Investigation of Ion Trapping and Beam-Induced Fluorescence at the Electron Cooler Test-Bench at HIM

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Beam-Induced Fluorescence at the Electron Cooler Test Bench at HIM

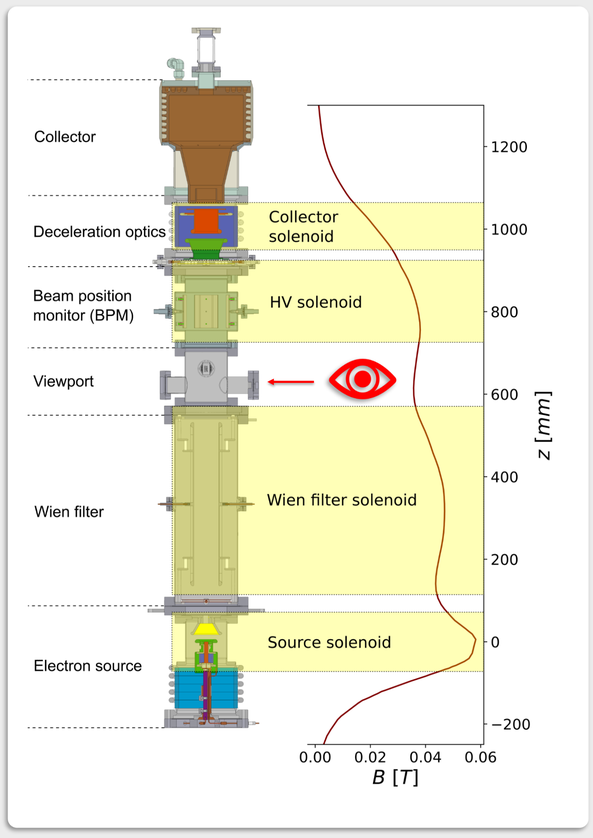

Fig. 1: Schematic of the test bench with the solenoid field-strength along the beam path

- Energy-recovery setup → electron beam (**1 A, 30 keV e⁻** for **3 kW** wall power)
- **Beam-Induced Fluorescence (BIF)** observed in residual gas (p = **$3 \cdot 10^{-10}$ mbar**)
- Measurements at **550 mA**, **18 keV e⁻** (to limit the X-Ray exposure of the sCMOS camera)
- Images: acquired over **30s;** resulting profiles averaged over 500 pixel rows (Fig.2, Fig.3)
- Intensity increase of BIF over time (for 3-5 min. even if normalized for pressure)
- Measurements of BIF for beam currents from 0 to 550 mA (Fig.4)
- **Overproportional correlation** of the integrated signal intensity with the beam current (Fig.5)
- Suggested the **trapping of photon-emitting ions**.

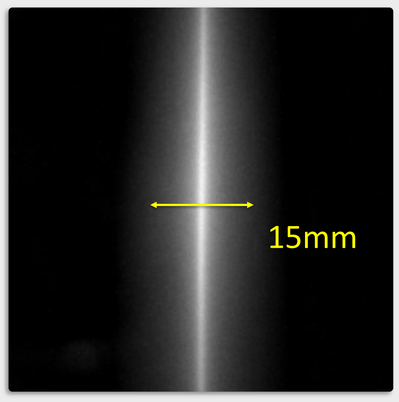

*Fig.2: Image of BIF produced by a **30 keV, 1A** electron beam*

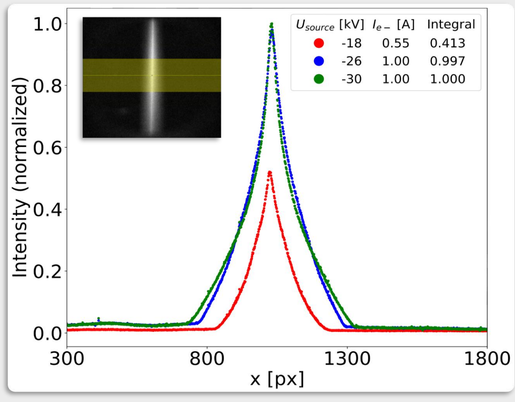

Fig.3: Averaged profiles of BIF for several parameters (Averaged region: yellow)

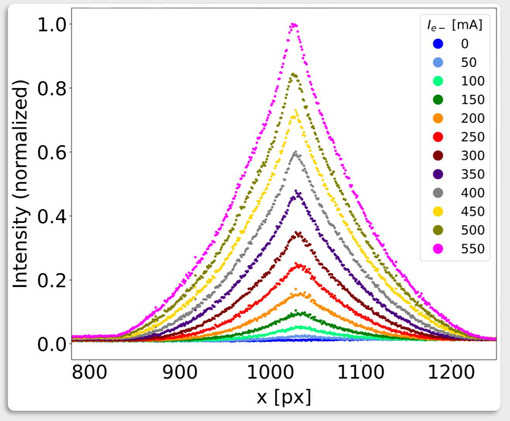

Fig.4: Averaged profiles of BIF for several beam currents

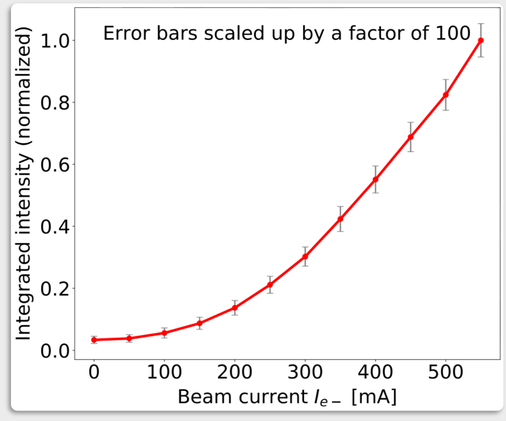

Fig.5: Integrated intensity of BIF profiles correlated with beam current

Ion Trapping in the Electron Beam

- Residual gas particles ionized by the electron beam
- *Trapping mechanism (model):*
  - DC electron beam **approximated** as cylindrical **homogeneous charge distribution**
  - Rotational symmetry → radial trapping (Fig.6)
  - **Grounded, small apertures** of the anode and the deceleration optics **shape the beam potential** and facilitate **longitudinal trapping** (Fig.7)
- *Simple model to explain the **shape of the BIF**:*
  - **BIF photons** are **emitted by trapped ions** that get **excited by the electron beam** repeatedly
  - Particles ionized at t_0 **oscillate inside the potential** and reach r = 0 at the same t_1
  - Charge distribution of the trapped ions can be derived to $\sigma(r) = \frac{e^{-r}}{r}$ (Fig.8) → resembles a **Laplace distribution** → **fit of observed data** (Fig.9)
  - The **center of charge was identified**, and through the sharp transition of the signal into the background, the **border of the electron beam was observed**.

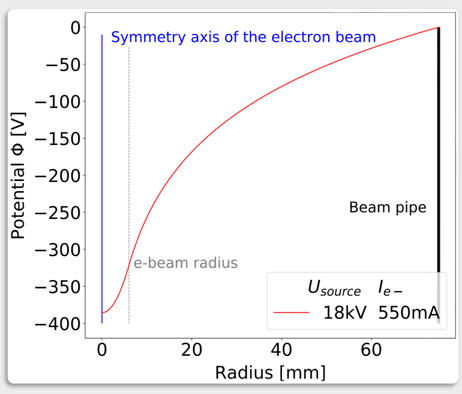

Fig.6: 1-dim electron beam potential (beam pipe: grounded)

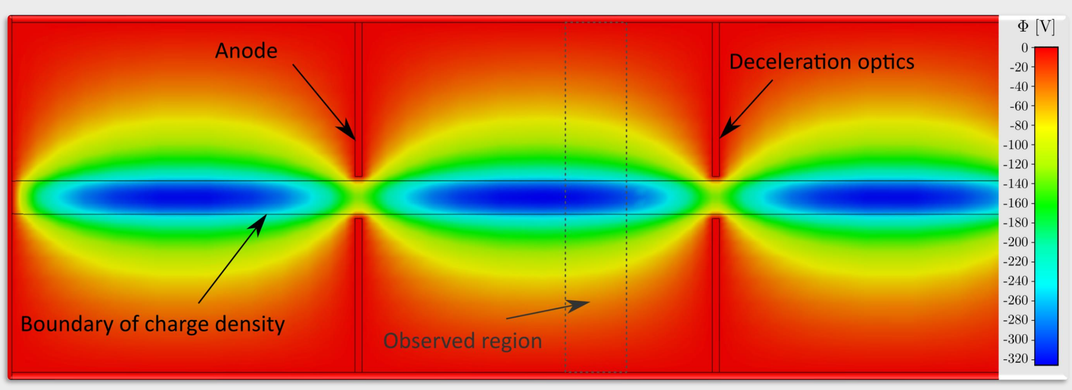

Fig.7: CST-simulated, simplified model of the test-bench and the potential of a homogeneous charge distribution (on the center plane)

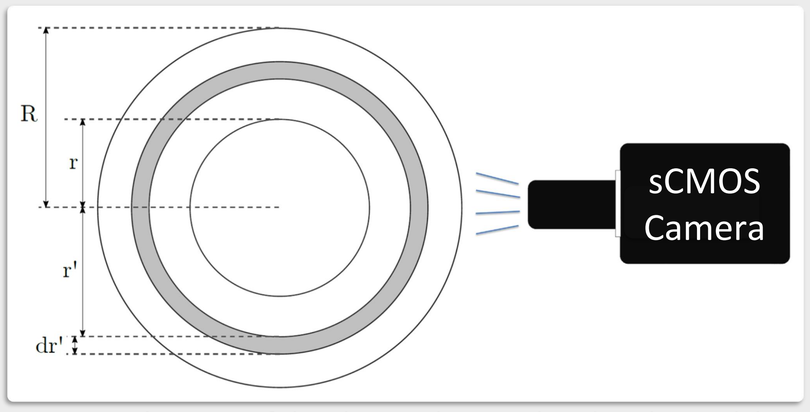

Fig.8: Schematic of the electron beam related to the model considerations with the radius of the electron beam R

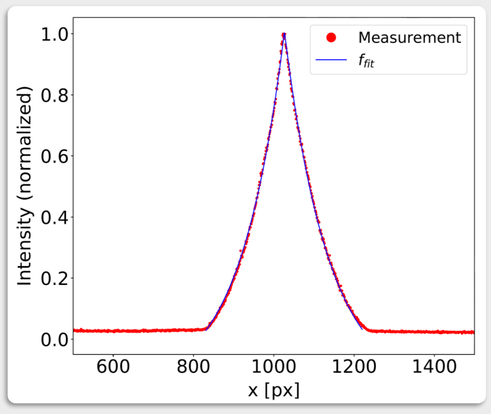

Fig.9: BIF profile with a 550 mA electron beam and the derived fit function

Ion Clearing through Beam Interruptions

- **Fast HV-switch** was implemented at the Pierce electrode → interrupted the beam with **15 Hz** (Fig.10)
- **Beam interruptions** resulted in **decrease of BIF photons** (Fig.11) (**previously only indirectly observed** via cooling power at Fermilab)
  [A. Shemyakin et al., "EFFECT OF SECONDARY IONS…", Proc. IPAC'10]
- Further measurements with different frequencies and switch-off durations were conducted to maximize the **duty cycle** of the electron beam while **minimizing the number of trapped ions** (Fig.12).

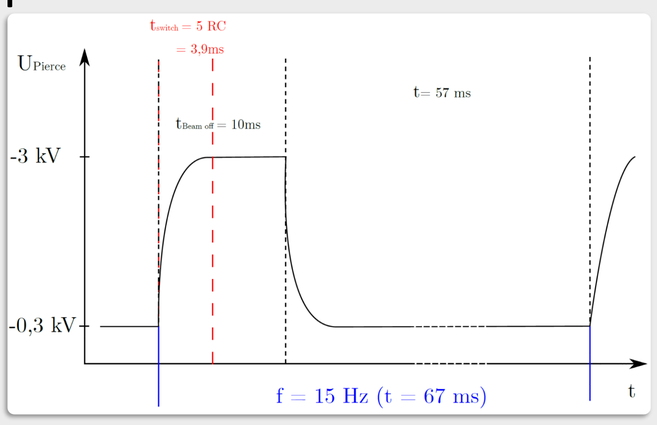

Fig.10: Pulsing scheme for ion clearing operation at the test bench

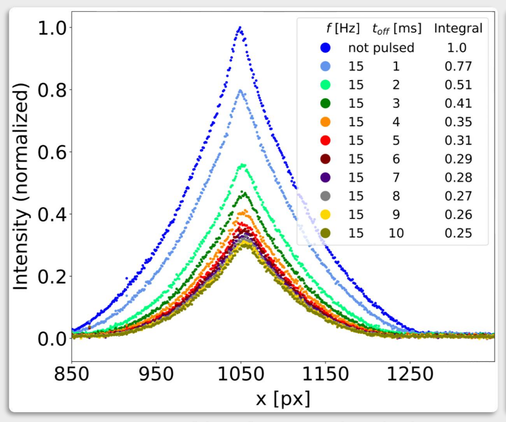

Fig.11: BIF profiles for a pulsed electron beam compared to a DC beam

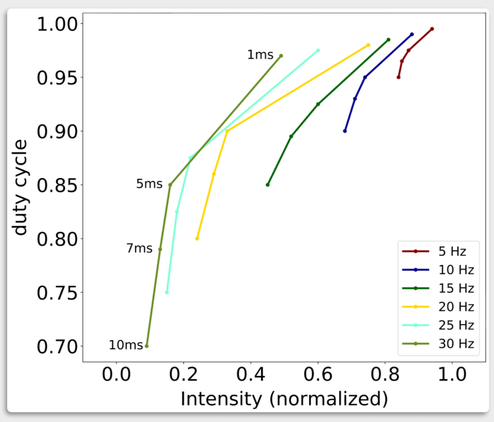

Fig.12: Duty cycle for several pulsing frequencies and switch-off durations

Spectrally-resolved BIF

- Expected H_2 spectral lines were not present
- **Ba-evaporation from dispenser cathodes** (as measured in comparable **E**lectron **B**eam **I**on **T**raps) was a particle source
  [R.E. Marrs, "Milestones in EBIT Spectroscopy…", CJP 86 (2007)]
- Data could be explained by different charge states of Ba, BUT it is not certain if they occur in the test-bench (Fig.13).

Partial pressure (beam path)	*e-impact ionization cross-sec.*
$p_{H_2} = 5.64 \cdot 10^{-11}\ mbar$	$\sigma_{H_2} = 0.02\ \mathring{A}^2$
$p_{Ba} = 1.37 \cdot 10^{-10}\ mbar$	$\sigma_{Ba} = 0.11\ \mathring{A}^2$

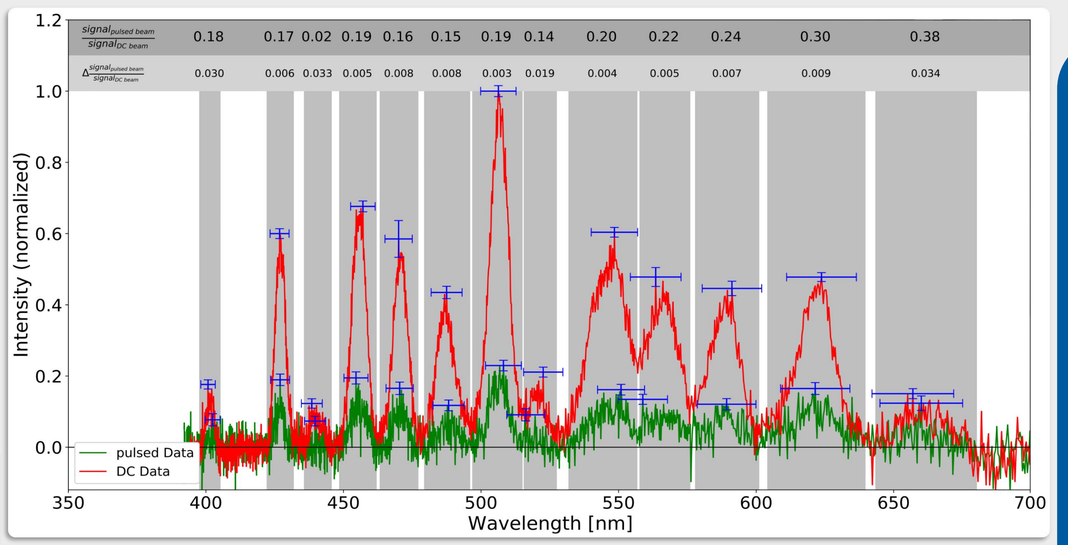

Fig.13: Spectrally-resolved measurements comparing DC and pulsed beam (15Hz)

Summary

- Observed **Beam-Induced Fluorescence** (BIF) photons emitted by **ions**, created and **trapped** by the e^- beam
- BIF photons can show **center** and **border** of the e^- beam
- **Ion clearing directly observed** for the first time
- Ba-dispenser cathode might be a particle source for ions

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