ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPM055

OVERVIEW OF FLASH*lab*@PITZ: THE NEW R&D PLATFORM FOR FLASH RADIATION THERAPY AND RADIATION BIOLOGY

X.-K. Li*, Z. Amirkhanyan[1], N. Aftab, P. Boonpornprasert, D. Dmytriiev, M. Frohme[2], G. Georgiev, A. Grebinyk, M. Gross, A. Hoffmann, Y. Komar[2], M. Krasilnikov, G. Loisch[3], A. Oppelt, C. Richard, F. Riemer, S. Philipp, M. Schmitz[3], F. Müller, F. Obier[3], G. Vashchenko, S. Worm, F. Stephan
Deutsches Elektronen-Synchrotron DESY, Platanenallee 6, 15738 Zeuthen, Germany
[1]on leave from CANDLE Synchrotron Research Institute, Yerevan, Armenia
[2]Technical University of Applied Sciences Wildau, 15745 Wildau, Germany
[3]Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany

Abstract

An R&D platform for electron FLASH radiation therapy and radiation biology is being prepared at the Photo Injector Test facility at DESY in Zeuthen (FLASH*lab*@PITZ). This platform is based on the unique beam parameters available at PITZ: ps scale electron bunches of up to 22 MeV with up to 5 nC bunch charge at MHz bunch repetition rate in bunch trains of up to 1 ms in length repeating at 1 to 10 Hz. It works together with the Technical University of Applied Sciences Wildau (TH Wildau) as partner in close vicinity for the biological resources.

A startup beamline has been installed to allow dosimetry studies and irradiation experiments on chemical, biochemical and biological samples after a 60-degree dispersive arm. The measured dose and dose rates under different beam conditions and first experimental results will be reported in this paper. In addition, a dedicated beamline for FLASH*lab*@PITZhas been designed for better control of the high brightness electron beams. This includes a dogleg to translate the beam and a 2D kicker system to scan the tiny beam focused by quadrupoles across the samples within less than 1 ms. Simulation studies will be presented to demonstrate the extremely flexible dose parameters with various irradiation options for electron FLASH radiation therapy and radiation biology studies.

INTRODUCTION

The FLASH radiation therapy (FLASH-RT) has drawn worldwide attention for its reduced damage to healthy tissues, while having the same tumor control as with conventional dose rate [1]. FLASH-RT usually uses an ultra-high dose rate (>40 Gy/s), which is three orders of magnitude higher than the conventional dose rate (a few Gy/min). While the underlying biological mechanisms are still not fully understood, a broad parameter space study will strongly help to understand the FLASH effects and to define the optimal tumor treatment. With its unique electron beam parameters, the photo injector test facility at DESY in Zeuthen (PITZ) is currently preparing a platform for radiation biology and the FLASH radiation therapy, which is called FLASH*lab*@PITZ [2]. This platform can provide an extremely wide dose and dose rate parameter range, from conventional dose rate of a few Gy/min to ultra high dose rate of 10^6 Gy/s to even 10^{12} Gy/s. As a first step, a startup beamline has been installed last year for studying dosimetry and the radiation effects on molecules and biological samples. In this paper, the capability of the PITZ accelerator will be summarized, followed by the experimental results from the startup beamline. The startup beamline is limited by the dispersion and will be replaced by a full beamline. The status of the full beamline will also be reported.

* xiangkun.li@desy.de

PITZ AS A PLATFORM FOR FLASH RADIATION THERAPY

The PITZ accelerator consists of a normal conducting photocathode RF gun and a booster accelerator, which together can accelerate the beam up to 22 MeV. The RF gun is operated in the burst mode. Currently, the latest prototype Gun5.1 runs with RF pulses up to 1 ms long and repeating at 1-10 Hz [3]. With 1 MHz repetition photocathode laser, the gun can accelerate up to 1000 bunches within one RF pulse, as shown by Fig. 1.

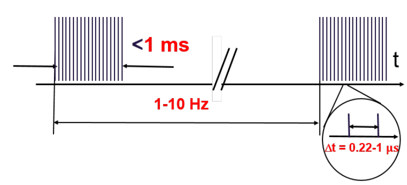

Figure 1: Electron bunch train structure at PITZ.

Table 1: Dose parameters available at PITZ.

Mode	Dose (Gy)	Dose rate (Gy/s)
single bunch	0.02-10^3	2×10^9-10^{13}
single train	0.02-10^6	2×10^4-10^9
multi train	0.02-∞	0.02-10^7

For the FLASH radiation therapy, the accelerator can run in three modes: single bunch, multi bunches in a single train and multi trains. For single bunch or single train mode, the irradiation window can be controlled by a fast shutter. The possible dose and dose rate range are given in Table 1, where the lower and higher limits are for bunch charges of 0.1 pC

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPM055

and 5 nC, respectively. The dose is calculated from the stopping power of 22 MeV electron beam in an irradiation volume of 1 mm^3. The dose rate is the average of the dose over the time the electron bunch or bunches lasts. With the installation of the new laser system in this summer, the laser repetition rate can go up to 4.5 MHz, therefore further boosting the dose rates.

STARTUP BEAMLINE AND EXPERIMENTAL RESULTS

A startup beamline has been installed at PITZ last year, on which dosimetry studies and first irradiation experiments have been performed. As shown in Fig. 2, the electron beam is bent by a 60 degree dipole, then goes through very detailed diagnostics devices (BPMs, ICT, Faraday cup and screen station) before the extraction with a Titanium window. A vertical kicker in the dispersive arm allows for scanning the electron beam in one direction. Lead bricks are installed after the window to block the tails of the beam. A hole of 30 mm in the brick makes way for the electron beams to arrive at the samples inside Eppendorf tubes. A second Faraday cup is installed after the samples. Without the samples in the way, the bunch charge measured by this Faraday cup can be used to estimate the dose. Due to the dispersion effect, the electron beam size is not small at the exit window, especially when high bunch charge beam is transported for ultra high dose rate (UHDR). But as shown by the experimental results later, besides the conventional dose rate (0.05 Gy/s), the startup beamline can also provide UHDR up to 10^6 Gy/s.

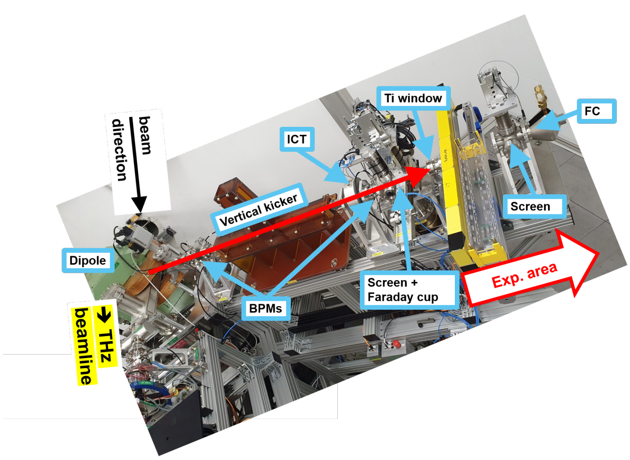

Figure 2: Startup beamline for FLASH*lab*@PITZ.

Dosimetry Studies

The purpose of dosimetry studies include: firstly, verifying the dose and dose rate from calculations using the ideal PITZ electron beam parameters; secondly, studying different materials/devices for better/online dose measurement; thirdly, optimizing the dose distributions, e.g., minimizing the dark current from the accelerator and the scattering radiation in the surrounding materials [5]; lastly, developing tools for online dose predictions.

The dose distributions at the sample location can be either simulated or measured. The simulation uses the beam distribution measured by the in-vacuum screen as input, normalized by the charge measured by the in-air Faraday cup. A quick online tool written in Python also allows to estimate the dose and its distribution within one minute; the whole experimental setup has also been modeled by FLUKA [6] to allow more precise dose simulation and comparison with measurement. The measurements were done by Gafchromic films, which get darkened after being irradiated. The conversion from the RGB colors of scanned films to dose has been calibrated in advance. In experiments, we put one film in front of and one film after each sample. In Fig. 3, it shows the simulated (FLUKA) and measured dose distributions from one experiment and they fit quite well.

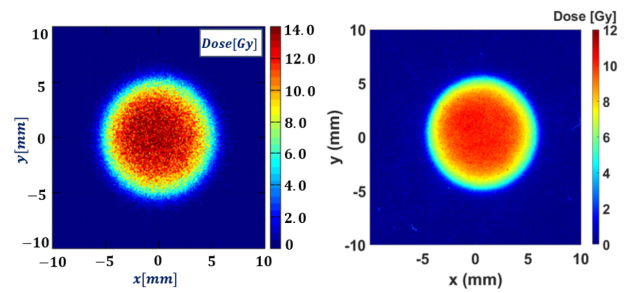

Figure 3: Dosimetry on the startup beamline: (left) FLUKA simulation using the measured electron beam distribution as input and (right) directly measured dose distribution by Gafchromic films.

The beam transport has been improved in order to reduce the dark current at the samples and the sample vicinity has been adjusted in order to minimize the radiation from scattered electrons. Currently, the background level is around 5% of the conventional dose rate.

Delivered Dose in Experiments

With the startup beamline, first in vitro experiments have been done, including studies of the radiation effects on molecules, their dose and dose rate dependency and the radiation depth in the water phantom.

Table 2: Delivered dose parameters in radiation experiments.

Mode	Charge	Delivered DR	Max. dose
multi train	10-30 pC	0.05 Gy/s	unlimited
single train	0.3-1 nC	0.1-1×10^6 Gy/s	<600 Gy

The radiation was delivered at the conventional dose rate of 0.05 Gy/s and the UHDR of 10^6 Gy/s. The achieved dose parameters are given in Table 2. They depended not only on the charge, but also on the thickness of the scattering plate (PMMA, usually 5-20 mm thick) installed after the exit window. For conventional, there was only one electron bunch in each RF pulse and the dose increases with the irradiation time. For UHDR, only one bunch train was sent

14th International Particle Accelerator Conference,Venice, Italy JACoW Publishing
ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPM055

to the samples and the dose was adjusted by the number of bunches in the train, which is currently up to 600, limited by the photocathode laser.

A fast dose estimation tool has been developed, which takes the beam distribution from the in-vacuum screen and the charge from the in-air Faraday cup as input and allows to plan the dose online during the irradiation experiments. The beam was tracked by taking into account the scattering effects in the window and the air with the Moliere's formula. Figure 4 shows the good agreement between the prediction and measured doses under the conventional dose rate.

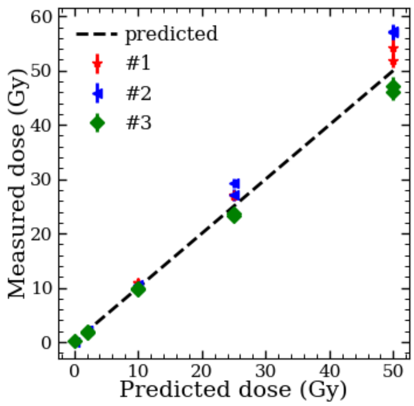

Figure 4: Comparison of doses between fast online estimation and measurements under the conventional dose rate.

Beside in vitro experiments, in vivo experiments are also being planned at PITZ and an animal container laboratory is being prepared.

THE FULL BEAMLINE FOR FLASHlab@PITZ

The startup beamline cannot cover the dose parameters that the PITZ accelerator could provide (Table 1) due to the dispersion. Therefore, it will be replaced by a dedicated beamline [4], which includes an achromatic dogleg to shift the electron beam, quadruple magnets to control the beam distribution and a 2D sweeper for tumor painting studies. The schematic layout is shown in Fig. 5.

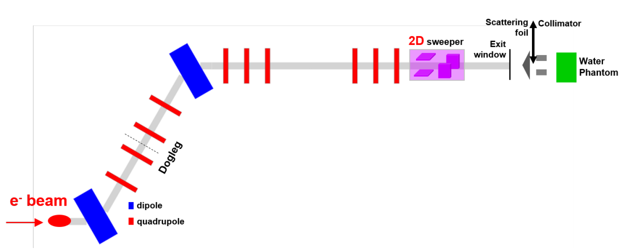

Figure 5: Schematic layout of the full beamline for FLASHlab@PITZ.

Start-to-end simulations by Astra [7] have been performed for various bunch charges [4] and demonstrated the capability of producing tiny electron beams over a huge charge range (10 pC to 5 nC) at the exit window, as shown in Fig.6. Such tiny beams make the dose distribution control more flexible. By using the 2D sweeper, an arbitrary transverse distribution can be produced, as shown in Fig. 7(left). By inserting a scattering foil after the exit window, a wide and uniform distribution can be produced, as shown in Fig. 7(right). The field size shown here are easily scalable, depending on the distance of the irradiation experiment from the exit window.

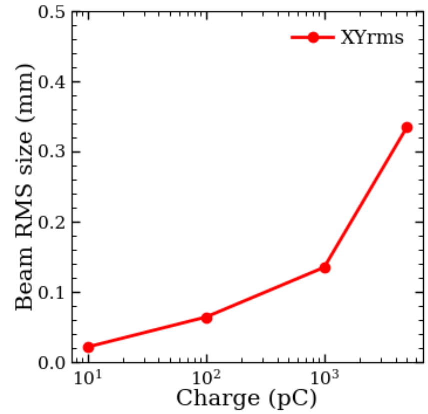

Figure 6: Minimum beam size at the exit window from start-to-end simulations.

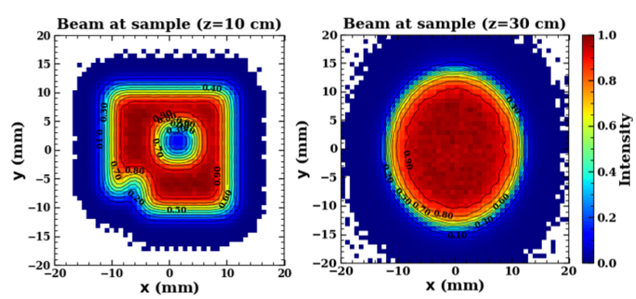

Figure 7: Possible dose distributions from the 2D sweeper (left) or from the scattering system (right) at PITZ.

CONCLUSION

With its unique electron beams, PITZ could provide an extremely wide range of doses and dose rates for radiation biology and FLASH radiation therapy studies. The capability of the FLASHlab@PITZplatform has been reviewed in this paper. On a startup beamline, we have demonstrated part of the dose parameters; the dose parameters used in the first in vitro experiments have showed consistent dose results with online predictions. To realize FLASHlab@PITZ, a dedicated beamline has been designed and its performance has been discussed. The preparation for installation this summer is ongoing.

ISBN: 978-3-95450-231-8 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2023-THPM055

REFERENCES

[1] V. Favaudon *et al.*, “Ultrahigh dose-rate FLASH irradiation increases the differential response between normal and tumor tissue in mice”, *Sci. Transl. Med.*, vol. 6, 2014. doi:10.1126/scitranslmed.3008973

[2] F. Stephan *et al.*, “FLASH*lab*@PITZ: New R&D Platform with unique Capabilities for Electron FLASH and VHEE Radiation Therapy and Radiation Biology under Preparation at PITZ”, *Physica Med.*, vol. 104, pp. 174–187, 2022. doi:10.1016/j.ejmp.2022.10.026

[3] M. Krasilnikov *et al.*, “RF Performance of a Next-Generation L-Band RF Gun at PITZ”, presented at the FEL2022, Triest, Italy, Aug. 2022, paper TUP03, unpublished.

[4] X.-K. Li *et al.*, “Physics Design of Electron Flash Radiation Therapy Bemaline at PITZ”, in *Proc. IPAC’22*, Bangkok, Thailand, Jun. 2022, pp. 2954–2957. doi:10.18429/JACoW-IPAC2022-THPOMS008

[5] A. Hoffmann *et al.*, “Comparison of measurements and simulation results of dose for the FLASH radiation therapy beamline at PITZ”, presented at the IPAC’23, Venice, Italy, May 2023, paper THPM049, this conference.

[6] FLUKA, http://www.fluka.org/fluka.php

[7] K. Flottmann, ASTRA particle tracking code, http://www.desy.de/~mpyflo/