Bullet points for the proposal for a research group

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Status quo

- radio therapy is an important tool in cancer therapy
- continuous development towards improved tolerability and increase of the therapeutic window
- two promising developments in recent years:
  - encouraging results with very short, high dose beams (FLASH RT)
  - recent further development of spatially fractionated RT towards Microbeam Radiation Therapy (MRT)
- both show improved sparing of healthy tissue and reduction of secondary cancer also increasingly important due to increase in overall life expectancy
- both are dependent on the use of particle accelerator facilities
  - for FLASH: to achieve the required intensity in short pulses, e.g. linear accelerators for electron FLASH RT
  - for MRT: in case of x-ray beams, a high brilliant synchrotron light sources are required to provide sufficiently parallel propagating Microbeams
- very high requirements on stability and metrology of the used beams

Motivation

The present advances in accelerator based RT, like FLASH RT or Microbeam RT, lead to operation parameters of the used accelerators that can not anymore be described by simple linear optics and beam dynamics. Instead, due to the development towards higher intensity combined with shorter pulse lengths and transverse modulations, the consideration of non-linear and complex optics as well as beam dynamics influenced by collective effects becomes necessary for accelerator RT sources.

Further closing the gap between accelerator science and medical physics from the accelerator side is an important step and will help in paving the way towards accurate predictability, diagnostic and metrology of advanced RT with particle accelerators.

Goals

- improve predictability of RT beam properties on target by improving understanding of dynamic in short and/or spatially structured RT beams
- study from accelerator point of view the beam dynamics effects relevant in the generation of such beams as well as the diagnostic to reliably deliver the requested conditions
- provide start-to-end simulations of the dynamic of RT beams, from inside the accelerator through the air into the target by combining beam dynamics, beam-matter interaction and collective effects simulations
- predicting the temporal and spatial shape of each individual RT pulse at any point on the way up to the target inside the patient

The goal is, by extending the calculation of these effects beyond the accelerator as a first step, to make the prediction of the resulting spatial distribution on target possible. And as a second step, it might allow to consider effects of the beam transport already during the generation of the beam.
Aiming towards the generation of a spatial distribution which preemptively compensates for the expected changes, possibly allowing arbitrary user-definable final distributions.

Existing infrastructure and knowhow (1)

Environment:

- ATP - accelerators as well as detector technologies
- HEIKA - Heidelberg Karlsruhe Strategic Partnership
- new KIT Center Health Technologies
- possible Cluster of Excellence AccelerateRT

Accelerators:

- FLUTE electron linear accelerator as electron source up to 40MeV and ultra short pulses down to femtoseconds
  - virtual diagnostic, spatial light modulator, ...
- KARA storage ring as synchrotron light source for x-ray (and also THz ?)
  - extensive diagnostics, variable, special operation modes, ...
- in the planing, CSTART innovative non-equilibrium storage ring will provide the possibility to study dynamics of changing pulse lengths
- coming, laser based accelerator

Existing infrastructure and knowhow (2)

Me:

- experience in longitudinal as well as transverse collective effects and instabilities influencing the electron bunch shape in all dimensions
- in general, investigating phenomena occurring under extreme operation modes, e.g. high charge, small transverse bunch-size, short bunch-length, sub-structures, ...
- on rings but focused on single bunch effects transferrable to linacs
- simulations of non-linear optics and beam dynamics, collective effects
- extensive experimental studies and measurements
- used diagnostics: electron-beam based as well as synchrotron-radiation based as well as improved and further-developed diagnostic methods
- data analysis of complex, big datasets with, amongst others, Python and HPC (high performance computing)

Plan

Simulations:

- start with simulations on the 6D particle distribution expected at the exit of the linear accelerator
- followed by simulation of the beam dynamics for this particle distribution on its trajectory to the target
  - based on existing simulation tools and models, e.g. transport/covariance matrices combined with average scattering angles based on existing beam-matter interaction descriptions
- add collective effects, e.g. space charge, via impedances and/or particle tracking

Experimental in parallel:

- survey of required vs available diagnostics to measure 6D particle distribution at different positions in the linac, e.g. virtual diagnostic available
- measurements of 6D particle distribution at accelerator exit based on starting distribution
- experimental studies of the propagation of 6D particle distribution through air and/or water, including acquiring and set up of necessary diagnostic/detectors/targets
- extend studies to X-ray(/THz?) at synchrotron light source (KARA)

periodical cross-checks between experimental results and simulations to iteratively improve both