Investigation of Optical Diffraction Radiation for Non-invasive Diagnostics in Circular Accelerators

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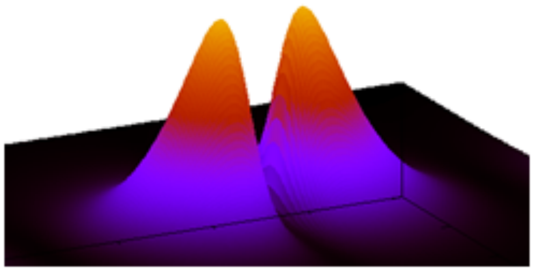
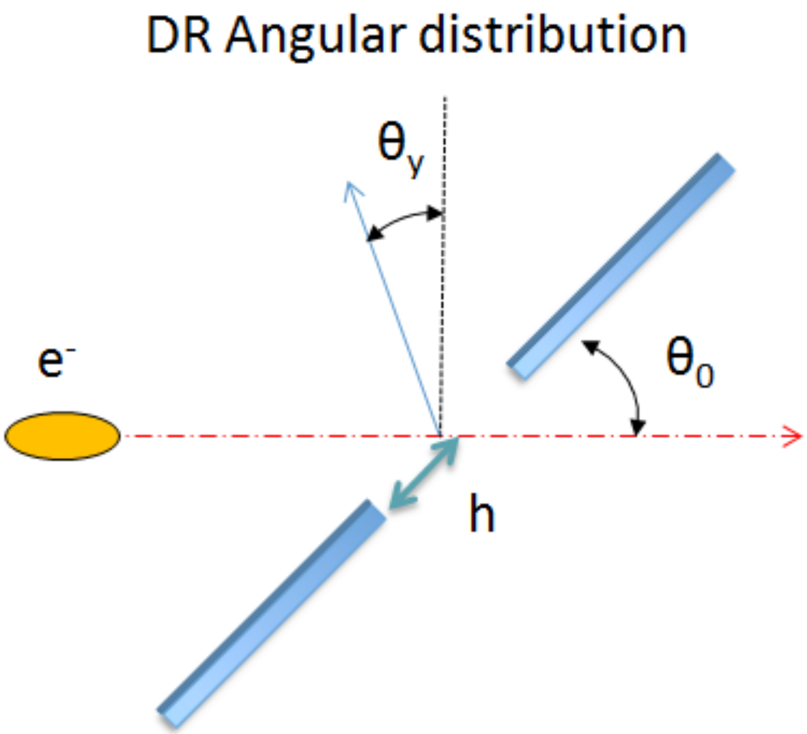
Diffraction Radiation





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)

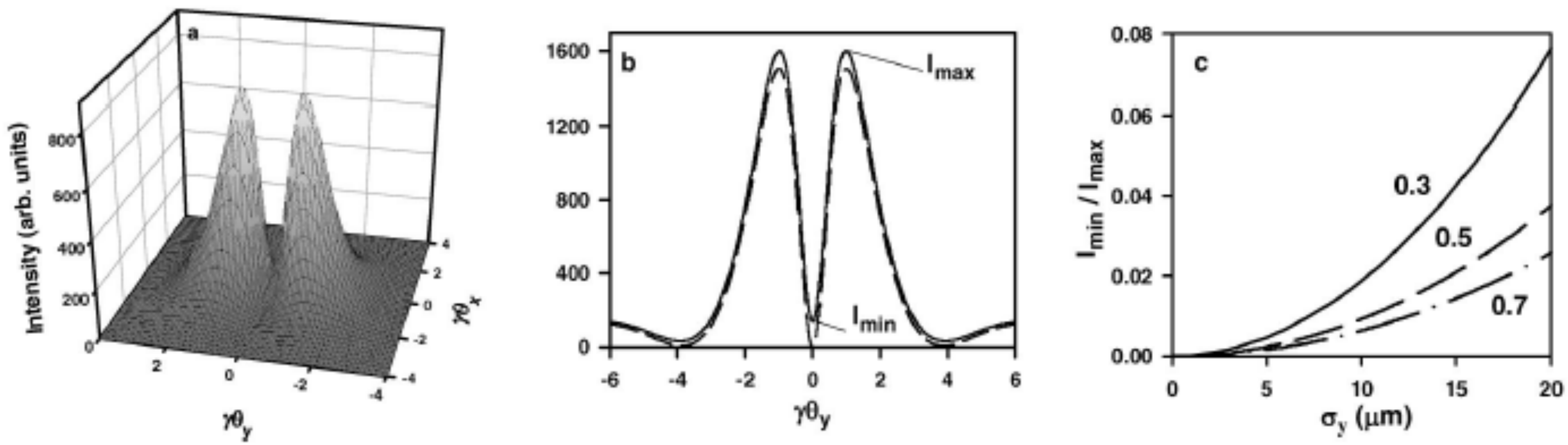
Impact parameter:
$h \leq \gamma\lambda/2\pi$

θ_y = observation angle in vertical direction
θ_0 = target tilt angle
λ = wavelength
γ = Lorentz factor

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.

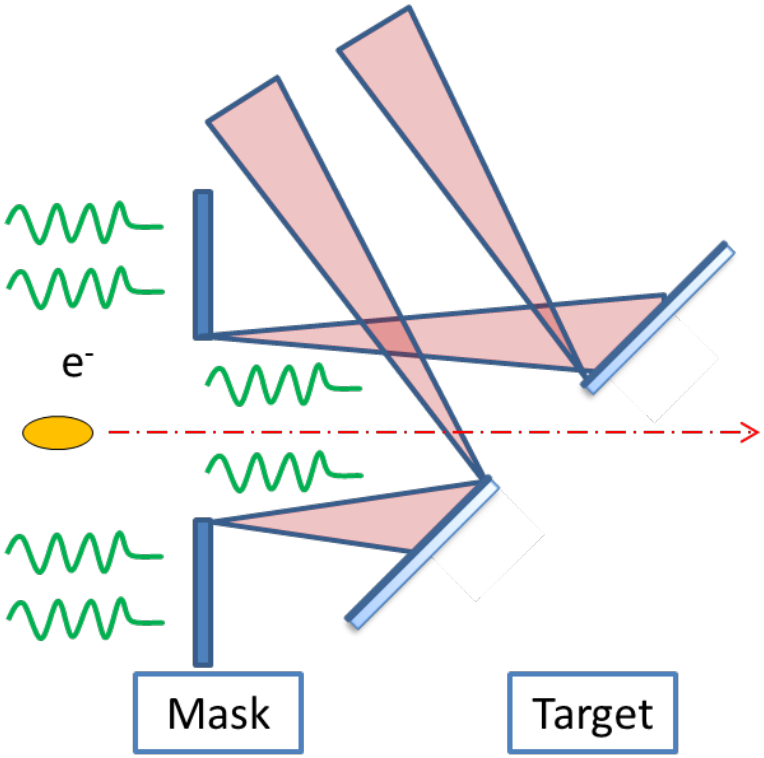
→

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

Synchrotron Radiation (SR)

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

Use a mask upstream of target to suppress SR contribution.

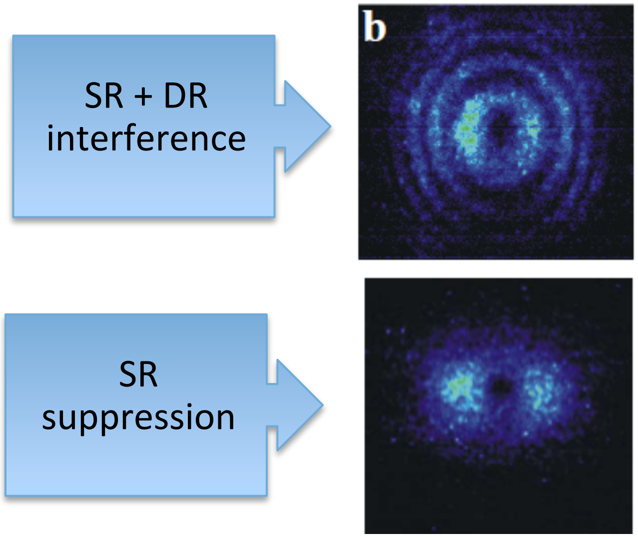


ODRI considerations:

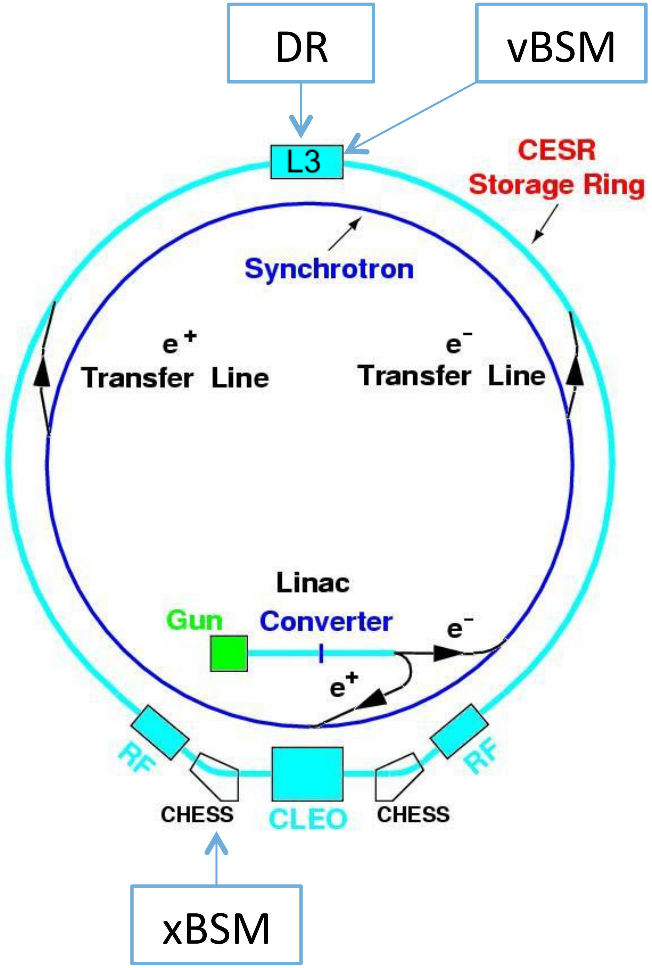
Aperture sizes	Interference
$a_{mask} = a_{target}$	Significant destructive interference of FDR + BDR
$a_{mask} \approx 2 \cdot a_{target}$	Measureable interference
$a_{mask} \geq 4 \cdot a_{target}$	Negligible interference

A. Cianchi et al. Phys. Rev. S. T., 14 102893 (2011)

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



CesrTA – Cornell electron synchrotron Test Accelerator



http://www.cs.cornell.edu

DR:

- Located in L3 straight section
- Target is inserted from the radial outside

vBSM (Visible Beam Size Monitor)

- measures horizontal beam size σ_x

(S. Wang et al., IPAC2013, MOPWA073, p. 849.)

xBSM (X-ray Beam Size Monitor)

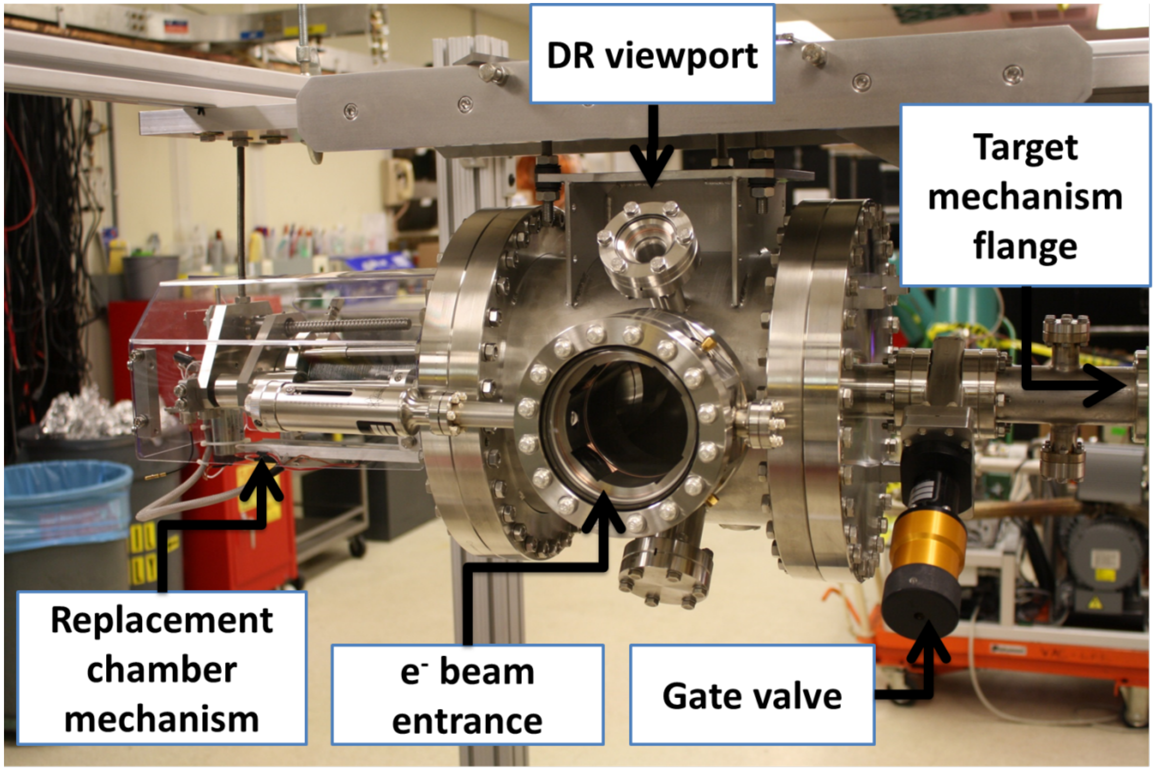
- measures vertical beam size σ_y

(N. Rider et al., IBIC2012, WECD01, p.585.)

Beam lifetime + beam current monitor

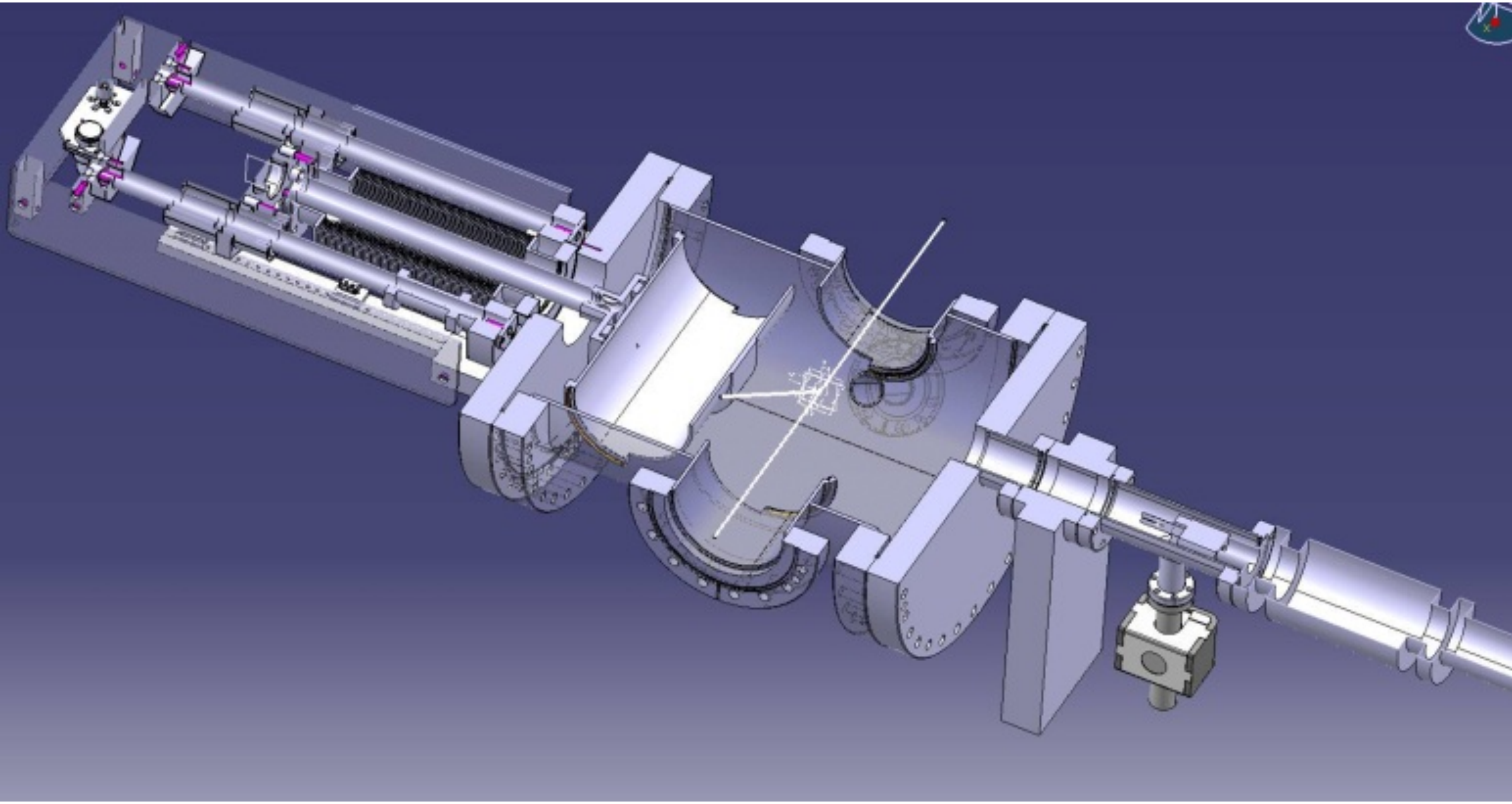
Beam loss monitors downstream of DR target

Vacuum chamber assembly



- LHS : CHESS operation
- RHS: DR experiment
- Optical system connected to DR viewport
- Gate valve to disconnect CESR vacuum for target changeover
- Target mechanism: rotation + translation IN/OUT

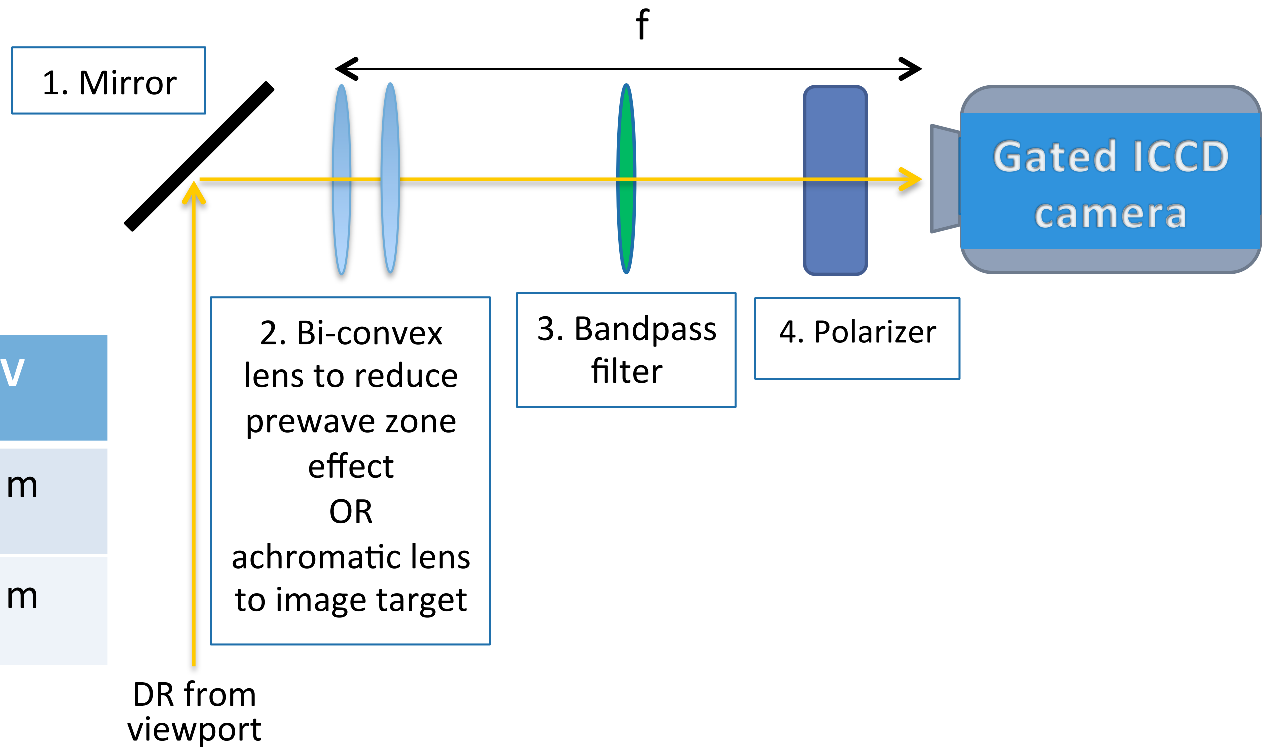
LHS = Left Hand Side
RHS = Right Hand Side

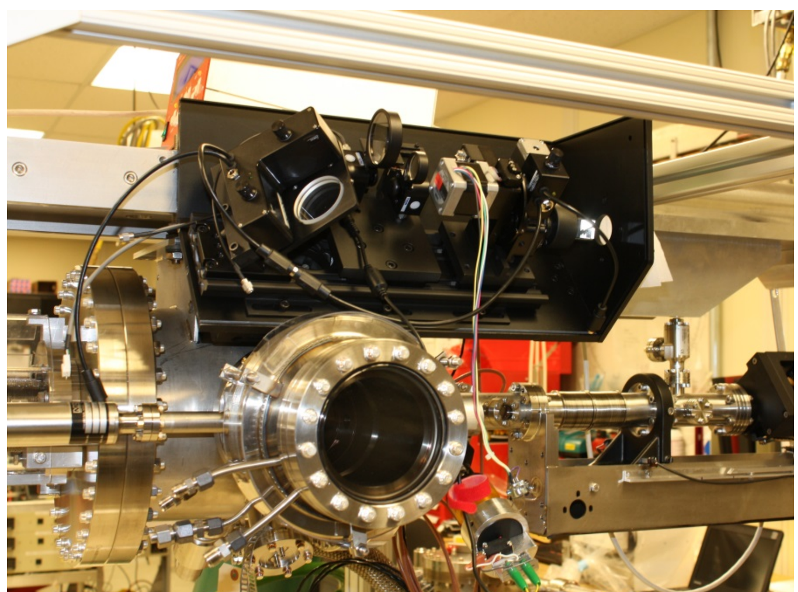


Optical System

$\gamma^2 \lambda/2\pi$ given γ and λ:

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

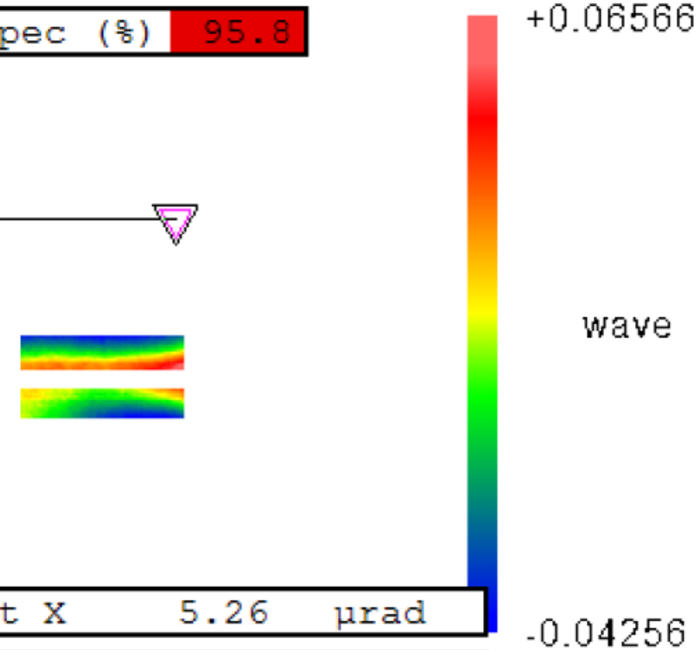




Molecular adhesion target

Molecular adhesion target (2mm version shown here). 1mm aperture version was used at CesrTA.

Points	7952
Pts in PV Spec (%)	95.8



Size X	9.96	mm	Tilt X	5.26	µrad
Size Y	4.98	mm	Tilt Y	-59.30	µrad

"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.)."

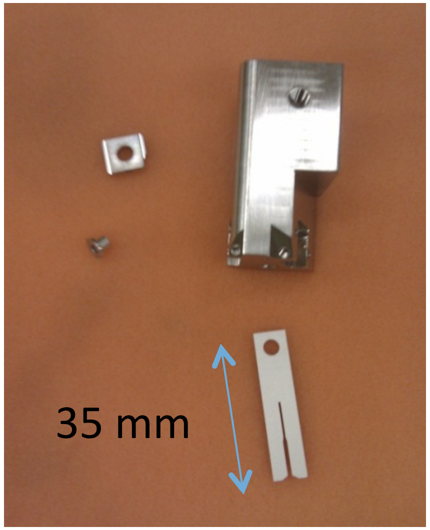
Patent US 8158013 B2

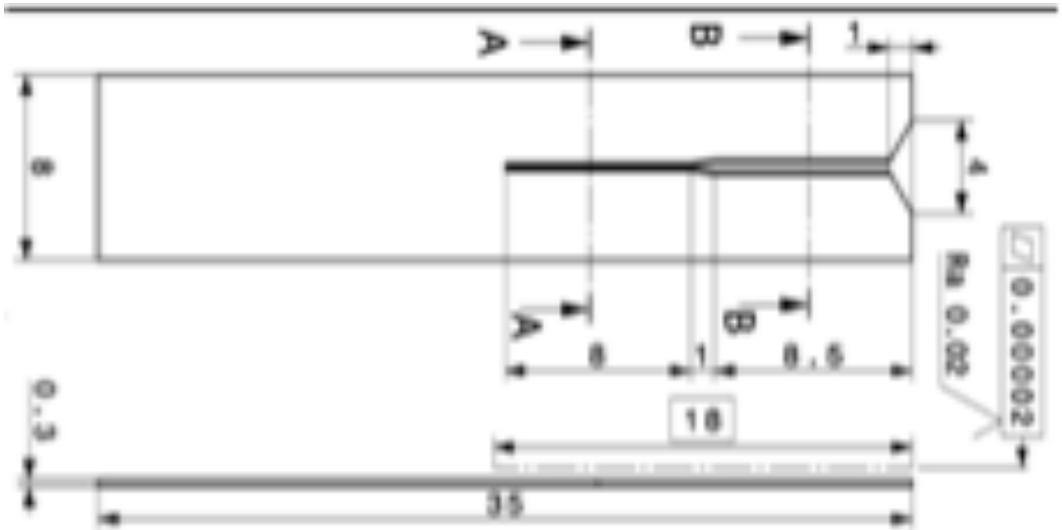
Coplanarity measurement:

PV	68.479	nm
rms	13.909	nm

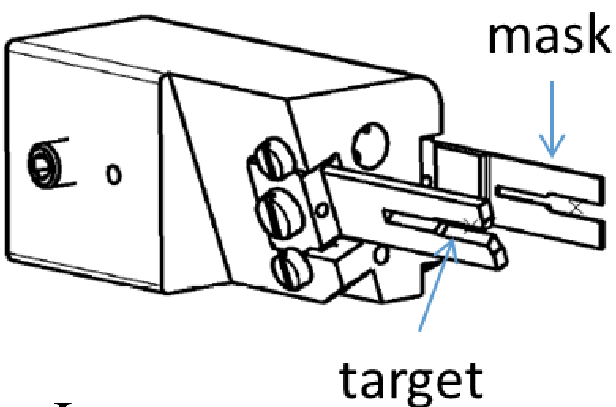
Metrology by Winlight Optics

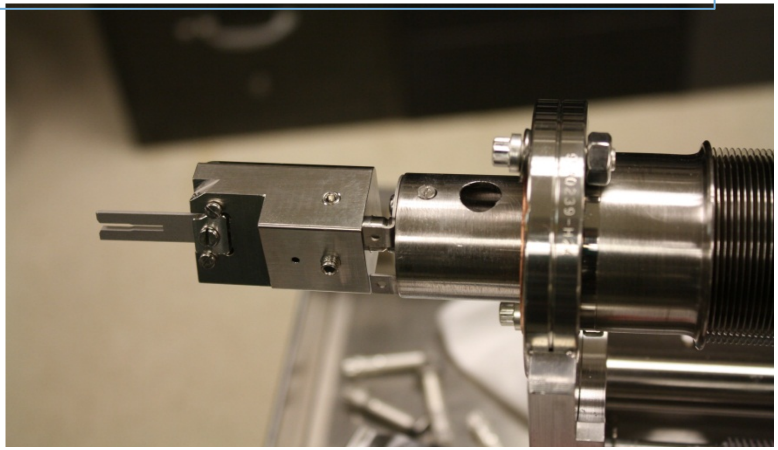
Target





Aperture sizes: 0.5 mm and 1 and 2 mm masks
Material: Aluminised suprasil fused Silica (SiO_2)
Thickness: 1 mm
Tilt angle wrt beam: 70 °

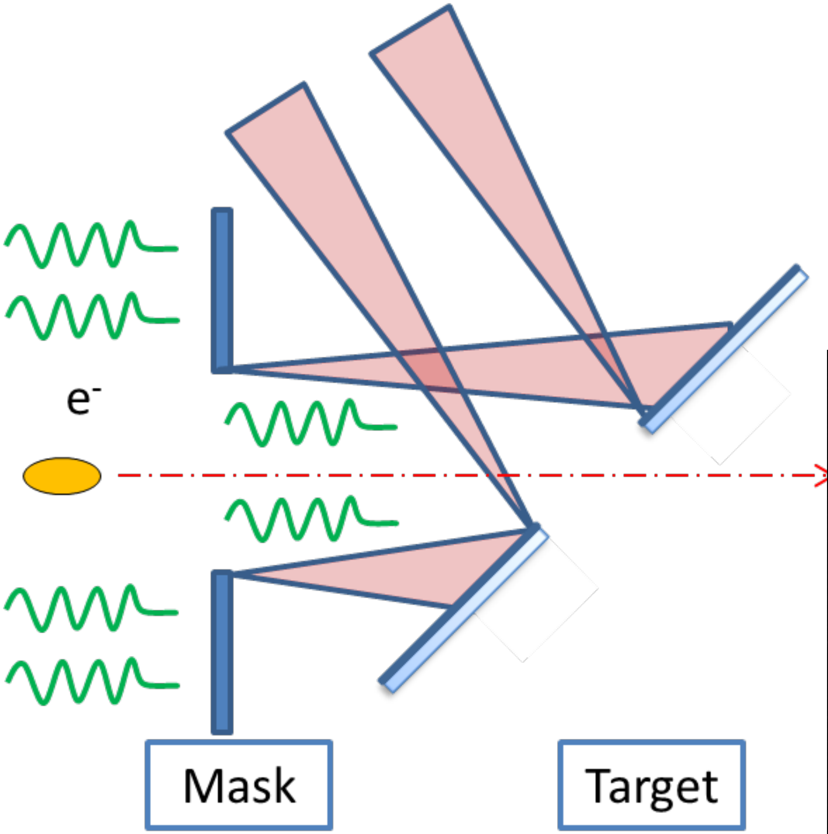


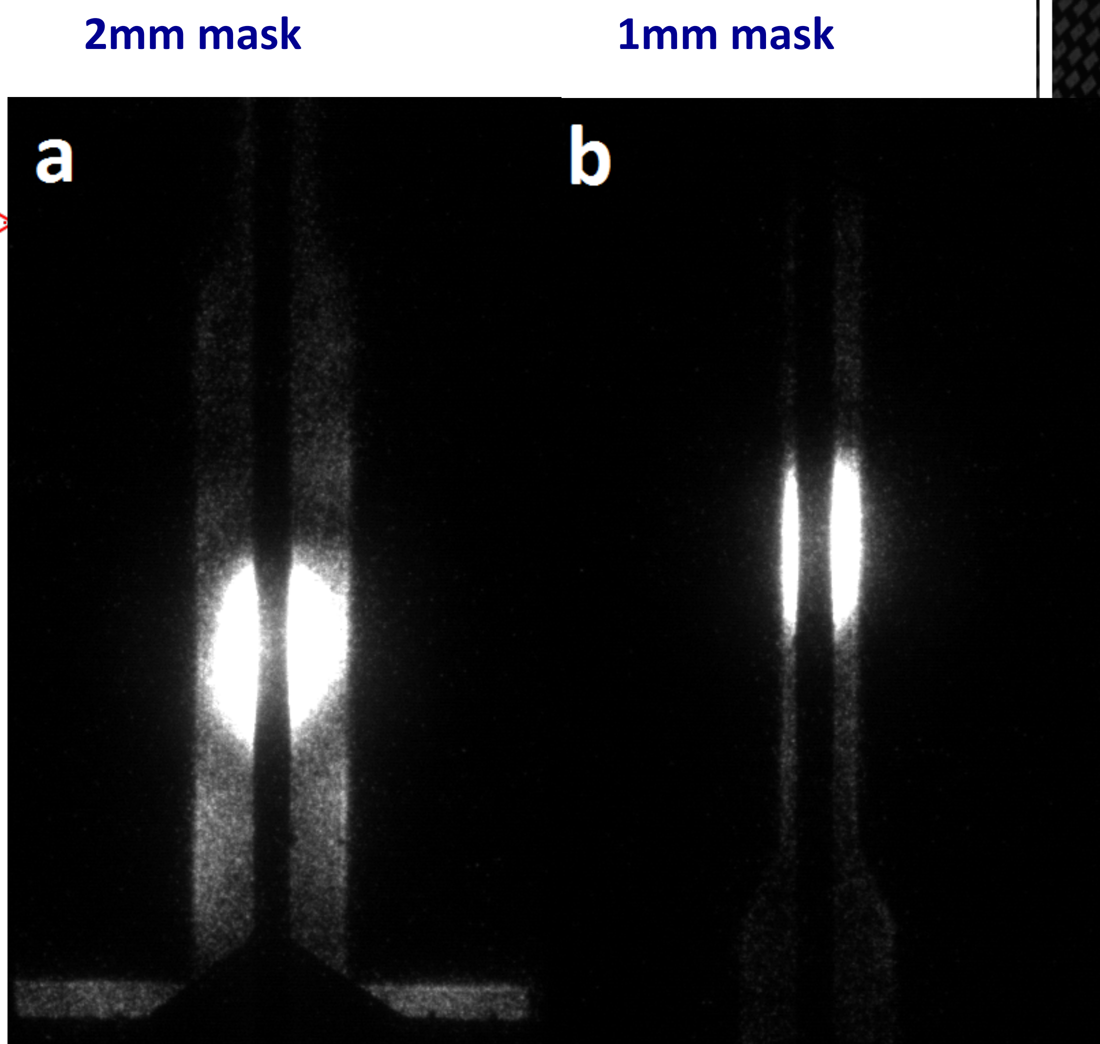


$$L = 15\text{mm}; \frac{L}{\gamma\lambda} = 6$$

Technical drawings by N. Chritin
Images by Y. Li

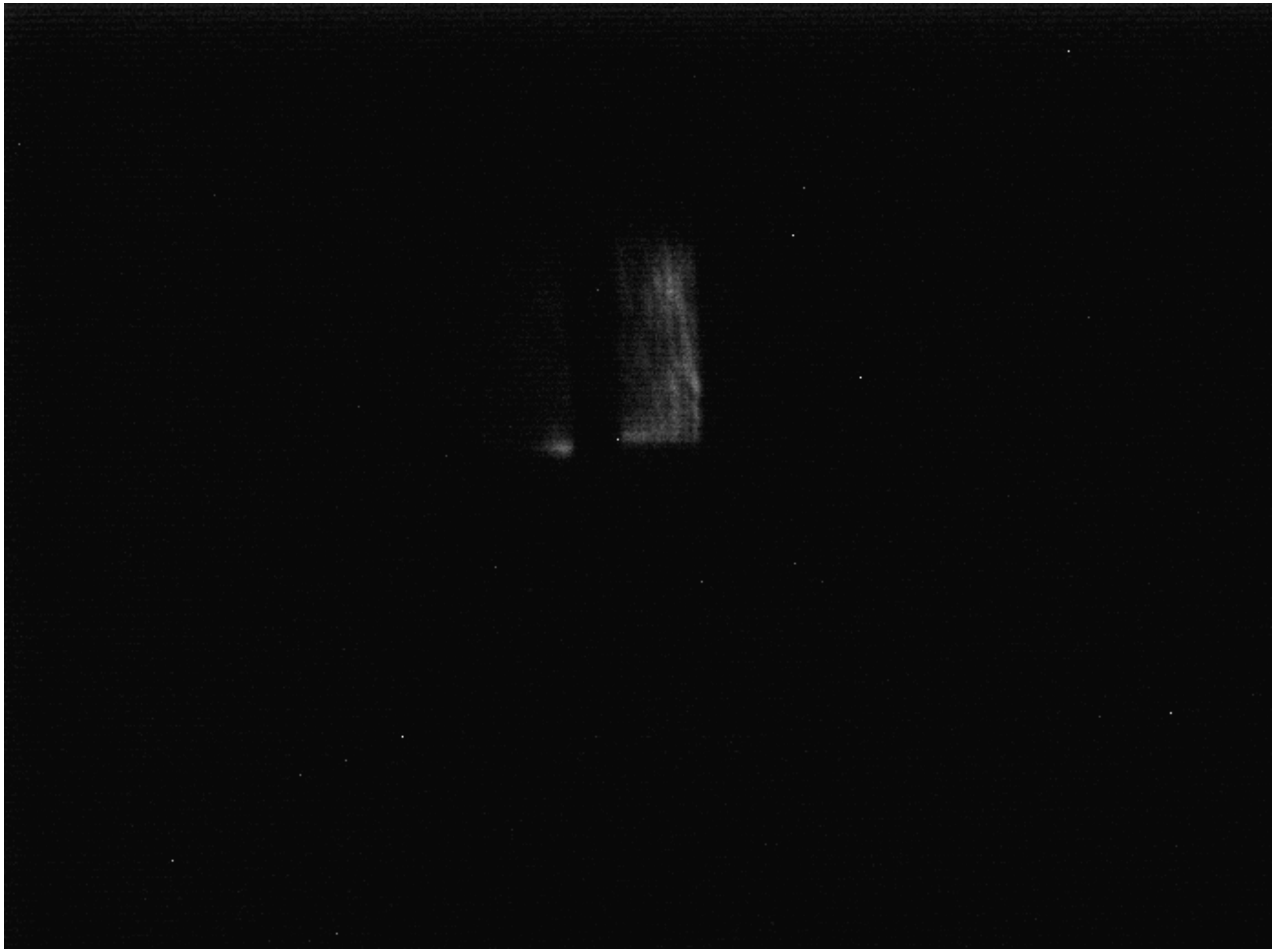
ODR imaging





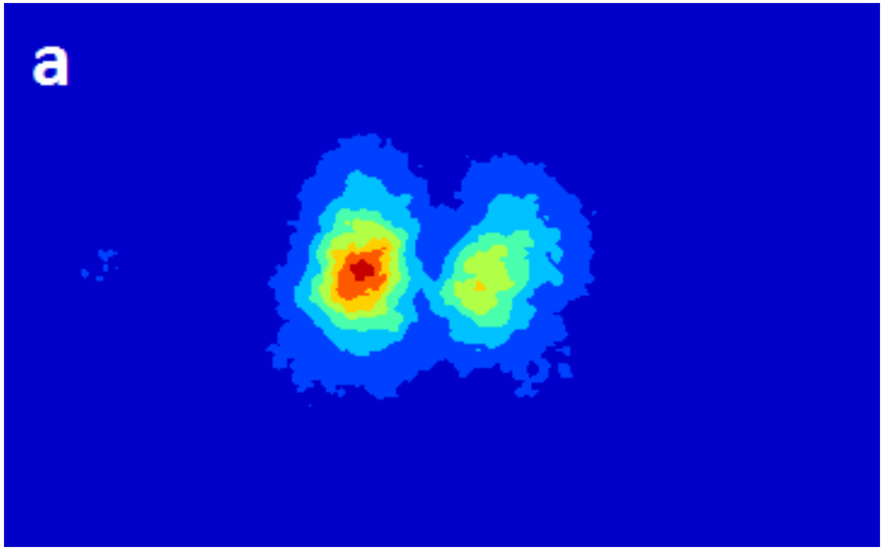
ODR imaging

Beam lifetime with target inserted ≈ 2-3 minutes

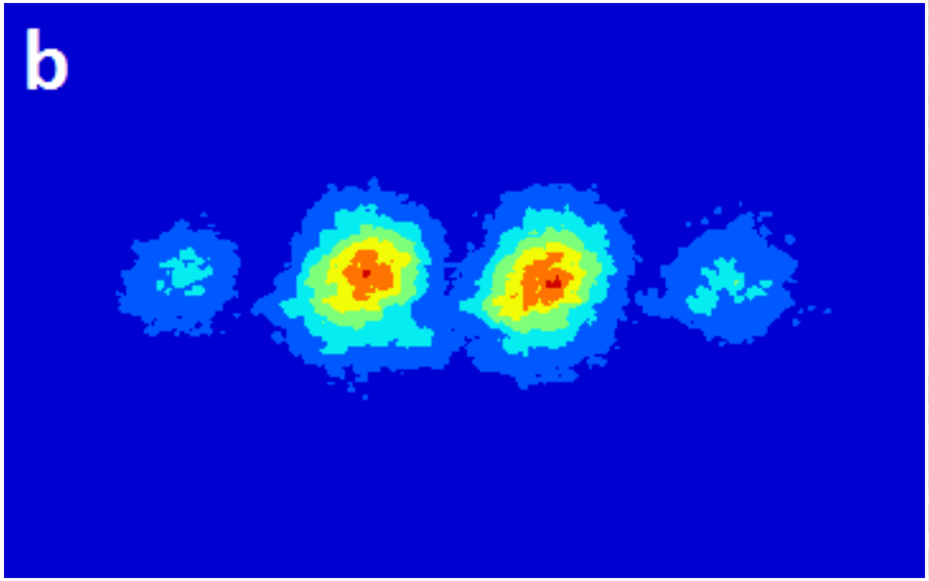


ODR Angular Distribution

2mm mask - ODR

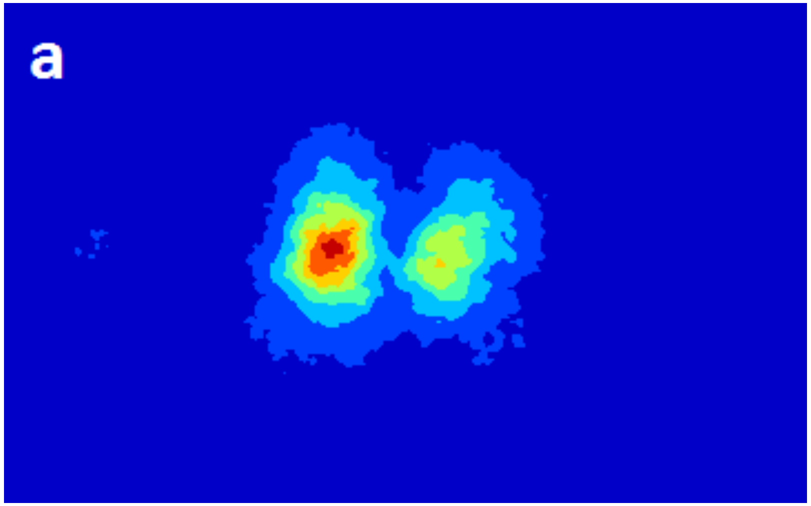


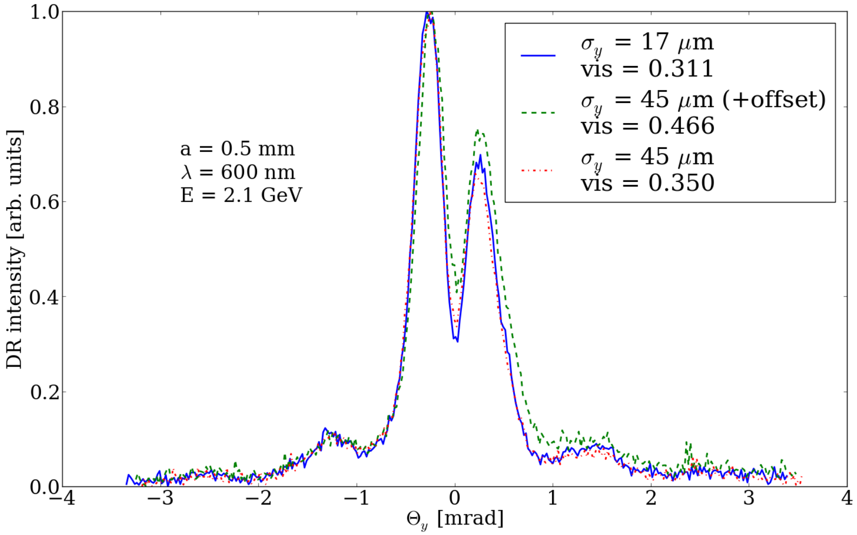
1mm mask - ODRI

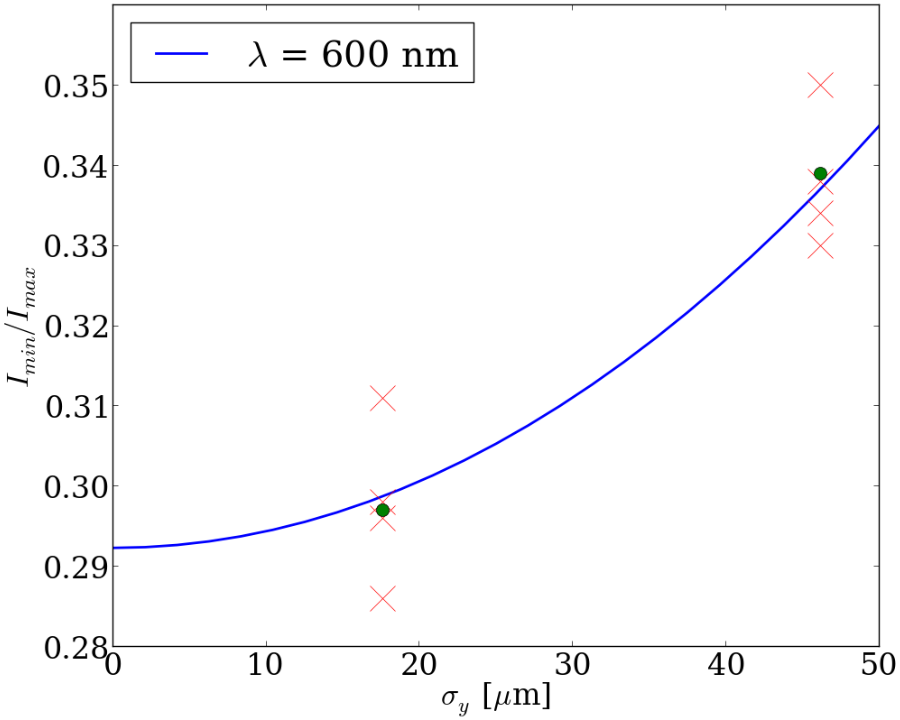


ODR beam size effect

2mm mask - ODR

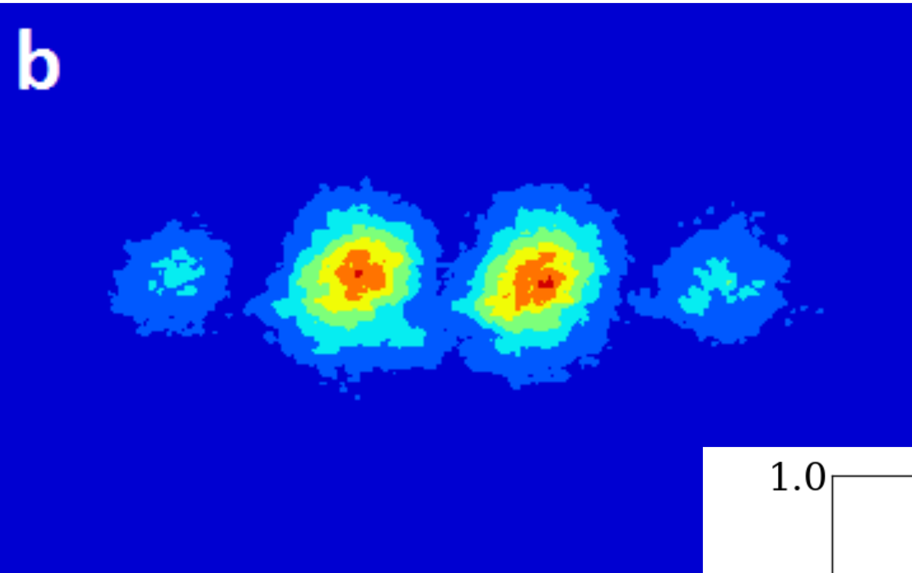




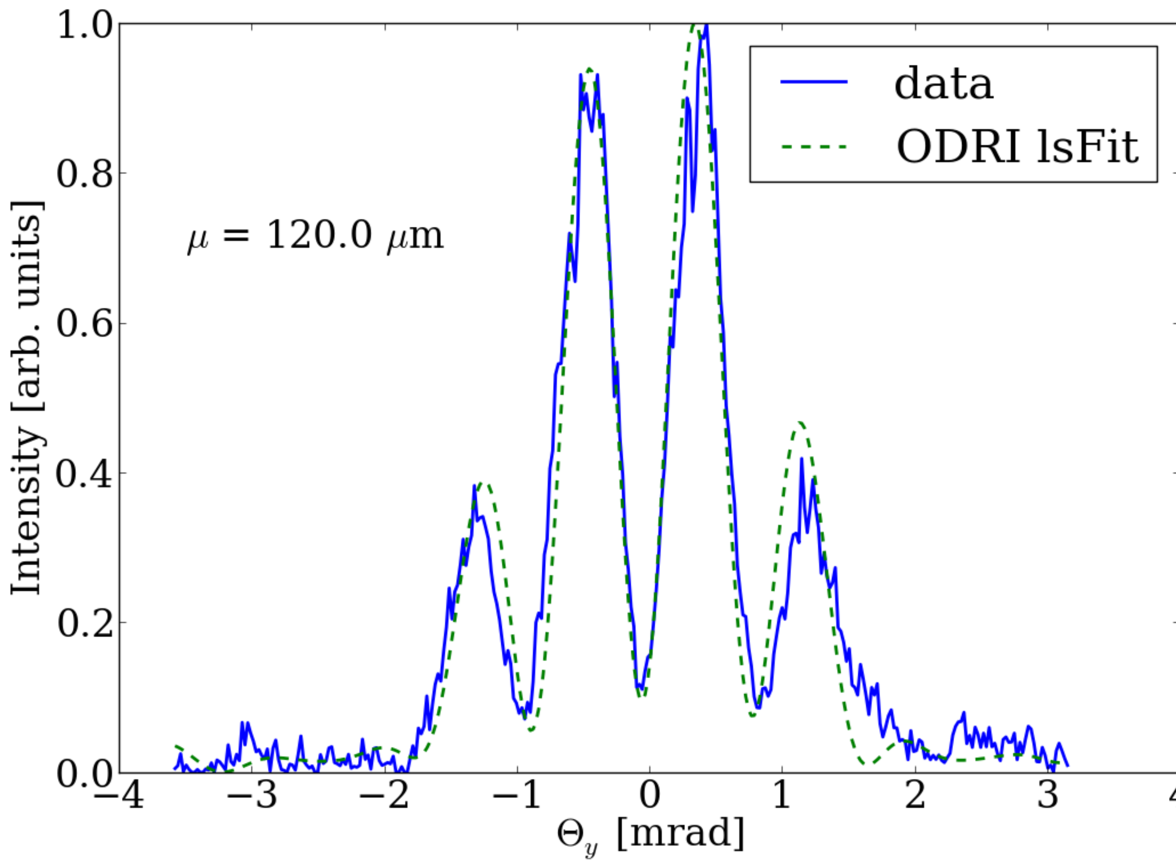


ODRI -Analysis

1mm mask - ODRI



A. Cianchi et al., “Nonintercepting electron beam size monitor using optical diffraction radiation interference”, Phys. Rev. ST Accel. Beams, 14, (2011), 10, p.102803-102812.



A beam offset of 120 µm obtained using a least squares fit for ODRI data given parameters: σ_y= 17.6 µm, σ'_y= 4.08 µrad and coplanarity offset 40 nm.

Summary

- ODR angular distribution in a circular accelerator was measured and analyzed
- We have measured the effect of the beam size effect
- ODRI was observed

Future plans

Evolution of technology

OTR
- Widely used
- Simple & robust
- Single shot 2D profile
- **But invasive**

OTR PSF
- Sub-micrometer Resolution
- 2 dimensions

ODR
- Non-invasive
- Many experiments: FLASH@DESY [1], APS@ANL [2], ATF2@KEK [3]

UV/X-Ray DR
- CesrTA
- Reduce resolution

TR/DR diagnostics @ATF2
- Imaging
- Angular distribution
- Energy spread
- Optical, UV, X-rays

[1] E. Chiadroni, et al., Proc. of PAC07, Albuquerque, NM, USA, FRPMN027.

[2] A.H. Lumpkin, et al., Phys. Rev. ST Accel. Beams 10, 022802 (2007).

[3] P. Karataev, et al., Phys. Rev. Lett. 93, 244802 (2004)