PILOT STUDIES ON OPTICAL TRANSITION RADIATION IMAGING OF NON-RELATIVISTIC IONS AT GSI

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Outline

Motivation

Introduction

- OTR characteristics

GSI facility

- Beam characteristics
- Experimental setup

First results

- Signal strength
- Profile measurements
- Spectroscopy

Summary

Further studies

Motivation

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,

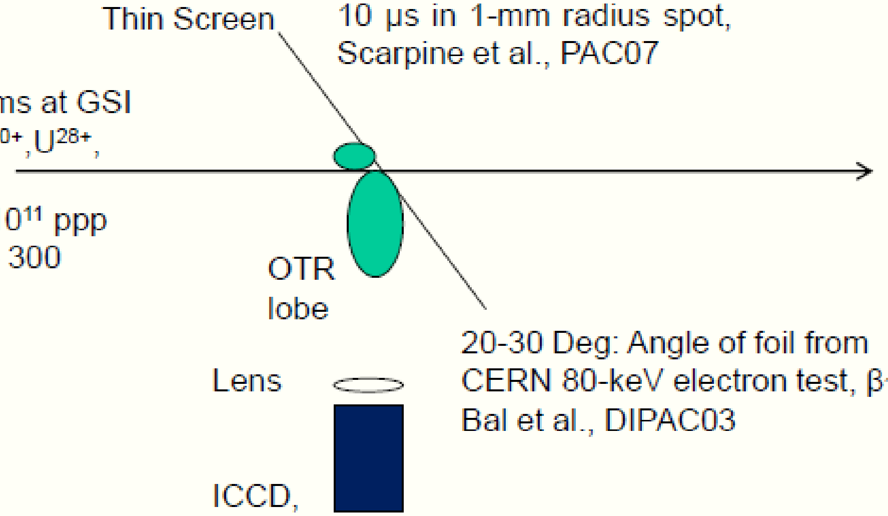
$W(\omega) = 4 Q^2 \beta^2 / 3\pi c$,

where β=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!



A.H. Lumpkin GSI Seminar February 16, 2011 27

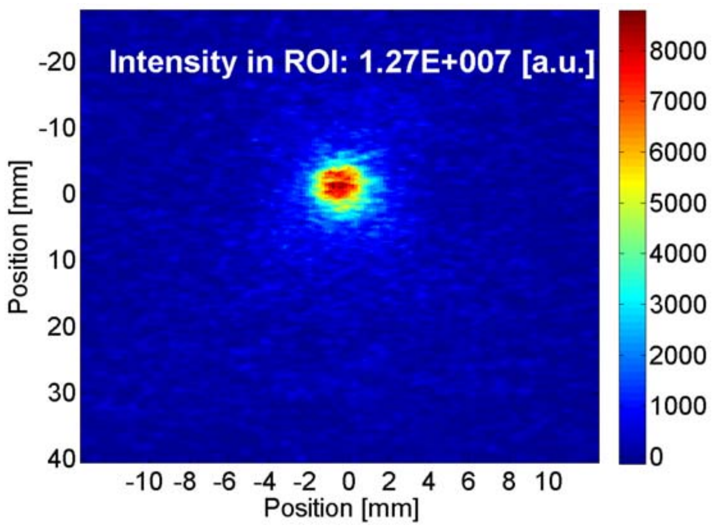
Introduction

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 charged particle
N 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

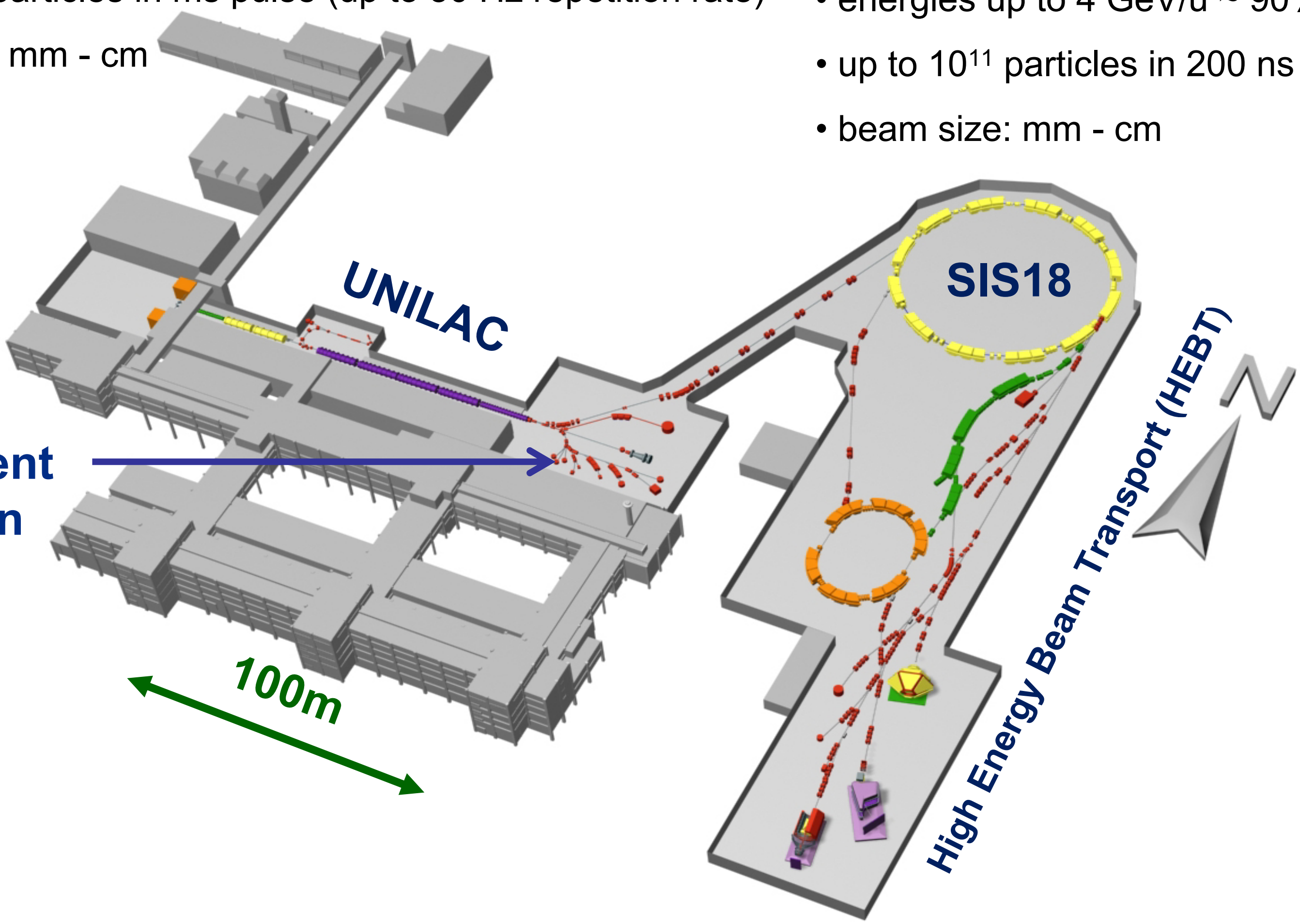
UNILAC:

- 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



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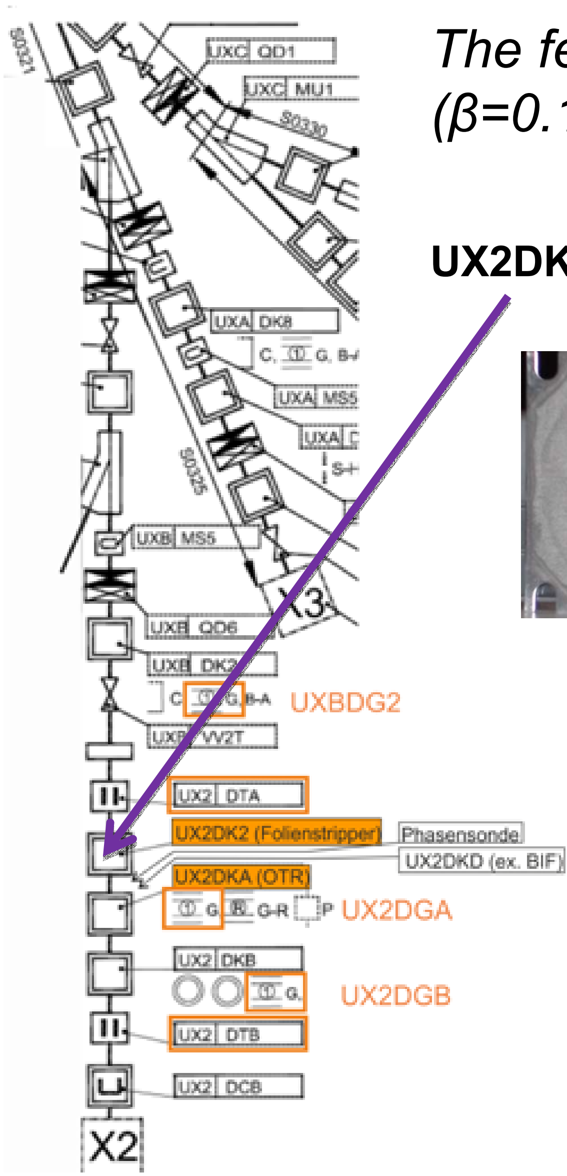
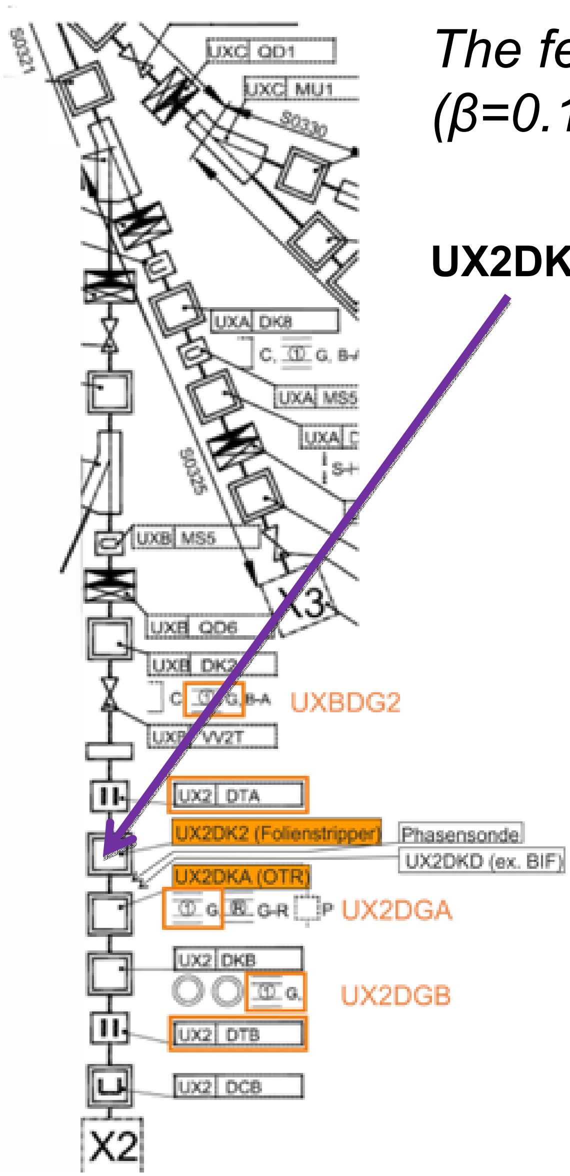


The feasibility of OTR has been evaluated with 11.4 MeV/u (β=0.16) U^{28+} beam at the UNILAC (X2 beam line).

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

Carbon 570 μg/cm²
Thickness of the foil: 2.5 μm
Ion energy loss in foil: 0.3 MeV/u

Experiment location



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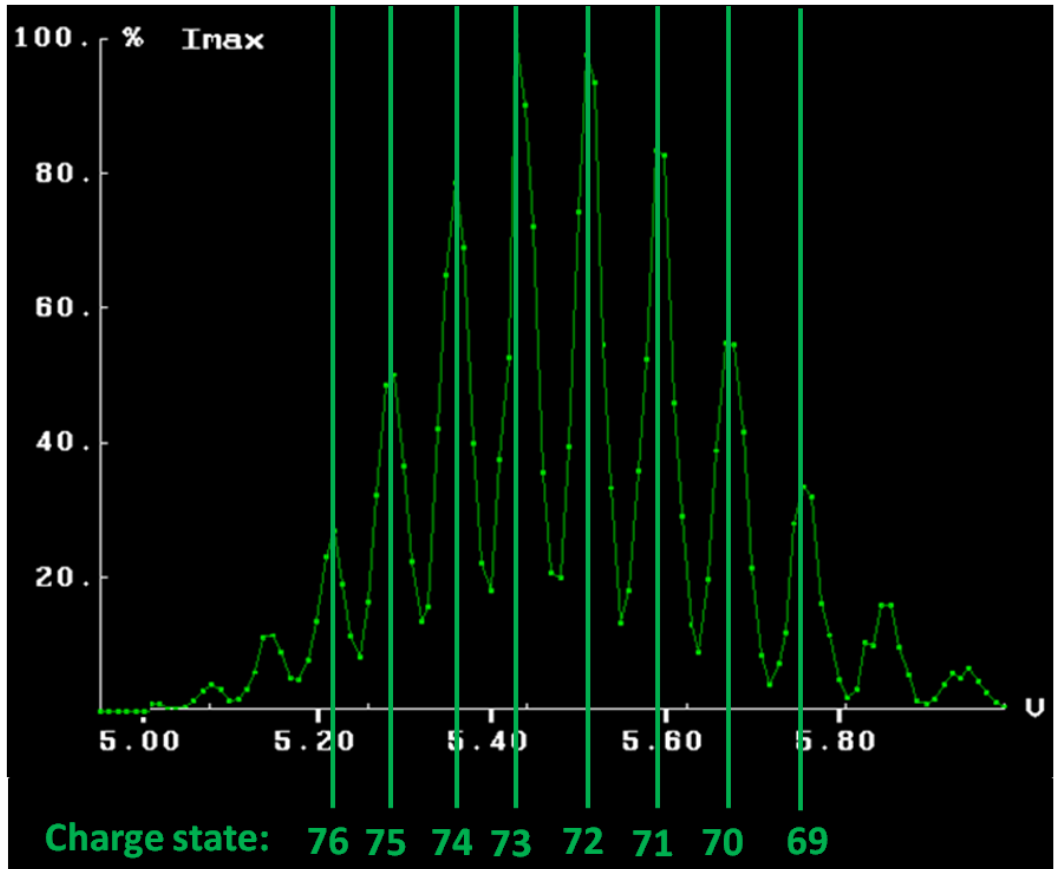
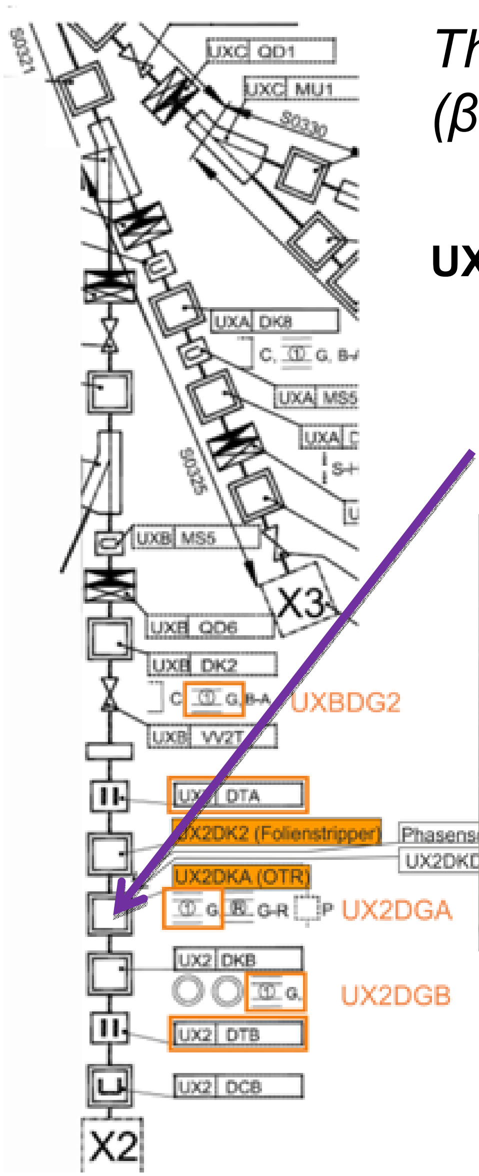
Charge state distribution of U^{28+} beam stripped at 11. 4 MeV/u



Experiment location



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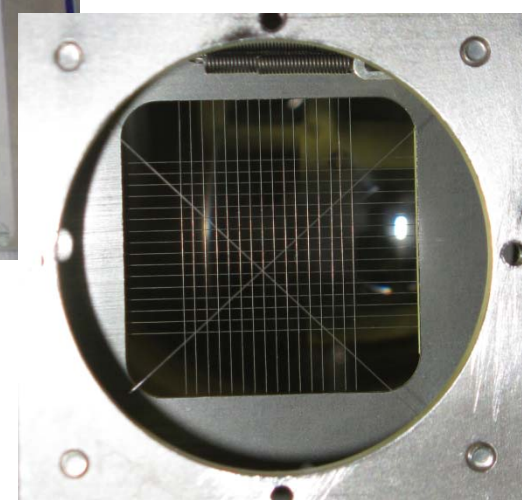
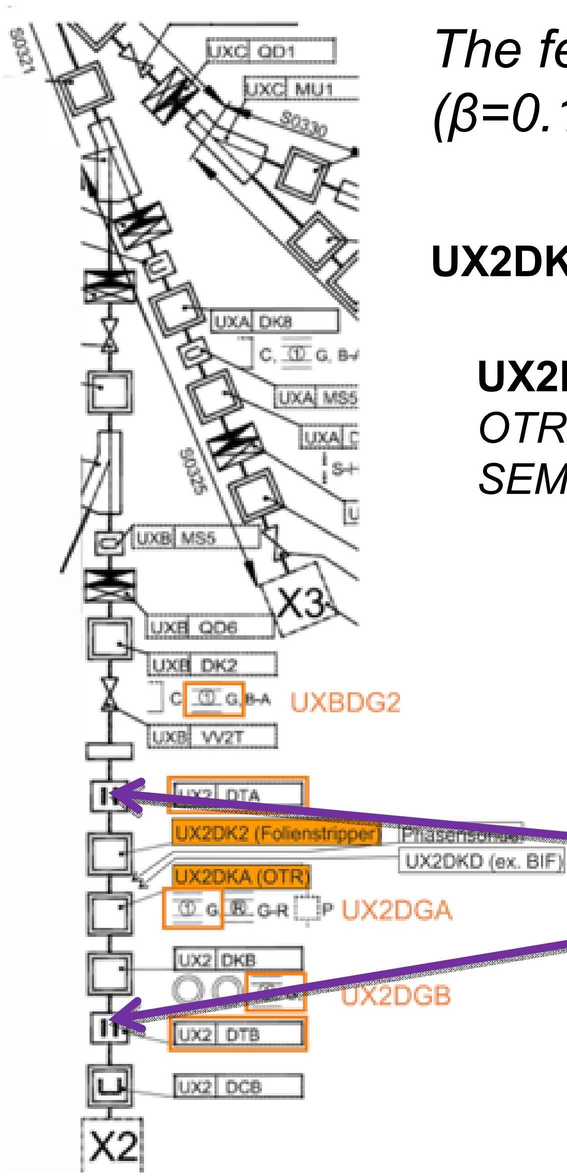
UX2DKA diagnostic chamber:

OTR Targets

SEM-Grid (UX2DGA) for transversal profile comparison



Experiment location



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UX2DKA diagnostic chamber:
OTR Targets
SEM-Grid (UX2DGA) for transversal profile comparison

UX2DTA transformer before stripping station
UX2DTB transformer behind target

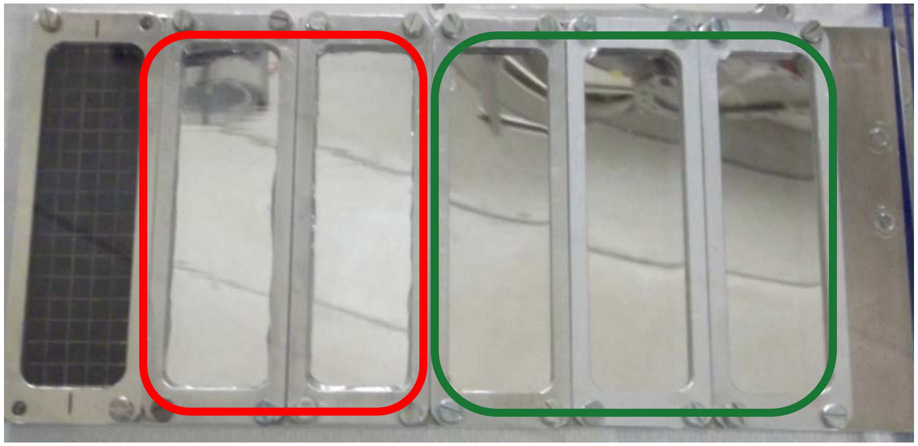
Experimental setup

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



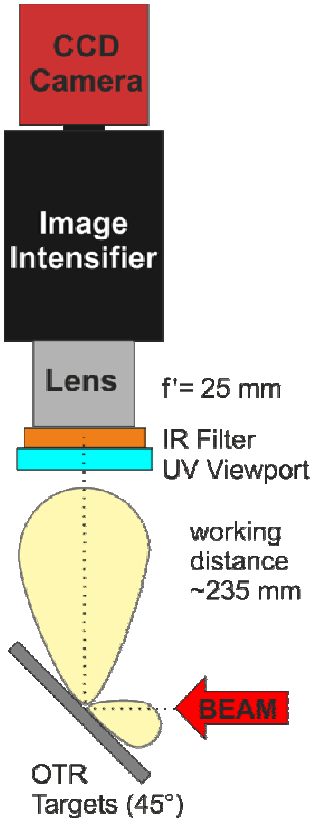
10 µm Al on Kapton

Ion energy loss in foil: 1.1 MeV/u

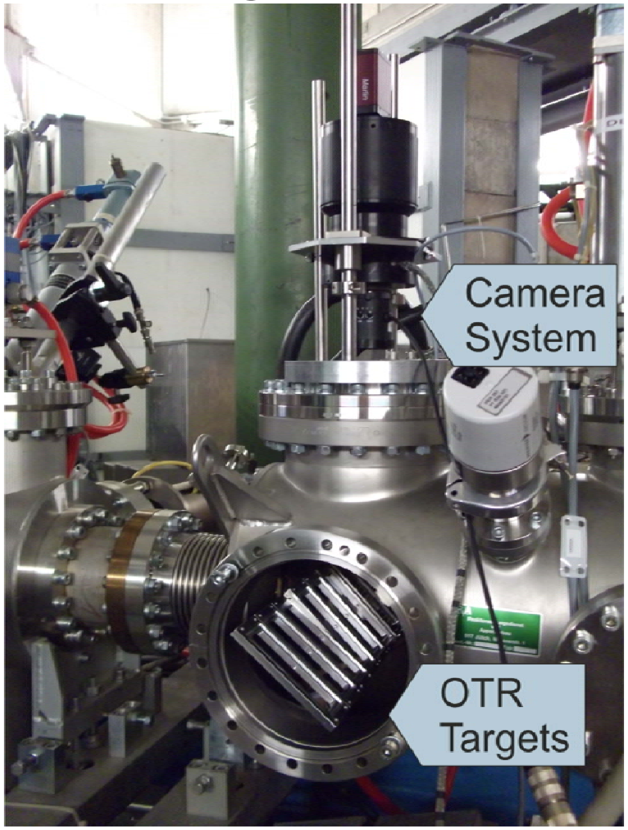
Stainless steel 500 µm

Ion range in material: 50 µm

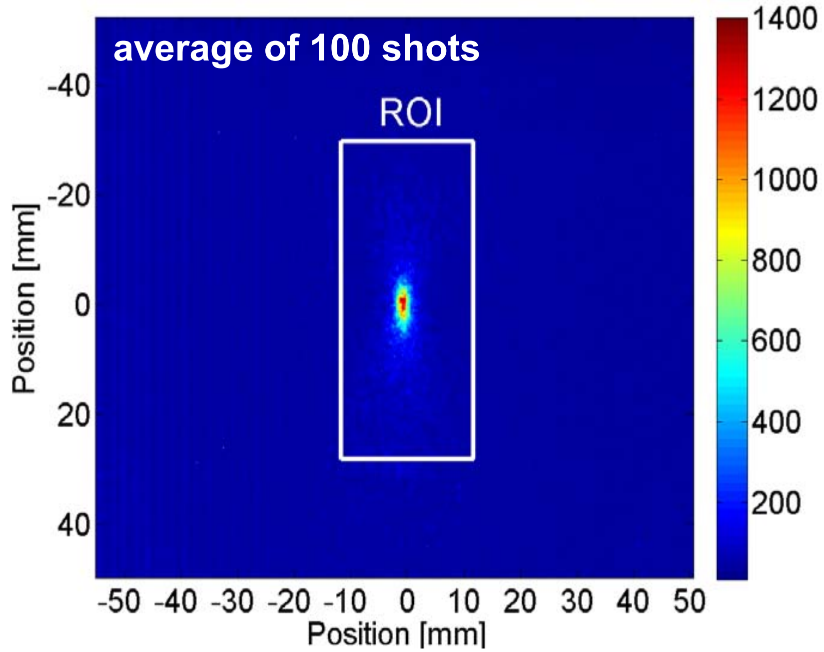
Ion energy loss in foil: 11.4 MeV/u



UX2DKA diagnostic chamber



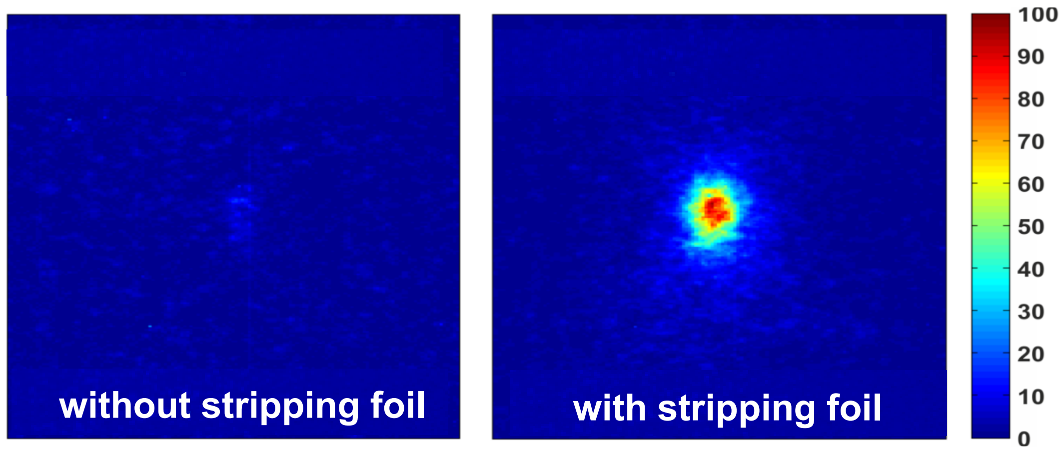
First results – first pictures

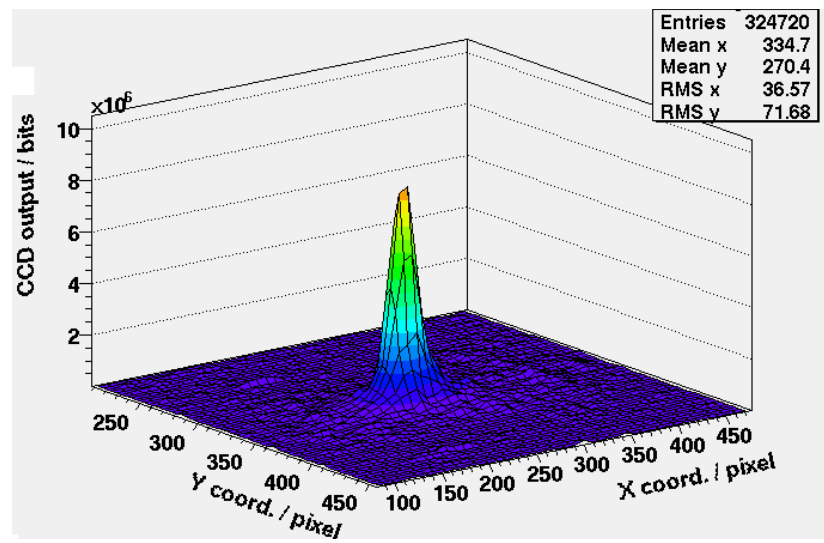


First, there is a signal!

→ transversal light distribution is observed

→ better signal by using stripping foil



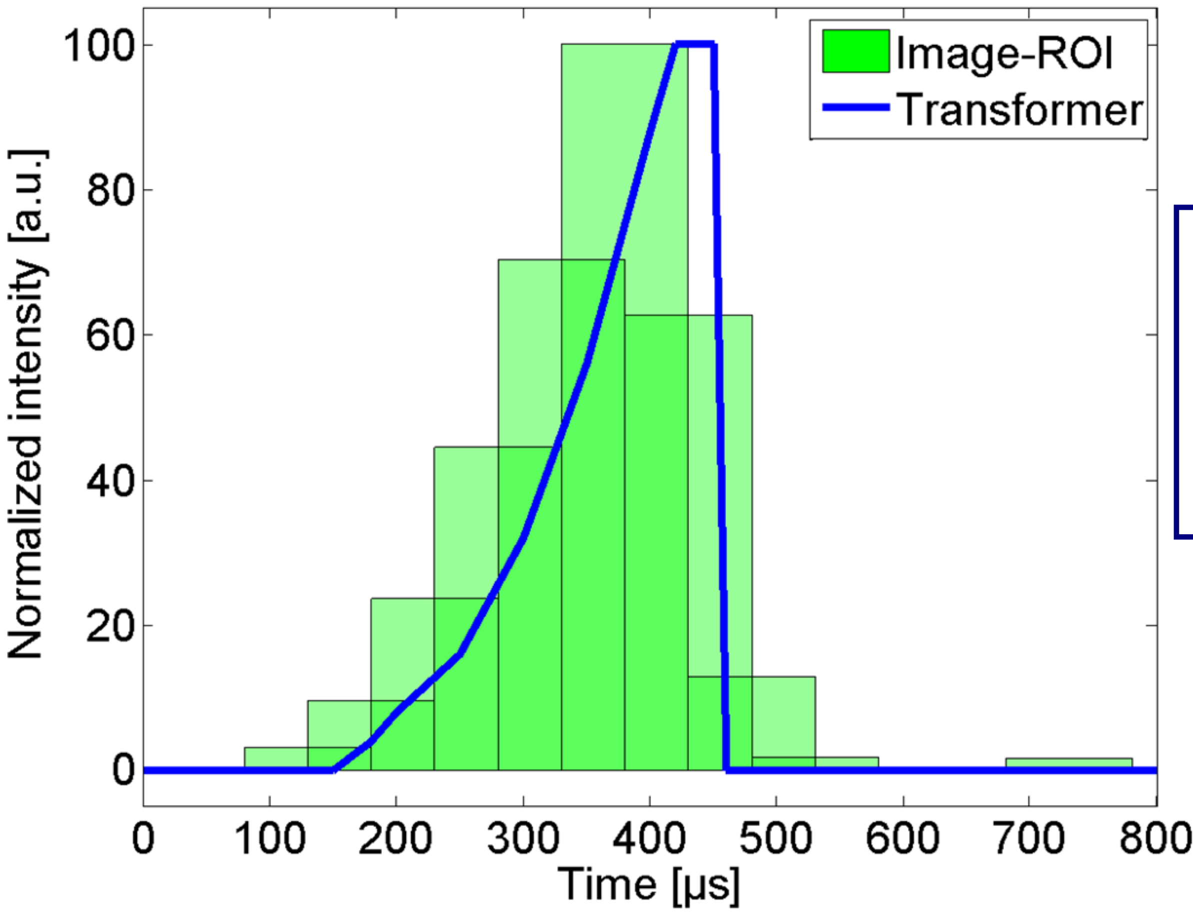


Beam parameters: Uranium, 11.4 MeV/u, **2.6 · 10⁸ ppp** in 300 µs

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

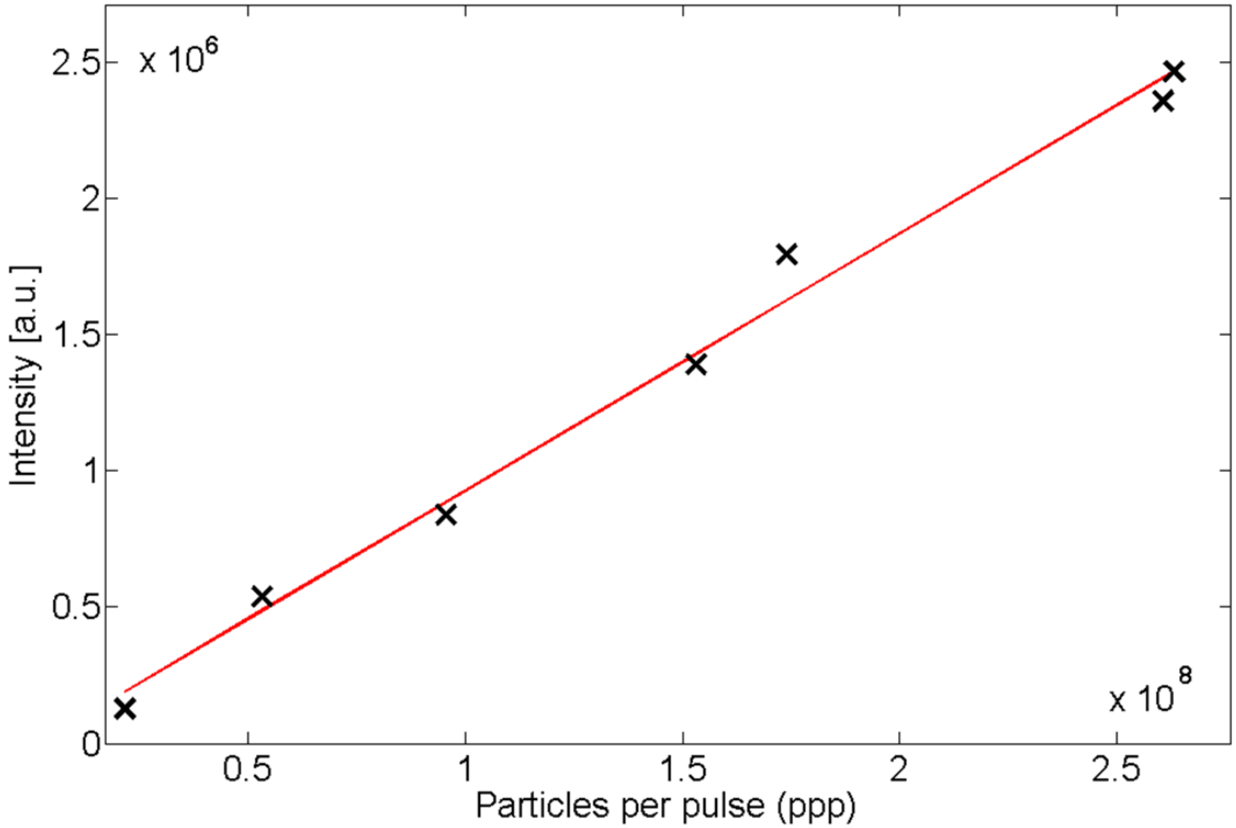
no background sources in the screen with a longer emission time

Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **2.6 · 10⁸ 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



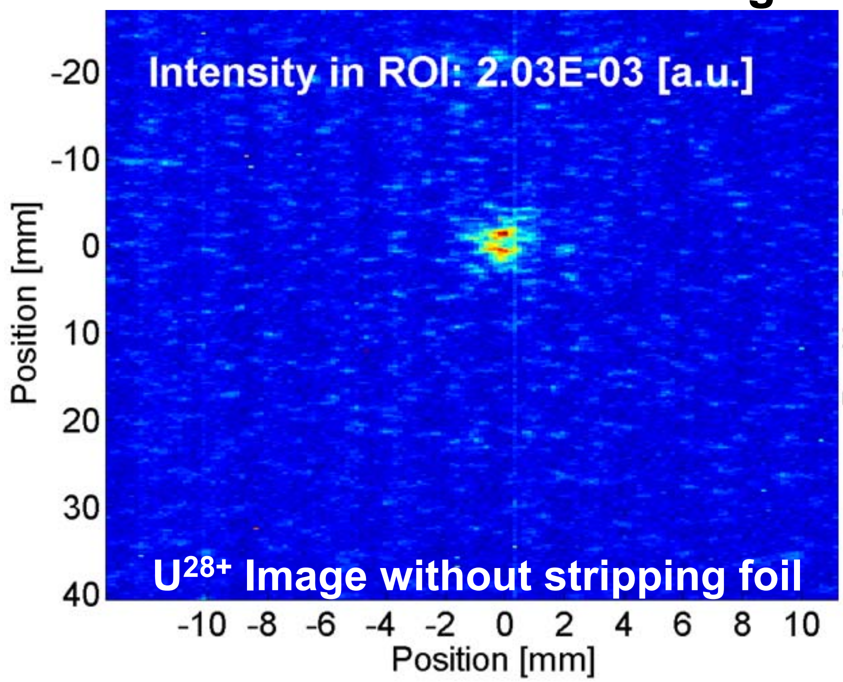
OTR signal strength scales linear with particle number

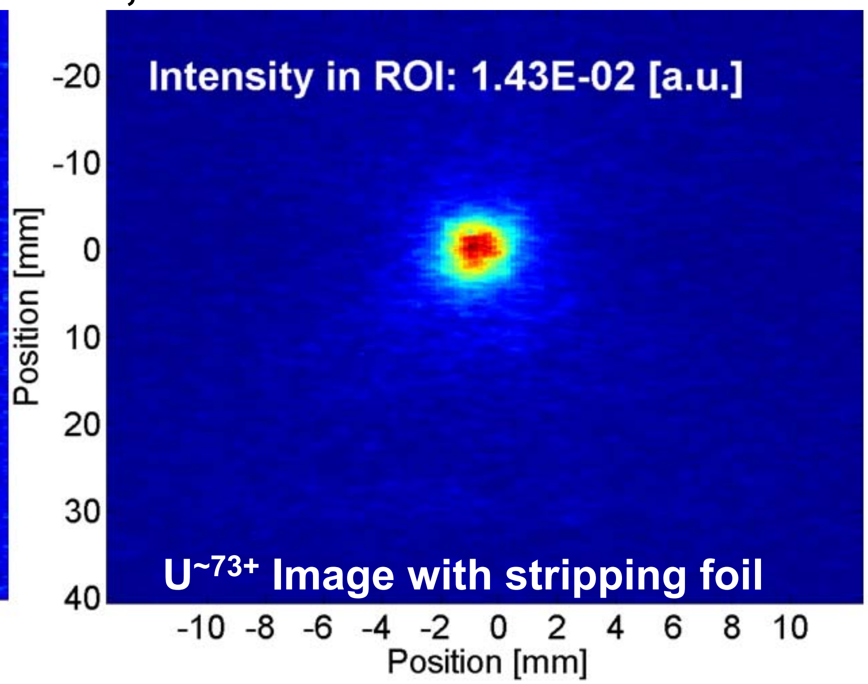
Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **$1 \cdot 10^7$ - $3 \cdot 10^8$ ppp** in 300 µs

First results – q^2 dependency

OTR photons number 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:

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

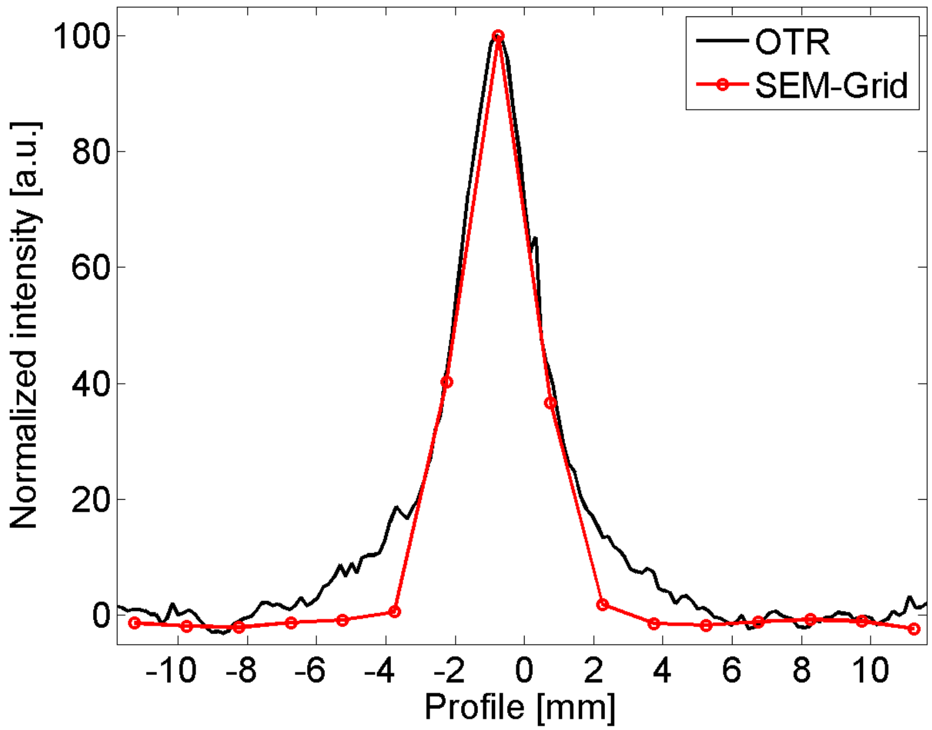
But:

→ 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 (black line) and SEM-Grid (red line)

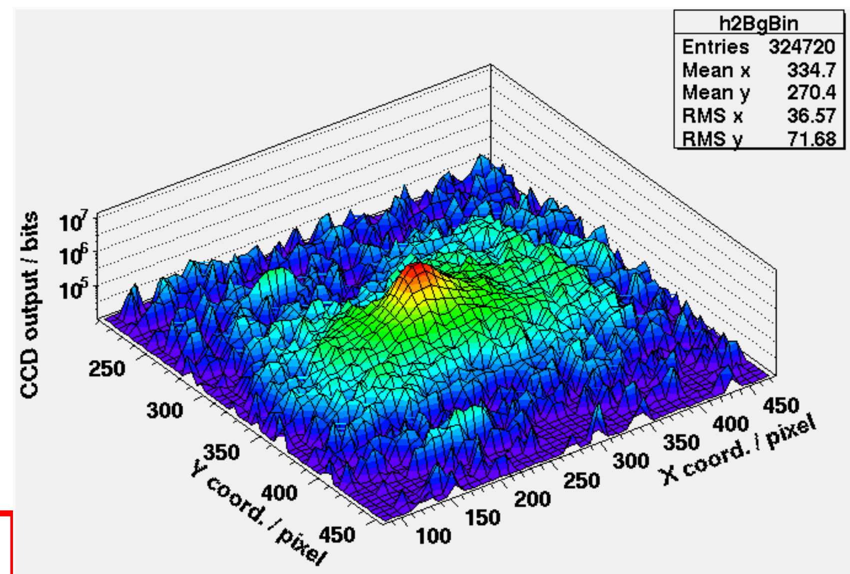


Good agreement in the core region of the distribution

But:

→ observed shoulder in OTR profile is not yet clear

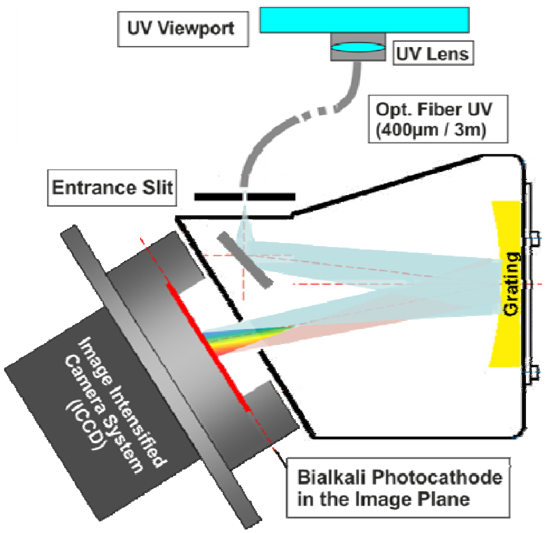
→ further studies required

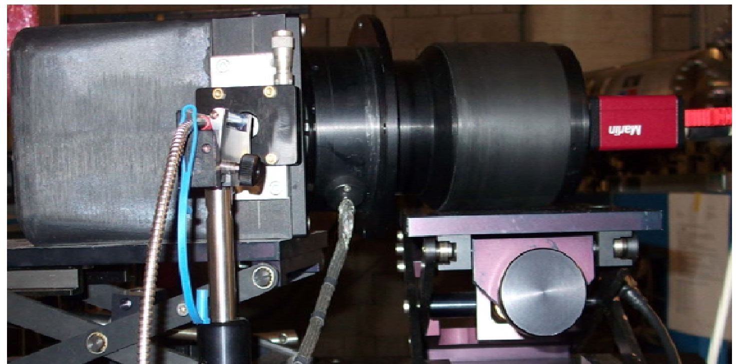


Beam parameters: $U^{\sim 73+}$, 11.4 MeV/u, **$2.6 \cdot 10^8$ ppp** in 300 μs

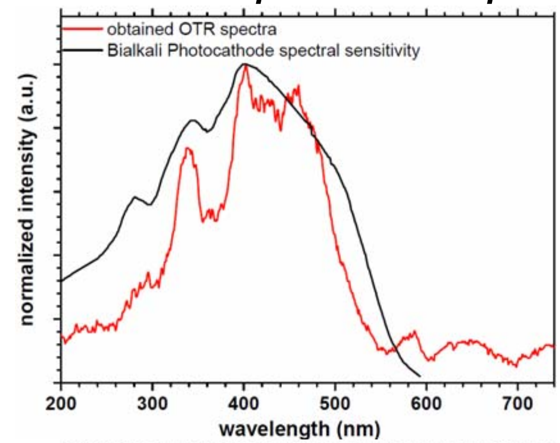
First results – spectroscopy

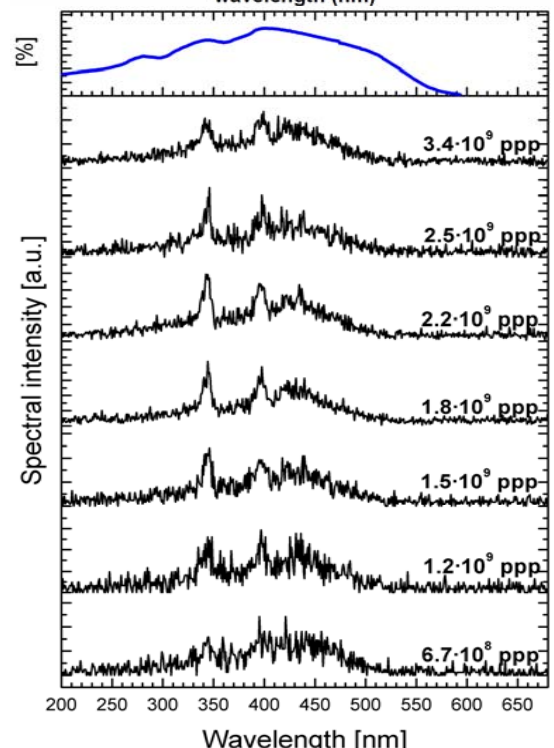
To clearly distinguish the OTR signal from blackbody radiation a spectroscopic investigations have been made.





Jobin Yvon Horiba CP140-202 spectrograph and an ICCD





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

→ spectrum is very stable

→ light spectrum is independent on particles number

→ all wavelengths above 550 nm are significantly suppressed

No significant contribution to spectrum from other sources

Summary

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

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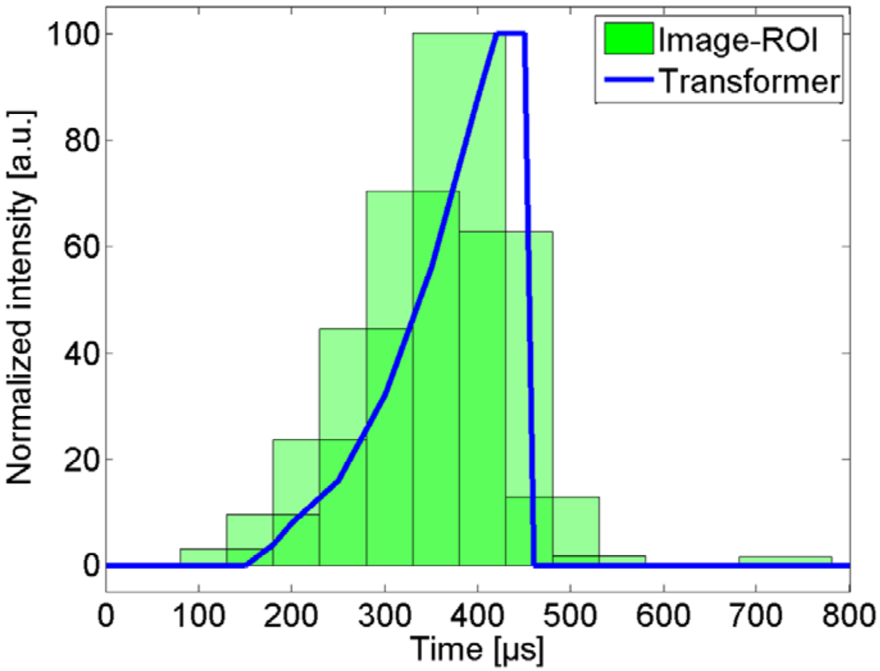
OTR signal strength as a function of time

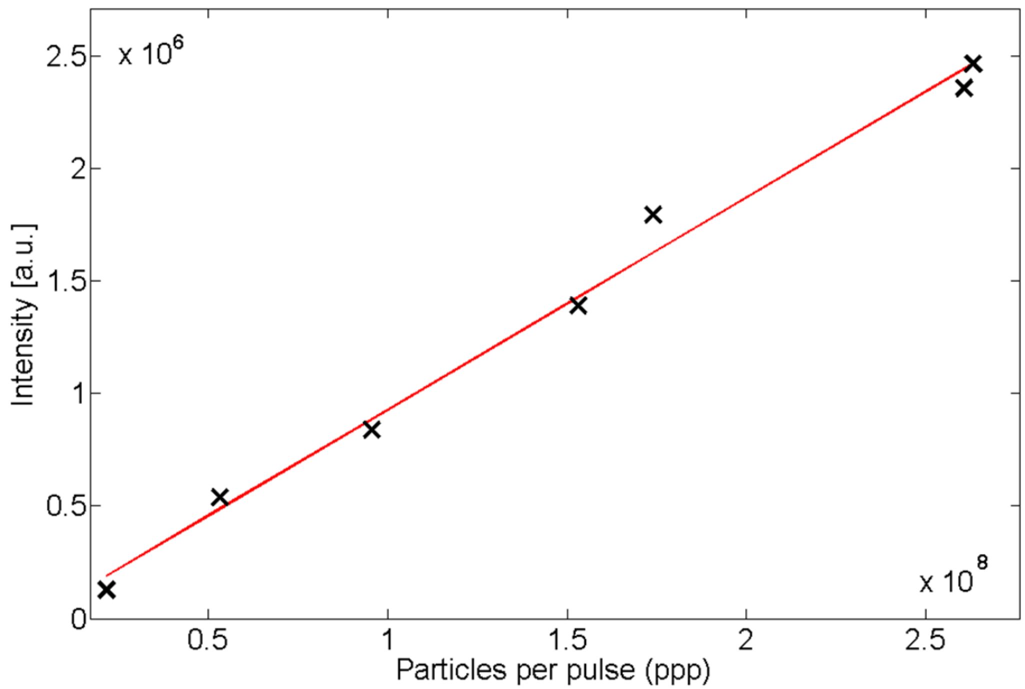


Summary

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

OTR signal strength as a function of time

OTR signal scales linear with the applied particles number



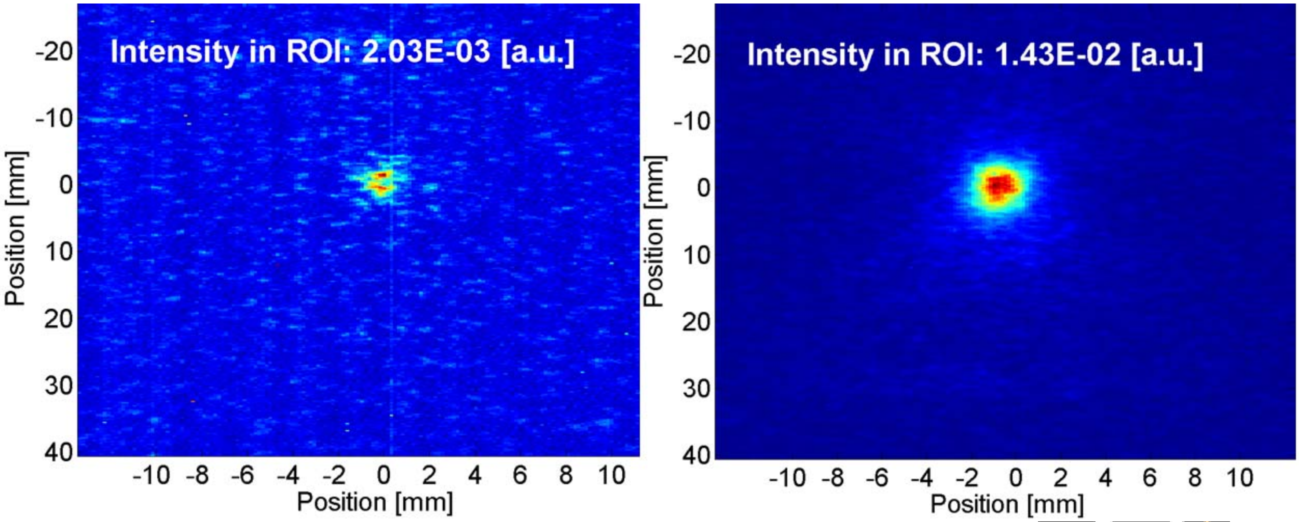
Summary

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

OTR signal strength as a function of time

OTR signal scales linear with the applied particles number

OTR signal strength roughly supports q^2 dependency



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

OTR signal strength as a function of time

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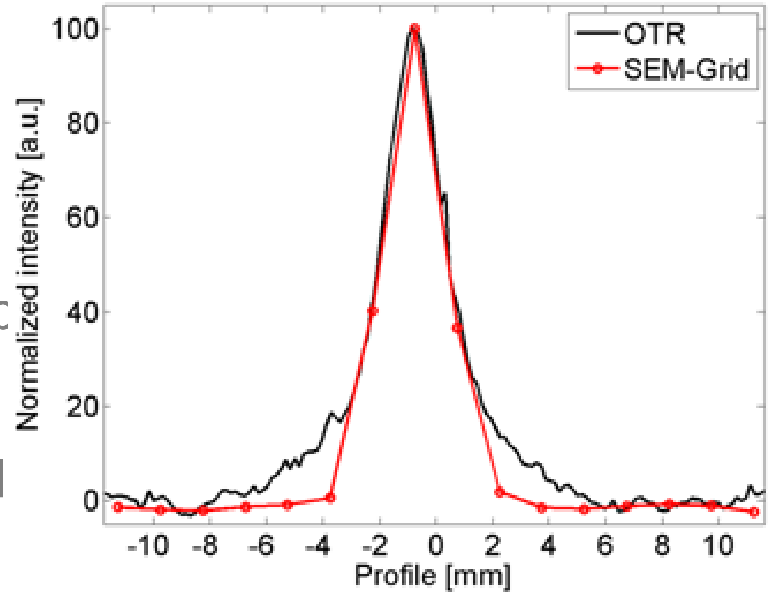

Beam profile measurements show good agreement

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

OTR signal strength as a function of time

OTR signal scales linear with the applied particles

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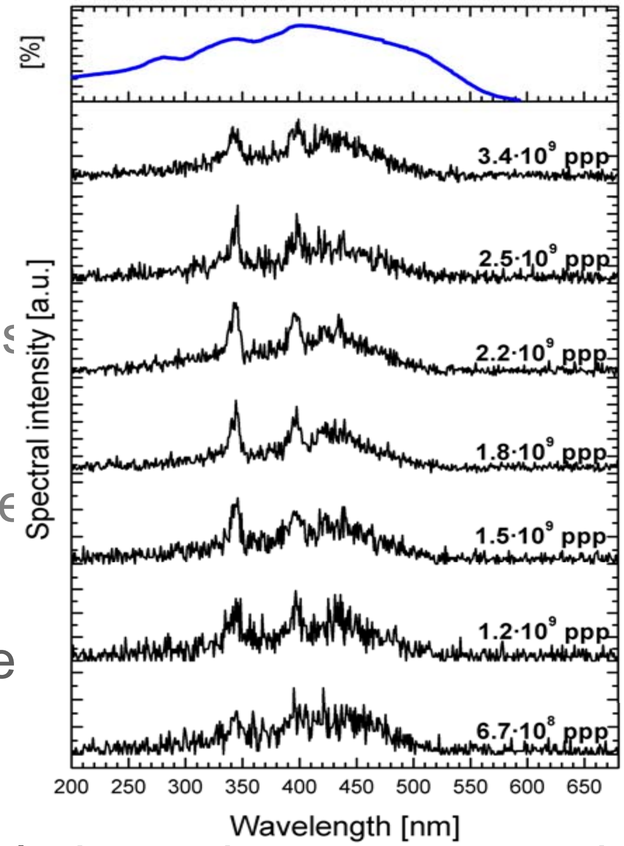
Beam profile measurements show good agreeme



Contribution of blackbody radiation can be ruled out by spectroscopic studies

What´s next?

Further studies at UNILAC

Advanced studies on polarization effects

Determinate origin of shoulder in beam profile

q^2 dependency

Calibration of experimental setup to obtain absolute number of photons

Theoretical predictions: Calculation of photon yield in experimental acceptance

Further studies at high energy beam transport lines

Test in preparation (autumn 2012/spring 2013), 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

Acknowledgements

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Alex Lumpkin who made the test possible
and
Christiane Andre for help and support!