Development of a combined TR/DR emittance station for future linear colliders such as CLIC or ILC at ATF2

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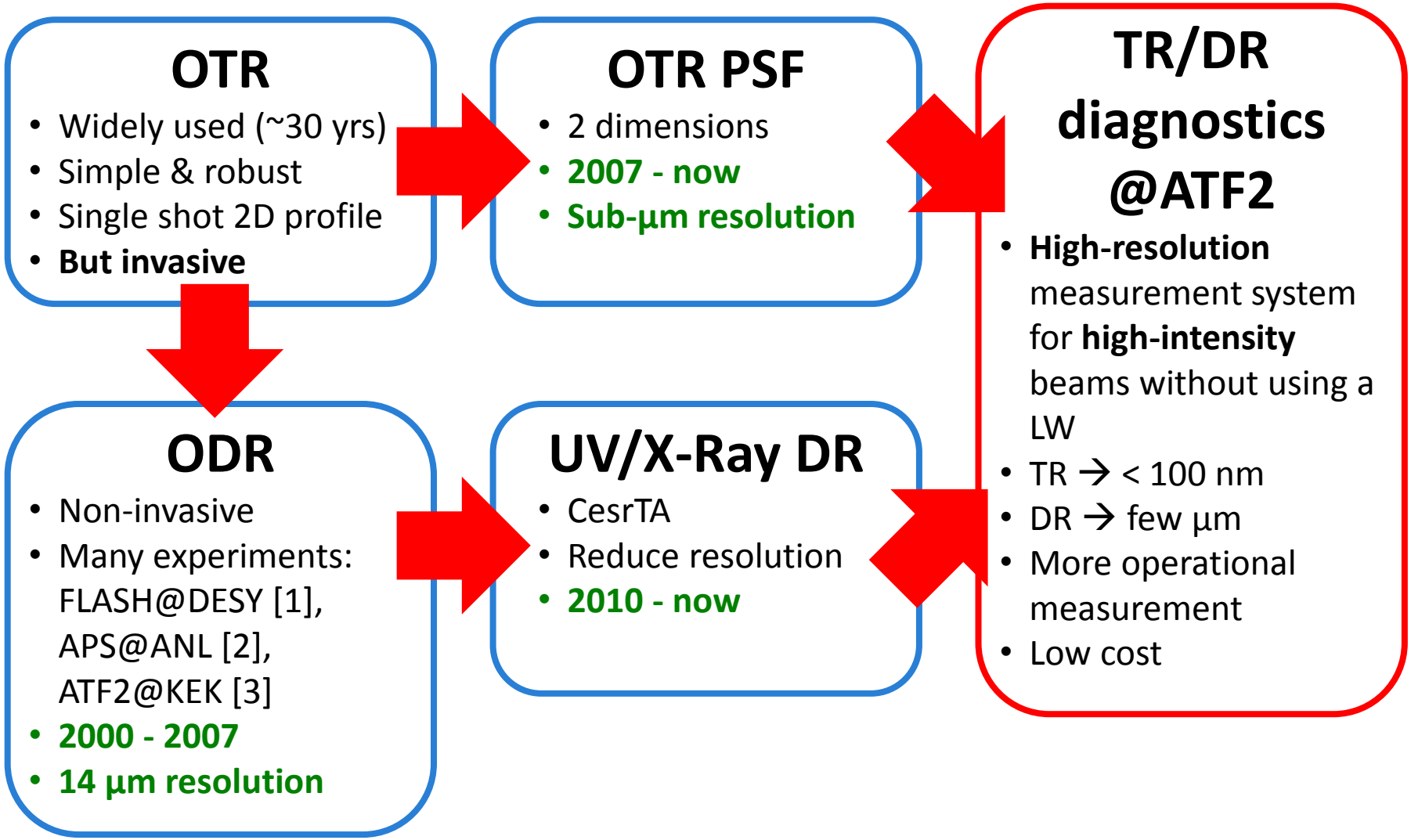
Evolution of technology

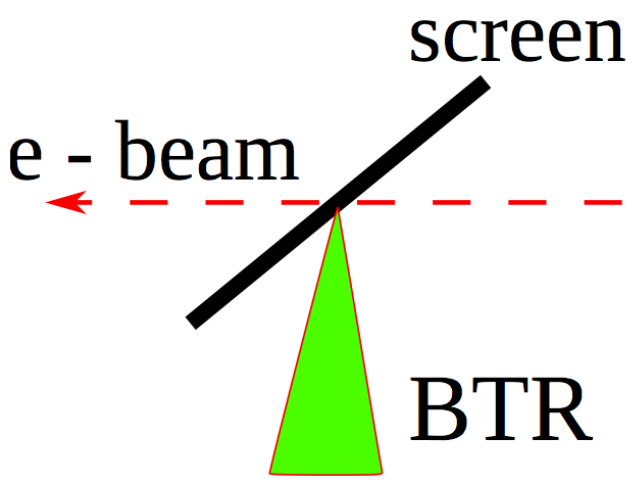


[1] E. Chiadroni, et al., Proc. of PAC07, Albuquerque, NM, USA, FRPMN027.

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

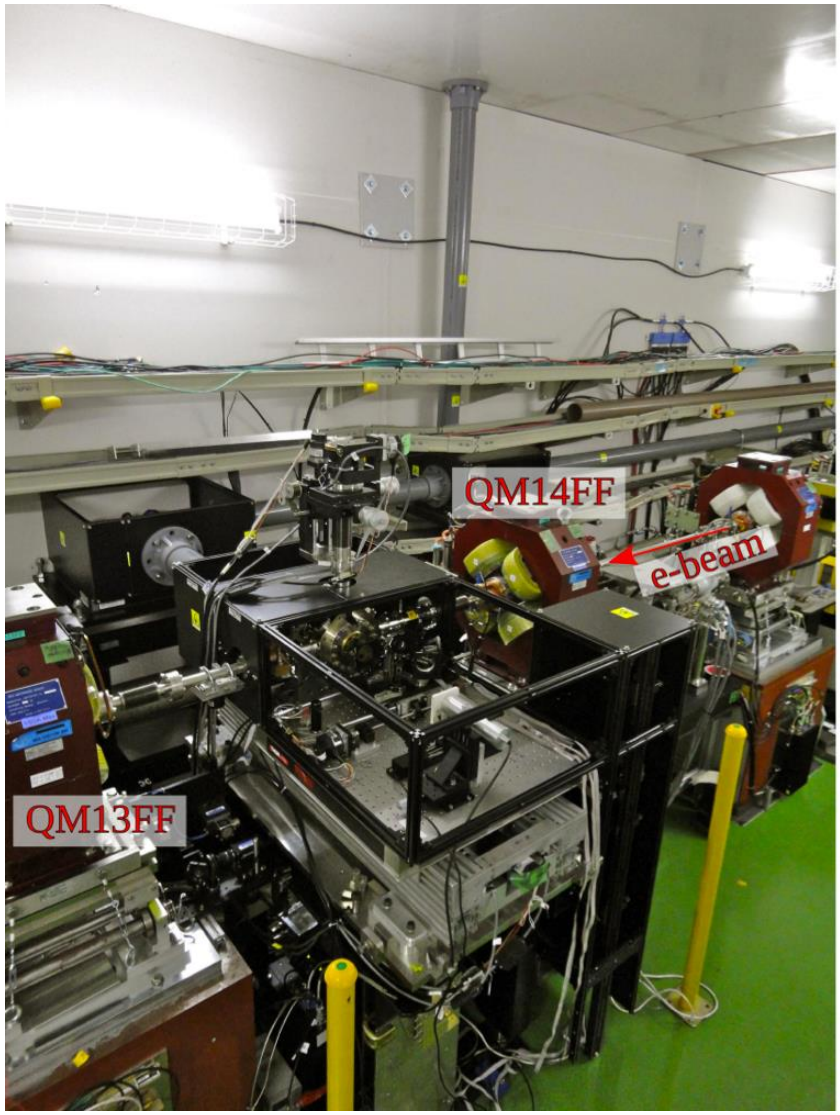
[3] P. Karataev, et al., Phys. Rev. Lett. 93, 244802 (2004)

Transition Radiation

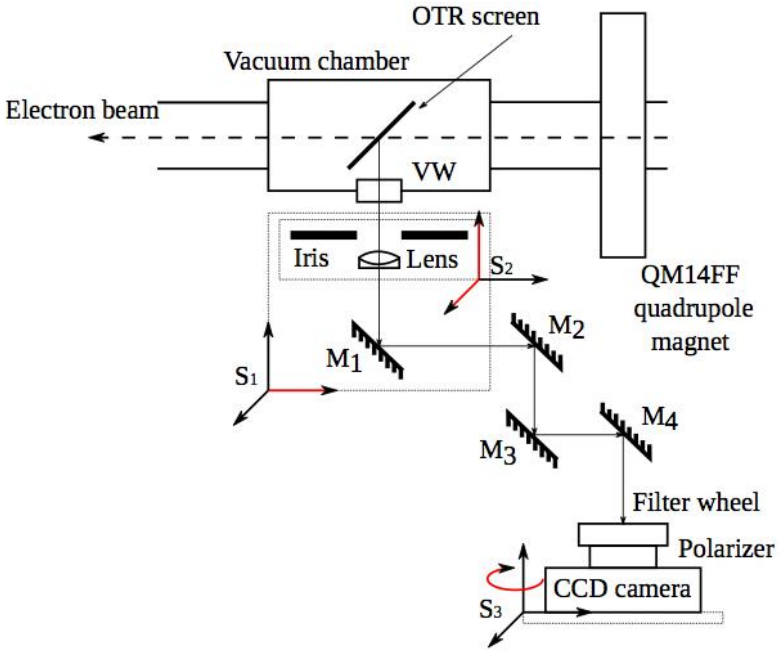


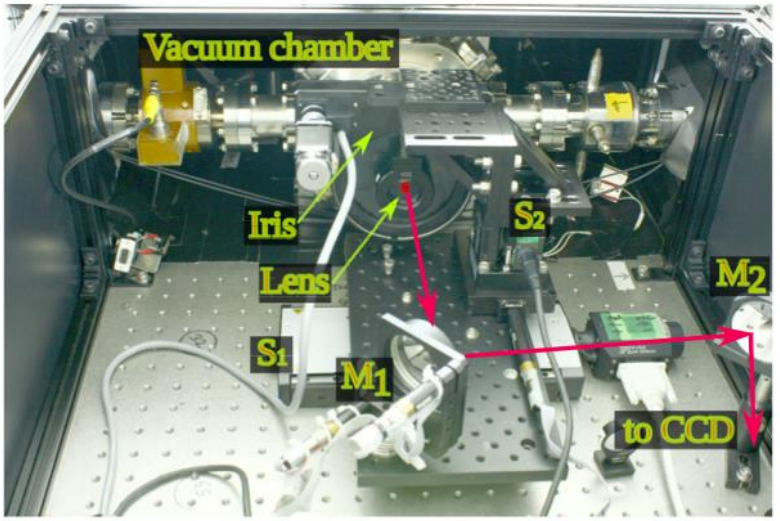
- Transition radiation (TR) appears when a charged particle crosses a boundary between two media with different dielectric constants.
- The resolution is determined by the source dimensions induced by a single particle plus distortion caused by the optical system (diffraction of OTR tails)

OTR monitor at the ATF2 Extraction Line (former LW system)

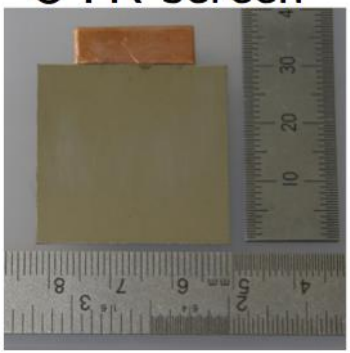


Experimental Setup





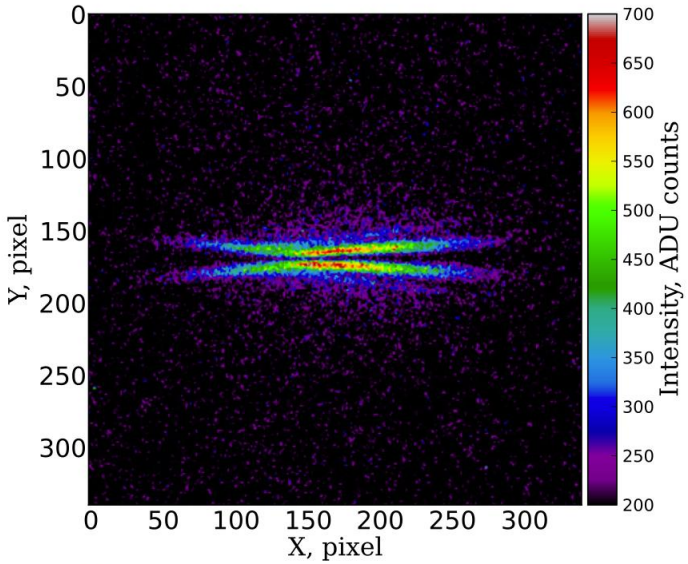
OTR screen

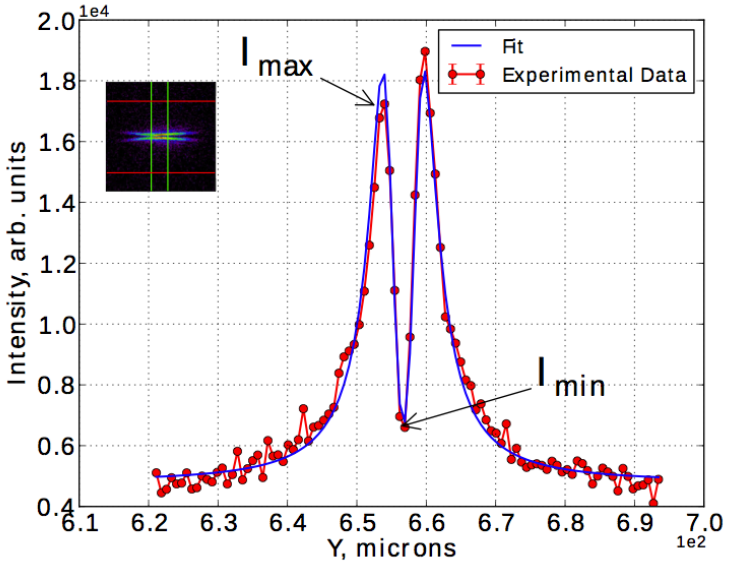


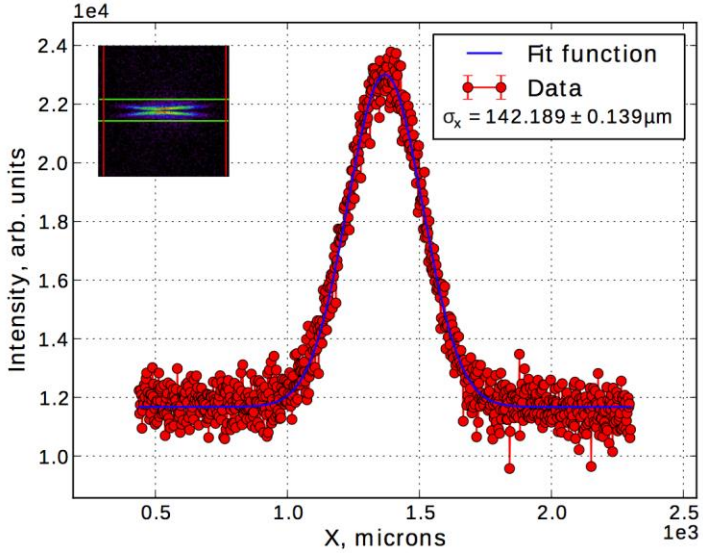
0.3×30×30 mm aluminized silicon

- Lens - "CVI Laser Optics" cemented achromat, f=120mm, ø=30mm
- CCD Camera - SBIG-ST8300M with 5.4 μm pixel size, 3352×2532 pixel array and ∼50% quantum efficiency

OTR Image and Projections



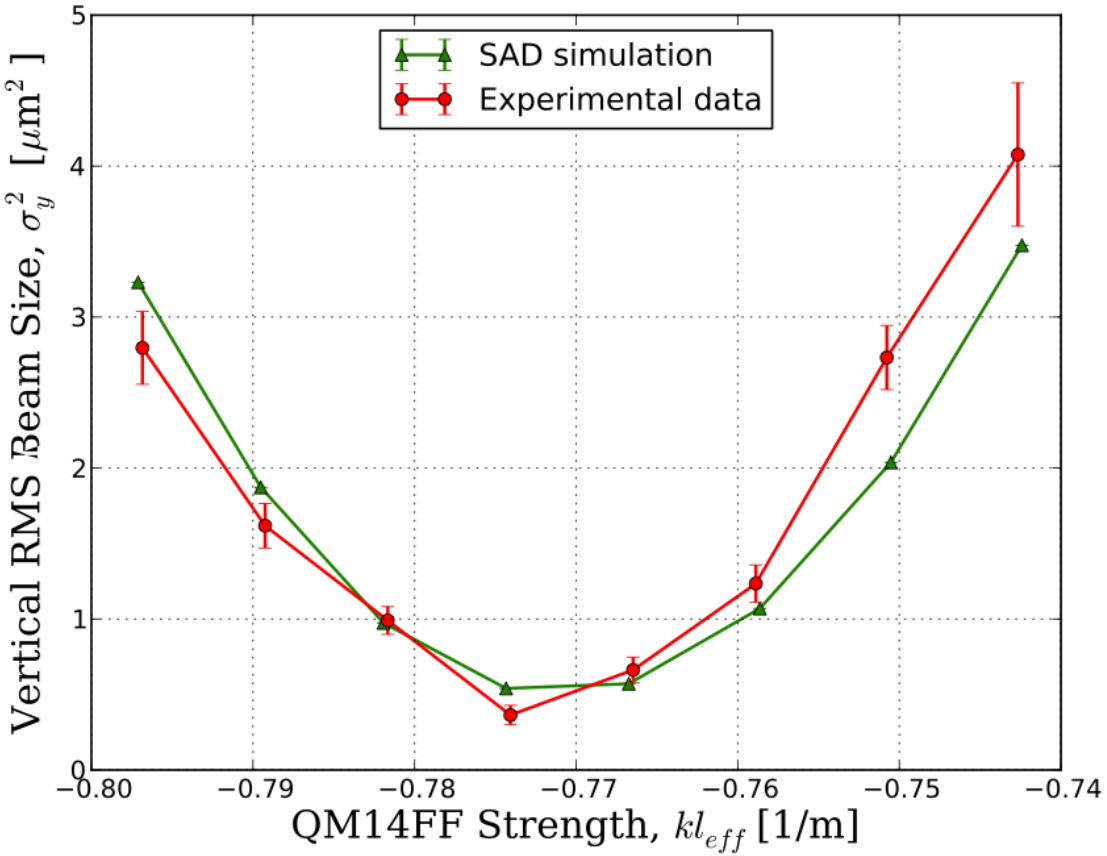




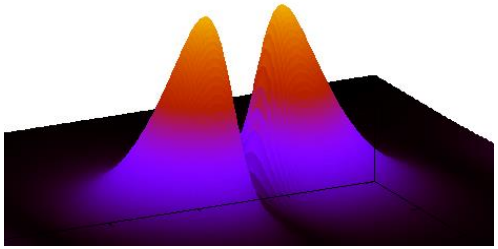
- H size: Gaussian fit
- V size: PSF-like fit function
- Achieved with self-calibration procedure → Rob Ainsworth's talk

Achievement 2013 – quadrupole scan

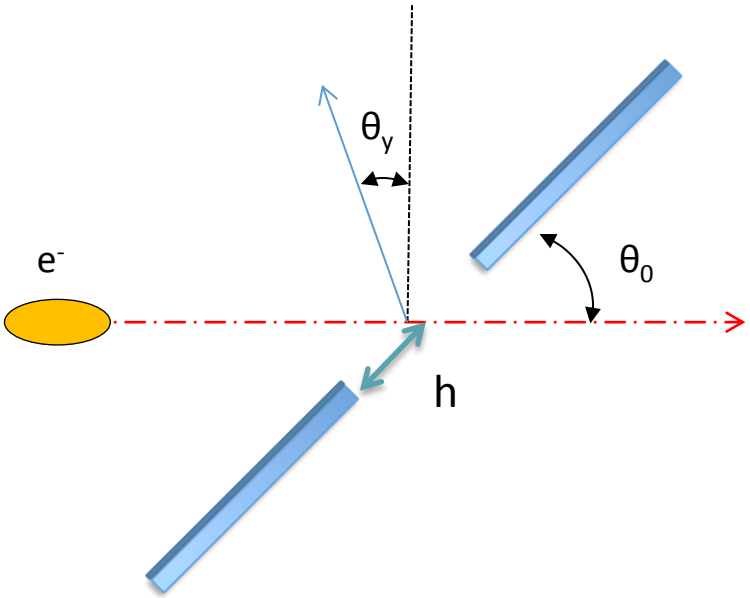
Minimum measured beam size was: 0.754±0.034 μm



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:

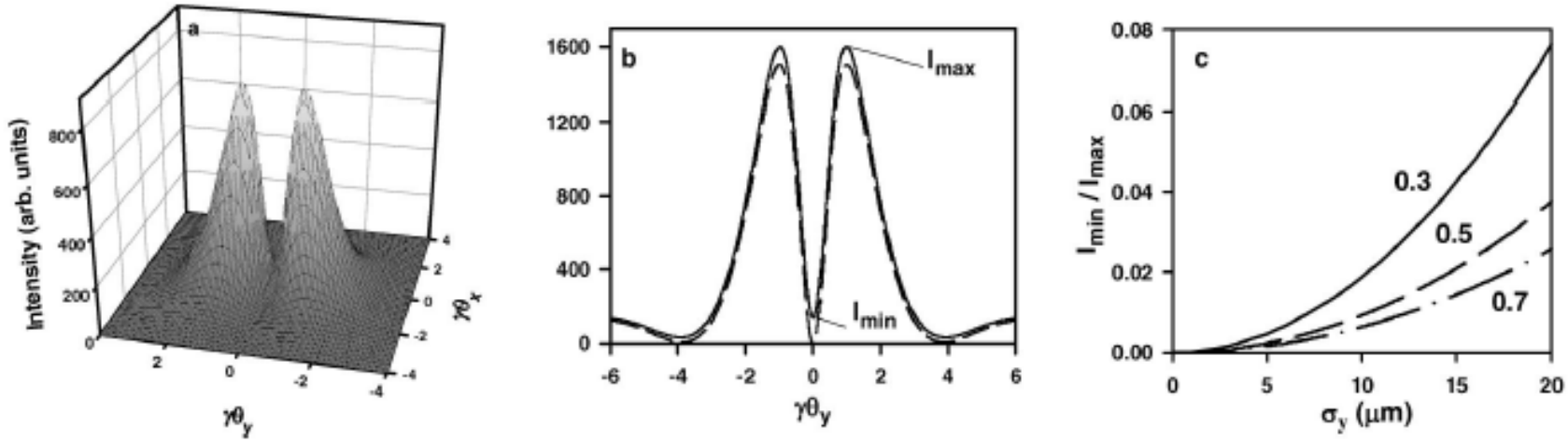
$$h \leq \frac{\gamma\lambda}{2\pi}$$

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.

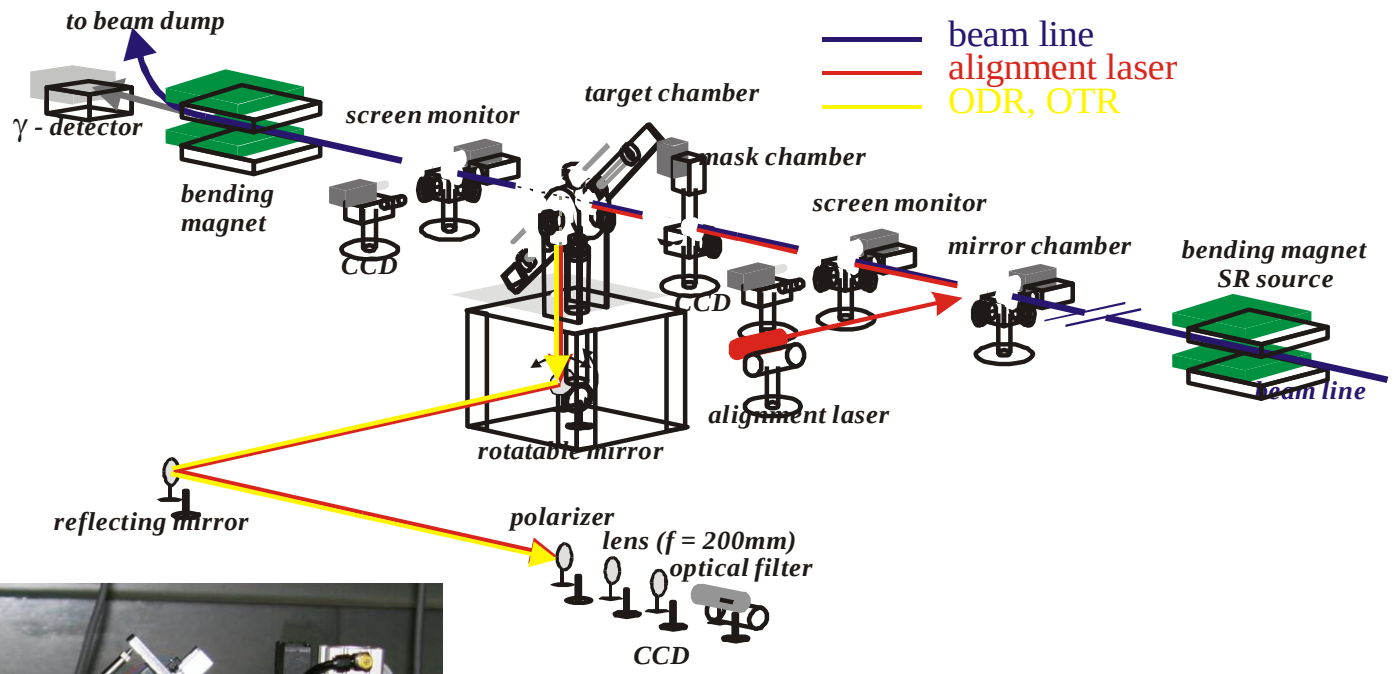
PRL 93, 244802 (2004) PHYSICAL REVIEW LETTERS week ending 10 DECEMBER 2004



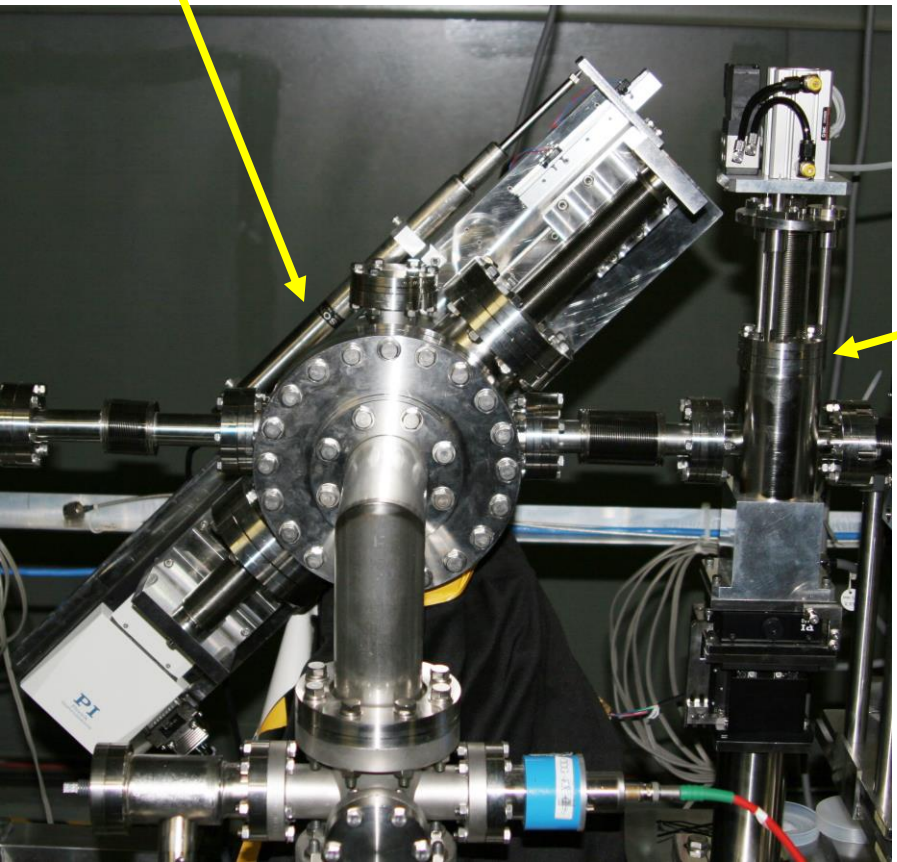
Vertical polarisation component of 3-dimensional (θ_x, θ_y, Intensity) DR angular distribution.

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.

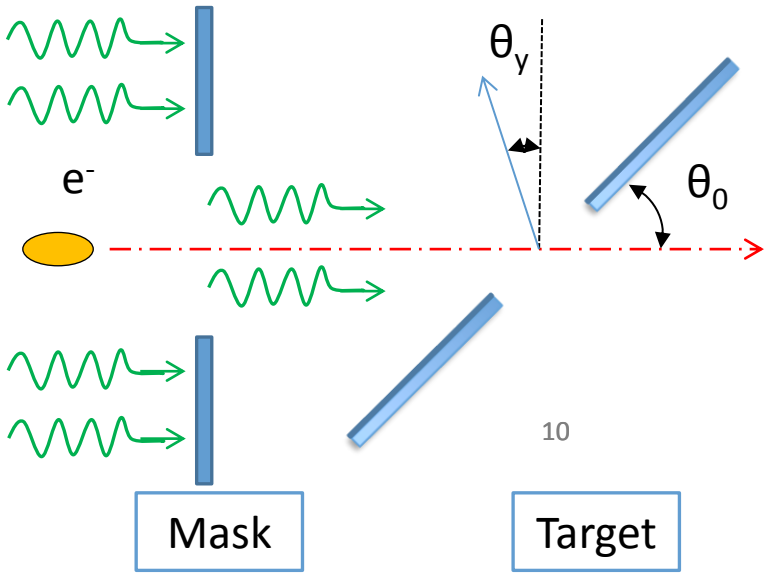


target chamber (at 45° to beam trajectory)



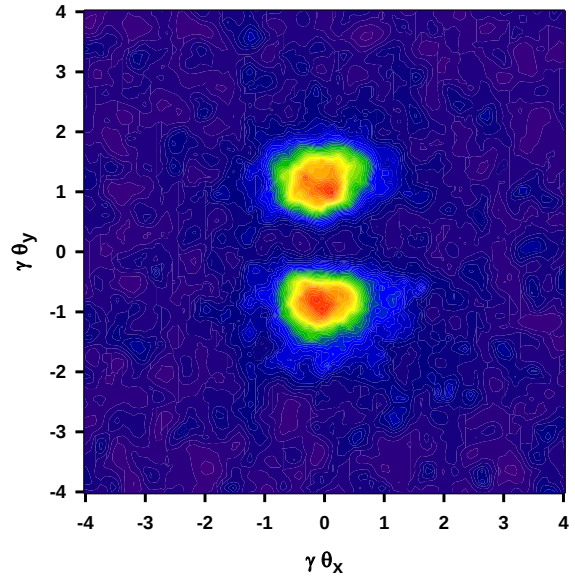
mask

Use a mask upstream of target to suppress SR contribution.

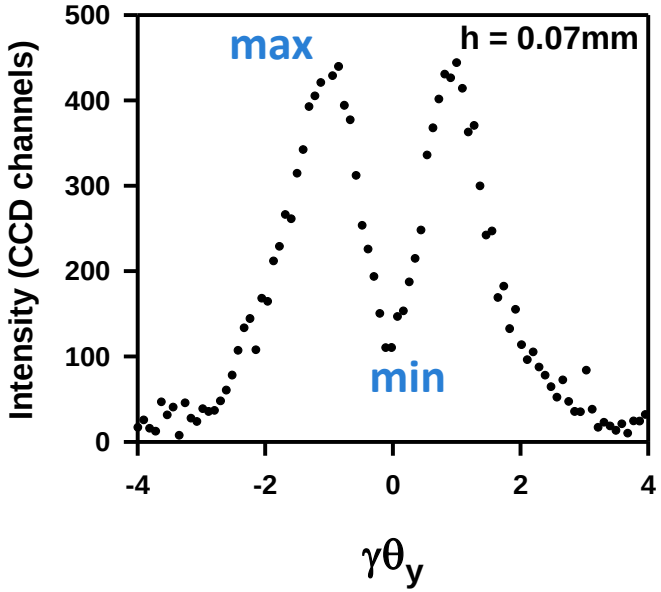


Beam size measurements using ODR

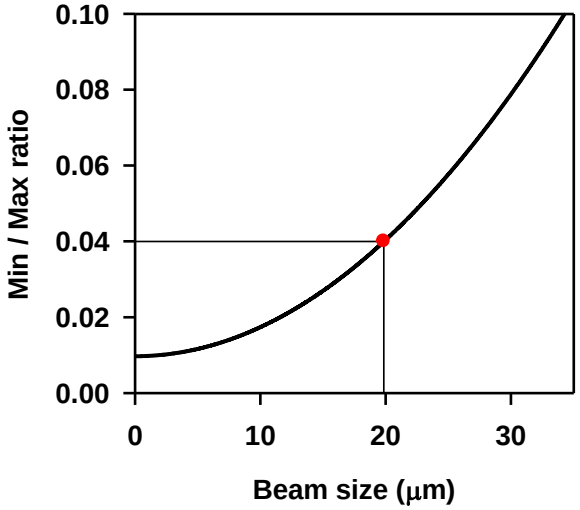
Typical CCD image of ODR vertical polarization component



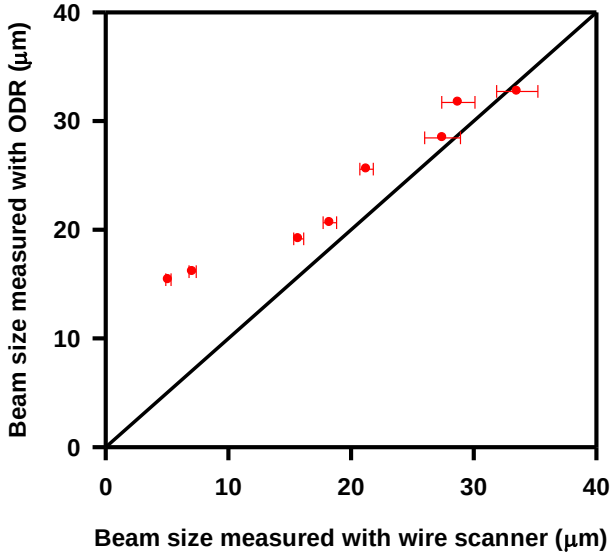
Beam size was changed by a quadruple magnet



Calibration curve



Measured minimum beam size: σ_y = 14 μm



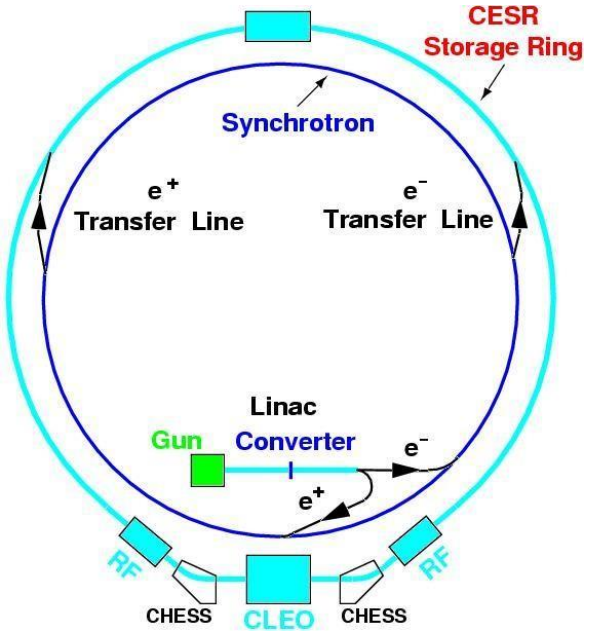
ODR experiment at CesrTA

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:

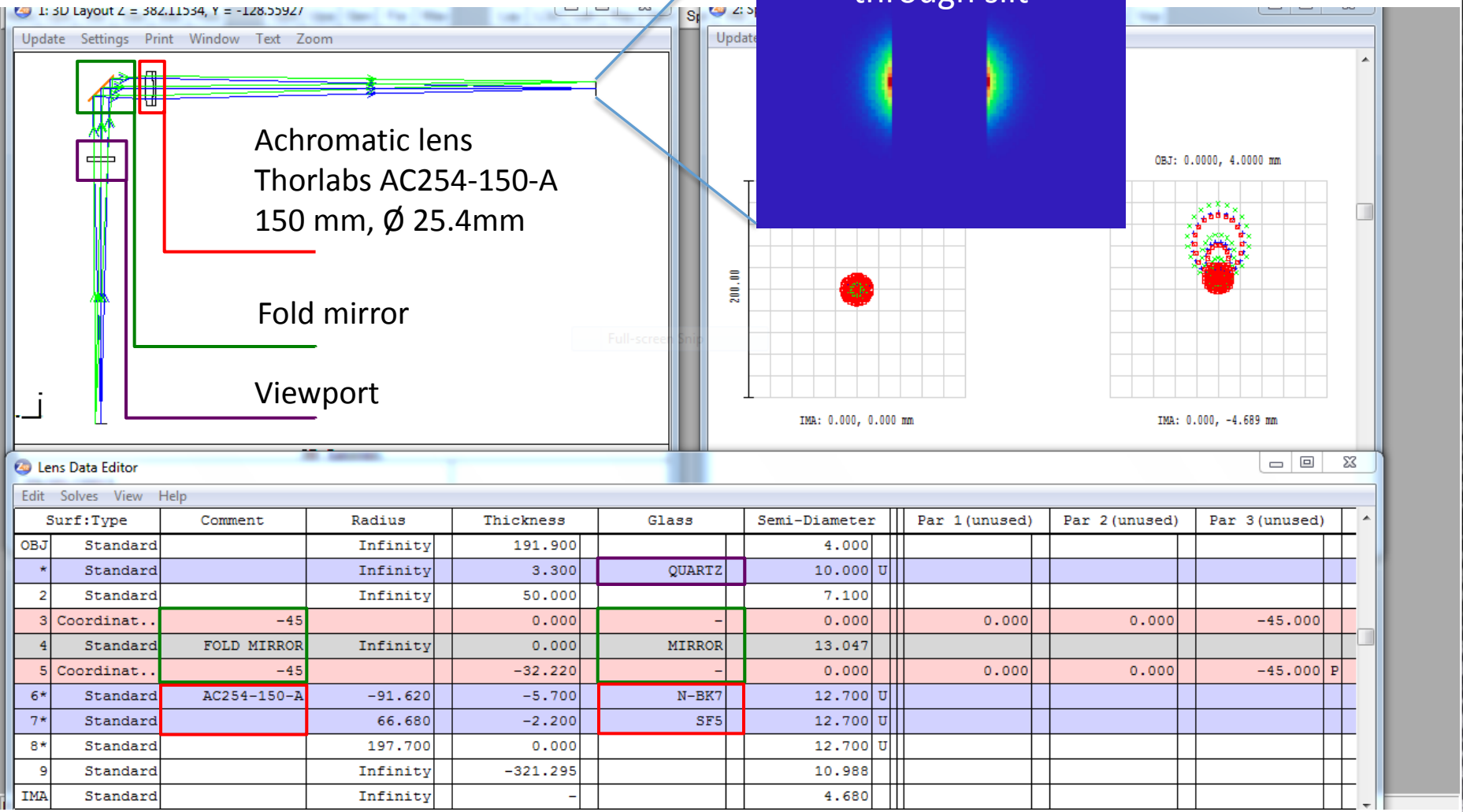
	E (GeV)	σ_H (μm)	σ_V (μm)
CesrTA	2.1	320	~9.2
	5.3	2500	~65



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

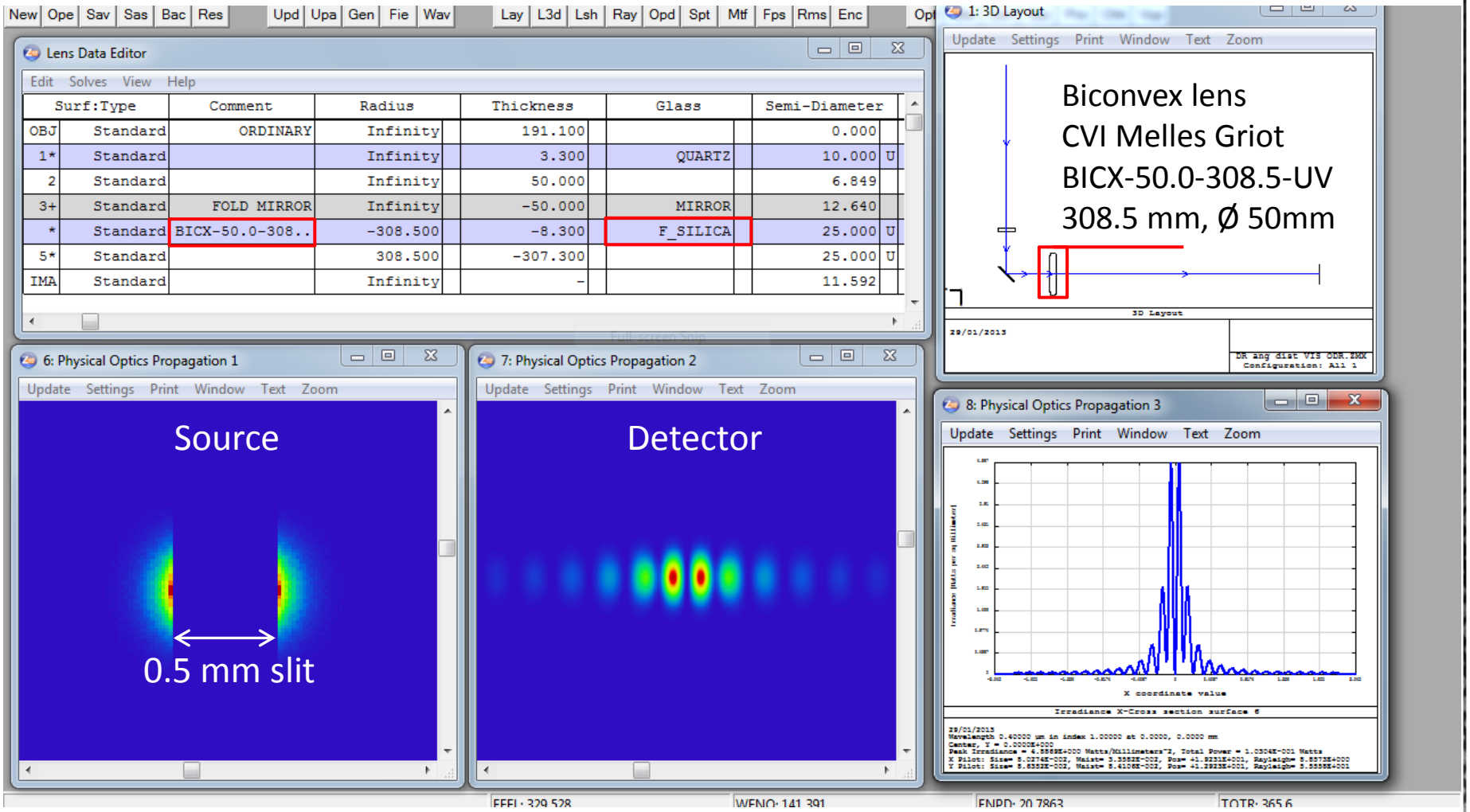
http://www.cs.cornell.edu

Simulations - Imaging the slit



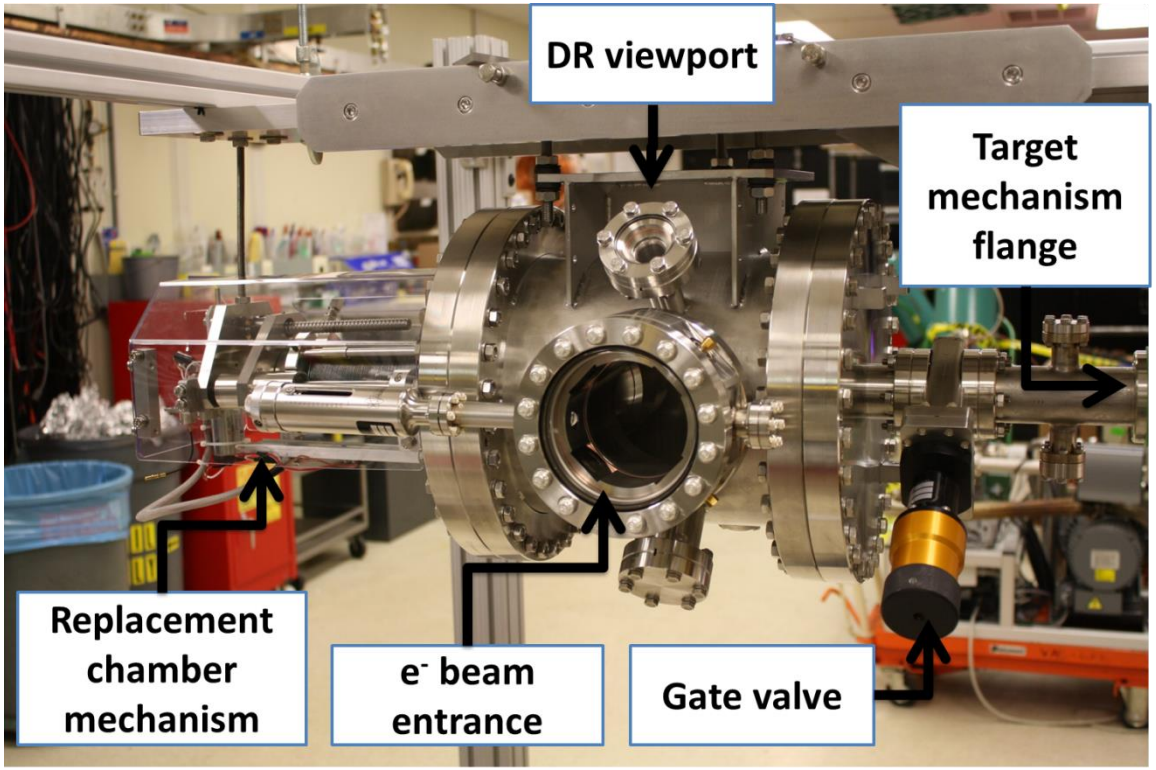
Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter		Par 1 (unused)	Par 2 (unused)	Par 3 (unused)	
OBJ	Standard		Infinity	191.900		4.000					
*	Standard		Infinity	3.300	QUARTZ	10.000	U				
2	Standard		Infinity	50.000		7.100					
3	Coordinat..	-45		0.000	-	0.000		0.000	0.000	-45.000	
4	Standard	FOLD MIRROR	Infinity	0.000	MIRROR	13.047					
5	Coordinat..	-45		-32.220	-	0.000		0.000	0.000	-45.000	P
6*	Standard	AC254-150-A	-91.620	-5.700	N-BK7	12.700	U				
7*	Standard		66.680	-2.200	SF5	12.700	U				
8*	Standard		197.700	0.000		12.700	U				
9	Standard		Infinity	-321.295		10.988					
IMA	Standard		Infinity	-		4.680					

Simulating DR from a single electron – real lens



ODR angular distribution is very sensitive to distances away from the focal plane. The detector must therefore be exactly in the back focal plane.

Vacuum chamber assembly

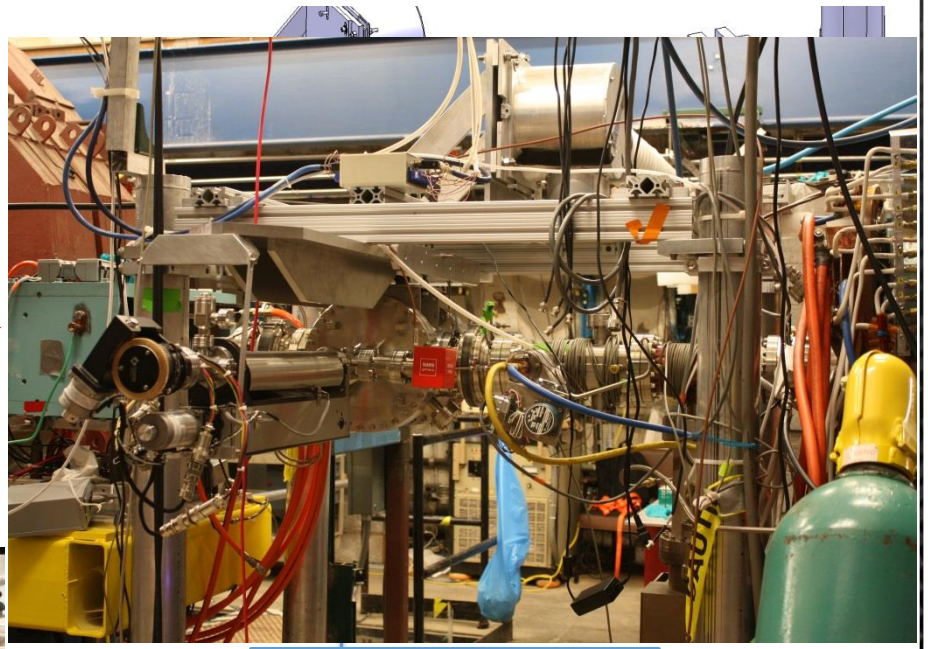


- LHS : CHESS operation
- RHS: DR experiment
- Optical system connected to DR viewport

- Gate valve to disconnect CESR vacuum for target changeover
- Target mechanism: rotation + translation IN/OUT

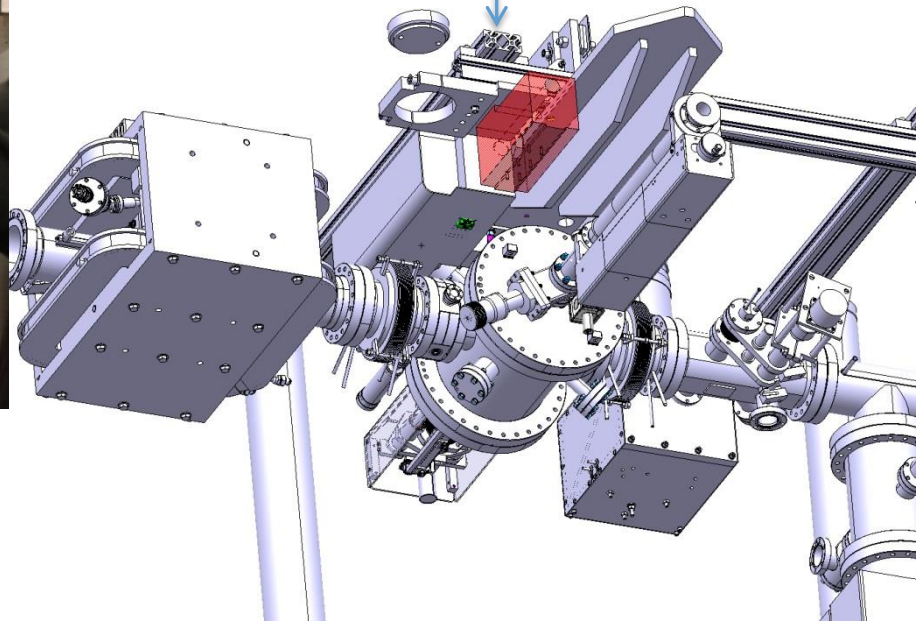
LHS = Left Hand Side
RHS = Right Hand Side

L3 layout @CesrTA



Electron beam direction

DR experiment

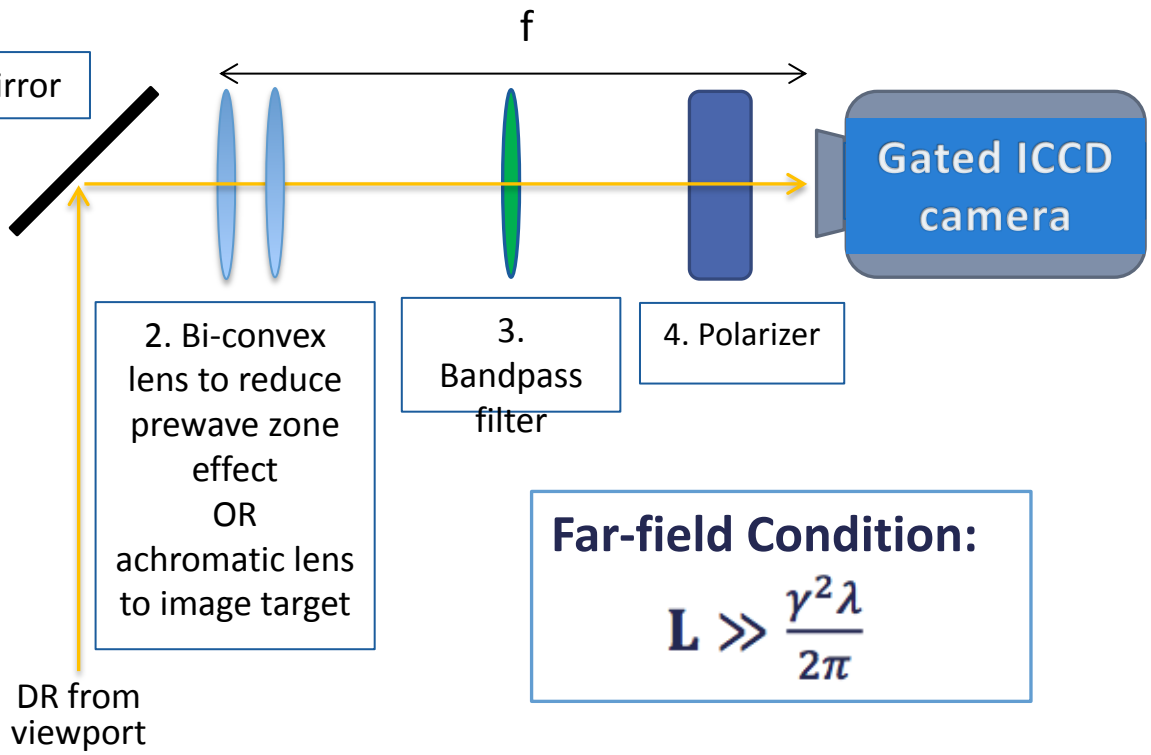


Technical drawings by N. Chritin

Optical System

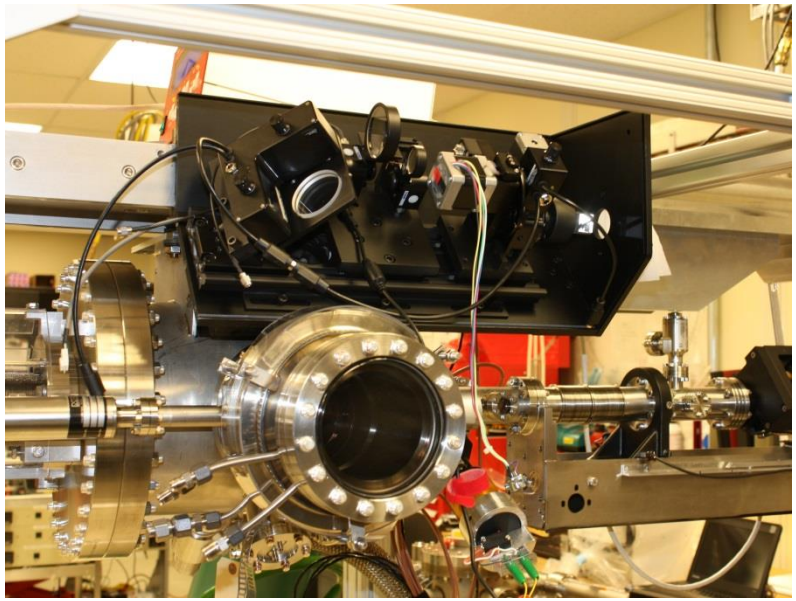
$\frac{g^2 l}{2p}$ given γ and λ:

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



Far-field Condition:

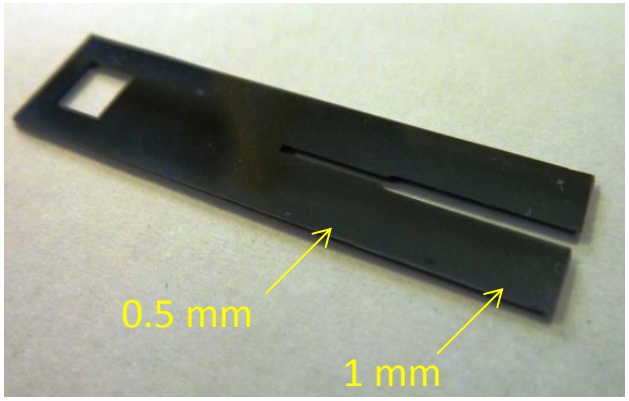
$$L \gg \frac{\gamma^2 \lambda}{2\pi}$$



- 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).

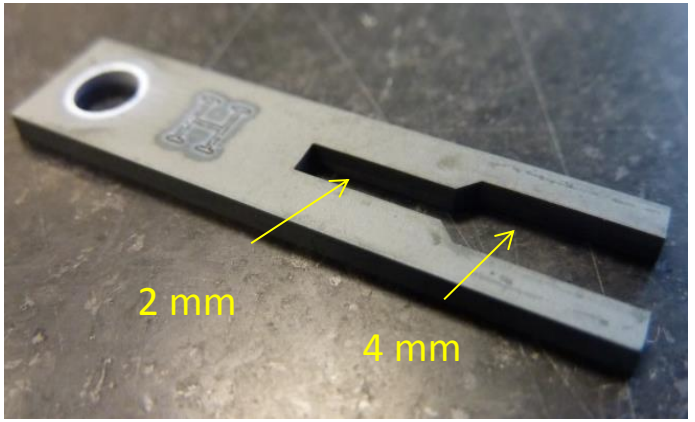
Target



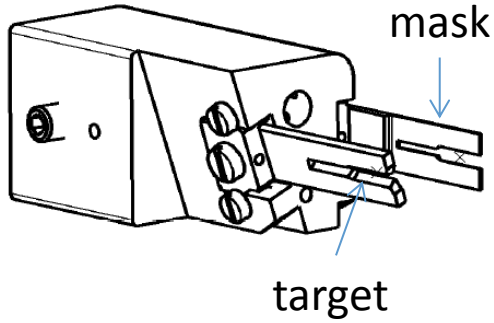
Chemical etching:
Silicon wafers are dipped into etchant (e.g. acidic mixture)

Molecular adhesion:
Two substrates with perfectly flat surfaces (e.g. polished mirror surfaces) adhere to one another, without adhesive (e.g. glue)

Mask

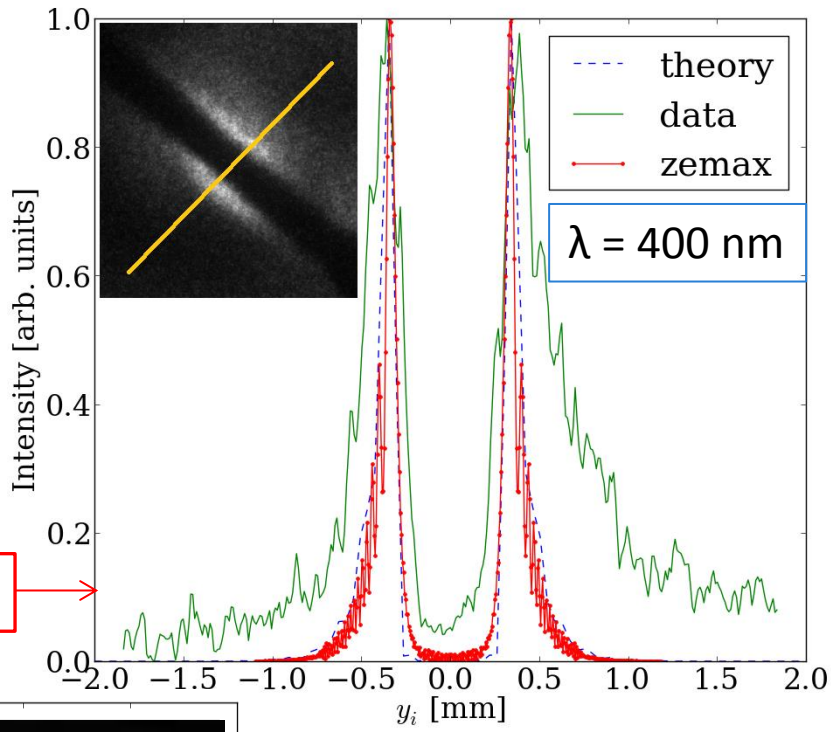


- Silicon Carbide
- **Laser machining**
- Not etched (orientated perpendicular to beam)

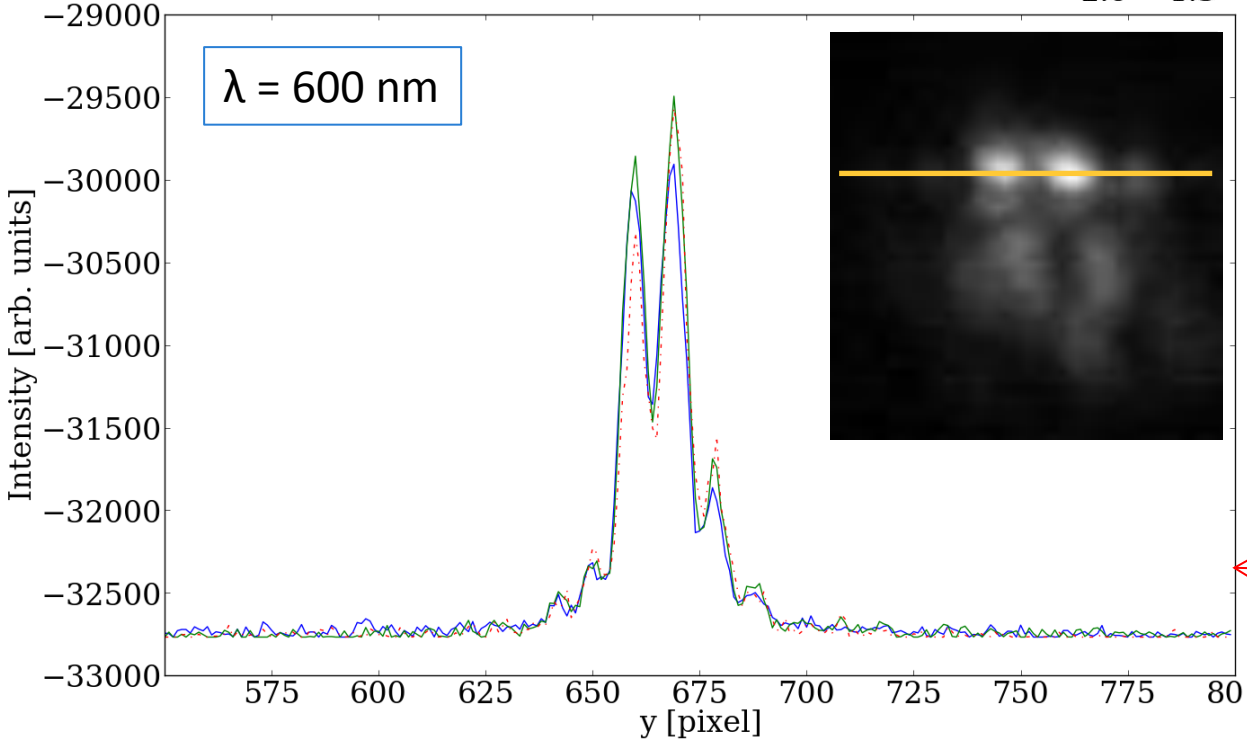


Example images

- 2.1 GeV
- 1 mm slit aperture
- 1 mA single- bunch beam



Imaging



Angular

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

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

OTR/ODR emittance station – proposed time table

- Keep OTR/LW location:
  - Beam optics verified and well understood
  - Beam size, flexibility and tunability known
  - Transversal beam size resolution still not good enough → replace existing vacuum chamber
- Attach currently used BPM to new chamber
- Schedule:
  - 0.5 years: simulation of the current system (capabilities, possible improvements) → potential experimental tests
  - 1 year: Design and simulation of new system. Installation: 09/2015 (till the end of the summer 2015 shutdown)
  - 1.5 years: Experimental tests from 10/2015 till 06/2017 (~ **2 operational years**).

Shift request

- **Year 1**:
  - **5 shifts**: Commissioning and observation of OTR/ODR angular distributions (initial tests < 400 nm)
  - **5 shifts**: Resolution optimisation of the OTR/ODR and demonstration of high-resolution beam size measurements
  - **5 shifts**: Beam dynamics studies (incl. quad scan and beam roll angle)
- **Year 2**:
  - During Year 1: analysis of the experimental conditions and design short wavelength measurement system (< 200 nm)
  - Summer 2016 shutdown: upgrade of optical system
  - Year 2 → demonstrate performance of short wavelength measurement. **Repeat the measurements** performed in the optical wavelength range for comparison

Thank you for your attention!

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KEK HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

CERN

UNIVERSITY OF LIVERPOOL

The Cockcroft Institute of Accelerator Science and Technology