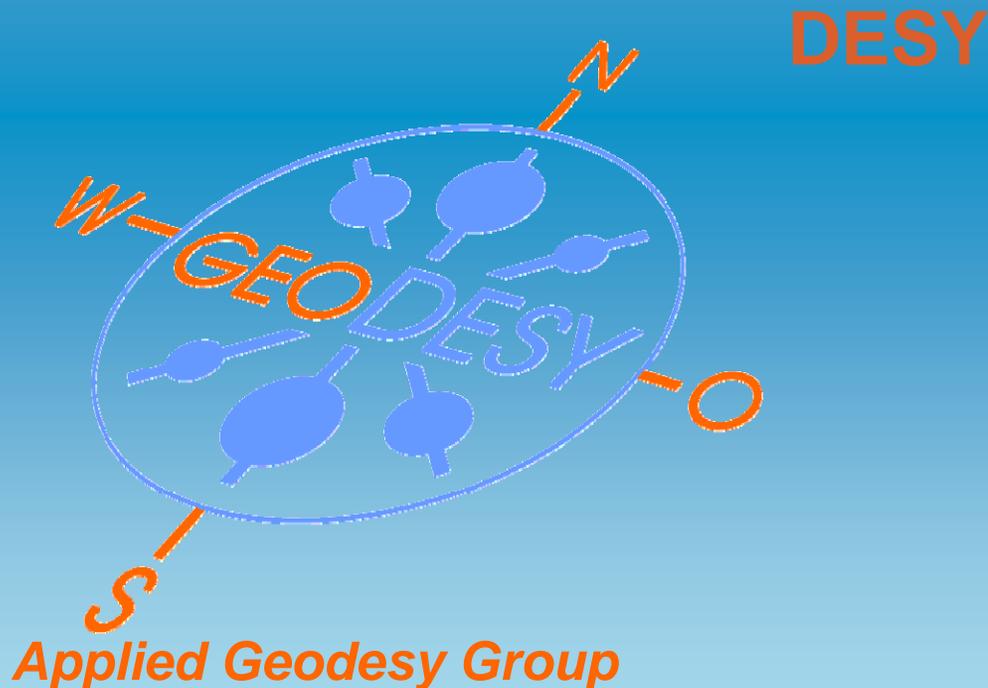


Straight Line Reference System (SLRS) for the adjustment of the X-ray free-electron Laser (XFEL) @ DESY

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**

Applied Geodesy Group



SLRS for XFEL @ DESY

NEW PROJECTS

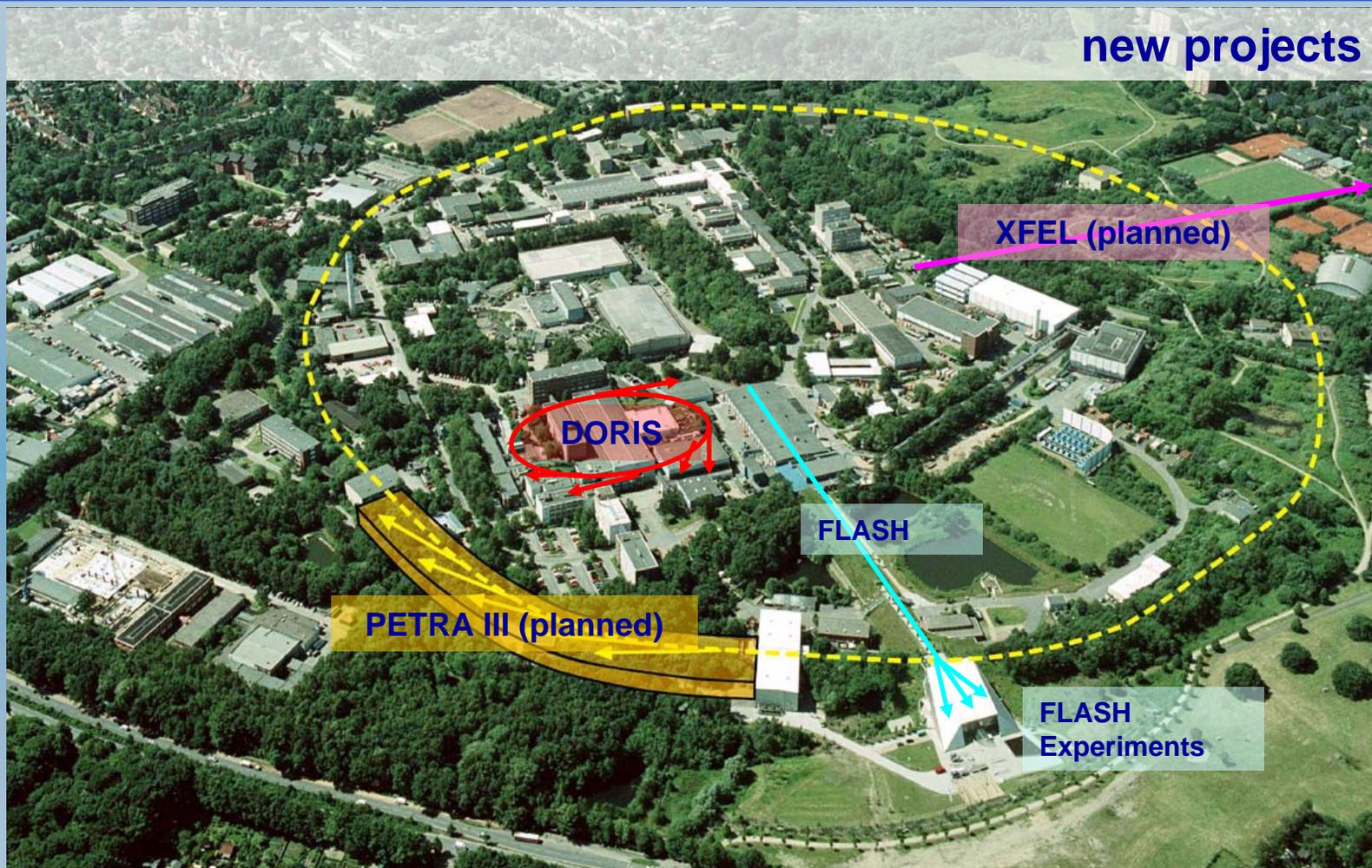
SLRS @ XFEL

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

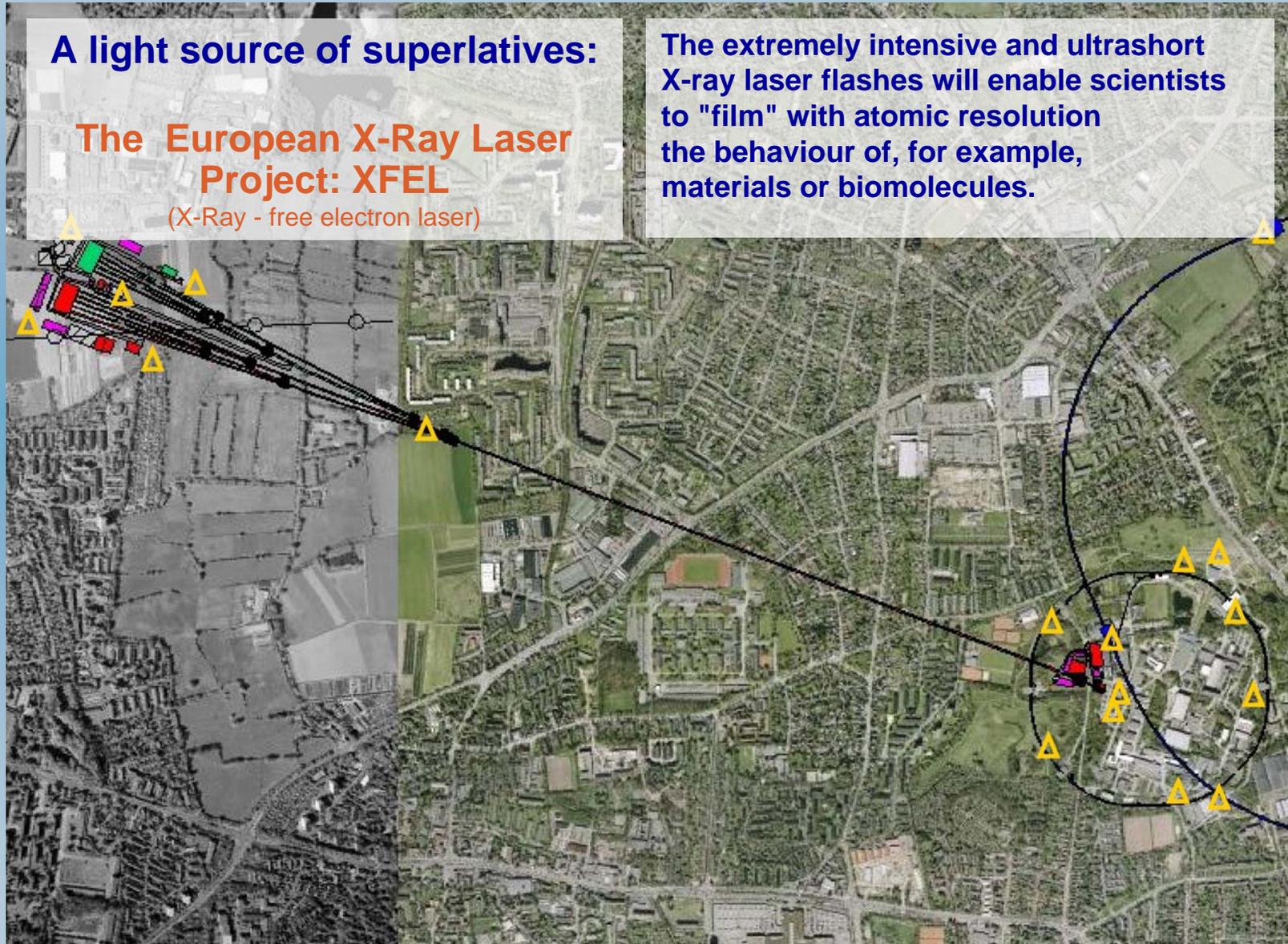
FUTURE
DEVELOPMENT

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.



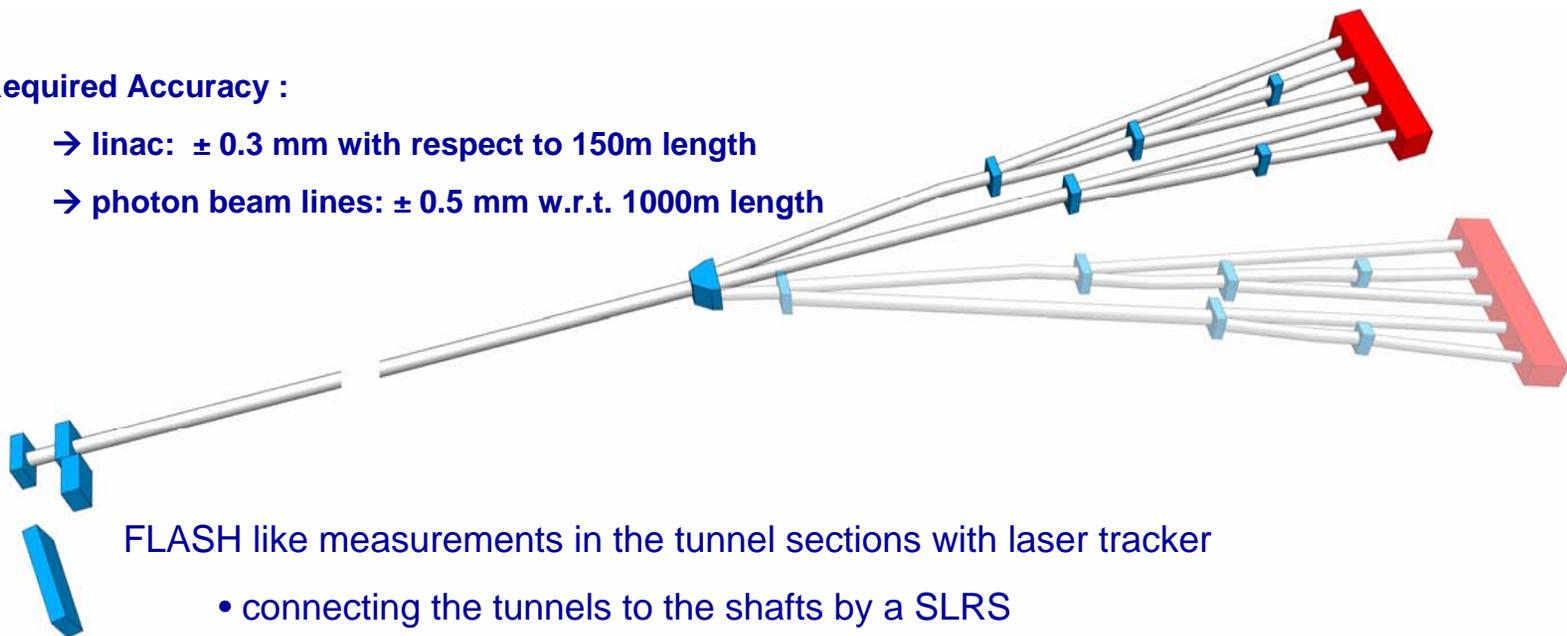


SLRS for XFEL @ DESY

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**

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

NEW PROJECTS

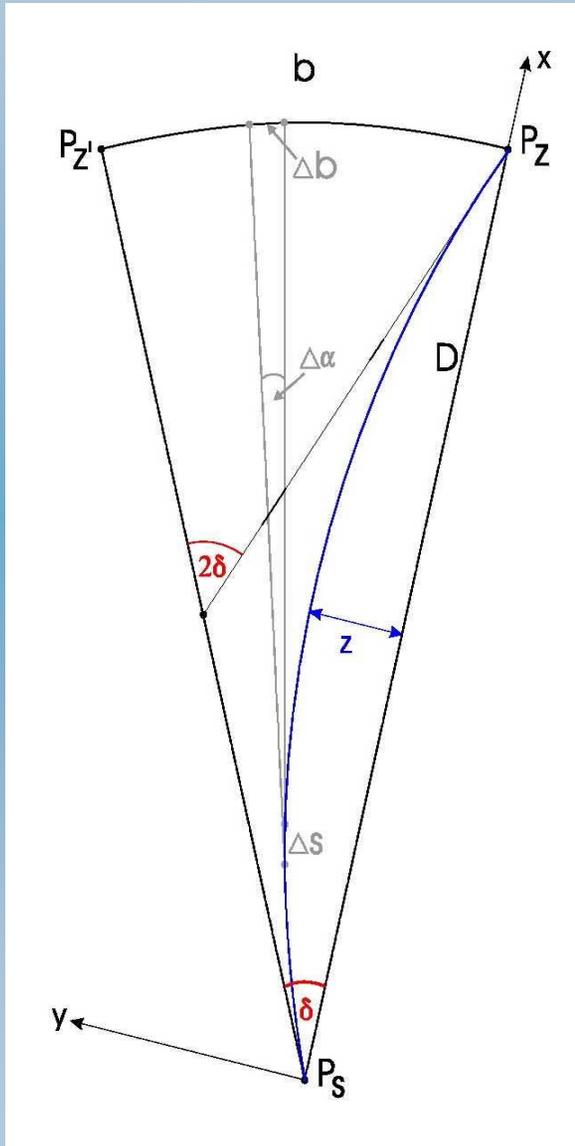
SLRS @ XFEL

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



SLRS for XFEL @ DESY

NEW PROJECTS

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

SLRS @ XFEL

POISSON ALIGNMENT SYSTEM

	lateral refraction $\frac{\delta T}{\delta y} = +0,1 K/m$		Comparison with altimetry $\frac{\delta T}{\delta y} = -0,065 K/m$	
distance [m]	angular error [mgon]	lateral error [mm]	angular error [mgon]	lateral error [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

DIRECT LIGHT SOURCE

SUMMARY

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

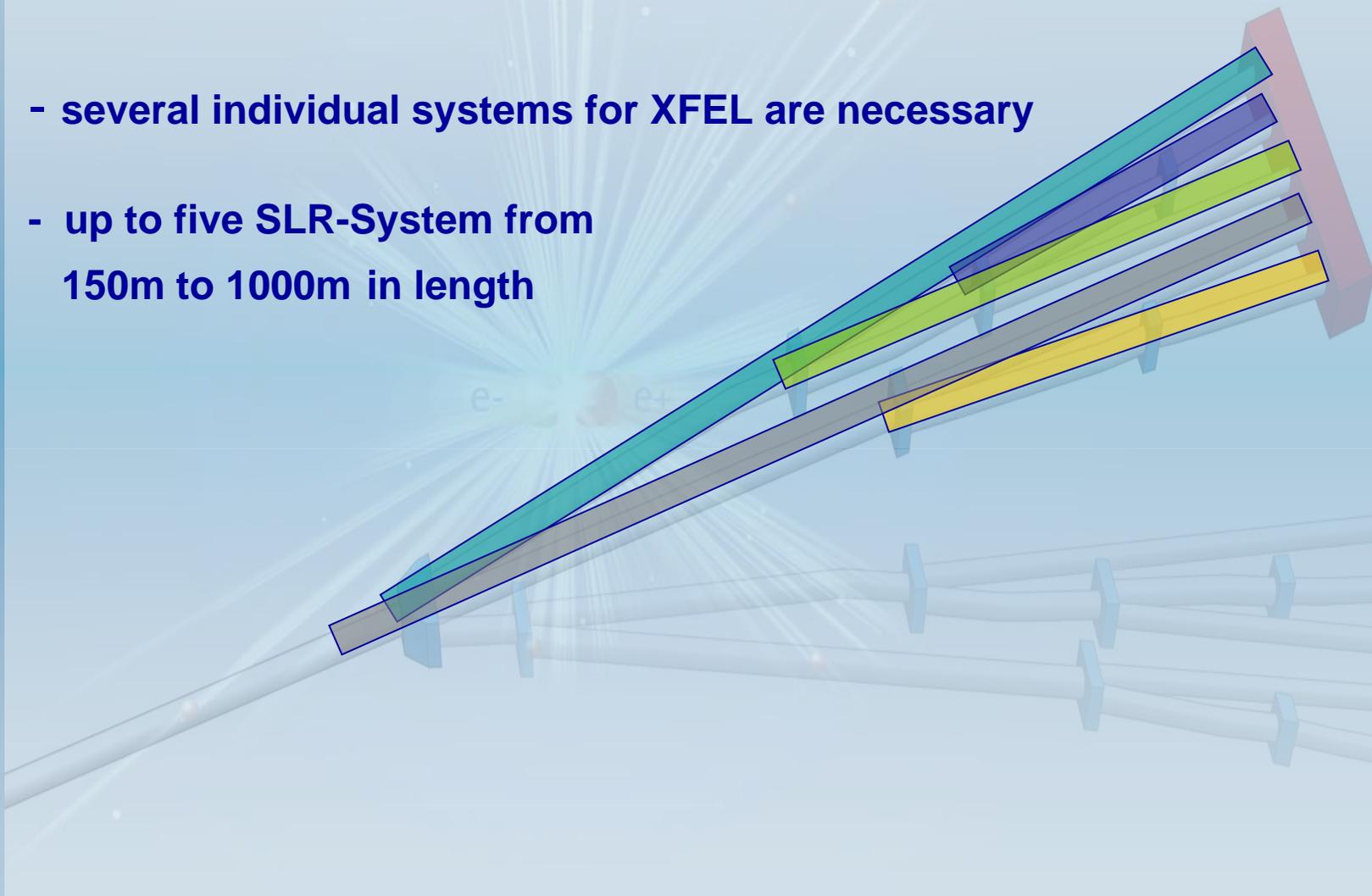
FUTURE DEVELOPMENT



SLRS for XFEL @ DESY

SLRS concept

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



NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

SLRS concept

NEW PROJECTS

SLRS @ XFEL

POISSON ALIGNMENT SYSTEM

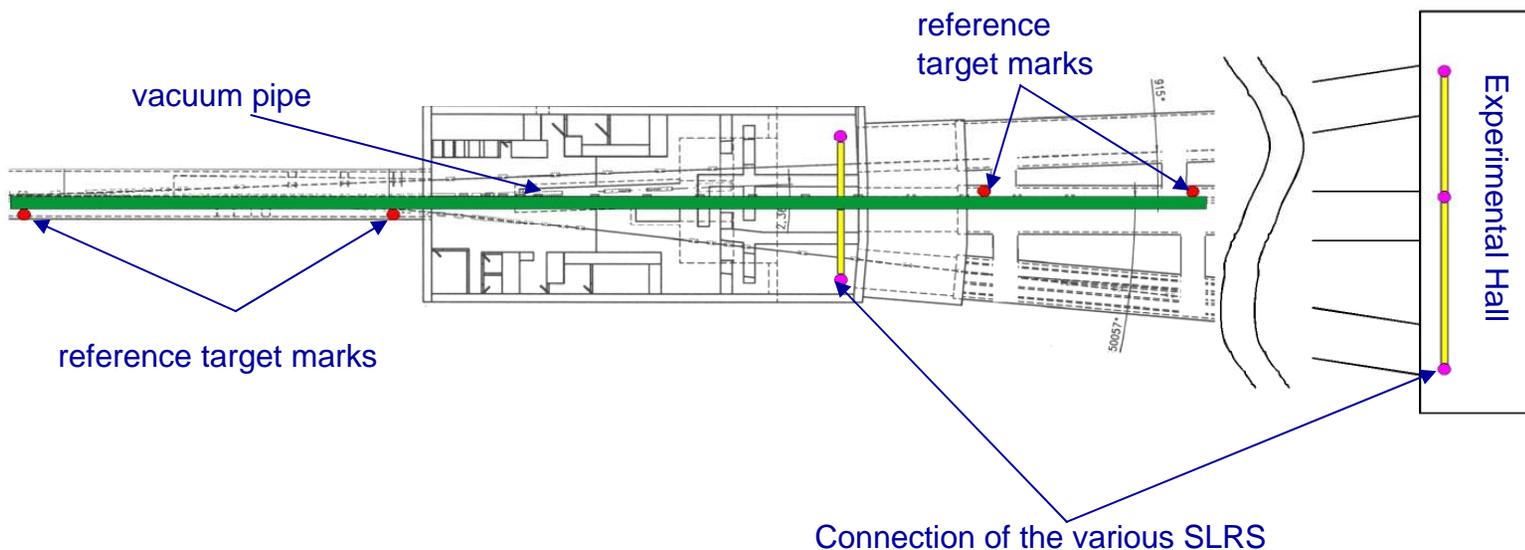
DIRECT LIGHT SOURCE

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

SLRS concept

NEW PROJECTS

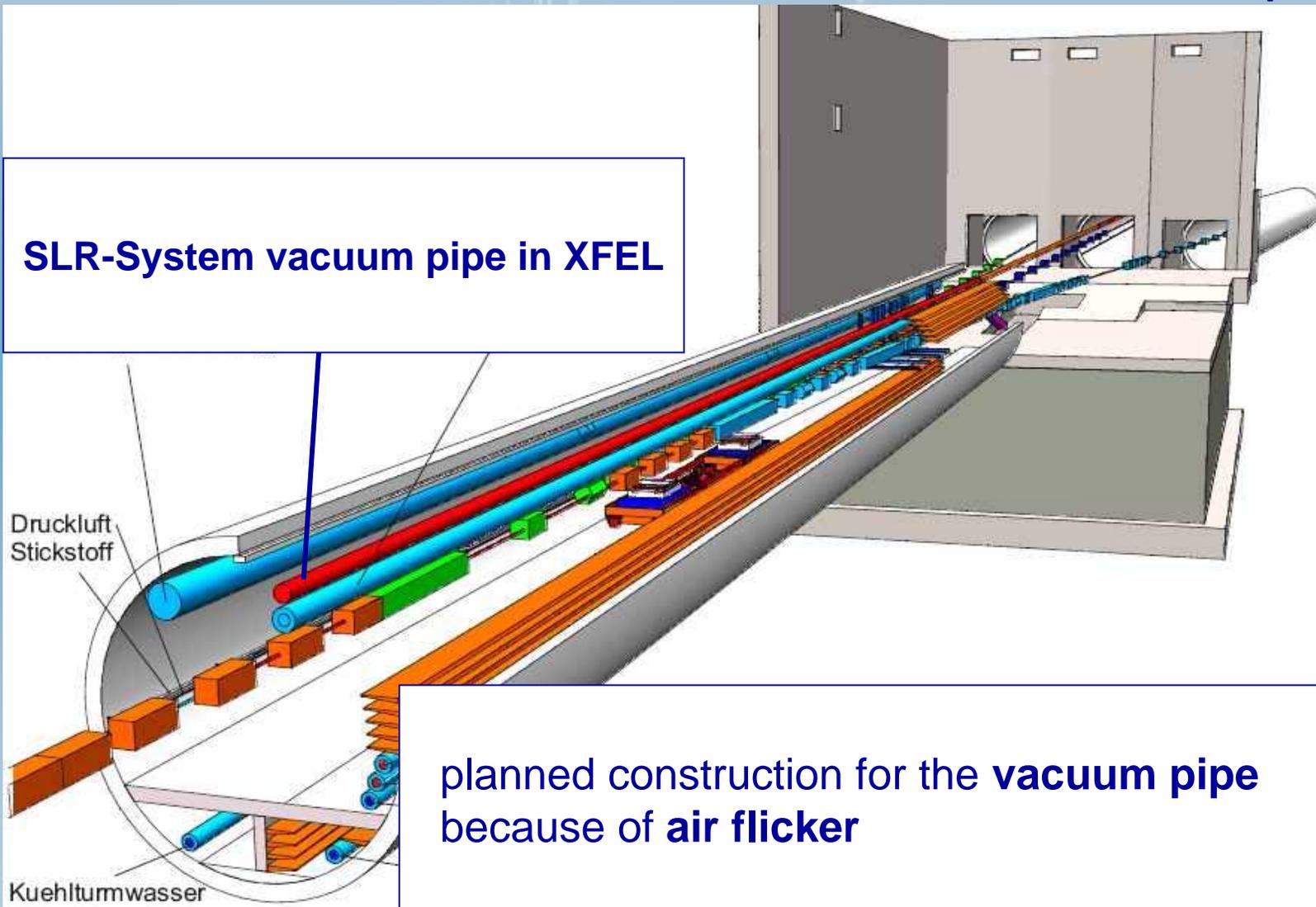
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT





SLRS for XFEL @ DESY

Poisson-Alignment-System

NEW PROJECTS

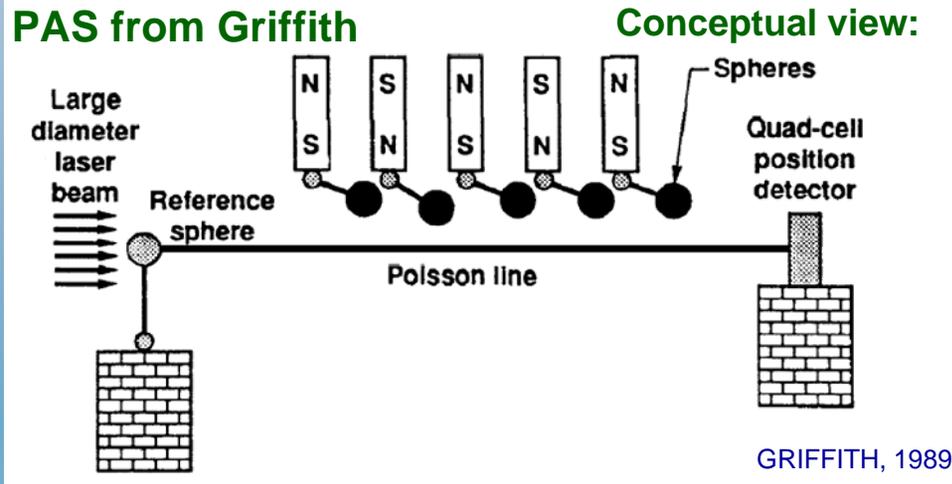
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

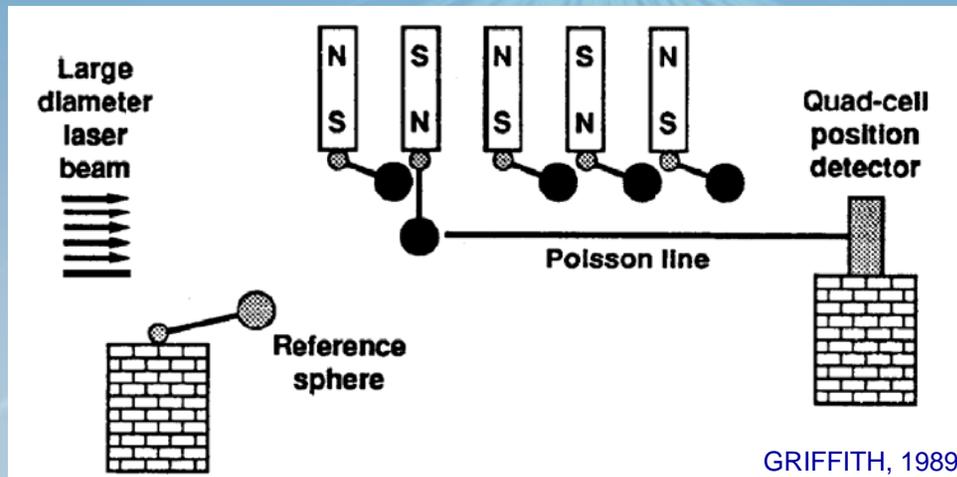
DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



optical reference line defined by reference sphere and detector



sphere on magnets can be turned into the beam



SLRS for XFEL @ DESY

Poisson-Alignment-System

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT

Specification for experiments @ Argonne National Laboratory (1997):

Laser source:

laser diode, 635nm , 3 mW

Equipment:

10µm pinhole from platinum iridium

7,5cm diameter collimating lens

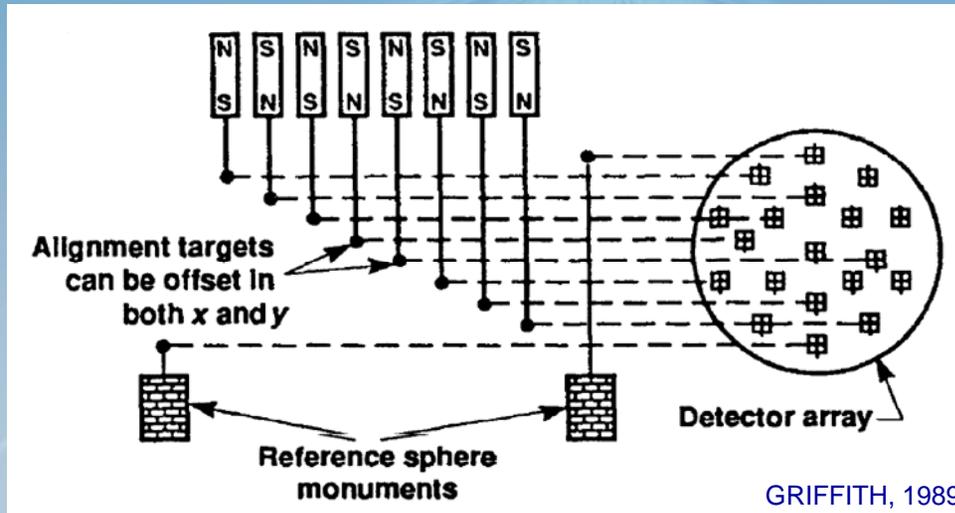
Detector:

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

Measurement resolution :

+/- 25 µm over 300m distance

FRIEDSAM, 1997



advanced system: detect many more Poisson spots

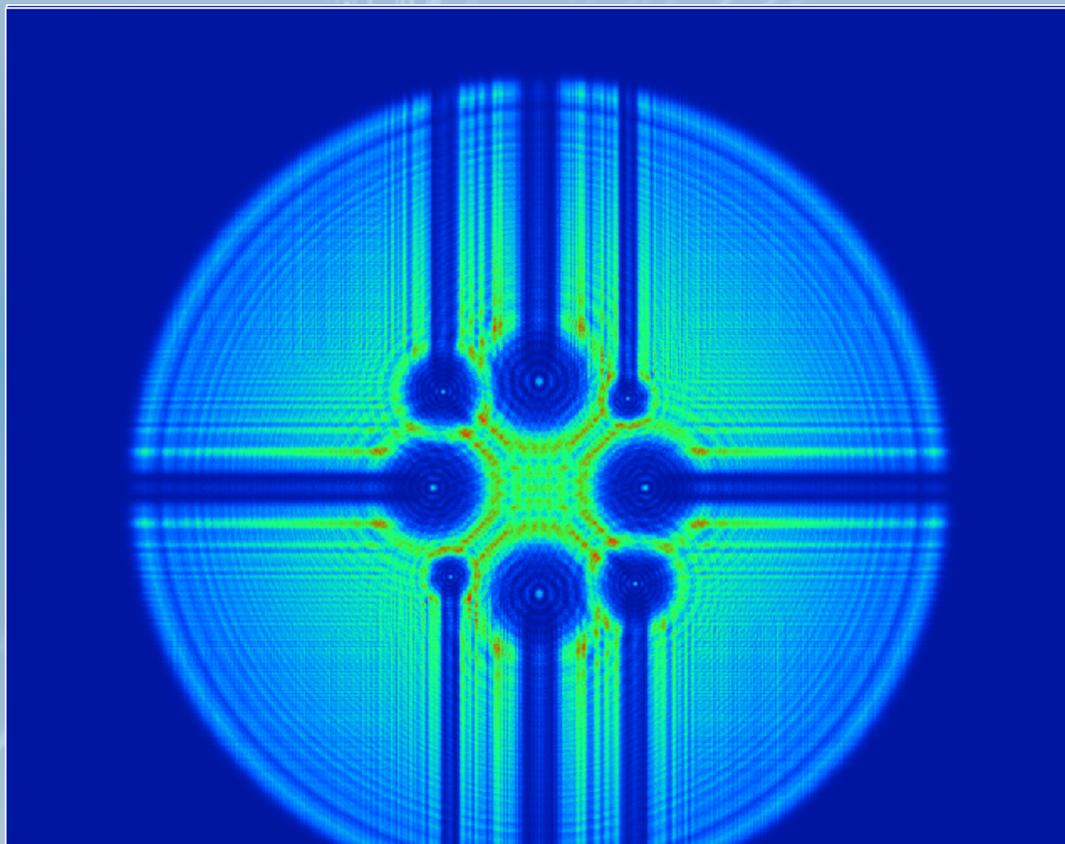


SLRS for XFEL @ DESY

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

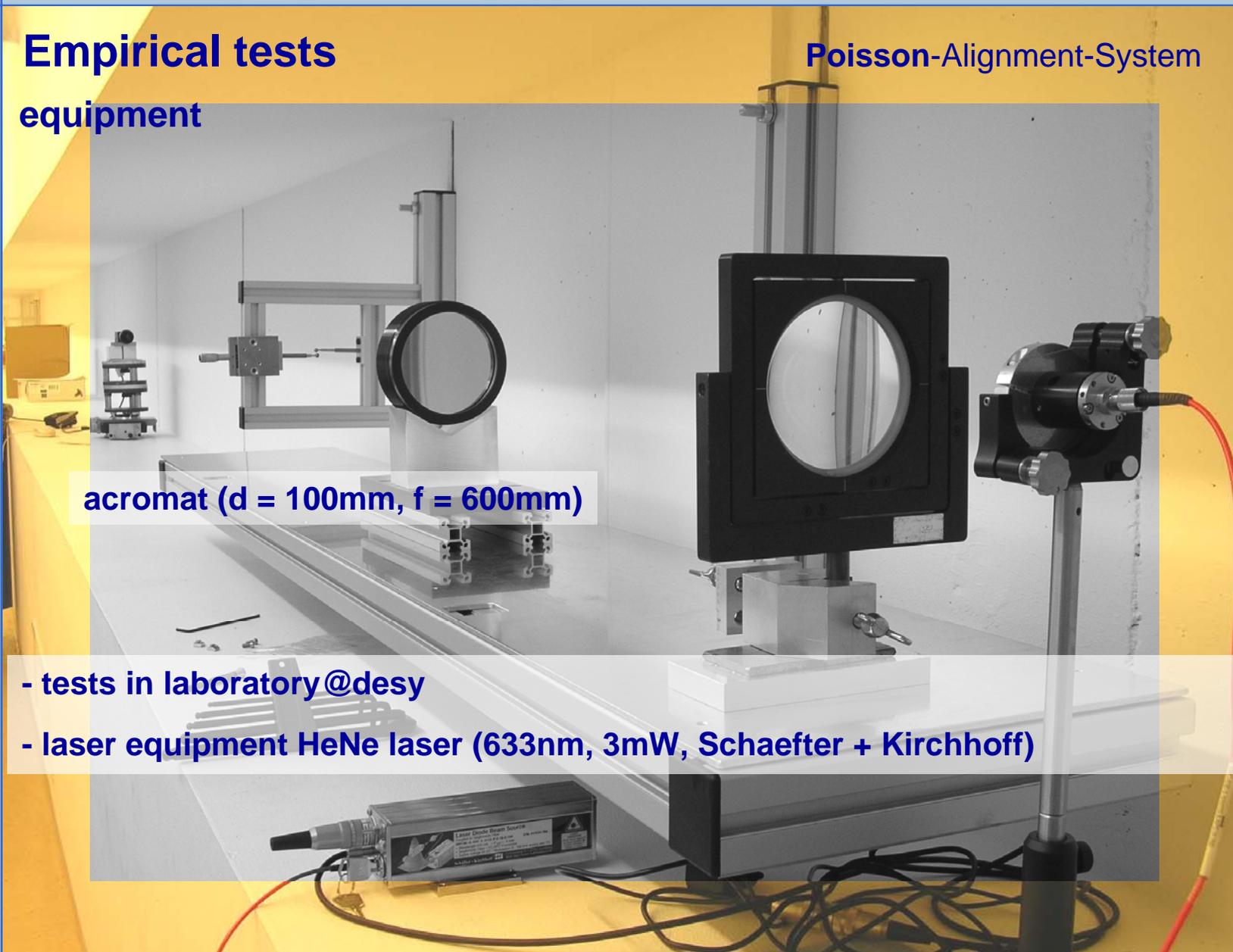
FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

Empirical tests equipment

Poisson-Alignment-System



acromat (d = 100mm, f = 600mm)

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

NEW PROJECTS

SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

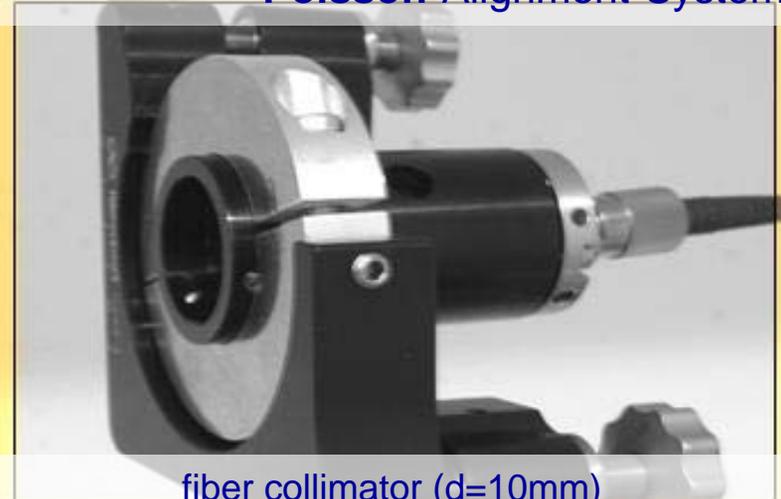
Empirical tests

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	23m
		2 x 12mm	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

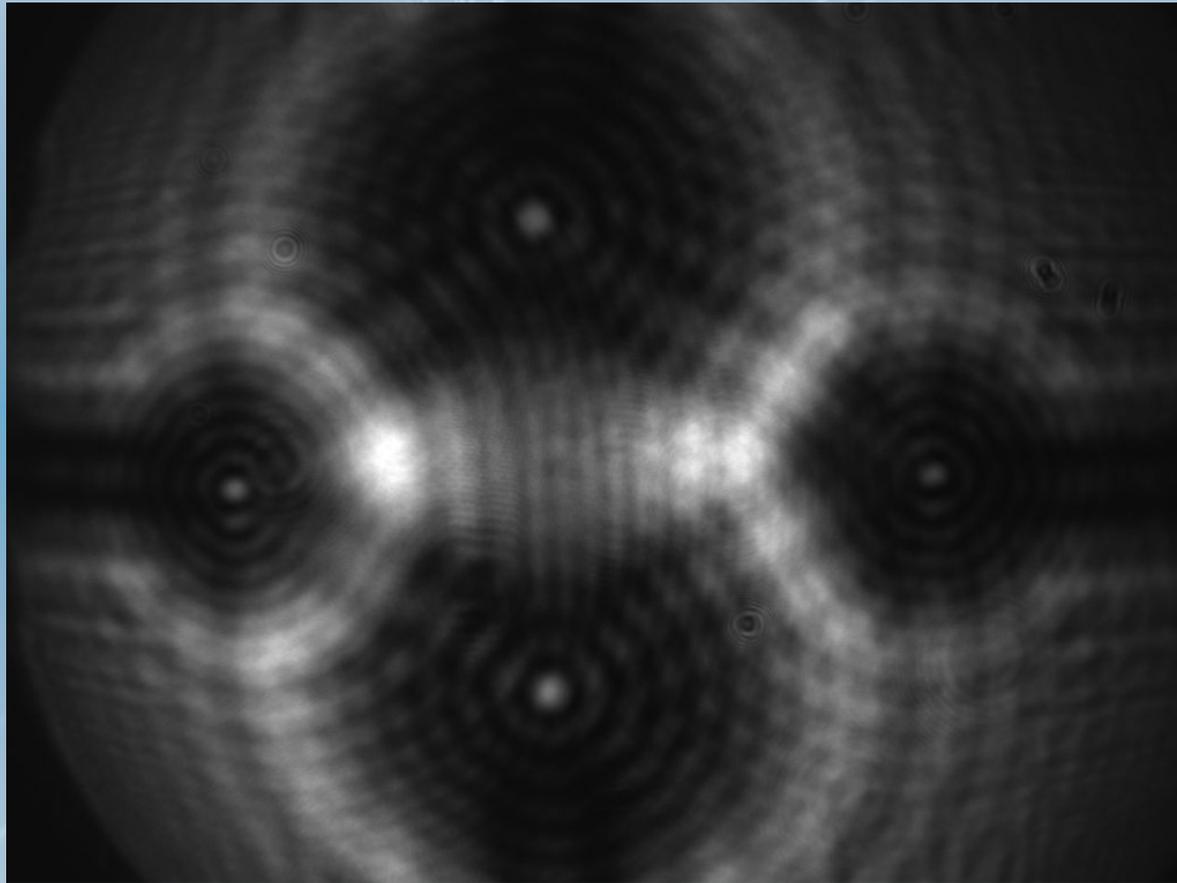
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



real image of four spots from a sony 1/2" CCD-Chip camera

impossible to analyse because of air flicker



SLRS for XFEL @ DESY

2nd setup: 5m in length

Poisson-Alignment-System

NEW PROJECTS

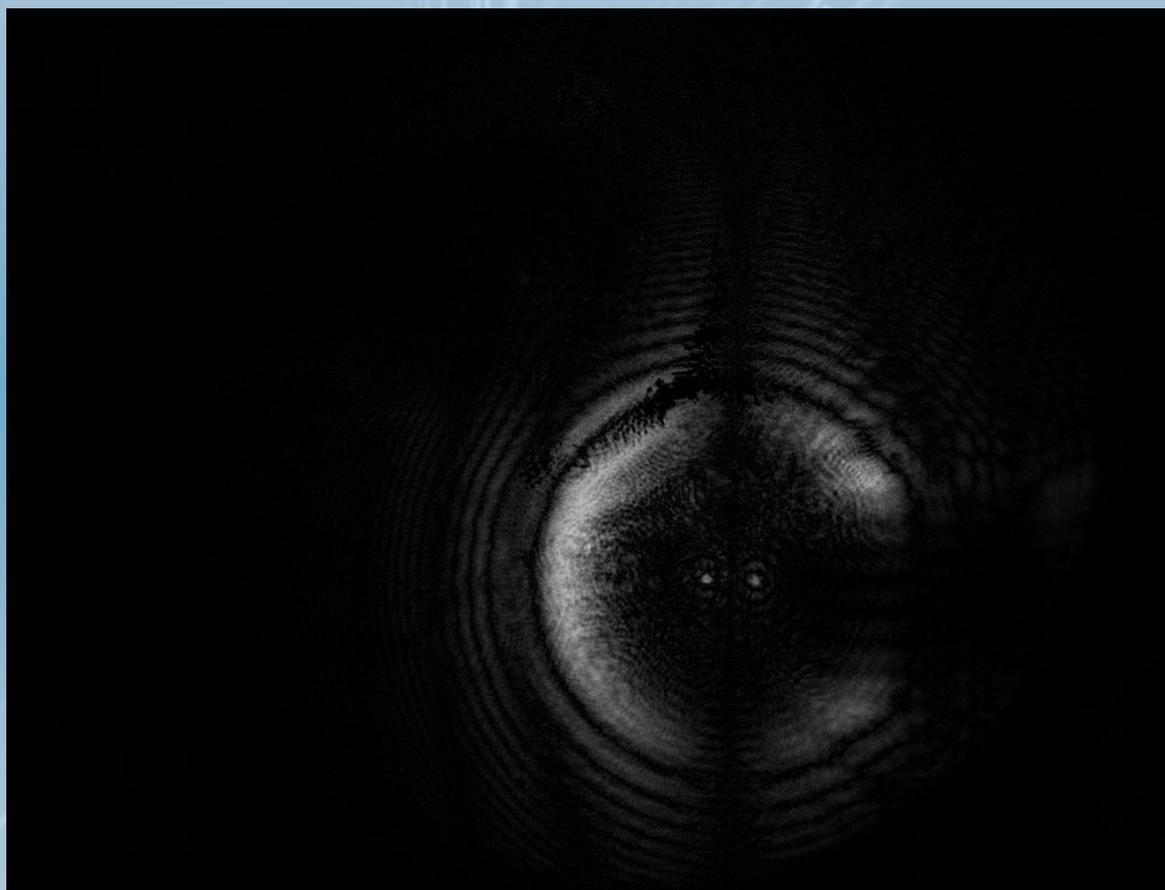
SLRS @ XFEL

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

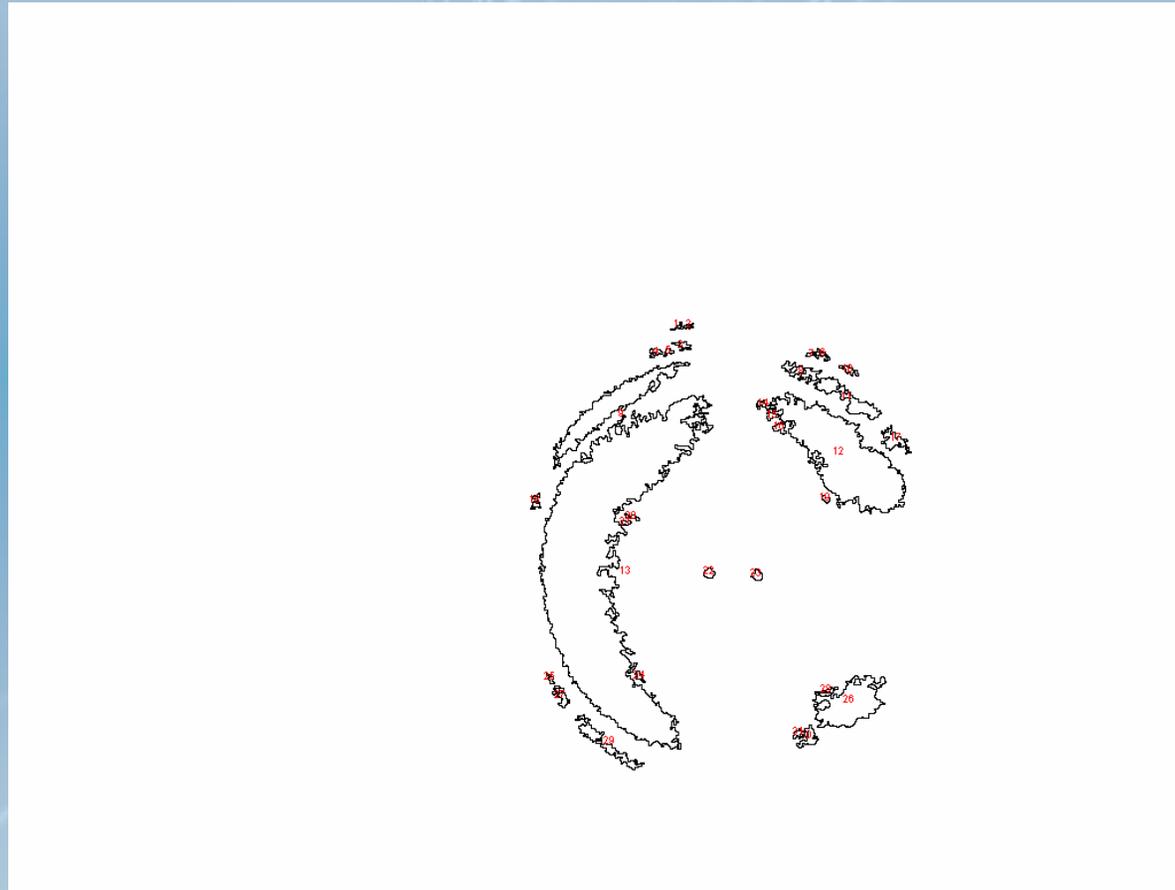
SLRS @ XFEL

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

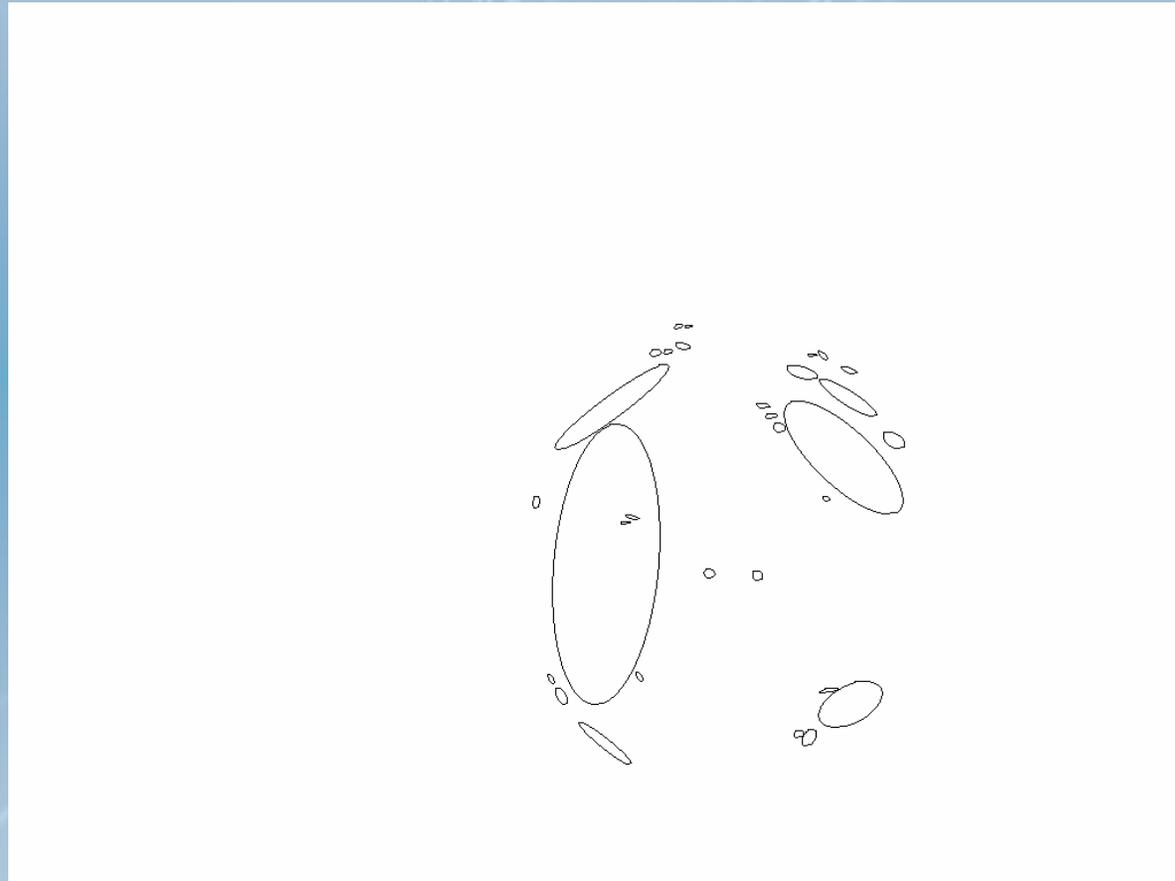
SLRS @ XFEL

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

3rd setup: 1.7m in length

Poisson-Alignment-System

NEW PROJECTS

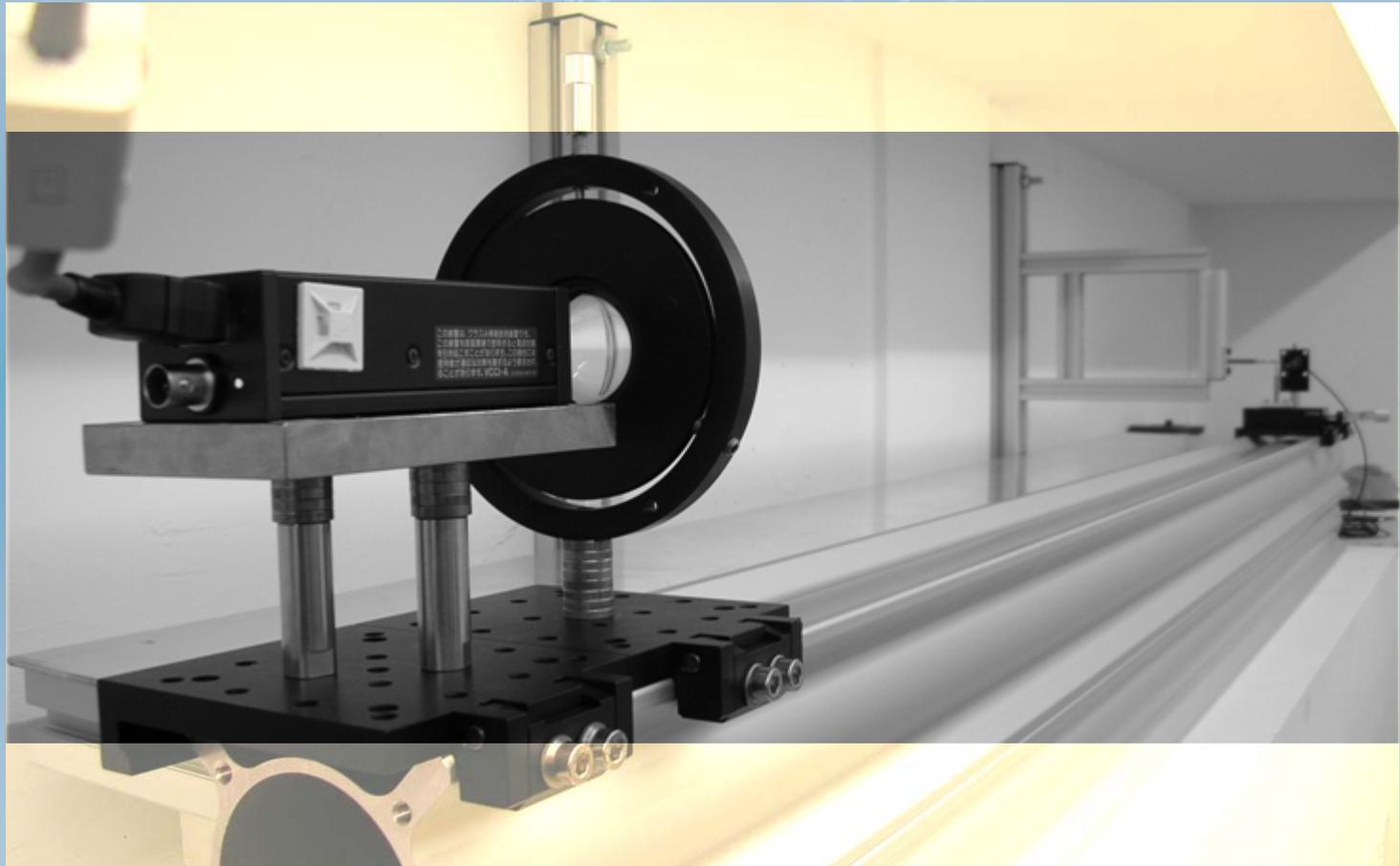
SLRS @ XFEL

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

3rd setup: 1.7m in length

Poisson-Alignment-System

NEW PROJECTS

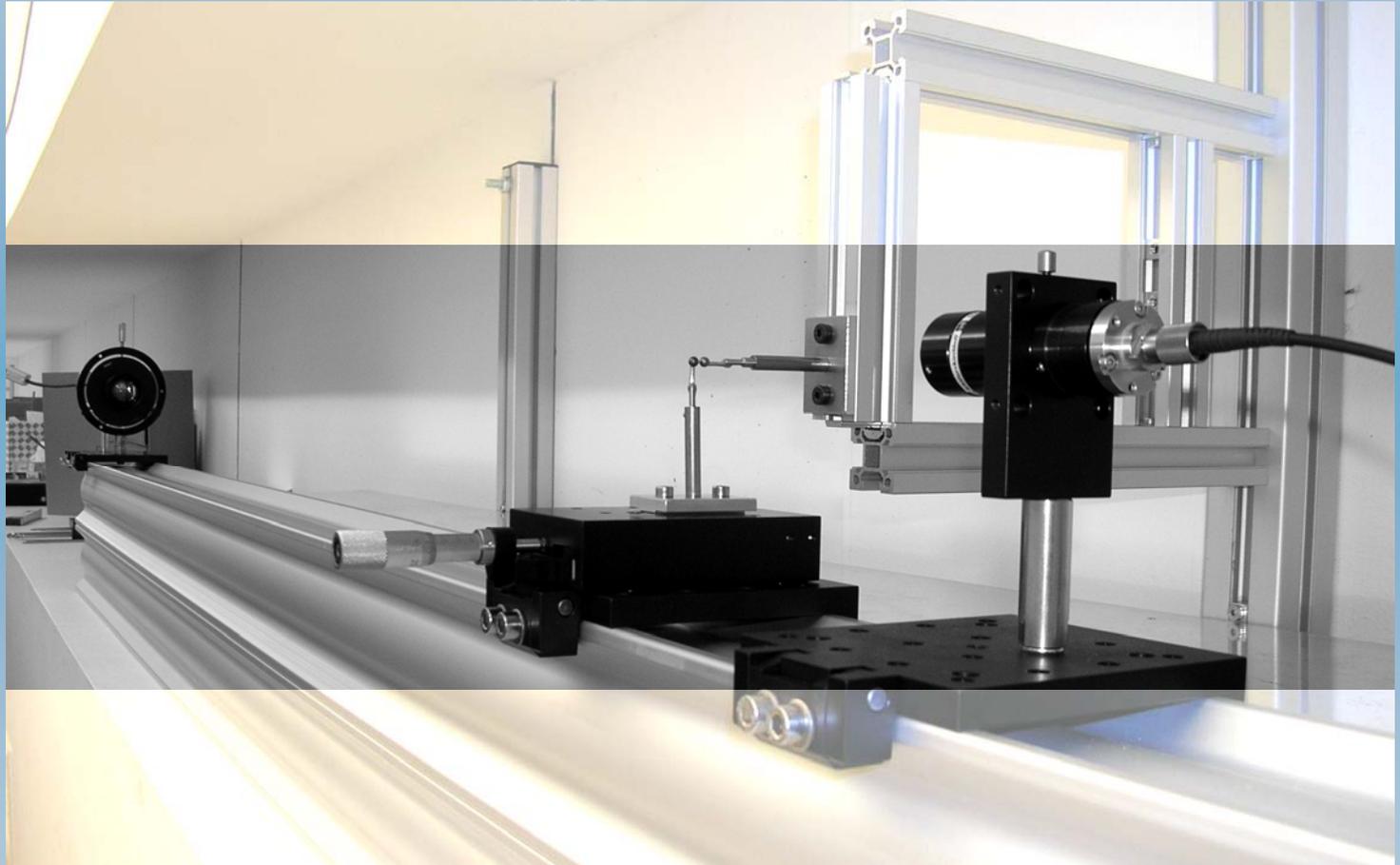
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



micrometer stage and two spheres with a diameter of 4mm



SLRS for XFEL @ DESY

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

Poisson-Alignment-System

NEW PROJECTS

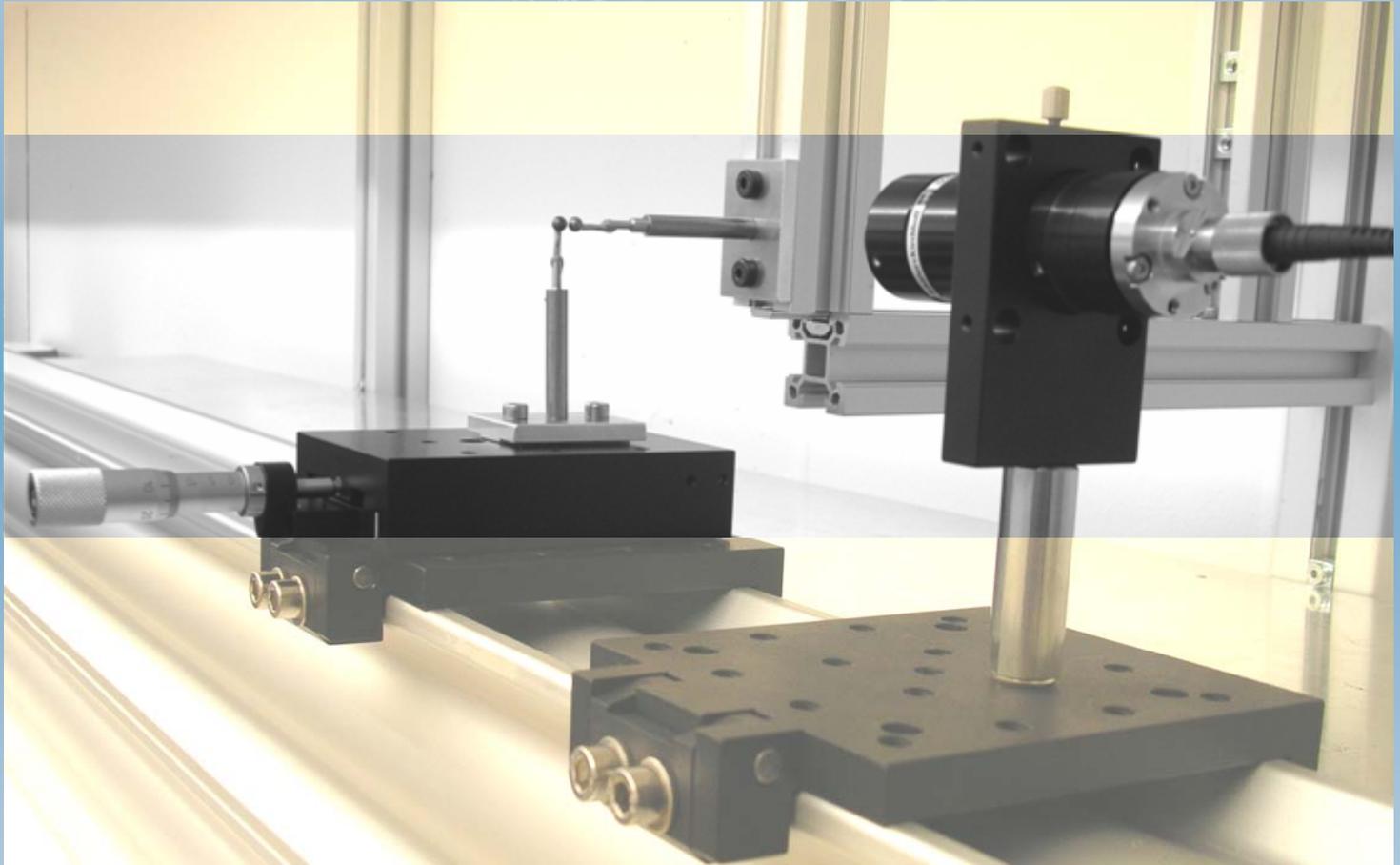
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



two spheres in expanded 10mm collimated laser beam



SLRS for XFEL @ DESY

3rd setup: 1.7m in length

Poisson-Alignment-System

NEW PROJECTS

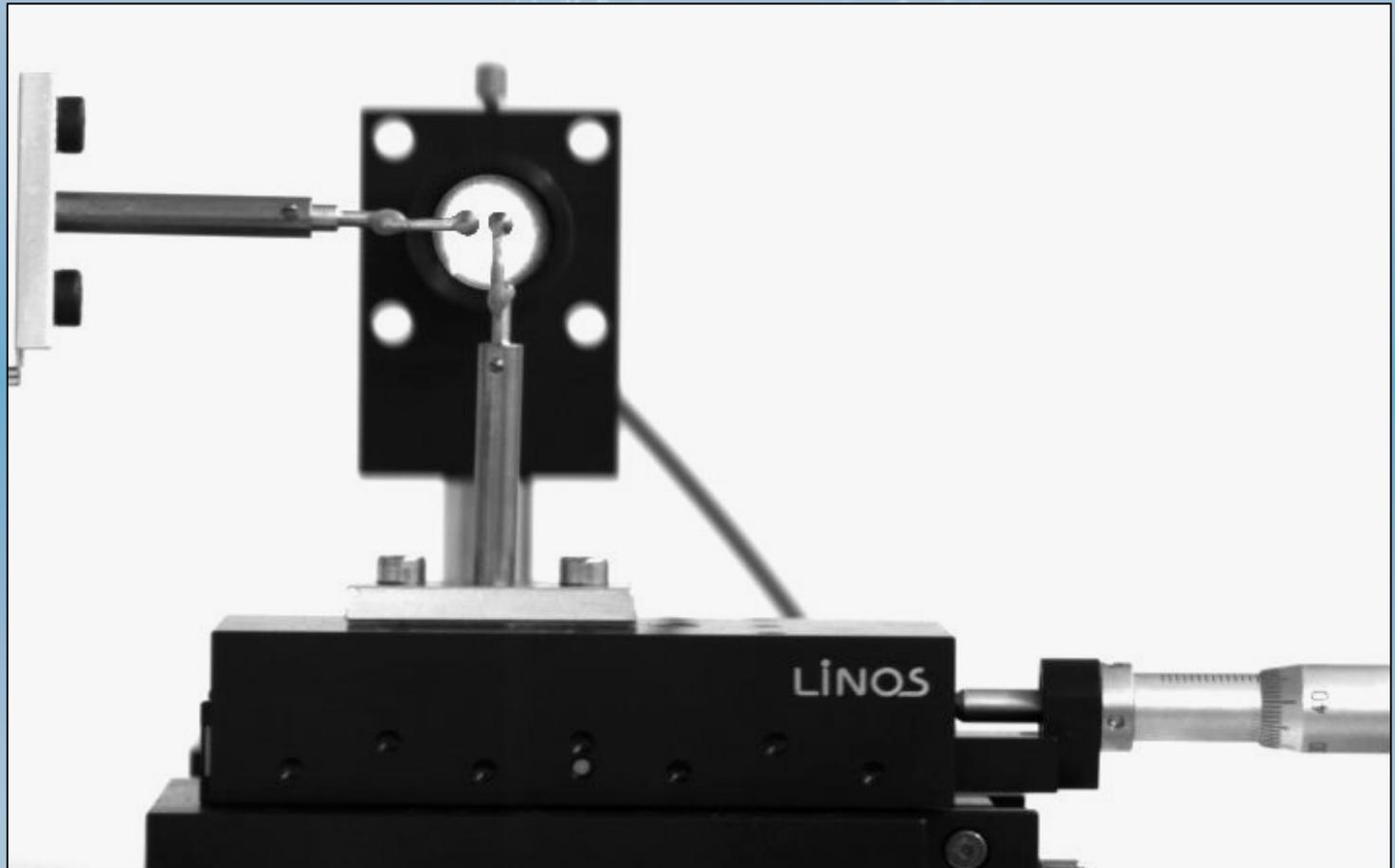
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



configuration of spheres in front of Camera



SLRS for XFEL @ DESY

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

Poisson-Alignment-System

NEW PROJECTS

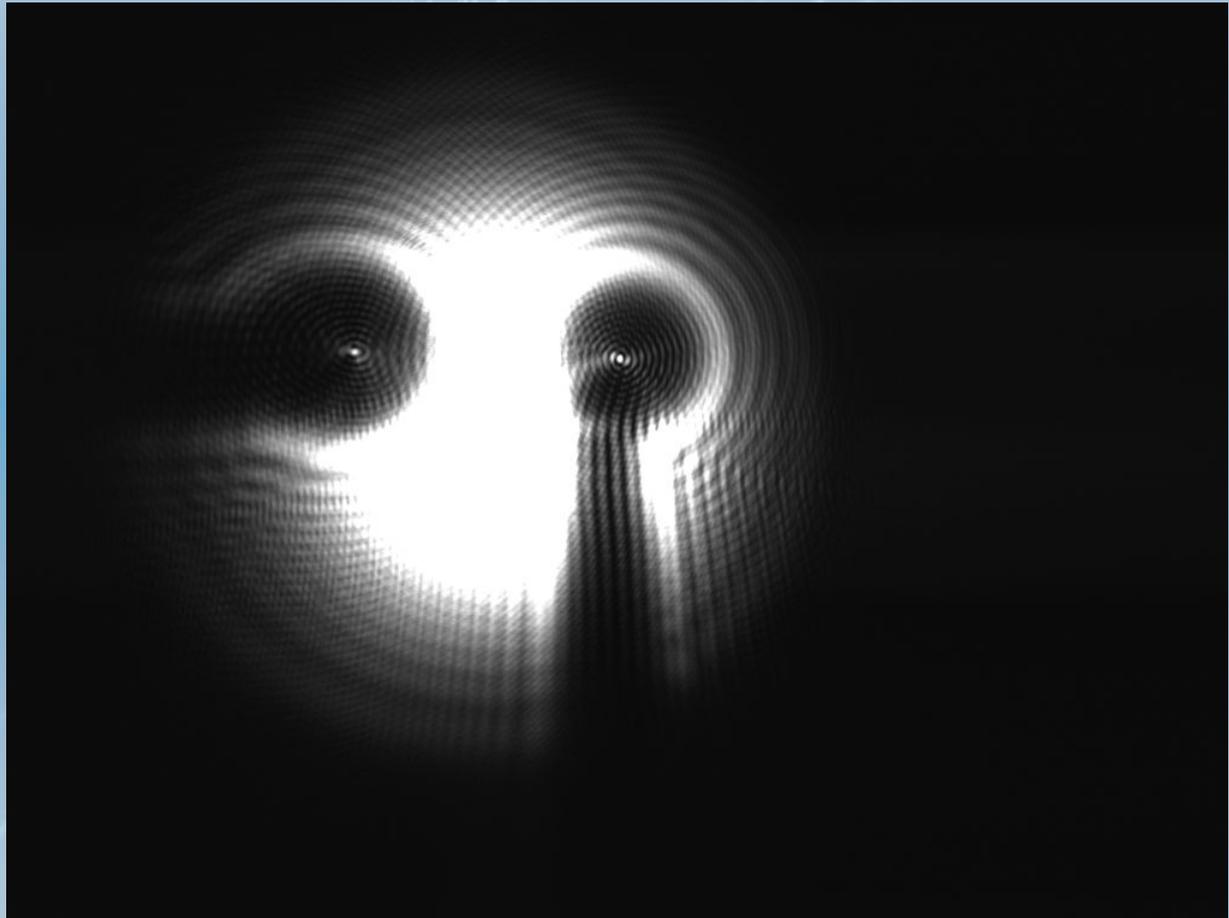
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



real image with two poisson spots



SLRS for XFEL @ DESY

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

Poisson-Alignment-System

NEW PROJECTS

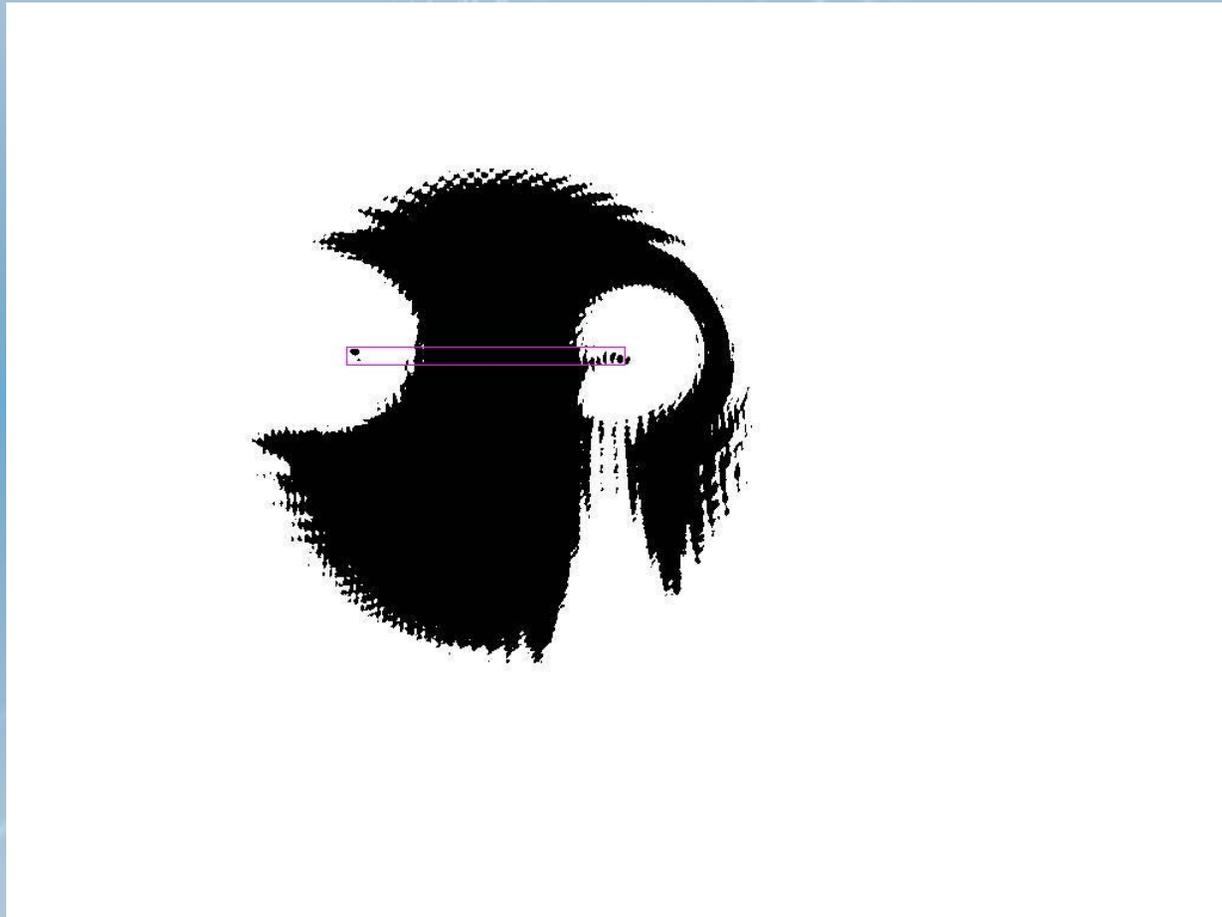
SLRS @ XFEL

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

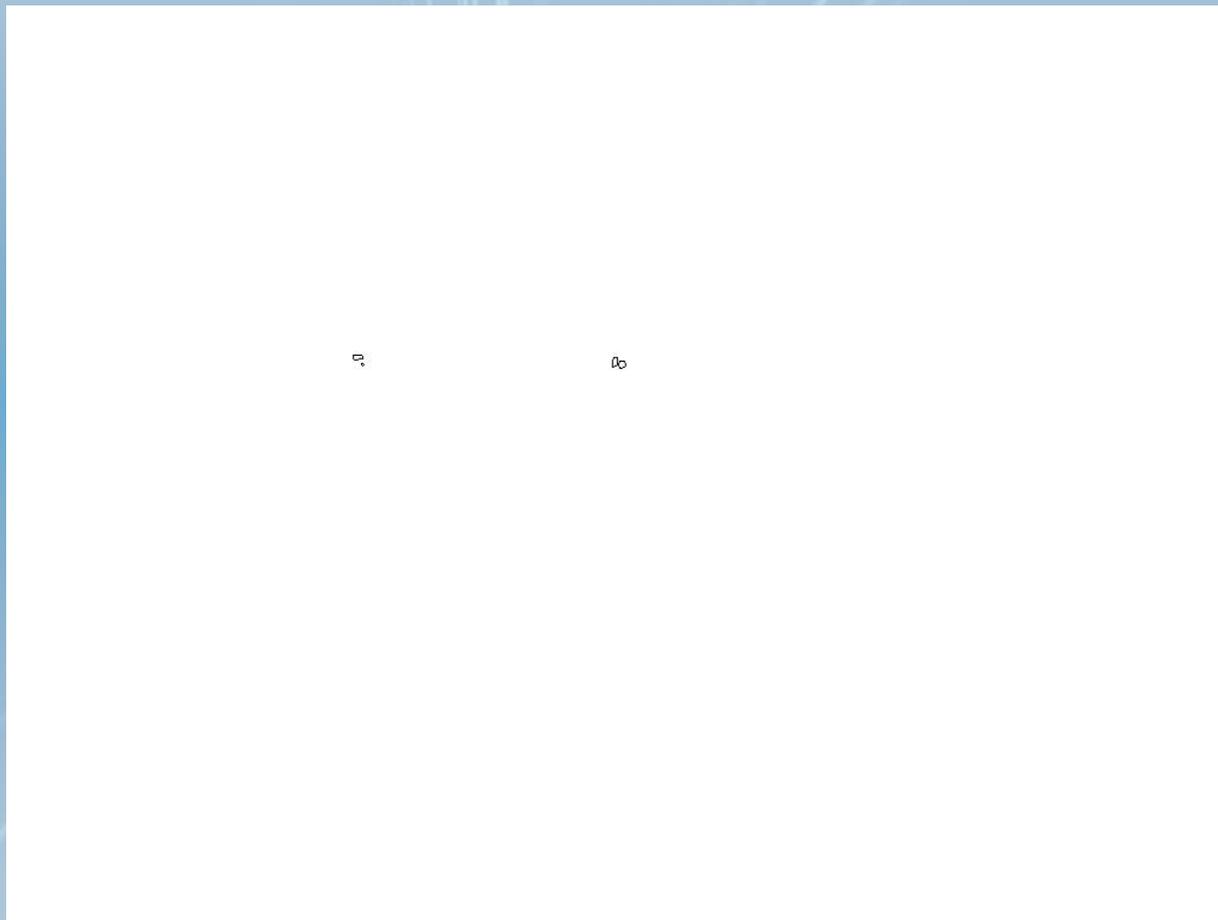
SLRS @ XFEL

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

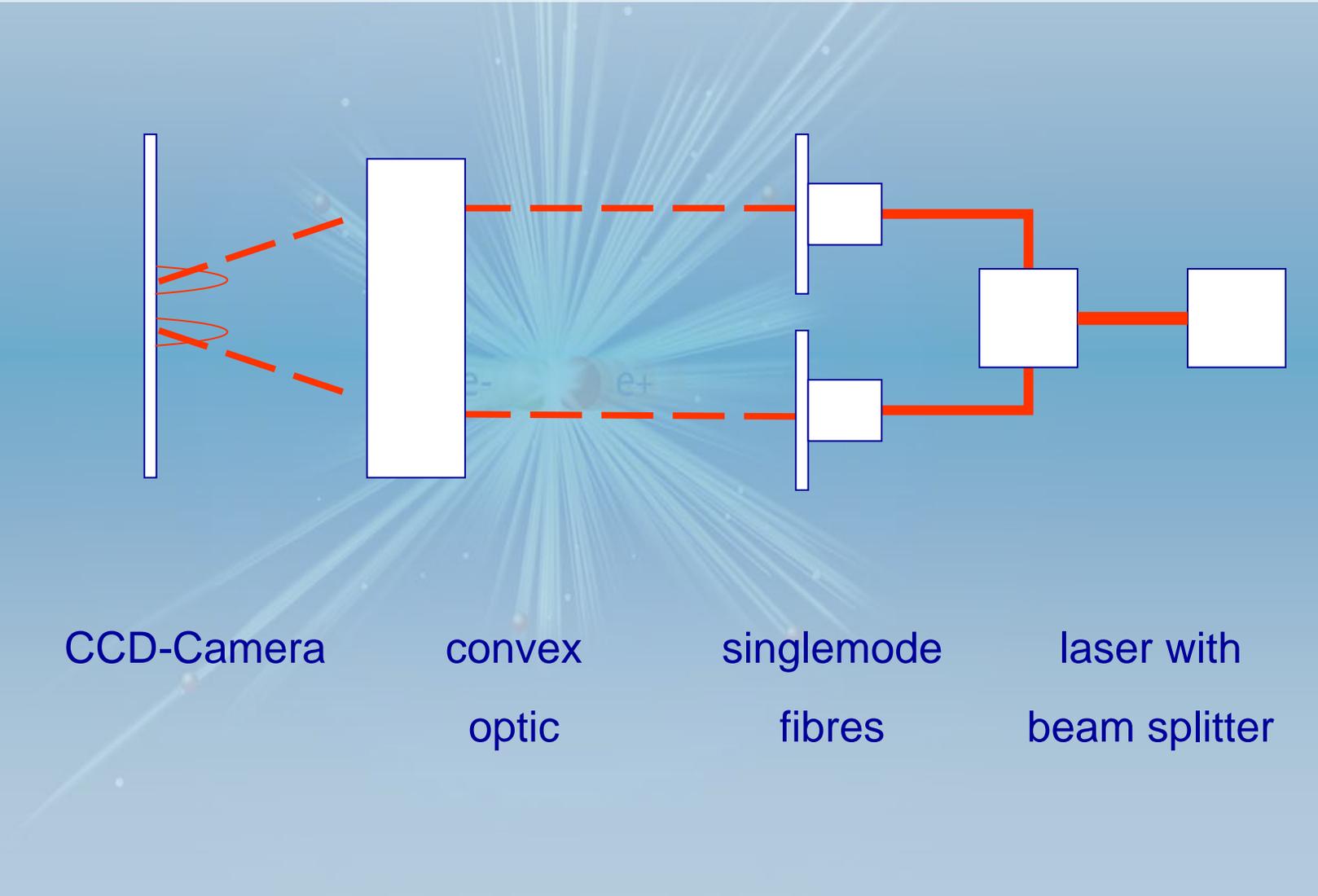
translation of sphere [mm]	error of translation detection [μm]			
	1st epoch	2nd epoch	3rd epoch	4th epoch
0.00	0	0	0	0
0.20	-2	4	10	4
0.50	-5	4	4	4
1.00	-23	-16	-15	-12
2.00	-21	-18	-15	-20

mean error from this setup is 17 microns



SLRS for XFEL @ DESY

Direct light source System



NEW PROJECTS

SLRS @ XFEL

POISSON ALIGNMENT SYSTEM

DIRECT LIGHT SOURCE

SUMMARY

FUTURE DEVELOPMENT



SLRS for XFEL @ DESY

Direct light source System

NEW PROJECTS

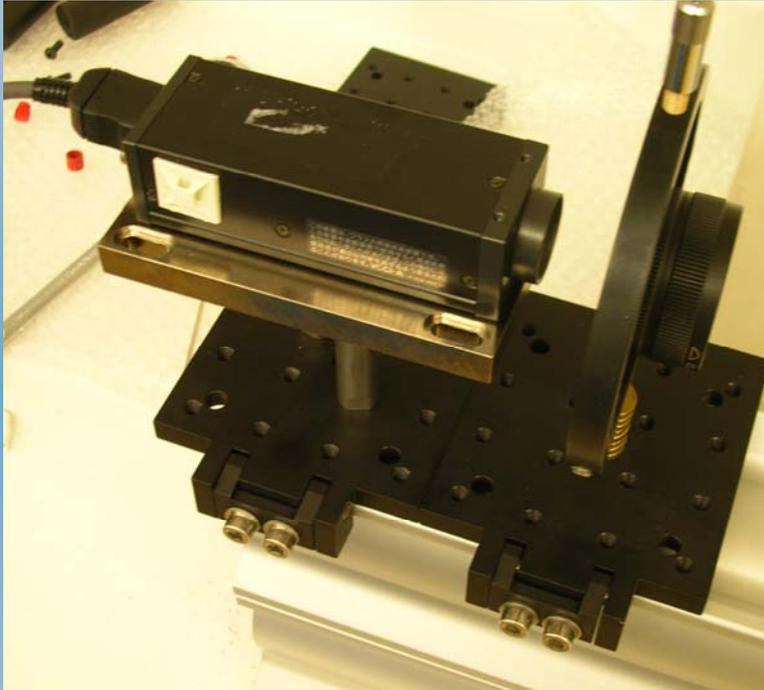
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

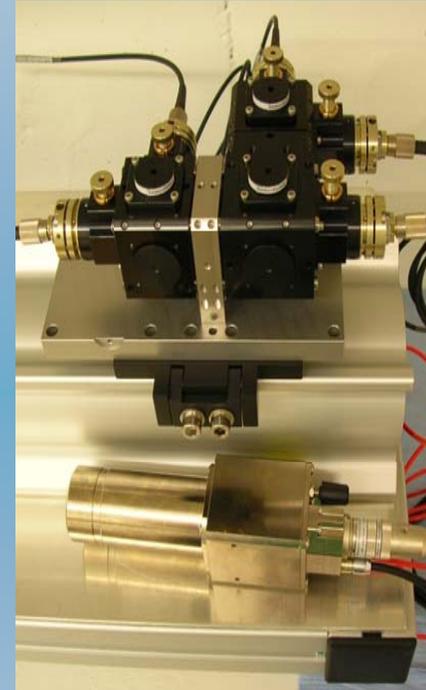
FUTURE
DEVELOPMENT



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

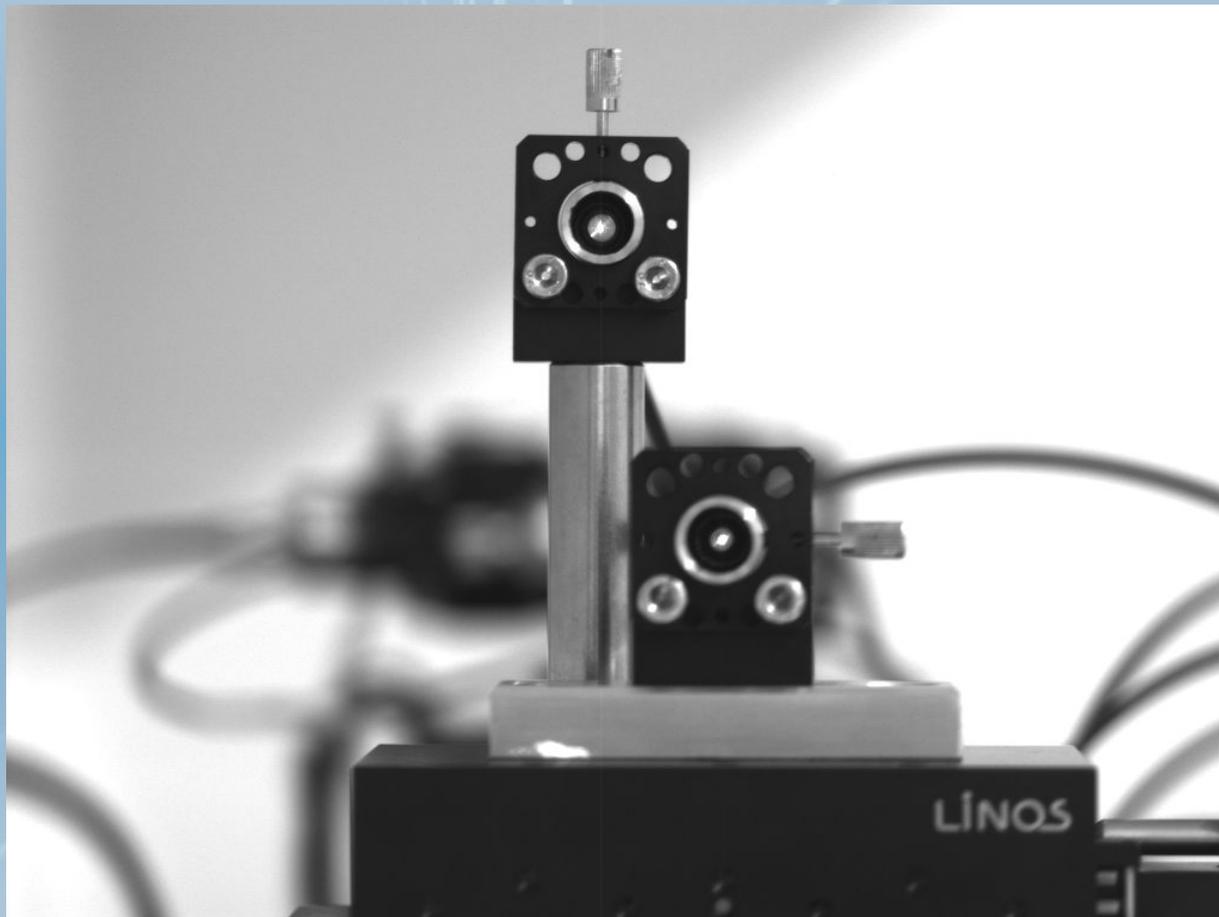
SLRS @ XFEL

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

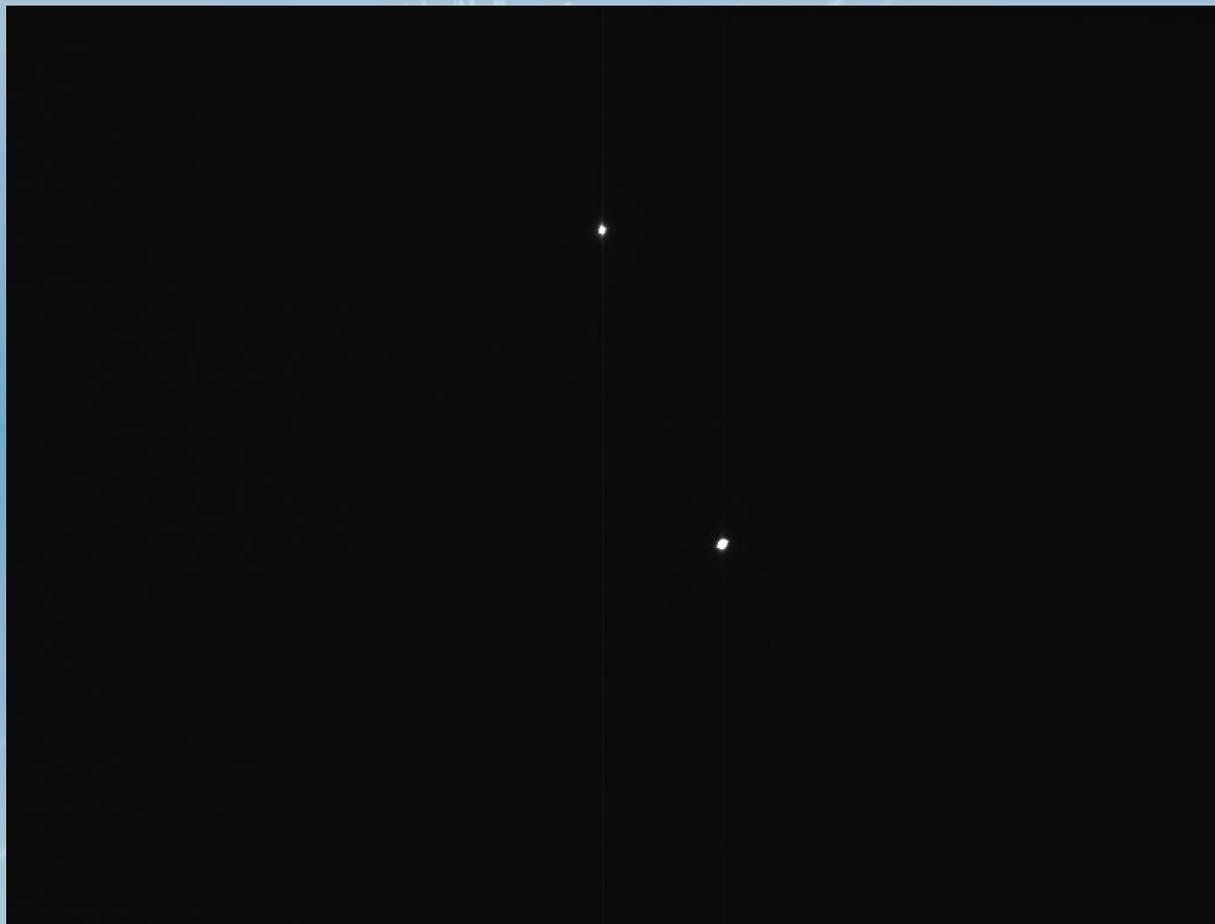
SLRS @ XFEL

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

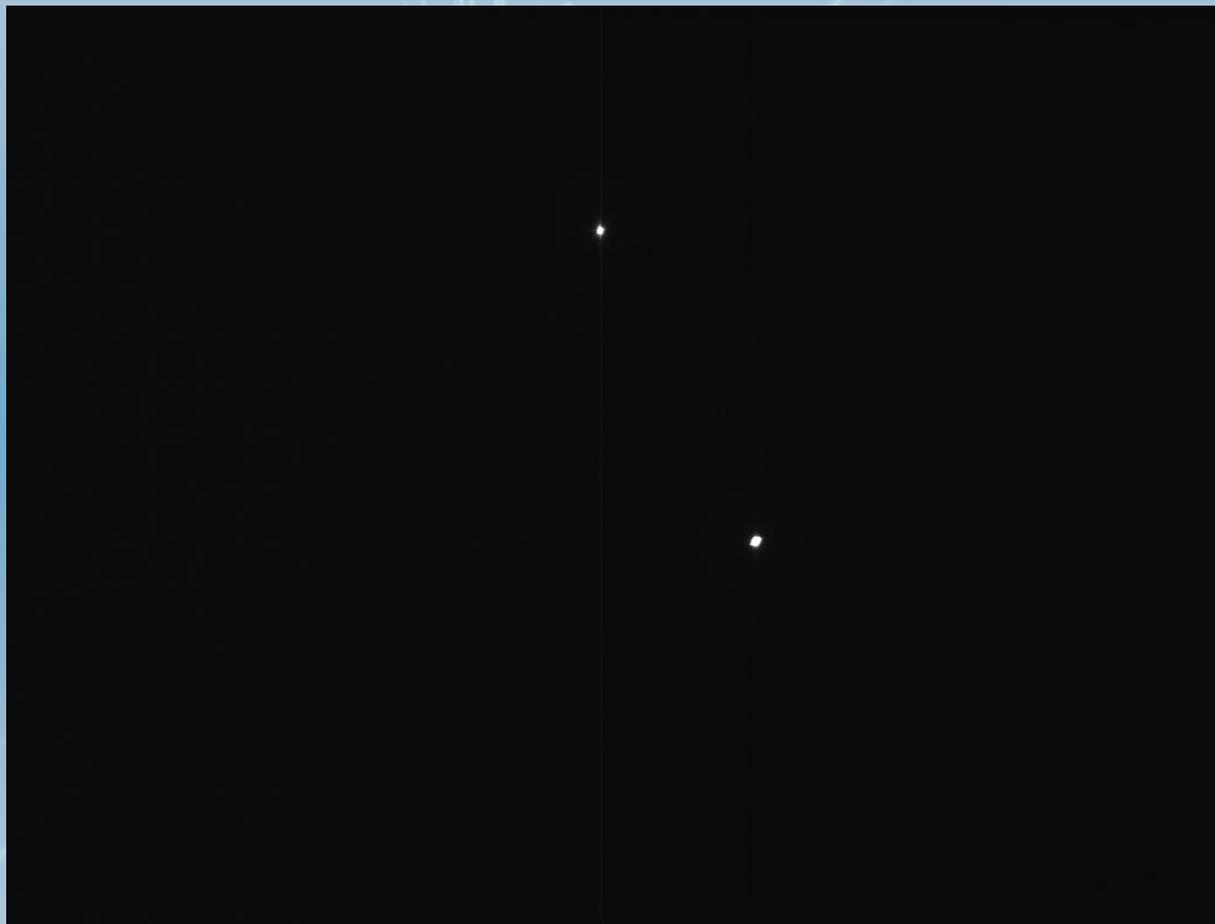
SLRS @ XFEL

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

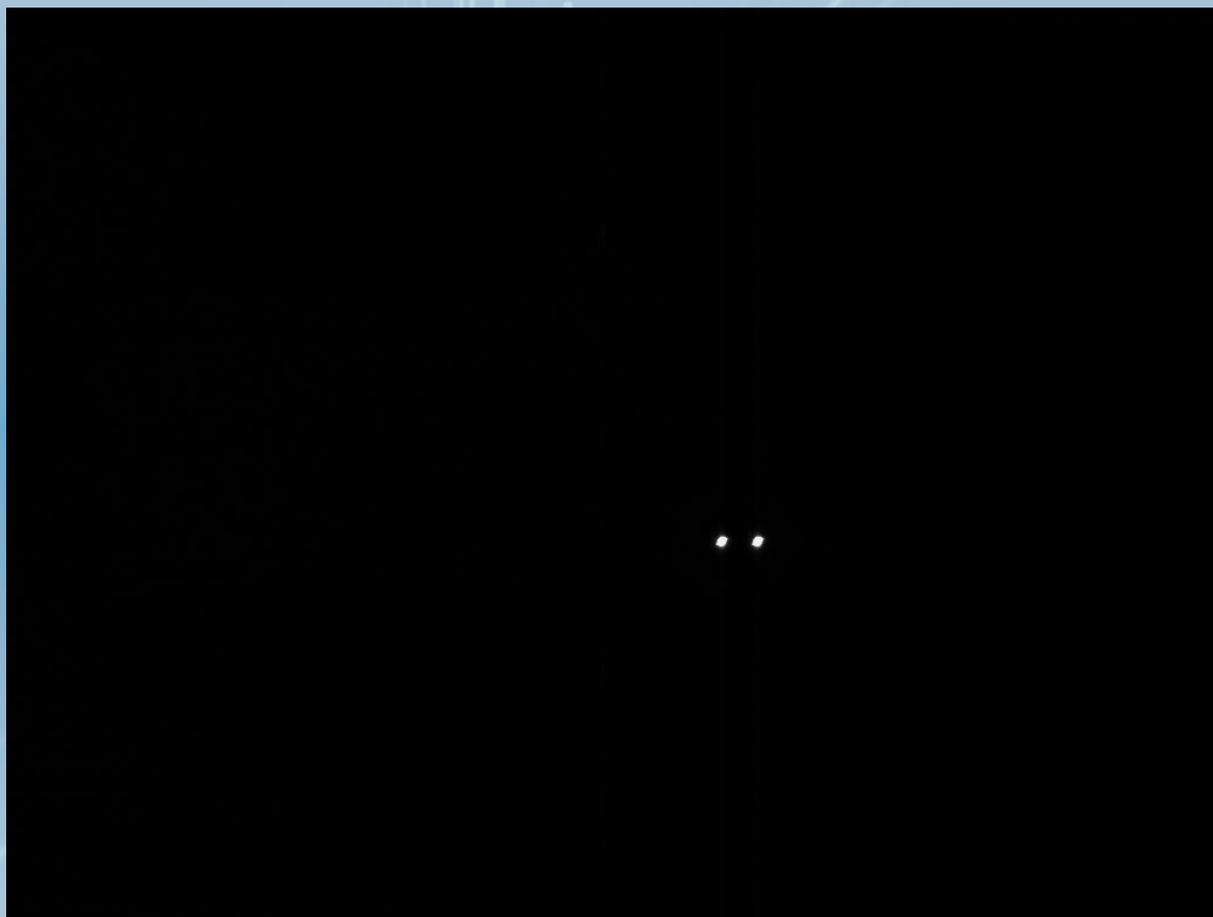
SLRS @ XFEL

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

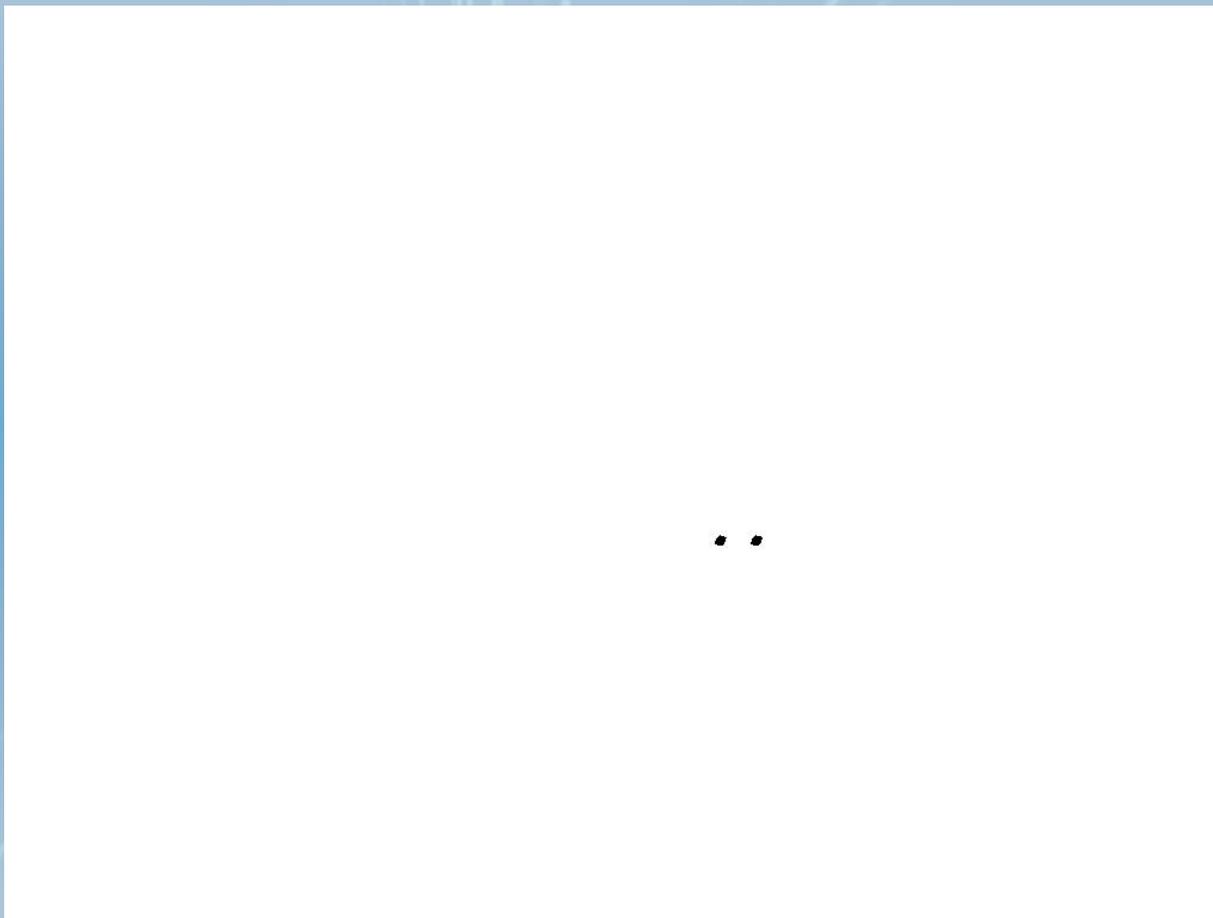
SLRS @ XFEL

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

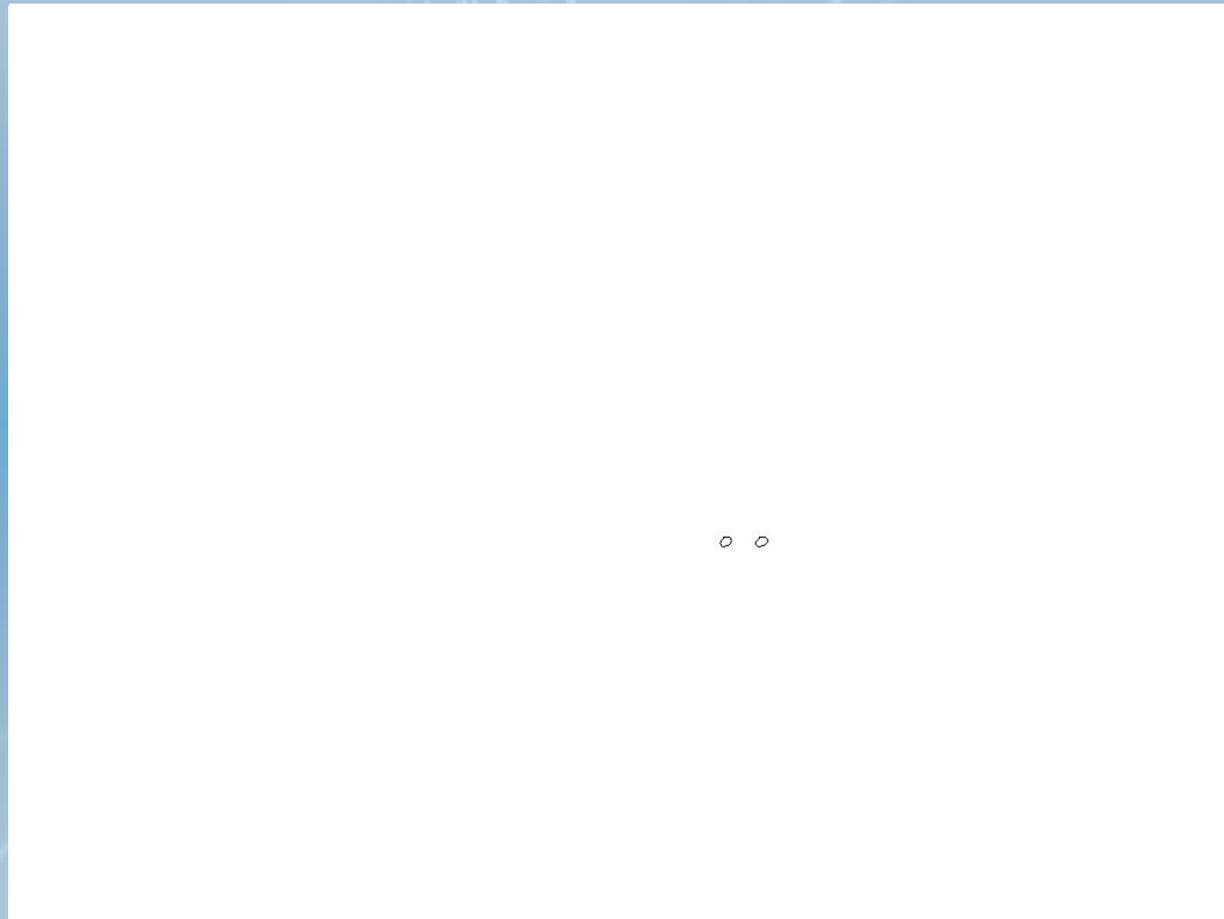
SLRS @ XFEL

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

	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

DIRECT LIGHT
SOURCE

mean error between translation and calculated distance = 3 microns

SUMMARY

FUTURE
DEVELOPMENT



SLRS for XFEL @ DESY

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

Direct light source System

NEW PROJECTS

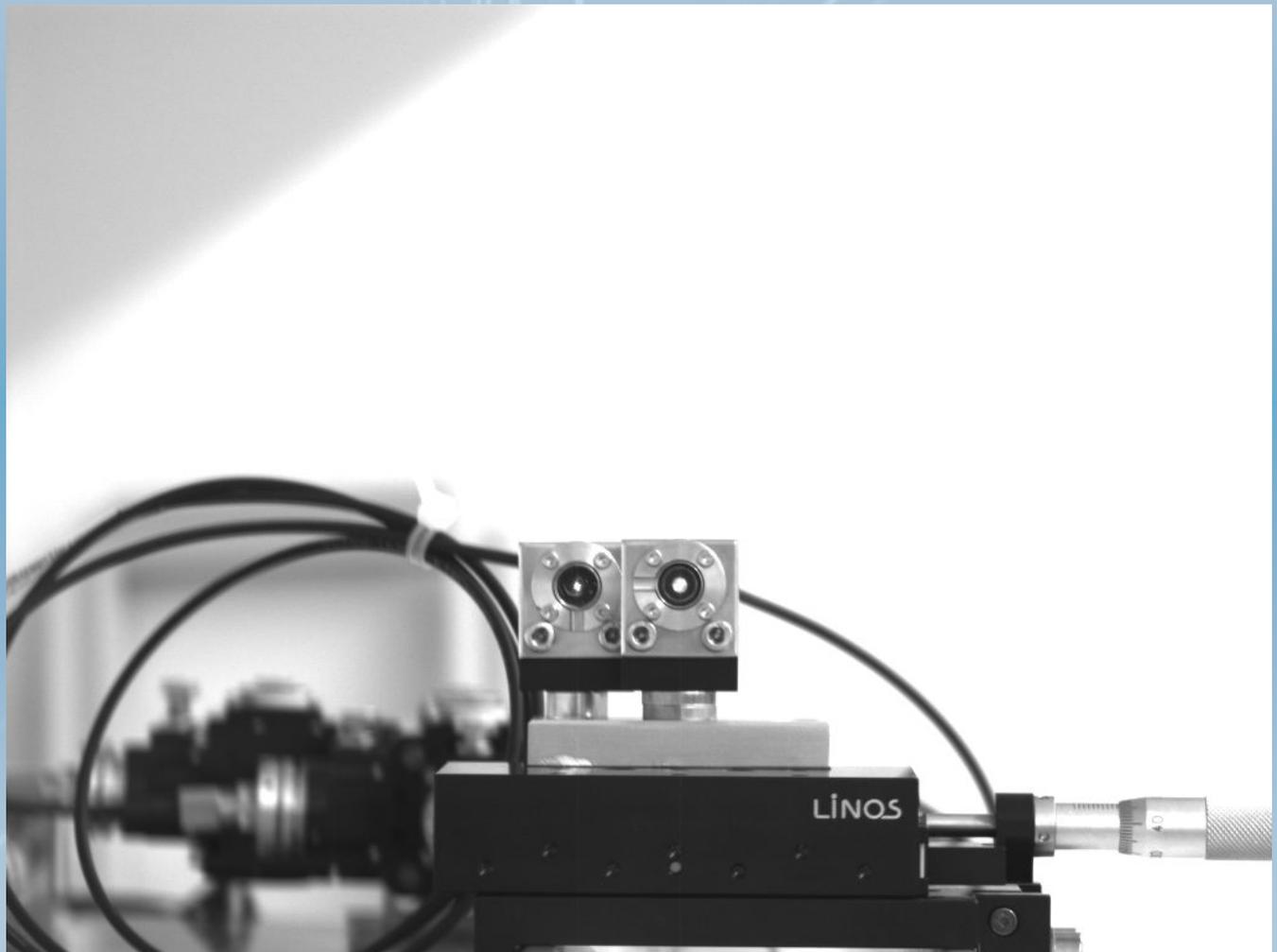
SLRS @ XFEL

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

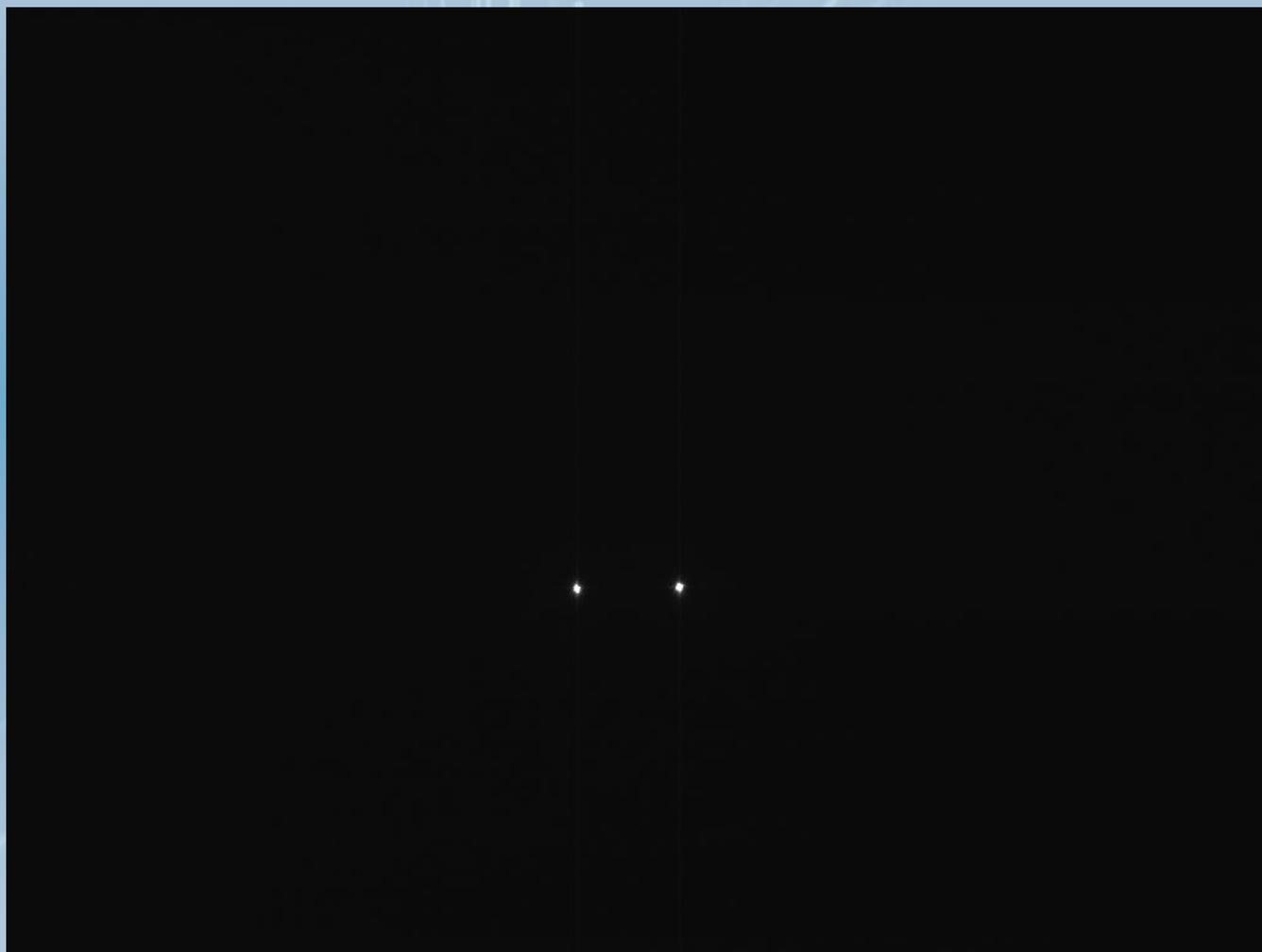
SLRS @ XFEL

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

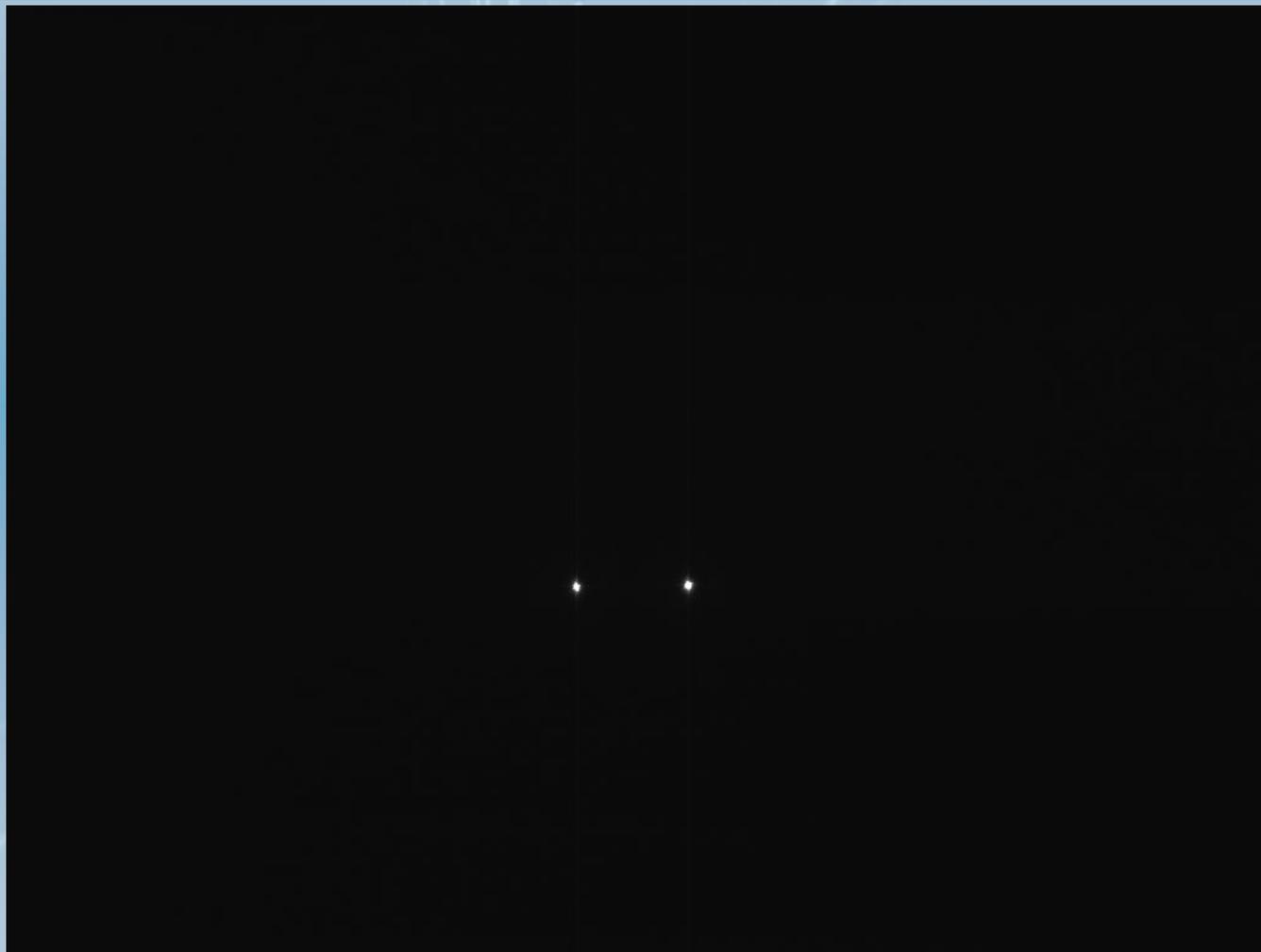
SLRS @ XFEL

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

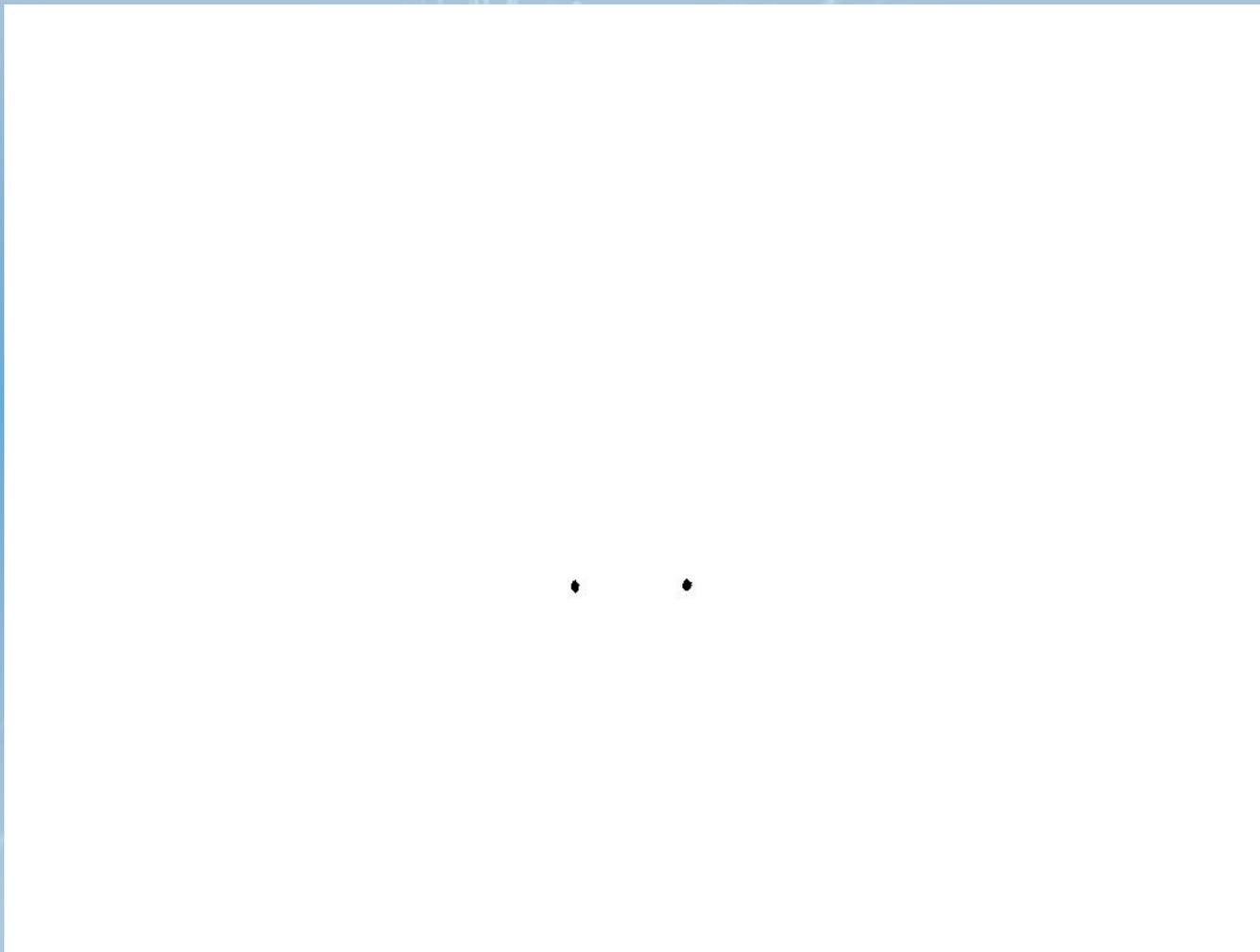
SLRS @ XFEL

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

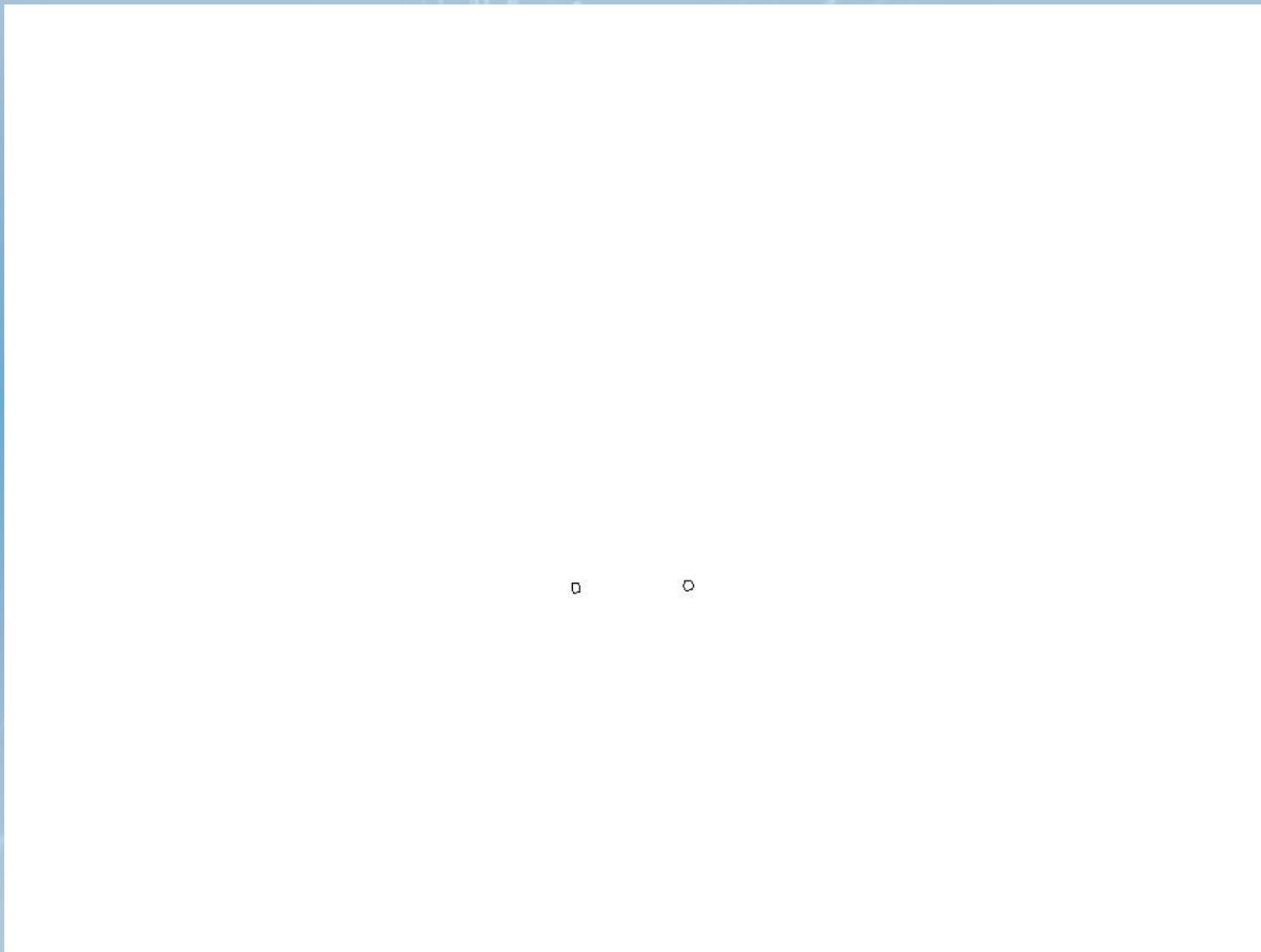
SLRS @ XFEL

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

Poisson-Alignment-System

NEW PROJECTS

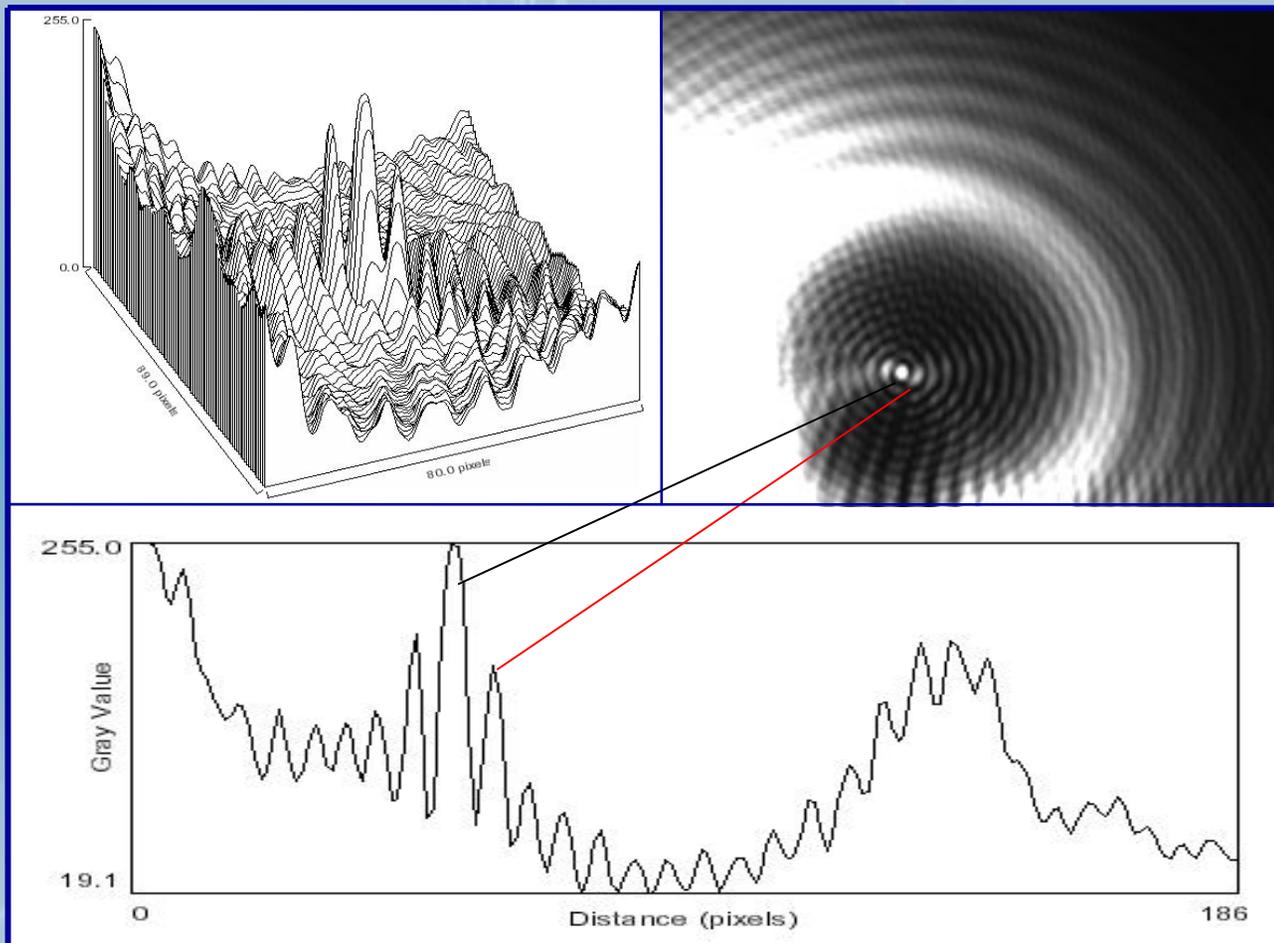
SLRS @ XFEL

POISSON
ALIGNMENT
SYSTEM

DIRECT LIGHT
SOURCE

SUMMARY

FUTURE
DEVELOPMENT



multiple maxima are a problem for automatic calculations



SLRS for XFEL @ DESY

Direct light source System

NEW PROJECTS

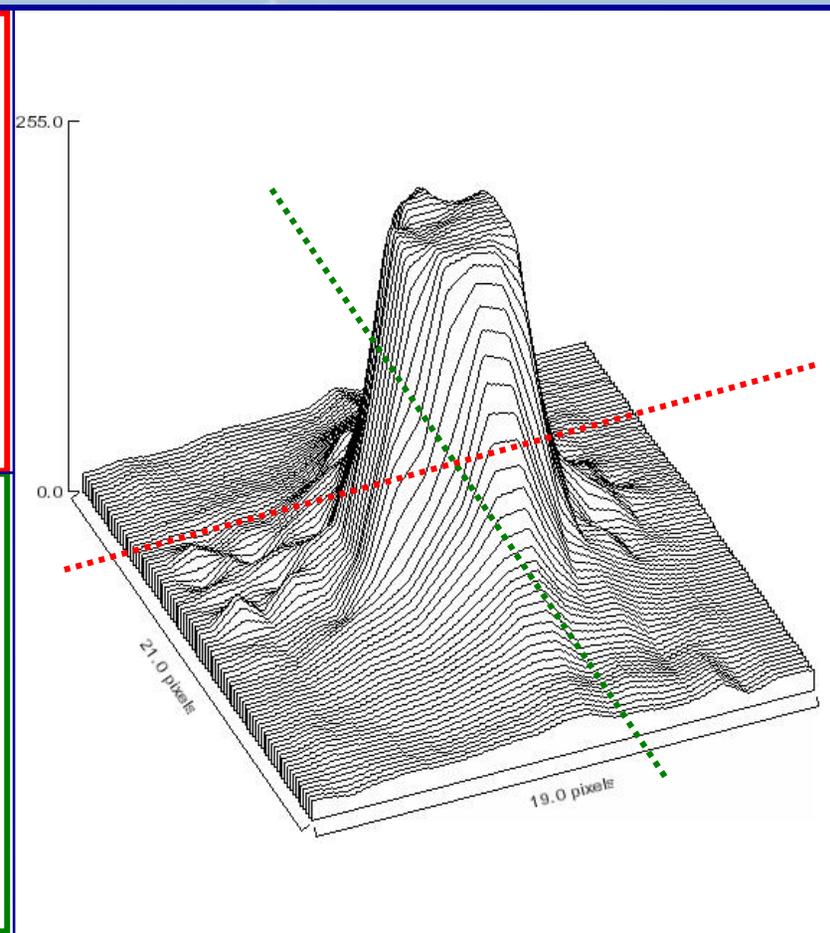
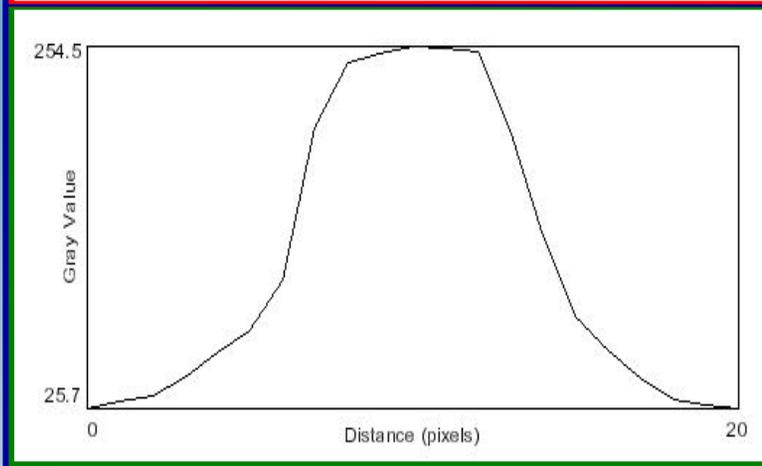
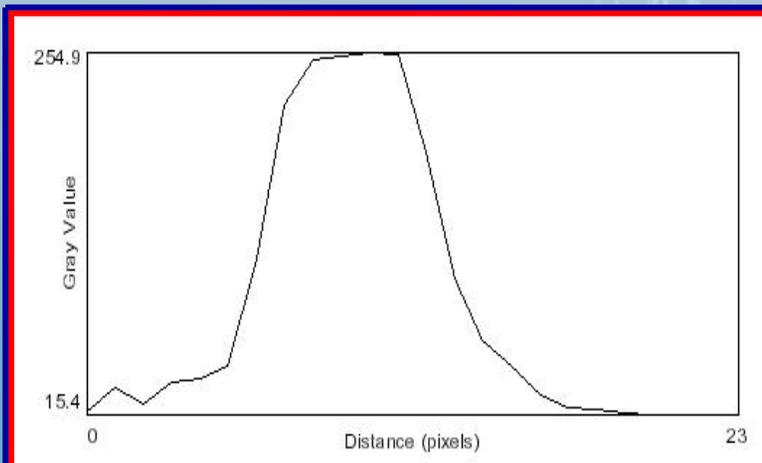
SLRS @ XFEL

POISSON ALIGNMENT SYSTEM

DIRECT LIGHT SOURCE

SUMMARY

FUTURE DEVELOPMENT



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...

