Small beam size monitoring using OTR and ODR at ATF2

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ATF2 10th Project Meeting, 15 March 2017

1. John Adams Institute at Royal Holloway, Egham, United Kingdom
2. CERN European Organisation for Nuclear Research, Geneva, Switzerland
3. KEK High Energy Accelerator Research Organization, Tsukuba, Japan

Outline

- Project Overview
- ODR/OTR at ATF2
- Optical Transition Radiation (OTR) and results at ATF2
- Optical Diffraction Radiation (ODR)
- Synchrotron Radiation Contribution at ATF2
- ODR results and future plan at ATF2
- Summary

Overview

Motivations and Goals:

- Develop a non-invasive transverse profile station for CLIC/ILC beams that can be scaled up
- Develop, install and test a combined Optical Transition Radiation (OTR) and Optical Diffraction Radiation (ODR) emittance station at ATF2 at High Energy Accelerator Research Organisation (KEK)
- To optimize sensitivity to micron and sub-micron beam sizes, we plan to observe ODR/OTR in the visible and far-UV wavelength range, down to approximately 190 nm

Overview

Manpower		
RHUL	P. Karataev	Scientific coordination Beam tests
	M. Bergamaschi	Simulation, Beam test, Instrumentation
	K. Kruchinin	Beam test, Instrumentation
CERN	R. Kieffer	Beam test, Instrumentation
	S. Mazzoni	Overall coordination Beam test
	T. Lefevre	
KEK	A. Aryshev	Beam test

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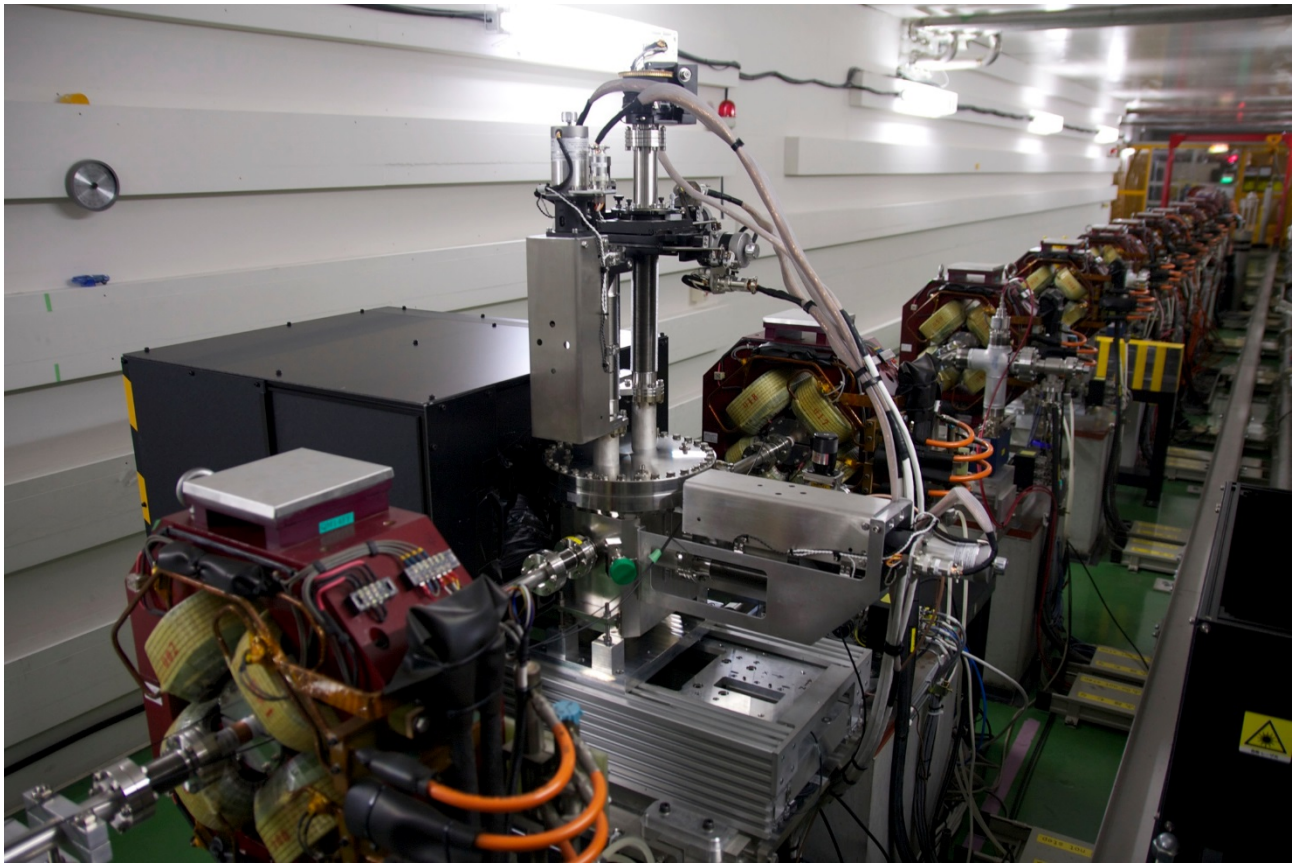
OTR-ODR experiment at KEK ATF2

Experiment installed at ATF2 in February 2016, in the laser-wire previous location where vertical beam can be focused to < 1um



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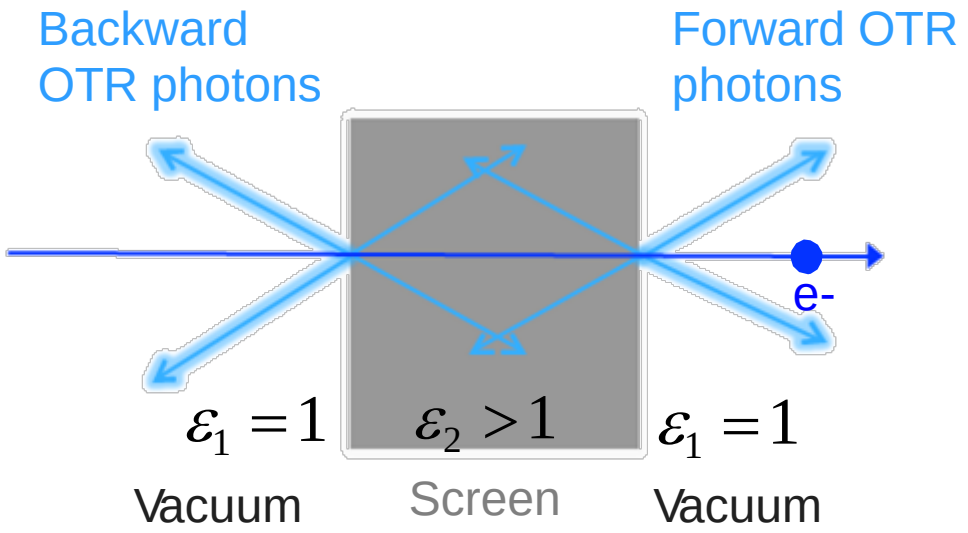
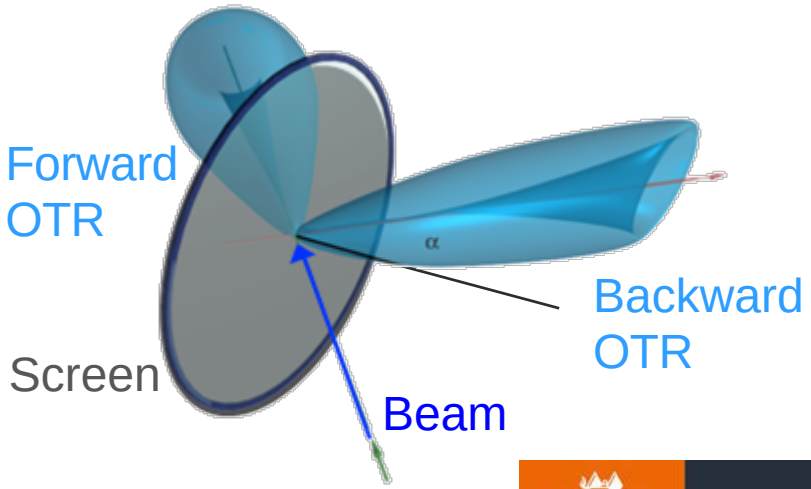
Optical Transition Radiation (OTR)

As predicted in 1946 by Frank and Ginzburg[1], **Optical Transition Radiation** is a broadband electromagnetic field emitted by a relativistic charged particle when it crosses boundary between two mediums of different dielectric constants.

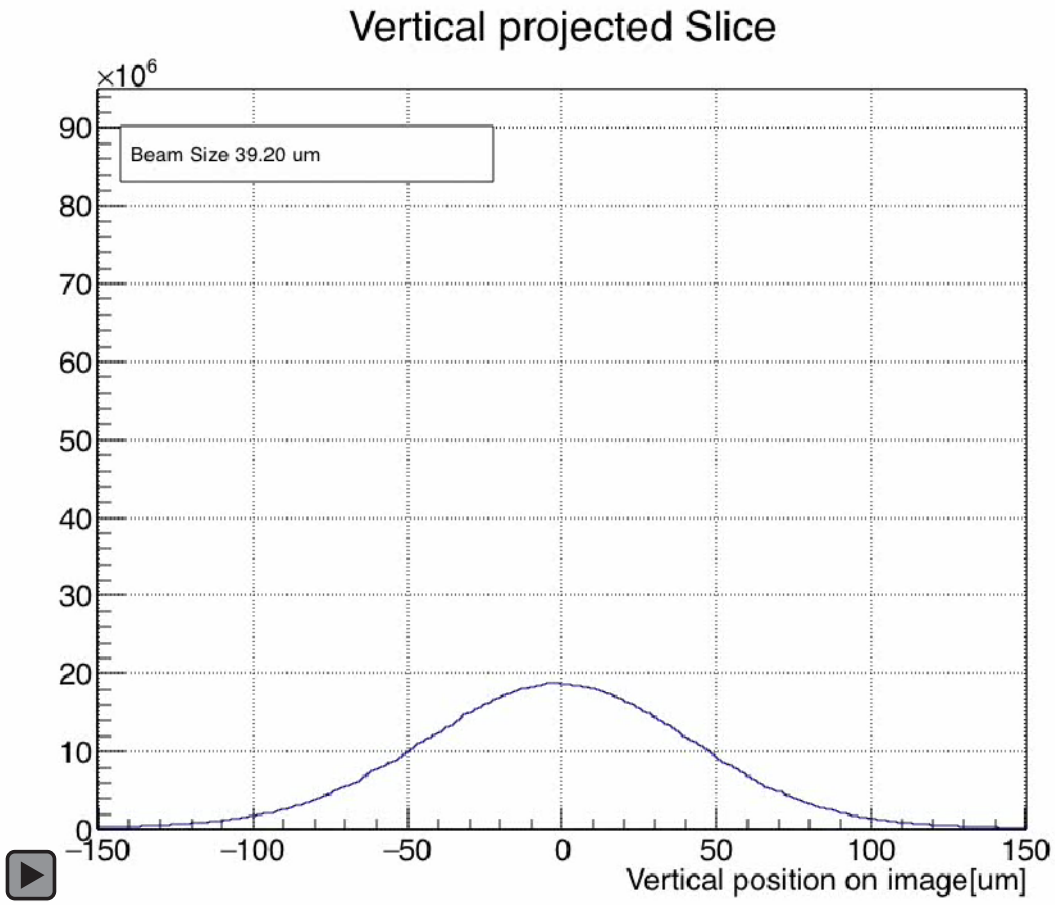


The transverse component of the particle electric field produces surface **polarization currents** on the dielectric target. Target's atoms are polarized, their **relaxation** lead to the emission of OTR photons (femtosecond time response)



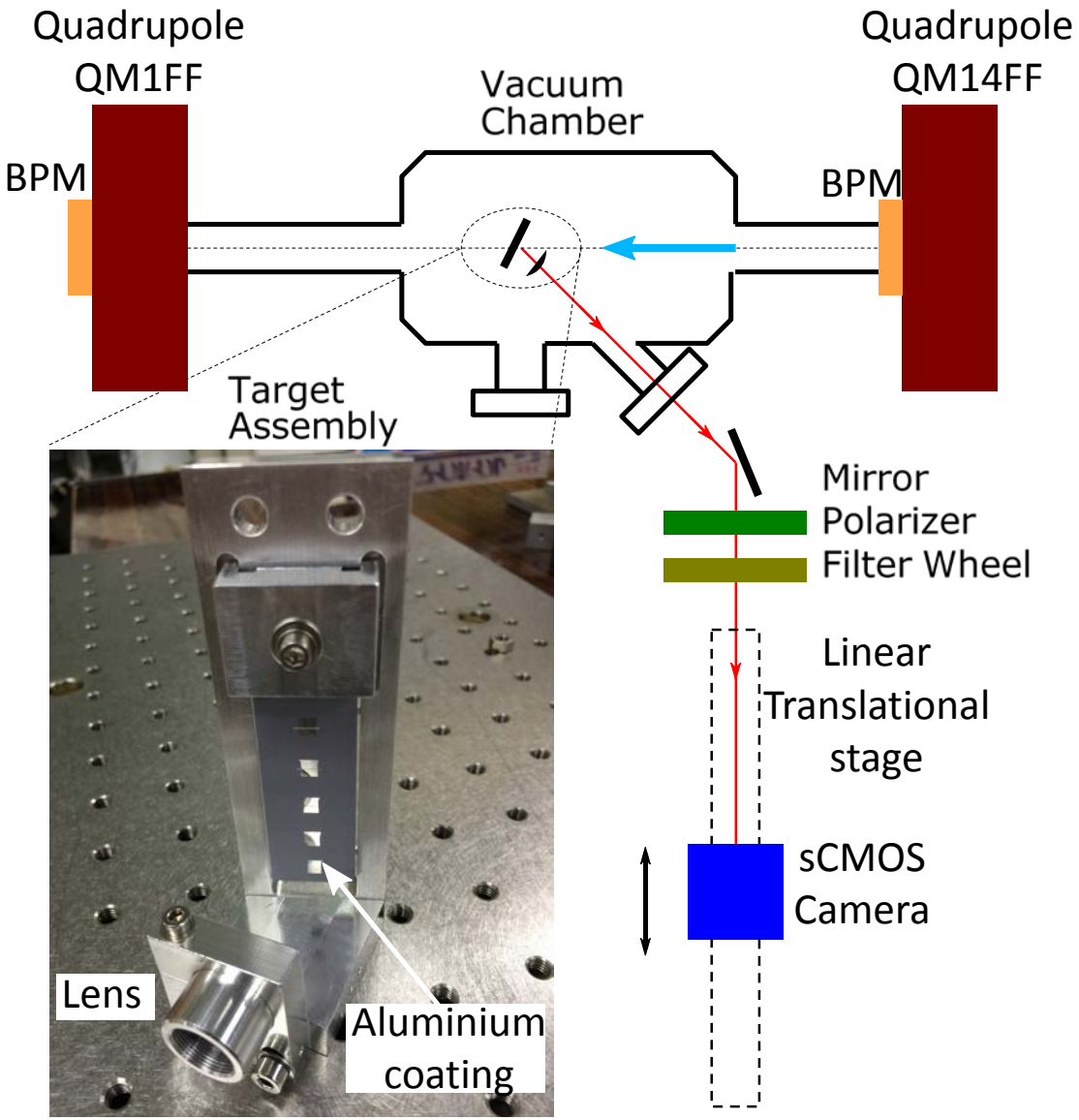
1 V. L. Ginzburg and I. M. Frank, Zh. Éksp. Teor. Fiz. **16**, 15 (1946); J. Phys. (Moscow) **9**, 353 (1945)

OTR Point Spread Function (PSF) for beam size measurement

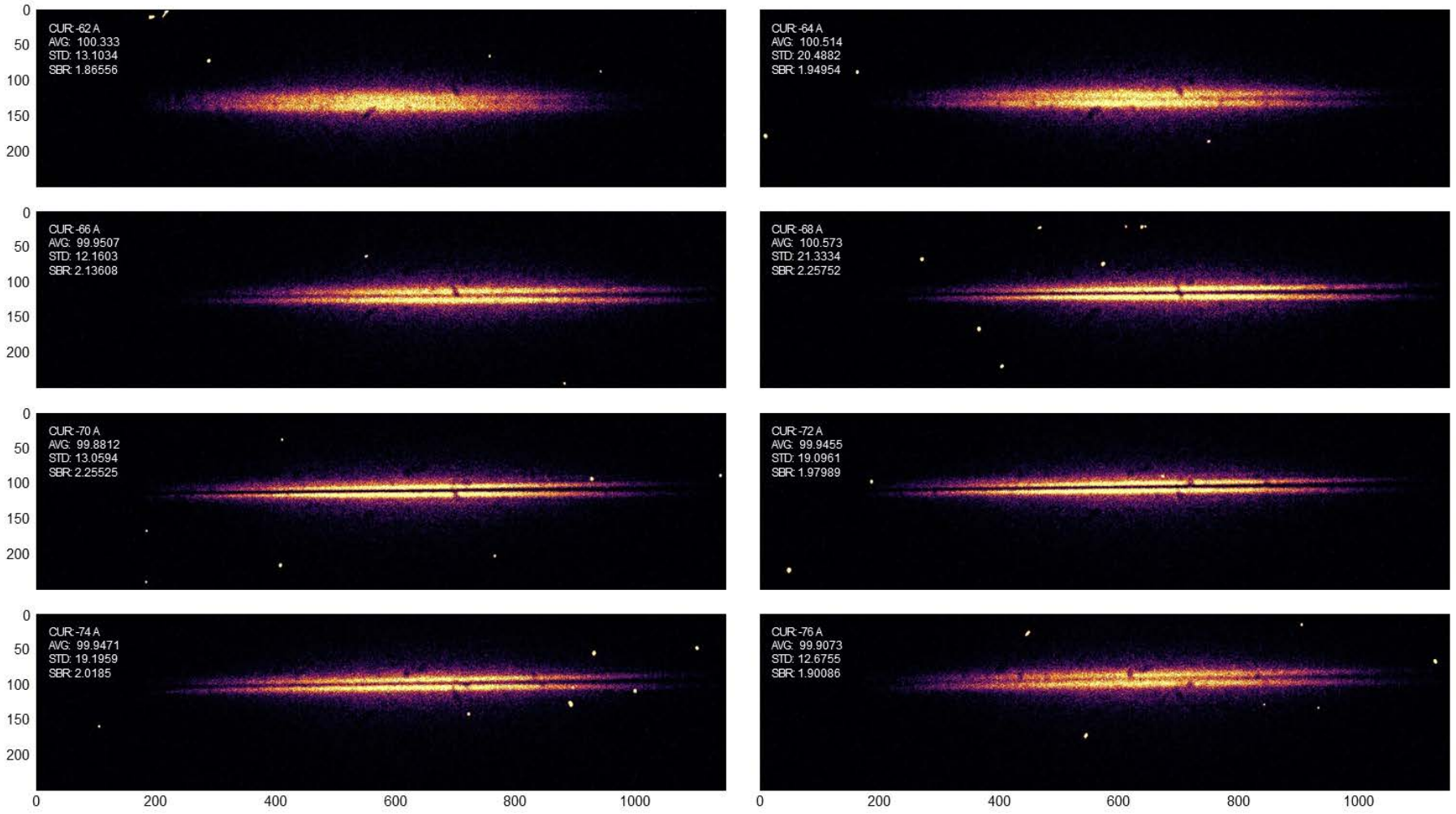


A Gaussian fit works fine down to approximately 10 microns beam size.
As the beam size decreases, the projected OTR vertical polarization component is dominated by the point spread function PSF of the OTR => smaller beam sizes using the visibility (Imin/Imax)

OTR experiment at ATF2

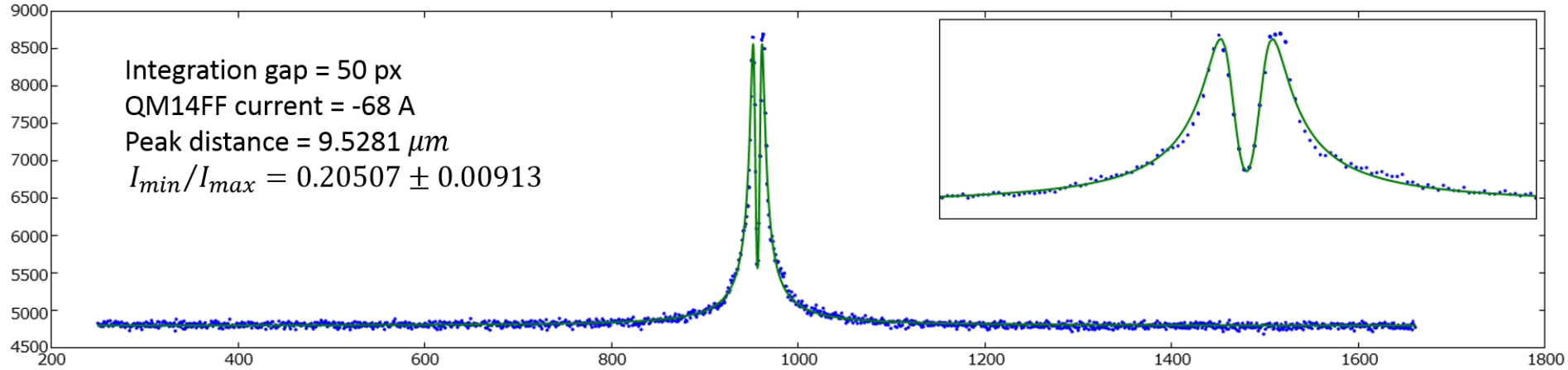


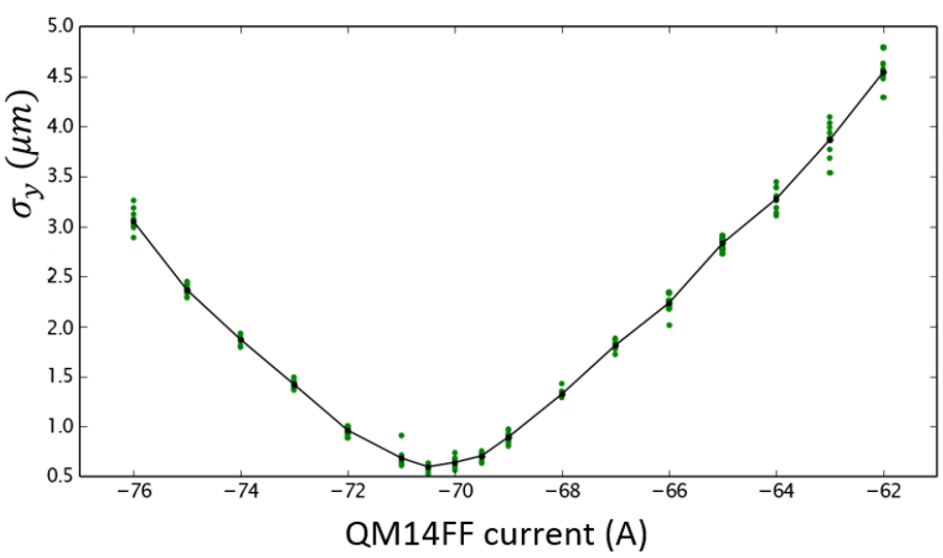
OTR beam size measurement at ATF2

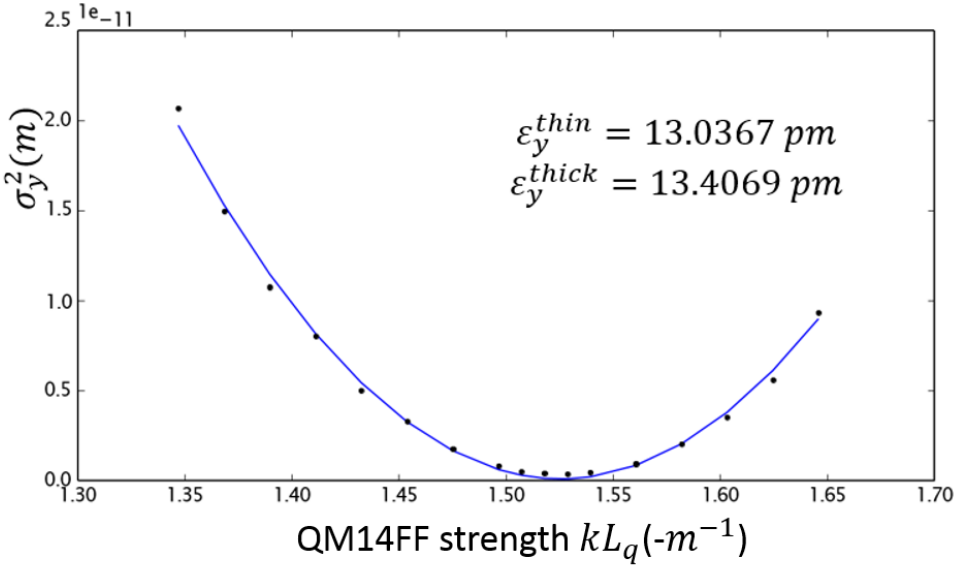


OTR images for different value of QM14FF current => PSF sensitivity to different beam sizes

OTR beam size measurement at ATF2



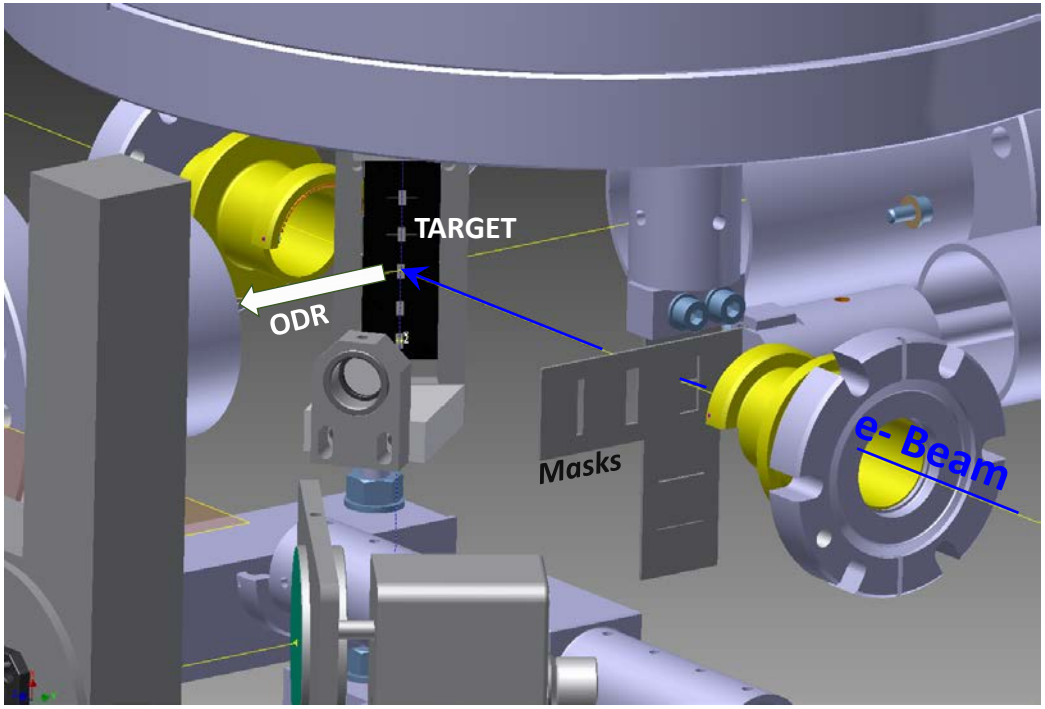


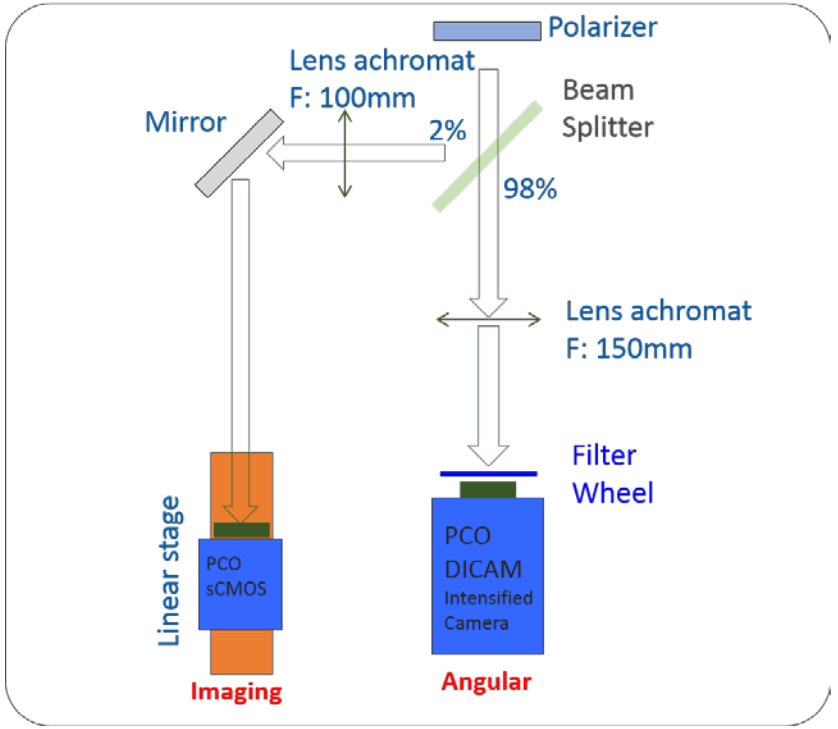


Smallest beam size measured 600nm, **emittance** calculated with quadrupole scan and thin lens approximation **13.034 pm**

ODR experiment at ATF2

- The **target** as **4 slits for ODR (81 to 327um)**
- A couple of vertical and horizontal **mask slits** can be inserted 12.5cm upstream the target

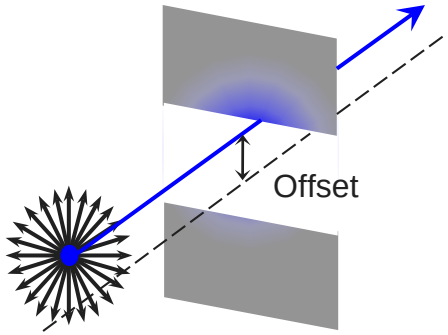


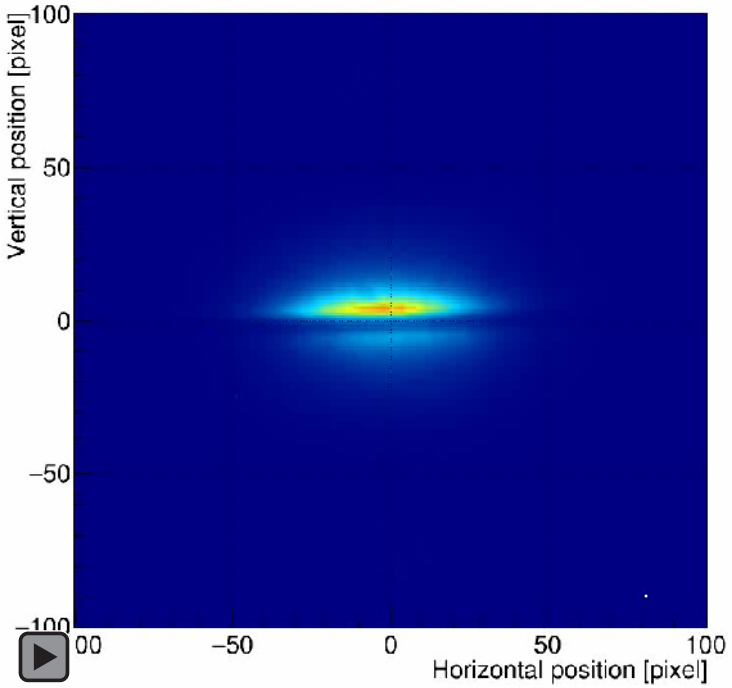


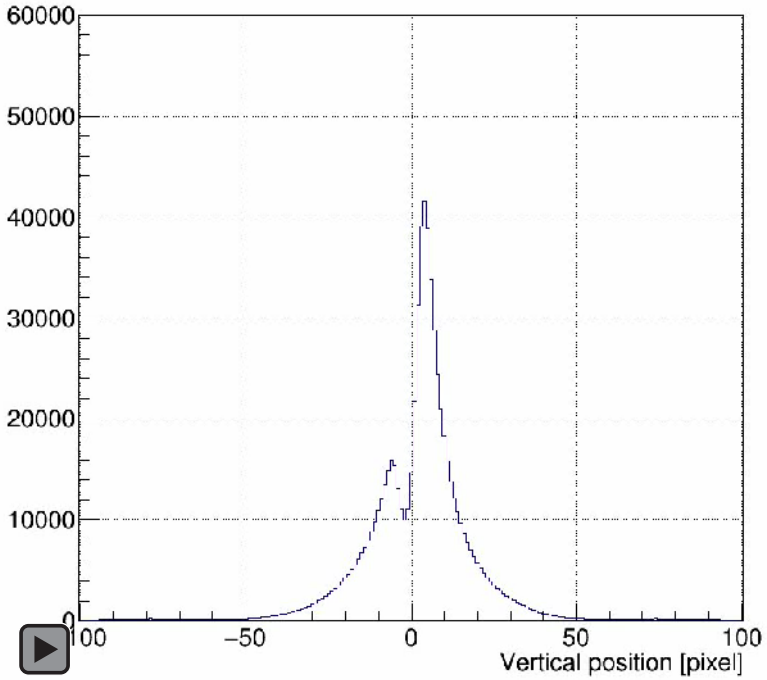
Synchronous Imaging and Angular acquisition for position filtering in angular

ODR in imaging

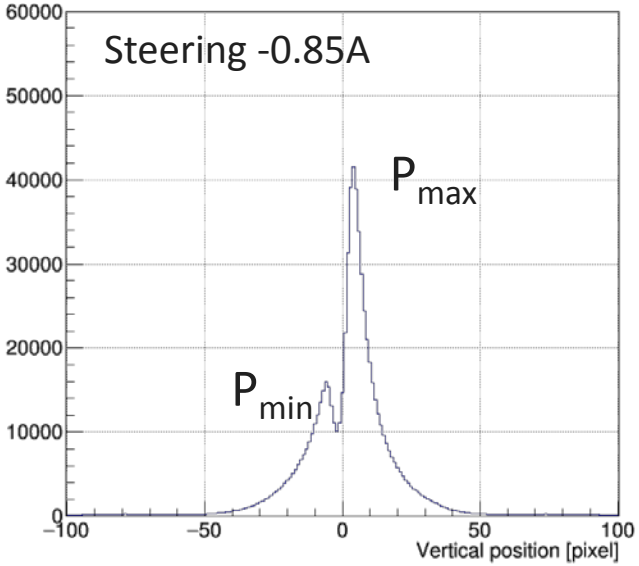
There is **no visible beam size dependency** of the pattern in **imaging**.
But the **vertical position** into the slit change the profile **asymmetry** => **Optical Beam Position Monitor (BPM)**

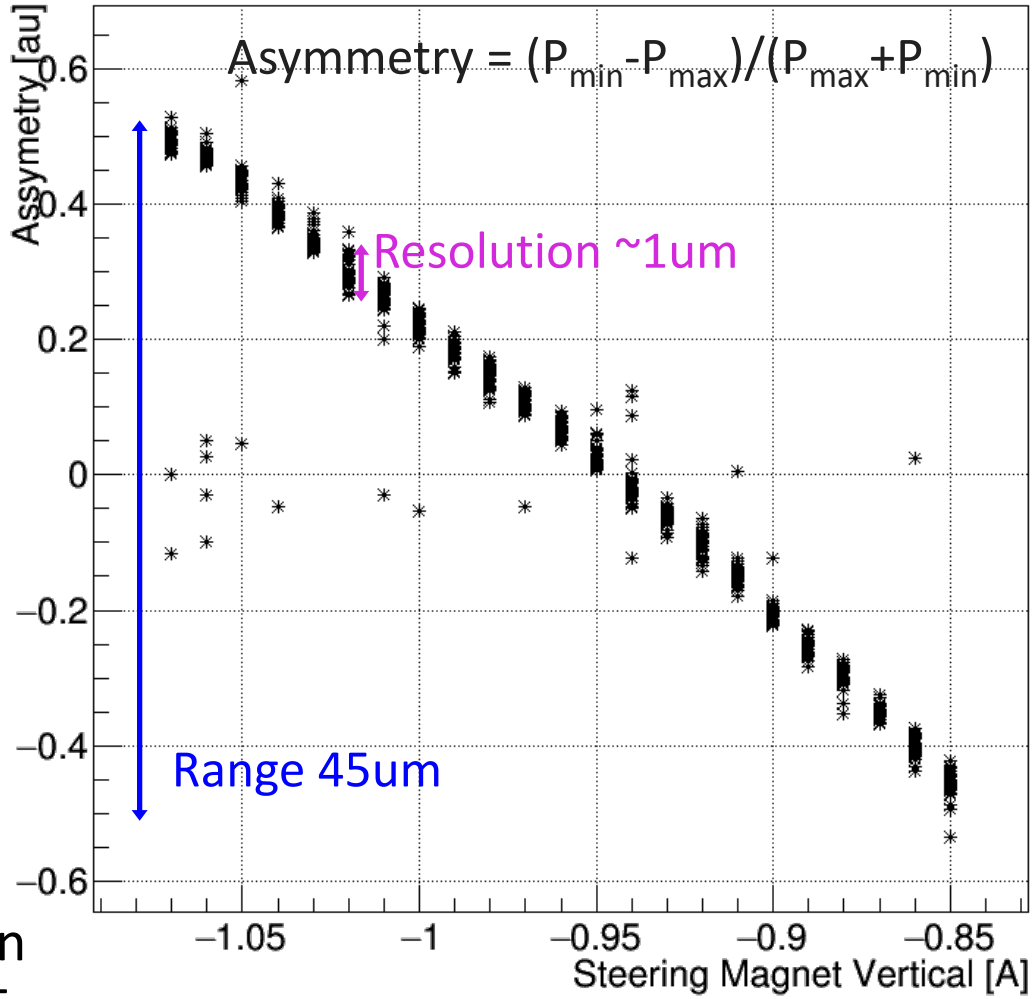






ODR imaging as an optical BPM

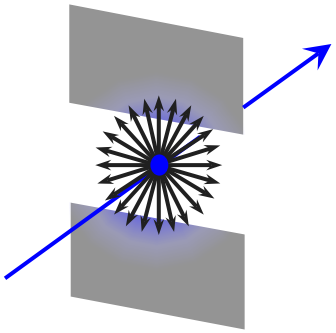


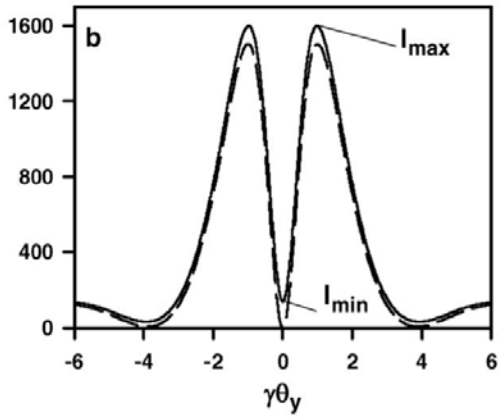


- Slit: **56um**
- Beam size: **1um**
- 30 shots statistics
- **Position resolution: about 1um**
- Steering magnet to scan the beam inside the slit

ODR for beam size measurements

The **beam size** is extracted from the **visibility I_{min}/I_{max}** of the projected vertical component of the ODR **angular distribution**

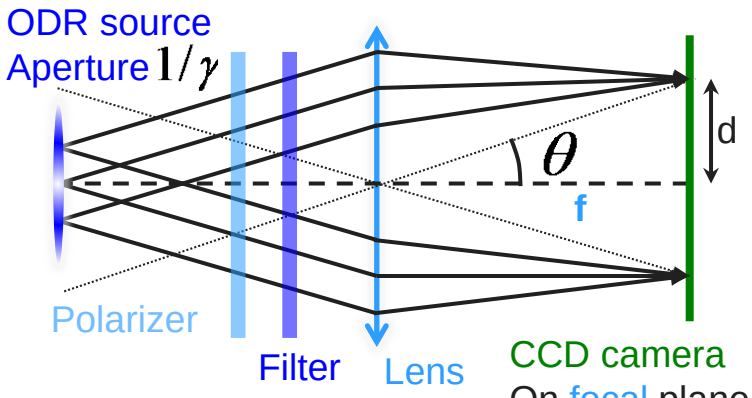




An **horizontal slit** is used to measure a **vertical beam size**.

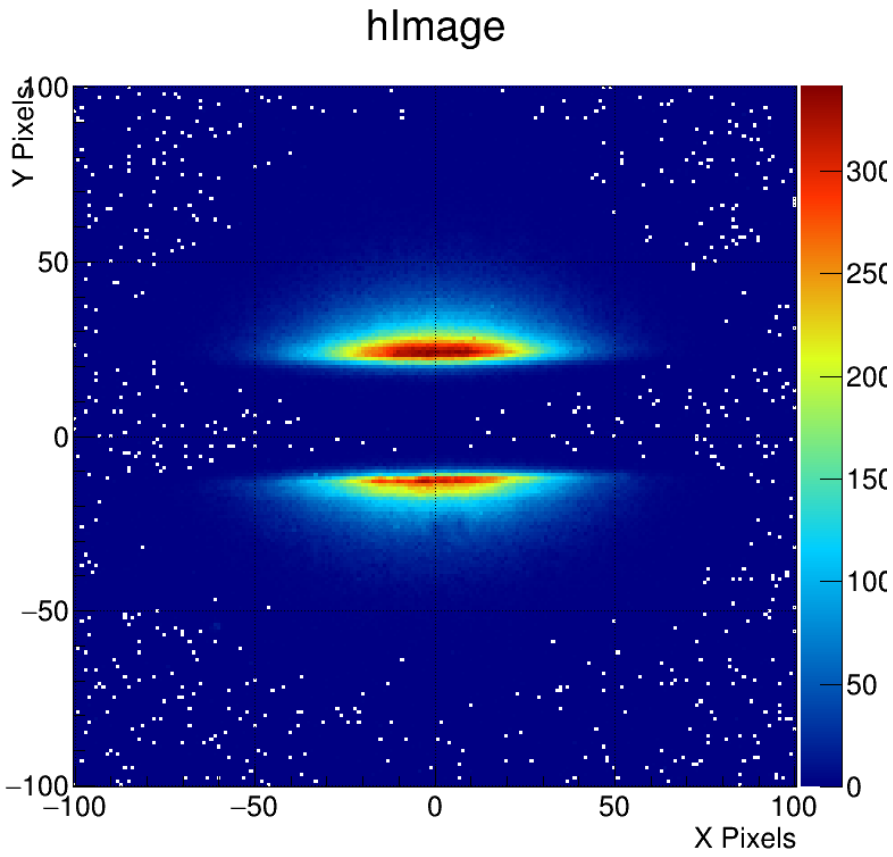
We use a polarizer to select only the **vertically polarized ODR photons** and 40nm BW **filters** to select the **wavelength**

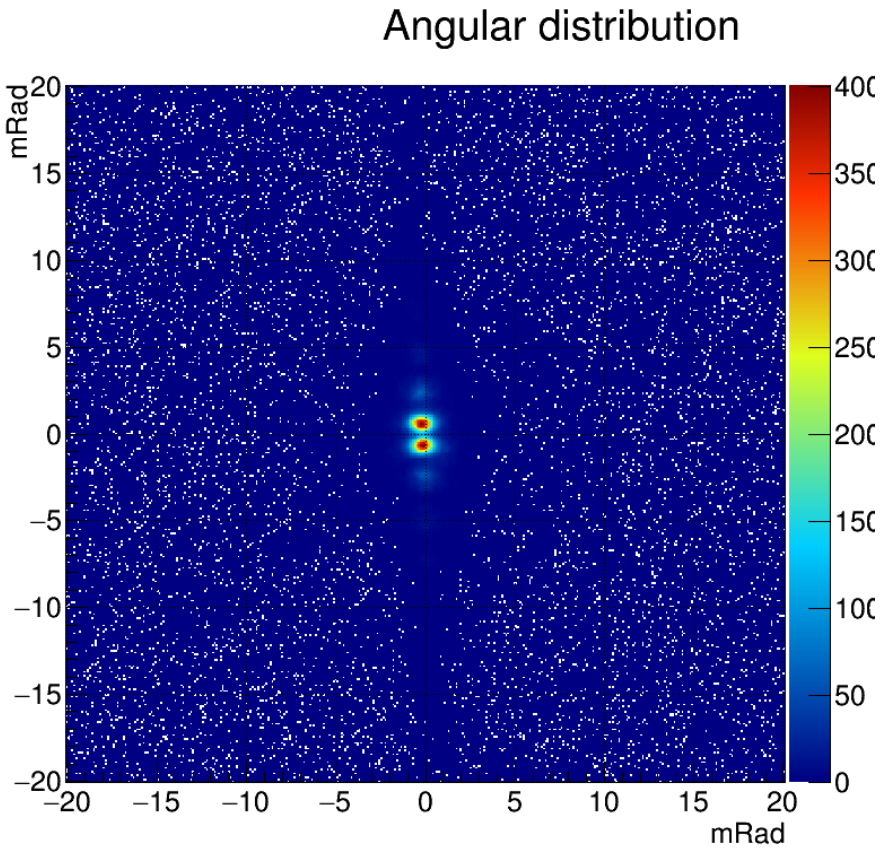
The **angular distribution** is obtained using a camera located at the back focal plane of an optical **lens** (effective infinity)



Angular magnification $\theta = \arctan(d/f)$

ODRI at ATF2 February 2017





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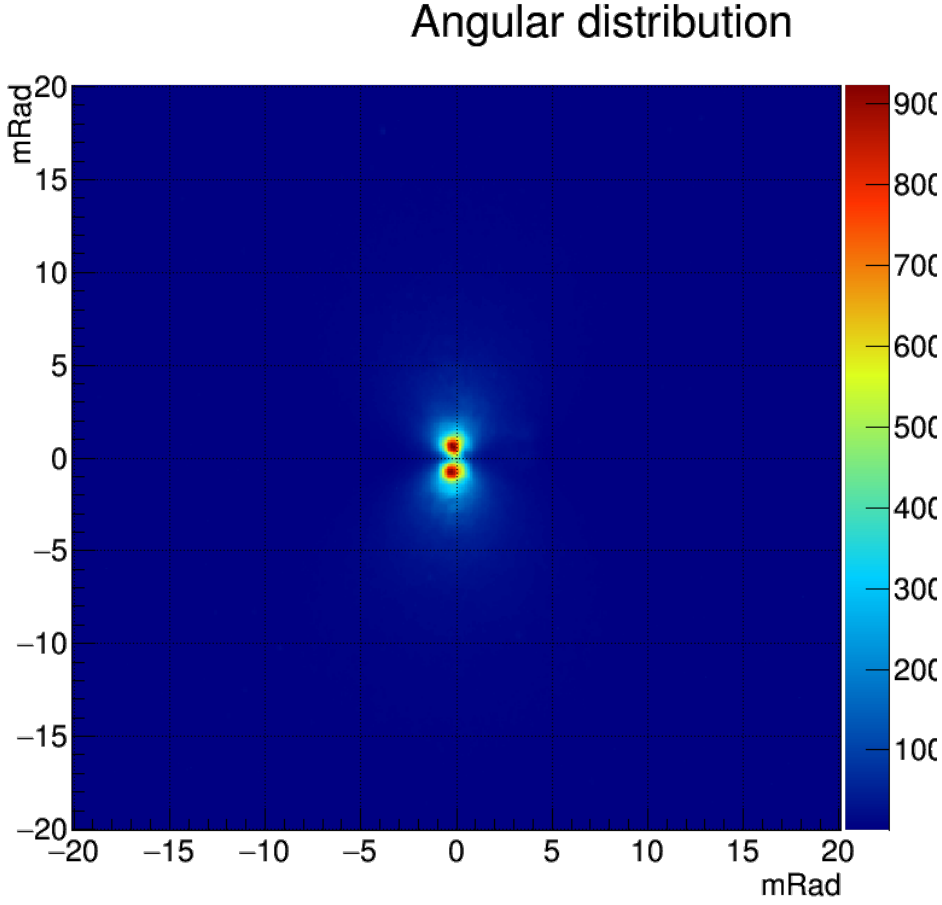
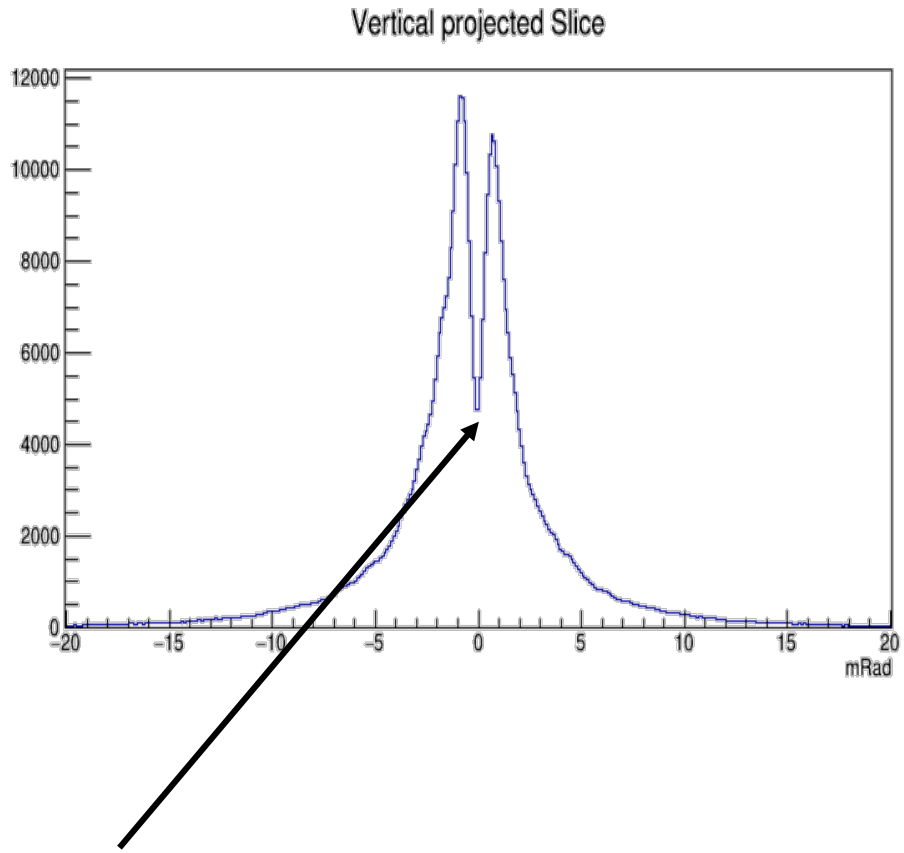
Synchrotron Radiation Contribution at ATF2

Observation of the angular pattern with target in the OTR position with mask inserted to evaluate Synchrotron Radiation Contribution



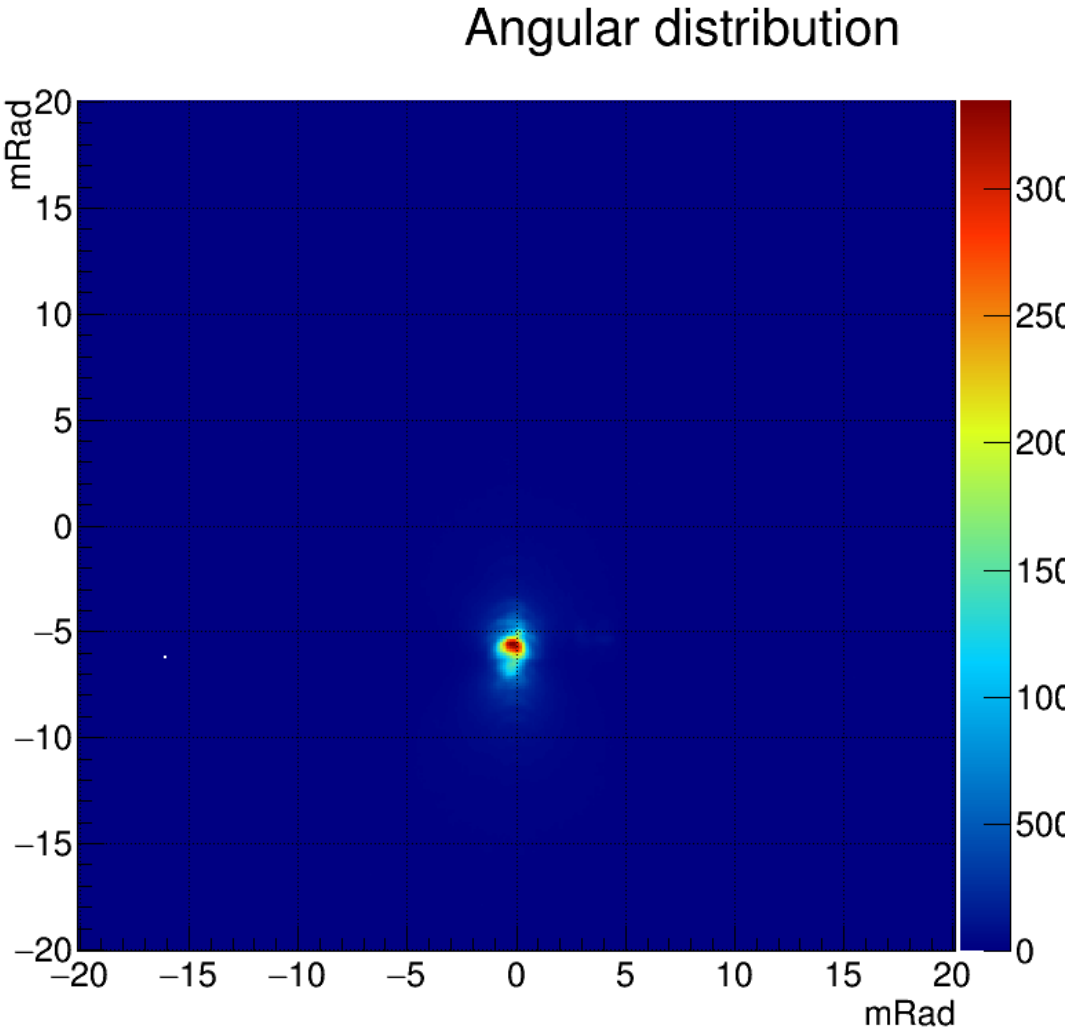


Minimum too high = high SR Contribution

Synchrotron Radiation Contribution at ATF2

OTR Angular pattern with steering magnet off and without mask

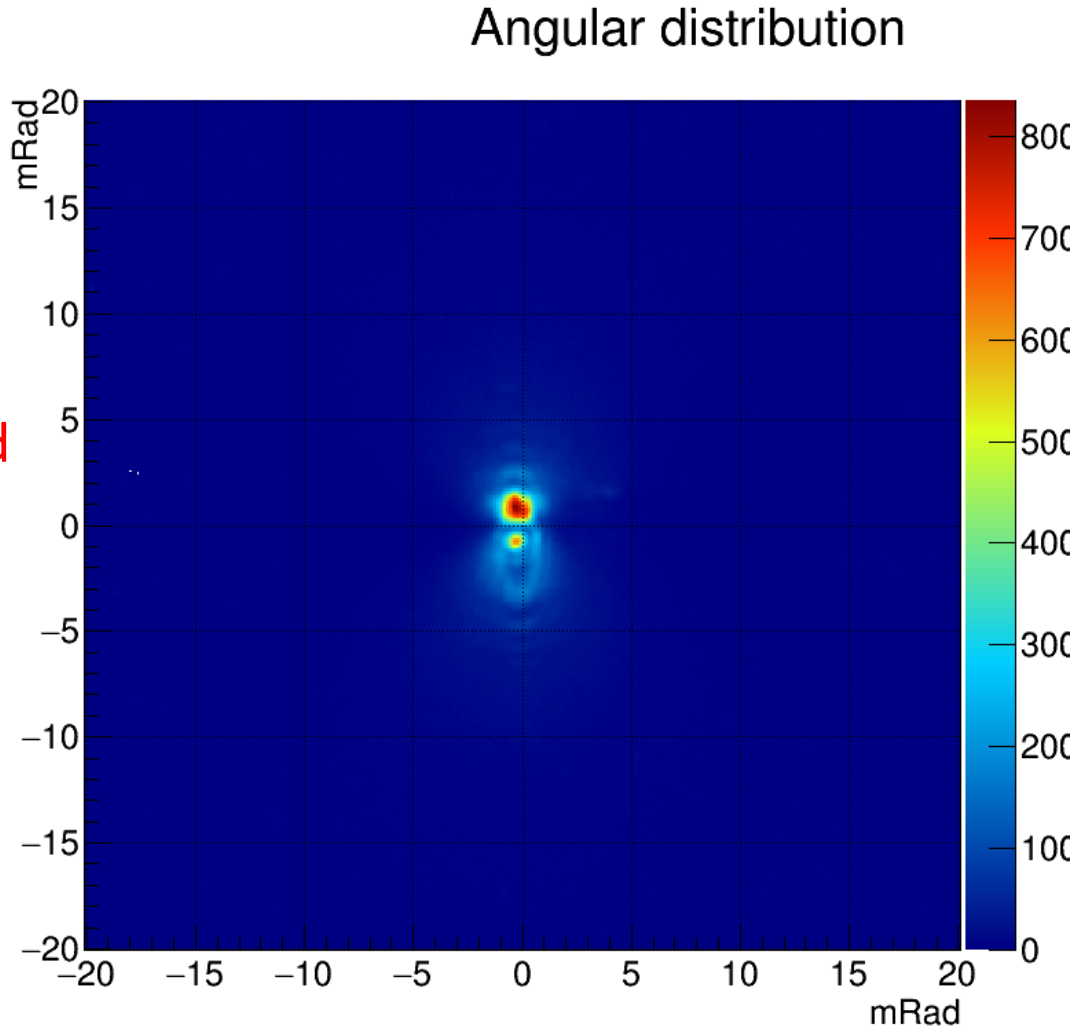
Strong Contribution, impossible to evaluate the TR angular pattern



Synchrotron Radiation Contribution at ATF2

Insertion of the mask (582 µm aperture)

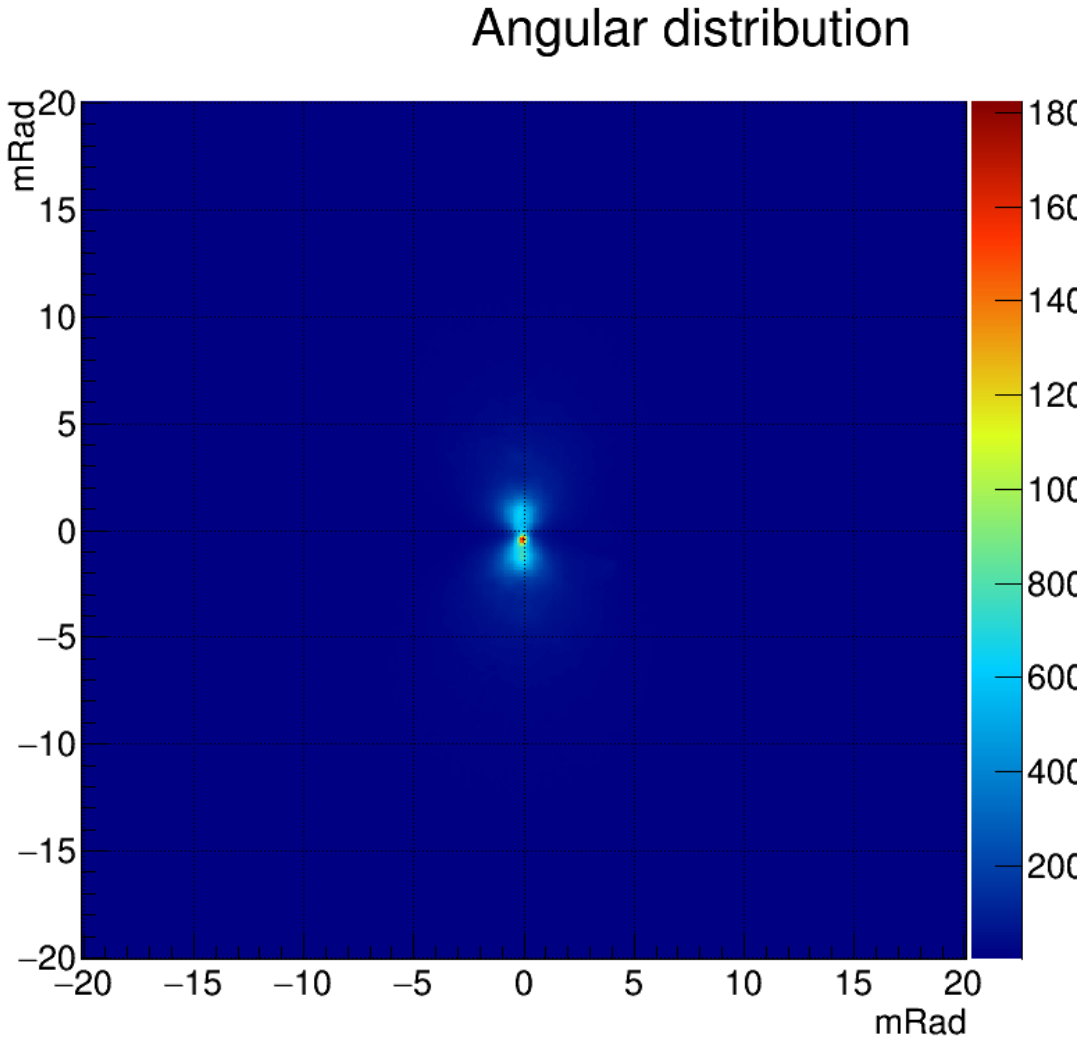
Although mask is inserted there is a strong Interference between Synchrotron Radiation and Transition Radiation because beam is not centered in the quadrupole (QM14FF) before the target.



Synchrotron Radiation Contribution at ATF2

No mask present, Alignment of the quadrupole magnet present before the target (QM14FF)

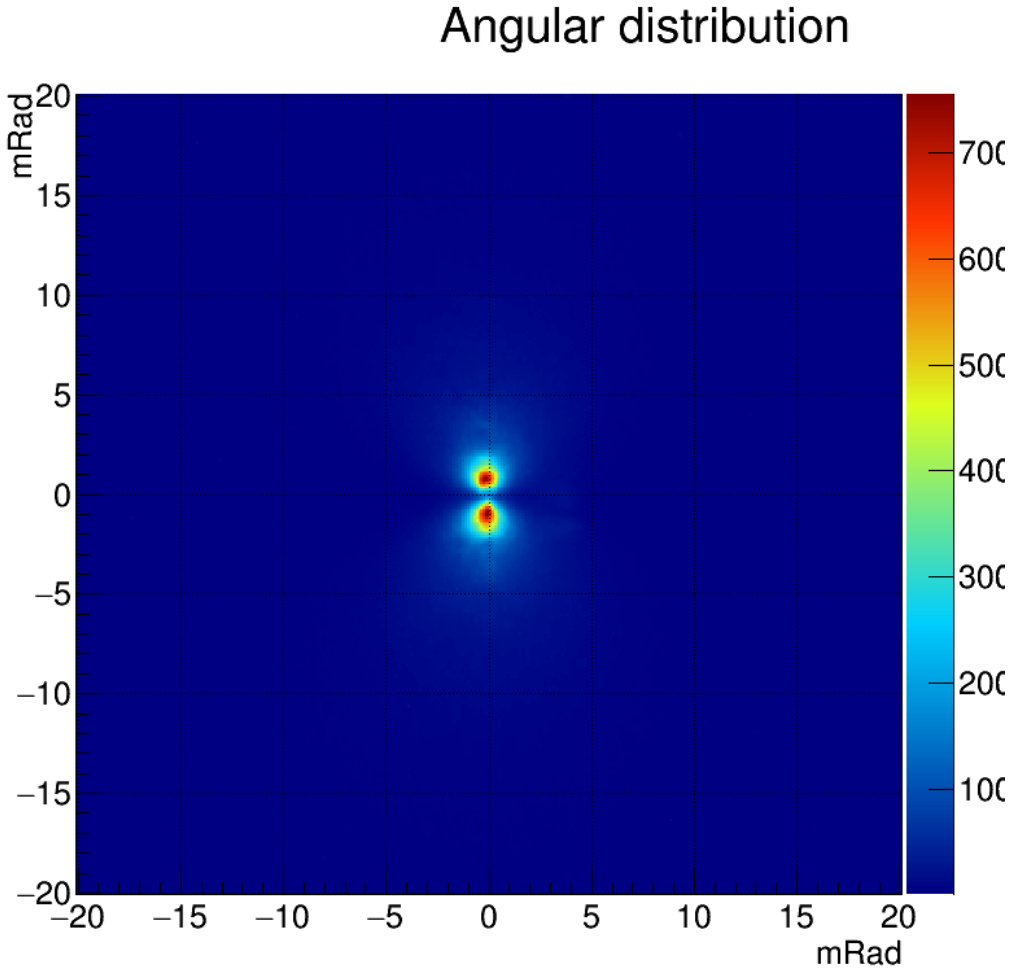
Better profile but peak present in the middle of the pattern due to Synchrotron Radiation generated upstream in the beam-line



Synchrotron Radiation Contribution at ATF2

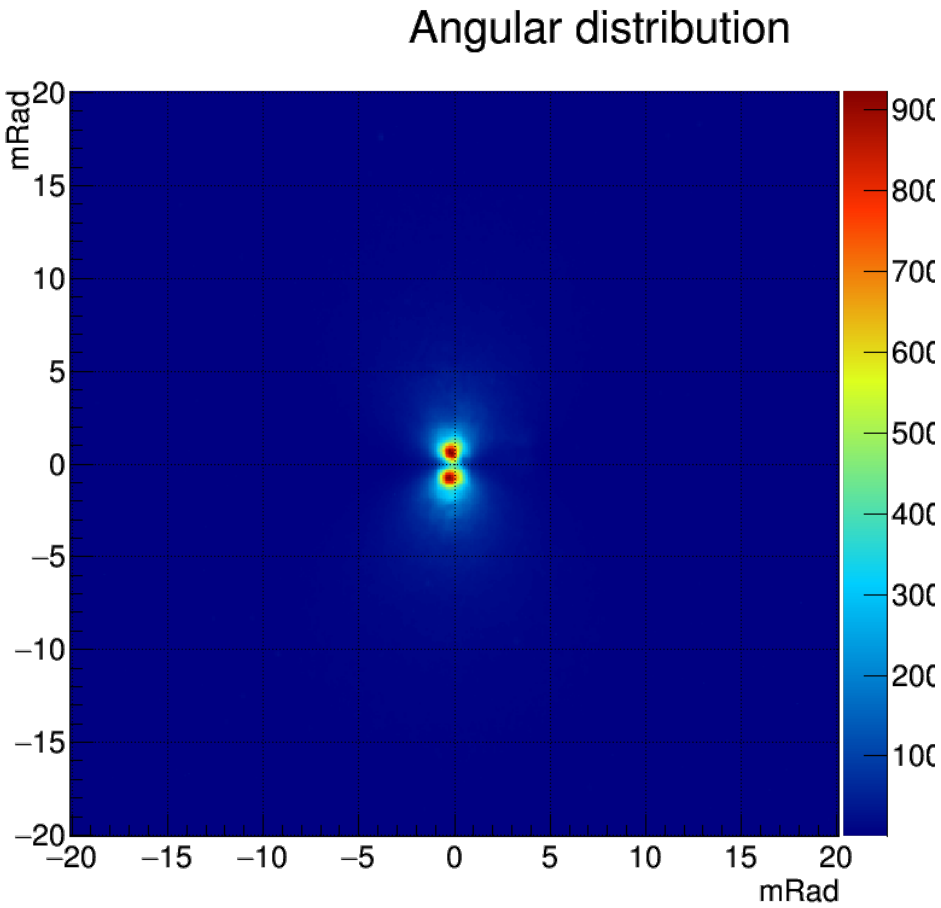
Re insertion of the mask (582 µm)

Maximum reduction of the Synchrotron Radiation Contribution

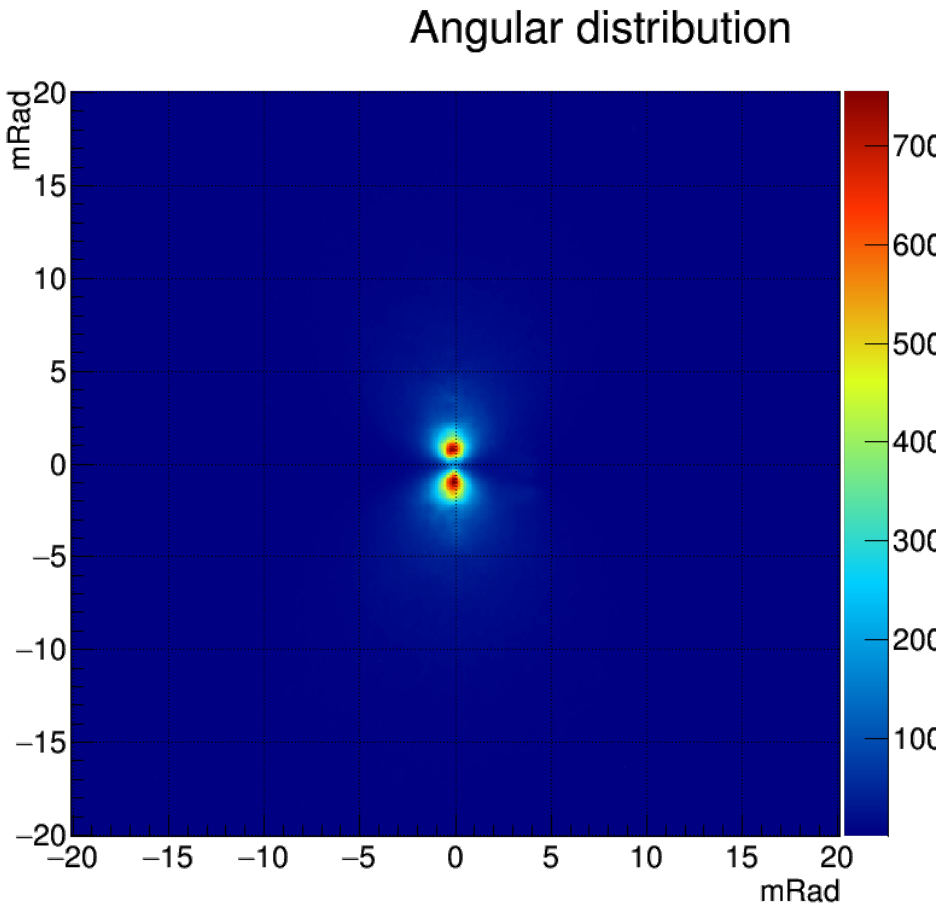


Synchrotron Radiation Contribution at ATF2

Before beam line optimization



After beam line optimization



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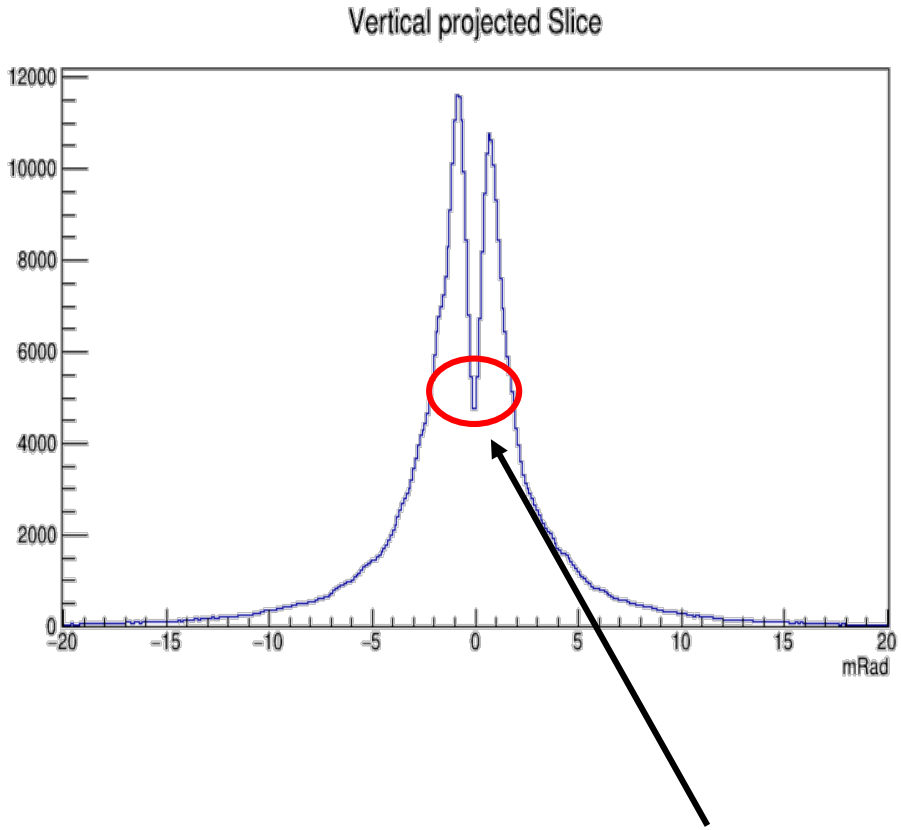
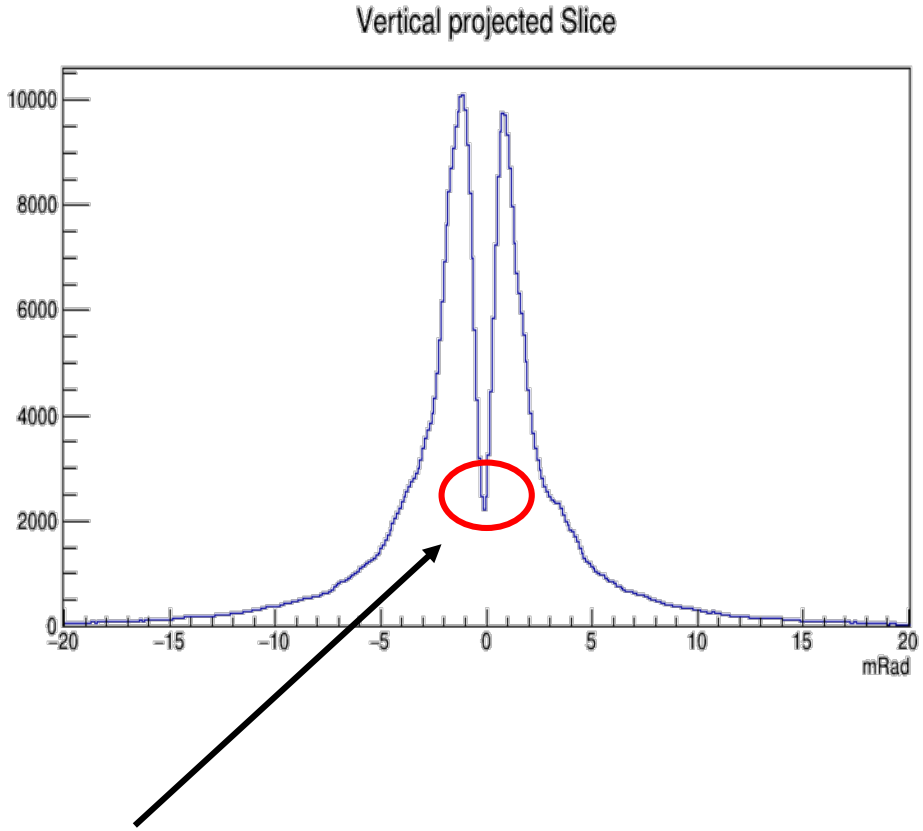
Synchrotron Radiation Contribution at ATF2

Before beam line optimization

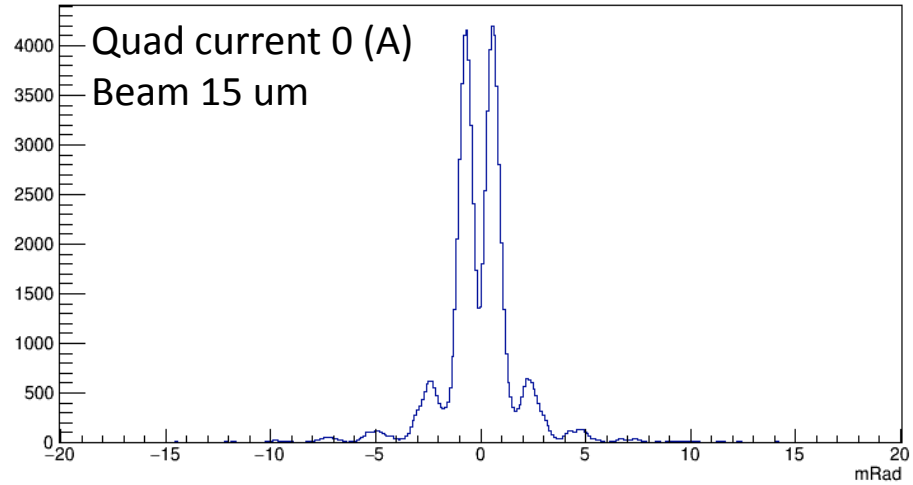


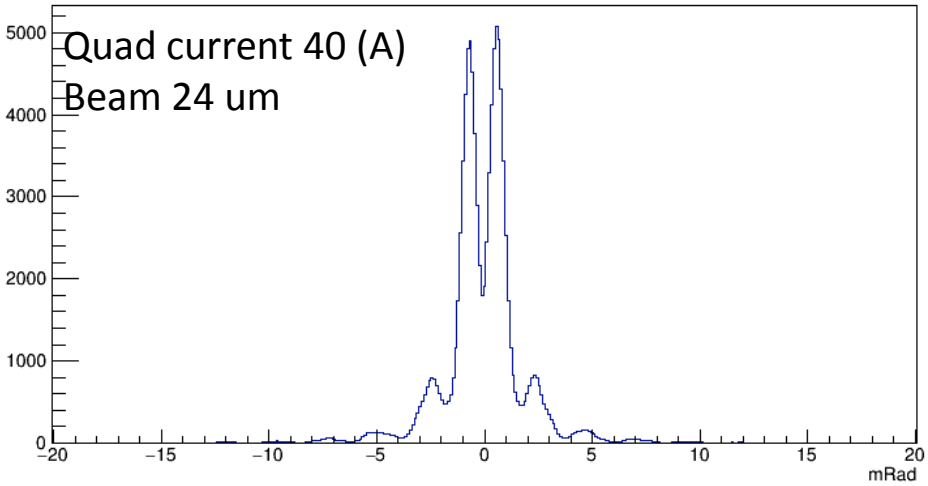
After beam line optimization



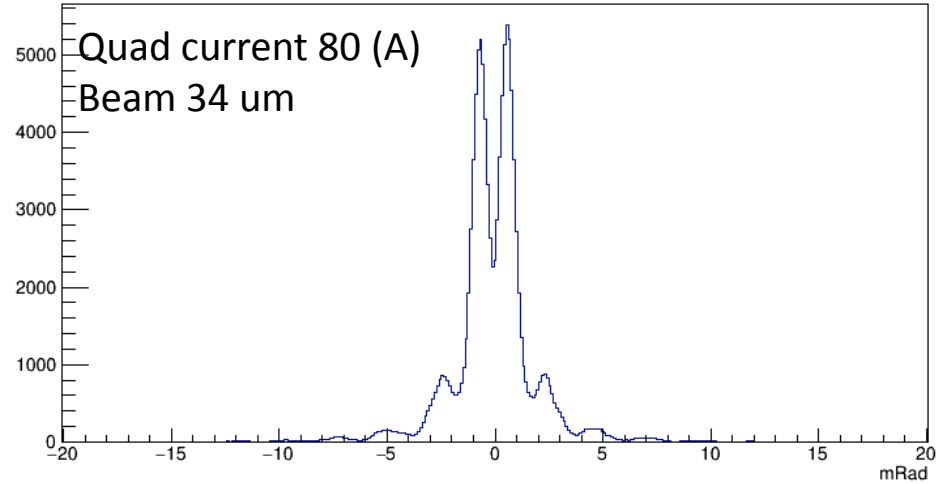
Lower minimum = lower SR Contribution

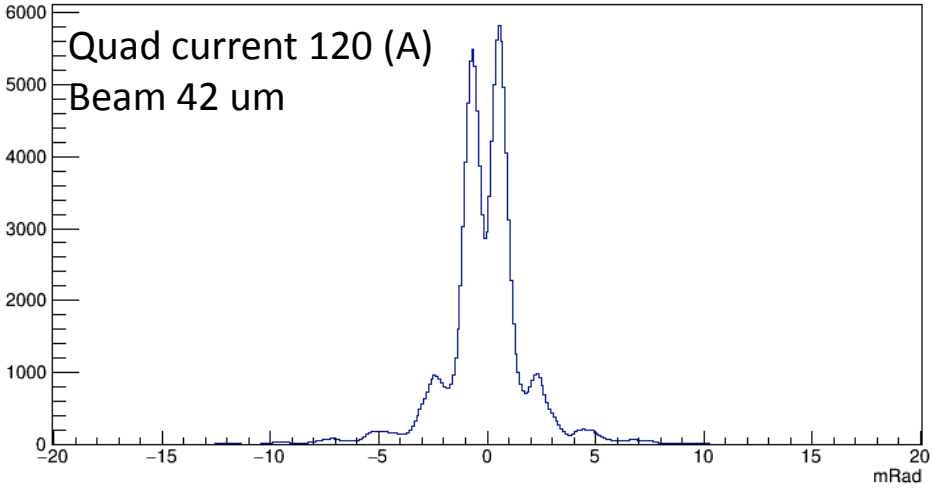
ODR visibility Quad Scan





Visibility = I_{min} / I_{Max}





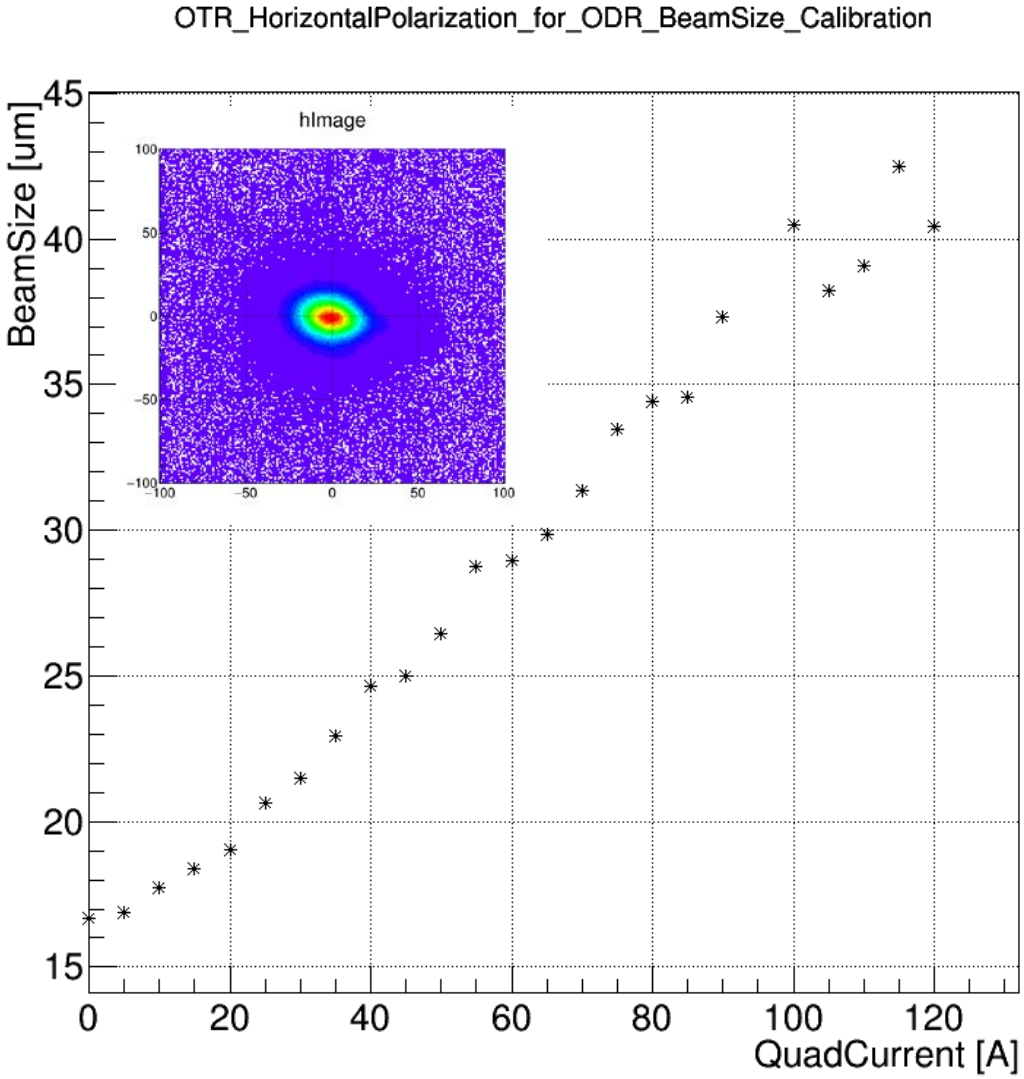
Filter:450nm Slit:201.7 µm Mask: 582 µm

OTR Beam size calibration

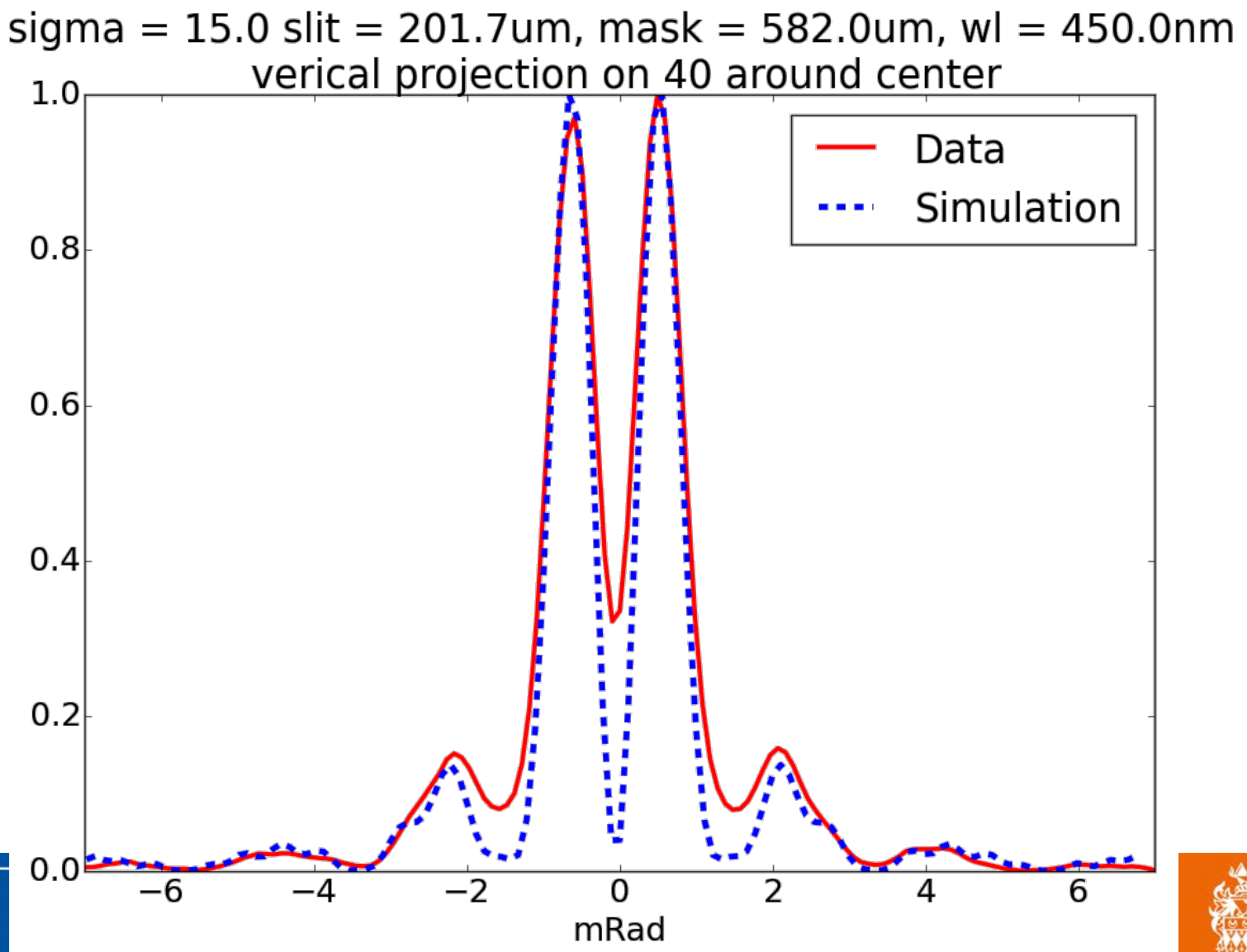
The side mirrors of the ODR slit were used to record reference OTR beam size measurement.

This could be done in CLIC/ILC using pilot beam (no target damage).

Then ODR can then be used for full beam charge.

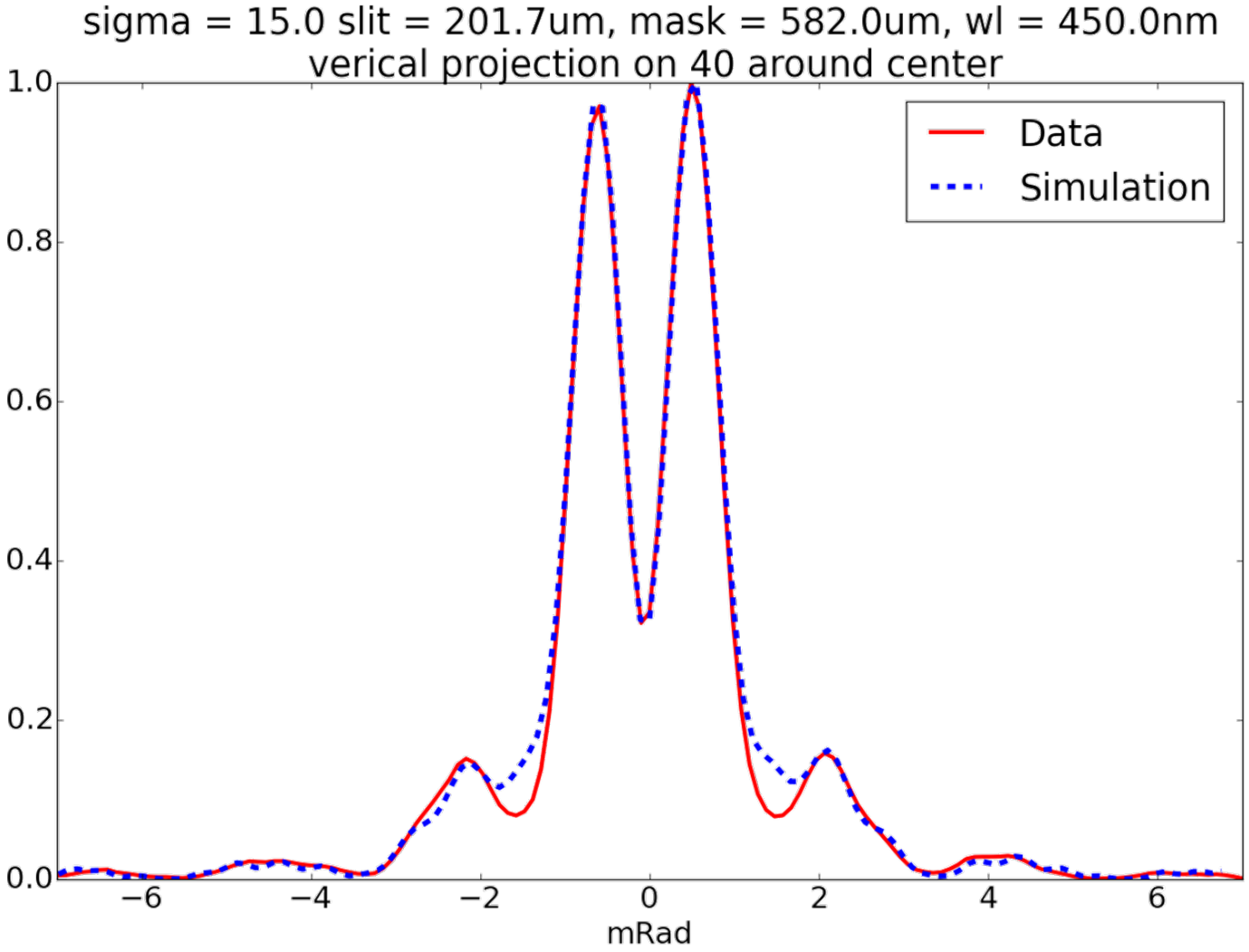


ODR angular data vs simulation



ODR angular data vs simulation

Synchrotron background Gaussian + 6 µm offset in the vertical alignment between slit and mask



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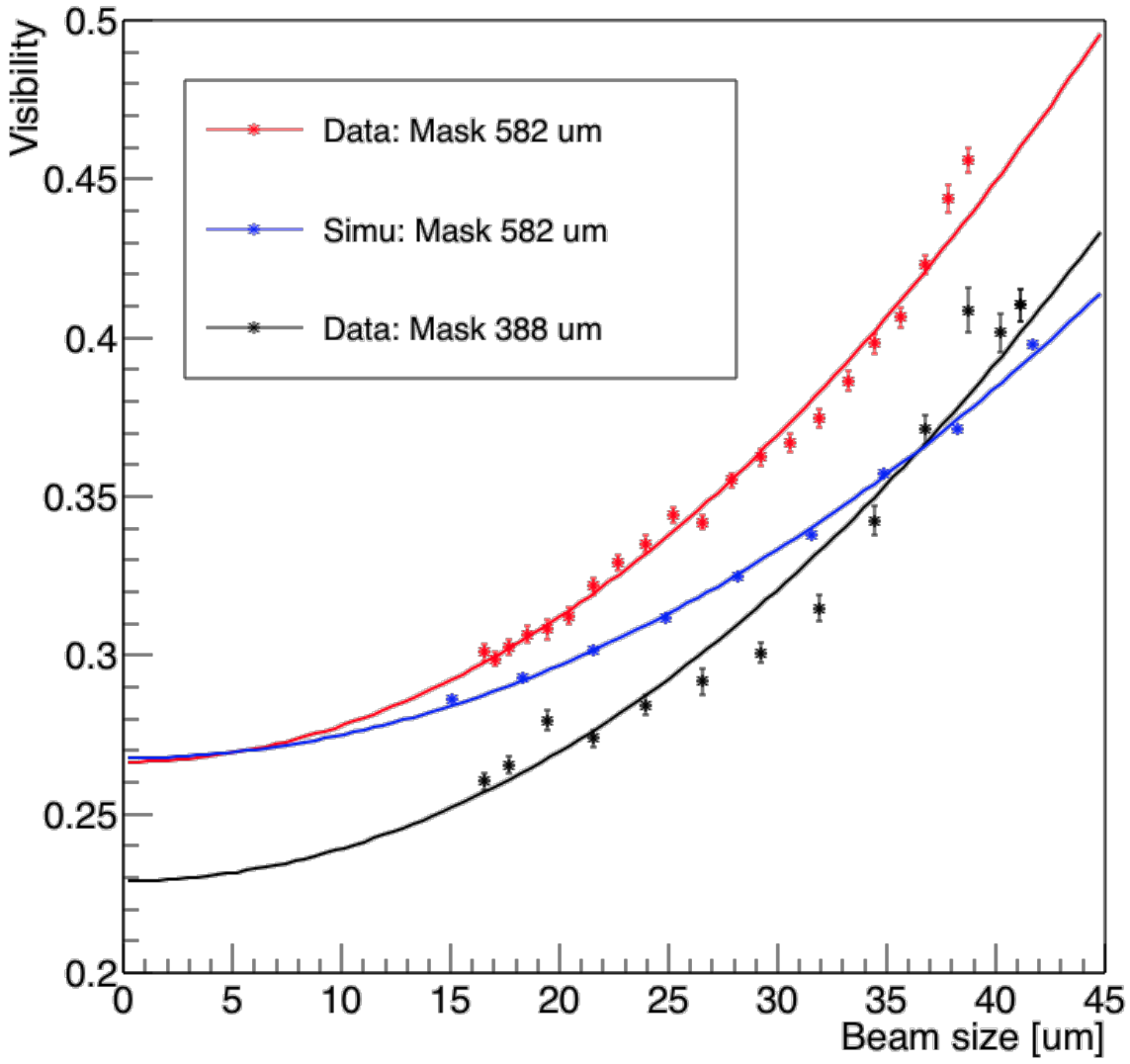
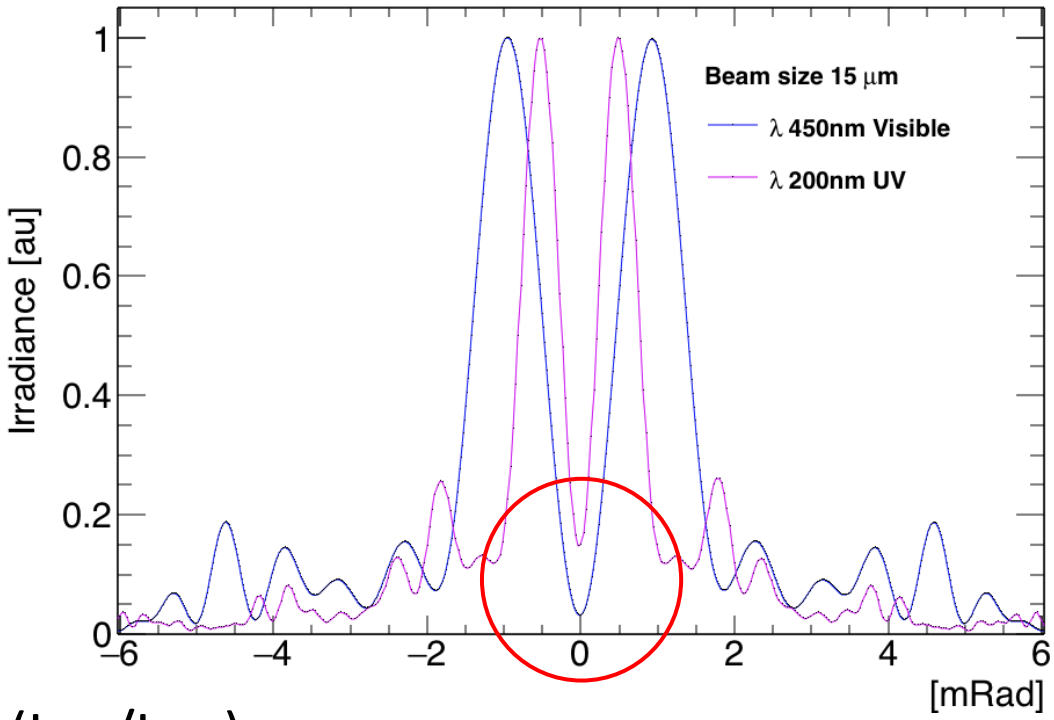
ODR angular visibility for beam size measurement



DR at ATF2 planned upgrade

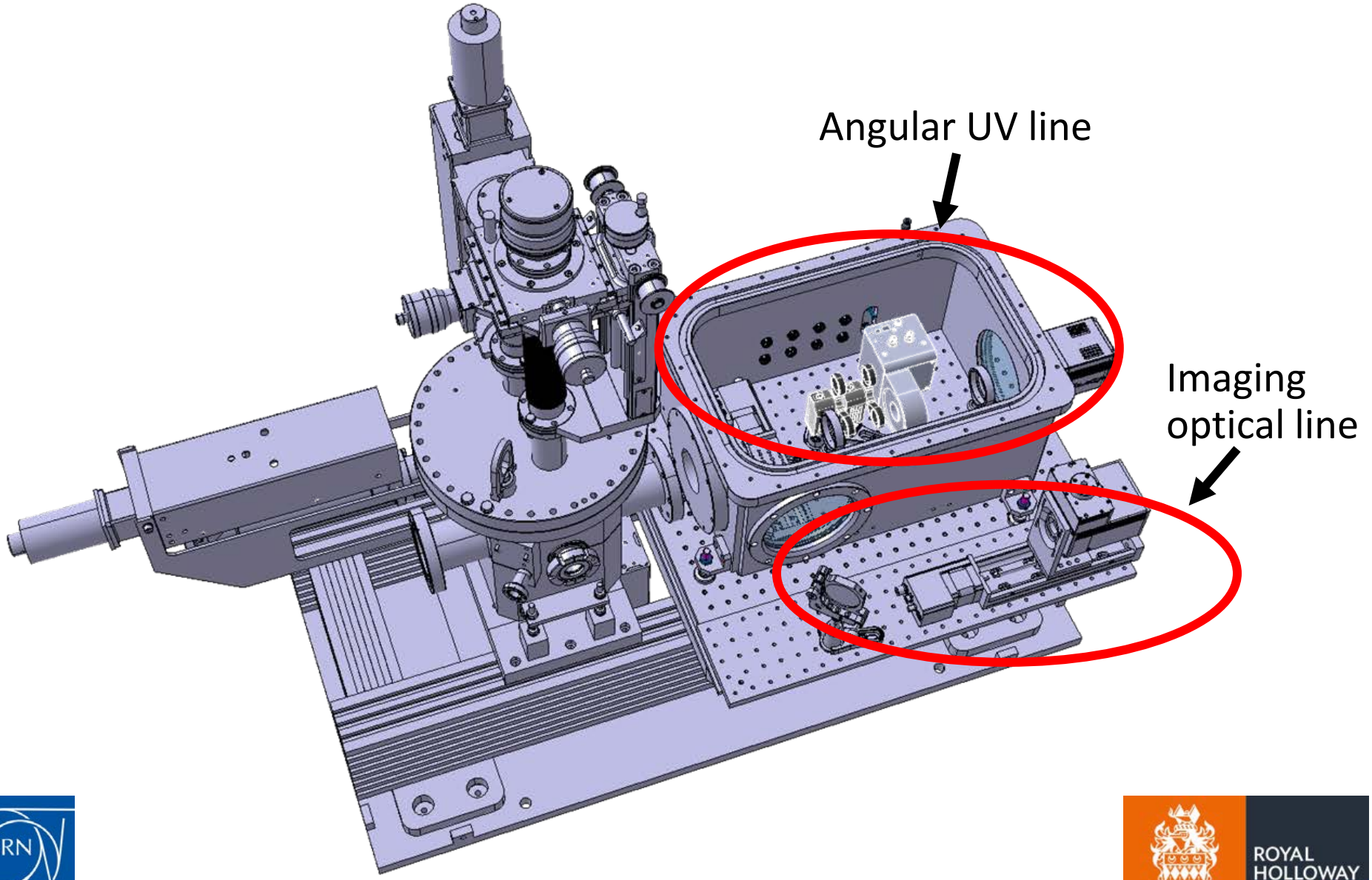
Upgrading the setup to perform UV/Far-UV (180-200nm) angular beam size measurement



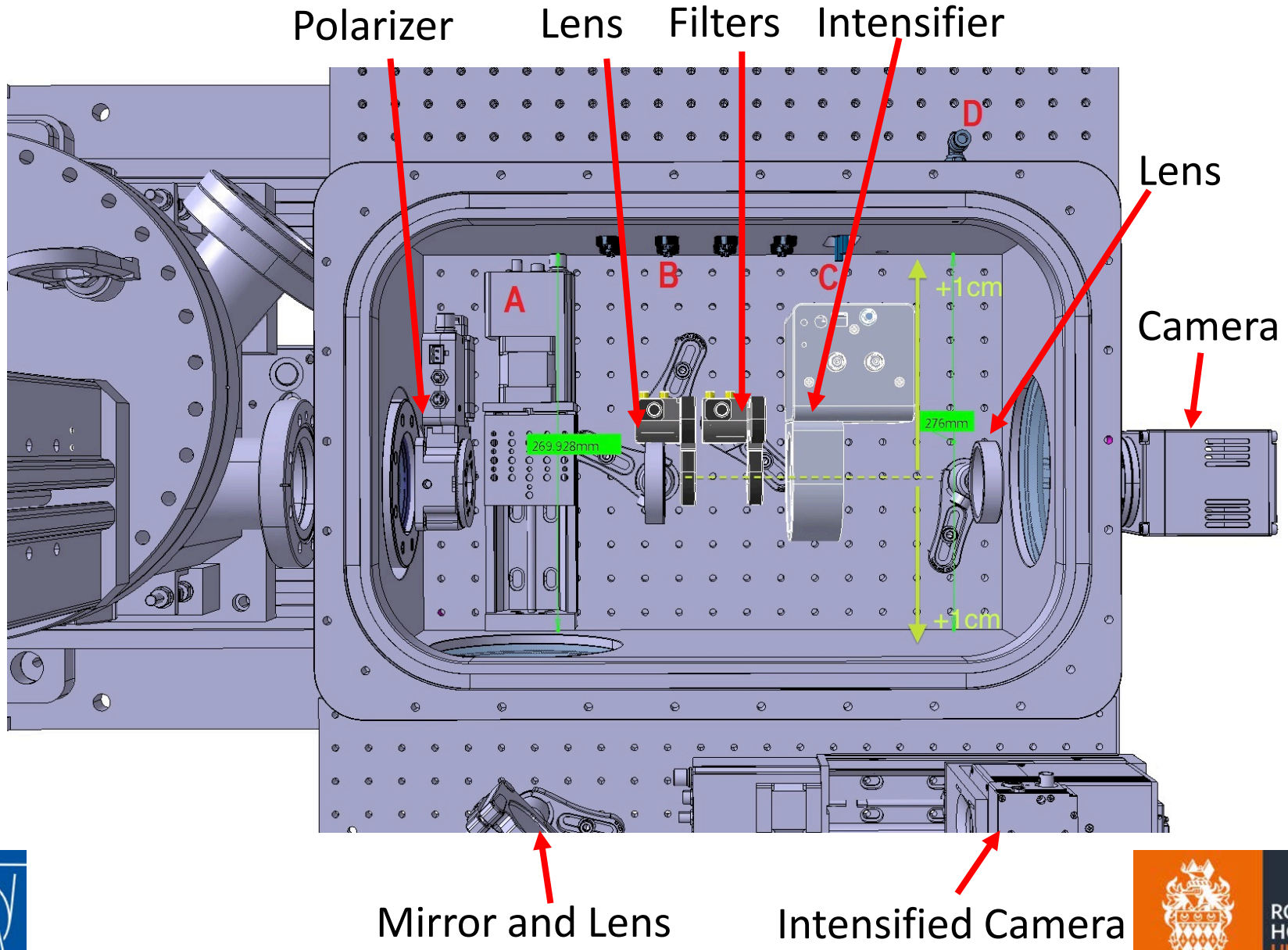
From visible range to UV

- Enhance the sensitivity: (I_{min}/I_{max})
- Imply the use of a smaller slit to respect the rule: $a \cong \frac{\gamma\lambda}{2\pi}$
- Give the possibility to **measure smaller beam sizes**!
- Optical line under **1mBar vacuum** will be needed.

DR at ATF2 planned upgrade



DR at ATF2 planned upgrade



Summary

OTR achievements

- Sub-micrometer beam size has been demonstrated
- Emittance measurement by the OTR PSF method are in good agreement with the measurements performed by conventional multi-otr system

OTR future development

- More systematic studies are required to fully understand the performance of the system and define the resolution limits and accuracy of the device
- A new intensified camera has been installed to increase the signal to noise ratio (one of the instrument limitation)

Summary

ODR achievements

- Possibility to use DR as an optical beam position monitor has been tested
- Sensitivity to beam size of tenth of micrometers has beam demonstrated
- Mask contribution to block synchrotron radiation has been observed

ODR future development

- More systematic studies are required to define the resolution limits and accuracy of the device
- Far-UV optical line designed to optimize sensitivity to small beam sizes, manufacturing of the UV tank is ongoing. It will be ready next week, foreseen to been installed in the May 2017

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Thank you for your attention!

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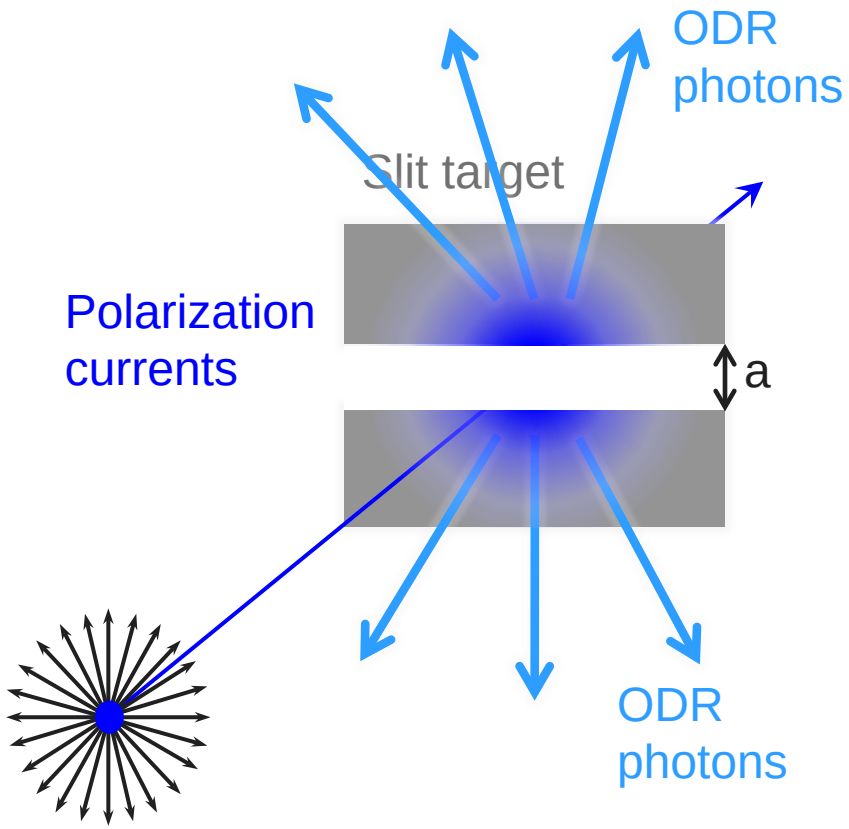
Backup slides

Optical Diffraction Radiation (ODR)

The transverse component of the electric field from the charged particle produces surface **polarization currents** on the dielectric slit. Atoms on the edge of the slit are polarized, their **relaxation** lead to the emission of ODR photons



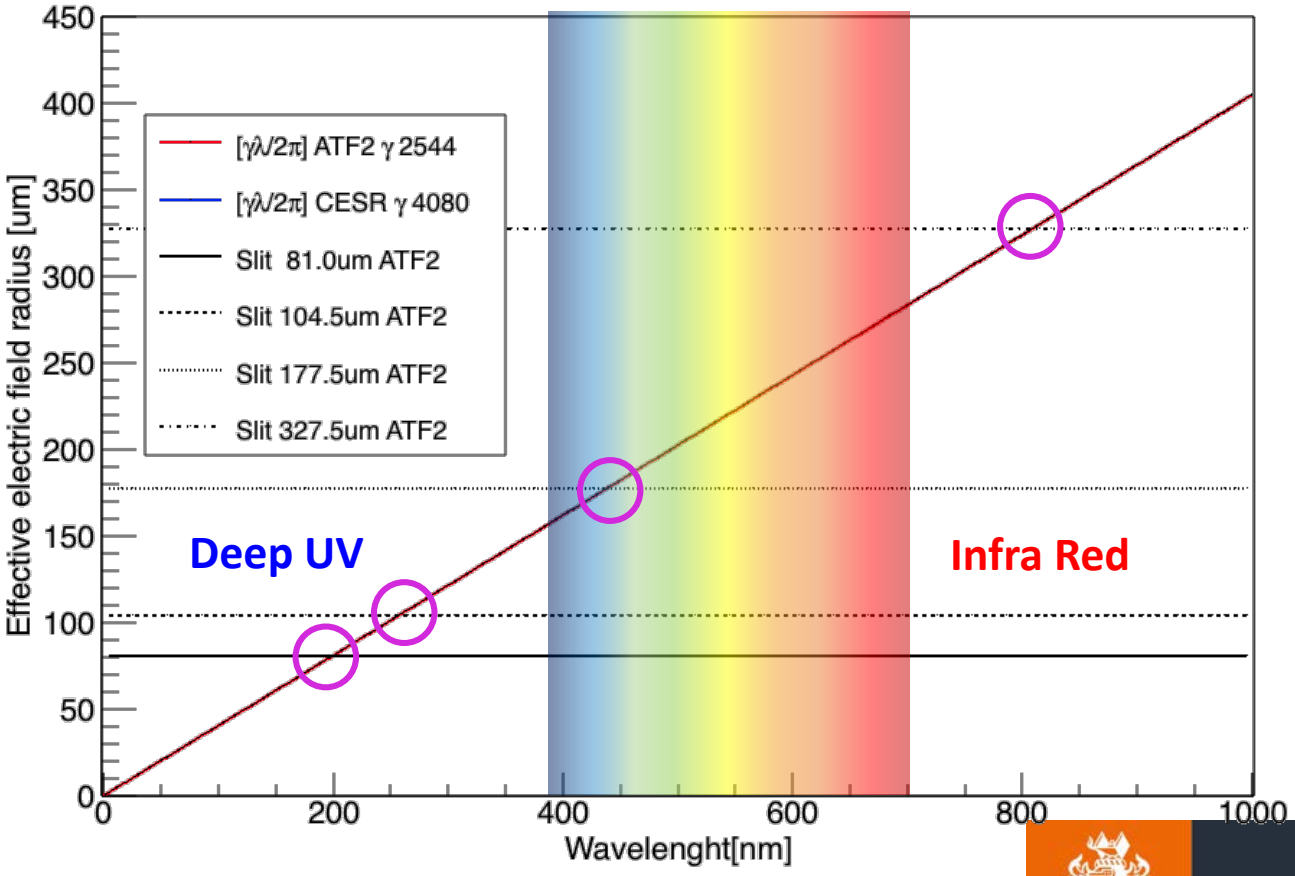
Optical Diffraction Radiation

The **ODR** photons yield is strongly dependent on the **effective electric field radius** and the **slit aperture a** (impact parameter)

$$a << \frac{\gamma\lambda}{2\pi}$$ OTR

$$a >> \frac{\gamma\lambda}{2\pi}$$ No radiation

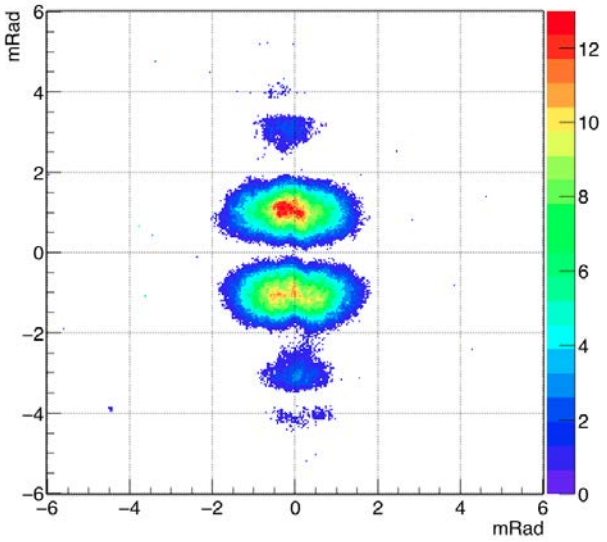
$$a \cong \frac{\gamma\lambda}{2\pi}$$ **ODR**



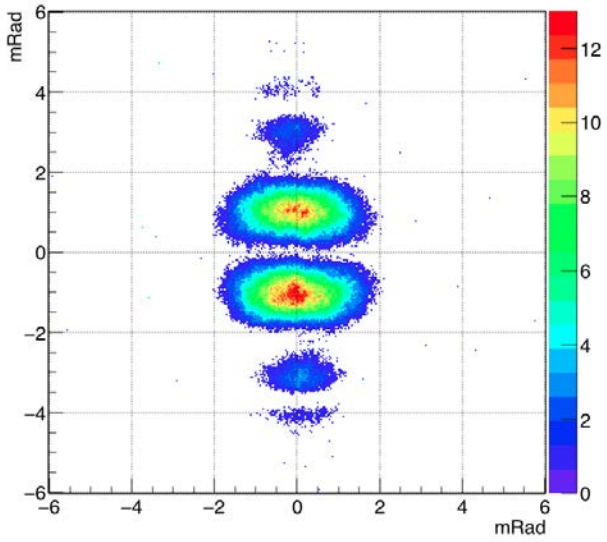
ODR angular distribution at ATF2

Filter:450nm Slit:105um Mask:202um

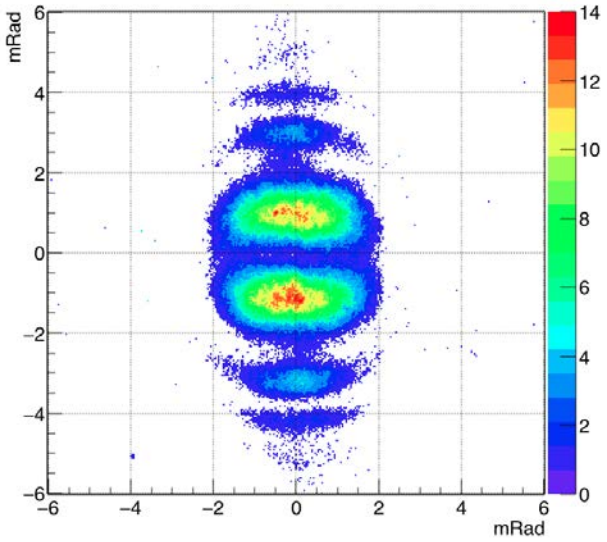
Beam 1um (100images)



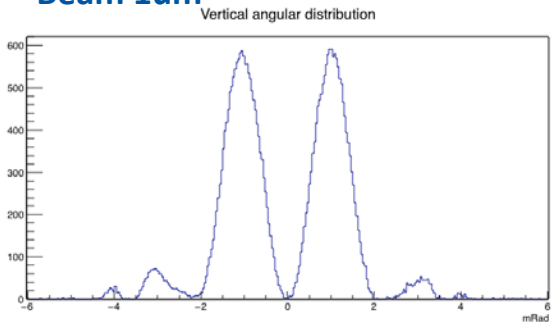
Beam 18um (100images)



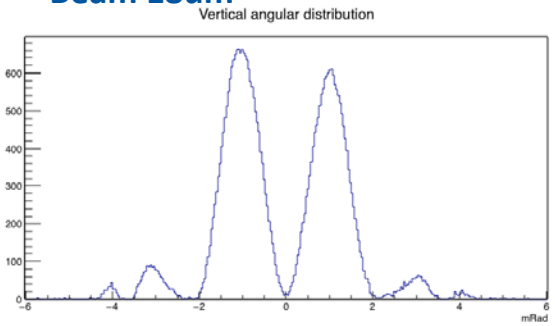
Beam 30um (100images)



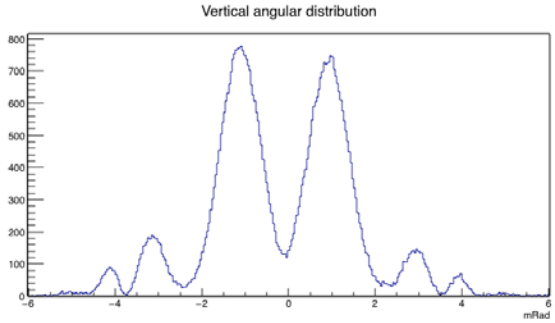
Beam 1um



Beam 18um



Beam 30um



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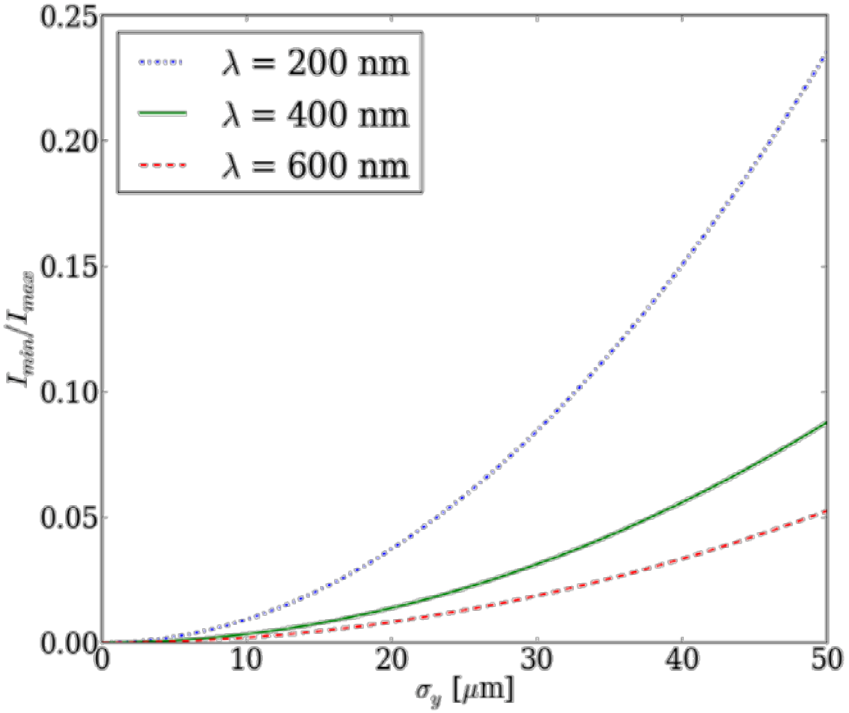
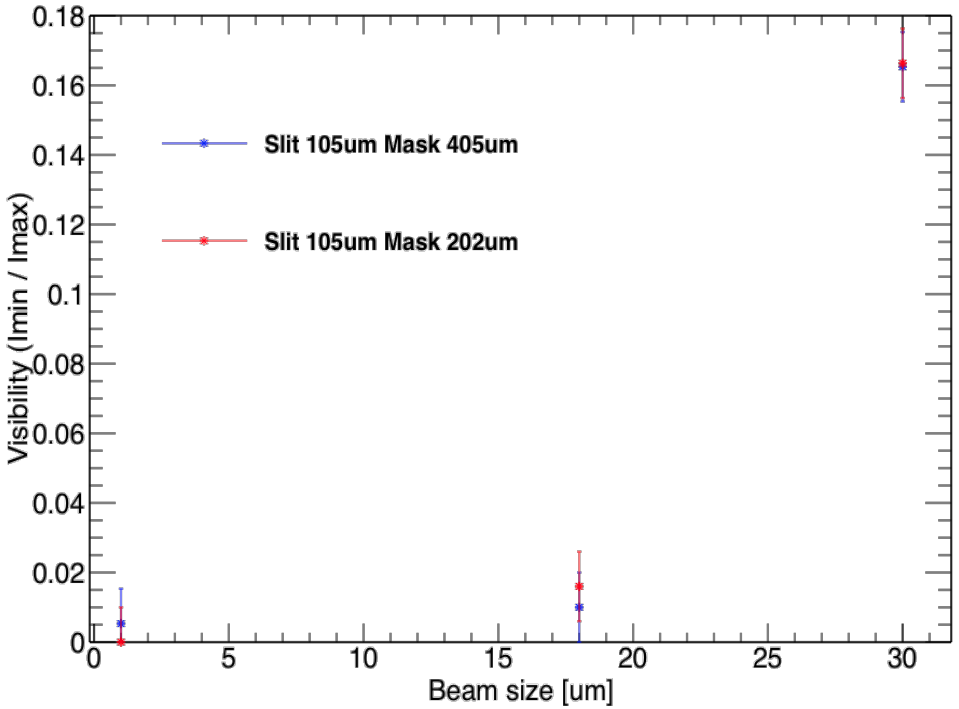
ODR beam size measurement

MC simulation from theoretical model **500um slit @ 2.1GeV**



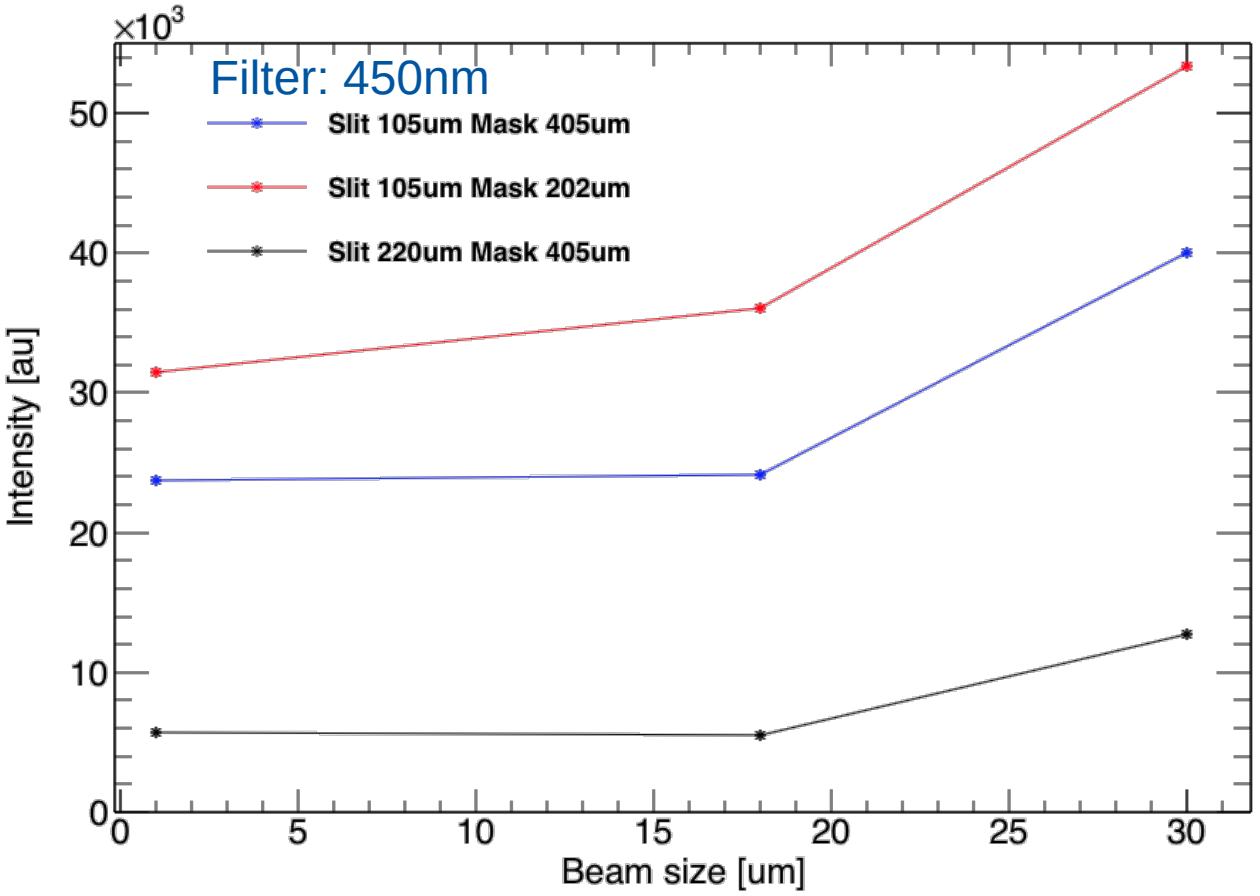
ATF2 ODR interference measurement **105um slit and 202um mask @ 1.3GeV**

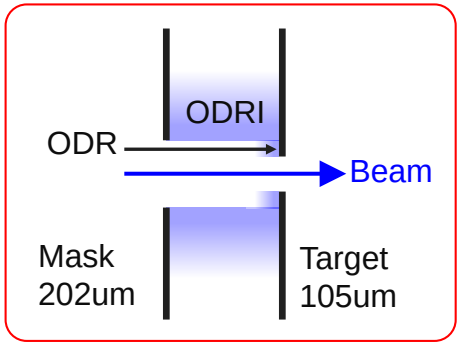


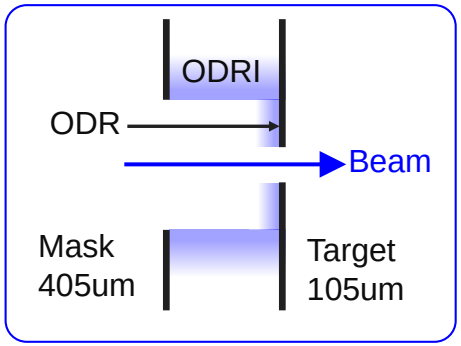
The visibility of **ODR angular profile** can be calibrated using simulation to extract the **beam size**

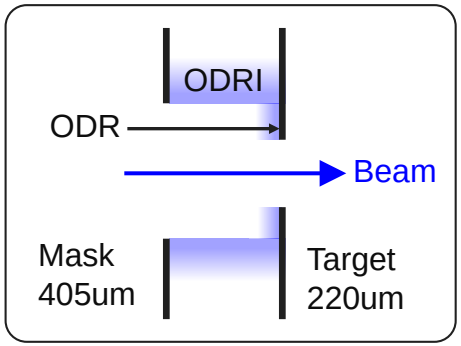
Simulation of all ATF2 Mask and Slit combinations are on-going

ODR light intensity with different mask







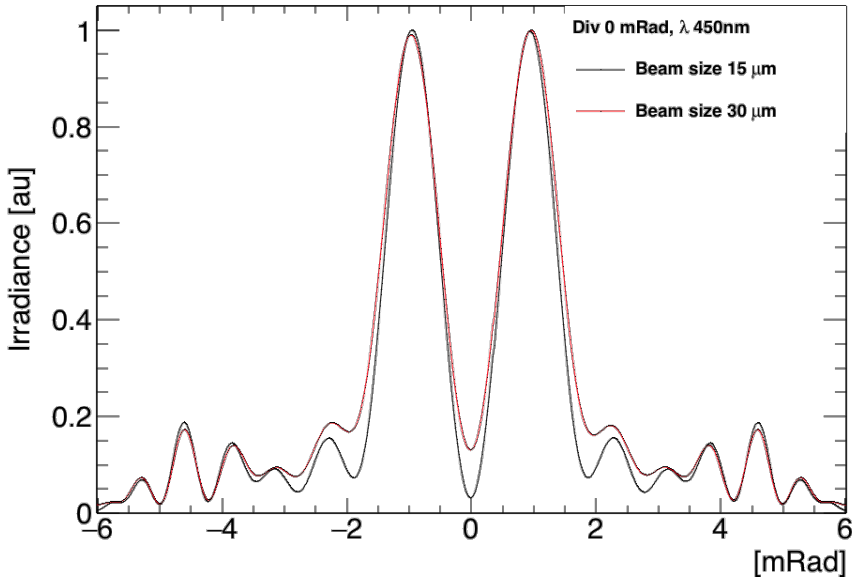


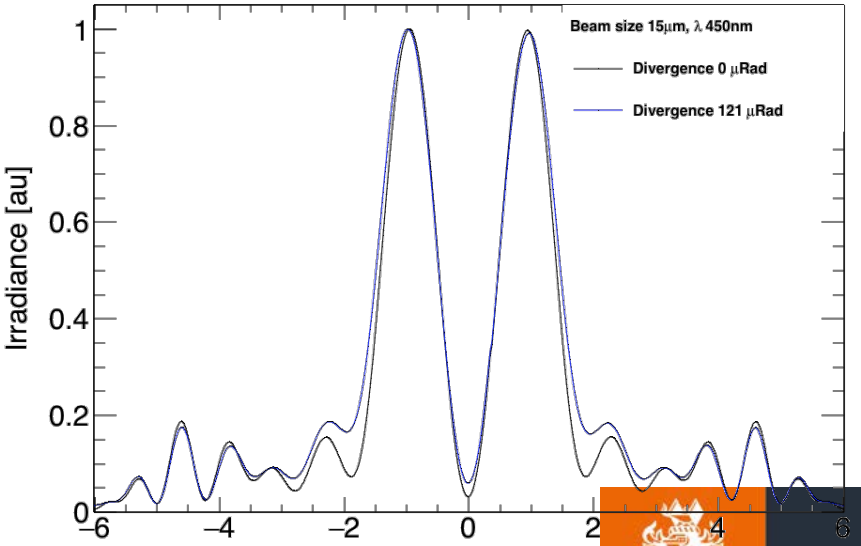
With a distance of 12.5cm between Mask and Target at 1.3GeV the **ODR Interference** is **constructive** and increases **integrated image intensity**

ODR angular distribution

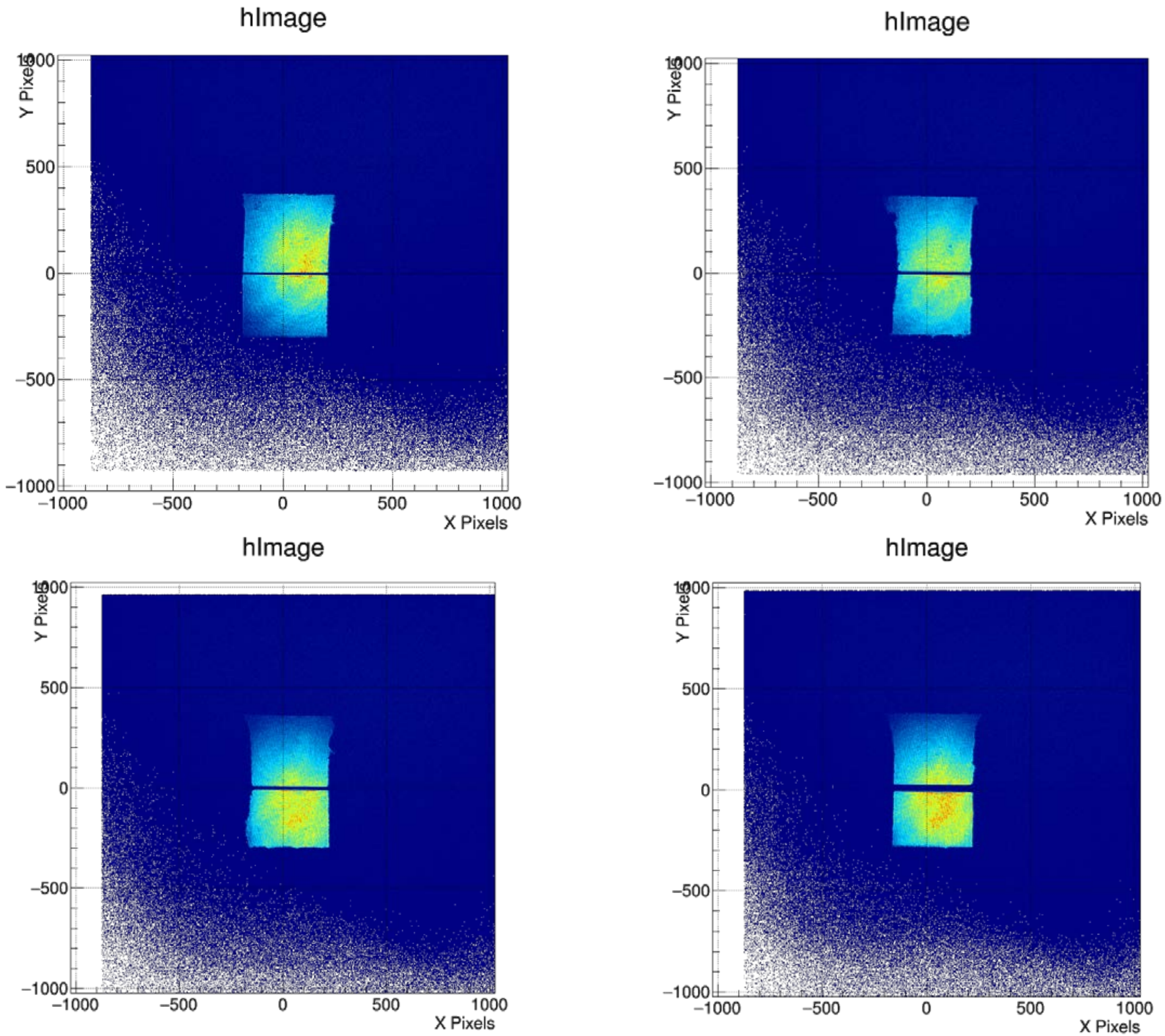
Both **beam size** and **beam divergence** have an effect on the **visibility** of the ODR pattern

In the **ATF2** case, using low emittance beams the impact of the beam **divergence** (nrad) on the visibility is **negligible** compared to the **beam size**

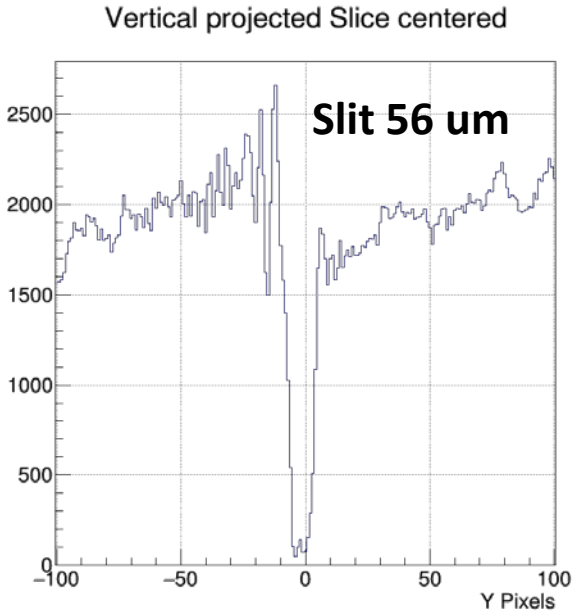


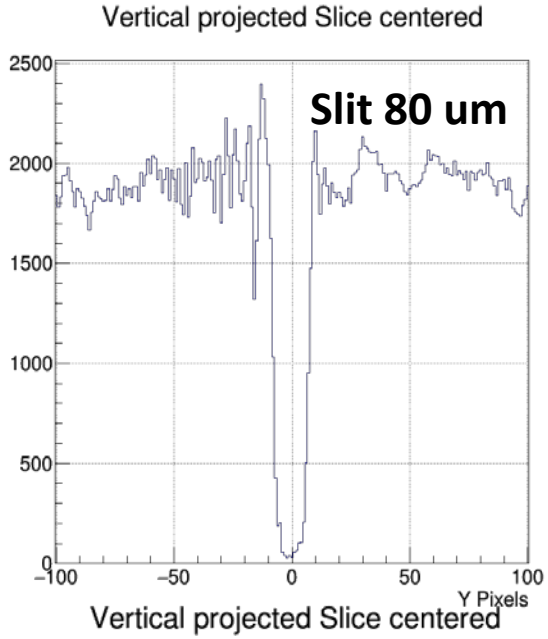


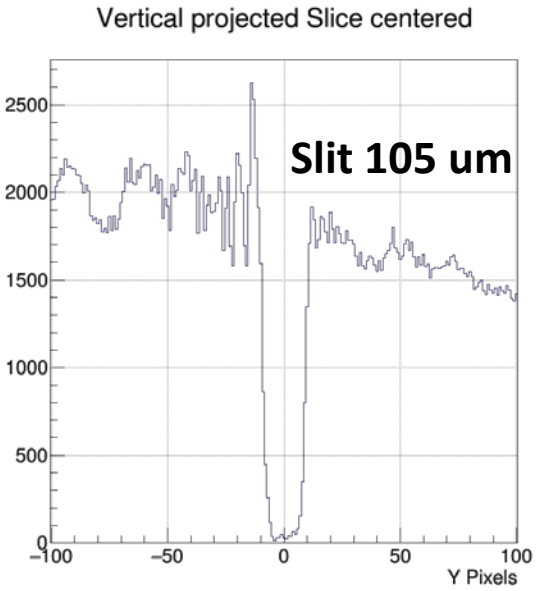
Imaging Magnification with laser

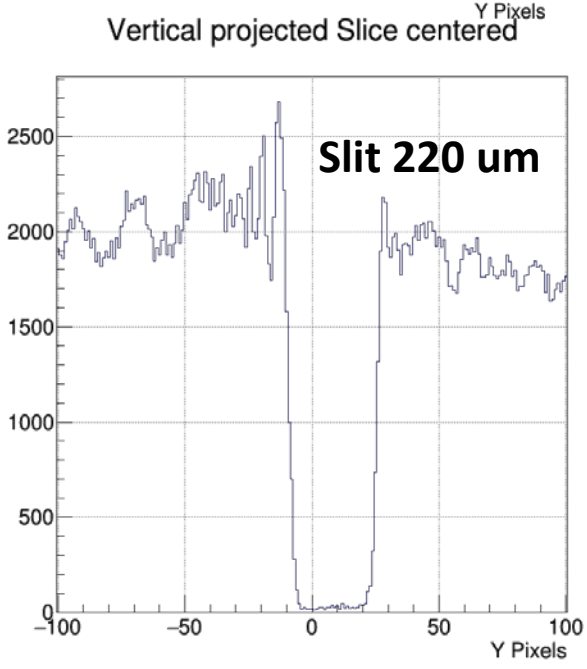


Imaging Magnification with laser









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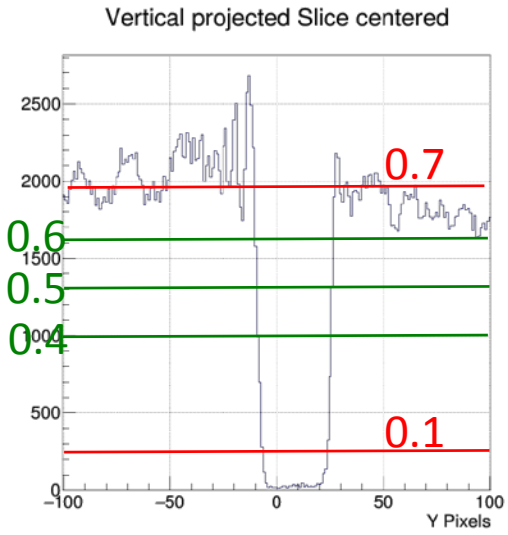
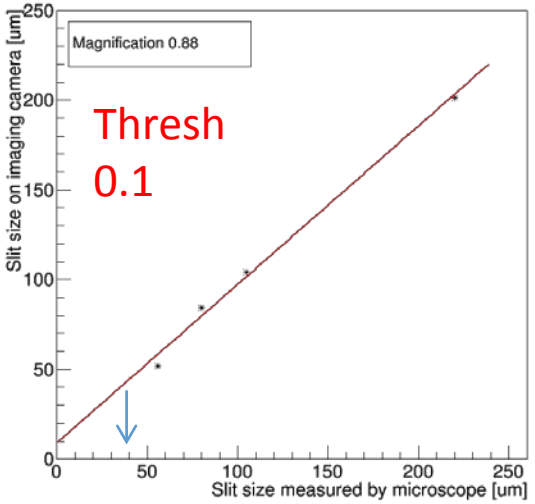
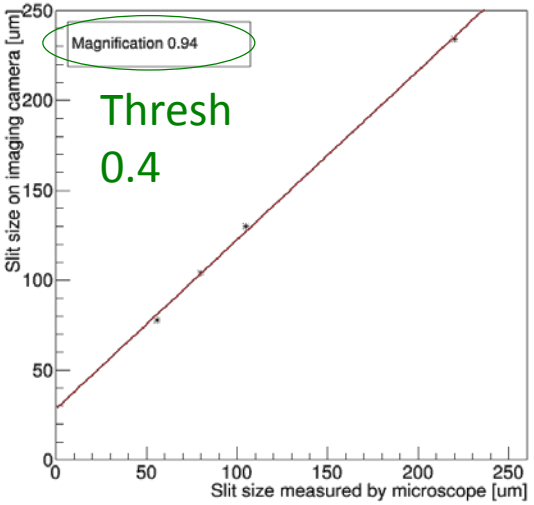
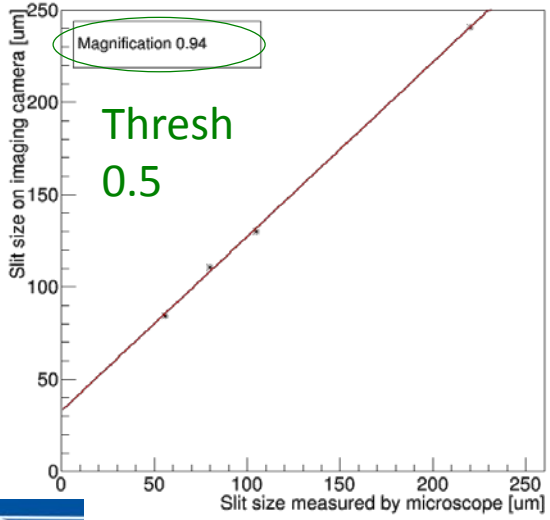
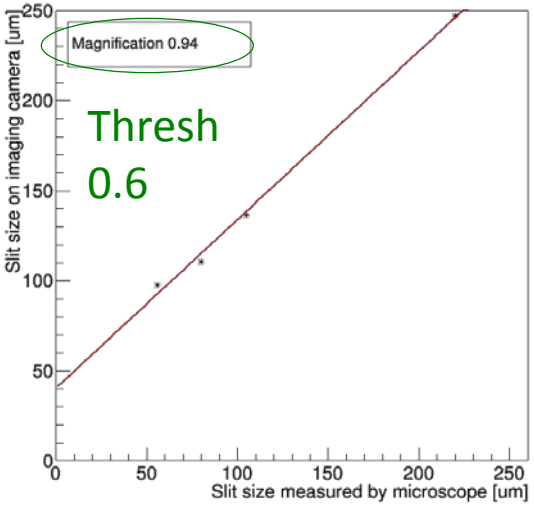
Imaging Magnification with laser

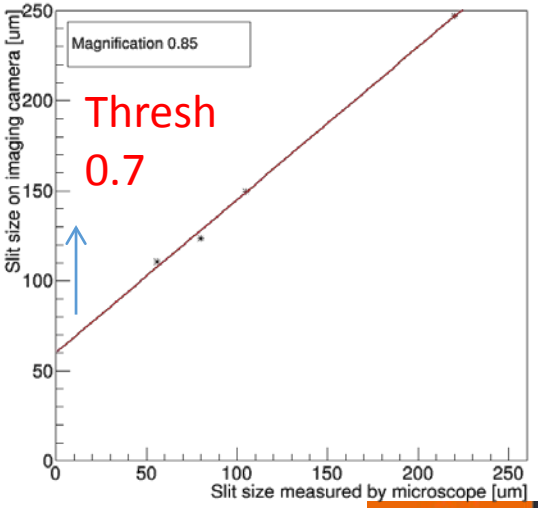












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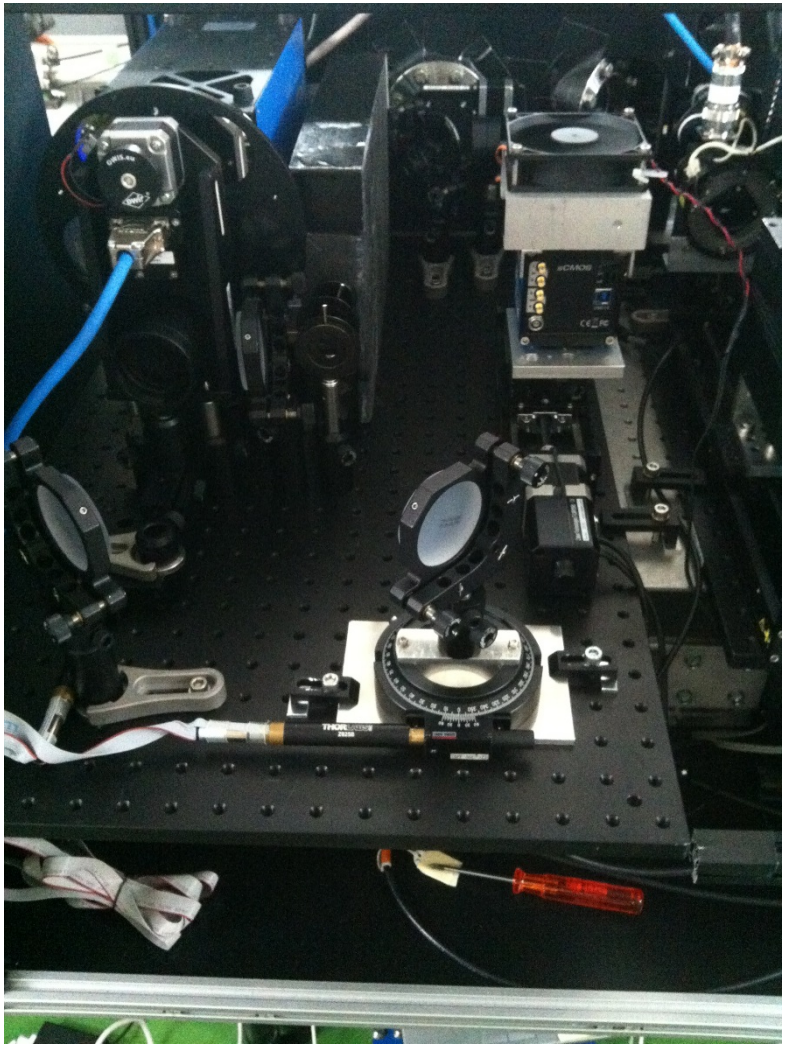
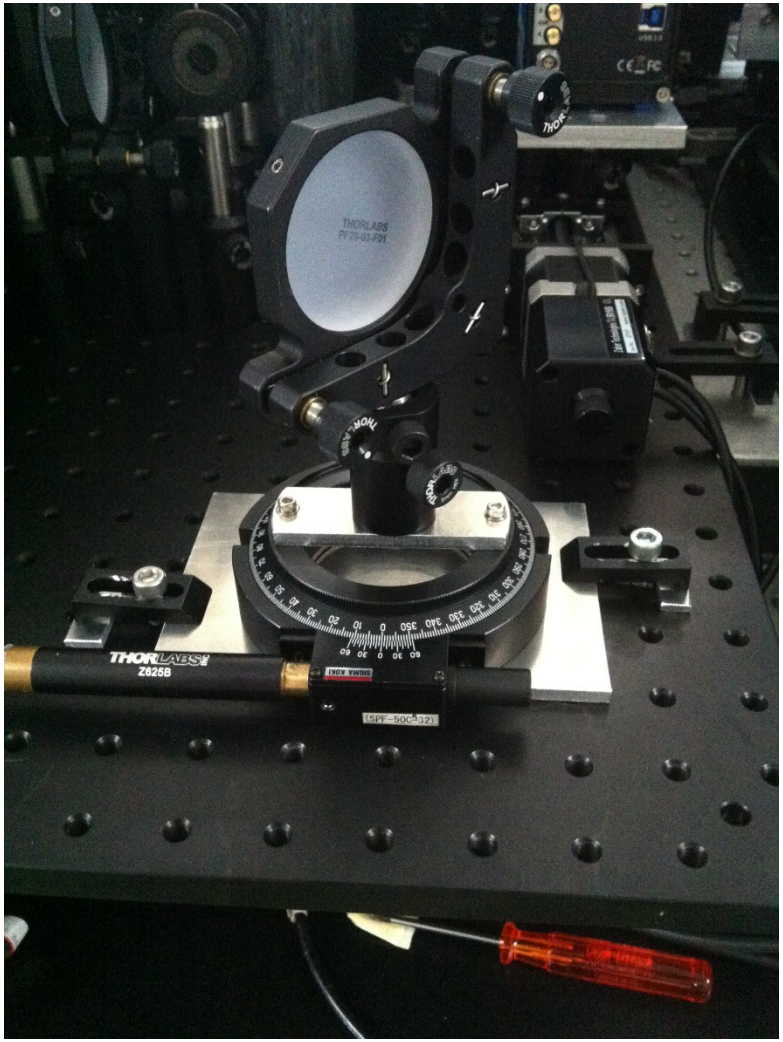
Angular calibration with laser





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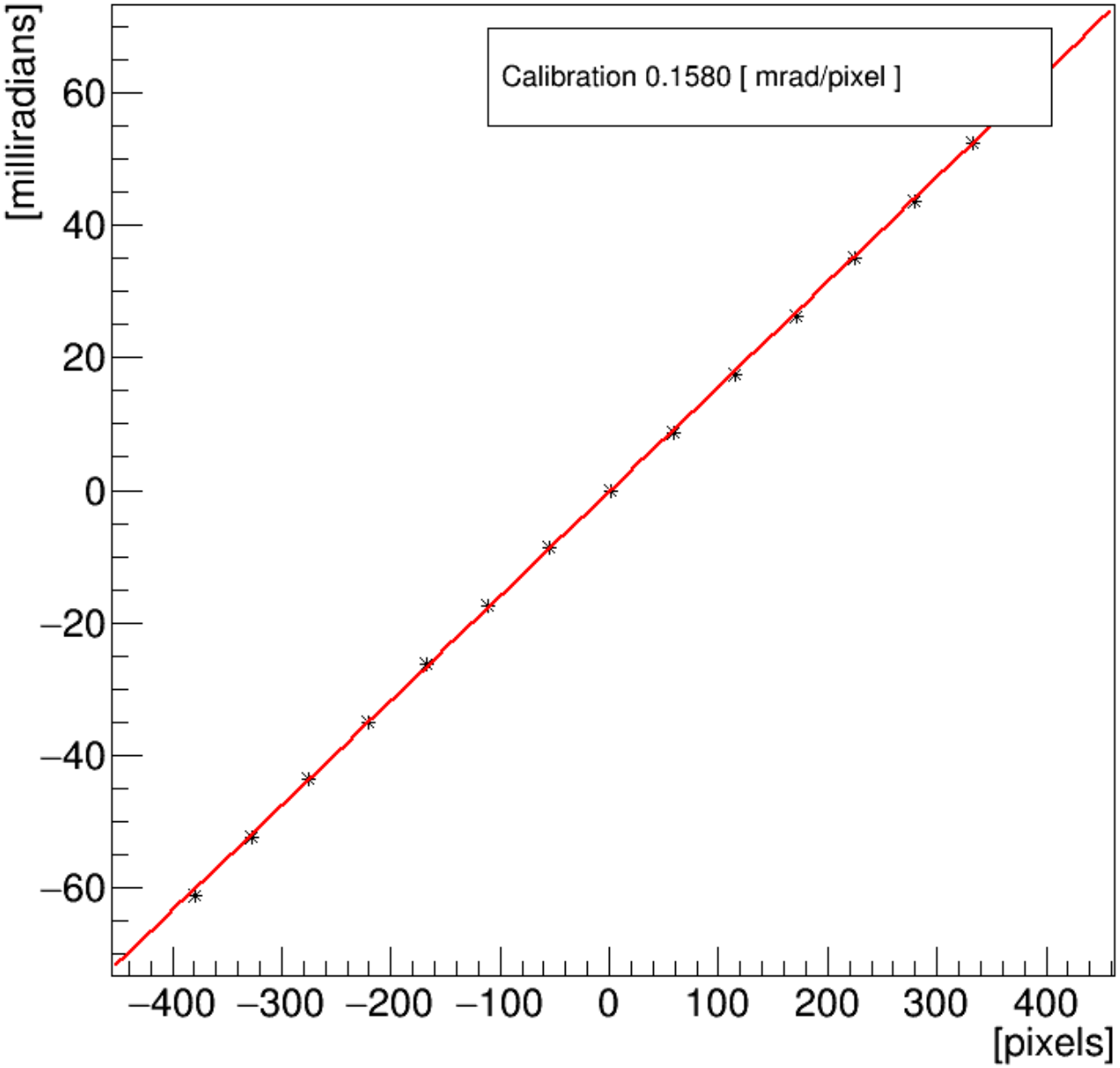
Angular calibration with laser



Measured value 0.1580 [mrad/pixel] Obtained for the focal distance used during beam time.

Stepper motor goniometer helped us to improve the calibration curve linearity.

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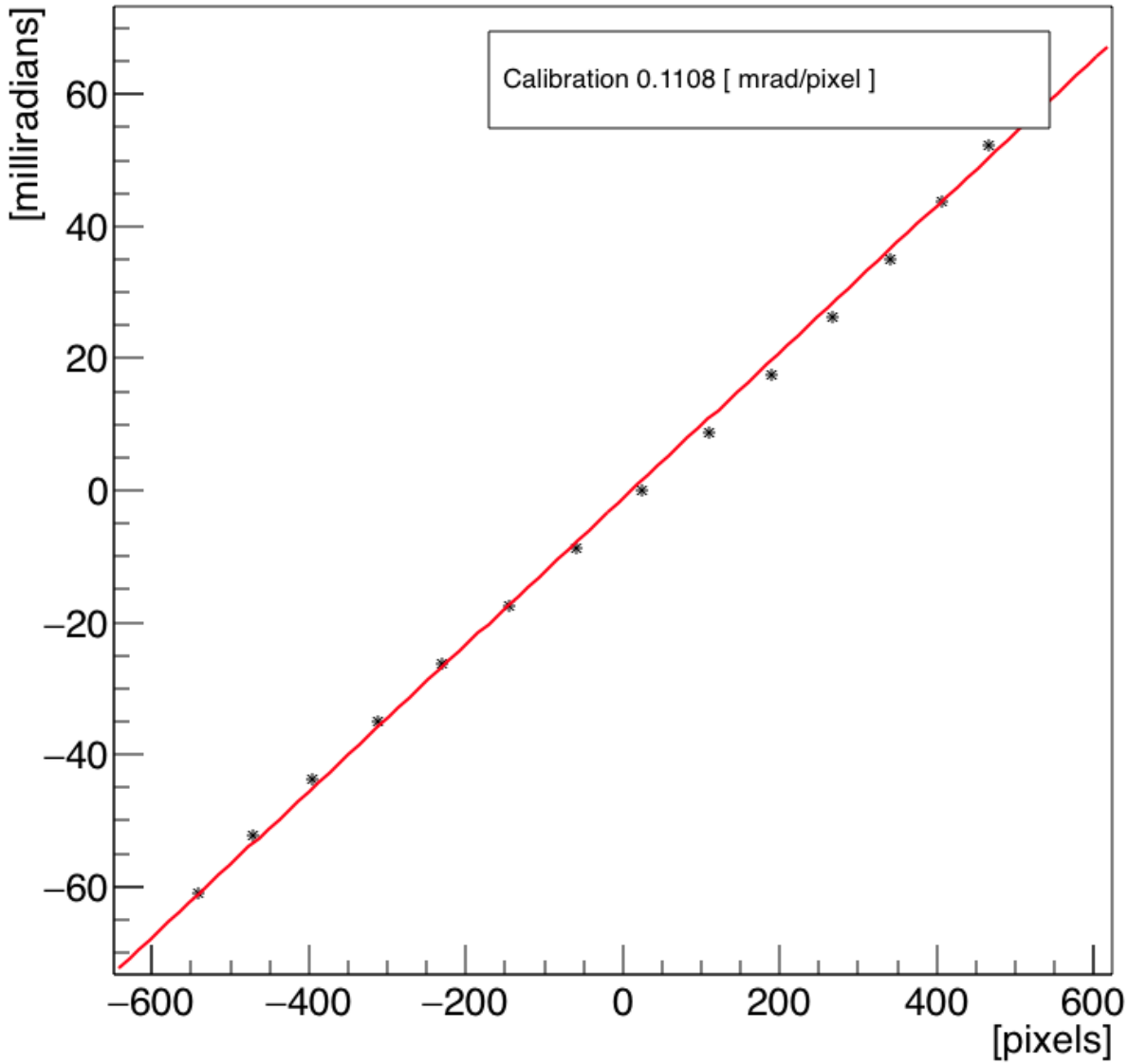
Angular calibration LA4904 f=150mm



Recorded after the shifts before reconfiguring the optical lines.

The lens have the flat side to target and the round one to CCD

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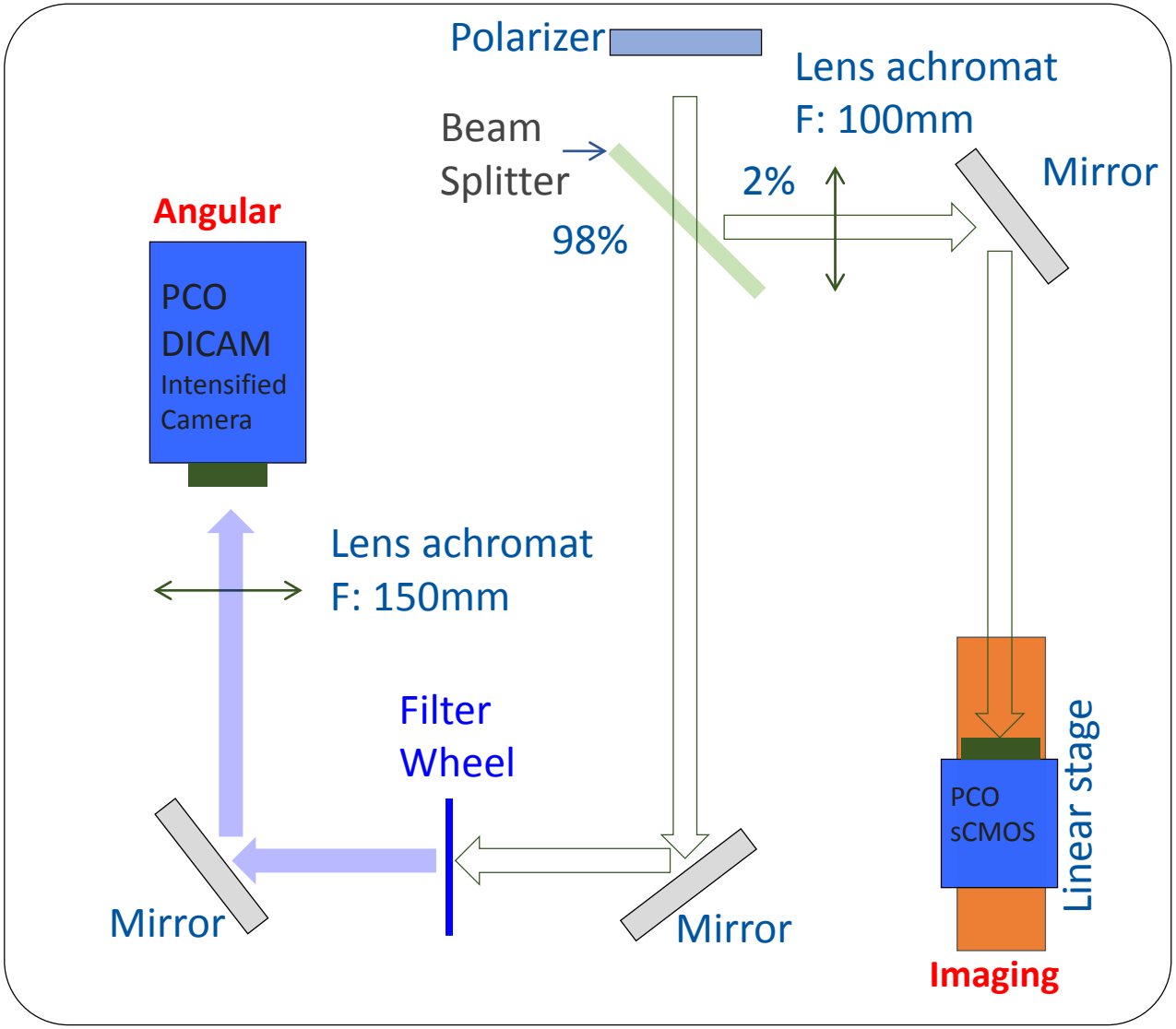
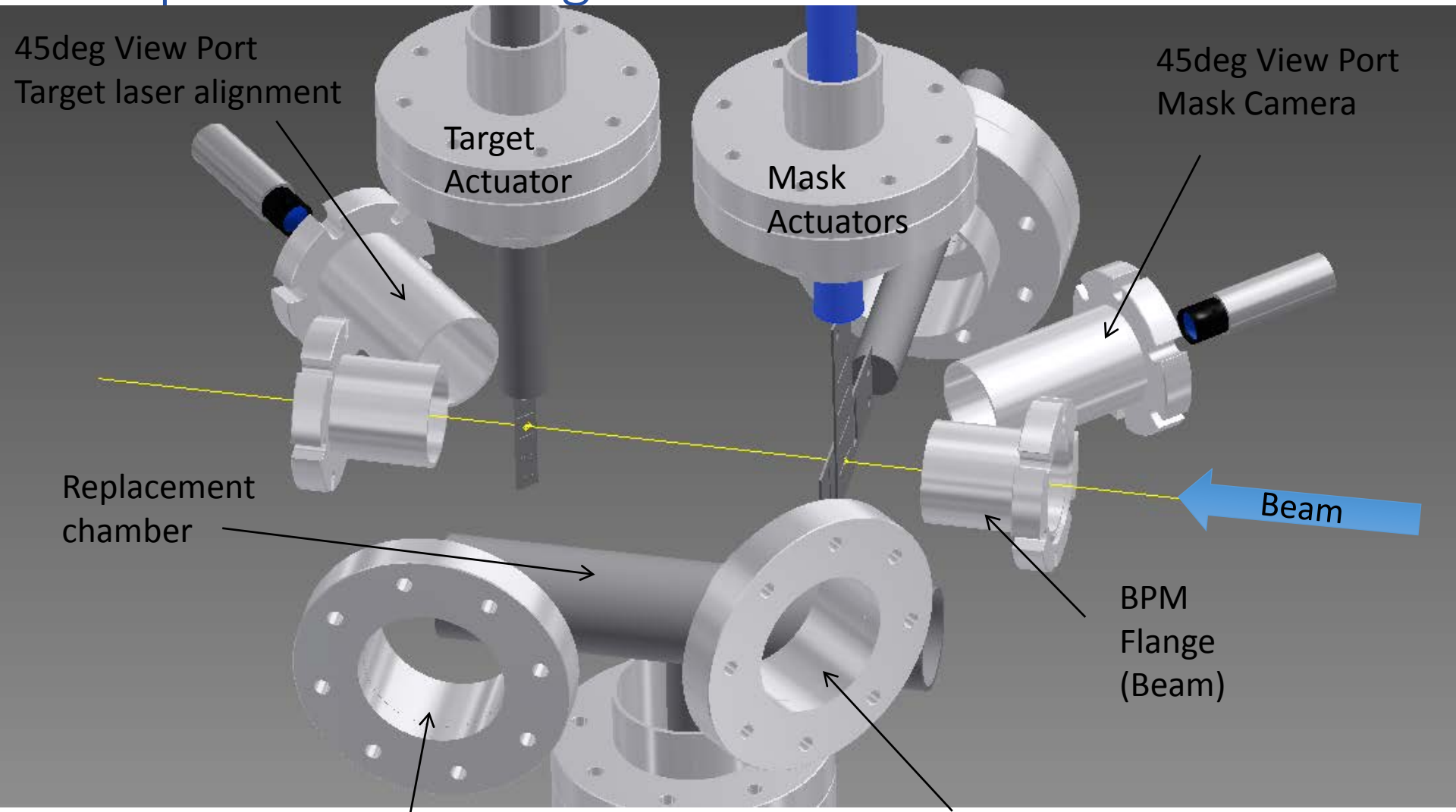
ATF2 ODR Optical line upgrade (Installed)

AIM: Synchronous Imaging and Angular acquisition for position filtering in angular.



Experimental design



OTR Point Spread Function (PSF) for beam size measurement