2023
Annual report

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Foreword

We started a new journey as the Particle Therapy Research Center (PARTREC) at the University Medical Center Groningen at the end of 2019. The PARTREC community had to embrace not only the change to a new organizational structure but also the unprecedented changes brought about by the worldwide 2020 Covid pandemic. We all have heard that the success of an individual or of an organization can be measured in the way it responds to change. At PARTREC, we embraced together the change and managed to transform it into new opportunities.

When I reflect on the year 2023, I am struck by the trailblazing nature of our staff who support each other and have been part of many impressive initiatives, within PARTREC and in collaboration with scientists in academia and the private sector. It is because of our team enthusiasm that we have continued to successfully carry out our missions in service, training, research and innovation in physics, radiobiology and radiation therapy while preparing new initiatives in nuclear and veterinary medicine.

We have faced together major challenges in the stability of the accelerator due to known and unknown reasons. We have embraced these challenges and made the major decision to shift from a reactive work culture to a proactive one, entering the longest facility maintenance period in decades. This was much needed as the scope of our research shifted fully to medical applications which require a high level of customization and highly variable particle beam settings over short periods, in much contrast with the era of nuclear physics experiments.

We started to investigate and address the causes of the accelerator instability, knowledge transfer in general and new hires training in particular. Technical, academic, business and organizational initiatives were undertaken for the short and long-term development of PARTREC.

As one browses the Annual Scientific Report, one will quickly realize that it is a reflection of our community's impressive commitment to PARTREC's future and the potential for PARTREC to play a central role in advancing radiation medical sciences and helping patients around the world.

For all this, I am grateful to our staff and faculty and remain confident that together we can make PARTREC a big success.

Prof. Dr. Stefan Both
Scientific Director PARTREC

August 2024

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About PARTREC

General information

The UMCG Particle Therapy Research Center (PARTREC) is a dedicated research facility embedded in the Departments of Radiation Oncology, and Biomedical Sciences of the UMCG. It operates a large superconducting cyclotron for experimental research, mainly in radiation physics and biology, to support further development of radiotherapy with beams of protons and other ions. The cyclotron delivers beams of ions ranging from protons to oxygen with energies up to 190 MeV for protons and 90 MeV per nucleon for ions of helium to oxygen. The accelerator is furthermore used for research in nuclear chemistry by the faculty of the University of Groningen and for radiation hardness testing by science and industry. Some 25 FTE of technical staff operate the accelerator facility and provide the support to design, build, and operate experimental stations.

The UMCG PARTREC accelerator facility is well integrated with the research landscape and participates in various EU projects. The facility is open to the worldwide scientific community and industry.

PARTREC mission statement

PARTREC, the UMCG Particle Therapy Research Center, promotes multidisciplinary research in which accelerator physics, radiation physics, medical physics and biology, imaging, nuclear medicine, radiotherapy, big-data analysis and clinical research come together to improve the quality of proton therapy treatment and explore potential benefits of other particles for cancer treatment.

PARTREC combines in a unique way technology development, preclinical research and patient studies into an R&D program to continuously improve proton therapy technology and treatment and to demonstrate the accompanying clinical and economic benefits. Proton Flash and the usefulness of particles other than protons for high-precision radiotherapy is investigated as well.

The physics and biology of particle therapy, with a special focus on proton therapy, is a strategic research priority of UMCG. PARTREC is a dedicated research facility functioning in cooperation with the UMCG Groningen Proton Therapy Center (GPTC): patient care and clinical research are performed at the GPTC, while radiation biology and physics are investigated at PARTREC.

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Facilities at PARTREC

PARTREC is a dedicated research facility functioning in cooperation with the UMCG Groningen Proton Therapy Center (GPTC). We uniquely combine technological development, preclinical and patient studies with an R&D program to continuously improve proton therapy technology and the treatment itself, while assessing the feasibility of other particles for high-precision radiotherapy.

Resources

The AGOR Cyclotron

- The superconducting AGOR cyclotron provides protons at up to 190 MeV and heavy-ion beams at 30MeV per amu (up to Xenon) or 90 MeV per amu (up to Oxygen).
- For more specifications of our equipment, please contact us. Our contact details can be found below.

In-air Irradiation Facility

- This setup can be used for cell culture irradiations and various tests for medical diagnostic equipment as well as for commercial irradiations of electronic devices to be used for space research.

Laboratory Space Facilities

- For cell cultures, a flow cabinet and incubators are available. This equipment can be used in two separate laboratories.
  a. Incubators
  b. Flow cabinets
  c. Cell culture facilities

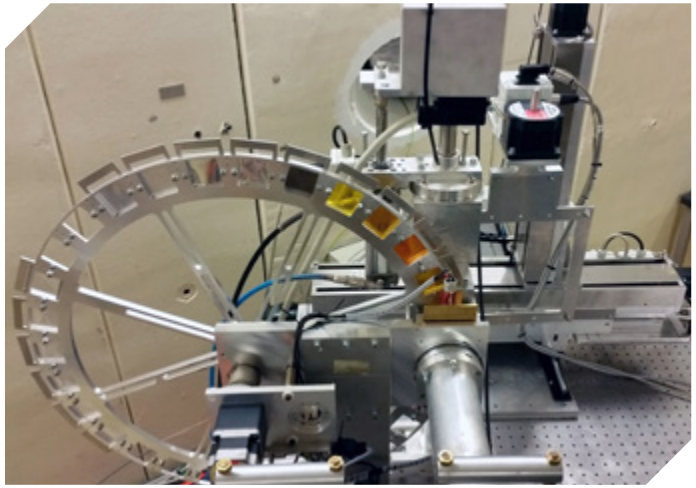
Features of the Proton and Heavy Ion Irradiation Facility

Irradiation and Field Forming System

- Device-Under-Test (DUT)s are irradiated in air
- Scatter foils and an X-Y scan magnet system provide a homogeneous beam
- The magnets scan the heavy ion beam
- Changing beam parameters:
  a. Seconds to change beam intensity
  b. One hour between different species in the ion cocktail
  c. Eight hours from protons to ions (or from ions to protons)
  d. Eight hours to change ion cocktail energy

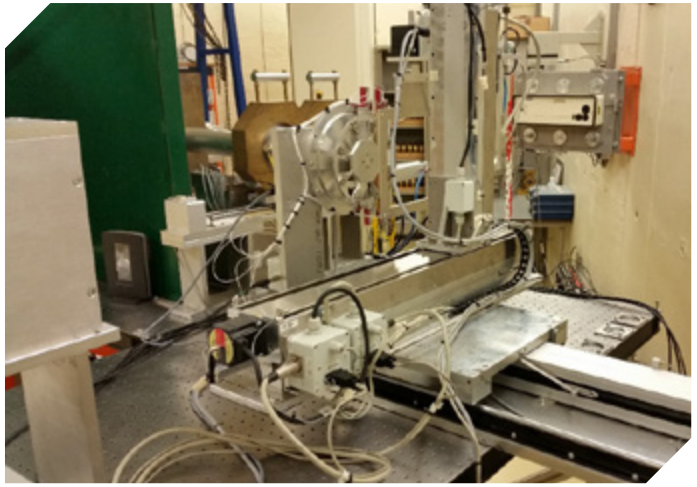
Degrader System

- A remotely controlled degrader is used to vary proton beam energy on DUT
- Degrader consists of movable carbon slabs of various thicknesses.
- A Si detector is used to guarantee beam purity
- A scintillation foil (LanexTM) is used to check field homogeneity (figure to the right)



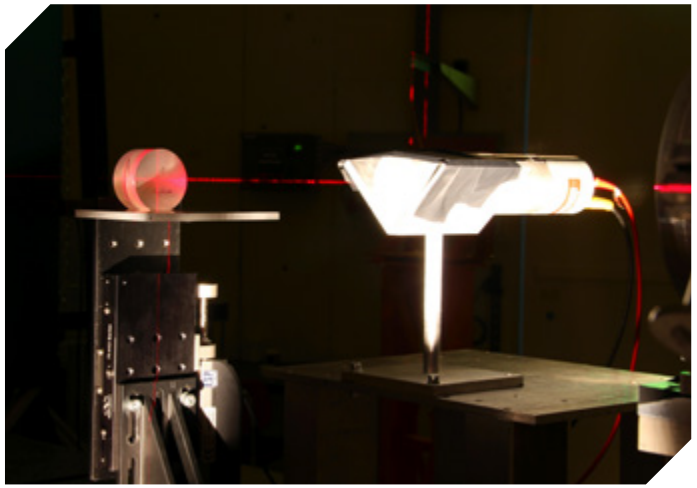
Positioning

- The X-Y-table is also movable in z-direction for tuning the beam energy
- A rotation stage is included to allow the device to be irradiated at any angle
- Alignment is done via the lasers
- Video cameras for live view on DUT



Fluence Monitoring and Measurement

- Flux is monitored using four fast scintillation ‘edge detectors’ (YAP:Ce crystals readout with a Hamamatsu R12421 photo multiplier) by SCIONIX
- The ratio between upper/lower left and right ‘edge detectors’ monitors whether or not the field uniformity is changing
- Fluence is measured using a scintillation detector with a known surface area



Services

Academic Research Services

For scientific research, there are several ways that beam hours can be funded at our facility. Proposals must be submitted through the website of the individual project (see list below) after first consulting PARTREC staff about the feasibility and overall planning of your experiment. We then appreciate receiving the proposals submitted in the framework of these projects.

Here are projects that currently offer funding:

1. RADNEXT: RADiation facility Network for the EXploration of effects for indusTry and research
2. RIANA: Continuously Open Research Announcement for Investigations into the Biological Effects of Space Radiations
3. CORA-IBER: Accelerator and Research reactor Infrastructures for Education and Learning

Previously, the following projects offered funding:

1. ARIEL: Accelerator and Research reactor Infrastructures for Education and Learning
2. INSPIRE: Infrastructure in Proton International Research
3. ENSAR2 (ended in 2021): European Nuclear Science and Applications Research - 2

Industrial/ Commercial Services

We have been selling our beam time to commercial clients since 2005. This consists of proton in-air irradiations to non-domestic aerospace companies. There have been over 50 companies requiring our service over the years, 16 are return customers and 5 companies return every year.

Commercial beam hours can be obtained without a proposal for a fixed rate. If you are interested in beam time, please send your inquiry to our irradiations liaison via email: irradiations.partrec@umcg.nl.

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Research and Development at PARTREC

The PARTREC research and development program covers a full range of work needed to convert fundamental physics and biology knowledge into clinically useful tools. Therefore, it has been focused on answering the physics-related needs of the radiation biology program and novel radiotherapy technology development in terms of hardware and software in collaboration with academic and industrial partners.

To meet the requirements of future experiments for internal and external users developments related to the beam (for ex. elements related to the beamline, FLASH mode, etc.) and upgrade of the irradiation facilities have been undertaken (for ex. infrastructure for high precision biology experiments).

The biology research continued to be directed to and translated into prediction, prevention and treatment of normal tissue side effects. The FLASH program has been added for Physics, Biology and Radiation Oncology research while new venues in Nuclear Medicine Physics, such as Theranostics, have been initiated in collaboration with UMCG Nuclear Medicine and Shine. All research should be aimed to produce high-impact results and publications both from a scientific and a societal point of view.

Research Groups from PARTREC

GROUP LEADER: Alexander Gerbershagen
GROUP NAME: Accelerator and Radiation Physics

PARTREC operates a superconducting cyclotron AGOR, providing proton and ion test beams to several test beam rooms. In addition to operating, maintaining and upgrading the facility, the Accelerator and Radiation Physics Team is working on further development of the accelerator system and its components for boosting of beam intensity and extension of accelerated particle types, as well as on advanced beam control, beam and patient diagnostics and dosimetry.

Topics within the research line

- Development of novel dose delivery methods and dose application techniques
- Increase of the beam intensity for FLASH irradiations
- Development of dosimetry and dose control for irradiations with ultra-high dose rates
- Extension of the ion cocktail to heavier ions
- Production of radioisotopes for nuclear medicine
- Combination of boron proton capture with FLASH irradiations

GROUP LEADER: Marco Schippers
GROUP NAME: Accelerator Physics

Research is focused on the optimization and development of new technologies for the use of the beams from AGOR. Beam development procedures are improved by developing and implementing standardized procedures. Driven by ongoing scientific projects, investigations are performed on methods of beam delivery under specific conditions.

GROUP LEADER: **Peter Dendooven**
GROUP NAME: **In vivo verification of proton therapy**

We investigate positron emission imaging for real-time dose delivery verification during proton therapy. We focus on the translation of nitrogen-12 imaging to the clinic, and on combining this with proton radiography.

GROUP LEADER: **Sytze Brandenburg (Emeritus)**
GROUP NAME: **Accelerator Physics and Delivery Room**

We primarily focus on advancing particle radiotherapy. Our expertise spans accelerator physics and technology, radiation physics, and medical physics. We lead projects in developing image-guided preclinical particle therapy research and supervise technical and engineering staff in accelerator R&D. Our work in radiation physics is dedicated to enhancing particle therapy, aiming to improve its efficacy and precision in medical treatments.

Research Groups associated with PARTREC

GROUP LEADER: Julia Even
GROUP NAME: Nuclear chemistry & physics

Our research focus are exotic, atomic nuclei far away from the valley of stability. In particular, we are interested in heavy, neutron-rich nuclei which are relevant for the synthesis processes of heavy elements in our universe. At PARTREC we are building a new experiment called NEXT to study Neutron-rich, heavy, EXOTIC nuclei produced in multinucleon Transfer reactions.

GROUP LEADER: Lara Barazzuol
GROUP NAME: Radiation-induced adverse effects in the brain

When using radiotherapy in the treatment of brain tumours, damage to normal brain tissue is an unavoidable side effect. Lara Barazzuol's research group aims to understand the underlying biological and molecular mechanisms of radiotherapy-induced neurocognitive dysfunction.

GROUP LEADER: Peter van Luijk
GROUP NAME: Translational normal tissue radiobiology

At the interface between lab and clinic, we use animal models to elucidate processes leading to normal tissue damage and translate this knowledge into clinically applicable strategies to reduce the side effects of radiotherapy. These strategies are subsequently tested in clinical studies.

GROUP LEADER: **Rob Coppes**
GROUP NAME: **Effects of radiation on normal tissues**

Our lab is investigating how radiation-induced environmental changes influence the regenerative response of tissues:

- Our main goal is to understand the molecular mechanism related to stem cell functioning after irradiation.
- We aim to unravel the processes that inhibit stem cell functioning after irradiation using in vivo and in vitro organoid models.
- We dissect changes in gene expression of cells in the tissue stem cell niche post-irradiation to study the interaction between stem cells and their surrounding cells to find tools to optimize regeneration.
- With this knowledge we aim to understand how to optimize stem cell therapies to ameliorate radiation-induced normal tissue side effects

GROUP LEADER: **Stefan Both**
GROUP NAME: **Instrumentation and FLASH Dosimetry**

Our research is focused on proton radiography measurements and interpretation towards clinical translation for static and moving targets. Currently materialized in two clinical programs in Head and Neck Cancer and Lung.

Flash research is focused on small animal high-precision irradiation employing conformal flash and experimental setup optimization in radiobiology. The first experiments were conducted in organoids and mice to follow.

Research Collaborations

Group leader	Collaboration partners
Alex Gerbershagen	
Academic/ Industrial	Beam Physics: • GaToroid (with CERN and Oxford University) • Statis Gantry (with MGH, Harvard Medical School and RCNP (Osaka University)) • CLEAR/FLASH VHEE (with CERN and Oxford University) • AWAKE (with CERN) • Experiments and detector technology • AMBER • NA60+ • SHADOWS • HIKE Networks we are in: • Next Ion Medical Machine Study (NIMMS) • Enlight • Joint Universities Accelerator School (JUAS) • The European Committee for Future Accelerators • (ECFA) Detector R&D Roadmap Process Group • COST Mission • "MultIChem "- Multiscale Irradiation and Chemistry Driven Processes

Julia Even	
Academic/ Industrial	• Superheavy element physics group at GSI Helmholtz Center for Heavy Ion Research, Darmstadt, Germany. • Superheavy element physics group at Helmholtz-Institute Mainz, Mainz, Germany • Superheavy element physics group at the Johannes Gutenberg University of Mainz, Mainz, Germany • Accelerator Laboratory, University of Jyväskylä, Jyväskylä, Finland • Darmstadt's MR ToF Collaboration (DA's MR-ToF): Technical University of Darmstadt (Germany), the University of Greifswald (Germany), the University of Groningen, the University of Manchester (UK), the Massachusetts Institute of Technology (U.S.A.), the Johannes Gutenberg University Mainz (Germany), and the University of Innsbruck (Austria). • Pre-enrichment of calcium: Radboud University, Nijmegen (the Netherlands) • ENW-XL: University of Amsterdam, Nikhef Amsterdam, University of Utrecht, University of Groningen, University of Maastricht

Lara Barazzuol	
Academic	• Martin McCabe, University of Manchester, UK. • Thomas Merchant, St. Jude Children's Research Hospital, US. • Ricardo M. Papaléo, Pontifical Catholic University of Rio Grande do Sul (PUCRS), Brazil. • Theodossis Theodossiou, University of Oslo, Norway.
Industrial	• IBA (Ion Beam Applications SA).

Peter Dendooven	
Academic	• GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
Industrial	• Siemens Healthineers • RaySearch Laboratories

Sytze Brandenburg	
Academic	• UMCG NGMB: development of radionuclide production and associated pre-clinical research at PARTREC
Industrial	• SHINE: development of radionuclide production at PARTREC • EVIDENSIA: development of small animal proton therapy clinic at PARTREC

Scientific Highlights

Julia Even

- Successful commissioning of the MutliReflection-Time-of-Flight Spectrometer for NEXT
- Arrival of the solenoid magnet of NEXT

Lara Barazzuol

- Irradiation of human brain organoids and experimental animal brains with SOBP protons.

Marc-Jan van Goethem

- **1st Remote irradiation:** We performed a commercial remote irradiation experiment in 2019 with an Italian commercial electronics company where we constructed their setup and they used a remote connection to the DAQ system computer which they sent to us along with their setup, to perform the measurements.
- **Carbon-radiation on cell:** Carbon ion irradiations of cell cultures and organoids have been performed since 2008. In 2019, we performed irradiations of plant seeds for a commercial company to increase the rate of naturally occurring mutations. By then selecting mutations with favourable characteristics like new flower shapes or colours one can breed new varieties. Without irradiations finding new varieties can take decades with irradiations it takes a few years. This method has the advantage that because the mutations take place by naturally occurring processes the product is not classified as gene-modified and can therefore be used and marketed without special permissions.
- **The first high-dose rate irradiations of organoids:** In 2023 we performed the first high-dose rate irradiations of organoids in order to study the FLASH effect in proton irradiations. The FLASH effect is an observation that the biological response of normal tissue to irradiations is reduced when using high dose rates (>40 Gy/s) while the tumour response remains unaffected. At PARTREC we have achieved a dose rate of 60Gy/s, in a scattered field this is a factor 3600 higher than what is normally used in proton therapy and normal dose rate experiments where the dose rate is of order of 1Gy per minute.
  These experiments are part of the first stage of a project with the aim to study if the FLASH effect can be used to improve the treatment of stage-1 breast tumours. The FLASH effect may help to reduce the chance of developing complications in healthy tissue surrounding the tumour. In the coming years, we will further develop FLASH spot scanning techniques to allow irradiation of larger targets and further escalate the dose rate to ~200Gy/s.

Peter Dendooven

- First experiments on nitrogen-12 positron emission imaging at a clinical proton therapy facility (GPTC).

Peter van Luijk

- May 2023 was the 5th lustrum of the radiobiology beam line/experiments that also in 2023 led to the clinical implementation of a stem cell-sparing radiotherapy technique that is now standard treatment for all head&neck cancer patients in Groningen. The technique has recently been tested in 6 other hospitals (national and international) and will be used by others as well. It's a nice example of long-term impact: the science for this was conceived @PARTREC in an elaborate series of experiments from 2001-2009.

Stefan Both

- The conformal FLASH irradiation basis was developed in a Monte Carlo simulation framework for the PARTREC TWIN Beam. In vitro experiments for its validation will be performed once the beam becomes available again to prepare a universal methodology to personalize small animal conformal flash irradiations.

Research Projects and Funding

Each year our researchers apply for and receive funding from various research funding agencies across the world. Below we list the projects that received funding and started with a starting date in 2023. Note that one or more of these projects may have been awarded with an acceptance letter in the year before. The starting date is when both the UMCG and the funding agency agree that the Grant Agreement enters into force.

#	Group Leader	Funding Body	Project Title	Funding Awarded
1	A. Gerbershagen	EU	(RIANA) Research Infrastructure Access in Nanoscience & nanotechnology	€ 49,725.00
2	A. Gerbershagen	NWO	(SOBP-FLASH) Development of Spread-Out-Bragg-Peak treatment techniques with hadron beams on FLASH time scale	€ 432,000.00
3	P. Dendooven	FSE, RuG	Learning by doing: Radiation physics and nuclear imaging	€ 36,801.00

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Facts and Figures

Facility uptime/ downtime summary

Year	% Downtime	Main Causes of Downtime
2020	79.1	Pandemic/EMC1
2021	42.3	EMC1/Cryo
2022	44.9	Cryo/He Compressor
2023	70.1	Cryo/He Compressor/Long Shutdown

Evaluation criteria for calculating downtime

Examine the weeks where the beam was scheduled to be delivered (26 weeks per year).

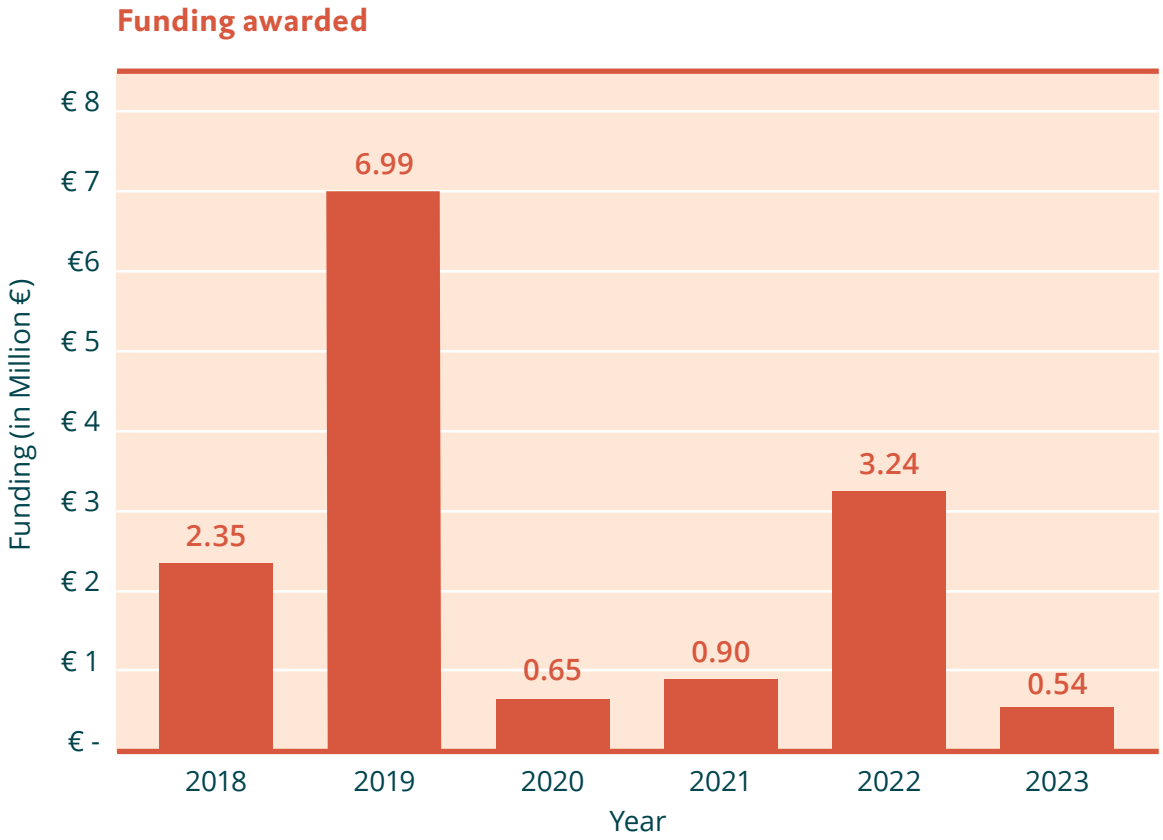
- Evaluate if it would be technically possible to deliver it or not.
- We ignore if we actually had customers or not.
- Major shutdowns due to technical failure (EMC1 and compressor) are considered downtime.
- COVID period:
  - Delays in repair due to COVID lockdown are considered downtime.
  - The machine is up, but customers are not able to travel is considered uptime.

In 2023, the operation periods were limited to January-March and May-June. In June, a prolonged technical shutdown was started, with the goal of restarting beam operation in spring 2024. There were three main reasons for the shutdown's execution.

a. Compensation for the maintenance backlog from the past decade and replacement of aged and obsolete components.
b. Installation of the beamline components and experimental stations for the IMPACT platform for small animal irradiations, and for the nuclear physics experiment NEXT.

c. The electricity price has peaked in 2023. Given the necessity of the shutdown for the two aforementioned reasons, performing it during 2023 has been considered to be financially advantageous for the facility, saving on excessive electric power costs.

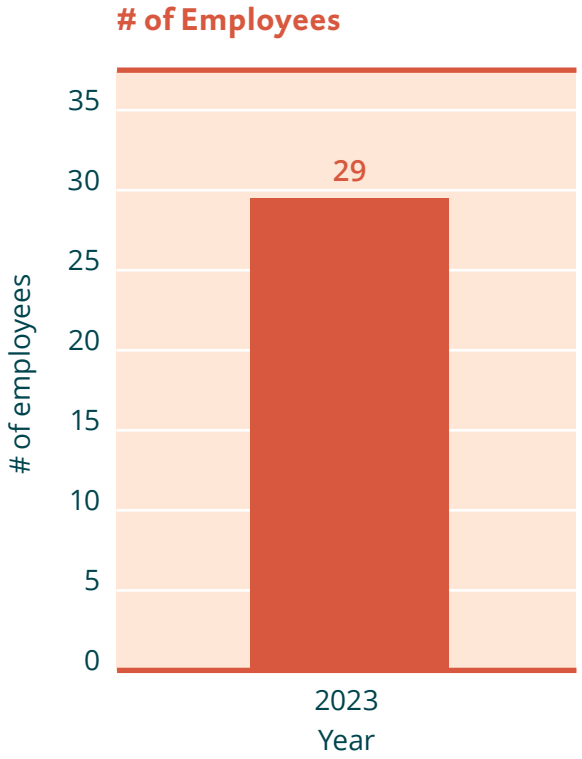
Research funding received/ Projects awarded

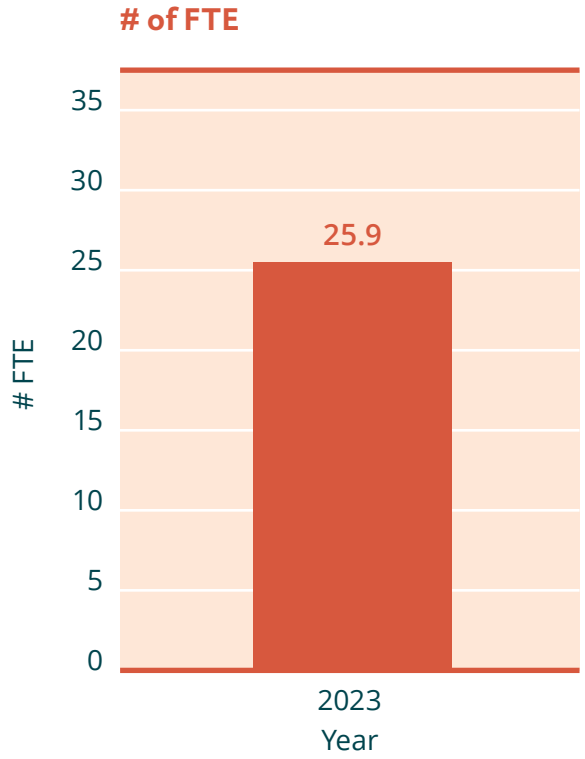


*See the previous section for a list of projects that started in 2023.

Personnel

Note that these facts and figures include only the staff from PARTREC and do not include the other academic staff who are associated with PARTREC.





Nationalities	
Belgium	1
Canada	1
Germany	1
Netherlands	25
Pakistan	1

Management team BBT	
Henk Heidekamp	Cluster Director
Prof. Dr. Stefan Both	Head of PARTREC
Prof. Dr. Alexander Gerbershagen	Head of AGOR
Dr. Marc-Jan van Goethem	Deputy Head of AGOR
Prof. Dr. Sytze Brandenburg	Emeritus Professor
Prof. Dr. Rob Coppes	Head of Radiobiology
Ria Woldhuis	Financial Controller
Ria Ubels	Quality Assurance Manager and Staff Advisor
Mallikarjuna Gurram	Project Manager and Grant support
Monique Grevens	Secretary (resigned in late 2023)

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Education

Teaching and training is also a core activity within the PARTREC. The staff from PARTREC is involved in a wide range of educational activities spanning multiple faculties and institutions within our university and multiple short courses or invited lectures outside the university. Below we provide a list of education activities that are being coordinated by the staff from the PARTREC.

Alexander Gerbershagen	
1	Alexander Gerbershagen, *"Particle Therapy as Cancer Treatment Modality"*, Evidensia Veterinary Oncology educational series: proton radiotherapy and other new developments (Nieuwegein, Netherlands)
2	Alexander Gerbershagen, *"Accelerator Science and Particle Therapy"*, University of Oxford Graduate Lecture Programme, Oxford, United Kingdom
3	Alexander Gerbershagen, *"Beamlines for Fixed Target Experiments"*, University of Oxford Graduate Lecture Programme, Oxford, United Kingdom
4	Marco Schippers, *"Accelerators for proton therapy"*, 16.1. 2023, invited lecture at PSI Winterschool, Switzerland
5	Marco Schippers, *"Basic Physics for proton therapy"*, 16.1. 2023, invited lecture at PSI Winterschool, Switzerland
6	Marco Schippers, *"Introduction to Cyclotrons"*, 2.3.2023, John Adams Inst. invited lecture at Graduate Accelerator Physics Course, Hilary Term 2020, Physics Department, University of Oxford, Great Britain
7	Marco Schippers, *"The SC-cyclotron at PSI for proton therapy"*, 15.3.2023, invited lecture at Joint University Accelerator school (JUAS), PSI, Villigen, Switzerland

Emiel van der Graaf

1	Emiel van der Graaf, *"Radiation Physics Course"*, Biomedical Engineering, Faculty of Science and Engineering, University of Groningen, Period 1a, 2023-2024, Course code: WMBE033-05, https://ocasys.rug.nl/current/catalog/course/WMBE033-05#eac15c95-001e-401e-850a-296d6c1a8667
2	Emiel van der Graaf, *"Neutron module"*, Course Radiation Protection Expert, 2022-2023, January 31, 2023. https://www.rug.nl/education/courses/other-education/radiation-protection/edu/cd/
3	Emiel van der Graaf, Member of the Programme Committee Biomedical Engineering (Master and Bachelor), Faculty of Science and Engineering, University of Groningen.

Julia Even

1	Julia Even, *"Physical Properties of Materials II"*, Faculty of Science and Engineering, https://ocasys.rug.nl/2022-2023/catalog/course/WBCH041-05
2	Julia Even, *"Nuclear Physics"*, Faculty of Science and Engineering, https://ocasys.rug.nl/2022-2023/catalog/course/WBPH011-05
3	Julia Even, *"Nuclear and Radiochemistry"*, Faculty of Science and Engineering, https://ocasys.rug.nl/2022-2023/catalog/course/WBCH052-05
4	Catherine Rigollet (second teacher: Julia Even), *"Nuclear Astrophysics"*, Faculty of Science and Engineering, https://ocasys.rug.nl/2022-2023/catalog/course/WMPH038-05
5	Julia Even & Han van der Straate, *"Frontiers of Science"* - Summer school & Attelier, Honours college, https://ocasys.rug.nl/2022-2023/catalog/course/HCSW000405
6	Han van der Straate & Julia Even, Honours college tutorial *"Masses from subatomic particles to galaxies"*, Honours College, https://ocasys.rug.nl/2022-2023/catalog/course/HCSE11002#b8da4b41-a09a-4533-af2b-37d5db5e2214

Peter Dendooven	
1	Peter Dendooven, *"Medical Imaging Instrumentation"*, Faculty of Science and Engineering, https://ocasys.rug.nl/2022-2023/catalog/course/WMME014-05
2	Peter Dendooven, *"Ionizing Radiation in Medicine"*, Faculty of Science and Engineering, https://ocasys.rug.nl/2022-2023/catalog/course/WBPH007-05
3	Peter Dendooven, Chair of the Programme Committee of the MSc programme Mechanical Engineering, Faculty of Science and Engineering, University of Groningen

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Business Development

Alexander Gerbershagen

1	There are improvements meant at providing heavy ion beams with higher penetration depth in silicon, making our offer more attractive for commercial companies.
2	An appointment has been set with ESA for a verification test.
3	Examination of an integration of potential veterinary clinic at PARTREC are ongoing.

Rob Coppes

1	Stem cell therapy: Radiotherapy of head and neck cancer is often accompanied with dysfunction of the salivary glands leading to xerostomia (dry mouth syndrome). Basic science by the Coppes' lab linked this to the identification of a salivary gland cell stem compartment that is depleted by radiation. This has now developed into a stem cell therapy in which stem cells from the patient are collected before and given back after radiation for the treatment of this side effect. After pre-clinical testing and development of a protocol for safe clinical use (https://ascopubs.org/doi/full/10.1200/JCO.21.01208), a first-in-man Phase I/II trial will start this summer at the UMCG.

Stefan Both

1	Patent: Positioning system for radiotherapy Both, S. (Inventor) & Guterres Marmitt, G. (Inventor), 31-Aug-2023, Patent No. WO2023163589, 21-Feb-2023, Priority date 22-Feb-2022

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Outreach

Besides research and education, all scientific staff members from PARTREC, including PhD students, postdocs, and group leaders, have been actively involved in the scientific outreach and dissemination activities. Below we list out the notable activities by PARTREC during the year 2023.

Alexander Gerbershagen

1 Zpannend Zernike event took place on 1.10.2023. PARTREC welcomed over 400 visitors.

2 Alexander Gerbershagen gave a seminar organizer and presenter of a lecture “Accelerator Physics and its Applications” for University of Groningen Honours College at Particle Therapy Research Center (PARTREC)

Emiel van der Graaf	
1	Emiel van der Graaf, Particle Therapy Research Center, presentation for high school students from Gymnasium Zwolle, September 28, 2023
2	Emiel van der Graaf, Decommissioning of large infrastructure, presentation at the graduation event of the Radiation Protection Expert course of the University of Groningen, July 5, 2023

Julia Even	
1	*The origin of the chemical elements – What is NEXT?* Lecture at the Online Bachelor Week organized by the promotional team for Physics and Applied Physics, University of Groningen.
2	*Een gastdocent in de klas* organized by the NNV in honor of the International Day of Women and Girls in Science, Praedinius Gymnasium, Groningen 01/06/2023
3	*International Day of Women and Girls in Science*: https://www.nnv.nl/Gastdocent-in-de-klas
	All group members:
5	Zpannend Zernike, Groningen. 01/10/2023 (https://zpannendzernike.nl/)
6	Honours festival, Groningen 25/06/2023: Honours students presented model accelerators, information about proton and carbon therapy, cloud chamber and also videos about proton therapy to the general public
7	Honours festival - links to the videos prepared by students about PARTREC and proton therapy How Does a Cyclotron Work? (Petrus Camper Festival Video 1): https://youtu.be/9FkG5pUy_MU What is Proton Therapy? (Petrus Camper Festival Video 2): https://youtu.be/XCcbdSE0Vi8 From bed to bench and back (Petrus Camper Festival Video 3): https://youtu.be/_9ToFdLMbHo

Peter Dendooven	
1	Participation in the PARTREC Open Day as part of Zpannend Zernike, 1 October 2023

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Awards

Alexander Gerbershagen

1 Joseph Bateman, under the co-supervision of Alexander Gerbershagen, has received the best poster award at the VHEE 2023 conference in Hamburg for his work on high-intensity beam diagnostics.

Rob Coppes

1 Luc Sondorp from the group of Rob Coppes: 21- 2023 Kolff Paper of the year - Societal Impact Award 2022 - Luc Sondorp (Rob Coppes group) and co authors recieved 2023 Kolff Paper of the year - Societal Impact Award 2022 – for: Noltes ME, Sondorp LHJ, Kracht L, Antunes IF, Wardenaar R, Kelder W, Kemper A, Szymanski W, Zandee WT, Jansen L, Brouwers AH, Coppes RP* and Kruijff S*. Patient-derived parathyroid organoids as a tracer and drug-screening application model. Stem Cell Reports 2022, 17, 2518–2530.

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APPENDIX 1:
PhD Graduations

More details about the PhD graduations can be found on the university research portal.

1	PHD STUDENT: PROMOTOR(S): CO-PROMOTER(S): THESIS TITLE: URL:	Steven van der Veeke Brandenburg, Sytze, Supervisor van der Graaf, Emiel, Co-supervisor UAV-borne radioelement mapping: towards a guideline and verification methods for geophysical field measurements https://research.rug.nl/en/publications/uav-borne-radioelement-mapping-towards-a-guideline-and-verificati
2	PHD STUDENT: PROMOTOR(S): CO-PROMOTER(S): THESIS TITLE: URL:	Carmen Seller Oria Both, Stefan, Supervisor Brandenburg, Sytze Proton radiography for in vivo range verification in adaptive proton therapy https://research.rug.nl/nl/publications/proton-radiography-for-in-vivo-range-verification-in-adaptive-pro
3	PHD STUDENT: PROMOTOR(S): CO-PROMOTER(S): THESIS TITLE: URL:	Adrian Thummerer Both, Stefan, Supervisor Langendijk, Johannes Albertus Deep learning-based cone beam CT correction for adaptive proton therapy https://research.rug.nl/en/publications/deep-learning-based-cone-beam-ct-correction-for-adaptive-proton-t

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APPENDIX 2: Publications

More details about these publications can be found on the university research portal.

Alexander Gerbershagen	
1	Upgrade of the AGOR Cyclotron Control System at UMCG-PARTREC Kuiken, O. J., Schwab, J., van Abbema, J. K., Schakel, P. & Gerbershagen, A., 1-Dec-2023, Proceedings of the 19th International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS'23). JACoW Publishing, p. 391-394 4 p.
2	The physics program of the NA60+ experiment De Falco, A. & NA60+ Collaboration, 1-Mar-2023, In: EPJ Web of Conferences. 276, 4 p., 05005.
3	Study of coil configuration and local optics effects for the GaToroid ion gantry design Oponowicz, E., Bottura, L., Dutheil, Y., Haziot, A. & Gerbershagen, A., 2023, 13th International Particle Accelerator Conference. IoP Publishing, 012100. (Journal of Physics: Conference Series; vol. 2420, no. 1).
4	SHADOWS Technical Proposal SHADOWS Collaboration, 30-Oct-2023, Geneva: CERN. 244 p.
5	PO - 1969: Microdosimetric approach for treatment planning in proton therapy Pisciotta, P., Magini, J., Traneus, E., Hussein, M., Both, S., Gerbershagen, A., Schettino, G. & Romano, F., 2023.
6	O 186 - Microdosimetry for treatment planning in proton therapy Pisciotta, P., Magini, J., Traneus, E., Hussein, M., Both, S., Gerbershagen, A., Schettino, G. & Romano, F., 2023.
7	Kaon beam simulations employing conventional hadron beam concepts and the RF separation technique at the CERN M2 beamline for the future AMBER experiment Metzger, F., Banerjee, D., Baratto Roldan, A., Bernhard, J., Brugger, M., Charitonidis, N., Dyks, L. A., Gatignon, L., Gerbershagen, A., Ketzer, B., Murphy, R., Mussolini, C. A., Nevay, L. J., Parozzi, E., Rae, B., Schuh-Erhard, S., Simon, P., Stergiou, V., Stummer, F. & van Dijk, M., 2023, In: Journal of Physics: Conference Series. 2687, 6 p., 052023.

8	HIKE: High Intensity Kaon Experiments at the CERN SPS Moulson, M. & The HIKE collaboration, 1-Feb-2023, In: Journal of Physics: Conference Series. 2446, 7 p., 012036.
9	High Intensity Kaon Experiments (HIKE) at the CERN SPS: Proposal for Phases 1 and 2 Lazzeroni, C. & The HIKE collaboration, 21-Nov-2023, CERN.
10	Dual-scattering foil installation at CLEAR Robertson, C., Bateman, J. J., Dosanjh, M., Korysko, P., Corsini, R., Farabolini, W., Latina, A., Malyzhenkov, A., Rieker, V. F., Wroe, L., Gerbershagen, A. & Aksoy, A., 26-Sept-2023, Proceedings IPAC'23. JACoW Publishing, p. 5059-5062 4 p.
11	Design of beam optics for RF-separated kaon and antiproton beams in the M2 beam line of the CERN North Area Gerbershagen, A., Andrieux, V., Bernhard, J., Brugger, M., Denisov, O., Friedrich, J., Gatignon, L., Gerigk, F., Guskov, A., Ketzer, B., Metzger, F., Nowak, W. D., Quintans, C. & Schuh, S., Mar-2023, In: Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 1048, 12 p., 168004.
12	Design of beam optics and radiation protection concept for NA60+ heavy-ion experiment at CERN Gerbershagen, A., Ahdida, C., Bernhard, J., Clerc, V., Girod, S., Scomparin, E., Usai, G. & Vincke, H., Feb-2023, In: Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 1047, 12 p., 167887.
13	Conceptual design of the magnetised iron block system for the SHADOWS experiment Stummer, F., Banerjee, D., Baratto Roldan, A., Bernhard, J., Boogert, S. T., Brugger, M., Charitonidis, N., D'Alessandro, G. L., Deniaud, M., Dyks, L. A., Gatignon, L., Gerbershagen, A., Gibson, S., Lanfranchini, G., Metzger, F., Murphy, R., Mussolini, C. A., Nevay, L. J., Parozzi, E. & Rae, B. & 6 others, , 26-Sept-2023, Proceedings IPAC'23. JACoW Publishing, p. 245-248 4 p.
14	Beam optics study for a potential VHEE beam delivery system Robertson, C. S., Burrows, P. N., Dosanjh, M., Latina, A. & Gerbershagen, A., 2023, In: Journal of Physics: Conference Series. 2420 , 6 p., 012102.

Emiel van de Graaf

1	A Monte-Carlo-based study of a single-2D-detector proton-radiography system Olivari, F., van Goethem, M.-J., Brandenburg, S. & van der Graaf, E. R., Aug-2023, In: Physica medica-European journal of medical physics. 112, 8 p., 102636.

Francesco Romano	
1	Recent developments in absolute dosimetry for FLASH radiotherapy Subiel, A. & Romano, F., 2023, In: British journal of radiology. 96, 1148, 10 p., 20220560.
2	Realization and dosimetric characterization of a mini-beam/flash electron beam Pensavalle, J. H., Romano, F., Celentano, M., Sarto, D. D., Felici, G., Franciosini, G., Masturzo, L., Milluzzo, G., Patera, V., Prezado, Y. & Di Martino, F., 16-Nov-2023, In: Frontiers in Physics. 11, 15 p., 1269495.
3	PO - 1969: Microdosimetric approach for treatment planning in proton therapy Pisciotta, P., Magini, J., Traneus, E., Hussein, M., Both, S., Gerbershagen, A., Schettino, G. & Romano, F., 2023.
4	O 186 - Microdosimetry for treatment planning in proton therapy Pisciotta, P., Magini, J., Traneus, E., Hussein, M., Both, S., Gerbershagen, A., Schettino, G. & Romano, F., 2023.
5	First Characterization of Novel Silicon Carbide Detectors with Ultra-High Dose Rate Electron Beams for FLASH Radiotherapy Romano, F., Milluzzo, G., Di Martino, F., D'Oca, M. C., Felici, G., Galante, F., Gasparini, A., Mariani, G., Marrale, M., Medina, E., Pacitti, M., Sangregorio, E., Vanreusel, V., Verellen, D., Vignati, A. & Camarda, M., Mar-2023, In: Applied Sciences (Switzerland). 13, 5, 12 p., 2986.

Julia Even	
1	Ion-extraction from the CISe gas catcher Cipagauta Mora, J., Brajkovic, M., Bouwman, N., Chen, X., Even, J., Hartigan, B., Soylu, A. & van der Werff, L., 4-Apr-2023.

Lara Barazzuol	
1	Social adversity during juvenile age but not adulthood increases susceptibility to an immune challenge later in life Guerrin, C. G. J., Doorduin, J., Prasad, K., Vazquez-Matias, D. A., Barazzuol, L. & de Vries, E. F. J., Mar-2023, In: Neurobiology of stress. 23, 10 p., 100526.

2	Prenatal infection and adolescent social adversity affect microglia, synaptic density, and behavior in male rats Guerrin, C. G. J., Prasad, K., Vazquez-Matias, D. A., Zheng, J., Franquesa-Mullerat, M., Barazzuol, L., Doorduin, J. & de Vries, E. F. J., Nov-2023, In: Neurobiology of stress. 27, 14 p., 100580.
3	Maternal infection during pregnancy aggravates the behavioral response to an immune challenge during adolescence in female rats Guerrin, C. G. J., de Vries, E. F. J., Prasad, K., Vazquez-Matias, D. A., Manusiwa, L. E., Barazzuol, L. & Doorduin, J., 24-Aug-2023, In: Behavioural Brain Research. 452, 10 p., 114566.
4	Effects of proton therapy on regional [18F]FDG uptake in non-tumor brain regions of patients treated for head and neck cancer Arif, W. M., Elsinga, P. H., Steenbakkers, R. J. H. M., Noordzij, W., Barazzuol, L., Siang, K. N. G. W., Brouwer, C. L., Giacobbo, B. L., Dierckx, R. A. J. O., Borra, R. J. H. & Luurtsema, G., Sept-2023, In: Clinical and Translational Radiation Oncology. 42, 14 p., 100652.
5	Mitophagy induction improves salivary gland stem/progenitor cell function by reducing senescence after irradiation. Cinat D, Lena De Souza A, Soto-Gamez A, Jellema-de Bruin AL, Coppes RP, Barazzuol L. Radiother Oncol. Radiother Oncol. 2023 Nov 23:110028. doi: 10.1016/j.radonc.2023.110028.

Marc-Jan van Goethem	
1	The Effects of Combined Exposure to Simulated Microgravity, Ionizing Radiation, and Cortisol on the In Vitro Wound Healing Process Radstake, W. E., Gautam, K., Miranda, S., Vermeesen, R., Tabury, K., Rehnberg, E., Buset, J., Janssen, A., Leysen, L., Neefs, M., Verslegers, M., Claesen, J., van Goethem, M. J., Weber, U., Fournier, C., Parisi, A., Brandenburg, S., Durante, M., Baselet, B. & Baatout, S., Jan-2023, In: Cells. 12, 2, 32 p., 246.
2	Impact of proton therapy on the DNA damage induction and repair in hematopoietic stem and progenitor cells Sioen, S., Vanhove, O., Vanderstraeten, B., De Wagter, C., Engelbrecht, M., Vandevoorde, C., De Kock, E., Van Goethem, M. J., Vral, A. & Baeyens, A., 2023, In: Scientific Reports. 13, 8 p., 16995.

3	A Monte-Carlo-based study of a single-2D-detector proton-radiography system Olivari, F., van Goethem, M.-J., Brandenburg, S. & van der Graaf, E. R., Aug-2023, In: Physica medica-European journal of medical physics. 112, 8 p., 102636.

Peter Dendooven

1	Quasi-real-time range monitoring by in-beam PET: a case for 15O Purushothaman, S., Kostyleva, D., Dendooven, P., Haettner, E., Geissel, H., Schuy, C., Weber, U., Boscolo, D., Dickel, T., Graeff, C., Hornung, C., Kazantseva, E., Kuzminchuk-Feuerstein, N., Mukha, I., Pietri, S., Roesch, H., Tanaka, Y. K., Zhao, J., Durante, M. & Parodi, K. & 1 others, , 2023, In: Scientific Reports. 13, 1, 17 p., 18788.
2	Precision of the PET activity range during irradiation with 10C, 11C, and 12C beams Super-FRS Experiment Collaboration, Kostyleva, D., Purushothaman, S., Dendooven, P., Haettner, E., Geissel, H., Ozoemelam, I., Schuy, C., Weber, U., Boscolo, D., Dickel, T., Drozd, V., Graeff, C., Franczak, B., Hornung, C., Horst, F., Kazantseva, E., Kuzminchuk-Feuerstein, N., Mukha, I. & Nociforo, C. & 9 others, , 1-Jul-2023, In: Physics in Medicine and Biology. 68, 1, 015003.

Peter van Luijk

1	Prediction of Radiation-Induced Parotid Gland-Related Xerostomia in Patients With Head and Neck Cancer: Regeneration-Weighted Dose van Rijn-Dekker, M. I., van Luijk, P., Schuit, E., van der Schaaf, A., Langendijk, J. A. & Steenbakkers, R., 1-Nov-2023, In: International Journal of Radiation Oncology Biology Physics. 117, 3, p. 750-762 13 p.
2	OC-0109 Functional dose to the parotid gland: a new regional based dose metric in NTCP models for xerostomia van Rijn-Dekker, M. I., van Luijk, P., Schuit, E., van der Schaaf, A., Langendijk, J. A. & Steenbakkers, R. J., 13-May-2023, p. S69-S70.
3	De volgende stap in het voorkomen van xerostomie bij hoofd-halskankerpatiënten na bestraling: stamcelsparende radiotherapie van Rijn-Dekker, I., van Luijk, P., Langendijk, J. A. & Steenbakkers, R., 13-Oct-2023.

4	Captopril mitigates radiation-induced cardiopulmonary side-effects only if the lung is spared Wiedemann, J., Brouwer, U., Schouten, M., Dickinson, M., de Boer, R., Coppes, R. P. & van Luijk, P., 2023.
5	Captopril mitigates radiation-induced cardiopulmonary side-effects only if the lung is spared Wiedemann, J., Brouwer, U., Schouten, M., Dickinson, M., de Boer, R., Coppes, R. P. & van Luijk, P., 2023.

Rob Coppes	
1	Mitophagy induction improves salivary gland stem/progenitor cell function by reducing senescence after irradiation. Cinat D, Lena De Souza A, Soto-Gamez A, Jellema-de Bruin AL, Coppes RP, Barazzuol L. Radiother Oncol . Radiother Oncol. 2023 Nov 23:110028. doi: 10.1016/j.radonc.2023.110028
2	Mesenchymal stem cell-derived HGF attenuates radiation-induced senescence in salivary glands via compensatory proliferation. Soto-Gamez A, van Es M, Hageman E, Serna-Salas SA, Moshage H, Demaria M, Pringle S, Coppes RP. Radiother. Oncol. Nov 4;190:109984. doi: 10.1016/j.radonc.2023.109984.
3	Clinical research for global needs of radiation oncology. Baumann M, Bacchus C, Aznar MC, Coppes RP, Deutsch E, Georg D, Haustermans K, Hoskin P, Krause M, Lartigau EF, Lee AWM, Löck S, Offersen BV, Thwaites DI, van der Heide UA, Valentini V, Overgaard J. Radiother. Oncol. Dec 28;190:110076. doi: 10.1016/j.radonc.2023.110076.
4	MET-receptor targeted fluorescent imaging and spectroscopy to detect multifocal papillary thyroid cancer. Metman MJH, Jonker PKC, Sondorp LHJ, van Hemel BM, Sywak MS, Gill AJ, Jansen L, van Diest PJ, van Ginhoven TM, Löwik CWGM, Nguyen AH, Robinson DJ, van Dam GM, Links TP, Coppes RP, Fehrmann RSN, Kruijff S. Eur J Nucl Med Mol Imaging. Nov 29. doi: 10.1007/s00259-023-06525-5.
5	Are hybrid conferences the new standard?. Michael Baumann, Carol Bacchus, Marianne C Aznar, Rob P Coppes, Eric Deutsch, Dietmar Georg, Karin Haustermans, Peter Hoskin, Mechthild Krause, Eric F Lartigau, Anne W M Lee, Steffen Löck, Birgitte V Offersen, Jens Overgaard, David I Thwaites, Albert J van der Kogel, Uulke A van der Heide, Vincenzo Valentini. Radiother. Oncol. 2023 Jul;184:109695. DOI: 10.1016/j.radonc.2023.109695.

6	Roadmap for precision preclinical x-ray radiation studies. Frank Verhaegen , Karl T Butterworth, Anthony J Chalmers, Rob P Coppes, Dirk de Ruysscher, Sophie Dobiasch , John D Fenwick, Patrick V Granton, Stefan H J Heijmans 0, Mark A Hill, Constantinos Koumenis, Kirsten Lauber , Brian Marples, Katia Parodi , Lucas C G G Persoon, Nick Staut, Anna Subiel, Rianne D W Vaes, Stefan van Hoof, Ioannis L Verginadis, Jan J Wilkens , Kaye J Williams, George D Wilson 0, Ludwig J Dubois. Phys. Med. Biol. 2023 Mar 31;68(6). DOI: 10.1088/1361-6560/acaf45.
7	The role of ESTRO guidelines in achieving consistency and quality in clinical radiation oncology practice. Birgitte Vrou Offersen, Marianne C Aznar, Carol Bacchus, Rob P Coppes, Eric Deutsch, Dieter Georg, Karin Haustermans, Peter Hoskin, Mechthild Krause, Eric F Lartigau 0, Anne W M Lee, Steffen Löck, David I Thwaites, Albert J van der Kogel, Uulke van der Heide, Vincenzo Valentini, Jens Overgaard, Michael Baumann. Radiother. Oncol. 2023 Feb;179:109446. DOI: 10.1016/j.radonc.2022.109446.
8	Organoids as a model to study intestinal and liver dysfunction in severe malnutrition. José M Horcas-Nieto, Christian J Versloot, Miriam Langelaar-Makkinje, Albert Gerding, Tjasso Blokzijl, Mirjam H Koster, Mirjam Baanstra, Ingrid A Martini, Robert P Coppes, Céline Bourdon, Sven C D van IJzendoorn, Peter Kim, Robert H J Bandsma, Barbara M Bakker. Biochim Biophys Acta Mol Basis Dis. 2023 Mar;1869(3):166635. DOI: 10.1016/j.bbadis.2022.166635.
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10	Esophageal Cancer-Derived Organoids to Predict Patients' Treatment Response. L Du, P W Nagle, P van Luijk, J Plukker, C Muijs, R P Coppes. Int J Radiat Oncol Biol Phys 2023. Oct 1;117(2S):e227.

Stefan Both	
1	TransRP: Transformer-based PET/CT feature extraction incorporating clinical data for recurrence-free survival prediction in oropharyngeal cancer Ma, B., Guo, J., van Dijk, L. V., van Ooijen, P., Both, S. & Sijtsema, N. M., 2023, p. 1640–1654. 15 p.
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3	Technical note: Evaluation of deep learning based synthetic CTs clinical readiness for dose and NTCP driven head and neck adaptive proton therapy de Koster, R. J. C., Thummerer, A., Scandurra, D., Langendijk, J. A. & Both, S., 2023, In: Medical Physics. 50, 12, p. 8023-8033 11 p.
4	SynthRAD2023 Grand Challenge dataset: Generating synthetic CT for radiotherapy Thummerer, A., van der Bijl, E., Galapon, A., Verhoeff, J. J. C., Langendijk, J. A., Both, S., van den Berg, C. A. T. & Maspero, M., Jul-2023, In: Medical Physics. 50, 7, p. 4664-4674 11 p.
5	Swin UNETR for Tumor and Lymph Node Segmentation Using 3D PET/CT Imaging: A Transfer Learning Approach Chu, H., De la O Arévalo, L. R., Tang, W., Ma, B., Li, Y., De Biase, A., Both, S., Langendijk, J. A., van Ooijen, P., Sijtsema, N. M. & van Dijk, L. V., 2023, Head and Neck Tumor Segmentation and Outcome Prediction - 3rd Challenge, HECKTOR 2022, Held in Conjunction with MICCAI 2022, Proceedings. Andrearczyk, V., Oreiller, V., Depeursinge, A. & Hatt, M. (eds.). Springer Science and Business Media Deutschland GmbH, p. 114-120 7 p. (Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); vol. 13626 LNCS).
6	Survival prediction for stage I-IIIA non-small cell lung cancer using deep learning Zheng, S., Guo, J., Langendijk, J. A., Both, S., N J Veldhuis, R., Oudkerk, M., van Ooijen, P. M. A., Wijsman, R. & Sijtsema, N. M., Mar-2023, In: Radiotherapy and Oncology. 180, 18 p., 109483.
7	Spot scanning proton arc therapy reduces toxicity in oropharyngeal cancer patients De Jong, B. A., Battinelli, C., Free, J., Wagenaar, D., Engwall, E., Janssens, G., Langendijk, J. A., Korevaar, E. & Both, S., Mar-2023, In: Medical Physics. 50, 3, p. 1305-1317 13 p.

8	Simple immobilization for stereotactic radiotherapy aimed at pelvic metastases Janssen, J., Brouwer, C. L., Staal, F. H. E., van Herpt, H. E., Both, S., Langendijk, J. A. & Aluwini, S., Jul-2023, In: Physics and imaging in radiation oncology. 27, 5 p., 100460.
9	PTV-based VMAT vs. robust IMPT for head-and-neck cancer: A probabilistic uncertainty analysis of clinical plan evaluation with the Dutch model-based selection Rojo-Santiago, J., Korevaar, E., Perkó, Z., Both, S., Habraken, S. J. M. & Hoogeman, M. S., Sept-2023, In: Radiotherapy and Oncology. 186, 8 p., 109729.
10	Proton arc therapy increases the benefit of proton therapy for oropharyngeal cancer patients in the model based clinic de Jong, B. A., Korevaar, E. W., Maring, A., Werkman, C. I., Scandurra, D., Janssens, G., Both, S. & Langendijk, J. A., Jul-2023, In: Radiotherapy and Oncology. 184, 9 p., 109670.
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12	Partitioning of discrete proton arcs into interlaced subplans can bring proton arc advances to existing proton facilities Engwall, E., Marthin, O., Wase, V., Sundström, J., Mikhalev, V., de Jong, B. A., Langendijk, J. A., Melbéus, H., Andersson, B., Korevaar, E. W., Both, S., Bokrantz, R., Glimelius, L. & Fredriksson, A., Sept-2023, In: Medical Physics. 50, 9, p. 5723-5733 11 p.
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14	Inter- and intrafractional 4D dose accumulation for evaluating ΔNTCP robustness in lung cancer Smolders, A., Hengeveld, A. C., Both, S., Wijsman, R., Langendijk, J. A., Weber, D. C., Lomax, A. J., Albertini, F. & Guterres Marmitt, G., May-2023, In: Radiotherapy and Oncology. 182, 6 p., 109488.
15	Dose evaluation of inter- and intra-fraction prostate motion in extremely hypofractionated intensity-modulated proton therapy for prostate cancer Feng, S. Q., Brouwer, C. L., Korevaar, E. W., Vapiwala, N., Kang-Hsin Wang, K., Deville, C., Langendijk, J. A., Both, S. & Aluwini, S., Jul-2023, In: Physics and imaging in radiation oncology. 27, 5 p., 100474.

16	Deep Learning and Radiomics Based PET/CT Image Feature Extraction from Auto Segmented Tumor Volumes for Recurrence-Free Survival Prediction in Oropharyngeal Cancer Patients Ma, B., Li, Y., Chu, H., Tang, W., De la O Arévalo, L. R., Guo, J., van Ooijen, P., Both, S., Langendijk, J. A., van Dijk, L. V. & Sijtsema, N. M., 18-Mar-2023, Head and Neck Tumor Segmentation and Outcome Prediction - 3rd Challenge, HECKTOR 2022, Held in Conjunction with MICCAI 2022, Proceedings. Andrearczyk, V., Oreiller, V., Depeursinge, A. & Hatt, M. (eds.). Springer Science and Business Media Deutschland GmbH, p. 240-254 15 p. (Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics); vol. 13626 LNCS).
17	CT-based deep multi-label learning prediction model for outcome in patients with oropharyngeal squamous cell carcinoma Ma, B., Guo, J., Zhai, T. T., van der Schaaf, A., Steenbakkers, R. J. H. M., van Dijk, L. V., Both, S., Langendijk, J. A., Zhang, W., Qiu, B., van Ooijen, P. M. A. & Sijtsema, N. M., Oct-2023, In: Medical Physics. 50, 10, p. 6190-6200 11 p.
18	Comparison of computed tomography image features extracted by radiomics, self-supervised learning and end-to-end deep learning for outcome prediction of oropharyngeal cancer Ma, B., Guo, J., Chu, H., van Dijk, L. V., van Ooijen, P. M. A., Langendijk, J. A., Both, S. & Sijtsema, N. M., Oct-2023, In: Physics and imaging in radiation oncology. 28, 8 p., 100502.
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20	Case-Matched Outcomes of Proton Beam and Intensity-Modulated Radiation Therapy for Localized Prostate Cancer Bao, A., Barsky, A. R., Both, S., Christodouleas, J. P., Deville, C., Tochner, Z. A., Vapiwala, N. & Maxwell, R., Oct-2023, In: International journal of particle therapy. 10, 1, p. 1-12 12 p.
21	Automated Robust Planning for IMPT in Oropharyngeal Cancer Patients Using Machine Learning van Bruggen, I. G., Huiskes, M., de Vette, S. P. M., Holmström, M., Langendijk, J. A., Both, S., Kierkels, R. G. J. & Korevaar, E. W., 1-Apr-2023, In: International Journal of Radiation Oncology, Biology, Physics. 115, 5, p. 1283-1290 8 p.

22	Assessment of residual geometrical errors of clinical target volumes and their impact on dose accumulation for head and neck radiotherapy Ng Wei Siang, K., Both, S., Oldehinkel, E., Langendijk, J. A. & Wagenaar, D., Nov-2023, In: Radiotherapy and Oncology. 188, 9 p., 109856.
23	Application of PHITS Monte Carlo code in ionization chamber dosimetry of high energy proton beams Chan, M. K. H., Wulff, J., Malimban, J., Baumann, K. & Both, S., 2023.
24	An efficient strategy to select head and neck cancer patients for adaptive radiotherapy Gan, Y., Langendijk, J. A., van der Schaaf, A., van den Bosch, L., Oldehinkel, E., Lin, Z., Both, S. & Brouwer, C. L., Sept-2023, In: Radiotherapy and Oncology. 186, 7 p., 109763.

Sytze Brandenburg

1	The Effects of Combined Exposure to Simulated Microgravity, Ionizing Radiation, and Cortisol on the In Vitro Wound Healing Process Radstake, W. E., Gautam, K., Miranda, S., Vermeesen, R., Tabury, K., Rehnberg, E., Buset, J., Janssen, A., Leysen, L., Neefs, M., Verslegers, M., Claesen, J., van Goethem, M. J., Weber, U., Fournier, C., Parisi, A., Brandenburg, S., Durante, M., Baselet, B. & Baatout, S., Jan-2023, In: Cells. 12, 2, 32 p., 246.
2	Technical note: Flat panel proton radiography with a patient specific imaging field for accurate WEPL assessment Seller Oria, C., Free, J., Marmitt, G. G., Knäusl, B., Brandenburg, S., Knopf, A. C., Meijers, A., Langendijk, J. A. & Both, S., Mar-2023, In: Medical Physics. 50, 3, p. 1756-1765 10 p.
3	A simulation framework of the preclinical proton irradiation workflow Malimban, J., Ludwig, F., Lathouwers, D., Staring, M., Verhaegen, F. & Brandenburg, S., 2023.
4	A Monte-Carlo-based study of a single-2D-detector proton-radiography system Olivari, F., van Goethem, M.-J., Brandenburg, S. & van der Graaf, E. R., Aug-2023, In: Physica medica-European journal of medical physics. 112, 8 p., 102636.

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APPENDIX 3: Contributions to conference talks, posters, workshops

Alexander Gerbershagen	
1	Bateman JJ, Gerbershagen A, et.al., A Novel Fibre Optic Monitor For VHEE UHDR Beam Monitoring: First Tests At CLEAR, International Particle Accelerator Conference (IPAC), Poster
2	De Falco A, Gerbershagen A. NA60+ Collaboration. The physics program of the NA60+ experiment. EPJ Web of Conferences. 2023 Mar 1;276(05005). doi: 10.1051/epjconf/202327605005
3	Gerbershagen A. Beamlines for fixed target experiments, test beams and particle therapy, Seminar at University of Palermo (Palermo, Italy)
4	Gerbershagen A. Hadron Therapy and the New PArticle Therapy REsearch Center (PARTREC), University of Mainz Physics colloquia series (Mainz, Germany)
5	Gerbershagen A. PArticle Therapy REsearch Center (PARTREC) at Beam Telescopes and Test Beams Workshop (Hamburg, Germany)
6	Gerbershagen A. Radiobiology Research and Treatment Planning at UMCG, Presentation at COST Action workshop (Prague, Czech Republic)
7	Gerbershagen A. The New PArticle Therapy REsearch Center (PARTREC) at the University Medical Center Groningen, Presentation at 'Nanoparticle enhanced radiotherapy workshop' (London, UK)
8	Gerbershagen A. The New PArticle Therapy REsearch Center (PARTREC) at the University Medical Center Groningen (Catania, Italy)
9	Gerbershagen A. The new Particle Therapy Research Center (PARTREC) at UMCG. 1st International UMCG Proton Therapy Lustrum Symposium (Groningen, April 13, 2023). Invited lecture.

10	Gerbershagen A, SHADOWS Collaboration. SHADOWS Technical Proposal. CERN Document Server. 2023 Oct 30;SPSC-P-367(CERN-SPSC-2023-029).
11	Gerbershagen A, The HIKE collaboration. HIKE: High Intensity Kaon Experiments at the CERN SPS. Journal of Physics, Conference Series. 2023 Feb 1;2446(1):012036. doi: 10.1088/1742-6596/2446/1/012036
12	Kremers HR, Jones BN, Tilman D, Brandenburg S, Gerbershagen A, et.al., Development of a New Electromagnetic Extraction Channel for the AGOR Cyclotron, International Particle Accelerator Conference (IPAC), Poster.
13	Kremers HR, Jones BN, Tilman D, Brandenburg S, Gerbershagen A, Installation and First Results of a 1.1 kW TWT System for the AECR-U Based Ion Source at UMCG-PARTREC, ISIC conference, Poster.
14	Kremers R, Jones B, Smit H, Gerbershagen A, Brandenburg S. Development of a New Electromagnetic Extraction Channel from the AGOR Cyclotron. Journal of Physics, Conference Series. 2023;2687 (082012). doi: 10.1088/1742-6596/2687/8/082012
15	Kuiken OJ, Schwab J, Gerbershagen A, Schakel P, van Abbema JK. Upgrade of the AGOR cyclotron control system at UMCG-PARTREC. Proc. ICALEPCS'23, Cape Town, South Africa, Oct 2023, JACoW-ICALEPCS2023-TUMBCMO18_TALK. Oral presentation
16	Kuiken OJ, Schwab J, Gerbershagen A, Schakel P, van Abbema JK. Upgrade of the AGOR cyclotron control system at UMCG-PARTREC. ICALEPCS'23 conference, Cape Town, South Africa, Oct 9-13, 2023
17	Robertson C, Burrows P, Dosanjh M, Latina A, Gerbershagen A. Beam optics study for a potential VHEE beam delivery system. Journal of Physics, Conference Series. 2023;2420 (012102). doi: 10.1088/1742-6596/2420/1/012102
18	Robertson C, Dosanjh M, Latina A, Gerbershagen A. et.al.. DUAL-SCATTERING FOIL INSTALLATION AT CLEAR. Journals of Accelerator Conferences Website (JACoW). 2023. doi: 10.18429/JACoW-IPAC2023-THPM073.
19	Robertson C, Gerbershagen A et.al.. CLEAR Vacuum Dual Scattering Foil Installation, International Particle Accelerator Conference (IPAC), Poster.
20	Romano F. Challenges and recent developments in dosimetry for FLASH radiotherapy. Mini-Micro- Nano- Dosimetry (MMND) Conference (Noosa Heads, Australia, February 14, 2023. Invited Lecture (online).

21	Romano F. Detectors for beam monitoring and dosimetry at ultra-high dose rates for FLASH Radiotherapy, High Precision X-ray Measurements Conference 2023, (Frascati, June 22, 2023). Invited Lecture.
22	Romano F. Dosimetry for FLASH radiotherapy: challenges and recent developments. ESTRO 2023, (Vienna, May 15, 2023). Invited Lecture.
23	Romano F. Instrumentation for FLASH Radiotherapy, 24th International Workshops on Radiation Imaging Detectors (IWORID), (Oslo June 27, 2023). Invited Lecture.
24	Romano F. Silicon Carbide detectors for dosimetry and beam monitoring for FLASH radiotherapy, SSD20 - 20th International Conference on Solid State Dosimetry, (Viareggio, September 20, 2023). Invited Lecture.
25	Romano F. Ultra-high dose rate dosimetry: Challenges and opportunities for FLASH radiation therapy, 4th International Conference on Dosimetry and its Applications, (Valencia, October 18, 2023). Invited Lecture.
26	Schippers JM, Wirkung von Protonen- und Heliumstrahlen, J.M. Schippers, invited talk at 25 Year Jubilee of eye, 30.6. 2023, Erzeugung und treatments at Helmholz Zentrum Berlin
27	Stummer F, Gerbershagen A, Baratto Roldan A, Rae B, Banerjee D, Metzger F et al.. Conceptual design of the magnetised iron block system for the SHADOWS experiment. Journals of Accelerator Conferences Website (JACoW). 2023 Sept 26. doi: 10.18429/JACoW-IPAC2023-MOPA088

Julia Even	
	Poster contributions:
1	J.B. Cipagauta Mora Ion-extraction from the CISe gas-catcher NWO Physics, Veldhoven, the Netherland, 04/04/2023 □ 05/04/2023
2	M. Brajković The stacked-ring ion guide and the MR-TOF MS developed for the NEXT experiment, ECTI 7th European conference on Trapped Ions, Schloss Bückeburg, Germany, 25/09/2023 - 29/09/2023
3	J. Even The NEXT setup to study Neutron-rich EXotic nuclei in multinucleon Transfer reactions, Advances in Radioactive Isotope Science, ARIS 2023, Avignon, France, 04/06-2023-09/06/2023

	Oral contributions at conferences:
1	M. Brajković The NEXT setup to study neutron-rich transfermium nuclei, LISA conference, Leuven, Belgium, 22/05/2023 - 26/06/2023
2	M. Brajković NEXT setup for precision mass spectrometry of neutron-rich heavy nuclei NWO Physics, Veldhoven, the Netherland, 04/04/2023 □ 05/04/2023
3	B.D. Hartigan Commissioning of the gas-catcher and Multi-Reflection Time-of-Flight Mass spectrometer for the NEXT experiment International Conference on Stopping and Manipulation of Ions and Related Topics (SMI-2023), Staufenberg, Germany, 08/05/2023-11/05/2023
4	B.D. Hartigan Commissioning of the NEXT mass separator and spectrometer, NNV section for (astro)particle physics fall meeting 2023, Lunteren, the Netherlands, 03/11/2023
5	A.Soylu Ion optical simulations for the NEXT solenoid separator The 86 Annual Meeting of DPG and DPG Spring Meeting of the Matter and Cosmos Section (SMuK) 2023, Dresden, Germany, 20/03/2023 - 24/03/2023
	Invited seminars & colloquia:
1	J.Even What is NEXT? Neutron-rich nuclei relevant for nuclear astrophysics, b@UM meeting, University of Maastricht, Maastricht, the Netherlands, January 16th, 2023.
2	J.Even. What is NEXT? A new setup to study heavy, Neutron-rich, EXotic nuclide produced in multinucleon Transfer reactions, Nuclear Cookies seminar, University of Padova, Padova, Italy, July 13, 2023.

Lara Barazzuol	
1	Voshart D. International Congress for Radiation Research (ICRR) (Montreal, Canada, August 2023). Poster presentation.
2	Voshart D. Wolfsberg meeting (Oslo, Norway, June 2023). Poster presentation.
3	Barazzuol L. Wolfsberg meeting (Oslo, Norway, June 2023). Poster presentation.
4	Barazzuol L. NVRO Scientific Meeting (Amersfoort, June 2023). Invited presentation.
5	Barazzuol L. 1st International UMCG Proton Therapy Lustrum Symposium (Groningen, April 2023). Invited presentation.

Peter Dendooven	
1	Ahmadi Ganjeh Z, Zapien-Campos B, Both S, Dendooven P. Nitrogen-12 real-time in vivo verification in proton therapy and the role of Monte Carlo simulations. 61st Annual PTCOG Conference (Madrid, June 10-16, 2023). Poster. https://www.ptcog61.org/
2	Zapien-Campos B, Ahmadi Ganjeh Z, Both S, Dendooven P. Real-time in vivo range verification for proton therapy based on 12N imaging. 61st Annual PTCOG Conference (Madrid, June 13, 2023). Oral presentation. https://www.ptcog61.org/
3	Ahmadi Ganjeh Z, Zapien-Campos B, Both S, Dendooven P. Nitrogen-12 Real-Time in Vivo Verification in Proton Therapy and the Role of Monte Carlo Simulations. AAPM 2023 (Houston, July 25, 2023). Oral presentation. https://w4.aapm.org/meetings/2023AM/
4	Zapien-Campos B, Ahmadi Ganjeh Z, Both S, Dendooven P. Investigation of Real-Time In Vivo Range Verification for Proton Therapy Using N-12 Imaging. AAPM 2023 (Houston, July 23, 2023). Oral presentation. https://w4.aapm.org/meetings/2023AM/
5	Zapien-Campos B. Nitrogen-12 positron imaging for real-time in vivo verification in proton therapy. 79th Crystal Clear Collaboration Meeting (Bydgoszcz, May 25, 2023). Oral presentation. https://co.bydgoszcz.pl/79th-crystal-clear-collaboration-general-meeting/
6	Ahmadi Ganjeh Z. Real-time in vivo range verification using N-12 imaging based on the new Monte Carlo framework for proton therapy. Workshop on INnovative Systems In radiation therapy: breakthrouGHs novel detectors, Treatments and AI techniqueS. (Pisa, October 18, 2023). Oral presentation.
7	Dendooven P. Precision of the positron emission activity range during irradiation with radioactive carbon and oxygen beams. Workshop on Innovative Systems In radiation therapy: breakthroughs novel detectors, Treatments and AI techniques. (Pisa, October 18, 2023). Oral presentation.

Peter van Luijk	
1	Van Luijk P. Radiation induced toxicities. 3rd RAPTOR School: Loop engagement (Ascona, Switzerland, Sept 10-15, 2023). Invited lecture.
2	Van Luijk P. The impact of tissue and organ interactions on the tolerance of normal tissues to radiation. MultiChem: Multiscale modeling of radiation-induced biodamage for radiotherapy applications. (Groningen, Sept 21-22, 2023).

3	van Rijn-Dekker MI, van Luijk P, Langendijk JA, Steenbakkers RJHM. De volgende stap in het voorkomen van xerostomie bij hoofd-halskankerpatiënten na bestraling: stamcelsparende radiotherapie. NWHHT congres 2023 (Rotterdam, October 13, 2023). Oral presentation. P
4	van Rijn-Dekker MI, van Luijk P, Schuit E, van der Schaaf A, Langendijk JA, Steenbakkers RJHM. Functional dose to the parotid gland: a new regional based dose metric in NTCP models for xerostomia. ESTRO 2023 (Vienna, May 13, 2023). Oral presentation.
5	Wiedemann J , Brouwer U, Sewdihal J, Schouten EM, Dickinson MG, de Boer RA, Coppes RP, van Luijk P. Captopril mitigates radiation-induced cardiopulmonary side-effects only if the lung is spared. NVRB Annual Symposium 2023 (Utrecht, The Netherlands, November 17, 2023).
6	Van Luijk P. Cardiopulmonary toxicity: Identifying new side-effects and a potential role for protons in their prevention. 1st International UMCG Proton Therapy Lustrum Symposium (Groningen, 12-15 April, 2023). Invited lecture.
7	Van Luijk P. Non-local mechanisms of normal-tissue response to radiotherapy. Seminar at Radiotherapy Physics and Engineering, Medical
8	van Rijn-Dekker MI. De volgende stap in het voorkomen van xerostomie bij hoofd-halskankerpatiënten na bestraling: stamcelsparende radiotherapie. NWHHT congres 2023 (Rotterdam, October 13, 2023). Oral presentation.
9	Barazzuol L, Voshart DC, Klaver M, van Weering HRJ, Yiang Y, Cinat D, van Buuren-Broek F, Scholma A, van Luijk P, Coppes RP. Proton therapy leads to a local neuroimmunological response. International Wolfsberg Meeting on Molecular Radiation Biology/Oncology 2023 (Oslo, June 17-19). Poster.
10	van Rijn-Dekker MI, van Luijk P, Langendijk JA, Steenbakkers RJHM. De volgende stap in het voorkomen van xerostomie bij hoofd-halskankerpatiënten na bestraling: stamcelsparende radiotherapie. NWHHT congres 2023 (Rotterdam, October 13, 2023). Oral presentation.
11	van Rijn-Dekker MI, van Luijk P, Schuit E, van der Schaaf A, Langendijk JA, Steenbakkers RJHM. OC-0109 Functional dose to the parotid gland: a new regional based dose metric in NTCP models for xerostomia. ESTRO 2023 (Vienna, May 13, 2023). Radiother Oncol 2023; 182 (suppl. 1): S69-S70. Oral presentation.

12	Voshart DC, Oshima T, Jiang Y, van der Linden GP, Klaver M, van Weering HRJ, Ainslie AP, Reali Nazario L, van Buuren-Broek F, Scholma AC, Brouwer N, Sewdihal J, Brouwer U, van Luijk P, Coppes RP, Holtman IR, Eggen BJL, Kooistra SM, Barazzuol L. Radiation induces persistent innate immune reprogramming in the brain. International Congress for Radiation Research (ICRR 2023) (Montreal, August 27-30). Poster.
13	Wiedemann J , Brouwer U, Sewdihal J, Schouten EM, Dickinson MG, de Boer RA, Coppes RP, van Luijk P. Captopril mitigates radiation-induced cardiopulmonary side-effects only if the lung is spared. NVRB Annual Symposium 2023 (Utrecht, The Netehrlands, November 17, 2023). Oral presentation.

Rob Coppes	
1	Abel Soto Gamez from the group of Rob Coppes: Presentation - Presentation at Cellular Senescence Network – April 13, 2023. Groningen
2	Abel Soto Gamez from the group of Rob Coppes: Presentation - Presentation at Dutch Society for Research on Aging (DUSRA) - June 15-16, 2023. Groningen
3	Abel Soto Gamez from the group of Rob Coppes: Poster presentation - Poster presentation at - Salivary Glands and Exocrine Biology, Gordon Research Conference (GRC) - Jan 28-Feb 3, 2023
4	Abel Soto Gamez from the group of Rob Coppes: Poster presentation - Poster presentation at - International Cell Senescence Association (yICSA) - Cambridge Symposium March 30, 2023
5	Abel Soto Gamez from the group of Rob Coppes: Poster presentation - Poster presentation at - International Wolfsberg Meeting on Molecular Radiation Biology/Oncology - June 17-19, 2023. Oslo, Norway
6	Abel Soto Gamez from the group of Rob Coppes: Poster presentation - Poster presentation at -International Congress for Radiation Research (ICRR) - August 27-30, 2023. Montréal, Canada.
7	Davide Cinat from the group of Rob Coppes: Presentation - Presentation at GRS and GRC meetings: Salivary glands and exocrine biology, Ventura, California (US).
8	Davide Cinat from the group of Rob Coppes: Presentation - Presentation at NVRB meeting, Utrecht (NL). Accepted for oral presentation. November 2023

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Location and travel

PARTREC is situated in the northern part of Groningen at the 'Zernike campus', which also accommodates the Faculty of Science and Engineering, the Faculty of Economics and Business and the Faculty of Spatial Sciences of the University of Groningen, the 'Hanzehogeschool' (University of Applied Sciences), IT and sports centers as well as the 'Zernike Science Park' industrial estate.
Groningen is a city in the North of the Netherlands. It has only a minor airport but has a direct train connection (about 2 hours travel) from the Schiphol airport in Amsterdam. It is also reachable by train from Bremen, Hamburg or Düsseldorf airports.
PARTREC is reachable from Groningen train station or the city center via frequent buses (bus stop 'Zernike Noord'). The schedule for intercity trains and buses is available at https://9292.nl/.

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