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

B. Walasek-Höhne, C. Andre, F. Becker, P. Forck, A. Reiter, M. Schwickert

GSI Helmholtz Centre for Heavy Ion Research GmbH, Darmstadt, Germany

A. Lumpkin

Fermi National Accelerator Laboratory, USA
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

- 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,

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

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!
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.

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

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

The number of emitted photons:

\[ I \propto q^2 \cdot \beta^2 \cdot N \]

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

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

Charge state distribution of $U^{28+}$ beam stripped at 11.4 MeV/u
The feasibility of OTR has been evaluated with 11.4 MeV/u ($\beta=0.16$) $U^{28+}$ beam at the UNILAC (X2 beam line).

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

**UX2DKA diagnostic chamber:**
- OTR Targets
- SEM-Grid (UX2DGA) for transversal profile comparison
The feasibility of OTR has been evaluated with 11.4 MeV/u ($\beta=0.16$) $U^{28+}$ beam at the UNILAC (X2 beam line).

**UX2DK2** (Stripping foil location), used material: Carbon 570 $\mu$g/cm$^2$

**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

**UX2DKA diagnostic chamber**

- **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
B. Walasek-Höhne, GSI-BD
Pilot studies on OTR imaging of non-relativistic ions at GSI

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, $2.6 \cdot 10^8$ ppp in 300 µs
First results – time structure of signal

OTR is a prompt process, signal observed only during irradiation.

Beam parameters: $\text{U}^{73+}$, 11.4 MeV/u, $2.6 \cdot 10^8$ ppp in 300 $\mu$s

→ visible signal only during pulse
→ no latency of light emission
no background sources in the screen with a longer emission time
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

Beam parameters: U^{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 $q\sim +73$. Expected signal growth by a factor of $\sim 7$.

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

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

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

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\(^{73+}\), 11.4 MeV/u, 2.6\(^{10}\)\(^{8}\) ppp in 300 \(\mu\)s
First results – spectroscopy

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

→ 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.
Summary

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

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

![Intensity plots comparison](image)
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 $q^2 d$

Beam profile measurements show good agreement
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
- OTR signal strength roughly supports $q^2$ dependence
- Beam profile measurements show good agreement

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

Sincere thanks to the GSI beam diagnostics group, Alex Lumpkin who made the test possible and Christiane Andre for help and support!