Diffraction Radiation Test at CesrTA for Non-Intercepting Micron-Scale Beam Size Measurement

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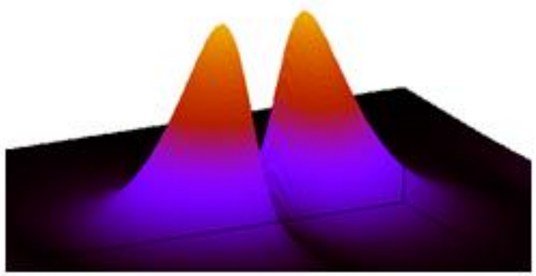
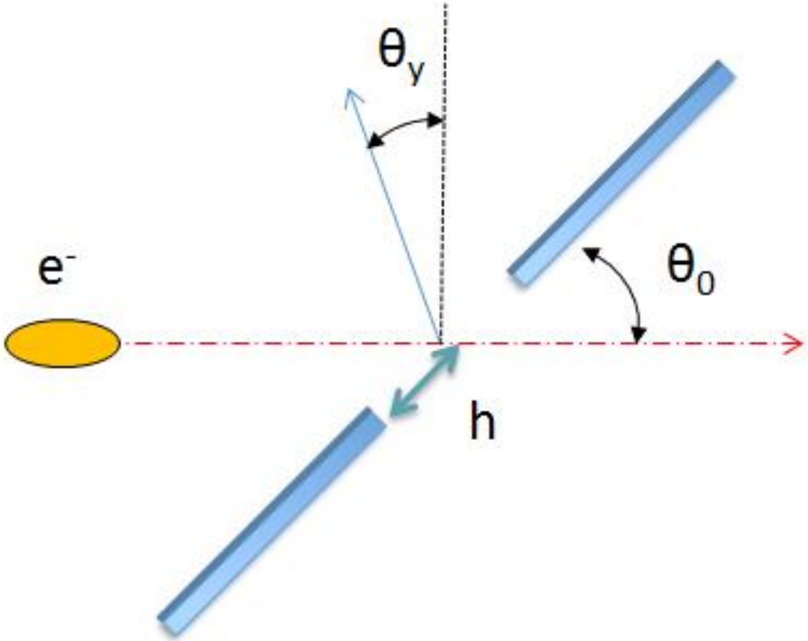
Diffraction Radiation



DR Angular distribution



Principle:

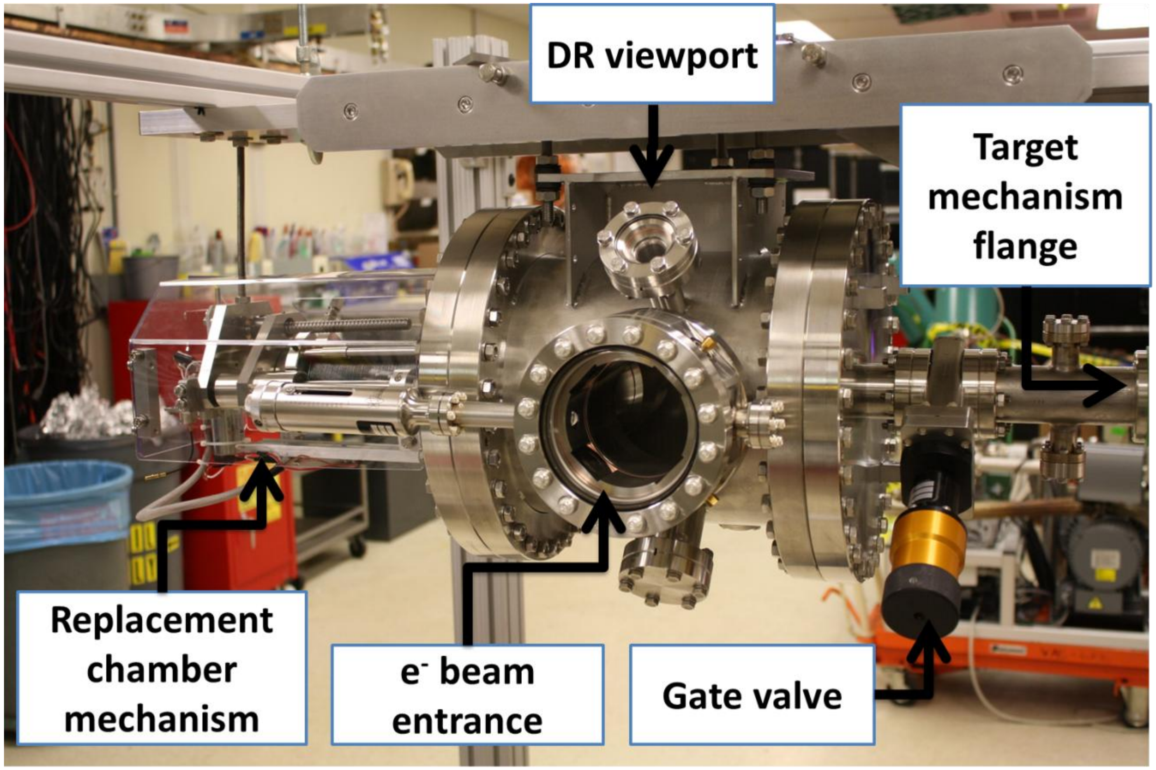
1. Electron bunch moves through a high precision co-planar slit in a conducting screen (Si + Al coating).
2. Electric field of the electron bunch polarizes atoms of the screen surface.
3. DR is emitted in two directions:
   - along the particle trajectory "Forward Diffraction Radiation" (FDR)
   - In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

Impact parameter:

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

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

Vacuum chamber assembly



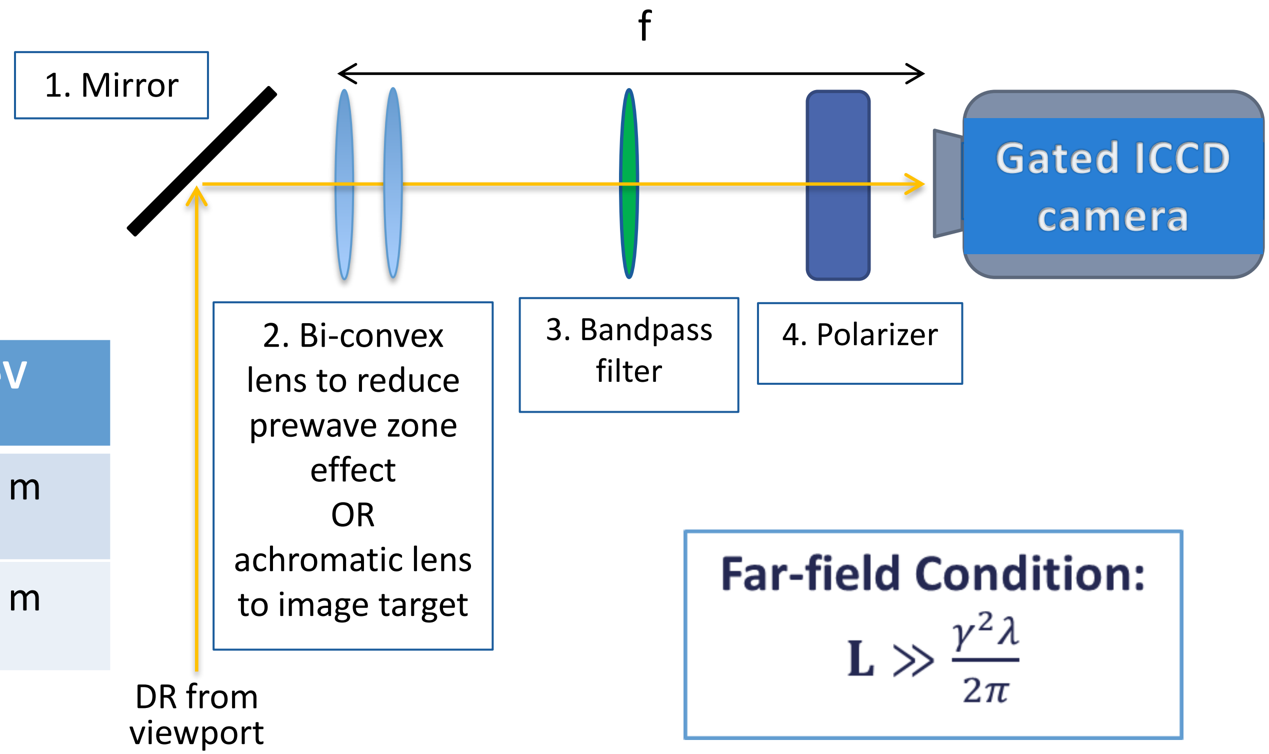
- LHS : CHESS operation
- RHS: DR experiment
- Optical system connected to DR viewport
- Gate valve to disconnect CESR vacuum for target changeover
- Target mechanism: rotation + translation IN/OUT

LHS = Left Hand Side
RHS = Right Hand Side

Optical System

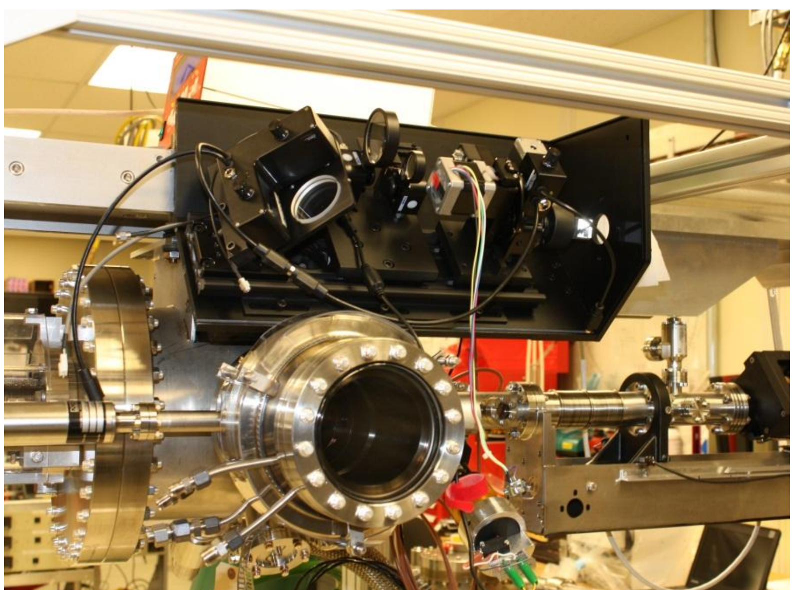
$\frac{\gamma^2\lambda}{2\pi}$ given γ and λ:

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



Far-field Condition:

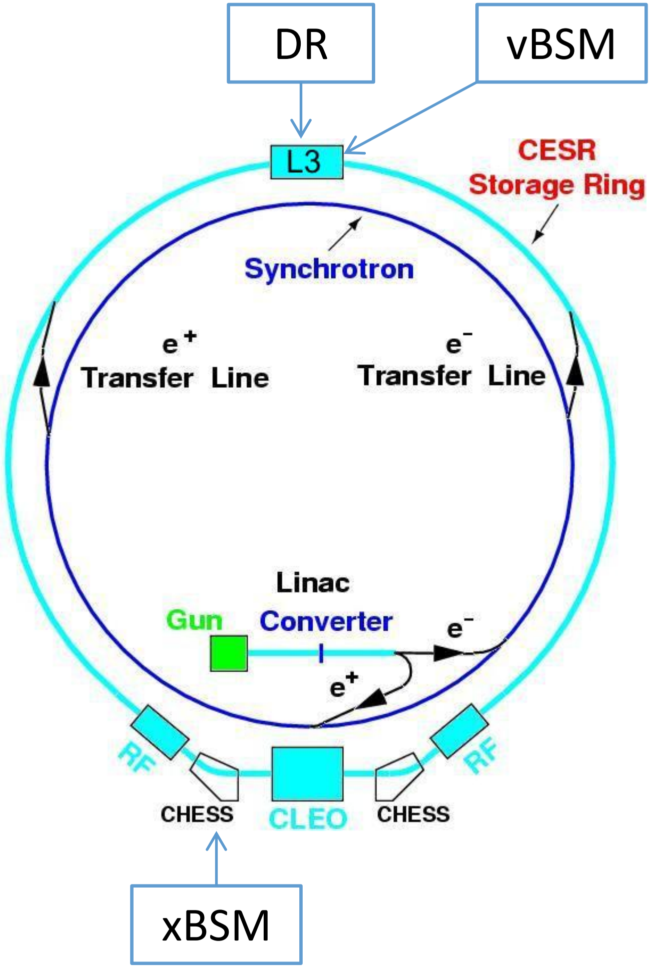
$$\mathbf{L} \gg \frac{\gamma^2\lambda}{2\pi}$$



- L = distance from source of DR to detector
- Compact optical system is in the prewave zone therefore a biconvex lens is used with detector in back focal plane to obtain the angular distribution.

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

Instruments at CesrTA



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.)

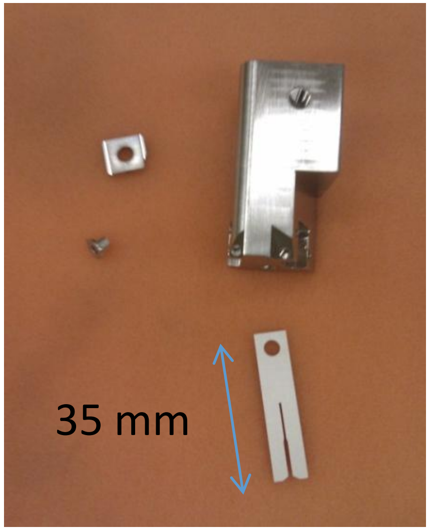
xBSM (X-ray Beam Size Monitor)
- measures vertical beam size σ_y

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

Beam lifetime + beam current monitor

Beam loss monitors downstream of DR target

Target

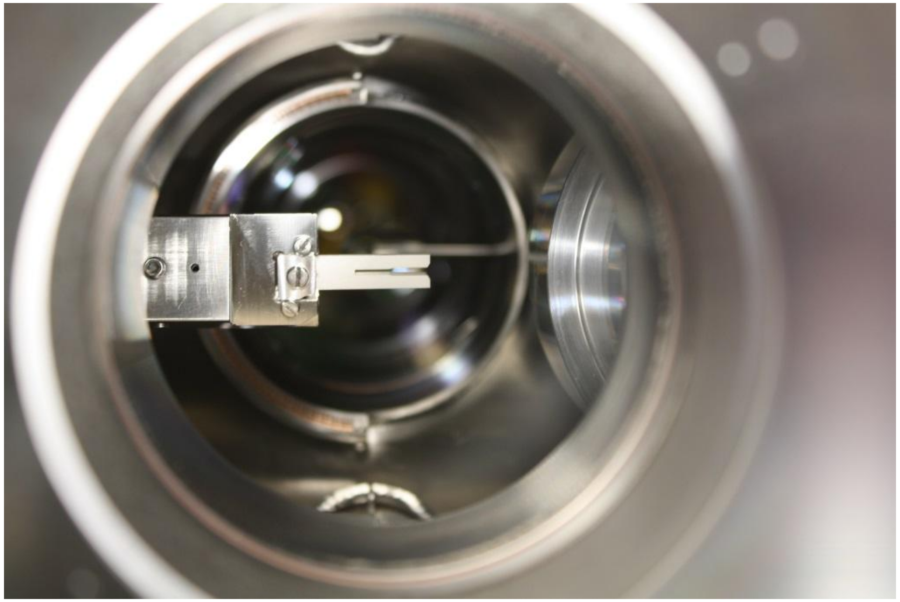


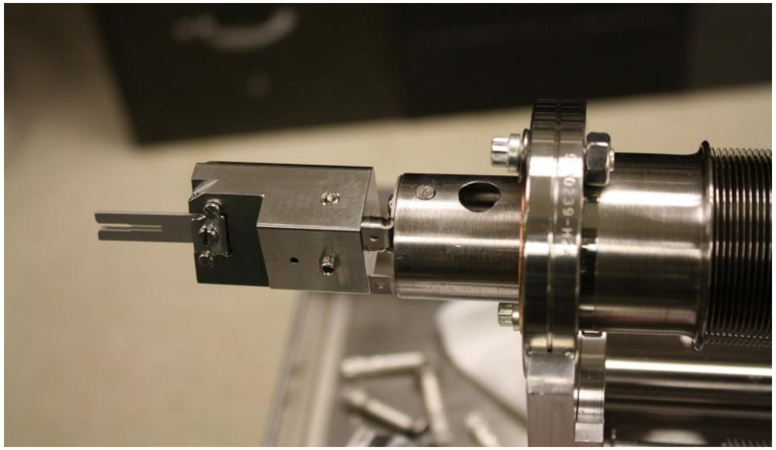
Aperture sizes: 0.5 mm and 1 mm (etched)

Material: Stainless steel (unpolished)

Thickness: 1 mm

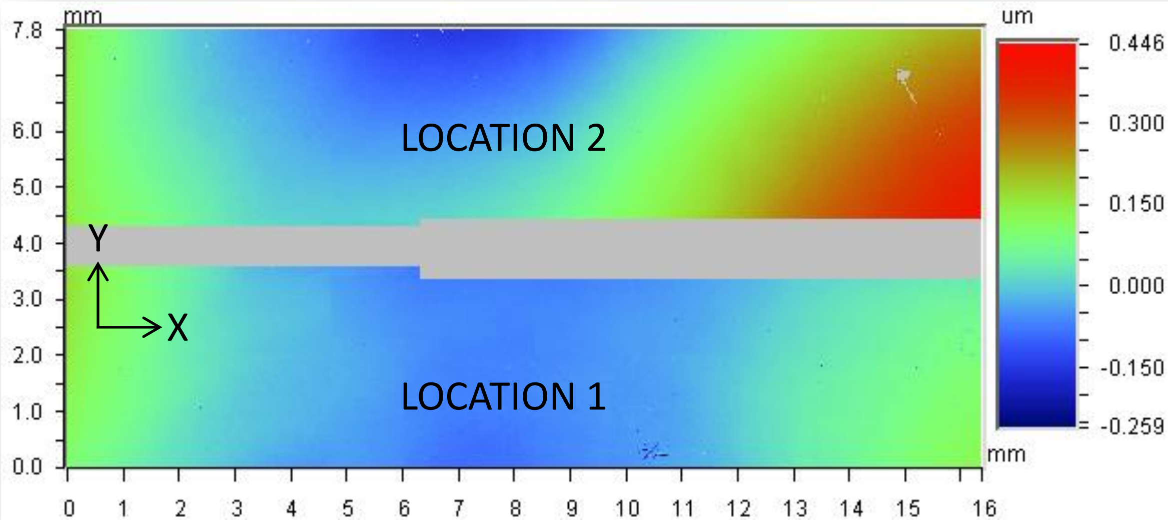
Tilt angle wrt beam: 70 °



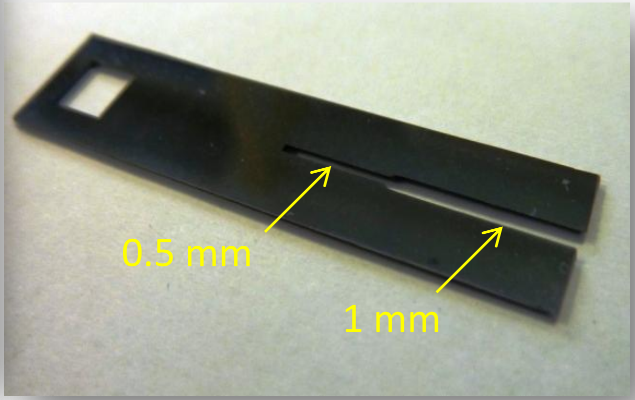


Technical drawings by N. Chritin
Images by Y. Li

Chemically etched target



Coplanarity = 0.1* wavelength



Specification	Location 1 (in µm or in µrad)	Location 2 (in µm or in µrad)
Maximum to minimum	0.64 µm	0.62 µm
Tilt in X direction	0 µrad	-17.6 µrad
Tilt in Y direction	0 µrad	37.9 µrad

Chemical etching:

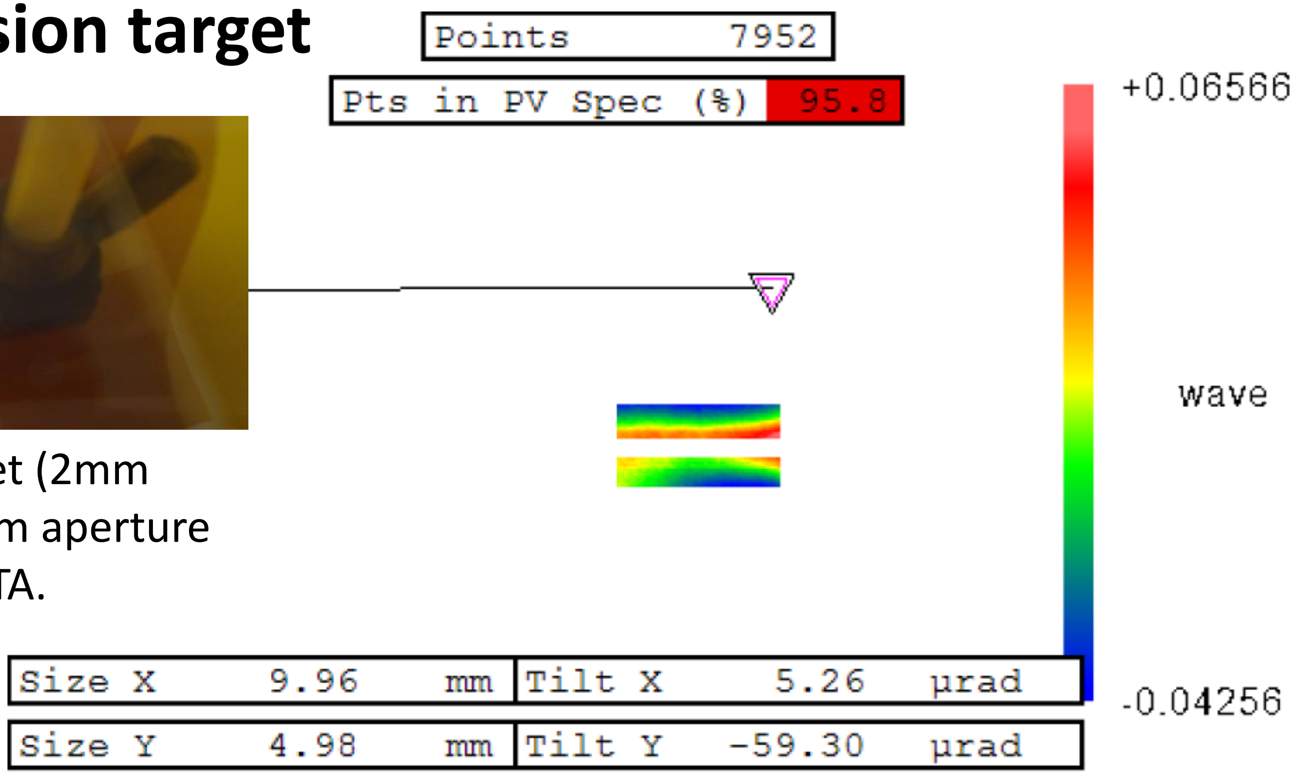
A process where silicon wafers are dipped into an etchant which is traditionally an acidic mixture.

M.S. Kulkarni and H.F. Erk, Journal of The Electrochemical Soc., 147 (1) 176-188 (2000)

Metrology by L. Remandet

Molecular adhesion target

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



"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.)."

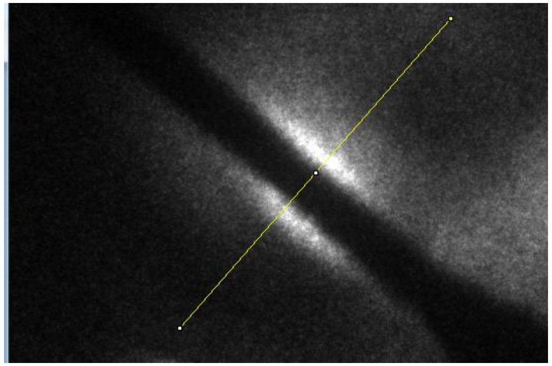
Patent US 8158013 B2

Coplanarity measurement:

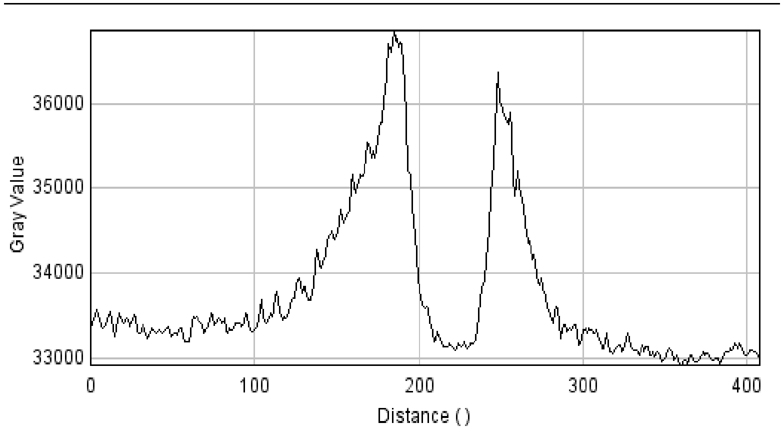
PV	68.479	nm
rms	13.909	nm

Metrology by Winlight Optics

Identification of DR in target imaging



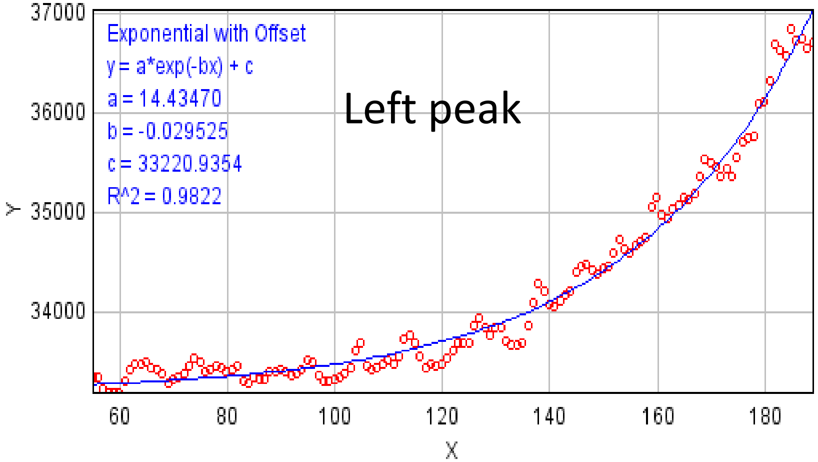
- DR intensity decays exponentially from slit edge
- SR intensity uniform over small regions
- From simulations, max SR intensity (vert. pol.) does not occur at slit edge

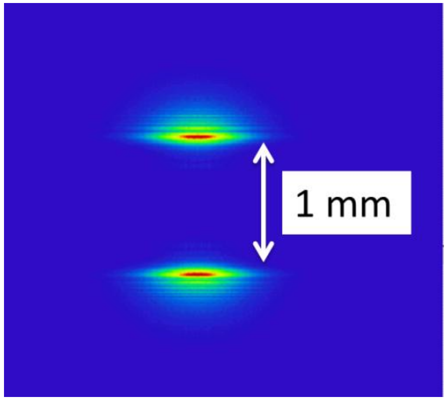


DR intensity [ph/e⁻]= k * SR intensity [ph/e⁻]

$k{\sim}50$ using real data from TR
$k{\sim}25$ using DR images

DR vert. pol. $\sim 4.0 \times 10^{-5}$ ph/e⁻
SR. vert. pol. $\sim 6.3 \times 10^{-7}$ ph/e⁻

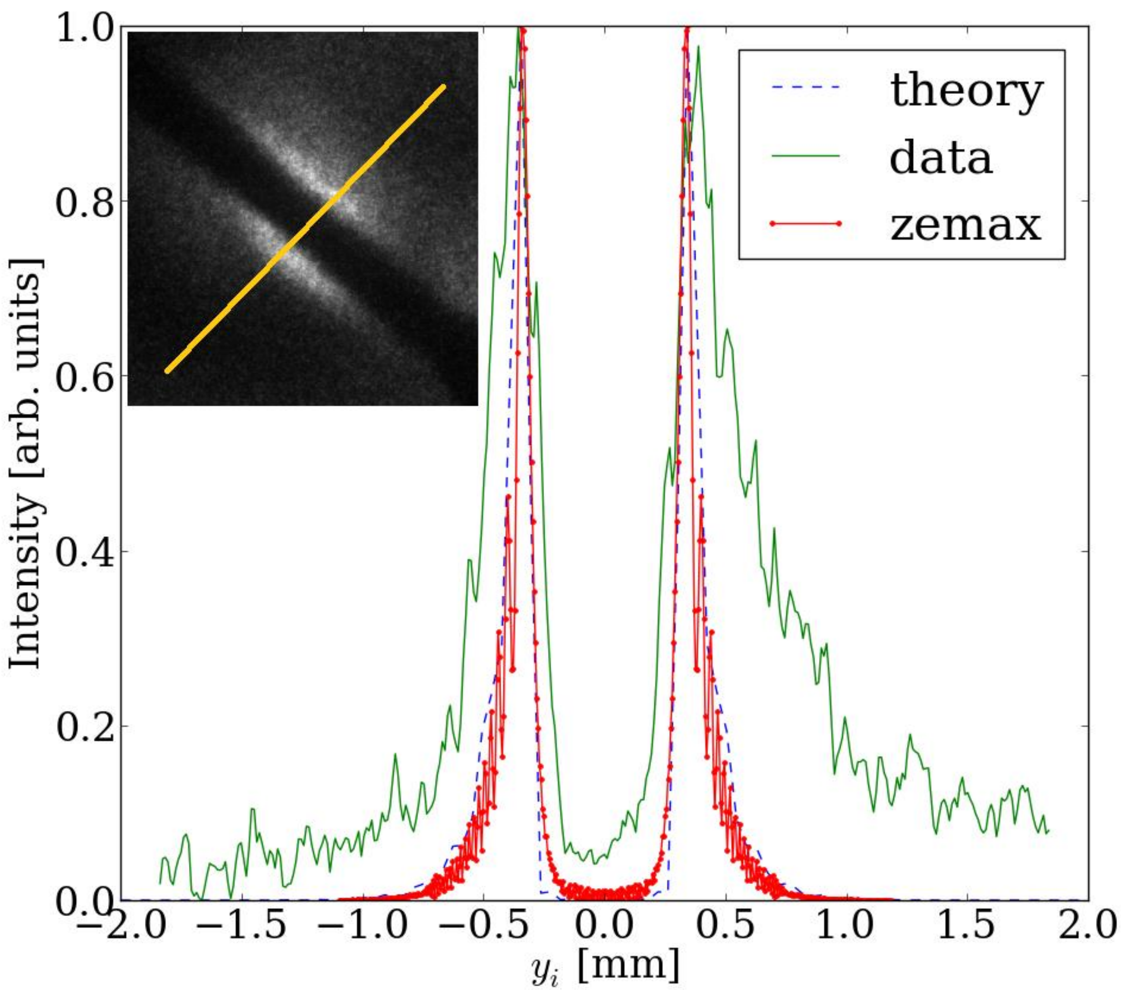




T. Aumeyr et al., IBIC2013, WEPF18.

DR target imaging

- 2.1 GeV
- 1 mA single- bunch beam
- 400 nm DR observation wavelength



Theory-
D. Xiang et al., Phys. Rev. ST Accel. Beams, 10 (2007) 062801.

Zemax-
T. Aumeyr et al., IBIC2013, WEPF18.

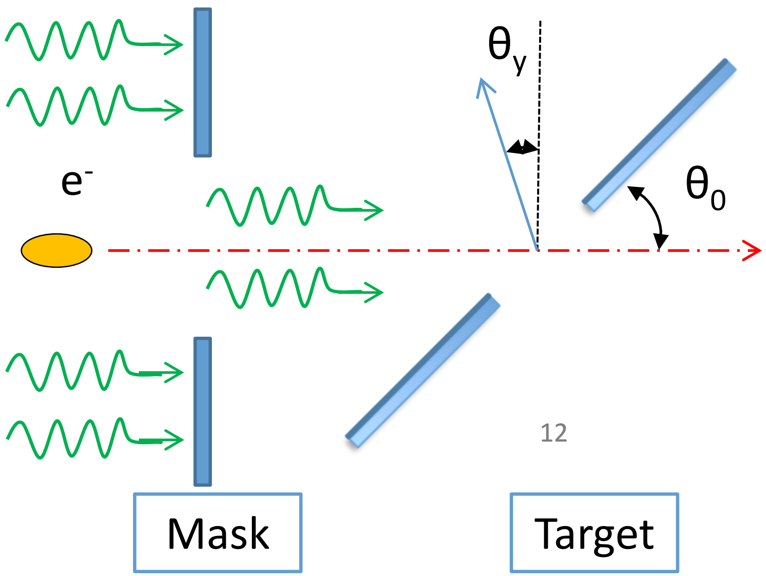
Data broadening possibly due to:

- data taken for $\sigma_y \sim 20$ µm
  theoretical model and Zemax : single e$^-$ $\sigma_y \rightarrow 0$
- Polariser misalignment → some horiz. pol. DR and synchrotron radiation (SR)
- 10 ± 2 nm bandwidth → data smearing (small)
- 15 ms exposure time (CesrTA rev. period $T = 2.56$ µs) → smearing from beam jitter

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.

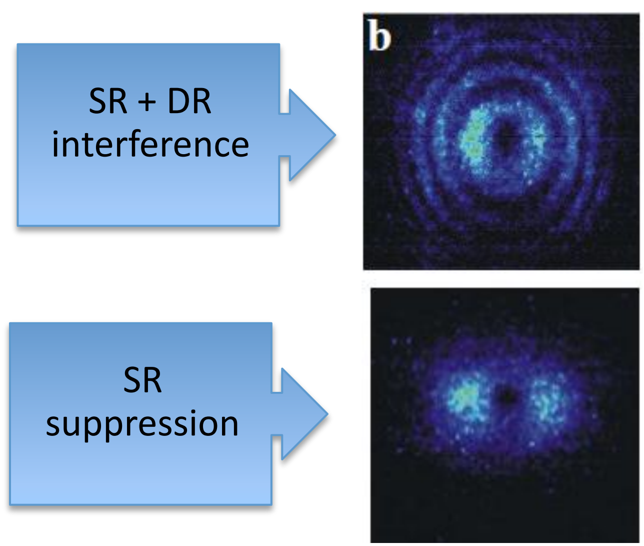


ODRI considerations:

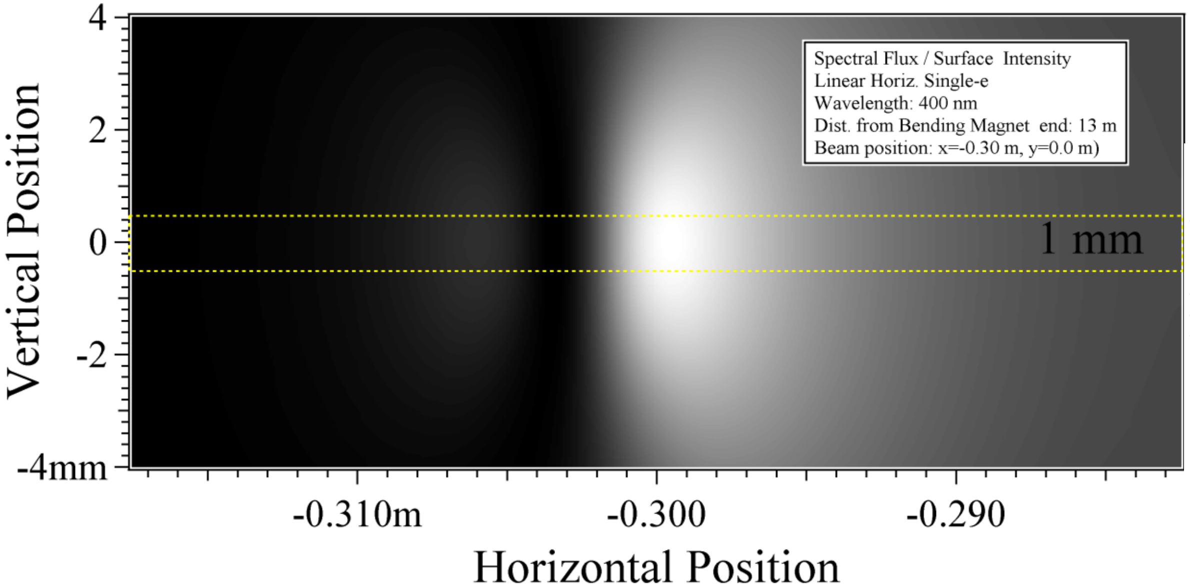
Aperture sizes	Interference
$a_{mask} = a_{target}$	Complete destructive interference of FDR + BDR
$a_{mask} \approx 2 \cdot a_{target}$	Measureable interference
$a_{mask} \geq 4 \cdot a_{target}$	Negligible interference

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

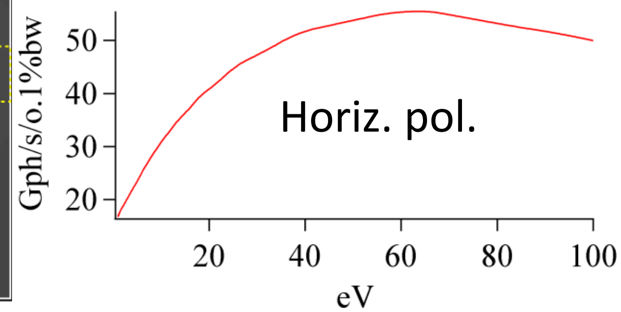
P. Karataev et al., Proc. of EPAC 2004, THPLT067

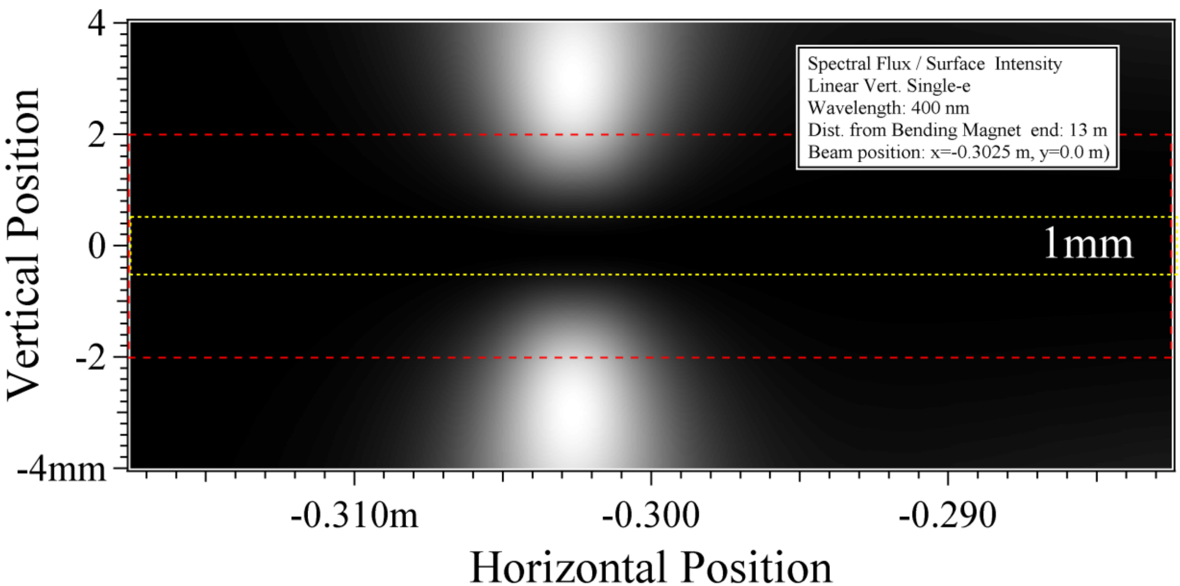


SRW simulations

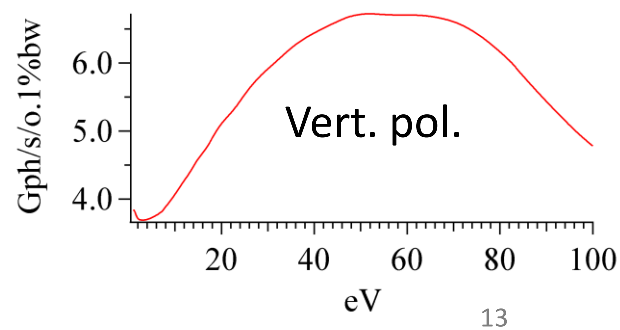


Total intensity at 400nm, 10%bw
= 2.30315e+10 ph/s





Total intensity at 400nm, 10%bw
= 4.31643e+09 ph/s



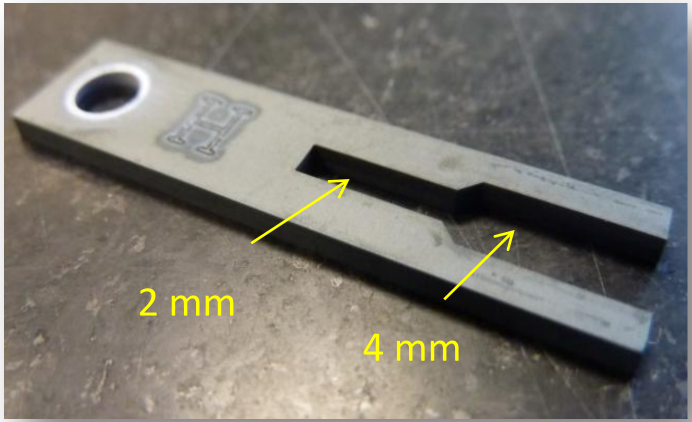
A. Jeff

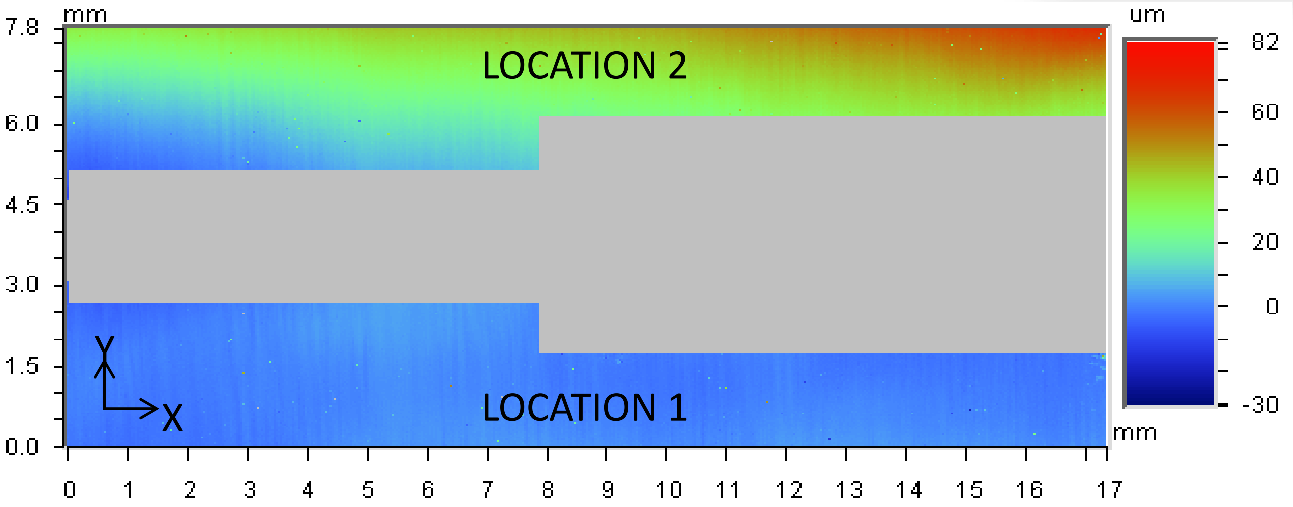
Mask

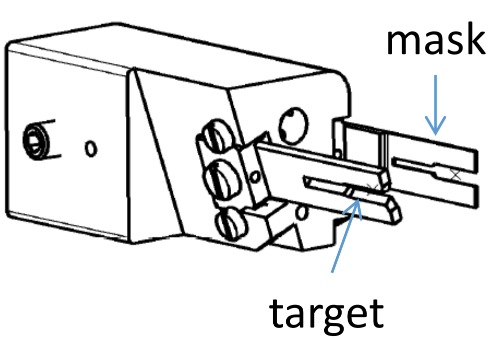
Technical drawings by N. Chritin,
Metrology by L. Remandet

- Silicon Carbide
- Laser machining
- Not etched (orientated perpendicular to beam)
- Mask aperture = 4 * target aperture
  → avoid destructive interference (ODRI)

Specification	Location 1 (in µm or in µrad)	Location 2 (in µm or in µrad)
Maximum to minimum	≈ 10 µm	≈ 80 µm
Tilt in X direction	0 µrad	-1897 µrad
Tilt in Y direction	0 µrad	-13913 µrad







Beam lifetime

Beam lifetime with target inserted ≈ 2-3 minutes

No change in beam lifetime :

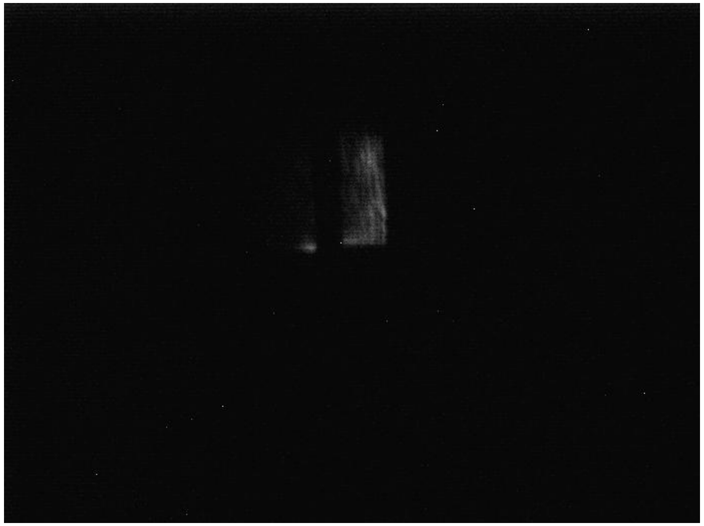
- for 1 mA single-bunch or 1 mA 10-bunch beams
  →not determined by charge-per-bunch dependent process
- for $13 \leq \sigma_y \leq 52\ \mu m$ at 50 µm lifetime could be regained through manual adjustment of vertical position

Lifetime dependent on:

- roll of the beam
- aspect ratio (σ_y : σ_x= 490 µm) which for this test was 1:38.

Process code:

- Approx. 5-10 minutes from losing beam to retract target, do the injection and align beam manually.
- Reduced turn-around time to 2-3 minutes.



Chemically etched target

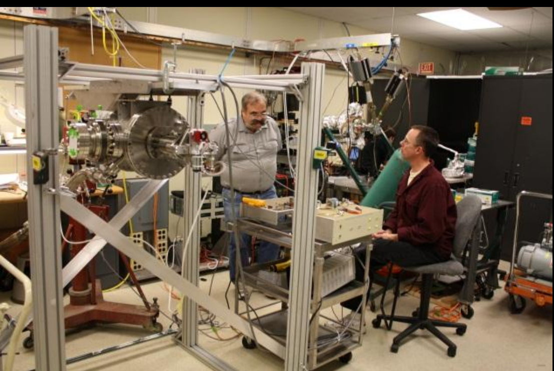
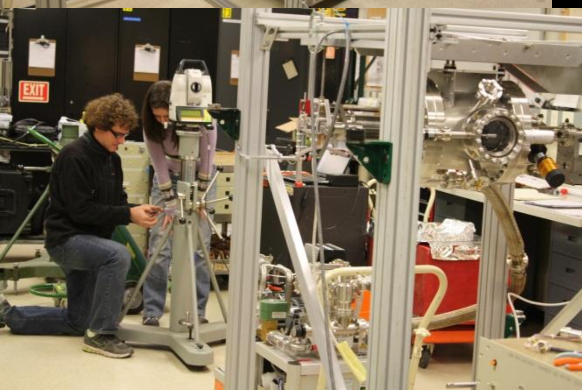
Conclusion

- Phase 1 hardware and instrumentation for DR experimental program have been installed and tested in CesrTA.
- A method of beam alignment in the target aperture has been established.
- The typical beam lifetime is 2-3 minutes with the target inserted.
- DR signals have been identified from SR background in target images.

Outlook

- Improvements were made to the optical system:
  - A plano-convex lens with 500 mm focal length will be used for improved angular resolution.
  - All optical components have 50 mm clear aperture to avoid clipping.
  - The whole system was also dismantled and realigned.
  - Turn-by-turn measurements using gating
- Preparations for DR angular distribution beam size measurements in winter 2013 are on-going.
- Testing different substrates for the target and ceramic target holders
- Comparison of simulations with experimental data –ODRI, suppression of SR
- Going to shorter wavelengths (≈230 nm) to improve beam size sensitivity

Acknowledgements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Thank you for your attention