Letter of intent: proposal template

Acronym: TIMEPATH

Project Title: TimePath: TIming MEasurements for PArticleTHerapy

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In the sections below, please provide details on *(2 pages max.):*

1. Research objectives

The goal of our proposal is to **develop and test innovative multi-detector systems for improving Particle Therapy, both for online monitoring and treatment verification and for measurements of double differential production cross section of neutral secondary particles, mainly neutrons**.
The approach we propose is based on **beam single particle tracking** and **high time resolution measurements** of the primary particle delivery time and the correlated secondary radiation detection time. **The basic elements of the proposed system are a beam monitor sensor with a time resolution better than 50 ps and secondary radiation detectors with a time resolution of at least 150-200 ps.** In Particle Therapy, this approach based on high precision time measurements could be adopted for different types of primary beams (particles, fluxes, particle spatial distributions) and irradiated targets (from thin high isotopic purity phantoms to human patients). For example, the Prompt Gamma Timing (PGT) technique [1], based on the detection of prompt photons emitted by nuclear de-excitation during Particle Therapy irradiations, has been recently assessed [2] in a 'no-collimation' configuration.
In this project we aim at:

- building a single particle beam monitor with active area of at least a 6x6 cm2 and developing a data acquisition system to give information about the fine structure (ns scale) of the beam;
- building secondary radiation detectors to measure both prompt photons and fast neutrons emitted during irradiation and developing a data acquisition system to trigger the measurement in coincidence with the beam monitor;
- test the multi-detector system in different configurations to assess treatment verification performance by means of prompt photons and the feasibility of measuring production cross section of secondary neutrons.

The successful completion of the proposed research program would open **new possibilities in Particle Therapy, increasing the sensitivity of beam monitoring systems, improving treatment planning tools and assessing the quality of the delivered treatment**. In addition, the developed technology will be of great importance for the **development of sensors and detectors with high time resolution** (tens of ps or hundreds ps depending on the detector type) **and for enabling new data acquisition tools at high data fluxes** (up to 10^{10} events/s).
The INFN-UniTo joint group has the needed expertise to carry out these challenging research activities and has been already involved in the development of detectors for dosimetry, beam monitoring and treatment verification in Particle Therapy.
Since 2016, our research group has explored the potential of solid-state technology for beam monitoring in Particle Therapy and FLASH Therapy. Very thin Low Gain Avalanche Detectors (50μm active thickness), segmented in strips and featuring a moderate proportional gain, and silicon strip sensors were developed and successfully tested with clinical proton and carbon ion

beams. Two detectors were developed: a) a small size (2.7×2.7 cm2) single proton counter able to cope with the high rates of a clinical beam and b) a time-of-flight system to measure the proton beam energy with minimum beam perturbation. These two prototypes can be considered as the starting point for this project. In addition, we want to compare the performance of silicon sensors with other emerging solutions such as Silicon Carbide (SiC) and diamonds. New sensors will be designed, produced, and optimised for different particle types (from Helium to Oxygen) and beam delivery modalities.
Online treatment verification is currently an open issue in Particle Therapy and, for some treatment configurations (e.g., moving target), it represents the only possibility to assess the actual patient morphology during beam delivery. Starting from 2013, our team was involved in the development of the in-beam PET system of the INSIDE project, currently under clinical trial at CNAO. Recently, our group started developing a high time resolution experimental setup for Prompt-Gamma-Timing (PGT), an approach that requires a strong integration and synchronization of beam monitoring and range verification systems. The Front-End electronics and DAQ systems suitable to achieve clinical rates are currently under development. Preliminary results obtained with silicon sensors as beam monitor and monolithic LaBr3 crystals coupled to PMTs or SiPMs as secondary radiation detectors are promising.

2. Connection to Transnational Access infrastructures (TAs) and / or Virtual Access projects (VAs)

The developed multi-detector systems will be tested at **different facilities such as GSI/FAIR and CNAO**. It is important to underline that for successfully achieving the project objectives. Conducting beam irradiation campaigns: a) in different configurations of particle flux and shape and b) with different beam types, is of utmost importance to test the system performance, assess the applicability of the Prompt Gamma Timing approach in a clinical environment and measure the double differential production cross sections of neutrons.

3. Estimated budget request

The estimated budget request considers the main activities to be performed for the successful completion of the research program.

- Beam monitor - new frontend board, new sensors: 50 kE
- Secondary radiation detectors - new scintillators, new sensors: 30 kE
- DAQ, targets and mechanics: 20 kE
- Travels: 20 kE
- two 2-year contracts: 200 kE
  Total: 320 kE

4. Participating and partner institutions

The participating institutions are Italian Institute of Nuclear Physics (INFN) and the University of Torino (UniTo).

[1] C. Golnik et al, Phys Med Biol. 2014 Sep 21;59(18):5399-422, doi: 10.1088/0031-9155/59/18/5399
[2] F. Pennazio et al., 2022 *Phys. Med. Biol.* **67** 065005, **DOI** 10.1088/1361-6560/ac5765.