TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Institut für Kern- und Teilchenphysik
Arbeitsgruppe Strahlungsphysik

Radiation Physics at IKTP

Institutsseminar, 14.01.2021

What is commonly understood under *radiation physics*?

At least my answer is:

The application of technologies related to the generation and detection of ionizing radiation to practical problems.

This is a wide field:

- Therapy
- Diagnostics
- Radiation safety
- Environmental questions
- Nuclear waste
- Technical imaging
- Material treatment
- …

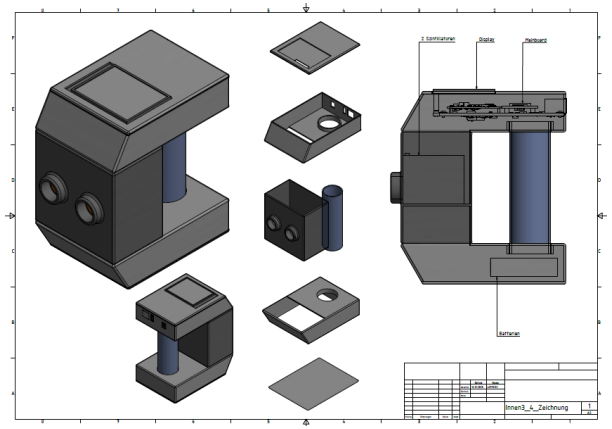
… and involves (aside physics and computers):

- Electronics
- Optics
- Biology
- Chemistry
- Jurisdiction
- …

Some aspects of radiation physics addressed by us

Radiation Protection

Development of a portable electronic dose rate meter especially for pulsed radiation fields



Medical dosimetry

Advanced quality assurance in proton therapy by means of LET (=linear energy transfer) sensitive probes

Radiation Safety

A dose rate meter for pulsed radiation fields

Motivation

Problem:
measurement of dose / dose rate in pulsed radiation fields is currently not possible

Aim:
development of a suitable system for real-time dosimetry to be certified by the PTB

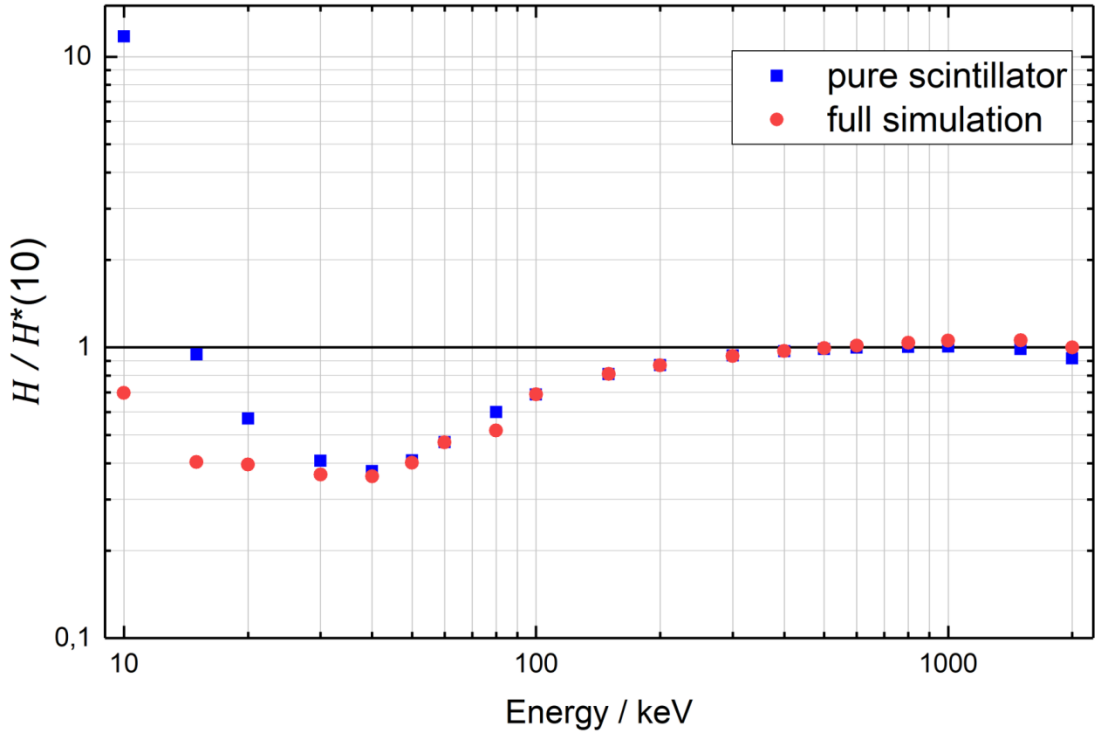
Challenges:
- high detector load within short radiation pulses
  - ➤ well known dead time behaviour
  - ➤ what happens with pile up?

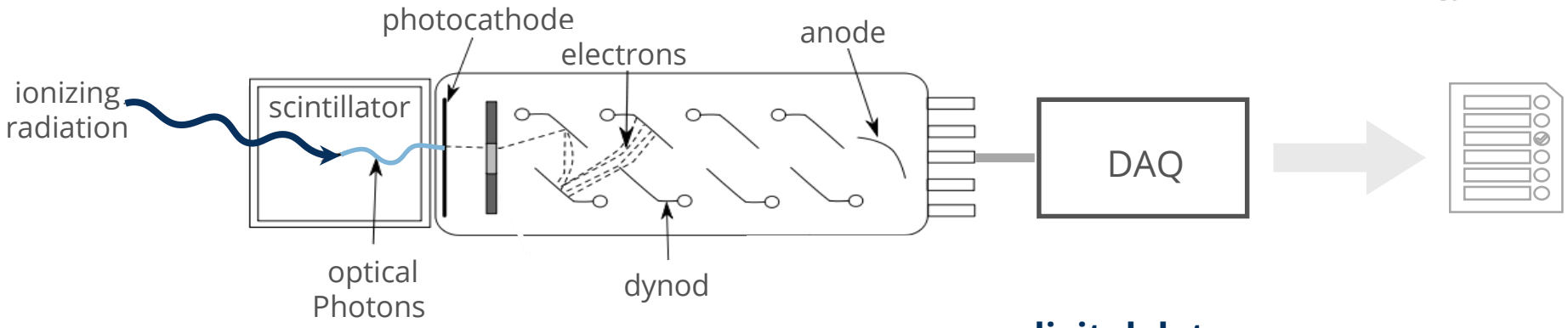
Applications
X-ray systems, lasers, medical / technical accelerators
energy: 10 keV to 1 MeV pulse rate: Hz bis >100 kHz pulse duration: 10 fs to 1 ms dose rate: µSv/h to mSv/h „puls-dose-rate“: mSv/s to 100 Sv/s

Concept

The problem can only be considered „solved“ if the instrument displays legally defined values:

$H^*(10)$ and $H'(0{,}07)$

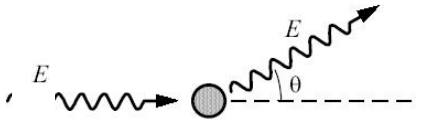


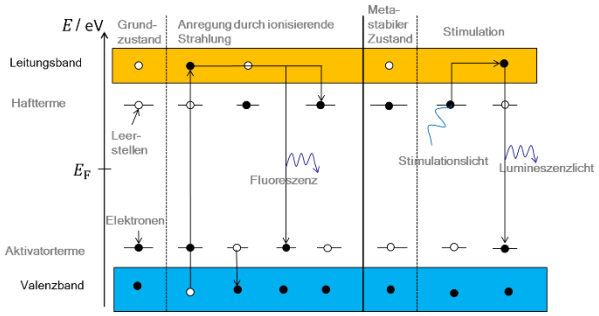


detector **PMT** **digital data acquisition system** **listmode-data**

Dose measurements in pulsed radiation fields

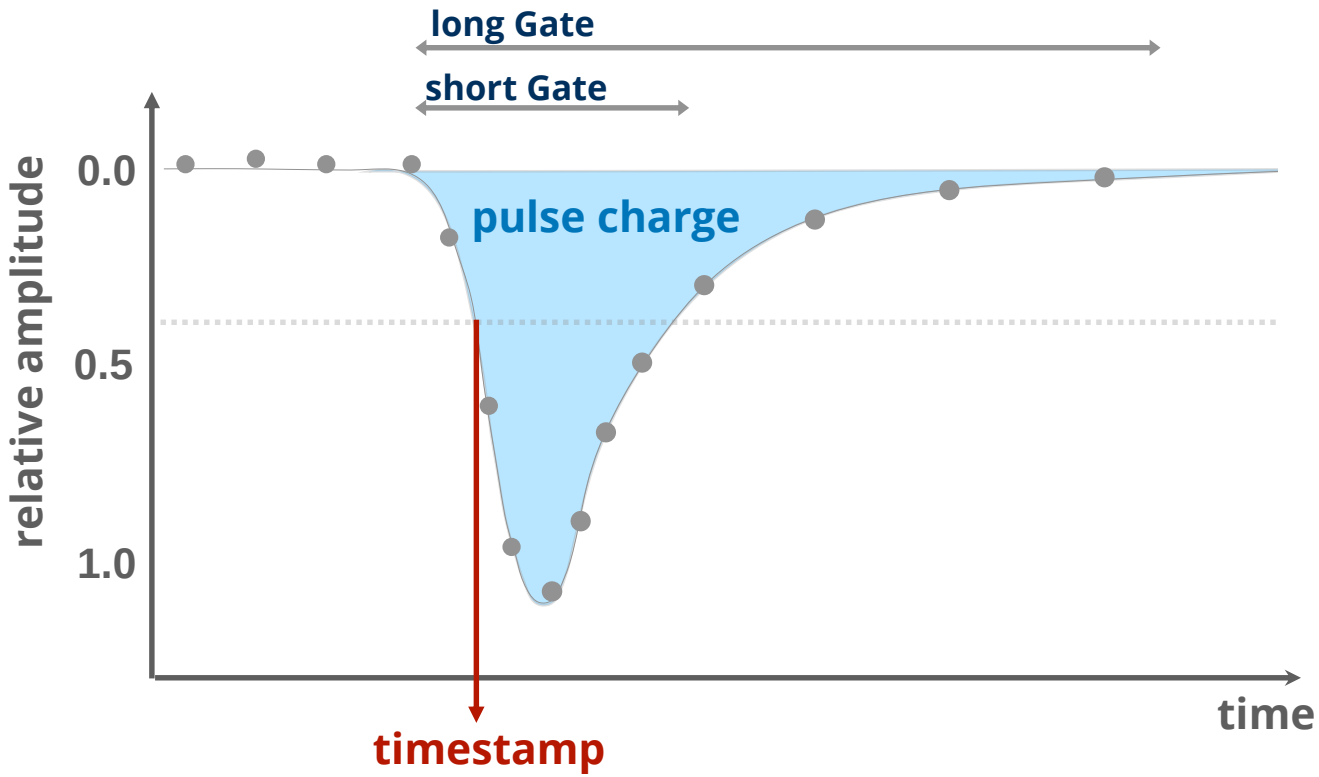
Signal generation	Time scale
Energy deposition of a single particle in the sensitive material	~ fs
Excitation of the material	~ ps
De-excitation (= scintillation)	2 ns
Conversion into an electric signal	5 ns
Signal shaping	160 ns
Sampling, triggering, integration, event formation, buffering	160 ns





Data acquisition

- determination of the signal charge (~ deposited energy in the detector material)
- 2 integration windows (long/short gate)
  ➤ Calculation of *pulse shape parameter (PSD)*
- timestamp for each detected event
- listmode - data



$$\text{pulse shape (PSD)} = \frac{\text{short Gate}}{\text{long Gate}}$$

Data acquisition

- determination of the signal charge (~ deposited energy in the detector material)
- 2 integration windows (long/short gate)
  ➤ Calculation of *pulse shape parameter (PSD)*
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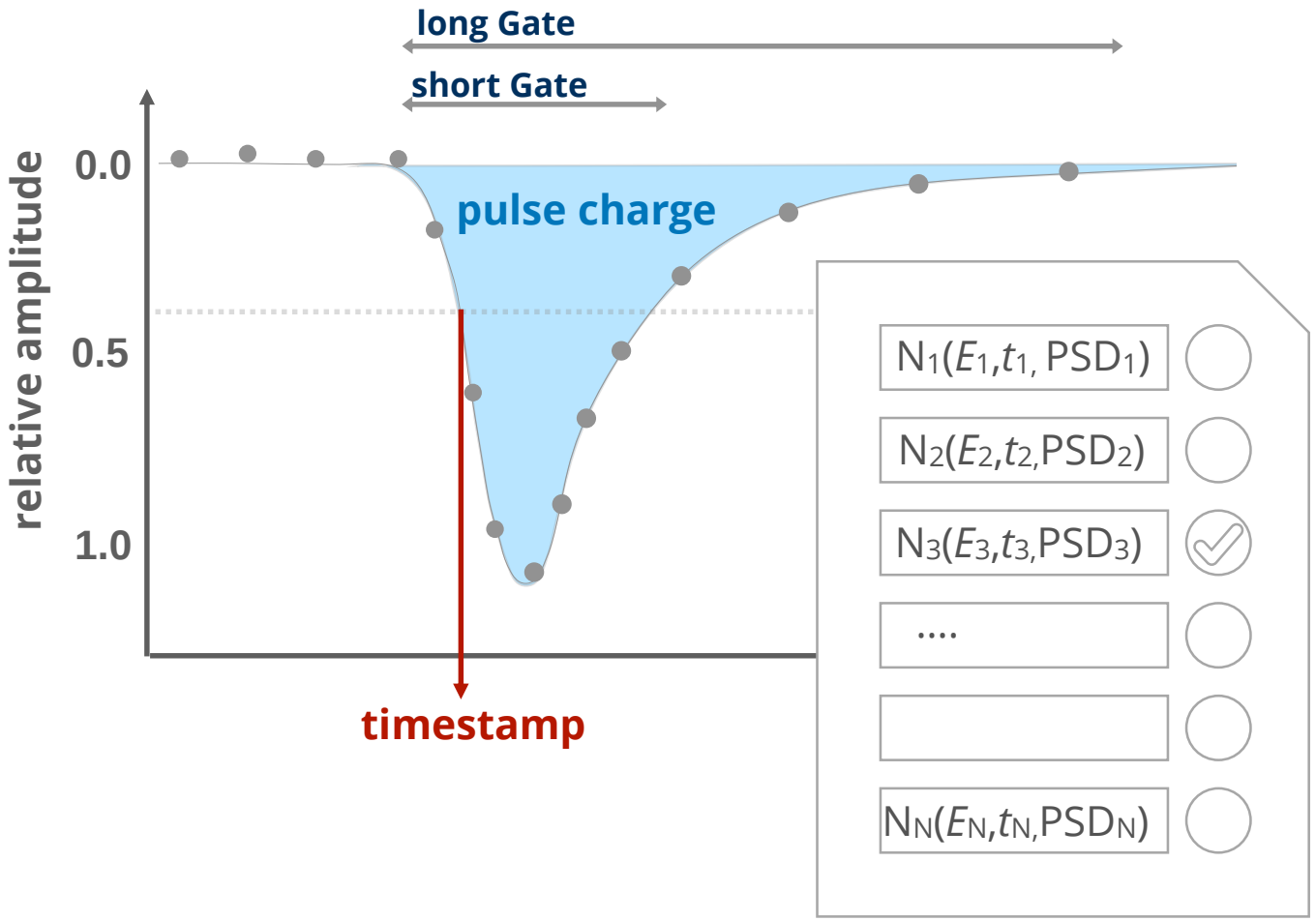
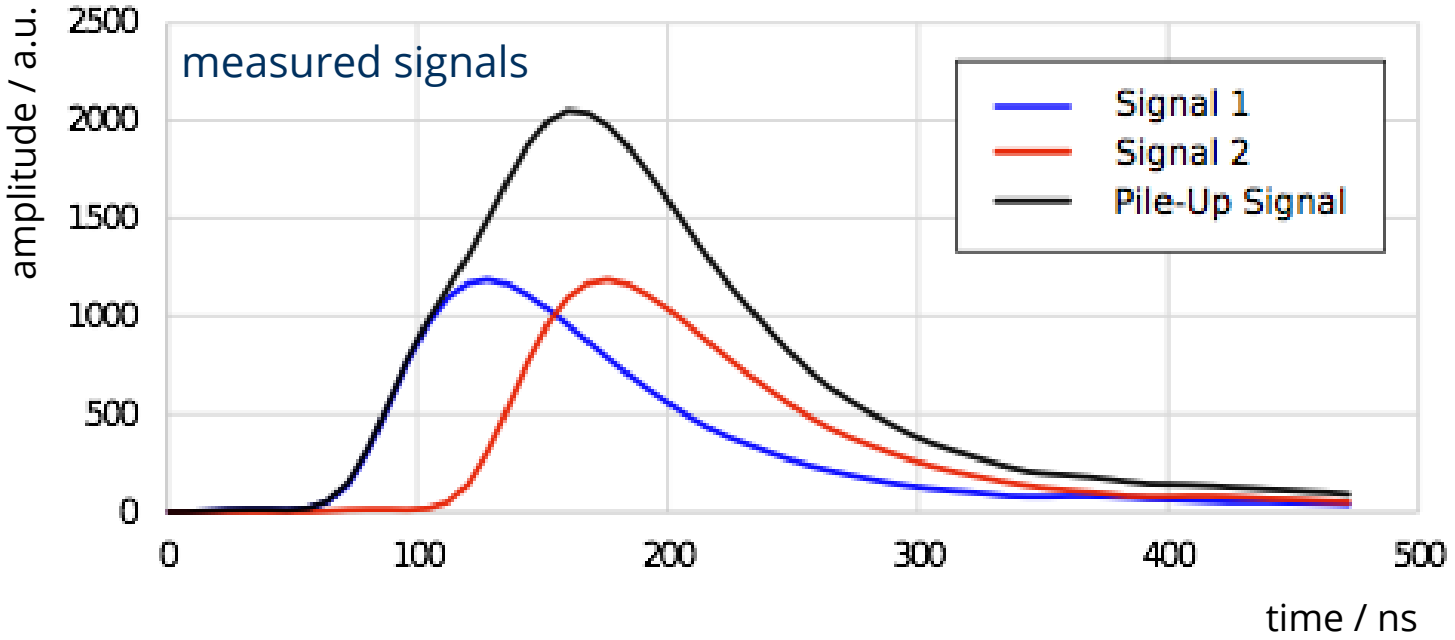


Dose measurements in pulsed radiation fields

What happens for increasing (pulse) dose rates ?

pile-up

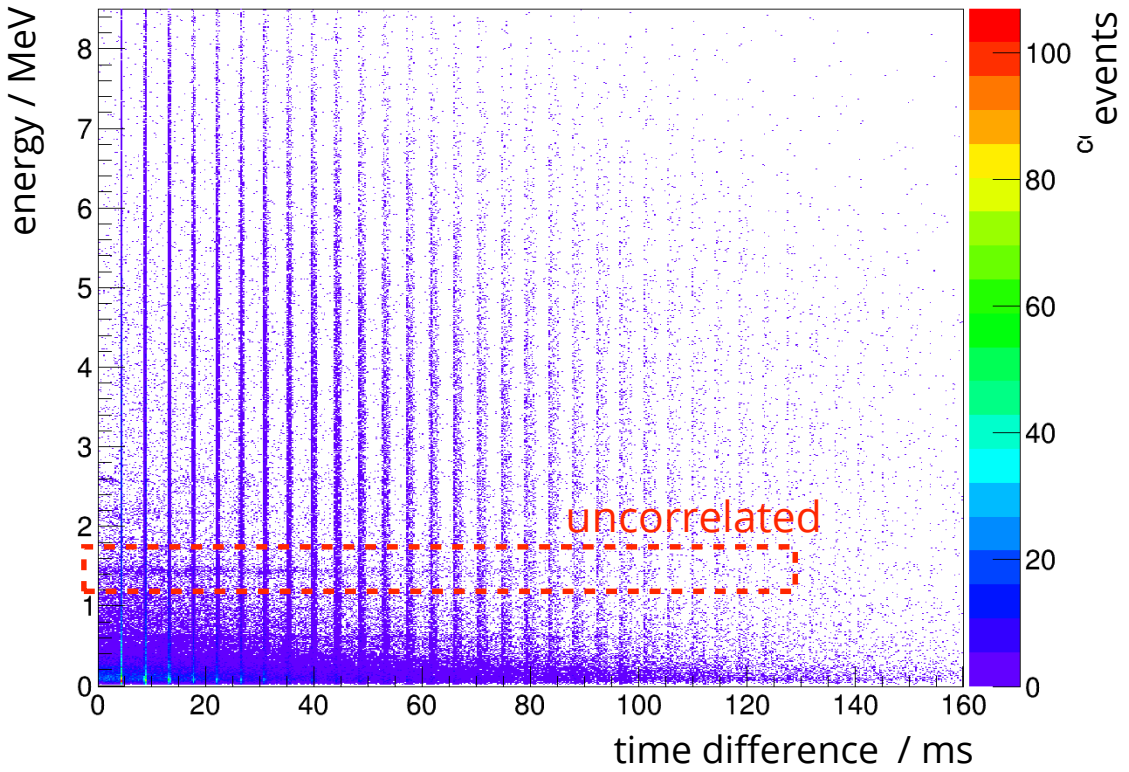
- integral correlates to the summed energy
- variation of the pulse shape parameter
- the measured pulse charge is still proportional to the deposited energy per pile-up event for large integration windows



Time difference histograms for pulsed / continuous radiation

comparison of time differences

- time difference for consecutive detected events
- *uncorrelated* time difference for ^{40}K events
- *correlated* time difference for pulsed radiation with time differences:
  $[k\,T_m - \Delta t_m;\ kT_m - \Delta t_m]$ with $k = 1,2,\ldots$
- T_m: macro pulse period ; Δt_m: macro pulse duration

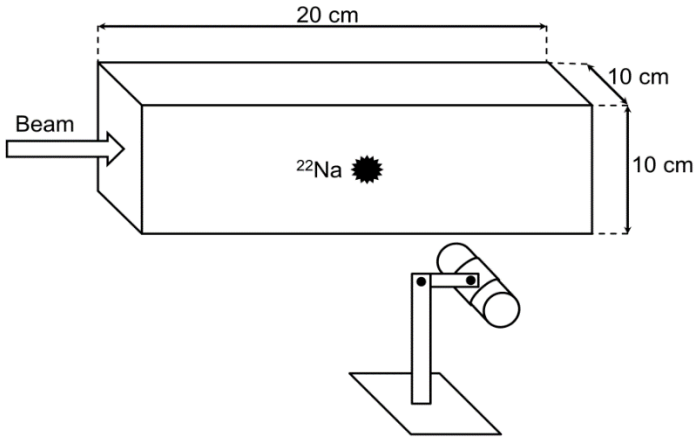


Data: measurement campaigns within the SSK A411 in Rostock and Dresden 2017 and 2018

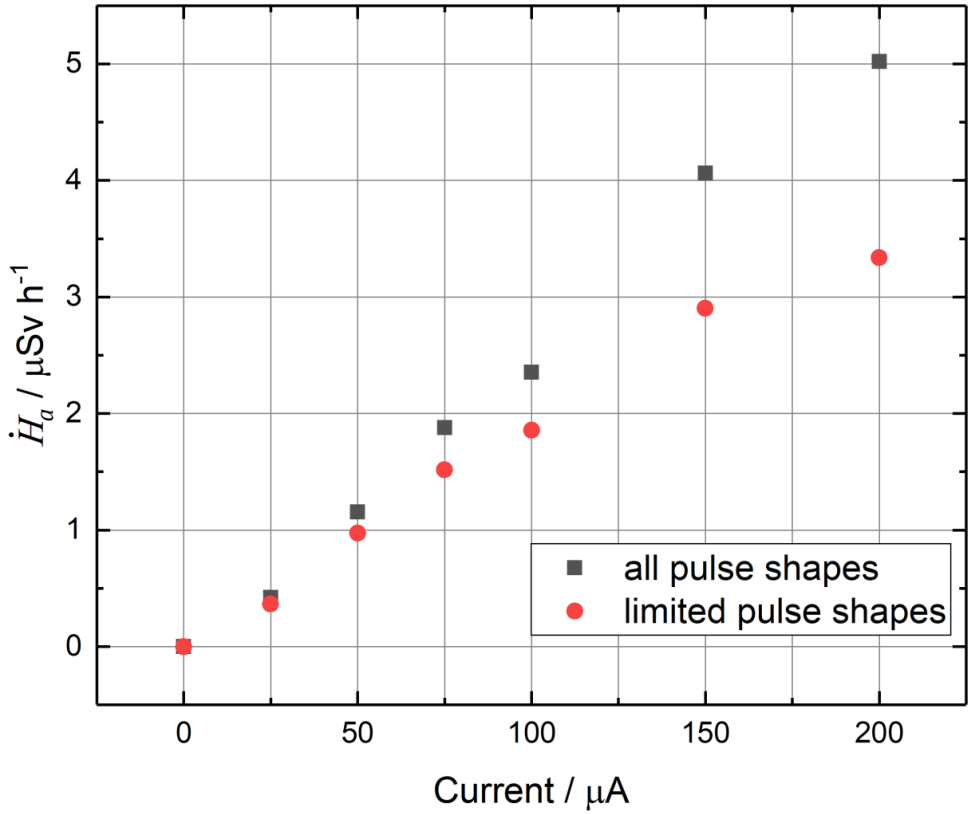
Time difference histograms for pulsed / continuous radiation

comparison of time differences

- Quantifying both components by their dime stamp
- Identification of the accelerator component in the presence of uncorrelated events



Data: ELBE accelerator 2019, mimicking a clinical machine

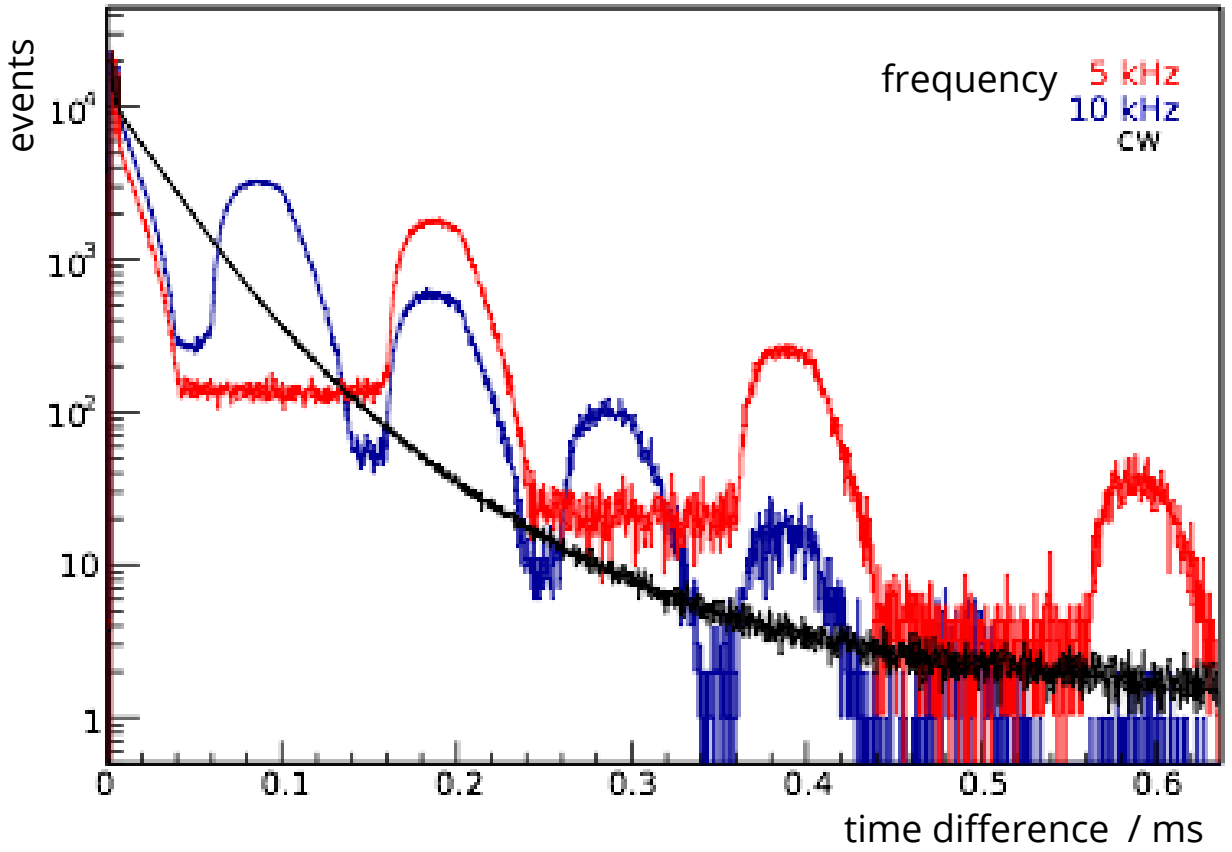


K. Makarevich et al., Rad. Prot. Dos. 2020

Experiments at the research accelerator ELBE (HZDR) September 2020

- time difference between two detected events
- reconstruction of the pulse structure

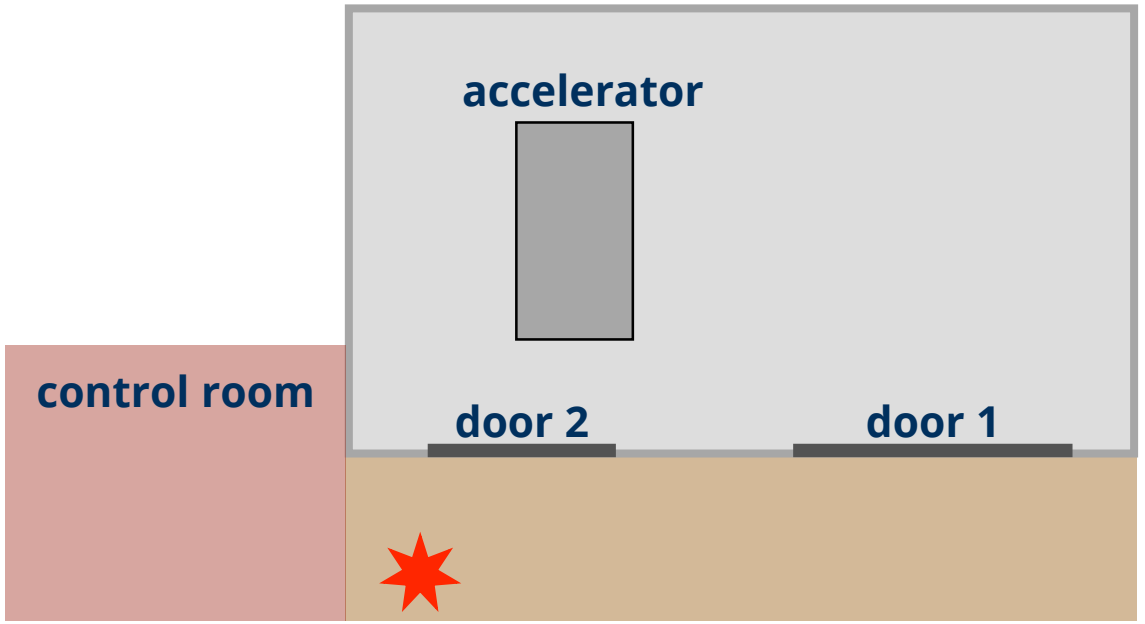
time structure of the beam	
pulse frequency	cw / 5 kHz / 10 kHz
Pulse duration	40 µs



T. Werner et al., *Dose rate measurements in pulsed radiation fields by means of an organic scintillator*, submitted ANIMMA, 2021

Clinical experiments at Helioskliniken Aue

- linear electron accelerator
  TrueBeam (Varian)
- 15 MV
- field size 30 cm x 30 cm
- dose rate in the treatment room: 5 Gy/min



position of the detector

Clinical experiments at Helioskliniken Aue September 2020

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- field size 30 cm x 30 cm
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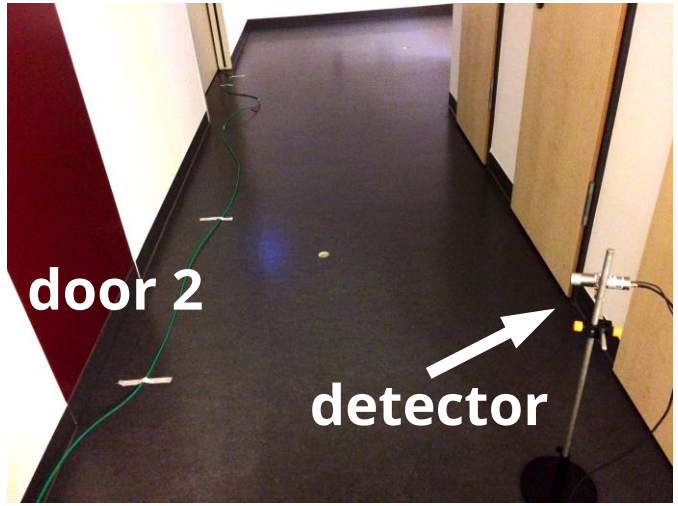
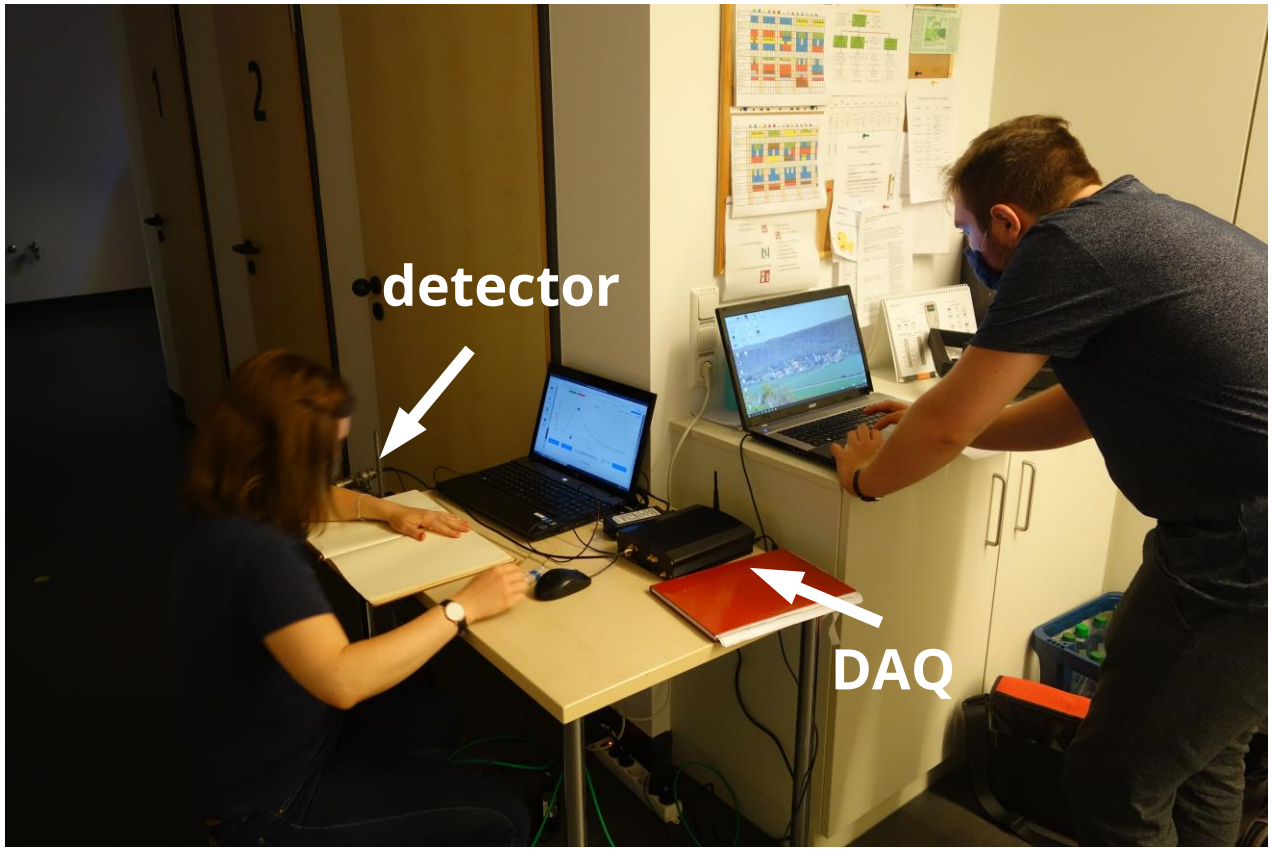
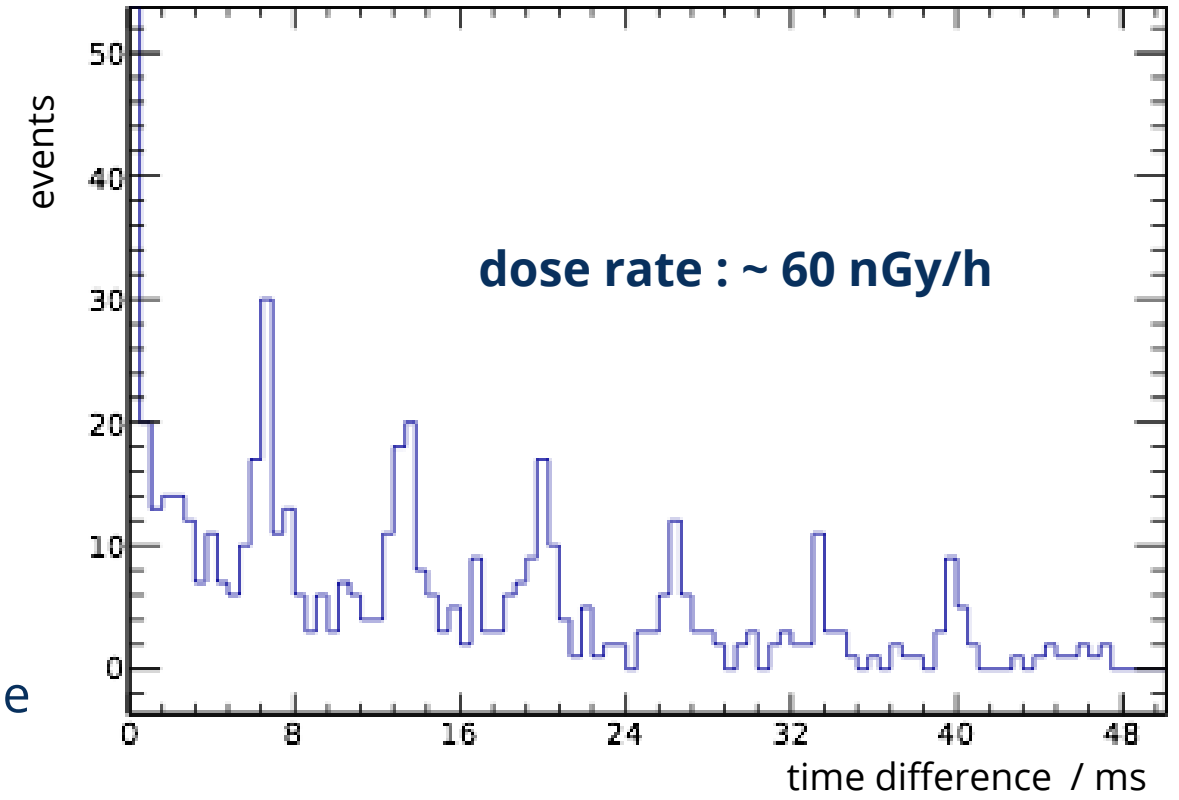




Clinical experiments at Helioskliniken Aue

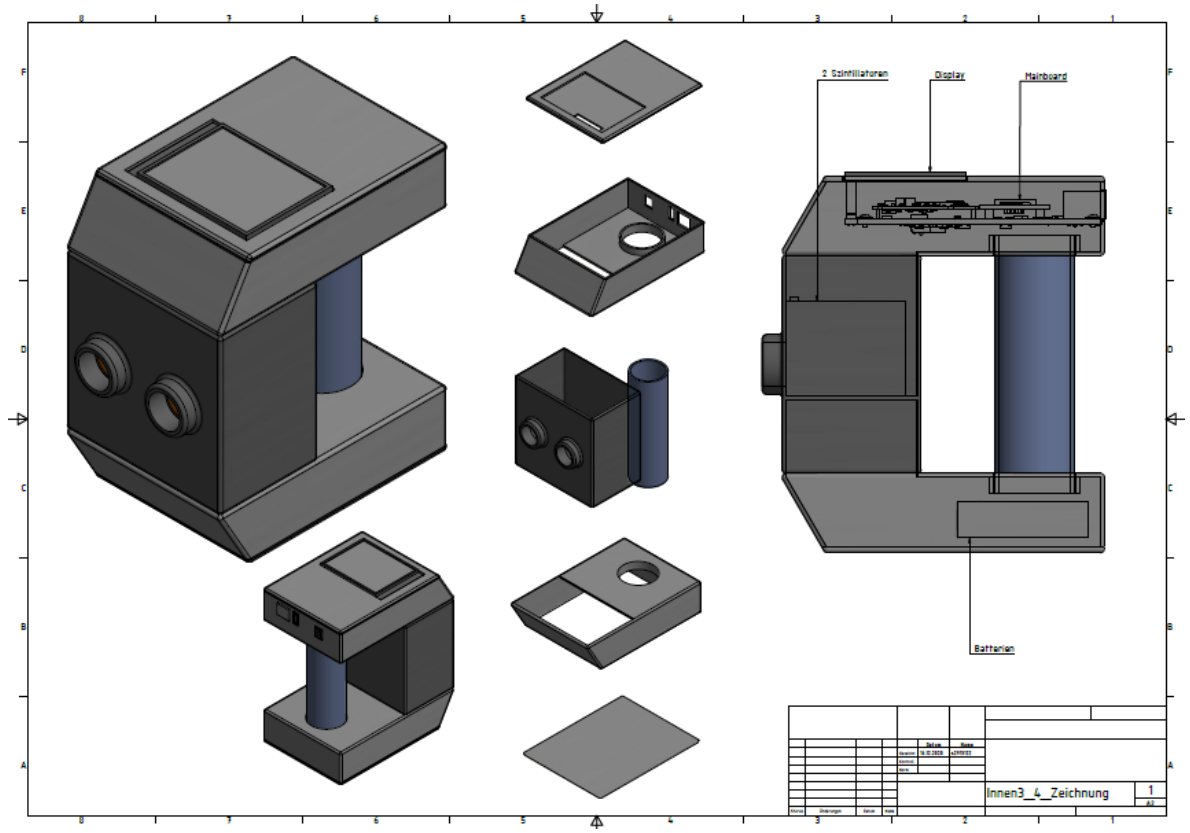
- linear electron accelerator TrueBeam (Varian)
- 15 MV
- field size 30 cm x 30 cm
- dose rate in the treatment room: 5 Gy/min

- First dosimetric measurement by this principle under field conditions!



It works in principle, but for a certified device, many thing remain to be done …

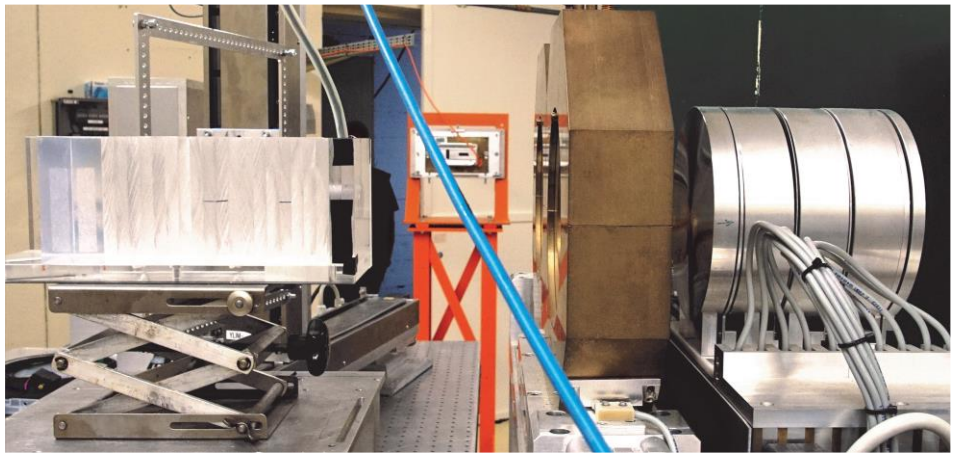
- Software: in a quality that permits certification
- Detector geometry: reach $H^*(10)$ and $H'(0{,}07)$ within the permitted limits
- Bring it into a case
- … with a battery that lasts long enough
- Documentation!
- And all this within 1½ years from now



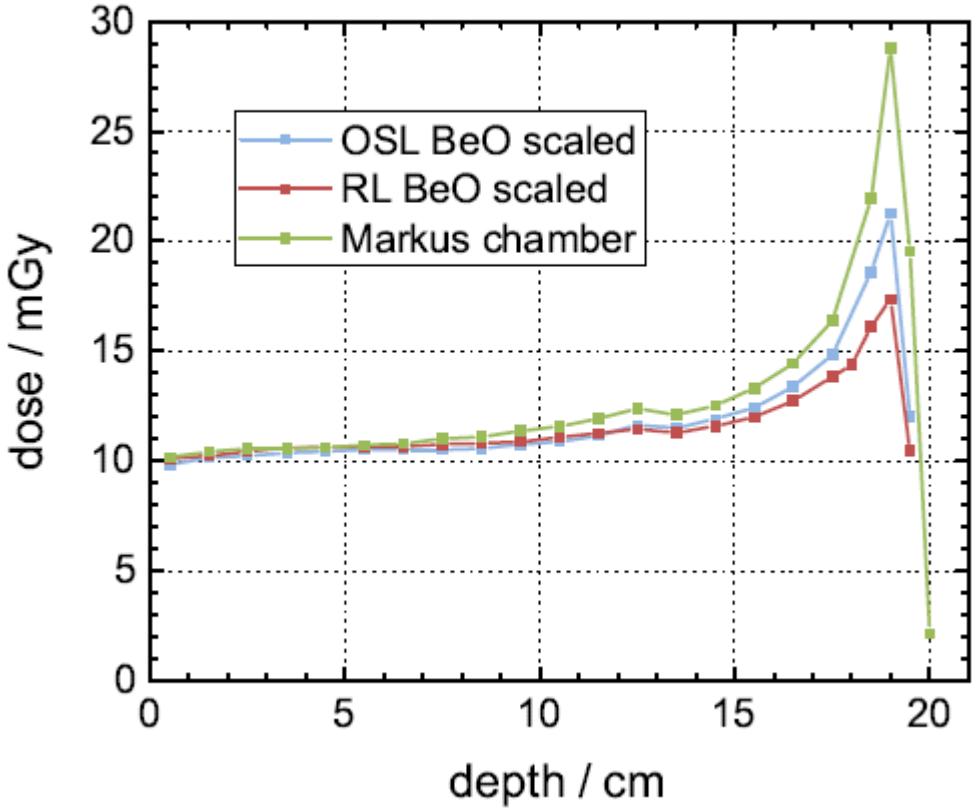
Medical Dosimetry

Advanced quality assurance for hadron therapy

In the ancient days of early 2018 …

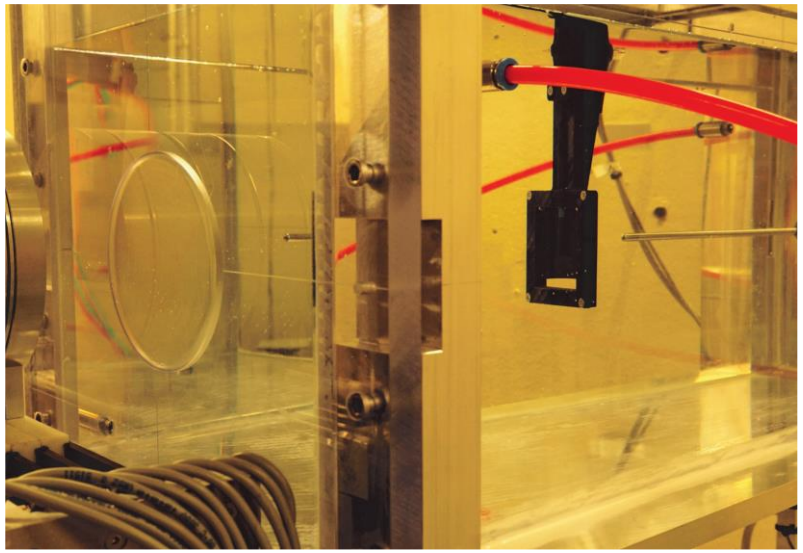


- AGOR cyclotron in Groningen: 190 MeV protons
- Fiber optical measurements of various materials, especially BeO
- Retrospective OSL measurement
- Dose calculated with our photon calibration and the stopping power of the materials

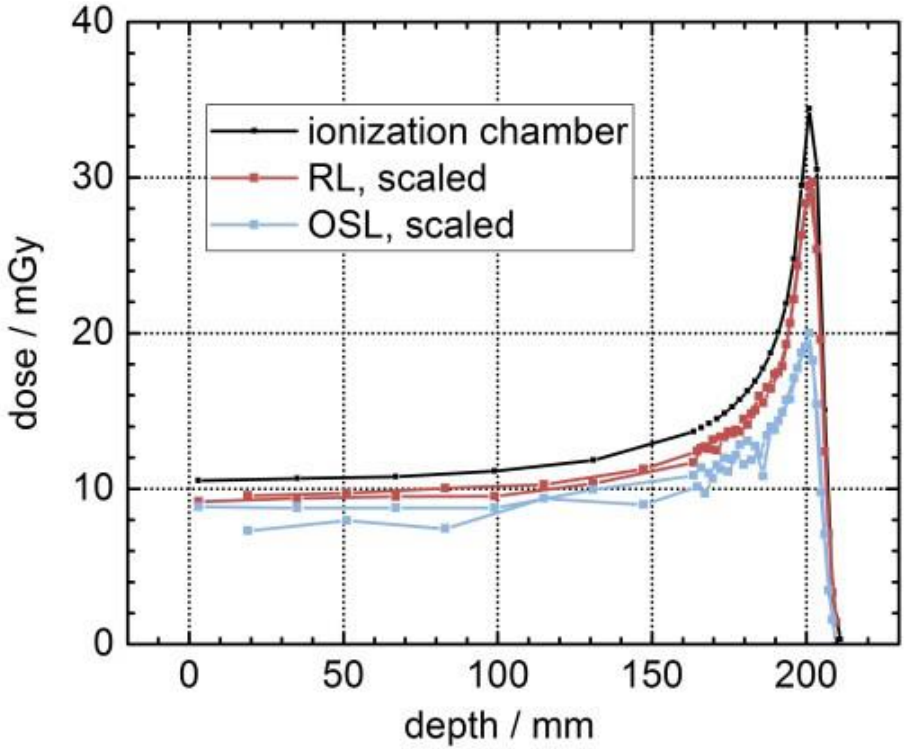


T. Teichmann et al., JINST 2018

In the ancient days of late 2018 …

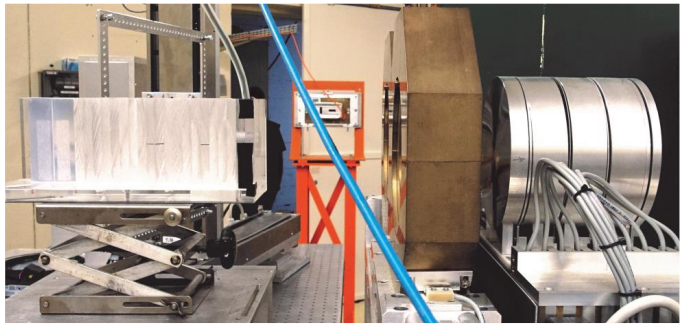


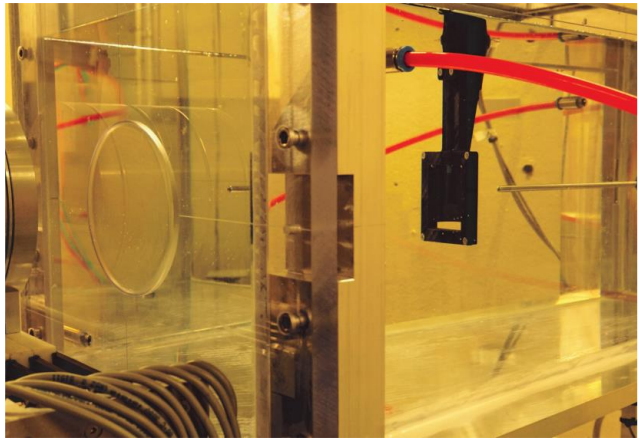
- AGOR cyclotron in Groningen: 190 MeV protons
- Combined radioluminescence and OSL measurement of BeO

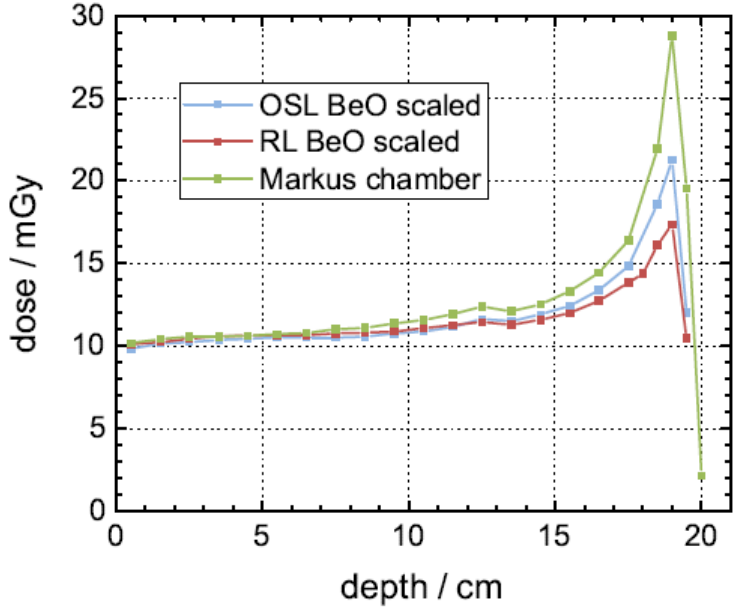


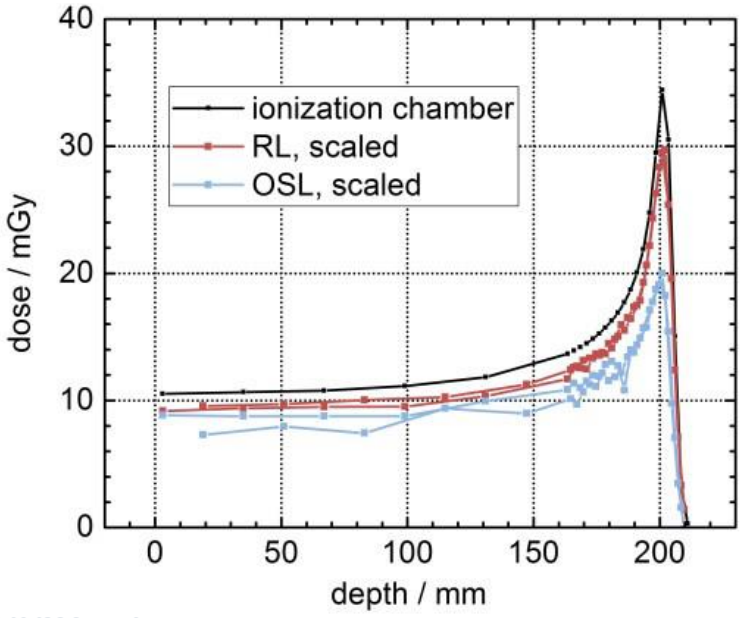
T. Teichmann et al., IEEE NSS/MIC 2019

Something was wrong …

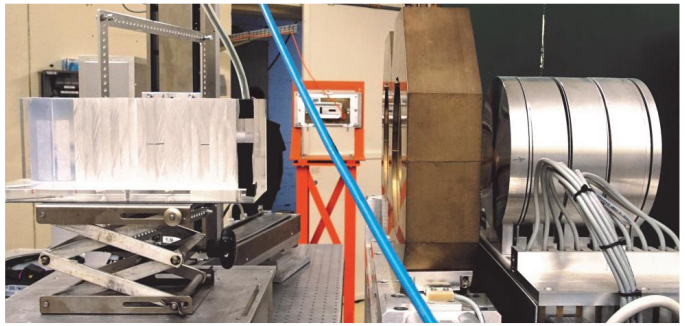


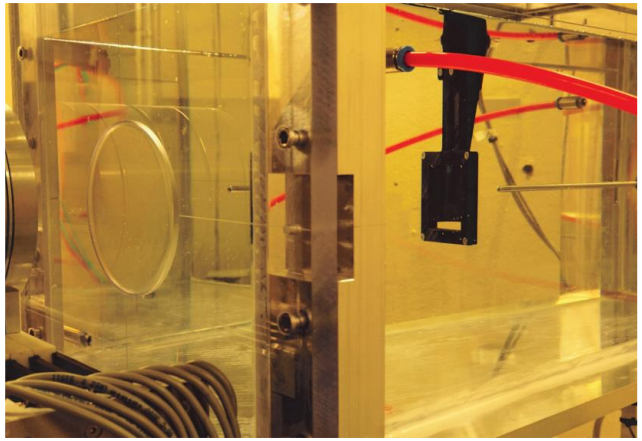


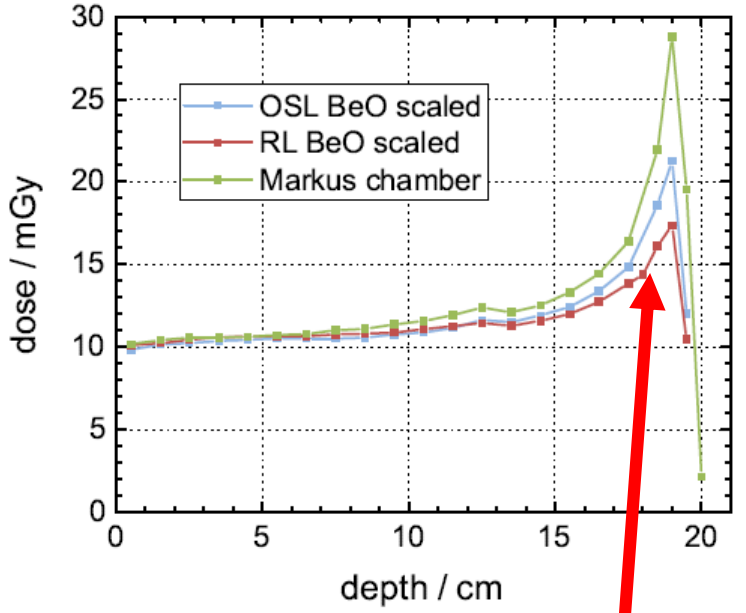


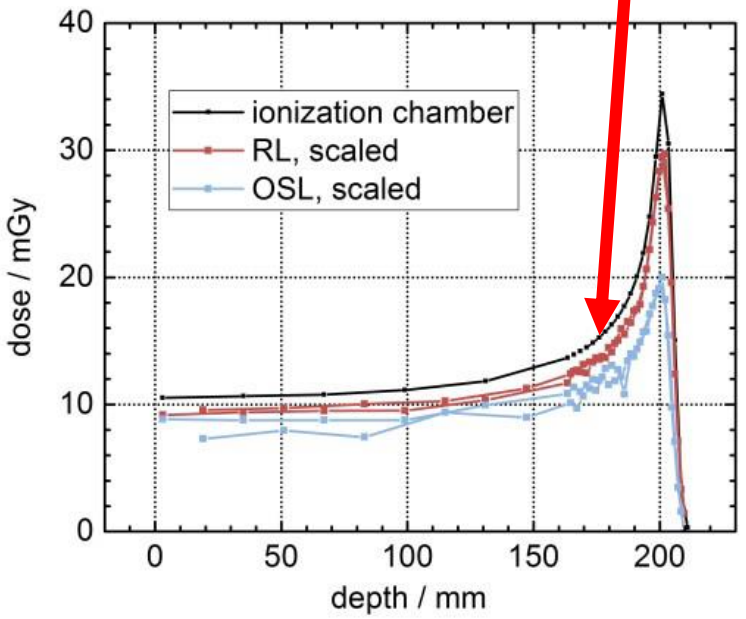


Something was wrong …





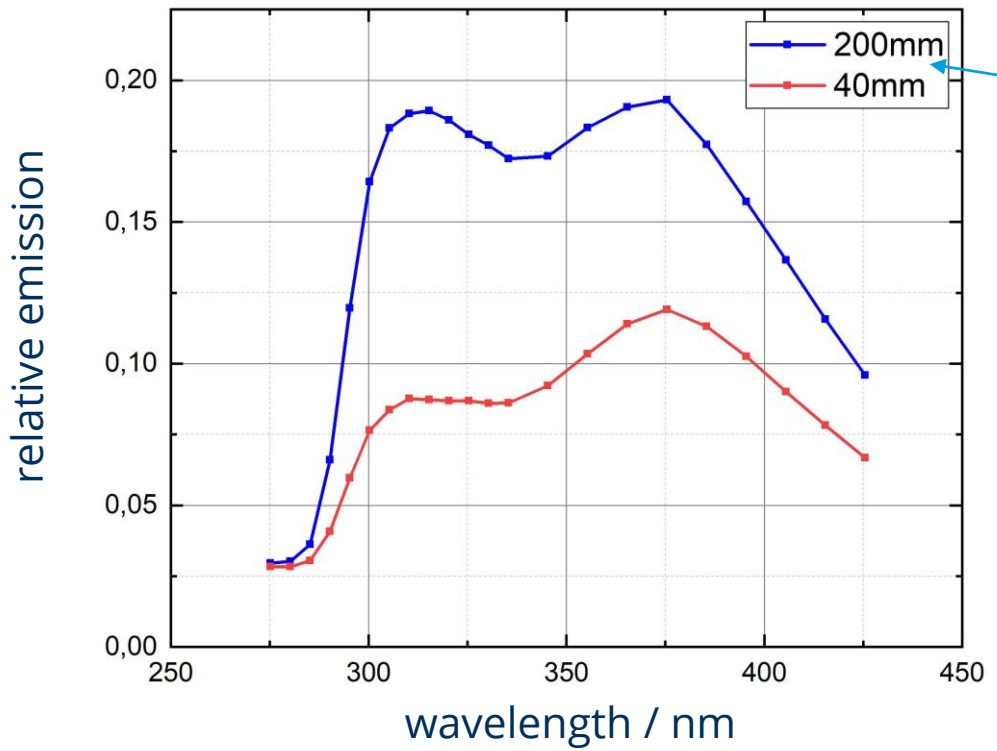




We used different fiber materials with different optical properties …

Could it be that the emission spectrum changes with depth?

- Back to AGOR in 2019 with a grating spectrometer (and lots of time):



Depth in the phantom:

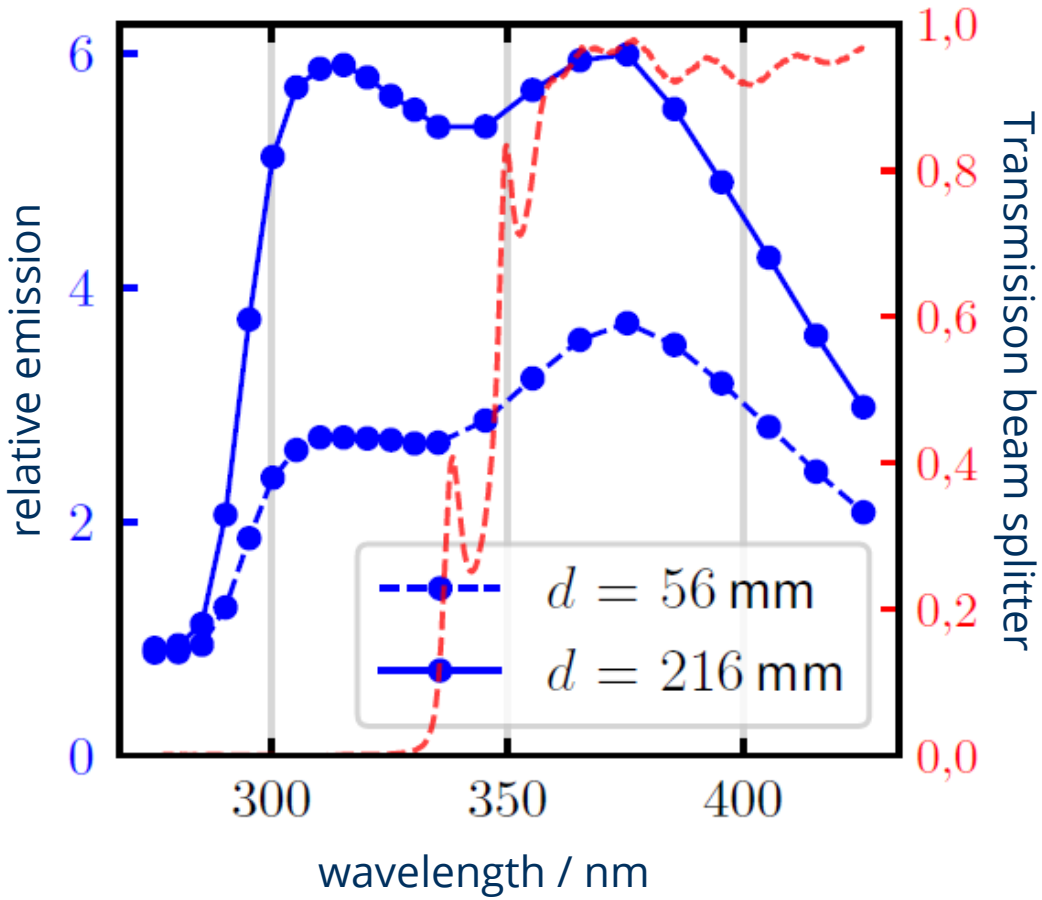
End of proton range and at the entrance

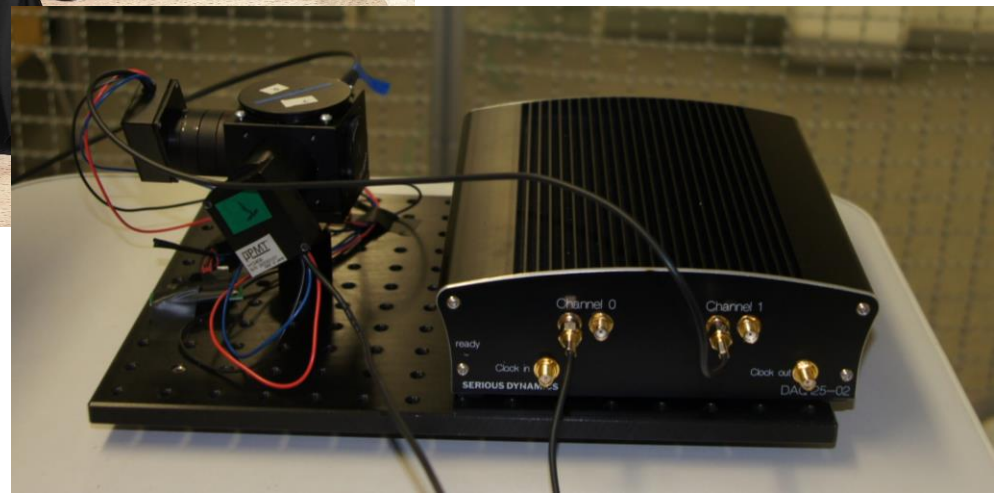
It took several hours to record these two curves.

If this could be exploited:

- One can calculate a correction factor and make highly accurate dose measurements in proton beams
- Say something on the residual range of the protons behind the probe
- Accurately probe the radiation field with mm resolution insensitive of magnetic fields, temeperature, pressure, etc.

Since spring 2020: Development of a dual channel fiber optical setup

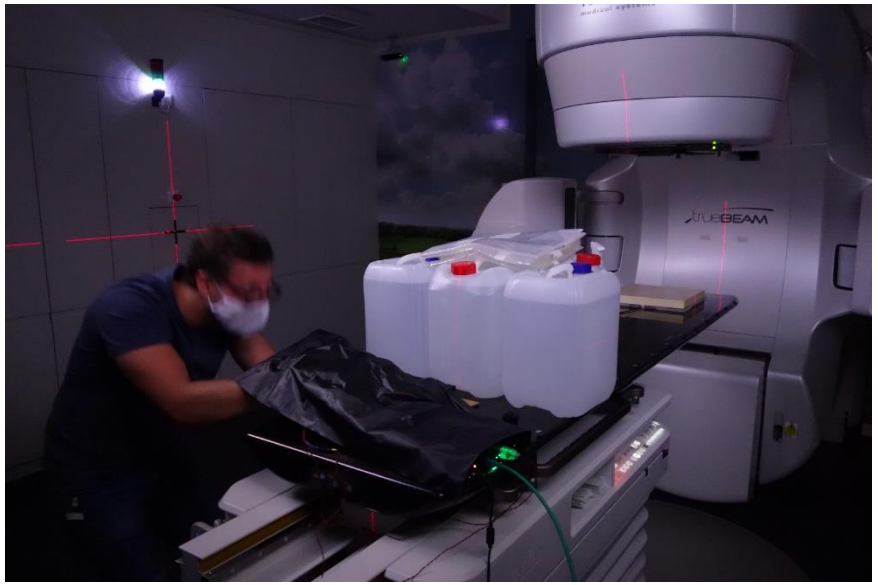


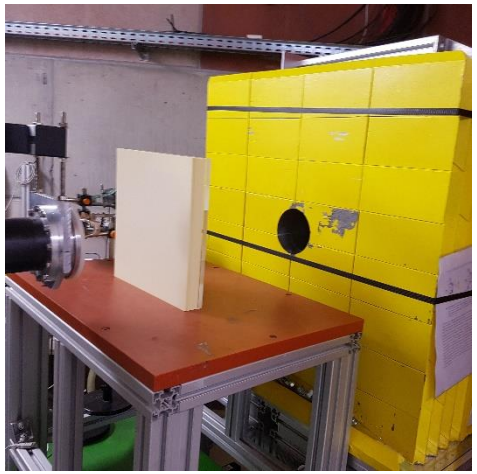


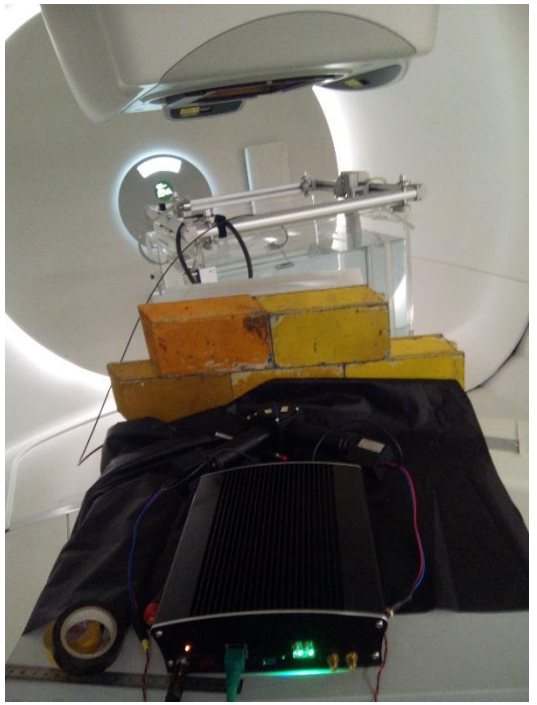
The latest setup

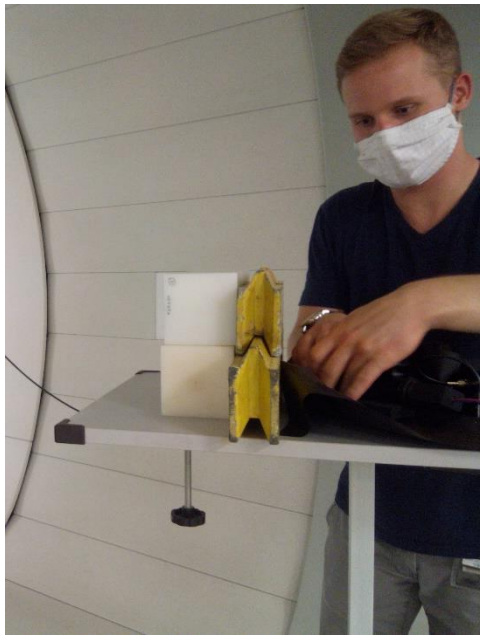
- Dichroic beam splitter
- The µPMT single photon counting heads
- Silica glass fiber of 0.4 mm diameter
- 125 MHz high rate capable sampling ADC

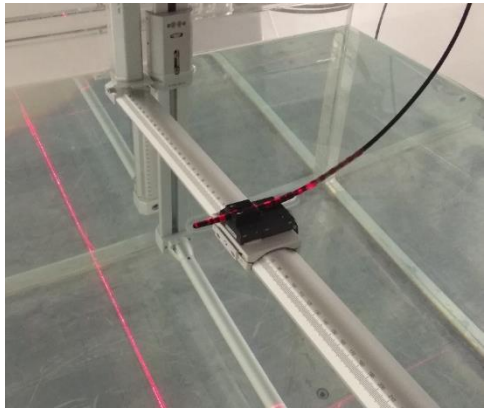
Summer 2020: Various measurements …







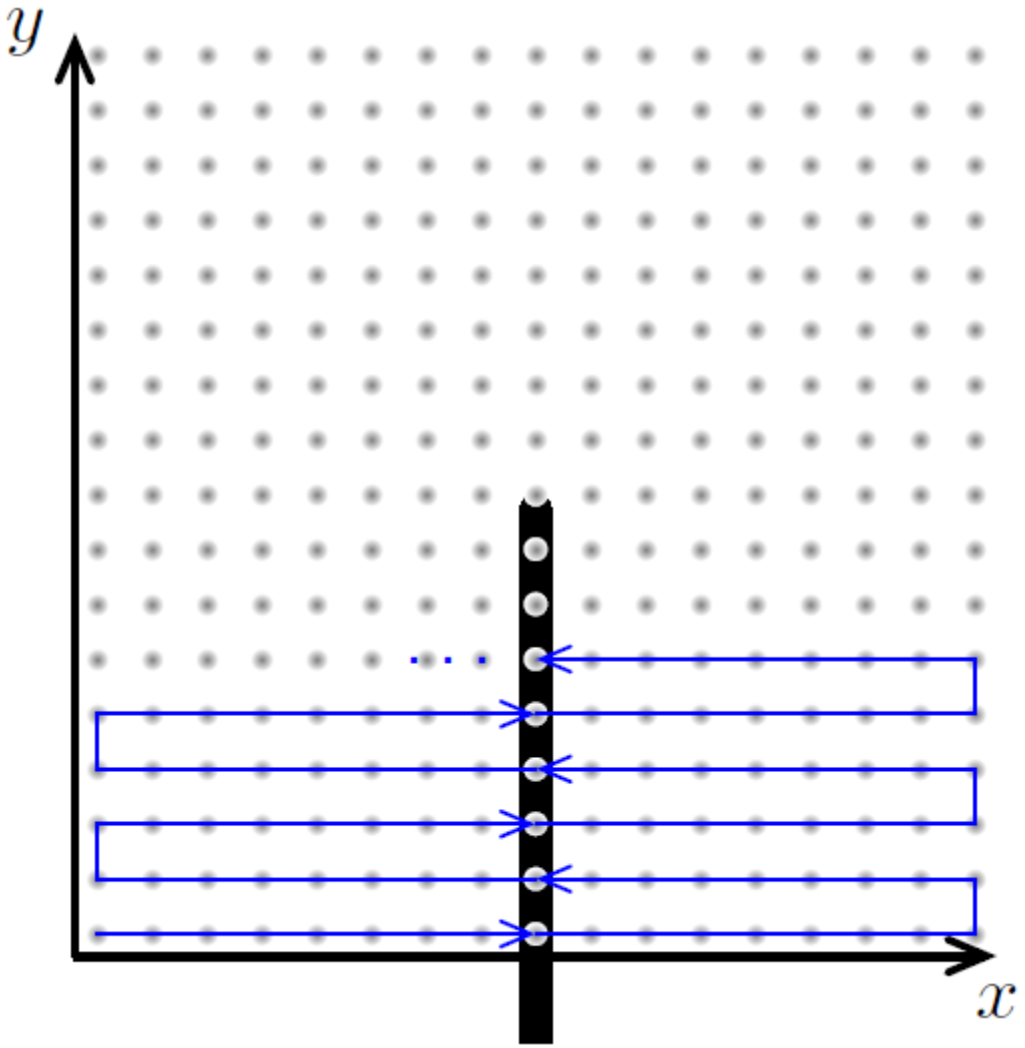


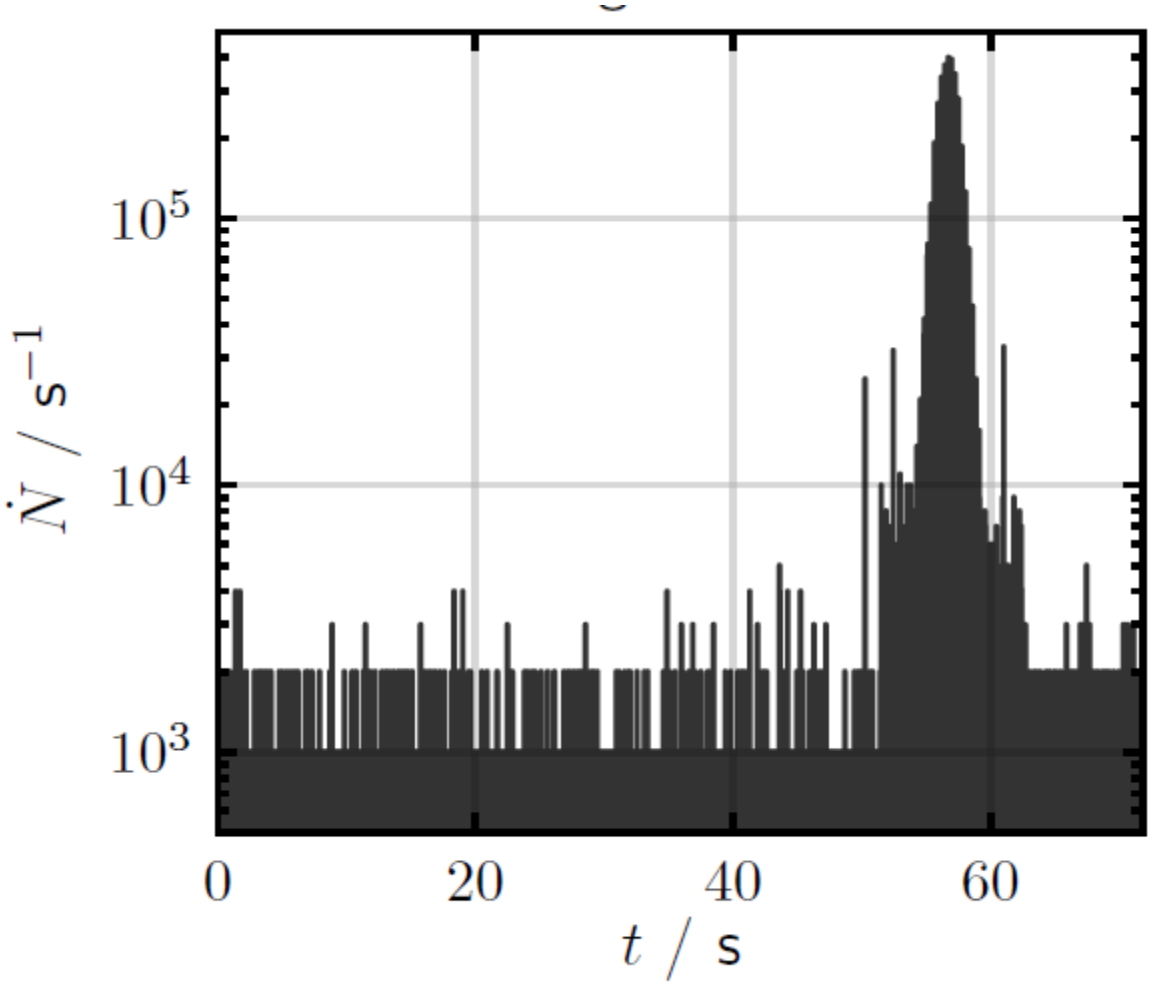


Calibration and characterization of this new setup in proton, photon and electron fields

Does it work in proton fields?

L. Grabs

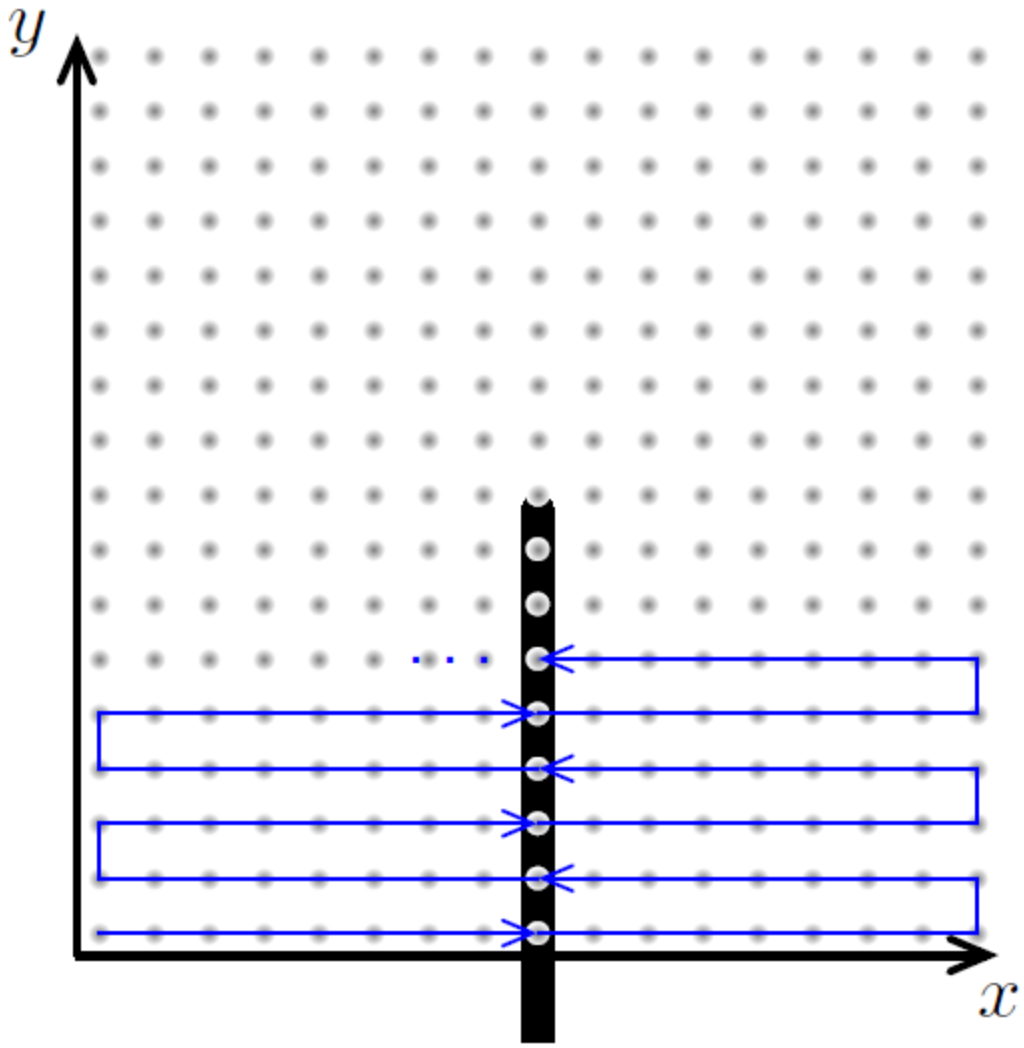


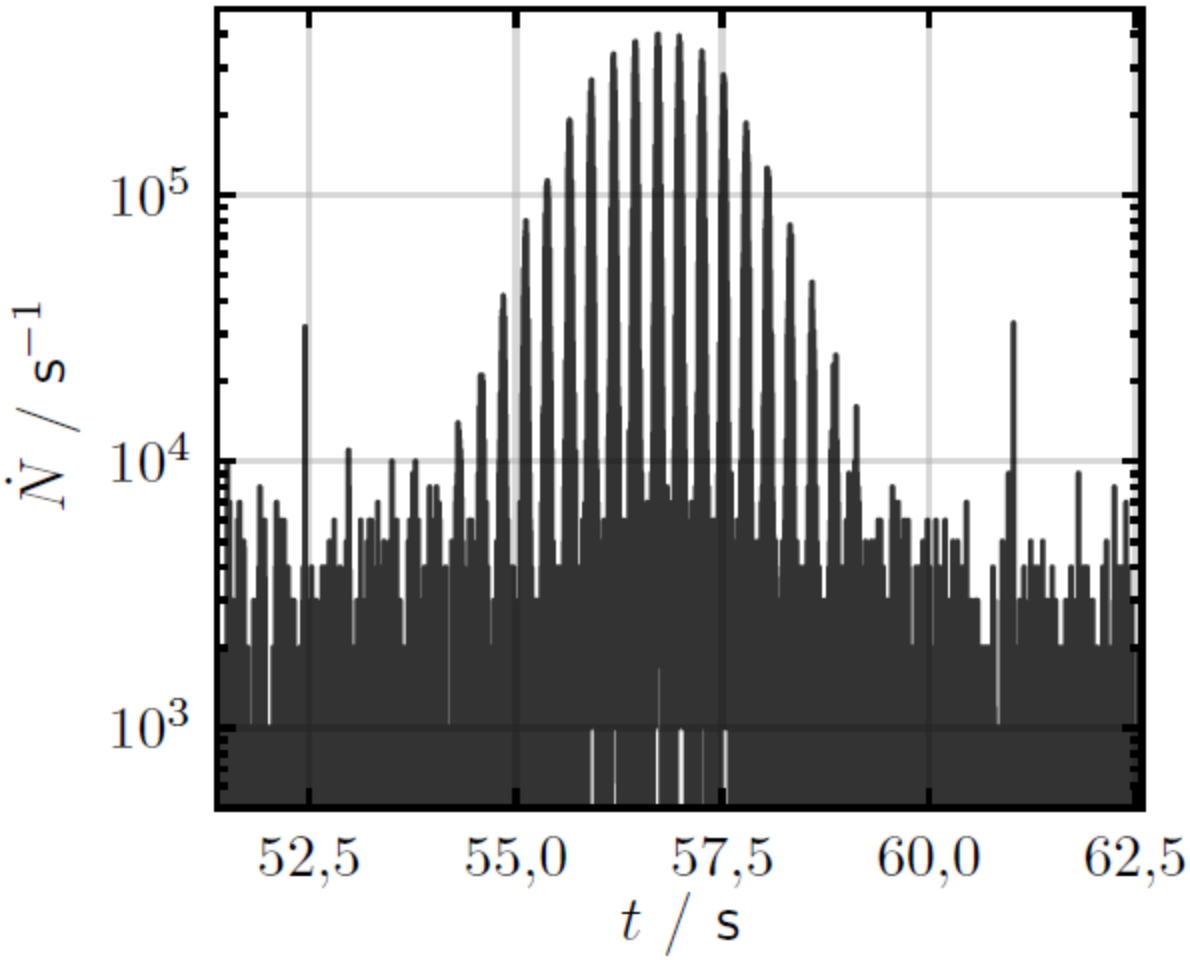


The whole irradiation plan

Does it work in proton fields?

L. Grabs

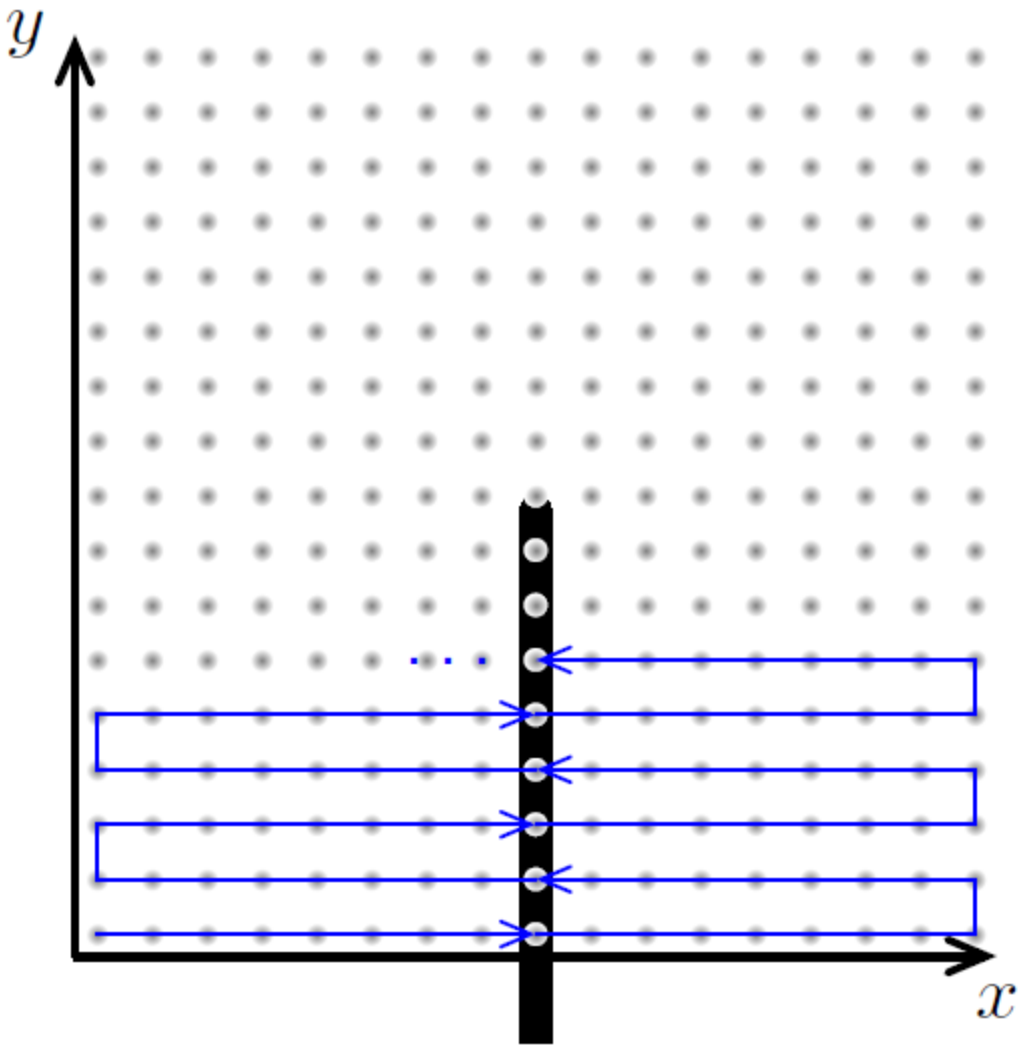


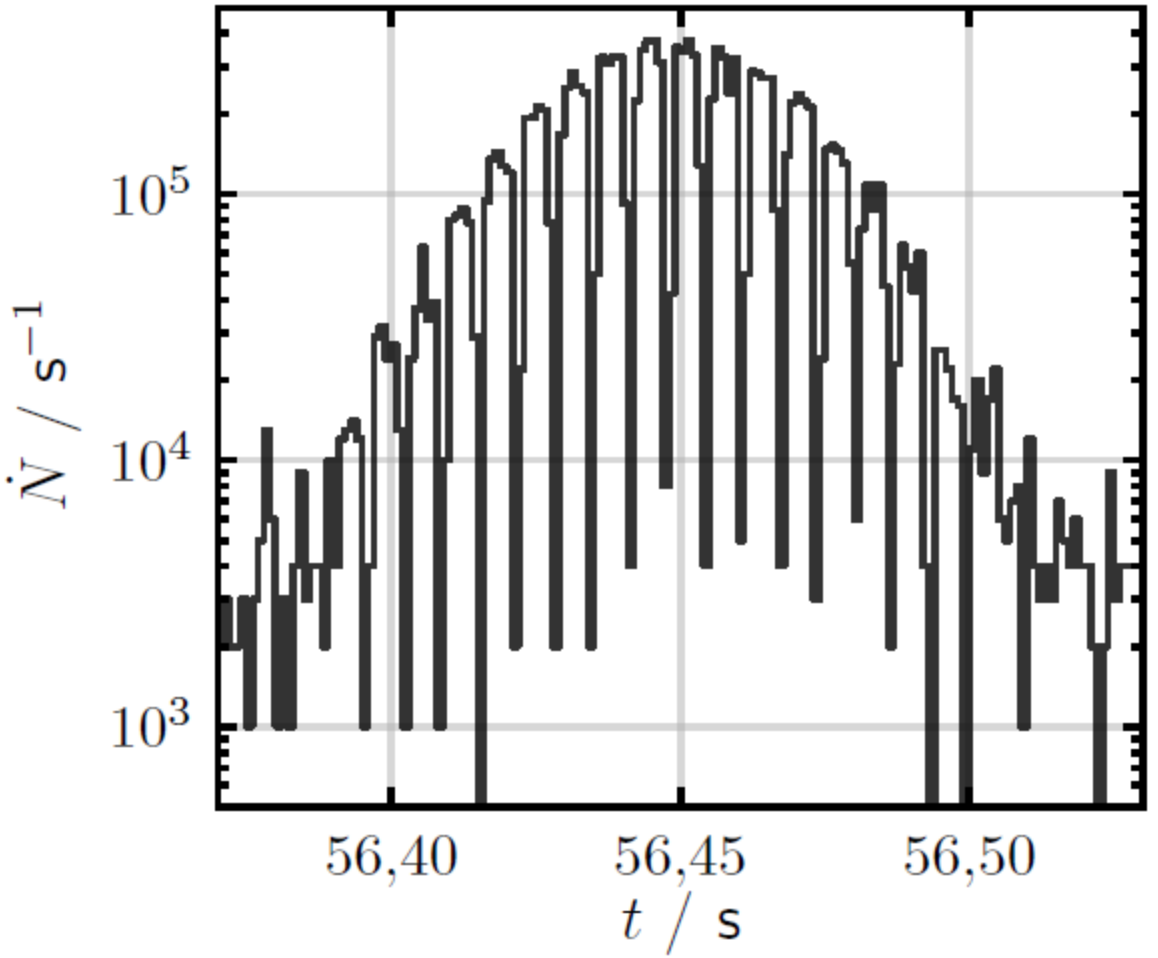


One peak = one line

Does it work in proton fields?

L. Grabs

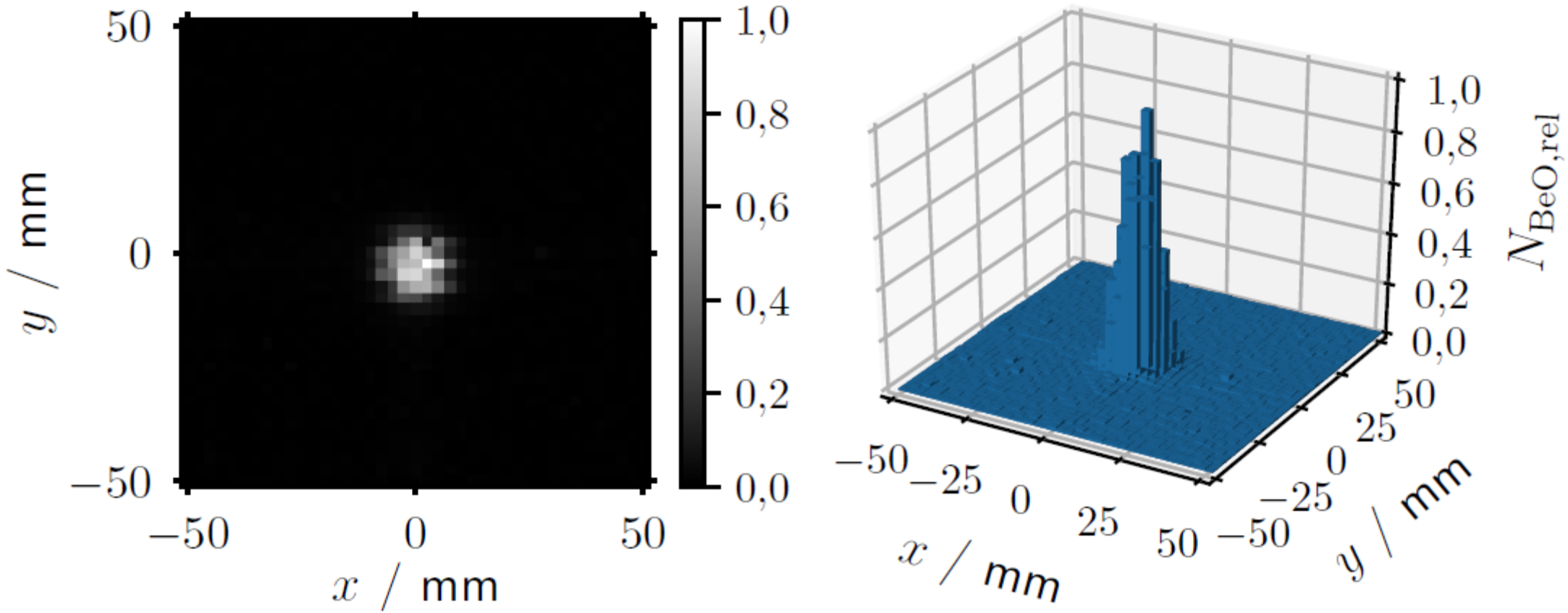




Within the line: one peak = one spot

Does it work in proton fields?

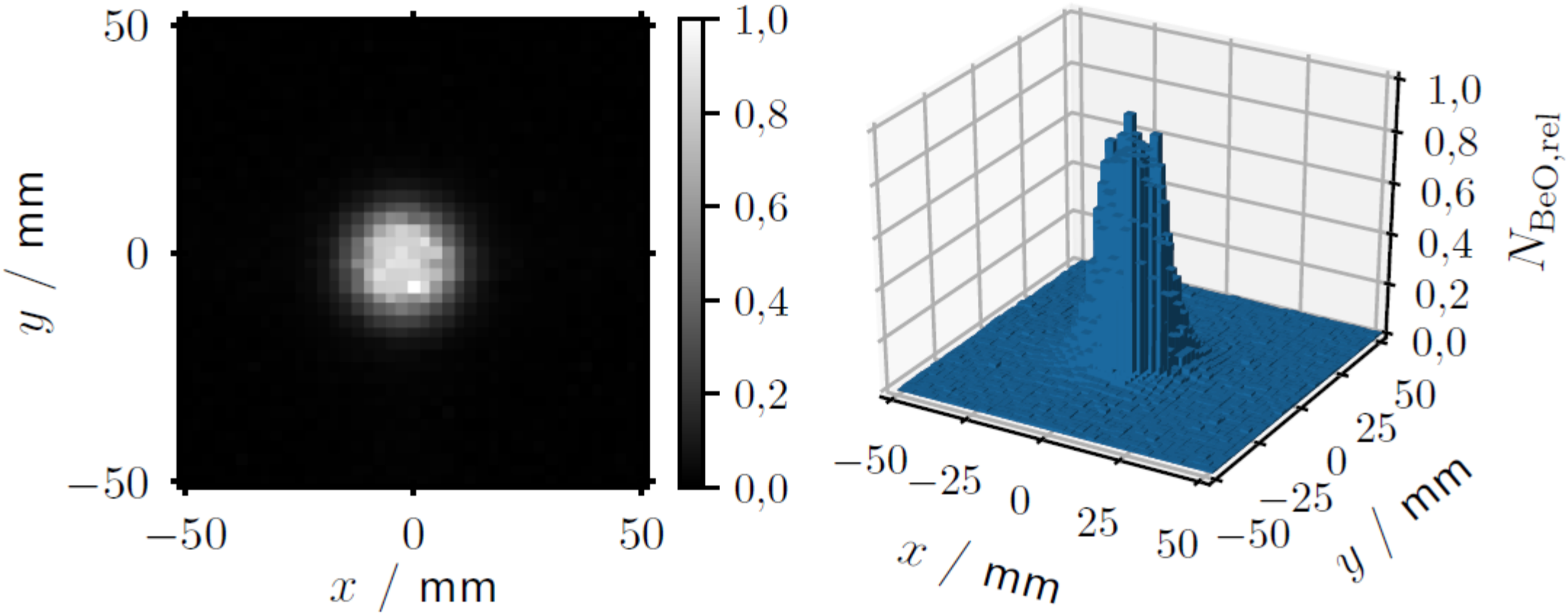
L. Grabs



Beam profile in 10 mm depth

Does it work in proton fields?

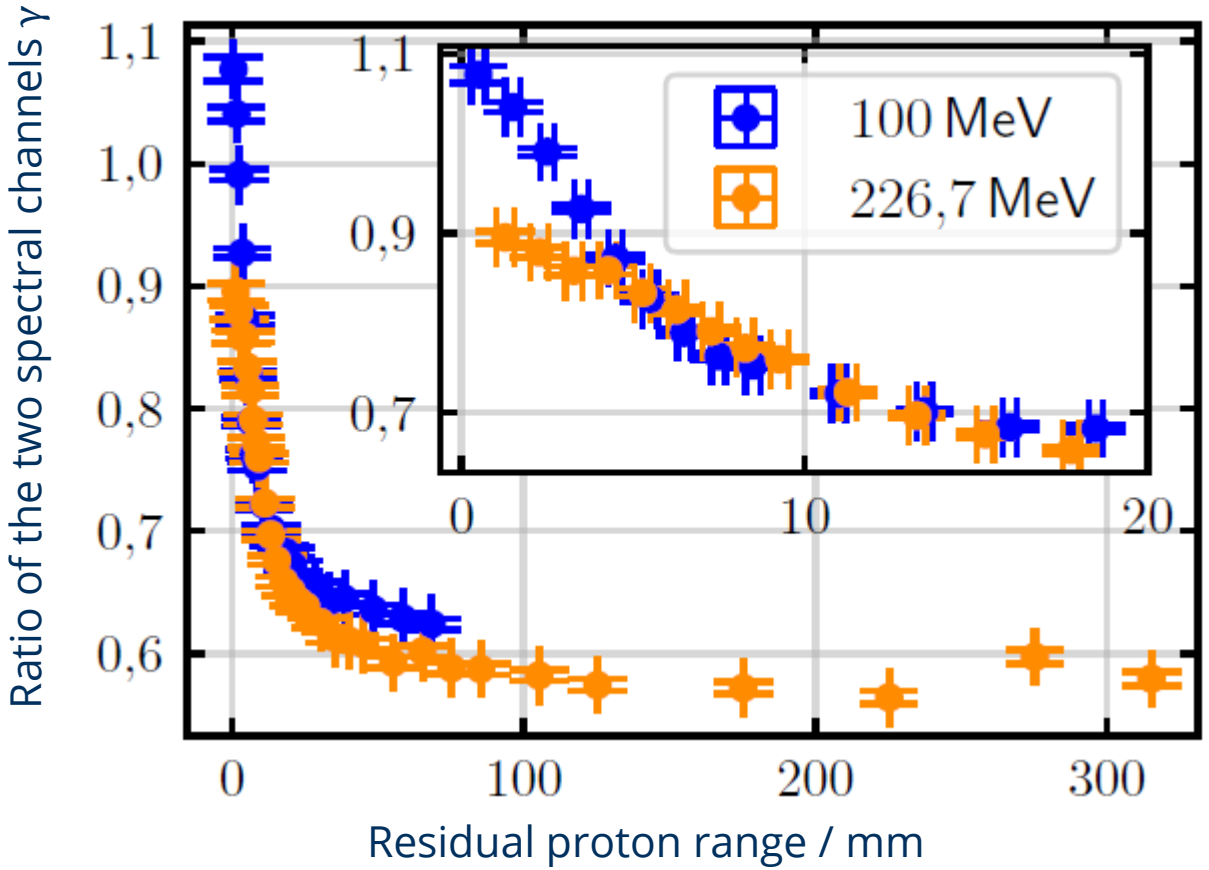
L. Grabs



Beam profile in 319 mm depth

Does it work in proton fields?

L. Grabs

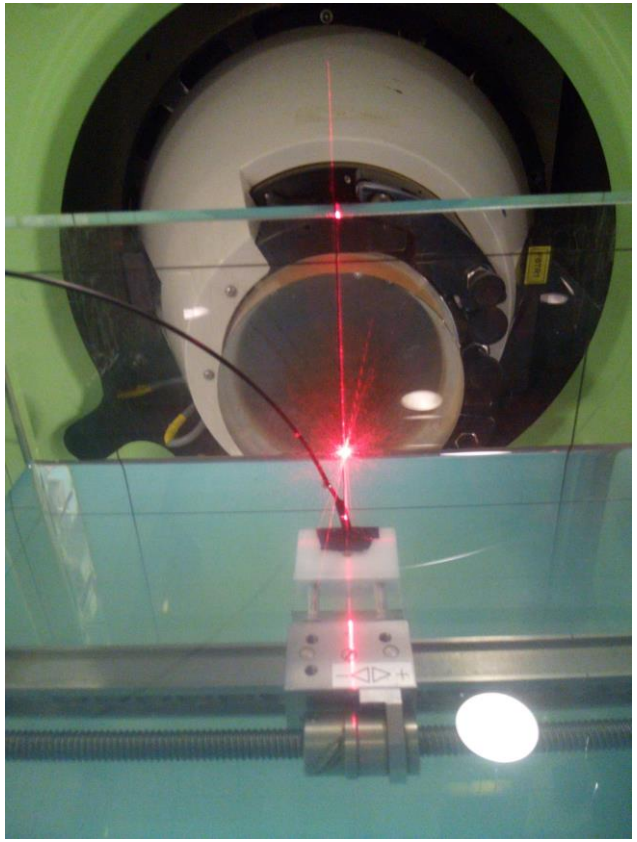


- The spectral shift is highly significant
- The last 10 to 20 mm are especially sensitive
- Dosimetric correction is possible

- The high sensitivy of this effect makes is also sensitive to the spectral composition of the beam
- Layer-wise or even spot-wise analysis necessary: improvements of the setup

Measurement: OncoRay August 2020

Last Friday and Saturday: Proton therapy Essen



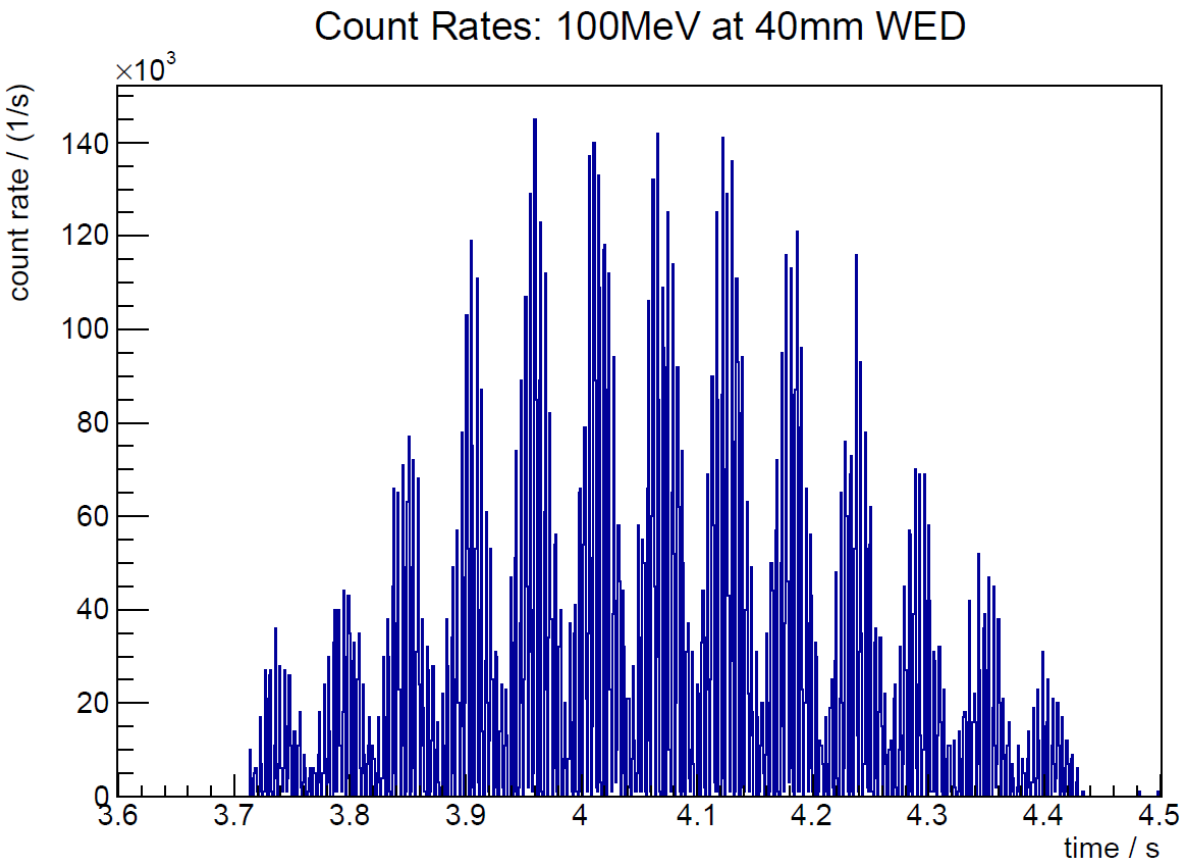
First measurement with:

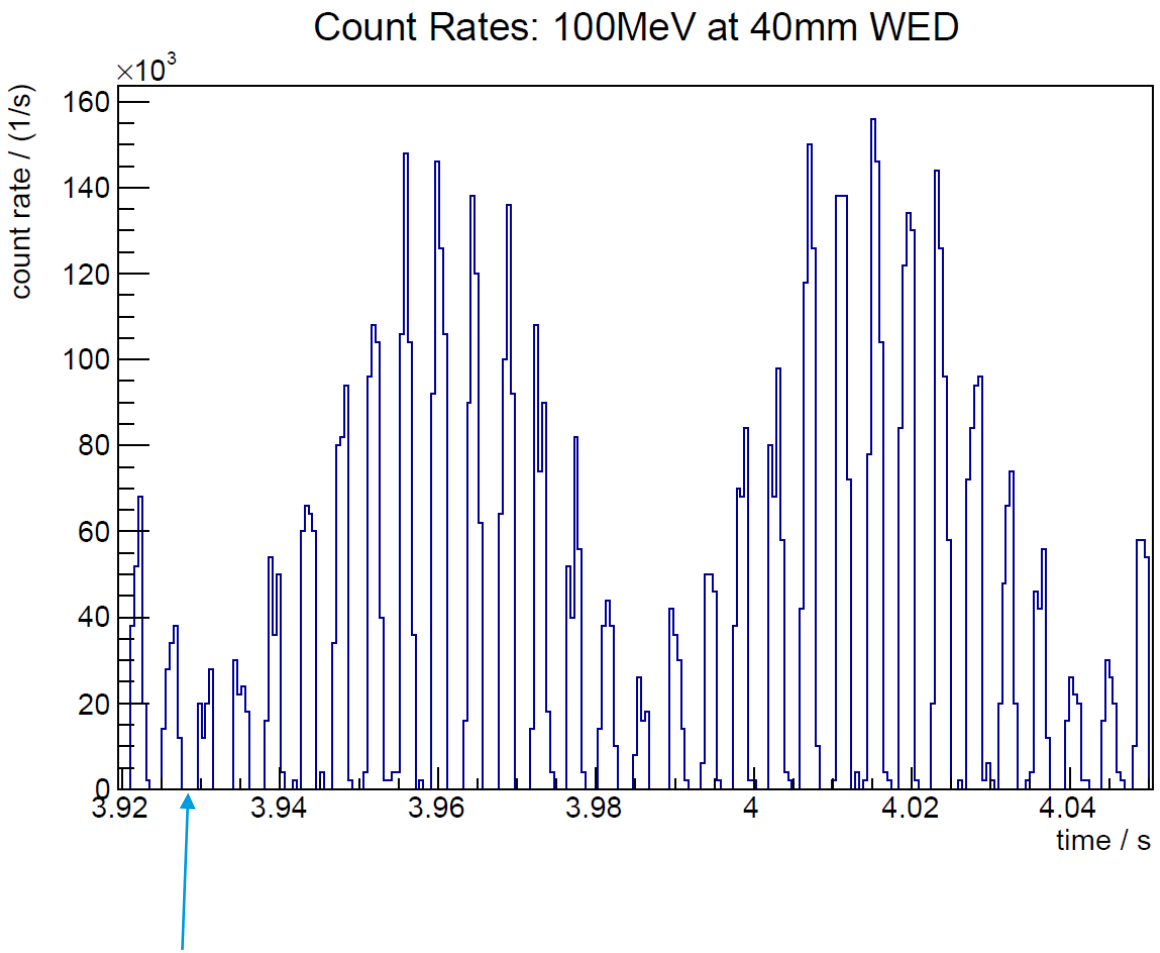
- A new probe: thinner fiber, longer fiber, new BeO
- The µPMT counting heads

Investigation of:

- Dose effects
- Scattered protons in the fringe field
- Radiography?

Last Friday and Saturday: Proton therapy Essen





Please take note of the signal to background ratio!

Advanced quality assurance for hadron therapy

- Data analysis!
- The new setup was a big step forward to exploit the potential
- Develop robust algorithm to extract the relevenant figures (dose, residual range, beam profile)
- Ultimate goal: bring all of this (hardware AND algorithms) into a single, easy to operate device

Thank you for your attention!

This (and more) is the work of many competent and very committed people:

Dr. Theresa Werner
Elena Metzner
Dieter Dirk Döhler
Vincent Melzer

Dr. Tobias Teichmann
Leopold Grabs
Richard Biedermann
Philipp Herzig
Pia Kahle
Kristina Makarevich

Jürgen Götze

Dr. David Weinberger

Dr. Stefan Menzel
Dr. Daniela Kunath
PD Dr. Steffen Löck
Prof. em. Wolfgang Enghardt
Dr. Elke Beyreuther

Prof. Armin Lühr
Carina Behrends
PD Dr. Christian Bäumer

Marian Sommer
PD Dr. Jürgen Henniger