Highlights from EMPIR and EPM JRPs: UHDpulse – “Metrology for advanced radiotherapy using particle beams with ultra high pulse dose rates”

Andreas Schüller
PTB Working Group 6.21 “Dosimetry for radiotherapy”
on behalf of the UHDpulse consortium

TC-IR Annual Meeting 2023, 27.2.-3.1.2023, Madrid and online

Joint Research Project UHDpulse

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

Duration: Sep/2019-Feb/2023

Coordinator: Andreas Schüller (PTB)

Topic: **dosimetry for**

FLASH radiotherapy & proton therapy,

VHEE and laser-driven beams

Website: http://uhdpulse-empir.eu


Outline
Highlights
Abstract
Keywords
1. Introduction
2. Overview of novel radiotherapy techniques using ultra-...
3. Metrological challenges and possible solutions for dosi...
4. The UHDpulse project
5. Conclusion
Acknowledgements
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Figures (15)

Physica Medica
Volume 80, December 2020, Pages 134-150

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

Andreas Schüller, Sophie Heinrich, Charles Fouillade, Anna Subiel, Ludovic De Marzi, Francesco Romano, Peter Peier, Maria Trachsel, Celeste Fleta, Rafael Kranzer, Marco Caresana, Samuel Salvador, Simon Busold, Andreas Schönfeld, Malcolm McEwen, Faustino Gomez, Jaroslav Solc, Claude Bailat ... Marie-Catherine Vozenin
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Highlights
- Ultra-high dose rate reduces adverse side effects in radiotherapy (FLASH effect).
- Studies and implementation in practice requires accurate dose measurements.
- An European joint research project was started to develop a measurement framework.
- Tools for dosimetry of ultra-high pulse dose rate beams will be provided.

Schüller et al., Physica Medica 80 (2020), 134-150
https://doi.org/10.1016/j.ejmp.2020.09.020

Joint Research Project UHDpulse

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

November 2020 · Physica Medica 80:134-150
DOI: 10.1016/j.ejmp.2020.09.020

Project: UHDpulse

Labs: Ralf-Peter Kapsch's Lab · Marco Borghesi's Lab · Jan Jakubek's Lab

Andreas Schüller · Sophie Heinrich · Charles Fouillade · Show all 32 authors · Marie-Catherine Vozenin

2.2 citations per month

Schüller et al., Physica Medica 80 (2020), 134-150
https://doi.org/10.1016/j.ejmp.2020.09.020

UHDpulse Partners and Collaborators (6 new in 2022)

Metrology Institutes

Irradiation facilities / providers

Detector developers

7 Metrology institutes
6 Hospitals
9 Universities
7 Research institutes
12 Companies
+ Inspire proton therapy network

Work package structure

WP1: Primary standards

- Definition of reference conditions
- Reference radiation fields
- Adapting primary standards (water calorimeter, Fricke dosimeter)
- Prototype graphite calorimeters

WP2: Secondary standards, relative dosimetry

- Transfer from primary standards
- Characterizing established detector systems
- Formalism for reference dosimetry for future Code of Practice

WP5: Impact, WP6: Coordination

WP4: Detectors and methods outside primary beam

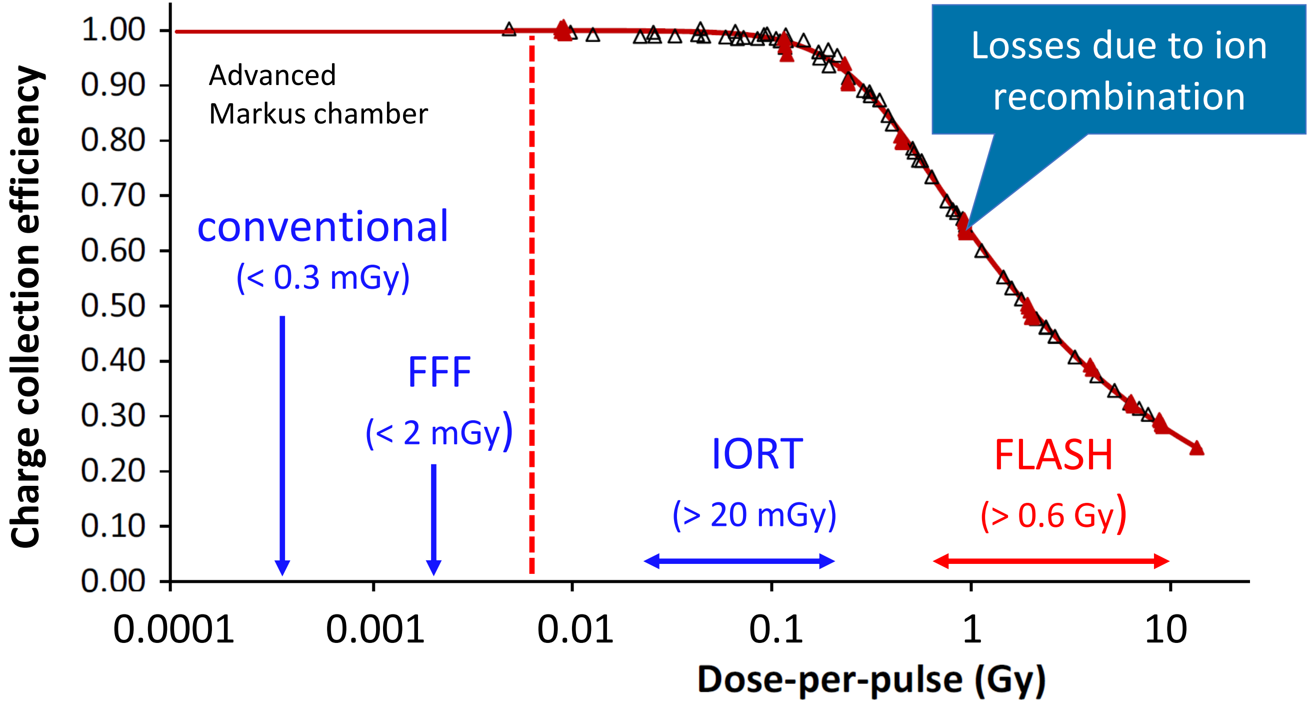
- Active detection techniques for pulsed mixed radiation fields of stray radiation and pulsed neutrons
- Methods with passive detectors

WP3: Detectors for primary beam

- Novel and custom-built active dosimetric systems
- Beam monitoring systems

Motivation

- Typical performance of ionization chambers



Initial situation:

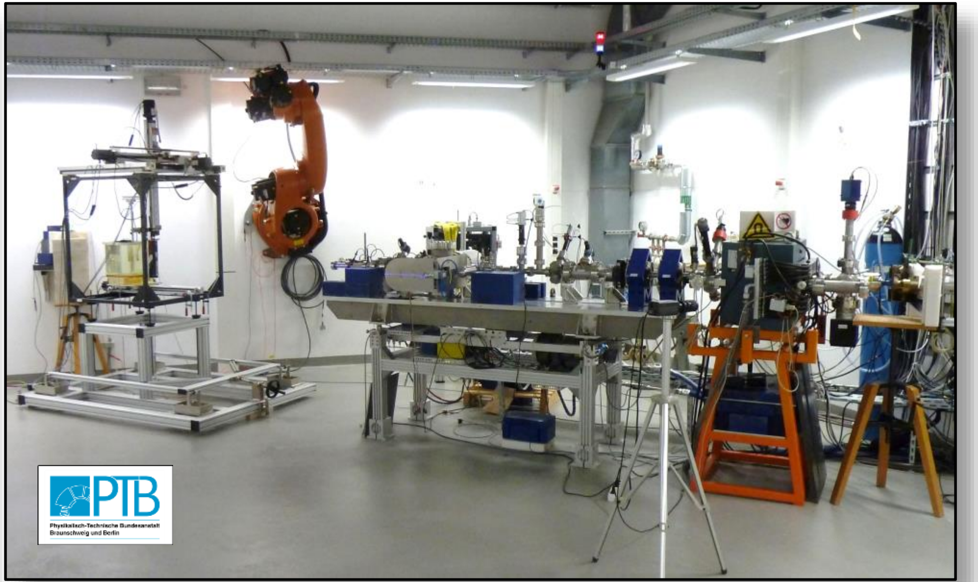
- **no** active dosimeters for real-time measurements
- **no** dedicated primary standard
- **no** formalism for reference dosimetry

K. Petersson *et al.*, Med. Phys. **44** (2017) 1157
https://doi.org/10.1002/mp.12111

UHPDR reference electron beam (D1)

ultra-high pulse dose rate

PTB's Research electron accelerator



Beam line with water phantom

E = 0.5 – 50 MeV, t_{pulse} = 0.1 – 3 us

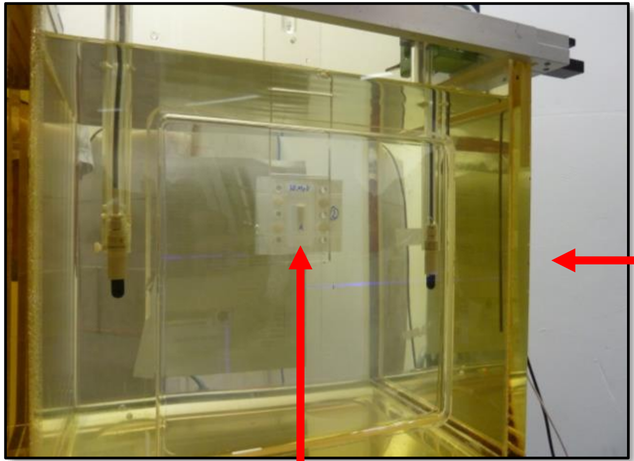
up to **12 Gy per pulse** (SSD 0.7 m, 20 MeV)

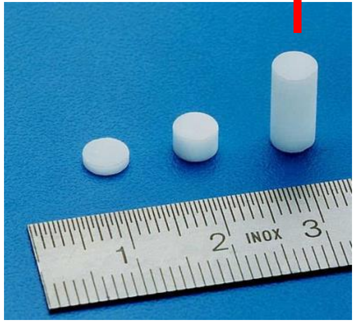
A. Bourgouin *et al*. "Characterization of the PTB ultra-high …"
Phys. Med. Biol. **67** (2022) 085013.
https://doi.org/10.1088/1361-6560/ac5de8

UHDpulse

UHPDR reference electron beam (D1)

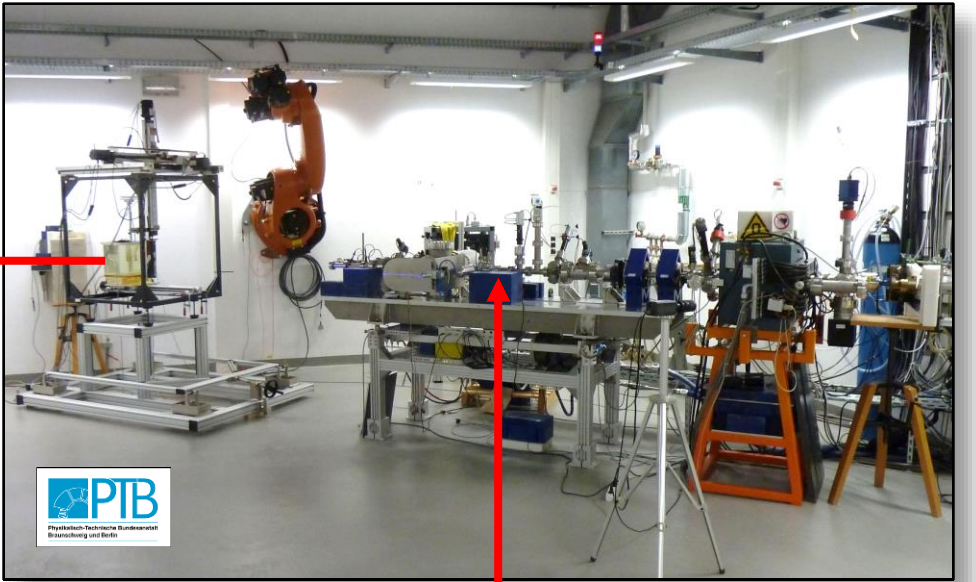
PTB





Alanine pellets at reference depth in water phantom

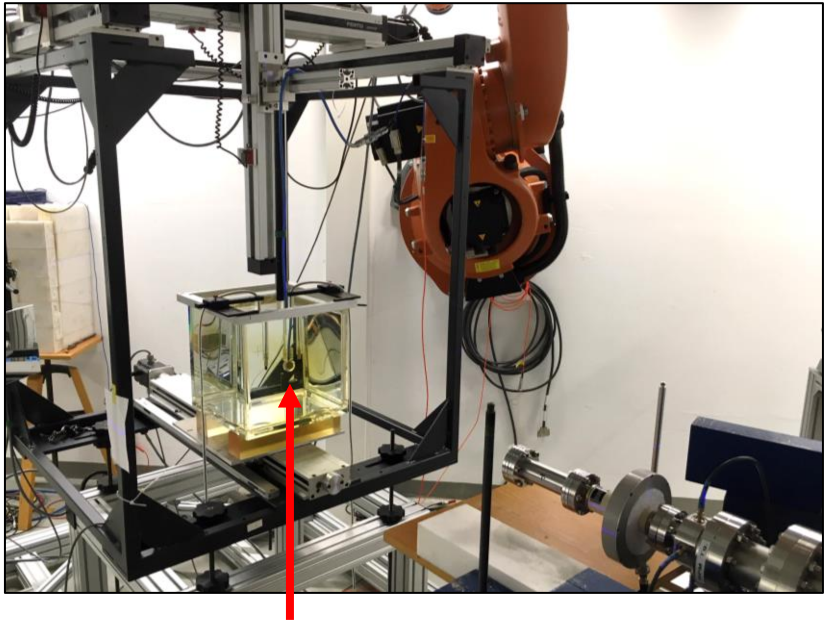
Dose traceable to PTB's primary standards

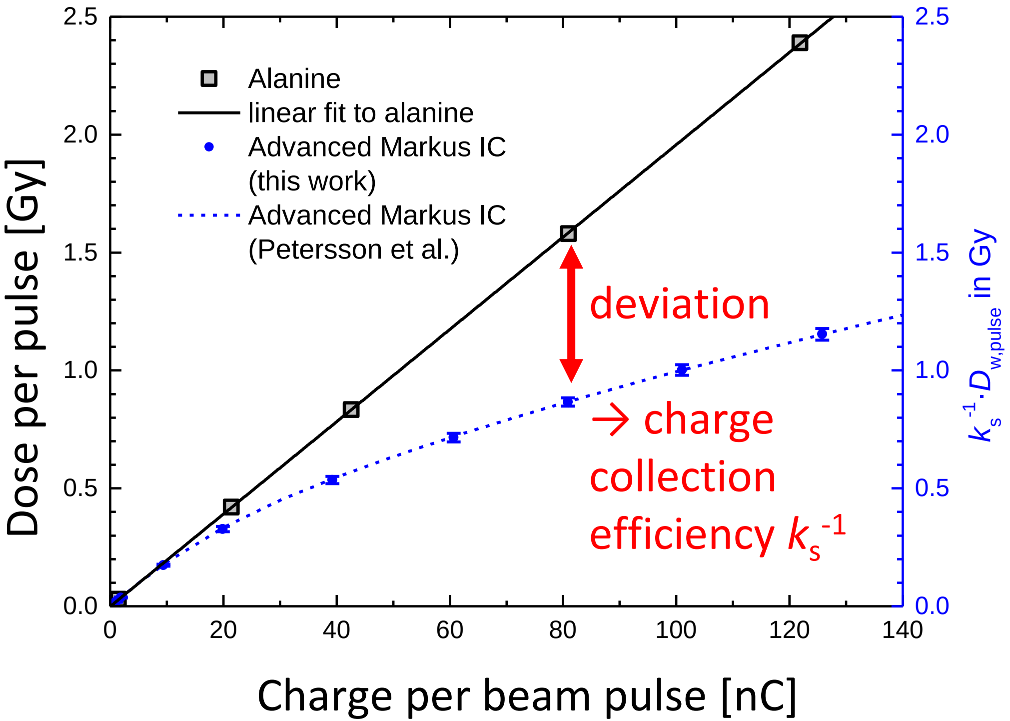


Current transformer (Bergoz ICT): Non-destructive absolute beam pulse charge measurement

A. Bourgouin *et al.*, "Absorbed-dose-to-water…"
Phys. Med. Biol. **67** (2022) 205011.
https://doi.org/10.1088/1361-6560/ac950b

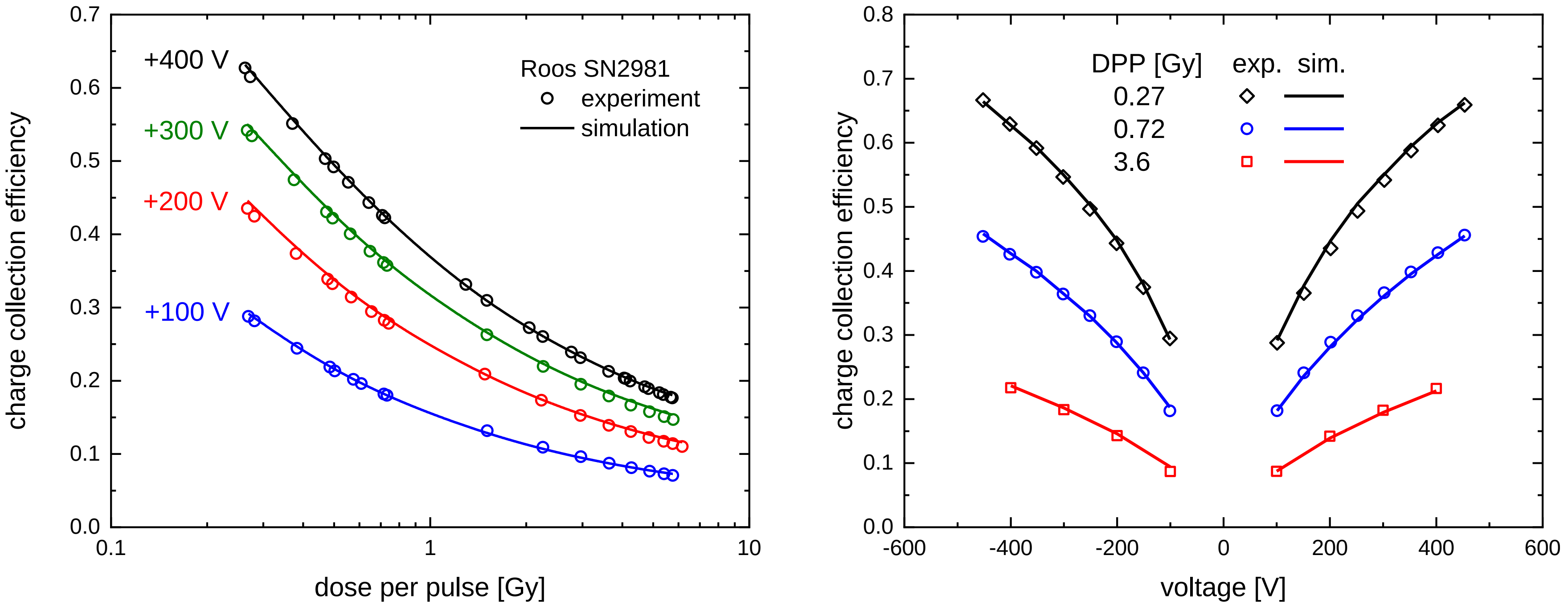
UHPDR reference electron beam (D1)





A. Bourgouin *et al.*, "Calorimeter for Real-Time Dosimetry …" Front. Phys. **8** (2020) 567340.
https://doi.org/10.3389/fphy.2020.567340

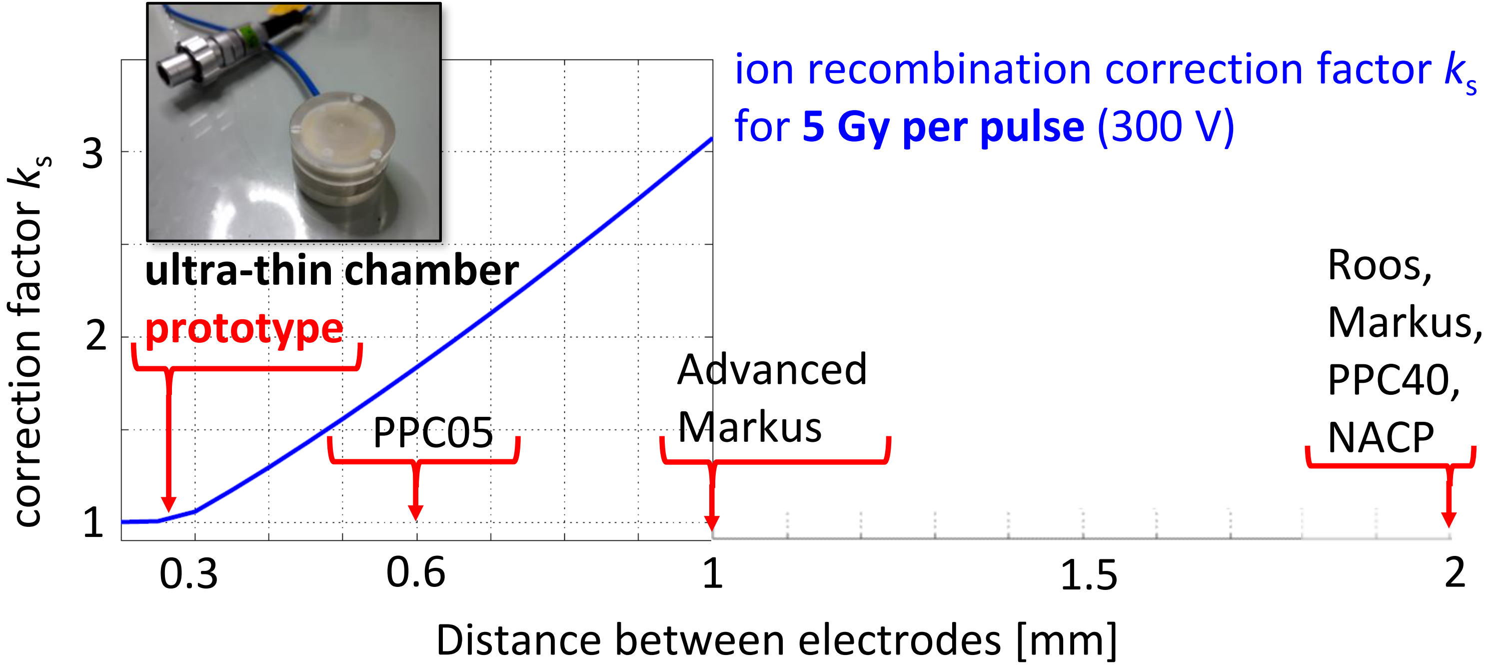
Calculation of charge collection efficiency



J. Paz-Martín *et al.*, "Numerical modelling …" Phys. Med. **103** (2022) 147.
https://doi.org/10.1016/j.ejmp.2022.10.006

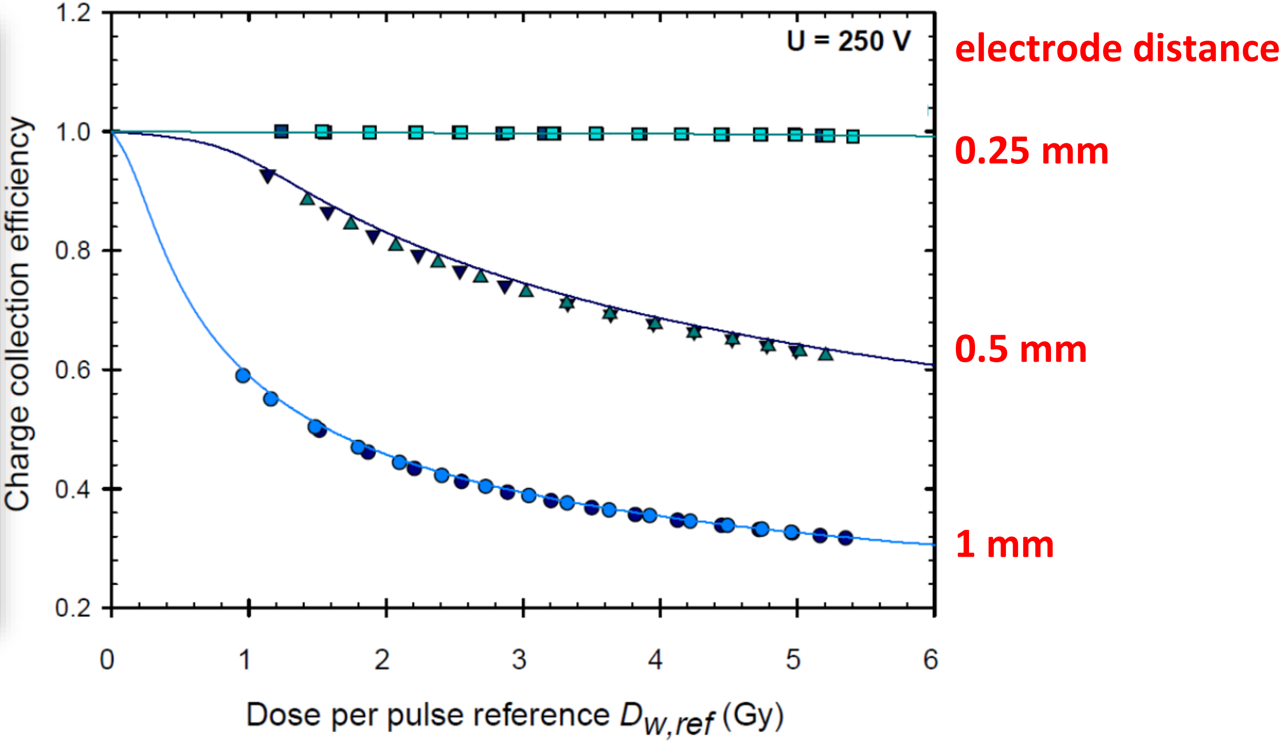
Calculation of charge collection efficiency

ion recombination correction factor k_s
for **5 Gy per pulse** (300 V)



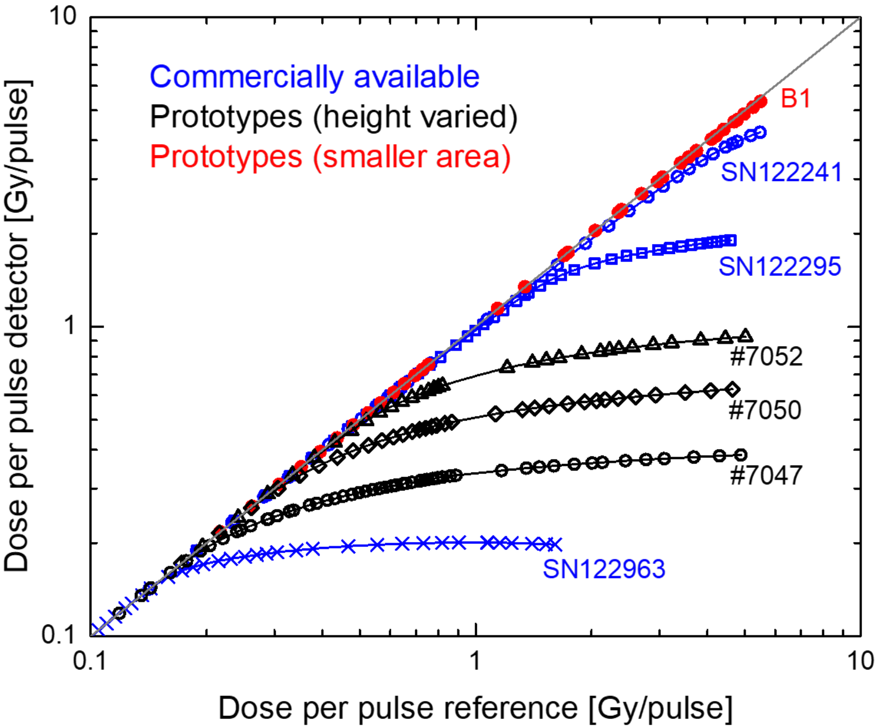
F. Gomez *et al.*, “Development of an ultra-thin …” Med Phys. **49** (2022) 4705.
https://doi.org/10.1002/mp.15668

Ultra-thin ionization chamber for FLASH RT



R. Kranzer *et al.* “Charge collection efficiency …” Phys Med **104** (2022) 10.
https://doi.org/10.1016/j.ejmp.2022.10.021

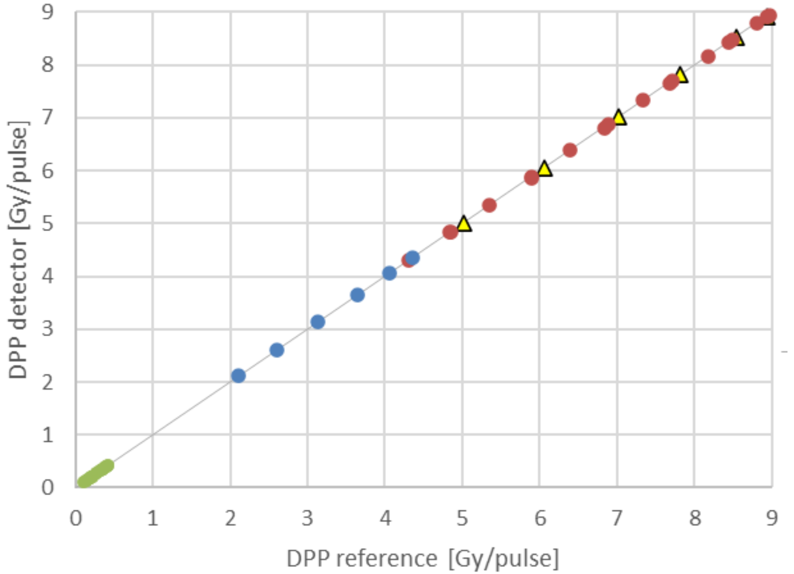
microDiamond → flashDiamond

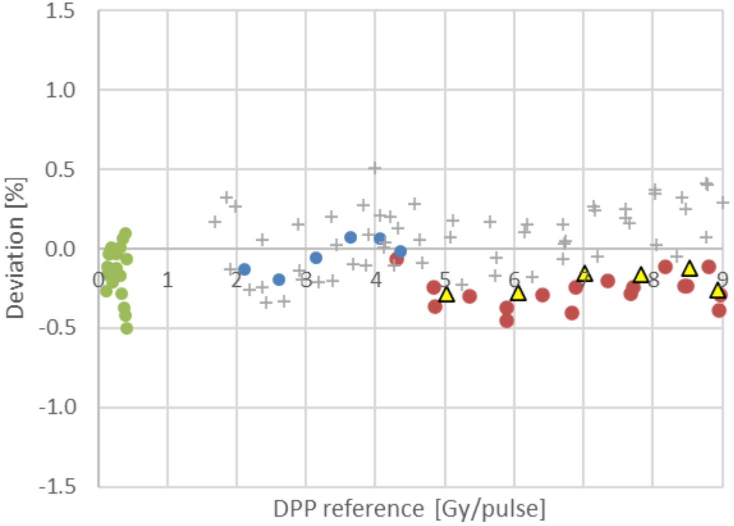


PTW THE DOSIMETRY COMPANY · TOR VERGATA UNIVERSITY OF ROME Dept. Industrial Engineering · PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

R. Kranzer *et al.* “Response of diamond …”
Phys. Med. Biol. **67** (2022) 075002.
https://doi.org/10.1088/1361-6560/ac594e

flashDiamond





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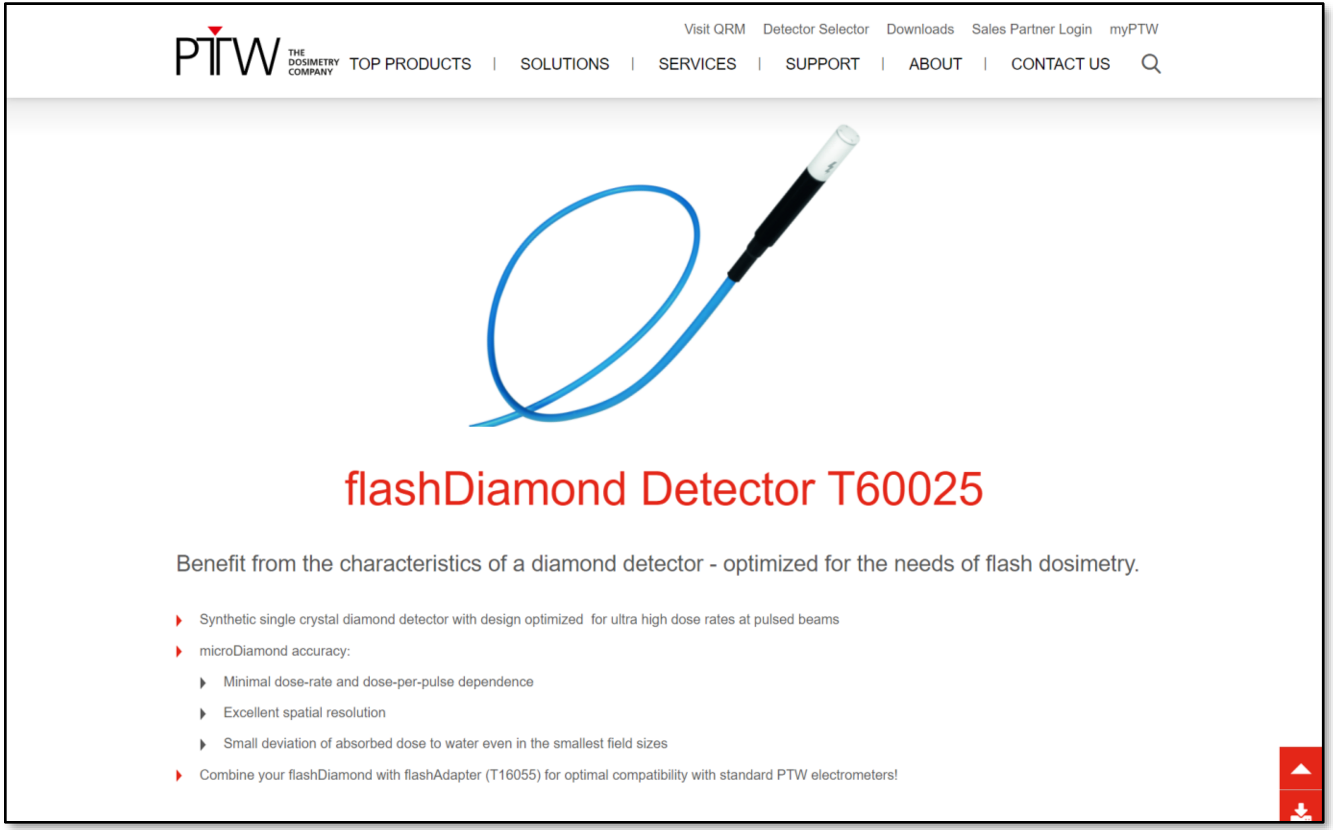
M. Marinelli et al.
"Design, realization, and …"
Med. Phys. **49** (2022) 1902.
https://doi.org/10.1002/mp.15473

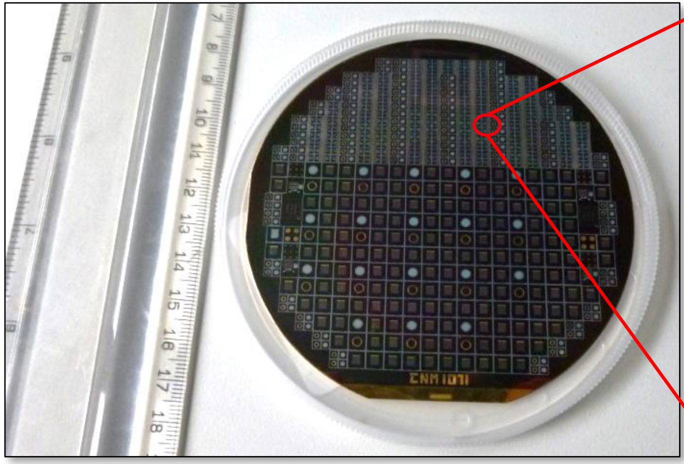
G. Verona Rinati et al.
"Application of a novel diamond …"
Med. Phys. **49** (2022) 5513.
https://doi.org/10.1002/mp.15782

flashDiamond (exploitable result)



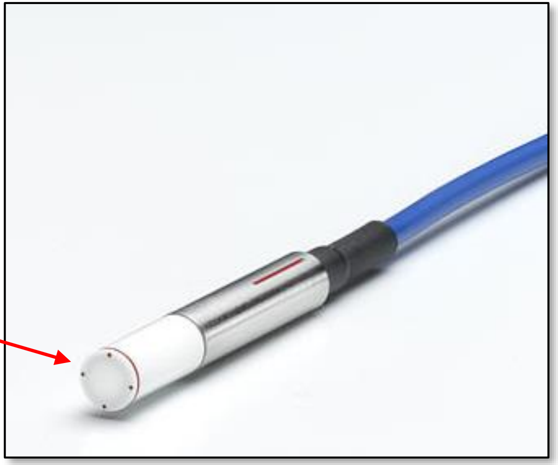
https://www.ptwdosimetry.com/en/products/flashdiamond-detector/

SiC diodes for FLASH dosimetry



4" SiC wafer

1 mm diode

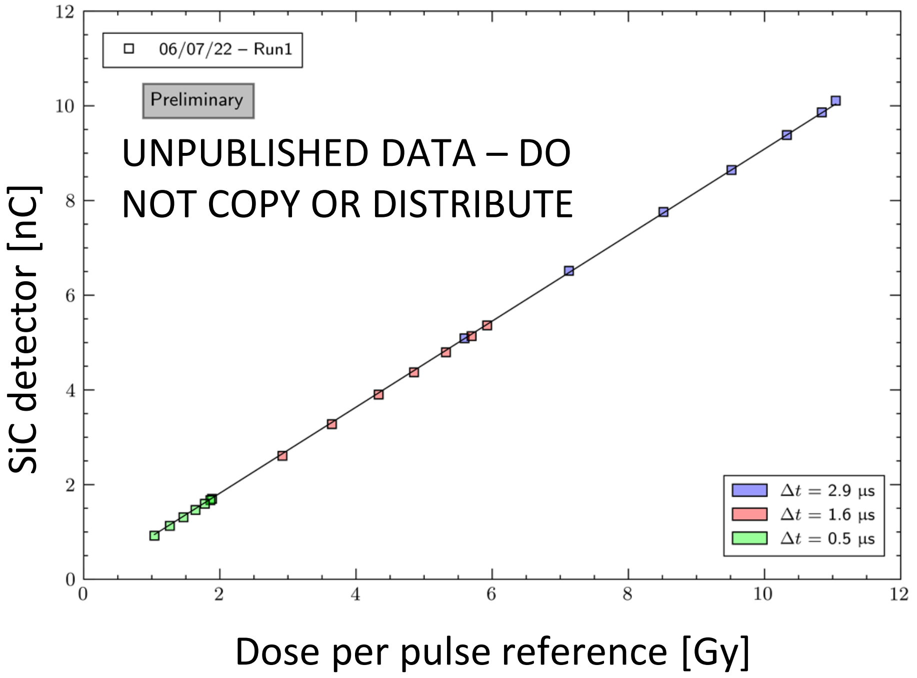


Encapsulation by PTW (microSilicon housing)

CSIC cnm | PTW THE DOSIMETRY COMPANY

Application for Patent EP22383168.6

SiC diodes for FLASH dosimetry

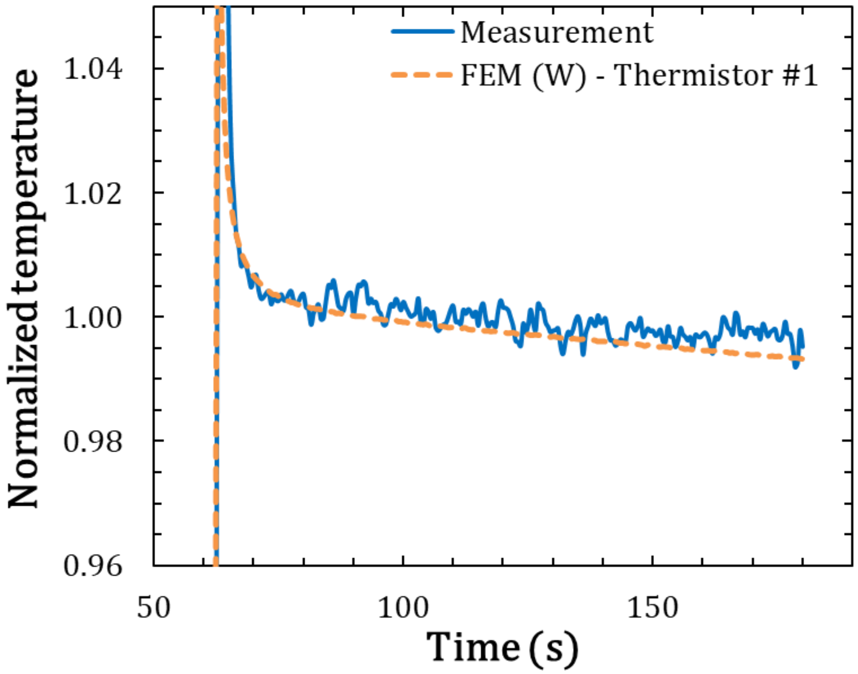


Celeste Fleta et al.
"Characterization of silicon carbide detectors in ultrahigh dose per pulse electron beams", in preparation

Application for Patent EP22383168.6

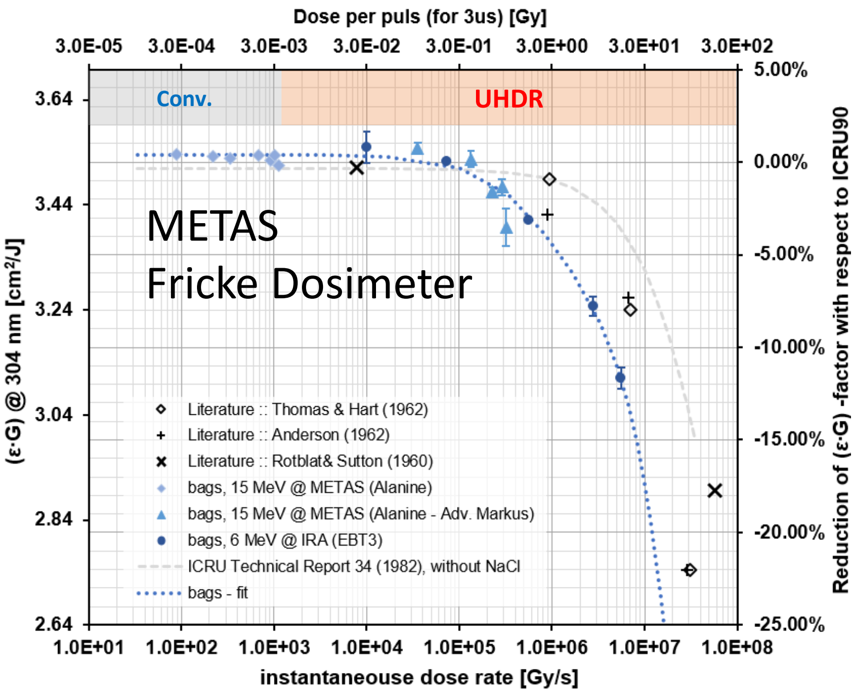
Water calorimeter primary standard

PTB's primary standard of the unit Gy in UHPDR reference electron beam



A. Bourgouin *et al.*, Phys. Med. Biol. (2023), under review

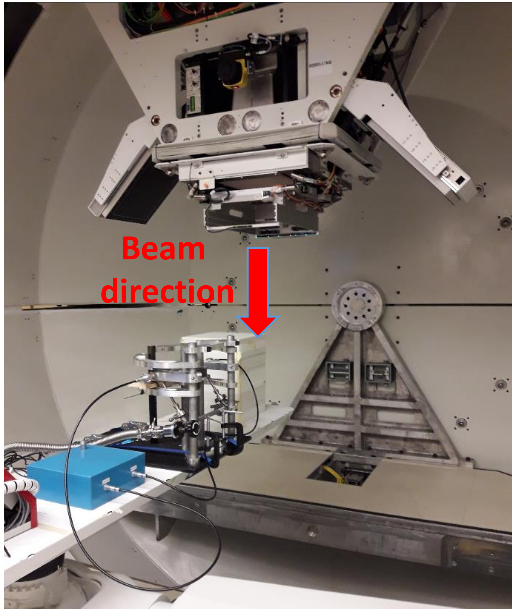
Comparison of primary standards (D3)



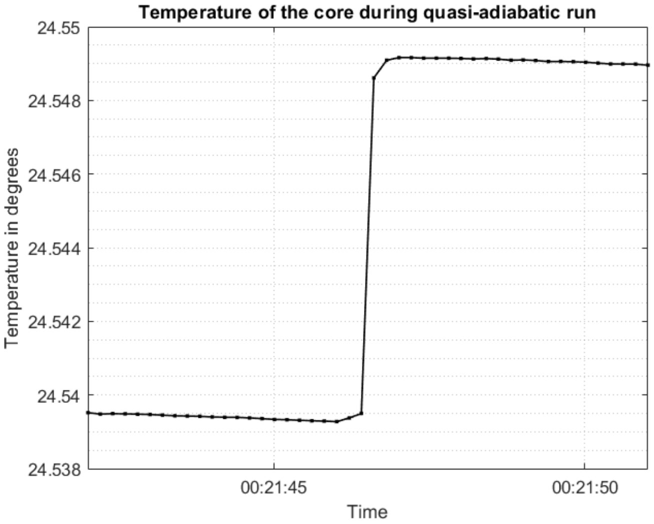
The ratio between the dose delivered by a calibrated ultra-high dose per pulse electron beam using the **METAS primary standard**, Fricke dosimeter, and the dose delivered by a calibrated ultra-high dose per pulse electron beam using the **PTB primary standard**, water calorimeter, was shown to be 1.002(12). Therefore, it can be concluded that both primary standards established in ultra-high dose per pulse electron beam **agree with each other** within the combined standard uncertainty.

METAS | Centre hospitalier universitaire vaudois | PTB | NRC·CNRC Canada

Calorimetry in UHDR proton beams (D2)



NPL's graphite calorimeter in FLASH proton beam (Cincinnati Proton Centre)



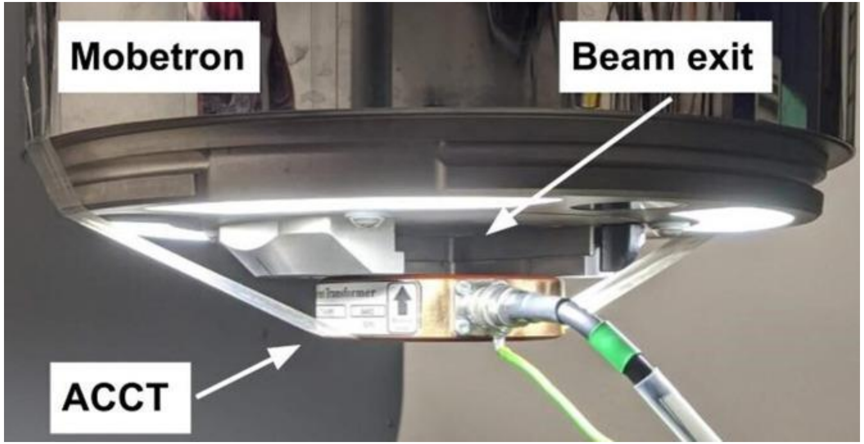
→ **First ever calorimetry measurements in UHDR proton beam**

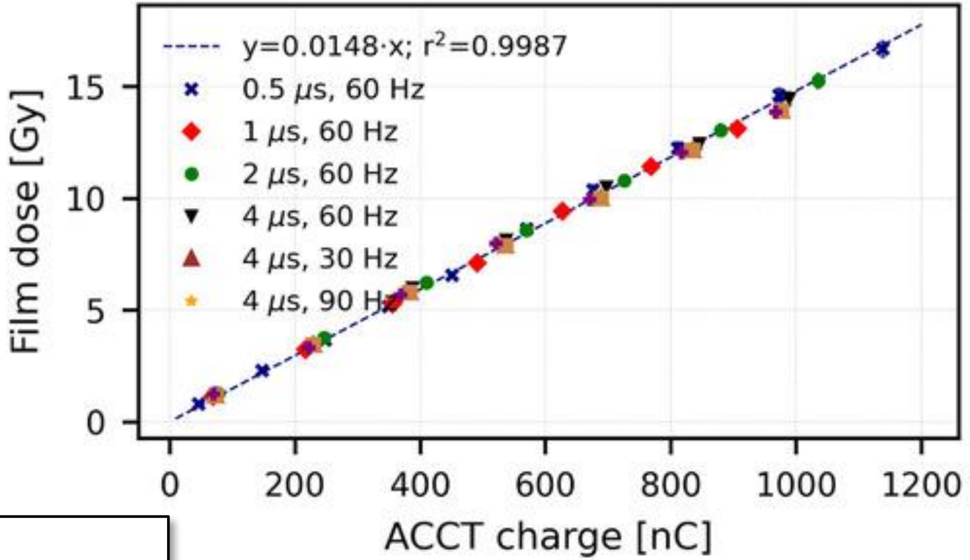
- Established the correction factors required for absolute dosimetry of FLASH proton beam radiotherapy
- Measurement uncertainty of 0.9% (k=1)
- **Underpinned the FDA approval and provided the hospital with confidence to commence clinical implementation**

A. Lourenco et al. "Absolute dosimetry for FLASH proton …" Scientific Reports **13** (2023) 2054.
https://doi.org/10.1038/s41598-023-28192-0

E. Lee et al. "Ultrahigh dose rate pencil beam …" Med. Phys. **49** (2022) 6171.
https://doi.org/10.1002/mp.15844

Beam monitors for FLASH RT



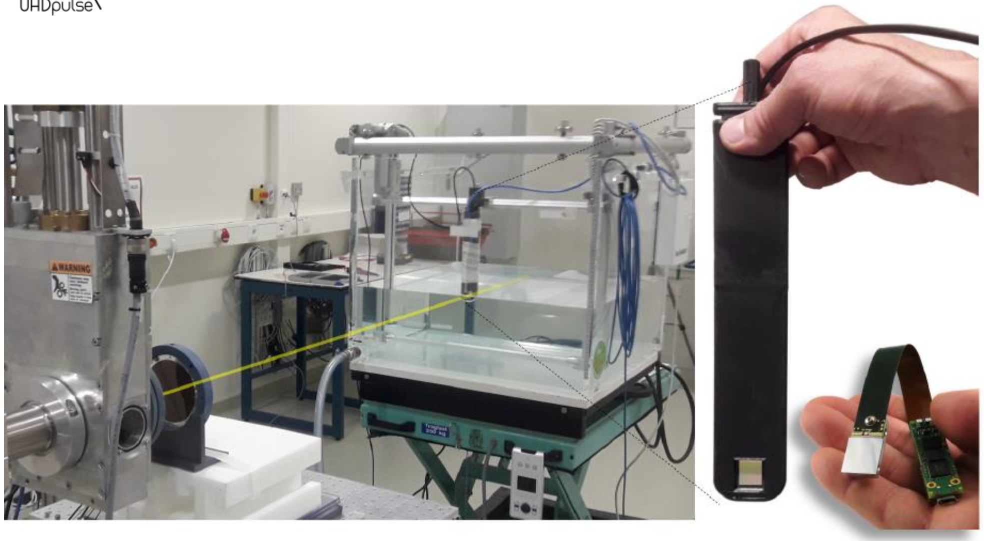


End user uptake:
IntraOp and SIT now installs Bergoz current transformers as beam monitors as standard in their FLASH Linacs

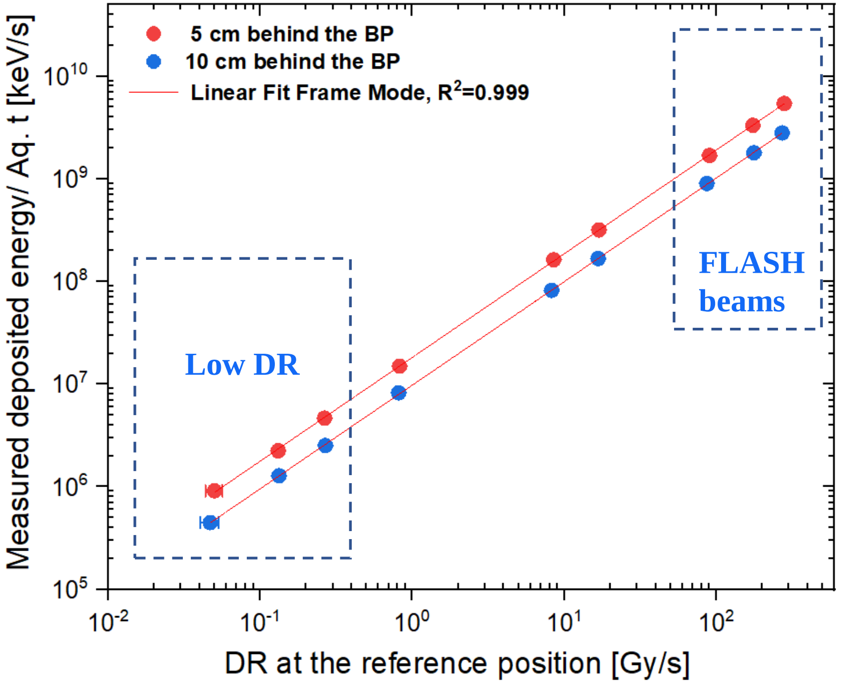
Centre hospitalier universitaire vaudois

R. Oesterle et al., "Implementation and validation of a beam-current …"
J Applied Clin Med Phys 22 (2021) 165
https://doi.org/10.1002/acm2.13433

Out-of-field measurements with TimePIX3



MiniPIX TPX3 Flex in a water phantom in an ultra-high dose rate proton beam



ADVACAM Imaging the Unseen | HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF | CZECH METROLOGY INSTITUTE | InspireProject | PTB

C. Oancea et al., "Out-of-field measurements…" Physica Medica, 2023
https://doi.org/10.1016/j.ejmp.2023.102529

1st UHDpulse stakeholder workshop

> 700 Participants (online)

34 UHDpulse contributions
(25 oral presentations, 9 poster)

Centre hospitalier universitaire vaudois | InspireProject | institut Curie | PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

FRPT follow-on

> 650 Participants,
~400 onsite

15 UHDpulse Contributions
(5 oral presentations, 10 posters)

UHDpulse

AAPM TG 359 "FLASH radiation dosimetry"

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AAPM COMMITTEE TREE

Task Group No. 359 - FLASH (ultra-high dose rate) radiation dosimetry (TG359)

AAPM Members, Affiliates and Non-Member Affiliates - Login for access to additional information

Chair: Dimitris Mihailidis, Task Group Chair

Charge

1. Review the uncertainty in determining the dose and need for standardization in dosimetry for FLASH beams to be used in experiments, research and potentially in pre-clinical applications.
   a. Assess the factors that would affect the beam dosimetric characteristics in FLASH mode, compared to standard delivery.
2. Assess the suitability of radiation measurement equipment (ion chambers, film, diodes, Faraday cap, etc) for FLASH mode.
3. Provide general guidelines on calibration, dosimetry and reporting of beams in FLASH mode.

Bylaws: Not Referenced. **Rules:** Not Referenced.

https://www.aapm.org/org/structure/default.asp?committee_code=TG359

UHDpulse members in TG359:

- NRC-CNRC Canada
- CHUV Centre hospitalier universitaire vaudois
- NPL National Physical Laboratory
- USC Universidade de Santiago de Compostela
- institut Curie
- SIT
- netwerk iridium Topzorg in radiotherapie
- PTW The Dosimetry Company
- iba Dosimetry Protect, Enhance and Save Lives

Output of UHDpulse

No.	Report (preliminary, 28.2.23)	No. of items reported
1	STANDARDS & REGULATORY ACTIVITIES (STAN)	33
2	PEER REVIEWED OPEN ACCESS SCIENTIFIC PUBLICATIONS (PUB)	39
3	CONFERENCE PRESENTATIONS & POSTERS (CONF)	119
4	TRAINING (TR)	2
5	OTHER DISSEMINATION (OTH)	49
6	FOLLOW-ON COLLABORATIONS (FOLL)	2
7	END USER UPTAKE & EXPLOITATION (UP)	9
8	COLLABORATORS & STAKEHOLDERS (COLL)	44
9	APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC (IP)	1
10	EXPLOITABLE RESULTS, ETC (RES)	3
11	FUTURE EVENTS (FUT)	
12	OPEN RESEARCH DATA (DATA)	13

http://uhdpulse-empir.eu/

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(in alphabetical order):

I. Ambrozova, U. Ankerhold, L. Archambault, R. Ashraf, C. Bailat, M. Borghesi, A. Boso, A. Bourgouin, P. Bruza, S. Busold, M. Caresana, A. Cimmino, L. De Marzi, V. Djonov, A.Douralis, M. Durante, M. Dutreix, F. Fausti, F. Keszti, G. Felici, C. Fleta, J.-M. Fontbonne, C. Fouillade, F. Frei, A. Gasparini, U. Giesen, L. Giuliano, F. Gomez, L. Grasso, T. Hackel, S. Heinrich, J. Jakubek, R.-P. Kapsch, K. Kirkby, A. Knyziak, R. Kranzer, C. Lahaye, M. Lavagno, A. Leite, V. Linhart, B. Lessard, H. K. Looe, C. Makowski, M. Marinelli, S. McCallum, M. McEwen, M. McManus, T. Michel, G. Milluzzo, S. Motta, C. Oancea, V. Olsovcova, H. Palmans, K. Parodi, J. Pawelke, J. Paz-Martin, P. Peier, K. Petersson, J. Pivec, B. Poppe, D. Poppinga, M. Pullia, J. Renaud, N. Roberts, F. Romano, S. Rossomme, K. Roškar, S. Safai, S. Salvador, C. S. Schmitzer, A. Schönfeld, B. Simon, J. Solc, F. Stephan, A. Subiel, F. Therriault-Proulx, R. A. Thomas, M. Togno, E. Touzain, M. Trachsel, F. Vanhavere, V. Vanreusel, D. Verellen, G. Verona Rinati, J. Seuntjens, R. Versaci, P. von Voigts-Rhetz, M. Zboril

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