Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

EMPIR project UHDpulse
“Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates”

Andreas Schüller
Department 6.2 “Dosimetry for Radiation Therapy and Diagnostic Radiology”

International Conference on Medical Accelerators and Particle Therapy
4-6.9.19, CNA, Seville

EMPIR project UHDpulse

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

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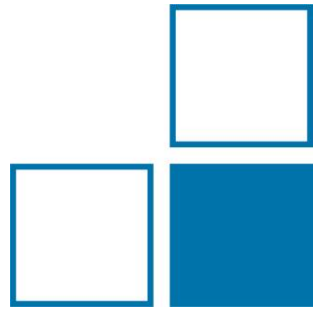


EMPIR project UHDpulse

EMPIR Call:	2018 / Health
Type:	Joint Research Project
Duration:	2019-2022
Start:	1. Sept. 2019
Funding:	2.1 M €
Coordinator:	Andreas Schüller (PTB)
Topic:	tools for traceable dose measurements for:

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

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 on a wide variety of joint research projects

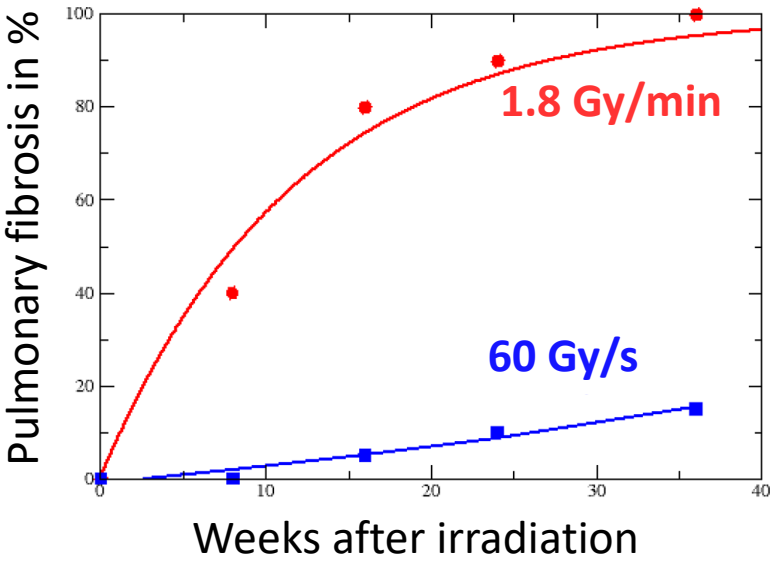
https://www.euramet.org/research-innovation/search-research-projects/details/project/metrology-for-advanced-radiotherapy-using-particle-beams-with-ultra-high-pulse-dose-rates/

FLASH radiotherapy

FLASH effect

institutCurie

thorax irradiation of mice (17 Gy)



ultra-high dose rate →

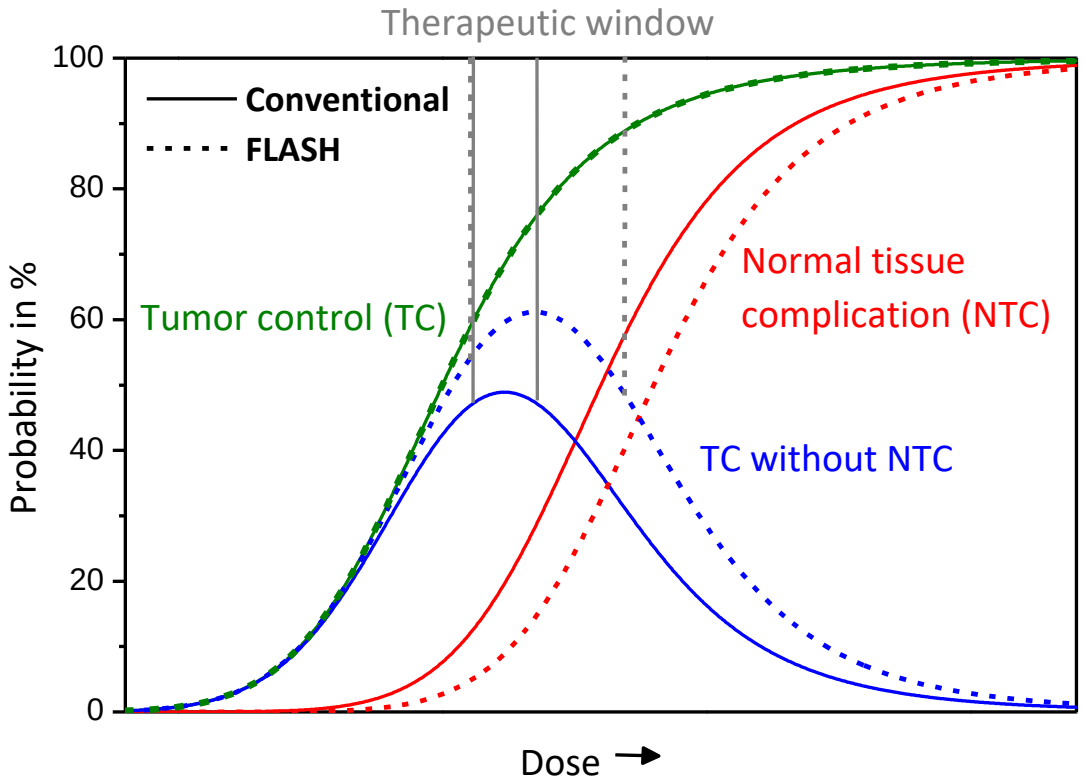
- reduction of the normal tissue complications
- maintains tumour control level

Favaudon et al., Sci Transl Med 6 (2014) 245ra93
DOI: 10.1126/scitranslmed.3008973

(Durante et al., Br J Radiol 91 (2018) 20170628)
DOI: 10. 1259/ bjr. 20170628

FLASH radiotherapy

FLASH effect



ultra-high dose rate →

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

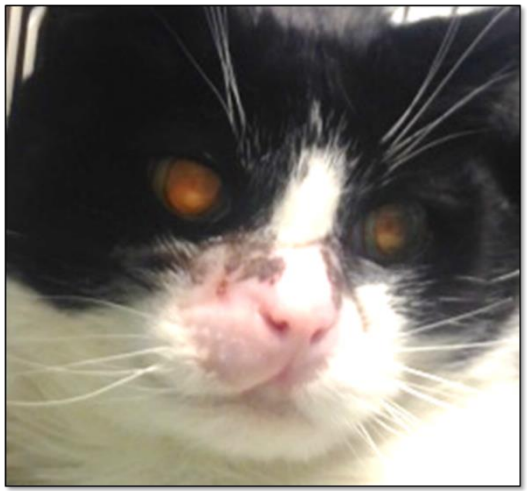
FLASH radiotherapy

Cat cancer patient trial

Centre hospitalier universitaire vaudois

before FLASH

7 month after FLASH



nasal carcinoma not eligible for surgery

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

FLASH radiotherapy

Reduced pig skin toxicity with FLASH-RT

Centre hospitalier universitaire vaudois

Irradiation with 22 - 34 Gy

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 us duration) in 90 ms with 1.5 Gy/pulse

Day 0

3 weeks

(max. of skin reactions)

5 months

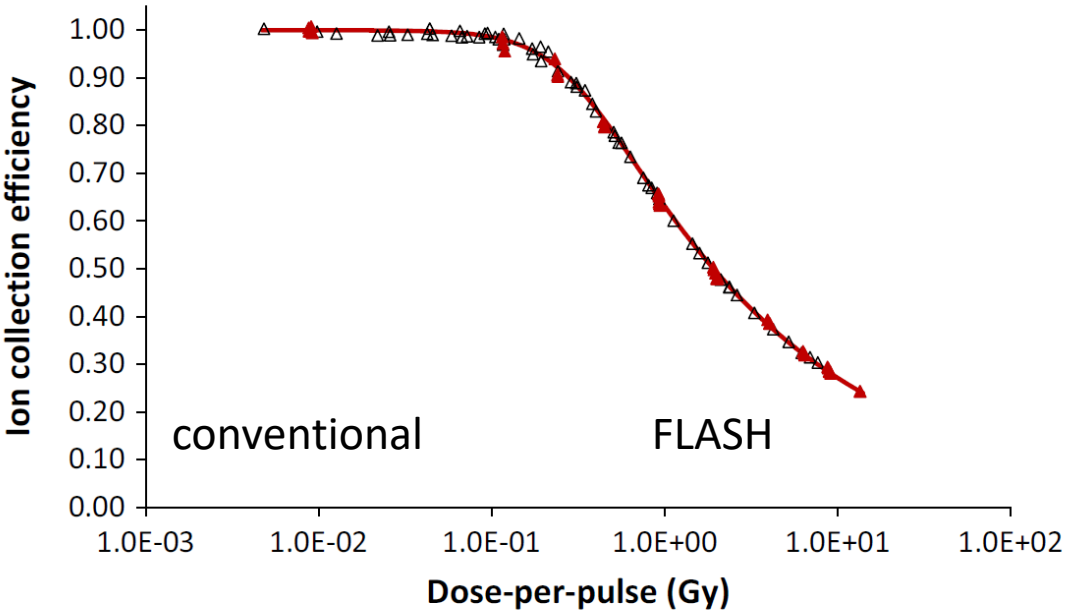
Bourhis et al., Radiother. Oncol. (2019)
DOI: 10.1016/j.radonc.2019.06.019

metrological challenges

	FLASH	conventional
dose per pulse	1 – 10 Gy	0.3 mGy
pulse width	1 -2 us	3 us
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

metrological challenges



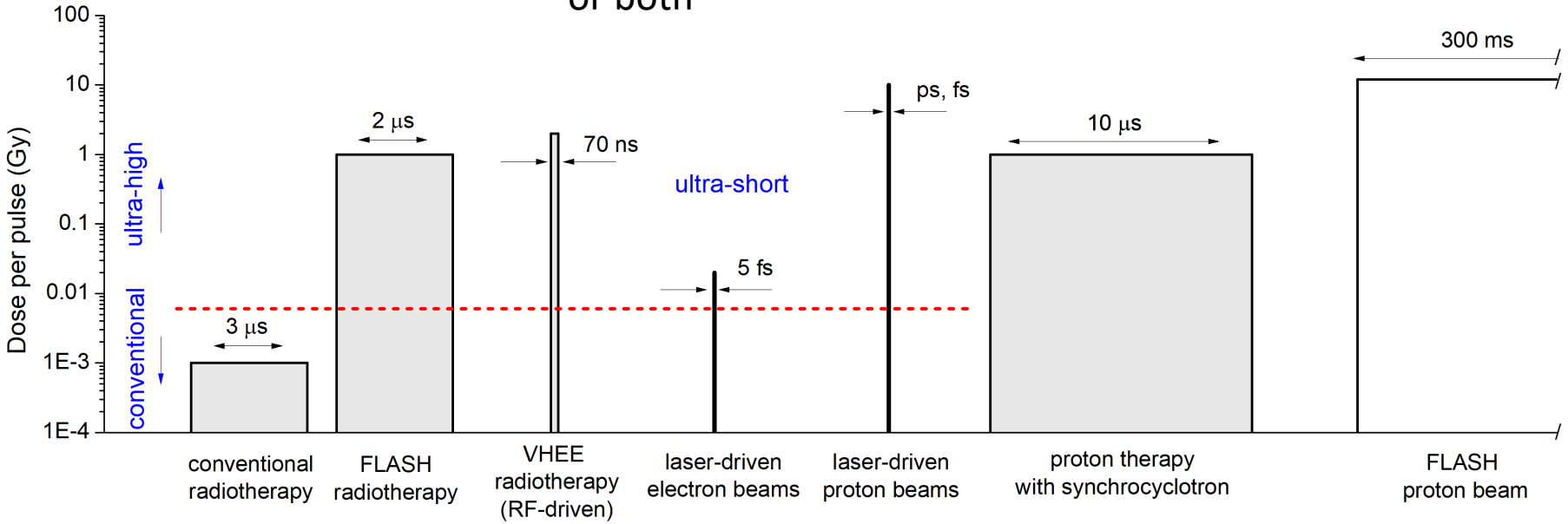
typical behavior of ordinary ionization chambers

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

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

beams with ultra-high pulse dose rates

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



EMPIR project 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

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin — WP6 (coordin.)

NPL National Physical Laboratory — WP1

METAS — WP2

CMI Czech Metrology Institute — WP5 (impact)

Central Office of Measures

Irradiation facility provider

CHUV Centre hospitalier universitaire vaudois — WP3

institutCurie

eli beamlines

Nuclear Physics Institute of the CAS public research institution

Queen's University Belfast

HZDR Helmholtz Zentrum Dresden Rossendorf

Radiation detector developer

ADVACAM Imaging the Unseen — WP4

CSIC Consejo Superior de Investigaciones Científicas · CNM Centre Nacional de Microelectrònica IMB

USC Universidade de Santiago de Compostela

Politecnico Milano 1863

PTW The Dosimetry Company

Contributions of the partners

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

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

Contributions of the partners

NPL - National Physical Laboratory (Teddington, UK) 05

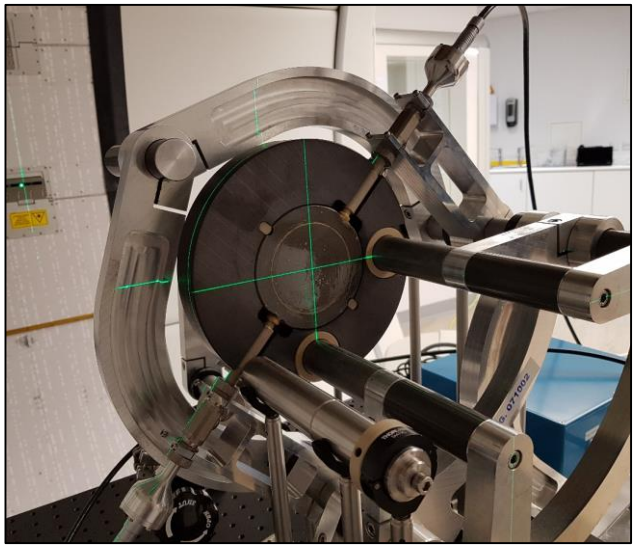
contact:
Anna Subiel,
Francesco Romano

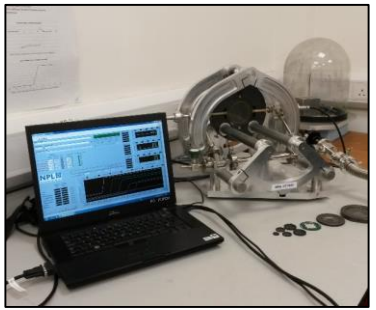
skills

- 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: primary standard for proton beam

Contributions of the partners

NPL - National Physical Laboratory (Teddington, UK) 05

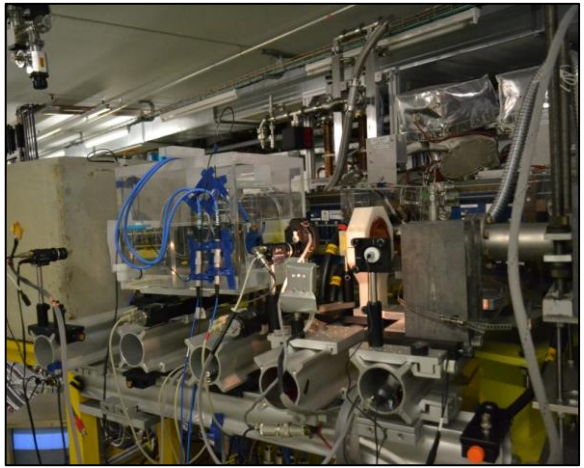
contact:
Anna Subiel,
Francesco Romano

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 setup for VHEE dosimetry at CERN's CLEAR (60 - 200 MeV Linac)

Contributions of the partners

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

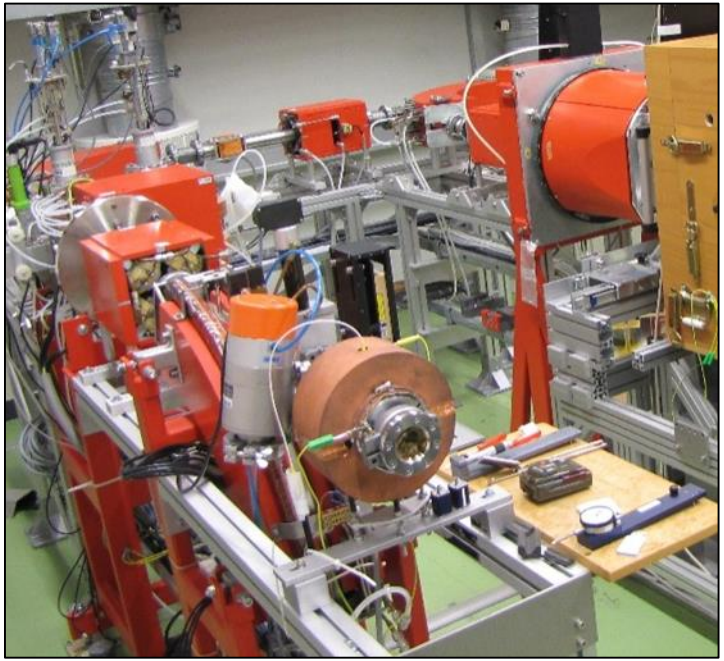
contact:
Christian Kottler

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

Contributions of the partners

CMI - Czech metrology institute (Prague, CZ) 02

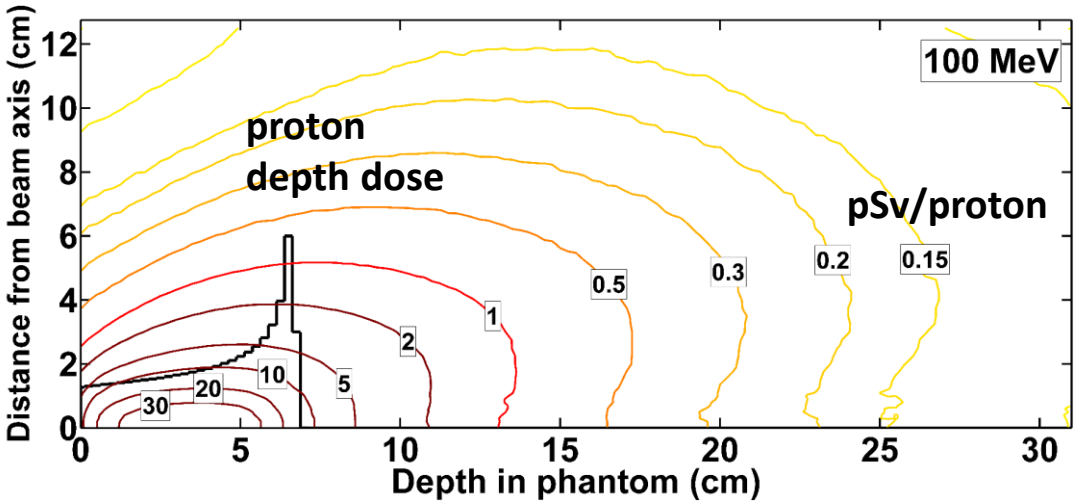
contact:
Jaroslav Solc

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

Contributions of the partners

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

Central Office of Measures

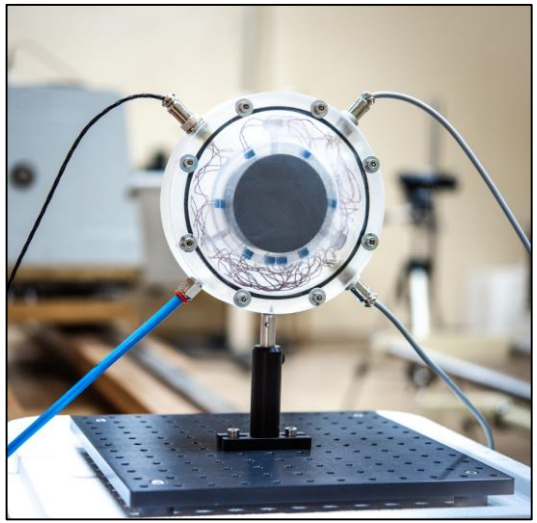
contact:
Adrian Knyziak

skills

- developing primary standards for absorbed dose to water
- Monte Carlo simulation

tasks

- measurements of FLASH electron and proton beams with graphite calorimetry
- MC sim. of FLASH beams



GUM's portable graphite calorimeter

Contributions of the partners

Institut Curie (Orsay, FR) 09

institutCurie

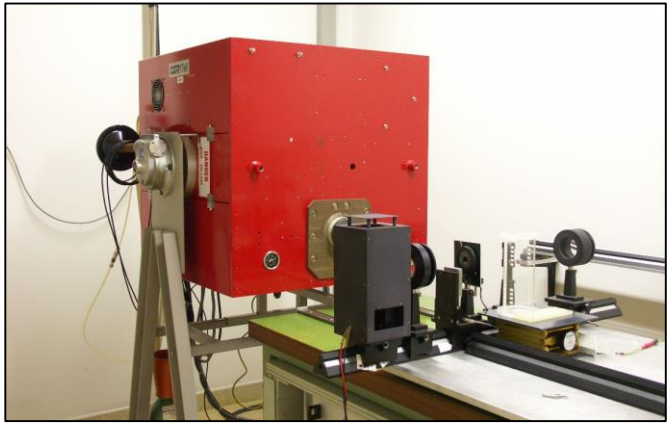
contact:
Charles Fouillade

skills

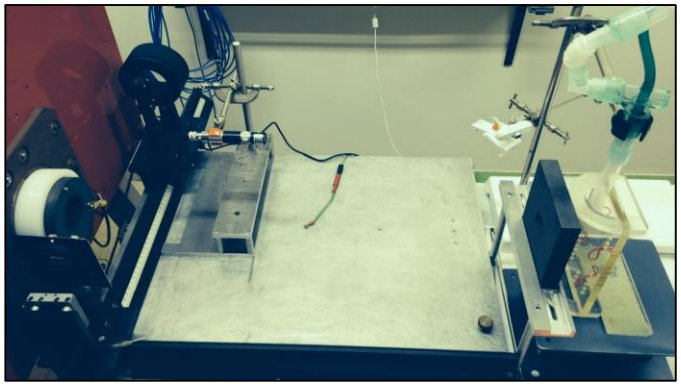
- leading center for cancer treatment research
- pioneers of FLASH radiotherapy

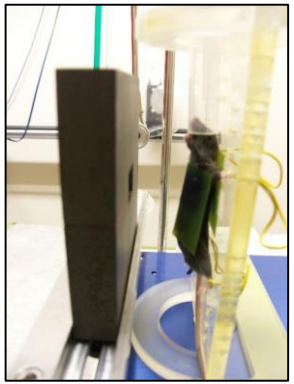
tasks

- access to a FLASH electron beam
- access to a FLASH proton beam
- new transmission monitor chamber for FLASH proton beam



FLASH electron accelerator





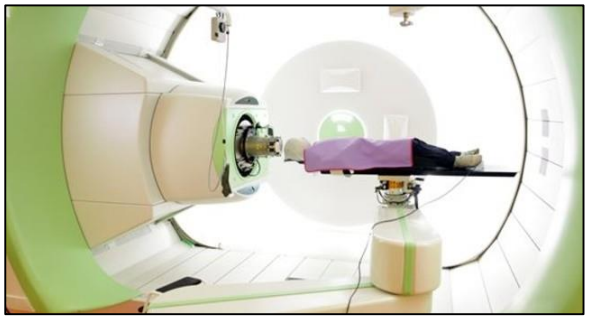
setup for FLASH irradiation of mice

Contributions of the partners

Orsay Proton Therapy Center (Orsay, FR) 09

institutCurie

contact:
Ludovic De Marzi

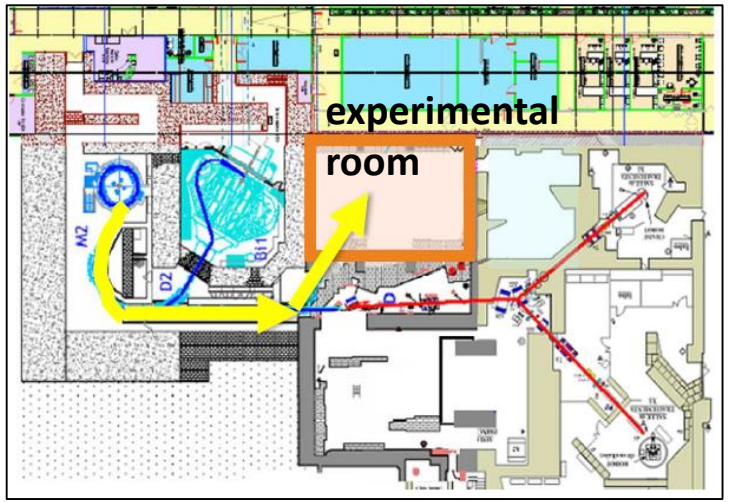


skills

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

tasks

- access to a FLASH electron beam
- access to a FLASH proton beam
- new transmission monitor chamber for FLASH proton beam



CPO Layout in 2019

Contributions of the partners

CHUV - Lausanne university hospital (Lausanne, CH) 07

Centre hospitalier universitaire vaudois

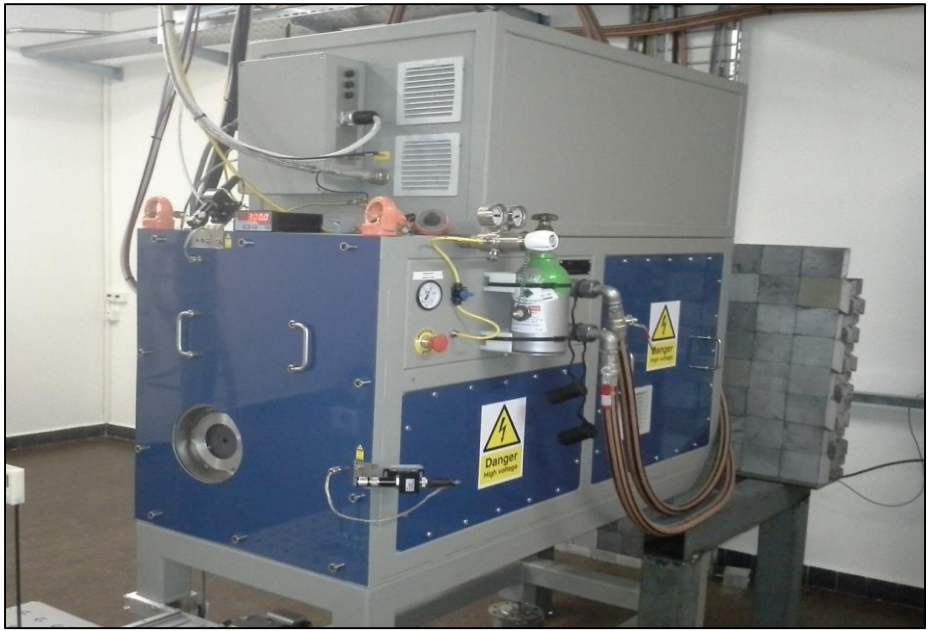
contact:
Claude Bailat

skills

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

tasks

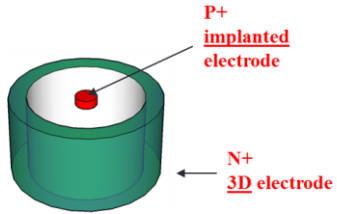
- access to a FLASH-RT facility as well as dosimetry tools and methods
- establish a code of practice



clinical FLASH electron accelerator

Contributions of the partners

Instituto de Microelectrónica de Barcelona (Barcelona, ES) 08



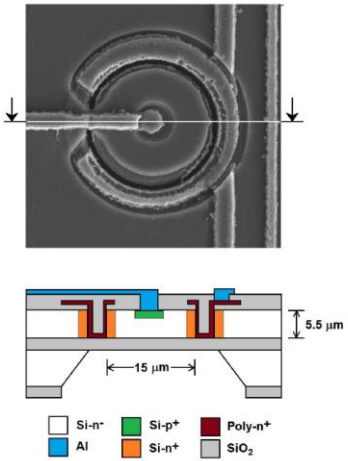
contact:
Celeste Fleta,
Giulio Pellegrini

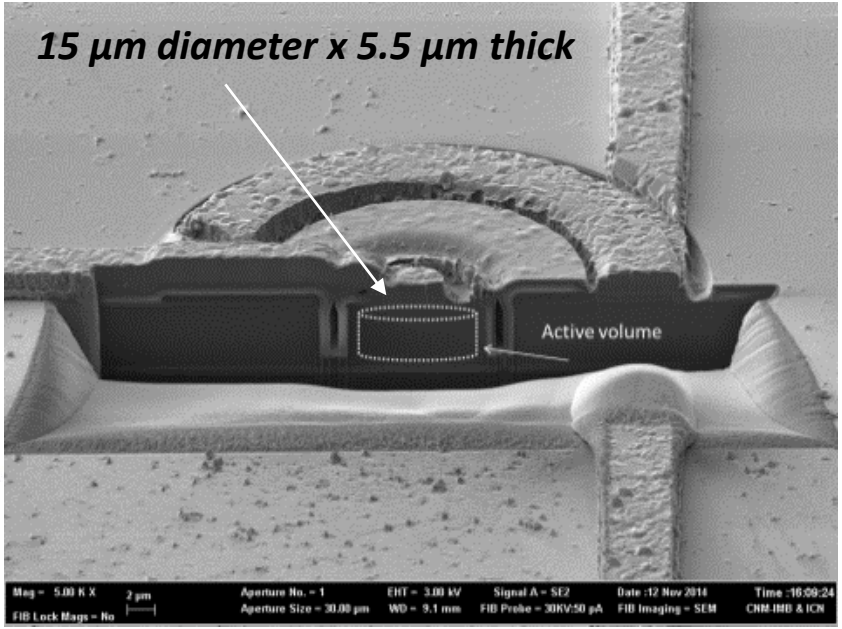
skills

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

tasks

- prototype detectors for dosimetry for FLASH proton and electron beams





Si microsensor with ion collection time < 1 ns

Contributions of the partners

University of Santiago de Compostela (ES)

contact:
Prof. Faustino Gómez

skills

- expert in R&D on dosimetry techniques

Microdosimeter with electronics assembly from USC

Radiation Physics Laboratory (accredited SSDL)

tasks

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

Contributions of the partners

Nuclear Physics Institute (Prague, CZ) 13

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

Contributions of the partners

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

ADVACAM
Imaging the Unseen

contact
Cristina Oancea,
Jan Jakubek

skills

- semiconductor sensor manufacturing
- commercialises Timepix technology

tasks

- Timepix-3 based detectors for FLASH beams and for stray radiation

Timepix-3 Si detector with readout unit

Contributions of the partners

ELI Beamlines (Prague, CZ)

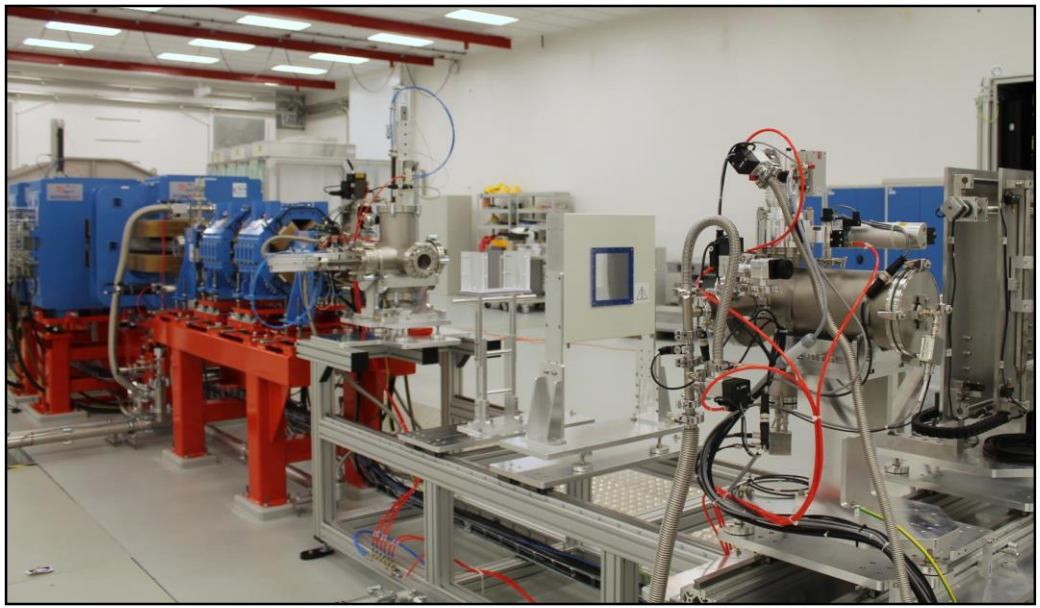
contact:
Veronika Olsovcova,
Roberto Versaci

skills

- new laser research facility
- beamline to investigate medical applications of laser-driven beam

tasks

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



ELIMAIA
(ELI Multidisciplinary Applications of laser-Ion Acceleration)

Contributions of the partners

Queen's University Belfast (Belfast, UK) 12

QUEEN'S UNIVERSITY BELFAST

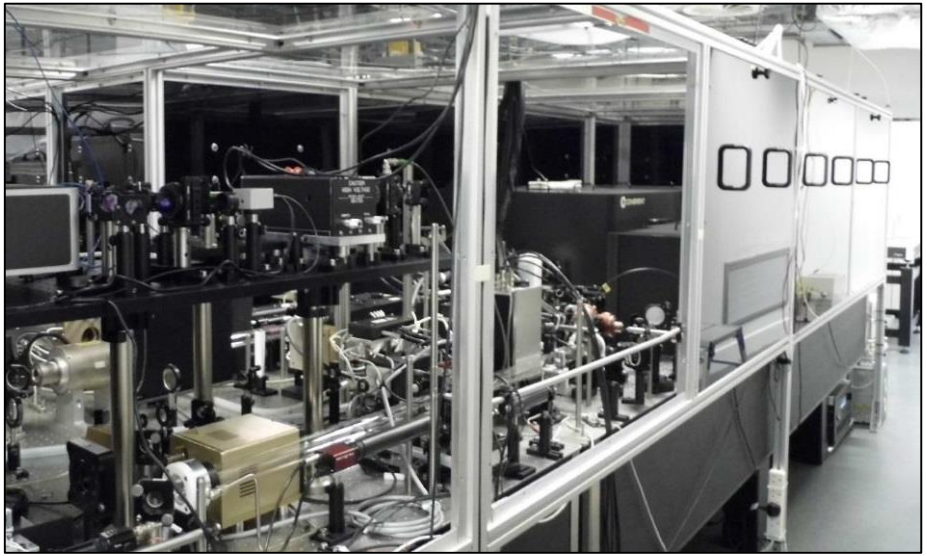
contact:
Prof. Marco Borghesi

skills

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

tasks

- provision of laser-driven proton beam
- dosimetry for laser-driven beams



TARANIS laser for ion acceleration

Contributions of the partners

Politecnico di Milano (Milano, IT) 11

POLITECNICO MILANO 1863

contact
Prof. Marco Caresana

skills

- expert for R&D in the field of radiation detection

tasks

- adapt a detector system for pulsed neutron stray radiation

LUPIN neutron detector at HIMAC, Osaka

Contributions of the partners

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

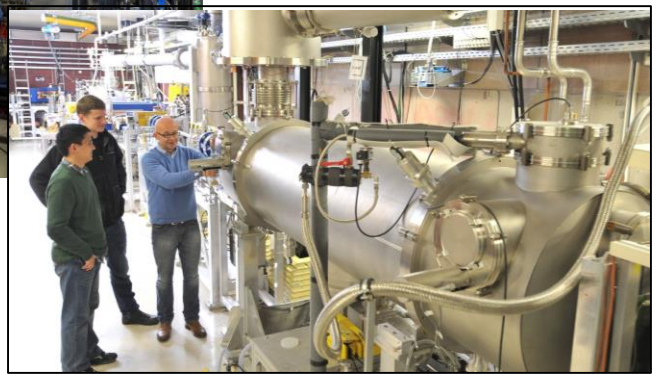
contact:
Jörg Pawelke

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)

Contributions of the partners

PTW The Dosimetry Company (Freiburg, DE)

PTW THE DOSIMETRY COMPANY

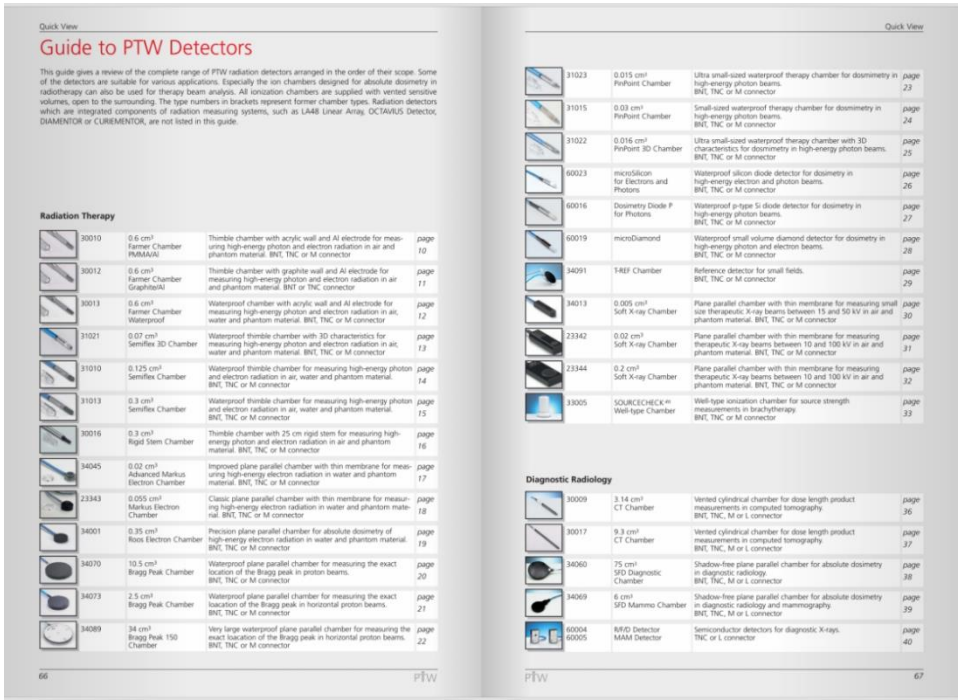
contact:
Daniela Poppinga,
Rafael Kranzer

skills

- designs, develops, manufactures and distributes 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^HR Well-type Chamber	Well-type ionization chamber for source strength measurements in brachytherapy. BNT, TNC or M connector	page 33

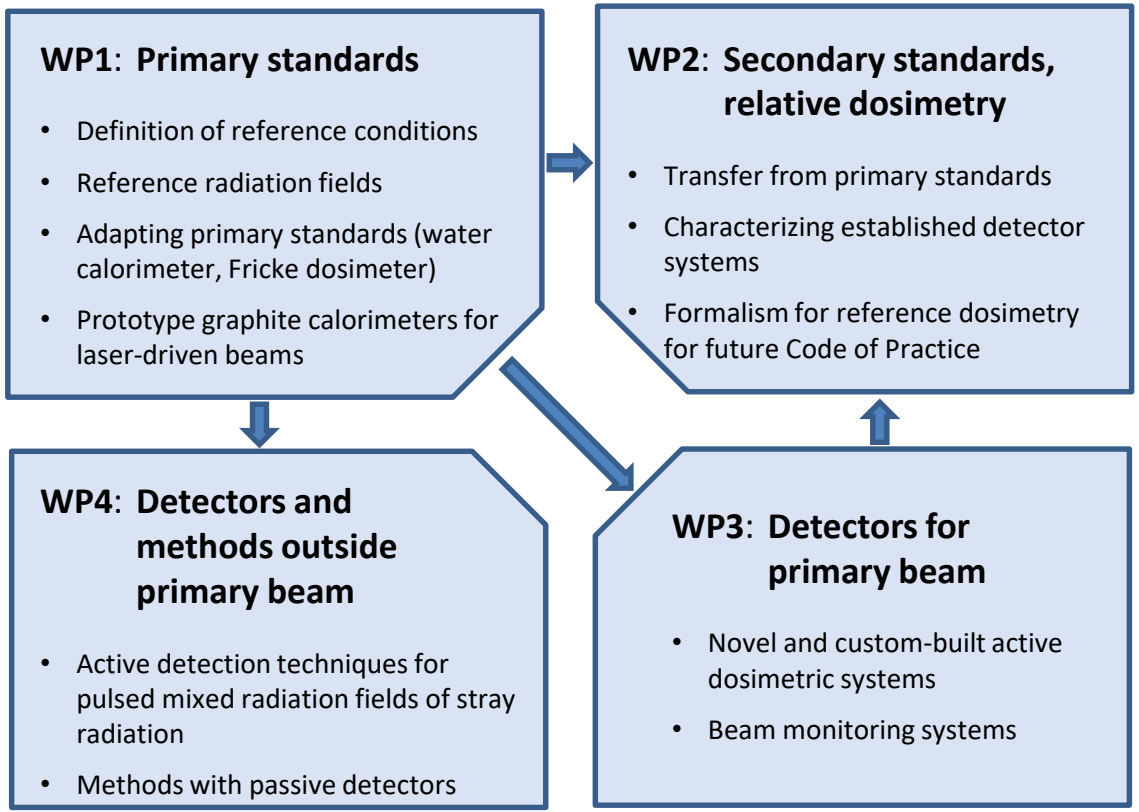
Diagnostic Radiology

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 M&M Detector	Semiconductor detectors for diagnostic X-rays. TNC or L connector	page 40

PTW 67

Variety of PTW's detectors for radiotherapy

UHDpulse - Work Package Structure



EMPIR project 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

PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin — WP6 (coordin.)

NPL National Physical Laboratory — WP1

METAS — WP2

CMI Czech Metrology Institute — WP5 (impact)

Central Office of Measures

Irradiation facility provider

CHUV Centre hospitalier universitaire vaudois — WP3

institutCurie

eli beamlines

Nuclear Physics Institute of the CAS public research institution

Queen's University Belfast

HZDR Helmholtz Zentrum Dresden Rossendorf

Radiation detector developer

ADVACAM Imaging the Unseen — WP4

CSIC Consejo Superior de Investigaciones Científicas · CNM Centro Nacional de Microelectrónica IMB

USC Universidade de Santiago de Compostela

Politecnico Milano 1863

PTW The Dosimetry Company

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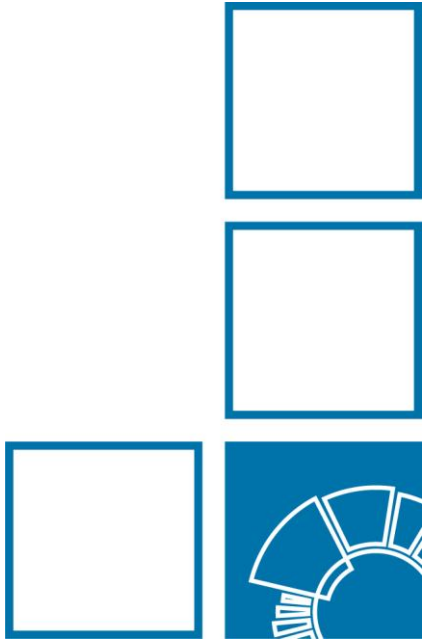

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