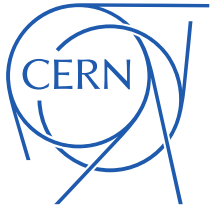
OTR/ODR emittance measurement system at ATF2

M. Bergamaschi[1,2], A. Aryshev[3], P. Karataev[1],
R. Kieffer[2], T. Lefevre[2], S. Mazzoni[2], N. Terunuma[3]

CLIC Workshop 2018, CERN, 23rd January 2018

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
- ODRI experiment at ATF2
- Operational year 2017 ODRI results at ATF2
- Summary and outlook

CERN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Overview

Motivations and Goals:

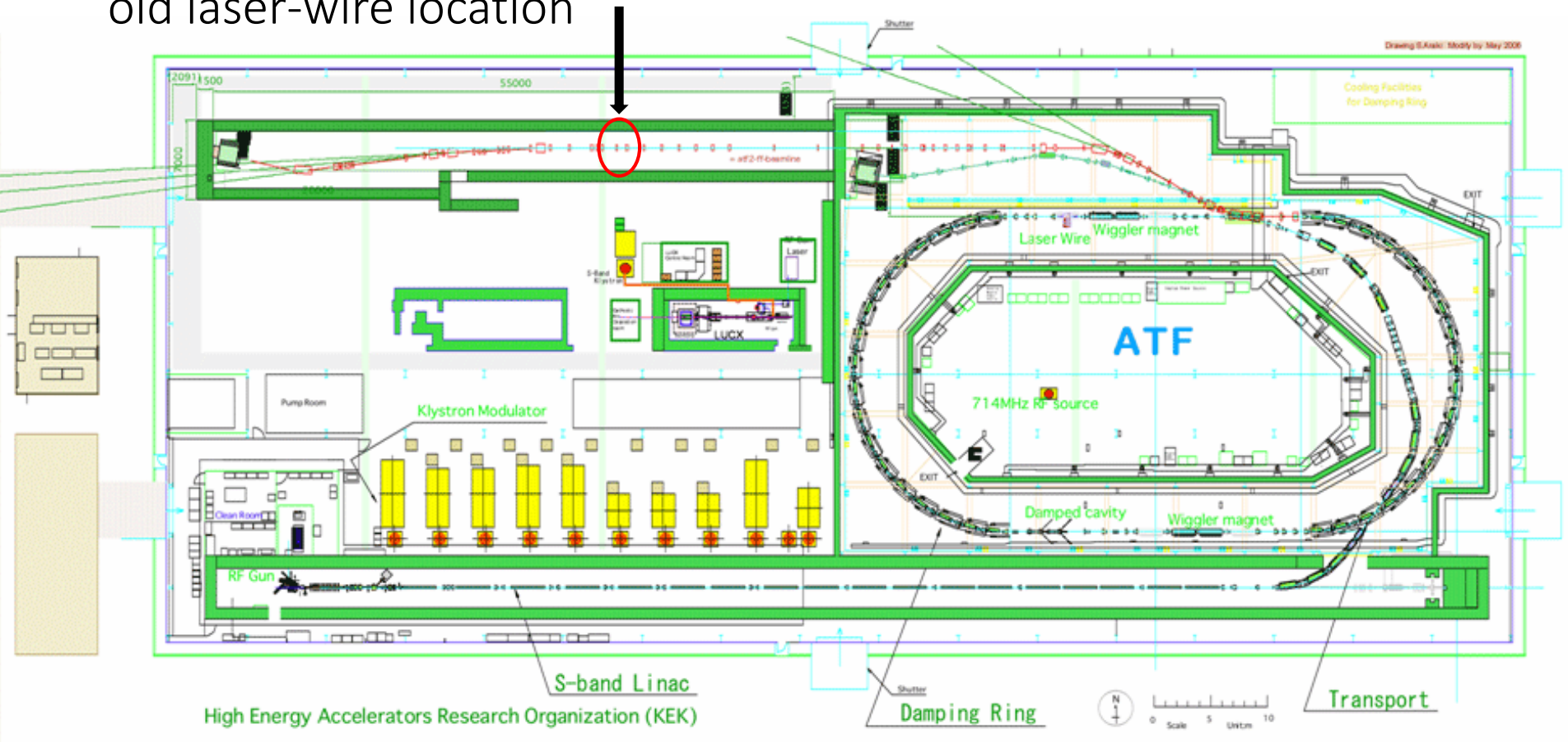
- Develop a non-invasive transverse profile station for CLIC/ILC beams with micron resolution
- Develop, install and test a combined Optical Transition Radiation (OTR) and Optical Diffraction Radiation Interference (ODRI) emittance station at ATF2 at High Energy Accelerator Research Organisation (KEK)
- To optimize sensitivity to smallest beam sizes, we plan to observe ODRI in the visible and far-UV wavelength range, down to approximately 200 nm

CERN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

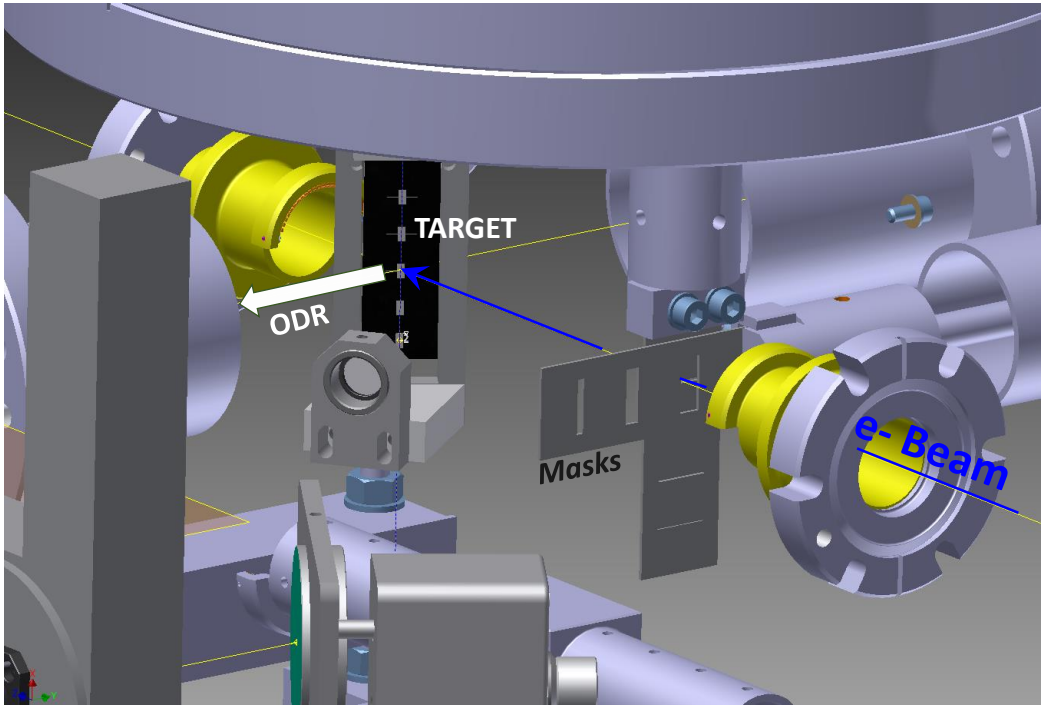
ODRI experiment at KEK ATF2

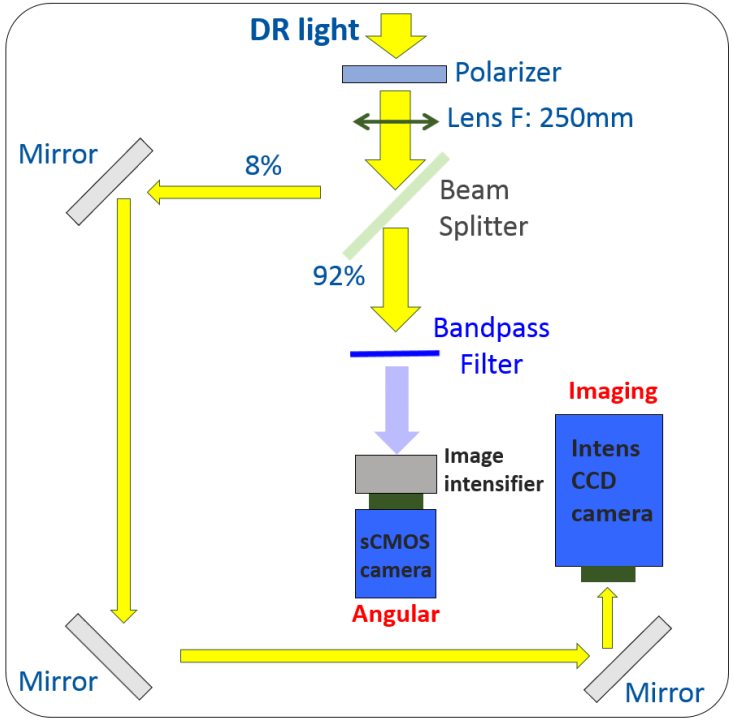
ODRI experiment location between QM14FF and QM13FF
old laser-wire location



ODRI experiment at ATF2

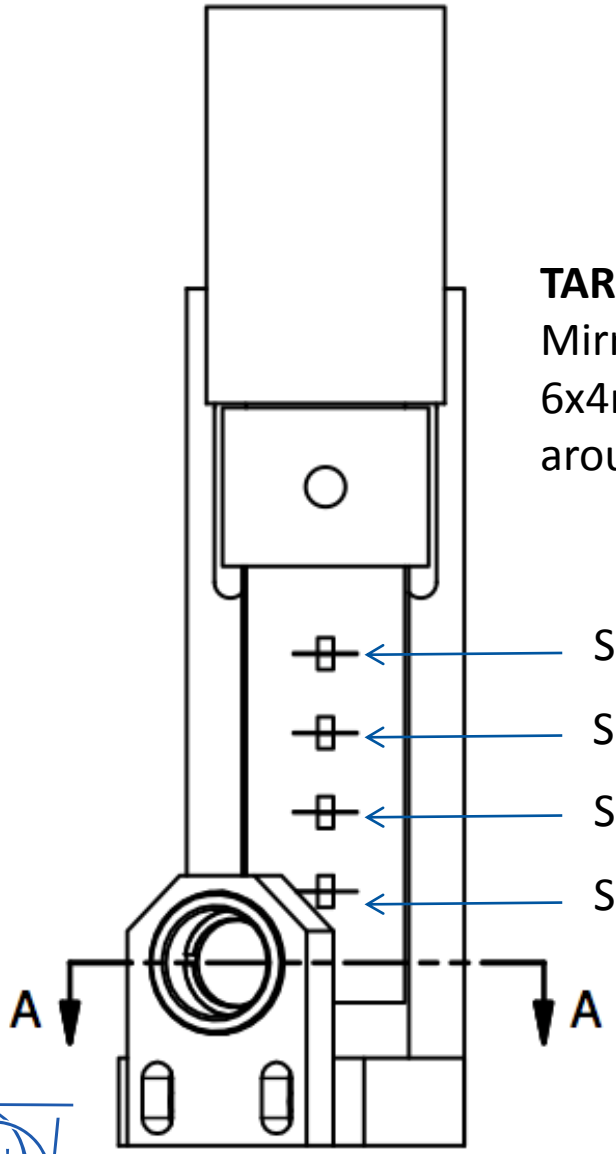
- The **target** has **4 slits for DR (50 to 201 µm)**
- A couple of vertical and horizontal **mask slits** can be inserted 13 cm upstream the target





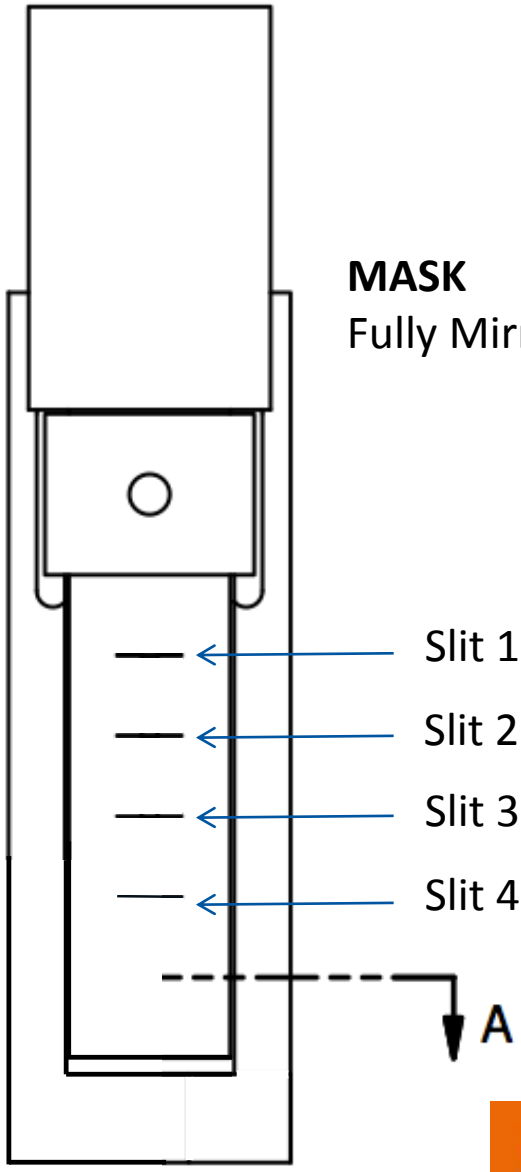
Synchronous Imaging and Angular acquisition for position filtering in angular

ODRI experiment at ATF2



TARGET
Mirrored areas
6x4mm^2
around slits

Slit 1 201.7um
Slit 2 100.6um
Slit 3 77.2um
Slit 4 49.57um



MASK
Fully Mirrored

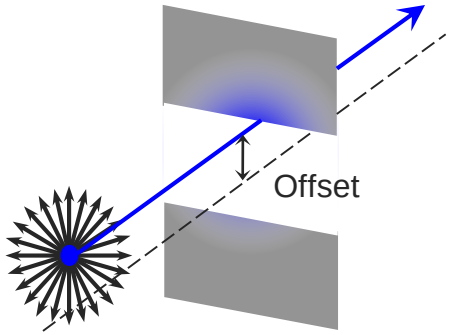
Slit 1 399um
Slit 2 198.9um
Slit 3 149.2um
Slit 4 100um

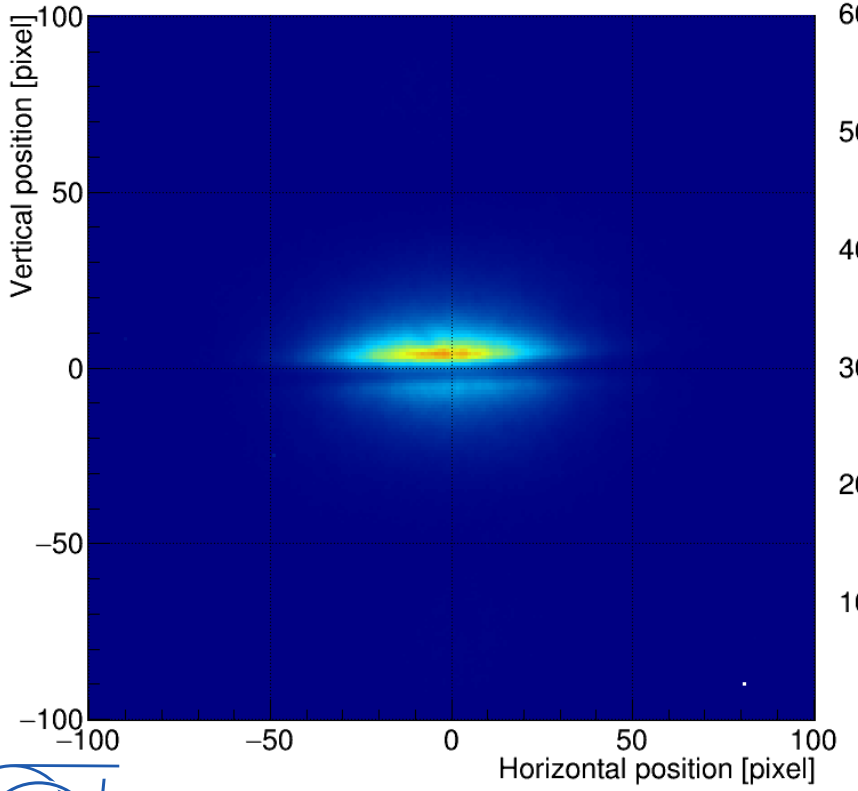
CERN

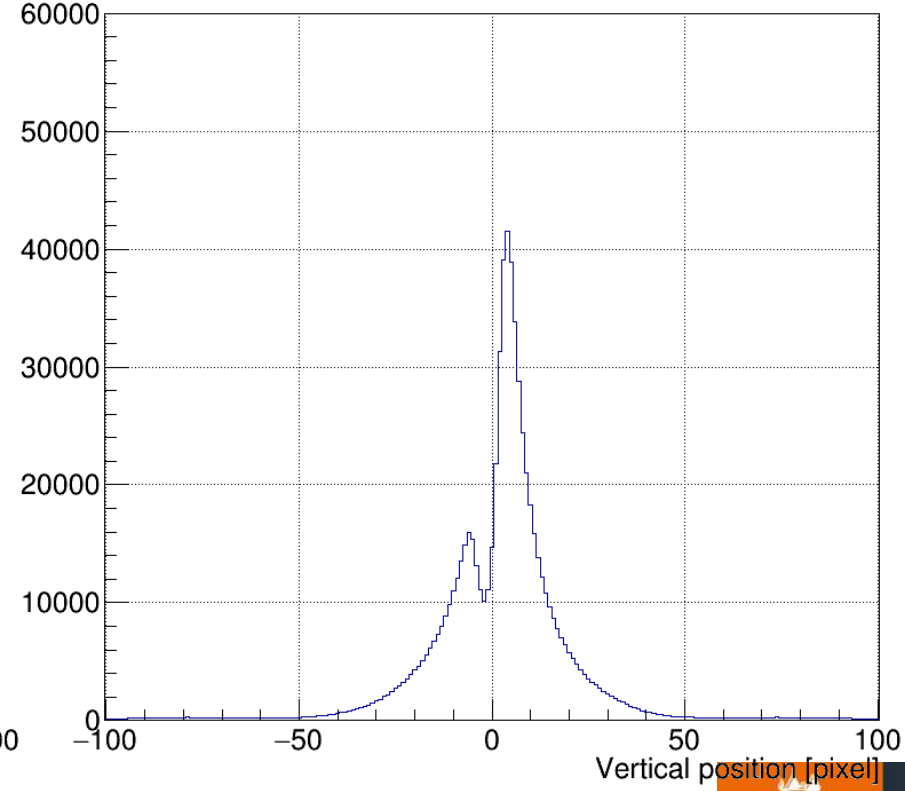
ROYAL HOLLOWAY UNIVERSITY OF LONDON

ODR in imaging

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



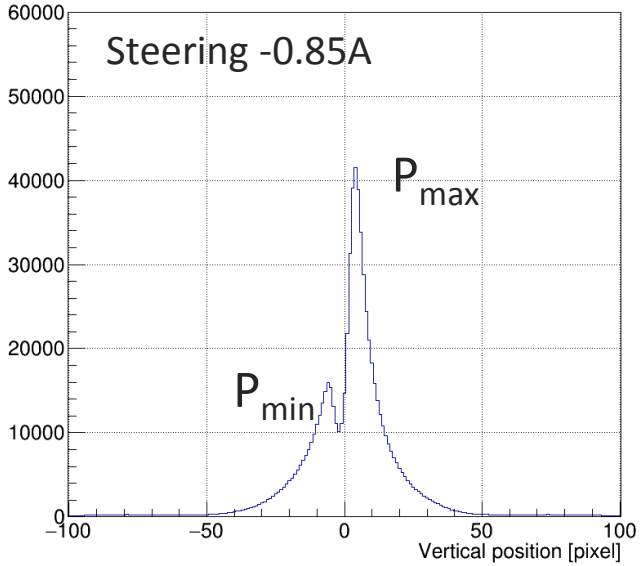


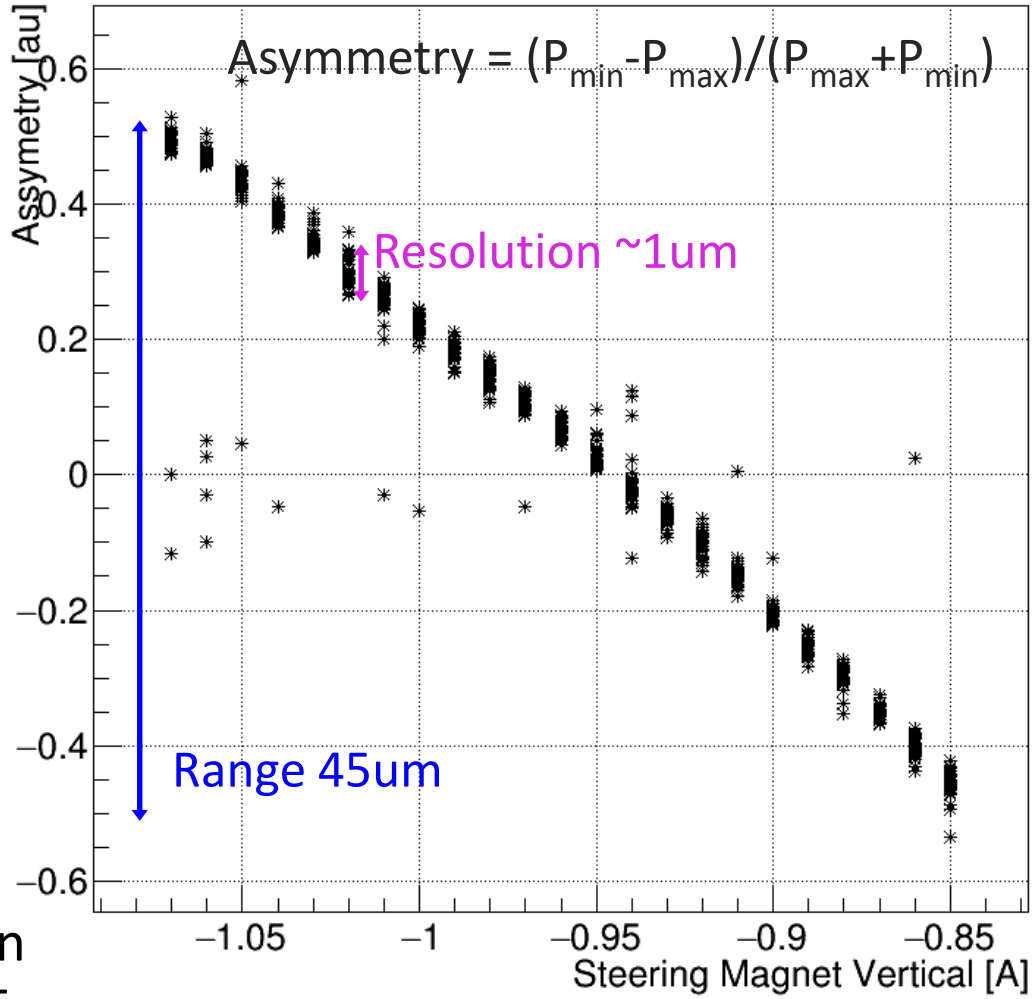


CERN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

ODR imaging as an optical BPM

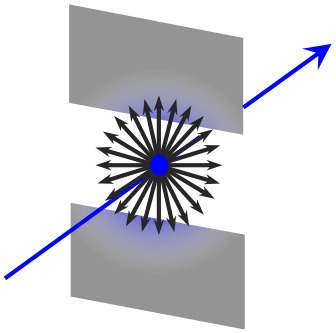


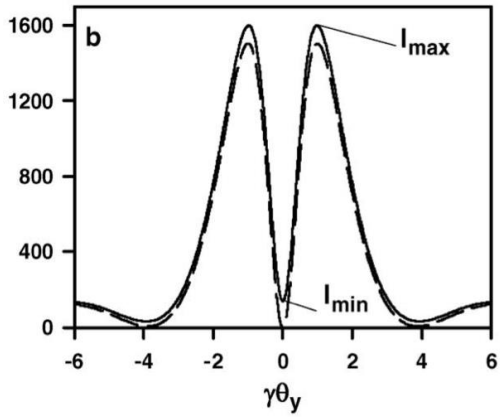


- Slit: **56um**
- Beam size: **1 µm**
- 30 shots statistics
- **Position resolution: about 1 µm**
- Steering magnet to scan the beam inside the slit

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**

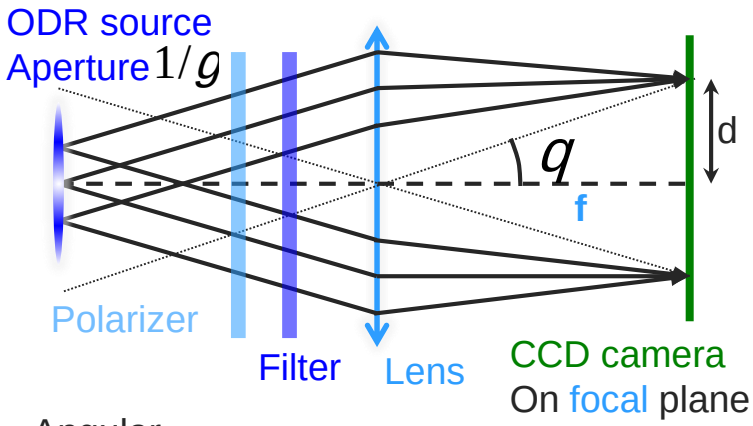




An **horizontal slit** is used to measure a **vertical beam size**.

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

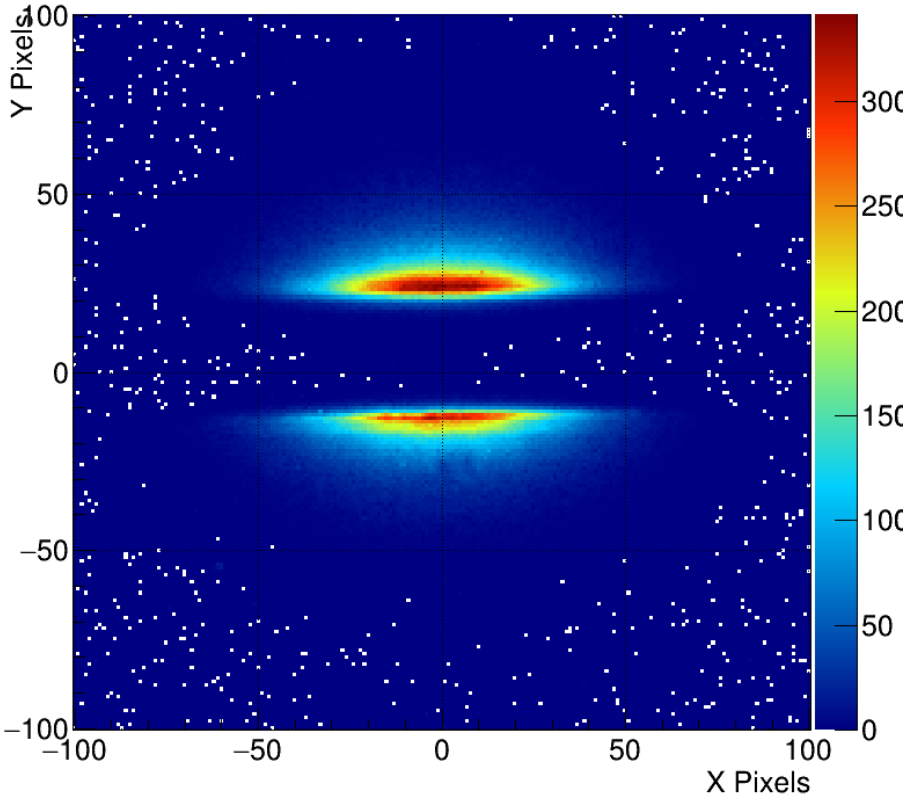
The **angular distribution** is obtained using a camera located at the back focal plane of an optical **lens** (effective infinity)



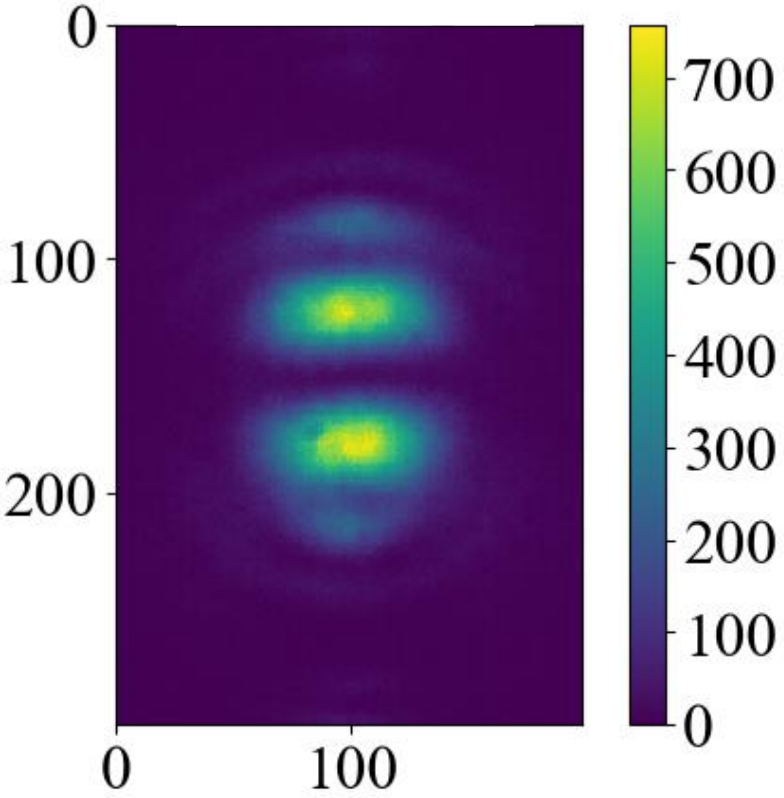
Angular magnification $q = \arctan(d/f)$

ODRI at ATF2

Direct Image of the ODRI



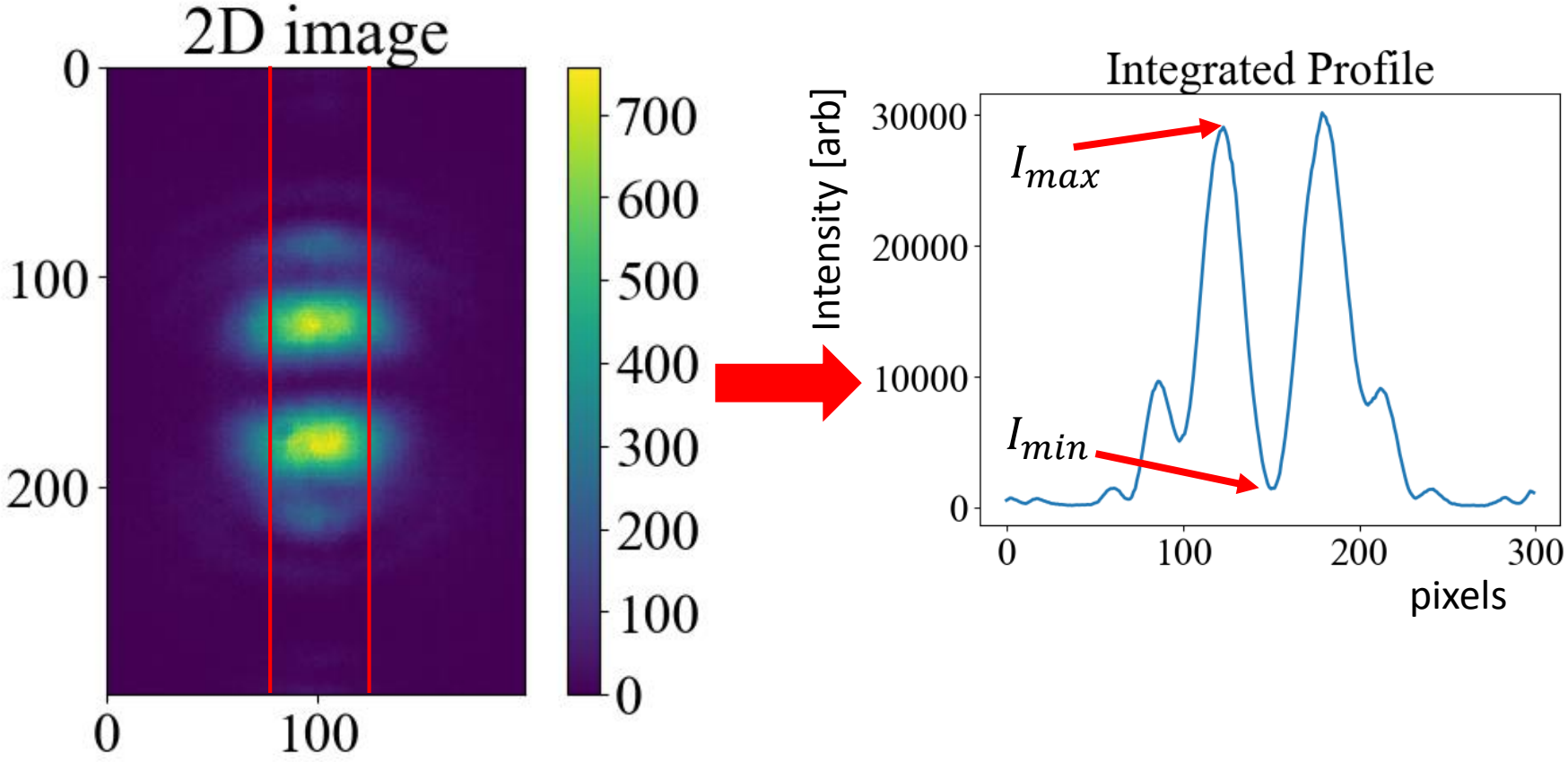
2D Angular distribution of the ODRI



CERN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

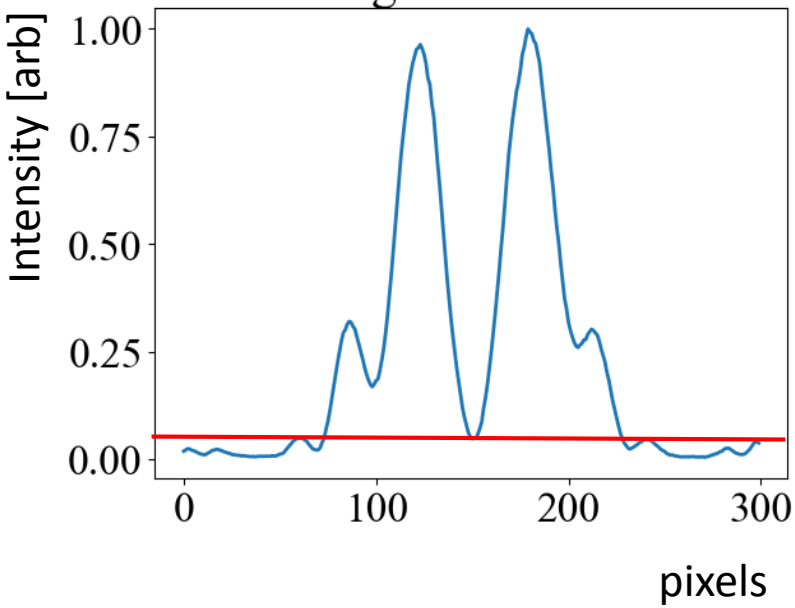
ODRI at ATF2


2D image
0
100
200
0
100
700
600
500
400
300
200
100
0
Integrated Profile
Intensity [arb]
30000
20000
10000
0
I_{max}
I_{min}
0
100
200
300
pixels

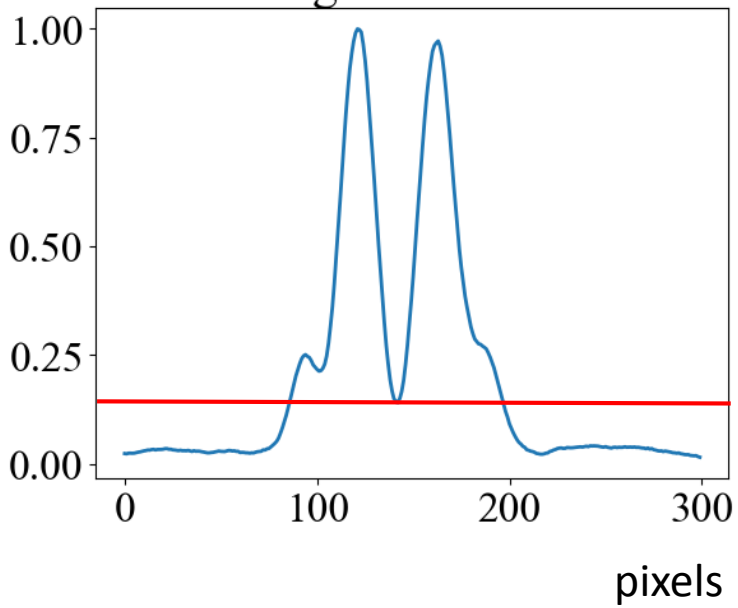
ODRI at ATF2

mask $= 100.0\ \mu m$, target $= 49.7\ \mu m$, same beam condition

$\lambda = 400\ nm$



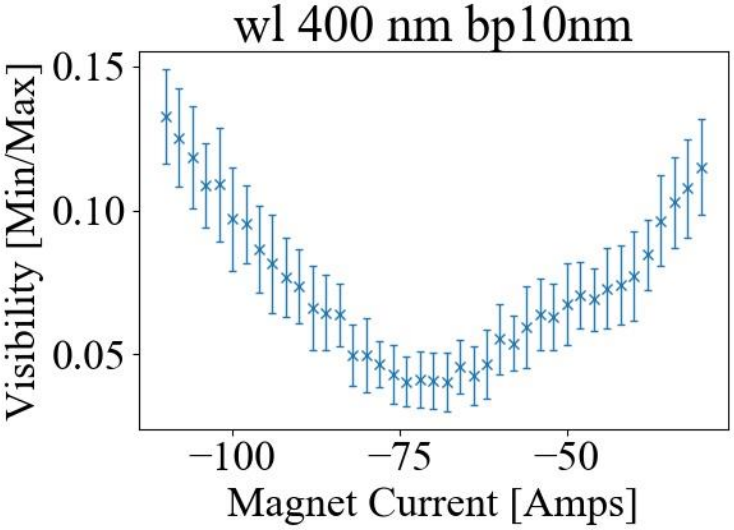
$\lambda = 250\ nm$



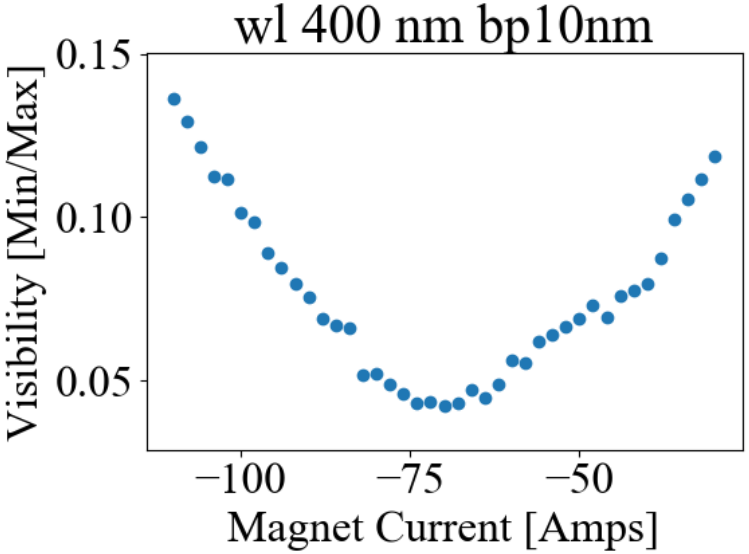
ODRI at ATF2

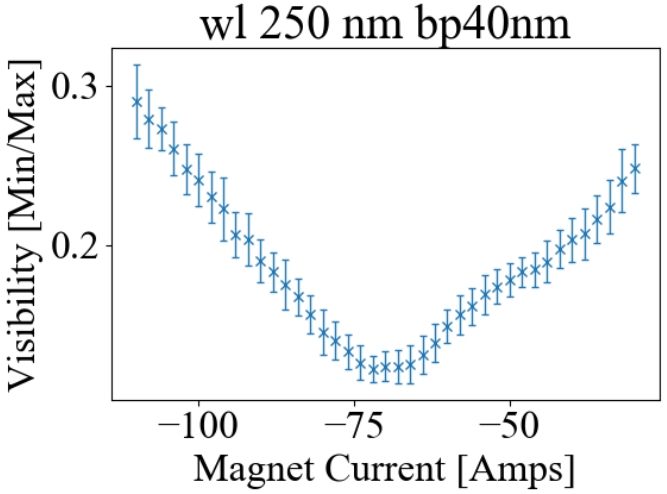
Quadrupole scan around beam waist

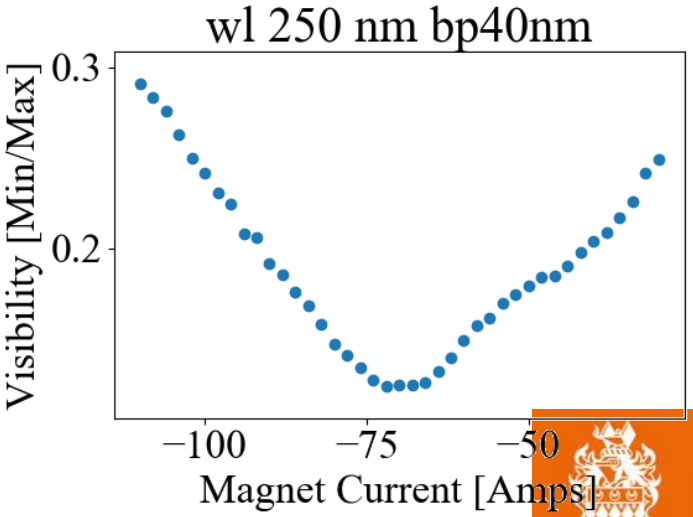
Single image acquisition



Averaged image over 100 pulses







CERN

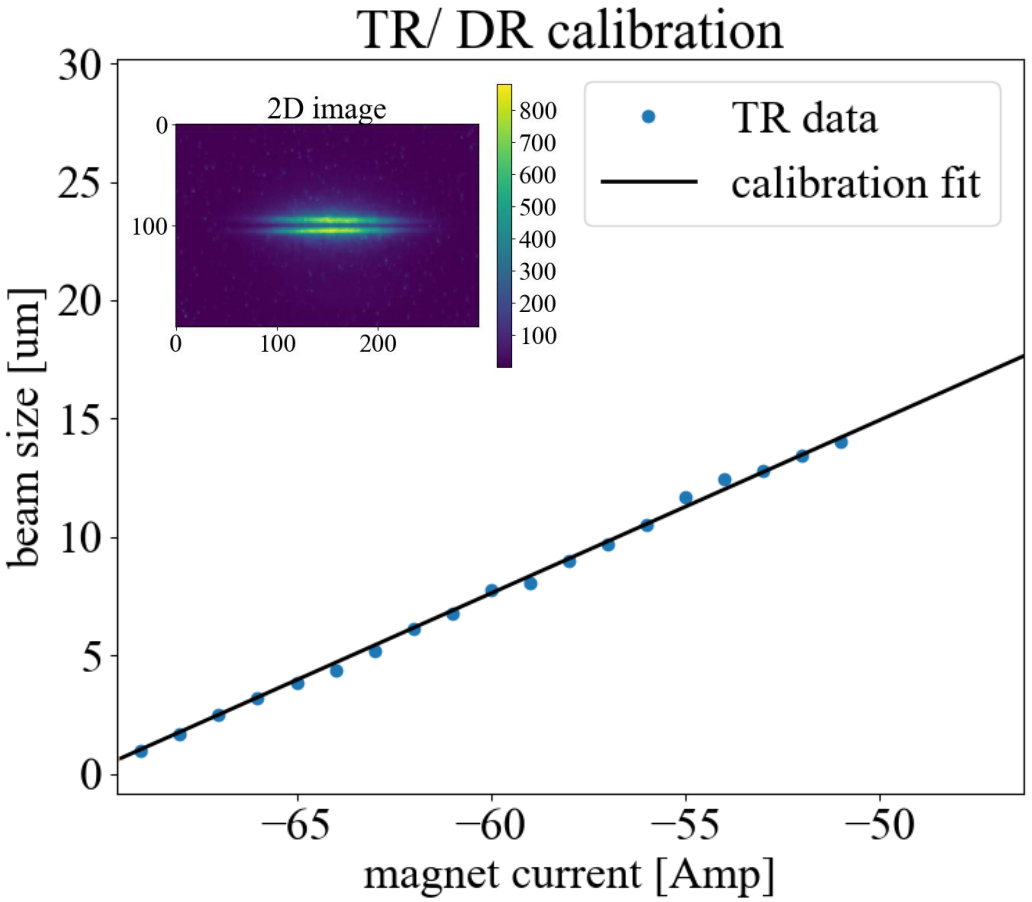
ROYAL HOLLOWAY UNIVERSITY OF LONDON

OTR Beam size calibration

The side mirrors of the ODR slit were used to record reference TR beam size measurement using PSF technique[1]

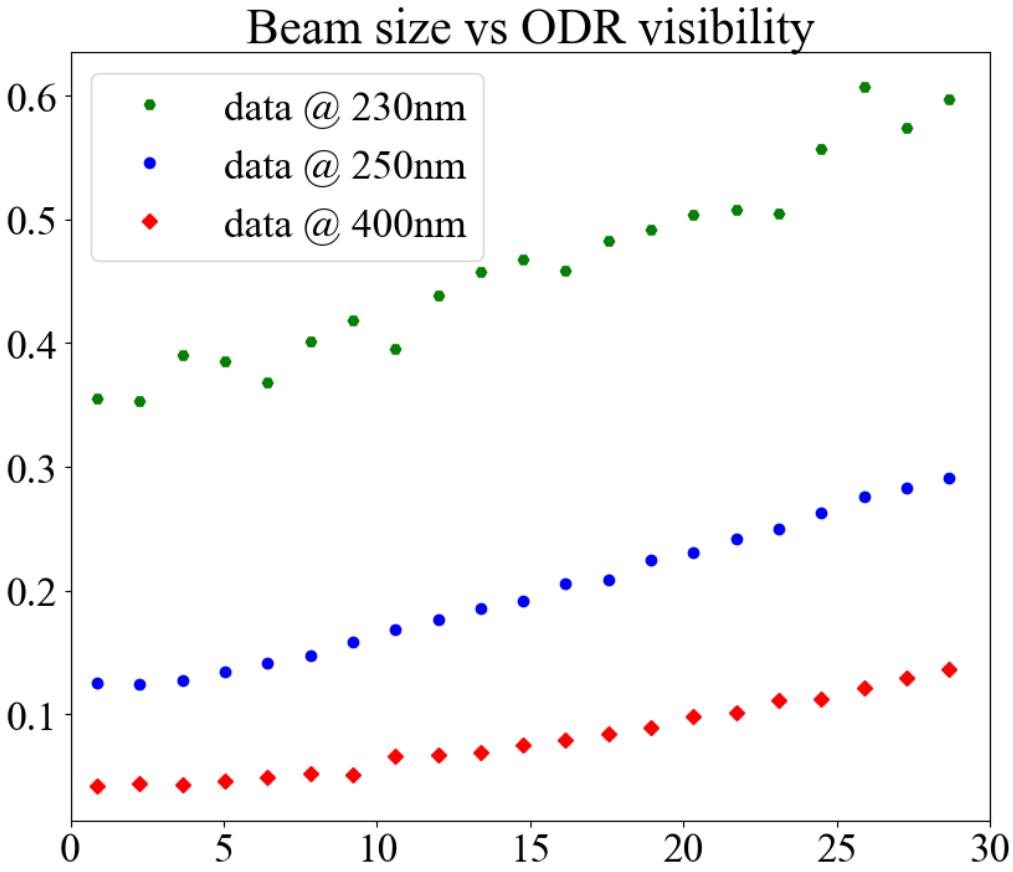
OTR PSF could be used in CLIC/ILC with single bunch.

Then ODR can be used for full beam charge.



1. Very high resolution optical transition radiation imaging system: Comparison between simulation and experiment, B. Bolzon et al., 2015, Physical Review Special Topics - Accelerators and Beams , 18

ODRI at ATF2



As expected sensitivity increase with decreasing wavelength, good sensitivity for UV down to 5 micrometers.

Previous measurements minimum was 14 μm^2

mask $= 100.0\ \mu m$, target $= 49.7\ \mu m$

2. Beam-Size Measurement with Optical Diffraction Radiation at KEK Accelerator Test Facility, P. Karataev et al., 2004, Phys. Rev. Lett., 93

Summary

2017 ODRI Achievements

- Imaging the DR source to monitor the position of the beam during angular data acquisition => beam in the slit centre
- Data successfully collected also in the far UV (230/250nm)
- Sensitivity to micrometer scale beam size has been demonstrated down to 5 um
- Beam orbit optimisation needed to minimize SR contribution
- Mask contribution to block SR has been observed

CERN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Outlook

- Reproduce measurement for small beam size during February operations:
  - DR in the visible and UV
  - Cross-calibration with OTR PSF for micron size beam
- Test of horizontal mask to reduce SR contribution
- Test of iris on the lenses to reduce background light form other mirrors on target

CERN

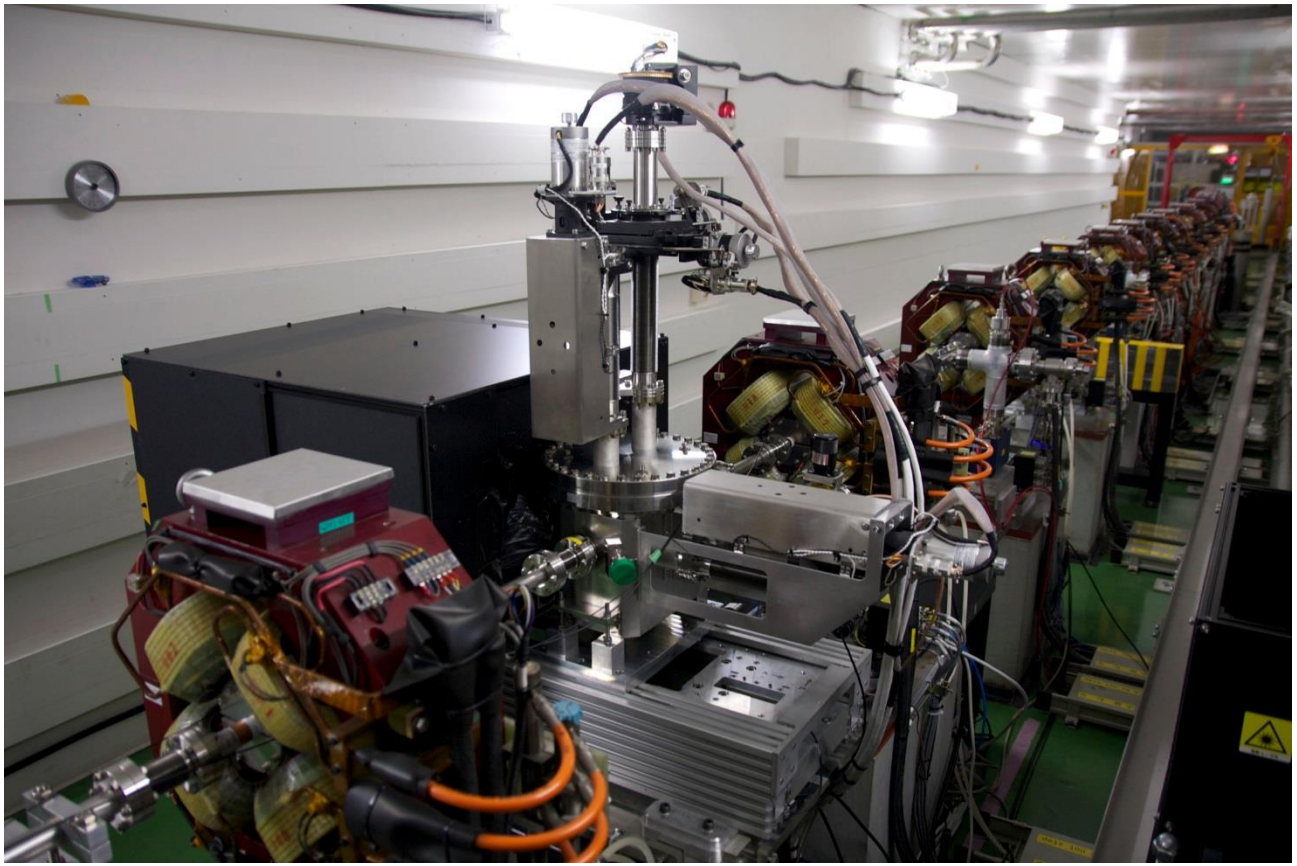
ROYAL HOLLOWAY UNIVERSITY OF LONDON

Thank you for your attention!

Back-up slides

ODRI experiment at KEK ATF2

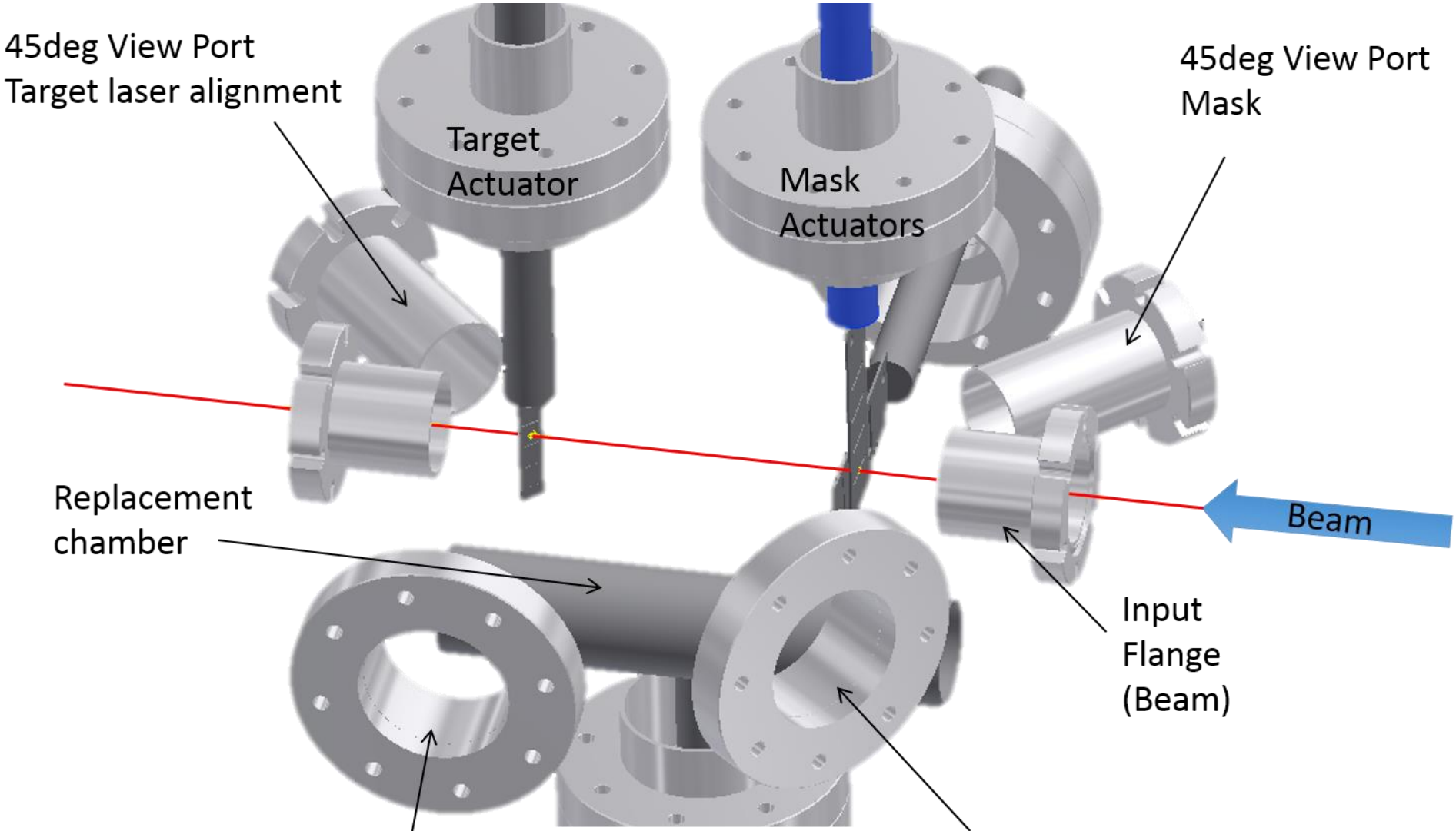
Experiment installed at ATF2 in February 2016, in the laser-wire previous location where vertical beam can be focused to < 1um



CERN

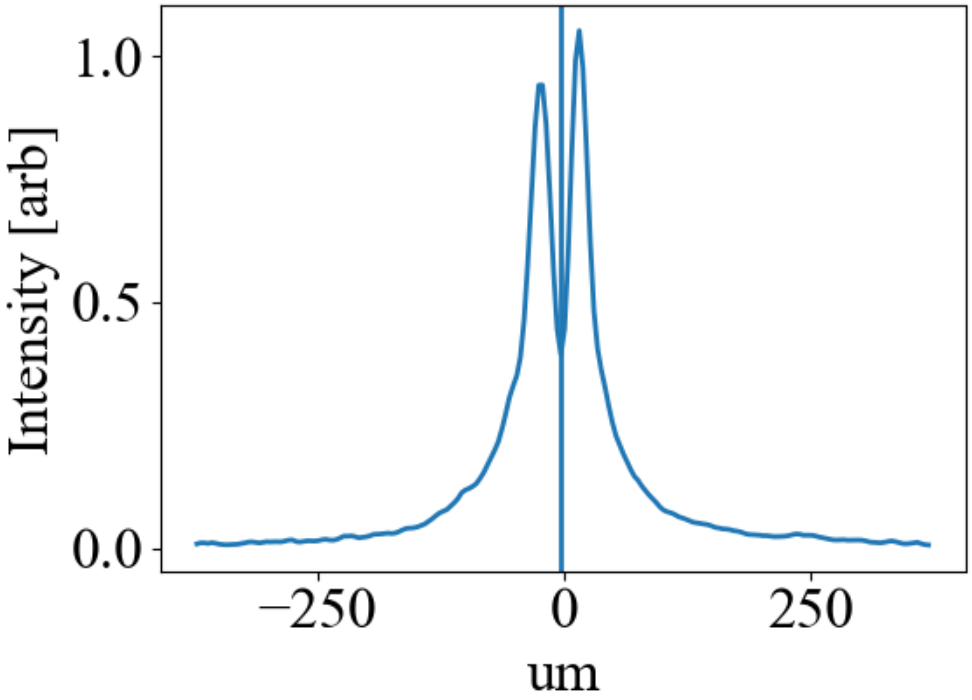
ROYAL HOLLOWAY UNIVERSITY OF LONDON

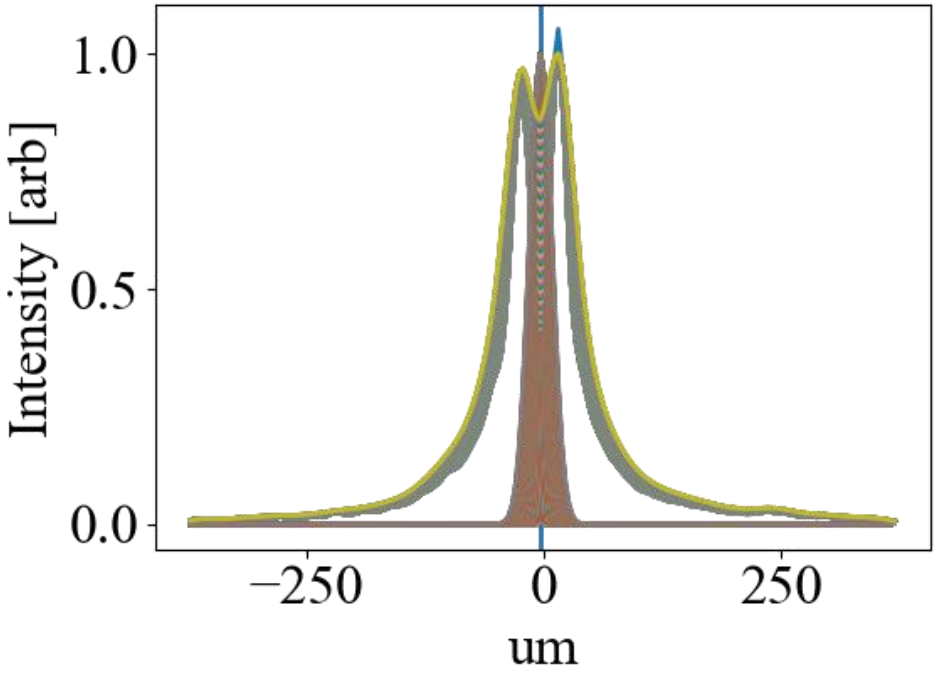
ODRI experiment at KEK ATF2

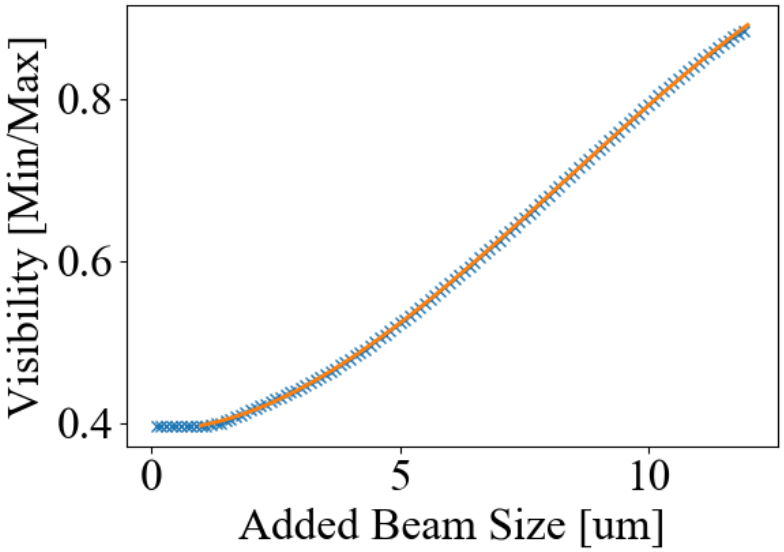


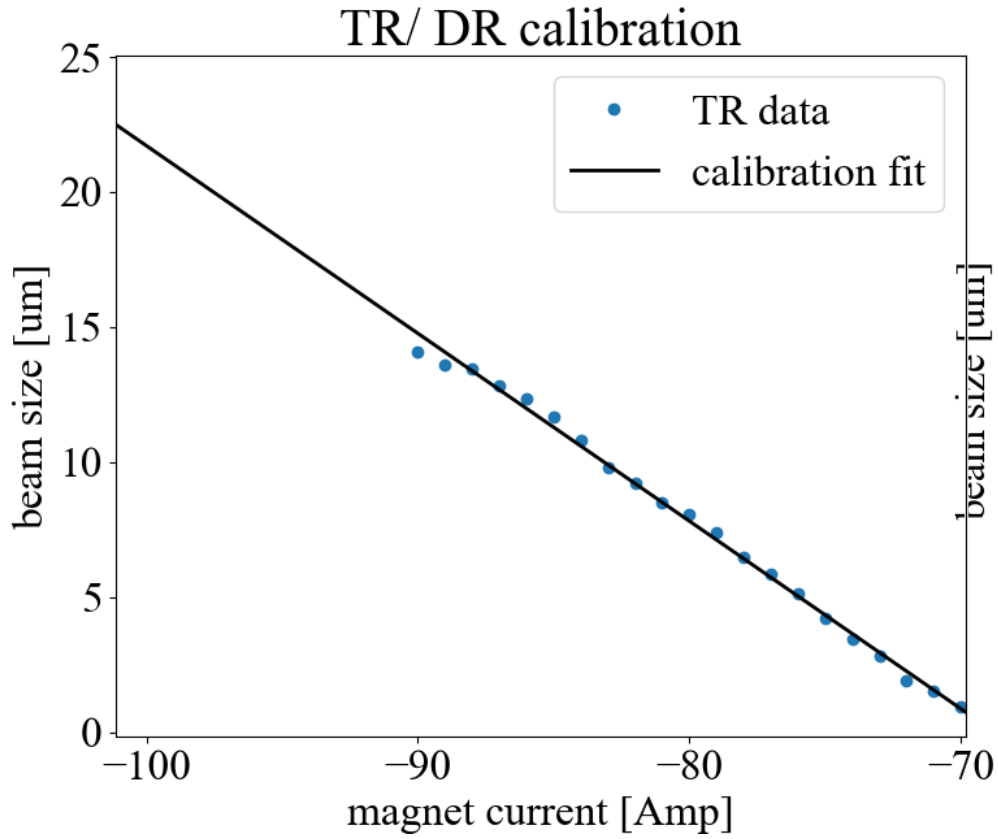
CERN

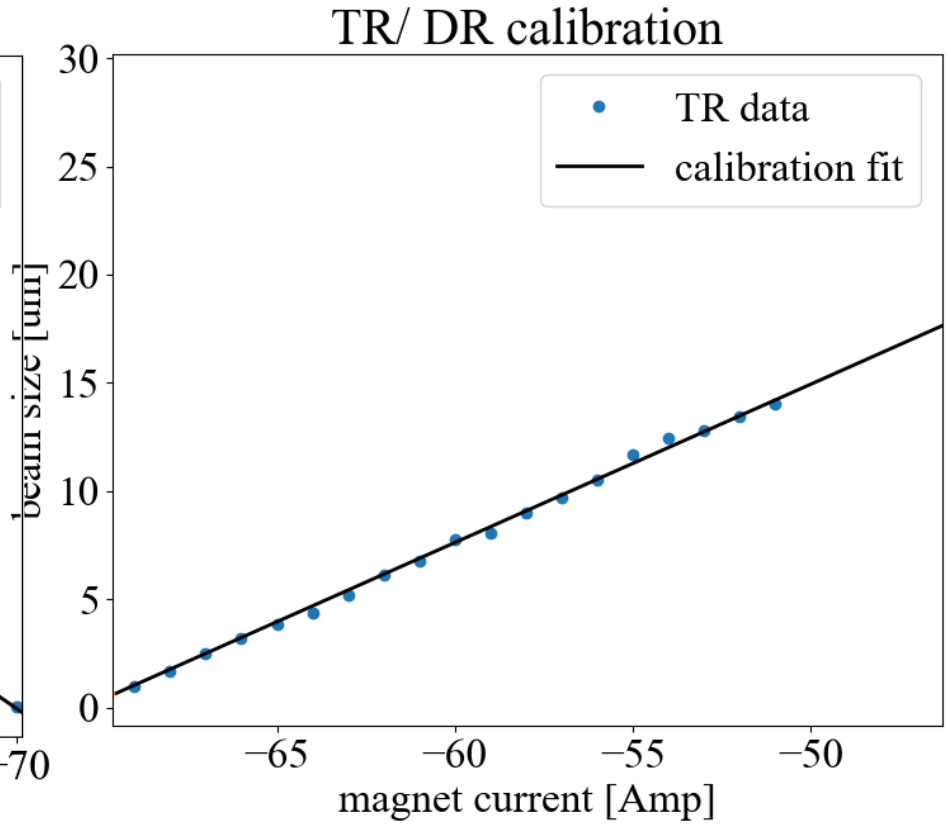
ROYAL HOLLOWAY UNIVERSITY OF LONDON


Intensity [arb]
1.0
0.5
0.0
−250
0
250
um


Intensity [arb]
1.0
0.5
0.0
−250
0
250
um

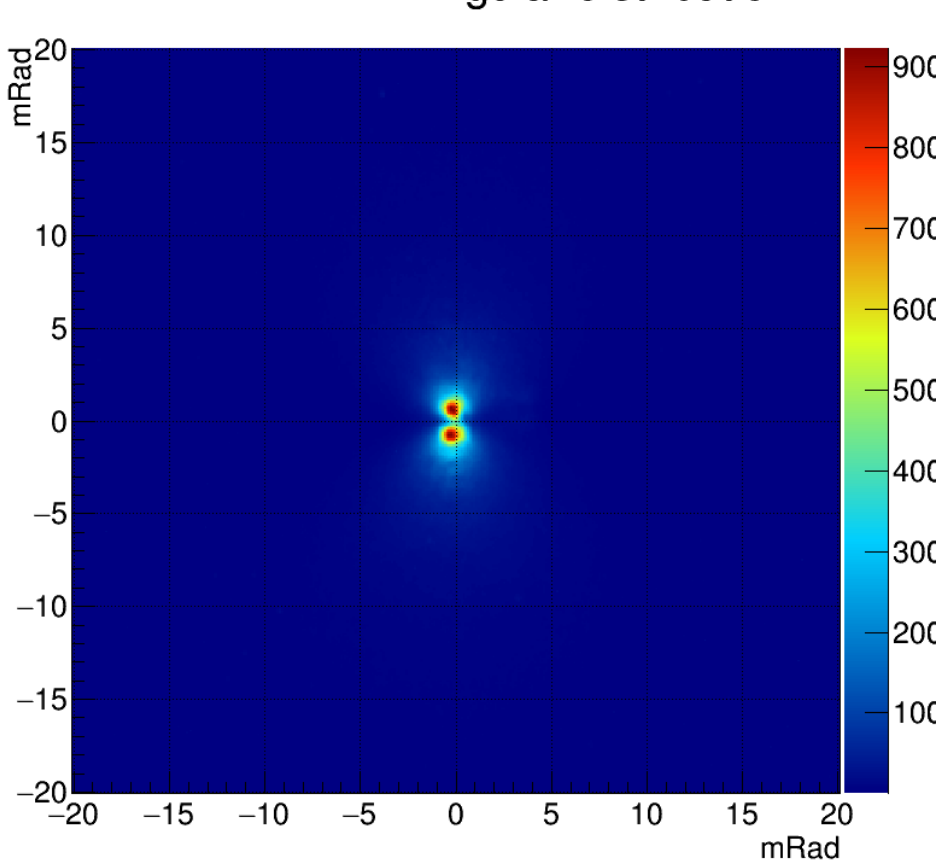

Visibility [Min/Max]
0.8
0.6
0.4
0
5
10
Added Beam Size [um]

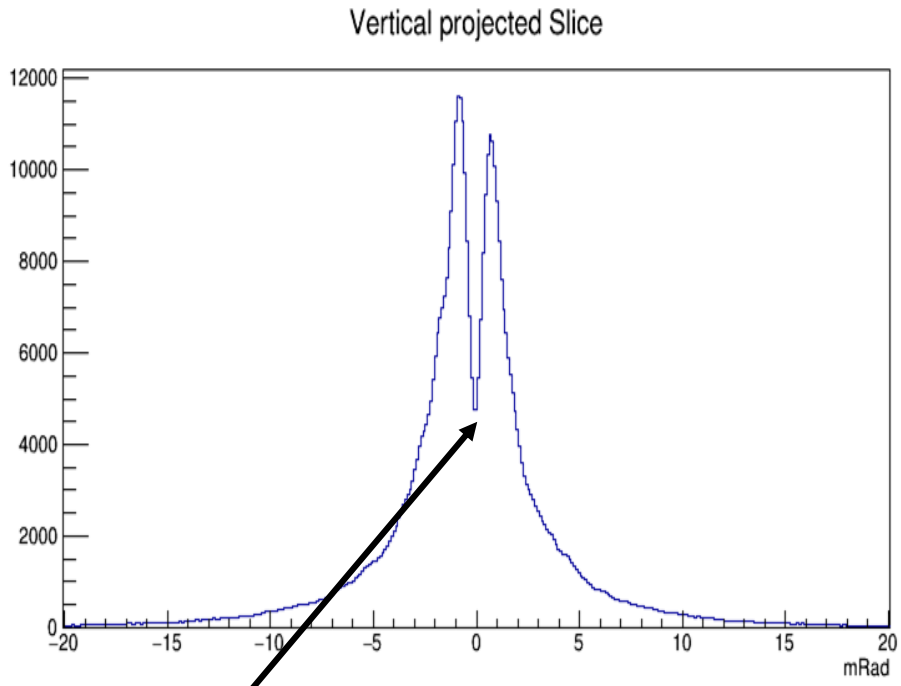

TR/ DR calibration
TR data
calibration fit
beam size [um]
magnet current [Amp]
25
20
15
10
5
0
−100
−90
−80
−70


TR/ DR calibration
TR data
calibration fit
beam size [um]
magnet current [Amp]
30
25
20
15
10
5
0
−65
−60
−55
−50

Synchrotron Radiation Contribution at ATF2

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



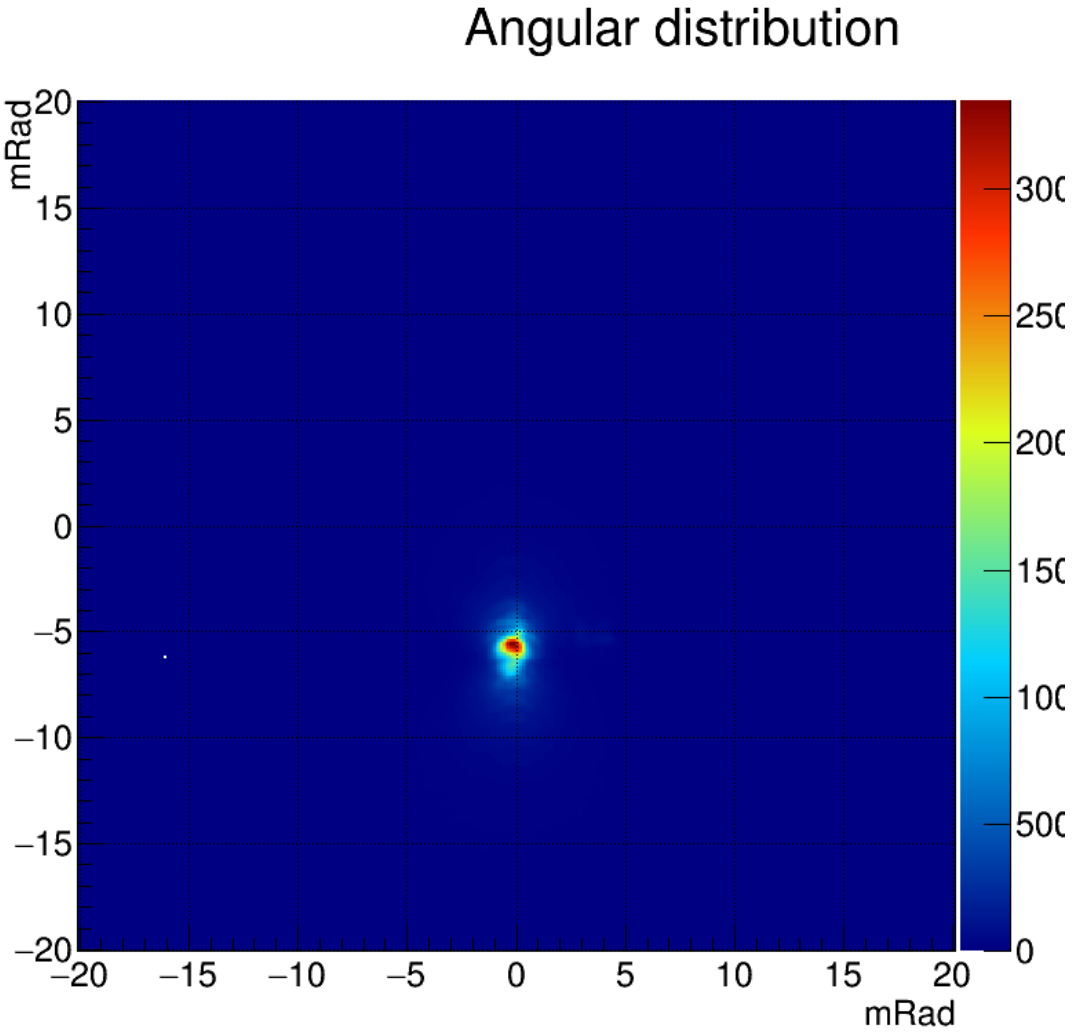


Minimum too high = high SR Contribution

Synchrotron Radiation Contribution at ATF2

OTR Angular pattern with steering magnet off and without mask

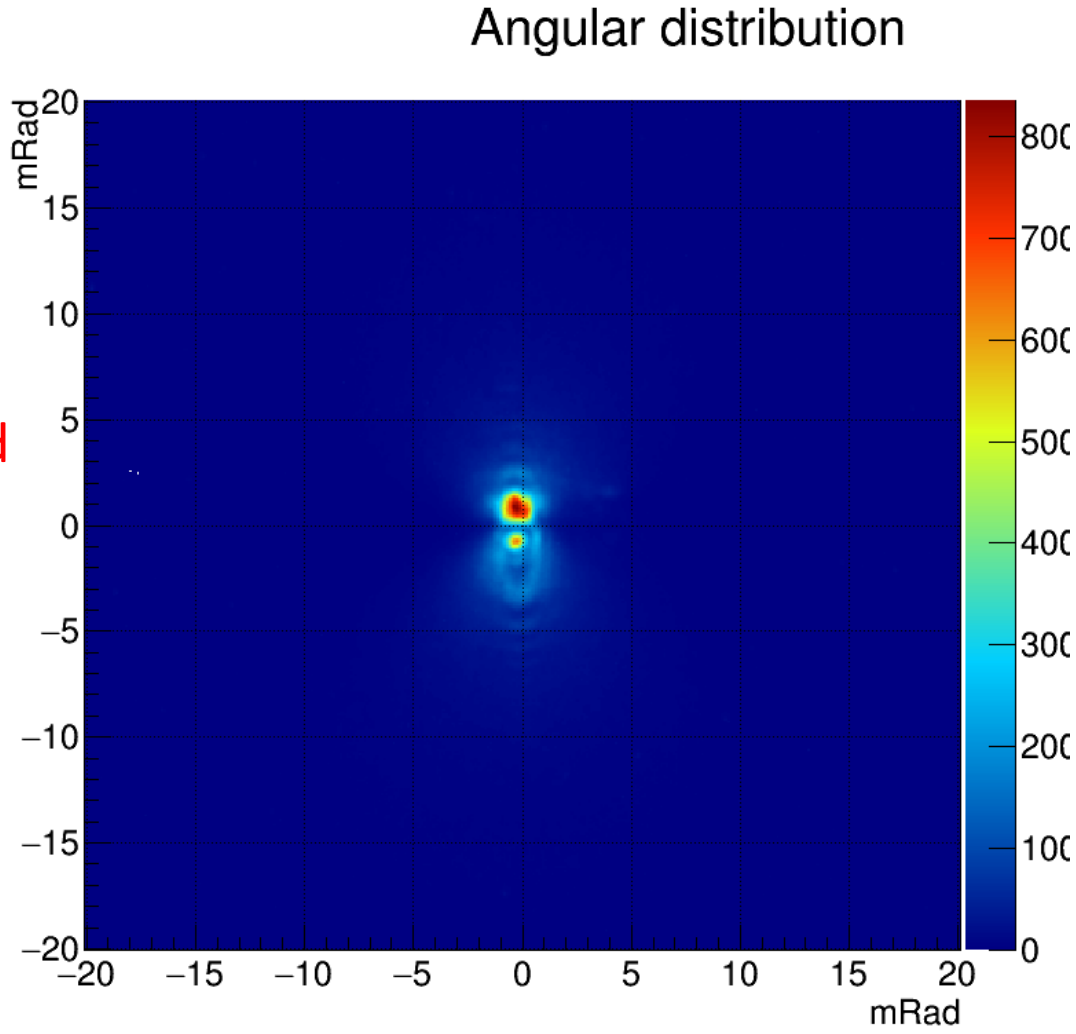
Strong Contribution, impossible to evaluate the TR angular pattern



Synchrotron Radiation Contribution at ATF2

Insertion of the mask (582 µm aperture)

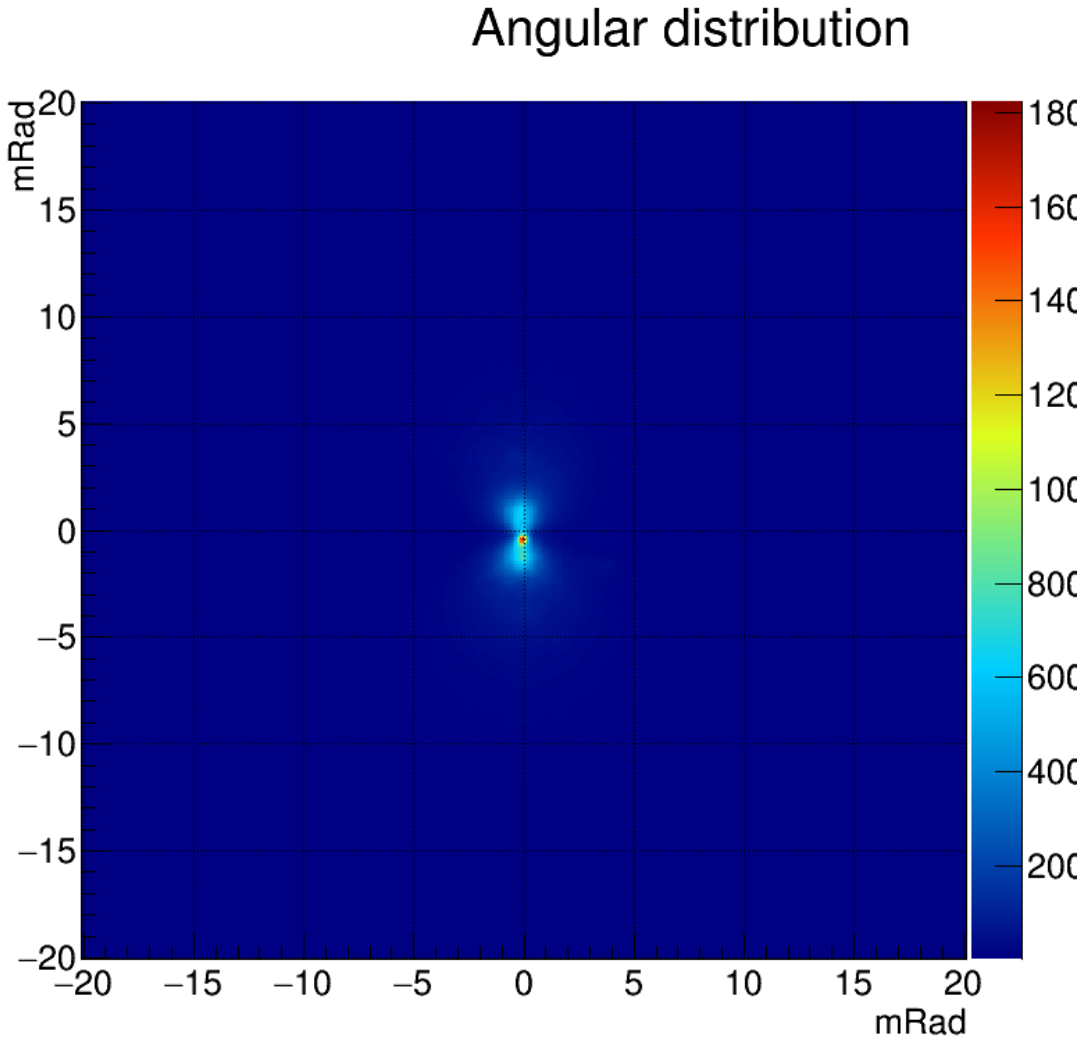
Although mask is inserted there is a strong Interference between Synchrotron Radiation and Transition Radiation because beam is not centered in the quadrupole (QM14FF) before the target.



Synchrotron Radiation Contribution at ATF2

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

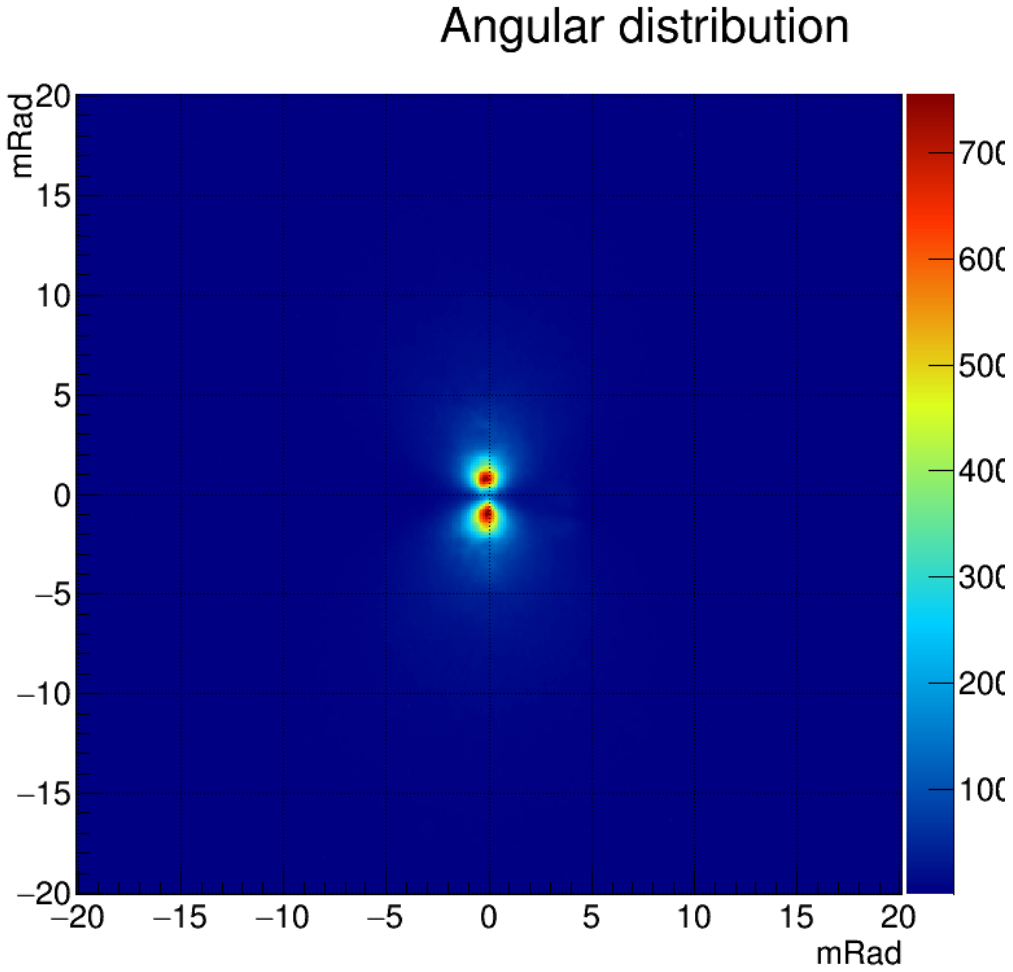
Better profile but peak present in the middle of the pattern due to Synchrotron Radiation generated upstream in the beam-line



Synchrotron Radiation Contribution at ATF2

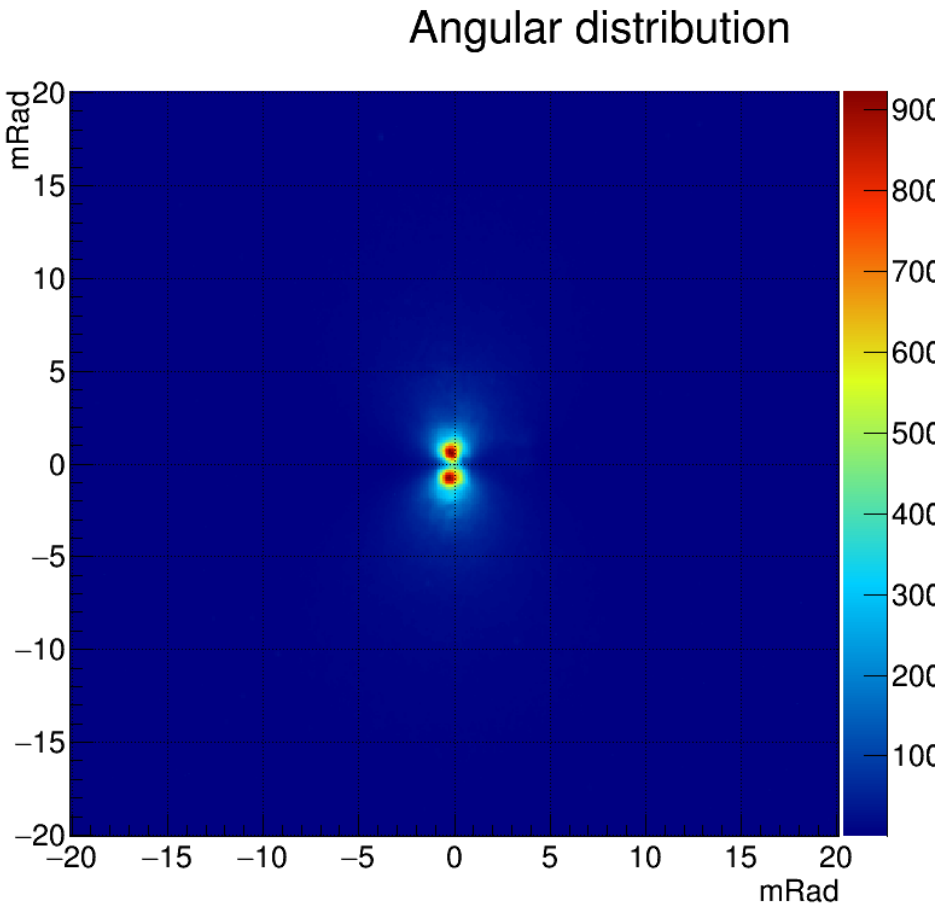
Re insertion of the mask (582 µm)

Maximum reduction of the Synchrotron Radiation Contribution

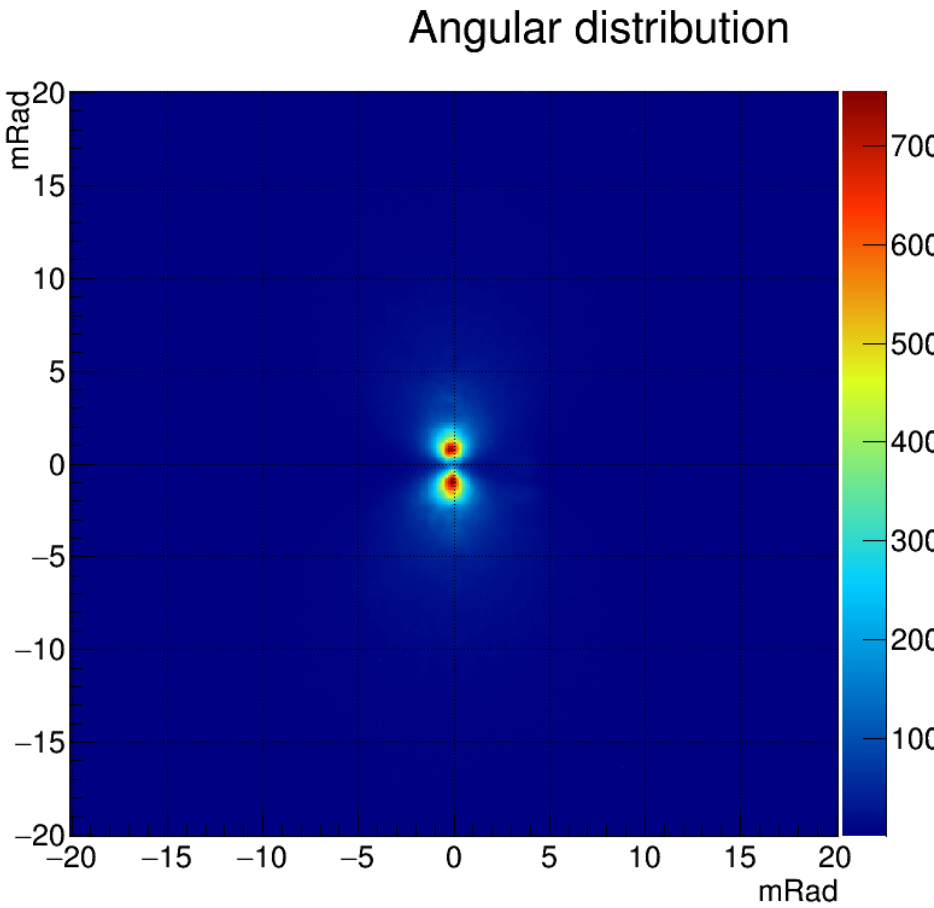


Synchrotron Radiation Contribution at ATF2

Before beam line optimization

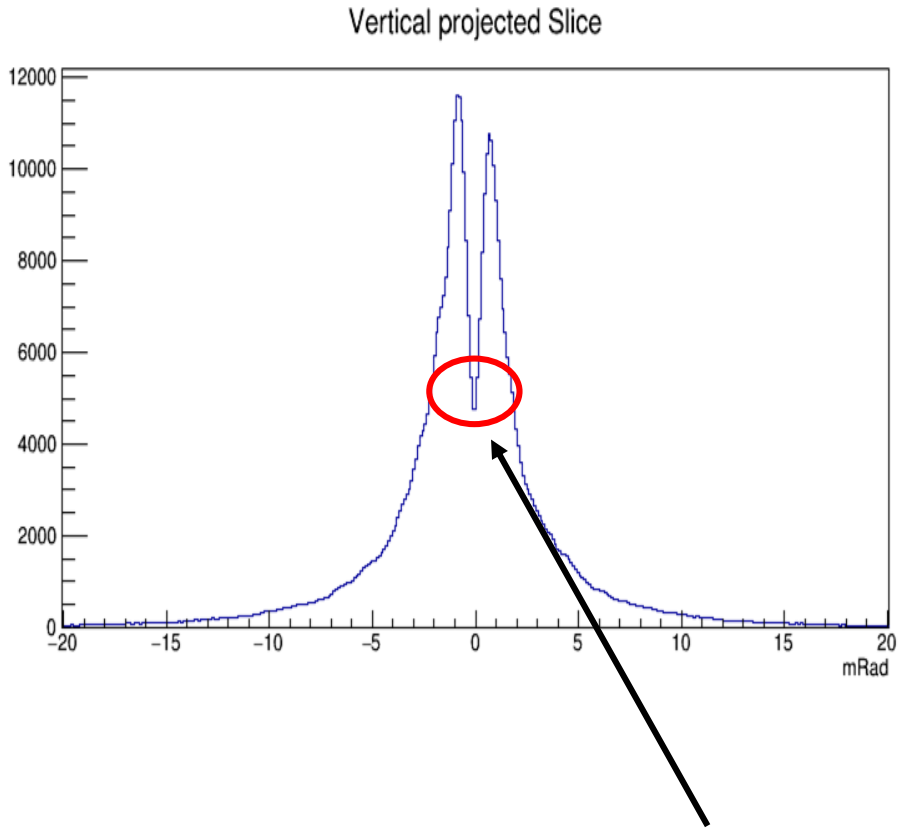


After beam line optimization

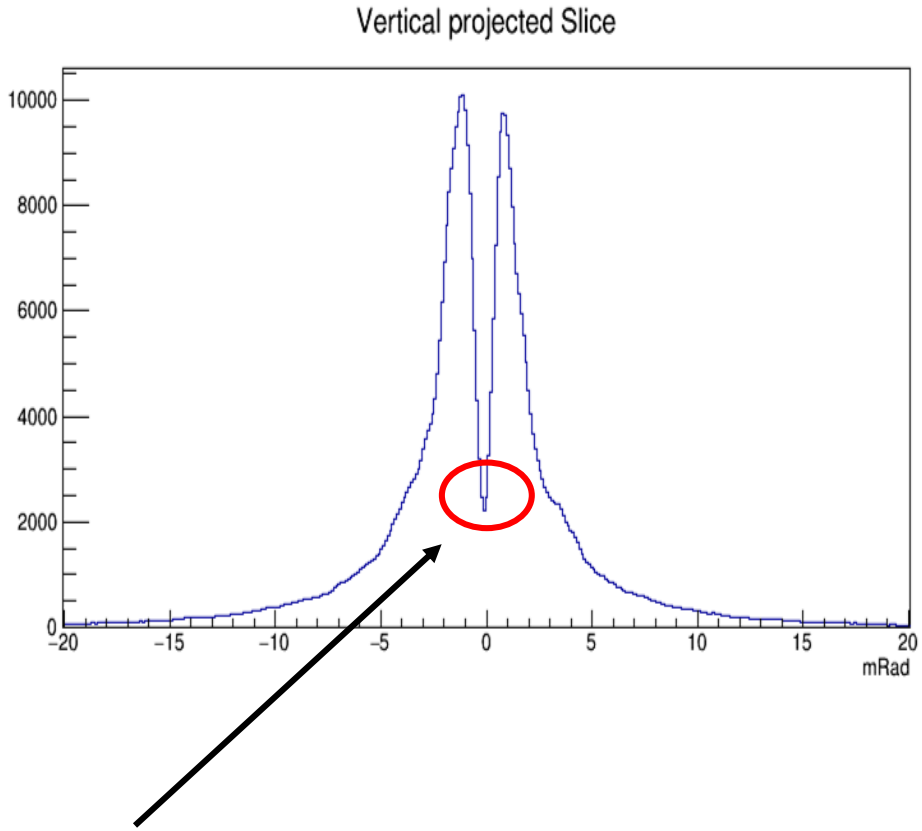


Synchrotron Radiation Contribution at ATF2

Before beam line optimization



After beam line optimization

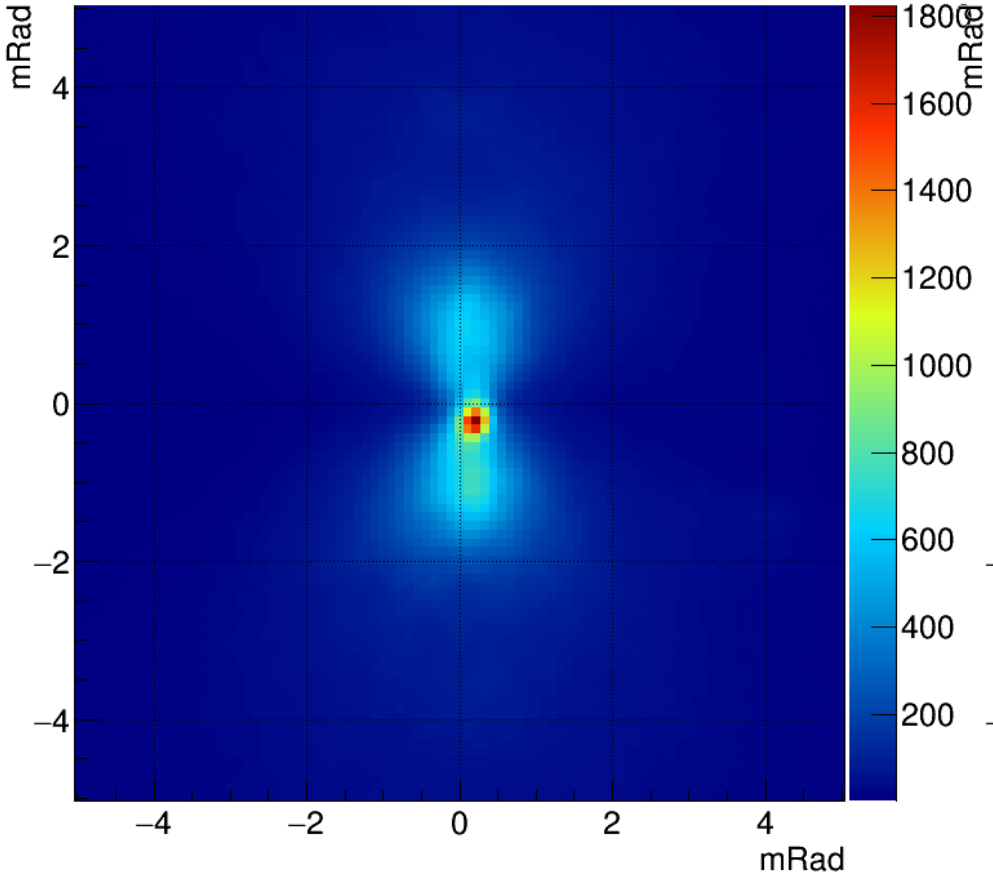


Lower minimum = lower SR Contribution

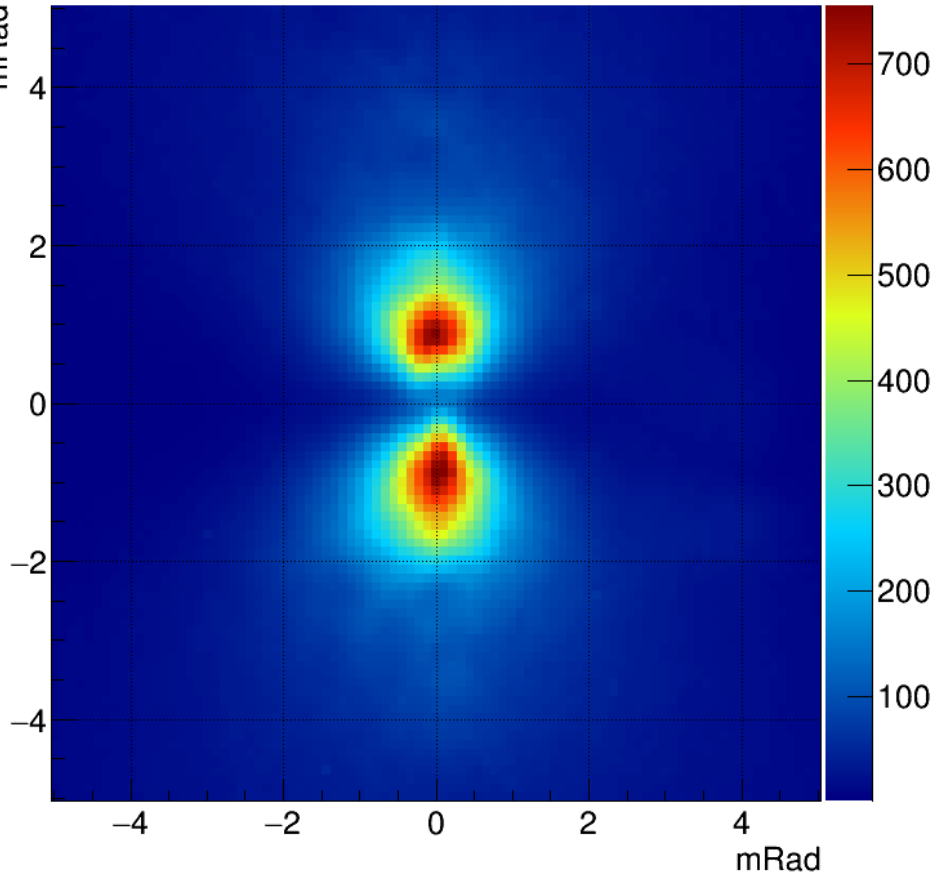
Binning limit the minima => bigger angular magnification needed

Synchrotron Radiation Contribution at ATF2

TR 2D profile without mask



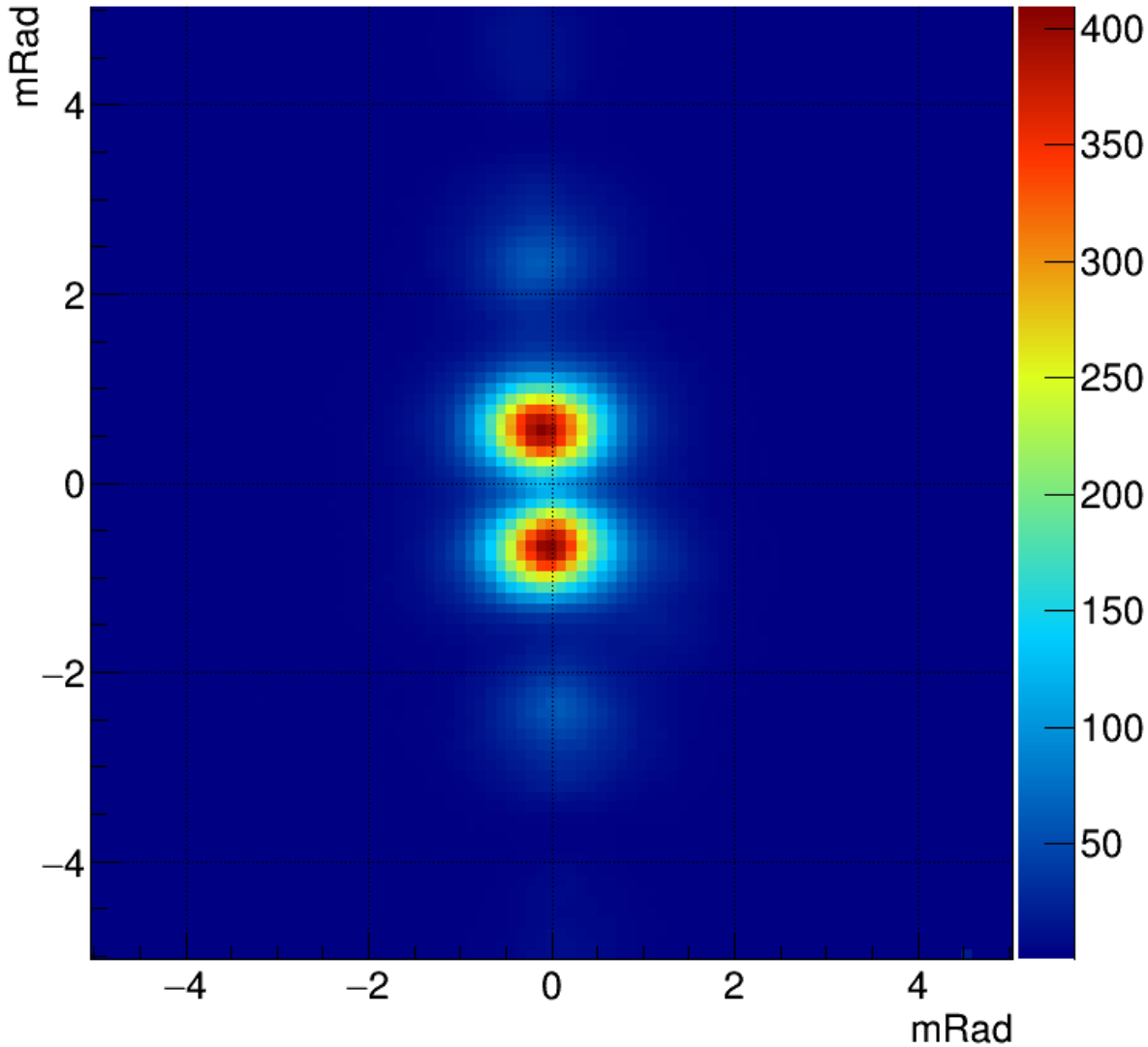
TR 2D profile with mask



CERN

ROYAL HOLLOWAY UNIVERSITY OF LONDON

ODRI 2D angular intensity



$\lambda = 450\ nm$, beam size = 15.0 μm,
mask $= 582.0\ \mu m$, target $= 201.7\ \mu m$

ODRI simulation

$$E_{y,i} = \left\{ \frac{e^{-[(a_1/2)+z_1](f-ik_y)}}{f-ik_y} - \frac{e^{-[(a_1/2)-z_1](f+ik_y)}}{f+ik_y} \right\} -$$

$$-e^{i\Phi_0} \left\{ \frac{e^{-[(a_2/2)+z_2](f-ik_y)}}{f-ik_y} - \frac{e^{-[(a_2/2)-z_2](f+ik_y)}}{f+ik_y} \right\} \text{[1]}$$

With a_1 mask slit aperture, a_2 target slit aperture , z_1 and z_2 particle position at mask and slit, γ relativistic factor, λ observation wavelength, β ratio between the particle velocity and the speed of light, $k = (2\pi/\lambda)$, $\eta = (k/\beta\lambda)$, $\mathrm{f} = \sqrt{k_x^2 + \eta^2}$, $k_x = k \sin\theta \cos\phi$, $k_y = k \sin\theta \sin\phi$, $\Phi_0 = \eta d(1 - \beta \cos\theta)$, θ and ϕ angular coordinates in the observation plane.

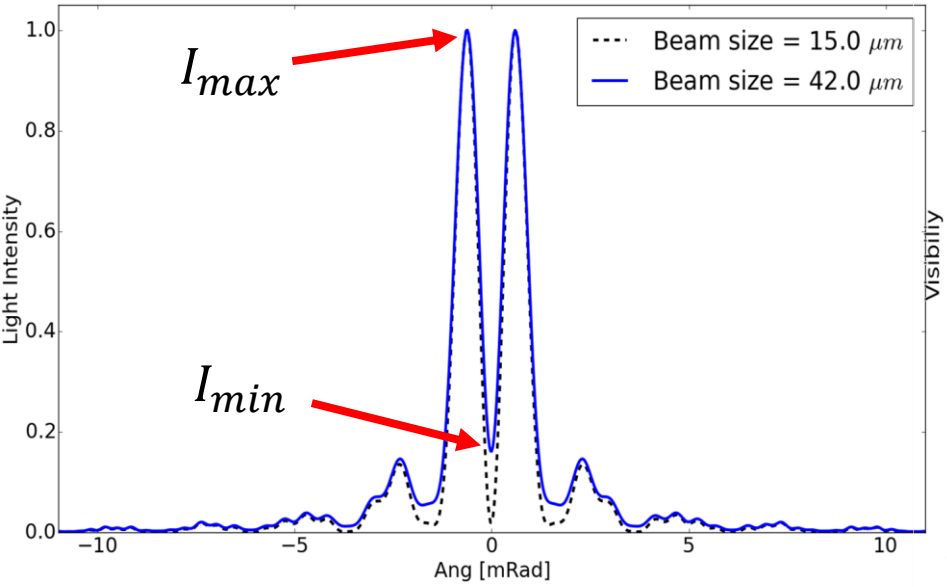
[1] A. Cianchi et al., *Non-intercepting electron beam size monitor using optical diffraction radiation interference*, Phys. Rev. ST Accel. Beams 14,102803 (2011)

ODRI simulation

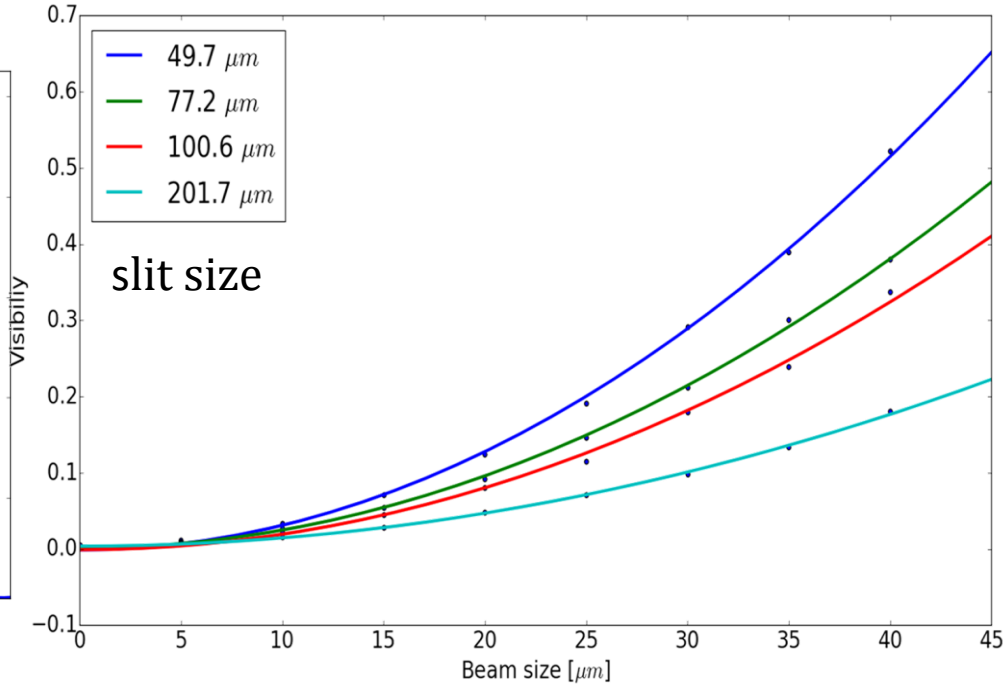
$$I = \sum_i^n E_{y,i}^2$$

$$n = 5000$$
$$d = 130\ mm$$

Projected Vertical Polarization Component (PVPC) [2] of DR angular Intensity for 2 beam sizes



Simulated Visibility vs Gaussian beam size for different target slit sizes



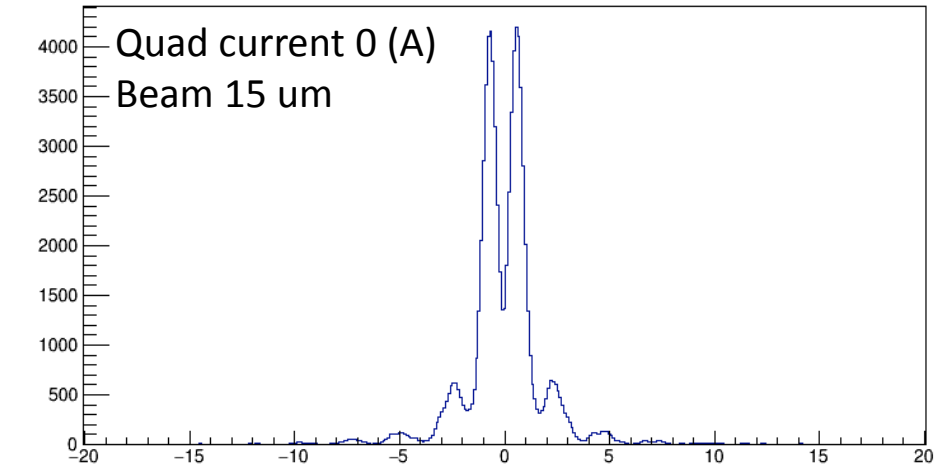
$\lambda = 450\ nm$, mask $= 582.0\ \mu m$, target $= 201.7\ \mu m$

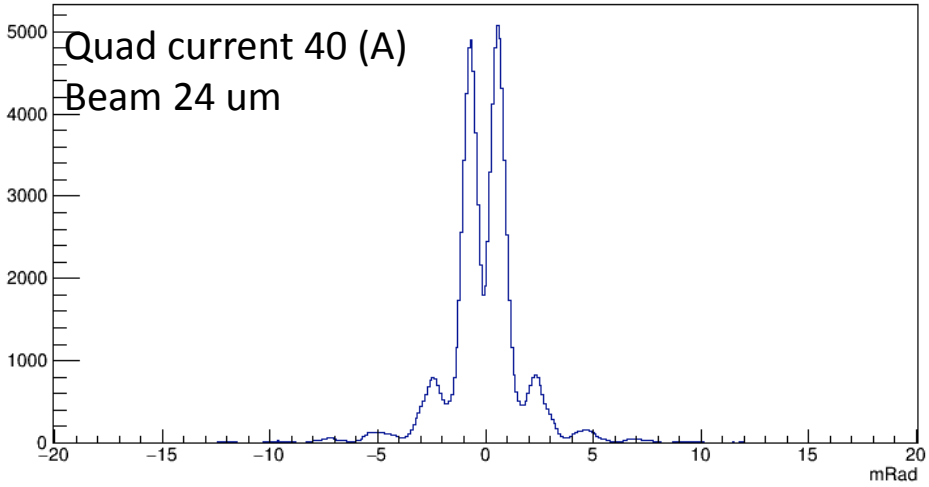
$$Visibility = I_{min}/I_{max}$$

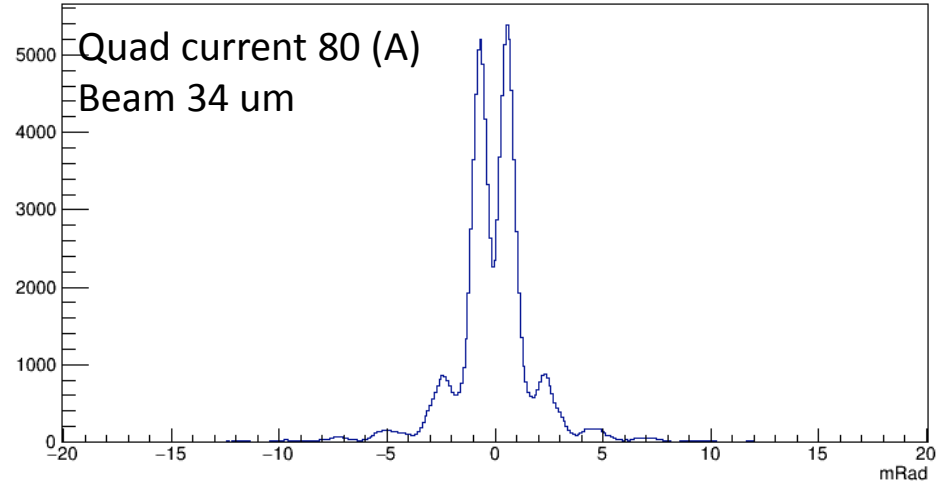
[2] P. Karataev, et al, *Beam Size Measurements with Optical Diffraction Radiation at KEK Accelerator Test Facility,* Phys. Rev. Lett. 93, 244802 (2004)

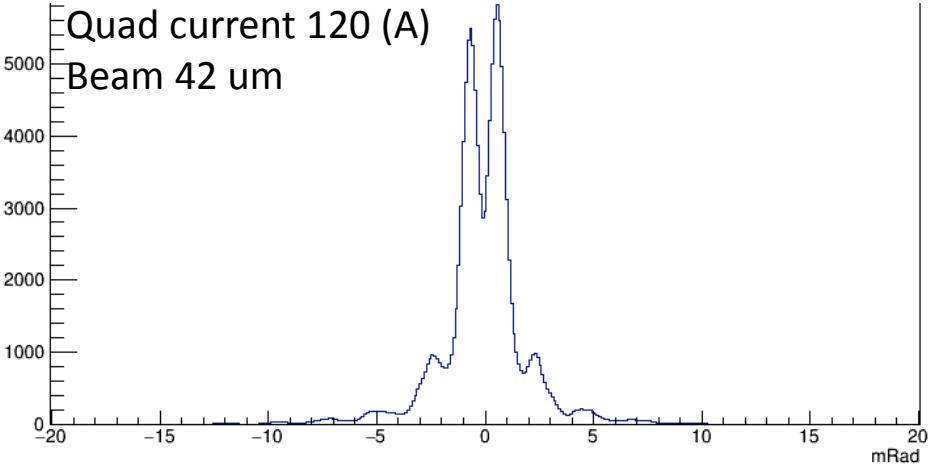
ODRI visibility Quad Scan

PVPC of DR angular intensity for different beam sizes









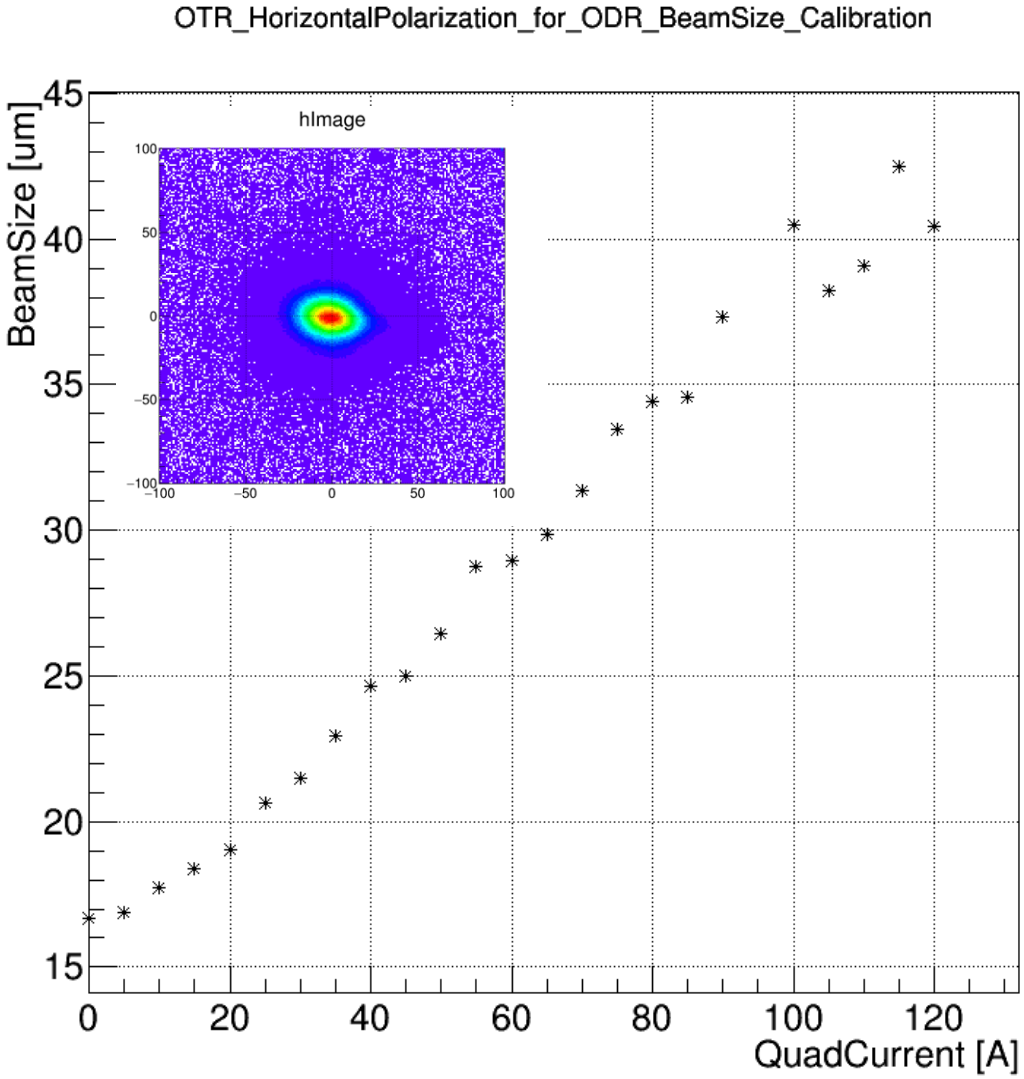
Filter:450nm Slit:201.7 µm Mask: 582 µm

OTR Beam size calibration

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

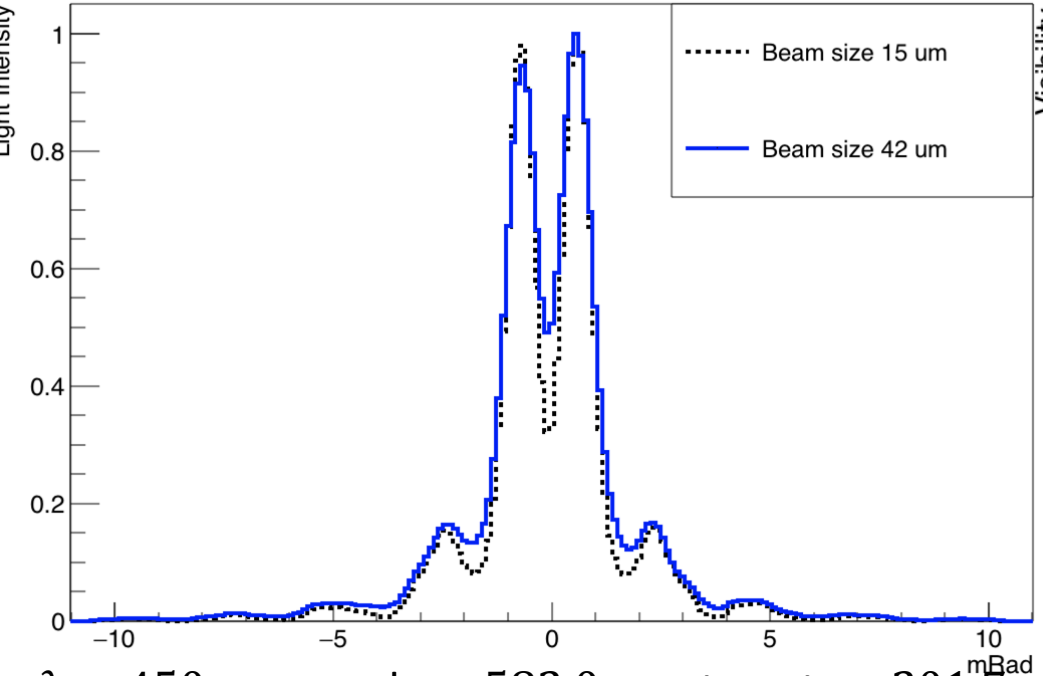
This could be done in CLIC/ILC using pilot beam (no target damage).

Then ODR can then be used for full beam charge.



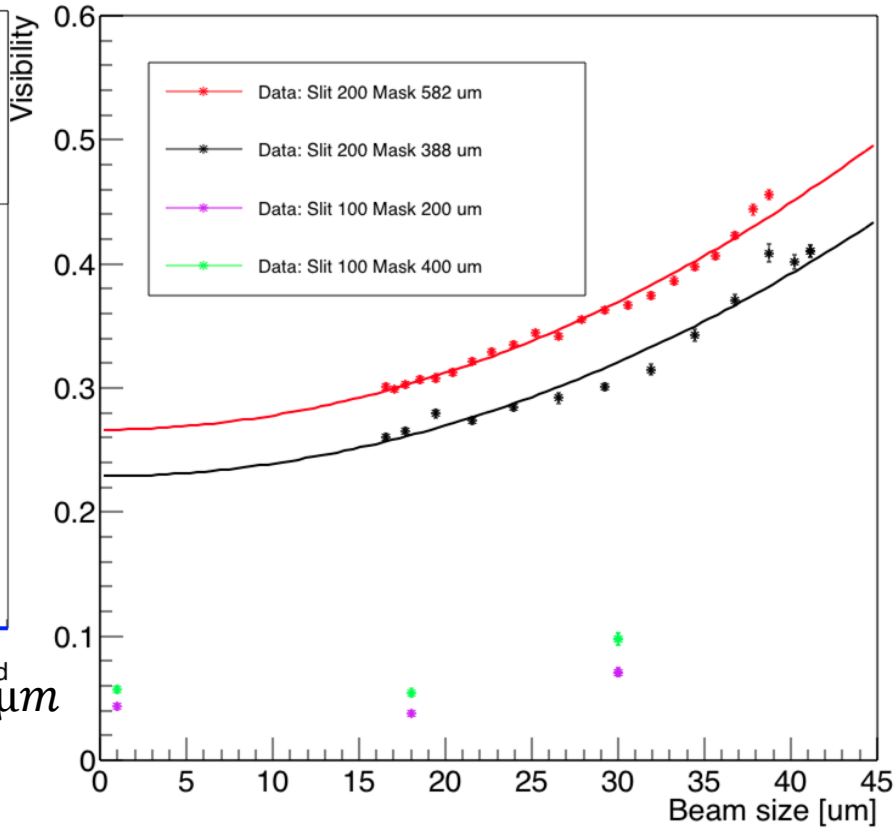
ODRI angular intensity

PVPC of DR angular intensity for 2 beam sizes



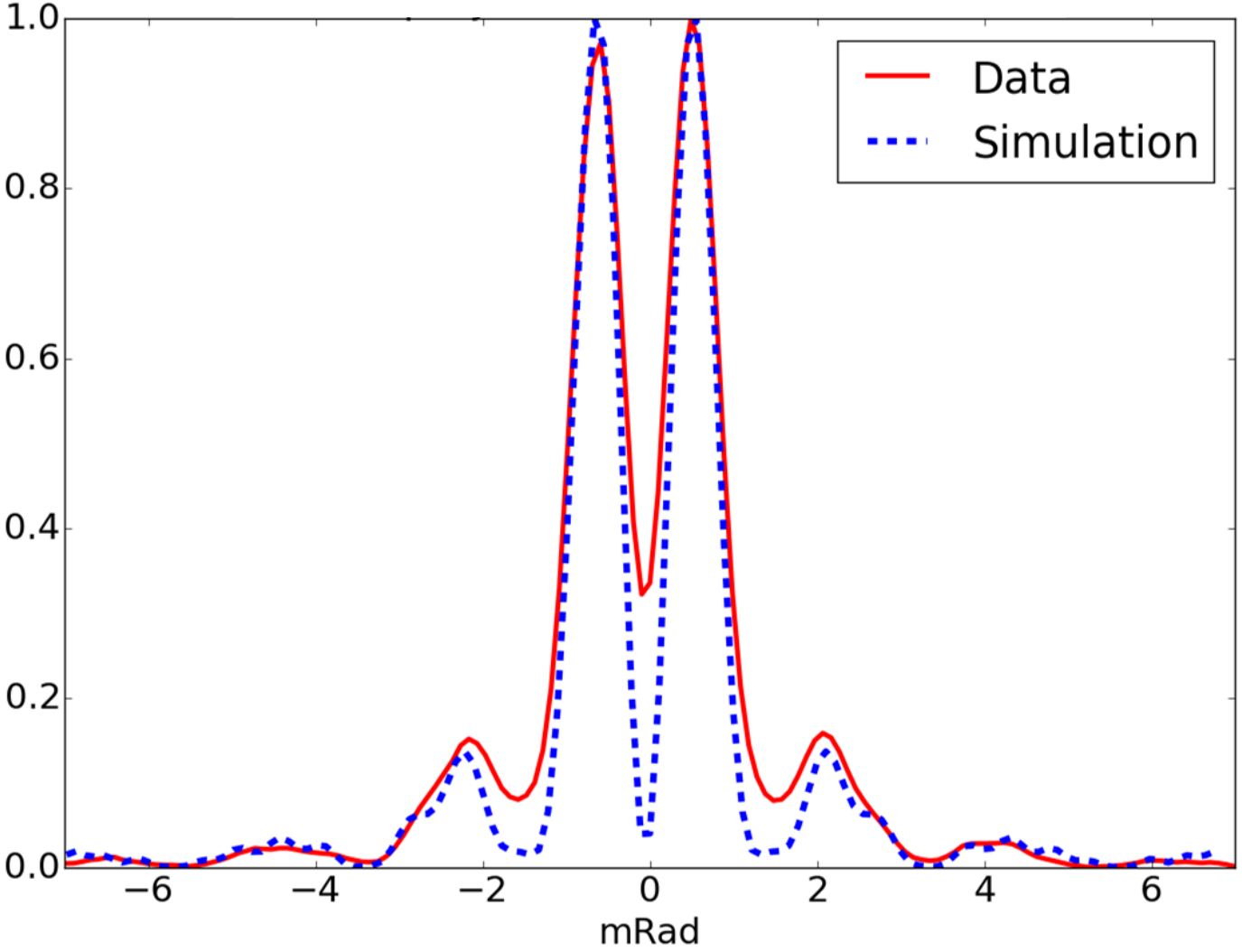
$\lambda = 450\ nm$, mask $= 582.0\ \mu m$, target $= 201.7\ \mu m$

Measured Visibility for different beam sizes and mask/target combination



ODR angular data vs simulation

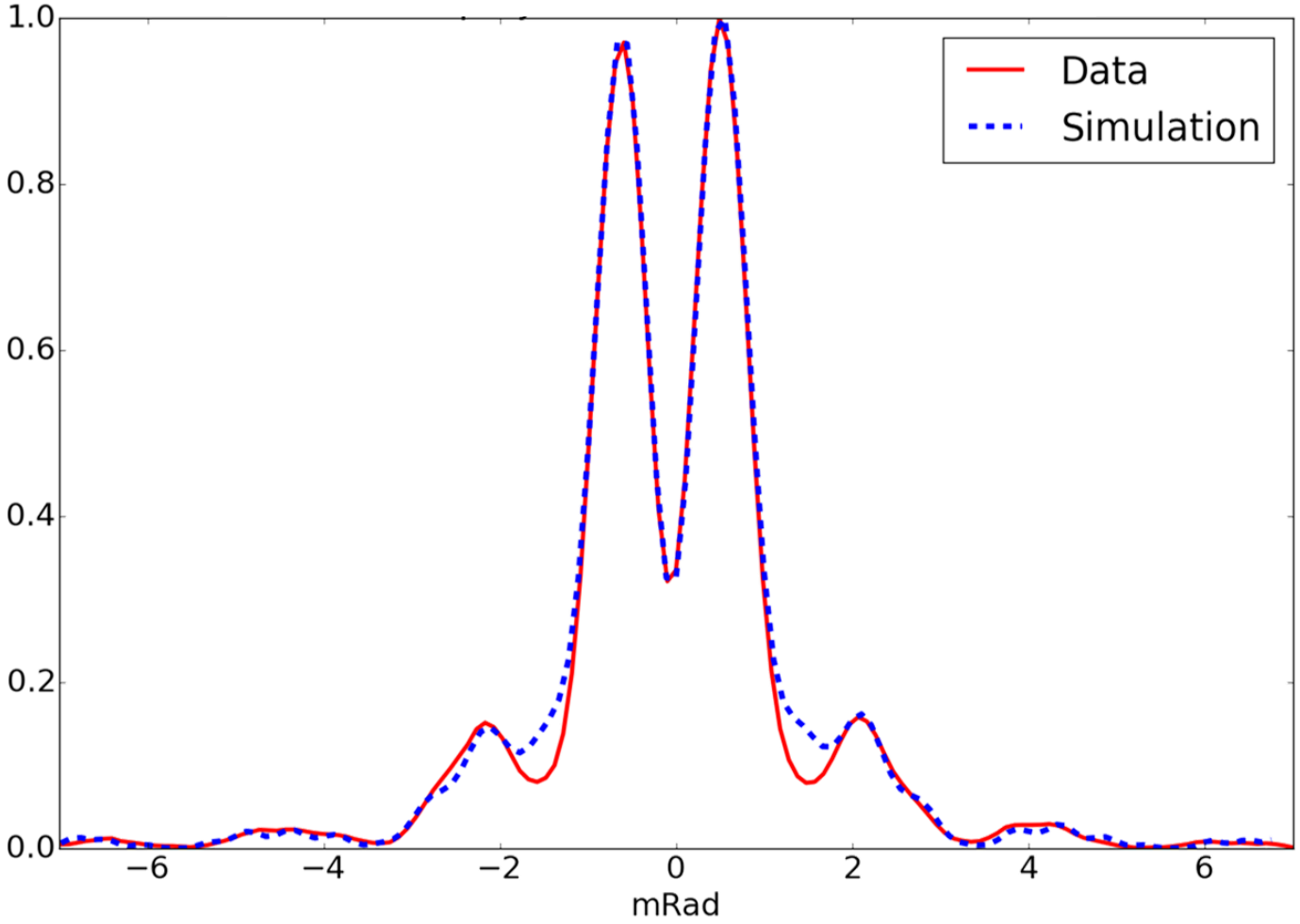
$\sigma = 15\ \mu m, \lambda = 450\ nm$, mask $= 582.0\ \mu m$, target $= 201.7\ \mu m$



ODR angular data vs simulation

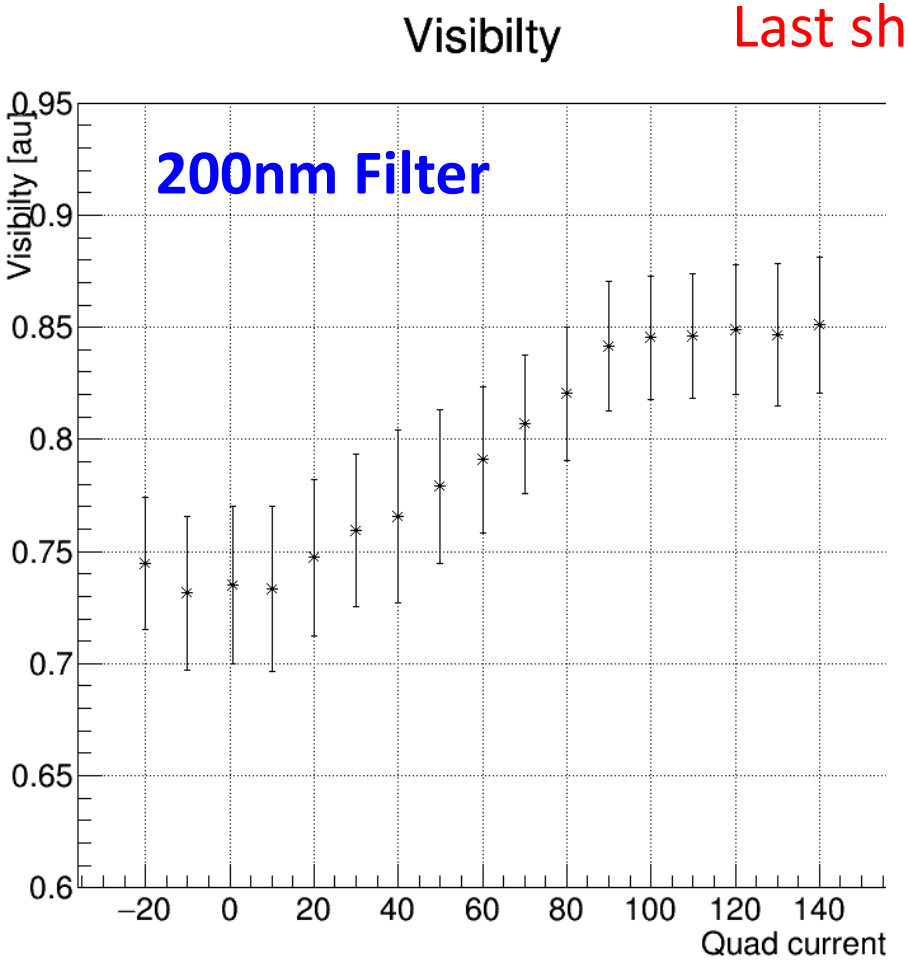
Synchrotron background Gaussian + 6 µm offset in the vertical alignment between slit and mask

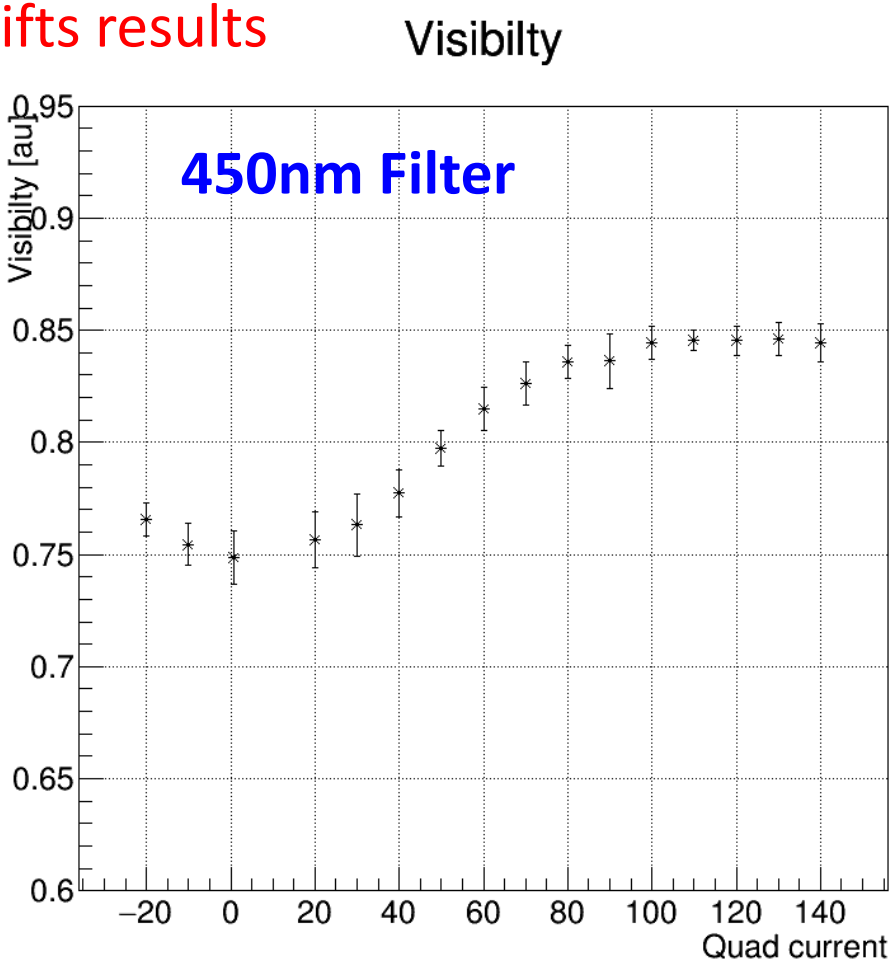
$\sigma = 15\ \mu m, \lambda = 450\ nm$, mask $= 582.0\ \mu m$, target $= 201.7\ \mu m$



ODR angular data

Last shifts results





mask $= 100\ \mu m$, target $= 77.2\ \mu m$

Minimum beam size around 5 um (not calibrated, OTR PSF)