A. Denker, J. Bundesmann, T. Damerow, A. Dittwald, T. Fanselow, D. Hildebrand, U. Hiller, Y. Jlassi, I. Kailouh, G. Kourkafas, S. Ozierenski, R. Pena Freitas Mendes, J. Röhrich, C. Zimmer

D. Cordini, J. Heufelder, S. Seidel, R. Stark, A. Weber

A. Kwamou, Z. Önal, D. Rössink

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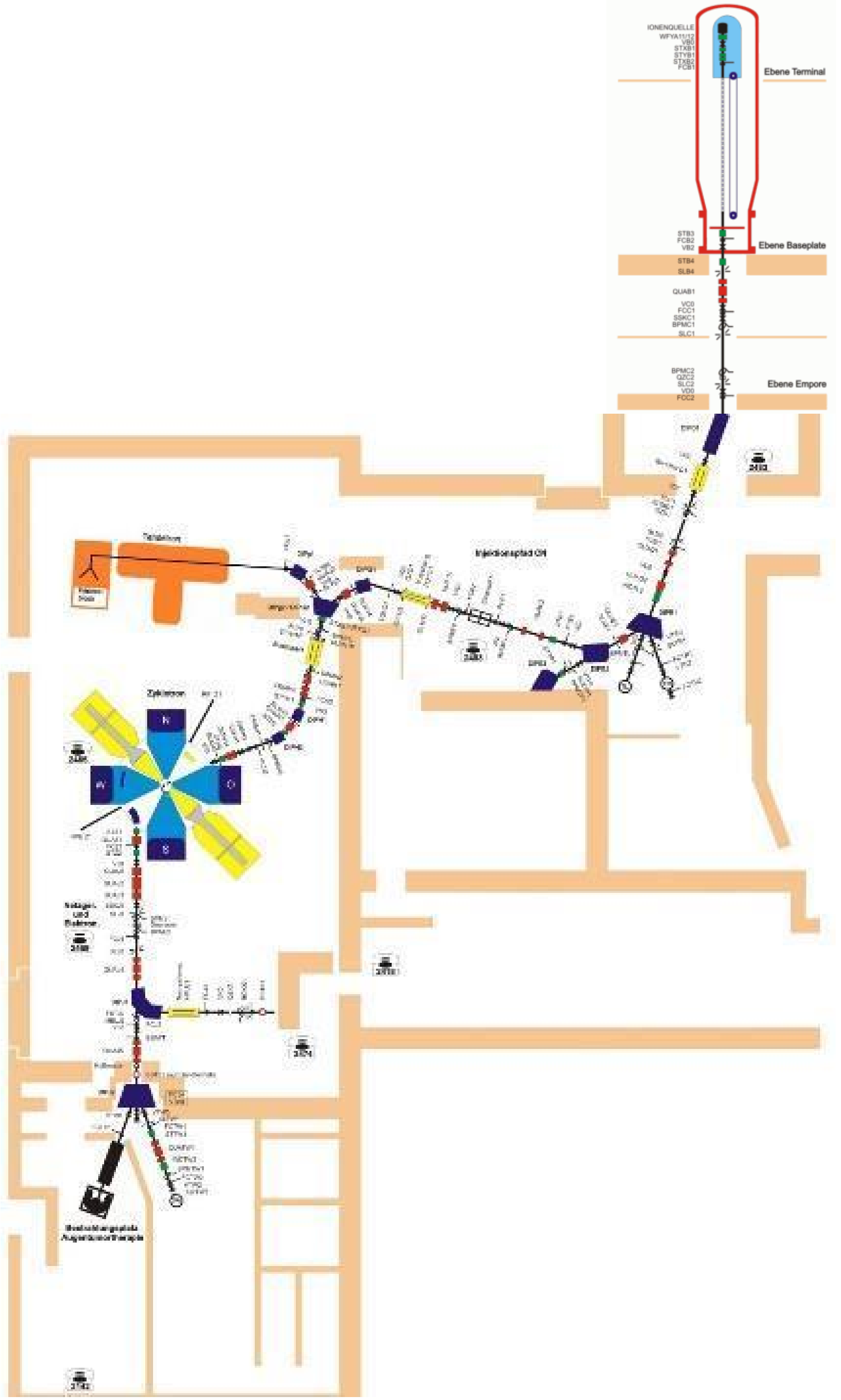
STATUS OF THE HZB CYCLOTRON

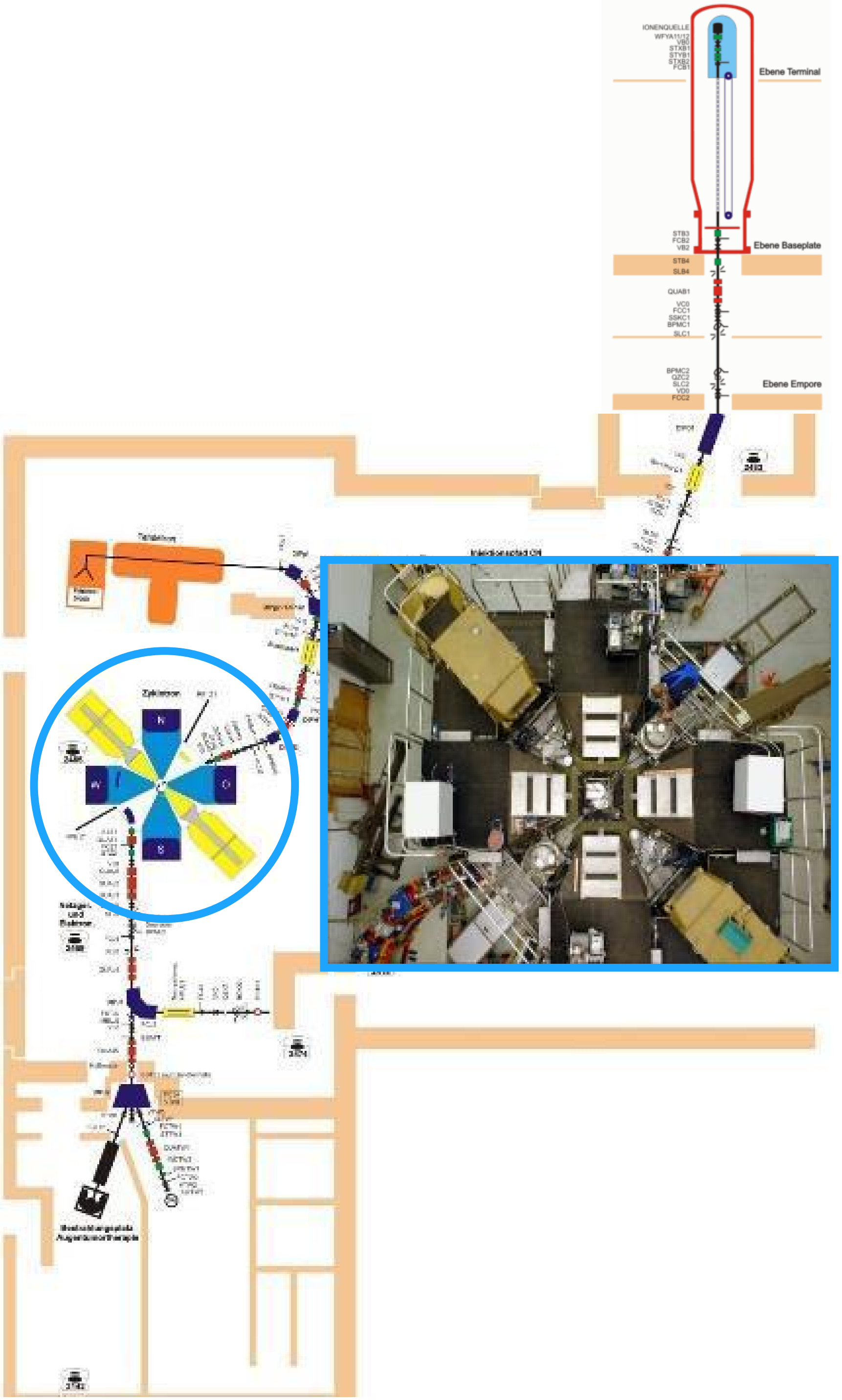
23rd International Conference on Cyclotrons and their Application

Layout of the accelerator complex



Layout of the accelerator complex

- k = 130 isochronous sector cyclotron
  10 – 20 MHz



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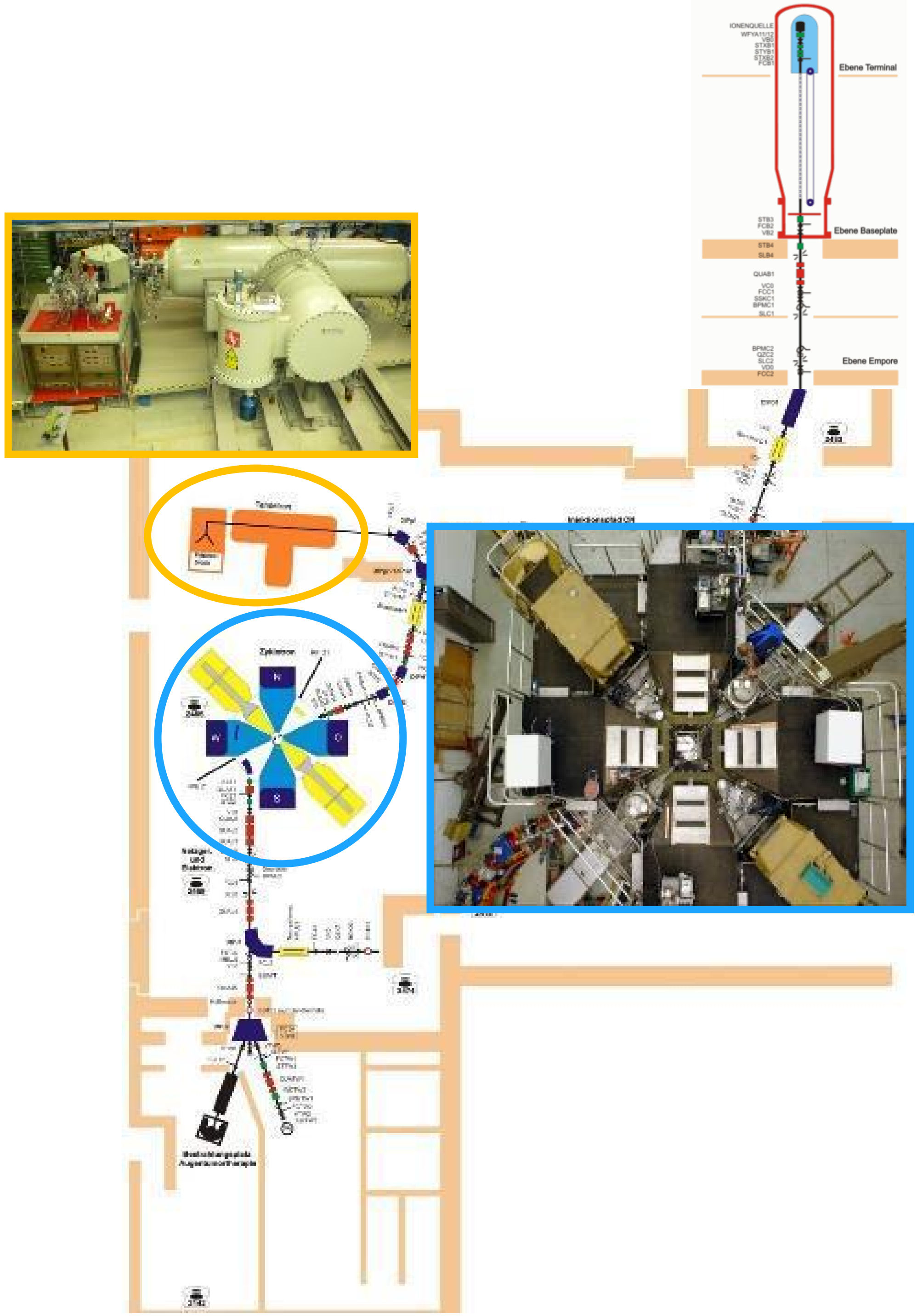

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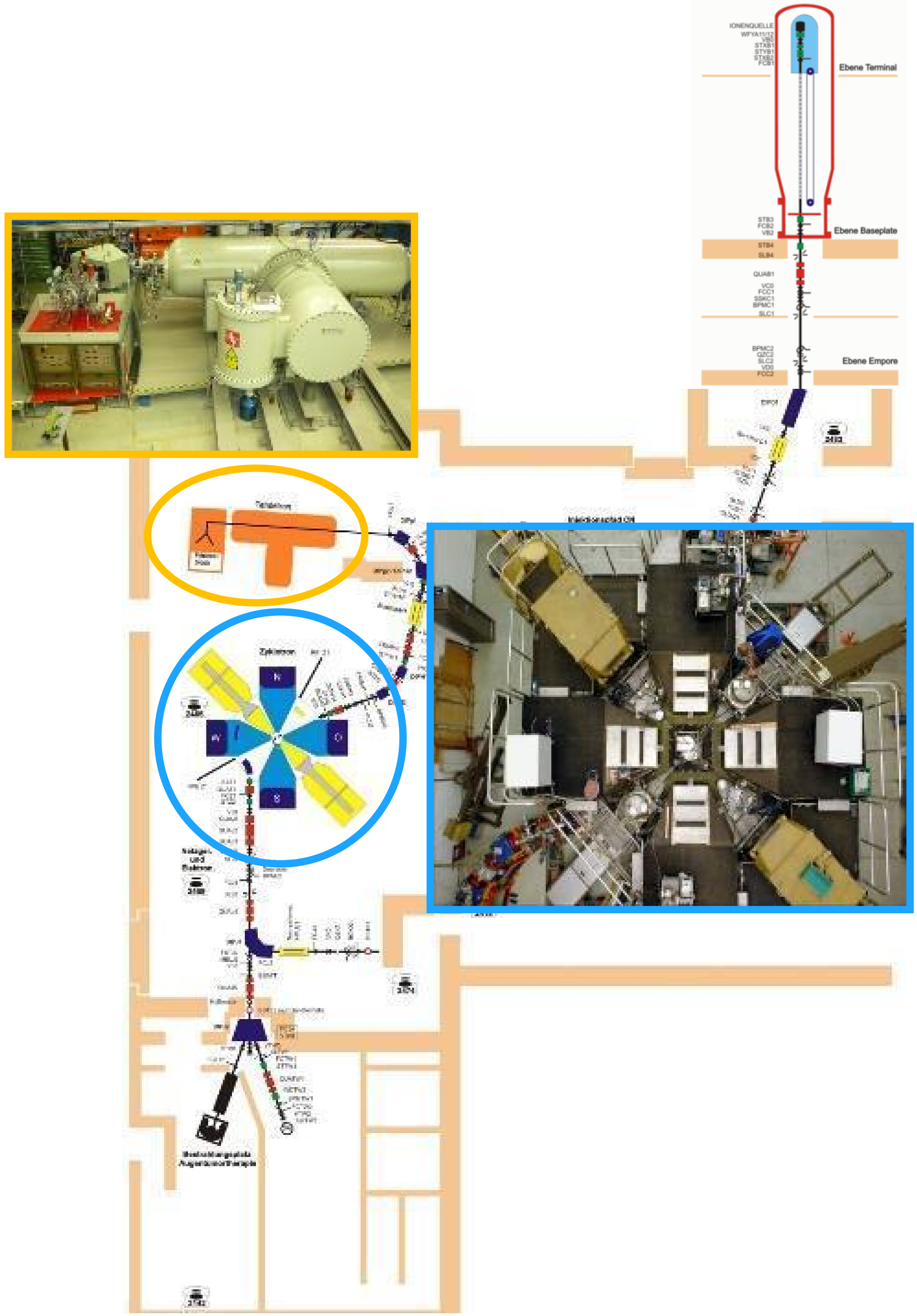

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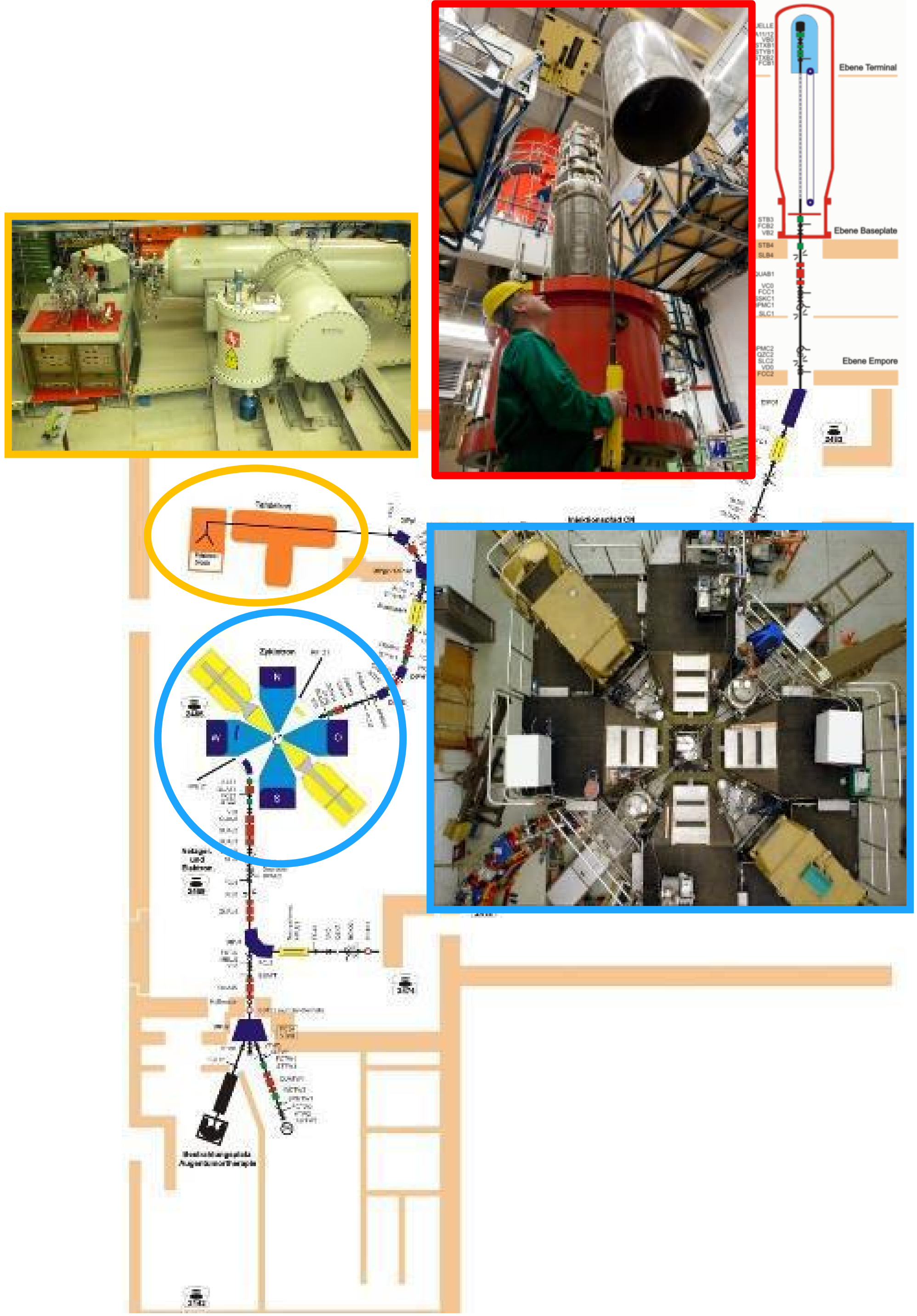

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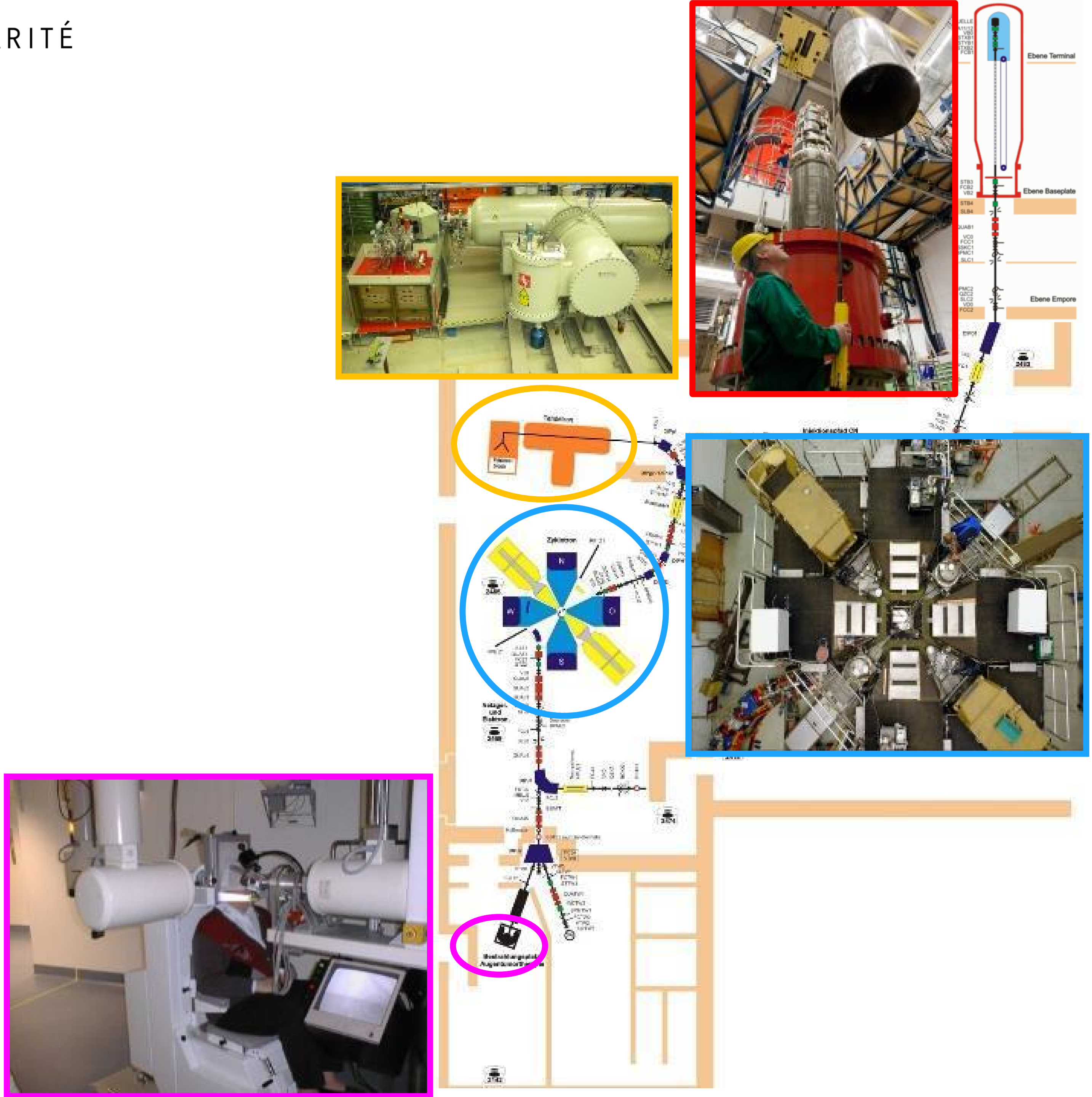

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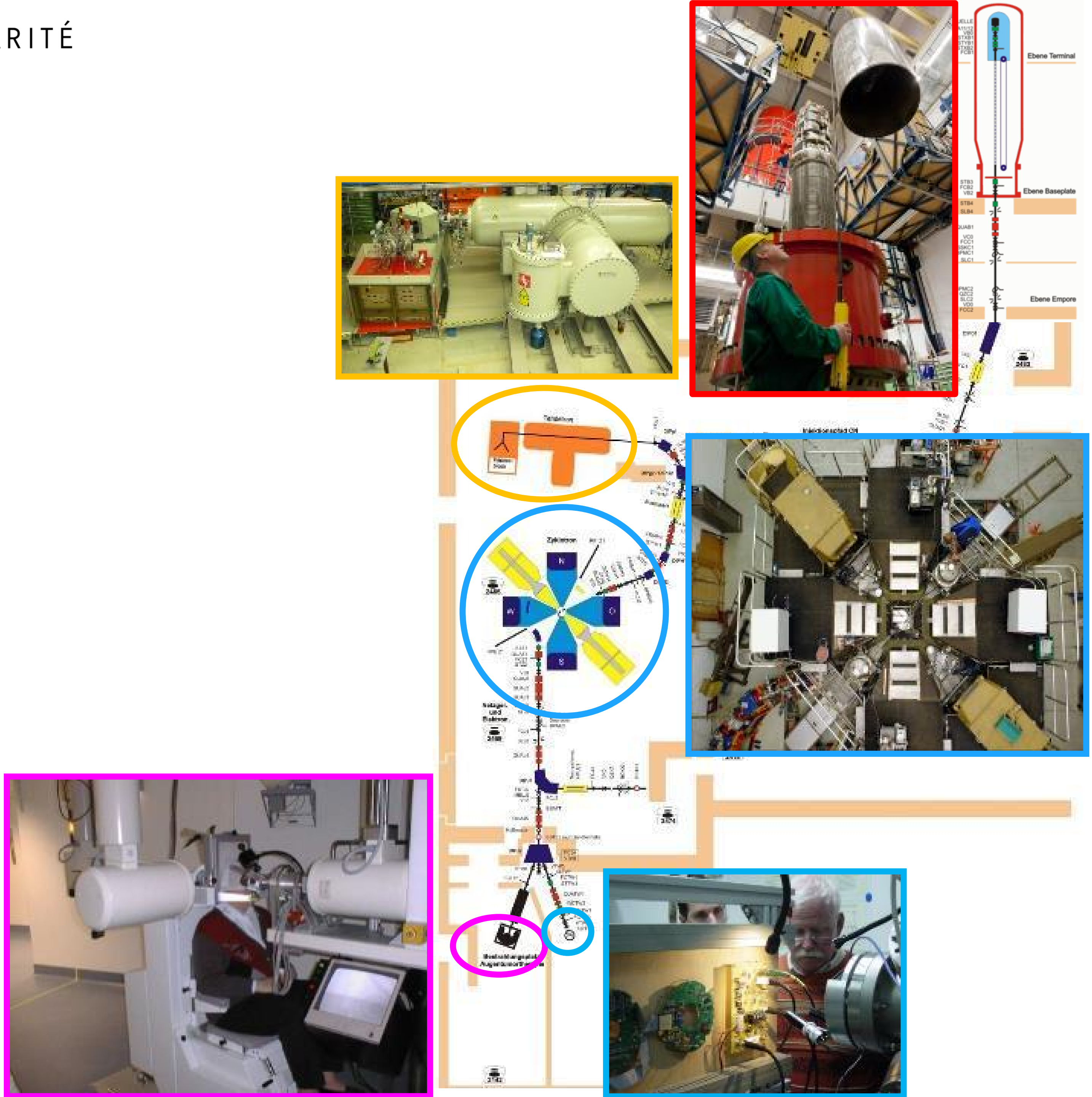

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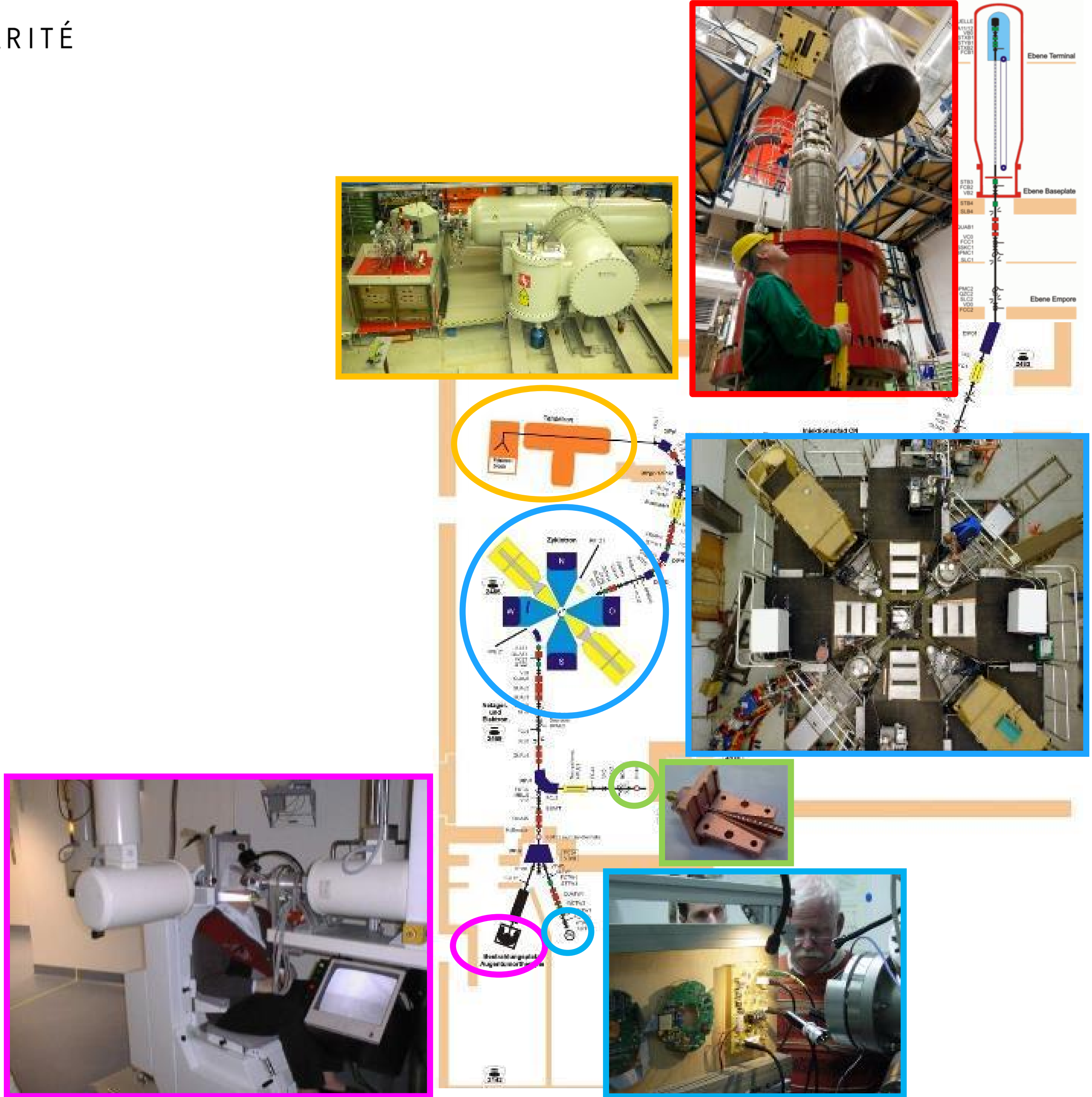
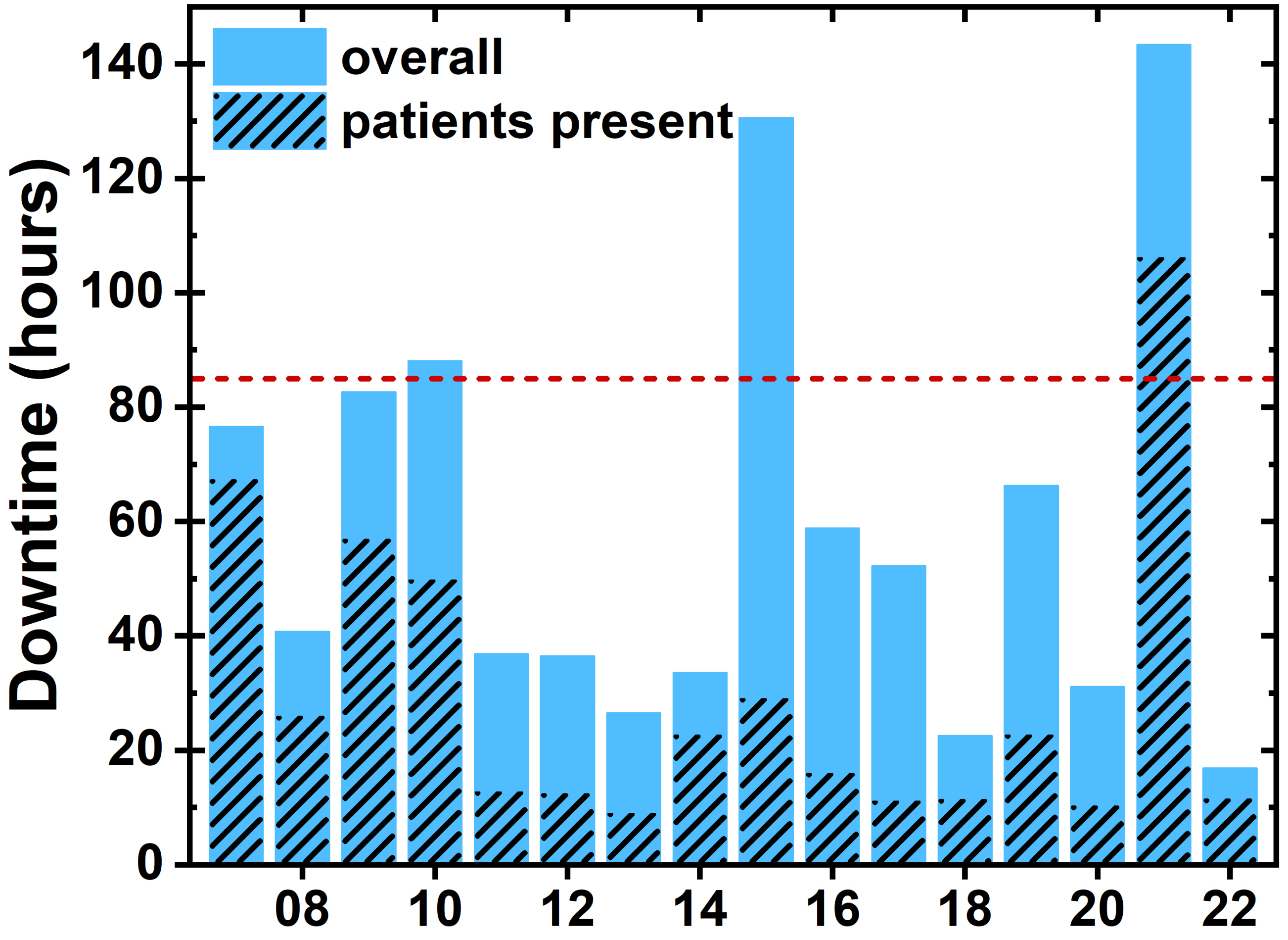


Accelerator Performance

- only 1700 hours of scheduled beam time: major events → huge impact on statistics



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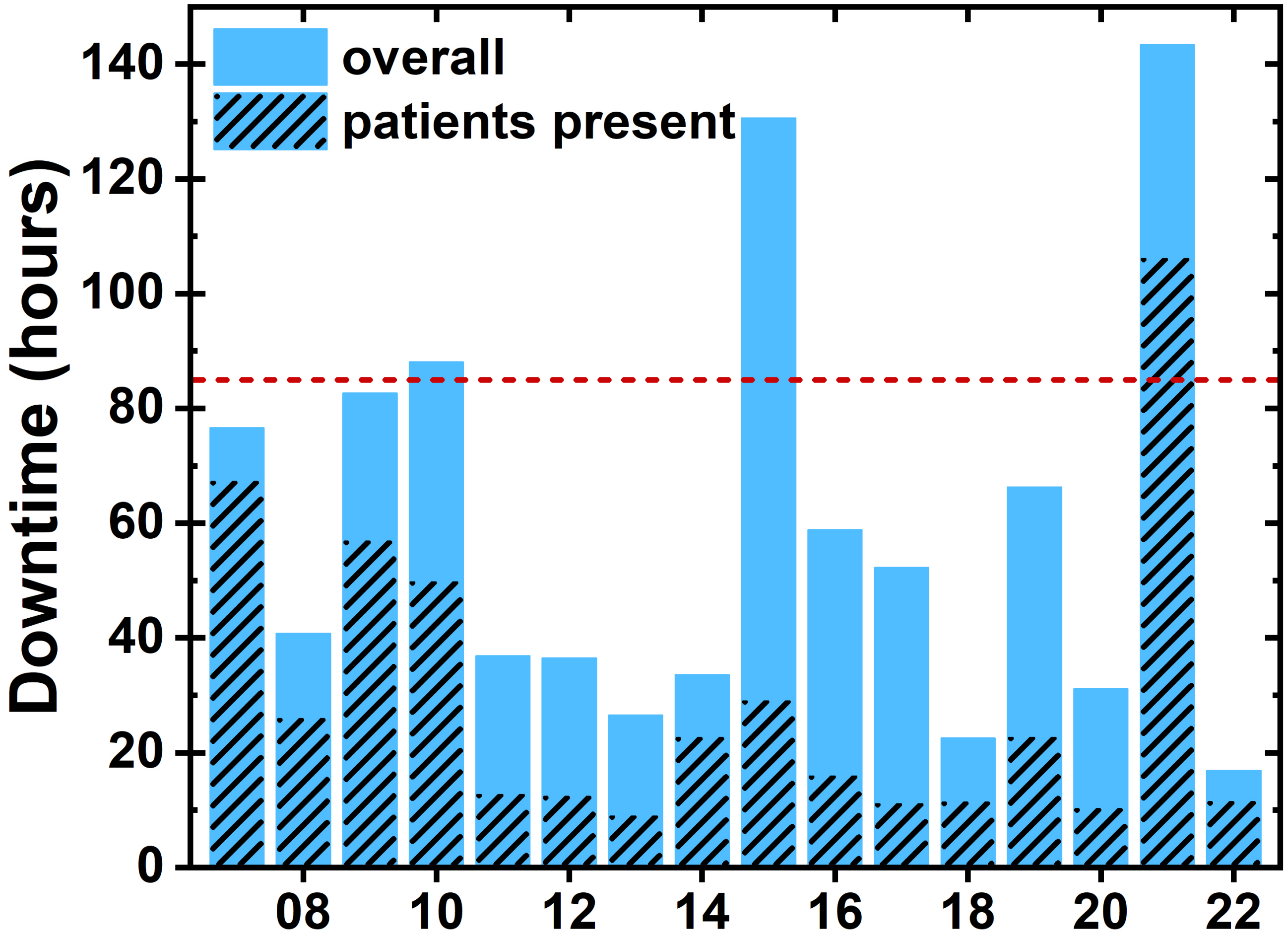

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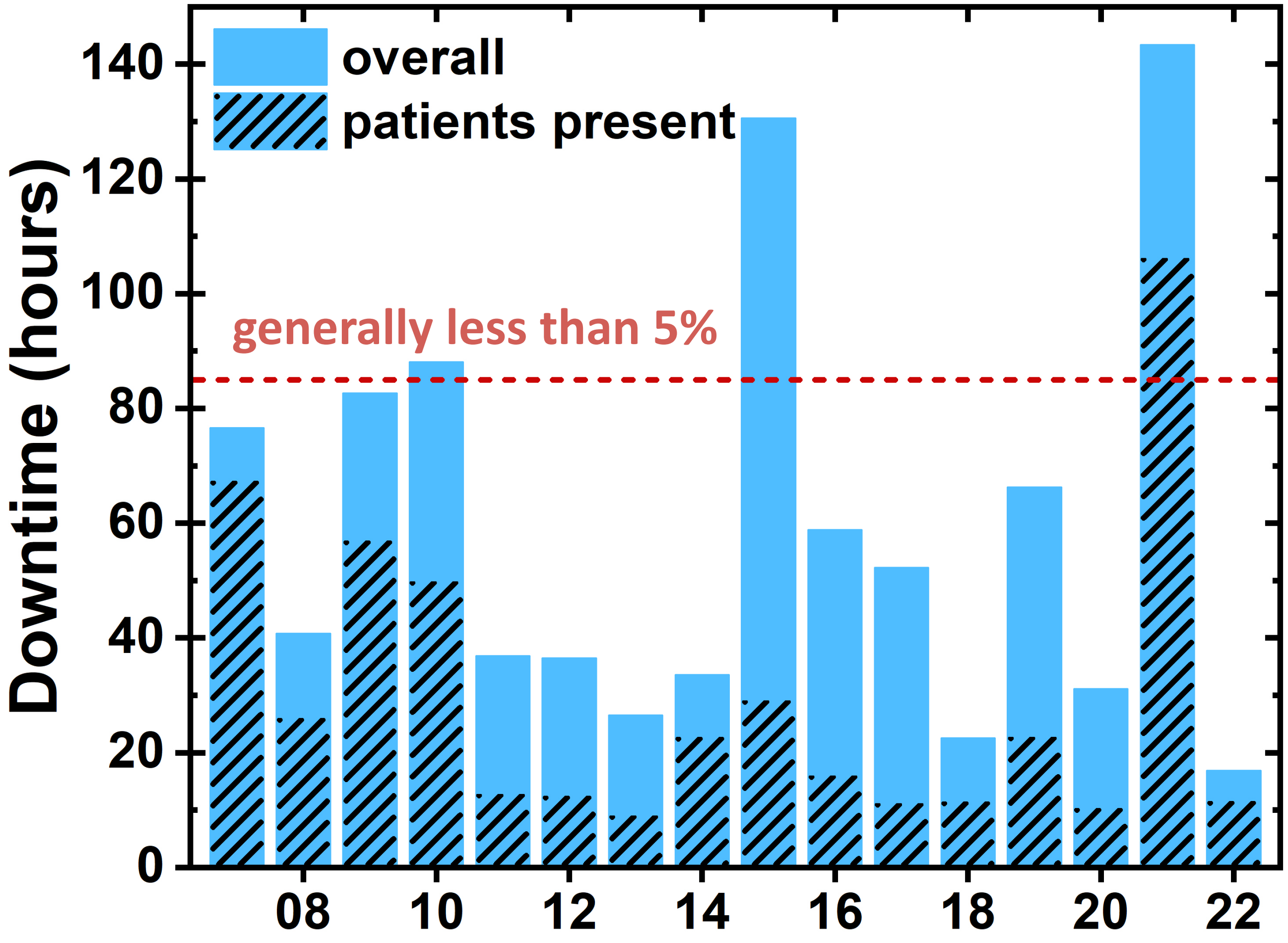

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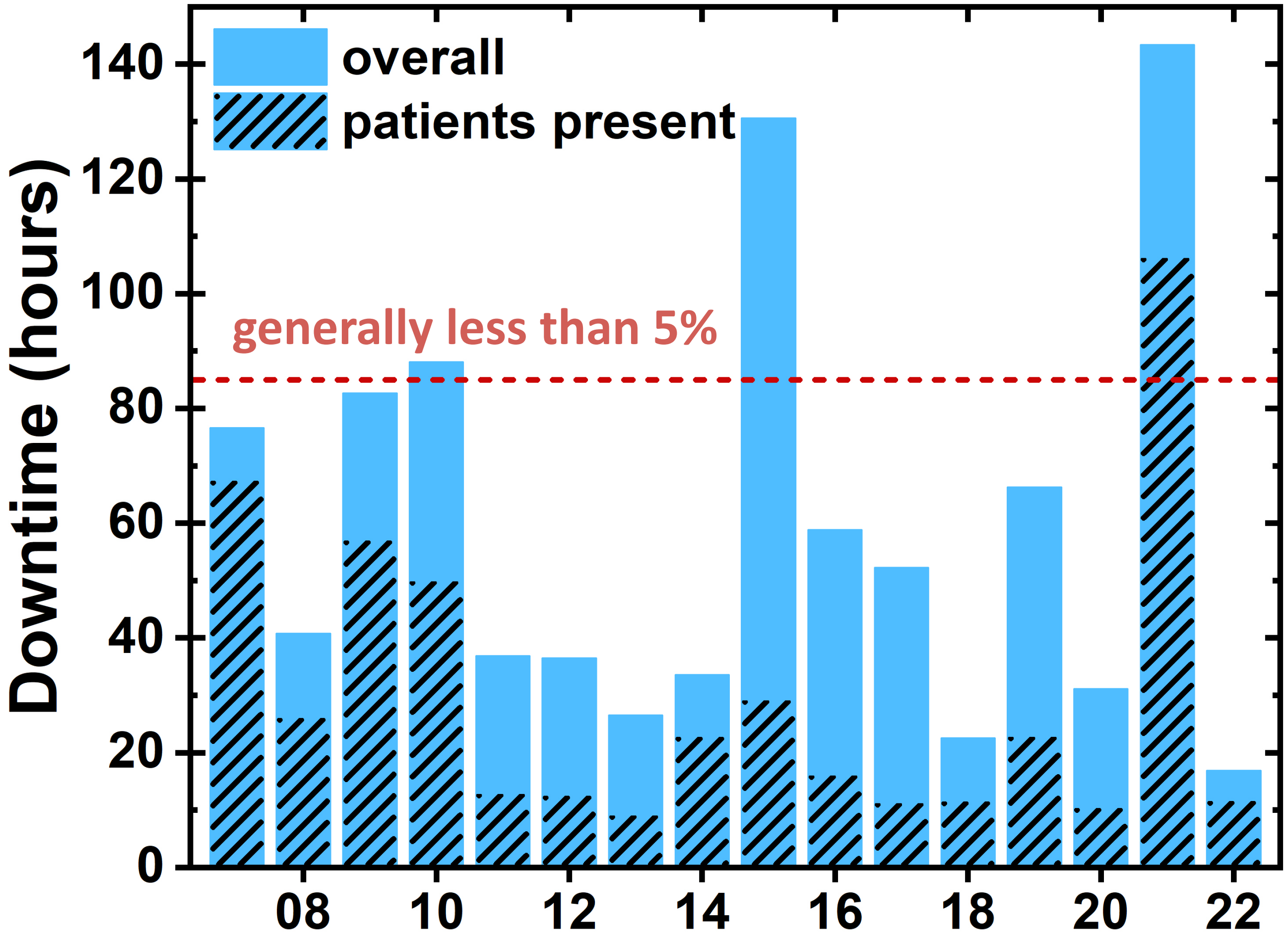
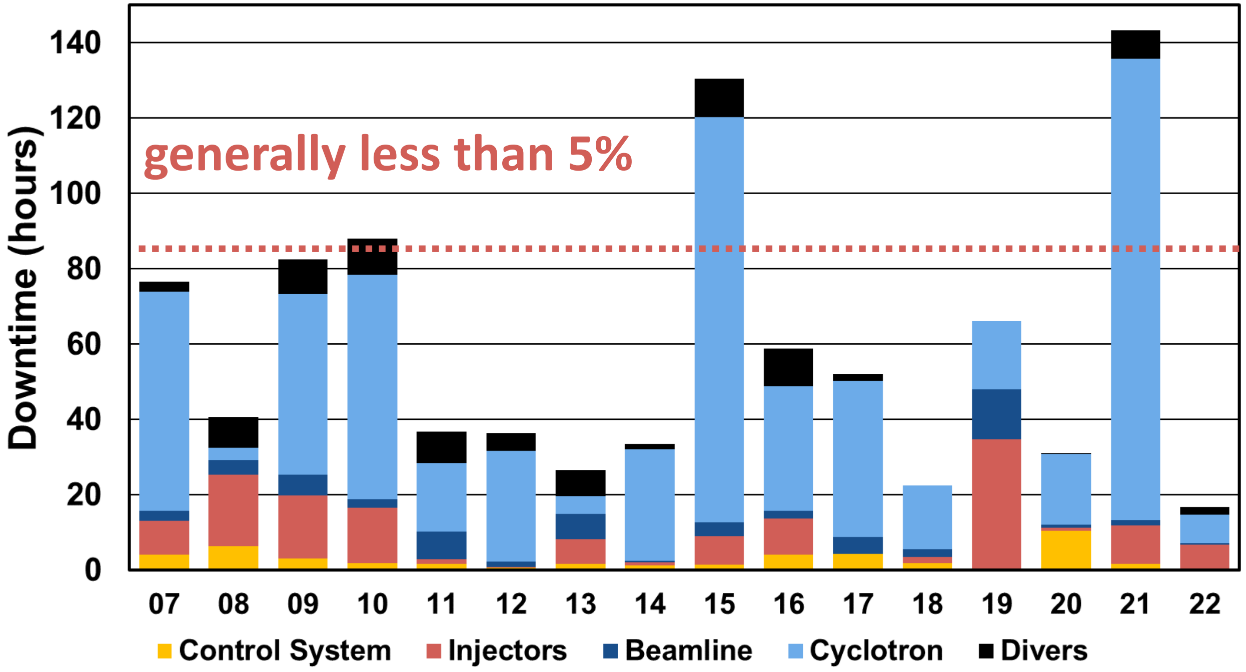
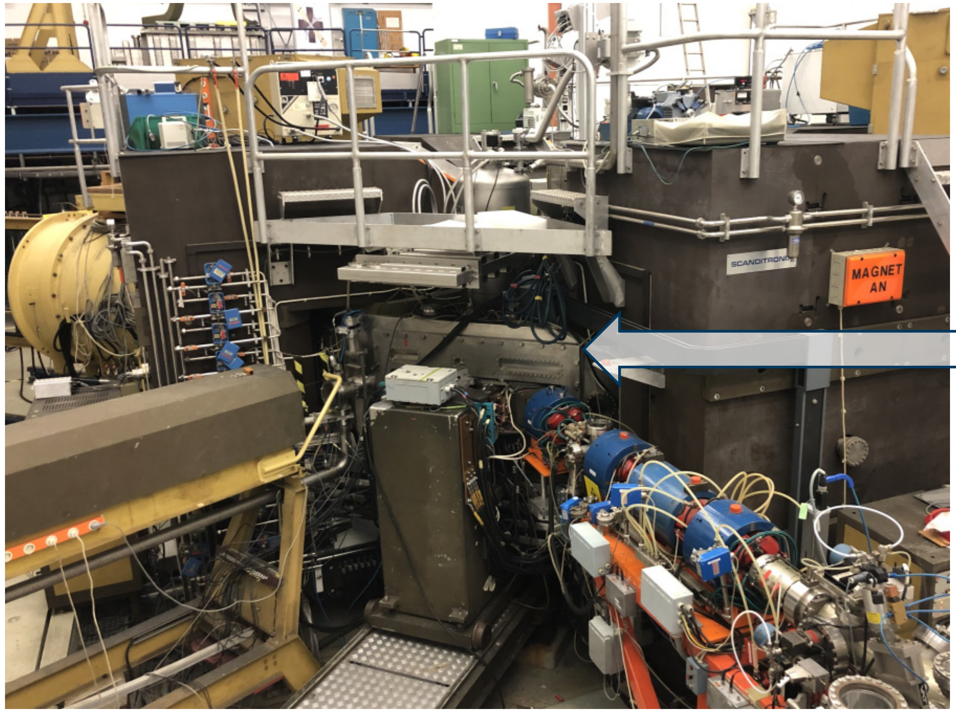
- many errors appear during start-up of accelerator
- with few exceptions: downtime < 5% (Jan. – Nov. 2022: < 1%)
- good performance in spite of:
  - problems with suppliers (main issue: ultra long delivery times)
  - new safety regulations, requiring exchanges of perfectly working parts
- good performance thanks to huge efforts of the staff



Reasons for Down Time

- major events: cyclotron
- 2015: human error
  - increase of injector voltage too fast
- 2021: water leak in extraction coil
  - shifting of therapy week necessary (shifting counts as downtime)





behind:
extraction coil

Major Event: Repair of Extraction

- time consuming:
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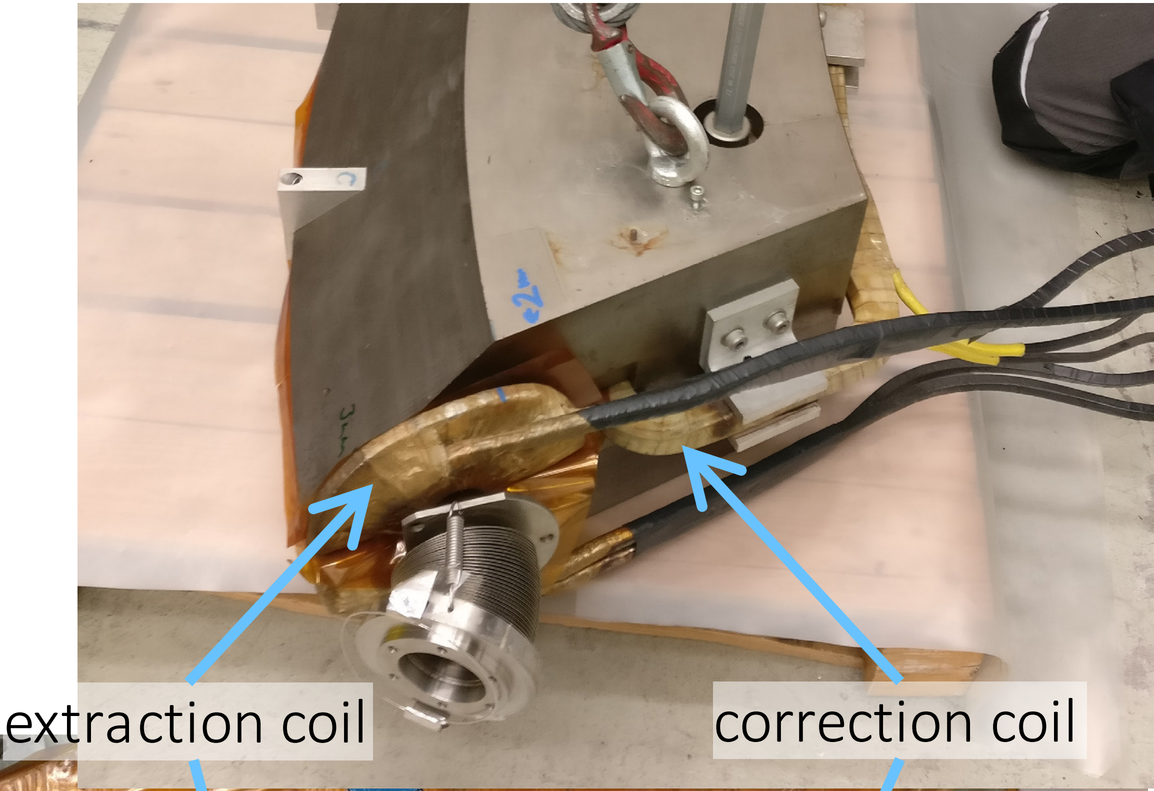

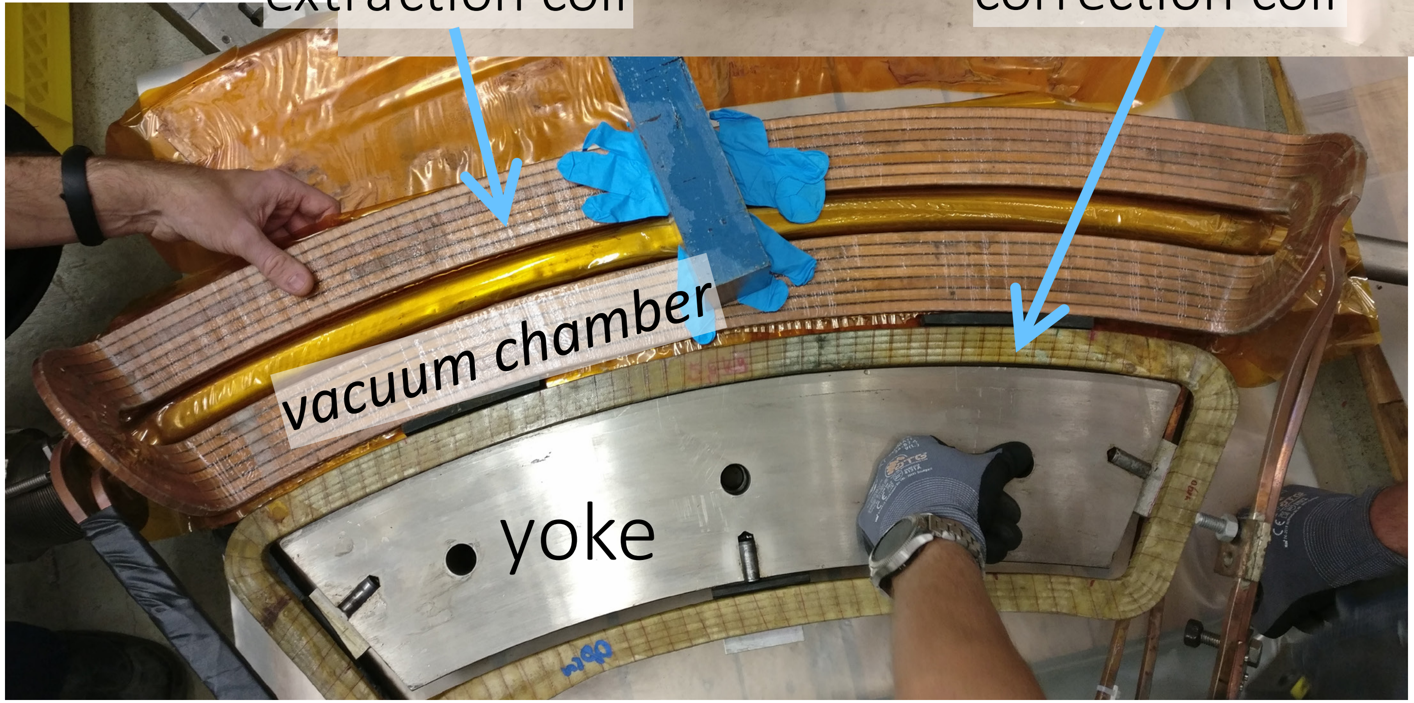

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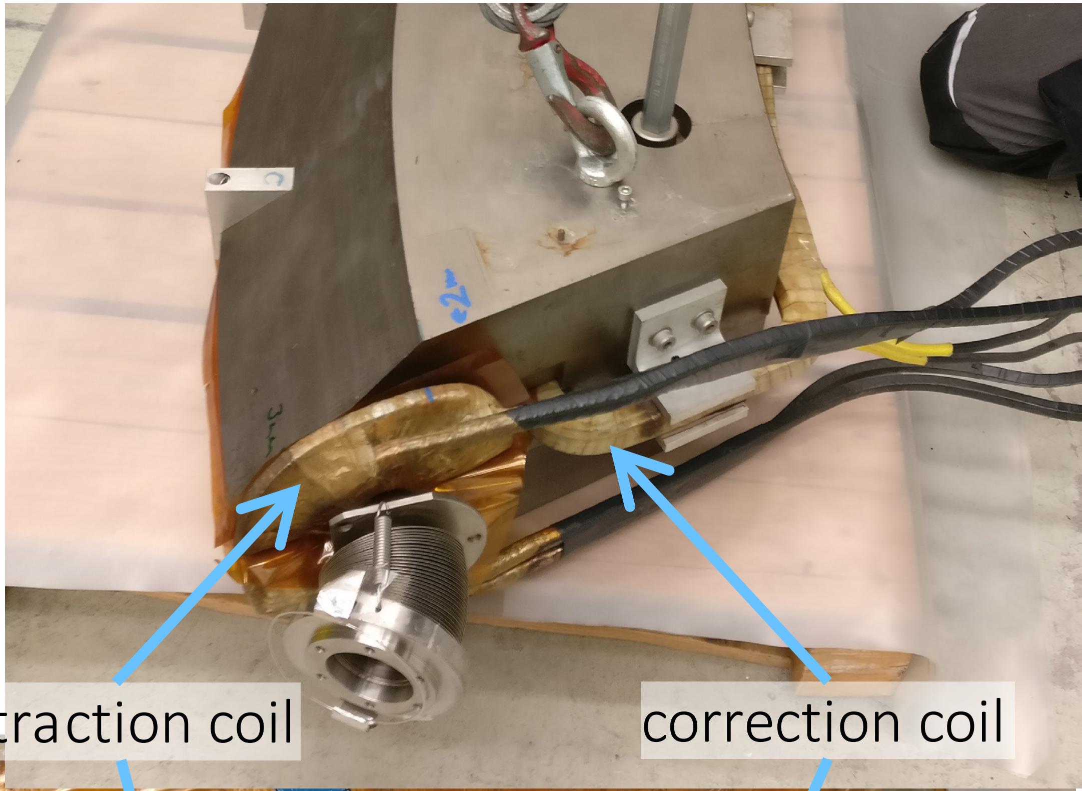

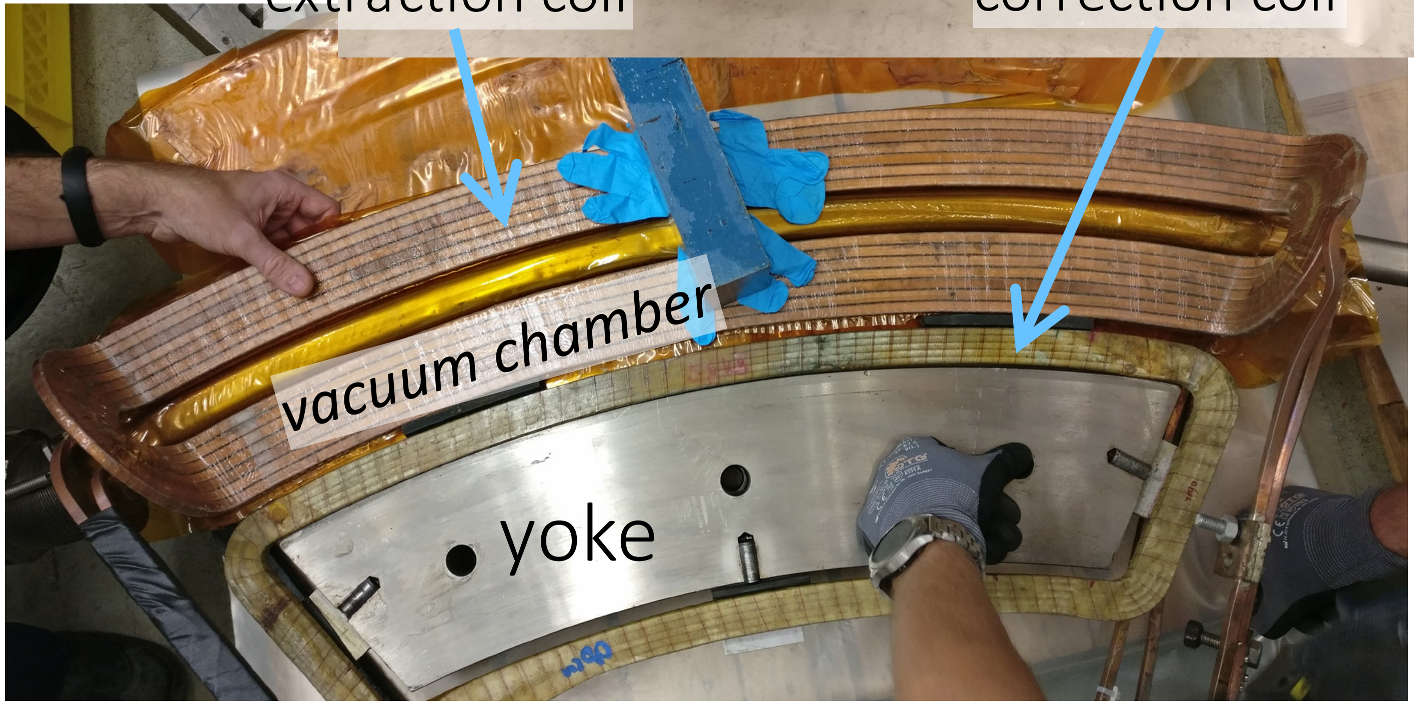

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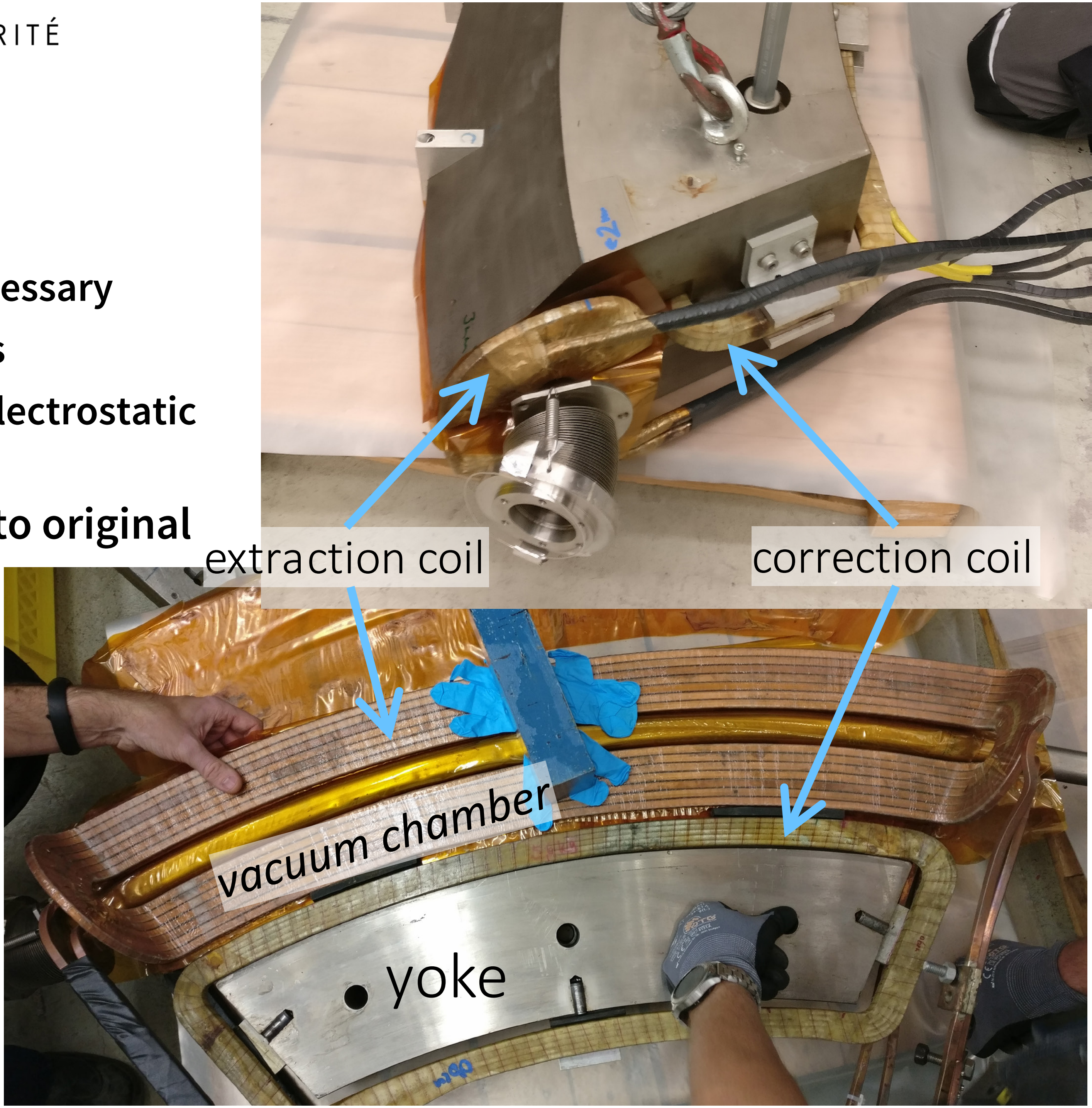
- most likely: slightly different position of vacuum chamber



Research & Development

- accelerator R & D (ARD):
  - beam delivery for Flash irradiations (extremely high doses in short times)
    see also poster MOP11 – Timo Fanselow
  - digitize beam profile monitors
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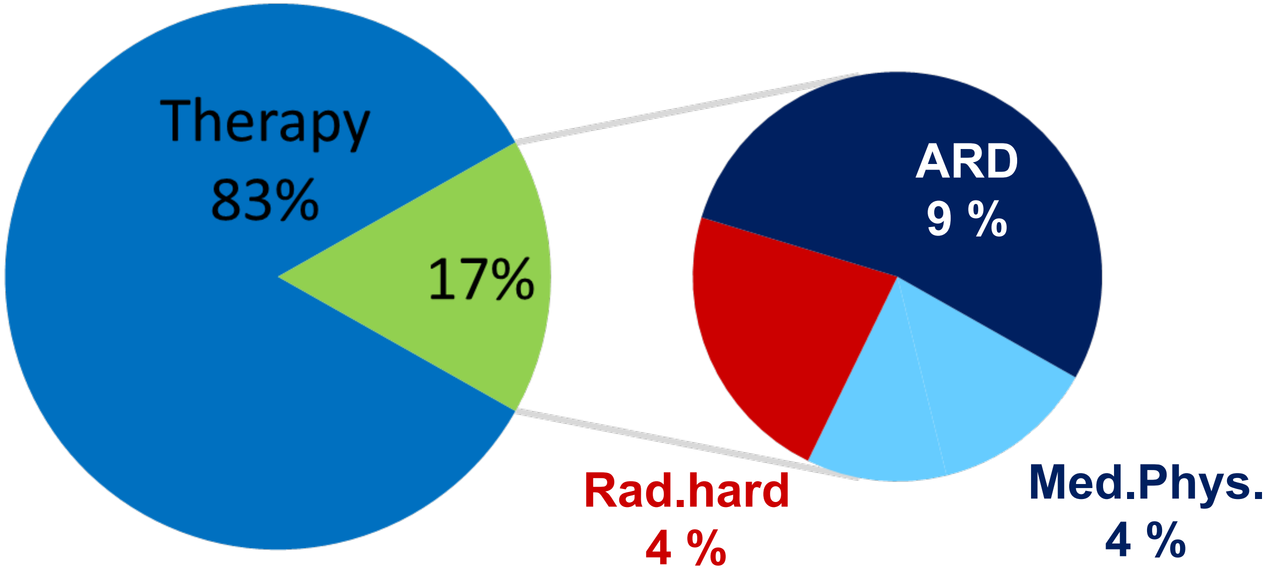

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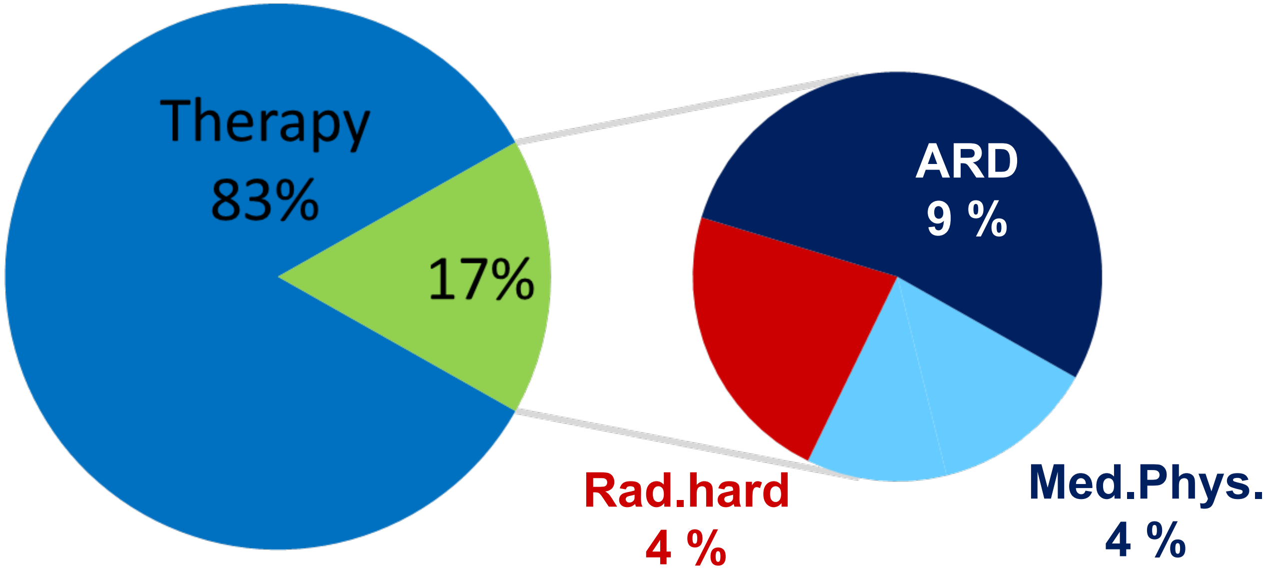

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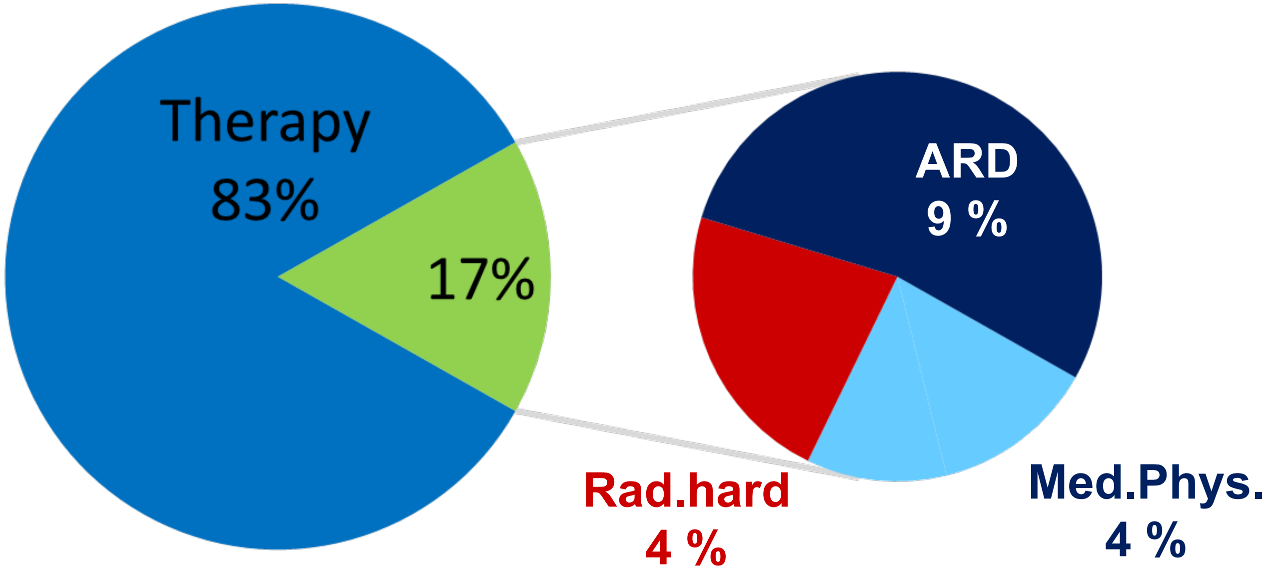
- Radiation hardness tests:
  external users, e.g. DLR, universities, industry



beam delivery for FLASH irradiations

intensity

- definition: dose rate > 40 Gy/s, t < 1s
  → extremely high dose rates
- idea: maintain tumour control, reduce side effects
- dose applied in a very short time → high dose rates required
- challenges:
  - dosimetry: linearity, saturation effects, …
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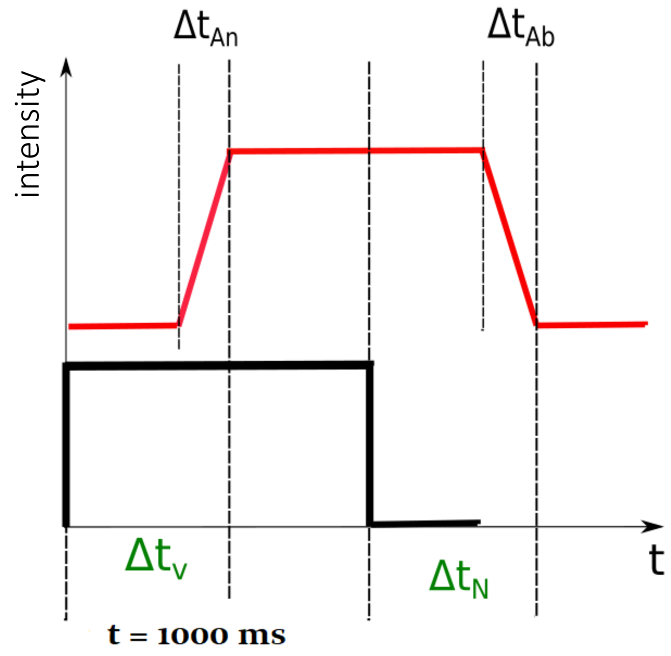

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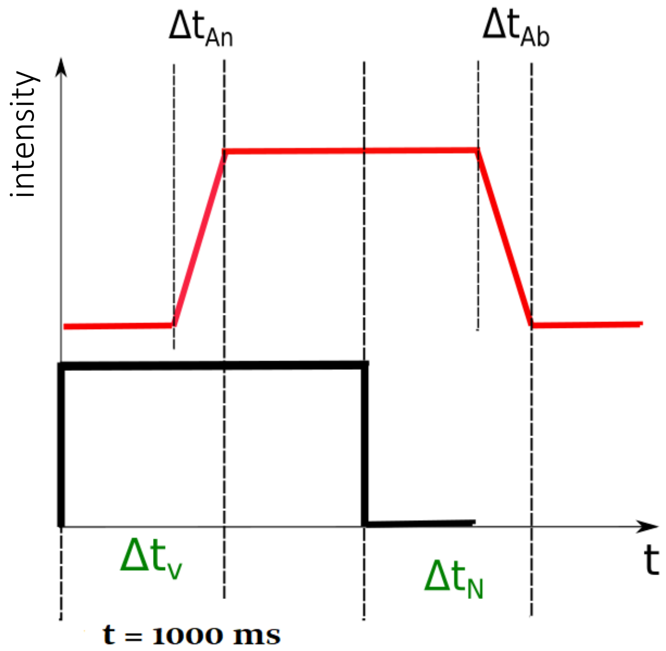

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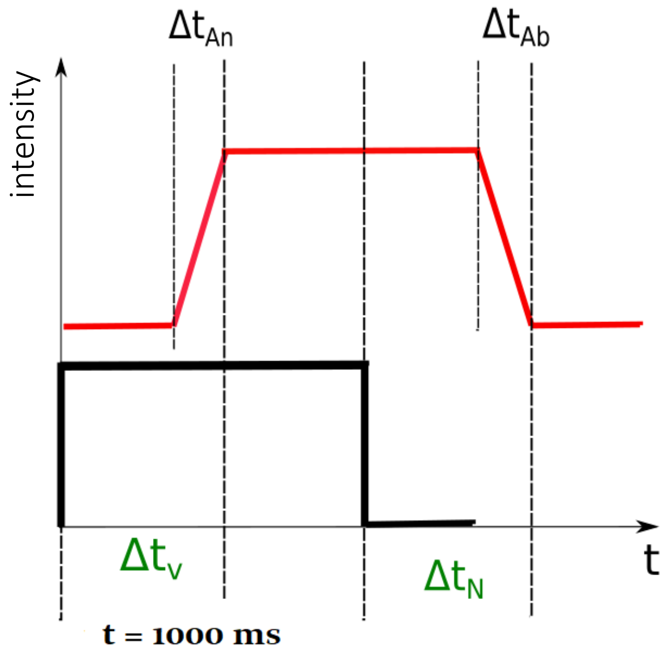

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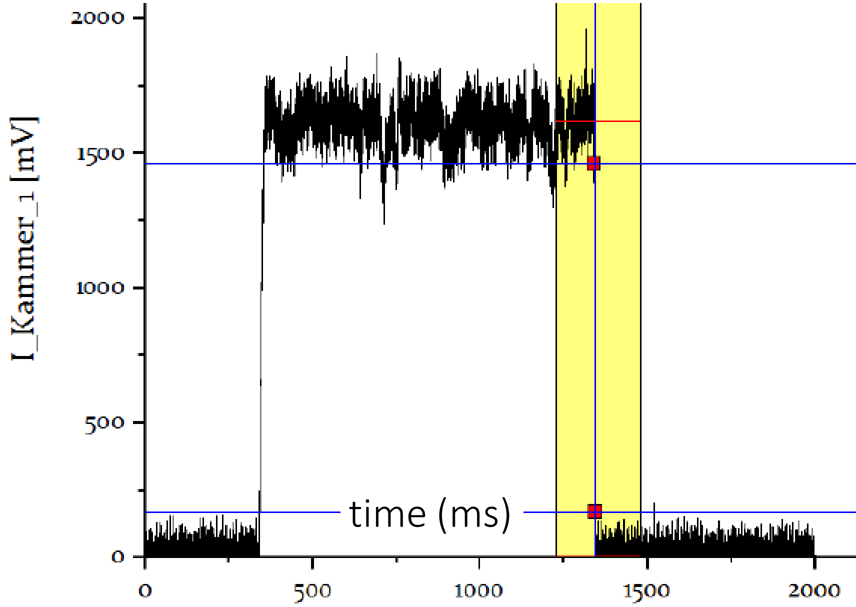
- Faraday Cup: > 100 ms (50 mm stroke)
- therapy: fast mechanical beam stop (scissors):
  opening time ~ 10 ms, closing time ~ 5 ms



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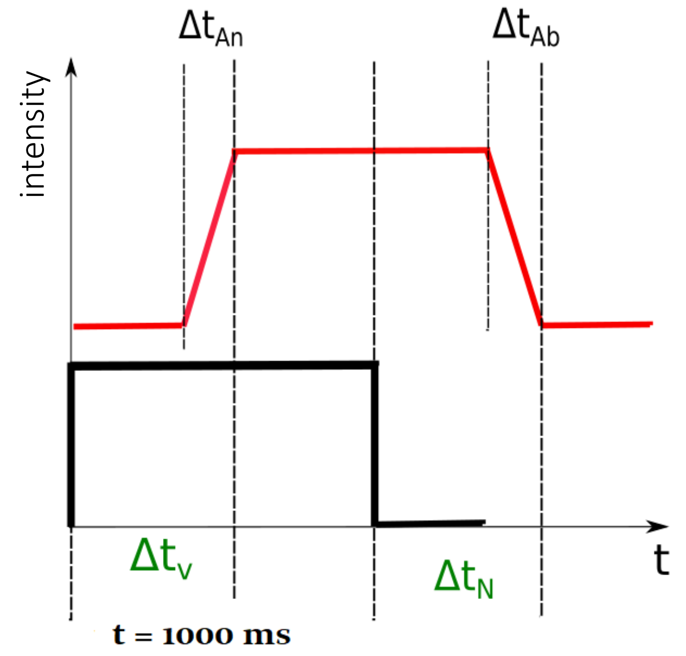

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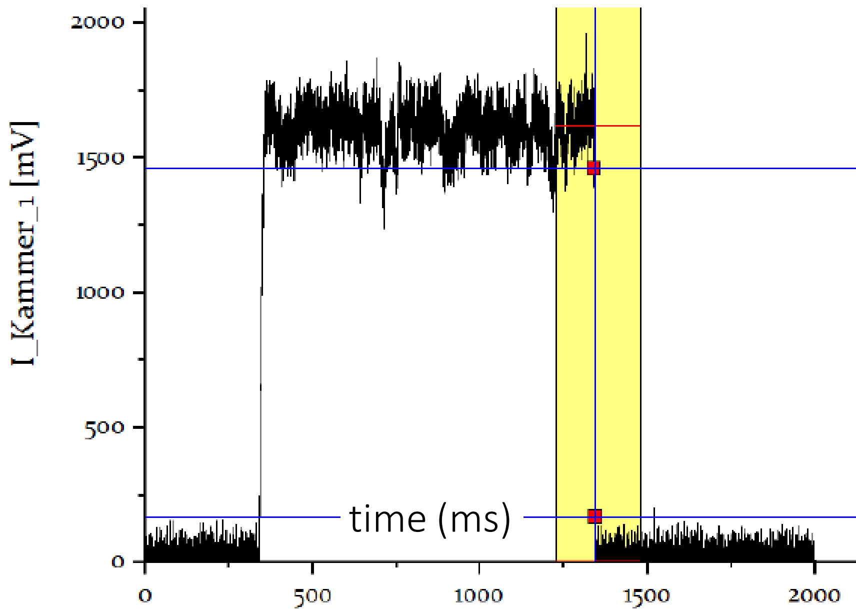

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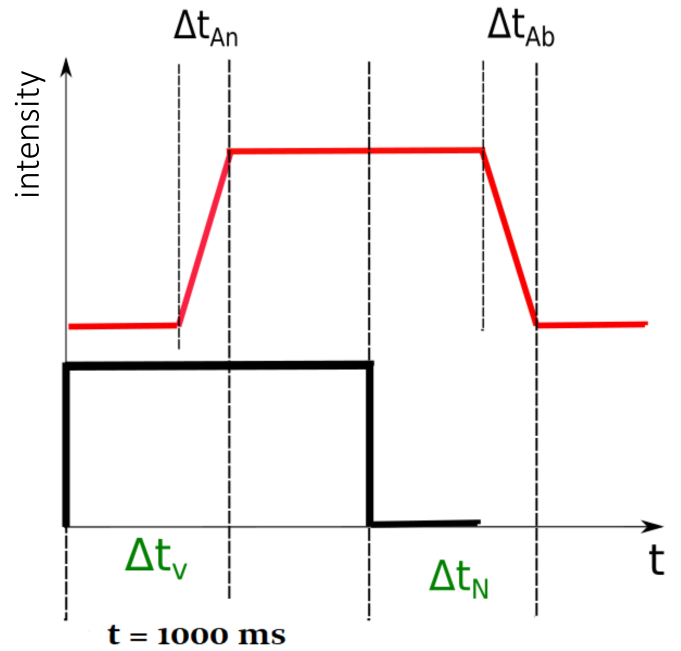

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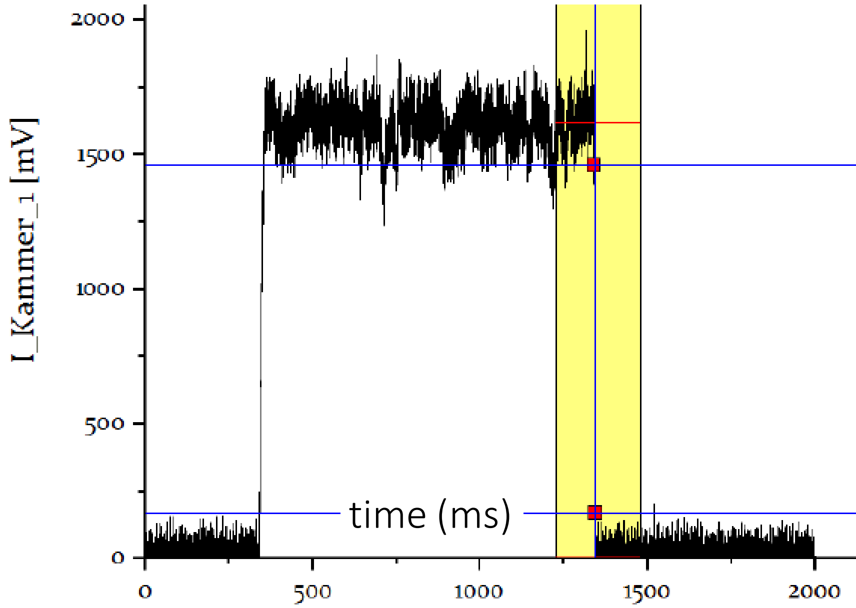
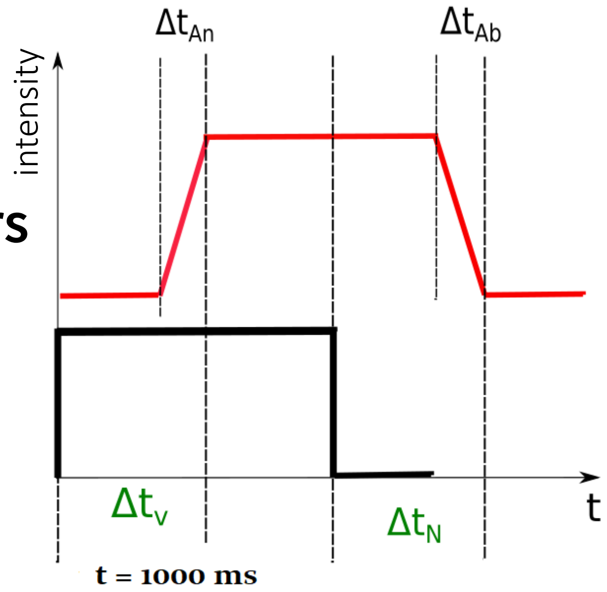


beam delivery for Flash irradiations – control by FPGA & LabVIEW

- two ionization chambers for beam monitoring
- FPGA board processes signals of Farady Cup (FC) and ionization chambers



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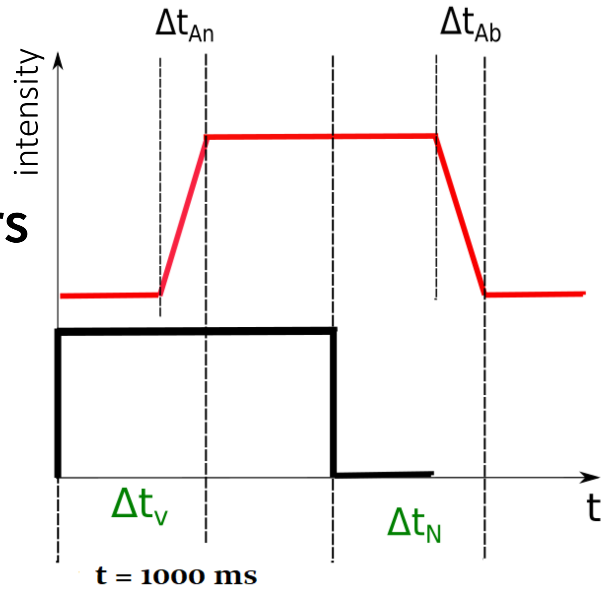

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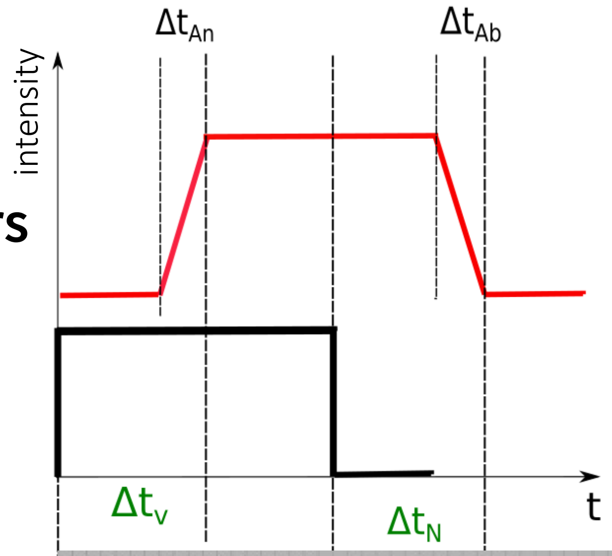

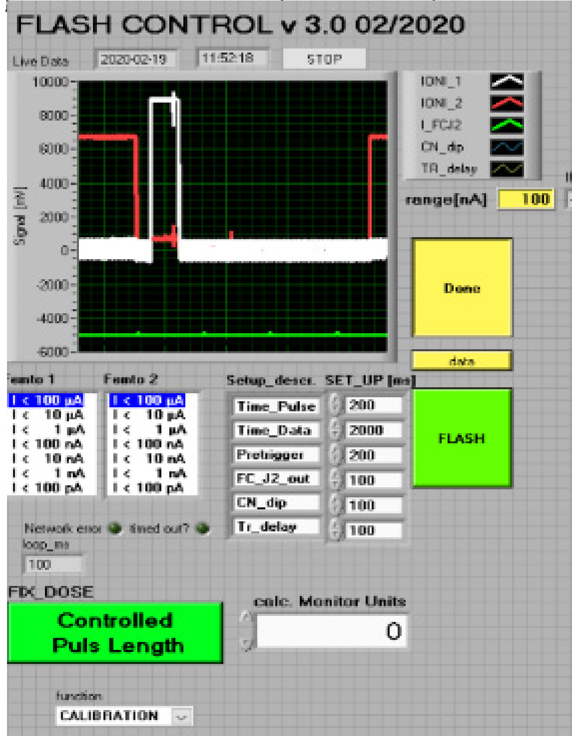

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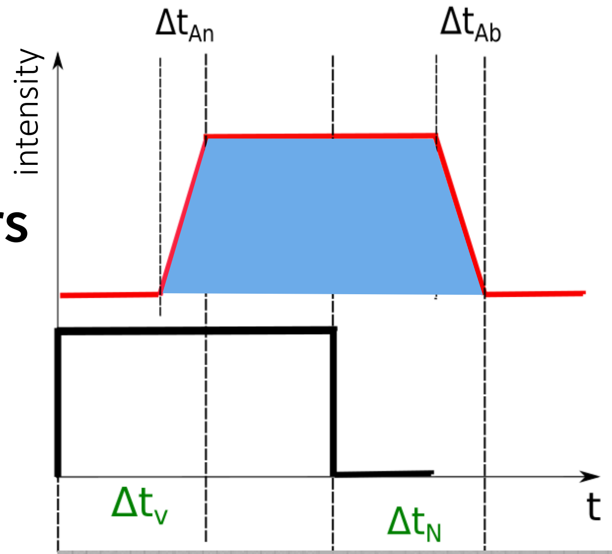

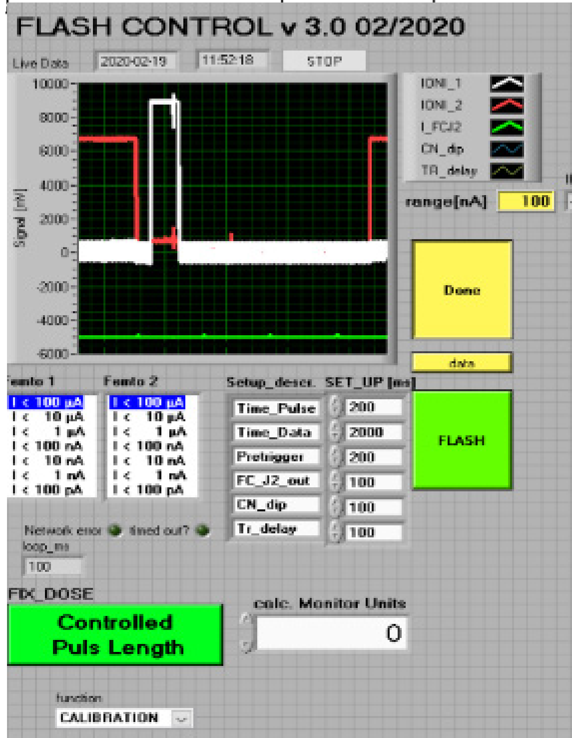

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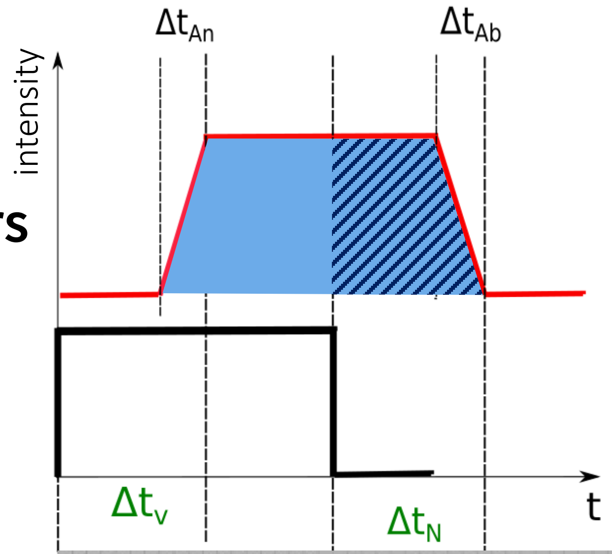

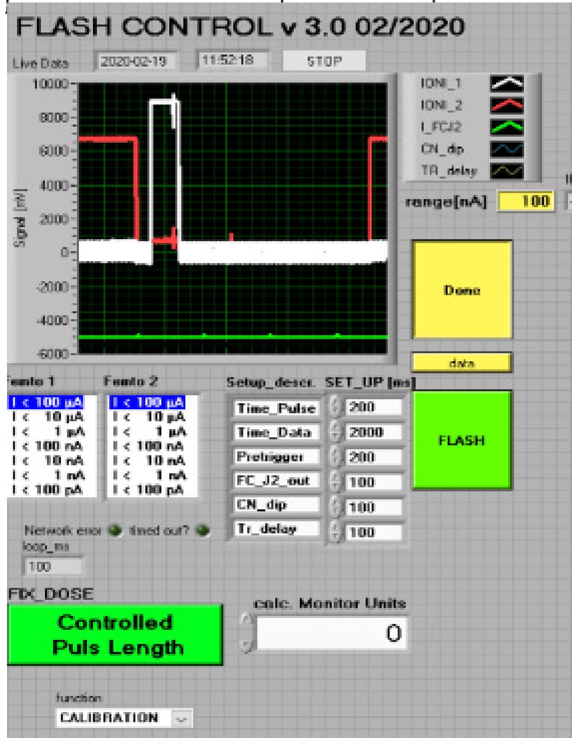

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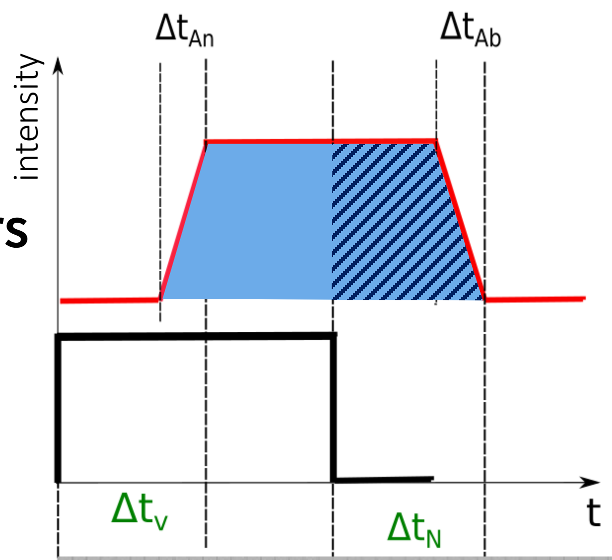

- preset time = calibration mode
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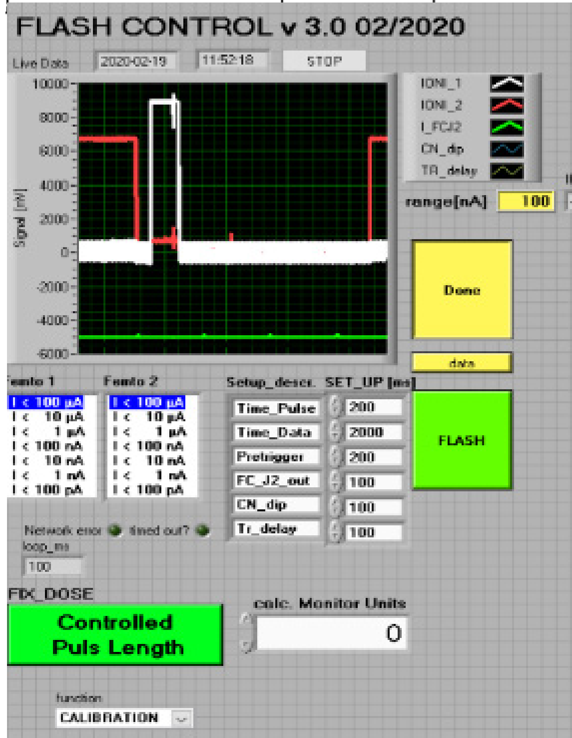
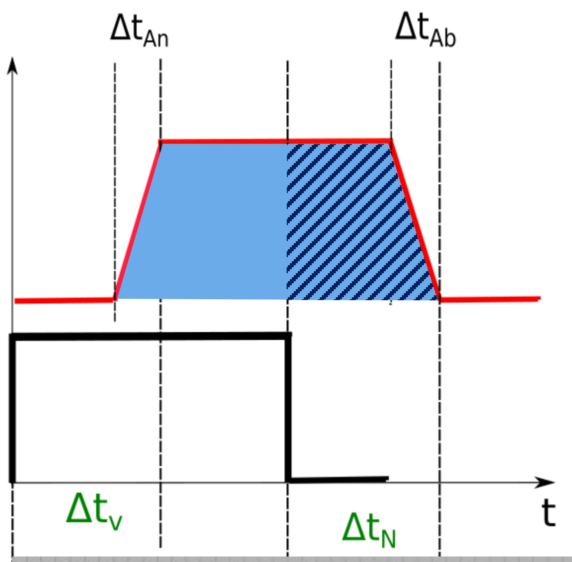
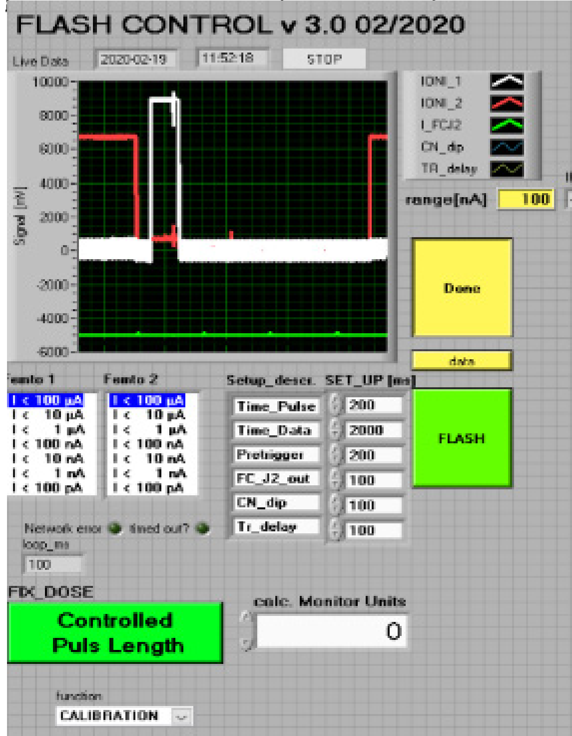
- code correlates the sum of the counts to measured dose
- integrates the counts after stop-signal was triggered (excess counts)
- defines switch-off strategy: in “dose mode” the stop-signal is given for corresponding dose minus expected excess counts



beam delivery for Flash irradiations – control by FPGA & LabVIEW

- several trial runs to verify the set-up for the day (few minutes only)





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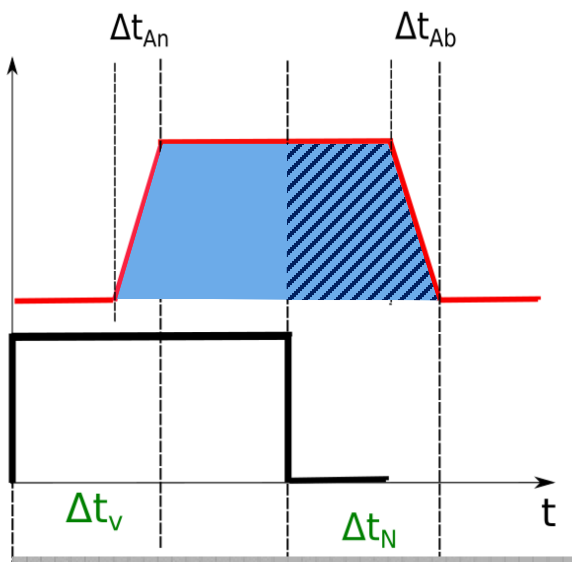

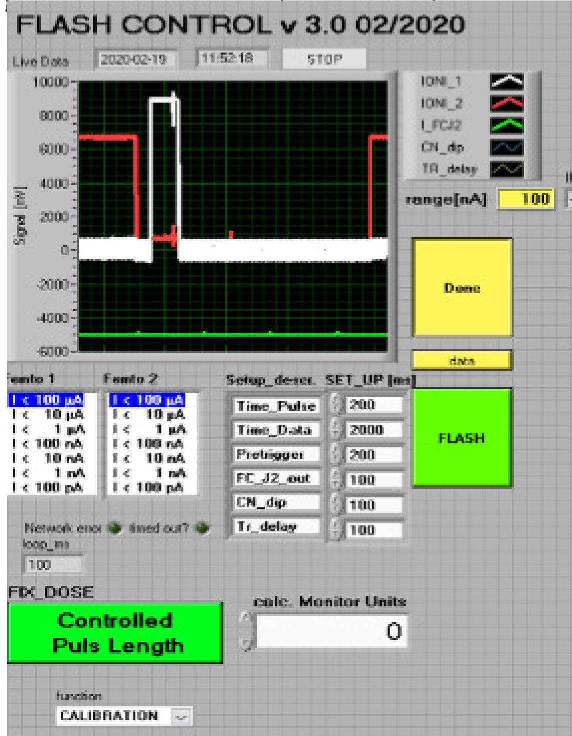

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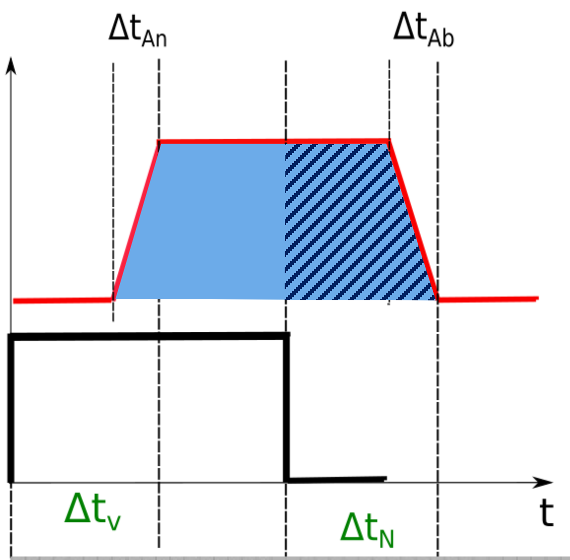
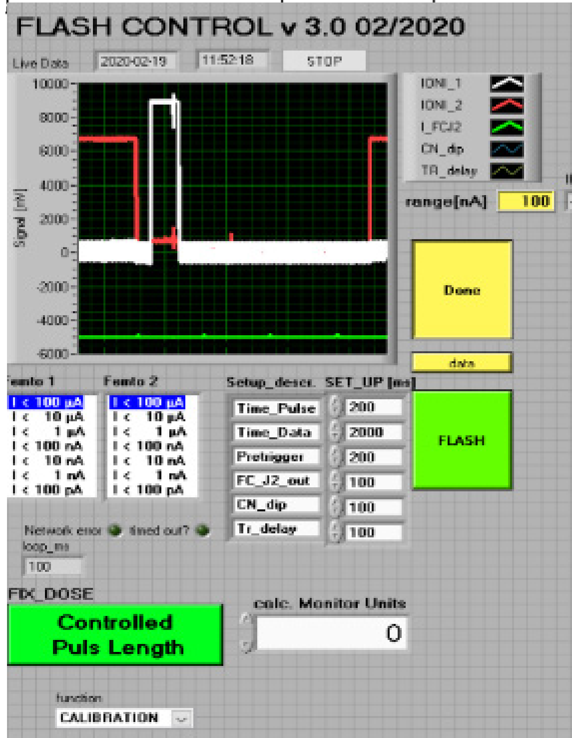
- Flash ~ 50 nA , dose rate 75Gy/s - 30 trial runs to estimate error:
  14.9 Gy with a standard deviation of 0.6%





beam delivery for FLASH irradiations – irradiation of mice eyes

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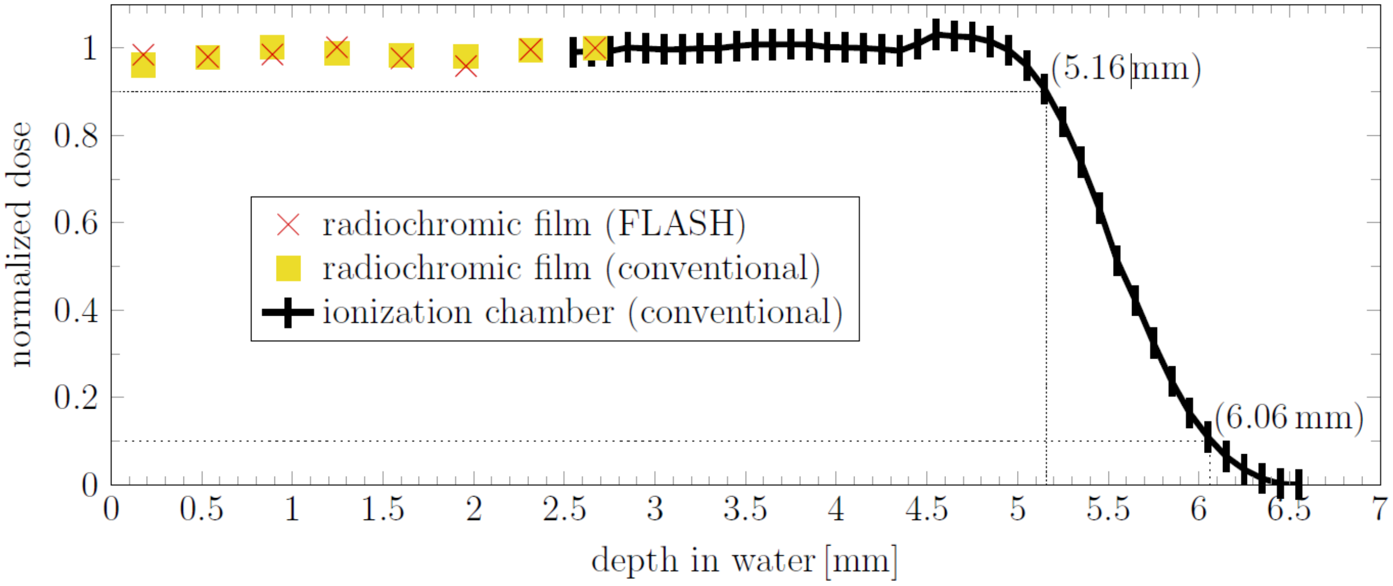
- modulator wheel for Spread Out Bragg Peak (960 SOBP/s)



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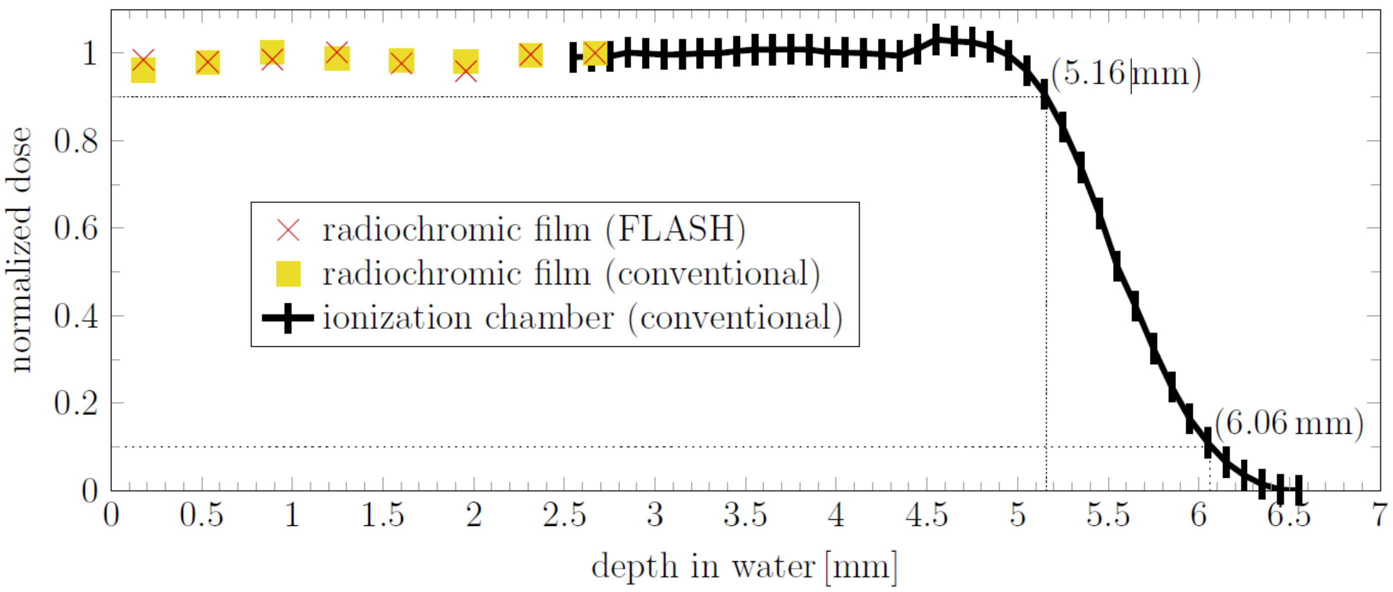

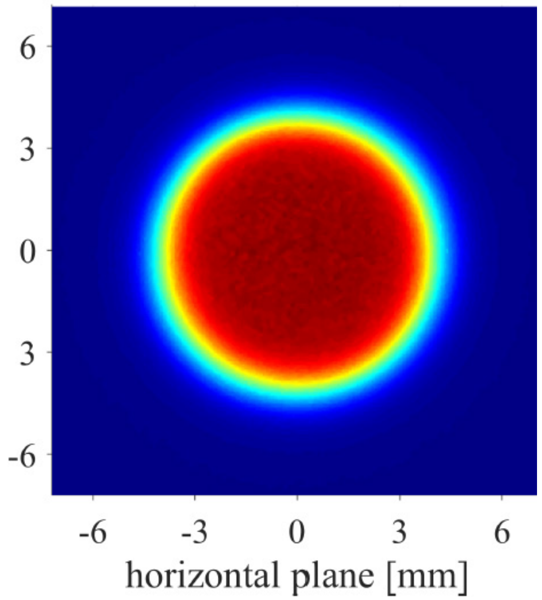

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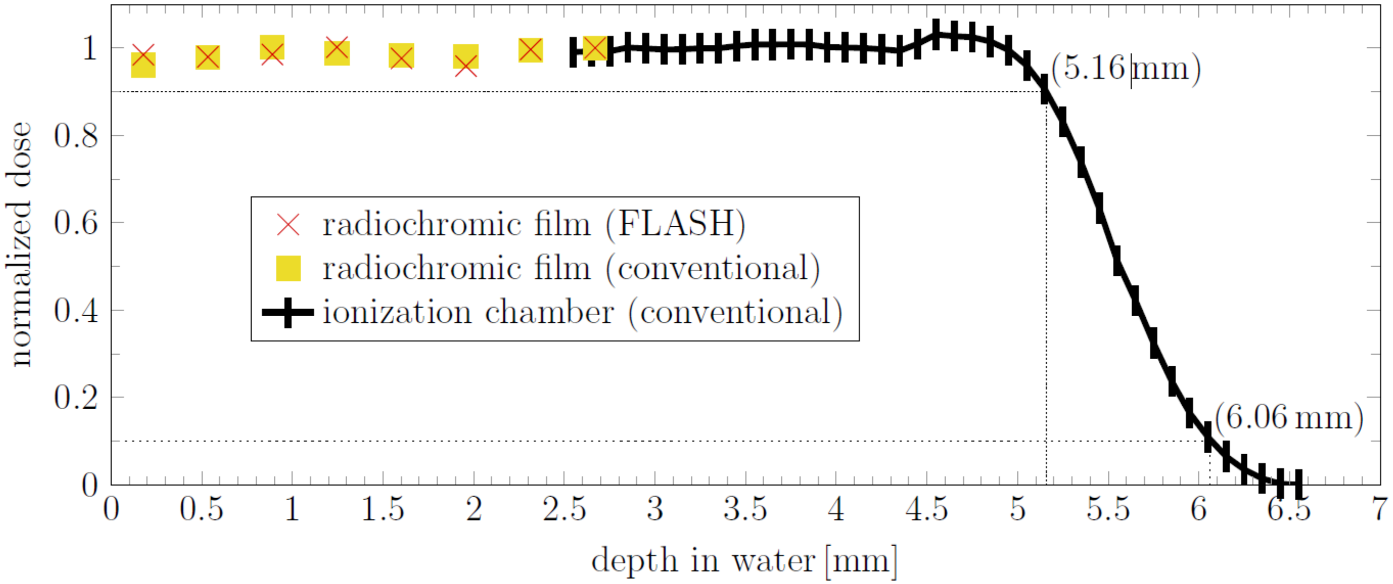
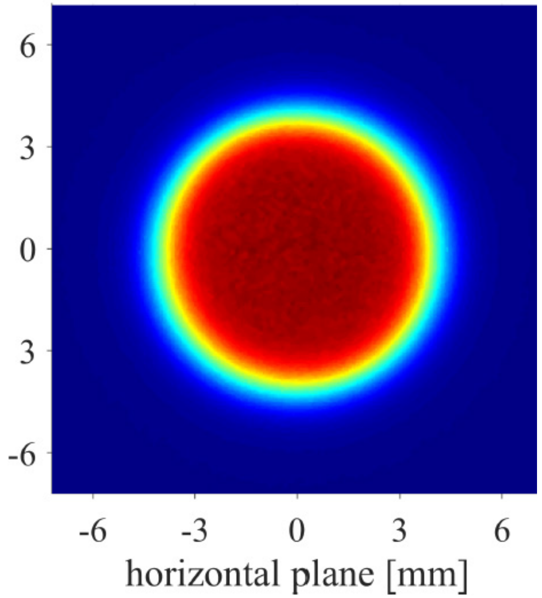
G. Kourkafas et al., Med. Phys. 2021





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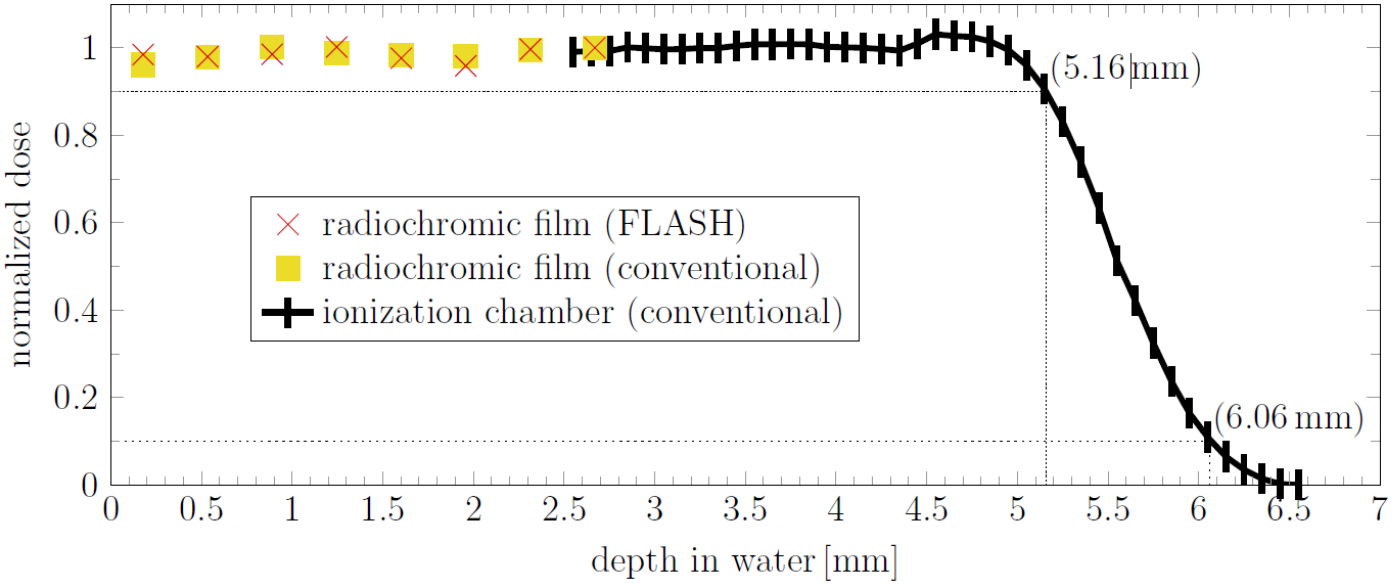
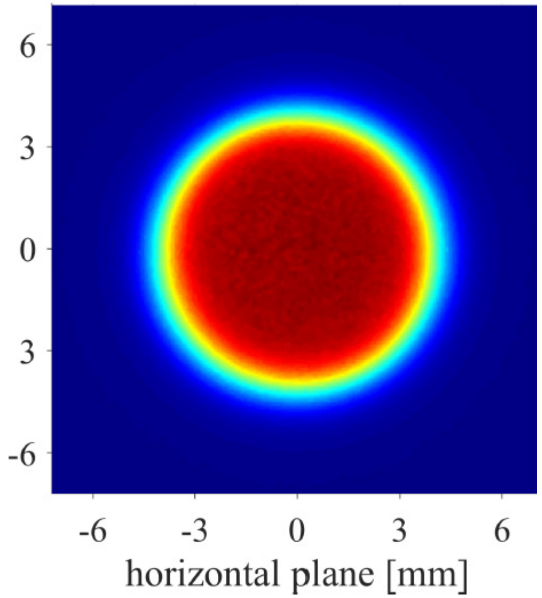
- Early normal tissue reactions after FLASH proton beam exposure of mice eye: preliminary results from in-vivo investigation using optical coherence tomography

  Flash Radiotherapy & Particle Therapy, 30.11.22 – 2.12.22,Vienna





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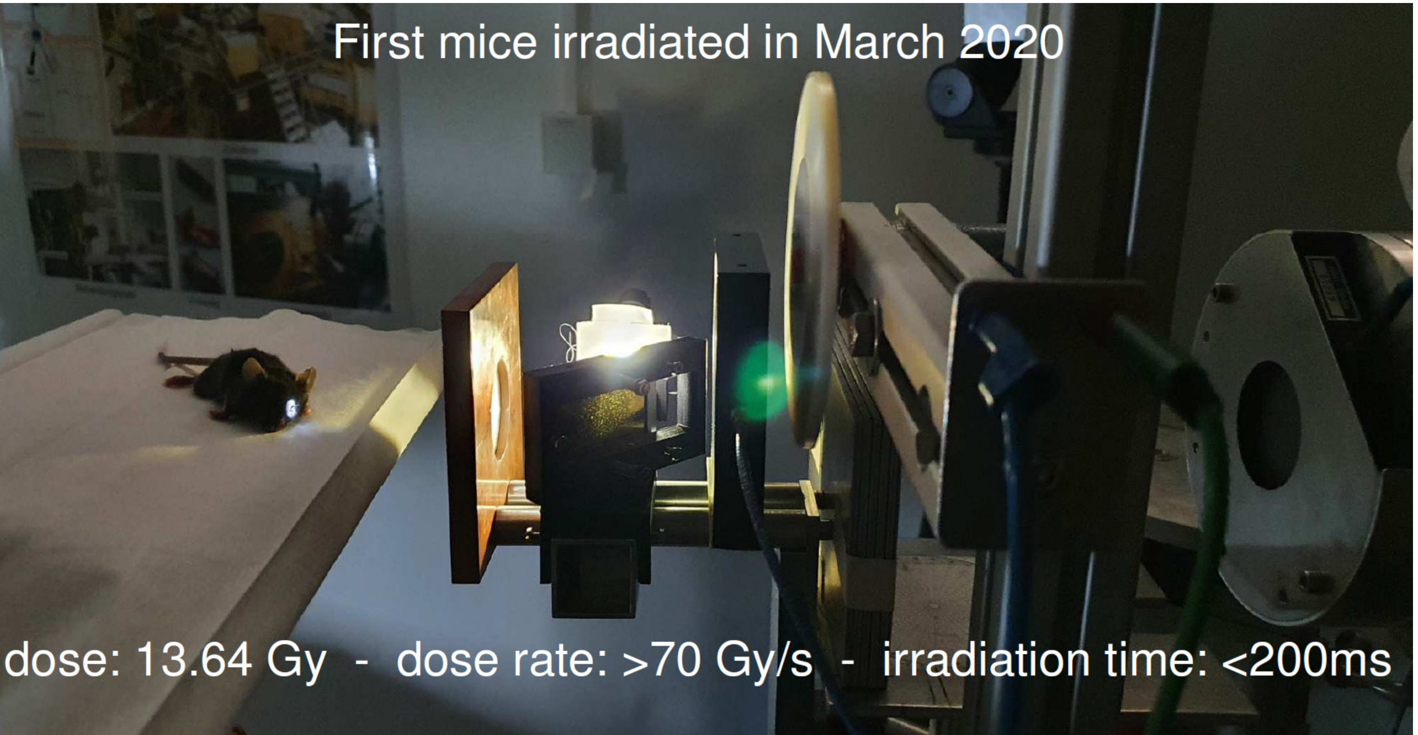
- new set-up at experimental station:
  → control group with conventional irradiation: 15 Gy in 60s (0.25 Gy/s)
  → flash irradiations: 15 Gy in 200 ms (75 Gy/s)
- in total: ~ 80 mice



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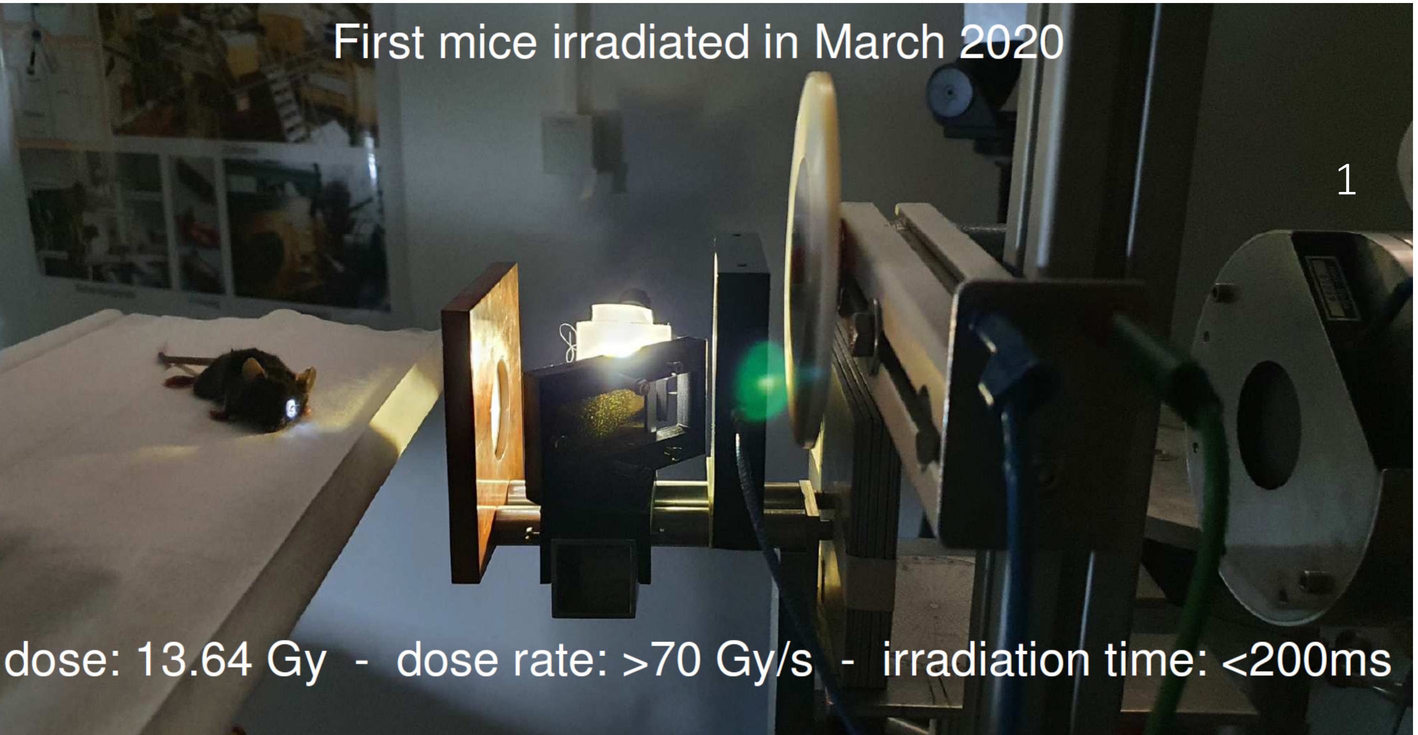

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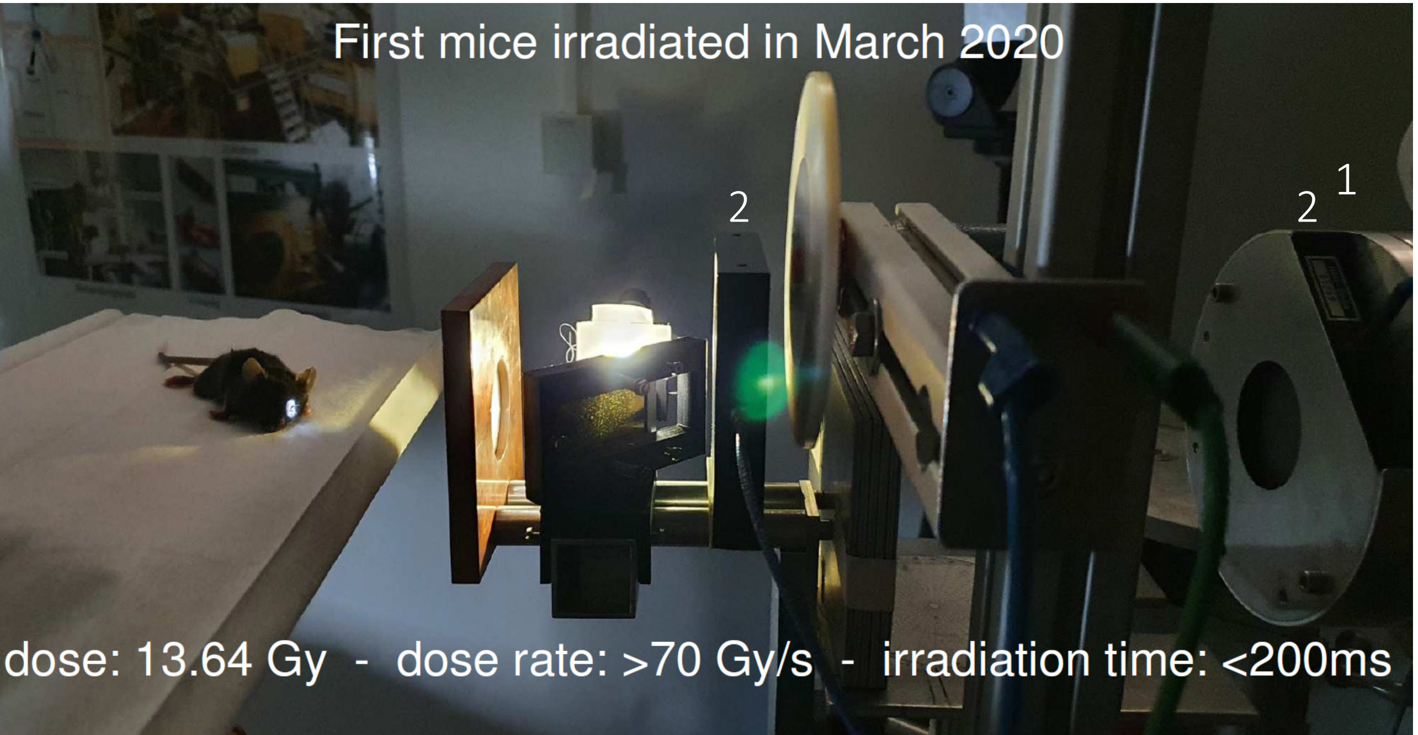

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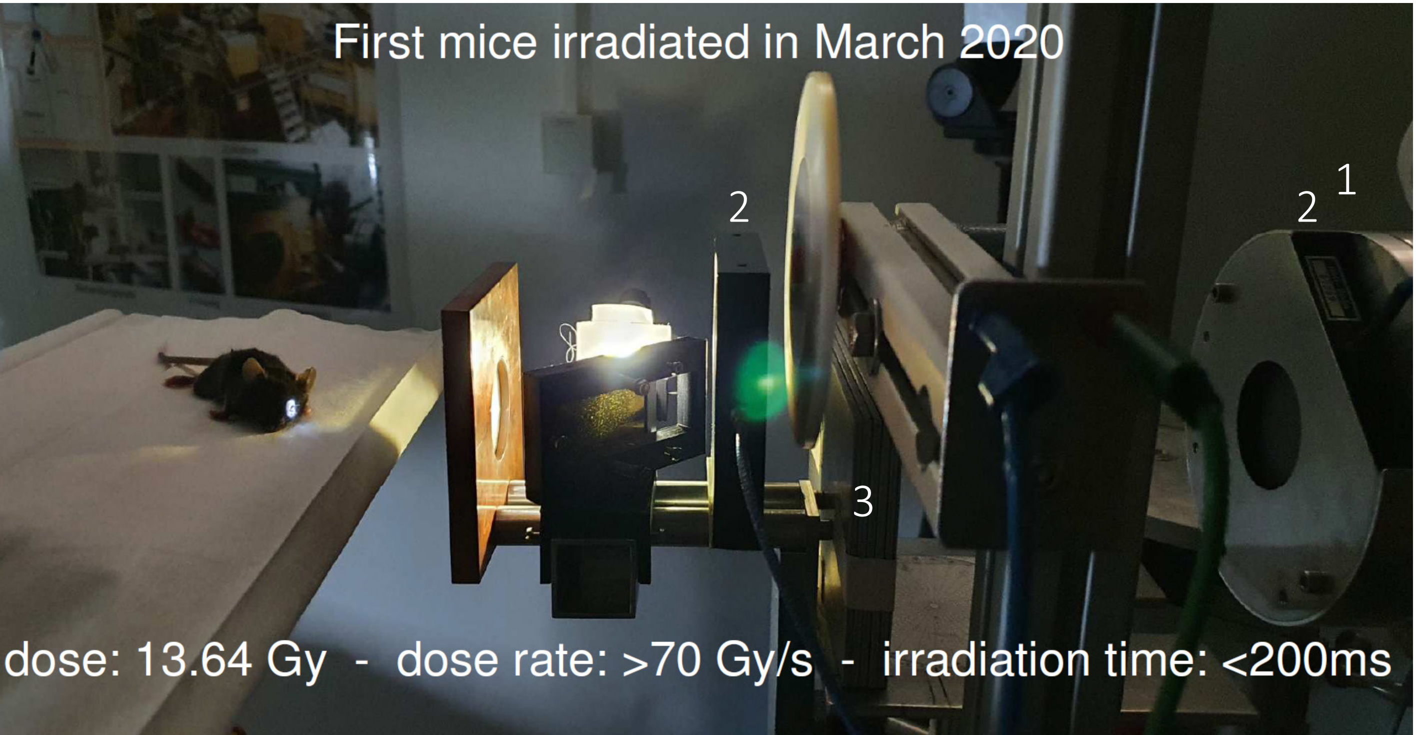

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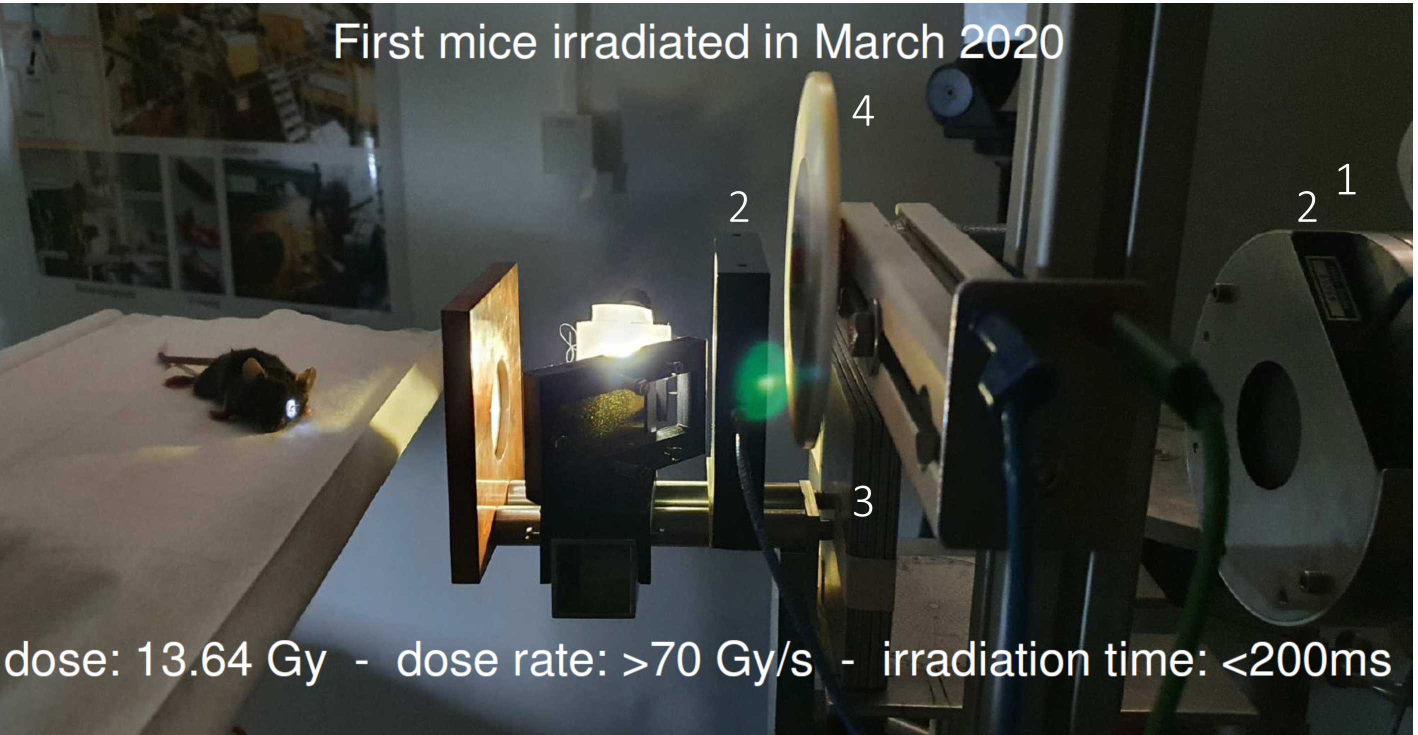

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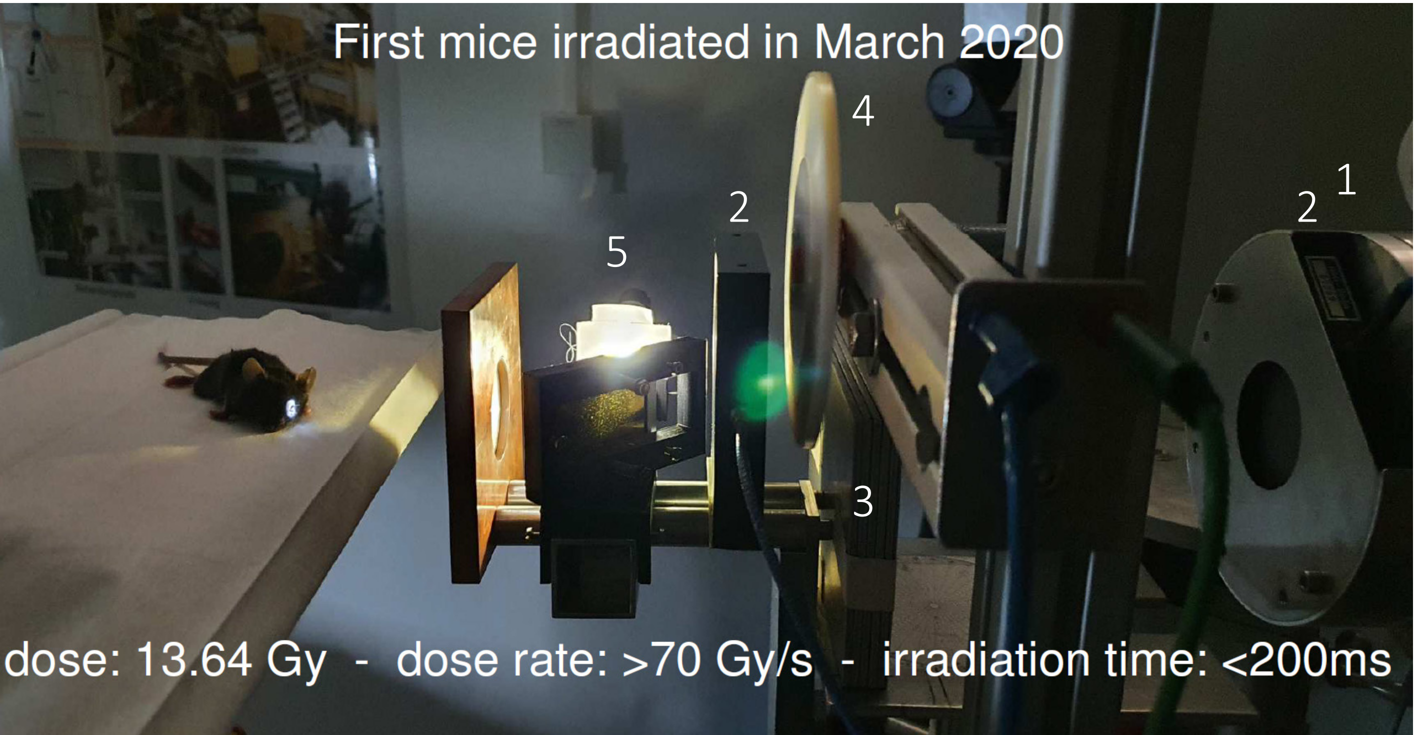

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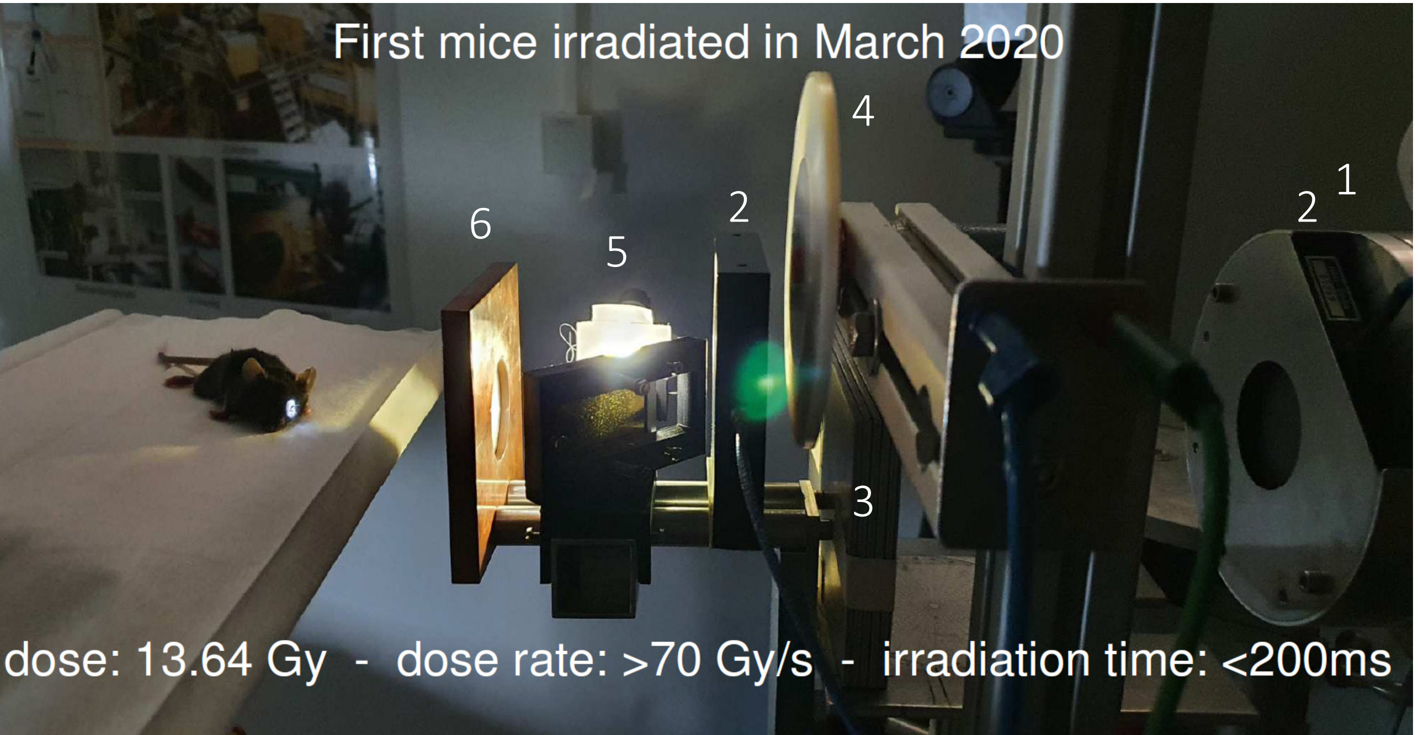

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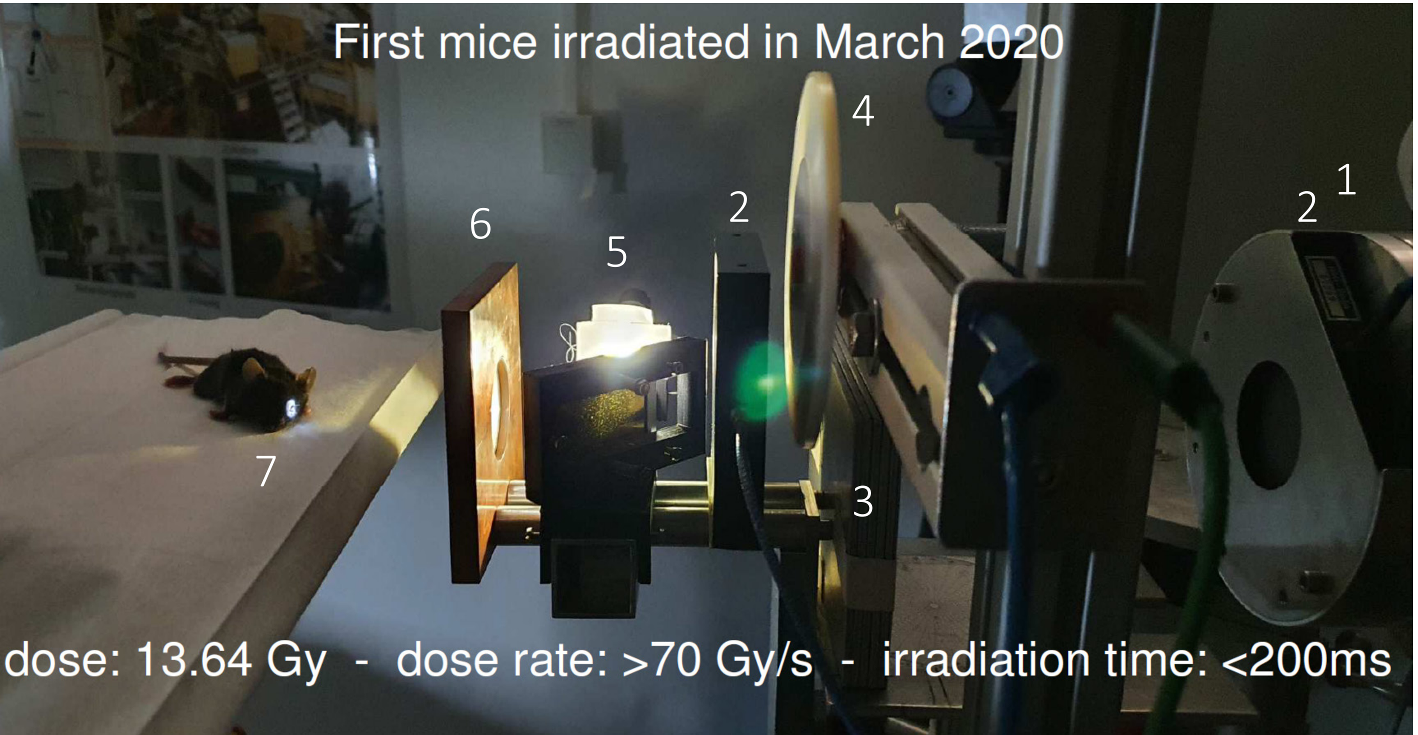

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7. anesthetized mouse with light field for positioning

beam delivery for FLASH irradiations – further developments

- currently ideal irradiation time unknown (definition Flash: < 1 s)
- indications that irradiation times should be shorter than 100 ms

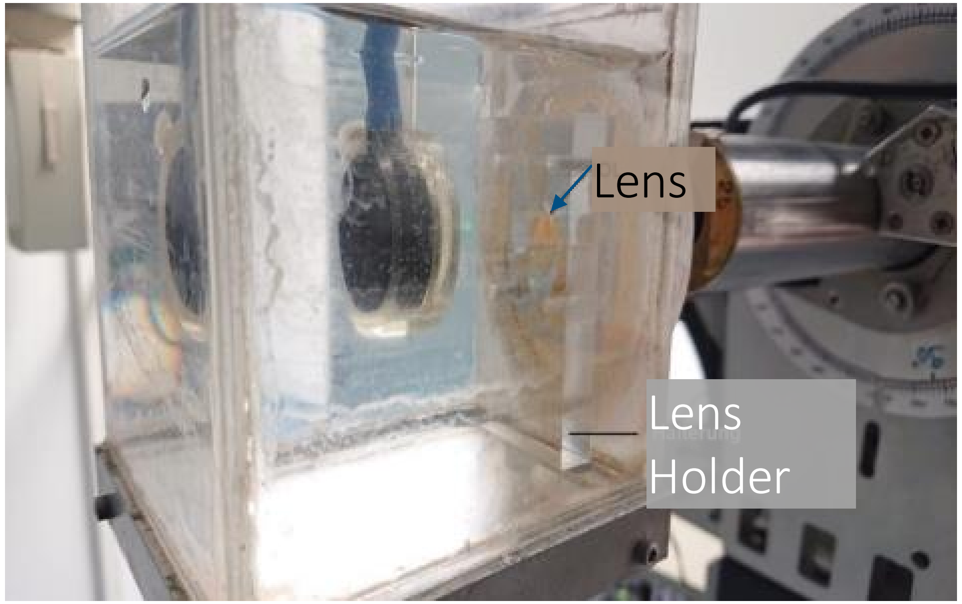
→ mechanical beam stop too slow

→ electrical beam deflector

- recently: electrical beam deflector only for the Van-de-Graaff injector available
  single pulses with 1ns pulse width and 2.4 MHz repetition rate feasible
- now: installation of a second chopper on the DC-beam from the Tandetron
  MOP11 – Timo Fanselow: Design and Operation of the new fast beam chopper between Tandetron and cyclotron
- replace modulator wheel with ridge filters
- near future: irradiations of sarcoma and uveal melanoma organoids

determination for appropriate material for artificial lenses in ocular proton therapy

- artificial lenses from various manufacturers irradiated with protons under conventional and Flash mode
- lenses mounted in front of the water phantom with Markus chamber for absolute dosimetry
- identical irradiation field size for both modes
- conventional: 60 Gy, dose rate 0.2 Gy/s
- Flash: 60 Gy, dose rate 70 Gy/s



determination for appropriate material for artificial lenses in ocular proton therapy

- Manufacturers:
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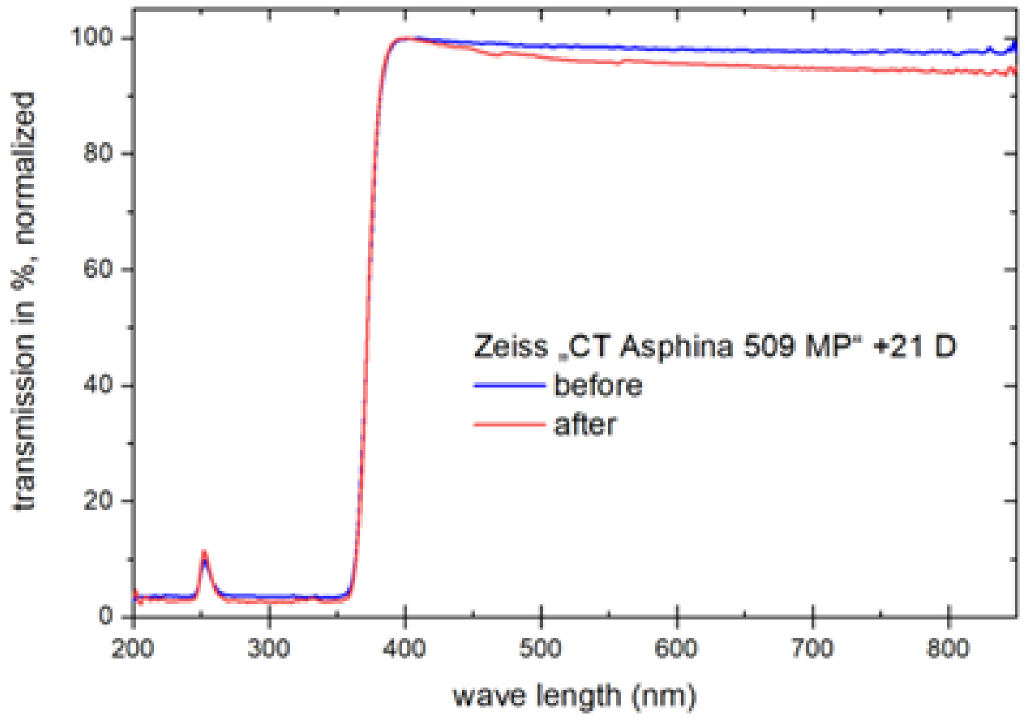
- no significant changes in transmission before/after irradiation
- edges at the same wavelength



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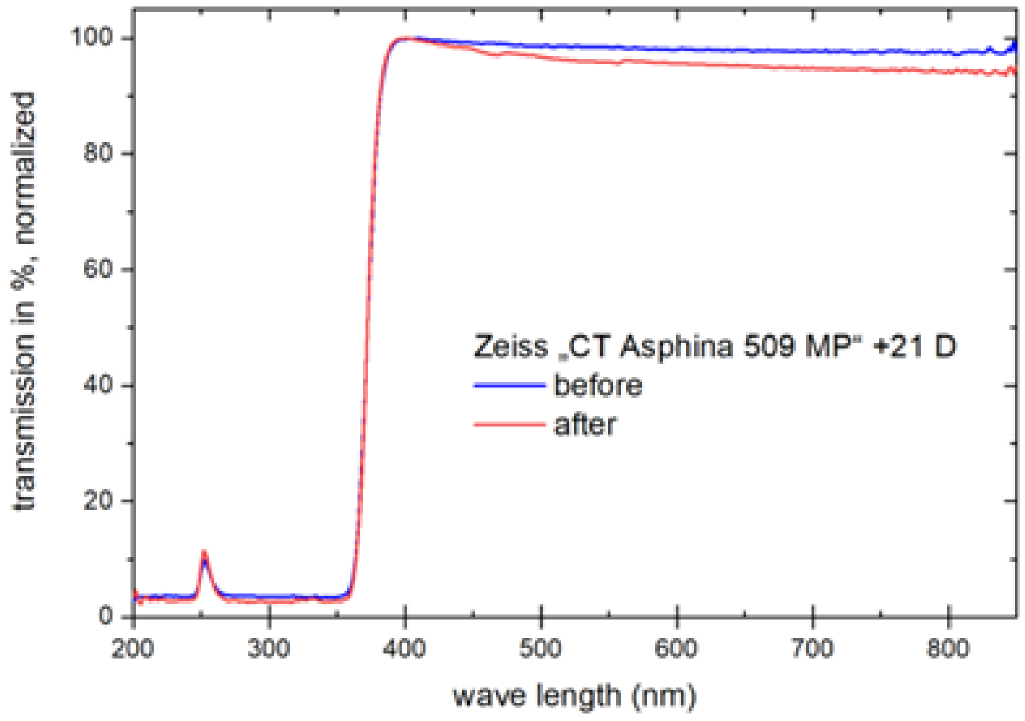

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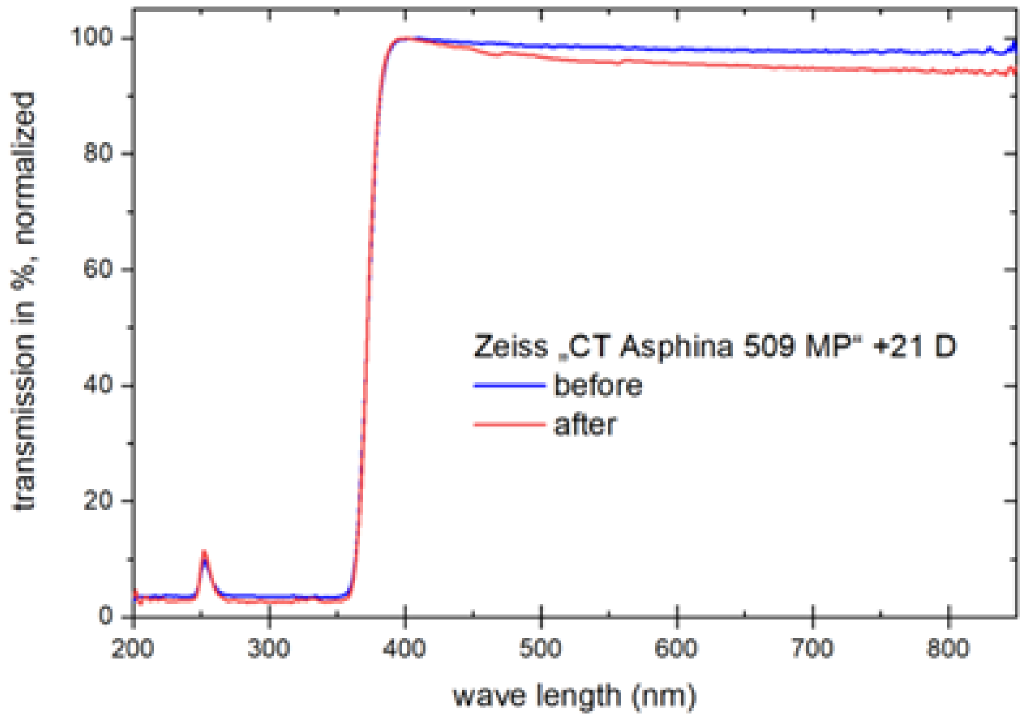
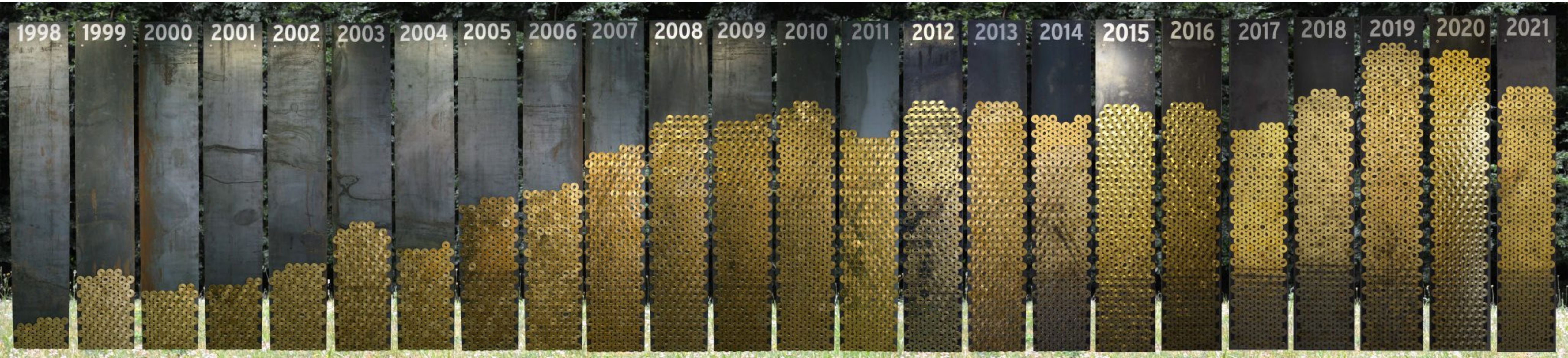


- only after irradiation with ^{60}Co, 20000 Gy (typical sterilisation dose) changes in transmission observed

Conclusion and Outlook

- more than 4400 patients treated (Nov. 2022)
- in spite of Covid-19: high patient numbers



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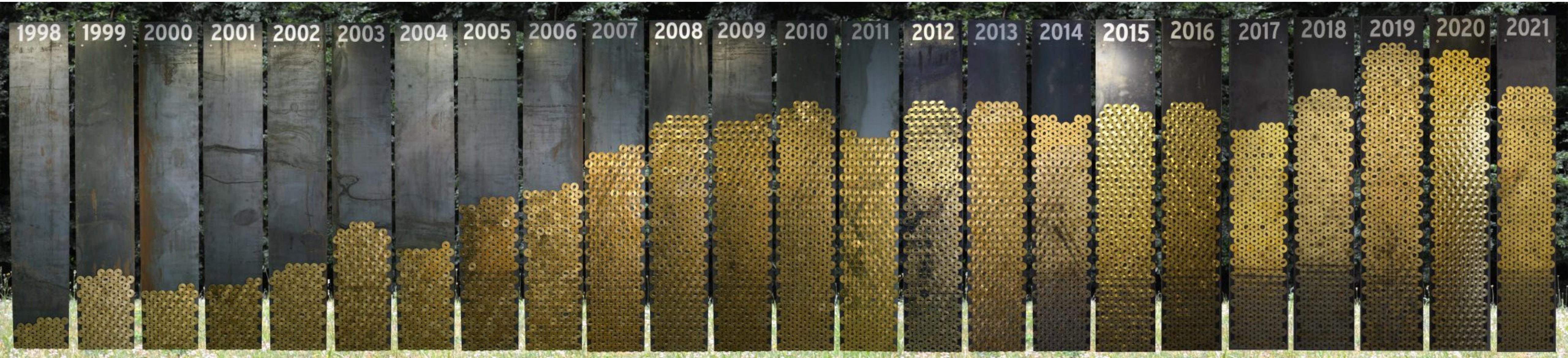

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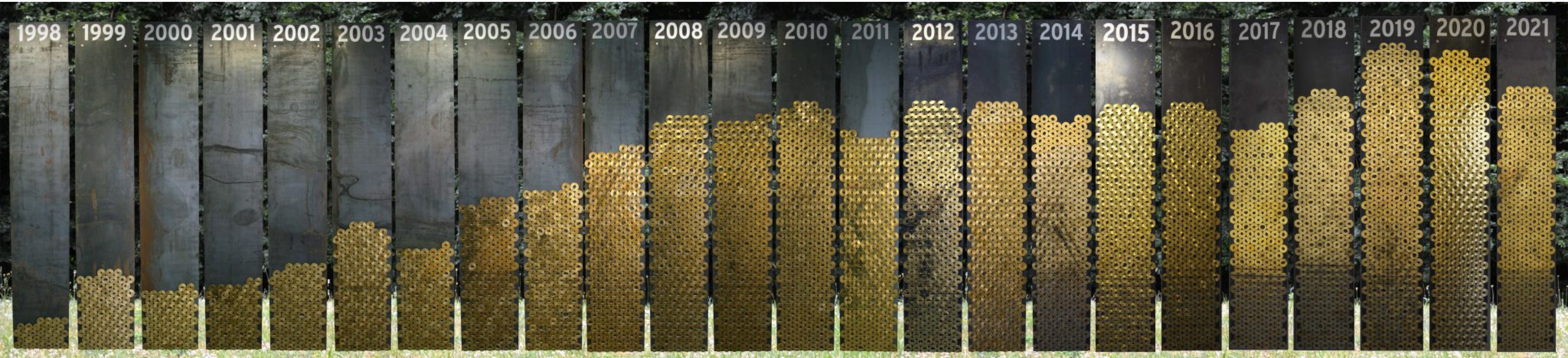

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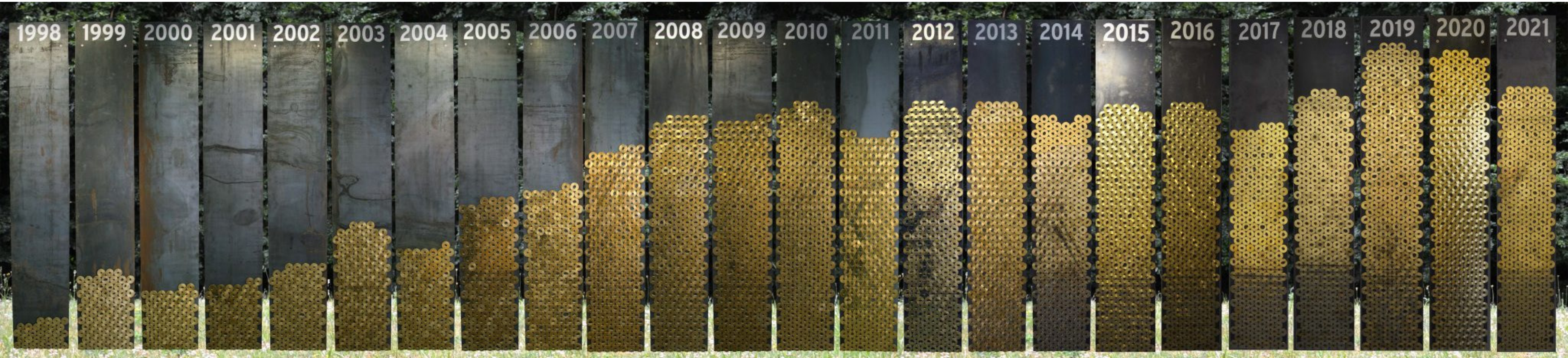

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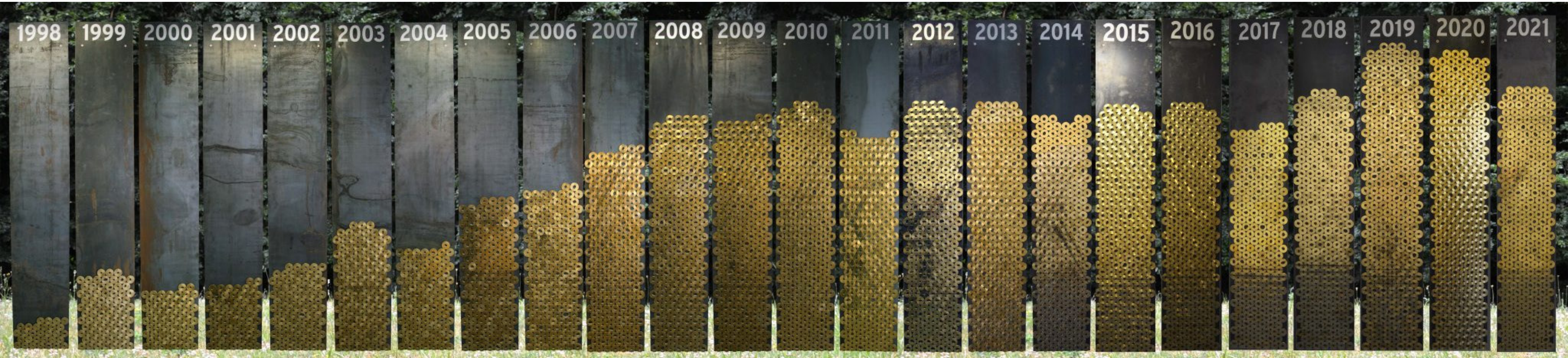

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- 30.6.2023: 25 years of eye tumour therapy at HZB