OPTICAL TRANSITION RADIATION FOR NON-RELATIVISTIC ION BEAMS

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Outline

Motivation

Introduction

- OTR characteristics

GSI facility

- Beam characteristics
- Experimental setup

First results

- Signal strength
- Profile measurements
- Spectroscopy

Further studies

Summary

Motivation

Talk of A. H. Lumpkin at GSI seminar, February 2011:

Proposed OTR Application to Heavy Ions

Fermilab

- **Consider applying technologies and concepts for ions.**
- **Take advantage of charge state for OTR generation.**

For a non-relativistic charge Q, traveling with velocity v, the spectral energy density of transition radiation is,

$W(\omega) = 4\,Q^2\,\beta^2/3\pi c$,

where $\beta = v/c$ and c is the speed of light.

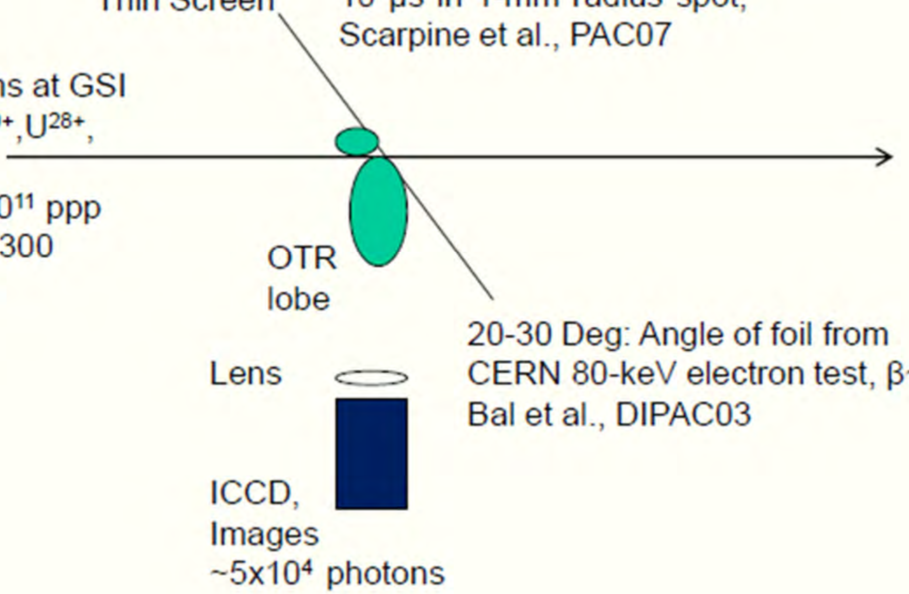
Ginzburg and Tsyovich,(1984)

Hypothesize $Q^2 = (Ze)^2$ where Z is the ion charge state and e is the magnitude of electron charge.

More than a “gedanken” experiment!

Alum. Kapton at FNAL handled 10^{13} protons in 10 μs in 1-mm radius spot, Scarpine et al., PAC07

HI beams at GSI
e.g. Ar^{10+}, U^{28+}, U^{73+}
10^9 to 10^{11} ppp
11.4 to 300 MeV/u



20-30 Deg: Angle of foil from CERN 80-keV electron test, β~0.6, Bal et al., DIPAC03

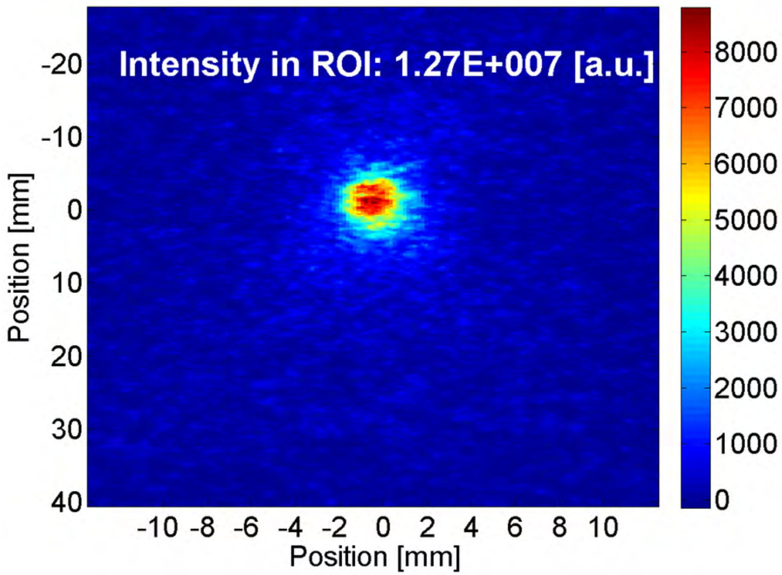
Introduction

When a particle travels with constant velocity and crosses the boundary between two media with different electromagnetic properties, it emits radiation with particular angular distribution, polarization and spectra.

The number of emitted photons:

$$I \propto q^2 \cdot \beta^2 \cdot N$$

q ion charge state
β velocity of the charge
N is the number of particles



Optical Transition Radiation (OTR) can be used in beam diagnostics for:

- beam size/profile
- position
- divergence
- energy
- relative intensity
- bunch length info

Predicted by Ginzburg and Tamm in 1946
First observed by Goldsmith and Jelley in 1959

GSI facility

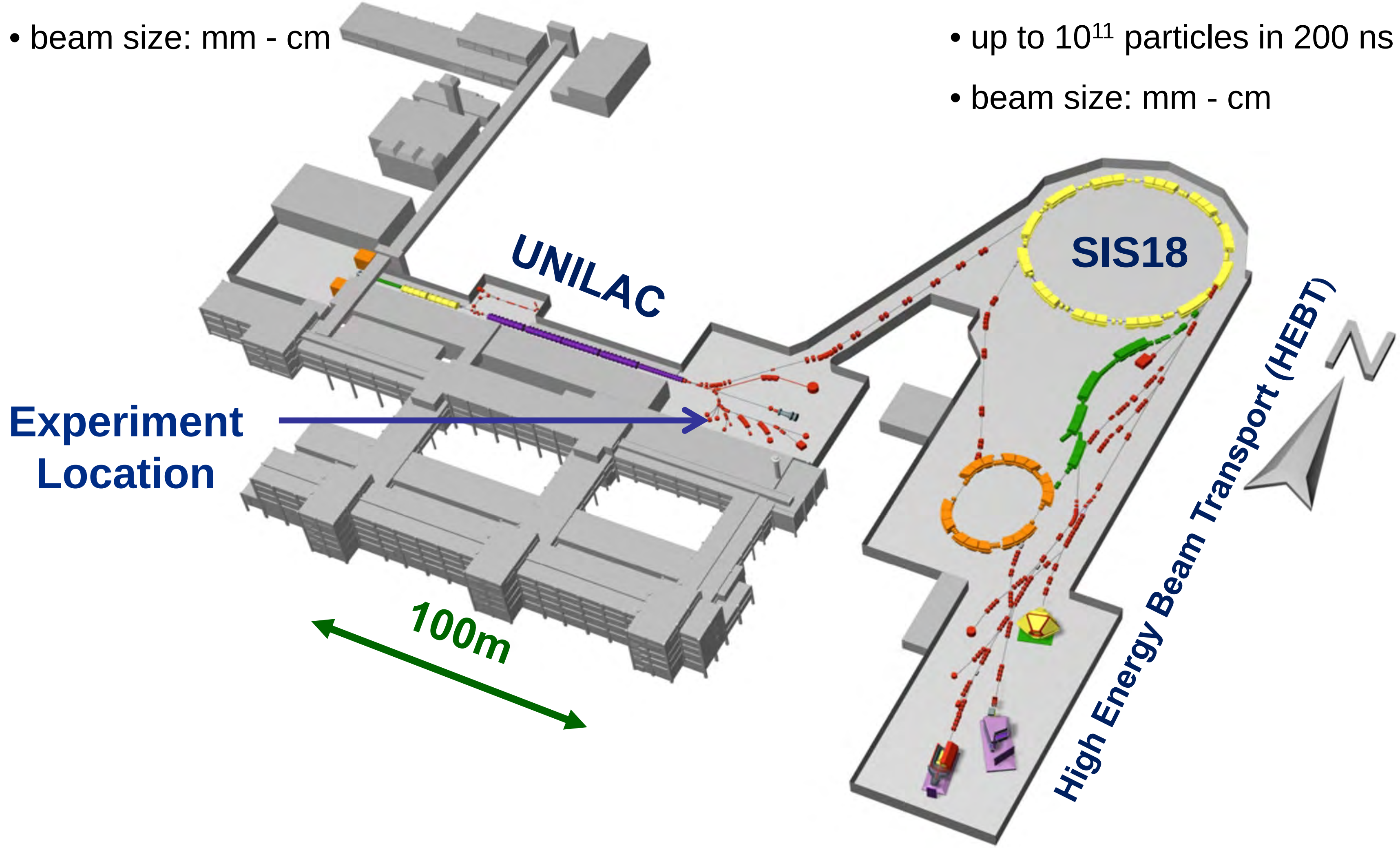
GSI accelerates all ions from protons up to Uranium

UNILAC:

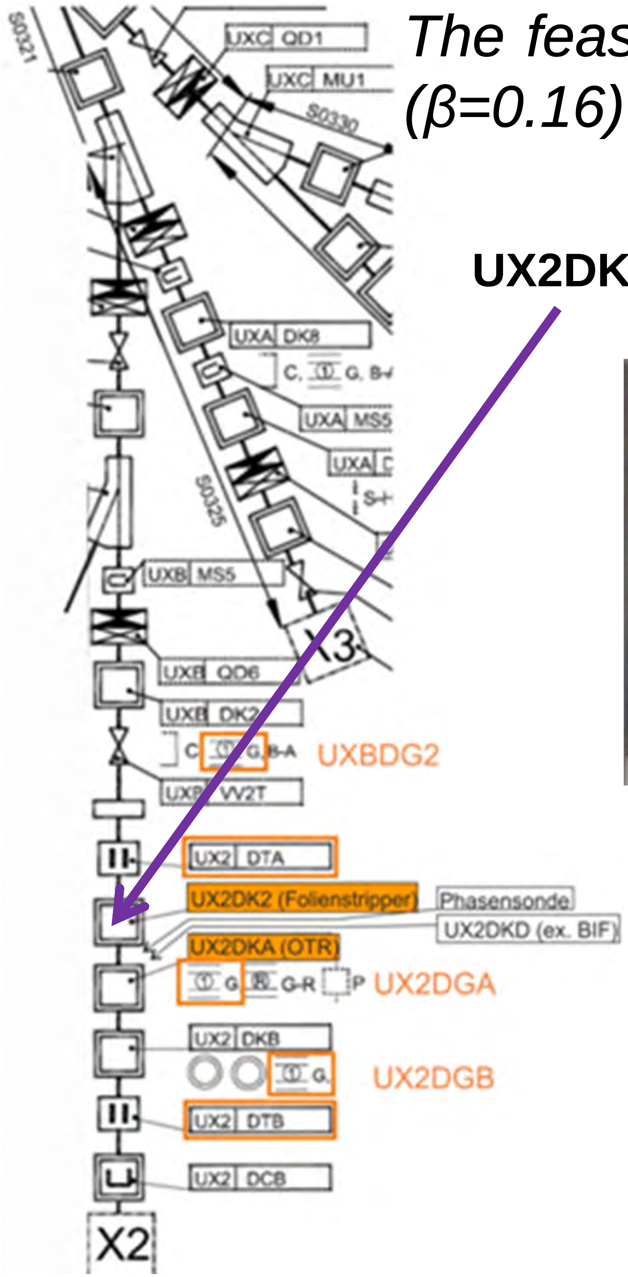
- energies up to 11.4 MeV/u ~ 16% speed of light
- up to 10^{12} particles in ms pulse (up to 50 Hz repetition rate)
- beam size: mm - cm

Synchrotron SIS18 and High Energy Beam Transport:

- energies up to 4 GeV/u ~ 90% speed of light
- up to 10^{11} particles in 200 ns – 10 s pulse
- beam size: mm - cm



Experiment location



The feasibility of OTR has been evaluated with an 11.4 MeV/u (β=0.16) U^{28+} beam at the UNILAC (X2 beam line)

UX2DK2 (Stripping foil location), used materials: Carbon 570 µg/cm^2

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Thickness of the foil: 2.5 µm

Ion energy loss in foil: 0.3 MeV/u

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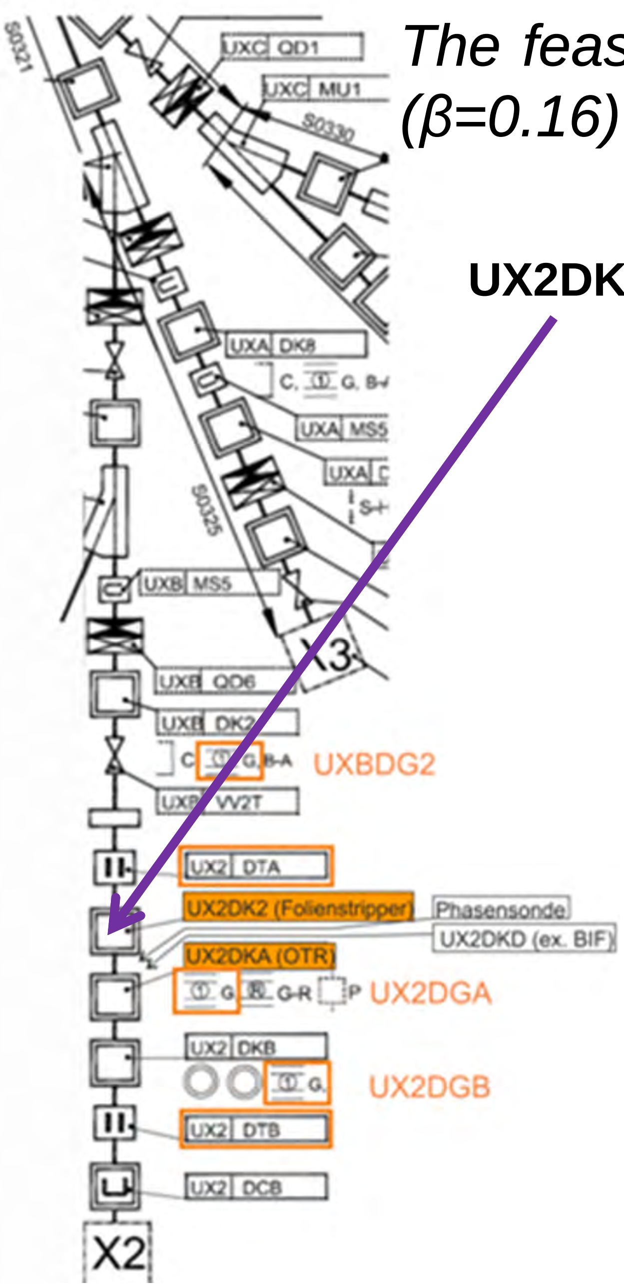
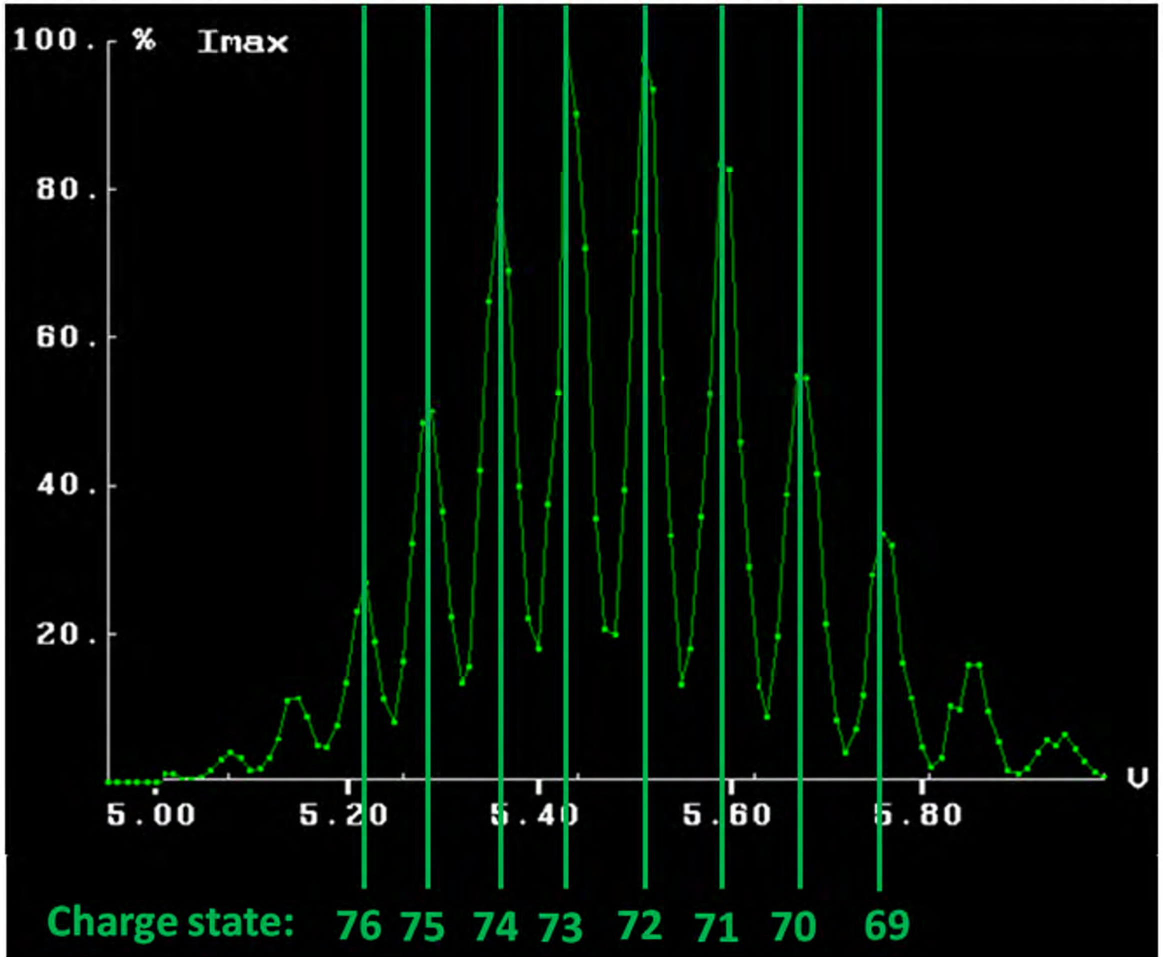


UX2DK2 (Stripping foil location), used materials: Carbon 570 µg/cm²

Charge state distribution of U^{28+} beam stripped at 11. 4 MeV/u



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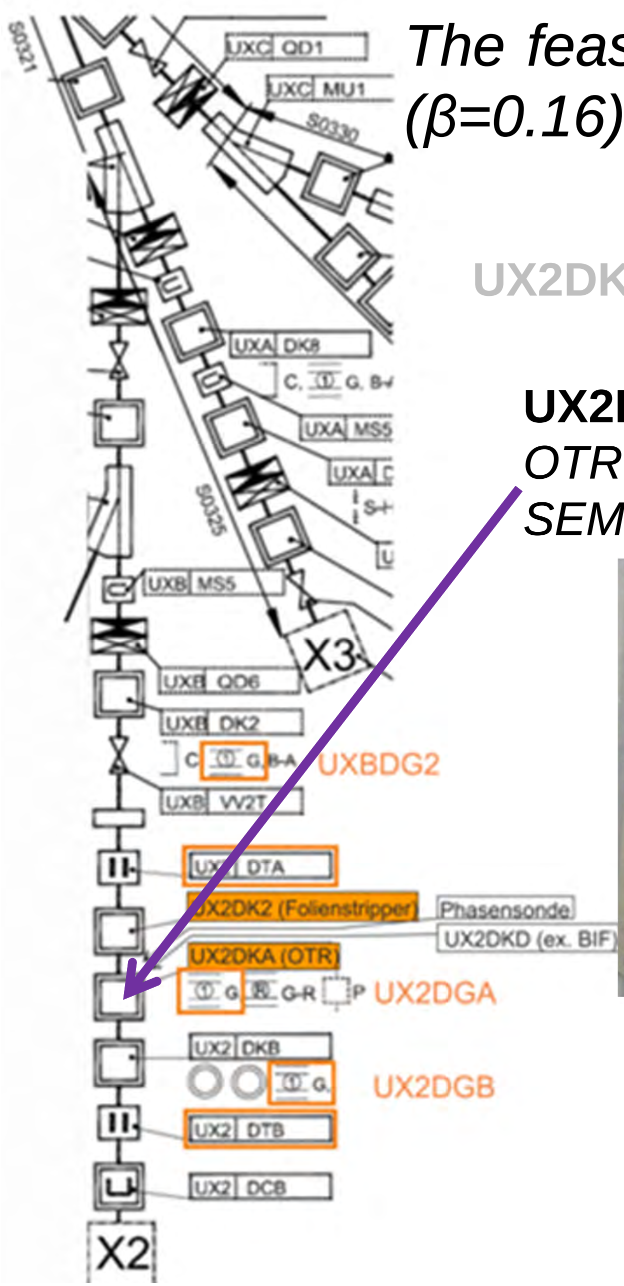

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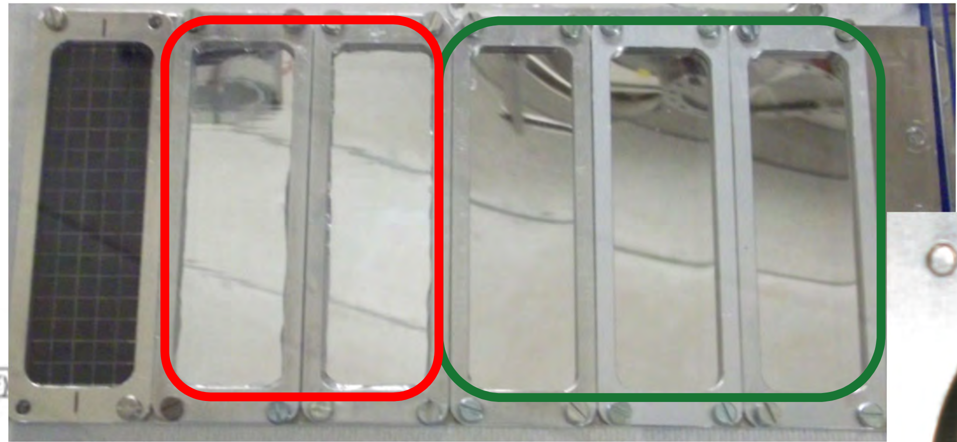
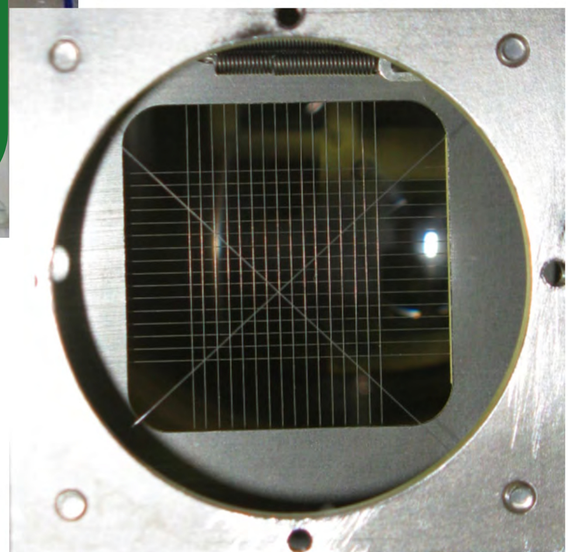
UX2DKA diagnostic chamber:

OTR Targets: 10 µm aluminum on Kapton foil and 500 µm stainless steel

SEM-Grid (UX2DGA) for transversal profile comparison





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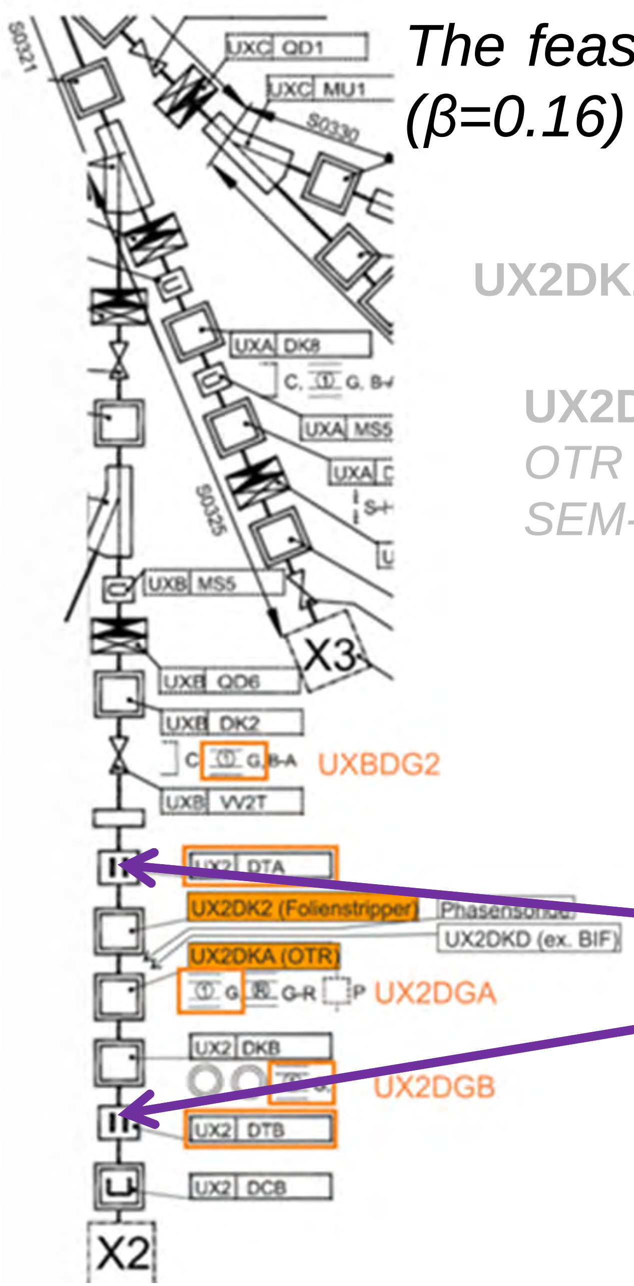

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SEM-Grid (UX2DGA) for transversal profile comparison

UX2DTA transformer before stripping station
UX2DTB transformer behind target

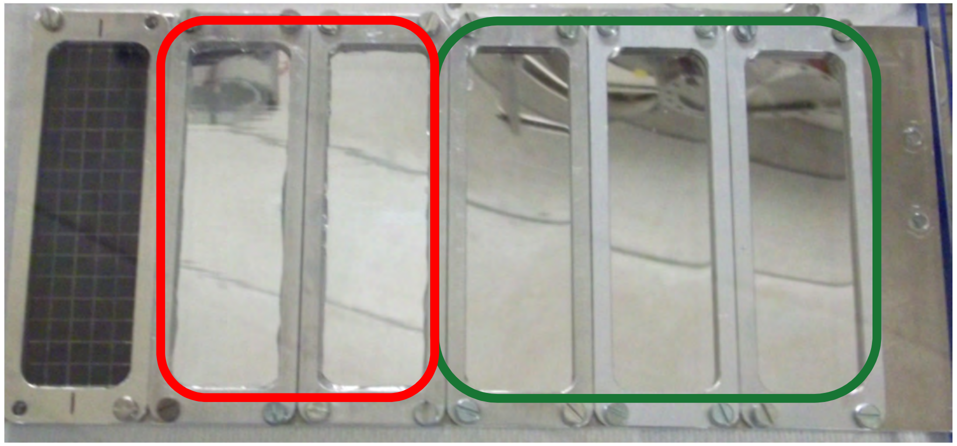
Experimental setup

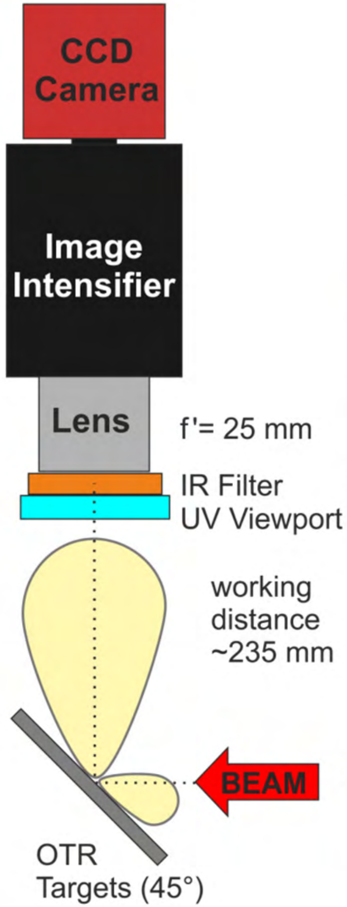
Experimental setup consists of an OTR target ladder (6 targets on one ladder) and image-intensified CCD camera system (ICCD)

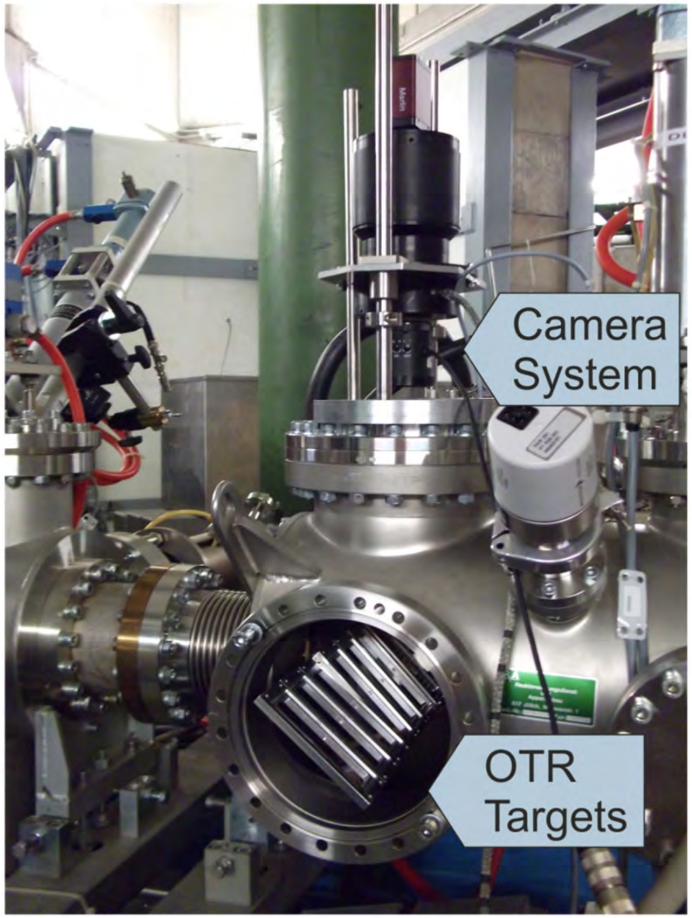
***OTR Targets*:**

10 µm aluminum on Kapton foil

500 µm stainless steel







10 µm Al on Kapton

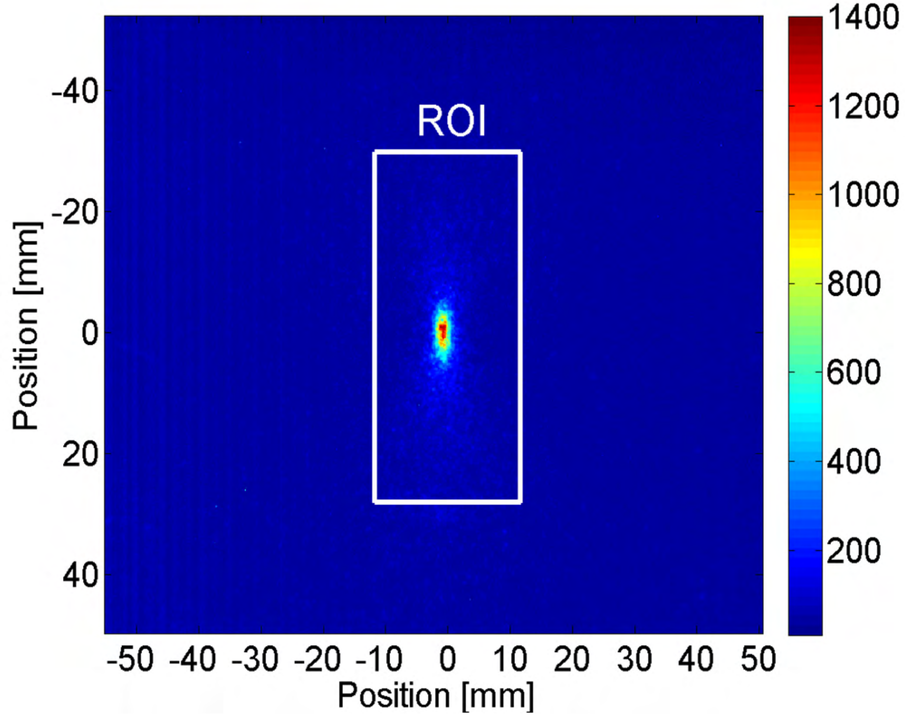
Ion energy loss in foil: 1.1 MeV/u

Stainless steel 500 µm

Ion range in material: 50 µm

Ion energy loss in foil: 11.4 MeV/u

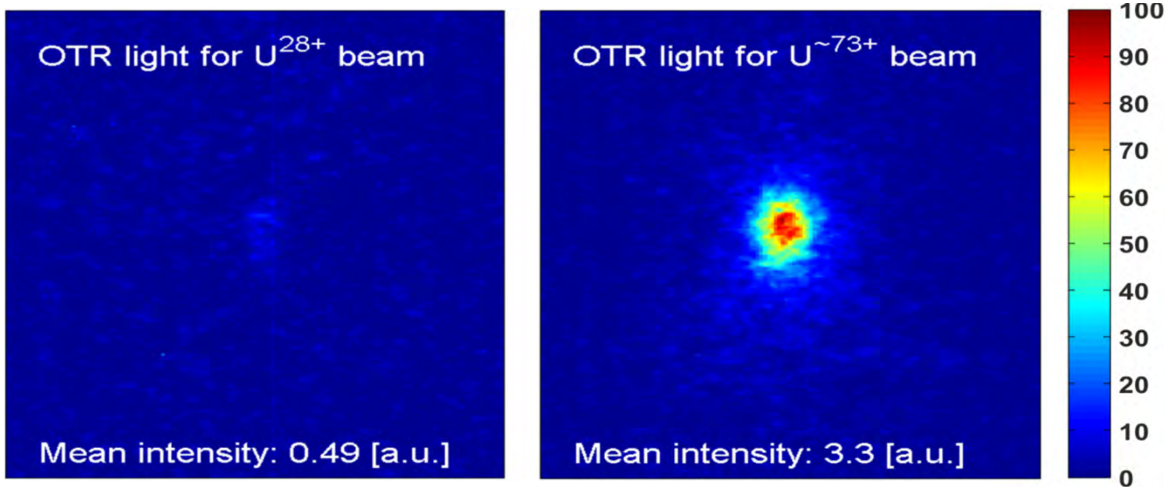
First results – first pictures

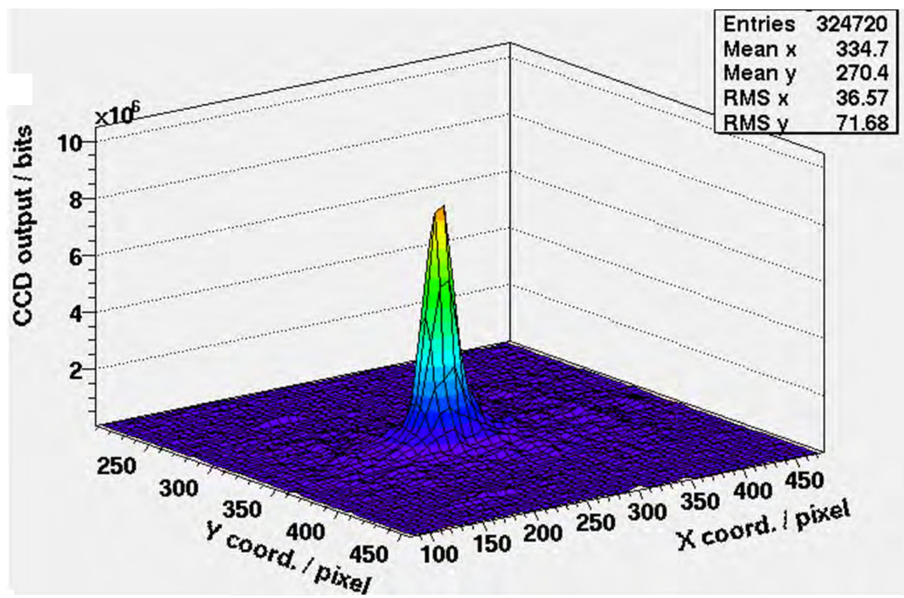


First, we saw signal!

→ transversal light distribution is observed

→ better signal by using stripping foil



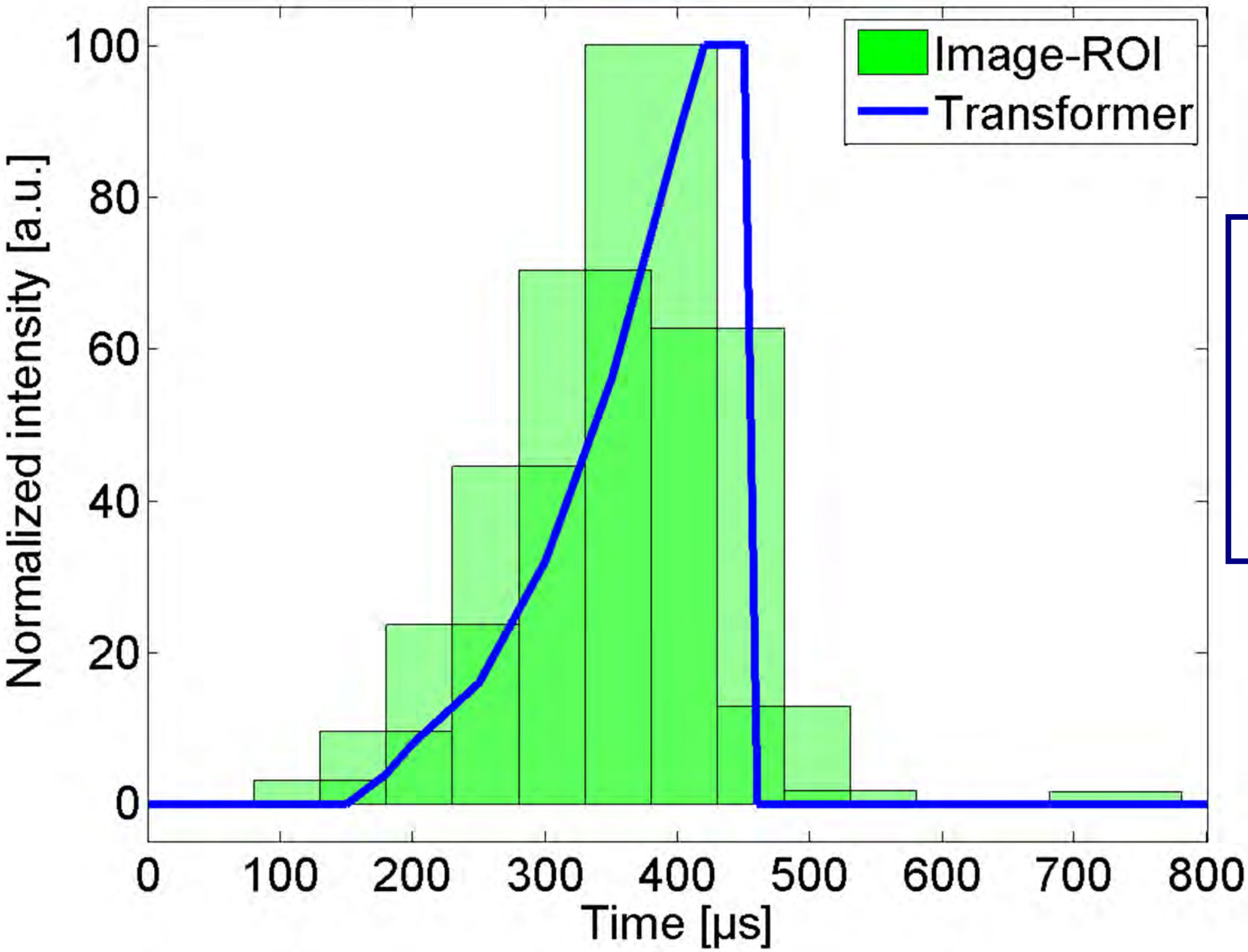


Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **6.7 · 10^7 ppp** in 300 µs

First results – time structure of signal

OTR is a prompt process, signal observed only during irradiation

OTR signal strength as a function of time



→ visible signal only during pulse

→ no latency of light emission

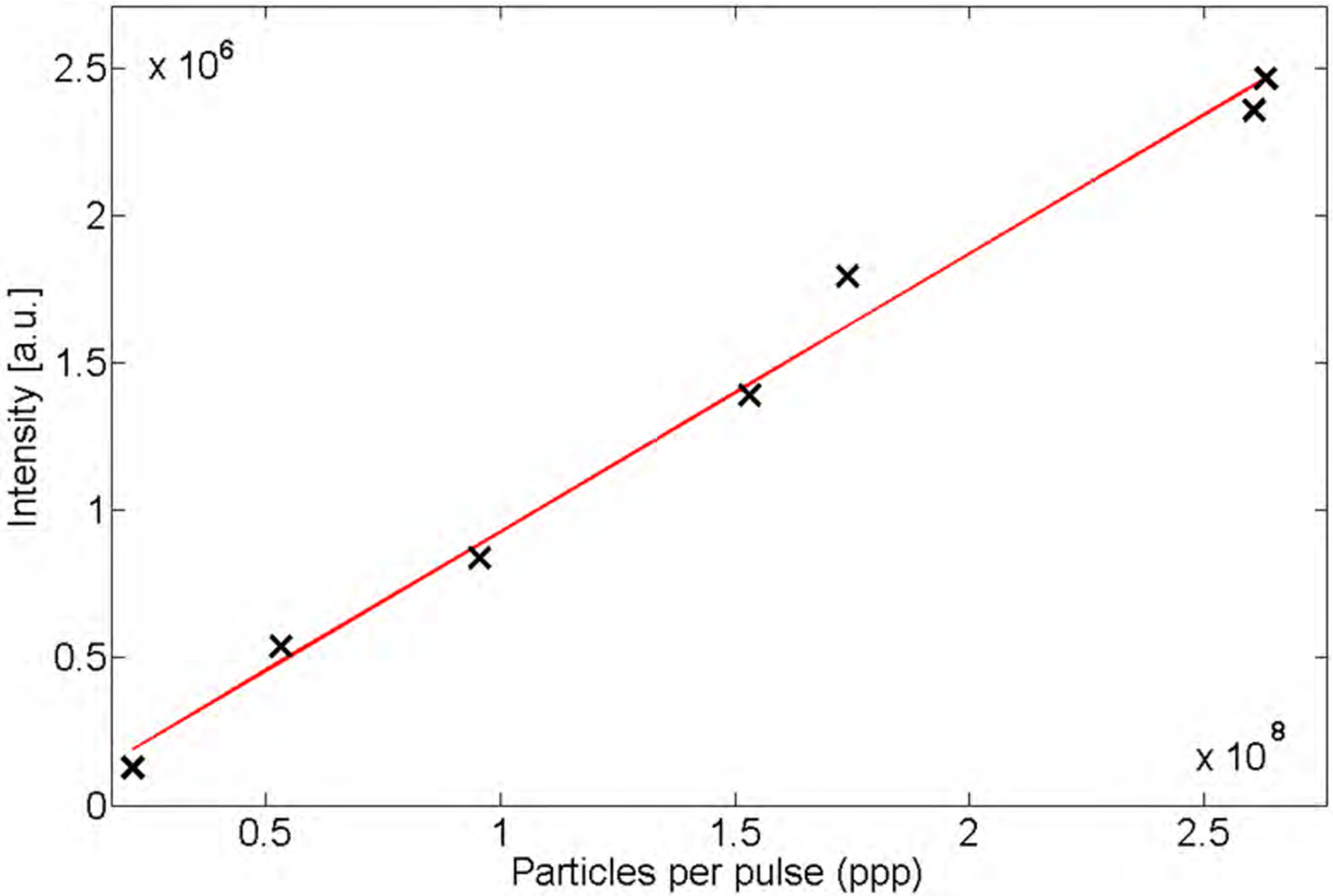
no background sources in the screen with a longer emission time

Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **6.7 · 10^{8} ppp** in 300 µs

First results – signal strength

OTR is expected to show perfect linearity to the number of charges crossing without risk of saturation

OTR signal strength as relative total ICCD intensity for different particle number



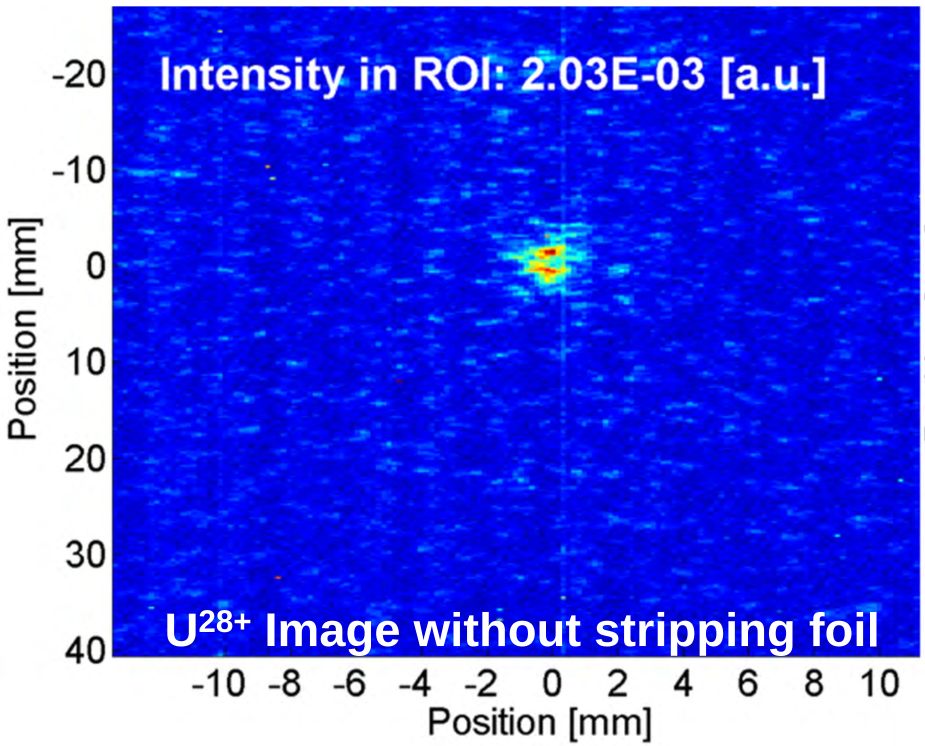
OTR signal strength scales linear with particle number

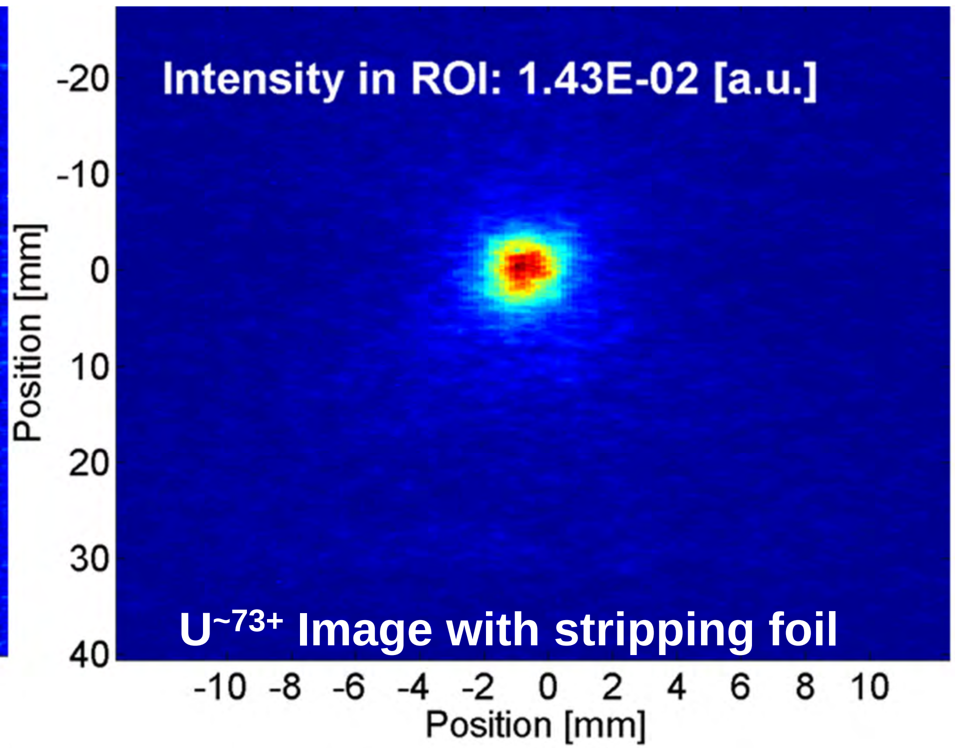
Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **$1 \cdot 10^7$ - $3 \cdot 10^8$ ppp** in 300 µs

First results – q^2 dependency

Number of emitted OTR photons depends on q^2. Stripping foil increased mean charge state from q=28 to q~73. Expected signal growth by a factor of ~7.

Beam distributions for both charge states, but same ion number of ~$2.6 \cdot 10^8$





→ the ratio of the integral ICCD intensities roughly supports q^2 dependency:

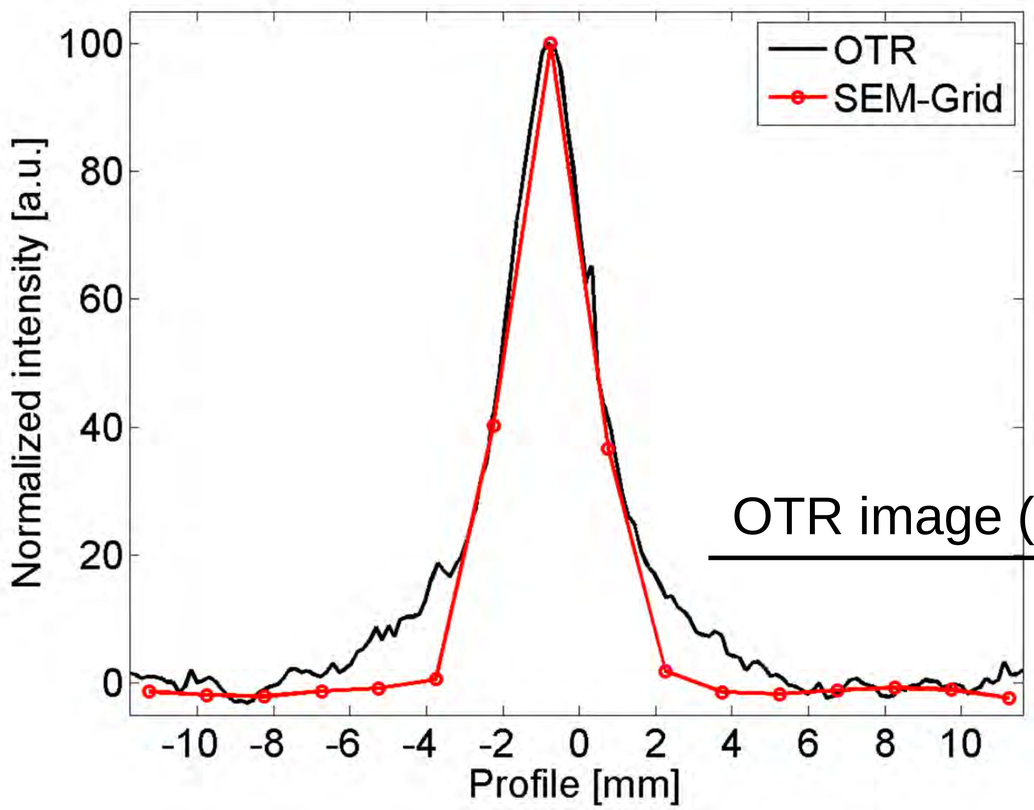
$$1.43 \cdot 10^{-2} / 2.03 \cdot 10^{-3} \sim 73^2/28^2 \sim 7$$

But: due to low signal strength, results are very sensitive to noise and chosen ROI

First results – beam profile comparison

To determine the imaging qualities of the OTR method, additional profile measurements with a SEM-Grid have been applied

Beam profile comparison between OTR and SEM-Grid



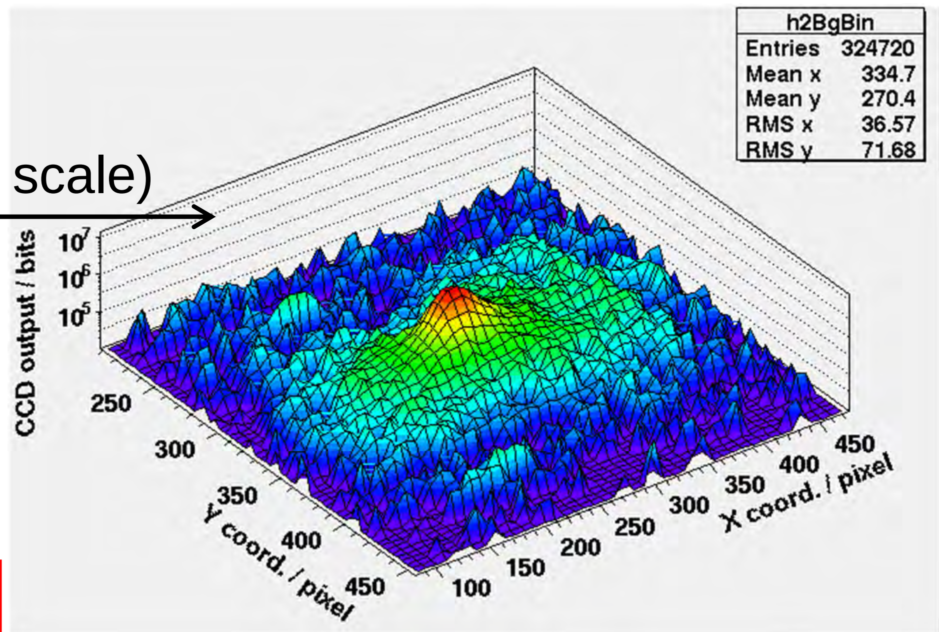
Good agreement between different methods

But:

→ observed shoulder in OTR profile is not yet clear

→ further studies required

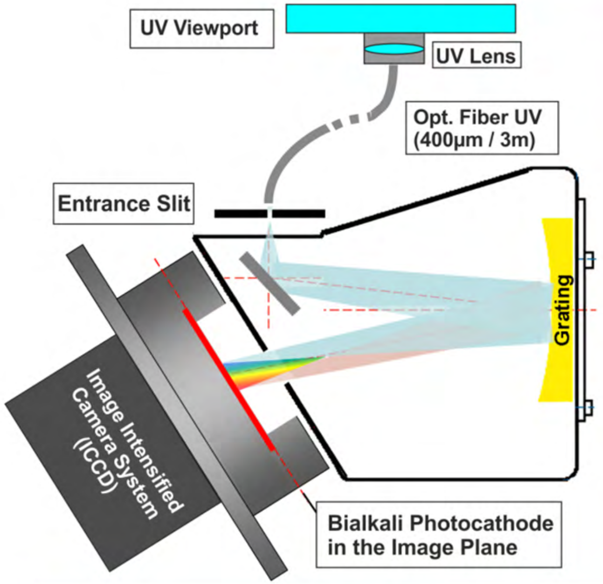
OTR image (log scale)

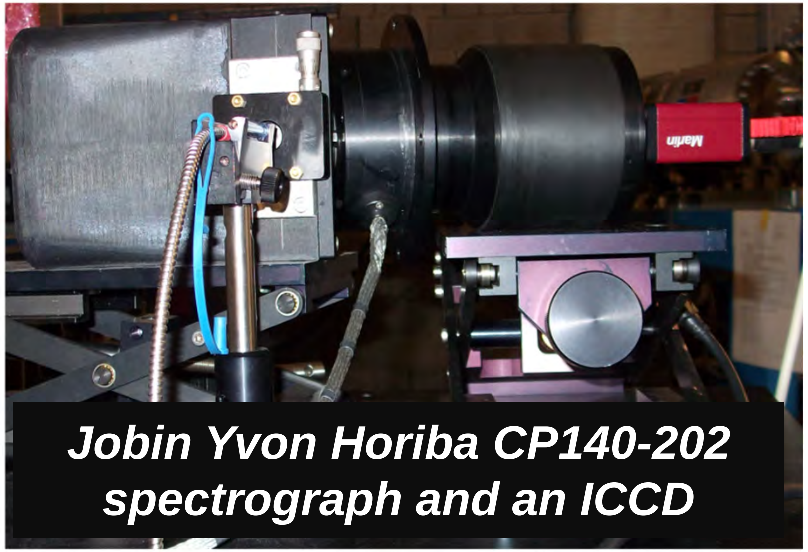


Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **7 · 10^8 ppp** in 300 µs

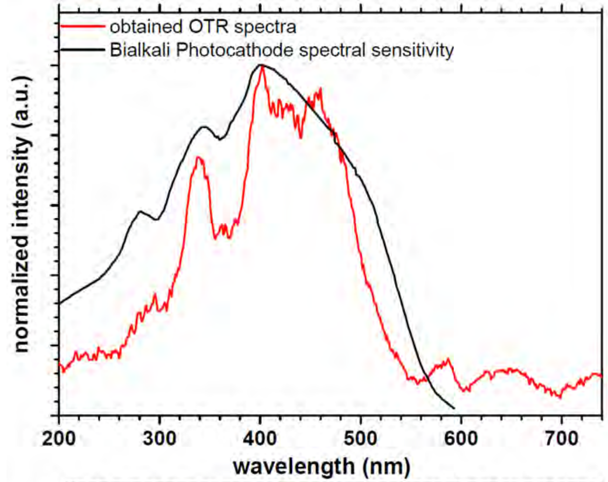
First results – spectroscopy

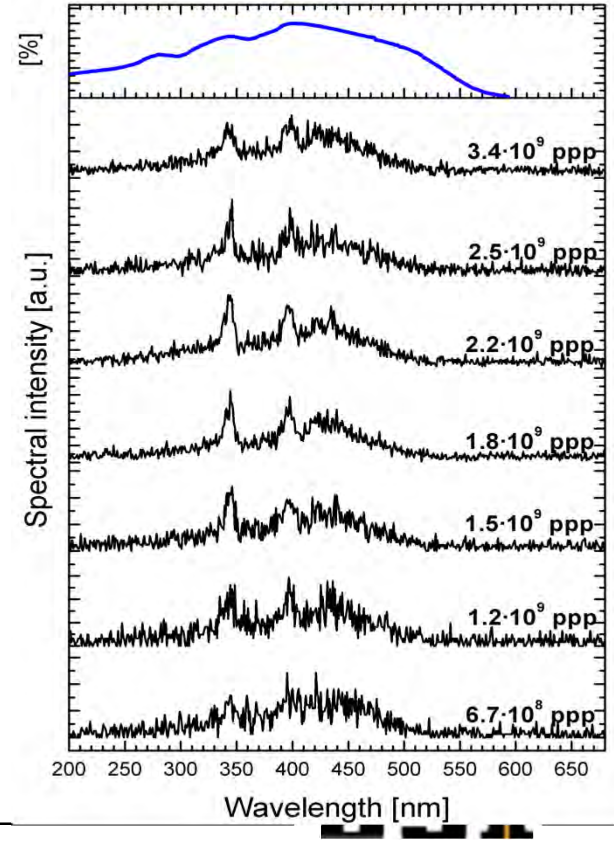
To clearly distinguish the OTR signal from blackbody radiation spectroscopic investigations have been done





Jobin Yvon Horiba CP140-202 spectrograph and an ICCD





→ light spectrum roughly fits to the sensitivity of the photocathode and the optical system

→ all wavelengths above 550 nm are significantly suppressed

→ spectrum below 550 nm is stable

→ light spectrum is independent on particles number

No significant contribution to spectrum from other sources

What´s next?

Further studies at UNILAC energy (11.4 MeV/u)

Advanced studies on polarization effects

q^2 dependency

Shoulder in beam profile

Further studies at high energy beam transport lines (up to 4 GeV/u)

Test in preparation, to provide necessary data required for more intense and energetic ion beams as planned for the Facility for Antiproton and Ion Research (FAIR)

Usage of very thin aluminized Kapton (e.g. 0.1 µm Al on 6 µm Kapton), Ti or Al foils to reduce ion energy loss in OTR screen

Summary

The OTR method for non-relativistic ion beams in the UNILAC was successfully demonstrated

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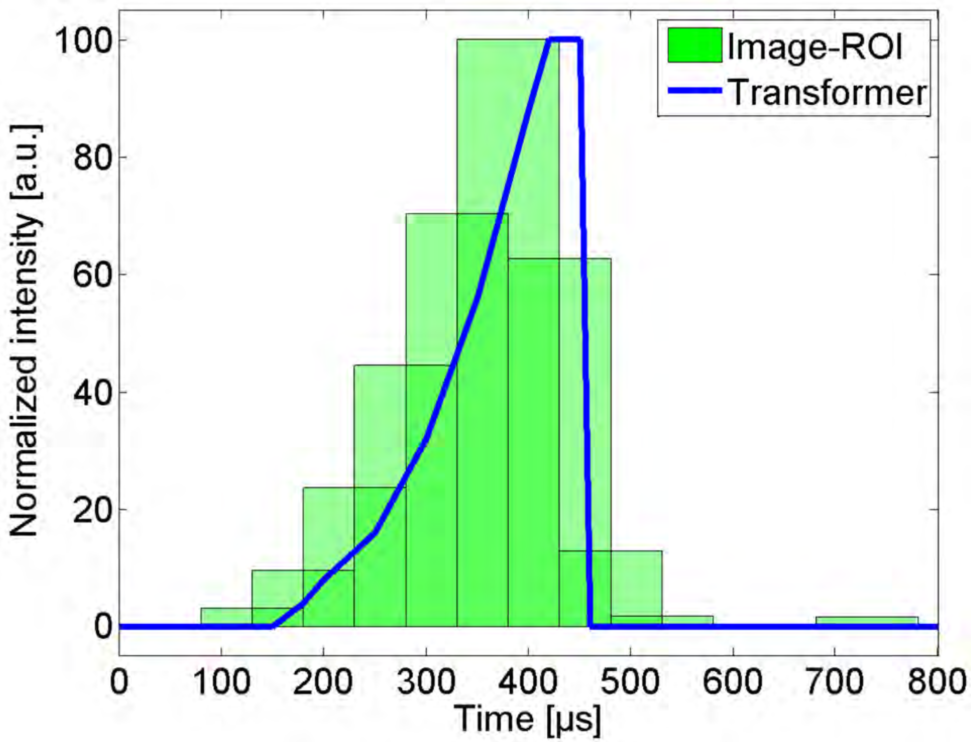
As OTR is instantaneously formed, OTR signal strength as a function of time



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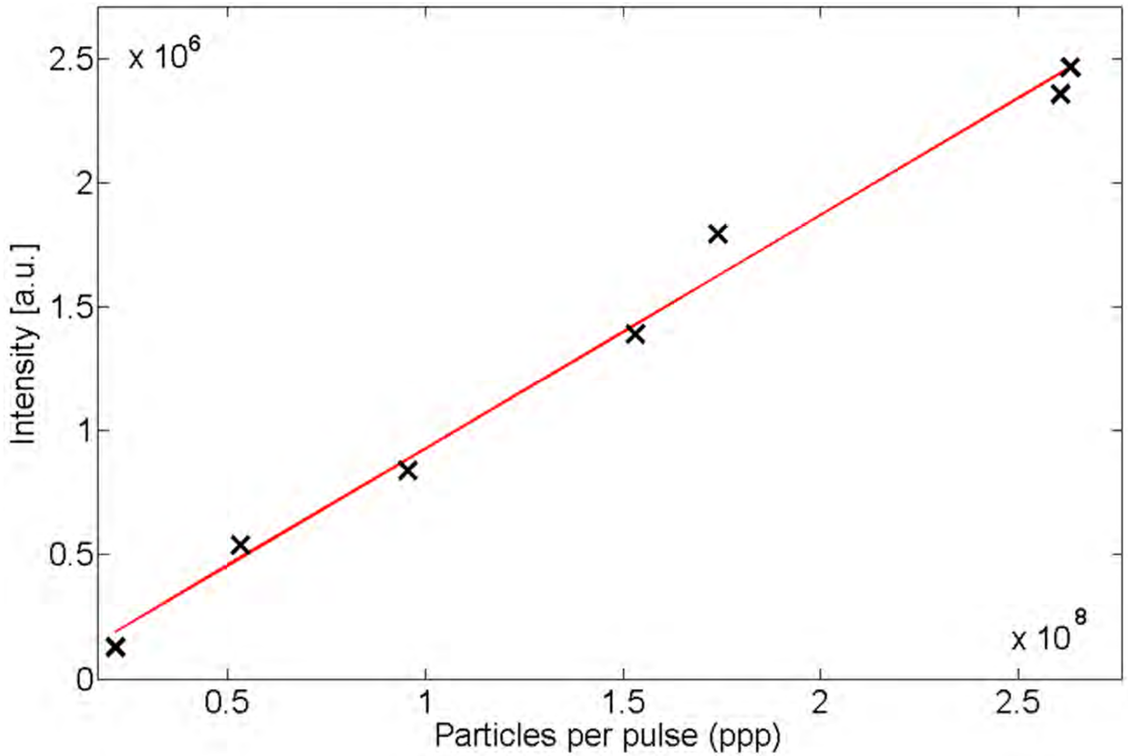

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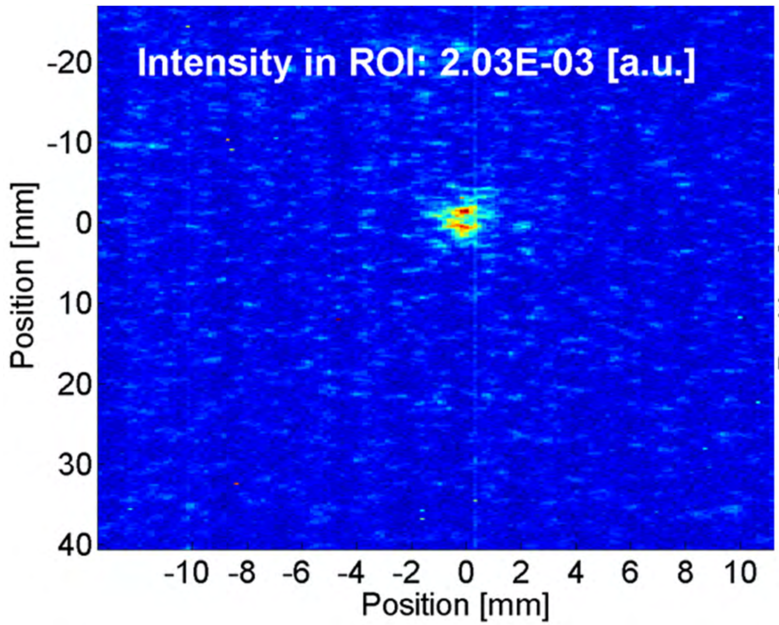
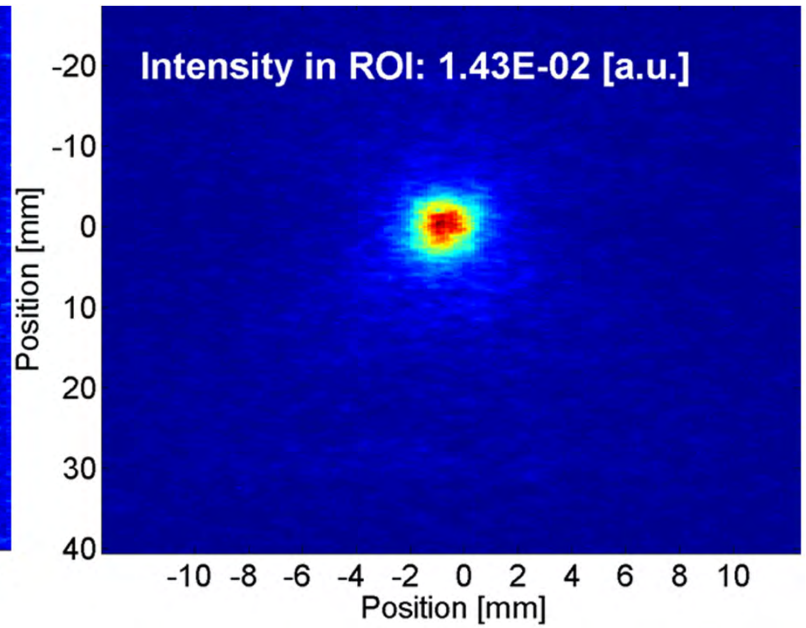
OTR signal strength roughly supports q^2 dependency





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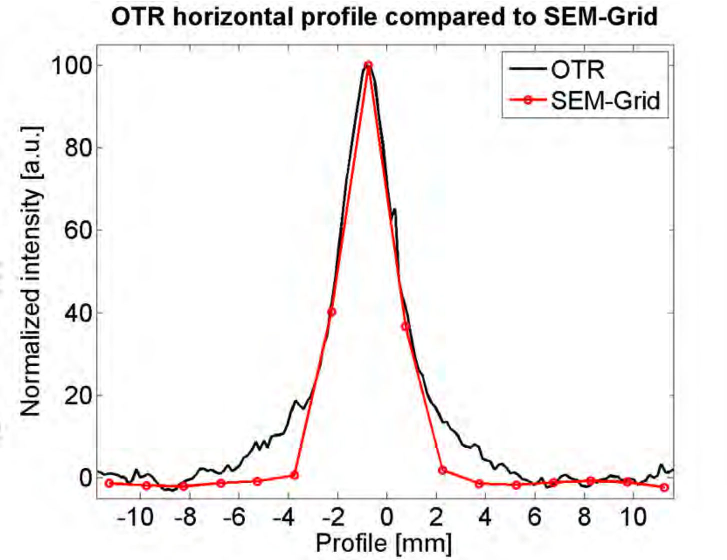

Comparison of beam size measurements with SEM-Grid and OTR shows good agreement

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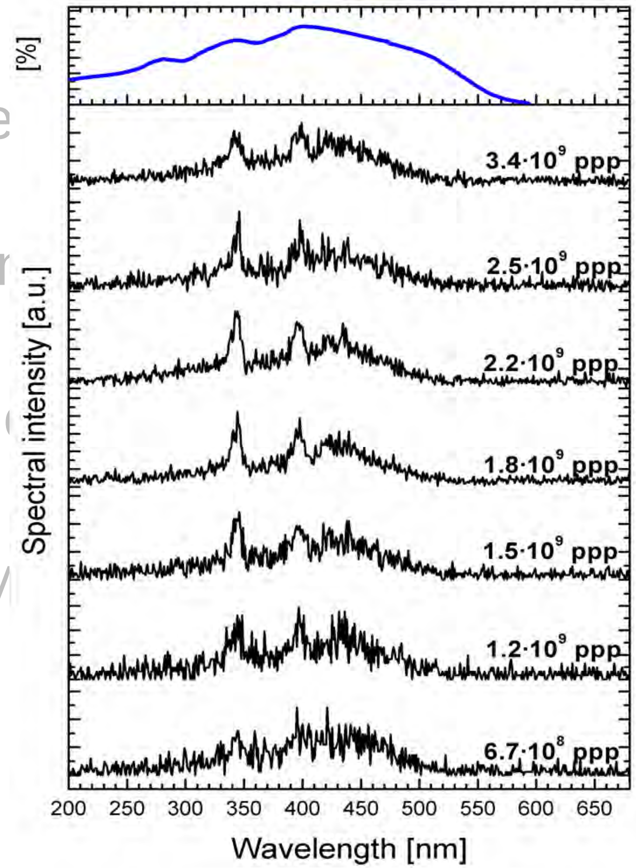

Contribution of blackbody radiation can be ruled out by spectroscopic studies

Acknowledgements

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