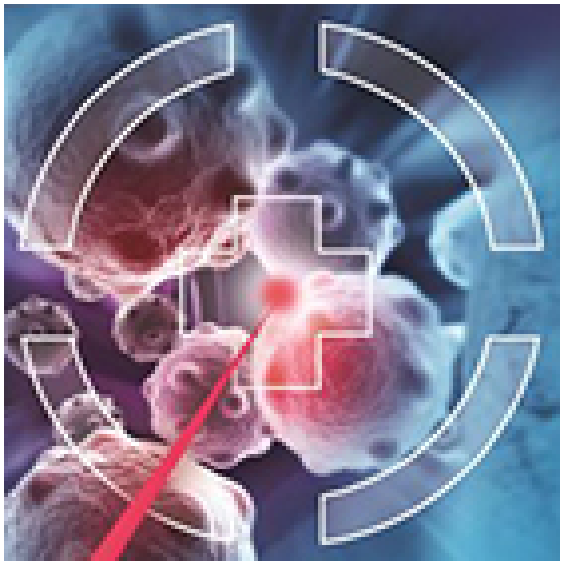
# International Conference on Medical Accelerators and Particle Therapy



# Report of Contributions

https://indico.cern.ch/e/803528

Contribution ID: **1** Type: **not specified**

# Welcome and Introduction

*Wednesday, 4 September 2019 09:00 (15 minutes)*

Contribution ID: **2** Type: **not specified**

# State of the art in ion beam therapy

*Wednesday, 4 September 2019 09:15 (15 minutes)*

**Presenter:** WELSCH, Carsten Peter (Cockcroft Institute / University of Liverpool)

Contribution ID: **3** Type: **not specified**

# Next-generation therapy accelerators

*Wednesday, 4 September 2019 09:30 (30 minutes)*

**Presenter:** JONGEN, Yves (IBA)

Contribution ID: **4** Type: **not specified**

# Beam Diagnostics

*Wednesday, 4 September 2019 14:30 (30 minutes)*

**Presenter:** CALDARA, Michele (AVO/ADAM)

Contribution ID: **5** Type: **not specified**

# Dose Delivery

*Wednesday, 4 September 2019 16:30 (30 minutes)*

**Presenter:** LOMAX, Antony (PSI)

Contribution ID: **6** Type: **not specified**

# Monte Carlo Dosimetry

*Thursday, 5 September 2019 09:00 (30 minutes)*

**Presenter:** LALLENA, Antonio (University of Granada)

Contribution ID: **7** Type: **not specified**

# Dosimetry and Quality Assurance

*Thursday, 5 September 2019 11:30 (30 minutes)*

**Presenter:** MARCELIS, Simon (IBA)

Contribution ID: **8** Type: **not specified**

# Imaging beam in patient

*Wednesday, 4 September 2019 11:30 (30 minutes)*

**Presenter:** PARODI, Katia (Ludwig-Maximilians-Universität München)

Contribution ID: **9** Type: **not specified**

# 4D Patient monitoring

*Friday, 6 September 2019 09:00 (30 minutes)*

**Presenter:** Prof. BARONI, Guido (CNAO)

Contribution ID: **10** Type: **not specified**

# Summary

*Friday, 6 September 2019 12:30 (30 minutes)*

**Presenter:** WELSCH, Carsten Peter (Cockcroft Institute / University of Liverpool)

Contribution ID: **11** Type: **not specified**

# Public Talk - Acelerando partículas para tratar el cáncer

*Wednesday, 4 September 2019 19:30 (1 hour)*

**Presenter:** GALLARDO, María Isabel

Contribution ID: **12** Type: **not specified**

# Dosimetric effects of thermoplastic masks on skin dose

ABSTRACT

In radiotherapy, treating of cancer patients require the use of immobilizing devices such as thermoplastic masks. These masks increase the patient skin doses, but its effect is normally overlooked. This work is done to determine the thermoplastic mask factor to compensate for it just as applied to trays and wedges. Measurements are done at source-to-suface distance of 80 cm for external radiation beams produced by Cobalt 60 using the Farmer type ionization chamber and the Unidos electrometer. Measurements are carried out with and without mask material on the surface of a solid water phantom. Initial and final temperatures and pressures were recorded. The doses then calculated and the thermoplastic mask factor determined. The thermoplastic factor is defined at the ratio of the doses obtained with mask to the doses obtained without mask on the phantom. The mask factor is then incorporated into the treatment planning system to correct for it just as is done to tray.

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**Session Classification:** Poster Session

Contribution ID: **13** Type: **not specified**

# Uncertainty Quantification Analysis and Optimization For Proton Therapy Beam Lines

*Friday, 6 September 2019 10:30 (30 minutes)*

Since many years, proton therapy is used as an effective treatment solution against deep-seated tumors. A precise quantification of sources of uncertainties in each proton therapy aspect (e.g. accelerator, beam lines, patient positioning, treatment planning) is of extreme importance to increase the robustness of the dose delivered to the patient.
Together with Monte Carlo techniques, a new research field called Uncertainty Quantification (UQ) has been recently introduced to verify the robustness of the treatment planning. We apply here, for the first time, UQ methods to identify the typical errors in transport lines of a cyclotron-based proton therapy facility and analyze their impact on the properties of the therapeutic beams. The potential of UQ methods in developing optimized beam optics solutions for high-dimensional problems is also demonstrated. Sensitivity analysis and surrogate models offer a fast way to exclude unimportant parameters from complex optimization problems such as the superconducting gantry project studied at Paul Scherrer Institut in Switzerland.

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**Presenter:** Dr RIZZOGLIO, Valeria (Paul Scherrer Institut)

Contribution ID: **14** Type: **not specified**

# FlashTherapy: an innovation in radiation therapy

*Wednesday, 4 September 2019 10:00 (20 minutes)*

The Radiation Therapy (RT) goal is to destroy cancer cells, minimizing the damage to the rest of the body as well as any side effect. The "FLASH" Therapy, an innovative technique in radiation therapy, has shown that short pulses of electrons at very high dose rates are less harmful to healthy tissues but just as efficient as conventional dose rate radiation to inhibit tumour growth.
The therapy has been successfully tested with low energy electrons in small animals. It foresees millisecond pulses of radiation (beam on time < 100-500ms) delivered at a high dose-rate (>40-100 Gy/s), over 2000 times faster and more than 1000 more intense than conventional RT. We will discuss the genesis of this methodology, the instrumentations used and its evolution.

**Primary author:** GIULIANO, Lucia (INFN - National Institute for Nuclear Physics)

**Co-authors:** PALUMBO, LUIGI (UNIVERSITA' DI ROMA LA SAPIENZA); SPATARO, Bruno (Istituto Nazionale Fisica Nucleare (IT)); Prof. MOSTACCI, Andrea (Sapienza University of Rome e INFN-Roma I (IT)); Dr FAILLACE, Luigi (INFN Milano )

**Presenter:** GIULIANO, Lucia (INFN - National Institute for Nuclear Physics)

Contribution ID: **15** Type: **not specified**

# FOOT: FragmentatiOn Of Target experiment

Charged Particle Therapy (CPT) is a highly effective method for treating several types of solid tumours. However, in heavy ion therapy nuclear inelastic interactions of the incident beam with the patient tissues lead to the break-up of the incident ion. The produced fragments of projectile have a longer range with respect to the primaries and lead to an undesirable dose deposition beyond the Bragg peak. On the other hand, in proton therapy, the nuclear inelastic interactions results in the fragmentation of the target nuclei, producing fragments with low energy and high Linear Energy Transfer (LET) which may alter the estimated local dose deposition, especially in the entry region. At present there is still a lack of complete and reliable experimental measurements of nuclear reaction cross sections of fragments produced by 60-250 MeV protons and 100-400 MeV/u carbon, helium and oxygen ions impinging on tissues nuclei (H, C, Ca, O, N). These data is important to develop a new generation of high quality treatment planning systems for CPT. Further interest in this type of measurements derives from the radioprotection in long duration and far from earth space missions, in which the particle energy to be considered is close to 1 Gev/u. In particular, nuclear fragmentation induced by proton and light nuclei is a relevant issue for the choice of the spacecraft shielding material, since the evaluation of radiation doses induced by the exposure to galactic cosmic rays are evaluated by means of Monte Carlo simulation codes, without a complete benchmark of dedicated experimental data.
The FOOT (FragmentatiOn Of Target) experiment is conduct by 15 institutions from 4 countries. The main goal is to perform a set of measurements of nuclear fragmentation cross sections relevant for CPT and radioprotection in space. Concerning target fragmentation, an inverse kinematic approach will be applied to overcome the difficulties related to the short fragments range (~μm). Moreover, the final cross section on Hydrogen will be obtained with the technique of subtraction of cross sections, adopting a double target separately made of C and C2H4. FOOT consists of two different setups for the detection of heavy and light fragments: the former are detected by a high precision tracking system in magnetic field, a time of flight measurement system and a calorimeter, while the latter are measured by a separated emulsion cloud chamber detector. Both the experimental setups are designed as portable detector that can easily operate in different clinical and experimental facilities. The optimization and the performance analysis of the setups have been studied by means of FLUKA Monte Carlo code and different detectors have been tested separately. A first data taking with both of the experimental setups has been performed at the GSI (Darmstadt, Germany) laboratory on April 2019.
An overview of the FOOT experiment and a report on the detector performances will be presented.

**Primary author:** DONG, Yunsheng (INFN - National Institute for Nuclear Physics)

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**Session Classification:** Poster Session

Contribution ID: **16** Type: **not specified**

# Digital LLRF system: concepts and requirements for proton therapy based on a linear accelerator

*Friday, 6 September 2019 12:10 (20 minutes)*

Modern particle therapy requires systems which enable precise control over delivered dose depth. That translates into the ability to program the accelerator to quickly modulate the beam energy in order to deposit the treatment dose into predefined tissue regions. In particle therapy applications linear accelerators have advantages in terms of compactness and beam modulation ability. However to control the particle acceleration process from the beginning it's crucial to precisely stabilize the RF field inside the cavities through Low Level Radio Frequency feedback system. This talk introduces the concepts and the specific requirements of a LLRF system for a proton therapy LINAC. As an example the Libera LLRF implementation for the AVO-ADAM LIGHT linear accelerator will be presented.

**Primary author:** Mr BARICEVIC, Borut (Instrumentation Technologies)

**Presenter:** Mr BARICEVIC, Borut (Instrumentation Technologies)

Contribution ID: **17** Type: **not specified**

# Design of SC230 - the new cyclotron for proton therapy

SC230 a 230 MeV superconducting cyclotron designed in JINR. It is intended to be developed as a joint project with ASIPP. The cyclotron is designed for proton therapy and biomedical research. This presentation focuses on the results of the conceptual design of the accelerator. In the process of physical design, simulations of the magnetic and RF systems were carried out, the main characteristics of the accelerator were established. Magnetic field was isochronized with sufficient precision, as well as yoke mechanical stress simulation was performed. Beam tracking was conducted to determine whether the quality of the extracted beam is in accordance with project requirements.

**Primary authors:** POPOV, Dmitry (Joint Institute for Nuclear Research); KARAMYSHEV, Oleg (J); Dr KARAMYSHEVA, Galina; GURSKIY, Semion; MALININ, Vladimir; SHIRKOV, Grigori (JINR); SHIRKOV, Stepan; SMIRNOV, Victor; VOROZHTSOV, Serguei (Joint Institute for Nuclear Research (RU))

**Presenter:** POPOV, Dmitry (Joint Institute for Nuclear Research)

**Session Classification:** Poster Session

Contribution ID: **18** Type: **not specified**

# Design considerations of a superconducting gantry with alternating-gradient combined-function magnets

*Wednesday, 4 September 2019 17:20 (20 minutes)*

A proton therapy facility based on the superconducting cyclotron is under development in HUST (Huazhong University of Science and Technology), which uses warm magnets for beam transport lines and gantries. For future upgrade, a lightweight superconducting gantry is under consideration. This paper describes the design of a superconducting gantry with alternating-gradient combined-function magnets and downstream scanning. +/-15% momentum acceptance is achieved from demonstration of beam optics including high order aberrations and realistic fringe field effect. From the viewpoint of systematic design for this superconducting gantry, an integrated fast degrader and a compact scanner to perform fast 3D pencil beam scanning will also be introduced.

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**Presenter:** Dr QIN, Bin (Huazhong University of Science and Technology)

Contribution ID: **19** Type: **not specified**

# Design of a fast energy degrader for a compact superconducting gantry with large momentum acceptance

Recently, the superconducting gantry is gained more and more attentions due to the advantages on the reduction of the footprint and weight. Aiming at the light weight gantry beamline with a large momentum acceptance, we proposed a superconducting gantry scheme employing a fast degrader, combined-function AG-CCT magnets and downstream scanning nozzle. To reduce the secondary neutrons on the iso-center, a fast energy degrader is placed at the entrance of the gantry beamline, which requires the large momentum acceptance of the downstream combined function AG-CCT magnets. In this paper, we present the design result of a fast degrader system and carry out the detailed Monte Carlo simulation of the whole superconducting gantry beamline by importing the 3D magnetic field of the magnets. In addition, some clinical impacts with the large momentum deviation beam are also studied.

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**Presenter:** Dr LIU, Xu (Huazhong University of Science and Technology)

**Session Classification:** Poster Session

Contribution ID: **20** Type: **not specified**

# A Monte Carlo study of target fragmentation in Protontherapy

*Thursday, 5 September 2019 10:30 (30 minutes)*

In protontherapy, secondary particles can be produced through primary beam interactions with the patient's body. Fragments created in inelastic interactions of the beam with the target nuclei have low kinetic energy, high atomic number and high LET as compared to primary protons.
These secondary particles produce an altered dose distribution, due to their different ranges. The residual range of such fragments is of the order of 10-100 $\mu m$ so they are in general confined within a single cell [1]. They have high LET, locally leading to an increase of RBE for the same delivered dose. The energy dependence of the nuclear interaction cross section makes target fragmentation relevant mostly in the entrance region [2] for normal healthy tissues.
The inclusion of target fragmentation processes can be important for the accurate calculation of the dose in the treatment. Nowadays, target fragmentation is not implemented in commercial TPSs.
Furthermore, the production yield of fragments at therapeutic energy is still poorly measured.
In the MoVe IT (Modeling and Verification for Ion beam Treatment planning) project, the effect of target fragmentation will be included in the TPS. The TRiP98 code[3] is able to properly account for the mixed radiation field for the description of biological effects of target fragmentation. In order to implement the transport of fragments in the TPS, a database for fragments fluence will be created.
In this work, Monte Carlo simulations were employed to evaluate the impact of target fragmentation in protontherapy. MC codes are able to take full account of the mixed radiation fields and provide detailed predictions of particles originating in the nuclear interactions [4].
To include the impact of fragmentation in the TPS and estimate the biological effect of fragments,the fluence of target fragments at different depths has been calculated with FLUKA MC code [5].

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[2] T. Pfuhl et al., Dose build-up effects induced by delta electrons and target fragments in proton bragg curves - measurements and simulations. PMB, 63(17):175002, 2018
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[5] A. Ferrari, P. R. Sala, A. Fasso, and J. Ranft, FLUKA: A multi-particle transport code(program version 2005). Technical report, 2005

**Primary authors:** Dr EMBRIACO, Alessia (INFN - National Institute for Nuclear Physics); DONG, Yunsheng (INFN - National Institute for Nuclear Physics); MATTEI, Ilaria (INFN - National Institute for Nuclear Physics); MURARO, Silvia (INFN); VALLE, Serena Marta (University of Milan & INFN Sezione di Milano); BATTISTONI, Giuseppe (Università degli Studi e INFN Milano (IT))

**Presenter:** Dr EMBRIACO, Alessia (INFN - National Institute for Nuclear Physics)

Contribution ID: **21** Type: **not specified**

# A data-driven nuclear fragmentation model for a fast Monte-Carlo code, FRED, in Particle Therapy with Carbon beams

*Thursday, 5 September 2019 09:50 (20 minutes)*

To really exploit the potential benefits of Particle Therapy (PT), the highest possible accuracy in the calculation of dose and its spatial distribution is required in treatment planning. Commonly used Treatment Planning Software (TPS) solutions adopt a simplified beam–body interaction model using a 3D water equivalent representation of the patient morphology. An alternative is the use of Monte Carlo (MC) simulations which explicitly take into account the interaction of charged particles with actual human tissues. Full MC calculations are not routinely used in clinical practice because they typically demand for substantial computational resources and they are usually only used to check treatment plans for a restricted number of difficult cases. Therefore, presently one of the major issues related to TPS improvement is the high computational time required in order to meet the goal of high accuracy. The code FRED (Fast paRticle thErapy Dose evaluator) has been developed to allow a fast optimization of the treatment plans in charged PT while profiting from the dose release accuracy of a MC tool. Within FRED the proton and ion interactions are described with the precision level available in leading edge MC tools used for medical physics applications, with the advantage of reducing the simulation time up to a factor 1000. Moreover, running on GPU cards, the code allows a plan re-optimization in few minutes instead of several of hours on CPU hardware. FRED can transport particles through a 3D voxel grid using a class II MC algorithm. Both primary and secondary particles are tracked, and their energy deposition is scored along the trajectory. Effective models for particle–medium interaction have been implemented, balancing accuracy in dose deposition with computational cost. Currently, the most refined module is the transport of proton beams in water and the code is already used as research tool for proton beams at several clinical and research centres in Europe (Krakow, Trento, Maastricht, Lyon). The excellent results achieved with protons determined the interest of the CNAO (Centro Nazionale di Adroterapia Oncologica) center (Pavia, Italy) to develop FRED also for Carbon therapy applications. Models for the interaction of Carbon ions with matter are currently under development to be implemented in the FRED code. In particular, the main difference is in the fragmentation of the projectile since protons do not fragment while ions do. As the beam fragmentation process is related to the dose release outside the tumor region its description is of paramount importance and has to be accurately modeled. Currently, the development of the model is based on the use of data taken during experiments at GANIL (laboratory of CAEN, France) where the fragmentation of Carbon ions on thin targets (H, C, O, Al and Ti) has been studied (J. Dudouet, et al, DOI:10.1103/PhysRevC.88.024606). To tune the algorithm in the energy range used in PT treatments, and not only at beam energies of the GANIL experiment, an appropriated scaling is used, obtaining energy and angular cross-sections specific for every energies. In the next future, new data from other experiments (i.e. FOOT experiment) will be used to improve the model. The status of new developments and the performance of FRED will be presented.

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**Presenter:** Mrs DE SIMONI, Micol (Università di Roma "La Sapienza", Fisica, Rome, Italy)

Contribution ID: **22** Type: **not specified**

# Spectrum and flux measurements of secondary ultra-fast neutrons produced in Particle Therapy treatments using the innovative MONDO tracker.

The secondary neutrons produced in Particle Therapy treatments can travel along the path inside the patient and contribute with additional dose in-and out-of-field. This unwanted dose increases the risk of developing secondary cancers: late insurgences are particularly crucial in paediatric patients where the closeness of the organs and the recurrence onset strongly impacts the life expectation and quality [1].
A precise measurements of neutron flux, spectra and angular distributions is eagerly needed so to predict the normal tissue toxicity in the target region and the risk of late complications in the whole body.
Nowadays, no existing detector is able to separate efficiently the secondary neutrons from the ternary neutral component generated in the iterative interactions of fragmentation products with the treatment room (walls, nozzle, etc···) and the patient itself.
MONDO is a tracker tailored for the ultra-fast neutron detection in the [20-400] MeV energy range [2]. The detector, based on the reconstruction of the recoil protons produced in two consecutive (n,p) elastic scattering interactions (DES events), is a matrix of thin scintillating fibers (˜250 µm side), arranged in layers orthogonally oriented, for a total size of 16x16x20 $cm^3$.
An innovative silicon SPAD based sensor with integrated electronics has been designed for the detector readout (SBAM sensor [3]) in collaboration with Fondazione Bruno Kessler. The MONDO performance has been evaluated by means of a Monte Carlo simulation developed in FLUKA: a detection efficiency of $10^{-2}$ -$10^{-3}$ is expected for single and double elastic scattering respectively. The achievable relative energy resolution for the reconstructed neutrons is ˜8% and the expected back-pointing resolution is < 1 cm (for a neutron source placed at 20 cm from the detector).
The MONDO detector, its expected performance and the readout calibration results with a matrix prototype will be presented.

[1] W. Newhauser and M. Durante, "Assessing the risk of second malignancies after modern radiotherapy"Nat. Rev. Cancer. 11 (2011) 438
[2] M. Marafini et al., "MONDO: a neutron tracker for Particle Therapy secondary emission characterization"Phys. Med. Biol. 62 (2017)
[3] R. Mirabelli et al., "The MONDO detector prototype development and test: steps towards a SPAD-CMOS based integrated readout (SBAM sensor)"Trans. on Nucl. Science 65 (2018)

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**Session Classification:** Poster Session

Contribution ID: **23** Type: **not specified**

# A Modular Control System for Treating Moving Targets with Scanned Ion Beams: Design, Development, and Preliminary Test Results

*Friday, 6 September 2019 10:10 (20 minutes)*

**Introduction**
Lung and other thoracic cancer survival rates have shown limited improvements despite generally more effective local control rates. Scanned particle beam therapy has the potential for dose escalation while sparing healthy tissue, but it requires a practicable solution to the longstanding problem of the adverse effects from the interplay of moving ion beams and moving tumors. We designed and implemented a modular dose delivery system to synchronize moving tumors with scanned ion beams for safer and more effective treatment of late stage lung cancers and lung metastases. This capability will enable subsequent clinical studies to evaluate the role of scanned ion beams in treating moving tumors. The objective of this study is to confirm that a modular dose delivery system which synchronizes the motion of tumors and scanned ion beams can irradiate tumors with portability, safety, and dosimetric accuracy, while sparing surrounding healthy tissues.

**Methods and Materials**
A modular motion-synchronized dose delivery system (M-DDS) was designed, developed and tested at GSI Helmholtz Centre for Heavy Ion Research and Centro Nazionale di Adroterapia Oncologica (CNAO). The operation of the M-DDS and its subsystems, including the timing, beam request, detector, magnet, memory, and motion mitigation systems, was validated to ensure the M-DDS, when integrated into the treatment control system, functions according to design specifications. This as done by testing the transmission, reception, timing, and synchronization of signals used by each subsystem. Integration tests were performed by delivering test-case library of 10 3-dimensional (static) treatment plans, which together comprise a complete plan for a moving tumor. Additionally, the interlock and safety systems within the M-DDS were tested by inducing a series of critical and non-critical errors.
Finally, the quality of delivered dose distributions was assessed in simple geometries by considering dosimetric uniformity and conformity. Simple geometries were delivered to a 2-dimensional ionization chamber array detector and radiochromic films mounted on a sinusoidal moving platform. Various plans designed for 1, 3, 6, and 10 respiratory states were delivered to investigate the degree of motion compensation and the extent of residual motion within a single motion state. The delivered geometries were assessed for delivery quality via gamma index analysis with a 3%/3mm criteria.

**Results**
The modular M-DDS subsystem functionality, motion mitigation functionalities, and treatment delivery were experimentally verified, including synchronization of timing events, magnet interfaces, beam request software and beam monitors. Loading of treatment plan libraries into dynamic random access memory (DRAM) and synchronous delivery, where treatment sequence is directed by the detected motion state was verified. Duty cycles of 80-95% were achieved for these deliveries. The performance of a critical component of DDS safety, the gating system, was also verified at both GSI and CNAO. Complete beam disruption was possible with the chopper magnet, while residual intensities on the order of 10 % of full intensity compromised experimental results at GSI. At both facilities, rapid gating was verified.
The delivered geometries were assessed for delivery quality via gamma index analysis with a 3%/3mm criteria. 6 and 10 motion phase plans for 40 and 20 mm amplitude motion showed >95% gamma index pass rates for 50x50mm squares at CNAO. A homogeneity of 90% was measured for 50x100mm rectangles at GSI. Dose outside the target region showed a rapid fall-off, comparable to static plans.

**Summary**
Preliminary results have validated the basic functionality and feasibility of the implemented motion mitigation strategy. Further tests, including clinical safety and more complex phantoms are necessary to translate this strategy to lung or pancreas cancer patients.

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**Presenter:** Ms LIS, Michelle (GSI Helmholtzzentrum fur Schwerionenforschung, Louisiana State University)

Contribution ID: **24** Type: **not specified**

# Review of the improved nuclear physics models in FLUKA for helium and carbon ion therapy

*Thursday, 5 September 2019 09:30 (20 minutes)*

FLUKA (Ferrari et al. 2005, Böhlen et al. 2014) is a multi-purpose Monte Carlo code for particle transport, developed by a CERN-INFN collaboration. In hadron therapy it is used to generate the basic input data for the treatment planning systems (e.g. at CNAO in Italy, and at HIT and MIT in Germany), to validate the dose calculations, and for research purposes (Battistoni et al. 2016).

Besides proton and carbon ions, already in use in several facilities worlwide, HIT is planning to exploit helium ions for cancer treatments in the near future. In order to provide accurate dose calculations in FLUKA, as a support for the treatment planning system at HIT, refinements of the total and non-elastic cross section models embedded in FLUKA were carried out. Experimental data acquired at HIT (Horst et al. 2017, Horst et al. 2019) were used to benchmark the code. A better agreement between FLUKA and experimental measurements of depth-dose profiles was achieved, especially in the Bragg peak. The dose distributions predicted by the previous and revised FLUKA versions were compared in realistic clinical cases. This work is crucial in view of the use of helium ions for hadron therapy at HIT.

For estimation of the cell lethal lesions induced by the radiotherapy treatments, accurate calculations of the RBE-weighted dose are needed. Different radiobiological models have been developed, among which there are the local effect model I (LEM I) (Scholz et al. 1997, Krämer and Scholz 2006) and the microdosimetric kinetic model (MKM) (Inaniwa et al. 2010), both used in clinics. LEM IV (Grün et al. 2012, Krämer et al. 2016) is a revised version of LEM I, which has been optimized particularly for heavy ions. In addition, the biophysical analysis of cell death and chromosome aberrations (BIANCA) model (Carante et al. 2018) has been developed at the University of Pavia and INFN-Pavia (Italy).
In our research we interfaced the FLUKA code with the four above-mentioned radiobiological models. For a given physical dose, the resulting RBE-weighted dose distributions obtained using different models were compared. Real clinical cases treated at the CNAO facility were used for studies with primary carbon ions. Comparisons between simulations and in-vitro experimental data were performed for helium ion and carbon ion beams. The most relevant achievements will be presented.

*References*:
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Contribution ID: **25** Type: **not specified**

# Characterisation of the LHCb VELO detector modules as a non-invasive Proton Beam Monitor

*Wednesday, 4 September 2019 15:00 (20 minutes)*

In proton beam therapy, knowledge of the detailed beam properties is essential to ensure effective dose delivery to the patient. In clinical practice, currently used interceptive ionisation chambers require daily calibration and suffer from slow response time. Therefore, novel silicon-based detector technologies are developed. This contribution presents a non-invasive method for dose online monitoring. It is based on the silicon multi-strip sensor LHCb VELO (VErtex LOcator), developed originally for the LHCb experiment at CERN. The semi-circular detector geometry offers the possibility to measure beam intensity through halo measurements without interfering with the beam core.
The technology has been recently tested at the MC40 proton beamline at the University of Birmingham, UK. Precise measurements of the proton beam halo were performed by synchronising the readout of the VELO detector with the RF cyclotron frequency and an in-beam ionisation chamber. Different beam sizes and beam current settings were recorded and are presented. The experimental results are compared to beam tracking simulation and summarised to characterise the VELO detector as a halo beam monitor.

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Contribution ID: **26** Type: **not specified**

# Optimization of high-performance 3D/4D surface scanning technology for patient monitoring in radiotherapy environment

*Friday, 6 September 2019 09:50 (20 minutes)*

Nowadays different electronic devices are used in radiotherapy to improve and optimize the treatments. The scattered radiation in the radiotherapy environment can cause failures and/or damages to the electronics and therefore the devices must be radiation resistant in order to assure a secure treatment.
ViALUX developed in the last years a new 3D scanning technology that allows increasing the performance of its previous 3D scanners, in particular in terms of speed, precision and interface. Since these new devices will be used also in radiotherapy for patient positioning and monitoring, a radiation hardness test is necessary to assess their reliability in this environment.
The devices were tested during short tests in the conventional radiotherapy and carbon therapy environment and during a 2-day radiation test at FRM II nuclear reactor. Temporary malfunctions due to Single Event Effects and permanent damages due to the Total Ionizing Dose were investigated.
The ViALUX 3D scanners showed a good reliability in the radiotherapy environment, except from rare and recoverable interruptions of functionality detected during the tests at the nuclear reactor. The CMOS image sensor, which is a key part of the 3D scanners, showed an increase in the number of bright pixels after the irradiation. Further analysis showed that these bright pixels don't affect the 3D image quality in the typical working conditions (no gain, exposure time < 10 ms). Hardware and software solutions to further improve the 3D scanners radiation hardness are currently under study.

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Contribution ID: **27** Type: **not specified**

# Treatment facility optimization

*Thursday, 5 September 2019 16:30 (20 minutes)*

MedAustron is an Ion Beam Therapy center where patients are treated with protons and carbon ions beams. A performance increase project has been started in 2016 in parallel to further commissioning of the facility. The machine was and keep being optimized to reduce the time necessary for a treatment, in order to increase patient throughput, enhance safety and quality of the treatment and provide a more comfortable therapy experience to patients. The improvements range from upgrades of the control system to optimization of the beam dynamics of the third order slow extraction. In this work we present the machine limitations, a cost/benefit analysis of different solutions, the achieved improvements and a look into the future.

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Contribution ID: **28** Type: **not specified**

# Inter-fractional monitoring in Carbon ions Particle Therapy treatments with the Dose Profiler detector

*Thursday, 5 September 2019 12:20 (20 minutes)*

The use of C, He and O ions in Particle Therapy (PT) exploits the enhanced Relative Biological Effectiveness and Oxygen Enhancement Ratio of such projectiles to improve the treatment efficacy in damaging the cancerous cells while reducing the dose to the surrounding Organs At Risk.
The possible occurrence of inter-fraction morphological changes into the patient or patient mis-positioning with respect to the planned position are taken into account by the Treatment Planning System introducing safety factors preventing the target volume under-dosage. The treatments are optimised also avoiding an over-dosage of the healthy tissues surrounding the tumour area at the cost of reducing the very high tumour control PT capability.
An online monitoring device, whose technical implementation is still missing in clinical routine, is eagerly awaited in order fully profit from the PT efficacy reducing the needed safety margins.
Nowadays in clinical practice the re-planning of the treatment, and hence the acquisition of a new Computed Tomography scan of the patient, is done only in the occurrence of macroscopic morphological changes or whenever severe toxicities are expected or observed.
The Dose Profiler (DP) detector was developed within the INSIDE project as a beam range monitor for the CNAO (Centro Nazionale d'Adroterapia Oncologica) therapy center (Pavia, Italy) where it is currently installed and ready for use in the clinical environment.
It consists of a scintillating fibre tracker that exploits the detection of charged secondary fragments escaping from the patient, reconstructing their emission vertex.
The DP capability to spot the inter-fractional changes in the dose deposition has been investigated by means of a Monte Carlo simulation using the FLUKA software based on a dataset of patients that underwent a treatment re-planning because of the appearance of severe toxicites. The acquired emission profiles in different conditions have been compared by means of statistical tests. The expected performance of the technique for different treatments and patient conditions will be reviewed.
The results have also been validated using the data taken during a clinical trial occurred at the therapy center of Pavia in the summer of 2019. The simulation and data-taking results will be discussed, in view of assessing the DP capability of spotting inter-fractional changes in clinical conditions.

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Contribution ID: **29** Type: **not specified**

# Optimisation of graphite energy degrader geometry for proton therapy facility

*Introduction*: Cyclotron-based proton therapy facilities use an energy degrader of variable thickness to deliver the beam of the energy required by treatment plan. Together with the energy reduction, the transverse size and energy spread increase. The collimation and energy selection systems downstream of the degrader cut the beam to match the following beamline, that introduces energy-dependent beam losses. To mitigate it, alternative degrader designs were proposed and Monte Carlo simulations were performed to accurately reproduce the degrader performance.

*Methods*: Studies of several geometries of graphite energy degrader were conducted to decrease the beam emittance growth and improve the transmission. This included a single block and multi-slab degraders, along with multi-wedge geometry, currently used at the Centre for Proton Therapy at Paul Scherrer Institute (PSI), Switzerland. G4Beamline Monte Carlo simulations of the multi-wedge degrader were benchmarked against the measurements in the PROSCAN beamline at PSI.

*Results*: The beam transmission at the block degrader exit is significantly higher when compared to multi-wedges, particularly for lower energies (35% increase at 75 MeV). However, for the complete collimation system following the degrader, the transmission is the same for all geometries.

*Discussion/Conclusions*: None of the alternative designs showed transmission benefit over the currently used multi-wedge graphite degrader. Optimisation of the degrader geometry could be followed by studies into novel materials, i.e. boron carbide, to potentially minimise beam losses and mitigate their energy dependence. More complex geometries and degraders consisting of different materials could also be examined.

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**Session Classification:** Poster Session

Contribution ID: **30** Type: **not specified**

# Superconducting gantry for proton therapy and imaging

*Wednesday, 4 September 2019 17:00 (20 minutes)*

*Introduction*: Proton computed tomography can reduce uncertainties in proton therapy treatment planning. It requires a 330 MeV proton beam for full imaging of an adult body and the beam rigidity increases to 2.8 Tm (from 2.3 Tm at 230 MeV). If such rotating beam delivery system is to be placed in a hospital-based facility, superconducting technology must be employed to minimise the gantry weight and volume. A compact superconducting gantry of large energy acceptance is presented.

*Methods*: The initial gantry optics design was modelled in MAD-X, followed by the design of superconducting bending magnets. Canted cosine theta dipoles of 3.9 T central field were complete in Opera-3D software for electromagnetic simulations. Monte Carlo simulations of the full design, including the energy degrader mounted on the gantry, were performed in G4Beamline.

*Results*: An isocentric superconducting gantry for both proton therapy and proton computed tomography was designed. It is an achromatic design with normal-conducting quadrupoles and superconducting CCT dipoles. The gantry is equipped with a boron carbide energy degrader to minimise space requirements and downstream pencil beam scanning system.

*Discussion/Conclusions*: Whilst superconductivity ensures no significant volume reduction for typical proton treatment gantries, high field superconducting magnets are of benefit at higher energies. A compact large acceptance superconducting gantry can be placed in a conventional proton treatment room to deliver protons for both imaging and therapy. This improves the precision of treatment planning and allows for the patient's setup to remain the same for both procedures.

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Contribution ID: **31** Type: **not specified**

# Challenges in assessing risks for particle accelerators as medical devices

*Friday, 6 September 2019 11:50 (20 minutes)*

Particle accelerators used for cancer treatment have made tremendous progress in the recent decades in respect to performance, dose delivery and control techniques as well as their usability within clinical environments. This area is currently experiencing a growing development that promises even bigger achievements in the future regarding treatable indications, cure rates and side effects. More effective medical prescriptions will be technically feasible, with a resulting higher chance of healing and quality of life for the patient. The required higher beam intensities and precision of dose distribution for the treatment of patients increase the consequences and risks for the patients in case of failure of the particle accelerator, caused by either technical faults or human errors. This means that every progress in this field needs to be accompanied by an effective risk management process leading to an acceptable level of residual risk in relation to the expected clinical benefit. The European Medical Device Directive (93/42/EEC) and the European Medical Device Regulation (2017/745/EU) define requirements for dealing with safety and performance for medical devices, including the implementation of risk management processes and application of medical safety standards. Compliance with these requirements turns to be particularly challenging for a particle therapy accelerator. This contribution summarizes the risk management experience gained for the MedAustron Particle Therapy Accelerator with a focus on the results from the risk assessment and a few examples.

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Contribution ID: **32** Type: **not specified**

# Monitoring intra-fractional motion using a novel range telescope in a mixed He/C beam

*Thursday, 5 September 2019 12:40 (20 minutes)*

It has been proposed recently that a mixed helium carbon beam could be used for online monitoring of carbon ion therapy. At the same energy per nucleon, helium ions have about three times the range of carbon ions, which would allow for certain tumours to simultaneously use the carbon beam for treatment and the helium beam for imaging (theranostics). Here, the results of a measurement in which simple PMMA phantoms as well as anthropomorphic phantoms have been irradiated with a helium and a carbon beam with the same parameters are presented. The helium peak and the carbon tail exiting the phantoms are detected using a novel range telescope made of thin plastic scintillator sheets read out by a flat panel CMOS sensor. It is shown that a 10:1 carbon to helium mixing ratio generates a helium signal well above the carbon background while only adding 0.5% to the RBE-corrected dose in the carbon SOBP. A small air gap of 1 mm thickness in the simple PMMA phantom can be detected, demonstrating the achievable sensitivity of the presented method. In anthropomorphic phantoms it is shown that small displacements and rotations of the phantom as well as simulated rectal gassing cause detectable changes in the He/C beam exiting the phantom. The future prospects and limitations of the helium-carbon mixing as well as its technical feasibility are discussed. The group is currently working towards a system for real-time theranostics for carbon therapy.

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Contribution ID: **33** Type: **not specified**

# The SiFi-CC project - prompt gamma imaging for real time monitoring of proton therapy

*Wednesday, 4 September 2019 12:40 (20 minutes)*

As proton therapy has become a well-established cancer treatment modality, research towards improvement of quality assurance and new treatment monitoring methods have intensified. Proton therapy offers more favorable dose deposition pattern than conventional radiotherapy, however it could be further improved if currently applied safety margins were reduced. This would be possible if methods of real time monitoring were introduced into standard clinical practice. Various real time treatment monitoring techniques based on the detection of secondary radiation have been proposed so far, with prompt gamma imaging (PGI) being one of the most promising candidates.

In my presentation I will introduce the SiFi-CC project, which is a joint effort of physicists from the Jagiellonian University and the RWTH Aachen University. The aim is to develop a method for real time monitoring of dose distribution deposited during proton therapy exploiting prompt gamma radiation. For that reason, a dedicated setup is being under development, taking advantage of the latest advances in the field of scintillating detectors - heavy inorganic scintillating fibers read out by silicon photomultipliers (SiPMs). Hence the name of the collaboration - SiPMs and Fiber-based Compton Camera. The proposed detection setup will be operating in two modes: as a Compton camera (CC) and as a coded mask detector (CM). In order to optimize performance of the detector, Monte Carlo simulations of the geometry and physics performance have been carried out. Similarly, laboratory tests of various inorganic scintillators have been conducted in order to find the optimal material. The use of suitable heavy scintillating material for the active part of the detection system ensures large light output, high detection efficiency, good energy resolution and timing properties. High granularity of the proposed detector along with the fast signals and modern electronics allow for high rate capability and reduced background. The data acquisition system will be based on FPGA technology, with first stage of data processing and reduction performed on-board, which will provide high throughput, fast image reconstruction and flexibility needed for the operation of the two detection modalities.

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# A high repetition laser-plasma proton accelerator for radioisotope production

At present, radioisotope production for medical imaging and treatment is principally done at conventional accelerators. Over the last decades, the use of ultraintense lasers for this purpose has been proposed and studied [1], as an alternative in terms of availability an size. These compact systems can accelerate, via laser-plasma interaction, charged particles like protons, ions or electrons [2,3], as well as neutrons and x-ray generation [4], which can induce radioisotope production through nuclear reactions [5].
At the Laser Laboratory for Acceleration and Applications (L2A2) of the Universidad de Santiago de Compostela a high repetition rate femtosecond laser of 45 TW is used for proton acceleration. It can deliver pulses of 1.2 J and 25 fs at 10 Hz, which are then focused on a few micron spotsize area achieving intensities of 1019 W/cm2. The high repetition rate of the laser requires a positioning mechanical assembly that maintains the same focal incidence conditions while refreshing the target material at each shot. A wheel-like holder containing target sheets of few micron thickness is placed on a three mechanical stages assembly (two linear combined with a rotational one) to perform the positioning. A map of the target surface is generated by measuring the deviation of each shot point from the focal reference position with a laser-position sensor. The map is then programmed into the stages which automatically correct the laser focal position on the target shot-by-shot with micron resolution. This procedure allows to perform series of tens to hundreds of shots in a row in the same focal conditions.
Proton pulses of few MeV have been measured using a time-of-flight detector during the experiments, with an stability both in maximum energy and spectra temperature of about 3%. We expect to increase the proton maximum energy in future campains by optimizing this correction procedure and by using thinner target sheets. Once we reach protons of enough energy, we aim to achieve the production of radioisotopes like 11C for PET imaging and study its viability in relation to conventional accelerators.

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**Session Classification:** Poster Session

Contribution ID: **35** Type: **not specified**

# Quantifying DNA Damage in Comet Assay images using Neural Networks

Proton therapy for cancer treatment is a rapidly growing field as increasing evidence suggests it induces more complex damage in DNA than photons [1]. Accurate comparison between the two requires quantification of the damage caused, one method being the comet assay [2]. The program discussed here, based on neural network architecture, aims to speed up analysis of comet assay images and provide accurate assessment of the DNA damage levels apparent in them.

The comet assay is an established technique in which DNA strand breaks are spread out via an electric field, creating a comet-like object. The elongation and intensity of the comet tail indicate the level of damage incurred. Many methods to measure damage exist, from "by eye"ranking systems to computer software, which can be time consuming [2]. They result in analysing only a small fraction of images, which is a problem addressed by this program.

The neural network performs object detection and localisation using instance segmentation. Rather than extracting features to distinguish if and where an object is, instance segmentation incorporates the bounding-box method with pixel-wise classification, aiming to sort pixels into one of two classes: comet or background. The identified comet instances are then saved as masks, with a minimum identification accuracy of 90%. The purpose is to provide accurate comet detection in order to perform measurements of the comet tail length and tail DNA fraction, some common features used to measure DNA damage following a comet assay [3].
Further, modelling of the comet assay process is underway to provide a better understanding of the relationship between the assay images and the underlying level of DNA damage.

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**Session Classification:** Poster Session

Contribution ID: **36** Type: **not specified**

# Exploring of advances in high gradient technologies for use in hadron therapy accelerators

*Wednesday, 4 September 2019 10:40 (20 minutes)*

Research in the field of hadron therapy has led to a new perspective for radiotherapy treatment of cancer patients through the development of a linear proton accelerator based on high gradient technology. The main challenges of such a facility are the effective acceleration of low energy beams and the reduction of the facility footprint and its electricity consumption. All-linac designs for proton and light ion therapy linacs have potential advantages over existing circular facilities. Recent developments at CERN high frequency RFQs and high-gradient accelerating structures can make important contributions to linac-based facilities. High performance of these components during high power test indicates their potential. The maximum gradient and high gradient limiting factors of linacs are described.

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Contribution ID: **37** Type: **not specified**

# Monte Carlo modelling of the Clatterbridge Proton Therapy beamline for Beam Diagnostics integration

*Thursday, 5 September 2019 10:10 (20 minutes)*

The Clatterbridge Cancer Centre (CCC) in the United Kingdom is the world's first hospital proton beam therapy facility, treating patients with ocular cancer since 1989. In recent years there has been rapid growth across Europe in both the demand and provision of particle radiation therapy treatments, with multiple centres under development in the UK. Correspondingly, this has brought about the need for advanced diagnostics and technologies, to fully exploit the fundamental benefits of ion beam therapy. One such device currently under development by the QUASAR group, is an online beam monitor based on LHCb VErtex LOcator (VELO) detector technology. The capability of the detector as a beam halo, dose monitor for clinical ion beam accelerators is being investigated and is planned for implementation into the CCC beamline. In order to assess the performance and suitability of the system, it is important to know the characteristics and operational parameters of the beam. Facility related constraints have required extensive study and modelling of the beamline and recent work toward complete characterisation of the beam is presented. This is the first comprehensive end-to-end model of the CCC beamline, developed using the Monte Carlo toolkit, Geant4 and with extensions, Beam Delivery Simulation (BDSIM) and TOol for PArticle Simulation (TOPAS). This has allowed the possibility of simulating the beam anywhere from the exit of the cyclotron to beyond the treatment nozzle and simulation results are shown alongside experimental measurements obtained for comparison and validation. The specific application of detector integration and several other anticipated outcomes is also discussed; planned experimental campaigns, halo maps for VELO and verification as a standard model for all related work performed at the beamline.

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Contribution ID: **38** Type: **not specified**

# Technical Challenges for FLASH Proton Therapy

*Wednesday, 4 September 2019 10:20 (20 minutes)*

There is growing interest in the radiotherapy community over the applications of FLASH radiotherapy, wherein the X-ray dose is delivered to the entire treatment volume in less than a second. Early pre-clinical evidence suggests that these extremely high dose rates provide significant sparing of healthy tissue compared to conventional radiotherapy without reducing the damage to cancerous cells. This interest has been reflected in the proton therapy community, with early tests indicating that the FLASH effect is also present with high dose rate proton irradiation. In order to deliver clinically relevant doses at FLASH dose rates, significant technical hurdles must be overcome before FLASH proton therapy can be realised, particularly for modern spot-scanning dose delivery.

The current state of the art in clinical proton therapy technology is discussed, along with the current specification for clinical FLASH proton therapy. The technical challenges are outlined for each of the existing accelerator and beam delivery technologies, with possible routes discussed by which the technology can evolve to meet these challenges.

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Contribution ID: **39** Type: **not specified**

# Organ motion quantification and margins evaluation in carbon ion therapy of abdominal lesions

*Friday, 6 September 2019 09:30 (20 minutes)*

In particle therapy, image guidance is vital for planning and treating, especially for abdominal lesions, where the respiratory motion hinders treatment accuracy. In this study, fast acquired interleaved 2D CINE MR images were used to quantify the tumour (GTV) motion over several breathing cycles, to evaluate the clinical approach based on deriving an internal target volume (ITV) from a 4DCT.

Data from seven patients treated with pencil-beam scanning carbon-ion therapy for abdominal lesions at the National Centre of Oncological Hadron-therapy (CNAO, Italy) were considered. For moving targets, a combined approach with abdominal compression, rescanning and gating at end-exhale is employed. The MR scan was performed on the same day of 4DCT acquisition. For 4 patients, an additional MR was acquired approximately after 1 week. The 2D CINE MR (300 frames acquired in 1.13 min) images centered on the target, along with a deformable image registration algorithm were used to quantify tumour motion. Afterwards, two ITVs were defined considering: (1) all the respiratory phases ($ITV_FB$), (2) only phases within the gating window ($ITV_G$). The generated ITVs were compared with the clinical ITV ($ITV_C$) as defined at CNAO using phases within 30%-exhale and 30%-inhale of the 4DCT.

CINE MRI captured images from 12-20 breathing cycles in contrast to 4 from 4DCT. The ITV normalized for the GTV had median(iqr) values of 0.15(0.19), 0.32(0.52) and 0.8(0.97) for $ITV_C$, $ITV_G$ and $ITV_FB$, respectively. The median(iqr) Hausdorff distances (p=95%) from the GTV were 3.40(1.57), 2.18(2.23) and 9.71(6.99) mm for $ITV_C$, $ITV_G$ and $ITV_FB$, respectively. According to both metrics, the $ITV_C$ was significantly different from the $ITV_FB$, but not significantly different form $ITV_G$.

Spatial differences between $ITV_G$ and $ITV_C$ are due to more breathing cycles captured by MR, thought these were not-significantly different, indicating the effectiveness of the adopted gating approach to mitigate tumour motion.

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Contribution ID: **40** Type: **not specified**

# Non-invasive beam profile monitor for medical accelerators

A beam profile monitor based on a supersonic gas-curtain is currently under development for transverse profile diagnostics of electron and proton beams in the High Luminosity LHC . This monitor uses a thin supersonic gas sheet that crosses the primary beam to be characterised under an angle of 45 degrees. The fluorescence caused by the interaction between the beam and gas-curtain is detected using a specially designed imaging system to determine the 2D transverse profile of the primary beam.

This contribution presents the design features of the monitor, discusses the gas-jet curtain formation and presents various experimental tests, including profile measurements of an electron beam, using nitrogen and neon as gases. Such a non-invasive online beam profile monitor would be highly desirable also for medical linacs and storage rings as it can characterize the beam without stopping machine operation. The presentation discusses opportunities for simplifying the monitor design for integration into a medical accelerator and expected monitor performance.

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**Session Classification:** Poster Session

Contribution ID: **41** Type: **not specified**

# Measurement of PET isotope production cross sections for protons and carbon ions for applications in particle therapy range verification

Range uncertainties are among the major problems in modern particle therapy 1. The measurement of the activation pattern induced by the beam with positron emission tomography (PET) is a promising technique for in-vivo range verification and is investigated at different facilities worldwide (e.g. CNAO in Italy) in different setups (in-beam, in-room, offline). The accuracy that can be achieved by the particle therapy PET technique relies heavily on the quality of the nuclear reaction models implemented in the radiation transport code used to calculate the reference activation pattern from the treatment plan (e.g. FLUKA [2, 3]).
To support the development and validation of such transport codes, an experimental setup to measure production cross sections for the isotopes 10C, 11C and 15O on target materials of interest (12C and 16O) was built of three BaF2-scintillators and a coincidence unit. It measures the time course of the decay of the β+-activity induced in the target by a proton or carbon ion beam pulse. The production cross sections for 10C, 11C and 15O are obtained by fitting the measured decay curve with a composite exponential decay function with the half-lives corresponding to the different isotopes.

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First experiments with protons and carbon ions were conducted at the Trento proton therapy center and at the Marburg Ion-Beam Therapy center (MIT). Cross sections on 12C were obtained by irradiation of graphite targets and cross sections on 16O were measured using beryllium oxide targets. Some of the measured cross sections are shown in Figure 2.

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The cross sections obtained in the experiments at MIT are in good agreement with literature data and complement them well. In order to validate the nuclear models embedded in the FLUKA code the corresponding cross sections were extracted and compared with the experimental data. Good agreement between experiment and FLUKA was found for incident protons while some refinement of the nuclear models of FLUKA is required for carbon projectiles. Preliminary improvements in FLUKA to better match the measured production cross sections have been presented in [5].

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International Conference on Nuclear Data for Science and Technology, Beijing (2019).

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**Session Classification:** Poster Session

Contribution ID: **42** Type: **not specified**

# Toward a novel treatment planning approach accounting for prompt gamma range verification

*Wednesday, 4 September 2019 12:20 (20 minutes)*

Toward a novel treatment planning approach accounting for prompt gamma range verification

Introduction:

Prompt gamma (PG) monitoring is widely investigated to reduce range uncertainties in proton therapy. Our previous study proposed to re-optimize the treatment plan (TP) based on spot-by-spot conformities between the PG and the dose (so called PG-dose correlation). However, a good PG-dose correlation on the planning CT could still be affected by fractional anatomical changes, for which a new approach is proposed and investigated in this study.

Materials and Methods:

In this work, Monte Carlo (MC) TPs are created using an extension of a research computational platform, combining MC (Geant4) pre-calculated pencil beams with the TP system (TPS) engine CERR (A computational Environment for Radiotherapy Research). Other than the previously proposed PG-dose correlation indicator, which compares the laterally integrated PG and dose profiles, a new indicator is proposed to account for the sensitivity of individual pencil beams to heterogeneities in the 3D dose distribution. This is accomplished by using a 2D distal surface derived from 3D dose distributions of single pencil beams. Combining the indicators above, new TPs are created by boosting a few pencil beams (PBs) recommended for better PG imaging. TPs are MC-recalculated on three different fractional CT scans of a head and neck and a prostate cancer patient and then compared. Advantages over other proposed methods such as spot aggregation are also investigated.

Results:

Re-optimized and initial TPs are comparable in terms of dose distribution and dose-averaged linear energy transfer distribution on all CTs, while the PBs boosted in the new TP maintain good PG-dose correlation in the cases of fractional anatomical changes. Comparison to the performance of the spot aggregation will be also discussed.

Conclusion:

Based on our previous proposal to re-optimize treatment plans using the spot-by-spot conformities of PG and dose, an improved approach is put forward to ensure enhanced robustness of the PG-dose correlation of boosted PBs in presence of interfractional anatomical changes.

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Contribution ID: **43** Type: **not specified**

# Beamline characterization of a Dielectric-filled Reentrant Cavity Resonator as a Beam Current Monitor for medical cyclotron beamline at PSI, Switzerland: Its advantanges and limits

*Wednesday, 4 September 2019 15:20 (20 minutes)*

At PSI (Paul Scherrer Institute) Villigen, Switzerland, a superconductive cyclotron called "COMET" delivers pulsed proton beam of 250MeV at 72.85MHz for proton radiation therapy. Measuring proton beam current (0.1-40 nA) is of crucial importance and is traditionally measured with invasive monitors such as ionization chambers. A new non-invasive beam current monitor working on the principle of resonance is envisaged to replace ionization chambers (due to associated scattering) and to preserve the beam quality delivered. The resonator working on its fundamental mode is tuned to the second harmonic of the pulse rate at 145.7MHz, thus providing signals proportional to beam current. The cavity resonator installed in the PROSCAN beamline of the COMET is used to measure beam current at different energies: 141, 171, 201 and 231 MeV with multiple current sweeps. This paper focuses on the signal processing chain, its noise figure evaluation and helps to identify the relationship of the resonator calibration factor as a function of beam energy. We summarize the paper with measured resonator sensitivity, its potential advantages compared to invasive beam diagnostic such as an ionization chamber and its limitation due to noise

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Contribution ID: **44** Type: **not specified**

# Beam and detector characterisation using Medipix3 at MedAustron IR1 using protons and carbon ions at clinical flux rates and full energy range

*Wednesday, 4 September 2019 15:40 (20 minutes)*

MedAustron is a synchrotron based medical accelerator using protons and carbon ions for cancer treatment, it is based near Vienna in Wiener-Neustadt, Austria. It has been operational since 2016 and it treated 193 patients in 2018.

Simultaneous beam intensity and beam profile measurements over time with various beam parameters at the IR1 non-clinical research beamline have been performed with Medipix3, a single quantum counting hybrid pixel detector typically used for x-ray and electron detection.

The energy range used in these measurements for protons is 62 to 800 MeV and for carbon ions is 120 to 400 MeV/A, which is the full clinical range with the addition of the experimental 800 MeV proton option intended for various research applications including proton CT.

Count rate linearity was investigated using degrader plates to vary between approximately 10 and 100% of the beam intensity, resulting in count rates of up to $10^9$ particles per second over the whole sensitive area of 28 x 28 $mm^2$.

In addition, experimental low flux proton beams have been measured reducing the intensity over intermediate steps down to $10^3$ particles per second. With and without the measurements using degrader discs, current analysis shows very high linearity ($R^2$ = 0.9995) between the expected proton fluence at 62 MeV and the integrated counts on the Medipix3 from $10^7$ to $10^{11}$ total counts. Average deviations of the measurements from the linear fit were found to be 2.9% without the degrader measurements and 36.2% with them.

Another set of linearity measurements were performed using 800 MeV protons and degrader discs, they show high linearity ($R^2$ = 0.9749) between the integrated counts over the whole detector and the degrader percentage, excluding the degrader 10 measurements.

Frequency components in the intensity of the beam have been calculated for proton beams at 50 to 1000 FPS (frames per second), significant components at 252.51 Hz ($\sigma$ = 0.83), 49.98 ($\sigma$ = 0.29) and 30.55 ($\sigma$ = 0.55) were observed.

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Contribution ID: **45** Type: **not specified**

# Assessment of Beam Profile Monitors for medical and research beams in the MedAustron Facility

MedAustron is an Cancer treatment and research facility specialized on hadron therapy. The heart of the facility is a synchrotron providing proton and carbon beams with energies of 62-252 MeV and 120-400 MeV/u respectively. Extracted beams are distributed via a xxx m long HEBT to 5 different beam lines in 4 irradiation rooms intensities ranging from 10e6-10e10 particles per second. New requirements for lower flux rates (10e2 parts/s), improved time resolved measurements and increased precision motivate an upgrade of detector technology. Currently integrated scintillating fibre detectors are characterzed and compared with different scintillating screens and silicon based technologies. Beam measurements with proton and carbon beams of different intensity ranges as well as an outlook of potential developments are presented.

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**Presenter:** SCHMITZER, Claus (MedAustron)

**Session Classification:** Poster Session

Contribution ID: **46** Type: **not specified**

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

*Friday, 6 September 2019 11:30 (20 minutes)*

Several animal studies demonstrated that delivering radiation dose in a short time, i.e. with only a few beam pulses of ultra-high dose per pulse, may dramatically reduce adverse side effects, while the anti-tumoural efficacy is preserved. Due to this so-called FLASH effect, the prescribed dose could also be increased resulting in a more effective tumour control. The future application of FLASH radiation therapy requires that its performance, safety and effectiveness are reliably measured and optimised. Accurate dosimetry is vital in delivering successful radiotherapy.

Additionally, laser-driven accelerators are being considered as the next generation of cost-effective accelerators for radiotherapy, which enable further alternative advanced treatment modalities. Furthermore, novel laser wakefield accelerators allow the cost-effective generation of very high energy electrons (VHEE) which enable further alternative advanced treatment modalities, as for e.g. VHEE radiotherapy. The pulse duration of laser-driven beams is much shorter than that of conventional clinical accelerators and the dose rate in the pulse can be orders of magnitude higher.

FLASH radiotherapy, VHEE radiotherapy as well as laser-driven beams, cause significant metrological challenges related to the ultra-high pulse dose rates, which need to be addressed to enable the translation of these advanced radiotherapy techniques to clinical practice. The complexity and the resources needed for research in advanced radiation therapy using particle beams with ultra-high pulse dose rates requires wide, multidisciplinary scientific approaches that go beyond the capabilities of a single research institute. In the framework of the European Metrology Programme for Innovation and Research (EMPIR) the Joint Research Project "Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates"will address this problem.

This work outlines the challenges and approaches at dosimetry for particle beams with ultra-high pulse dose rates and introduces the partners of the EMPIR research consortium as well as their task allocation.

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Contribution ID: **47** Type: **not specified**

# Development and calibration of a Multi-Leaf Faraday Cup for the determination of the beam energy of a 50 MeV electron LINAC in real time

The Physikalisch-Technische Bundesanstalt (PTB), Germany's national primary standard laboratory, operates a custom-designed electron LINAC for the generation of high energy electron and photon radiation for research in the field of dosimetry for radiation therapy. The beam energy of this LINAC is variable in the range from 0.5 MeV up to 50 MeV.

The preparation of a beam at a LINAC is an optimization problem with several parameters. The energy of the beam depends simultaneously on several variable settings. All parameters which influence the RF power (as e.g. via the high voltage at the modulator) as well as the number of charged particles in a bunch to be accelerated (as e.g. via the gun emission) also change the energy of the beam.

To measure the beam energy during the preparation or optimization of the beam, a Multi-Leaf Faraday Cup (MLFC) was developed and installed instead of the beam dump at the end of the accelerator structure. This MLFC allows pulse-resolved measurement of beam energy and power in real time, so that the influence of the manipulated variables on the energy can be immediately assessed during beam optimization. This drastically shortens the time required to create a new setting (list of all parameters) for a new desired combination of beam energy and power.

The MLFC consists mainly of 128 electrically isolated Al plates where the thickness of the stack is sufficient to stop a 50 MeV electron beam. After each beam pulse, the charge collected by the individual Al plates is recorded sequentially. For this purpose, an electronic system based on inexpensive current integrators has been specially developed. The range of the electrons and thus the distribution of the charge on the Al plates depends on the energy.

The MLFC was calibrated with monoenergetic electron beams. The MLFC was attached to the output of a 180-degree magnetic spectrometer at the beam line. Several characteristics of the charge distribution measured by the MLFC were then recorded as a function of the known beam energy. The MLFC was then installed at the end of the accelerator structure. Using a computer program, the characteristics of the charge distribution recorded by the MLFC are now determined in real time and the corresponding energy resulting from the previously determined calibration function is displayed for each beam pulse.

In this work we show example data from the calibration and compare the features and capabilities of the current MLFC with 128 leaf with those of a previously self-developed MLFC with only 4 leafs.

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**Session Classification:** Poster Session

Contribution ID: **48** Type: **not specified**

# Dosimetric commissioning of a pencil beam algorithm for the scanned carbon ion beam delivery system installed at MedAustron Ion Therapy Center.

**Purpose:** Since December 2016 at the MedAustron Ion Therapy center (MA) patients have been treated with protons. The synchrotron accelerator is also able to deliver carbon ions with energies between 120 and 402.8 MeV/u (ranges from 2.9 to 27 cm in water). In this work we report the results of dosimetric commissioning of the pencil beam algorithm PBv3.0 available in the treatment planning system (TPS) RayStation RSv8B (RaySearch Laboratories, RSL, Sweden) for a scanned carbon ion beam delivery in one fixed horizontal beamline at MA.

**Materials and Methods:** Measurements were performed with detectors and water phantoms positioned at different air gaps including cases with and without range shifter (RaShi). We introduced the ISD definition as the distance between the in-room isocenter and the detector/phantom surface with positive values for surfaces upstream of the isocenter (toward the nozzle) and negative values downstream of the isocenter. The validation of the PBv3.0 algorithm was done step by step by increasing the complexity of the tests. First, we evaluated the performance of the dose engine in reproducing dosimetric properties for the delivery of single static pencil beams (1D commissioning) and for a mono-energetic layer with multiple spots (2D commissioning). After that, the delivery of quasi-discrete scanned pencil beam for multiple energy layers to irradiate a 3D target was assessed (3D commissioning). In the first step, Integrated Radial Profiles as function of Depth (IRPDs) in water, lateral spot profiles in air and absorbed dose to water in reference conditions were measured. For the last step, test cases complexity was increased from the easier box-shaped fields in homogeneous phantoms to more complex clinical cases. For all the 1D-2D-3D tests, the same experimental setup was reproduced in the TPS. The IRPDs were measured in the water phantom. Measurements were carried out with a plane parallel ionization chamber PPIC (model 34070, sensitive diameter 81.6 mm, PTW- Freiburg) at ISD0cm (isocentric configuration) and at ISD50cm (non-isocentric configuration) for a sample of energies selected over the clinical range. Comparison between calculations and measurements was done in terms of physical range at 80% of the peak dose ($R_{80}$) and relative point-to-point dose deviations in percentage. The lateral spot profiles in air were acquired with a Lynx detector (IBA Dosimetry, Schwarzenbruck) at several ISDs (-20 cm, 0 cm, 20 cm, 30 cm, 40 cm, 50 cm, 58 cm) for different energies. Measurements and calculations were compared in terms of Full Width at Half Maximum (FWHM) in the two orthogonal planes. Beam model calibration in terms of absorbed dose to water were carried out at the center of mono-energetic layers with the PTW-34001 Roos type chamber positioned in water at the reference depths of 14 mm and at 75% of $R_{80}$. The relative deviations in percentage between the absorbed dose to water predicted by the TPS and the measured one were evaluated. Most of the treatment plans created for the validation of 3D delivery were optimized at ISD0cm and ISD50cm. Absolute doses were measured with 24 PinPoint ICs (PTW-31015) fixed to the 3D detector block holder in a MP3-P water phantom (PTW-Freiburg). The absorbed dose to water values were extracted from the TPS at the effective point of measurement of each PinPoint chamber and compared with the measured values. The agreement between the planned and the measured dose was evaluated based on the mean of the overall local or global (normalized to max dose per beam) deviations and the pass-rate of global deviations within 3 %, 5 % and 7 %.

**Results:** Relative dose difference between TPS calculated and measured IRPDs at ISD0cm shows an agreement within 1 % and within 5 % at ISD50cm with RaShi. The computed and measured $R_{80}$ are in very good agreement within ± 0.1 mm. For lateral spot profiles in air the computed FWHM is within 0.3 mm or 5 % of the measured one at ISD0. Larger deviations in terms of FWHM within ±12 % were found at a reduced air gap (ISD 58cm). Measured and computed absorbed doses to water at the reference conditions agree within ±1.5 %. The 3D commissioning for simple boxes in water at ISD0cm shows a mean local dose difference within ±2 % that increase to ±4 % for deep

seated targets. Similar behavior has been observed at ISD50cm. For box-like targets in presence of RaShi the mean global deviations are within ±1 %. Regarding the clinical cases for a temporal lobe sarcoma case, mean global dose deviations were within ±2 % for all the beams (see Figure 1).

**Conclusion:** Extensive TPS commissioning validation was done from April to June 2019 before starting treatment with carbon ions. Based on the positive results of the dosimetric commissioning the first patient has been safely treated with carbon ions at MA in July 2019. The described stepwise methodology is broadly applicable and the validation of different treatment plans gives an indication of capabilities and limitations of the PBv3.0 algorithm over the entire clinical range.

Figure 1. The mean of the global differences for all the eight beams composing the temporal lobe sarcoma patient plan.

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**Session Classification:** Poster Session

Contribution ID: **49** Type: **not specified**

# Luminescence imaging of proton beams in water: Is this method sufficient for use in clinical quality assurance?

*Thursday, 5 September 2019 12:00 (20 minutes)*

Proton therapy is increasingly used in modern radiation therapy. In the quality assurance of Proton therapy facilities, a recurring dosimetric task is the verification of the stability of the proton ranges in water for all energies provided by the system. The conventional measurement method using an ionization chamber with an adjustable water column (e.g. PTW Peakfinder) is very time-consuming, depending on the required spatial resolution and number of energies to be measured. The use of multi-layer ionization chambers (e.g. IBA Giraffe) is faster but limited in depth resolution.
Recently, luminescence light emitted from water irradiated with proton beams has been depicted and was subject of different studies x1,2x. It turned out that this luminescence light is strong enough to be detected by sensitive cameras at the dose levels typical for proton therapy. The local intensity of the luminescence light appears to depend on the dose.
In this work, we aim to prove the suitability of this method as a quality assurance tool in particle therapy, using the example of range measurements for proton beams within the therapeutical energy range.
For this purpose, a comparative measurement between standard measurement using multi-layer ionization chambers and an optical measurement using a high sensitive CMOS Camera was carried out in an experiment at the Westdeutsches Protonentherapiezentrum Essen (WPE). This work shall examine if the optical system is usable in a proton treatment room or if it gets disturbed by scattered radiation. The possibility to measure the proton ranges in water over the entire clinical energy range shall be determined. Furthermore, it shall be observed if the spatial resolution is sufficient to measure the smallest possible range difference of the therapy system

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It has been proven that it is possible to measure the luminescence signal for a Bragg peak in pure water without any detector perturbation although the signal intensity is very weak. For the observation of the peak position, our measurements reach a high conformity with the peak position measured by a multi-layer ionization chamber. A statement about the relationship between dose and luminescence signal is challenging and will be subject of further investigations.

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Med Phys. 2015 Nov; 42(11): 6498–6506. doi: 10.1118/1.4932630

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Contribution ID: **50** Type: **not specified**

# PET Imaging and Dose correlation from Proton Activation.

*Wednesday, 4 September 2019 12:00 (20 minutes)*

Range verification techniques for protontherapy include positron-emission tomography (PET) and prompt-gamma (PG) imaging. The main challenges preventing their clinical implementation are, in case of PET, the relatively long half-lives of the isotopes of interest and the large energy needed to activate PET-decaying nuclei 1.
We have investigated the use of certain isotopes as contrast agents for PET, increasing their activation rates and shifting the activity peaks towards the Bragg peak. For this purpose we have developed an activation calculation tool in different software packages such as TOPAS and PenH, and we have compared both. The experiental and theoretical results show an increased PET activation at the distal end of a 150 MeV proton beam, within 1 mm from the Bragg peak (BP), using Water-18O (H2O18) as a contrast agent.
The activation maps of 18F (T1/2≈110 min) and 15O (T1/2≈122 s) obtained from TOPAS and the SuperArgus 4R preclinical PET scanner 2 have been simulated with PeneloPET [3], in order to obtain 5-minute-long acquisitions right after irradiation and 15 minutes later. Results show the dominance of the 15O signal in a delocalized region far from BP in the first 5 minutes, but the BP distal end is perfectly identified for the 15 minutes delayed acquisition due to the 18F signal arising from the proton activation of 18O. The H2O18 is perfect for validation and verification with phantoms, and in vivo patients, provided if it could be biologically fixed in area of maximum dose deposition.
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Contribution ID: **51** Type: **not specified**

# Light ion therapy software for data exchange

*Thursday, 5 September 2019 17:10 (20 minutes)*

The Italian National Center for Oncological Hadrontherapy is currently upgrading one of the software environments of its medical accelerator control system. This environment, named configuration and support environment, is tasked with the configuration of accelerator components, management of the control system repository, and other support tasks. The objective of the three year technological upgrade project is to integrate of mobile devices into the environment, and update the technological stack used, resulting in a more maintainable, testable, and versatile software layer. For this project, product line architecture was designed for the new applications in this environment, which will slowly replace the legacy applications, while coexisting with them. A service oriented development approach was chosen, resulting in the development of several REST API services. Additionally, commonly used operations were implemented as reusable libraries, and a skeleton application generator, designed to create customized, yet fully functional, base applications.

This talk aims to describe the lifecycle of this project, while presenting several challenges tackled in areas such as authentication and authorization, planning for efficient medical certification, separation of concerns, and platform interoperability.

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Contribution ID: **52** Type: **not specified**

# Characterization of commercial photo-devices as dose-rate sensors

Characterization of commercial photo-devices as dose-rate sensors

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Introduction. The main application of photodiodes, phototransistors is to measure visible, ultraviolet or infrared light however some authors have reported their use as dose rate sensor with X-ray photon beams (M.S. Andjelkovic et al., Radiation Measurements 75, 2015).
Our research group previously developed a reader unit for MOSFET dosimeters (M.A. Carvajal et al., Sensors and Actuators A 247, 2016) and an external module to be able to measure the current produce by photo-devices by the radiation.
The aim of this work is to characterize commercial photodiodes and phototransistors as dose rate sensors for linear accelerators.
Method and materials.
The current voltage converter. It is based on the operational amplifier with a feedback resistor of 4.7 MΩ. The output is low pass filtered and adapted to our reader unit input, connected to our reader unit, achieving a resolution of 0.2 nA. The biasing voltage, -10 V, was obtained filtering the output of a DC-DC inverter.
Commercial devices under test. The devices selected as dose-rate sensor candidates were two photo-transistors, OP505 (Optek) and BPW85B (Vishay Siliconix); and one photodiode VTB8440BH (VTB Process Photodiode).
Experimental setup. Two experiments were carried out with an irradiation field of 10x10 cm2 in electronic equilibrium conditions, and placing the devices at the isocentre of the radiation sources (at 100 cm) of the linear accelerators:
- Siemens Artiste, 6 MV: Devices to test BPW85B and VTB8440BH.
- Siemens KDS, 18 MV: Device to test OP505.

Dose rates of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 Gy/min were used to characterize the response of the reader module and the phototransistors. To study the effect of the accumulate dose, the response of the devices were monitored from high-to-low dose rate, and after, from low-to-high dose rates. In order to minimize the effect of ambient light the devices were painted with nails polish and placed into a black plastic box.
Results. Linear dependence of the current with dose-rate was found in all the experiments with high linearity, correlation factors (R^2) between 0.995 and 0.998. However a degradation of the sensitivity of from high-to-low study and low-to-high (after the first 12 Gy) was of 3% for the OP505, 29% for the BPW85B and 32% for the VTB8440BH.
Conclusions. The OP505 presented a better response to be used as dose rate sensor with our reader module, and it will be characterized with photon beams of 6 and 12 MV.
Acknowledgments. This work has been partially supported by the Consejería de Salud (PI-0505-2017) and the Consejería de Conocimiento, Investigación y Universidad (FQM387) of the Junta de Andalucía, the Spanish Ministerio de Ciencia y Competitividad (FPA2015-67694-P) and the European Regional Development Fund (ERDF).

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**Session Classification:** Poster Session

Contribution ID: **53** Type: **not specified**

# PENH, an extension of PENELOPE code which includes proton induced nuclear reactions

PENH was initially developed as the extension of PENENELOPE (a code system for Monte Carlo simulation of electron and photon transport), which incorporated the electromagnetic transport of protons aiming to its application to protontherapy. Nevertheless, the absence of nuclear interactions prevented the accurate estimation of the dose deposition along the beam axis in protontherapy treatments, specially at the high energy entrance region of the beam, where the nuclear contribution is mostly concentrated. The inclusion of such effects has been recently accomplished by means of the use of evaluated nuclear data libraries in ENDF format, which are directly accessed by the code and used for the sampling of multiplicities and double differential cross sections of secondary particles. Among the later, light fragments (up to alphas) are transported as "equivalent protons" (with energies scaled to reproduce the range of the true particles and weight, which guarantees energy conservation) whereas the slower and more ionizing fragments (which include secondaries heavier than alphas and recoiling residual target nuclei) deposit their energy locally. Elastic scattering of protons is treated within an unified formalism which includes consistently the Coulomb and nuclear contributions. Cross-checks with Geant4 calculations using the same sets of evaluated data show excelent agreement

The Monte Carlo simulation of the production of beta+ emitters by a proton beam has recently atracted mayor interest, since the detection of the subsequent gamma rays allows the prediction of its range. It is a well known fact that the theoretical models implemented in the present day Monte Carlo codes are not capable of reproducing the experimental data on isotope production in this enery range and it's not foreseeable that they will be in the near future. Therefore, to get realistic estimations of the isototope production cross sections is a must for such calculations. Nevertheless different evaluated nuclear data libraries show noticeable discrepancies and the experimental data are usually scarce and/or do not cover te entire energy range of interest (experimental campaigns are under way to remedy it). Calculations with PENH have been performed with evaluated data extracted from the same libraries used for proton transportation and the available experimental data after interpolation. Also in this case, comparisons with Geant4 calculations on isotope production along the proton beam path in organic material at protontheray energies show excellent agreement. In particular, when experimental cross sections are provided, the agreement on the isotope production along the beam trajectory is also remarkable, which paves the way for the use of PENH in protontherapy treatment planning and verification.

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# Production cross section of the short-lived $\beta^+$ emitters $^{12}$N, $^{29}$P and $^{38m}$K for online PET verification in proton therapy

In proton therapy, in-vivo PET range verification requires a comparison of the measured and expected $\beta^+$ activity distribution produced by the proton beam by means of nuclear reactions on the most abundant elements in the body of the patient: C, O, N and, to a lesser extent, P and Ca. The accuracy of the expected activity distributions depends on the accuracy of the Monte Carlo simulations, dominated by that of the underlying cross sections data [1]. These are not available in the full energy range of interest (up to 230 MeV) and, when they are, there are sizable discrepancies between data sets. Several studies [2,3] confirm the need for more and better measurements, especially for the short-lived nuclides, for which there are no data whatsoever above 55 MeV [4].

In this context, we intend to improve the knowledge of the production yields of the long- and short-lived $\beta^+$ emitter isotopes of interest. Focusing on the short-lived ones (half-life shorter than the 19 s of $^{10}$C), an experiment has been carried out at KVI-CART (The Netherlands) to measure the most copiously produced isotopes: $^{12}$N ($t_{1/2}$=11 ms) on C, $^{29}$P ($t_{1/2}$=4.14 s) on P and $^{38m}$K ($t_{1/2}$=924 ms) on Ca [3]. The set-up (fig. 1) is designed to measure the production yield at four different energies for each selected primary beam energy. The targets are placed between 3 mm layers of aluminium, which degrade the beam energy and convert the positrons into 511 keV photons which are detected in coincidence by pairs of $LaBr_3$ detectors. The experimental setup, simulations and preliminary results of the production cross sections $^{12}$C(p,n)$^{12}$N, $^{31}$P(p,p2n)$^{29}$P and $^{40}$Ca(p,2pn)$^{38m}$K below 150 MeV are presented herein.

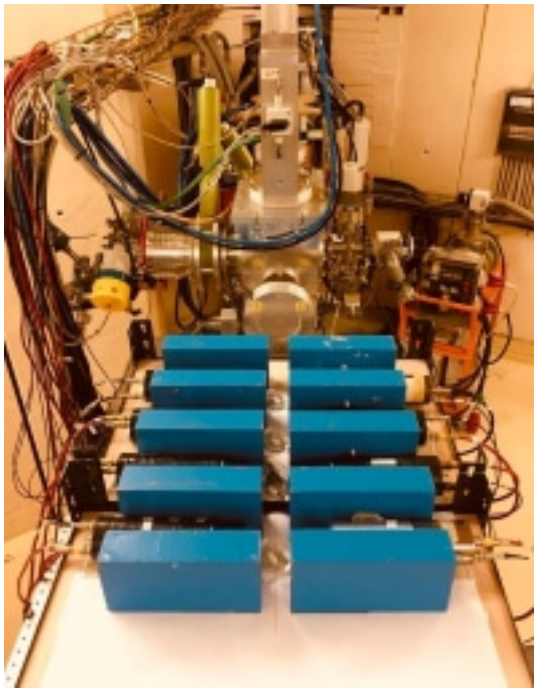

Figure 1: Figure 1. Set up for the measurement of proton induced short-lived β+ emitters at KVI-CART.

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**Session Classification:** Poster Session

Contribution ID: **55** Type: **not specified**

# Preliminary results of the INSIDE clinical trial for in-vivo treatment verification in particle therapy

In particle therapy, an on-line treatment verification device is highly required to reduce the uncertainty of the actual particle range during the patient irradiation and interfractional morphological changes. The final aim is to improve the robustness and effectiveness of the treatment in terms of conformity of the dose released to the target.
The INSIDE bi-modal system is currently in the commissioning phase at the CNAO centre (Centro Nazionale di Adroterapia Oncologica) in Pavia (Italy). It consists of an in-beam Positron Emission Tomography (PET) scanner and a scintillating fiber tracker, which exploit the beam-induced $\beta^+$ activity and secondary charged fragments, respectively.
A clinical trial (ClinicalTrials.gov Identifier: NCT03662373) is going to start in the next months. Patients affected by four selected pathologies of Head-and-Neck and Brain districts will be monitored.
In two of these pathologies (i.e. skull base (clivus) chordoma treated with carbon ion therapy and meningioma treated with proton therapy) no morphological changes are expected and, therefore, the results will be useful in the determination of the reproducibility of the measurements and the clinical limits for the detection of significant range differences. Instead, in the other two pathologies (i.e. adenoid cystic carcinoma treated with carbon ion therapy and squamocellular rhinopharynx carcinoma treated with proton therapy) morphological changes have been found and are known to require replanning in clinics. Therefore, they are included in order to test the sensitivity of the system and its effectiveness as supporting tool in the scheduling of personalized control exams.
In this contribution, a preliminary study of the interfractional monitoring capability of the INSIDE system will be shown.

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**Session Classification:** Poster Session

Contribution ID: **56** Type: **not specified**

# Preparation of a radiobiology beam-line at the 18 MeV proton cyclotron facility at CNA

*Thursday, 5 September 2019 16:50 (20 minutes)*

Biophysical investigations using particle accelerators have gained interest in the last decades, coinciding with the spread of particle therapy centres worldwide and with the establishment of proton and ion therapy as recognized treatments for different types of tumours, with excellent clinical outcomes. Radiobiological experiments at proton and heavy-ion accelerators pose stringent conditions both on the physical and on the biological point of view. Firstly, a homogeneous dose distribution throughout the biological sample must be ensured, with a meaningful dose rate comparable to that used in the clinic (of the order of 2 Gy/min). Furthermore, when dealing with low-energy accelerators, the limited particle range makes it difficult to irradiate samples in tissue flasks filled with medium, meaning that cells must be exposed inside open culture vessels, vulnerable to bacterial contaminations. Finally, as biological targets are always made of living material, the environmental parameters such as room temperature, air pressure and humidity must be taken under control, to ensure that there is no additional impact on the cell viability.
At the National Centre of Accelerators (CNA) in Seville, Spain, the experimental beam line installed at the 18 MeV proton cyclotron facility has been adapted for the irradiation of mono-layer cell cultures placed vertically with respect to the beam.
In order to improve the homogeneity and decrease the beam intensity, a completely defocused beam has been used, scattering it 1.7 m upstream the exit window by placing an aluminium foil of 0.5 mm thickness. With these arrangements, a beam of 14.5 MeV is extracted, with a size of 4 mm diameter. Measurements have been done at different distances from the beam exit window to find the best conditions for the irradiation of biological samples, ensuring homogeneous dose profiles with deviations lower than 5% in the central 35 mm of the beam. Furhtermore, dosimetric studies using EBT3 radiochromic films and a transmission ionization chamber have been performed and compared with a Geant4 Monte Carlo simulation, which reproduces accurately the cyclotron beam properties and experimental setup. Finally, a preliminary experiment with cell cultures has been carried out irradiating human bone osteosarcoma epithelial cells with two different proton doses.

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Contribution ID: **57** Type: **not specified**

# Advances in the FLUKA Particle Therapy Tool and its extensions for ion therapy optimization.

This work presents the recent developments of the FLUKA [1,2,3] Particle Therapy Tool [4]. FLUKA is a general-purpose Monte Carlo (MC), particle transport code, used for an extended range of applications including medical physics. Together with the support of its graphical user interface Flair [5,6], an easy-to use platform was developed for MC simulations in particle therapy. It has already proven its use in applications such: patient specific treatment plan quality assurance and biologically-oriented dose scoring in clinical and research scenarios.

Two novel additions to the FLUKA Particle Therapy Tool will be presented here: an extended validation of the tool for complex clinical carbon ion irradiation scenarios and an extension of the FLUKA Particle Therapy Tool for multiobjective optimization based on dose and dose-averaged Linear Energy Transfer (LET_D) distributions.

Four multi-field clinical carbon ion treatment plan scenarios from CNAO were studied, i.e. head and neck, liver, prostate and pancreas, of which two include range shifter. Together with their validation against commissioned clinical Treatment Planning System (TPS) results and analysis of the discrepancies, RBE-weighted dose (DRBE) distributions using clinical radiobiological models (LEM I [7], MKM [8]) were calculated. Uncertainties in predicting D_RBE using such models make the optimization of LET_D distributions as additional descriptor for estimating the biological tissue response a promising approach to improve clinical outcome. This idea was then used in a treatment planning re-optimization.

The extension of the FLUKA Particle Therapy Tool provides optimization functionalities with the support of the MC-based treatment planning tool [9]. An upgraded tool is now compatible with the standardized FLUKA functions and the current modular design allows to easily test new optimization algorithms. In order to cope with the multiobjective optimization problem (physical dose and LET_D distributions), various evolutionary algorithms were implemented and tested. Preliminary optimization results provide a reduction of the hight LET_D distribution in organs at risk (OAR), while still satisfying the clinical requirments on the Dose-Volume-Histograms for planned target volume (PTV). Results using MultiObjective Evolutionary Algorithm based on Decomposition (MOEA/D) algorithm [10] for optimizing carbon ion treatment plans will be presented.

Obtained results shows that FLUKA Particle Therapy Tool is suitable for clinical and research application in particle therapy. Moreover, it can be easily extended to other ion species such as helium ions, planned to be used at HIT clinically in close future.

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Contribution ID: **58** Type: **not specified**

# A collaborative compact linear particle accelerator project for Carbon therapy

Added Value Industrial Engineering Solutions S.L.U. is an international company which provides technology-based services to innovative and challenging projects. Strongly focused on the development of outstanding devices, instruments, mechanisms and structures, their expertise covers design, manufacturing, assembly, tests and supply under ISO 9001 EN 9100, providing customers all the way up from the conceptual design to the turnkey solution. From diagnostics in the accelerators field (emittance meters, water cooled scrapers, compact Diagnostic Boxes, high power collimators and slits, small angle X-ray scattering beamlines) to diagnostics in the Nuclear Fusion area (steady state outer vessel sensors, magnetic loops, fiber optics current sensors, fast ion loss detectors and Low noise TIAs, NBI beamline components···). From thrusters and mechanical devices for space for ESA (sampling tool mechanism) and NASA (MEDA MARS rover wind sensors and calibration target) to Spectrograph for large telescopes (MEGARA) or high precision alignment structures (crab cavities). Outstanding performance under operation is demonstrated day by day along the most recognized facilities (i.e. ITER, CERN, ESRF, ELI beamlines, ILL, RAL, NASA, ESA ···).

AVS is currently leading a consortium of companies in a collaborative project, which aims at developing components and systems that will result in the capability to develop a compact particle accelerator for Carbon therapy.

During the initial phase (2018-2020), the tasks triggering and defining the future accelerator performance and position within the market (analysis, conceptual engineering design, technical requirements and specifications) are being developed. AVS is collaborating with CERN and other institutions in the design and manufacturing of different subsystems, e. g. a fully striped carbon ion C6+ source. Besides, diagnostics instruments for the ion extraction line
such as deflector, beam stopper, degrader are under evaluation. In a subsequent phase (2021-2023), the review of the general engineering, the prototype testing and the manufacturing of the remaining components will take place.
In addition to those activities, AVS'developed a specific product (i.e. beam diagnostic boxes) for proton therapy accelerators with a high degree of market share.

Thus, AVS, as adjunct partner in the OMA project, brings its expertise in the network, proposing to the partner institutions innovative solutions beyond the state of the art, supporting and helping with the advances in the OMA's research projects.

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**Session Classification:** Poster Session

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# The role of image reconstruction and processing in image-based range verification for particle therapy: A Review

To fully exploit the advantages of therapeutic ion beams, on-line monitoring of the dose deposition would be highly desirable. At present, several methods have been proposed to determine the beam range using the secondary radiation originating from the interactions between the therapeutic beam and the tissues. Two main techniques are prompt gamma imaging (PGI) and positron emission tomography (PET). Among PGI approaches, tomographic imaging using Compton cameras (CC) have been proposed.

Both CC-based PGI and PET are aimed to reconstruct the measured data into a tridimensional image which describes the distribution of the secondary radiation sources. This process corresponds to solve an inverse problem under very adverse conditions, e.g., very low rates of useful events, background noise, geometrical constraints and subsequent data truncation, etc. In this work, we aim to provide an insight of current techniques, possibilities and challenges which affect the precision and accuracy of CC and PET based range estimations. We focus on the role of the system response model, the type of reconstruction algorithm, possible data selection and use of a-priori information, etc. The way image reconstructed images are further processed can also affect the estimation of the distal fall-off, which is often the piece of information used to identify possible range deviations.

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**Session Classification:** Poster Session

Contribution ID: **60** Type: **not specified**

# Design and optimization of beam optics for a superconducting gantry

Design study of a lightweight superconducting gantry applied to proton therapy was performed at HUST. By using alternating-gradient (AG) CCT magnets, the footprint and weight of the gantry can be significant reduced. Meanwhile, a large momentum acceptance avoids the requirement of fast magnetic field change of superconducting magnets during tumor treatment. We presented a beam optics design for this superconducting gantry with downstream scanning. Considering the operating mode in large momentum acceptance, second order aberration and fringe field effect have been studied using COSY INFINITY for optics optimization. And particle tracking is performed for design validation.

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**Session Classification:** Poster Session

Contribution ID: **61** Type: **not specified**

# ”Laser driven plasma X-ray microfocus source for phase contrast tomography

In this paper we describe the development of an stable, microfocus X-ray source driven by an ultrashort high intensity laser. This source follows a new route to high brightness and small source size somewhere in the middle of low cost microfocus X-rays and large scale synchroton facilities. We explore one application of this new type of sources with emphasis on the stability of the source at high repetition rate and the advantage over similar conventional sources.
The availability of ultrashort laser pulses with high power [1,2] has lead to the development of the Laser Driven Plasma Accelerator (LDPA) [3] where a short and ultraintense pulse can produce plasma structures which can accelerate particles to relativistic velocities.
In this paper, we report the development and application of a microfocus X-ray source for phase contrast tomography in the lambda cube regime. In this regime the laser pulse is compressed in space and time to the physical limit. This allow the use of laser with moderate energy (˜ 1 mJ) and high repetition rate (˜ KHz) to produce high intensities relevant to the physics of the LDPAs.
The X-ray source produced at the Laser Laboratory for Acceleration and Applications (L2A2) of the University of Santiago de Compostela (USC), is made by focusing a 1mJ, 35 fs, 1kHz pulses at 800 nm wavelength on metallic foils close to the diffraction limit. In this experiment, we use a microscope objective to focus the light to intensities larger than 1017 W/cm2
.
As the laser pulse destroy the target at every shot and due to the tight focusing (˜ 4 um Rayleigh length), the stable operation of the source must combine a fast refreshing of the target combined with a high precision positioning to maintain the target on focus as the intensity drops dramatically out of focus.
We first characterize the source and then optimize the stability to perform the applications. The X-ray spectra of this source are measured with a CdTe spectrometer and consist of a broad Bremsstrahlung continuum up to 150 of keV and K-alpha peaks of the target material (8.12 and 8.8 keV for Cu). Typical temperatures of the distributions are around 20 to 150 keV. The source size is measured by the knife edge technique and is 10 μm diameter.
We describe how the characteristics of this X-ray source can be used to produce high resolution images and how the online methods can be used to make phase contrast images. The stability of the source allows to do phase contrast tomography which can determine the real part of the index of refraction of materials. Finally, we compare different synchrotrons, conventional microfocus and laser driven X-rays with respect to this application to understand the opportunities of challenges of these new sources.

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**Presenter:** RUIZ MÉNDEZ, CAMILO

**Session Classification:** Poster Session

Contribution ID: **62** Type: **not specified**

# PADC nuclear track detector for ion spectroscopy in laser-plasma acceleration

The transparent polymer polyallyl-diglycol-carbonate (PADC), also known as CR-39, is widely used for ion detection in laser-plasma interactions. It allows for detection of single protons and ions via formation of microscopic tracks after etching in NaOH or KOH solutions. PADC combines a high sensitivity and high specificity with inertness towards electromagnetic noise.
We have developed techniques for the identification of different ion species and for the determination of particle energies based on the track characteristics. At the 3 MV tandem accelerator of CNA (Seville) about 300 CR-39 calibration samples have been irradiated with monoenergetic proton and carbon ion beams. These allow for systematic studies of the corresponding track diameters over a wide range of incident energies. Different etching conditions, especially concerning the temperature and etching time, have been tested to find an optimum procedure for particle identification. We have observed significant differences in the response of two types of PADC plastics.
Specific hardware and software have been developed and tested to meet the requirements on track analysis for spectroscopic purposes. Ideally, the entire surface of the CR-39 plates is scanned with resolution better than 1 µm to guarantee a precise determination of the track diameters. We have compared three different options comprising two commercial track readers and a laboratory microscope with home-made data acquisition system. The scanning procedures give rise to more than 100 microscopic images for each CR-39 plate. Further, we have developed algorithms for the automatic identification of circular patterns (up to several thousand per image) and the measurement of their sizes. These techniques have been successfully applied to laser-accelerated protons with energies up to 2.2 MeV. They may be useful as well for the precise characterization of ions in nuclear or biomedical applications.

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# Proton FLASH - a perspective

FLASH radiotherapy is a novel treatment modality, which promises reduced normal tissue toxicity while keeping the same tumor control. This so-called "FLASH effect" can be observed when delivering high doses of radiation in very short time and was demonstrated by Favaudon et al. in 2014 using a 4.5 MeV electron beam to irradiate mouse lungs in vivo. Since then multiple other experiments followed, mainly using electrons, but also with X-rays or proton beams. The creation of "FLASH beams" is technically demanding and in the range of currently clinically available treatment machines only specific particle therapy systems like Varian's ProBeam system might be able to provide these beams.

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# Advancements in particle therapy systems - acceleration and delivery

*Thursday, 5 September 2019 17:30 (20 minutes)*

Although the use of particle therapy continues to expand, specific challenges inhibit its broader penetration as well as its clinical efficacy under certain conditions: The size and cost of particle therapy systems and their operation are restrictions. Also, technical limitations associated with the achievable level of dose conformality often hinder the advancement of particle therapy in comparison to conventional techniques.

Current and up and coming technical innovations that may overcome these challenges will be discussed, including novel advancements in beam production, as well as advanced particle therapy delivery techniques.

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