TOWARDS FLASH PROTON IRRADIATION AT HZB

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ABSTRACT: The HZB cyclotron has been successfully providing protons for eye-tumor treatment for more than 20 years using conventional dose rates. Recent studies however indicate that rapid irradiation with very high dose rates (FLASH) might be equally efficient against tumors but less harmful to healthy tissues. The flexible operation schemes of the HZB cyclotron can provide beams with variable intensities and time structures, covering a wide unexplored regime within the FLASH requirements. This paper presents the results of the first FLASH beam production at HZB towards an in-vivo clinical irradiation in the future.

MOTIVATION

The cyclotron of Helmholtz-Zentrum Berlin has treated more than 3600 patients and achieved a local tumor control of 96%. Currently it is investigating the FLASH scheme, which may significantly reduce the side-effects to the healthy tissues according to recent studies.

FLASH uses much higher dose rates in much shorter irradiation times (**> 40 Gy/s** in **< 500 ms**) compared to conventional radiotherapy. Under these conditions, normal cells experience an equivalent dose of ~ 70% with respect to the dose received by the tumor, sparing thus selectively healthy tissues from radiation damage and enabling higher dose delivery to the tumor.

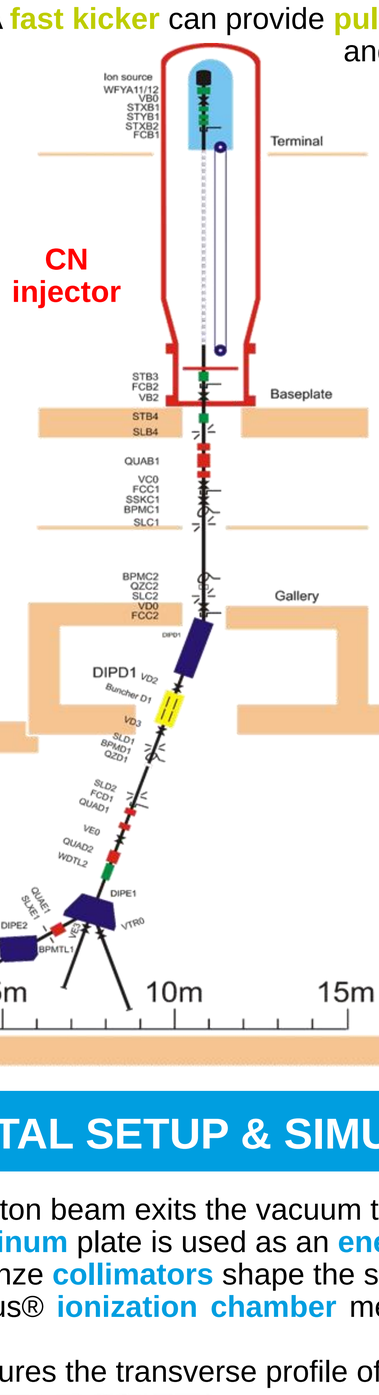
Different institutes worldwide are currently trying to test this new concept. The first application to a human was recently conducted on a skin tumor using a 5.6 MV electron linac. Experiments with protons on small animals with a clinical system are ongoing.

The **HZB cyclotron**, originally designed for ion experiments requiring various intensities and time structures, is an **ideal machine for testing a broad unexplored regime** of the FLASH radiotherapy – even **in-vivo** on mice in the near future.

MACHINE FEATURES

The cyclotron can be operated using either:
• a Tandetron (**TT**) **injector**, routinely used for medical operation due to its increased stability, or
• a Van-de-Graaff (**CN**) **injector**, for bunched beams of higher intensity.

A **fast kicker** can provide **pulses** with > 50 ns duration and < 2 MHz repetition rate.



The default **cyclotron** settings deliver:
- 68 MeV protons
- 20 MHz repetition rate
- bunch duration of 5 ns (TT) or 1 ns (CN) in quasi-DC mode
- average current of 40 nA (TT) or > 400 nA (CN)

at the experimental area.

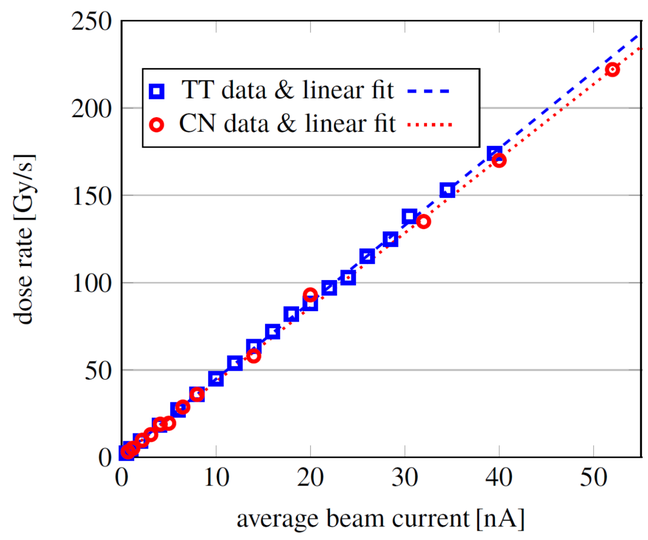
Mouse eyes require a 9 mm circular irradiation field with ~ 5 mm penetration depth (Bragg peak), corresponding to 23 MeV protons.

EXPERIMENTAL SETUP & SIMULATION

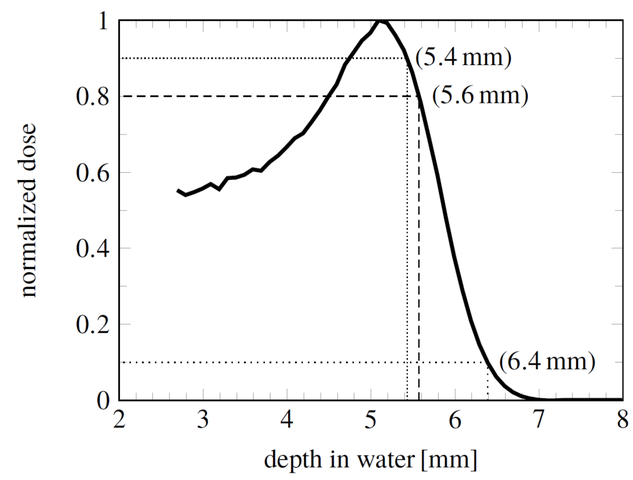
- The 1 mm round proton beam exits the vacuum tube and travels in air
- A 16 mm-thick **aluminum** plate is used as an **energy/range shifter**
- Interchangeable bronze **collimators** shape the scattered beam
- An Advanced Markus® **ionization chamber** measures the dose rate at the target position
- A **CCD camera** captures the transverse profile of the beam after the dose measurement.

The **simulation** of this setup using the LOOKUP code (B. Gottschalk) predicts 40 Gy/s for a 9 nA average beam current and a 9 mm uncollimated transverse RMS size at the target.

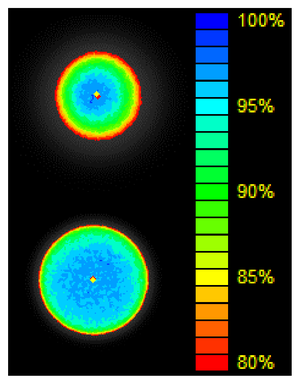
MEASUREMENTS



Both injectors satisfy the FLASH requirements, with the CN exceeding 1 kGy/s (not shown due to short measurement time). The **Bragg peak** was also measured **as predicted**:



The CCD captured a 9 mm circular field using a 5 mm collimating aperture with a poor **uniformity** of 27% →



A **clinically acceptable** uniformity of 6% was achieved for this field by using an 8 mm aperture and shifting the aluminum 19 cm upstream, but for 18% of the dose rate →

CONCLUSION

- With > 200 Gy/s and flexible pulsing, the HZB cyclotron can provide various FLASH schemes, already qualifying for irradiation of mouse eyes, as planned together with Charité in Berlin.
- An optimization of the setup is expected to further improve performance and deliver the first clinical results.

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