

FLASH*lab*@PITZ

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On behalf of the PITZ team

11th Beam Telescopes and Test Beams Workshop, 17. – 21. April 2023, Hamburg



Largest accelerator center in Germany, one lab - two locations: Hamburg + Zeuthen (near Berlin)

(ARES: single e^- bunches, 50Hz, 160 MeV)

Facts and Figures

- publicly funded national research centre of the Helmholtz Association
- **Employees** at DESY
 - approximately **2700**, including 1180 scientists
- Interdisciplinary research, international cooperation
- Research at DESY in 4 areas:
 - **Accelerators**
 - Photon Science (focus in Hamburg)
 - Particle Physics
 - Astroparticle Physics (focus in Zeuthen)



Courtesy of Ulrike Behrens & Frank Stephan

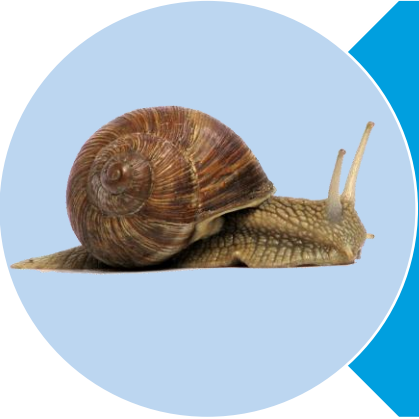


FLASH radiation therapy

The future of cancer treatment?

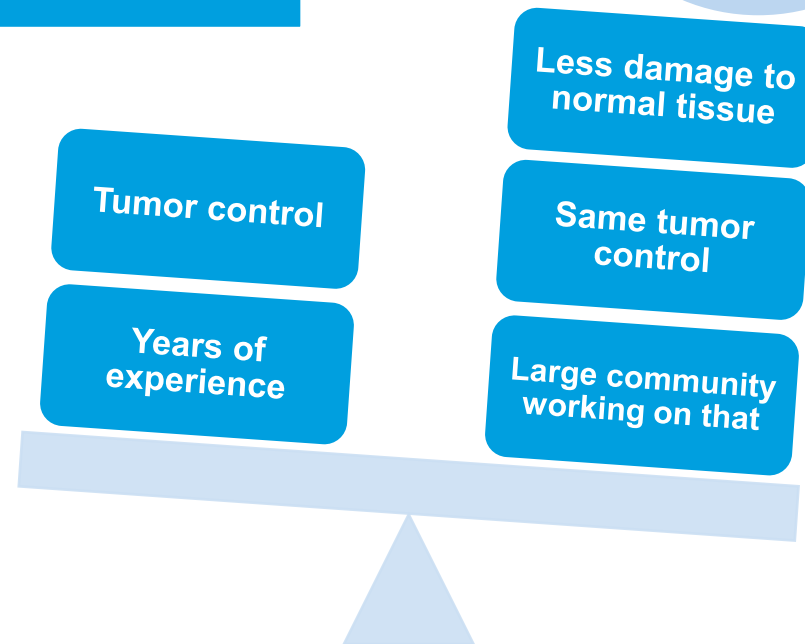
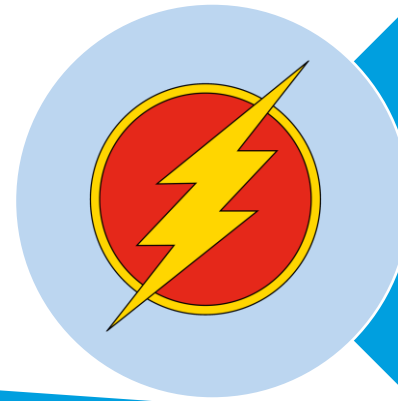
Conventional RT

- Dose: 30 – 60 Gy
- Multiple sessions (2 Gy per session)
- Usual dose rate: 2 Gy/min



FLASH RT

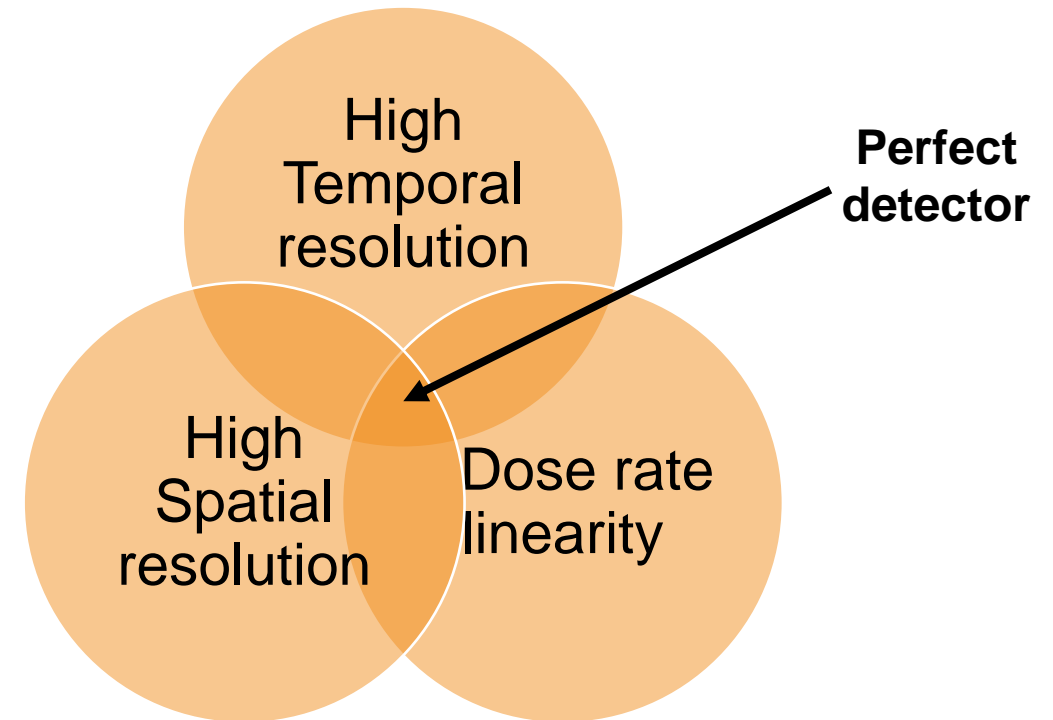
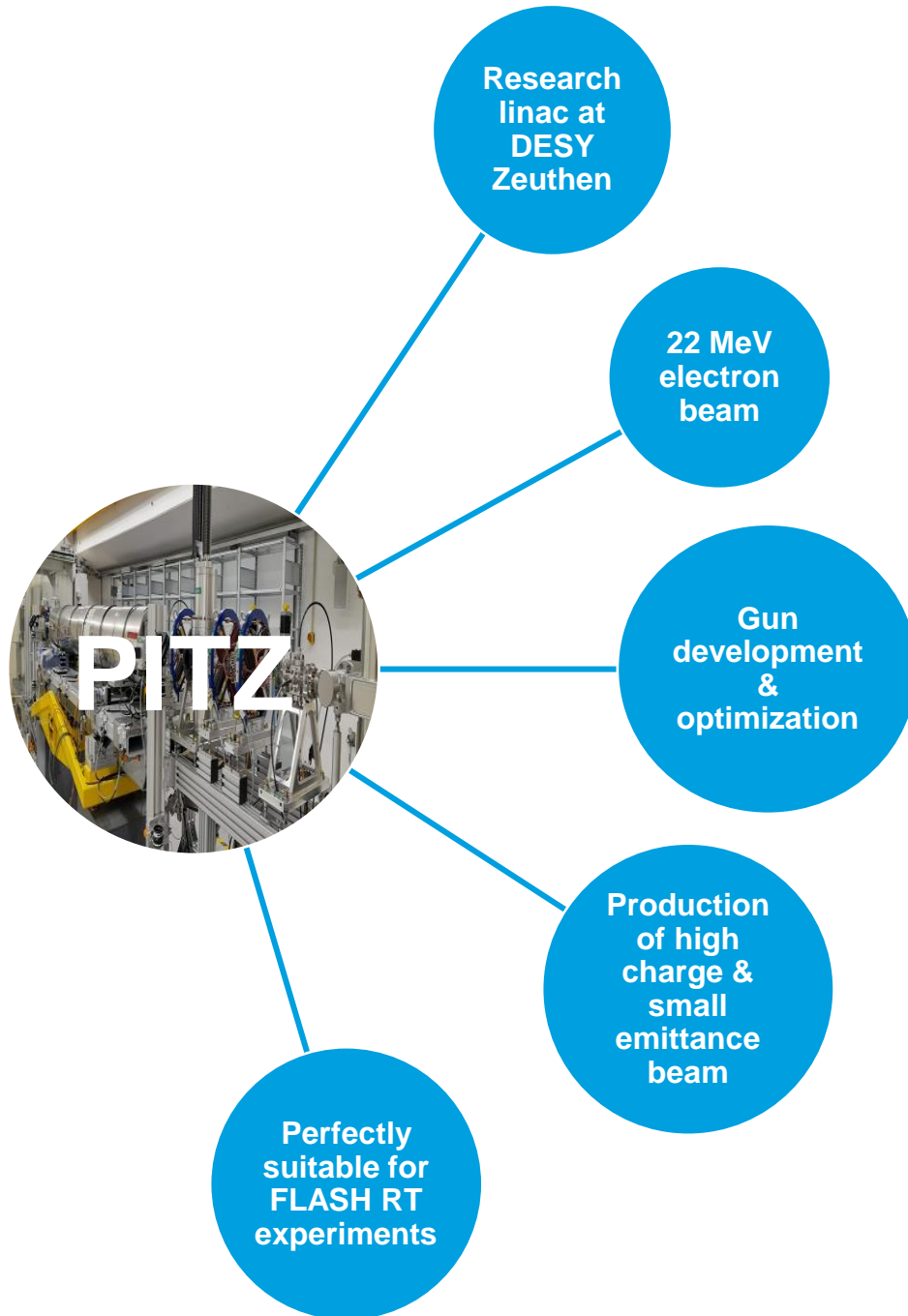
- Dose: 30 – 60 Gy
- Less than 100 ms of total irradiation
- Dose rate: > 30 Gy/s



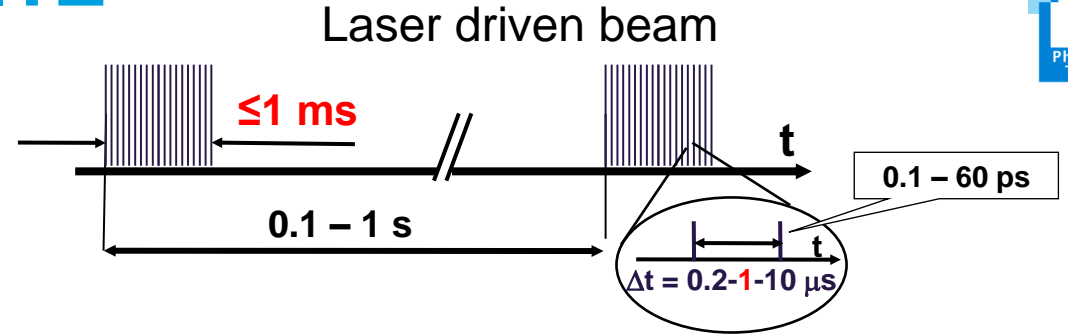
New challenge: Dosimetry

Detection of a huge amount of particles in a very short amount of time

PITZ:
Up to 3×10^{10} particles within 30 ps



Beam parameters available at PITZ



Options @PITZ:	low dose case	high dose case
Bunch charge	0.1 pC	5 000 pC
Single bunch OR train	single bunch	1ms train (1MHz)
RF pulse rep. rate	1 Hz	10 Hz
Bunch length	<1 ps	~30 ps
Dose per bunch	0.02 Gy	1000 Gy
Dose rate per bunch	2×10^{10} Gy/s	4×10^{13} Gy/s
Dose per train (ms)	0.02 Gy	1×10^6 Gy
Dose rate per train (ms)	20 Gy/s	1×10^9 Gy/s
Dose per second	0.02 Gy/s	1×10^7 Gy/s

Bunch/micropulse charge is tunable from 0.1 pC up to 5 nC

bunches/micropulses per pulse can be tuned from 1 up to 1000

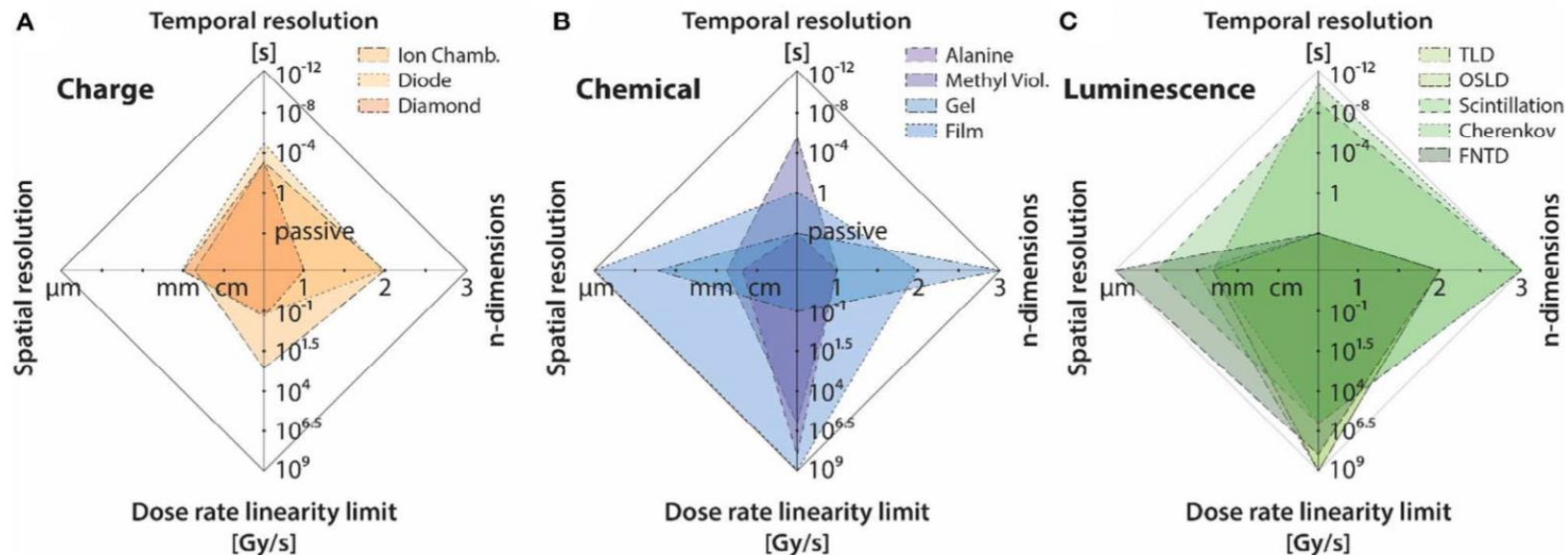
Dose rate can be tuned from conv. DR up to UHDR

Challenges of FLASH dosimetry: 3 critical parameters

Temporal resolution: very fast time resolution (at least bunch-train level) and readout is needed

Spatial resolution: imaging of dose distribution is needed (at least mm resolution)

Dose rate linearity: dose rate linearity for very high dose rates is needed for PITZ



There is no perfect dosimeter for FLASH available now.

Established detectors

Active detectors

- Ionization chambers
- Diamond detectors

Passive detectors

- Radiochromic films
- Alanine
- TLDs, OSLDs

HEP detectors (to be tested)

MALTA

DECAL

Customized
Timepix 3

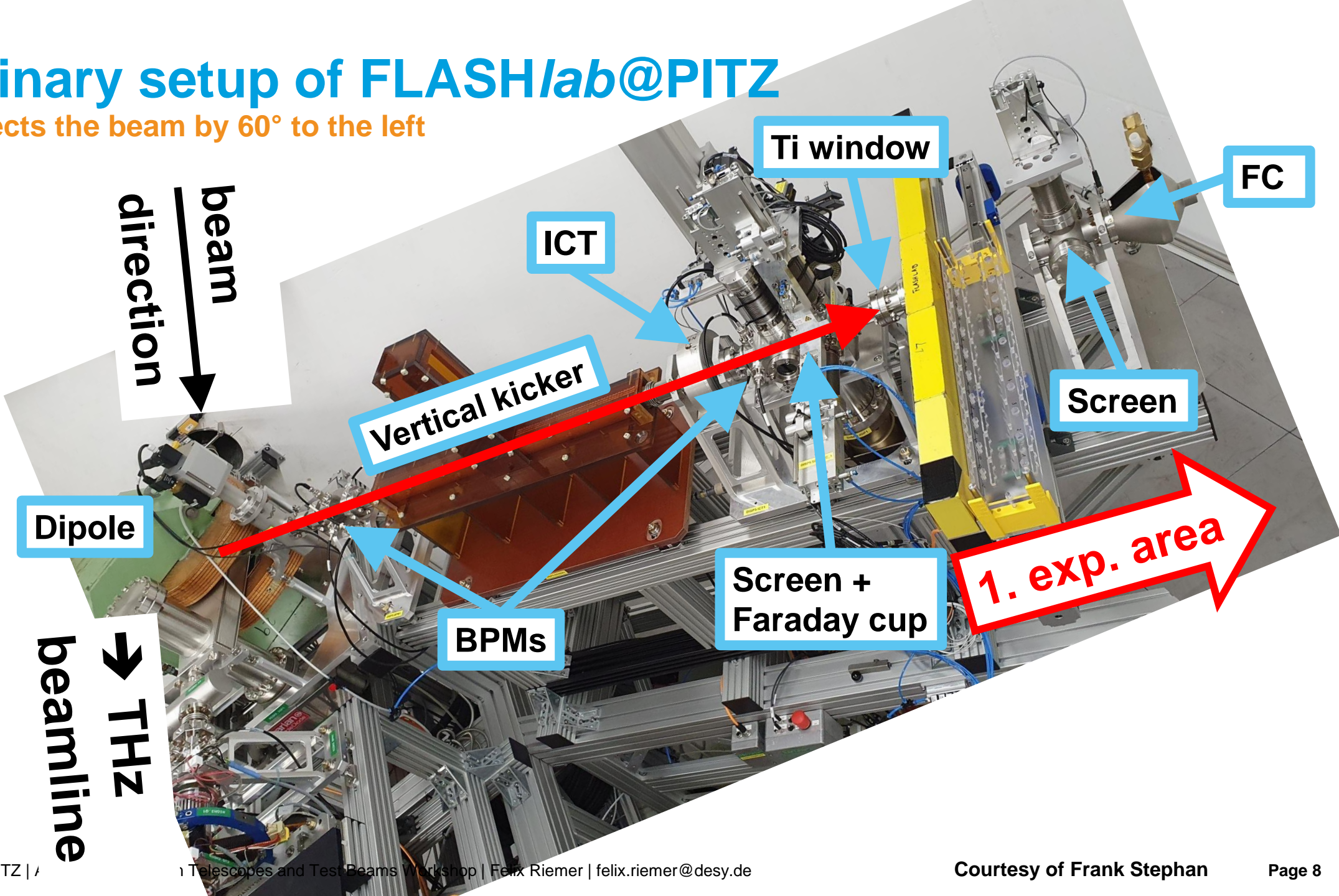
Diamonds

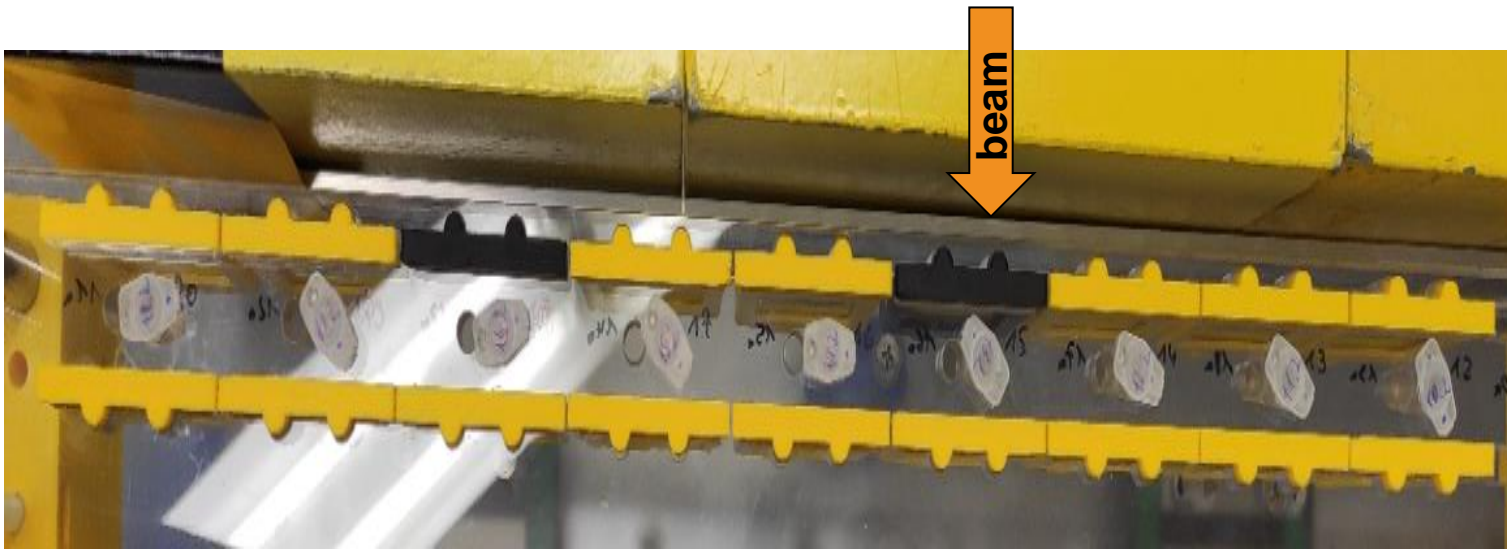
Timepix 4

LGADs

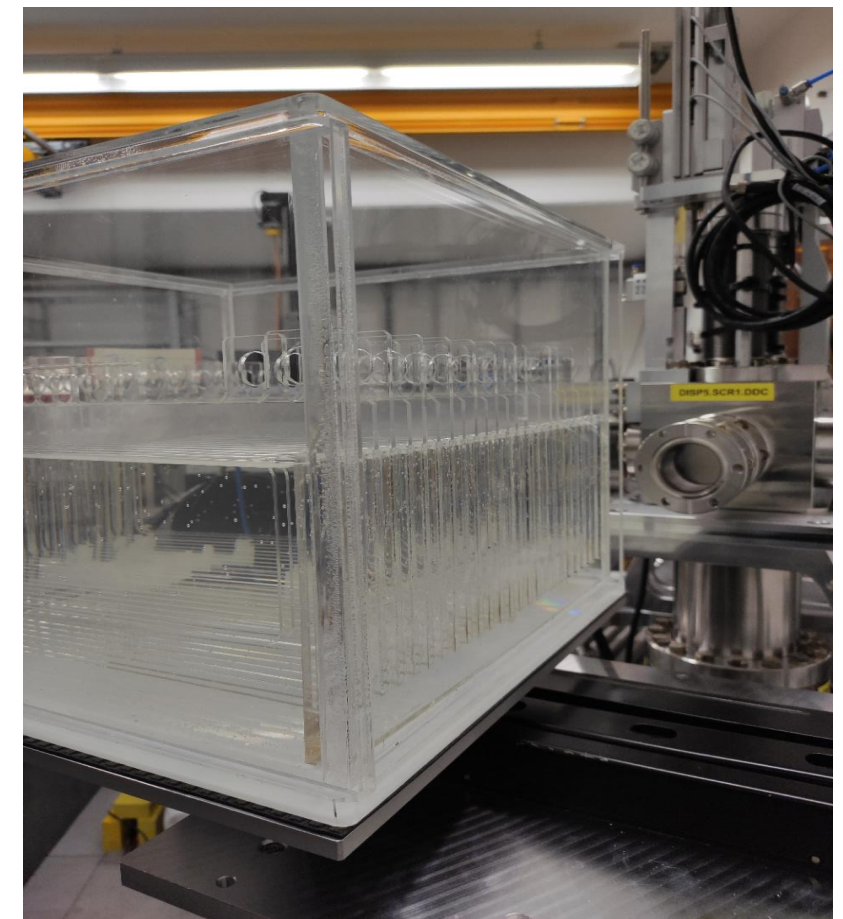
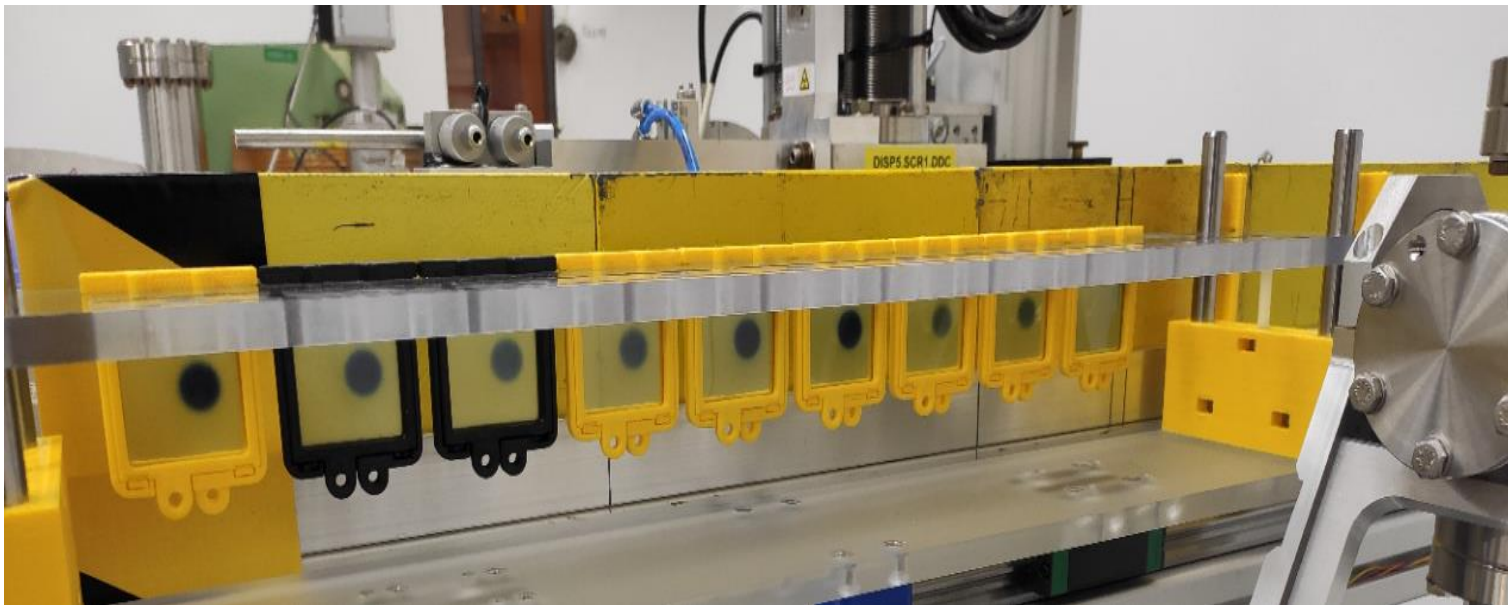
Preliminary setup of FLASHlab@PITZ

Dipole deflects the beam by 60° to the left





Preliminary setup of FLASHlab@PITZ



Characterization of films & experiments done/planned

Limit test:

- Calibration was done up to 300 Gy
- Irradiation up to 800 Gy -> Extrapolation of calibration
- Analysis ongoing

Experiments at PITZ

- We just started in November 2022
- Hydrogen peroxide production, irradiation of DNA plasmid & cells (cooperation with TH Wildau)
- Irradiation of sarcoma cancer cells (cooperation with Charité)
- Irradiation of lung cancer cells (cooperation with TH Wildau)

Planned experiments

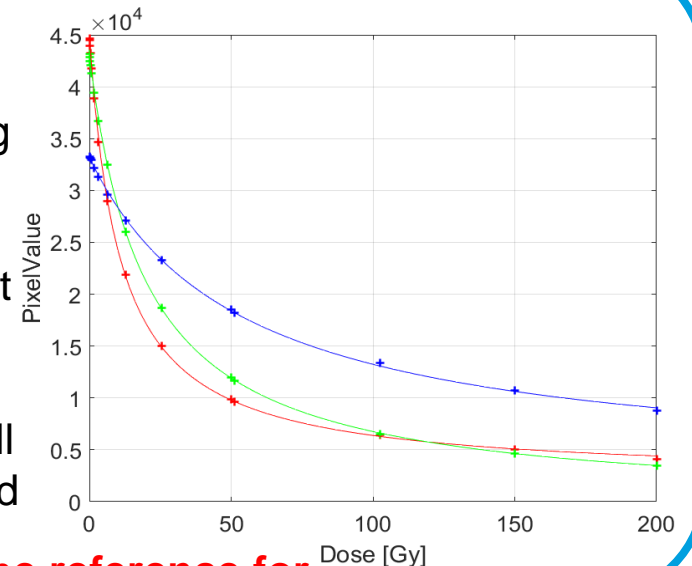
- Irradiation of zebrafish embryos (cooperation with HZDR)
- Alanine calibration (cooperation with PTB)

Dose rate linearity

- Dose rate linearity was confirmed up to 10^8 Gy/s as in literature
- Irradiation to dose rates up to 8×10^{10} Gy/s were done
- High background due to dark current (Background 3 times higher than signal)
- Dark current was decreased in the meantime: Experiment will be redone

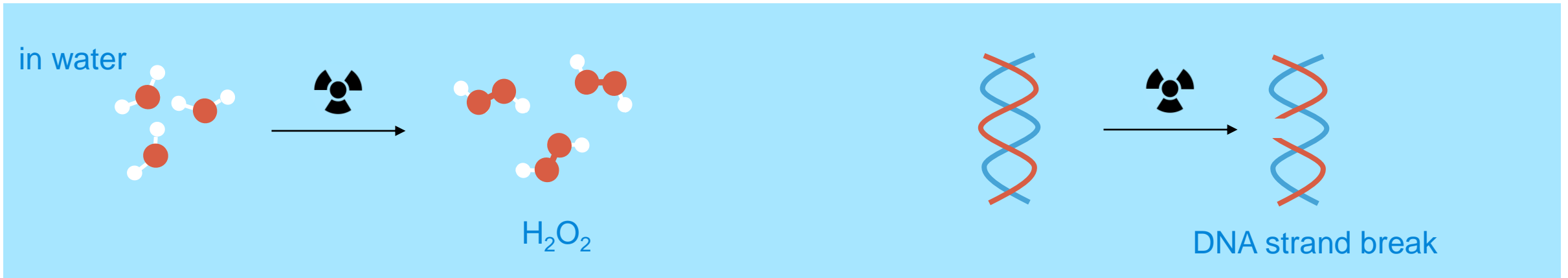
Readout of films:

- After 24h: Scanned using a professional scanner
- Relative Change of about 5%, 24h after irradiation
- For calculation of dose all 3 color channels are used

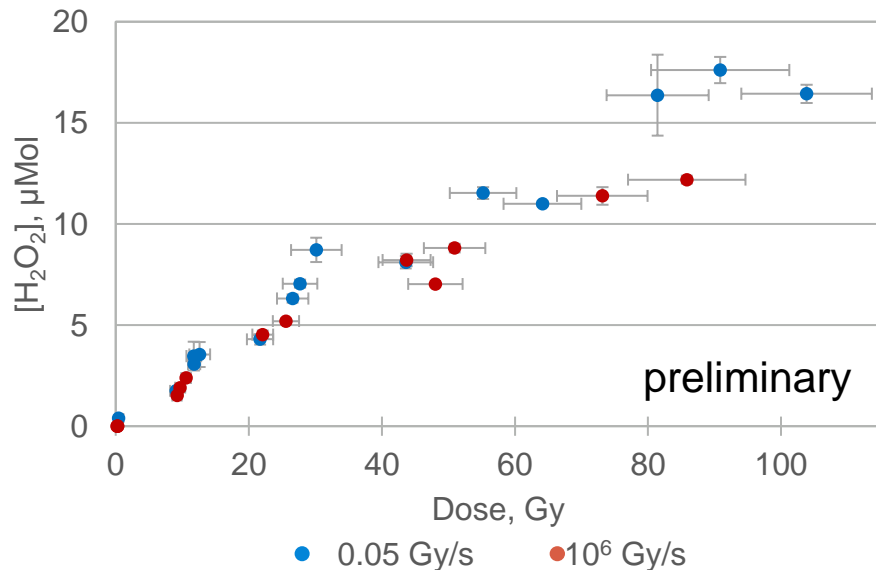


**Films will be the reference for
all planned detector tests**

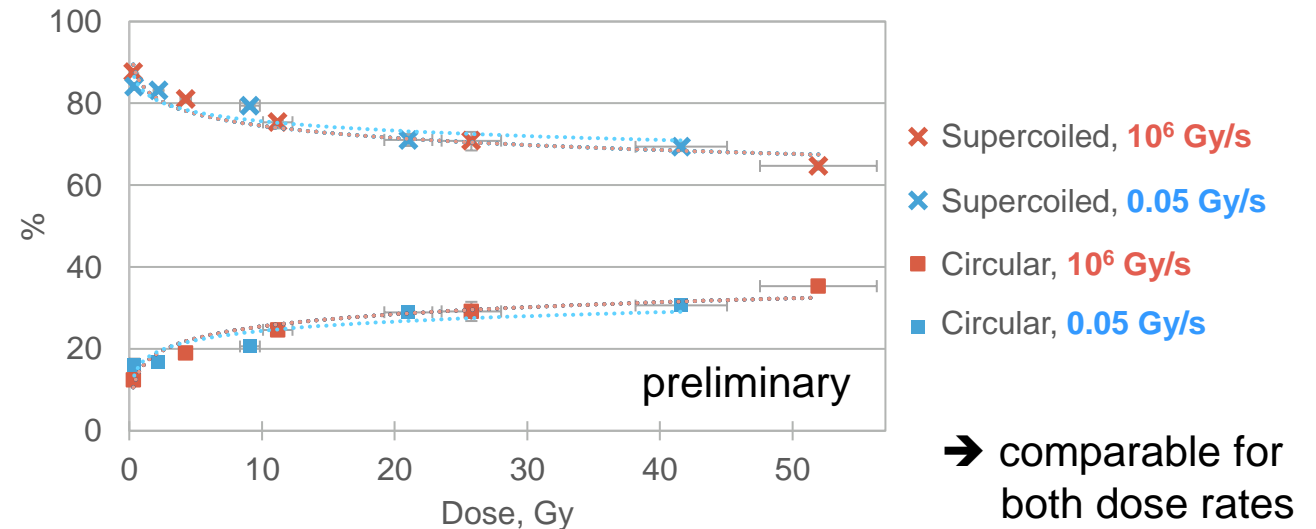
First chemical / biochemical experiments at PITZ



H_2O_2 generation



DNA plasmid conformation



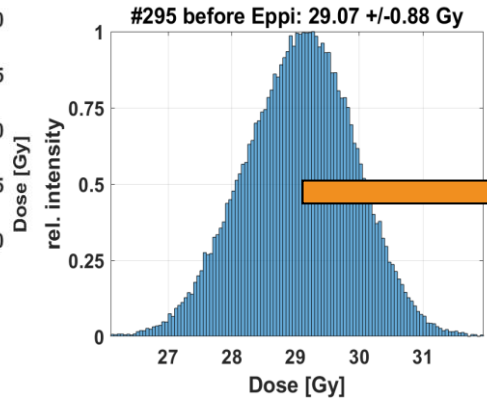
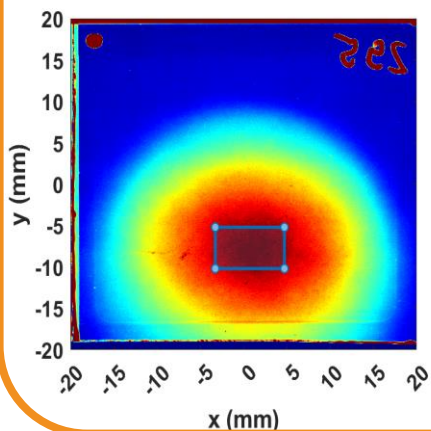
Depth dose profile and dosimetry for HZDR measurements

Uni Manchester/Daresbury provided water tank for depth dose profile measurements

Preparatory dosimetry for later measurement with zebra fish embryos from HZDR

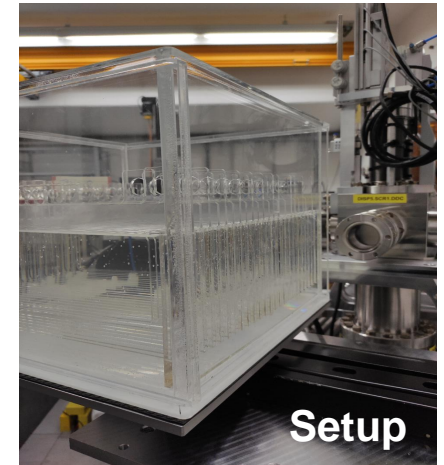
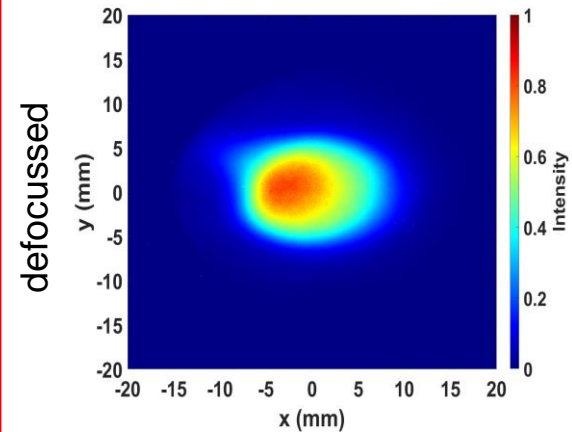
Goal for HZDR: 90% homogeneity in 5x8 mm rectangle, max dose 30 Gy

- Plexiglass plates were introduced to get a more homogeneous beam: 5 & 10 mm were tested.
- **Low dose rate:** 10 pC beam, defocussed, 1 bunch per train with 10 Hz -> dose rate of 0.055 Gy/s
- **High dose rate:** 300 pC beam, defocussed, 50 to 300 bunches per train, single train only -> $\sim 1.2 \times 10^5$ Gy/s
- **Result:** Homogeneity was achieved with 10mm scattering plate

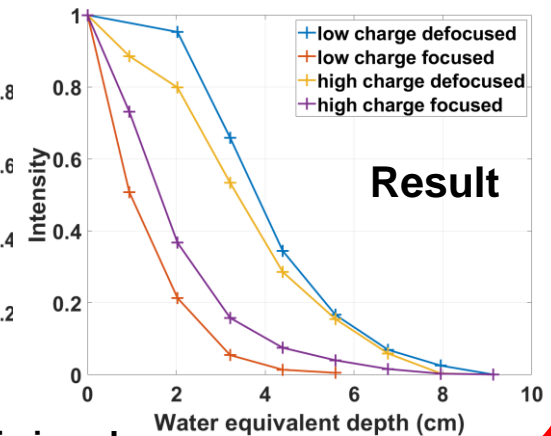
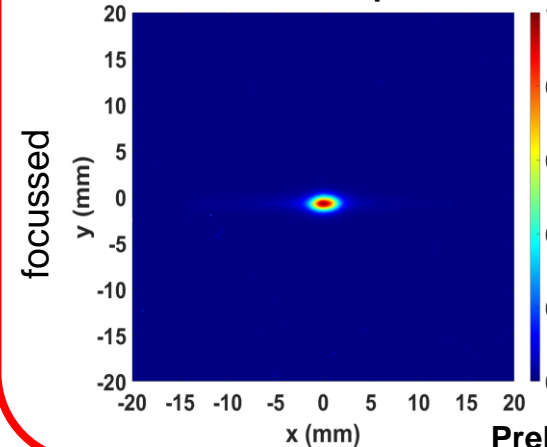


Homogeneity:
90.2 %
(Definition: Deviation of max/min in ROI from average in ROI)

Depth dose profile for 4 different beam parameters



Low charge beam on the outside of the phantom

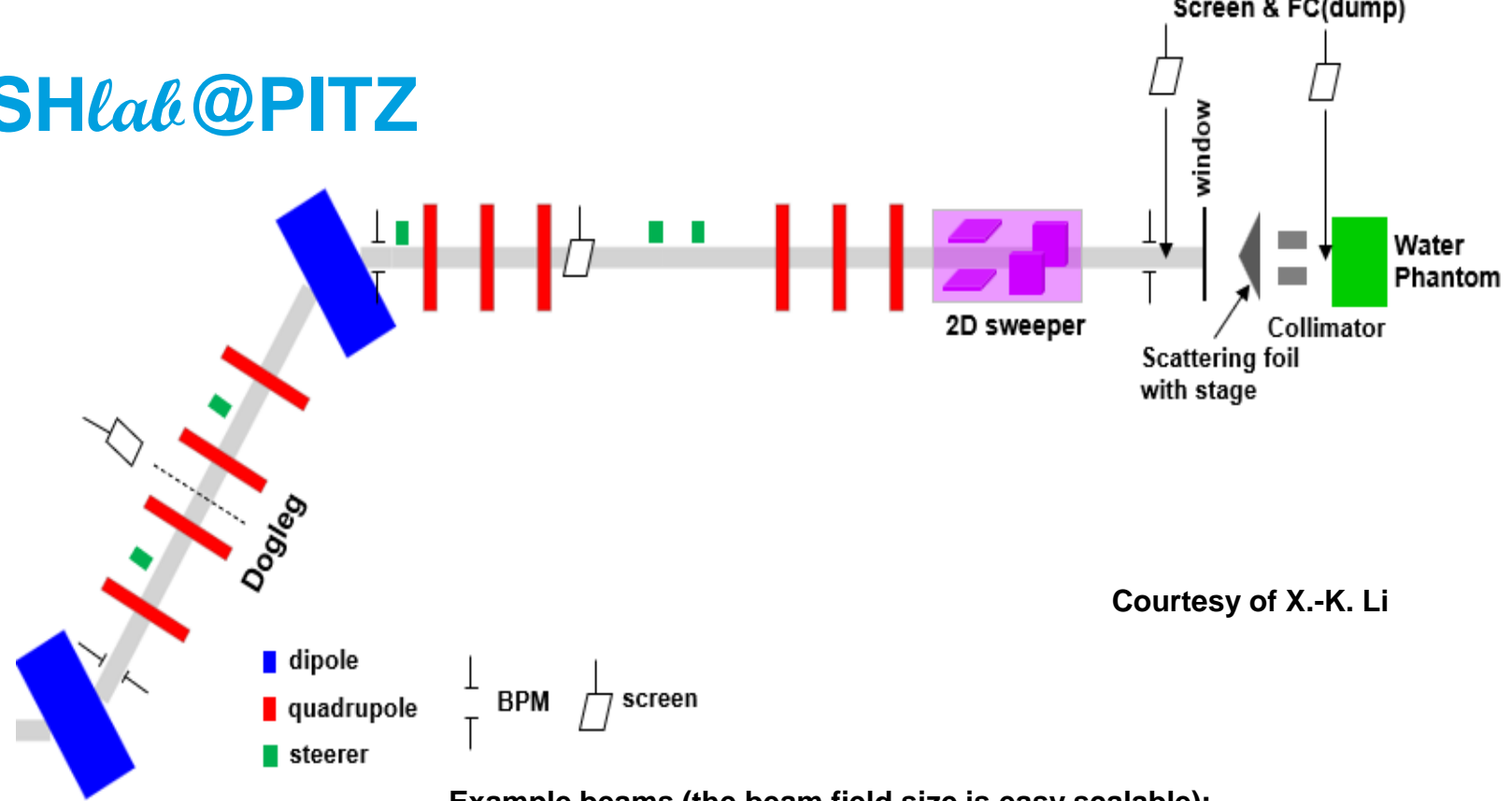


Result

Preliminary!
Analysis ongoing

Upgrade plan for FLASHlab@PITZ

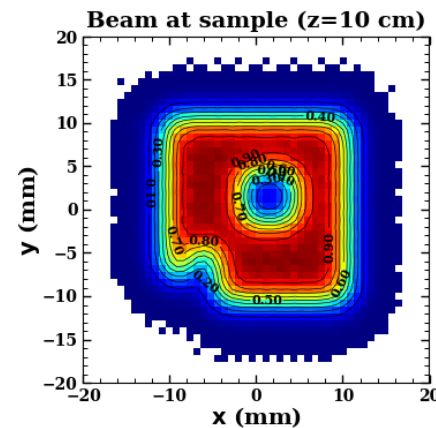
- Upgrade of existing setup is planned to be finished 2023/24
- More than 10 magnets for beam focusing are already ordered
- Beam diagnostics (BPM, screen, Faraday cup)
- 2D sweeper to scan the beam over surface



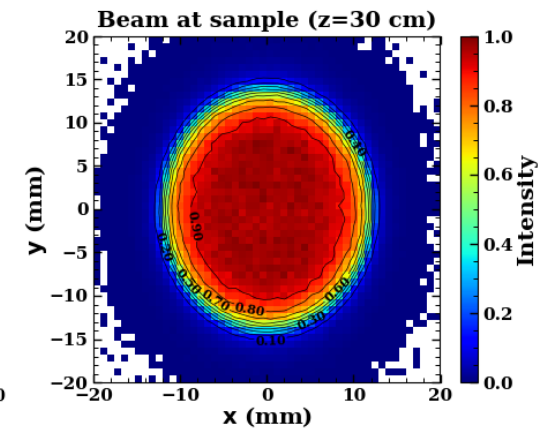
Courtesy of X.-K. Li

Example beams (the beam field size is easy scalable):

a) From **2D sweeper**

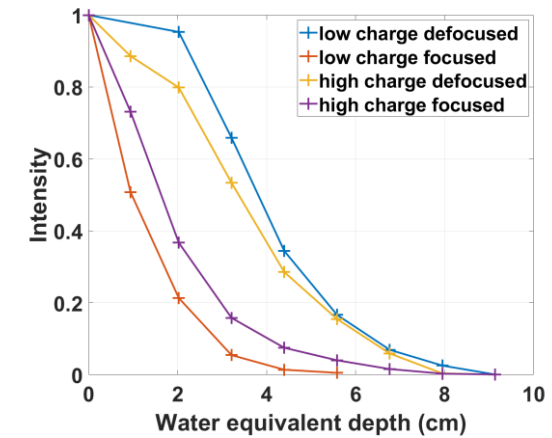
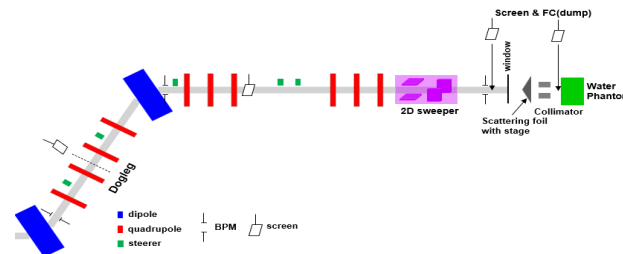
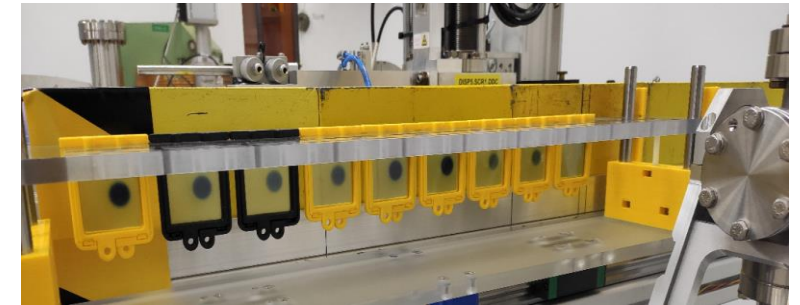
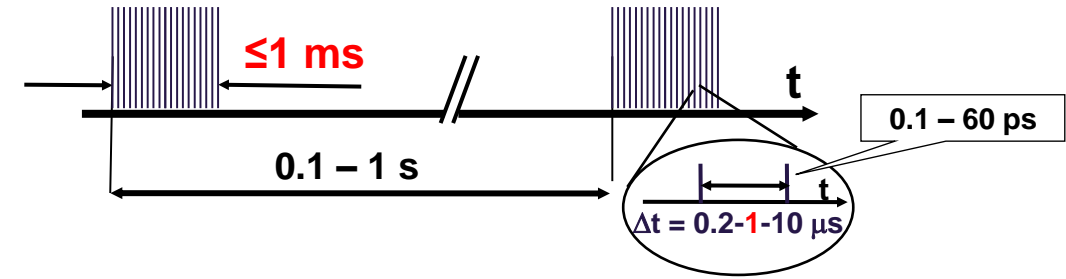


b) from **scattering foil**



Conclusion

- The PITZ accelerator at DESY Zeuthen can provide conv. dose rate up to ultra high dose rate.
- Setups: Water phantom & movable stage for irradiation of samples in Eppendorf tubes
- Dosimetry: Gafchromic films + more detectors planned
 - Limit test, dose rate linearity
 - Water phantom: Depth dose profile for 4 different beams
- Experiments done and planned
- Upgrade plan for PITZ



Acknowledgment



DESY & PITZ team:

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Thank you