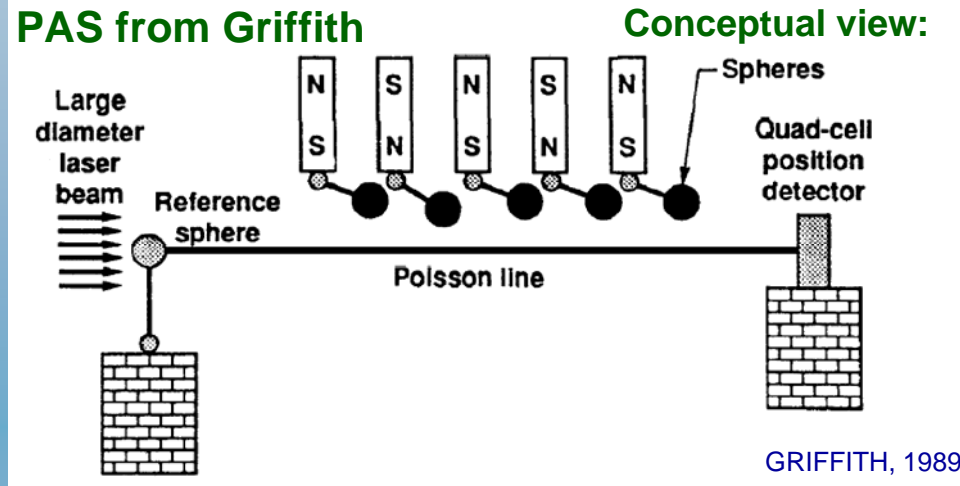
POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

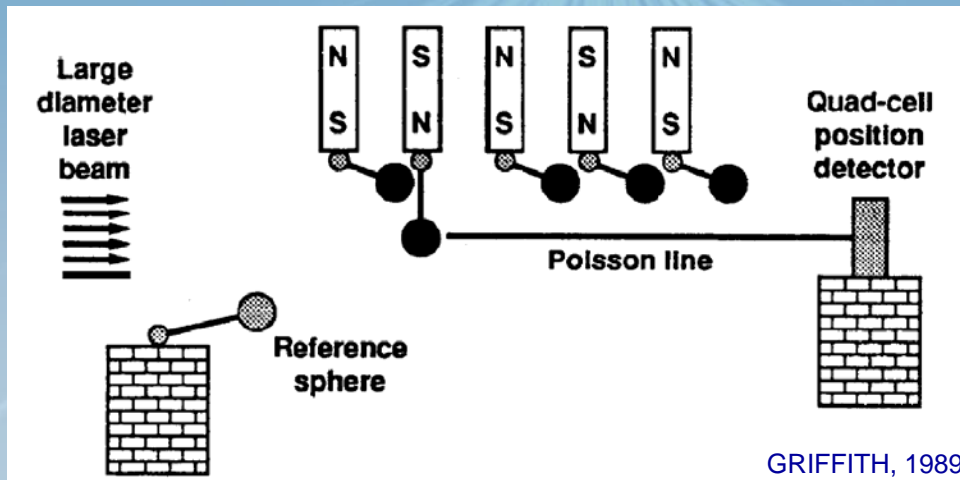
SUMMARY

FUTURE
DEVELOPMENT

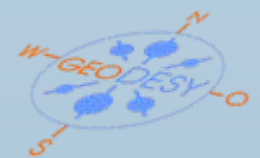
Poisson-Alignment-System



optical reference line defined by reference sphere and detector



sphere on magnets can be turned into the beam



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

Poisson-Alignment-System

Specification for experiments @ Argonne National Laboratory (1997):

Laser source:

laser diode, 635nm , 3 mW

Equipment:

10 μ m pinhole from platinum iridium

7,5cm diameter collimating lens

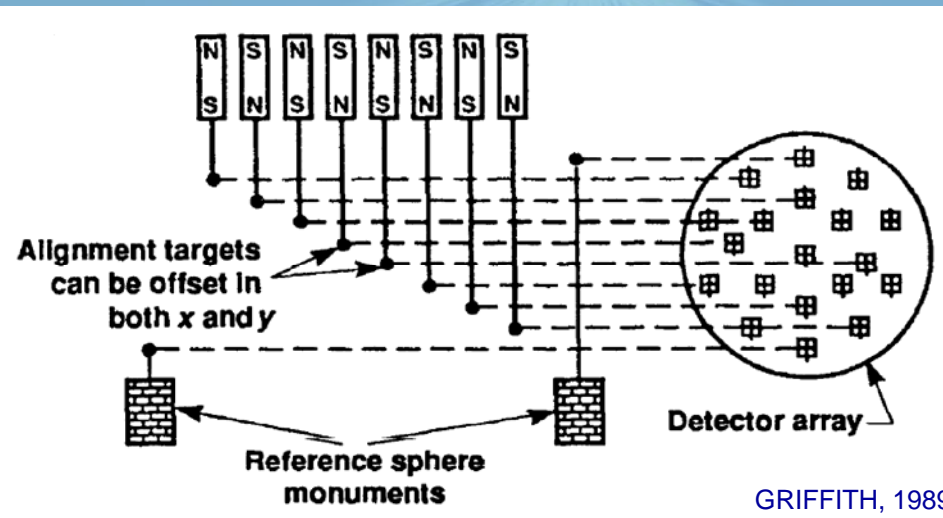
Detector:

quadrant silicon photovoltaic detector, -10V to +10V range

Measurement resolution :

+/- 25 μ m over 300m distance

FRIEDSAM, 1997



advanced system: detect many more Poisson spots

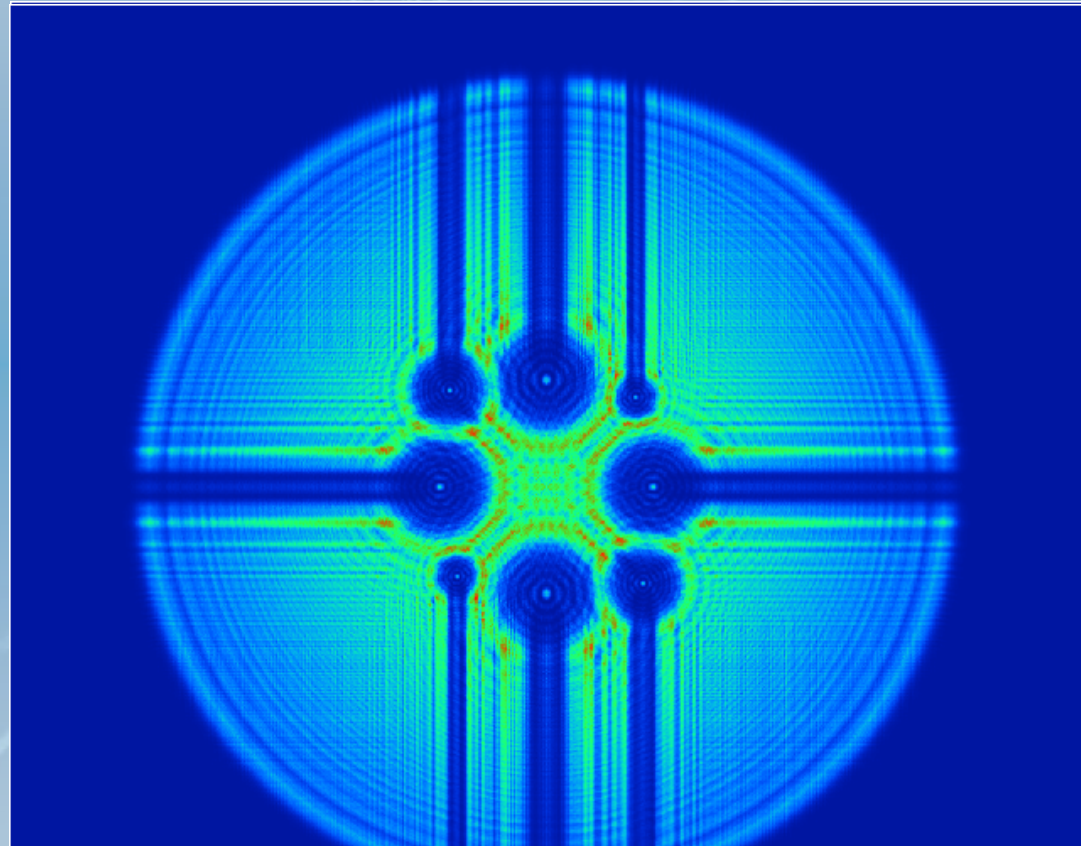


SLRS for XFEL @ DESY

Simulations

Poisson-Alignment-System

Various states of simulated images with ZEMAX



the size and quality of the Poisson spot depends on:

- the diameter of the sphere
- their respective distance to the detector

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

NEW PROJECTS

**Empirical tests
equipment**

Poisson-Alignment-System

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

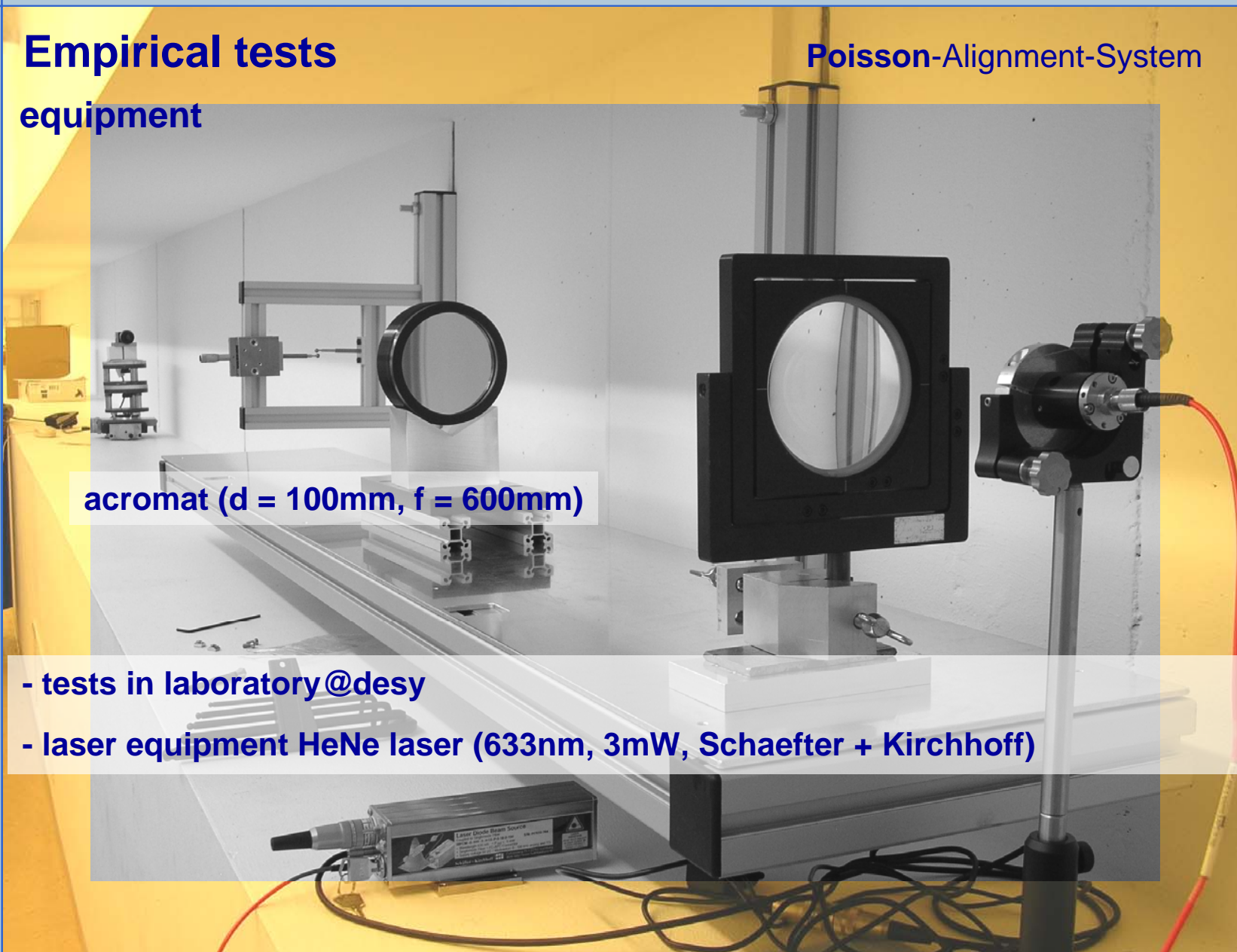
DIRECT LIGHT
SOURCE

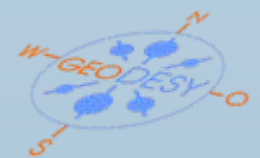
SUMMARY

FUTURE
DEVELOPMENT

acromat ($d = 100\text{mm}$, $f = 600\text{mm}$)

- tests in laboratory@desy
- laser equipment HeNe laser (633nm, 3mW, Schaefer + Kirchhoff)





SLRS for XFEL @ DESY

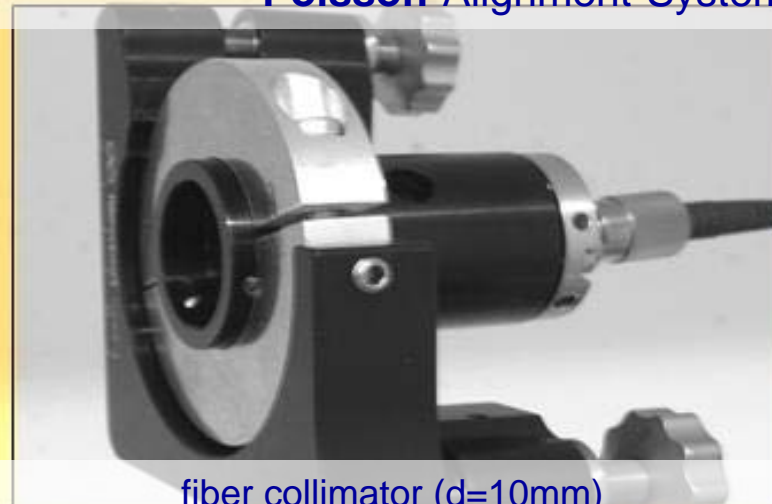
Empirical tests

equipment



lens (d=100mm, f=120mm)

Poisson-Alignment-System



fiber collimator (d=10mm)



two spheres with holders

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

Empirical tests

Poisson-Alignment-System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

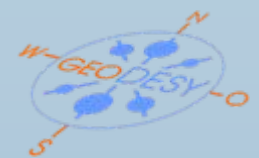
SUMMARY

FUTURE
DEVELOPMENT

setup length	spheres	diameters	distance: sphere to CCD
55m	4	2 x 10mm 2 x 12mm	23m 41m
5m	2	8mm	3m
1.7m	2	4mm	1.5m

micrometer stage for **controlled** translation

translation of spheres **perpendicular** to beam



SLRS for XFEL @ DESY

1st setup: 55m in length

Poisson-Alignment-System

NEW PROJECTS

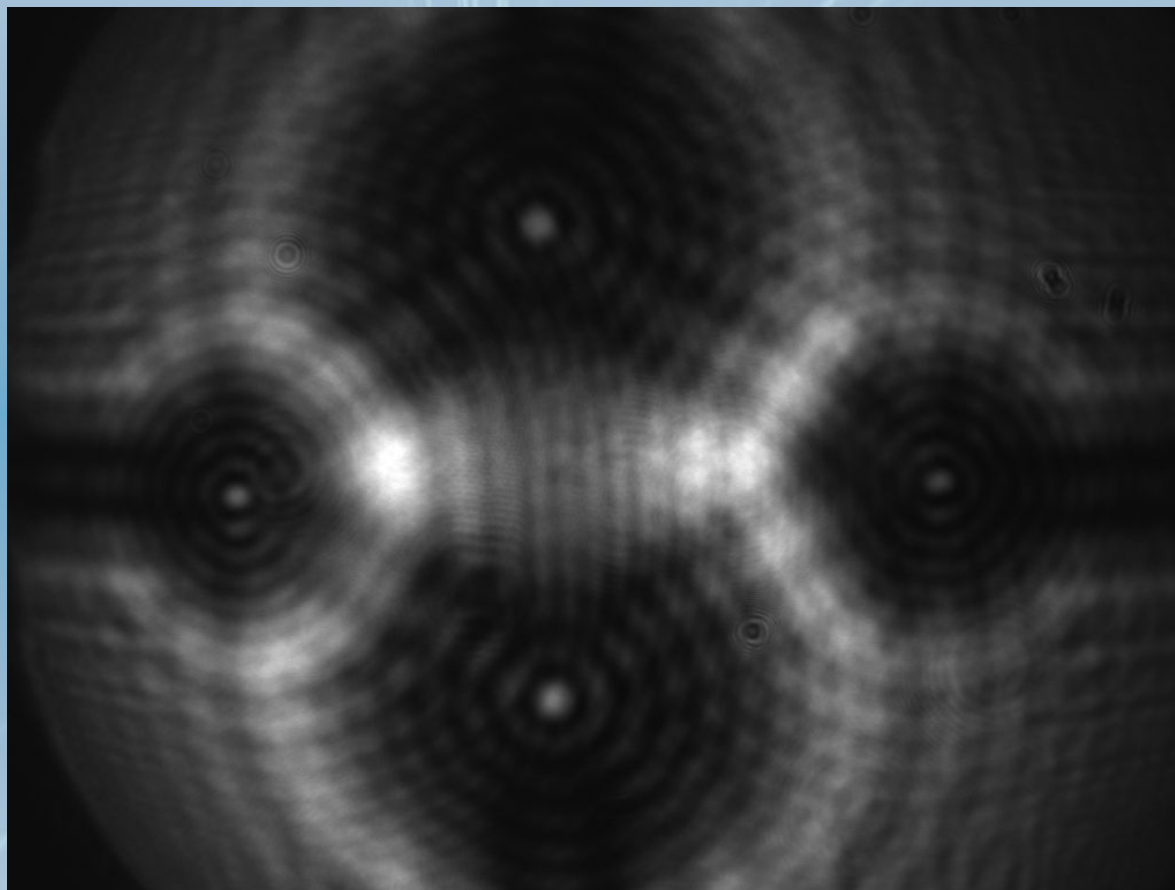
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

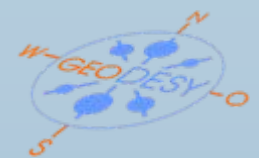
SUMMARY

FUTURE
DEVELOPMENT



real image of four spots from a sony ½" CCD-Chip camera

impossible to analyse because of air flicker



SLRS for XFEL @ DESY

2nd setup: **5m** in length

Poisson-Alignment-System

NEW PROJECTS

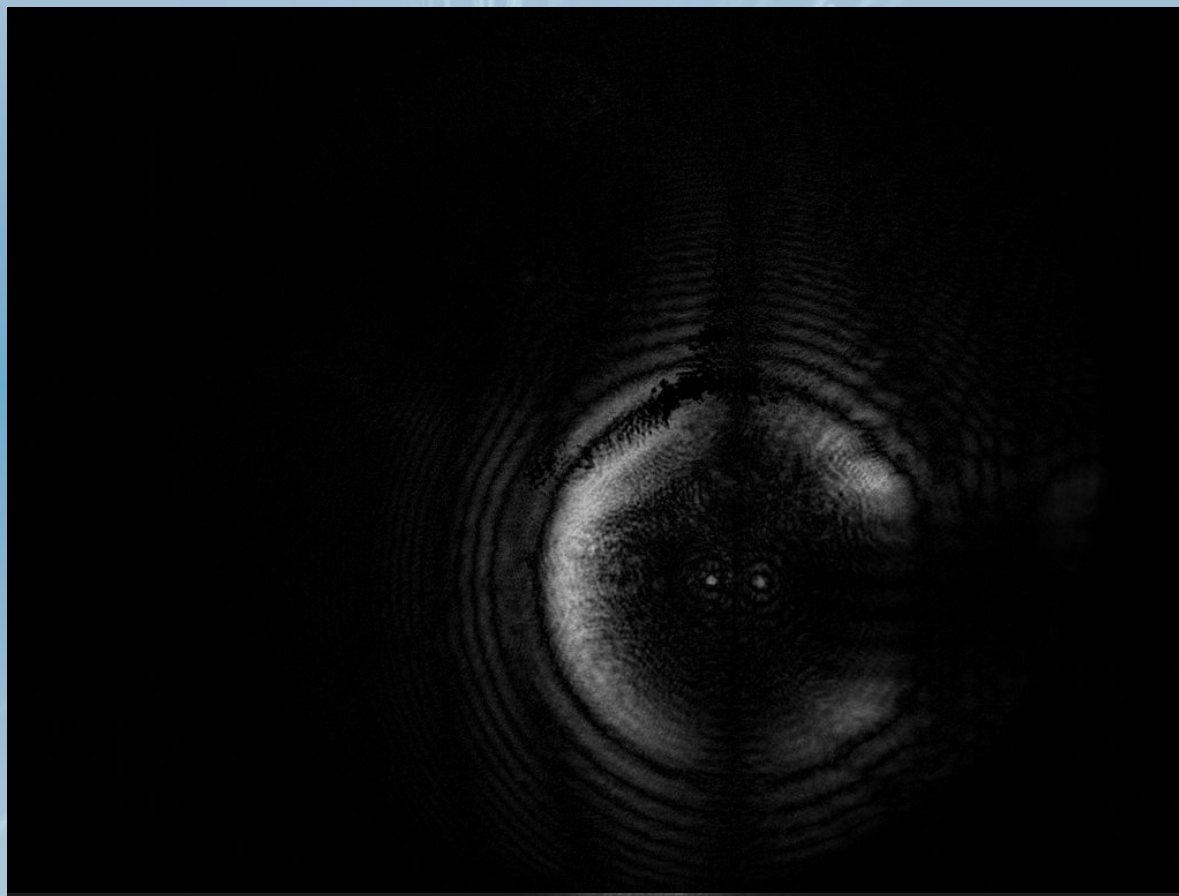
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



calculated difference between two consecutive images



SLRS for XFEL @ DESY

2nd setup: 5m in length

Poisson-Alignment-System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



after a binary transformation



SLRS for XFEL @ DESY

2nd setup: 5m in length

Poisson-Alignment-System

NEW PROJECTS

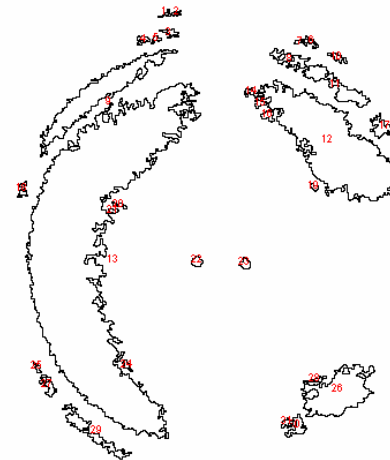
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



using an edge operator: not useful



SLRS for XFEL @ DESY

2nd setup: 5m in length

Poisson-Alignment-System

NEW PROJECTS

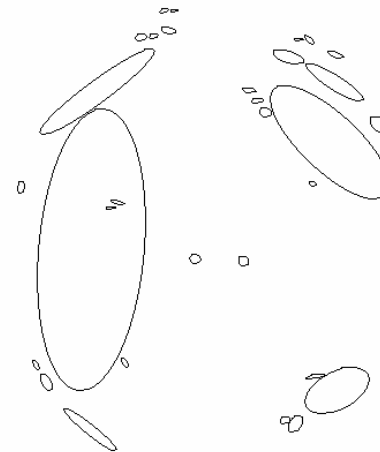
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



results of an ellipse operator



SLRS for XFEL @ DESY

2nd setup: **5m** in length

Poisson-Alignment-System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

nominal [mm]	actual distance by different image processing methods [mm]		error [µm]	
	<i>differential image</i>	<i>difference between two single images</i>	<i>differential image</i>	<i>difference between two single images</i>
0,99	0,9883	0,9916	16	-16
1,00	0,9991	1,0009	9	-9

mean error between translation and calculated distance = 12 microns



SLRS for XFEL @ DESY

NEW PROJECTS

3rd setup: 1.7m in length

Poisson-Alignment-System

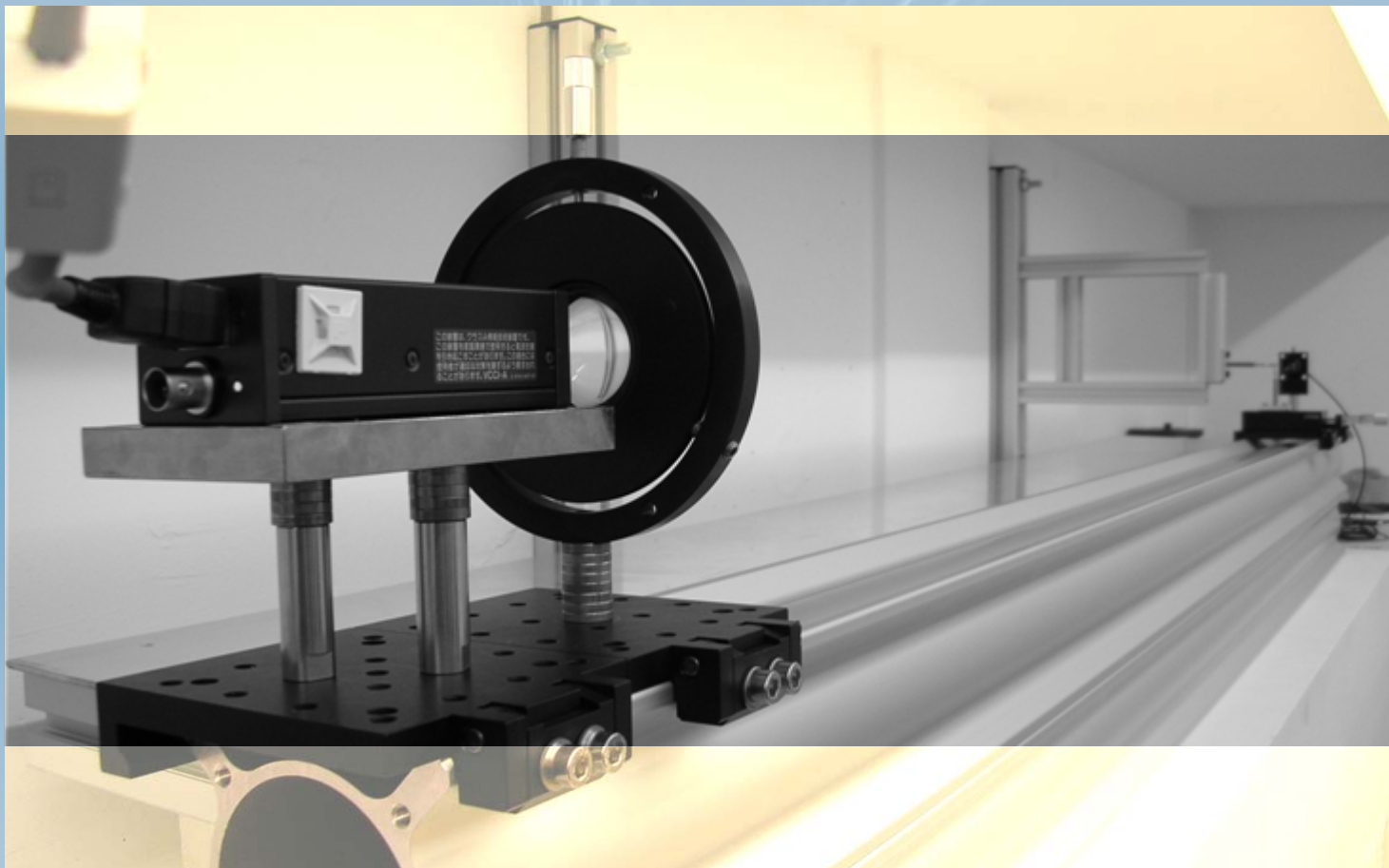
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



sony camera with convex lens ($d = 50\text{mm}$, $f = 50\text{mm}$)



SLRS for XFEL @ DESY

NEW PROJECTS

3rd setup: **1.7m** in length

Poisson-Alignment-System

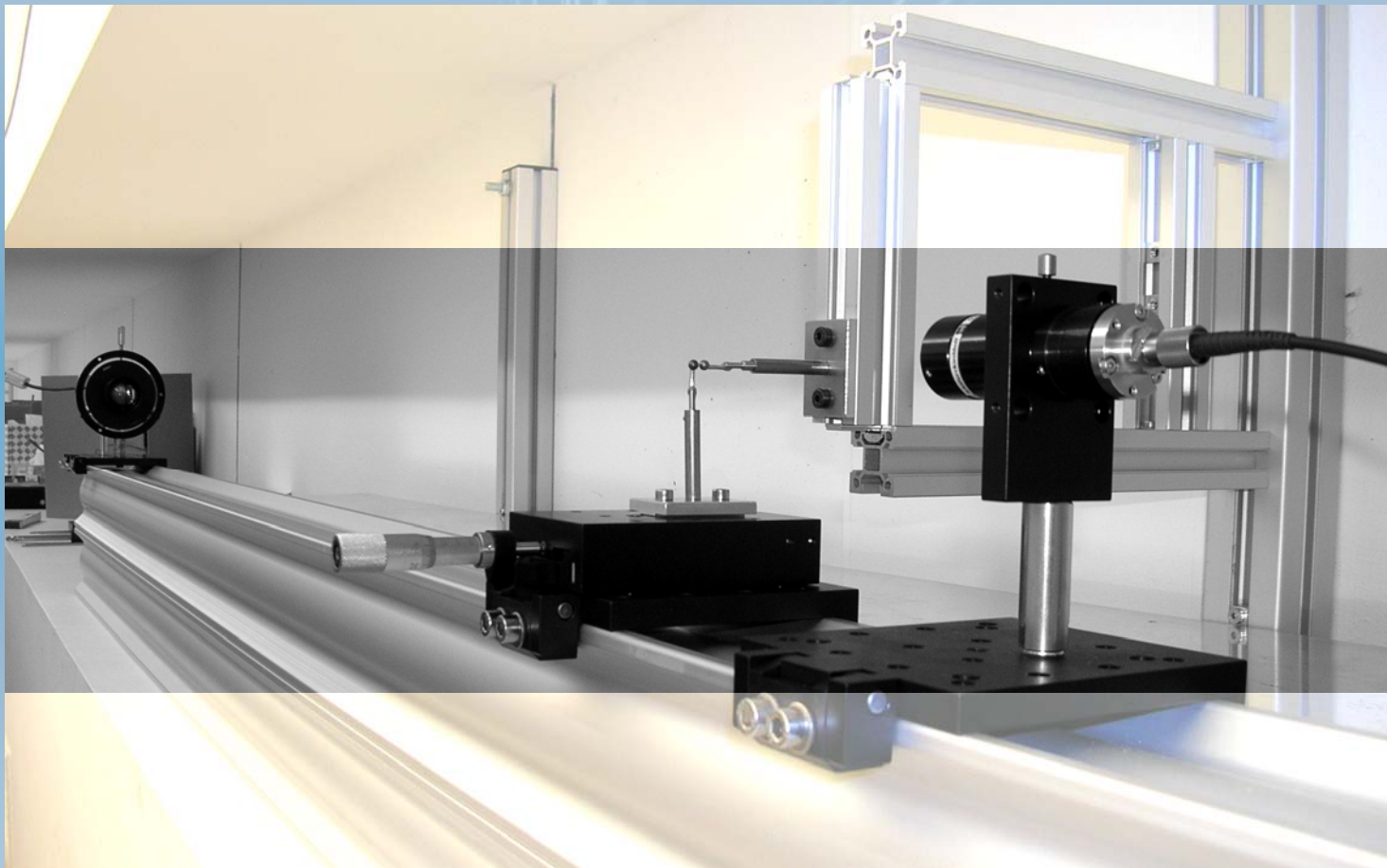
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

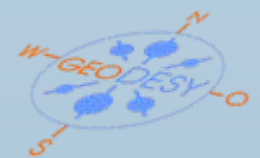
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



micrometer stage and two spheres with a diameter of 4mm



SLRS for XFEL @ DESY

NEW PROJECTS

3rd setup: **1.7m** in length

Poisson-Alignment-System

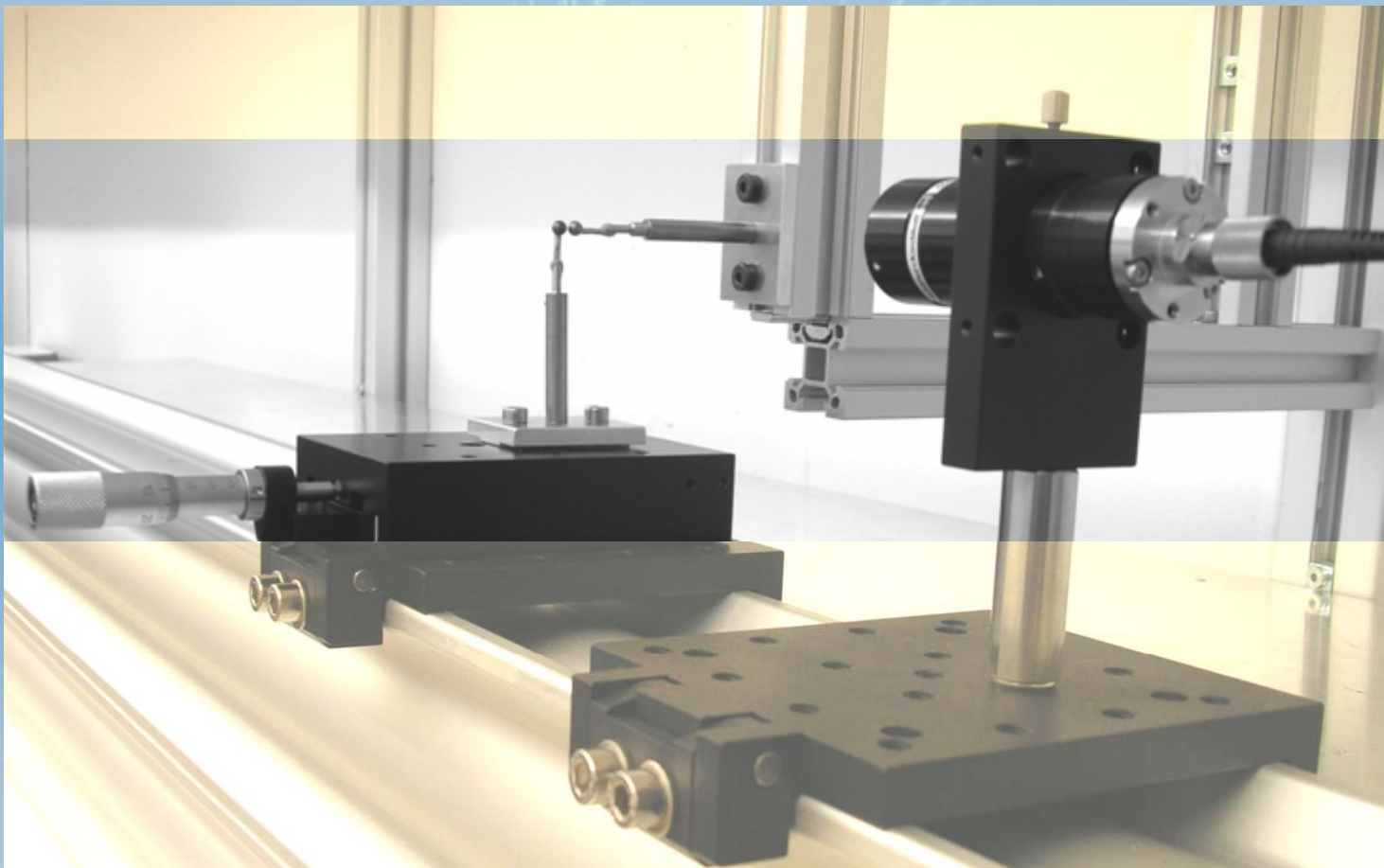
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



two spheres in expanded 10mm collimated laser beam



SLRS for XFEL @ DESY

NEW PROJECTS

3rd setup: **1.7m** in length

Poisson-Alignment-System

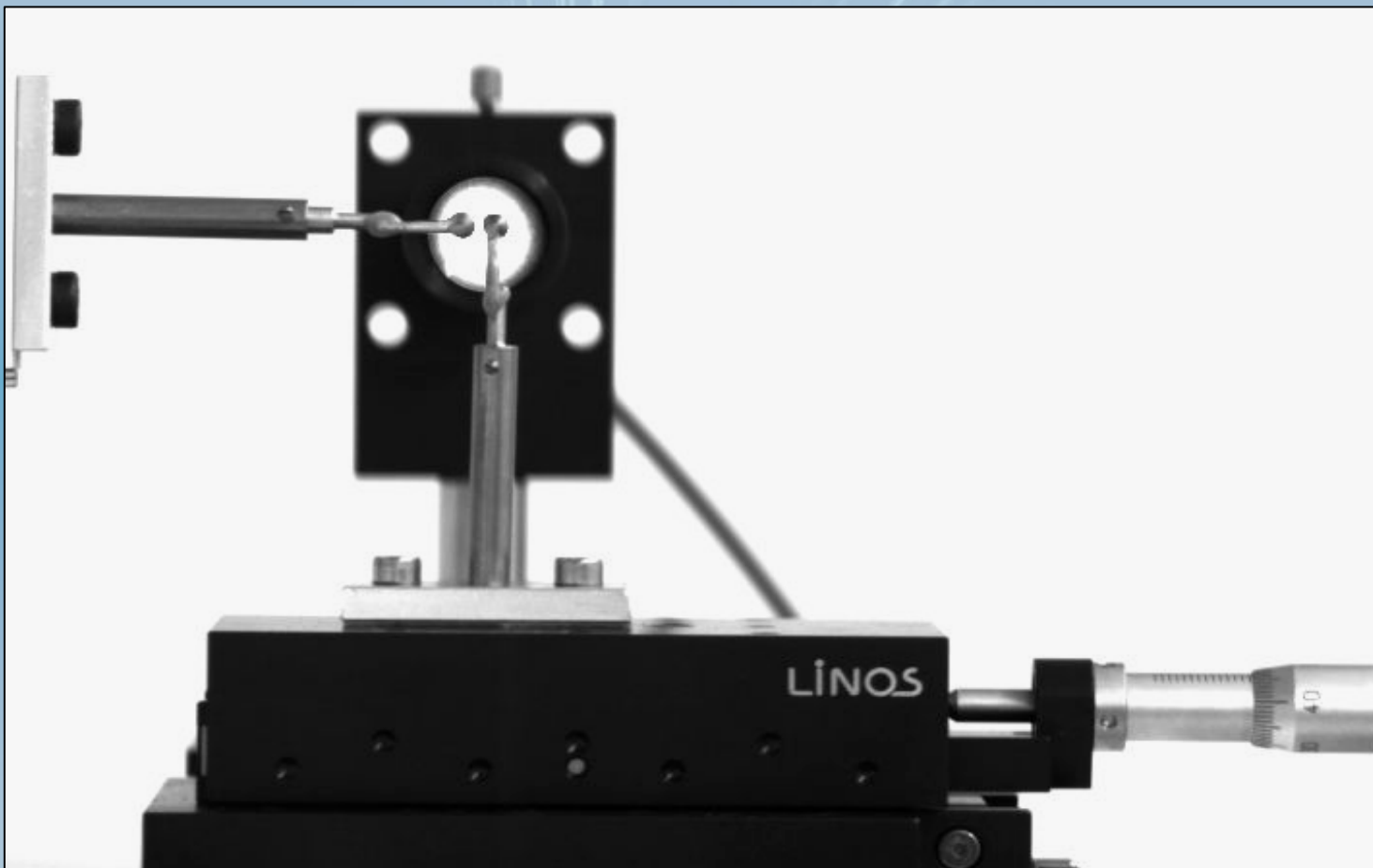
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



configuration of spheres in front of Camera



SLRS for XFEL @ DESY

NEW PROJECTS

3rd setup: **1.7m** in length

Poisson-Alignment-System

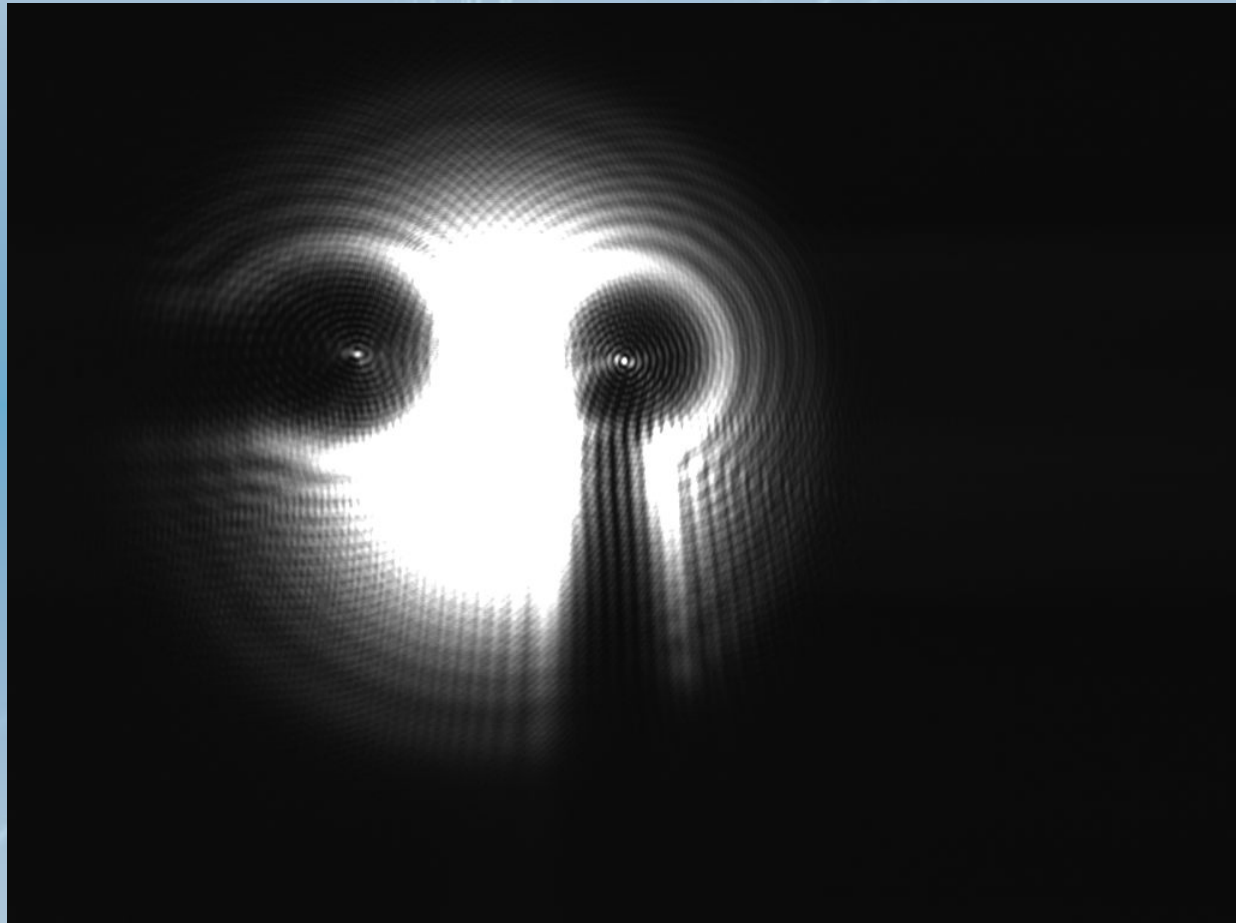
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



real image with two poisson spots



SLRS for XFEL @ DESY

3rd setup: **1.7m** in length

Poisson-Alignment-System

NEW PROJECTS

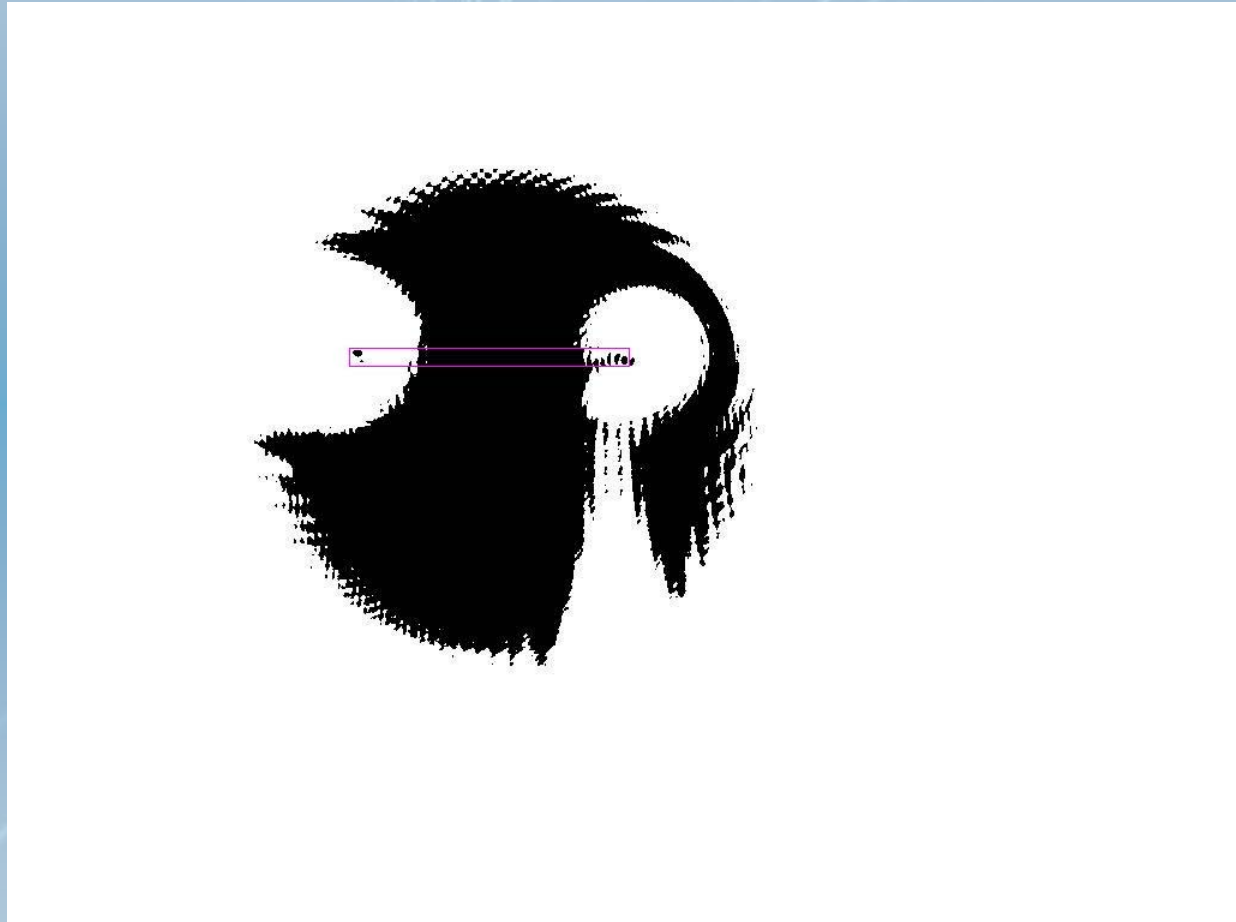
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

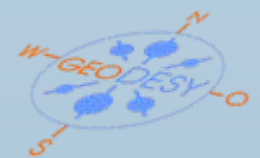
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



after a binary transformation



SLRS for XFEL @ DESY

3rd setup: **1.7m** in length

Poisson-Alignment-System

NEW PROJECTS

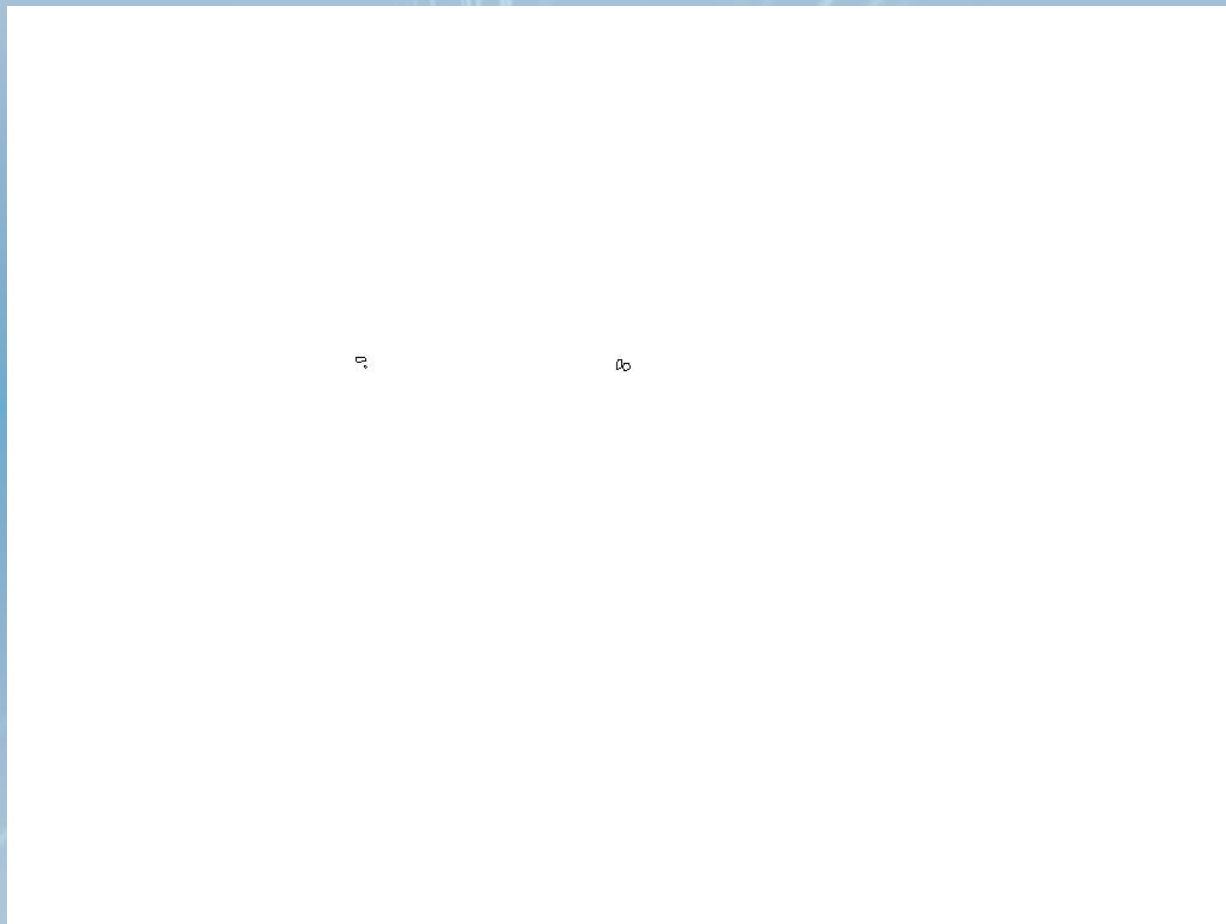
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

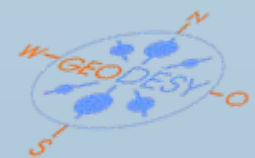
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



using ellipse operator



SLRS for XFEL @ DESY

3rd setup: **1.7m** in length

Poisson-Alignment-System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

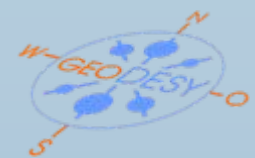
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

translation of sphere [mm]	error of translation detection [μm]			
	1st epoch	2nd epoch	3rd epoch	4th epoch
0.00	0	0	0	0
0.20	-2	4	10	4
0.50	-5	4	4	4
1.00	-23	-16	-15	-12
2.00	-21	-18	-15	-20

mean error from this setup is 17 microns



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

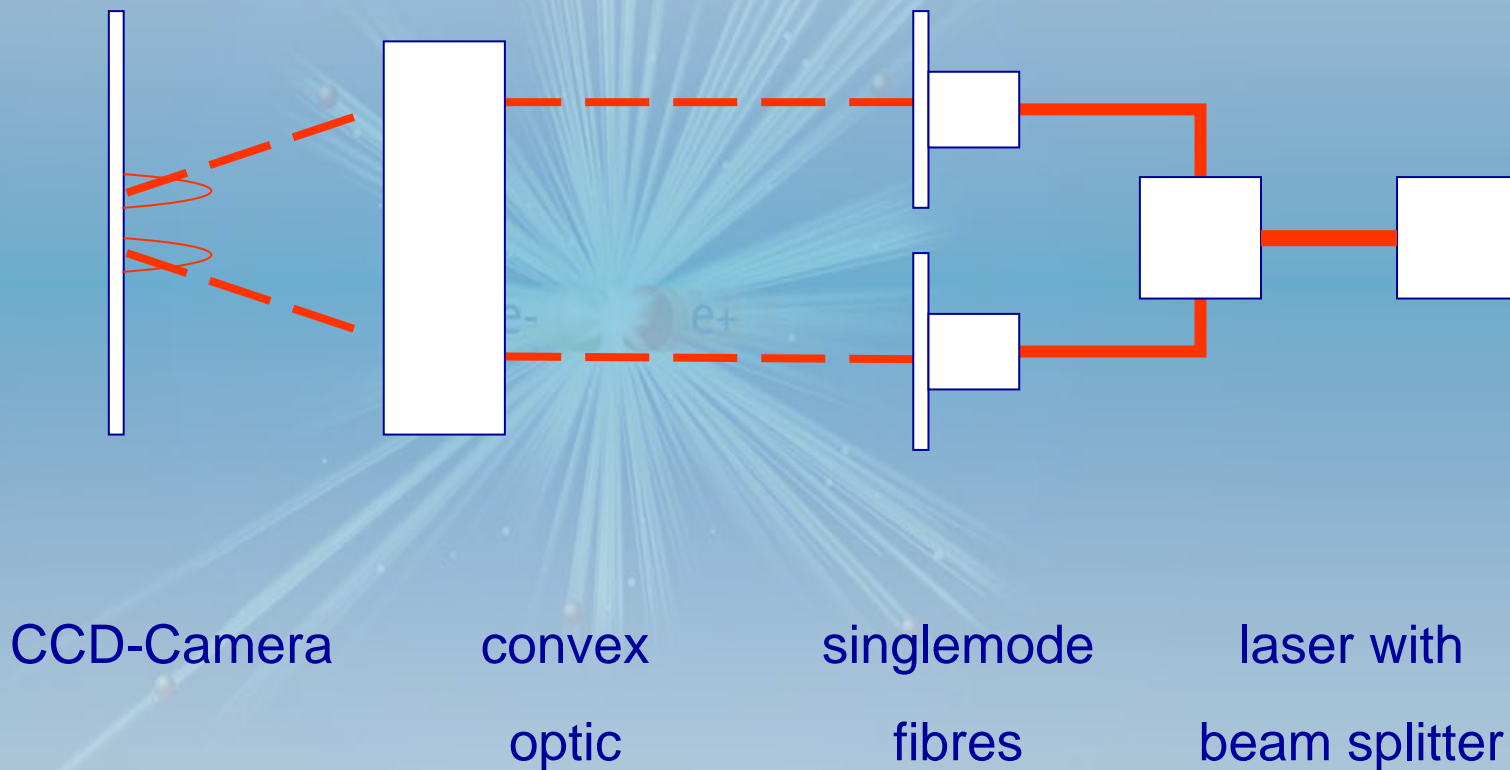
POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

Direct light source System





SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

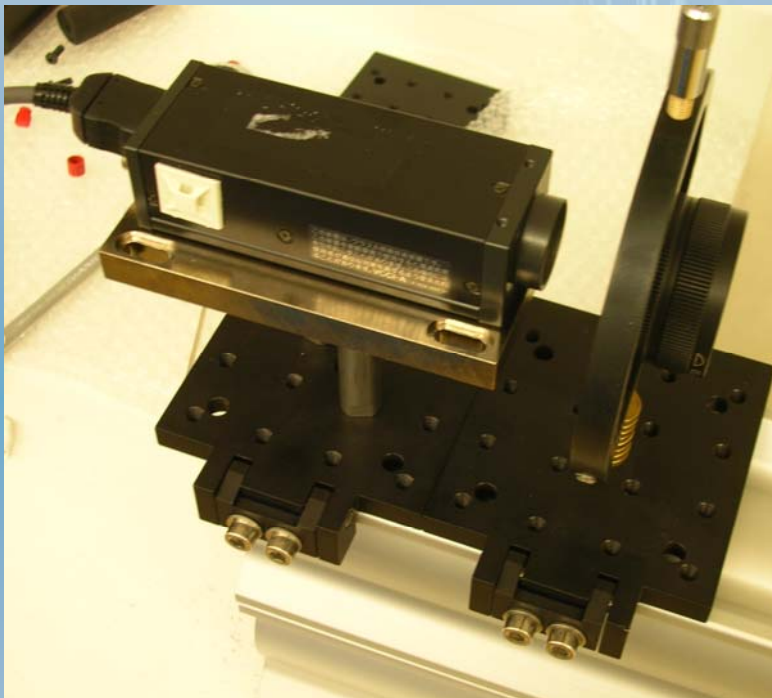
POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

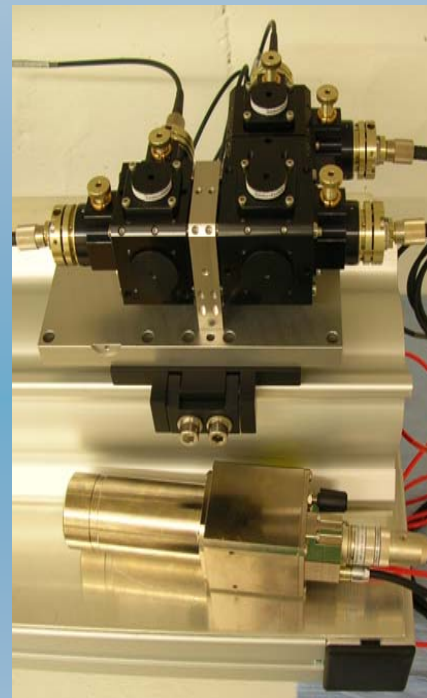
Direct light source System



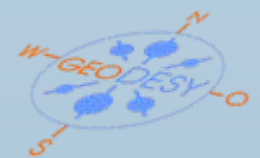
camera with
convex optic



singlemode
fibres



laser with
beam splitter



SLRS for XFEL @ DESY

1st setup: 1.2m in length

Direct light source System

NEW PROJECTS

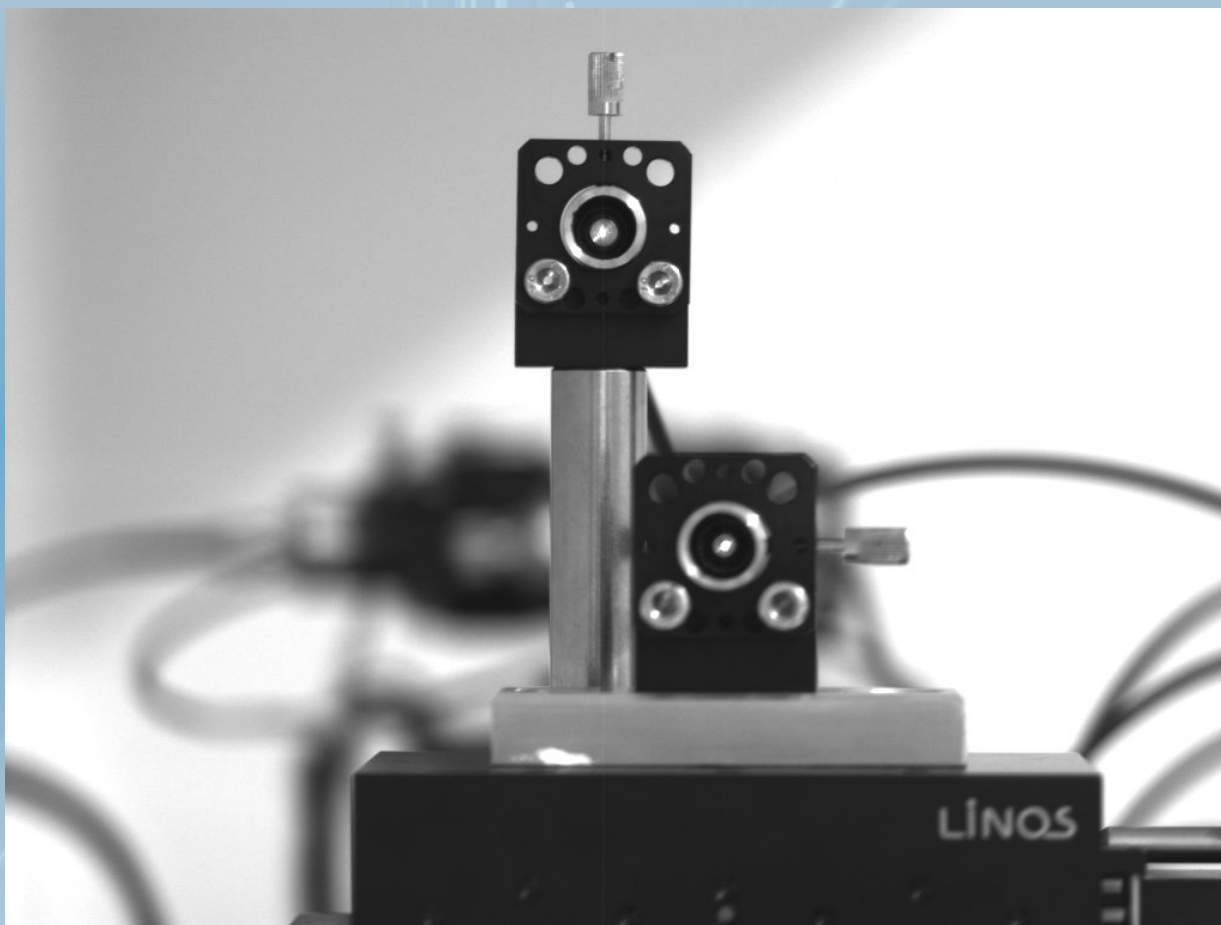
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

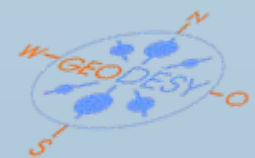
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



configuration of fibre optics in front of camera



SLRS for XFEL @ DESY

1st setup: 1.2m in length

Direct light source System

NEW PROJECTS

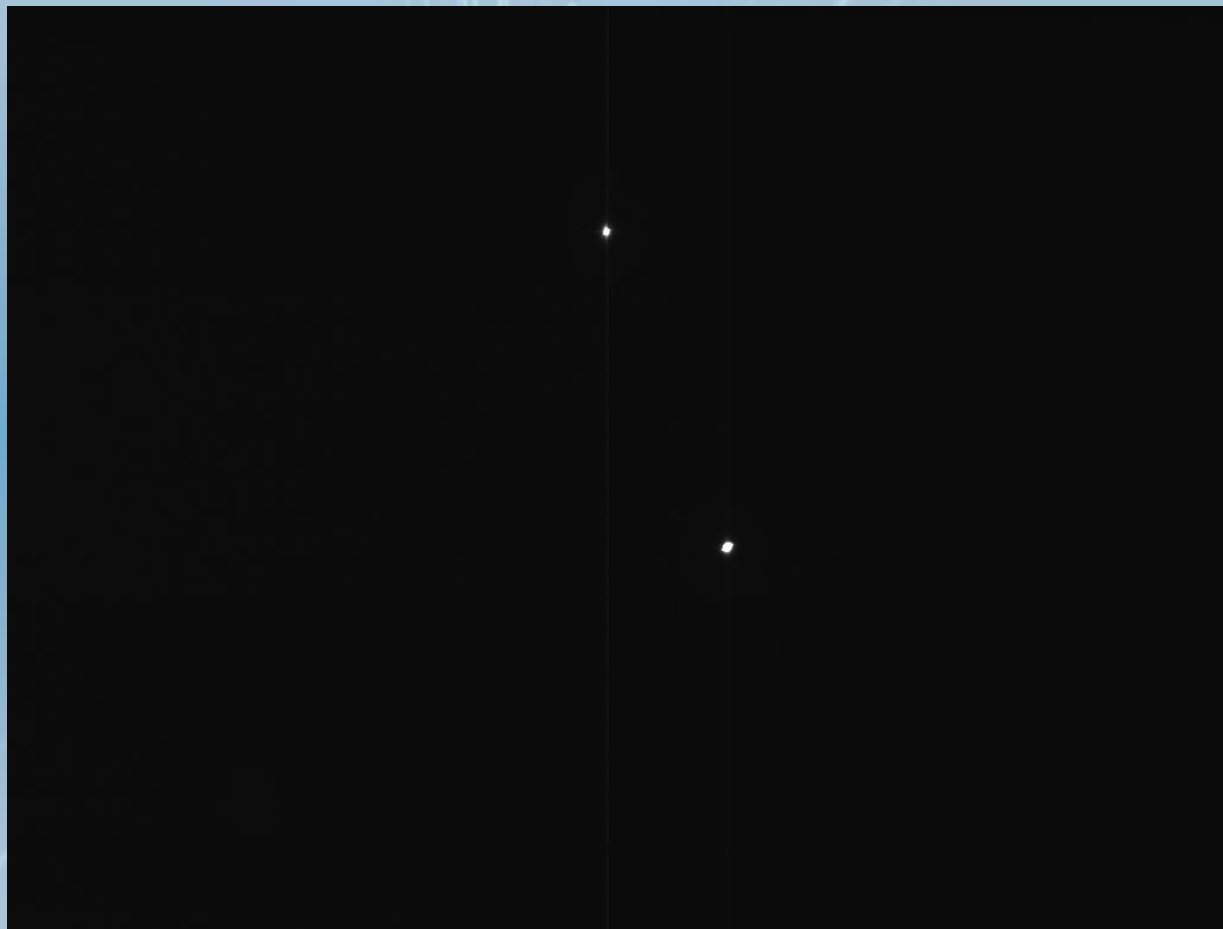
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

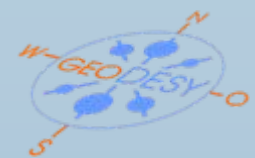
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



first real image with two spots from fibre optics



SLRS for XFEL @ DESY

1st setup: 1.2m in length

Direct light source System

NEW PROJECTS

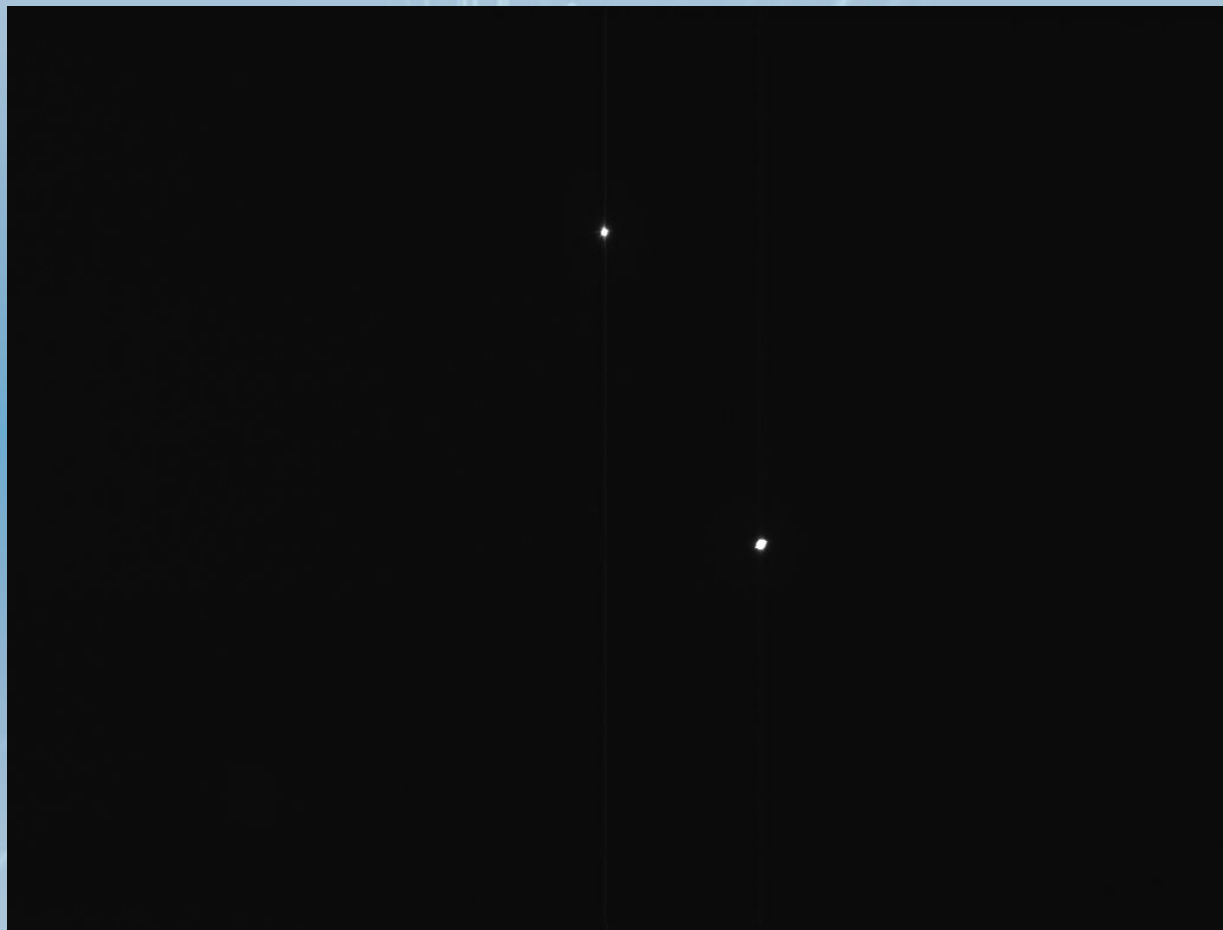
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



next image after a translation of one fibre optics



SLRS for XFEL @ DESY

1st setup: 1.2m in length

Direct light source System

NEW PROJECTS

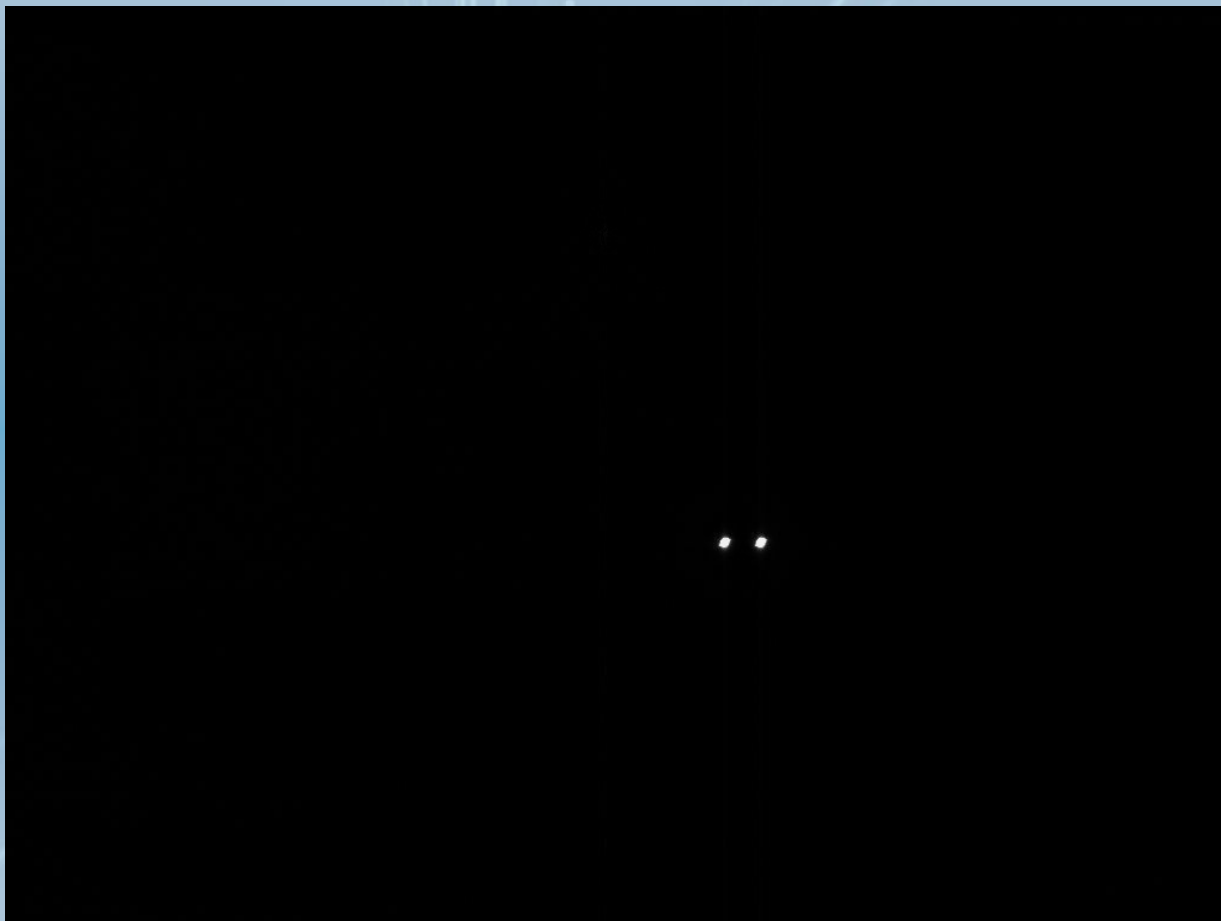
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

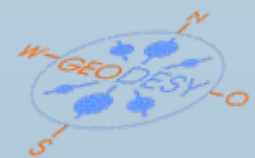
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



calculated difference between two consecutive images



SLRS for XFEL @ DESY

1st setup: 1.2m in length

Direct light source System

NEW PROJECTS

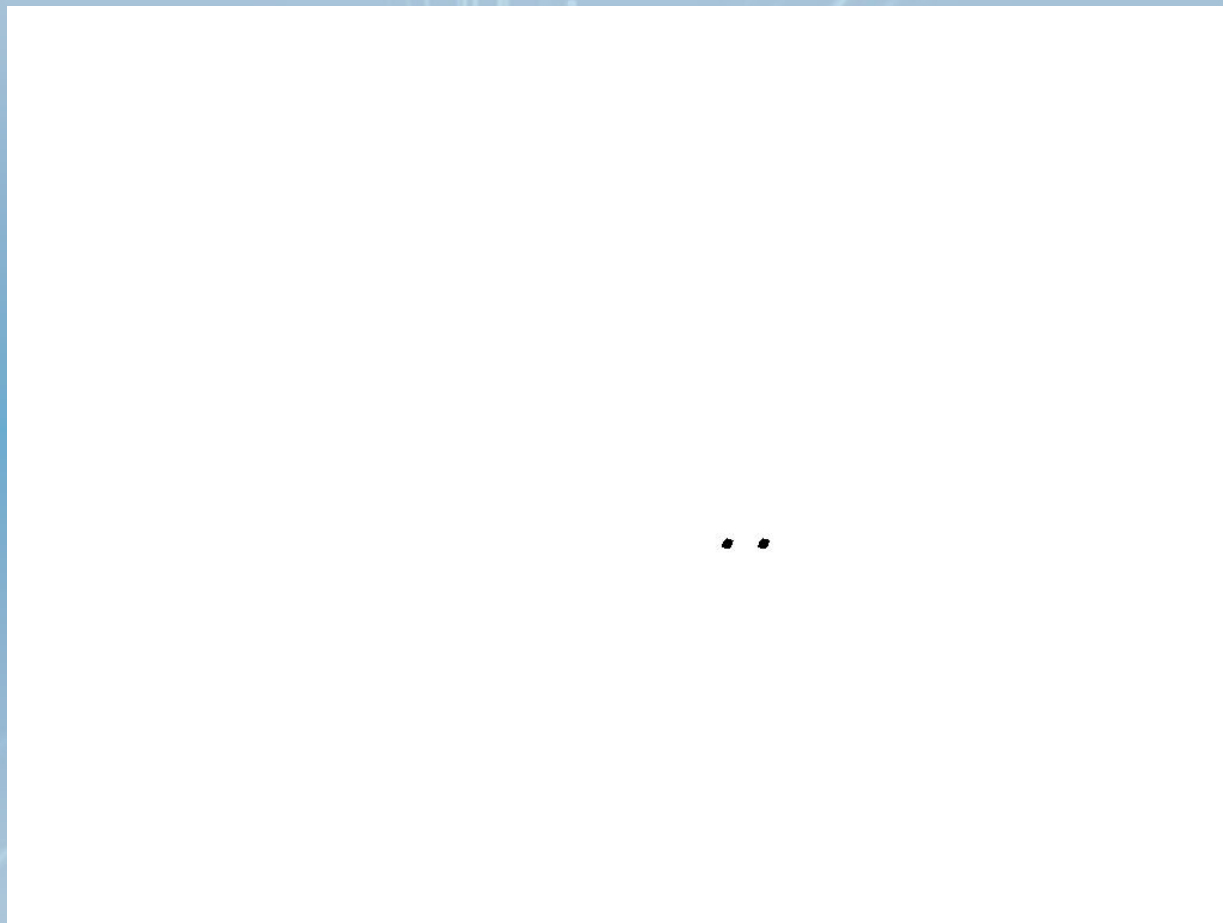
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



after a binary transformation



SLRS for XFEL @ DESY

1st setup: 1.2m in length

Direct light source System

NEW PROJECTS

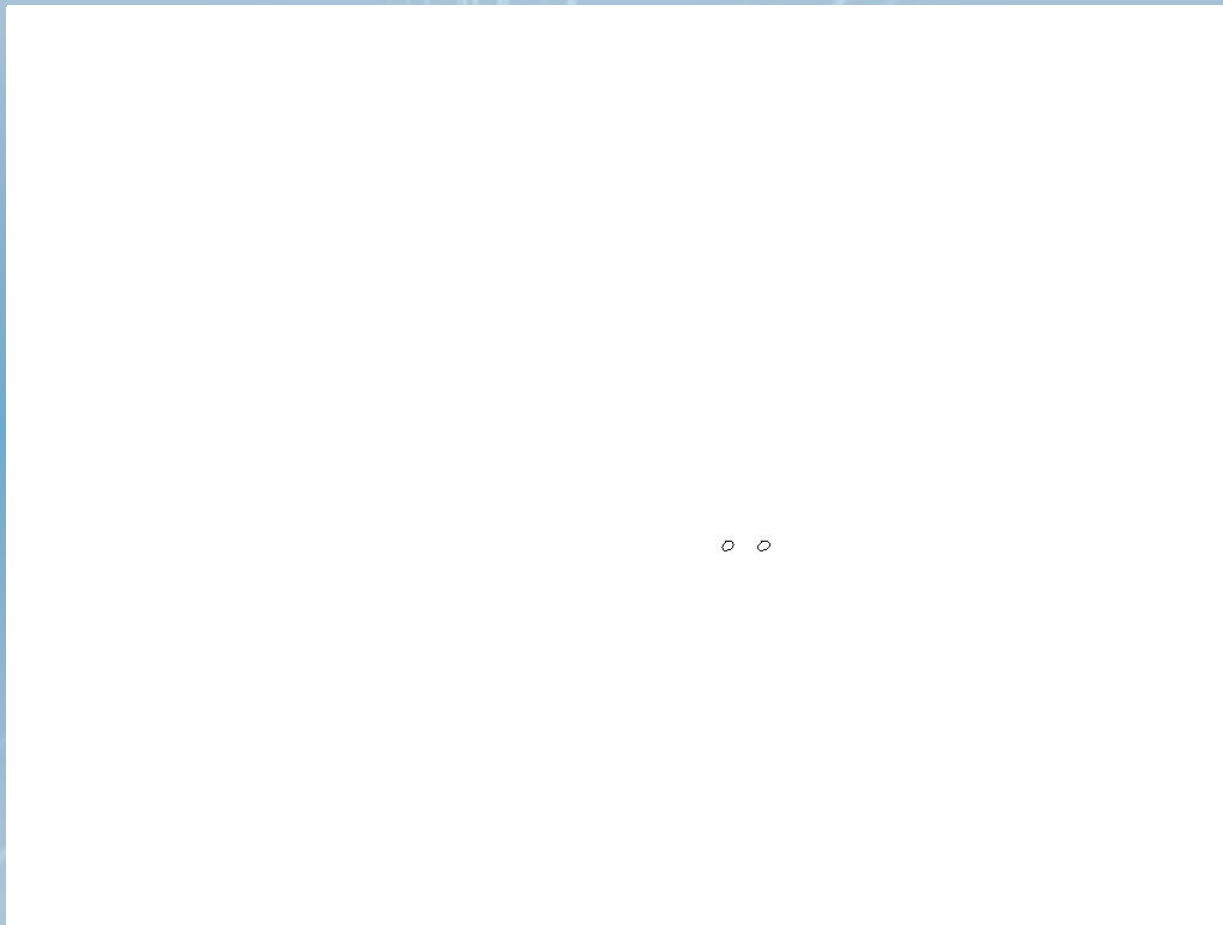
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



using ellipse operator



SLRS for XFEL @ DESY

1st setup: **1.2m** in length

Direct light source System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

	translation of fibre optic [mm]	distance from image processing [mm]	error [μm]
1st + 4th image	5.00	4.996	4
2nd + 4th image	4.80	4.799	1
3rd + 4th image	4.00	4.004	4

mean error between translation and calculated distance = 3 microns



SLRS for XFEL @ DESY

2nd setup: **1.7m** in length

Direct light source System

NEW PROJECTS

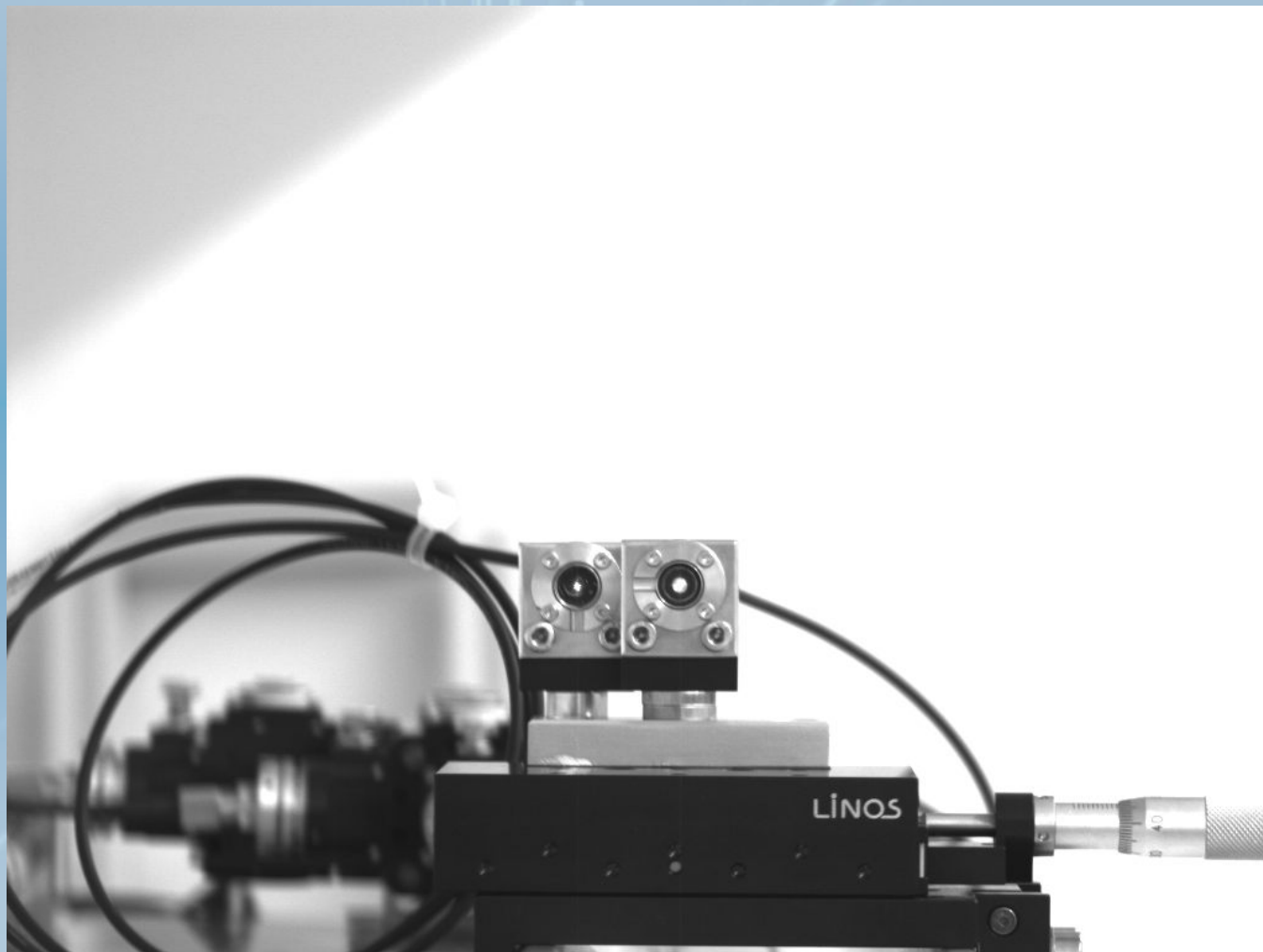
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

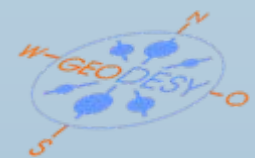
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



configuration of fibre optics in front of camera



SLRS for XFEL @ DESY

2nd setup: **1.7m** in length

Direct light source System

NEW PROJECTS

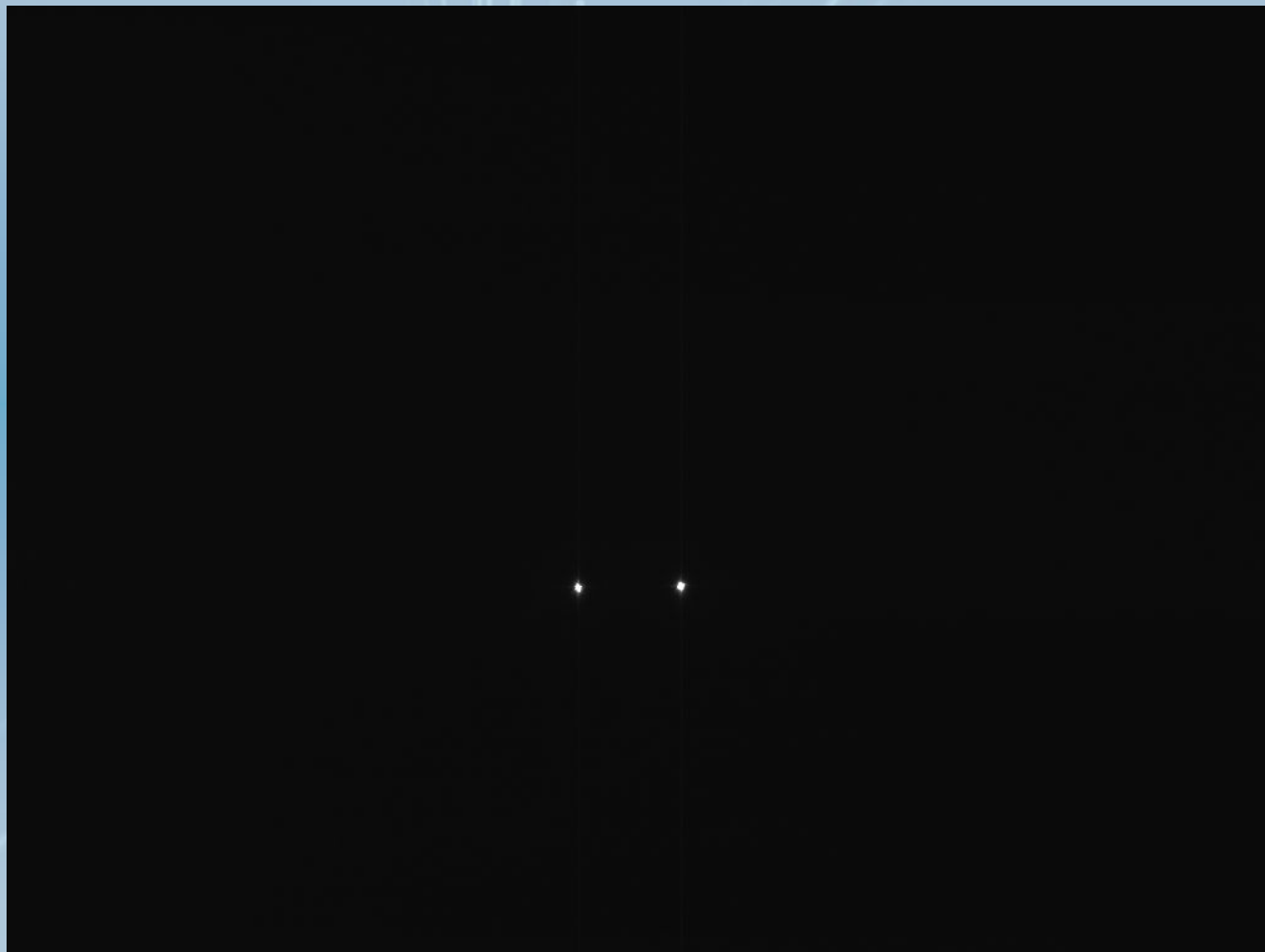
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

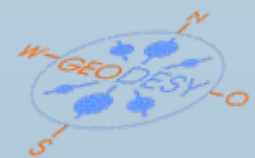
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



first real image with two spots from fibre optics



SLRS for XFEL @ DESY

2nd setup: **1.7m** in length

Direct light source System

NEW PROJECTS

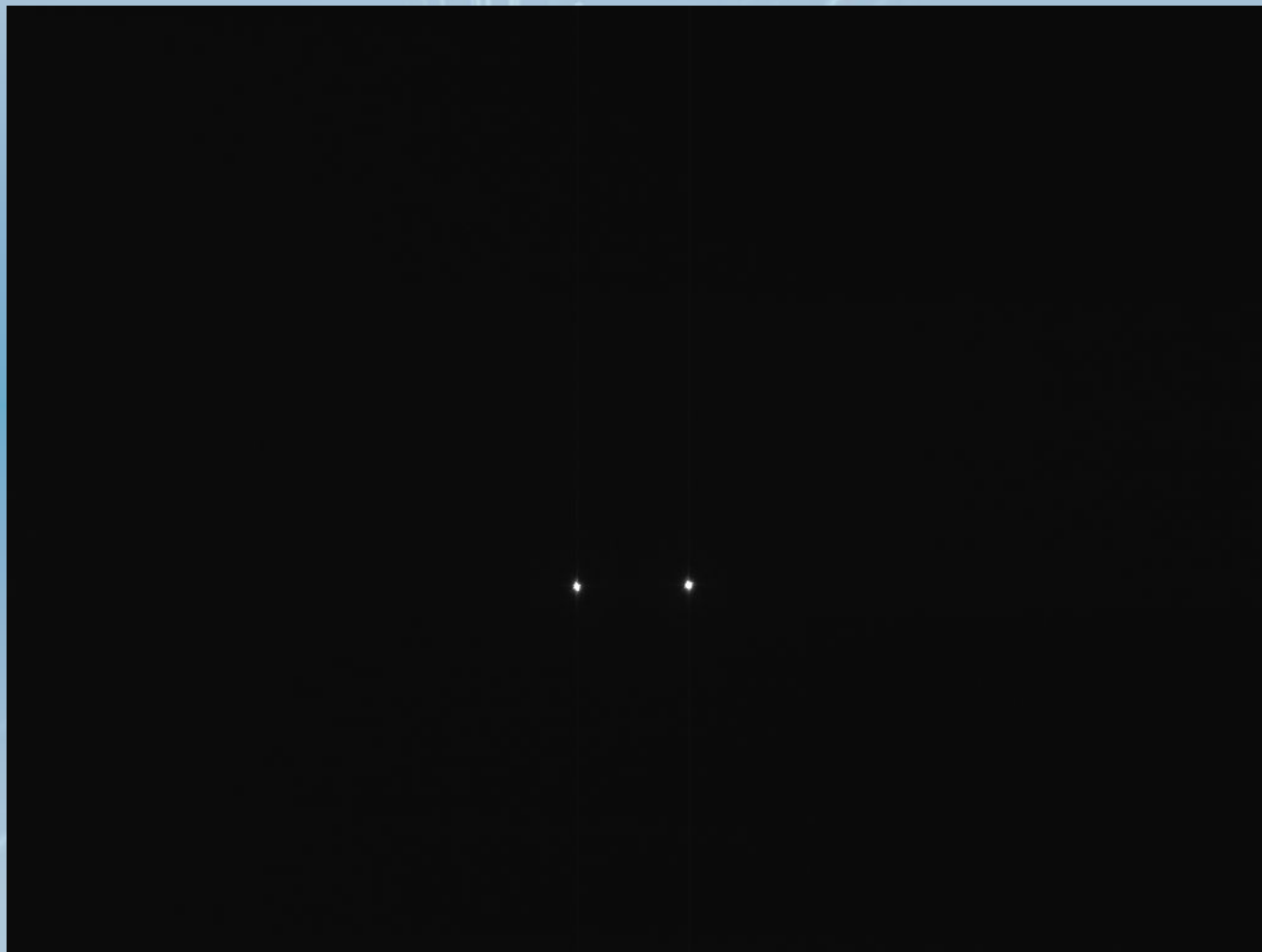
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

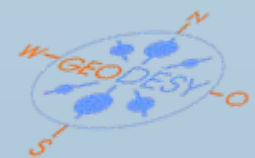
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



next image after a translation of one fibre optics



SLRS for XFEL @ DESY

2nd setup: **1.7m** in length

Direct light source System

NEW PROJECTS

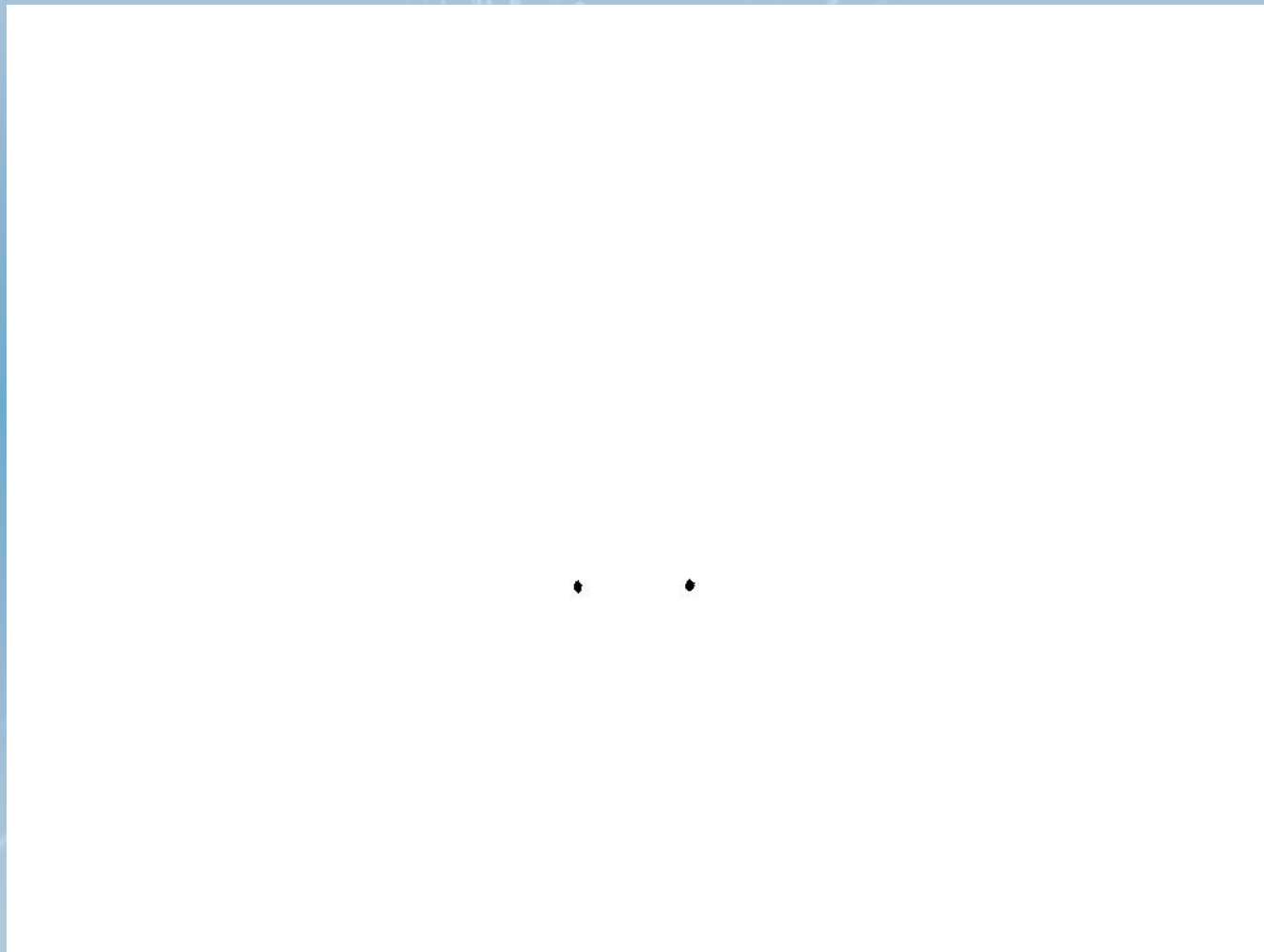
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

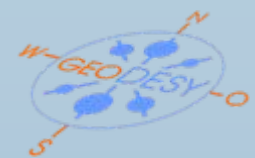
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



after a binary transformation



SLRS for XFEL @ DESY

2nd setup: **1.7m** in length

Direct light source System

NEW PROJECTS

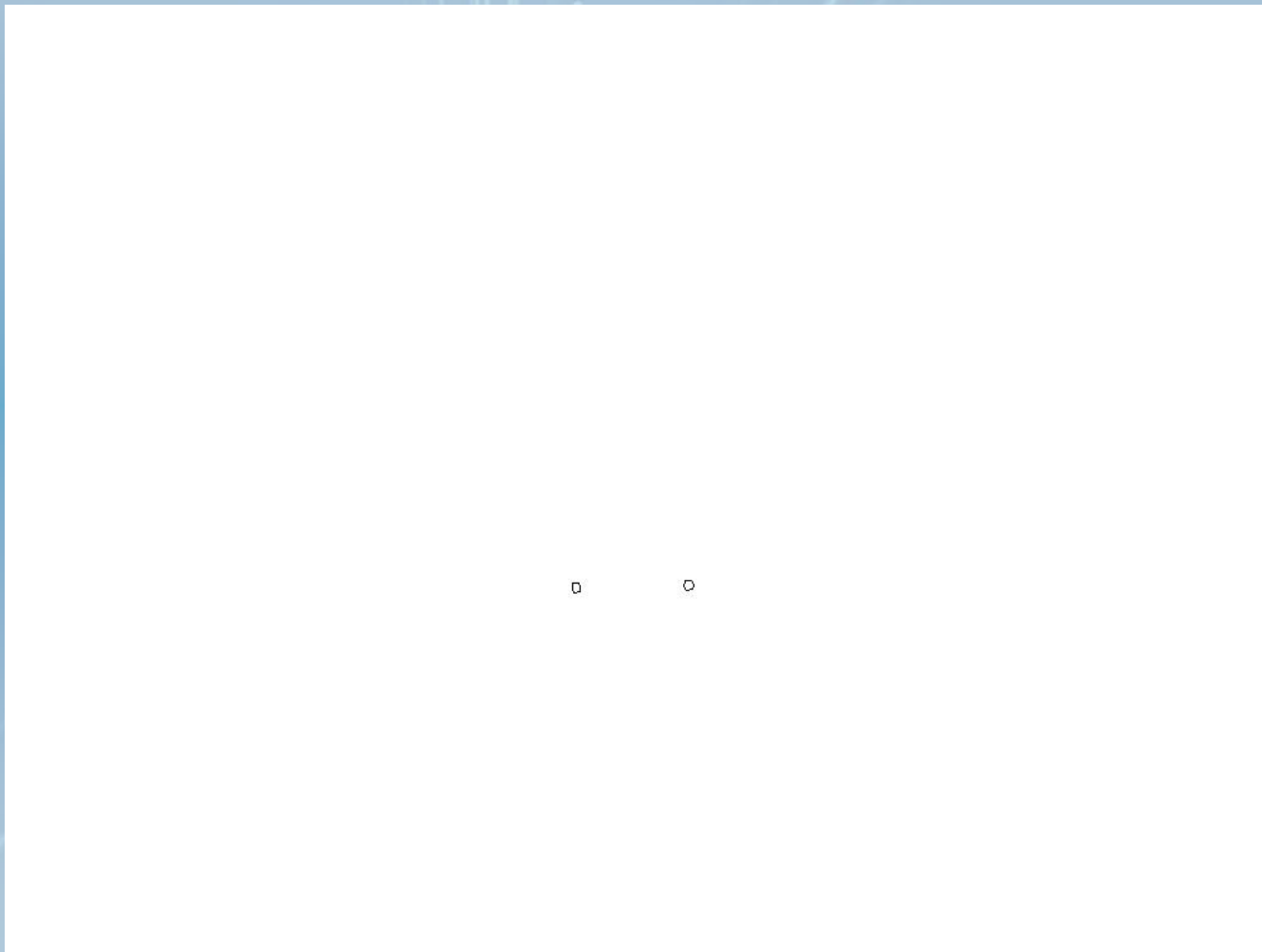
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

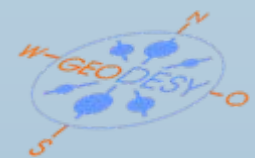
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT



using ellipse operator



SLRS for XFEL @ DESY

2nd setup: **1.7m** in length

Direct light source System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

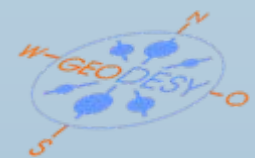
**DIRECT LIGHT
SOURCE**

SUMMARY

FUTURE
DEVELOPMENT

translation of fibre optic [mm]	error of translation detection [μm]			
	1st epoch	2nd epoch	3rd epoch	4th epoch
0.00	0	0	0	0
0.20	4	-2	0	-12
0.50	10	-5	7	-12
1.00	19	22	18	1
2.00	-5	-3	-5	-9

mean error from this setup is 10 microns



SLRS for XFEL @ DESY

Summary

NEW PROJECTS

SLRS @ XFEL

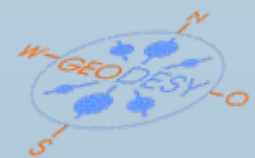
POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

	Poisson-Alignment-System	Direct light source System
mean error of translation detection [μm]	12	3
setup length [m]	5.0	1.2



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

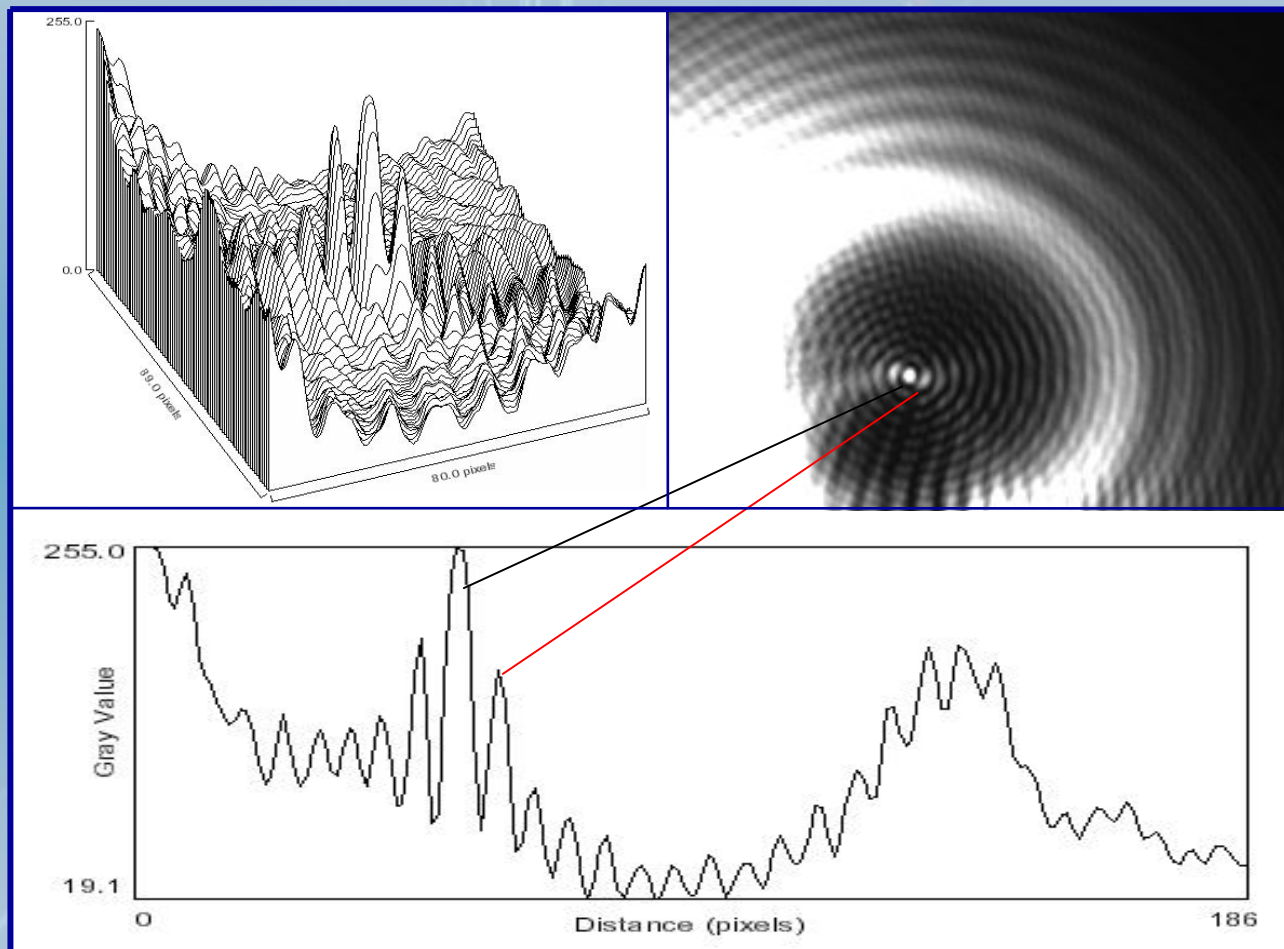
POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

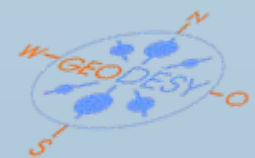
SUMMARY

FUTURE
DEVELOPMENT

Poisson-Alignment-System



multiple maxima are a problem for automatic calculations



SLRS for XFEL @ DESY

NEW PROJECTS

SLRS @ XFEL

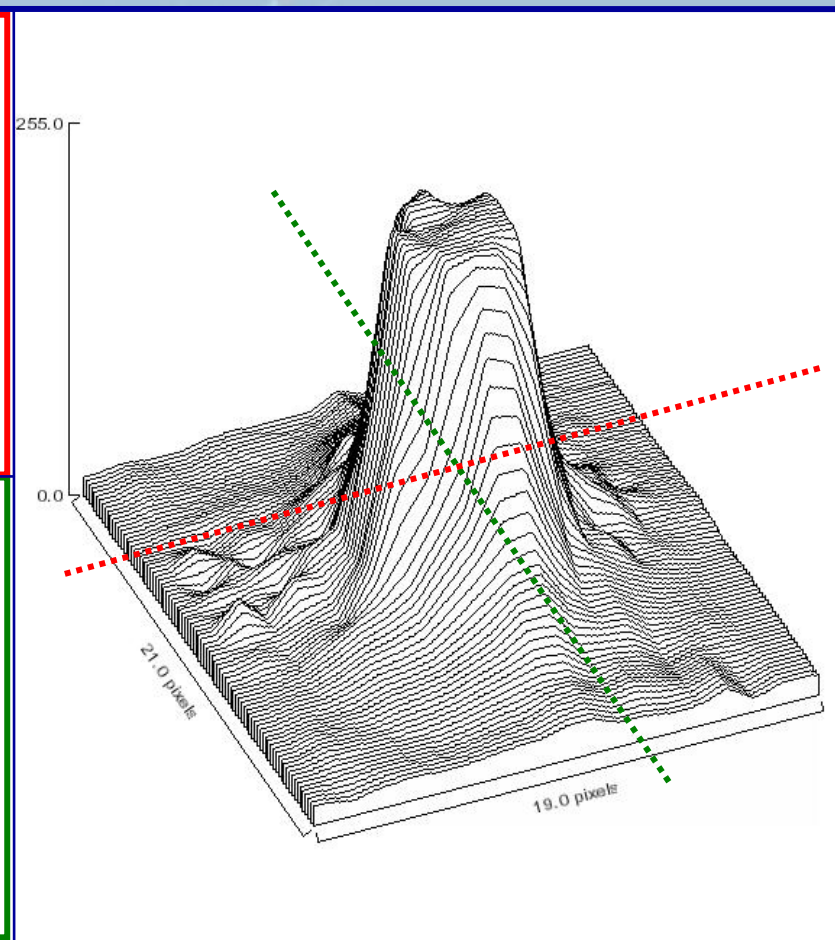
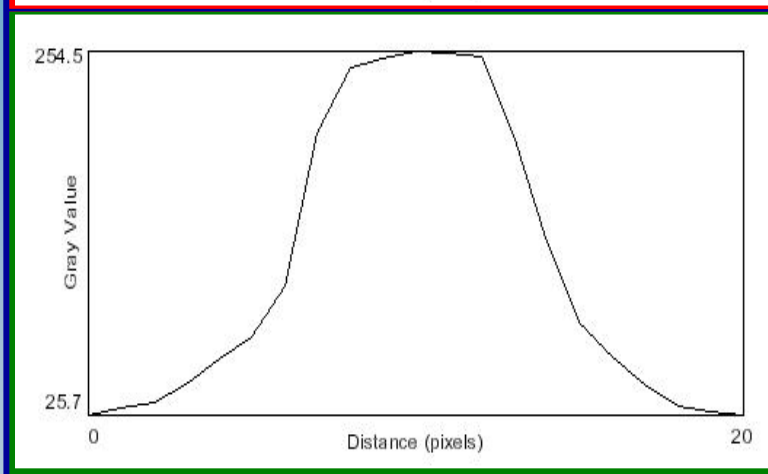
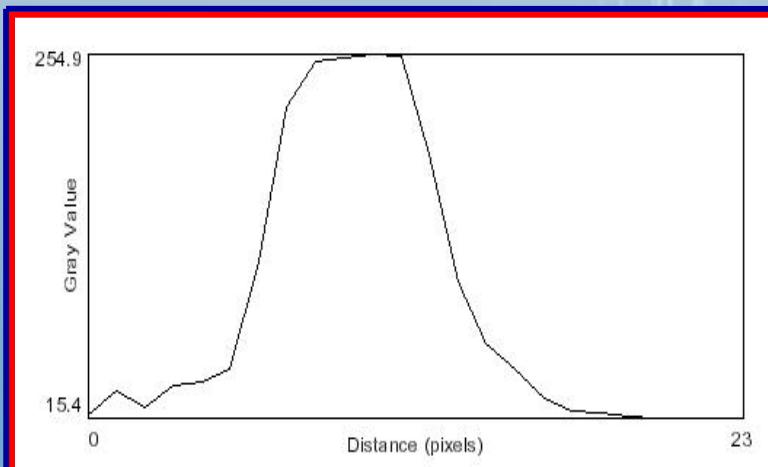
POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

Direct light source System



single maxima suitable for automatic calculations



SLRS for XFEL @ DESY

Future development

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

1. To work out the differences between both systems
 - Image processing (test various algorithms)
 - Precise measurement of translation (with interferometer)
 - Simulation for expanding and focusing of the beam (ZEMAX)
 - Build simulated optics
2. Tests with longer beam lengths
 - Build up a vacuum system for 55m in length
 - Using more fibre optics
 - 55m for direct light source system

Straight Line Reference System (SLRS) for the adjustment of the X-ray free-electron Laser (XFEL) @ DESY

Thank you...

