UHDpulse Project: Overview and Current Status

Andreas Schüller
PTB Working Group 6.21 “Dosimetry for radiotherapy

2nd UHDpulse Stakeholder Workshop 26.-27.1.23, Prague

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

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

enables European metrology institutes to collaborate with industrial and medical organisations, and academia

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Website: http://uhdpulse-empir.eu

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

UHDpulse Partners and Collaborators

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

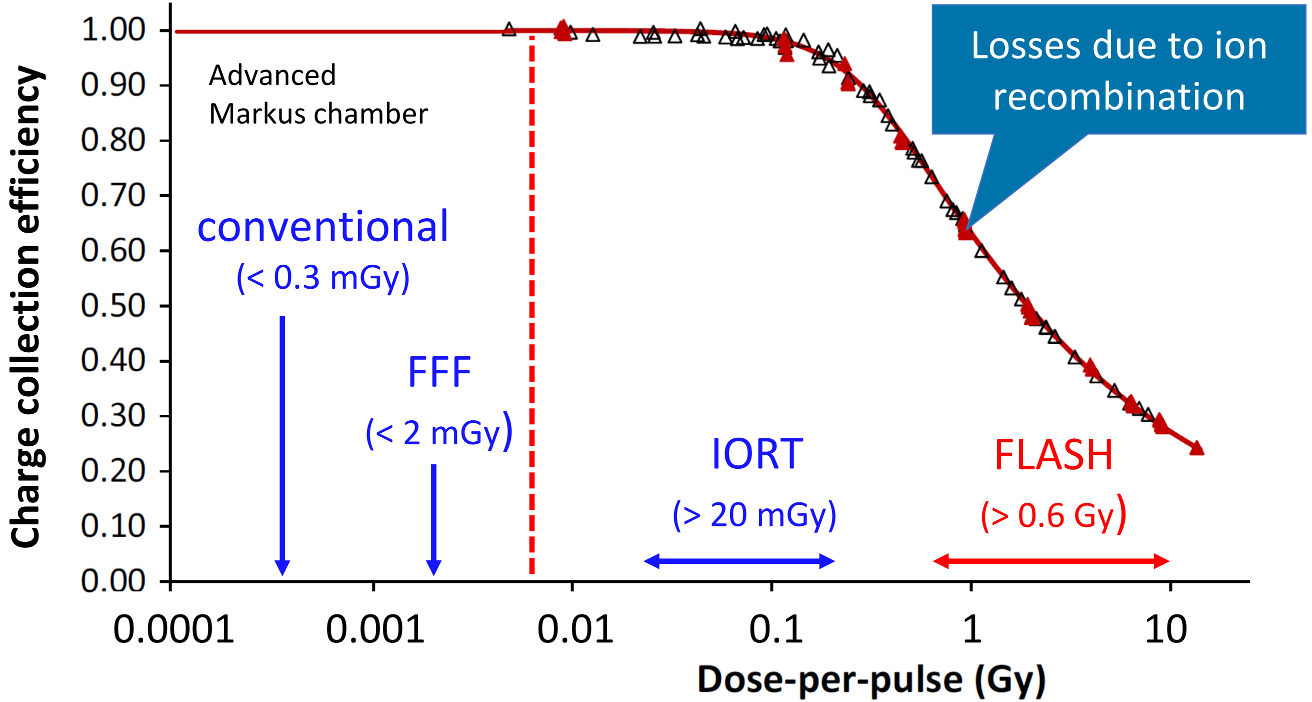
- Active detection techniques for pulsed mixed radiation fields of stray radiation and pulsed neutrons
- Methods with passive detectors

WP3: Detectors for primary beam

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

Motivation

- Typical performance of ionization chambers



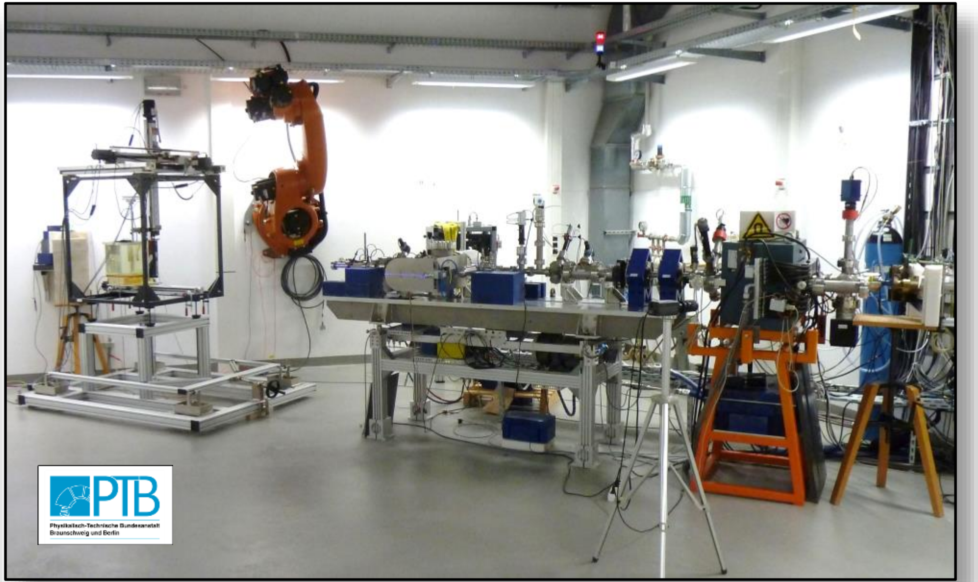
Initial situation:

- **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)

PTB's Research electron accelerator



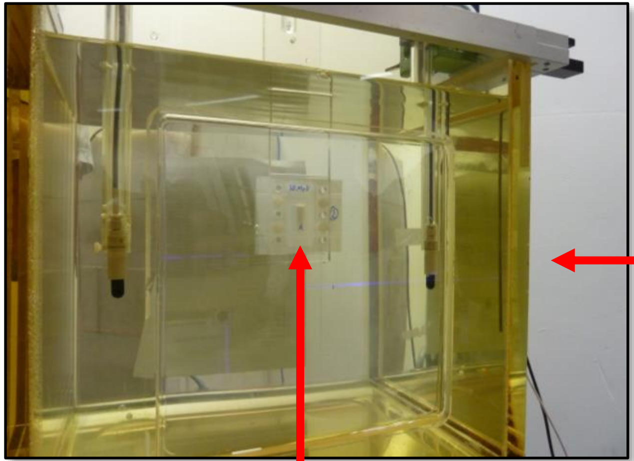
Beam line with water phantom

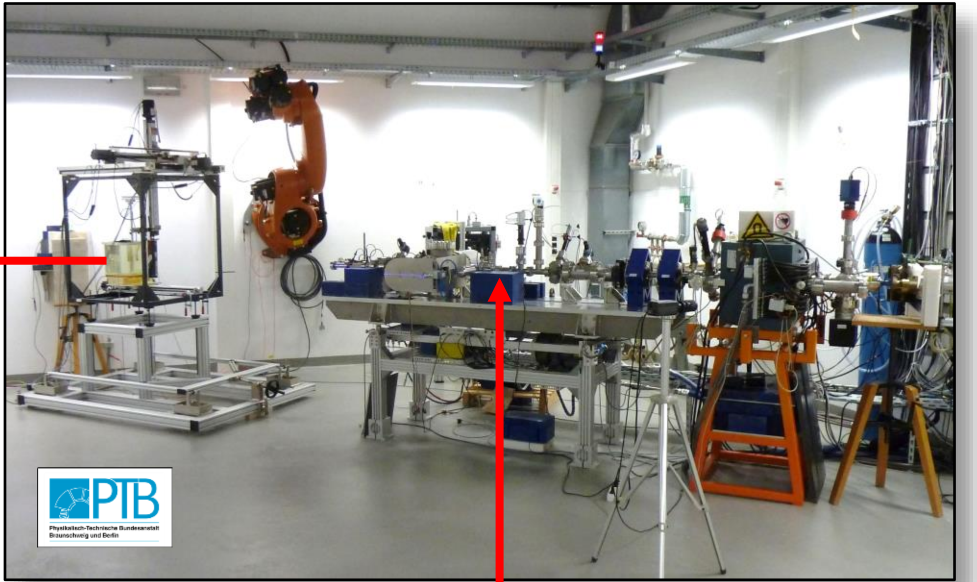
E = 0.5 – 50 MeV, t_{pulse} = 0.1 – 3 us
up to **12 Gy per pulse** (SSD 0.7 m, 20 MeV)

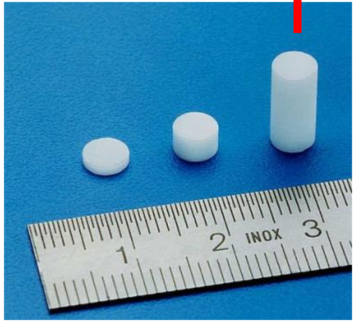
Alexandra Bourgouin (PTB), today WP1 and WP2

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

UHPDR reference electron beam (D1)







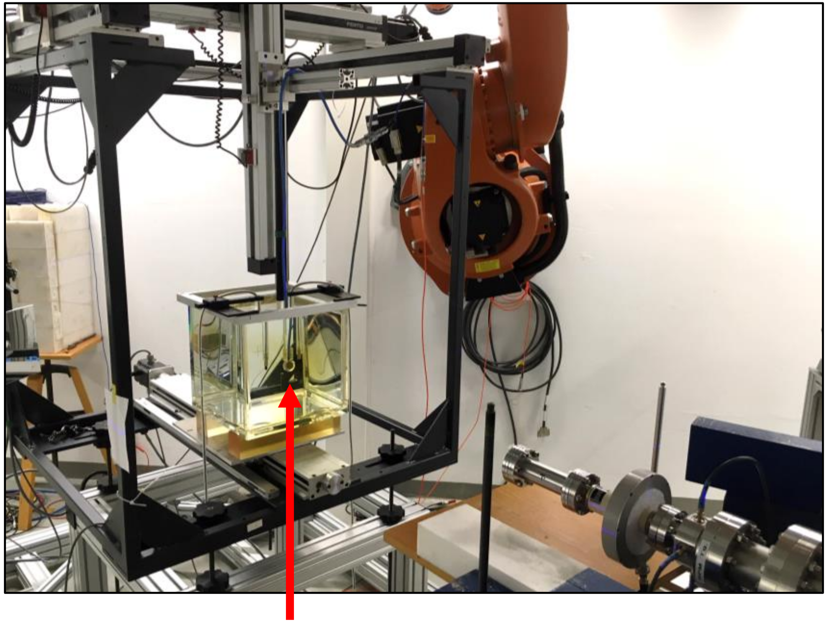
Alanine pellets at reference depth in water phantom

Dose traceable to PTB's primary standards

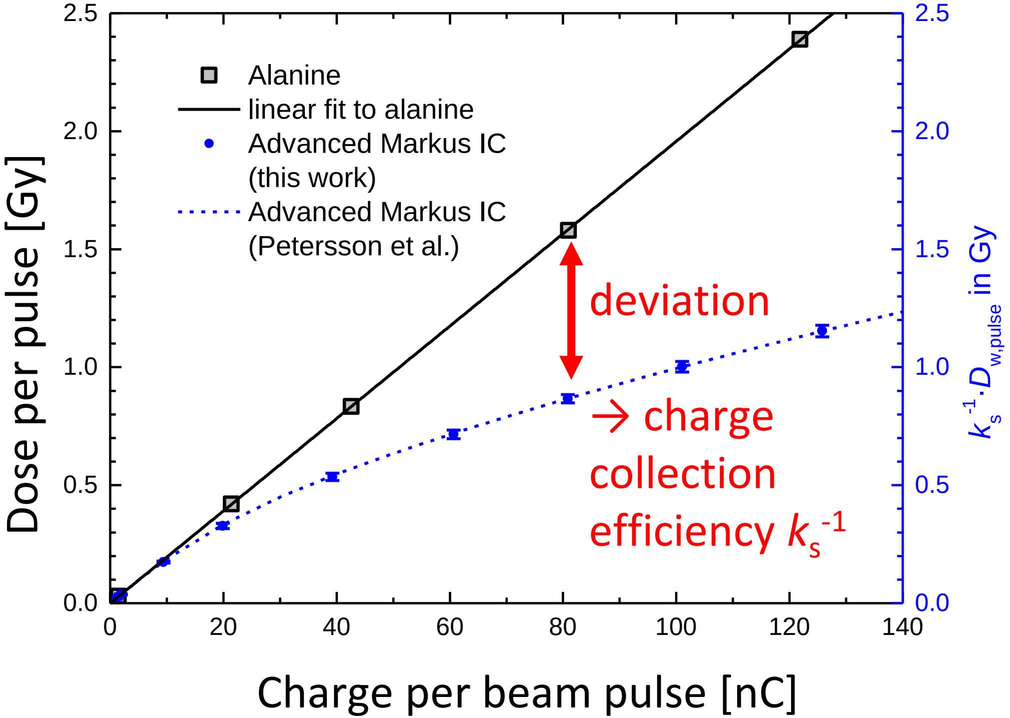
Current transformer (Bergoz ICT): Non-destructive absolute beam pulse charge measurement

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)

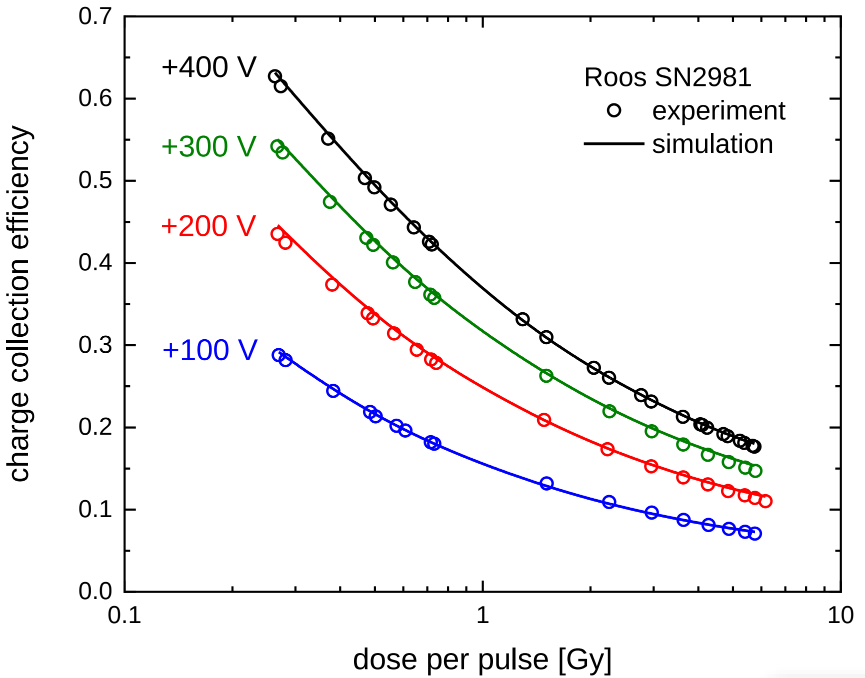


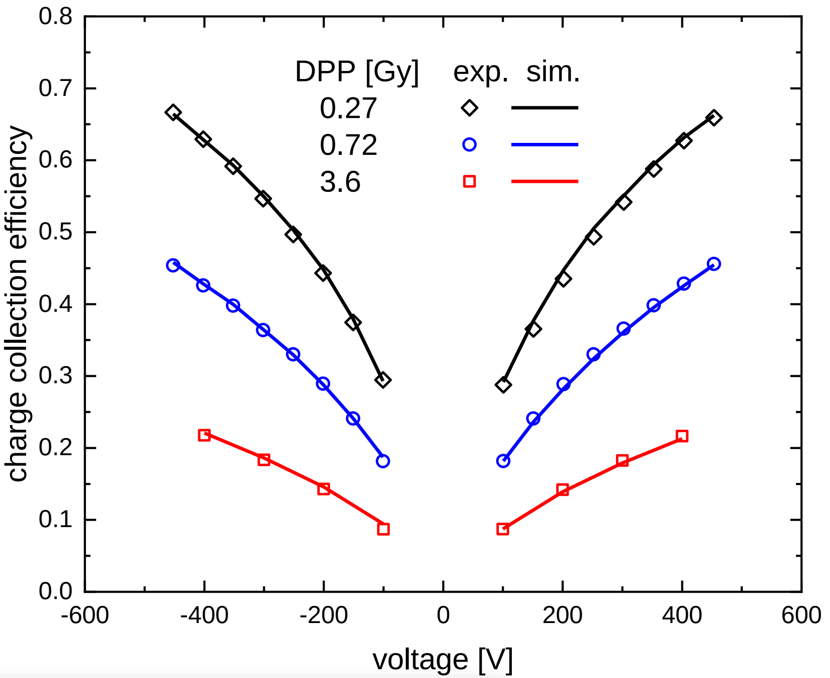
Detector under test at reference depth in water phantom



A. Bourgoin *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

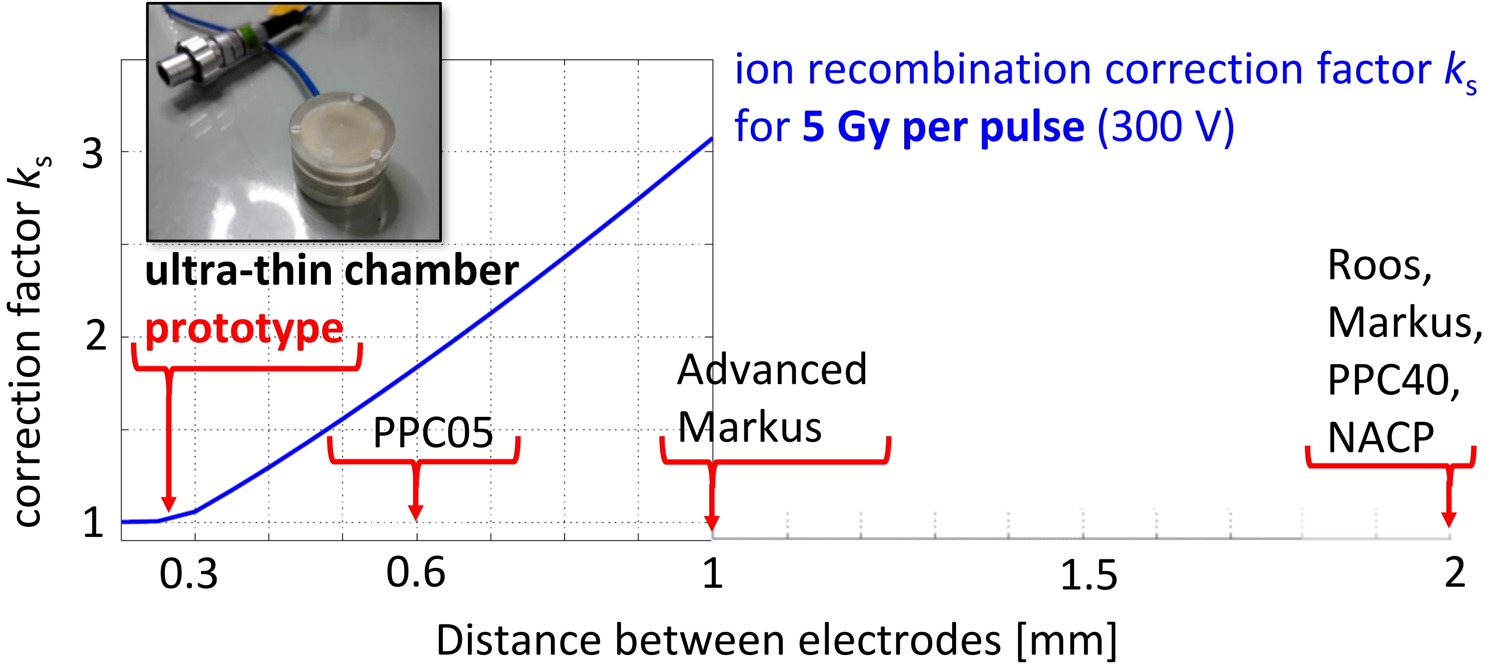




Jose Paz-Martín (USC), today WP2

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

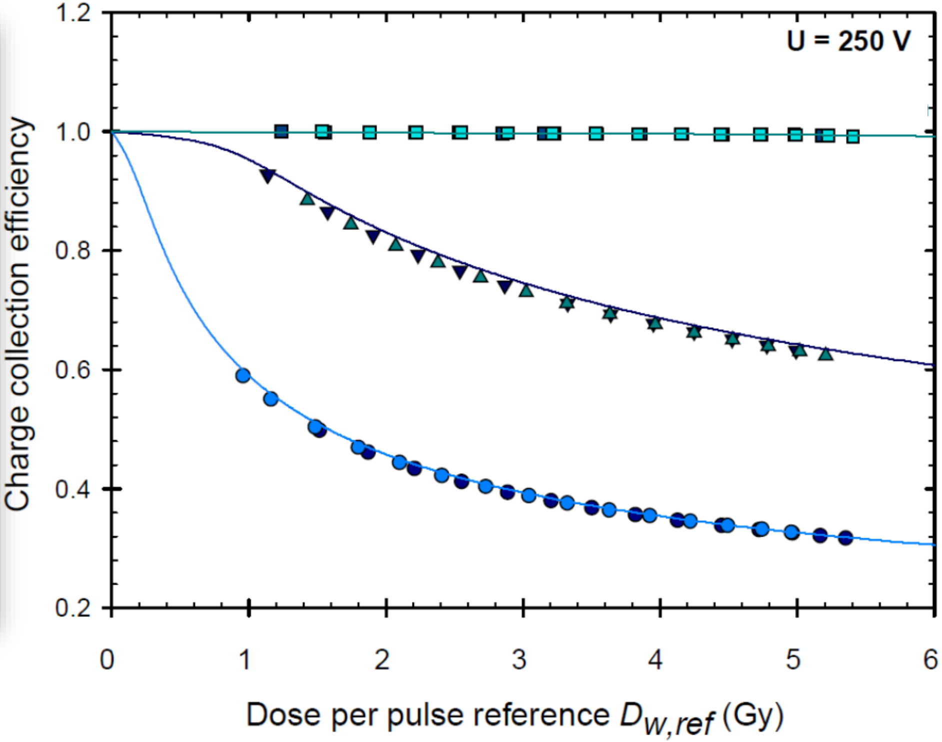


ion recombination correction factor k_s for **5 Gy per pulse** (300 V)

Faustino Gomez (USC), today WP2

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



electrode distance

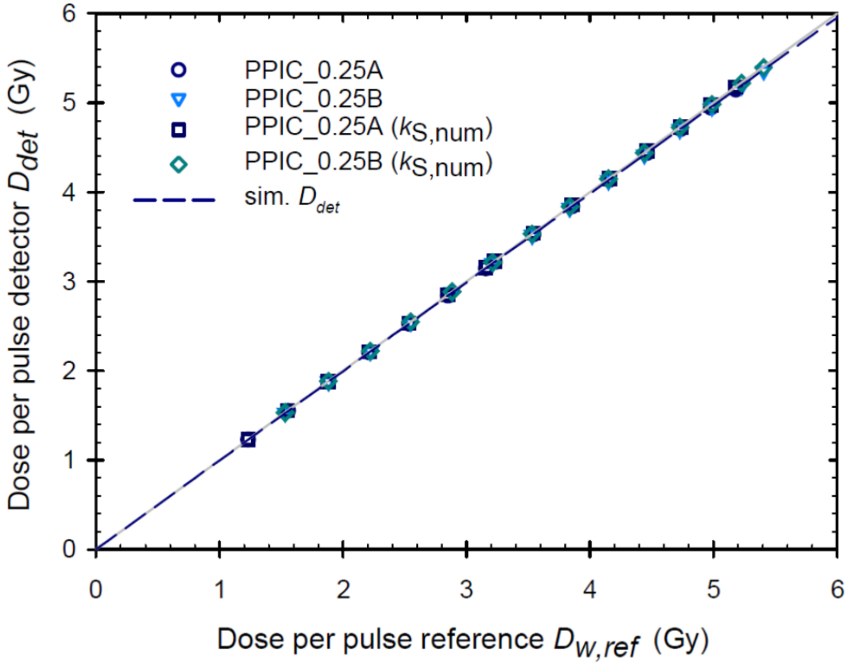
0.25 mm

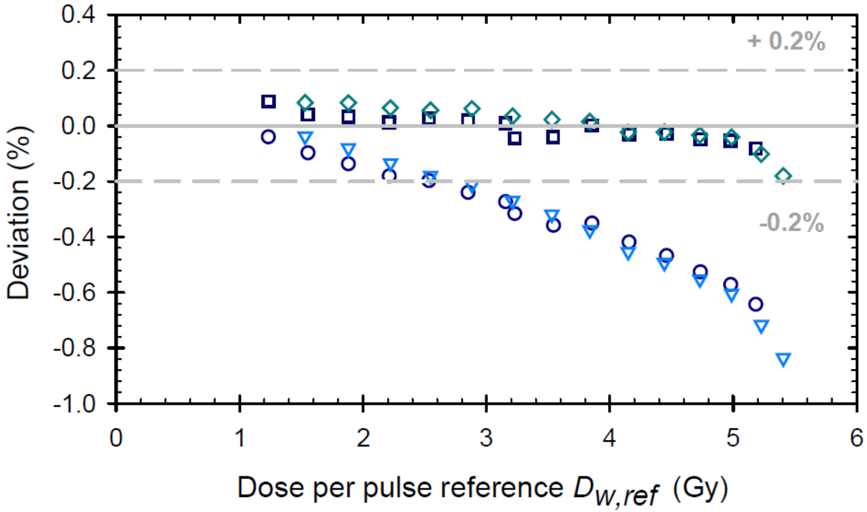
0.5 mm

1 mm

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

Ultra-thin ionization chamber for FLASH RT

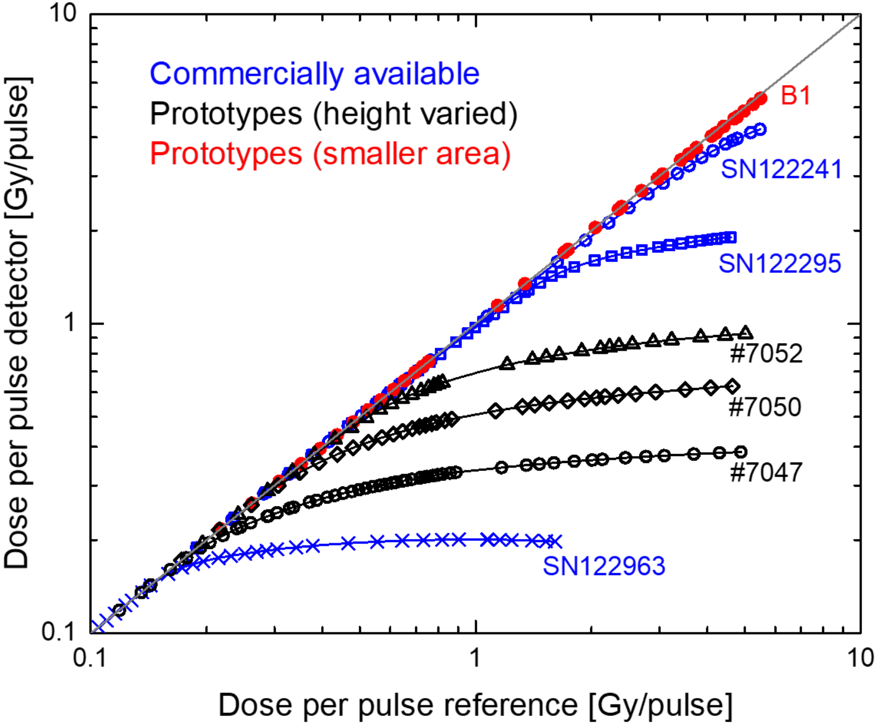




Faustino Gomez (USC), today WP2

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

microDiamond → flashDiamond

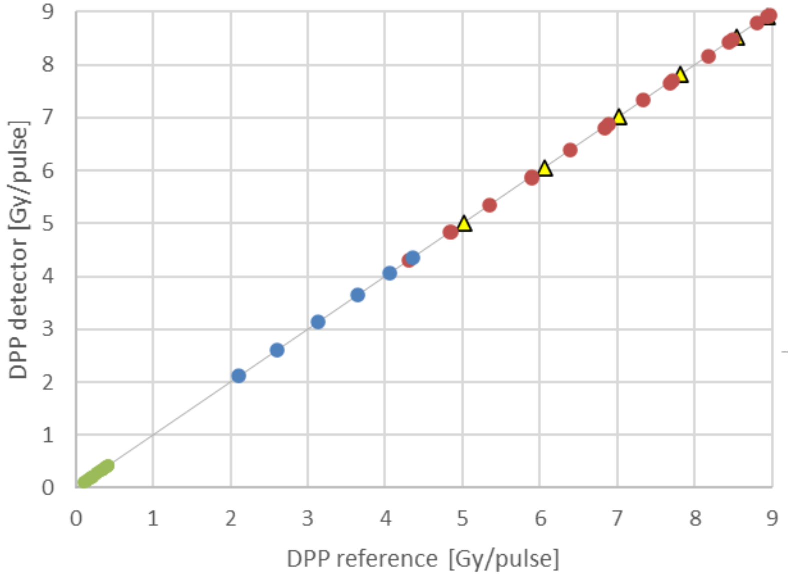


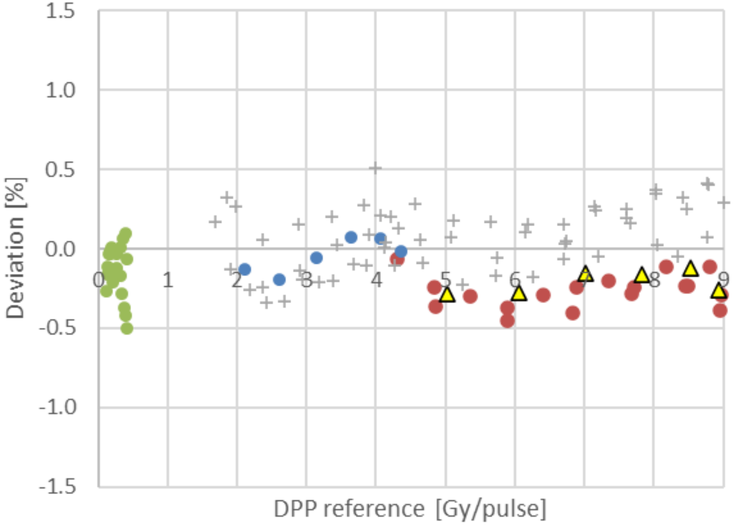
PTW THE DOSIMETRY COMPANY | TOR VERGATA UNIVERSITY OF ROME Dept. Industrial Engineering | PTB Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

Rafael Kranzer, today WP2

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

PTW T60025 flashDiamond



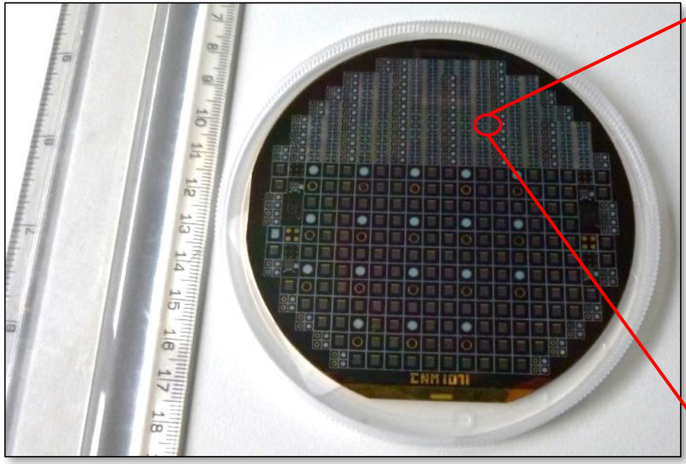


Gianluca Verona Rinati, today WP2

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

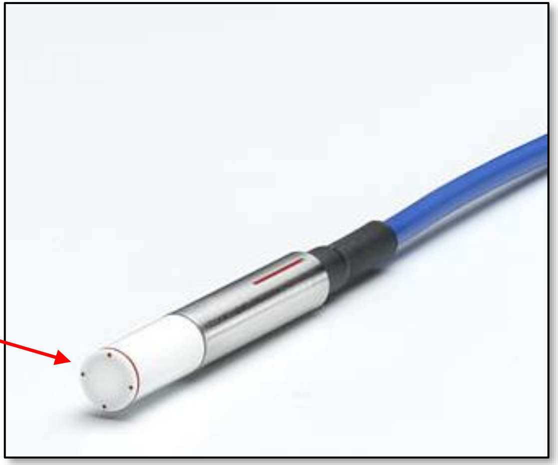
G. Verona Rinati et al.
“Application of a novel diamond …”
Med. Phys. **49** (2022) 5513.
https://doi.org/10.1002/mp.15782

SiC diodes for FLASH dosimetry



4" SiC wafer

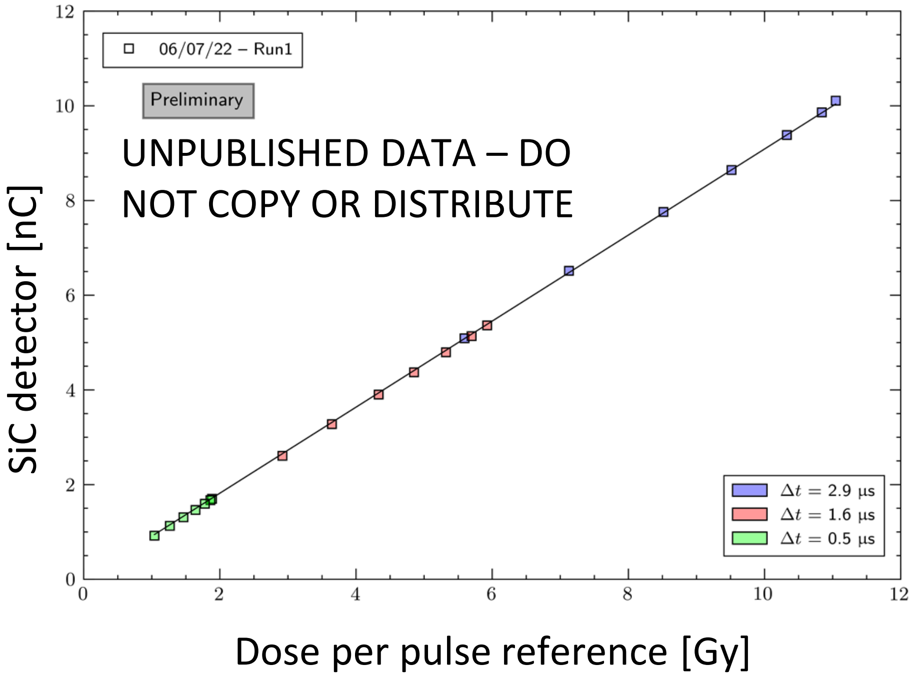
1 mm diode



Encapsulation by PTW (microSilicon housing)

Application for Patent EP22383168.6

SiC diodes for FLASH dosimetry



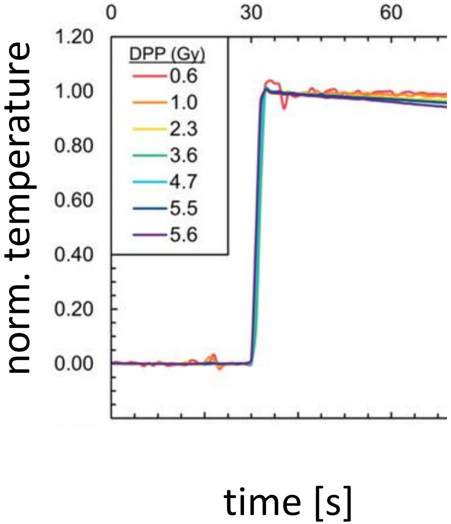
C. Fleta et al.
"Characterization of silicon carbide detectors in ultrahigh dose per pulse electron beams", in preparation

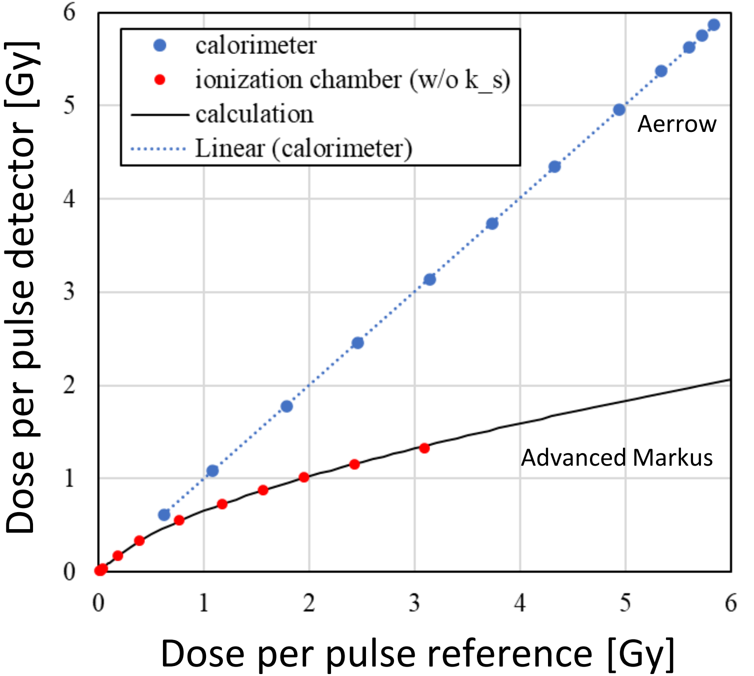
Celeste Fleta (CSIC), tomorrow WP3

Application for Patent EP22383168.6

Graphite probe calorimeter “Aerrow”

Calorimeter Aerrow
(and ionization chamber)



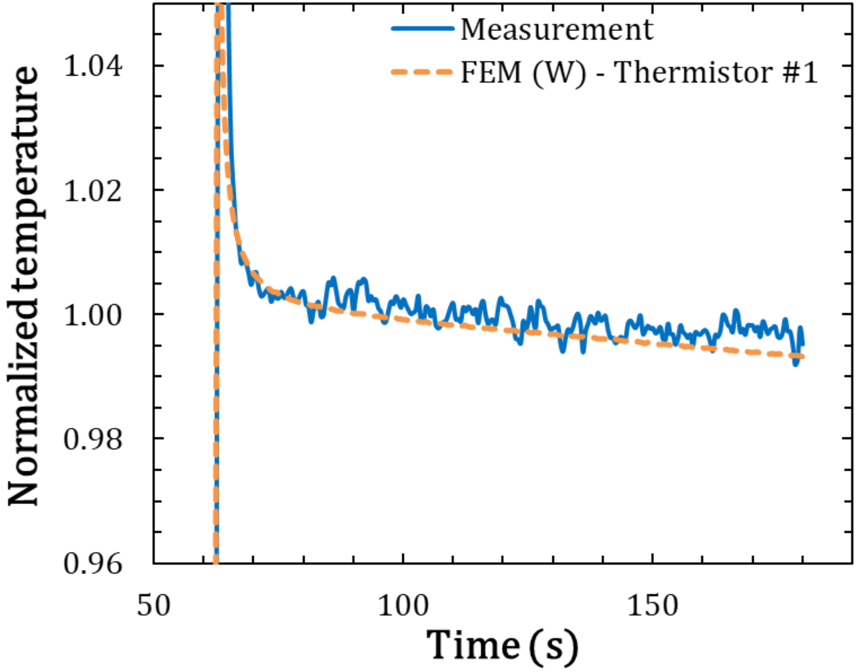


Alexandra Bourgouin (PTB), today WP2

A. Bourgouin *et al.*, “The probe-format graphite …”
Med Phys. **49** (2022) 6635.
https://doi.org/10.1002/mp.15899

Water calorimeter primary standard

PTB's primary standard of the unit Gy

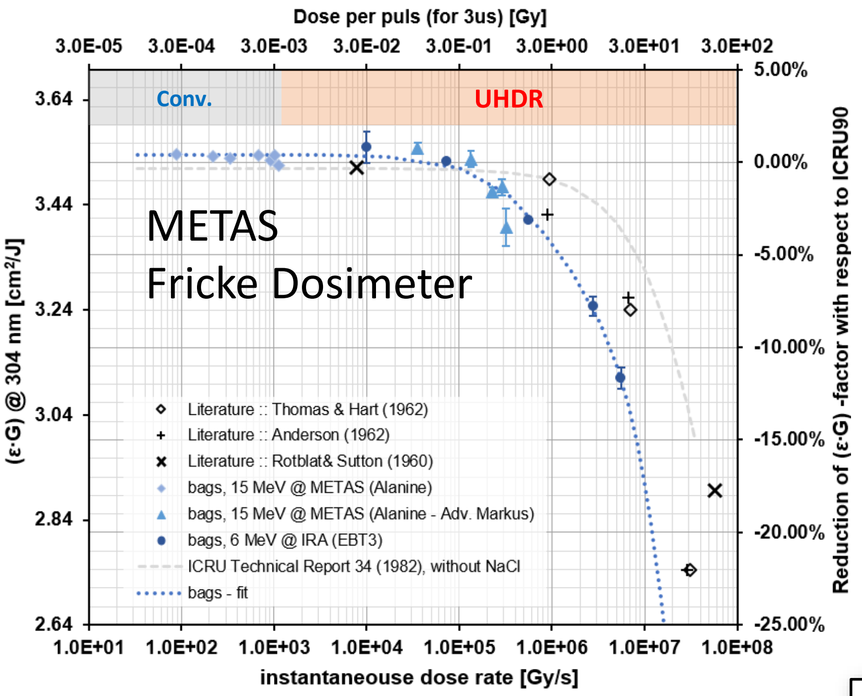


Alexandra Bourgouin (PTB), today WP1

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

Physikalisch-Technische Bundesanstalt Braunschweig und Berlin

Comparison of primary standards (D3)

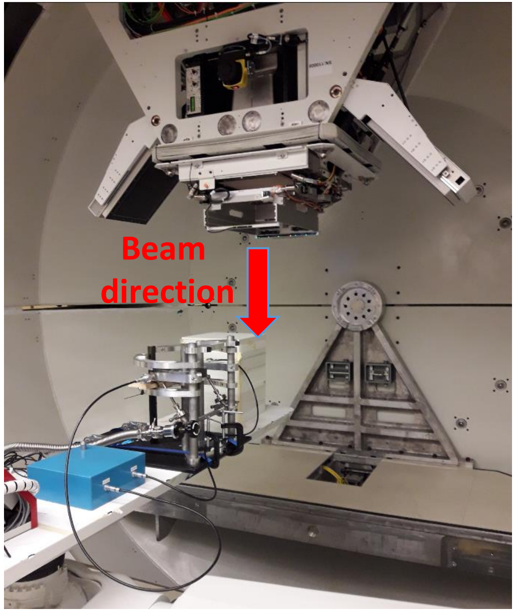


The ratio between the dose delivered by a calibrated ultra-high dose per pulse electron beam using the **METAS primary standard**, Fricke dosimeter, and the dose delivered by a calibrated ultra-high dose per pulse electron beam using the **PTB primary standard**, water calorimeter, was shown to be 1.002(12). 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.

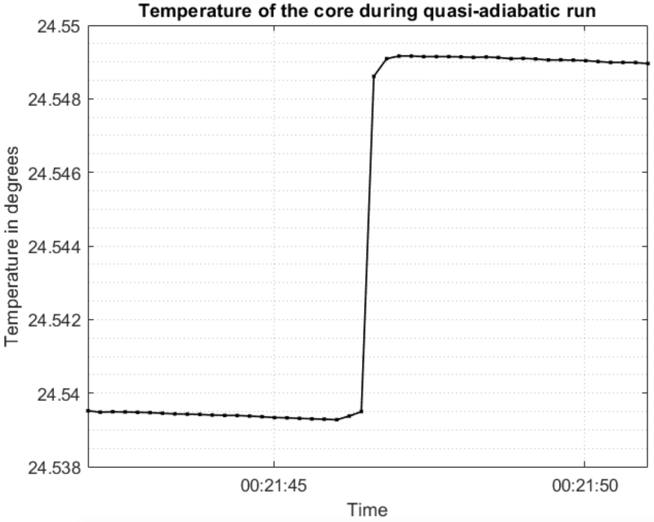
Alexandra Bourgouin (PTB), today WP1

Peter Peier (METAS), today WP1

Calorimetry in UHDR proton beams (D2)



NPL's graphite calorimeter in FLASH proton beam



Anna Subiel (NPL), today WP1

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

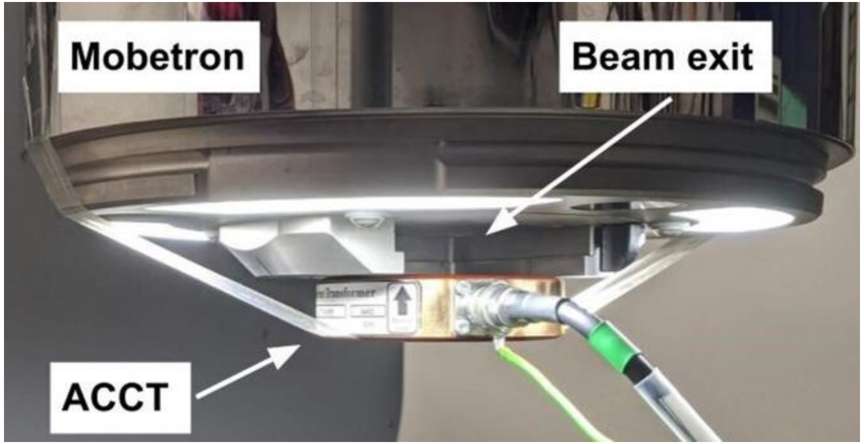
- Established the correction factors required for absolute dosimetry of FLASH proton beam radiotherapy
- Measurement uncertainty of 0.9% (k=1)
- **Underpinned the FDA approval and provided the hospital with confidence to commence clinical implementation**

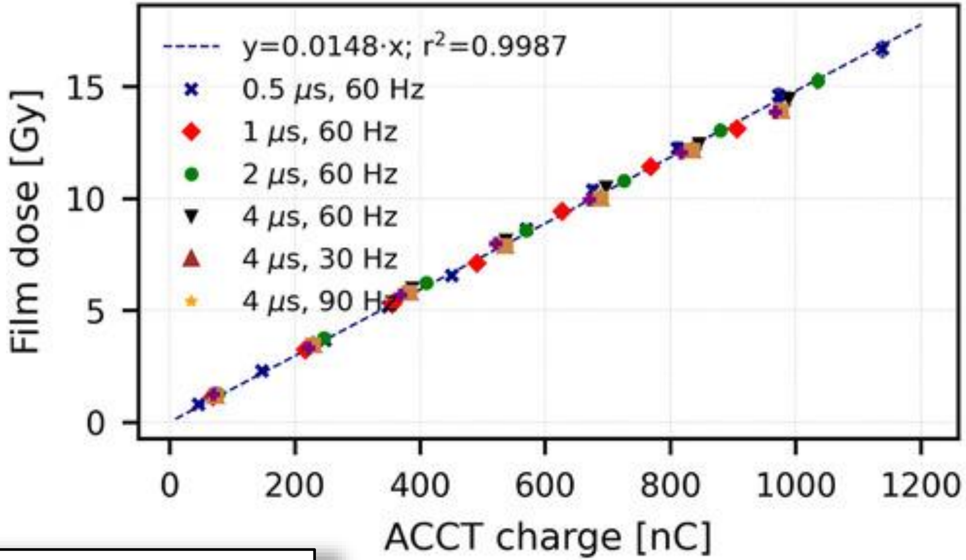
A. Lourenco et al. "Absolute dosimetry for FLASH proton ..."
Scientific Reports (2023), accepted.

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

NPL National Physical Laboratory | institut Curie | HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

Beam monitors for FLASH RT





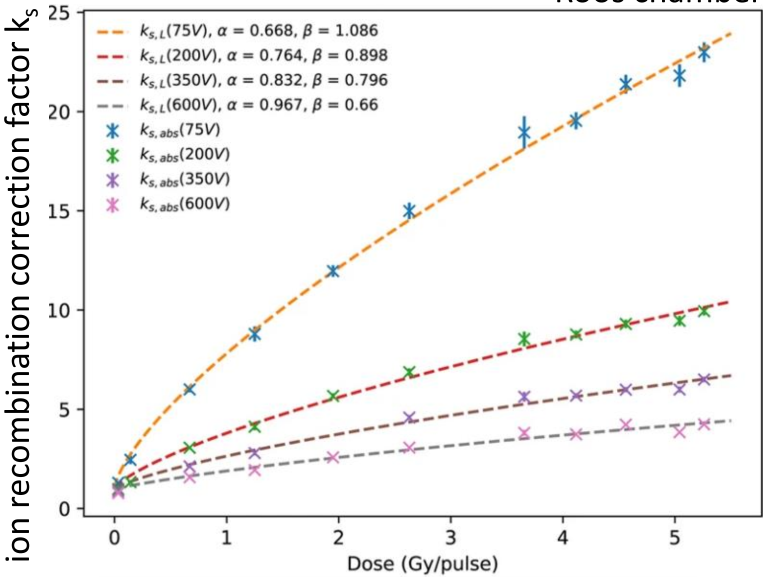
Claude Bailat (CHUV), tomorrow WP3

CHUV Centre hospitalier universitaire vaudois | bergoz INSTRUMENTATION | IntraOp

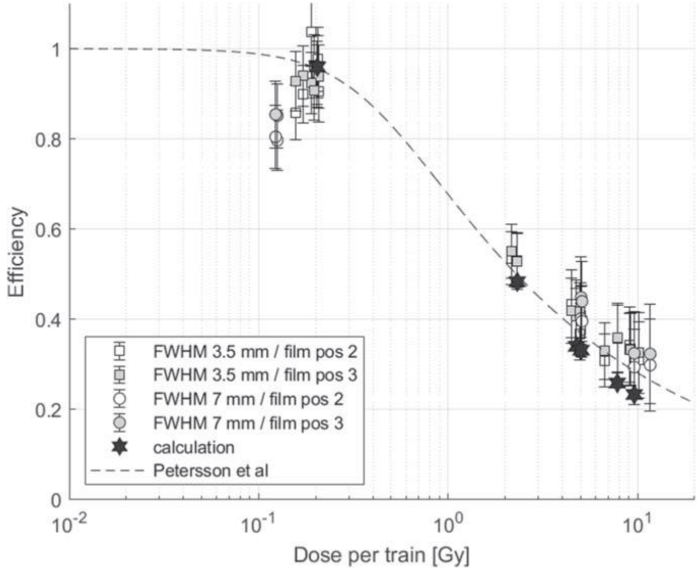
R. Oesterle et al., "Implementation and validation of a beam-current …"
J Applied Clin Med Phys 22 (2021) 165
https://doi.org/10.1002/acm2.13433

Dosimetry for VHEE

Roos chamber



Advanced Markus chamber

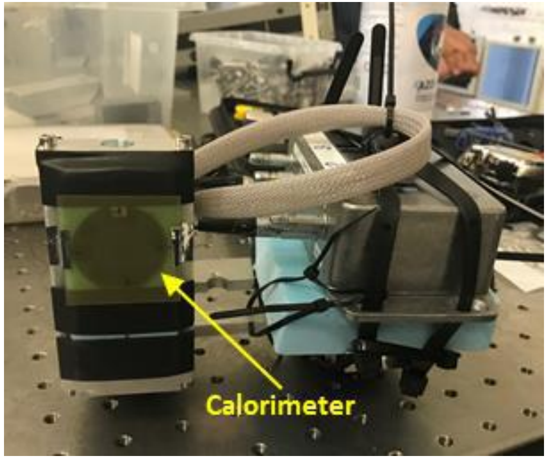


Anna Subiel (NPL), today WP2

M. McManus, et al. “The challenge of ionisation chamber…”
Sci Rep 10 (2020) 9089
https://doi.org/10.1038/s41598-020-65819-y

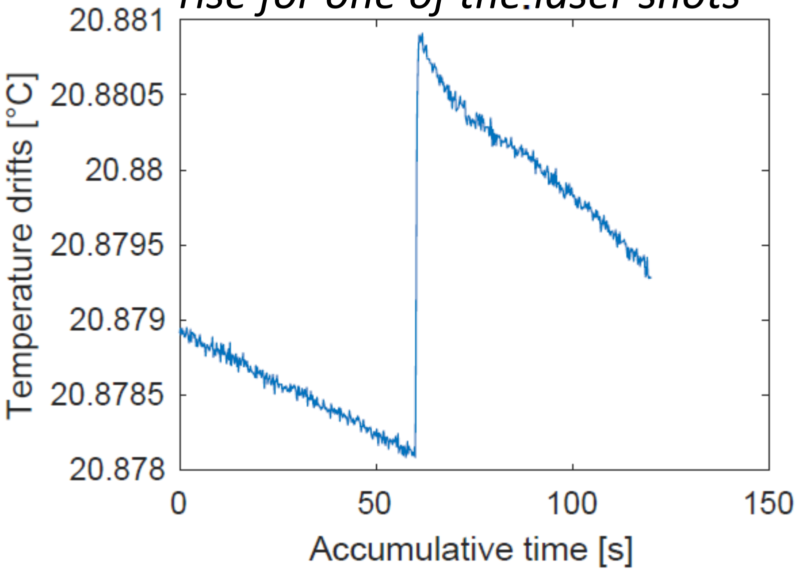
Daniela Poppinga et al. “VHEE beam dosimetry …”
Biomed. Phys. Eng. Express 7 (2021) 015012
https://doi.org/10.1088/2057-1976/abcae5

Dosimetry for laser driven beams



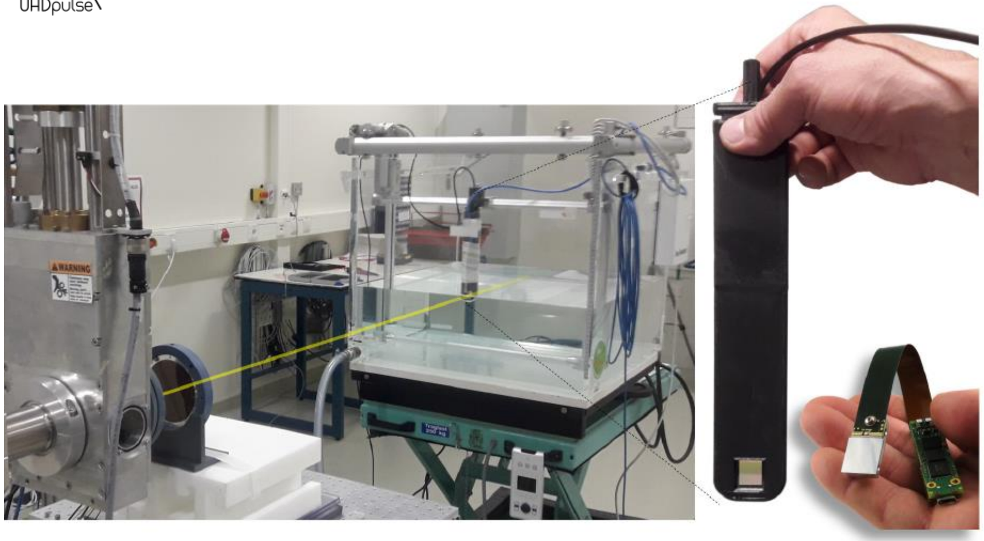
Sean McCallum (QUB), today WP1

Radiation induced temperature rise for one of the laser shots

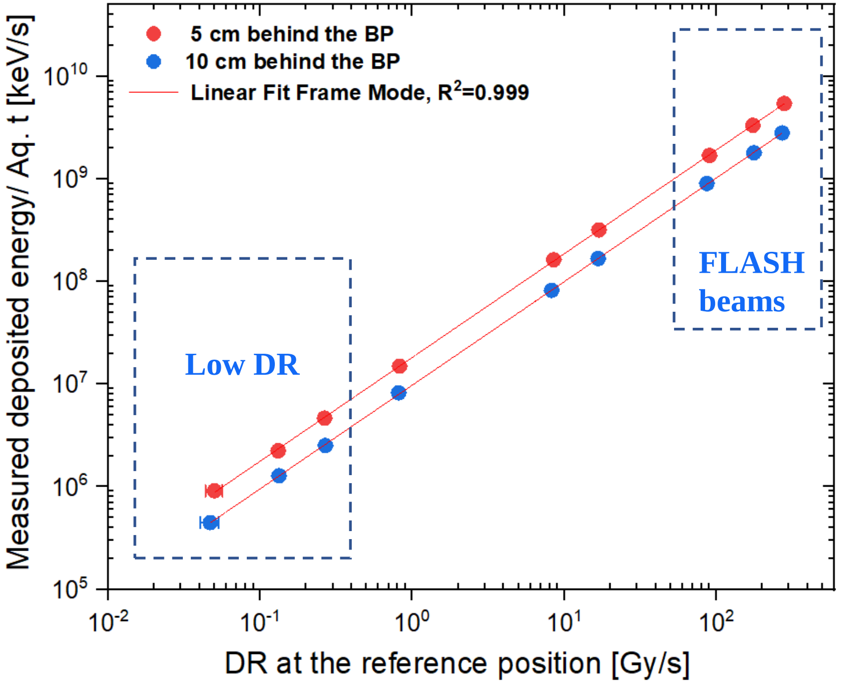


F. Romano et al., “Challenges in dosimetry …”
J. Phys.: Conf. Ser. 1662 (2020) 012028
https://doi.org/10.1088/1742-6596/1662/1/012028

Out-of-field measurements with TimePIX3



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



Cristina Oancea (ADVACAM), tomorrow WP4

ADVACAM Imaging the Unseen | HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF | CMI 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

34 Contributions with UHDpulse Acknowledgement
(25 oral presentations, 9 poster)
all abstracts and 5 UHDpulse full papers published in FRPT special issue in "Physica Medica"

Centre hospitalier universitaire vaudois | InspireProject | institut Curie | PTB

FRPT follow-up

> 650 Participants,
~400 onsite

to be discussed

15 UHDpulse Contributions
(5 oral presentations, 10 posters)
Offer: “UHDpulse final paper” in FRPT special issue in “Radiotherapy & Oncology”

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	No. of items reported	Previously reported	New items
1	STANDARDS & REGULATORY ACTIVITIES (STAN)	**5**	2	3
2	PEER REVIEWED OPEN ACCESS SCIENTIFIC PUBLICATIONS (PUB)	**33**	9	24
3	CONFERENCE PRESENTATIONS & POSTERS (CONF)	(72 Oral) **100**	21	79
4	TRAINING (TR)	**1**	1	0
5	OTHER DISSEMINATION (OTH)	**49**	9	40
6	FOLLOW-ON COLLABORATIONS (FOLL)	**1**	0	1
7	END USER UPTAKE & EXPLOITATION (UP)	**0**	0	0
8	COLLABORATORS & STAKEHOLDERS (COLL)	**28**	16	12
9	APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC (IP)	**1**	0	1
10	EXPLOITABLE RESULTS, ETC (RES)	**1**	0	1
11	FUTURE EVENTS (FUT)			
12	OPEN RESEARCH DATA (DATA)	**0**	0	0

Acknowledgement

(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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Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
Bundesallee 100
38116 Braunschweig

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

01/2023