Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

The Joint Research Project UHDpulse – "Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates"

UHDpulse

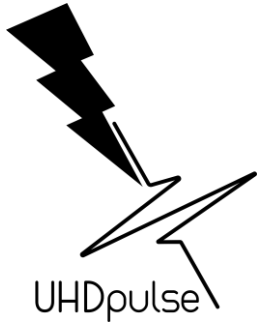
Andreas Schüller on behalf of the UHDpulse consortium
Department 6.2 "Dosimetry for Radiation Therapy and Diagnostic Radiology"

NCRI CTRad Meeting: "Transforming Radiotherapy in a Flash"
14.2.20, Wellcome Collection, London

Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

The Joint Research Project UHDpulse –

"Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates"



Contents

- EMPIR project
- FLASH radiotherapy
- Metrological challenges
- Project consortium, contributions of the partners

EMPIR project UHDpulse

Type:	Joint Research Project
Duration:	2019-2022
Start:	1. Sept. 2019
Funding:	2.1 M €
Coordinator:	Andreas Schüller
Topic:	tools for traceable dose measurements for:

- **FLASH radiotherapy**
- VHEE radiotherapy
- laser driven medical accelerators

http://uhdpulse-empir.eu/

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

The European Metrology Programme for Innovation and Research (EMPIR):

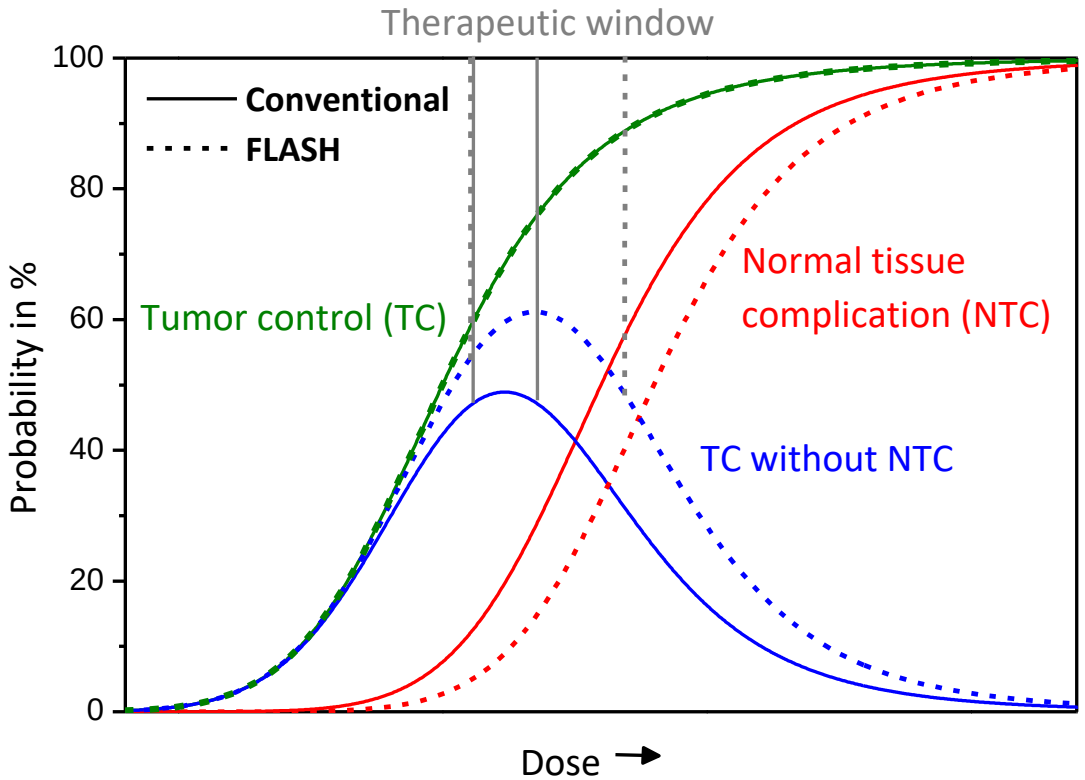
- metrology-focused programme of coordinated R&D
- enables European metrology institutes, industrial and medical organisations, and academia to collaborate

FLASH radiotherapy

FLASH effect

ultra-high dose rate →

- reduction of the normal tissue complications
- maintains tumour control level



FLASH radiotherapy

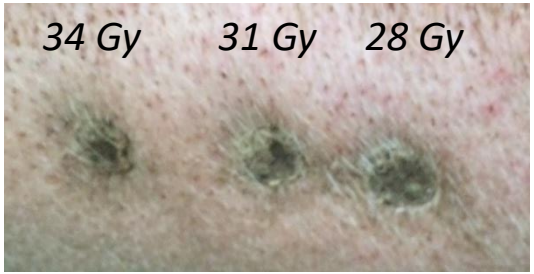
Reduced pig skin toxicity with FLASH-RT

Centre hospitalier universitaire vaudois

Conventional and FLASH Irradiation (with same total dose)

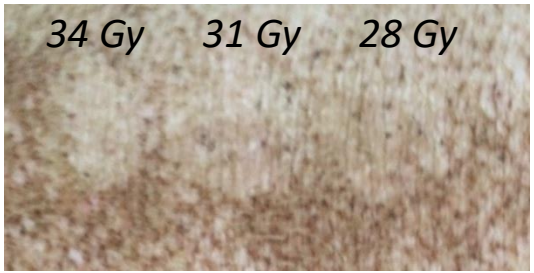
36 weeks post-RT

Conventional (5 Gy/min)



necrotic lesions

FLASH **(300 Gy/s)**



normal appearance of skin

Vozenin et al., Clin Cancer Res 25 (2019) 35
DOI: 10.1158/1078-0432.CCR-17-3375

FLASH radiotherapy

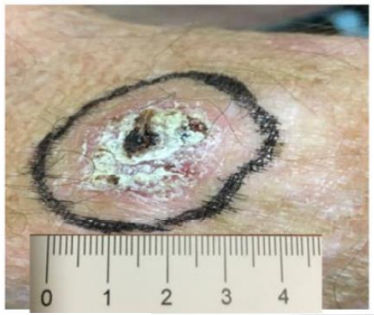
Treatment of a first human patient with FLASH-RT

Centre hospitalier universitaire vaudois

Patient:
lymphoma on skin

History:
110 different conventional irradiations in 10 years
(20 Gy in 6 - 10 fractions)
high grade acute skin reactions
takes >3 months to heal

FLASH-RT:
10 pulses (of 1 μs duration) in 90 ms
with **1.5 Gy/pulse**



Day 0

3 weeks

(max. of skin reactions)

5 months

Bourhis et al., Radiother. Oncol. (2019)
DOI: 10.1016/j.radonc.2019.06.019

metrological challenges at FLASH

	FLASH (with electrons)	conventional
dose per pulse	**1 – 10 Gy**	**0.3 mGy**
pulse width	1 -2 µs	3 µs
dose rate during pulse	10^6 Gy/s	10^2 Gy/s
pulse repetition frequency	10 – 100 Hz	200 Hz
mean dose rate	40 – 1000 Gy/s	0.05 Gy/s
time for dose delivery	100 ms	4 min

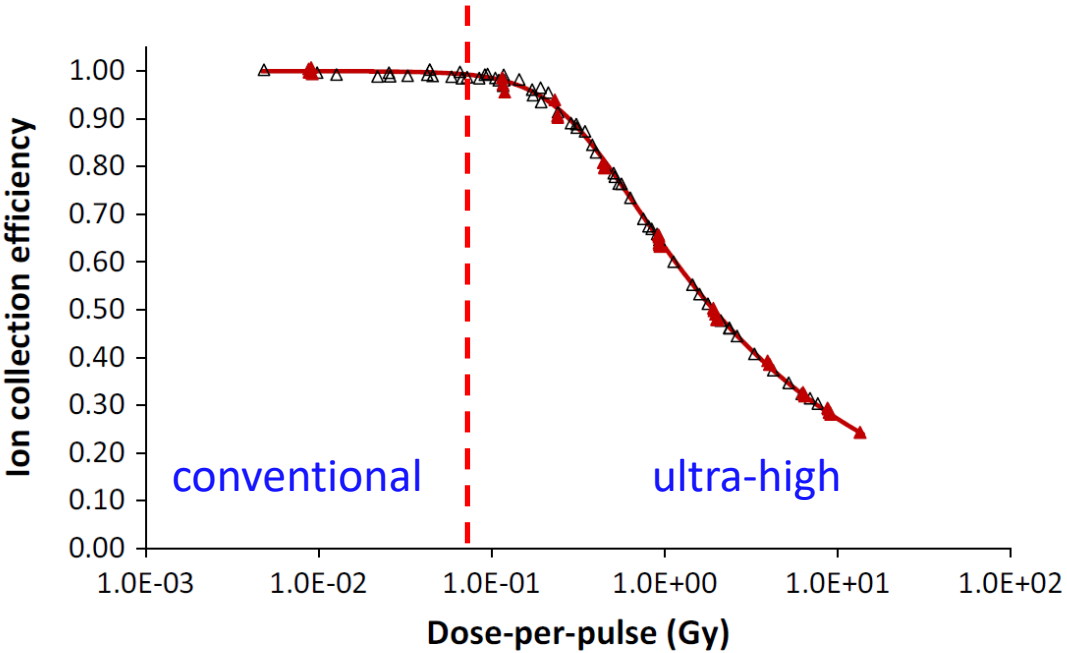
tools and methods established in dosimetry for conventional RT are not suitable for FLASH-RT

no active dosimeters
→ uneconomic effort for clinical practice

no formalism (Codes of Practice) for reference dosimetry

no corresponding primary standard

metrological challenges at FLASH



typical behavior of ordinary ionization chambers

tools and methods established in dosimetry for conventional RT are not suitable for FLASH-RT

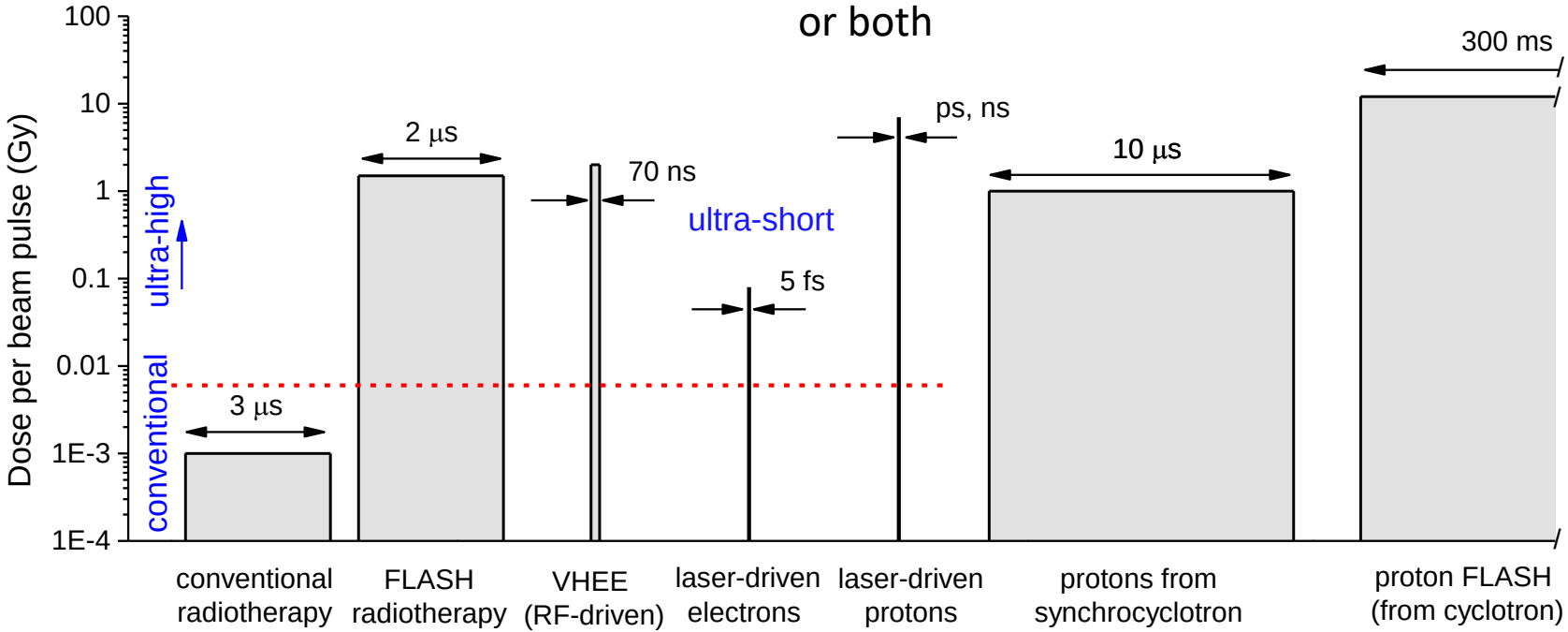
→ hampers
- preclinical studies
- translation to clinical practice
- safe operation

Petersson et al., Med Phys 44 (2017) 1157
DOI: 10.1002/mp.12111

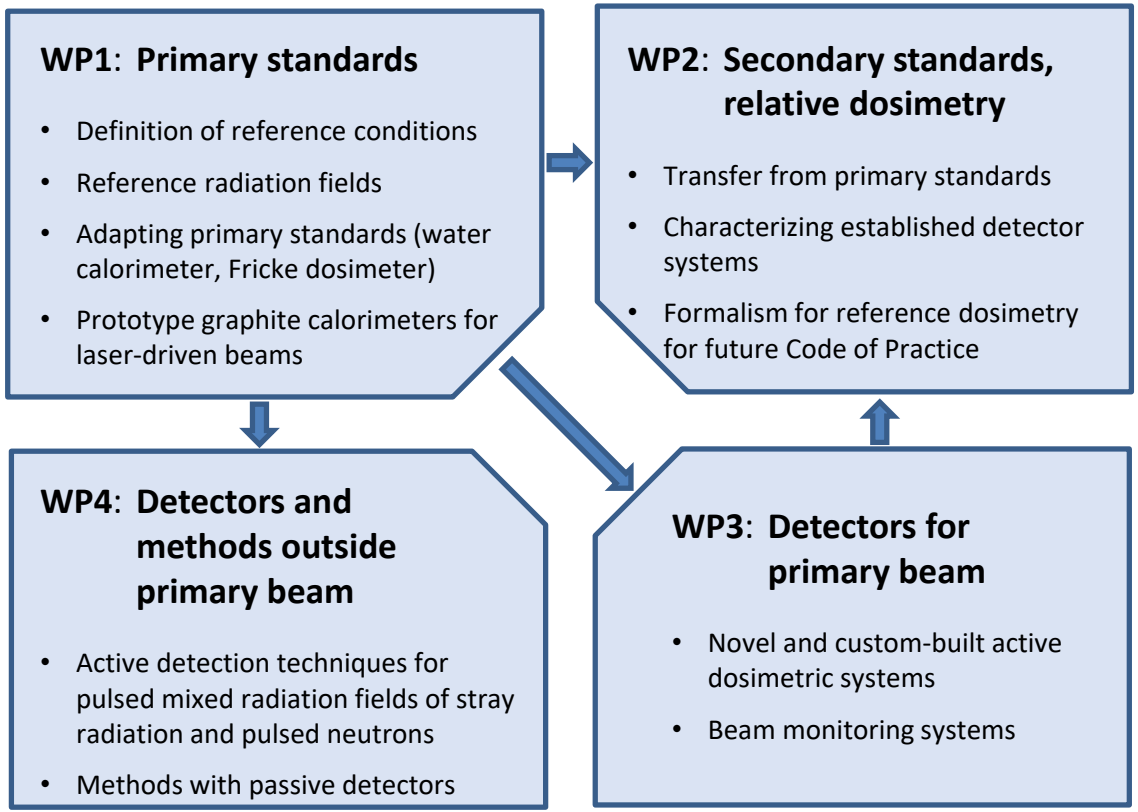
particle beams with ultra-high pulse dose rates

electrons, protons

ultra-high dose per pulse,
ultra-short pulse duration
or both



UHDpulse Work Package Structure



UHDpulse JRP protocol

4 technical WPs subdivided in

14 Tasks subdivided in 95 Activities

	facility (CHUV, Curie) in the frame of the planned comparisons of A3.2.5.	
A3.2.3 M20	*Designing custom-built detectors for FLASH proton beams* USC, CSIC, Curie, PTW and HZDR will evaluate some potentially suitable custom-built detectors for absorbed dose to water measurements in clinical FLASH proton beams. USC and CSIC will investigate the response of silicon microdosimeters already available at CSIC in FLASH proton beams available at Curie or HZDR. Curie will test a new developed prototype parallel-plate monitor chamber in the FLASH proton beam at Curie. PTW will test new developed ionization chambers in UHPDR proton beams at PTB and at Curie or HZDR. This activity also provides input to A1.2.11 and A1.3.7.	**USC**, CSIC, Curie, HZDR, PTW, PTB
A3.2.4 M30	*Improving custom-built detectors* Based on the results of A3.2.2 and A3.2.3, non-commercial detectors will be optimised for FLASH irradiation and re-evaluated.	**CSIC**, USC, ADVACAM, CMI, FZU, UJF

example for an Activity

8 technical Deliverables

4 (A2.3.6)	D8	Validated dosimetry protocol (Code of Practice) for traceable absorbed dose measurement in ultra-high pulse dose rate electron beams under reference conditions	Validated Code of Practice document	**PTB**, METAS, CHUV, Curie	Aug 2022 (M36)

example for a Deliverable

UHDpulse consortium

5 National Metrology Institutes
leading in the field of dosimetry

2 academic hospitals
pioneers in FLASH-RT

3 universities
experts in detector development
pioneer in laser-driven beams

3 national research institutes
pioneer in detector development
pioneer in laser-driven beams
dosimetry expert

1 European research institute
laser-driven beam research

2 companies
expert in detector development

NMI's		Irradiation facility provider		Radiation detector developer	
PTB	WP6 (coordin.)	CHUV Centre hospitalier universitaire vaudois	WP3	ADVACAM Imaging the Unseen	WP4
NPL National Physical Laboratory	WP1	institutCurie		CSIC CNM	
METAS	WP2	eli beamlines		USC Universidade de Santiago de Compostela	
CMI Czech Metrology Institute	WP5 (impact)	Nuclear Physics Institute of the CAS public research institution		Politecnico Milano 1863	
Central Office of Measures		Queen's University Belfast		PTW The Dosimetry Company	
		HZDR Helmholtz Zentrum Dresden Rossendorf		Carl von Ossietzky Universität Oldenburg	

UHDpulse consortium

PTB - Physikalisch-Technische Bundesanstalt (Braunschweig, DE) 01

contact:
Andreas Schüller,
Ralf-Peter Kapsch

skills

- accelerator for FLASH electron beams
- ultra-high dose rate proton beam
- water calorimeter primary standard
- alanine dosimetry system

tasks

- development and provision of electron FLASH reference fields
- testing and calibrations of dosimetric equipment for FLASH-RT

PTB's research electron accelerator (0.5 – 50 MeV)

UHDpulse consortium

PTB - Physikalisch-Technische Bundesanstalt (Braunschweig, DE) 01

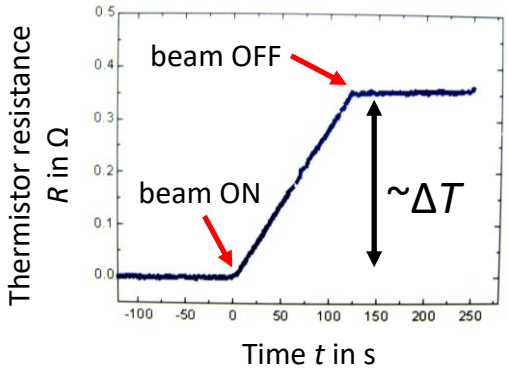
Primary standard of the unit “Gray” for absorbed dose to water

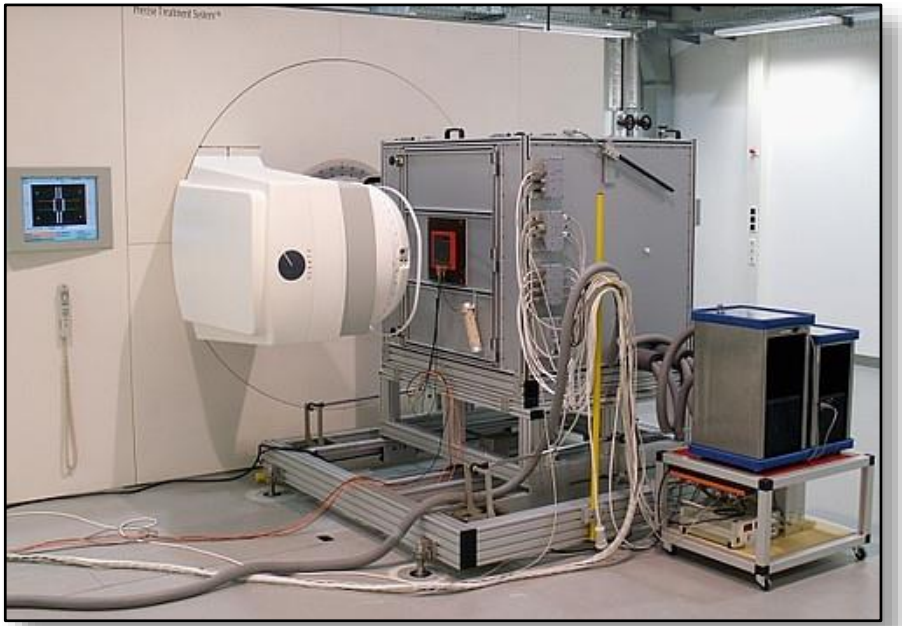
$D_w = d\varepsilon/dm$ 1 Gy = 1 J/Kg

ε: energy deposit in medium, *m:* mass of medium

$D_w = c_p \cdot \Delta T \cdot \Pi k_i$ ΔT = 0.24 mK/Gy

c_p: Heat capacity of water, ΔT: Radiation-induced temperature rise
Πk_i: corrections for perturbations (heat transport, etc.)



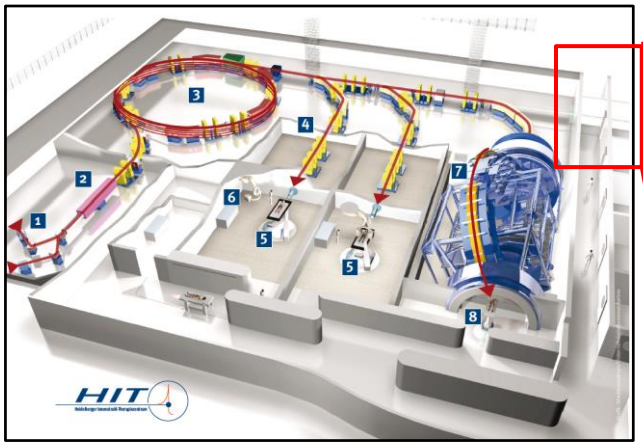


PTB water calorimeter in front of a medical accelerator

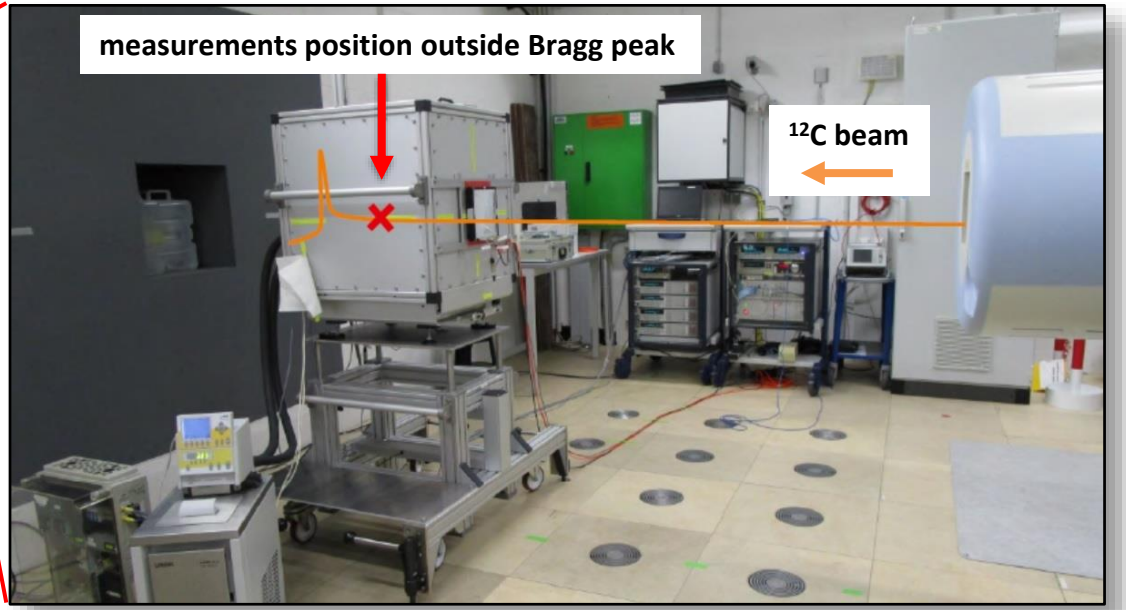
UHDpulse consortium

PTB - Physikalisch-Technische Bundesanstalt (Braunschweig, DE)

Dosimetry of hadron beams



Heidelberg Ion-Beam Therapy Center



Water calorimetry in a 430 MeV/u ^{12}C beam

Result: reduction of measurement uncertainty by factor 3

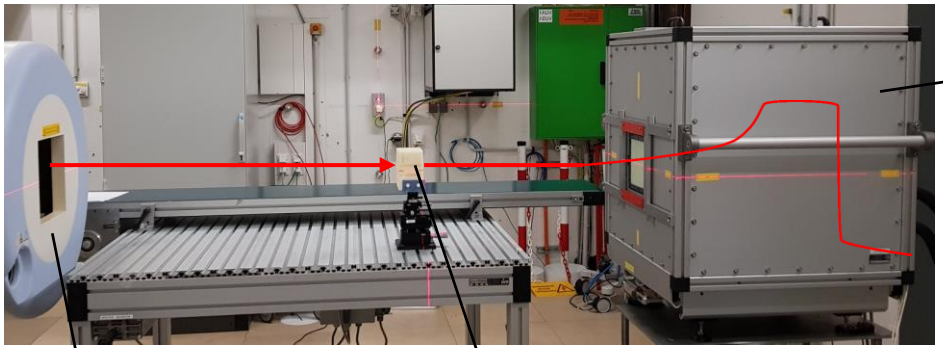
Osinga-Blättermann et al. Phys.Med.Biol.62 (2017) 2033
doi: 10.1088/1361-6560/aa5bac

UHDpulse consortium

PTB - Physikalisch-Technische Bundesanstalt (Braunschweig, DE) 01

Water Calorimetry in the SOBP of a ^{12}C-Beam

2D Raster Scanning ⟶ Modulation in depth ⟶ SOBP

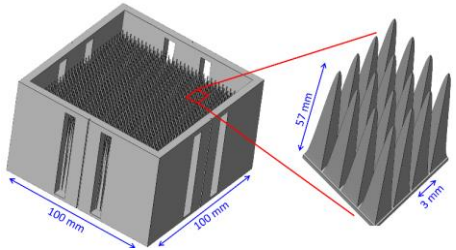


Portable PTB
Water Calorimeter

1,5 Gy
↓
~ 0,37 mK

Beam Nozzle HIT

Range Modulator:



Kim Holm et al., "2D range modulator for high-precision water calorimetry in scanned carbon-ion beams", submitted

UHDpulse consortium

NPL - National Physical Laboratory (Teddington, UK) 05

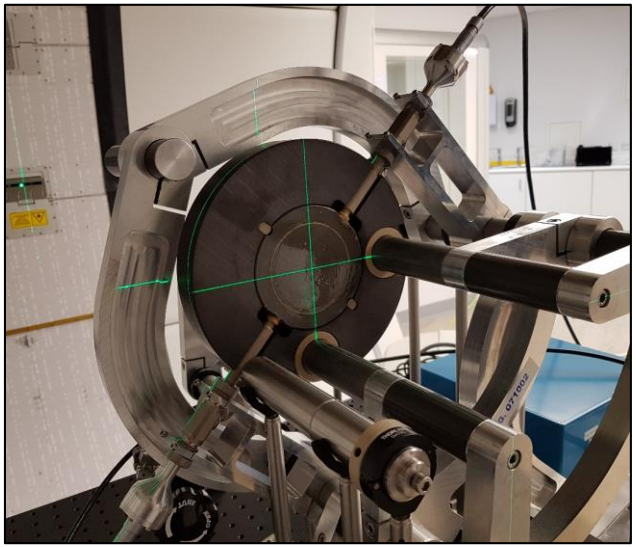
contact:
Anna Subiel,
Francesco Romano

skills

- primary standard for proton therapy
- primary standard for neutron radiation

tasks

- absolute dosimetry for FLASH proton beams
- dosimetry for laser-driven beams
- dosimetry for VHEE radiotherapy



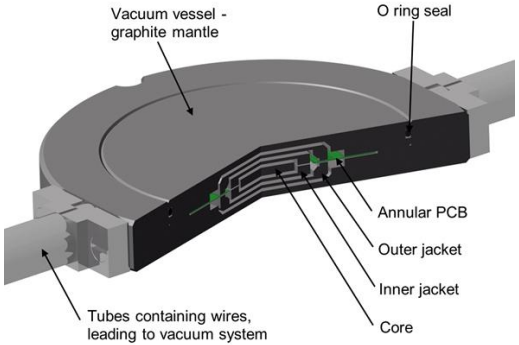
NPL's portable graphite calorimeter

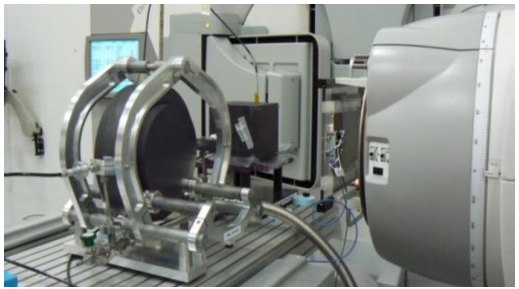
UHDpulse consortium

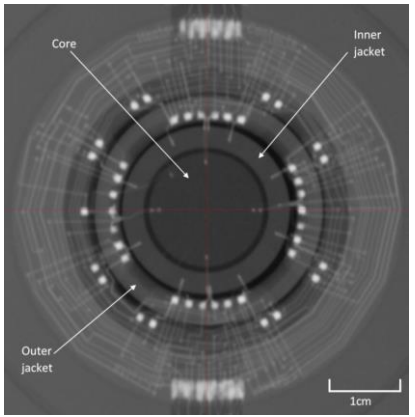
NPL - National Physical Laboratory (Teddington, UK)

IPEM Working Party for a new Code of Practice for Proton Dosimetry

- for calibration of proton beams both for scattered and scanned beam delivery
- new **primary standard graphite calorimeter** to be used in the end-user facility





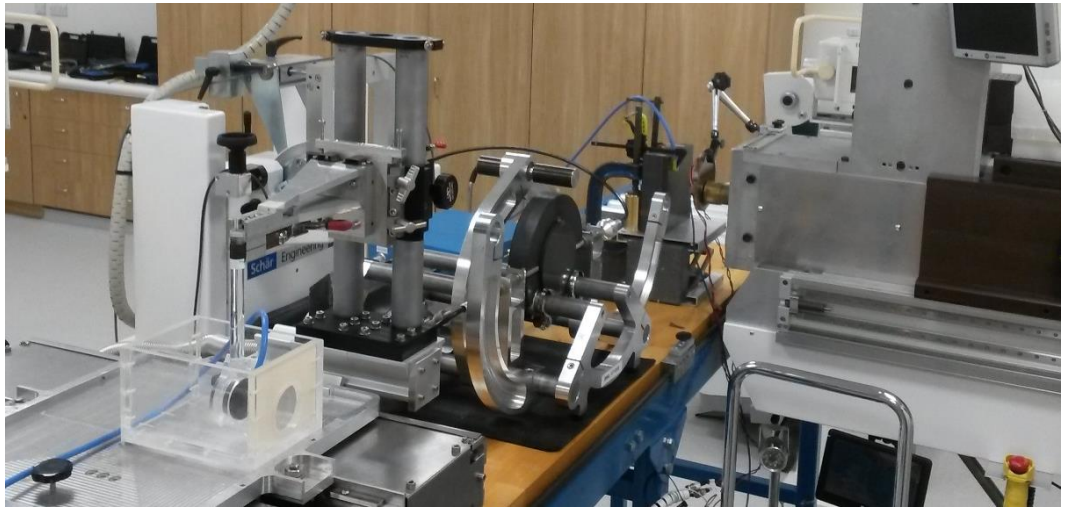


UHDpulse consortium

NPL - National Physical Laboratory (Teddington, UK)

IPEM Working Party for a new Code of Practice for Proton Dosimetry

- for calibration of proton beams both for scattered and scanned beam delivery
- new **primary standard graphite calorimeter** to be used in the end-user facility



experimental setup at Clatterbridge (CCC)

UHDpulse consortium

METAS - Swiss Federal Office of Metrology and Accreditation (Bern, CH)

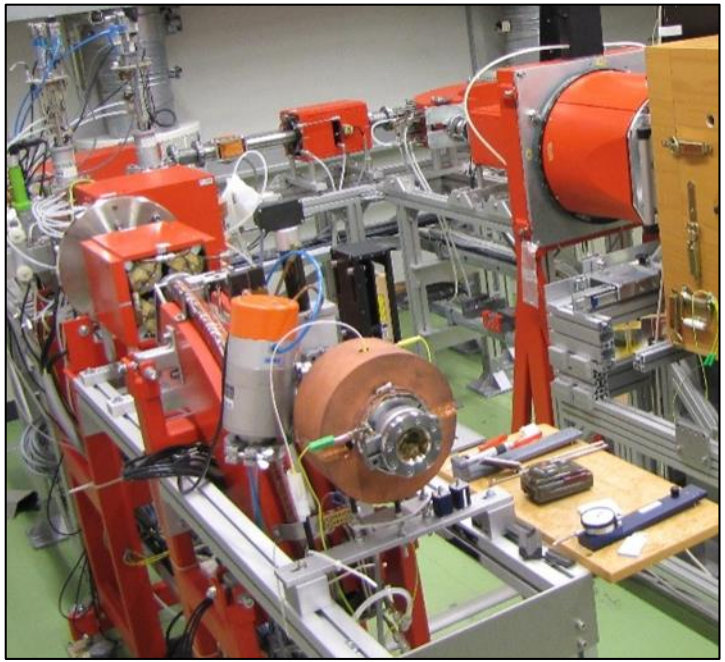
contact:
Christian Kottler

skills

- chemical dosimetry (Fricke dosimetry)
- accelerator for FLASH electron beams

tasks

- Fricke dosimetry as FLASH primary dosimetry technique
- provide reference FLASH electron beams



microtron electron accelerator beam line

Scanditronix 22 MeV microtron

UHDpulse consortium

CMI - Czech metrology institute (Prague, CZ) 02

CZECH METROLOGY INSTITUTE

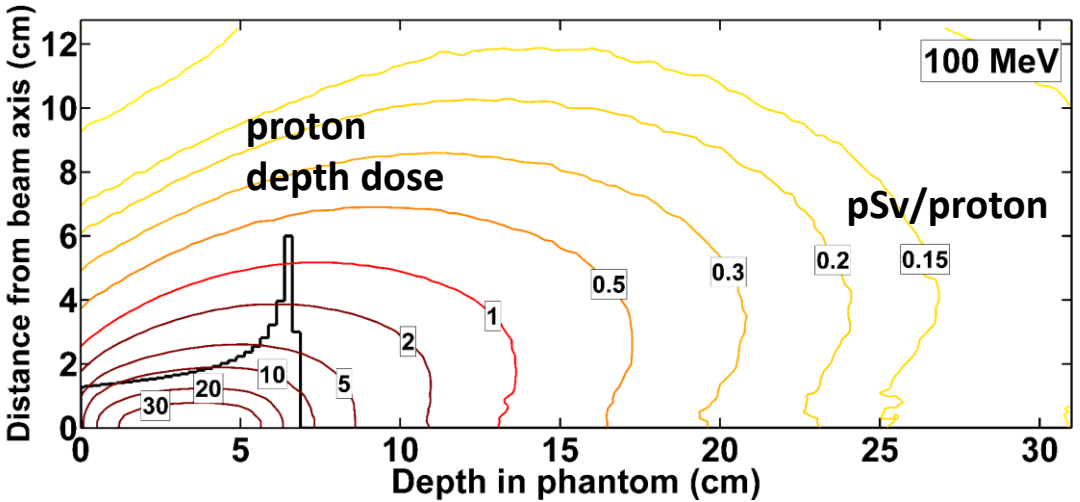
contact:
Jaroslav Solc

skills

- Monte Carlo simulations
- detector data analysis

tasks

- evaluation and interpretation of TimePix-3 data
- characterization of stray radiation



MC Simulation of secondary neutron dose equivalent from 100 MeV proton pencil beam in water phantom

UHDpulse consortium

GUM - Central Office of Measures (Warsaw, PL) 03

Central Office of Measures

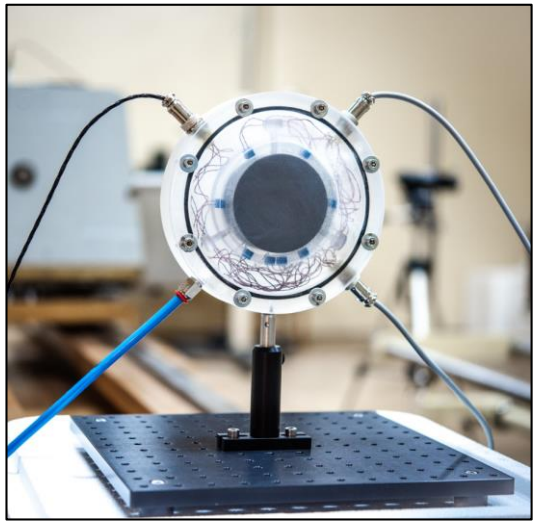
contact:
Adrian Knyziak

skills

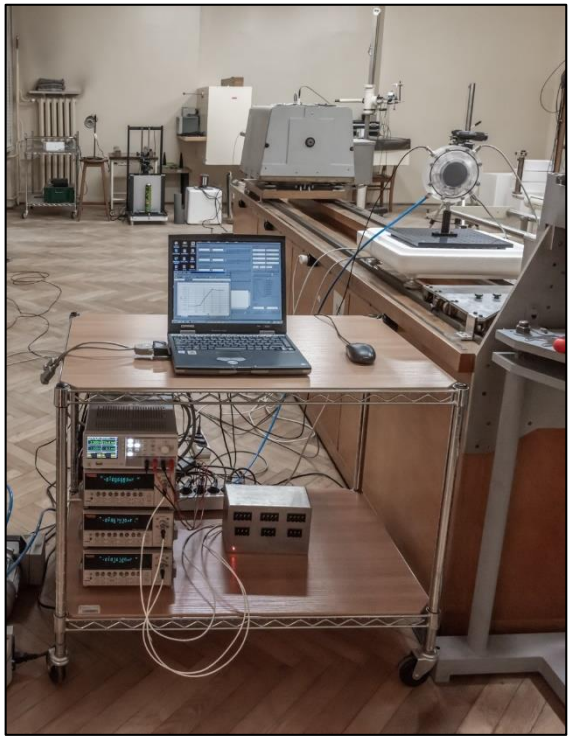
- developing primary standards
- Monte Carlo simulation

tasks

- measurements of FLASH electron and proton beams
- MC sim. of FLASH beams



GUM's portable graphite calorimeter

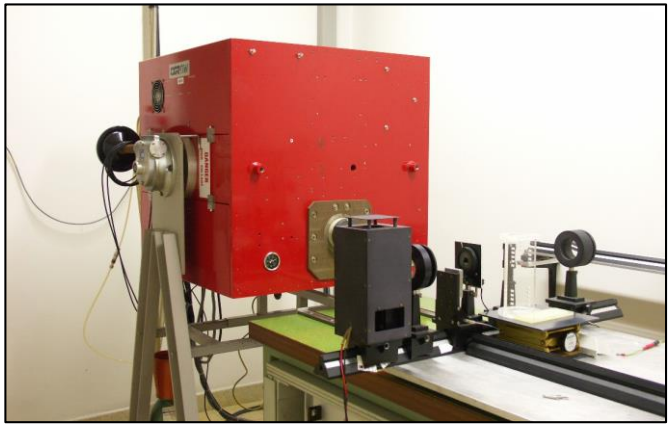


UHDpulse consortium

Institut Curie (Orsay, FR)

institutCurie

contact:
Charles Fouillade



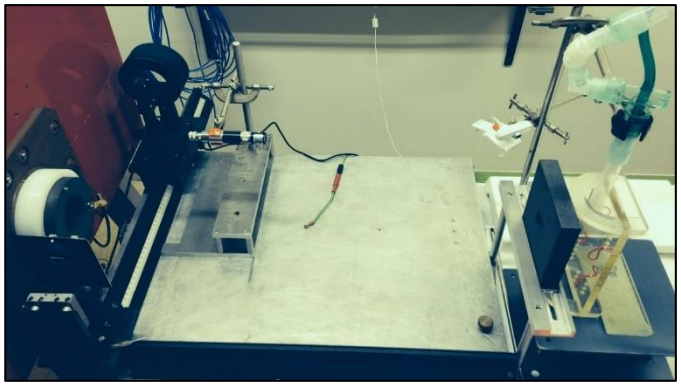
FLASH electron accelerator

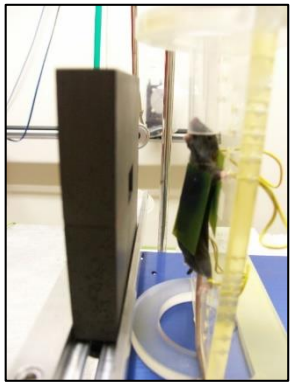
skills

- leading center for cancer treatment research
- pioneers of FLASH radiotherapy

tasks

- access to a FLASH electron beam
- establish a code of practice





setup for FLASH irradiation of mice

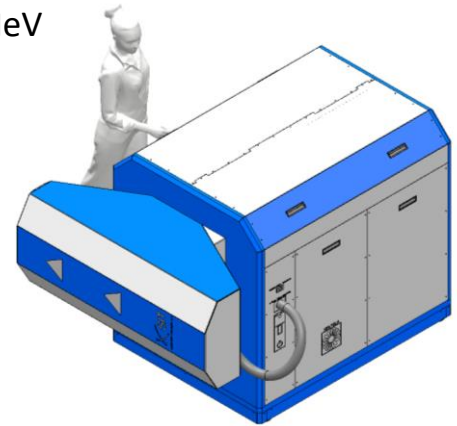
UHDpulse consortium

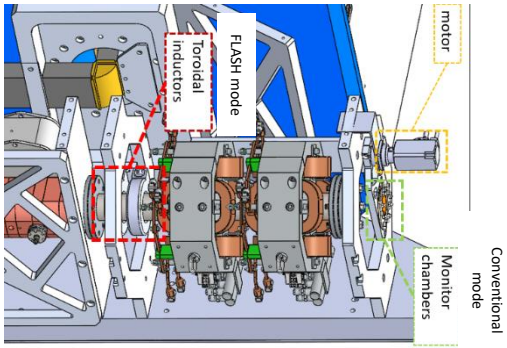
Institut Curie (Orsay, FR) 09

New electron FLASH accelerator

ELECTRONFLASH4000 linear accelerator developed by SIT & institutCurie

- D_p : 0,25 – **40 Gy/pulse**
- Dose rate: 0.1 – 1000 Gy/s over 10 x 10 cm, – **4000 Gy/s** over 4 x 4 cm
- Radiation field: 4 x 4 cm to 10 x 10 cm @ SSD 100 cm
- 2 nominal energies: 5 and 7 MeV
- PRF: 10 – 350 Hz





Real-time beam monitoring based on beam electrical measurement in vacuum

A. Leggieri, *Real-Time Beam Monitor for Charged Particle Medical Accelerators*, IEEE Transactions on Nuclear Science, 2016

UHDpulse consortium

Orsay Proton Therapy Center (Orsay, FR)

institutCurie

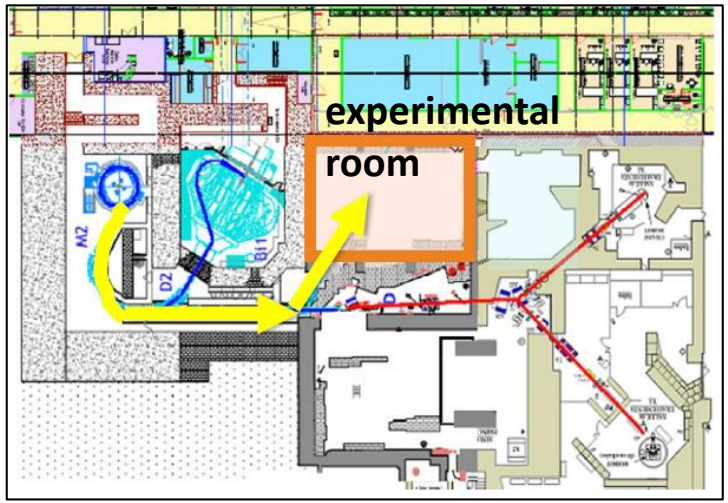
contact:
Ludovic De Marzi

skills

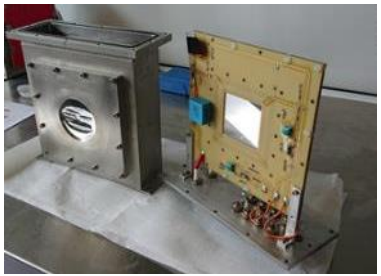
- leading center for cancer treatment research
- pioneers of FLASH radiotherapy

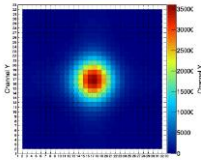
tasks

- access to a FLASH proton beam
- new transmission monitor chamber for FLASH proton beam in collaboration with LPC Caen



CPO Layout in 2019





DOSION detector, adapted for FLASH
LPC Caen (JM Fontbonne, S Salvador)

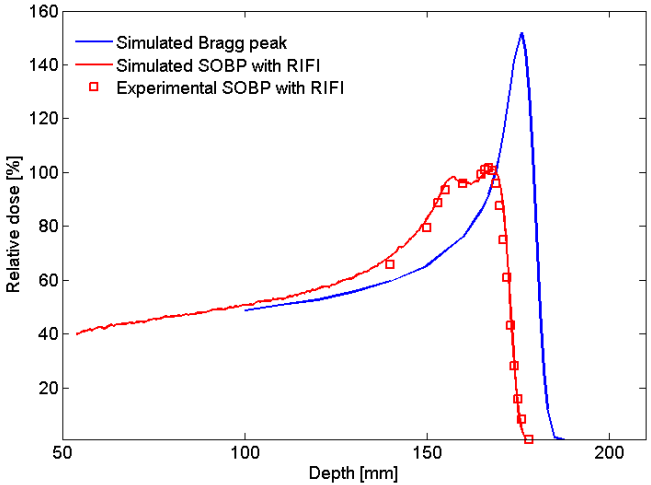
UHDpulse consortium

Orsay Proton Therapy Center (Orsay, FR) 09

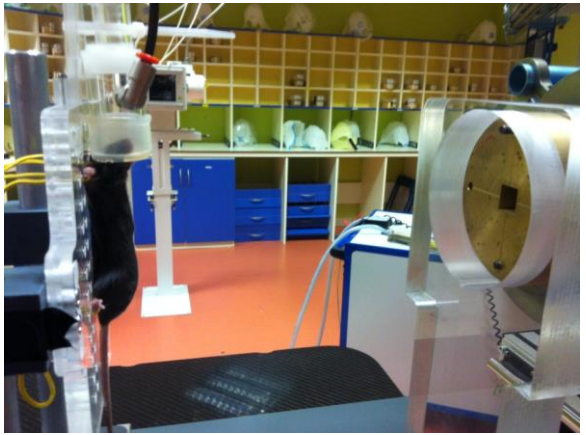
1st FLASH setup: with a scattered beam

80 Gy/s for 15x15 mm^2 field

ridge filter



SOBP 160 MeV



Lung experiments: CONV vs. FLASH

Patriarca et al. Int J Radiation Oncol Biol Phys, 102 (2018) 619
doi: 10.1016/j.ijrobp.2018.06.403

UHDpulse consortium

Orsay Proton Therapy Center (Orsay, FR)

2nd FLASH setup: with a scanned beam

Scanned pencil beam
220 Gy/s, 15x15 mm^2 field

collaboration between Institut Curie and IBA initiated in 2018

Beamline modifications :
- full Monte-Carlo modeling
- fast scanning
- modif. Electrometers
- adapted beam transport

CPO Gantry room – 230 MeV

UHDpulse consortium

CHUV - Lausanne university hospital (Lausanne, CH) 07

Centre hospitalier universitaire vaudois

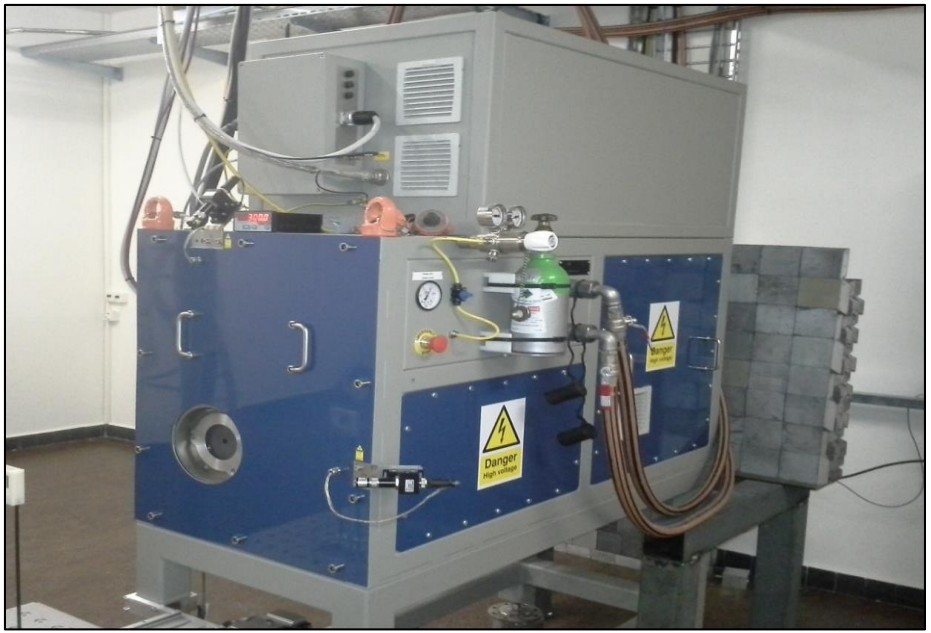
contact:
Claude Bailat

skills

- FLASH radiotherapy pioneering work
- clinical dosimetry for FLASH-RT

tasks

- access to a FLASH-RT facility as well as dosimetry tools and methods
- establish a code of practice

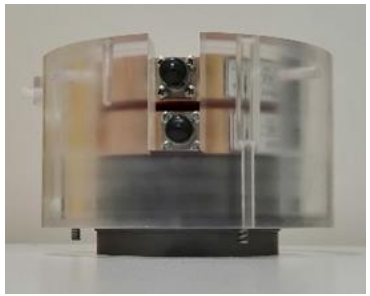


clinical FLASH electron accelerator

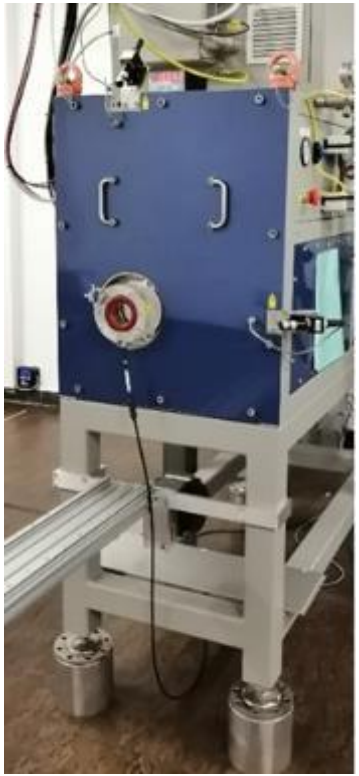
UHDpulse consortium

CHUV - Lausanne university hospital (Lausanne, CH) 07

New inductive pulse charge monitors

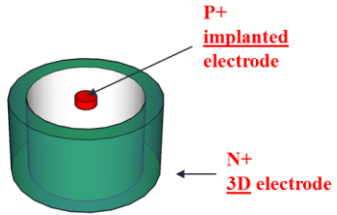


Current transformer (Bergoz ACCT)



UHDpulse consortium

Instituto de Microelectrónica de Barcelona (Barcelona, ES)



CSIC — Consejo Superior de Investigaciones Científicas
CNM — Centre Nacional de Microelectrónica — IMB

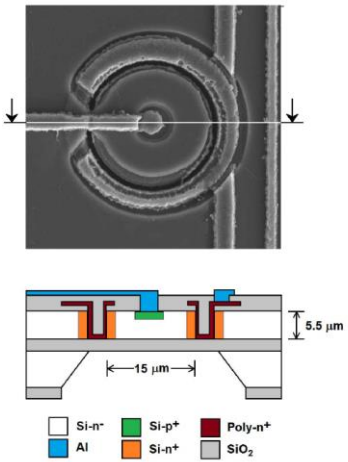
contact:
Celeste Fleta,
Giulio Pellegrini

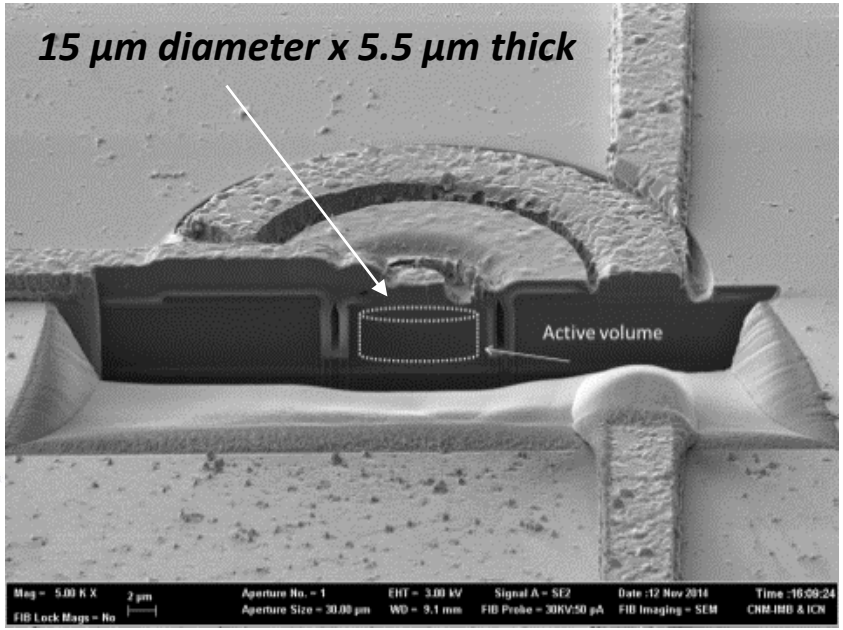
skills

- production of Si radiation detectors
- leads the development of Si detectors for CERN

tasks

- detectors for dosimetry for FLASH proton and electron beams





Si microsensor with ion collection time < 1 ns

Prieto-Pena et al. IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 66, NO. 7, JULY 2019

UHDpulse consortium

University of Santiago de Compostela (ES)

contact:
Prof. Faustino Gómez

skills

- expert in R&D on dosimetry techniques

tasks

- provide a prototype active dosimeter for FLASH-RT
- characterization of detectors in proton and electron FLASH beams

Microdosimeter with electronics assembly from USC

Radiation Physics Laboratory (accredited SSDL)

UHDpulse consortium

Nuclear Physics Institute (Prague, CZ)

Nuclear Physics Institute of the CAS
public research institution

contact:
Iva Ambrozova

skills

- electron accelerator for FLASH beams
- expert for dosimetry

tasks

- providing access
- will utilize passive detectors (TLD)

MT25 - The Prague microtron

UHDpulse consortium

ADVACAM s.r.o. (Prague, CZ)

ADVACAM
Imaging the Unseen

contact
Cristina Oancea,
Jan Jakubek

skills

- hybrid semiconductor sensor manufacturing
- commercialises Timepix technology
- particle tracking, spectrometry, physics

tasks

- Experimental work using Timepix-3 pixel detectors
- Characterisation of for FLASH stray radiation and primary beams (protons and electrons)

MiniPIX TimePIX3

AdvaPIX TimePIX3

Single chip Timepix 3 pixel detectors (each pixel records deposited energy)

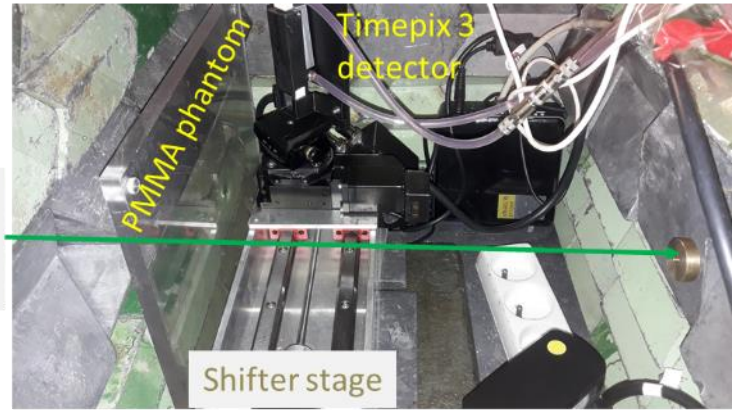
Prototype FLEX MiniPIX TimePIX3

UHDpulse consortium

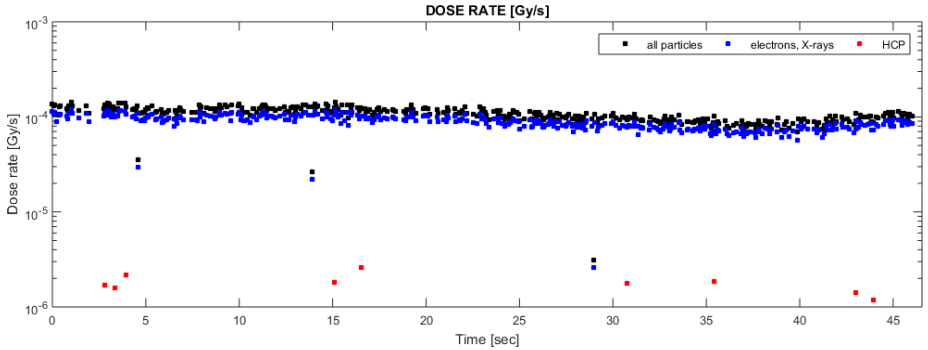
ADVACAM s.r.o. (Prague, CZ) 06

Measurements of pulsed stray radiation of FLASH electrons

23 MeV electrons
mean dose rate: 2Gy/s - 44Gy/s
intra-pulse dose rate: 1.4 kG/s – 30 kGy/s



20 Gy/s →
scattered (10 cm from beam, 1 cm from PMMA phantom) ~ 10E-5 Gy/s



UHDpulse consortium

ELI Beamlines (Prague, CZ)

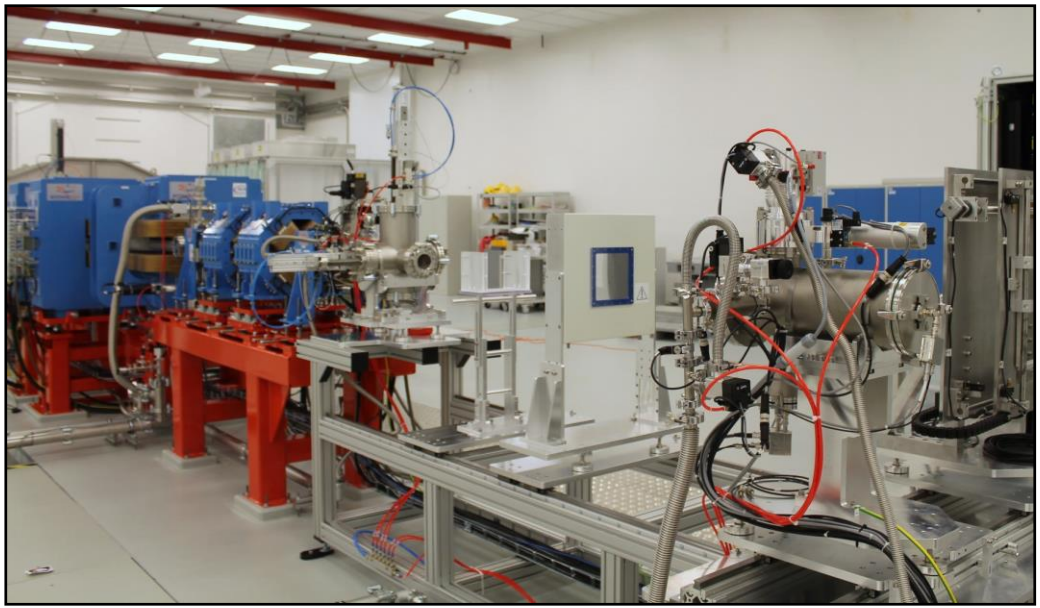
contact:
Veronika Olsovcova,
Roberto Versaci

skills

- new laser research facility
- beamline for medical applications of laser-driven beam

tasks

- providing access
- Monte Carlo simulation
- will utilize passive detectors



ELIMAIA
(ELI Multidisciplinary Applications of laser-Ion Acceleration)

UHDpulse consortium

Queen's University Belfast (Belfast, UK) 12

QUEEN'S UNIVERSITY BELFAST

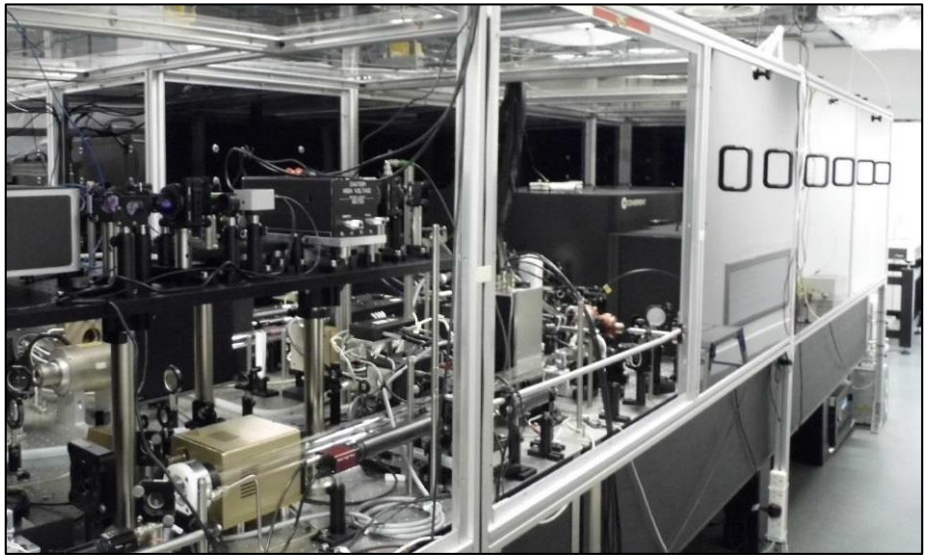
contact:
Prof. Marco Borghesi

skills

- expertise in laser-driven ion acceleration
- laser facility for ion beam acceleration (TARANIS)

tasks

- provision of laser-driven protons
- dosimetry for laser-driven beams



TARANIS laser for ion acceleration

UHDpulse consortium

Politecnico di Milano (Milano, IT) 11

POLITECNICO MILANO 1863

contact
Prof. Marco Caresana

skills

- expert for radiation detection and radioprotection

tasks

- adapt a detector system for pulsed neutron stray radiation

LUPIN neutron detector at HIMAC, Osaka

UHDpulse consortium

HZDR - Helmholtz-Zentrum Dresden-Rossendorf (Dresden, DE)

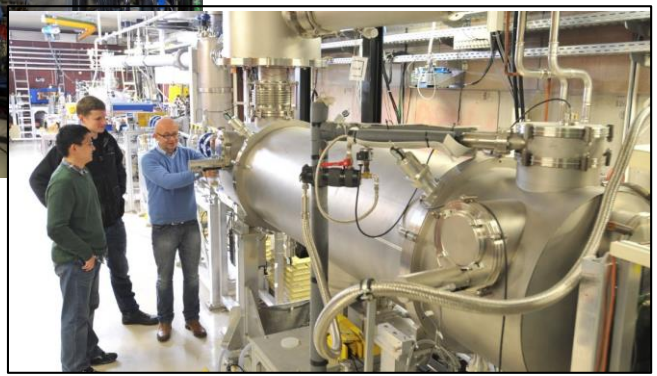
contact:
Jörg Pawelke

skills

- FLASH electron beam (ELBE)
- laser-driven protons and electrons (DRACO)
- pulsed neutron beam (nELBE)
- FLASH protons (medical cyclotron, OncoRay)

tasks

- providing access and dosimetry expertise

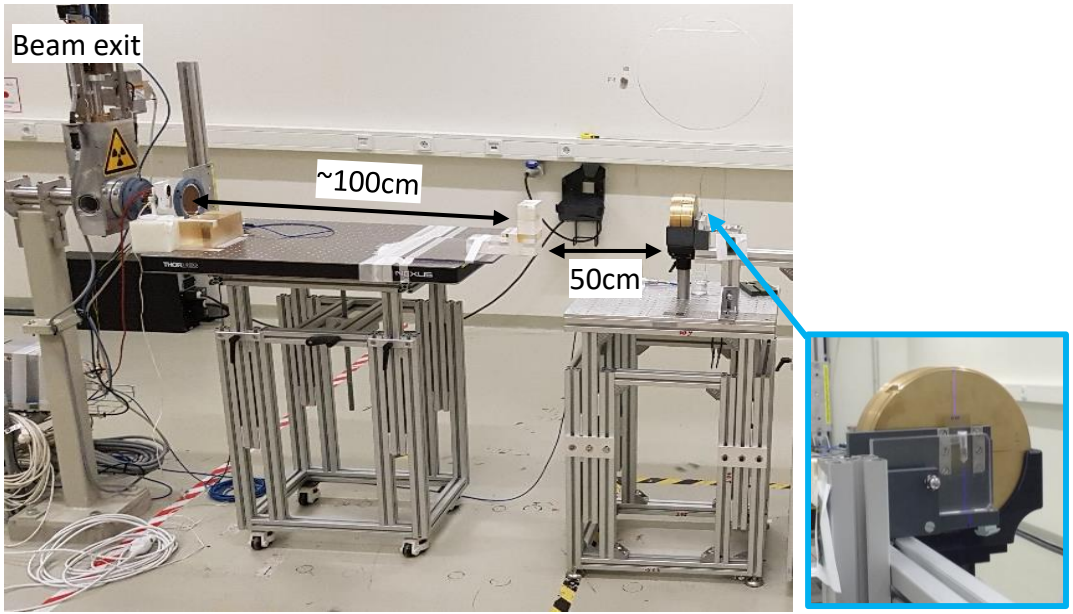


ELBE Center for High Power Radiation Sources
(Electron Linac for beams with high Brilliance and low Emittance, Petawatt laser)

UHDpulse consortium

HZDR - Helmholtz-Zentrum Dresden-Rossendorf (Dresden, DE)

Proton-FLASH @ University Proton Therapy Dresden



	Conv.	FLASH
Proton energy / field size	224 MeV / Ø 6.5 mm	
Beam current	0.3 nA	95 nA
Pulse frequency / length	106 MHz / 2 ns	
Mean dose rate	**5 Gy/min**	**100 Gy/s**
Pulse dose rate	0.4 Gy/s	10^3 Gy/s

Model:

- Wildtype zebrafish embryo, 24 hours old
- Endpoints: survival, pericardial edema, spine curvature, length

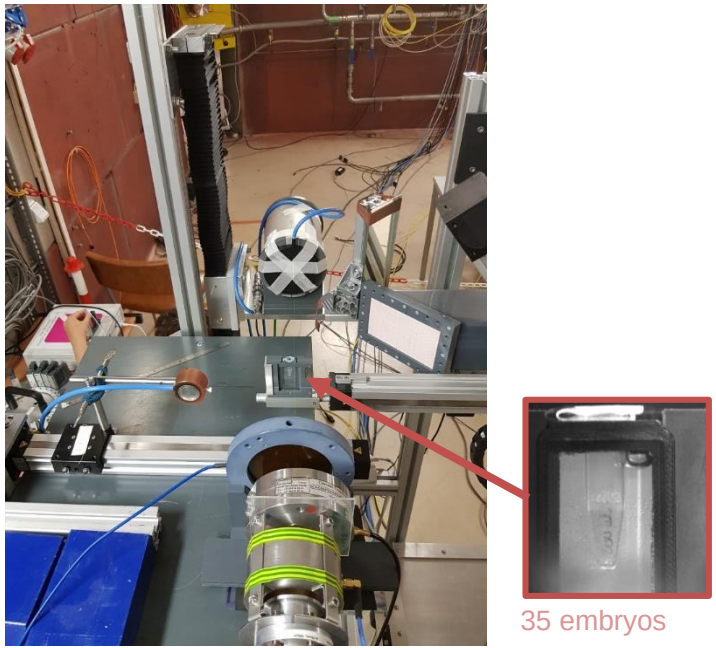
⇒ No significant influence of dose rate at all

E. Beyreuther et al. Radiother Oncol 139 (2019) 46–50

UHDpulse consortium

HZDR - Helmholtz-Zentrum Dresden-Rossendorf (Dresden, DE) 15

Electron-FLASH @ ELBE accelerator



35 embryos

	Conv.	FLASH
Electron energy / field size	20 MeV / Ø 6.5 mm	
Pulse frequency	13 MHz	
Irradiation time	4 min	111 µs
Pulse dose rate	1.9 x 10^3 Gy/s	2.0 x 10^9 Gy/s
Mean dose rate	**7 Gy/min**	**2.6 x 10^5 Gy/s**

- Model and endpoints like for proton experiment
- 3 independent experiment replications

⇒ Significant protecting effect of FLASH electron irradiation revealed for all endpoints

E. Beyreuther, J. Pawelke, publication in preparation

UHDpulse consortium

PTW The Dosimetry Company (Freiburg, DE)

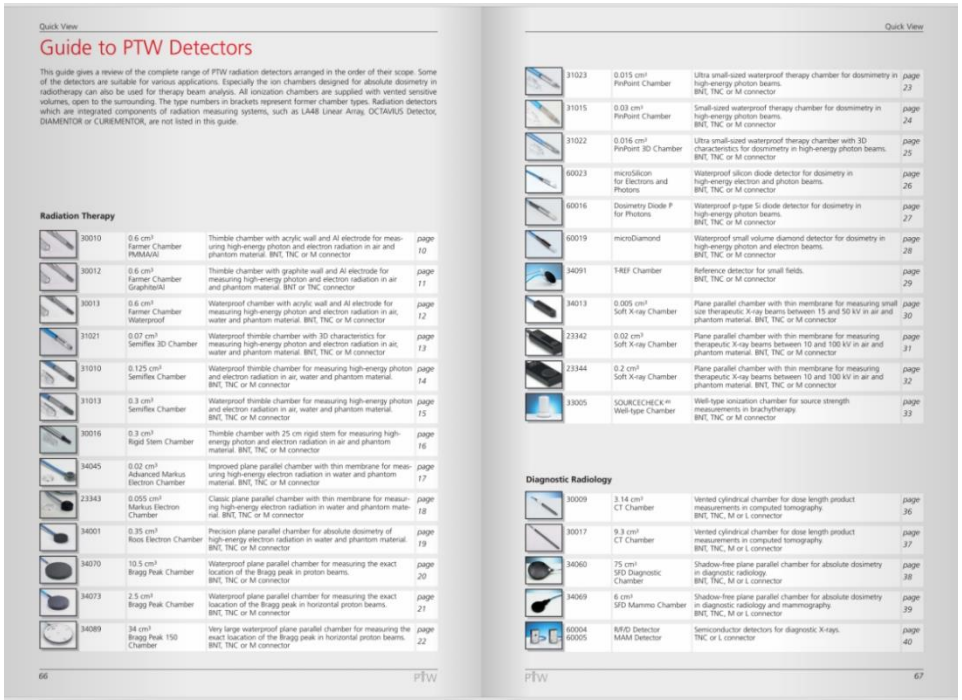
contact:
Daniela Poppinga,
Rafael Kranzer

skills

- designs, develops, manufactures dosimetry equipment for radiation therapy

tasks

- development of a new detector (ionization chamber) for FLASH proton and electron beams



Quick View

Guide to PTW Detectors

This guide gives a review of the complete range of PTW radiation detectors arranged in the order of their scope. Some of the detectors are suitable for various applications. Especially the ion chambers designed for absolute dosimetry in radiotherapy can also be used for therapy beam analysis. All ionization chambers are supplied with vented sensitive volumes, open to the surrounding. The type numbers in brackets represent former chamber types. Radiation detectors which are integrated components of radiation measuring systems, such as LA48 Linear Array, OCTAVIUS Detector, DIAMENTOR or CURIEMENTOR, are not listed in this guide.

Radiation Therapy

30010	0.6 cm³ Farmer Chamber PMMA/Al	Thimble chamber with acrylic wall and Al electrode for measuring high-energy photon and electron radiation in air and phantom material. BNT, TNC or M connector	page 10
30012	0.6 cm³ Farmer Chamber Graphite/Al	Thimble chamber with graphite wall and Al electrode for measuring high-energy photon and electron radiation in air and phantom material. BNT or TNC connector	page 11
30013	0.6 cm³ Farmer Chamber Waterproof	Waterproof chamber with acrylic wall and Al electrode for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 12
31021	0.07 cm³ Semiflex 3D Chamber	Waterproof thimble chamber with 3D characteristics for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 13
31010	0.125 cm³ Semiflex Chamber	Waterproof thimble chamber for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 14
31013	0.3 cm³ Semiflex Chamber	Waterproof thimble chamber for measuring high-energy photon and electron radiation in air, water and phantom material. BNT, TNC or M connector	page 15
30016	0.3 cm³ Rigid Stem Chamber	Thimble chamber with 25 cm rigid stem for measuring high-energy photon and electron radiation in air and phantom material. BNT, TNC or M connector	page 16
34045	0.02 cm³ Advanced Markus Electron Chamber	Improved plane parallel chamber with thin membrane for measuring high-energy electron radiation in water and phantom material. BNT, TNC or M connector	page 17
23343	0.055 cm³ Markus Electron Chamber	Classic plane parallel chamber with thin membrane for measuring high-energy electron radiation in water and phantom material. BNT, TNC or M connector	page 18
34001	0.35 cm³ Roos Electron Chamber	Precision plane parallel chamber for absolute dosimetry of high-energy electron radiation in water and phantom material. BNT, TNC or M connector	page 19
34070	10.5 cm³ Bragg Peak Chamber	Waterproof plane parallel chamber for measuring the exact location of the Bragg peak in proton beams. BNT, TNC or M connector	page 20
34073	2.5 cm³ Bragg Peak Chamber	Waterproof plane parallel chamber for measuring the exact location of the Bragg peak in horizontal proton beams. BNT, TNC or M connector	page 21
34089	34 cm³ Bragg Peak 150 Chamber	Very large waterproof plane parallel chamber for measuring the exact location of the Bragg peak in horizontal proton beams. BNT, TNC or M connector	page 22

66 PTW

Quick View

31023	0.015 cm³ PinPoint Chamber	Ultra small-sized waterproof therapy chamber for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 23
31015	0.03 cm³ PinPoint Chamber	Small-sized waterproof therapy chamber for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 24
31022	0.016 cm³ PinPoint 3D Chamber	Ultra small-sized waterproof therapy chamber with 3D characteristics for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 25
60023	microSilicon for Electrons and Photons	Waterproof silicon diode detector for dosimetry in high-energy electron and photon beams. BNT, TNC or M connector	page 26
60016	Dosimetry Diode P for Photons	Waterproof p-type Si diode detector for dosimetry in high-energy photon beams. BNT, TNC or M connector	page 27
60019	microDiamond	Waterproof small volume diamond detector for dosimetry in high-energy photon and electron beams. BNT, TNC or M connector	page 28
34091	T-REF Chamber	Reference detector for small fields. BNT, TNC or M connector	page 29
34013	0.005 cm³ Soft X-ray Chamber	Plane parallel chamber with thin membrane for measuring small size therapeutic X-ray beams between 15 and 50 kV in air and phantom material. BNT, TNC or M connector	page 30
23342	0.02 cm³ Soft X-ray Chamber	Plane parallel chamber with thin membrane for measuring therapeutic X-ray beams between 10 and 100 kV in air and phantom material. BNT, TNC or M connector	page 31
23344	0.2 cm³ Soft X-ray Chamber	Plane parallel chamber with thin membrane for measuring therapeutic X-ray beams between 10 and 100 kV in air and phantom material. BNT, TNC or M connector	page 32
33005	SOURCECHECK[HDR] Well-type Chamber	Well-type ionization chamber for source strength measurements in brachytherapy. BNT, TNC or M connector	page 33

Diagnostic Radiology

30009	3.14 cm³ CT Chamber	Vented cylindrical chamber for dose length product measurements in computed tomography. BNT, TNC, M or L connector	page 36
30017	9.3 cm³ CT Chamber	Vented cylindrical chamber for dose length product measurements in computed tomography. BNT, TNC, M or L connector	page 37
34060	75 cm³ SFD Diagnostic Chamber	Shadow-free plane parallel chamber for absolute dosimetry in diagnostic radiology. BNT, TNC, M or L connector	page 38
34069	6 cm³ SFD Mammo Chamber	Shadow-free plane parallel chamber for absolute dosimetry in diagnostic radiology and mammography. BNT, TNC, M or L connector	page 39
60004 60005	R/D Detector MAM Detector	Semiconductor detectors for diagnostic X-rays. TNC or L connector	page 40

PTW 67

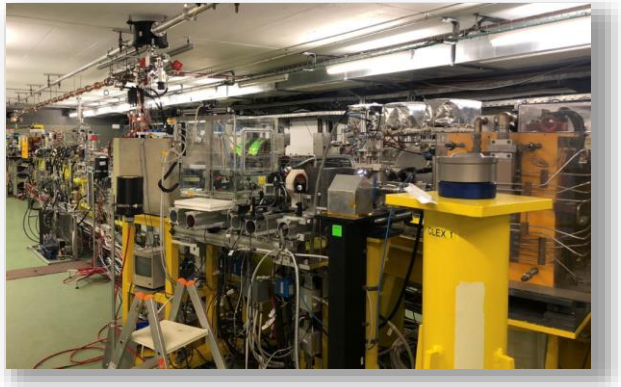
Variety of PTW's detectors for radiotherapy

UHDpulse consortium

University of Oldenburg (Oldenburg, DE)

CARL VON OSSIETZKY UNIVERSITÄT OLDENBURG

contact:
Björn Poppe,
Hui Khee Looe



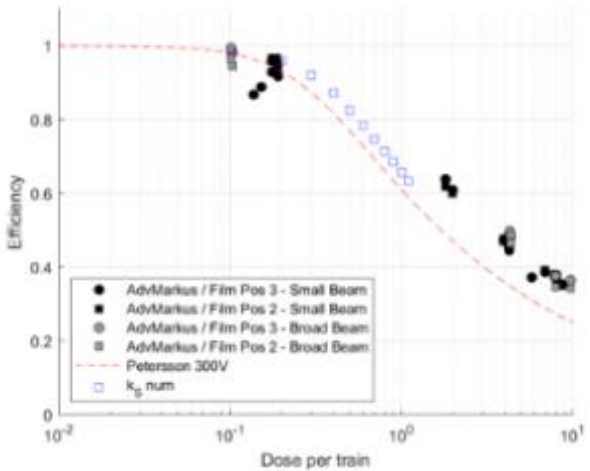
FLASH electrons from CLEAR @ CERN

skills

- Radiotherapy
- Radiation Detection
- Modelling
- Protons (in collaboration with KVI/university of Groningen)

tasks

- development of a new detector (ionization chamber) for FLASH proton and electron beams



UHDpulse consortium

Internal Funded Partners

PTB

CZECH METROLOGY INSTITUTE

Central Office of Measures

METAS

NPL National Physical Laboratory

External Funded Partners

ADVACAM Imaging the Unseen

CSIC Consejo Superior de Investigaciones Científicas

USC Universidade de Santiago de Compostela

FZU Fyzikální ústav Akademie věd České republiky

institut Curie

QUEEN'S UNIVERSITY BELFAST

POLITECNICO MILANO 1863

CHUV

eli beamlines

Ústav jaderné fyziky AV ČR veřejná výzkumná instituce

Unfunded Partners

HZDR Helmholtz Zentrum Dresden Rossendorf

PTW The Dosimetry Company

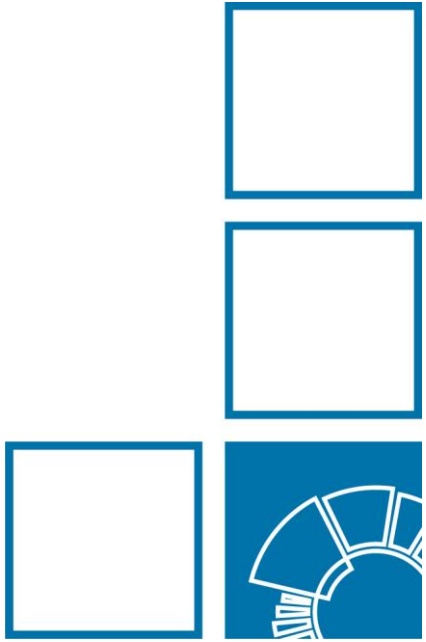
Collaborators

Carl von Ossietzky universität Oldenburg

Interested institutes that want to contribute to the goals of the project may join the consortium as **collaborator**

http://uhdpulse-empir.eu/

This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.



Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
Bundesallee 100
38116 Braunschweig

Dr. Andreas Schüller
Telefon: 0531 592-6209
E-Mail: andreas.schueller@ptb.de
www.ptb.de/MELAF

Stand: 02/2020