2026 JULY 19–22 VANCOUVER, BC
JOINT AAPM | COMP MEETING

A Tabletop Platform for In Vitro Irradiation with Low-Energy Electron Bunches

Julian Freier[1], Leon Brückner[1], Guilia Cramer[2], Bastian Löhrl[1], Lukas Kuhlmann[2], Christoph Bert[2], Luitpold Distel[2] and Peter Hommelhoff[1,3]

(1)Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg, Erlangen, Germany
(2)Department of Radiation Oncology, Uniklinikum Erlangen, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
(3)Department of Physics, Ludwig-Maximilian-Universität München, München, Germany

ABSTRACT

Purpose: Low-energy electrons (LEE, keV range) are expected to show elevated RBE due to high LET and limited penetration. Laser accelerator-on-a-chip concepts could enable minimally invasive clinical delivery. This work compares pulsed LEE radiobiology to conventional X-ray exposure.
Methods: Human fibroblasts and tumor cell lines were irradiated with a pulsed photoemission source (up to 50 keV) or a 120 kVp X-ray reference. DNA double-strand breaks were assessed via γH2AX staining and evaluated after different repair times. The cytoskeleton is stained with α-tubulin. The dosimetry is done with unlaminated EBT3 radiochromic film.
Results & Conclusion: LEE produced quantitatively distinct DNA damage patterns consistent with finite electron penetration depth and elevated LET. After 24h of repair time still DSB are visible and the cytoskeleton indicate a high level of stress. The established platform demonstrates clear radiobiological differences between LEE and photon irradiation, supporting further investigation toward localized LEE-based radiation therapy.

Contact

Julian Freier, M.Sc.
Chair for Laserphysics
Friedrich-Alexander-Universität (FAU)
Erlangen-Nürnberg
Staudtstraße 1 91058 Erlangen Germany
julian.j.freier@fau.de

INTRODUCTION

Particle accelerator on a chip (AChip)

- Double pillar nanostructures over a length of hundreds of micrometer
- Illuminate with femtosecond laser puls to induce a nearfield at structure
- Accelerate electron bunches from **28.4 keV** to **40.7 keV** along 500 µm structure

➢ Vision: Endoscopic system for local and precise tumour treatment [1,2,3]

Low-energy electrons (LEE)

- LEE bunches avaible from AChip-structures
- Low penetration depth and potential high biological effectiveness
- Accessible with tabletop systems [4, 5]
- Dosimetry with **unlaminated EBT3 GafChromic films** [6, 7]

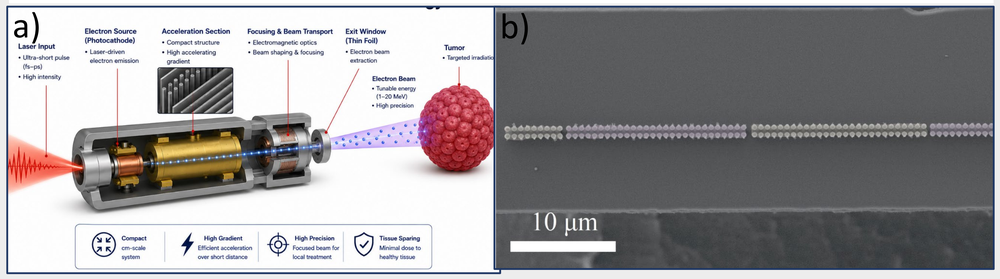


Figure 1: (a) Visual medical application of a AChip-using endoscopic device [1]. **(b)** The double-pillar nanostructure of an Achip. A femtosecond laserpuls induces a nearfield inside the 200 nm channel, which keeps and accelerate electrons through the structure [3].

METHODS AND MATERIALS

Compact electron source (CES) [4]

- Electron emission from nanotip array with Er:Fiber pulsed laser [5]
- Accelerated up to **50 keV**
- Transmit from vacuum through SiN-membrane into atmosphere
- Detect and control emission with Gafchromic film or TimePix 3

➢ Due to atmosphere possible to irradiate biological samples in vitro

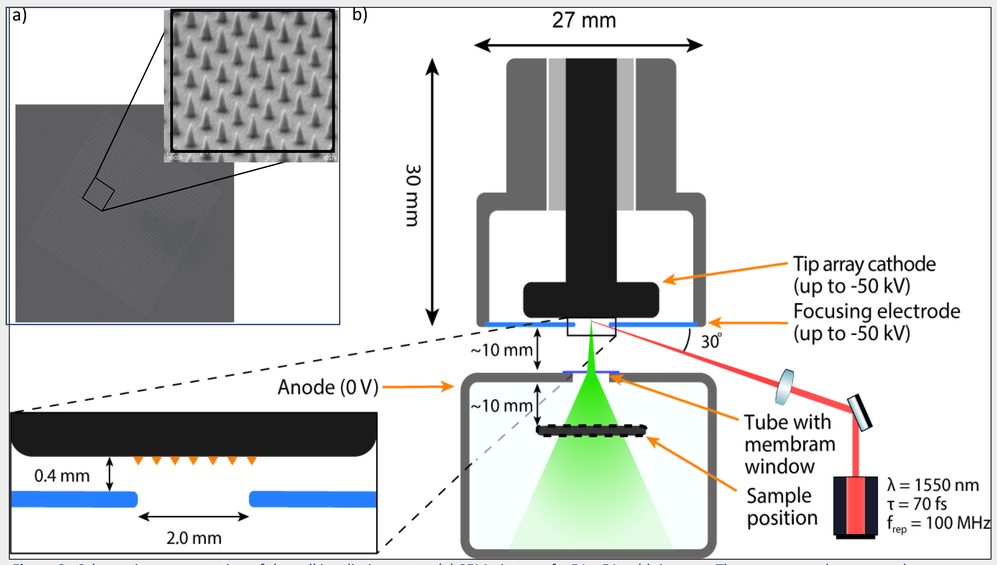
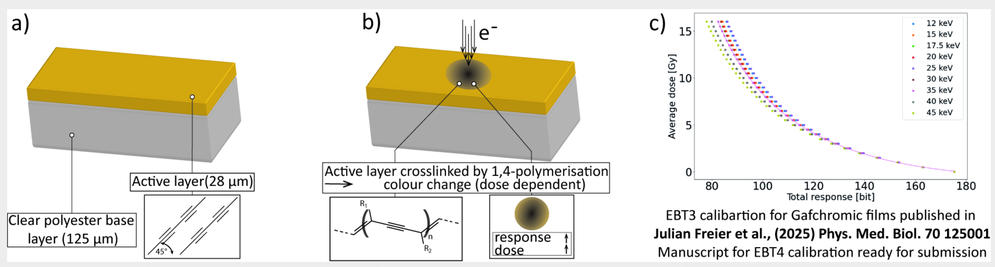


Figure 2. Schematic representation of the cell irradiation setup. (a) SEM picture of a 51 x 51 gold tip array. There are several arrays on the substrate, which can be illuminated separately. Due to the lithographic manufacturing, the dimensions of the array is variable. (b) Sketch of CES, where tip array (lbc) is illuminated with Erbium fiber laser. Electron get accelerated up to 50keV and transmit through SiN-membrane into atmosphere where sample get irradiated.

Unlaminated EBT3 Gafchromic films

- Surface is detecting layer right away (necessary for LEE)
- Pure energy dependent and tissue equivalent
- LEE have high dose gradient in matter
- Difference between dose at surface and average deposited dose

➢ Calibration links response to average deposited Dose



EBT3 calibartion for Gafchromic films published in **Julian Freier et al., (2025) Phys. Med. Biol. 70 125001**
Manuscript for EBT4 calibration ready for submission

Figure 3: Dosimetry for LEE using unlaminated EBT3 Gafchromic films. (a) Non-irradiated unlaminated film, where the active layer is on top of a clear polyester base. (b) When irradiated with ionising radiation, the active layer responds by darkening depending on the dose. (c) The apparent response is linked to the average dose deposited [7].

RESULTS – Cell irradiation

- Irradiated healthy fibroblasts with **45 keV** LEE
- Use γH2AX staining and fluorescence microscopy for evaluation

➢ Clear and bright foci visible
➢ Less quantity and homogenous damage pattern compared to x-ray irradiation

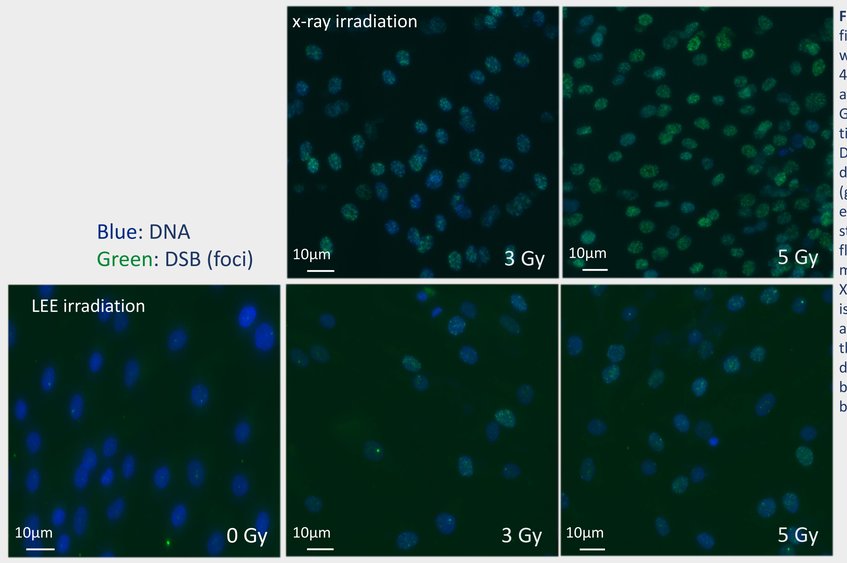


Figure 4. Comparing fibroblasts irradiated with X-rays (top) and 45 keV-LEE (bottom) at doses of 3 Gy and 5 Gy after 1h repair time, respectively. DNA (blue) and double-strand breaks (green) were examined using γH2AX staining and fluorescent microscopy. While the X-ray damage pattern is more quantitative and homogeneous, the LEE irradiation damage appears brighter, indicating bulky lesions.

- Irradiated healthy fibroblasts with **45 keV** LEE
- Fix cells after different times: **1h**, **8h** and **24h**
- Use γH2AX and α-tubulin staining and fluorescence microscopy for evaluation

➢ Even after long repair times clear and bright foci visible
➢ α-tubulin intensity might indicate high stress level even after long repair time
  ➢ May even be radiation-induced senescence

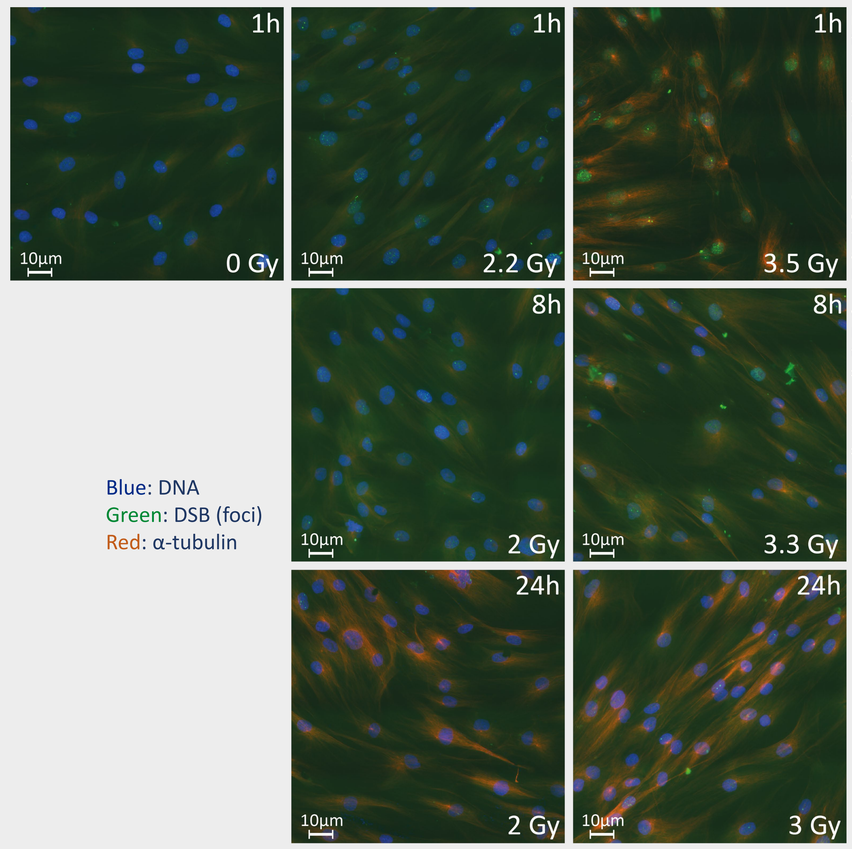


Figure 5: Comparing fibroblasts irradiated with 45 keV-LEE after 1h, 8h and 24h of repair time, respectively. DNA (blue), double-strand breaks (γH2AX, green), and α-tubulin (red) were examined using fluorescent staining and microscopy. Even after 24 hours, bright foci are visible. Furthermore, the α-tubulin for the 24h samples indicates a high stress level and might indicate induced senescence.

Conclusion

- Tabletop setup for cell irradiation with LEE up to **50 keV**
- Dosimetry using unlaminated EBT3 and EBT4 Gafchromic films
- Biological effectiveness of LEE comparable to that of 120 kVp X-ray

➢ Working on clonogenic assays for evaluation of relative biological effectiveness

REFERENCES: [1] England, R. Joel, et. al.,Reviews of Modern Physics 86.4 (2014): 1337 [2] Shiloh Roy et al., Nature 597, (2021) 498-502 [3] Chlouba, Tomas, Shiloh, Roy, Kraus, Stefanie, Brückner, Leon, et al., Nature 622, (2023) 476-480 [4] Hirano, Tomohiko, et. al., Applied Physics Letters 116.16 (2020): 161106 [5] Brückner, Leon, Nauk, Constantin, et al., Nano Lett. 2024, 24, 5018–5023 (2024) [6] Helt-Hansen, Jakob, et. al., Radiation Physics and Chemistry 79 (2010) 66–74 [7] Julian Freier *et al.,* (2025) *Phys. Med. Biol.* 70 125001