Diffraction Radiation Test: April 2013 Summary

L. Bobb[1, 2], T. Aumeyr[1], M. Billing[3], E. Bravin[2], J. Conway[3], P. Karataev[1], T. Lefevre[2], S. Mazzoni[2]

1. John Adams Institute at Royal Holloway, Egham, Surrey, United Kingdom
2. CERN European Organisation for Nuclear Research, CERN, Geneva, Switzerland
3. Cornell University, Ithaca, New York, USA

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- Introduction
- Diffraction Radiation
- Installation in CESR
- Target set-up + images acquired
- Outlook

Most recent experiments using Optical Diffraction Radiation (ODR) for beam diagnostics

- E. Chiadroni, M. Castellano, A. Cianchi, K. Honkavaara, G. Kube, V. Merlo and F. Stella, “Non-intercepting Electron Beam Transverse Diagnostics with Optical Diffraction Radiation at the DESY FLASH Facility”, Proc. of PAC07, Albuquerque, New Mexico, USA, FRPMN027.

- A.H. Lumpkin, W. J. Berg, N. S. Sereno, D. W. Rule and C. –Y. Yao, *“Near-field imaging of optical diffraction radiation generated by a 7-GeV electron beam”*, Phys. Rev. ST Accel. Beams 10, 022802 (2007).

- P. Karataev, S. Araki, R. Hamatsu, H. Hayano, T. Muto, G. Naumenko, A. Potylitsyn, N. Terunuma, J. Urakawa, *“Beam-size measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility”*, Phys. Rev. Lett. 93, 244802 (2004).

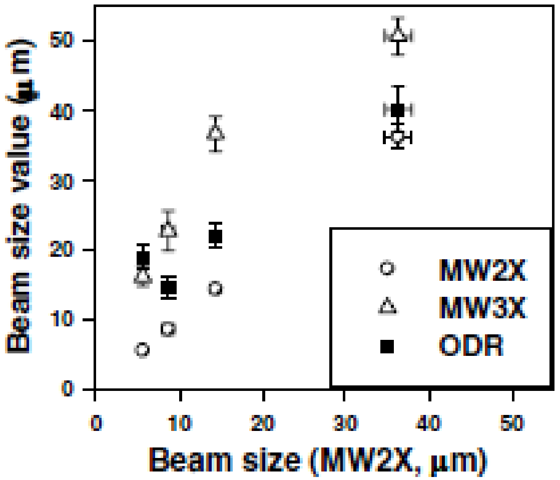


FIG. 7. The correlation between the beam size measured with ODR (black squares) and two wire scanners installed upstream (open circles) and downstream (open triangles) of the target.

σ_y = 14 μm measured
ATF2@KEK

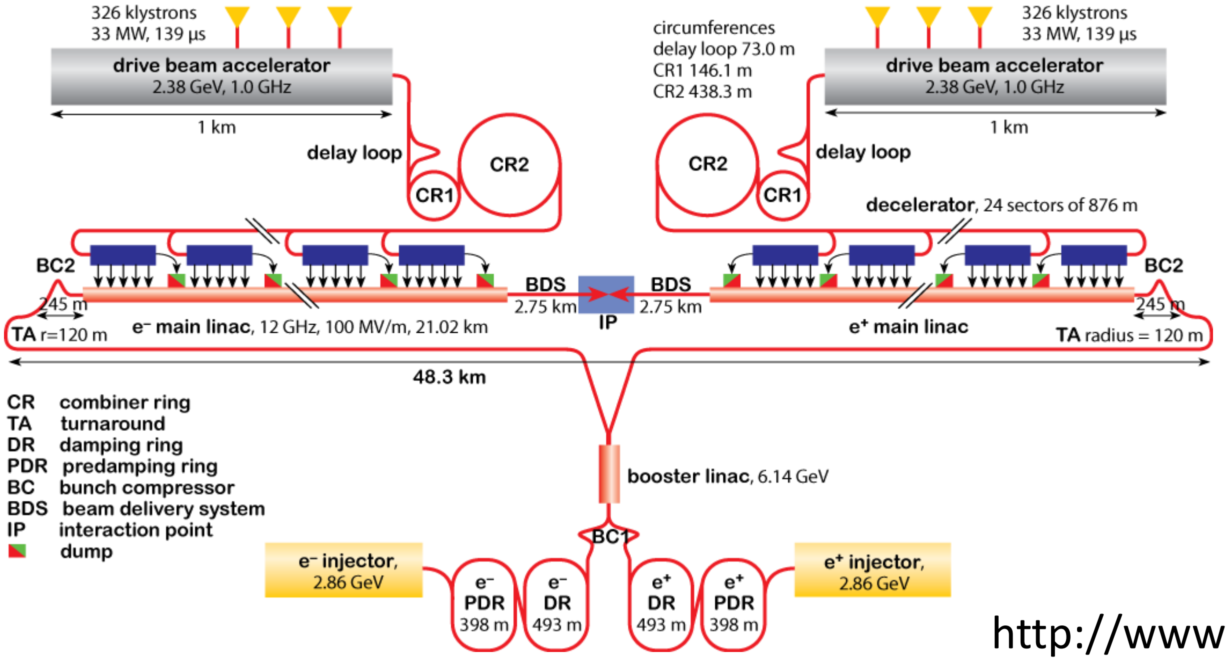
Motivation

Transverse beam size requirements for the Compact Linear Collider (*Table 5.62 CDR Volume 1, 2012*):

Section of machine	Beam Energy [GeV]	Beam size [µm]	Requirement
PDR (H/V)	2.86	50/10	Micron-scale resolution
DR (H/V)		10/1	
RTML (H/V)	2.86 - 9	10/1	
Drive Beam Accelerator	2.37	50 -100	Non-invasive measurement

Baseline high resolution non-interceptive beam profile monitor:
Laser Wire Scanners

S. T. Boogert et al., *"Micron-scale laser-wire scanner for the KEK Accelerator Test Facility extraction line"*, Phys. Rev. S. T. – Accel. and Beams 13, 122801 (2010)



http://www.clic-study.org/

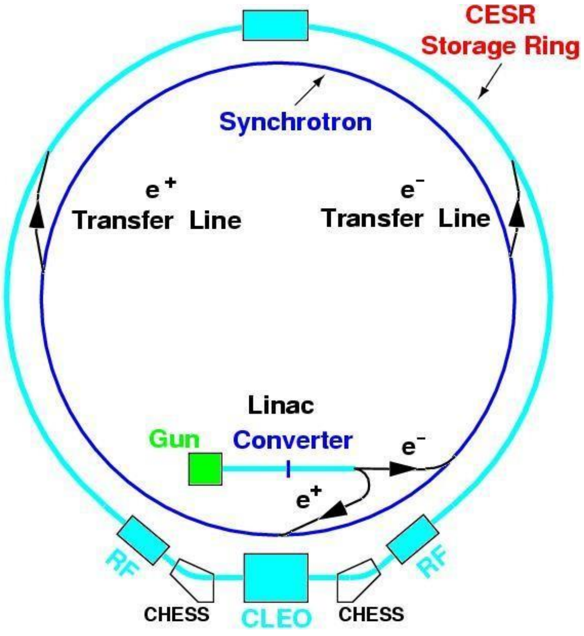
Our experiment

Project aim:

To design and test an instrument to measure on the micron-scale the transverse (vertical) beam size for the Compact Linear Collider (CLIC) using incoherent Diffraction Radiation (DR) at UV/soft X-ray wavelengths.

Cornell Electron Storage Ring Test Accelerator (CesrTA) beam parameters:

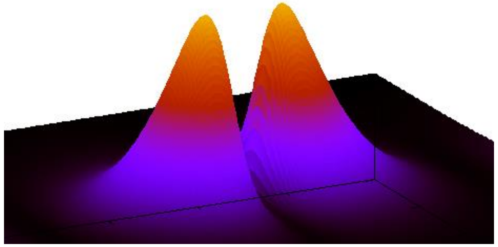
	E (GeV)	σ_H (μm)	σ_V (μm)
CesrTA	2.1	320	~9.2
	5.3	2500	~65



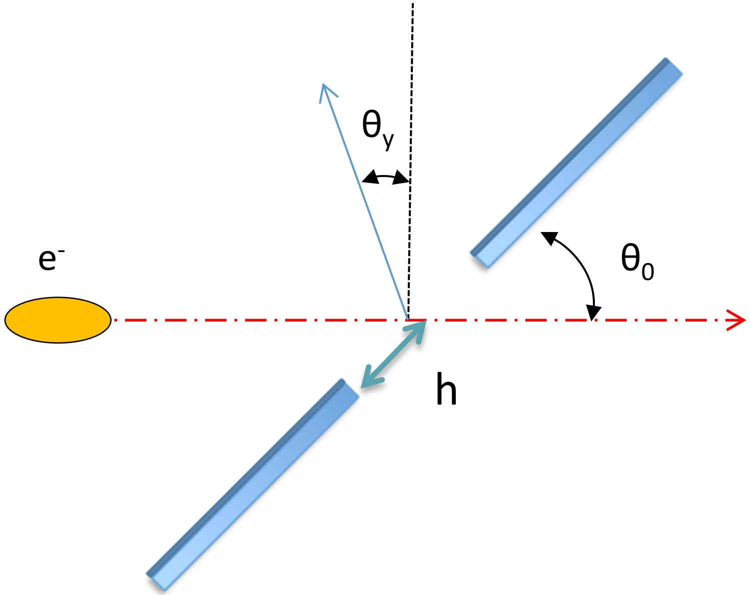
D. Rubin et al., "CesrTA Layout and Optics", Proc. of PAC2009, Vancouver, Canada, WE6PFP103, p. 2751.

http://www.cs.cornell.edu

Diffraction Radiation



DR Angular distribution



Principle:

1. Electron bunch moves through a high precision co-planar slit in a conducting screen (Si + Al coating).
2. Electric field of the electron bunch polarizes atoms of the screen surface.
3. DR is emitted in two directions:
   - along the particle trajectory “Forward Diffraction Radiation” (FDR)
   - In the direction of specular reflection “Backward Diffraction Radiation” (BDR)

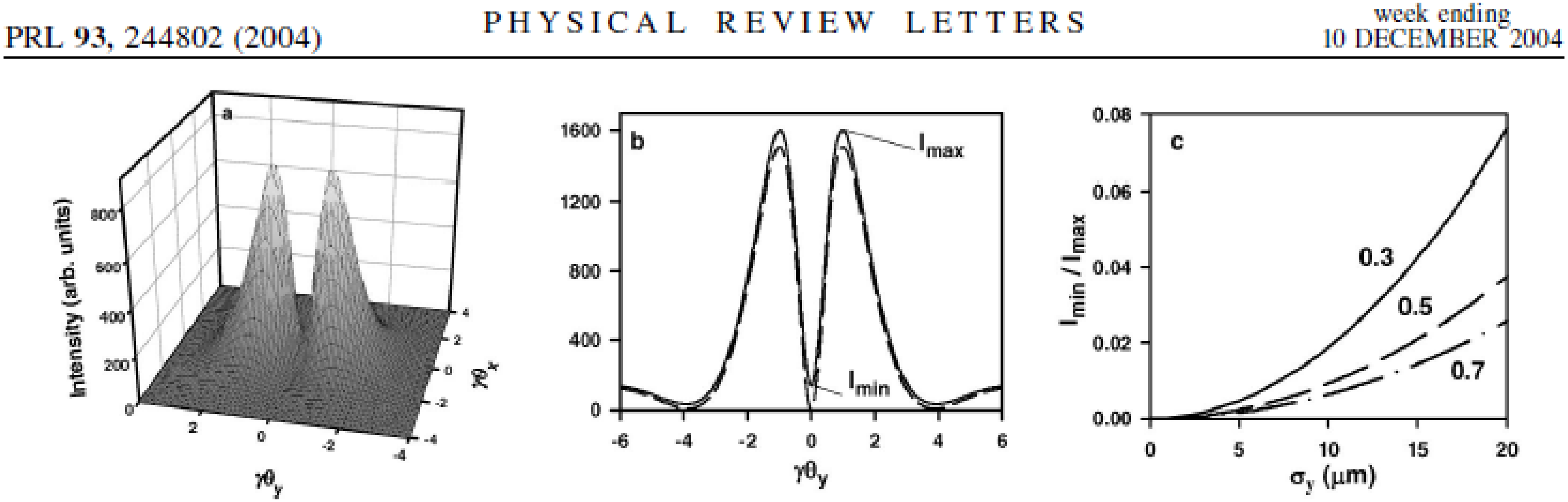
Impact parameter:

$$h \leq \frac{\gamma\lambda}{2\pi}$$

Generally:
DR intensity ⇧ as slit size ⇩

Vertical Beam Size Measurement using the Optical Diffraction Radiation (ODR) model + Projected Vertical Polarisation Component (PVPC)

P. Karataev et al.



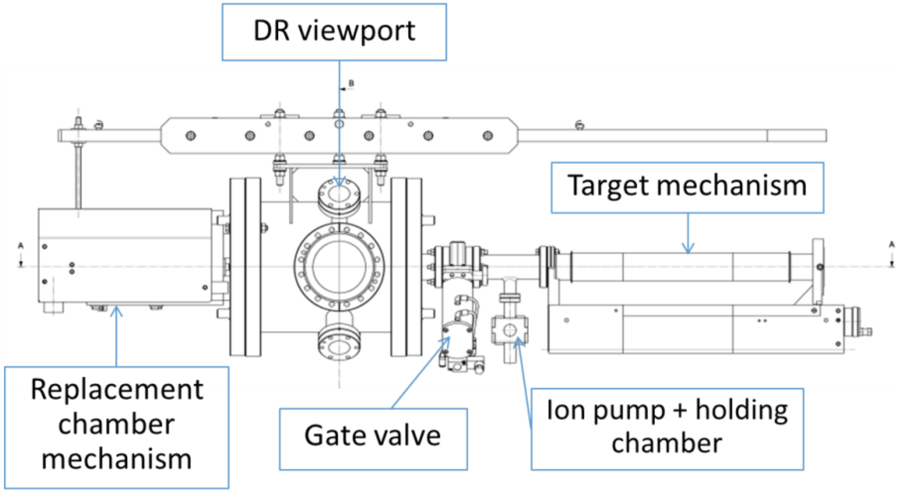
PRL 93, 244802 (2004) PHYSICAL REVIEW LETTERS week ending 10 DECEMBER 2004

Vertical polarisation component of 3-dimensional (θ_x, θ_y, Intensity) DR angular distribution.

PVPC is obtained by integrating over θ_x to collect more photons.

Visibility (I_{min}/I_{max}) of the PVPC is sensitive to vertical beam size σ_y.

Vacuum chamber assembly



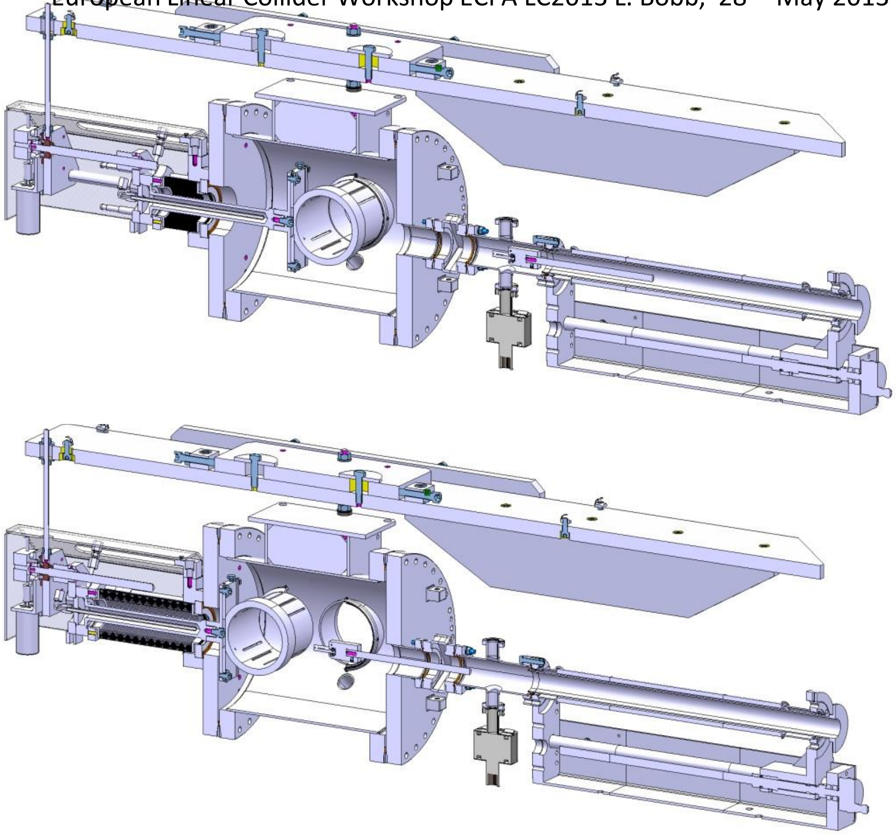
DR viewport

Target mechanism

Replacement chamber mechanism

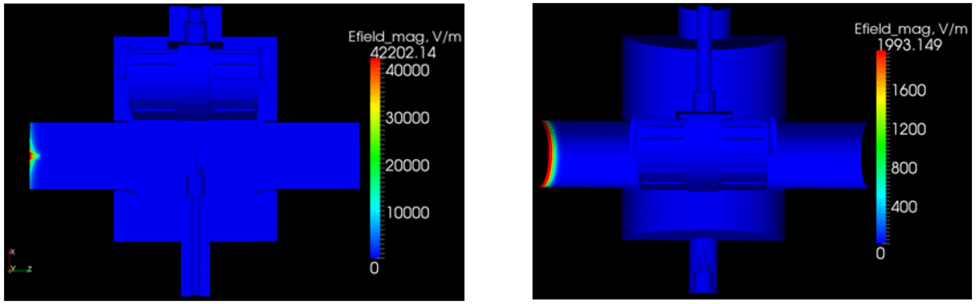
Gate valve

Ion pump + holding chamber

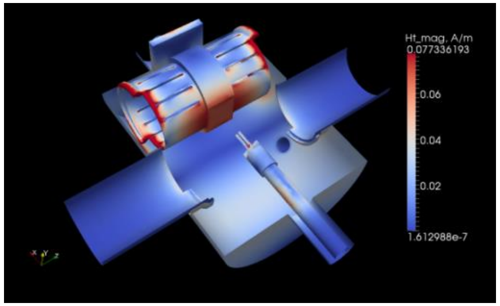


Technical drawings by N. Chritin
Simulations by A. Nosych

E-field magnitude of a single bunch pass in time domain (Gaussian bunch, length = [-4σ,4σ], σ = 10mm)



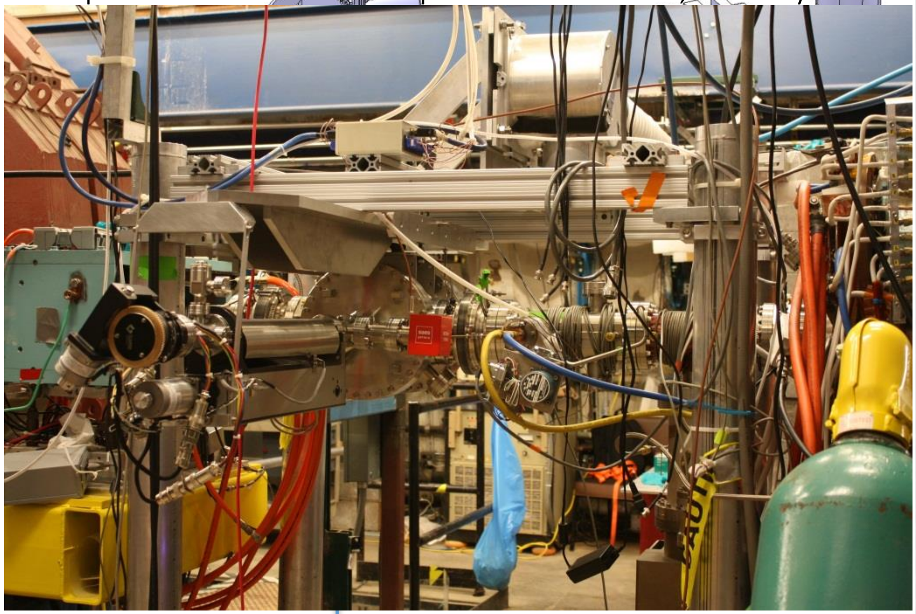
H-field surface tang complex magnitude (Loss map)
Mode Fr = 1.19 GHz, Q = 3309, Ploss = 0.075 W

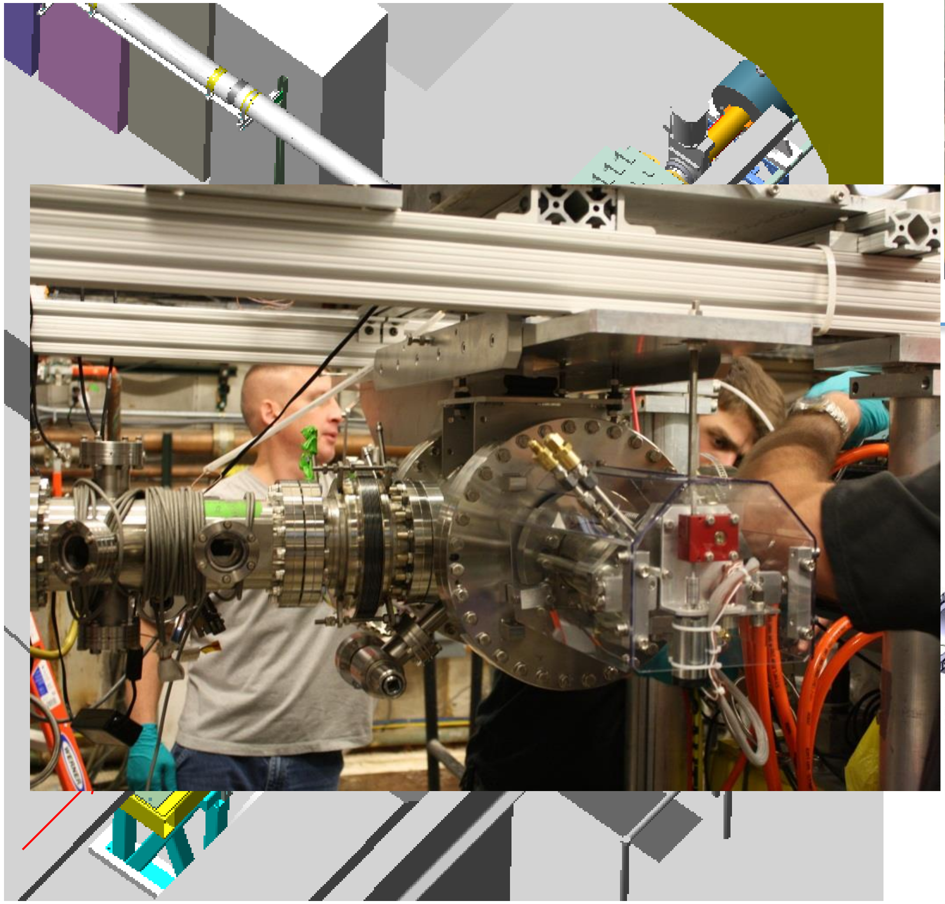


Total power loss for single bunch = 0.6 W

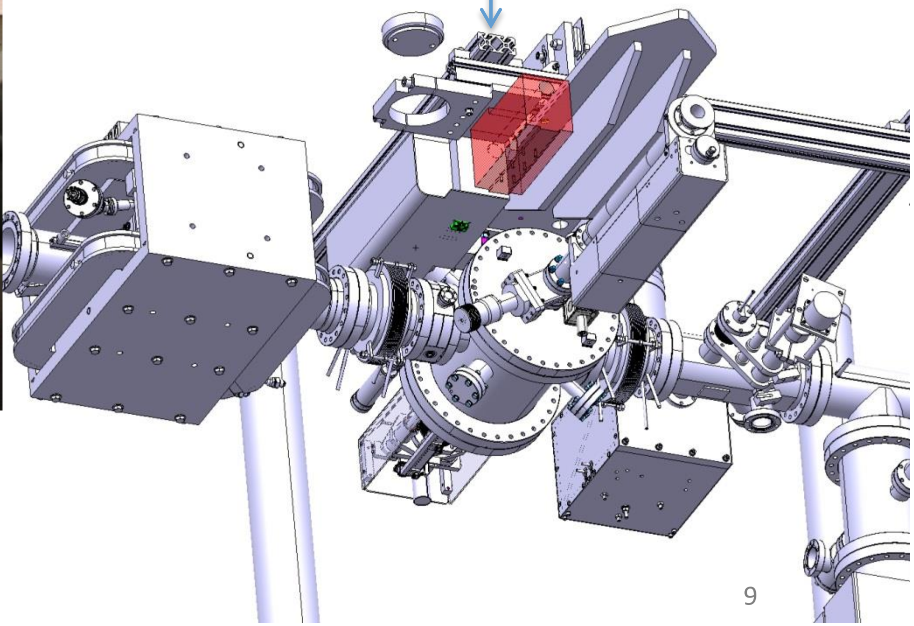
L3 layout @CesrTA

Electron beam direction





DR experiment



Technical drawings by N. Chritin

Optical System

Far-field Condition:

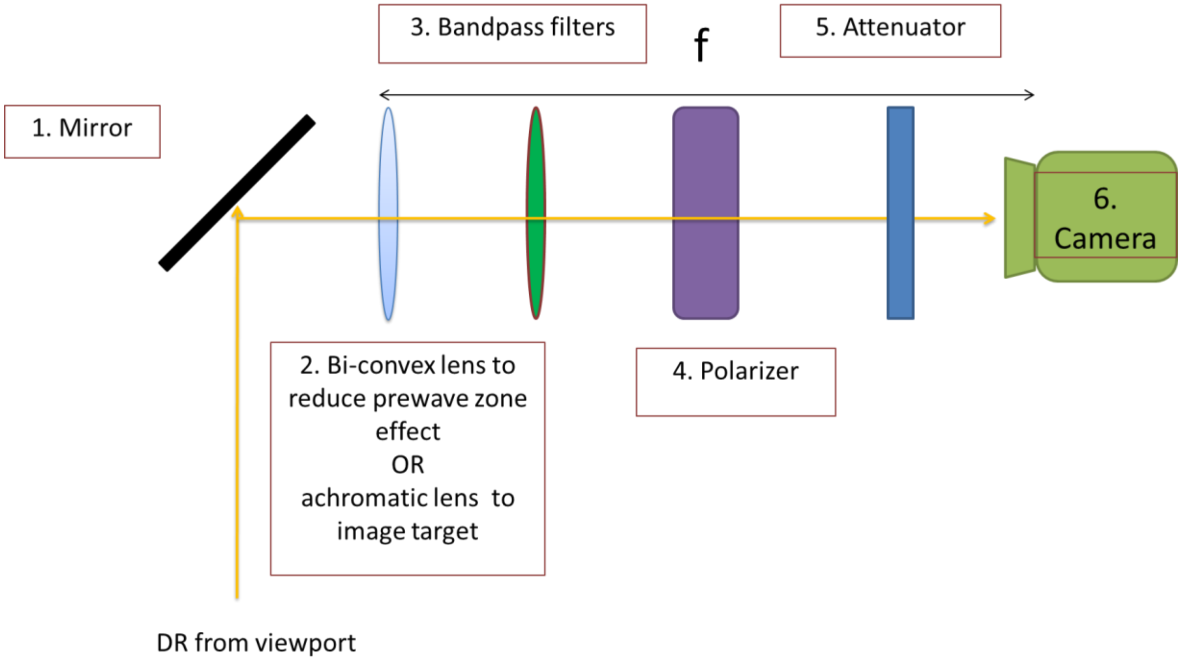
$$L \gg \frac{\gamma^2 \lambda}{2\pi}$$

- L = distance from source of DR to detector.
- Compact optical system is in the prewave zone

(*Pre-wave zone effect in transition and diffraction radiation: Problems and Solutions* -P. V. Karataev).

$\frac{\gamma^2 \lambda}{2\pi}$ given γ and λ:

	2.1 GeV	5 GeV
200 nm	0.54 m	3.18 m
400 nm	1.08m	6.37 m



3. Bandpass filters

f

5. Attenuator

1. Mirror

6. Camera

2. Bi-convex lens to reduce prewave zone effect
OR
achromatic lens to image target

4. Polarizer

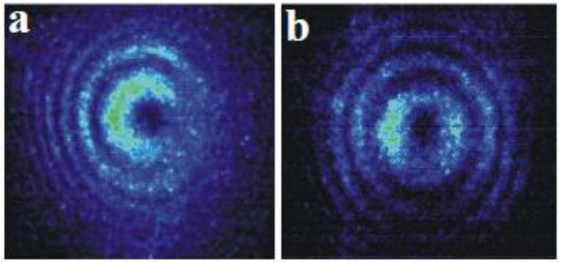
DR from viewport

Compact optical system (distance to detector $L \le \frac{\gamma^2 \lambda}{2\pi}$)	Long-range optical system (distance to detector $L \gg \frac{\gamma^2 \lambda}{2\pi}$)
Bi-convex lens required with camera in back focal plane.	Far-field zone
Dual purpose: 1. Image target 2. Image DR angular distribution	
DR observation wavelengths: λ = 400 nm	
In footprint of target mechanism (< 1m)	Determined by L and spatial constraints.

Synchrotron Radiation (SR)

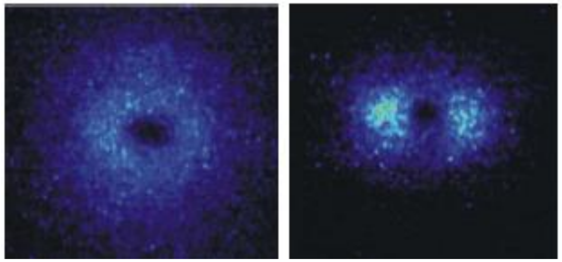
Source of background	Contribution
SR from beamline optics	High
Camera noise	Low
Residual background	

SR + DR interference

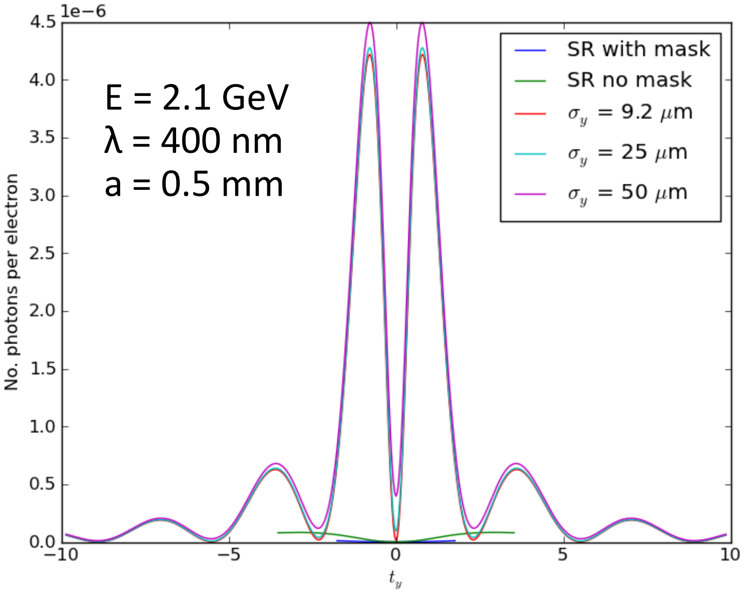


OTR ODR

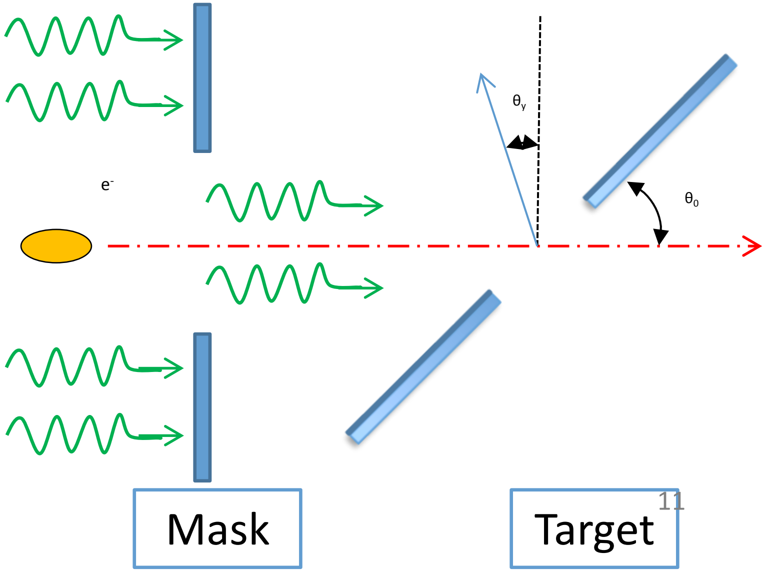
SR suppression



P. Karataev et al., Proc. of EPAC 2004, THPLT067



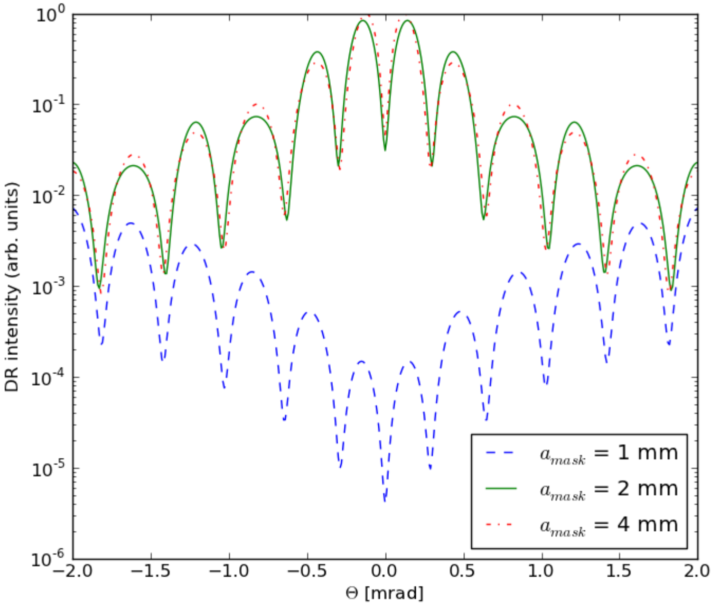
Use a mask upstream of target to suppress SR contribution.



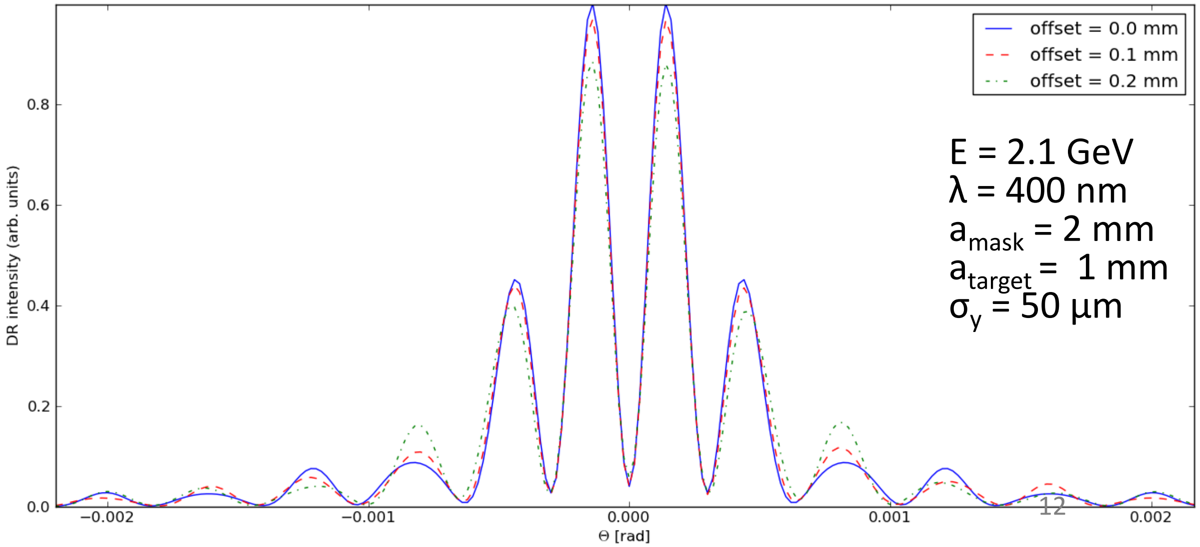
Optical Diffraction Radiation Interference (ODRI)

A. Cianchi et al., Phys. Rev. ST Accel. Beams 14 (10) 102803 (2011)

Aperture sizes	Interference
$a_{mask} = a_{target}$	Complete destructive interference of FDR + BDR (blue)
$a_{mask} \approx 2 \cdot a_{target}$	Measureable interference (green)
$a_{mask} \geq 4 \cdot a_{target}$	Negligible interference (red)



Using non-collinear slits (i.e. centres of mask + target do not coincide) allows measurement of beam size, beam offset from the target centre and angular divergence.



E = 2.1 GeV
λ = 400 nm
a_{mask} = 2 mm
a_{target} = 1 mm
σ_y = 50 μm

Goals

Experiment set-up

- Evaluate the beam lifetime within a 1 mm slit and 0.5 mm slit

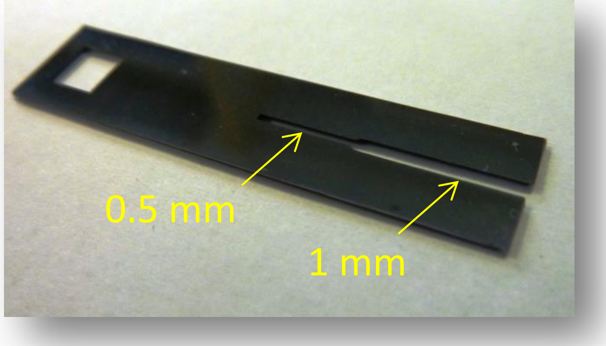
Target imaging using achromat

- Polariser scan to observe the Ex and Ey fields on the target
  - Correlate the Ey field width with vBSM (visible BSM) horizontal beam size
- Estimation of SR background contribution

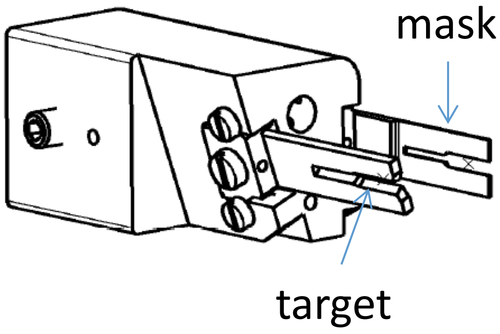
DR imaging using bi-convex lens

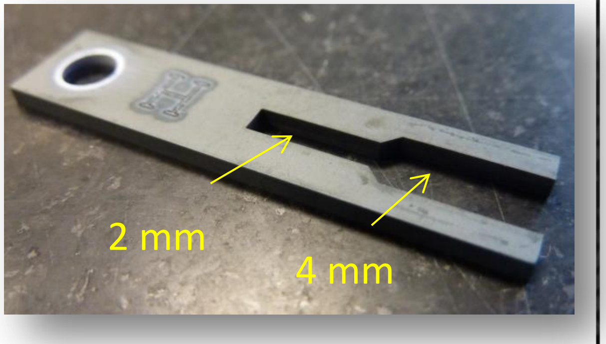
- Compare images with Zemax simulations
- Acquire DR multi-turn integrated images using a 400 nm optical filter for different beam sizes
- If possible, acquire single turn DR images

Chemically etched target setup

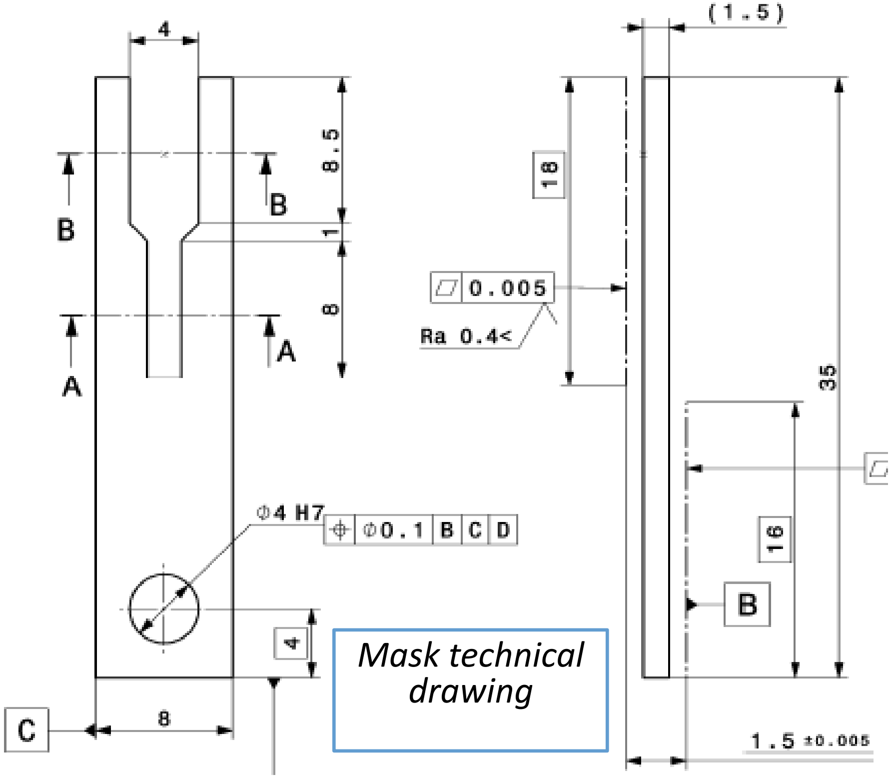


Silicon TARGET





Silicon Carbide MASK



Mask technical drawing

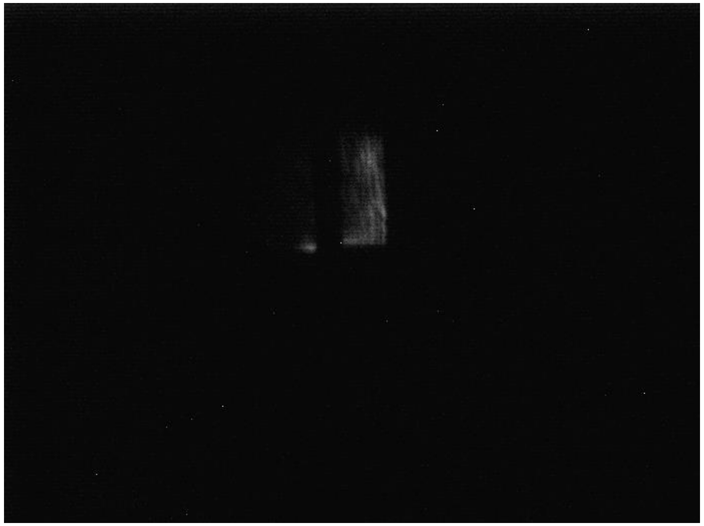
Machine Parameters:

- E = 2.1 GeV
- Single bunch
- $I_{max} \sim 1.11$ mA
- $13 < \sigma_y < 50$ µm

Technical drawings by N. Chritin,
Photographs by L. Remandet

Images from chemically etched target

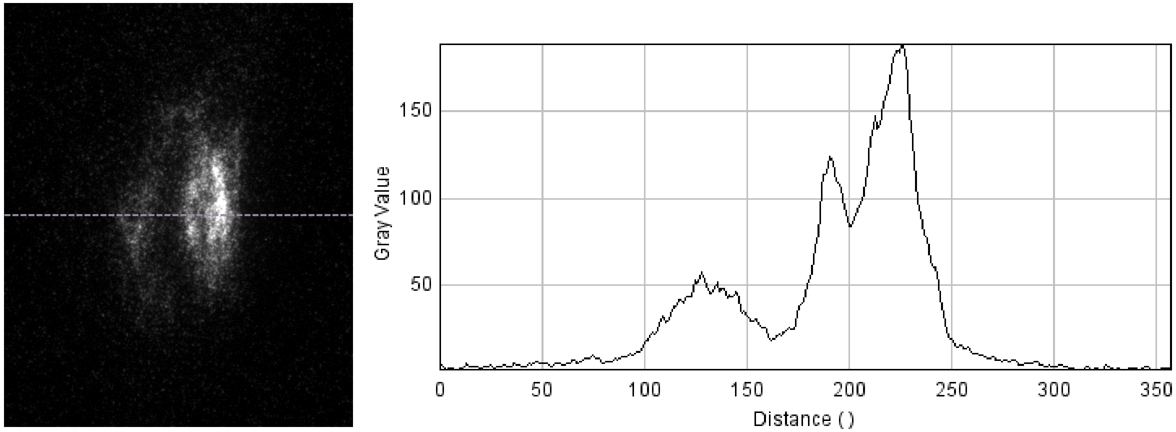
Target imaging using achromat:



Alignment of electron beam in target aperture:

- We see the shadow of the mask aperture on the target positioned behind. The mask edge is seen at the outer limits of the illumination by SR.
- The concentrated circle of light is from TR + DR from the target aperture.

DR observation using biconvex lens:



DR angular distribution image for 1mm aperture:

- Asymmetry due to poor coplanarity as expected.
- We are interested in the vertical cross-section.

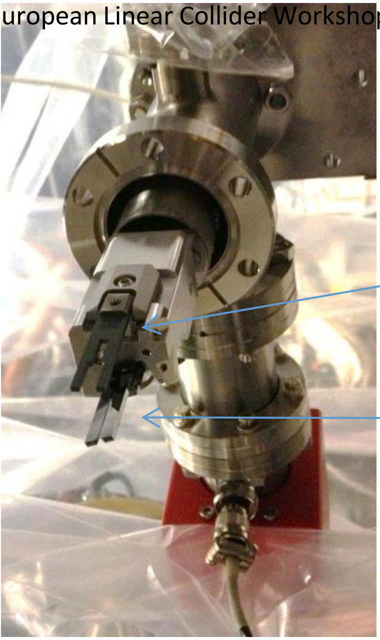
Molecular adhesion target

"Bonding by molecular adhesion (either 'direct wafer bonding' or 'fusion bonding') is a technique that enables two substrates having perfectly flat surfaces (e.g., polished mirror surfaces) to adhere to one another, without the application of adhesive (gum type, glue, etc.)."

Patent US 8158013 B2

Machine Parameters:

- E = 2.1 GeV
- Single bunch
- $I_{max} \sim 1.11$ mA
- $13 < \sigma_y < 50$ µm
- 1 mm target aperture
- 2mm, 4mm mask



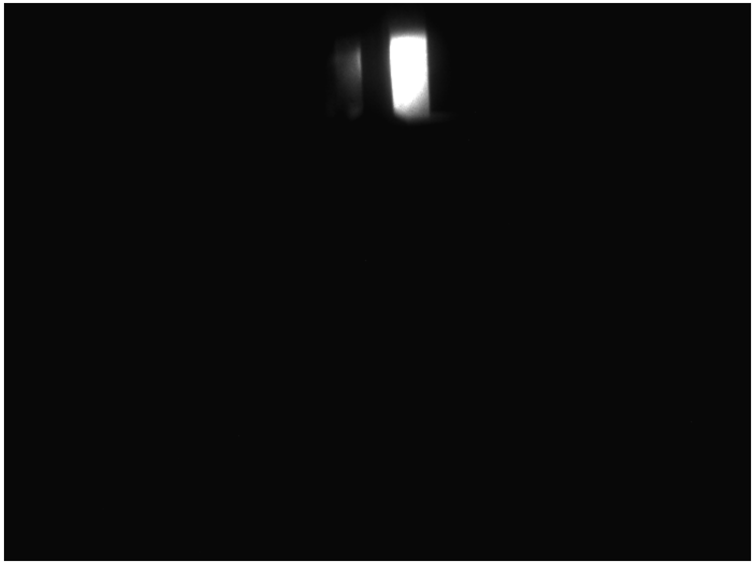
mask

target
(70° tilt angle wrt
to e-beam)

Photo taken during target changeover in L3.

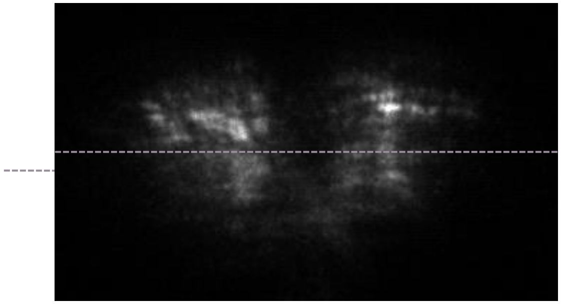
Molecular adhesion target (2mm version)

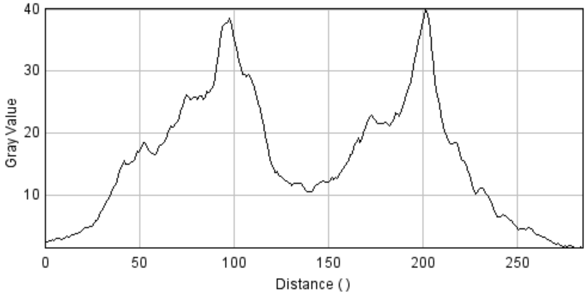
Images from molecular adhesion target



Alignment of electron beam in 1mm target aperture:

- We see the shadow of the mask aperture on the target positioned behind. The mask edge is seen at the outer limits of the illumination by SR.
- The concentrated circle of light is from TR + DR from the target aperture.





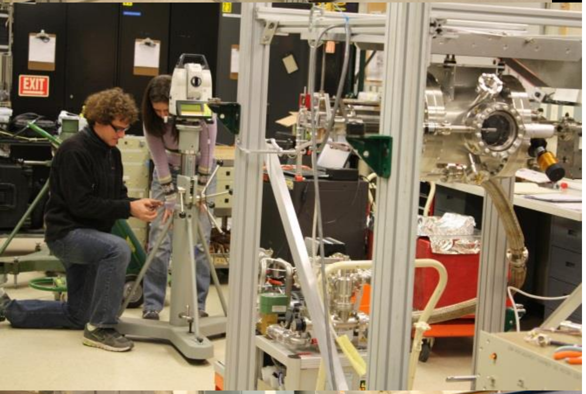
DR angular distribution image for 1mm aperture:

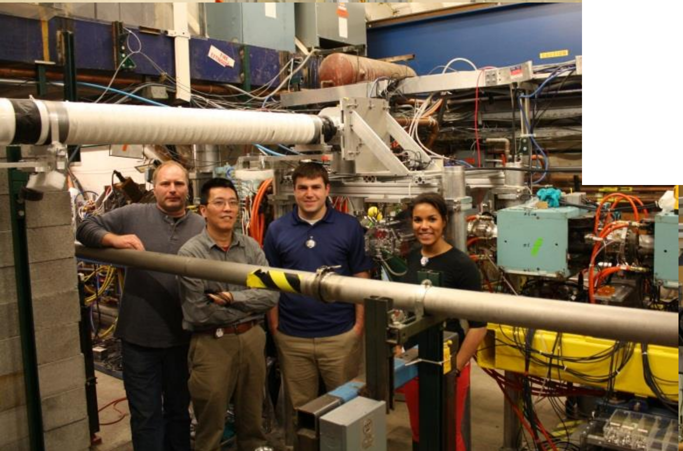
- Better coplanarity so a better symmetry in the amplitudes of the 2 lobes is observed as expected.

Outlook

- Detailed analysis of all target images and diffraction radiation images is on-going (comparison with DR theory , SRW and Zemax simulations).
- The results from these images (observed beam illumination width for target imaging and visibility measurements for DR imaging) will be cross-referenced with the machine parameters (recorded with the fast logger) and instrumentation measurements (xBSM for vertical beamsize measurement, cBPM system for beam orbits and vBSM for horizontal beam size).
- Further investigation into the beam lifetime is also required. (Approx 2-3 minutes independent of beam size ($\sigma_y \leq 50\ \mu\mathrm{m}$)). Changing metal components for ceramic versions, changing the aspect ratio etc. may improve the lifetime.
- Acquire single-turn images
- Improve optical system. This may involve opting for a long-line system to be in the far-field.

Acknowledgements





CERN:
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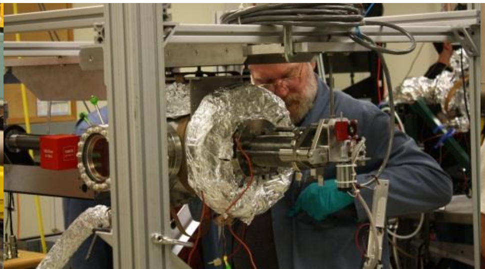
RHUL:
T. Aumeyr, P. Karataev



Thank you for your attention