ODR - a non-invasive Beam Size Measurement Technique for CLIC

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3. Cornell University, Ithaca, New York, USA

Contents

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).

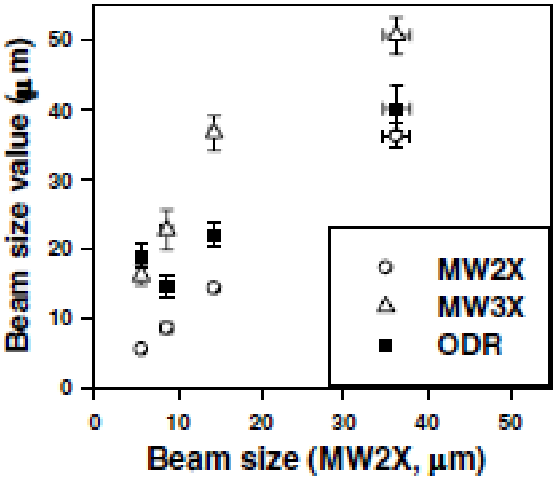


FIG. 7. The correlation between the beam size measured with ODR (black squares) and two wire scanners installed upstream (open circles) and downstream (open triangles) of the target.

σ_y = 14 μm measured ATF2@KEK

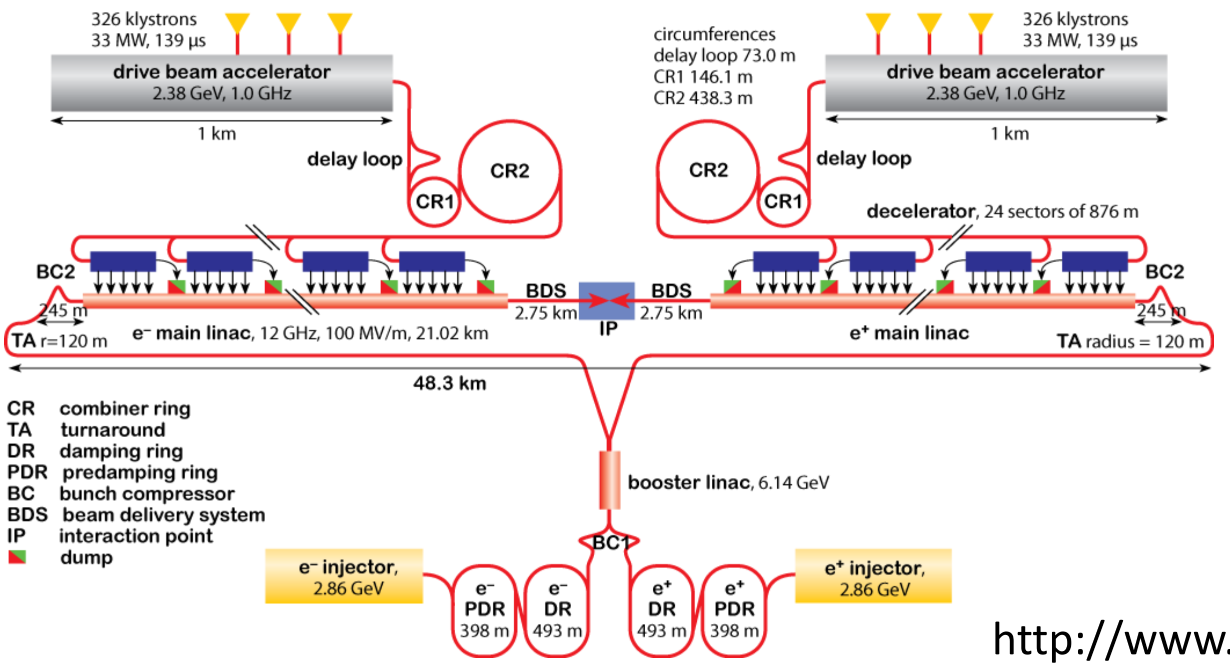
Motivation

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/

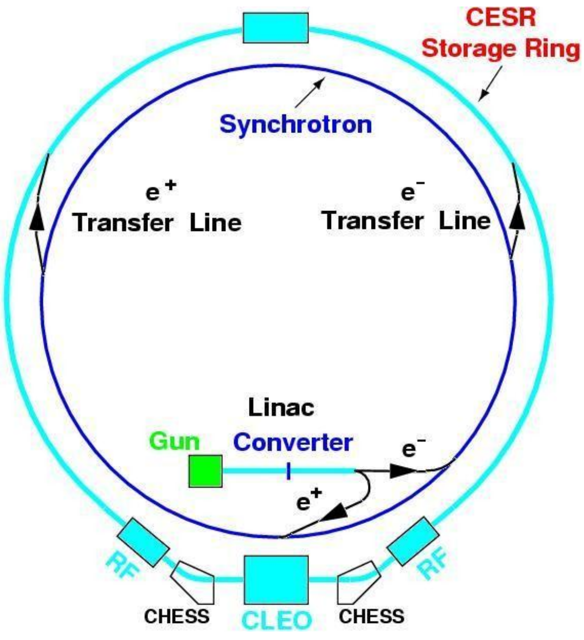
Our experiment

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:

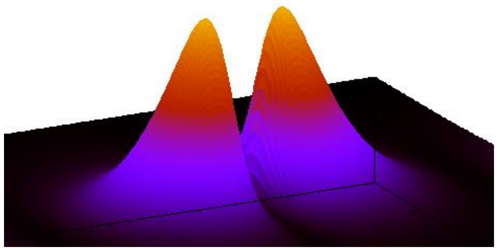
	E (GeV)	σ_H (μm)	σ_V (μm)
CesrTA	2.1	320	~9.2
	5.3	2500	~65



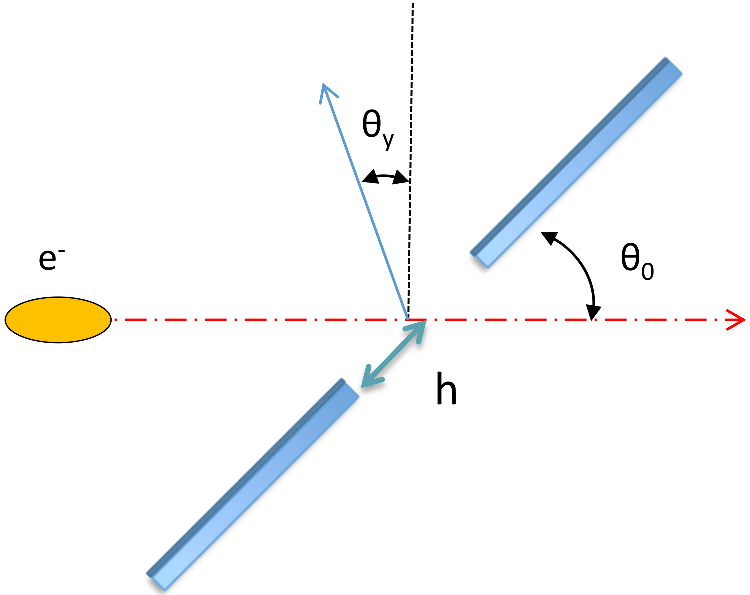
D. Rubin et al., "CesrTA Layout and Optics", Proc. of PAC2009, Vancouver, Canada, WE6PFP103, p. 2751.

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:

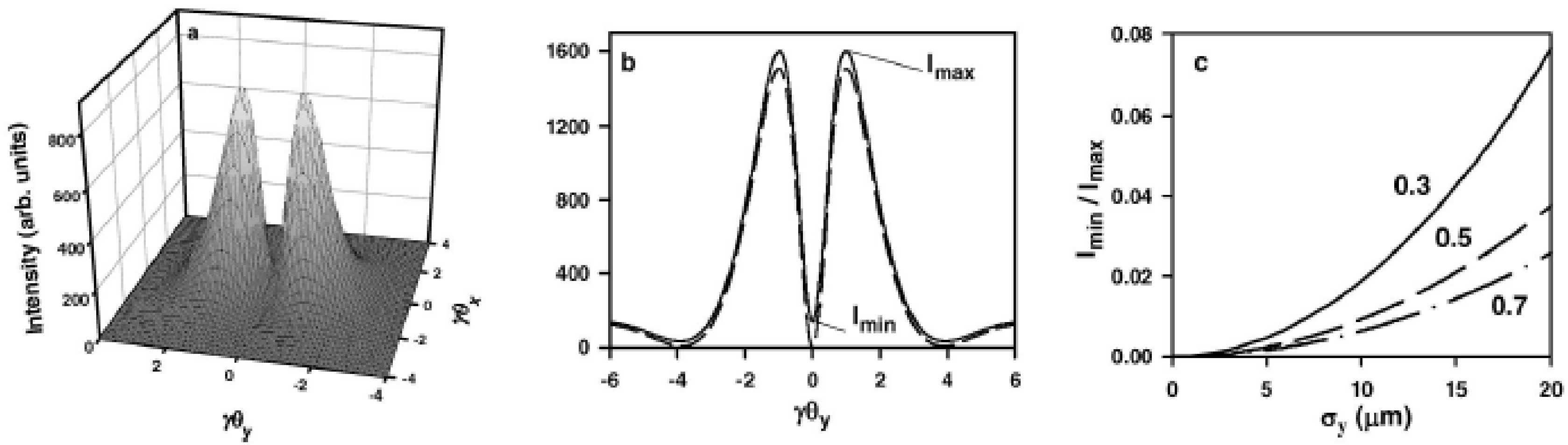
$$h \leq \frac{\gamma\lambda}{2\pi}$$

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.

→

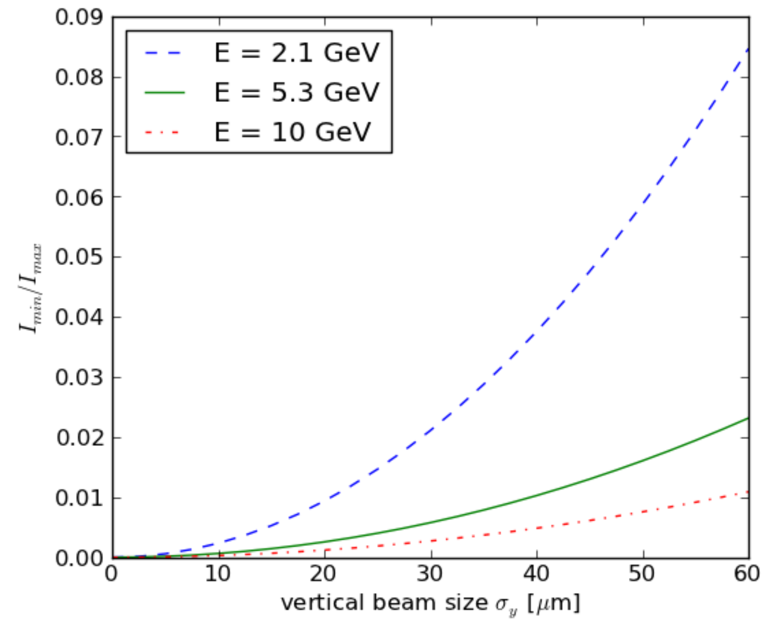
PVPC is obtained by integrating over θ_x to collect more photons.

→

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

Phase 1 Experiment Simulations for CesrTA

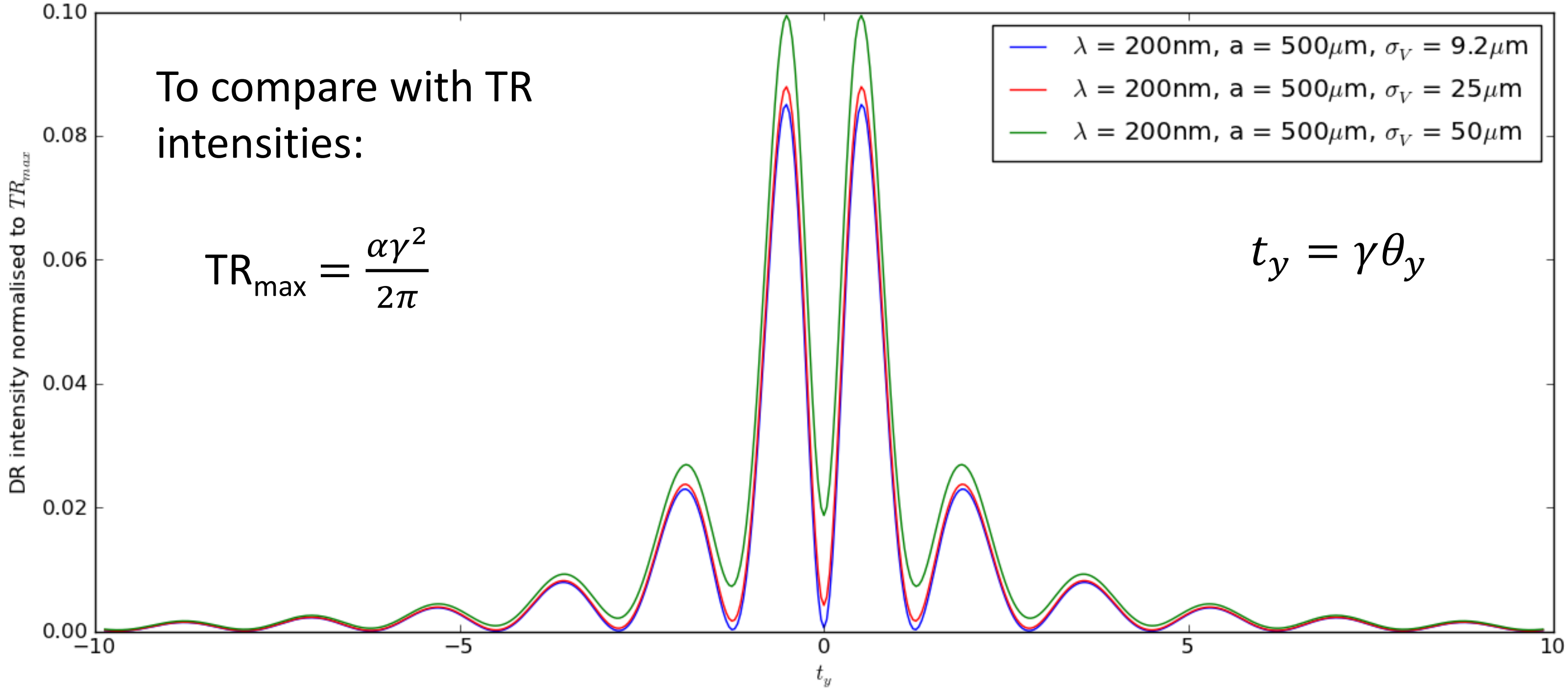
Measureable visibility for initial test at parameters:
λ = 200 - 400 nm
a = 0.5, 1 mm
σ_y = 50 µm



To compare with TR intensities:

$$\mathrm{TR_{max}} = \frac{\alpha\gamma^2}{2\pi}$$

$$t_y = \gamma\theta_y$$



Beam lifetime and beam jitter

M. Billing, *"Introduction to Beam Diagnostics and Instrumentation for Circular Accelerators"*, AIP Conference Proc. 281, AIP 1993, pg.75 ff.

target slit size [mm]	vertical beam size [µm]	beam lifetime [min]
0.1	9.2	2.40
0.5	30	60 (max)
	50	2.22
1.0	50	60 (max)

$a_{target} \geq 5 \cdot \sigma_{y}$,
preferably $a_{target} = 7\text{-}10 \cdot \sigma_y$

↓

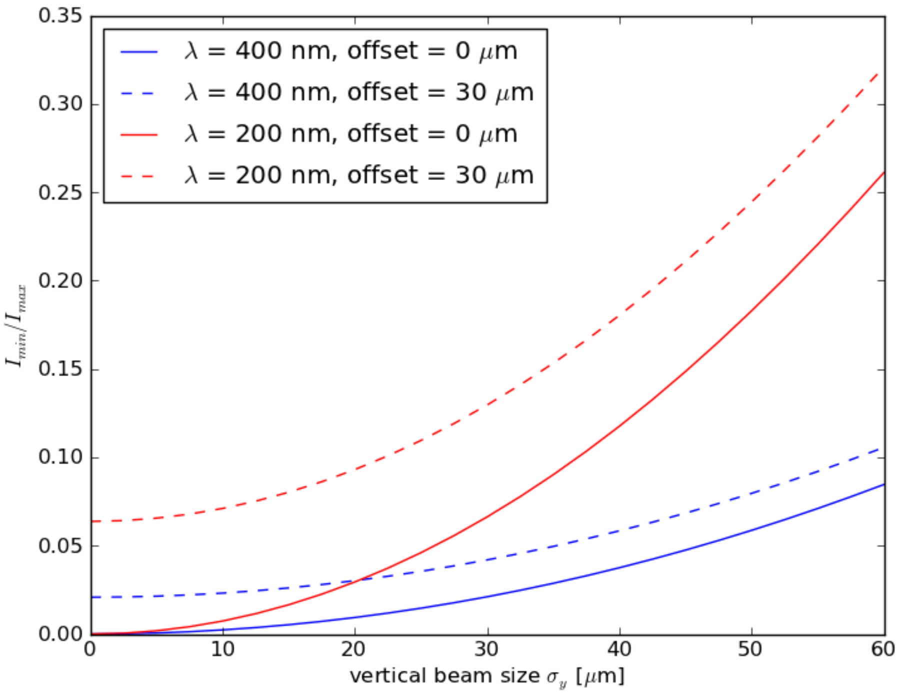
Large aperture = low DR intensity

↓

Multiple turns of a single bunch through the target aperture

↓

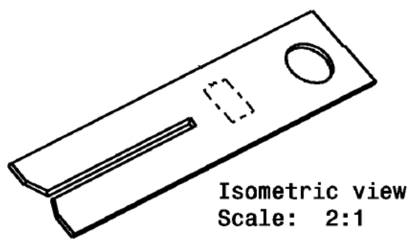
Errors due to beam jitter are reduced by including turn-by-turn vertical position measurements of the bunch in the target aperture.

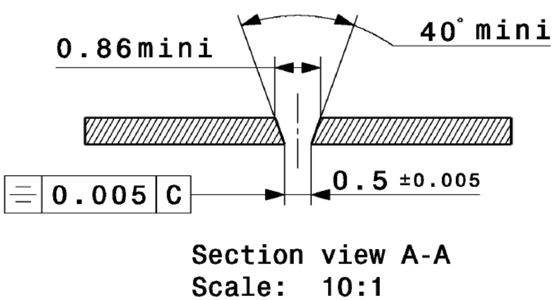


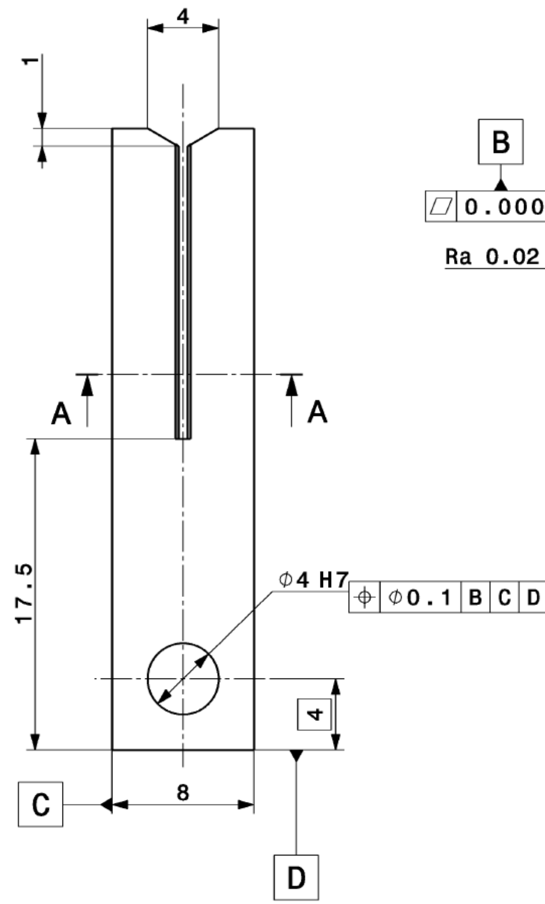
Target design

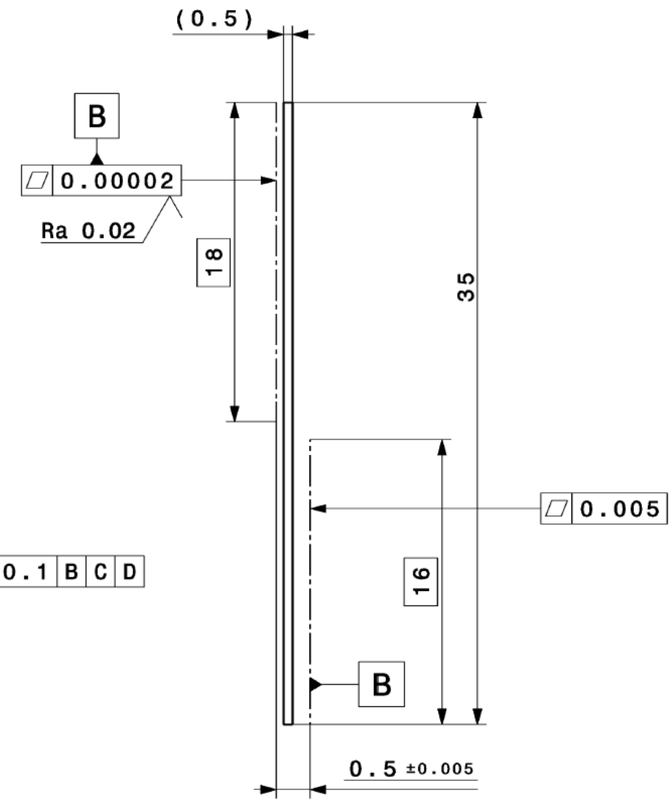
Requirements:
High precision slit size
Coplanarity ≤ 10% · λ
High reflectivity at λ

Aperture sizes a:
0.5 mm, 1 mm
Material: Si





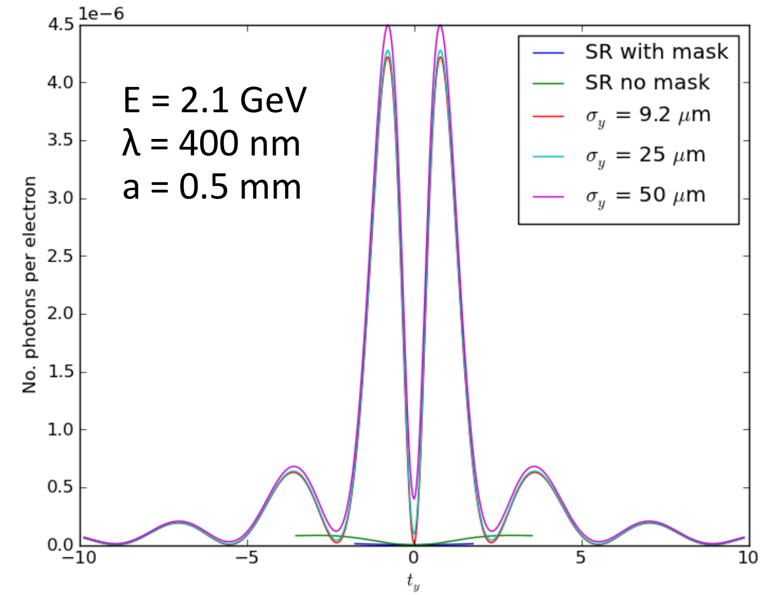




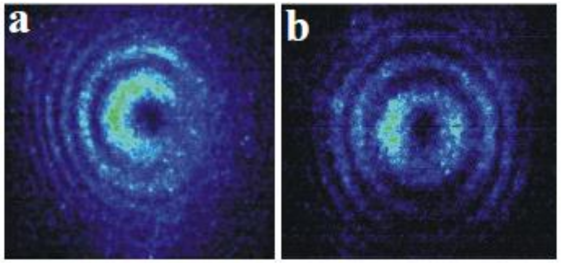
Technical drawings by N. Chritin

Synchrotron Radiation (SR)

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

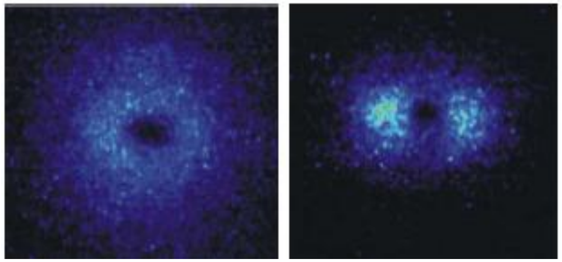


SR + DR interference



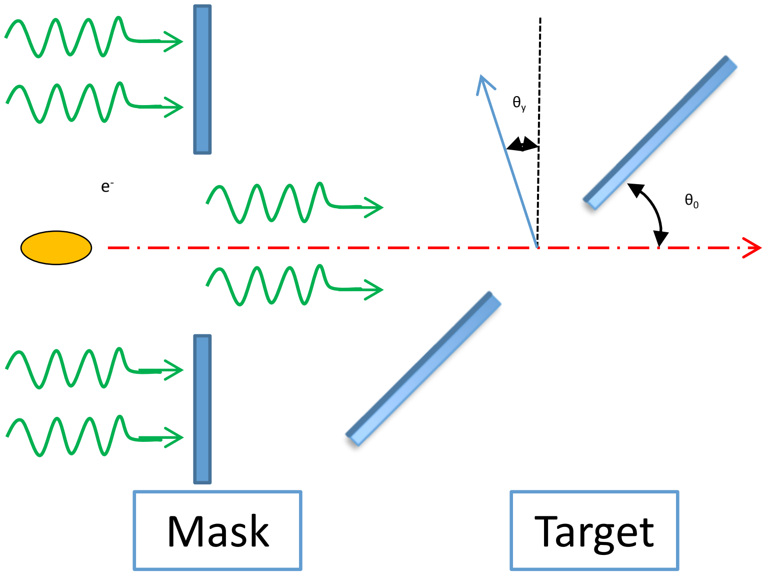
OTR ODR

SR suppression



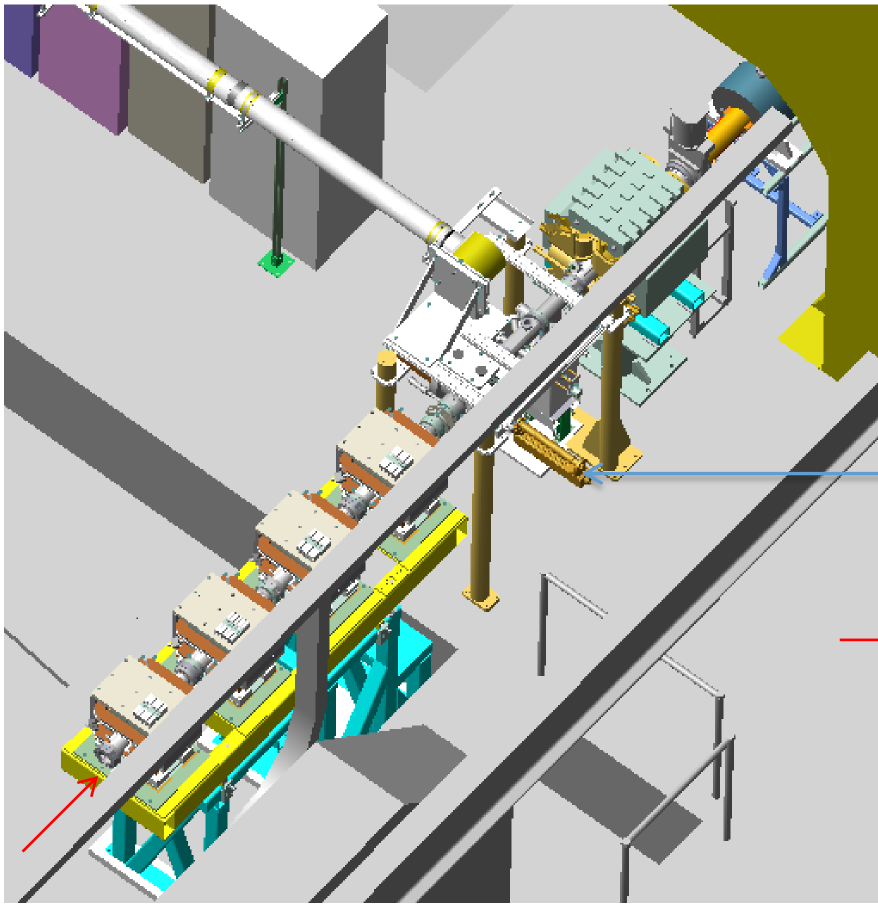
P. Karataev et al., Proc. of EPAC 2004, THPLT067

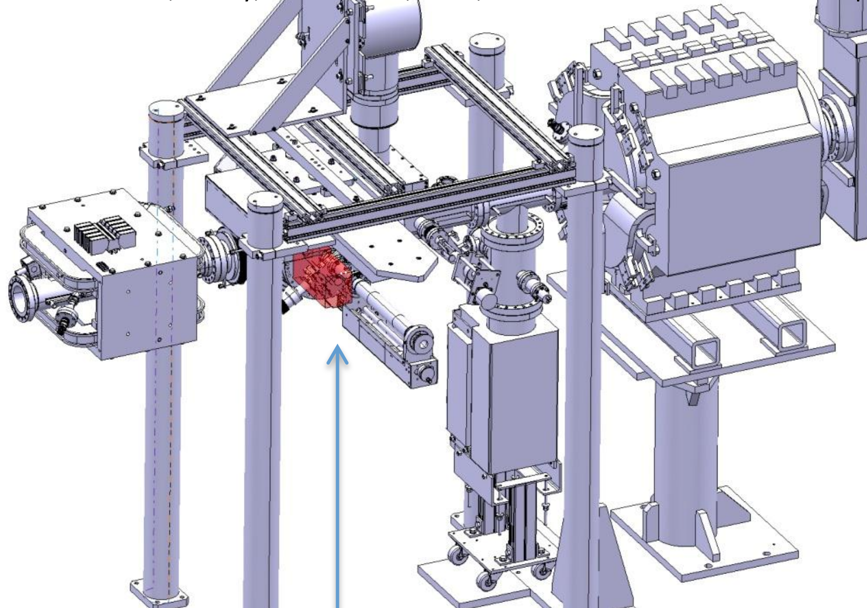
Use a mask upstream of target to suppress SR contribution.



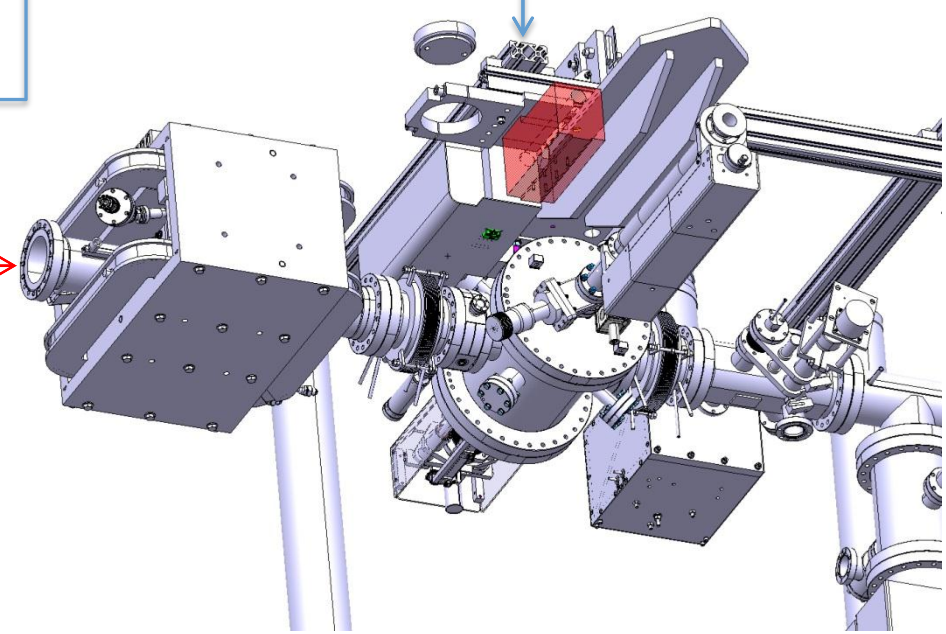
L3 layout @CesrTA

Electron beam direction



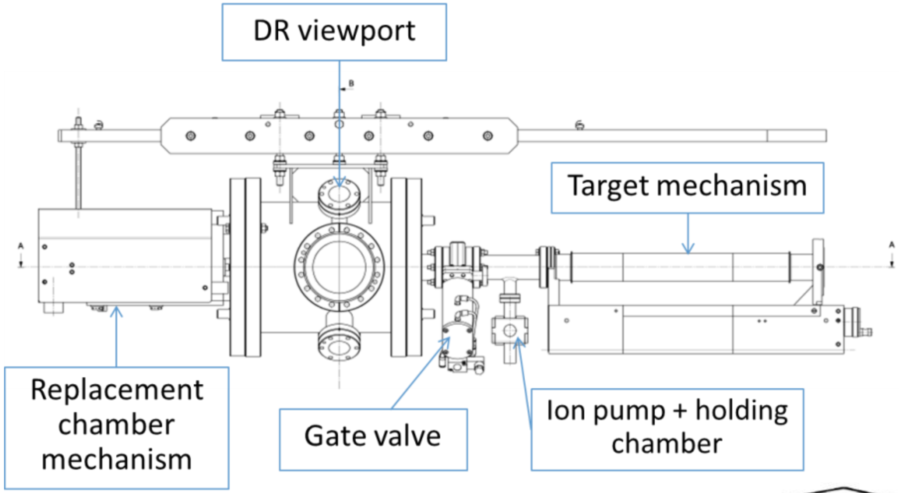


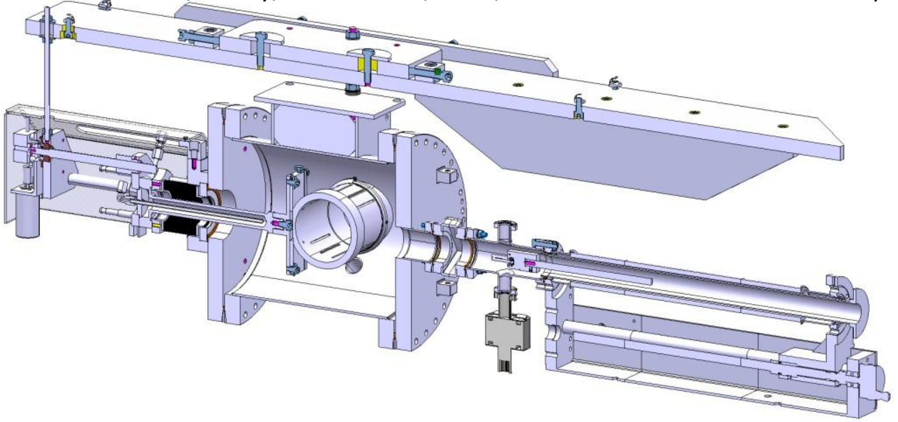
DR experiment

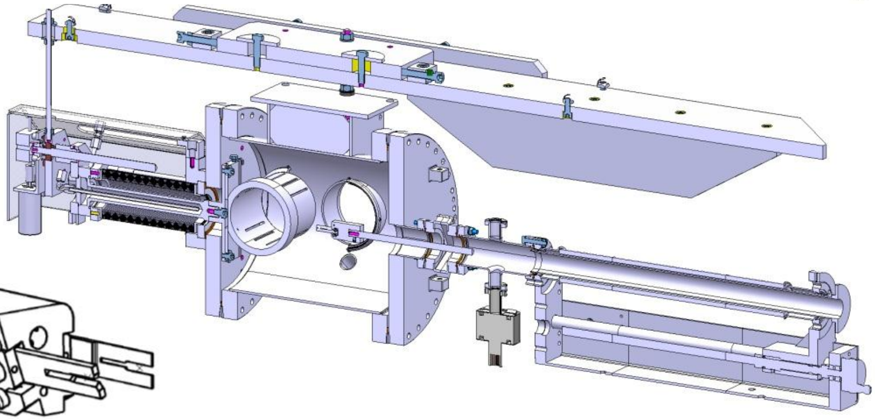


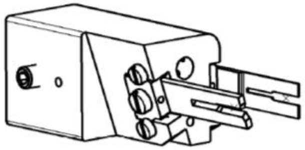
Technical drawings by N. Chritin

Vacuum chamber assembly



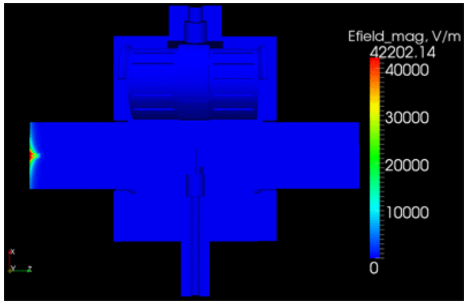


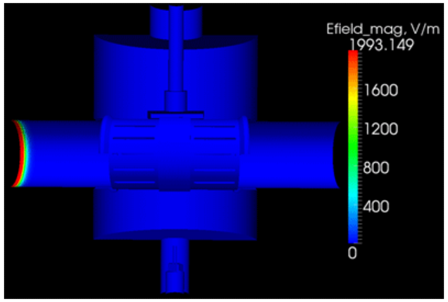




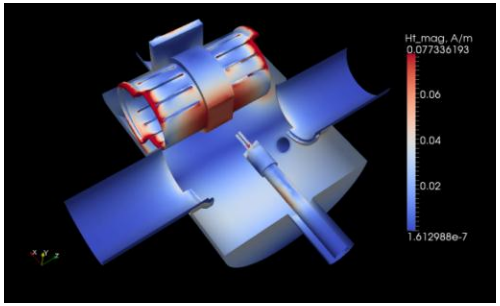
Technical drawings by N. Chritin
Simulations by A. Nosych

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



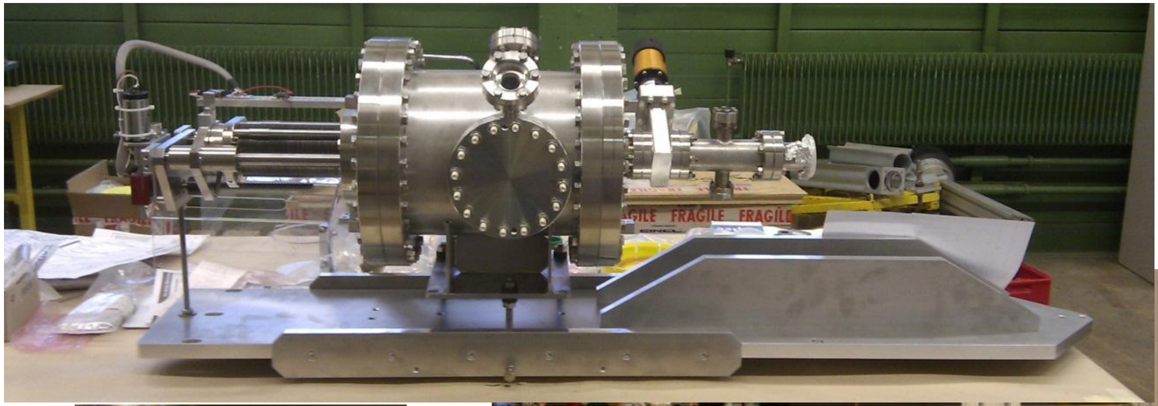


H-field surface tang complex magnitude (Loss map)
Mode Fr = 1.19 GHz, Q = 3309, Ploss = 0.075 W

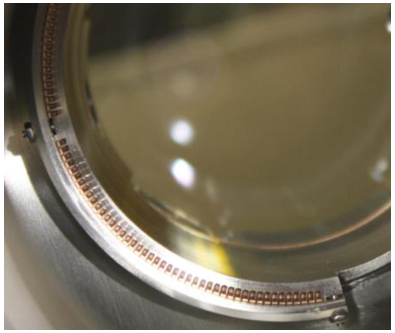


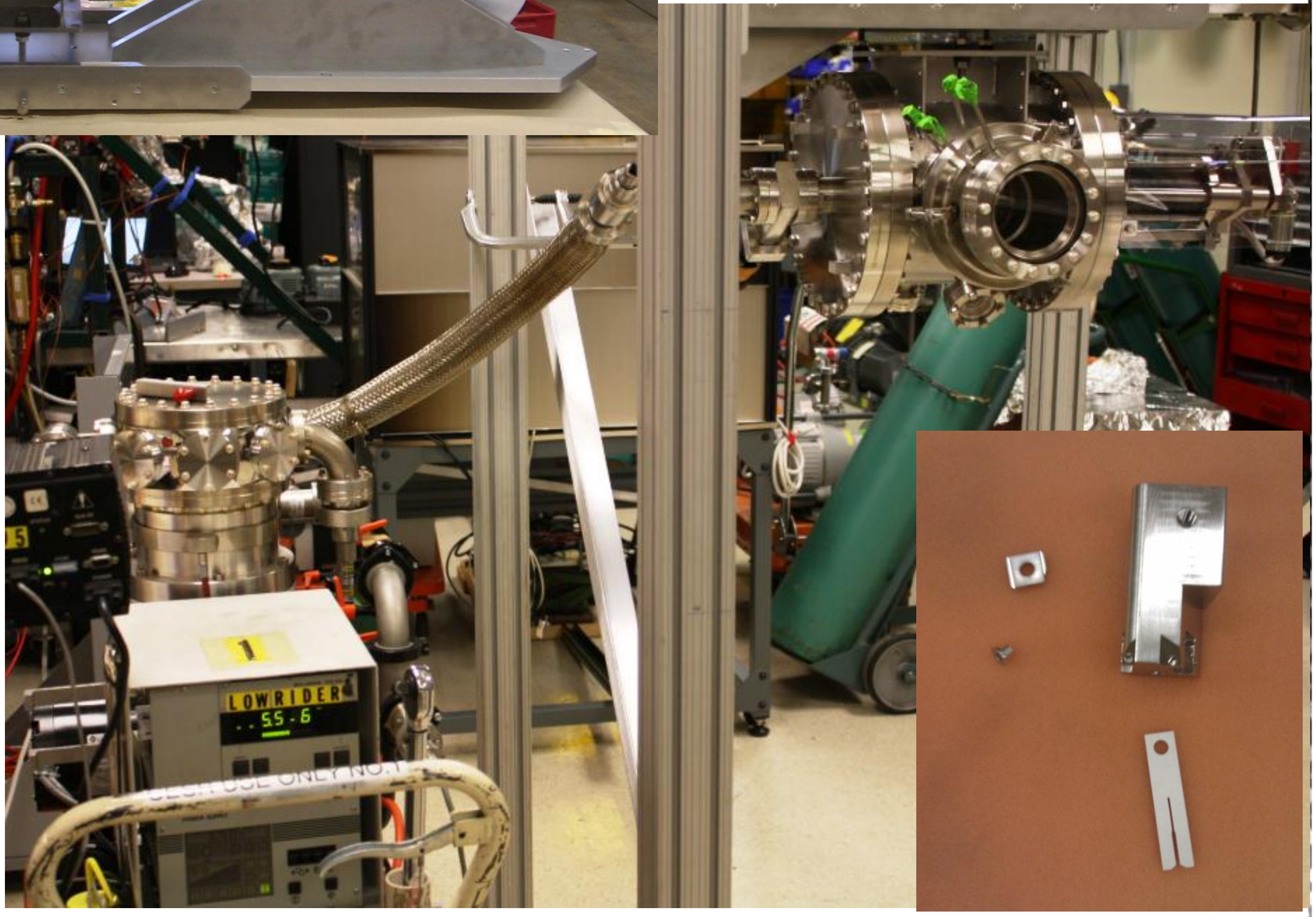
Total power loss for single bunch = 0.6 W

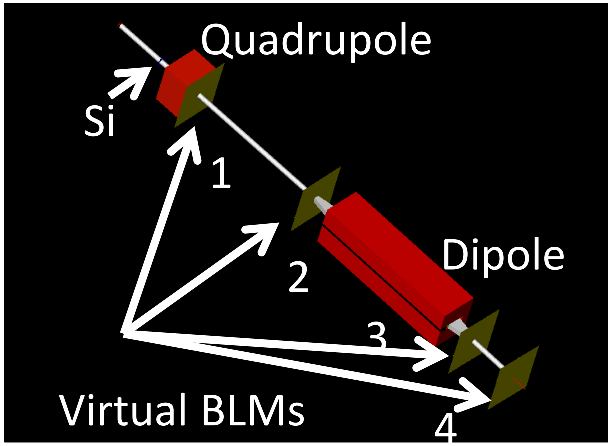
Vacuum chamber assembly cont'd



Images taken during assembly at CERN and current testing at Cornell.

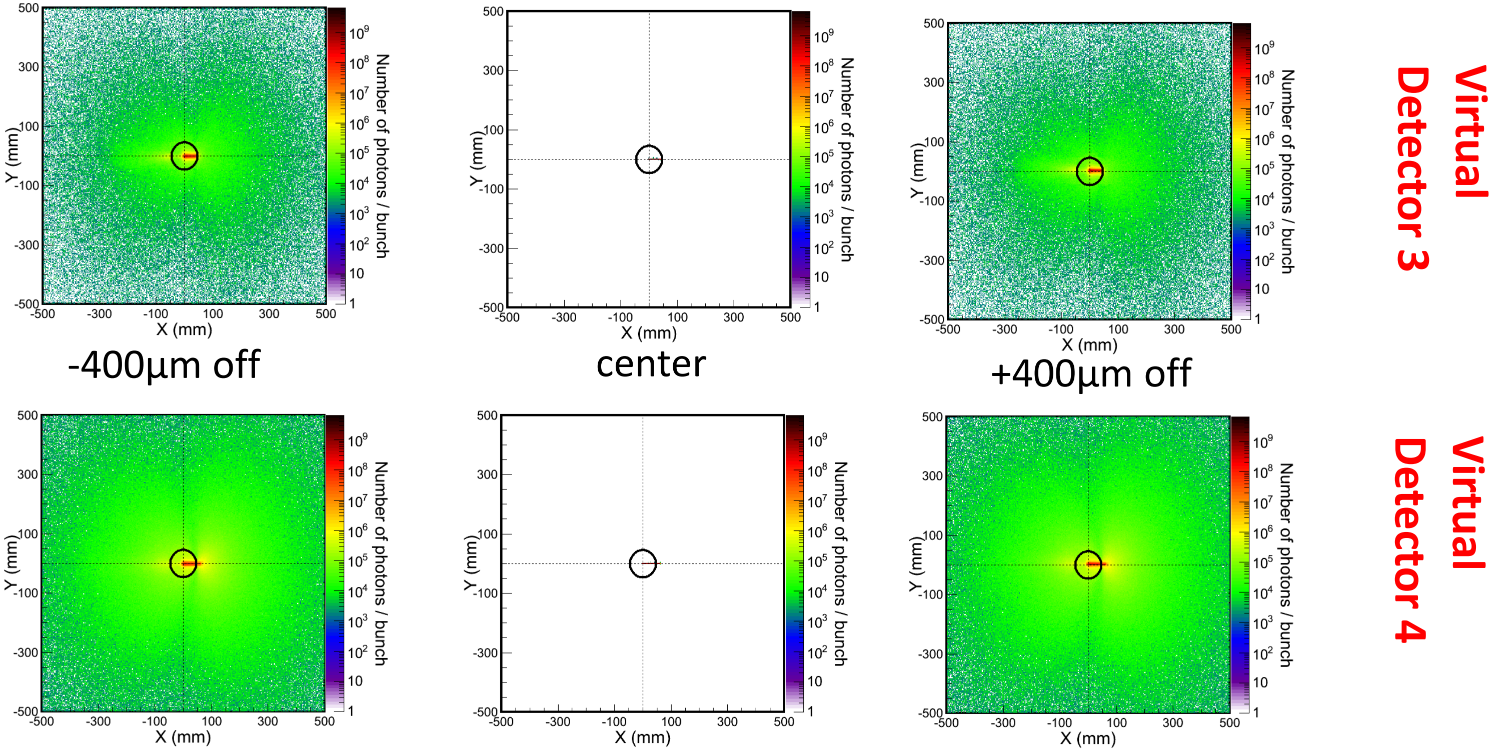






Method of Operation

1. Alignment of the electron beam with the target aperture:
   - BPMs for centering (~10 microns resolution)
   - Target imaging to look for OTR from beam halo
   - Correlate with BLMs:



2. DR vertical beam size measurement

Simulations by A. Apyan

Optical System

Far-field Condition:

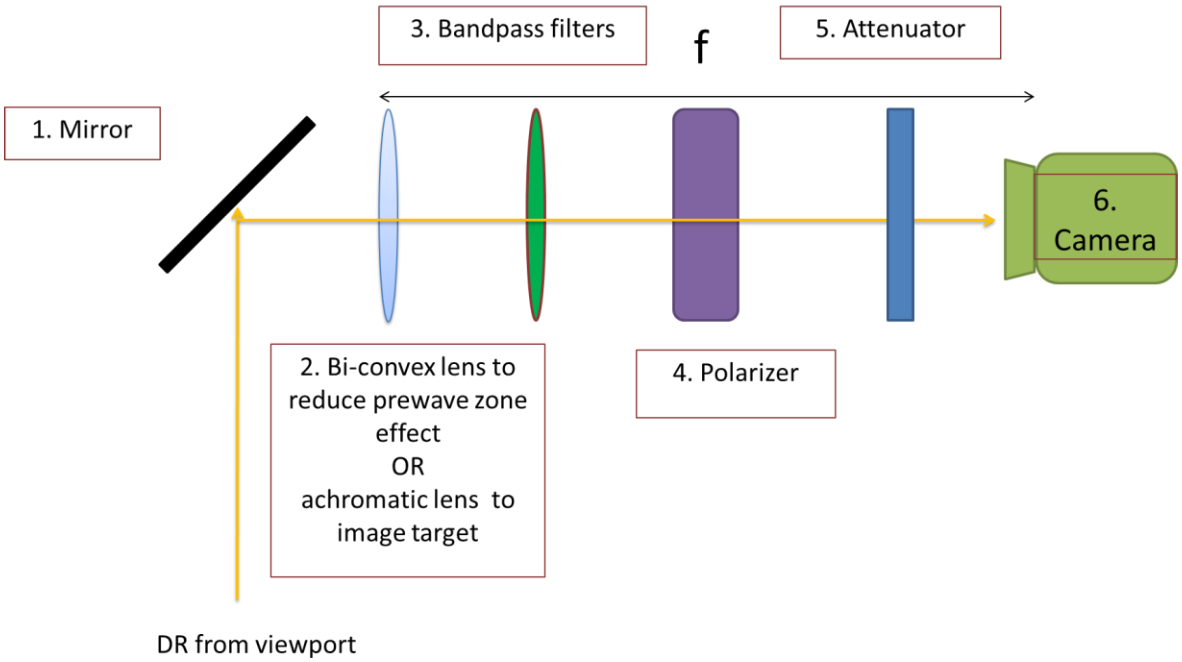
$$L \gg \frac{\gamma^2\lambda}{2\pi}$$

- 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:

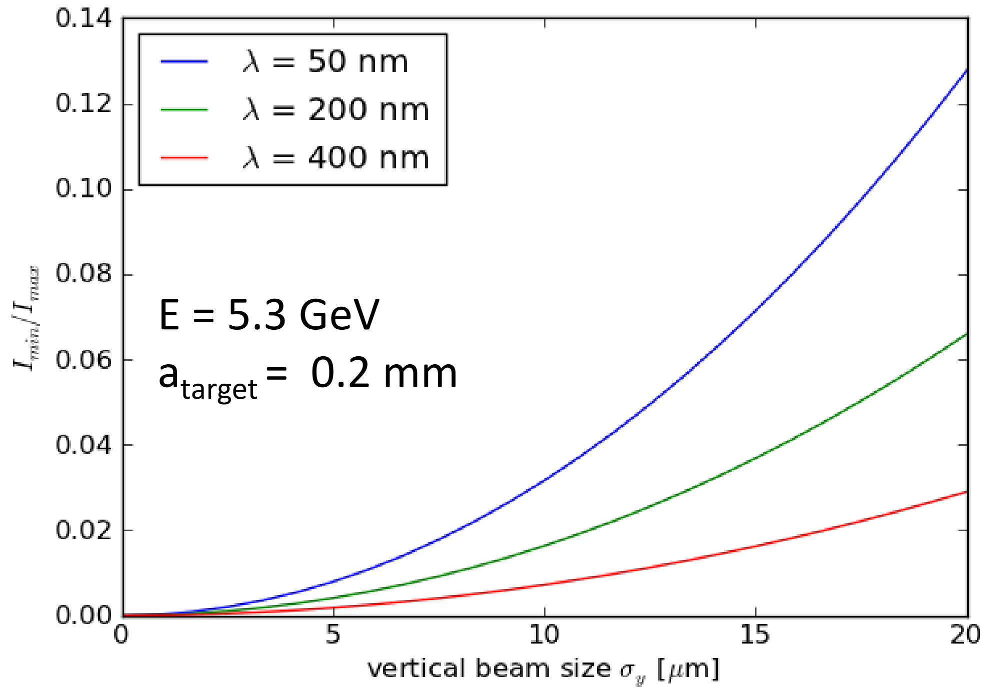
	2.1 GeV	5 GeV
200 nm	0.54 m	3.18 m
400 nm	1.08m	6.37 m



Compact optical system (distance to detector $L \leq \frac{\gamma^2\lambda}{2\pi}$)	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 = 200 nm, 400 nm	
In footprint of target mechanism (< 1m)	Determined by L and spatial constraints.

Phase 2: Micron-scale resolution

- DR at soft X-ray wavelengths:
  - More complex optical system.
  - Grazing target tilt angle
- Aperture size determined by impact parameter for given wavelength



Main requirement:
Micron-scale resolution

Must use shorter wavelengths

Sensitivity @50 nm ≈ 2x sensitivity @200 nm

Summary + Conclusion

- Simulations have demonstrated the feasibility of vertical beam size measurements at CesrTA. The preliminary phase 1 experiment will take place at the end of December 2012.
- The design must account for the experiment location in a circular machine. This introduces some advantages and disadvantages not applicable for linacs.
- Preliminary simulations for the phase 2 test aiming for the soft x-ray spectral range have been presented.

Acknowledgements

I would like to thank J. Barley, J. Conway, J. Lanzoni, Y. Li, T. O'Connell, M. Palmer, D. Rice, D. Rubin, J. Sexton, C. Strohman and S. Wang (@Cornell) for all technical contributions and advice. In addition, O.R. Jones and H. Schmickler for organisation of the collaboration, A. Apyan, S. Burger, A. Jeff, A. Nosych and S. Vulliez (@CERN).

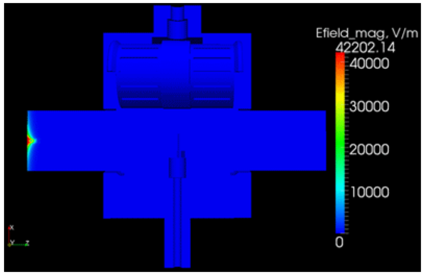
Thank you for your attention

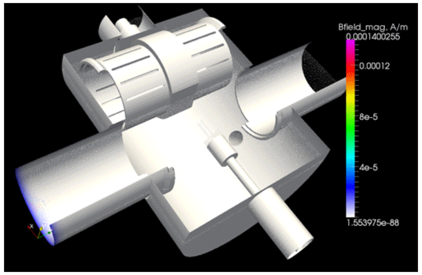
Questions?

Extra slides

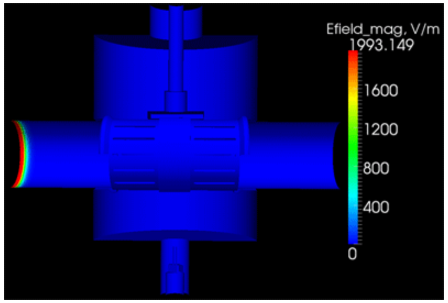
Higher Order Modes (HOMs)

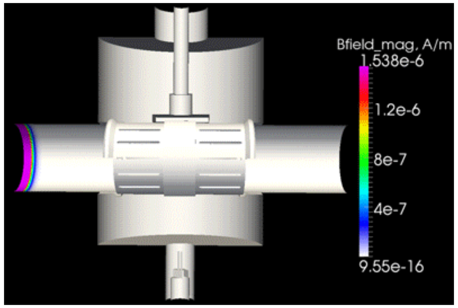
E-field + B-field magnitude of a single bunch pass in time domain (Gaussian bunch, length = [-4σ,4σ], σ = 10mm)



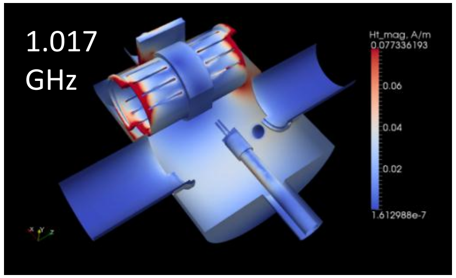


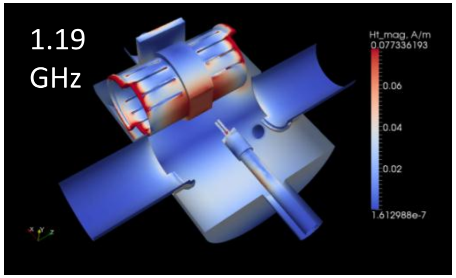
Fork OUT, Chamber IN

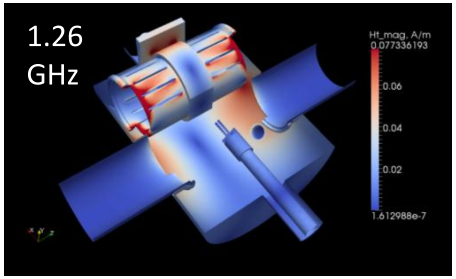


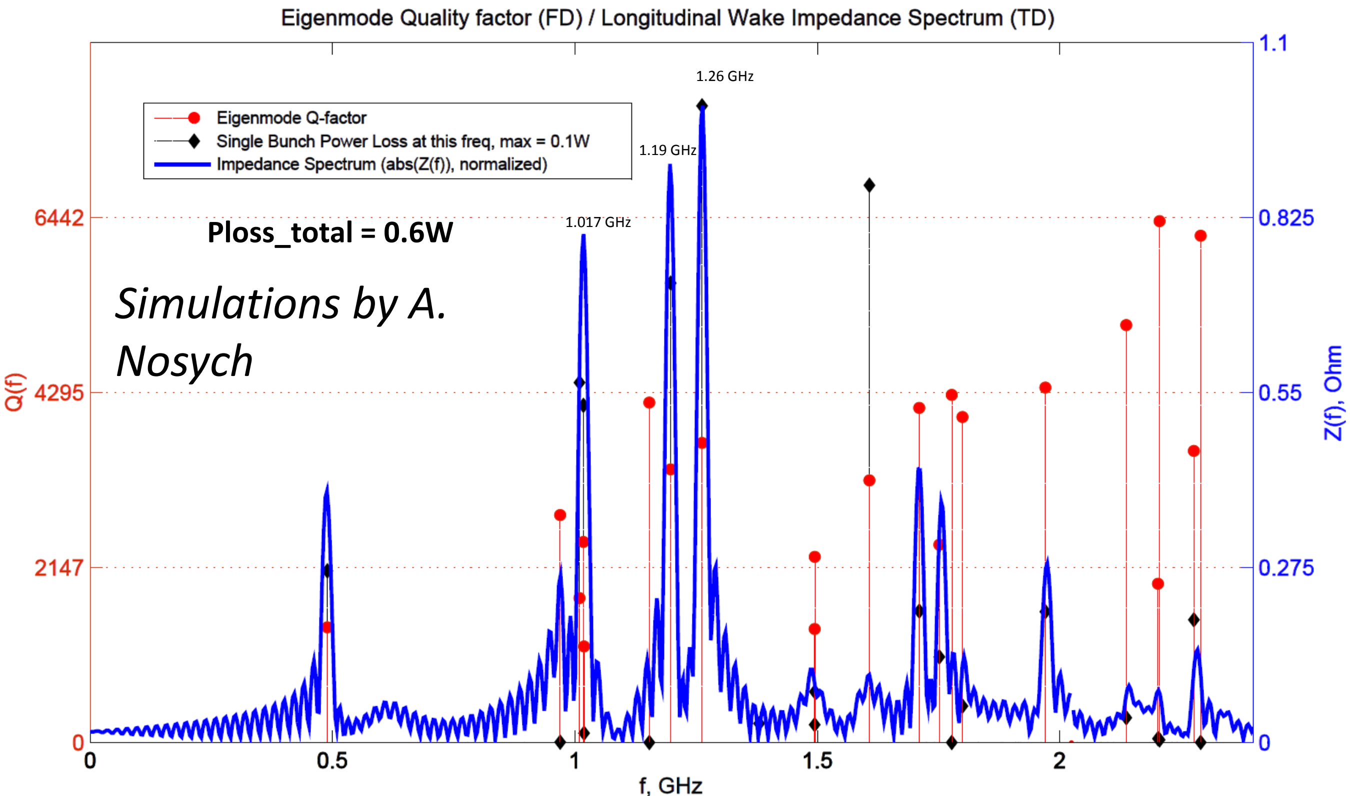


H-field surface tang complex magnitude (Loss map)









Simulations by A. Nosych

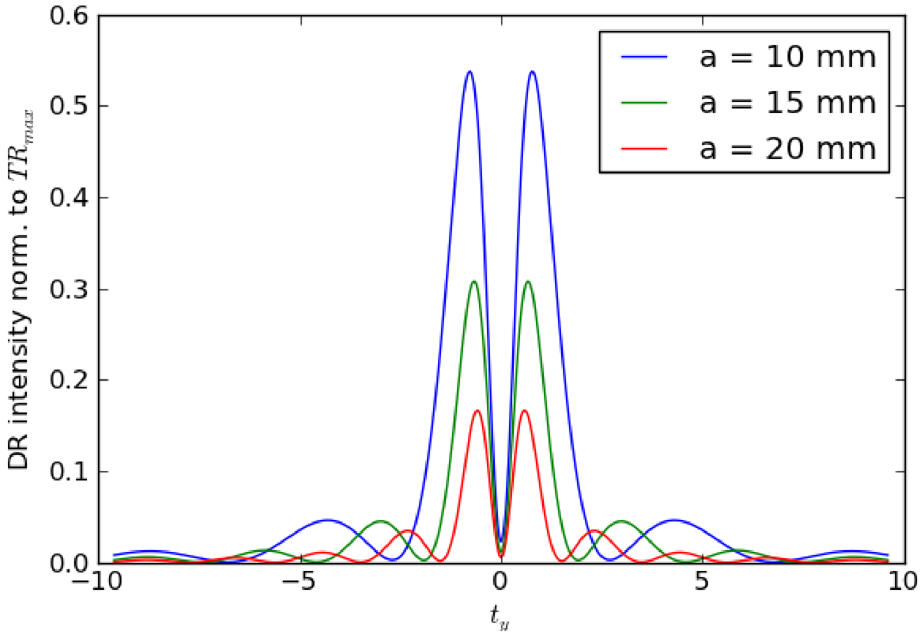
Feasibility of a ring beam size monitor

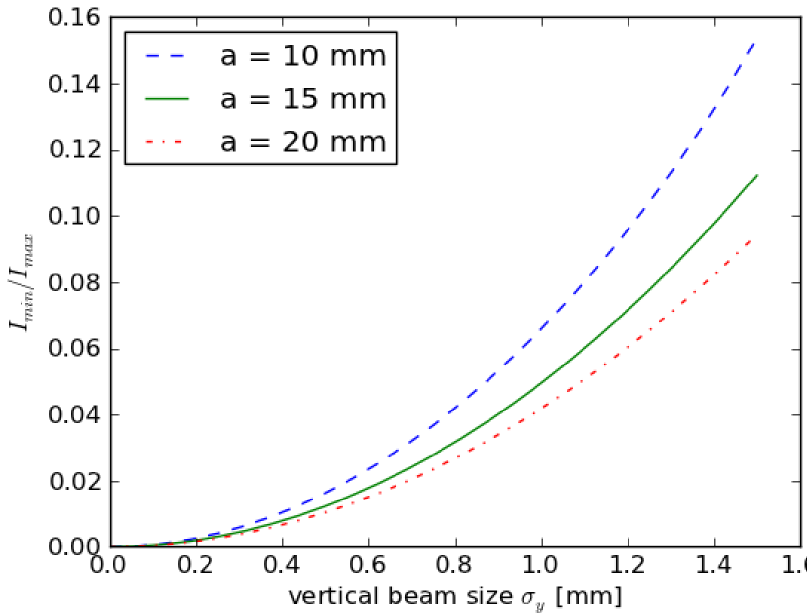
- LHC also has γ ≈ 4000 (@ E = 4000 GeV)
- Using proton beam:
  - Reduced SR background
  - Larger beam size
- Wavelengths in the infrared spectral range

Main requirement:
Non- invasive measurement

↓

Must use large target aperture

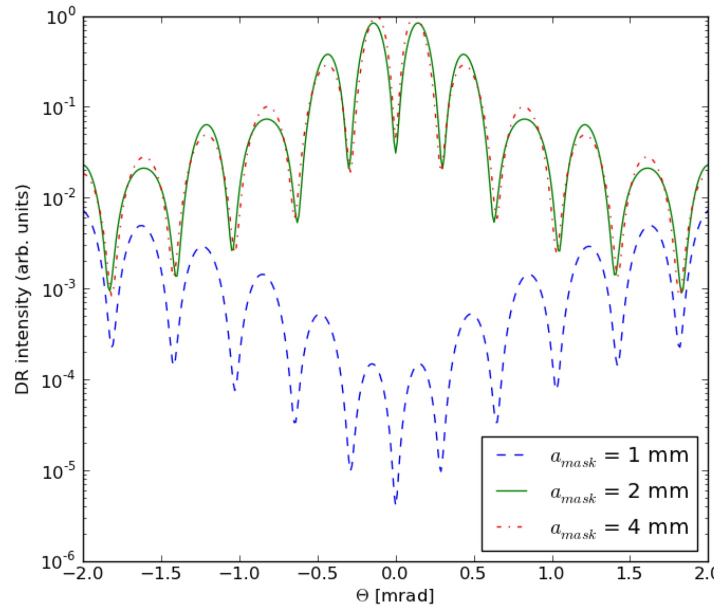




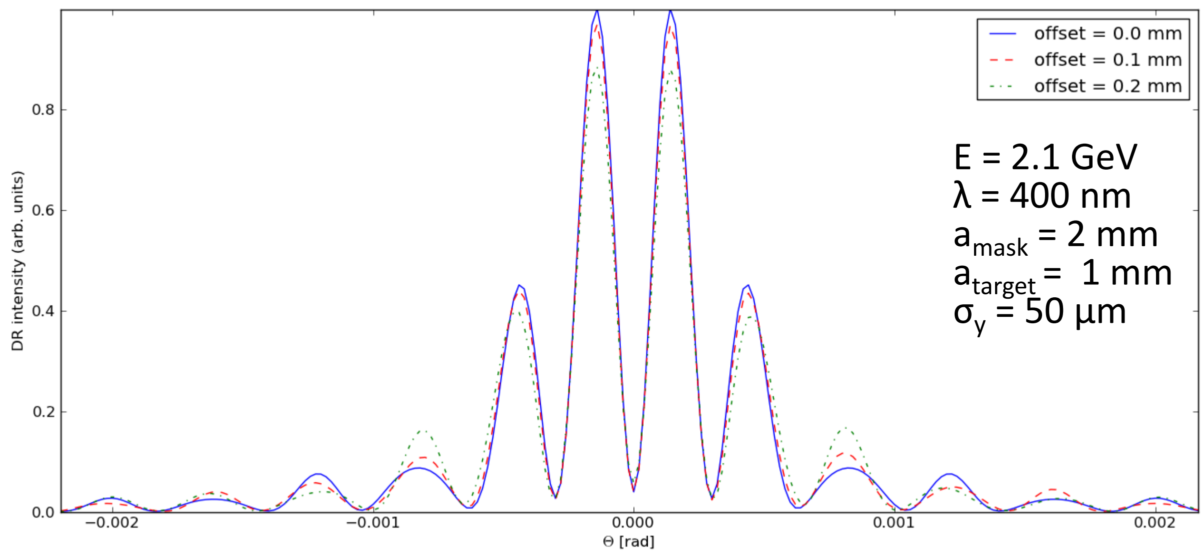
Optical Diffraction Radiation Interference (ODRI)

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)



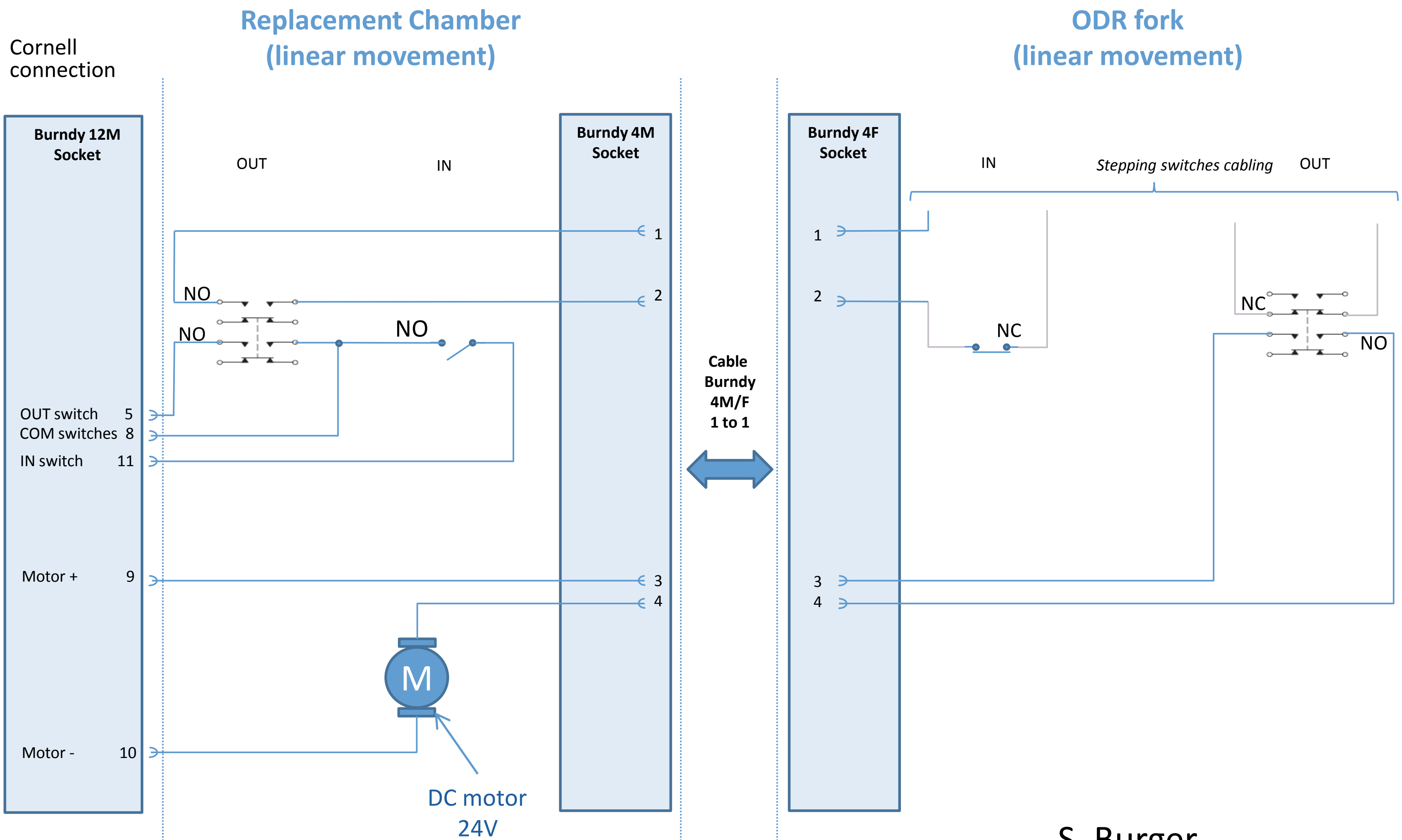
Using non-collinear slits (i.e. centres of mask + target do not coincide) allows measurement of beam size, beam offset from the target centre and angular divergence.



ODR movements

- There are 2 stepping motors:
  - 1x linear movement of the fork
  - 1x angular movement of the fork
- There is 1 DC (+24V) motor that drives a linear movement for the replacement chamber
- The linear (stepping) movement of the fork and the linear (DC) movement of the replacement chamber have to be interlocked one with respect to the other to avoid collision (see next slide)
- Cabling of stepping motors has to be adapted to available driver (unipolar/bipolar) (tests @ CERN were performed with bipolar driver and cabling)

S. Burger



S. Burger

Hardware INTERLOCK logic: ODR fork can not move if replacement chamber not OUT
Replacement chamber can not move if ODR fork not OUT

Interlock ODR movement

(as connected with CERN screen instrumentation 'standard' driver)

Stephane.burger@cern.ch