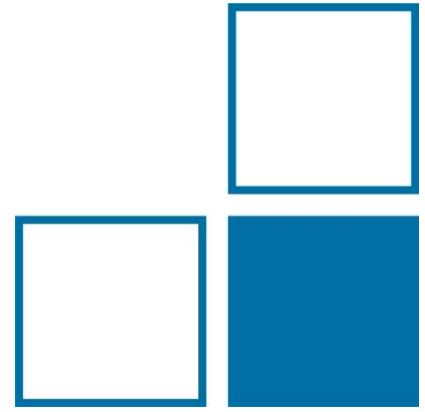
Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Radiation dosimetry of electron beams up to 50 MeV at MELAF

Andreas Schüller
Department 6.2 “Dosimetry for radiation therapy and diagnostic radiology”
Working group 6.21 “High-energy photon and electron radiation”



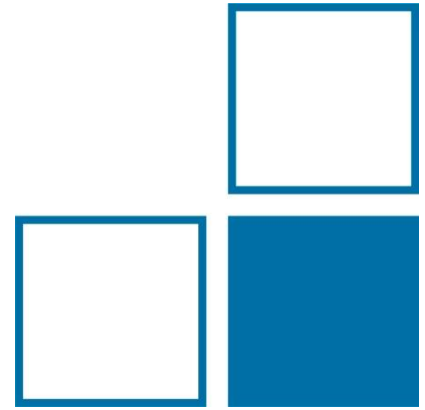
PRAE International Workshop 8.-10.10.18, Orsay

Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
National Metrology Institute

Radiation dosimetry of electron beams up to 50 MeV at MELAF

Contents:

1. Introduction of PTB
2. Introduction of the Metrological ELectron Accelerator Facility (MELAF)
3. Beam diagnostic at the 50 MeV beam line
4. Dosimetry procedure for up to 50 MeV
5. Outlook



Introduction of PTB - Historical remarks

… as state-financed, university-external, major research institution which combines free fundamental research with services for industry

Selected scientific highlights

- Planck's Law → Nobel Prize for Willy Wien in 1911
- Counters for α and β particles by Hans Geiger
- coincidence method for particle physics → Nobel Prize for Walther Bothe in 1954
- First measurement of the Quantum Hall resistance together with Klaus von Klitzing

Introduction of PTB - Today

Employees: ~2000

Budget: ~200 Mio. €/a

R&D: ~60 %

Central mission:
Provision of an innovative, **reliable measurement** infrastructure

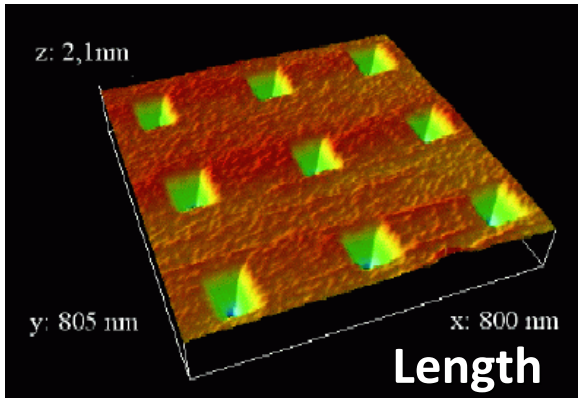
- associated services
- research and development on highest level
- internationally recognized and harmonized

- for the benefit of the *economy*
- for the (protection-) benefit of *society*
- to support *policy*
- to support internationally leading *science*

Introduction of PTB - National standards

Metrology

- Science of measurements
- correct, quality-assured measurements
- Traceability to the SI via national standards



Motivation

A **reliable radiation dosimetry** is a key for reliable radiobiological experiments as planned to be carried out at PRAE.

necessary for

- the comparison of radiobiological effectiveness for different irradiation modalities
- investigation of the relationship between dose and biological damage
- to carry out preclinical radiobiological studies to test efficacy of electron beams at PRAE for future radiotherapy applications

PTB Working group 6.21 -> Dosimetry for radiotherapy of high-energy electron radiation

MELAF - Metrological Electron Accelerator Facility

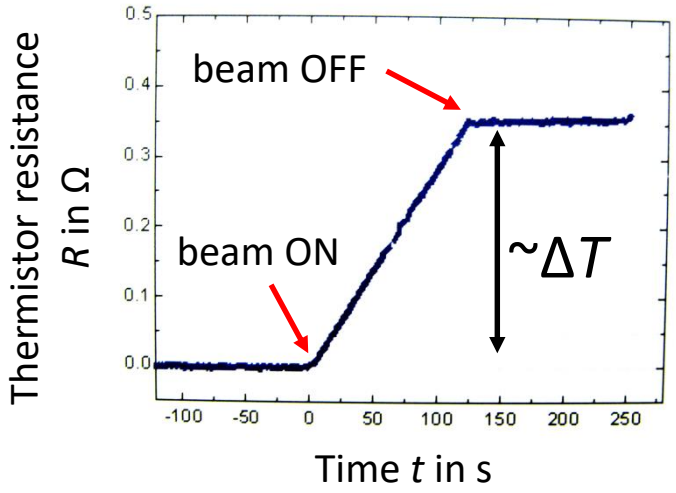
Primary standard of the unit “Gray” for **absorbed dose** to water

$$D_w = d\varepsilon/dm \qquad 1\ \text{Gy} = 1\ \text{J/Kg}$$

ε: energy deposit in medium, *m:* mass of medium

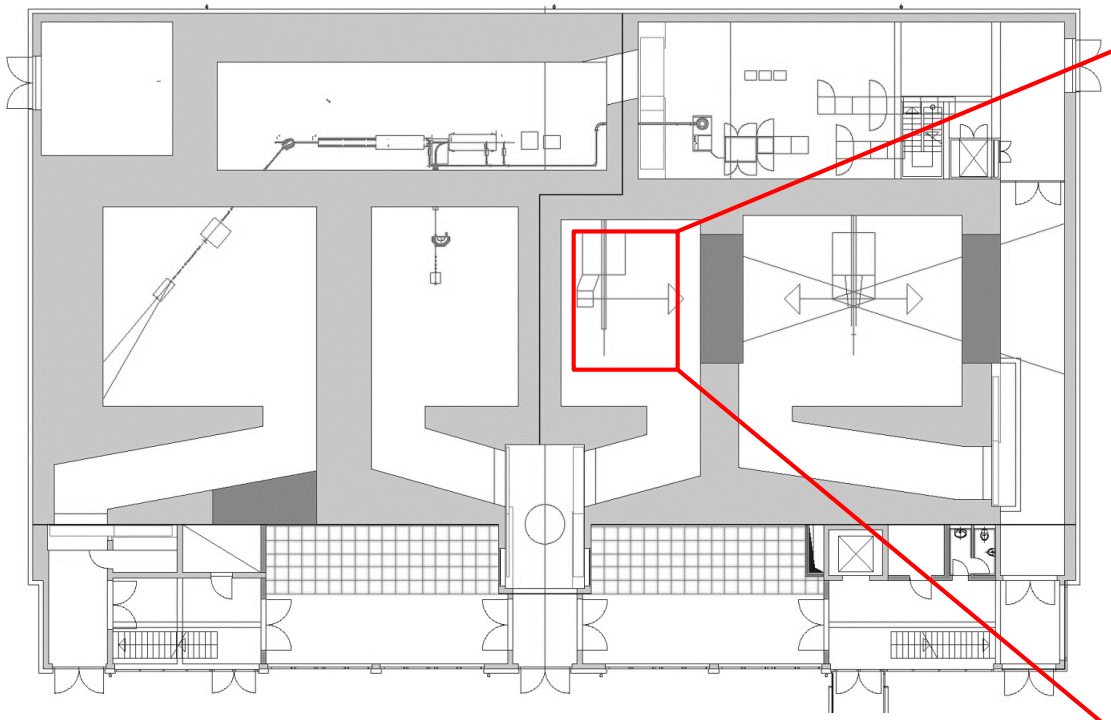
$$D_w = c_p \cdot \Delta T \cdot \Pi k_i \qquad \Delta T = 0.24\ \text{mK/Gy}$$

c_p: Heat capacity of water, ΔT: Radiation-induced temperature rise
Πk_i: corrections for perturbations (heat transport, etc.)

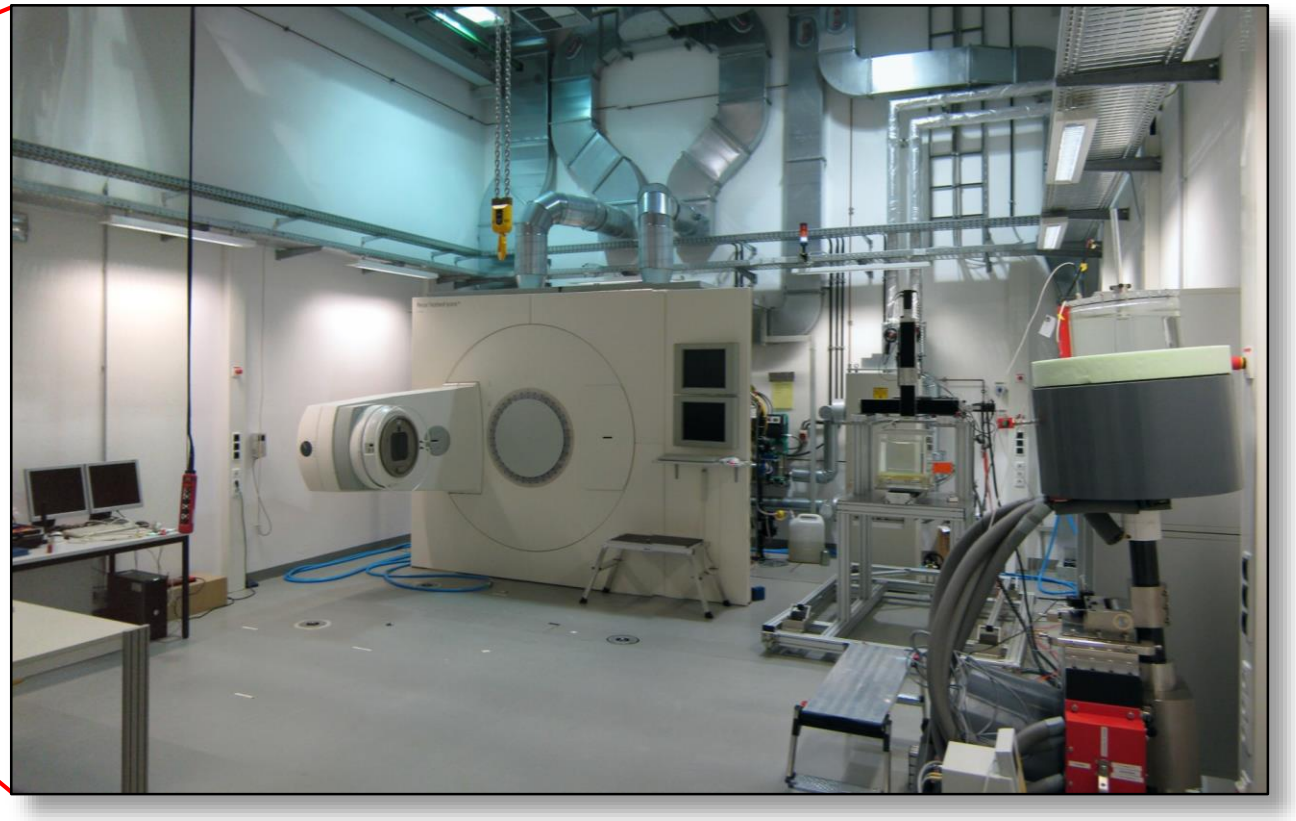


Water calorimeter in a clinical electron beam

MELAF - Metrological Electron Accelerator Facility



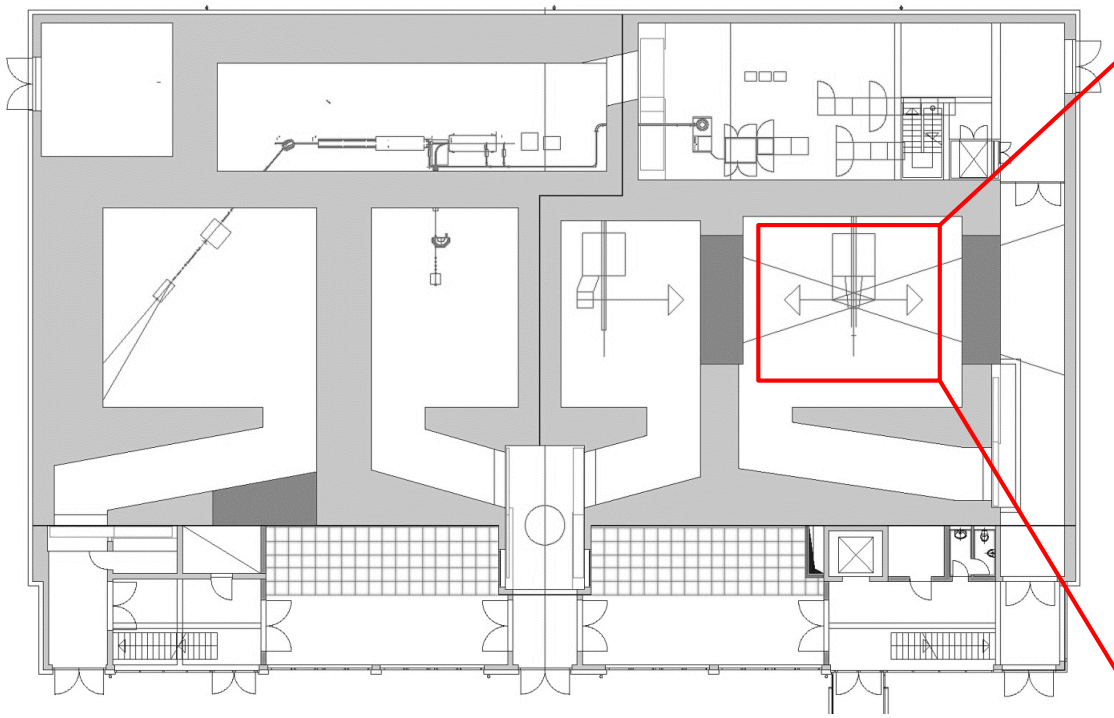
MELAF (sketch of building)



Clinical electron accelerator (LINAC #1)

E= 4 – 22 MeV, dose rate: < 5 Gy/min (@ 1 m)

MELAF - Metrological Electron Accelerator Facility

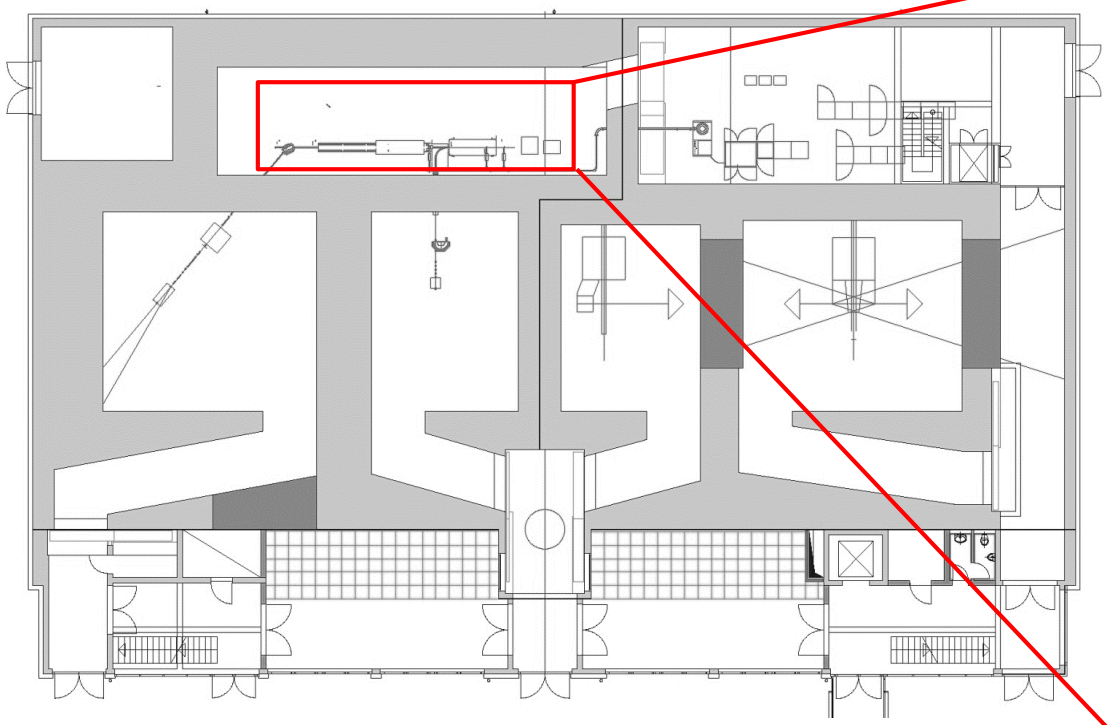


MELAF (sketch of building)

Clinical electron accelerator (LINAC #2)

E= 4 – 22 MeV, dose rate: < 5 Gy/min (@ 1 m)

MELAF - Metrological Electron Accelerator Facility

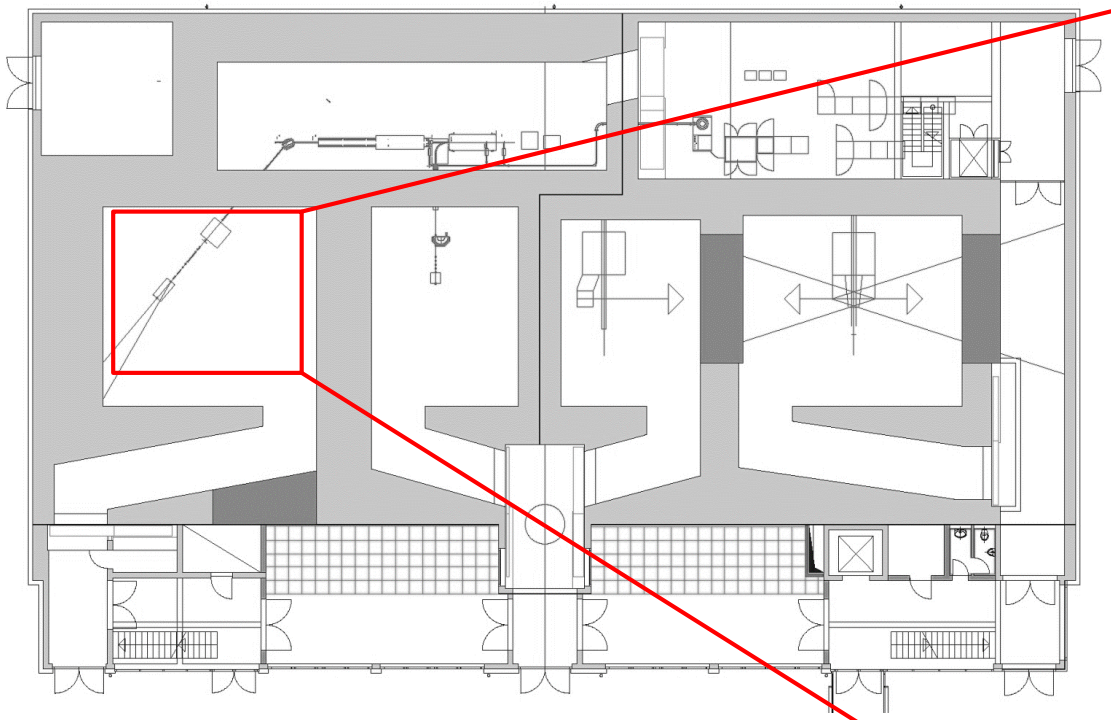


MELAF (sketch of building)

Research electron accelerator

E= 0.5 – 50 MeV, dose rate: < 100 Gy/min (@ 1 m)

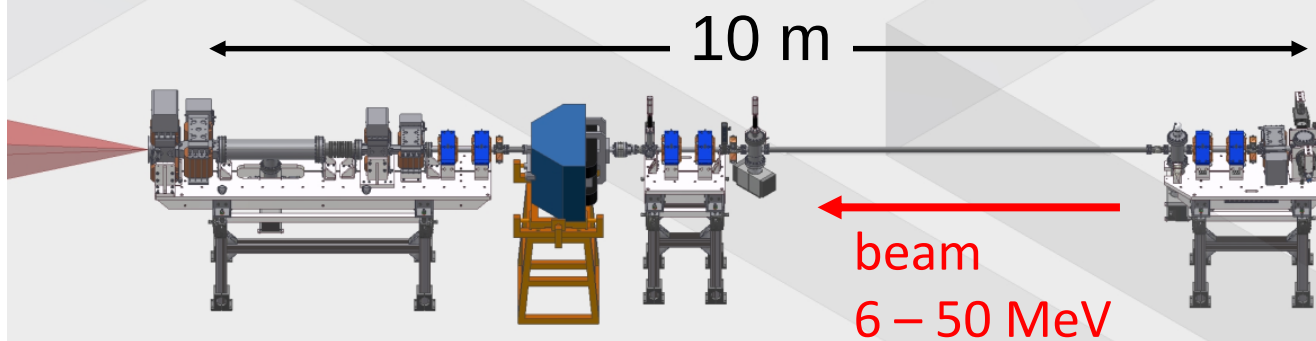
MELAF - Metrological Electron Accelerator Facility



MELAF (sketch of building)

High-energy (6 – 50 MeV) beamline

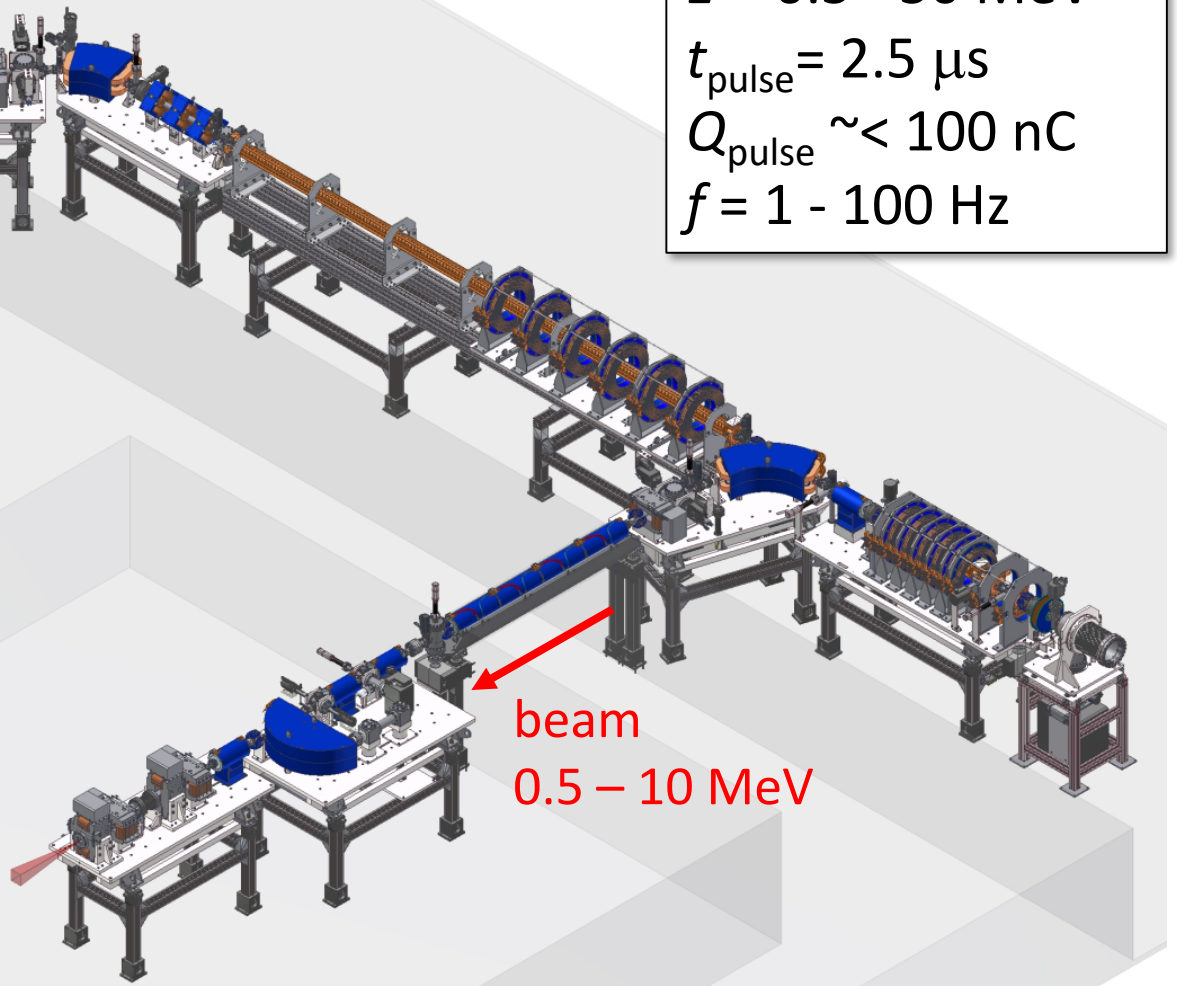
MELAF - Metrological Electron Accelerator Facility



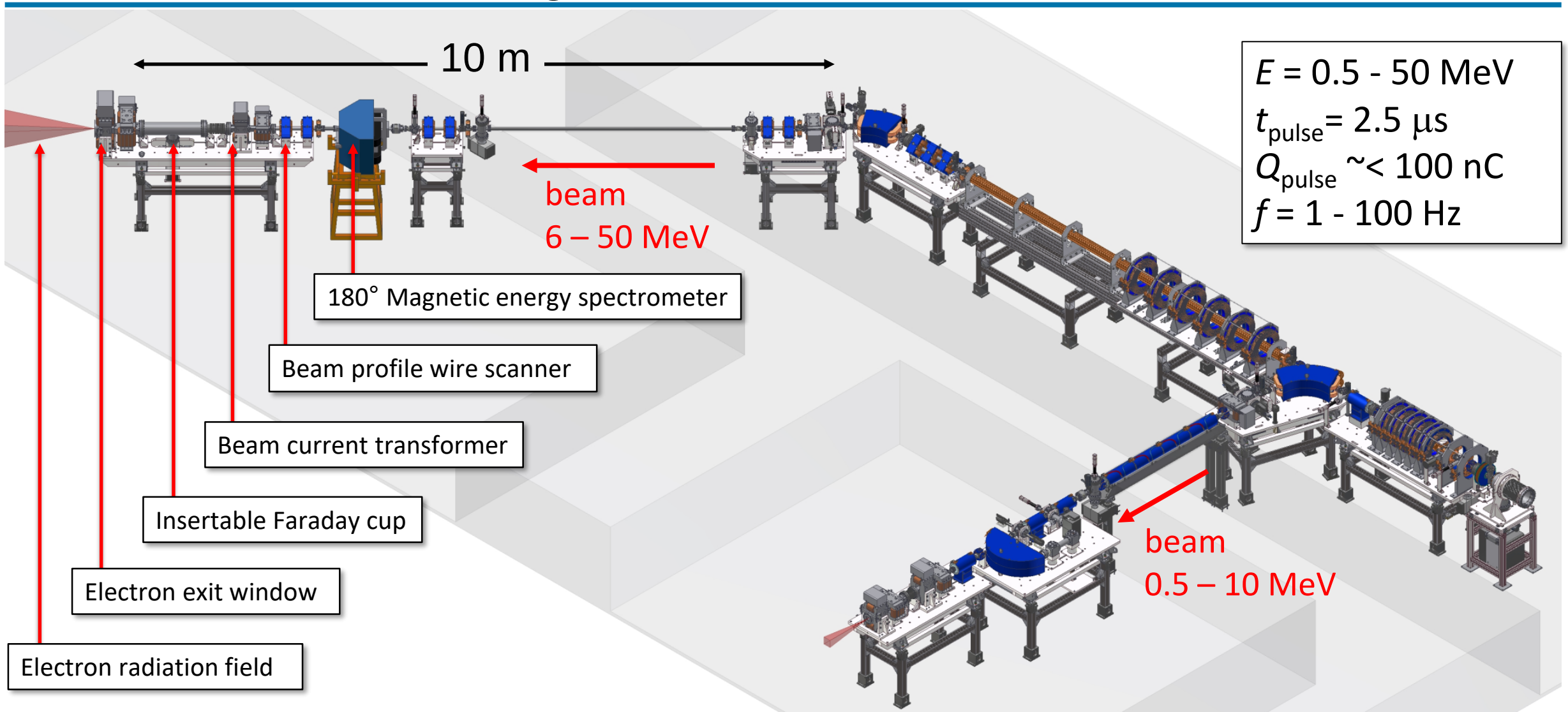
E = 0.5 - 50 MeV
t_{pulse} = 2.5 µs
Q_{pulse} ~< 100 nC
f = 1 - 100 Hz

Research electron accelerator (LINAC):

- supplied as a turn-key system by ACCEL Instruments (now RI Research Instruments)
- similar in construction to ACCEL's synchrotron light source pre-injector LINAC (Australian Synchrotron, Diamond Light Source, Bessy II, Swiss Light Source)
- two 3 GHz accelerating sections (travelling wave typ, DESY S Band Linear Collider Type II design)

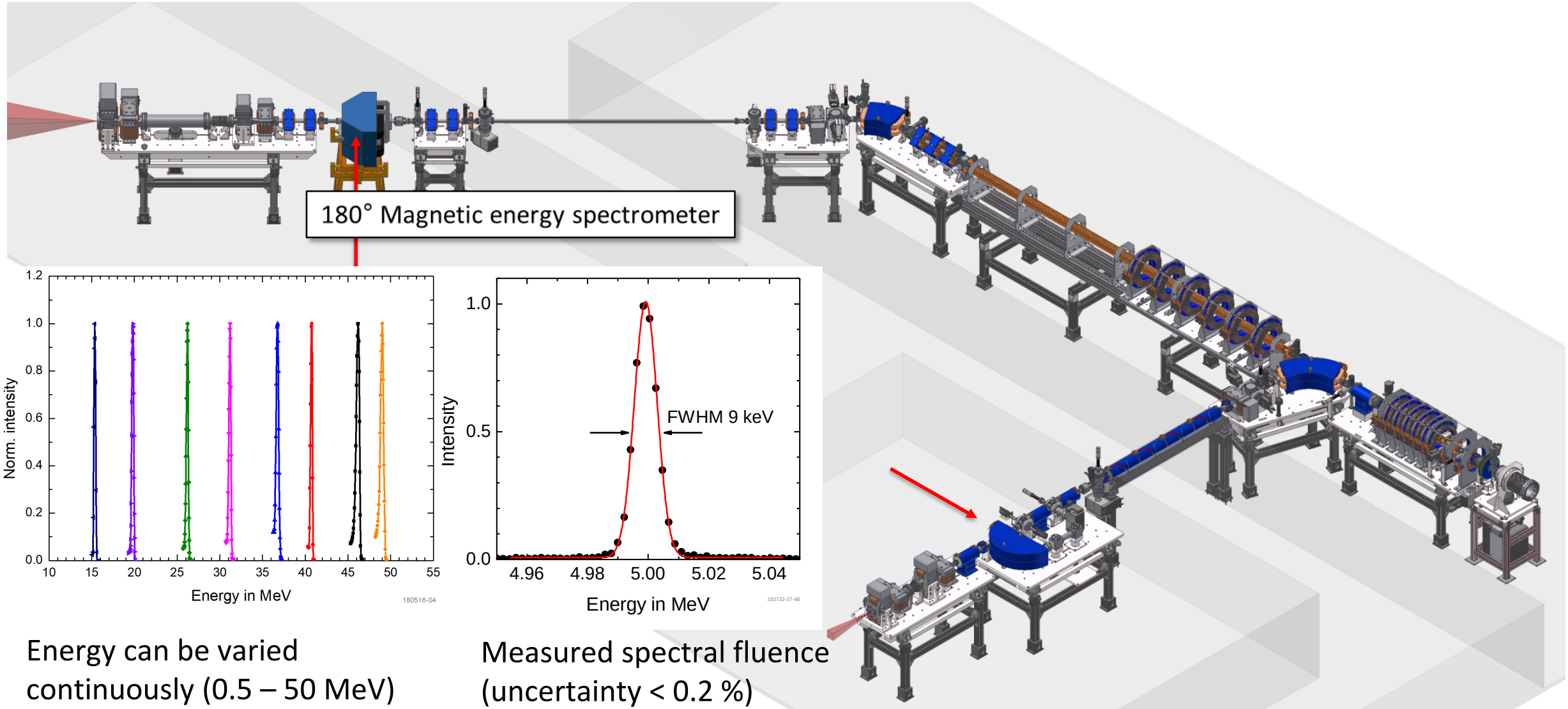


Beam diagnostic at the 50 MeV beam line



E = 0.5 - 50 MeV
t_{pulse} = 2.5 µs
Q_{pulse} ~< 100 nC
f = 1 - 100 Hz

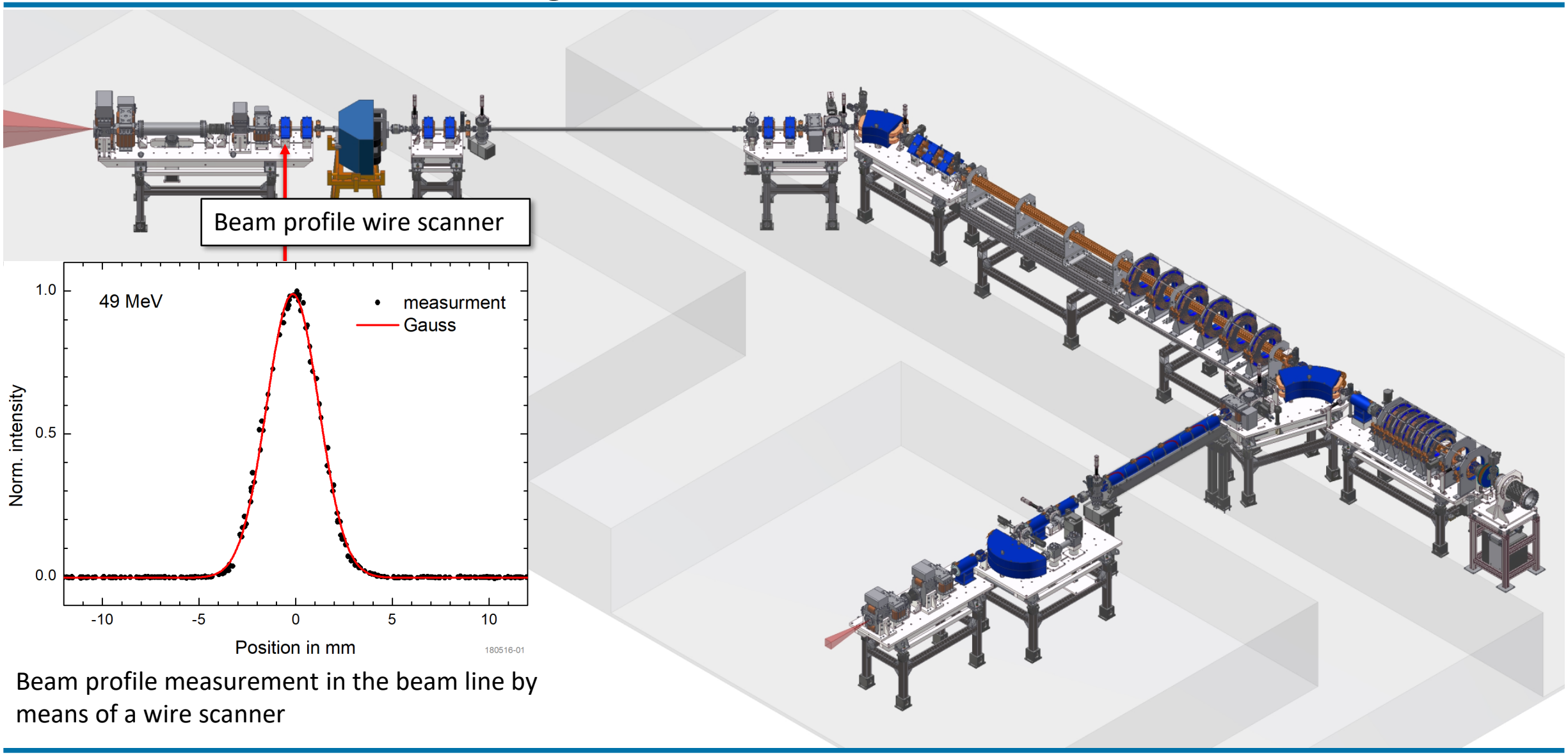
Beam diagnostic at the 50 MeV beam line



Energy can be varied continuously (0.5 – 50 MeV)

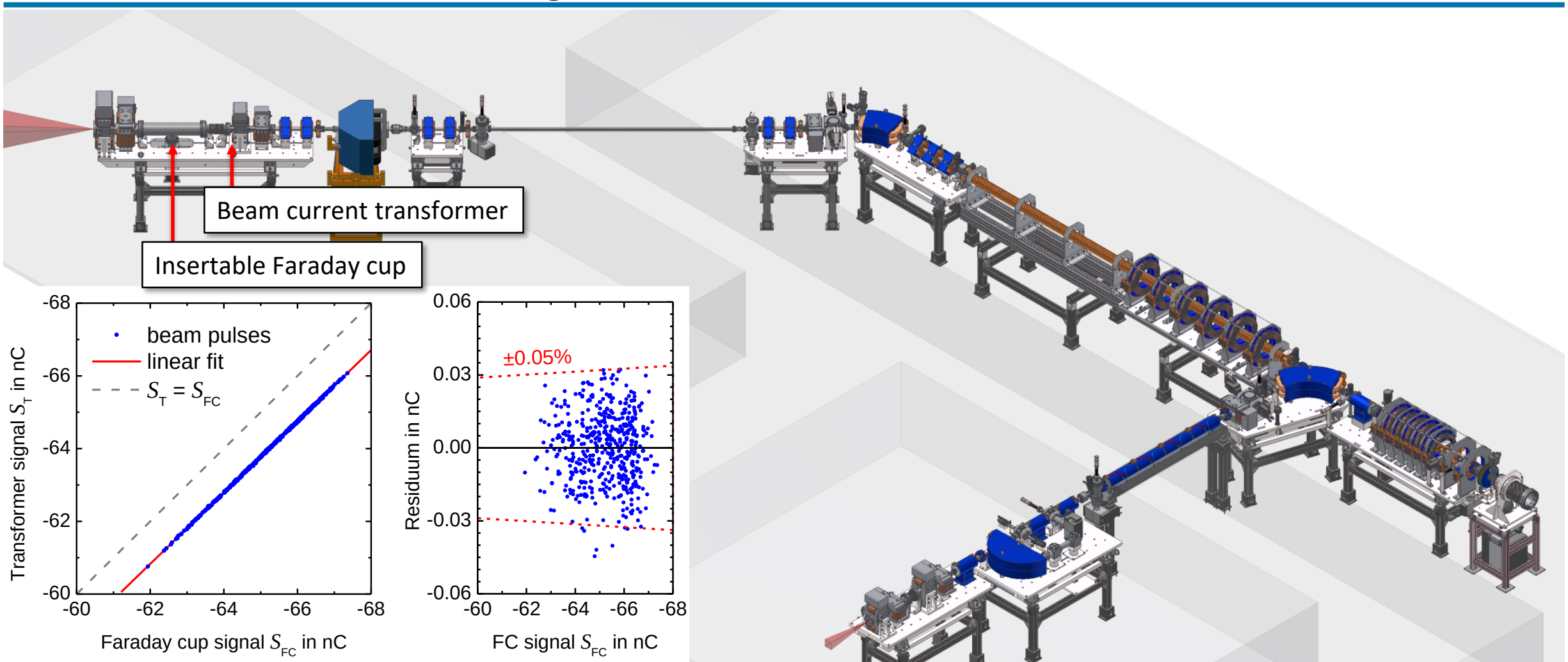
Measured spectral fluence (uncertainty < 0.2 %)

Beam diagnostic at the 50 MeV beam line



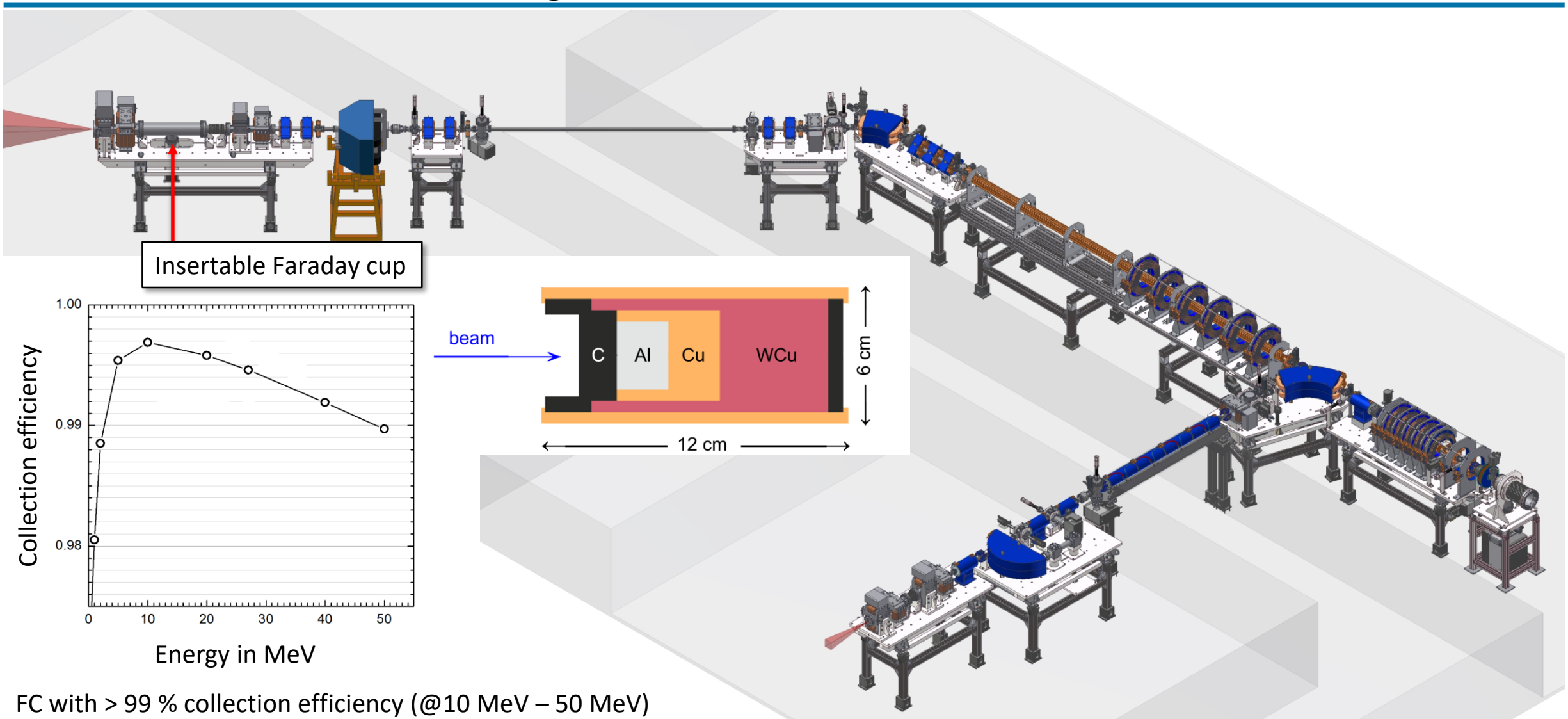
Beam profile measurement in the beam line by means of a wire scanner

Beam diagnostic at the 50 MeV beam line



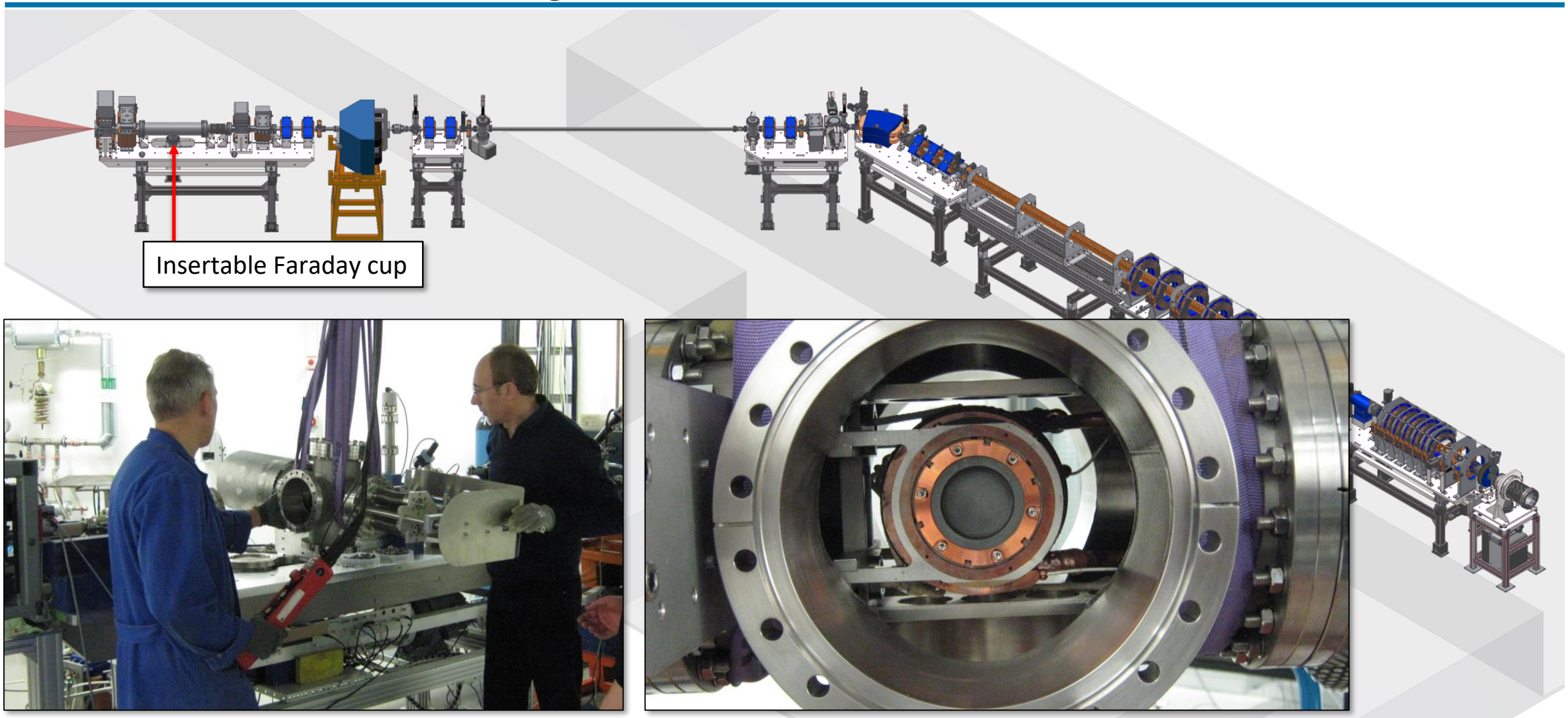
Non-destructive absolute beam charge measurement (uncertainty < 0.1 %)

Beam diagnostic at the 50 MeV beam line

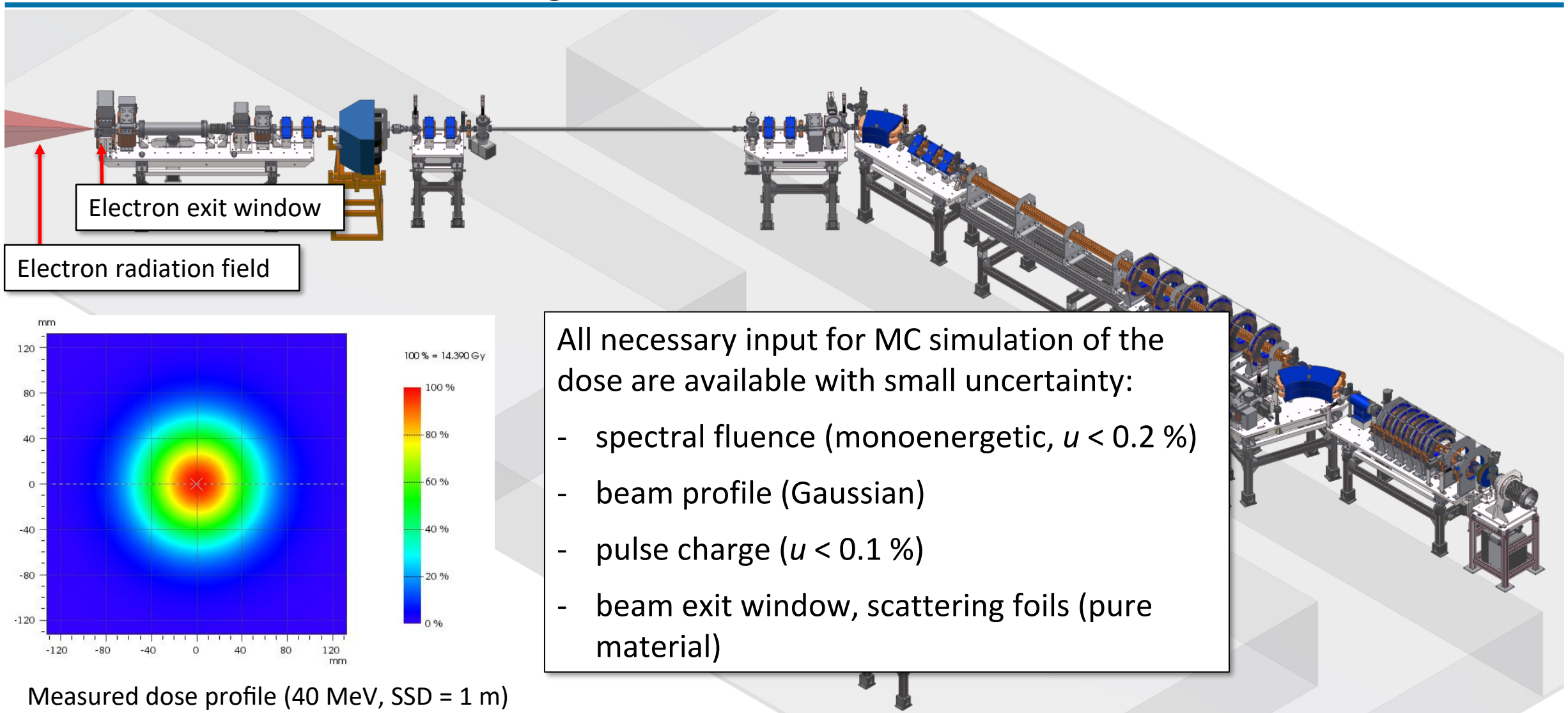


FC with > 99 % collection efficiency (@10 MeV – 50 MeV)

Beam diagnostic at the 50 MeV beam line



Beam diagnostic at the 50 MeV beam line



Measured dose profile (40 MeV, SSD = 1 m)

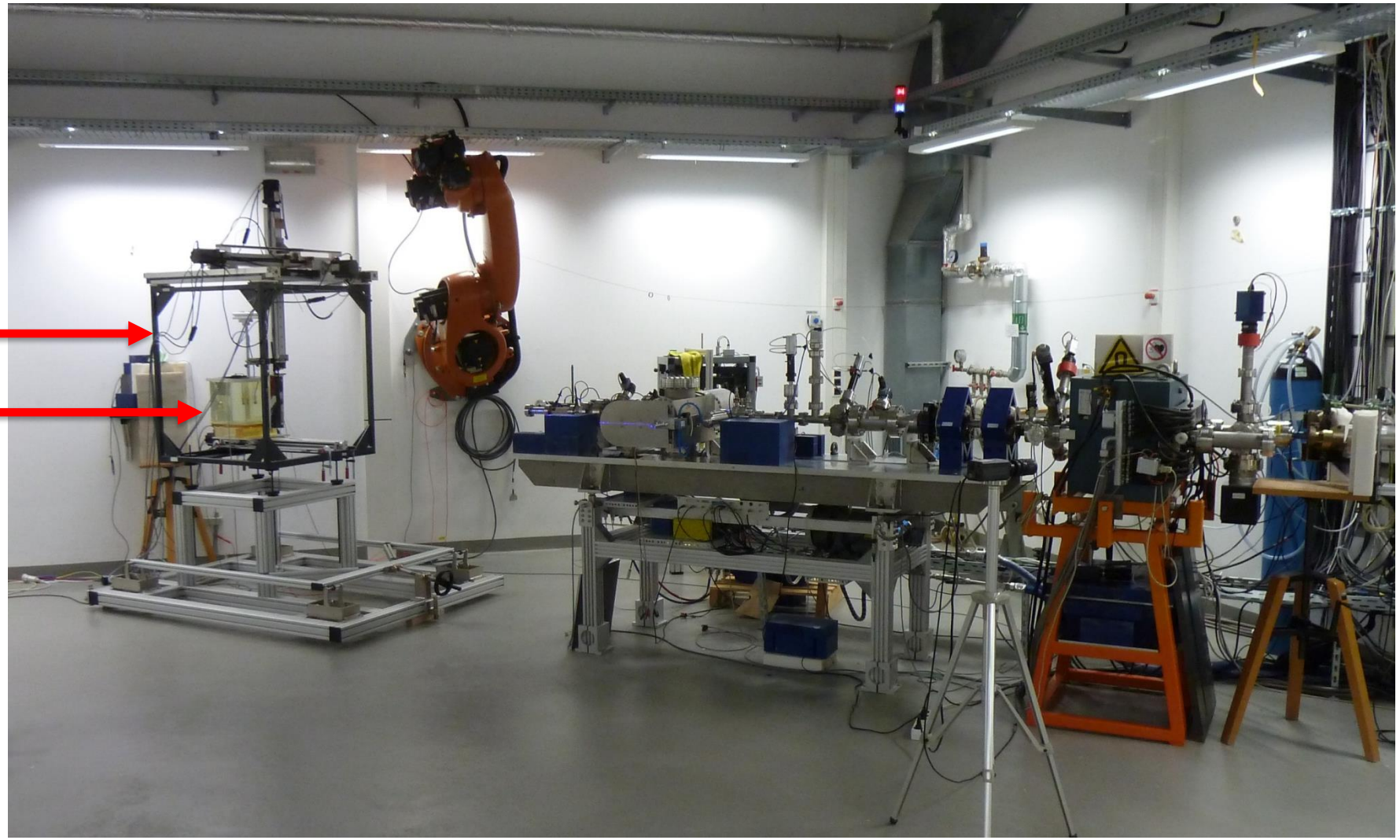
All necessary input for MC simulation of the dose are available with small uncertainty:

- spectral fluence (monoenergetic, $u < 0.2$ %)
- beam profile (Gaussian)
- pulse charge ($u < 0.1$ %)
- beam exit window, scattering foils (pure material)

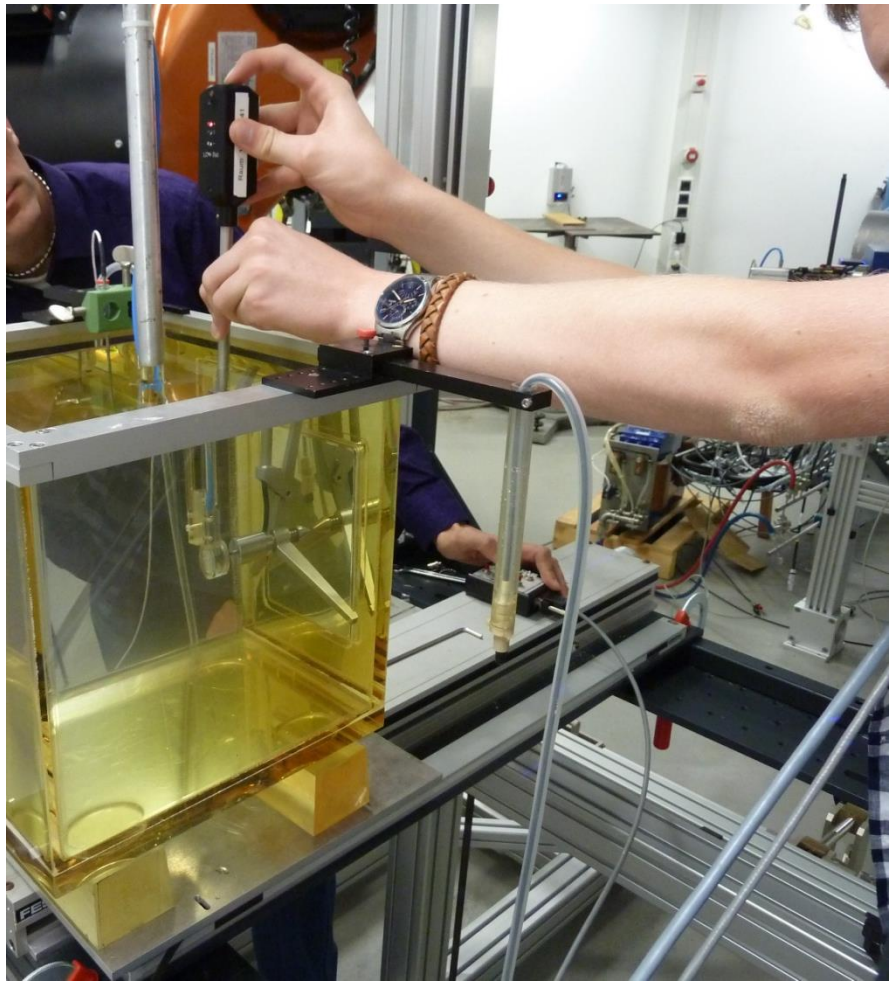
Dosimetry procedure for up to 50 MeV

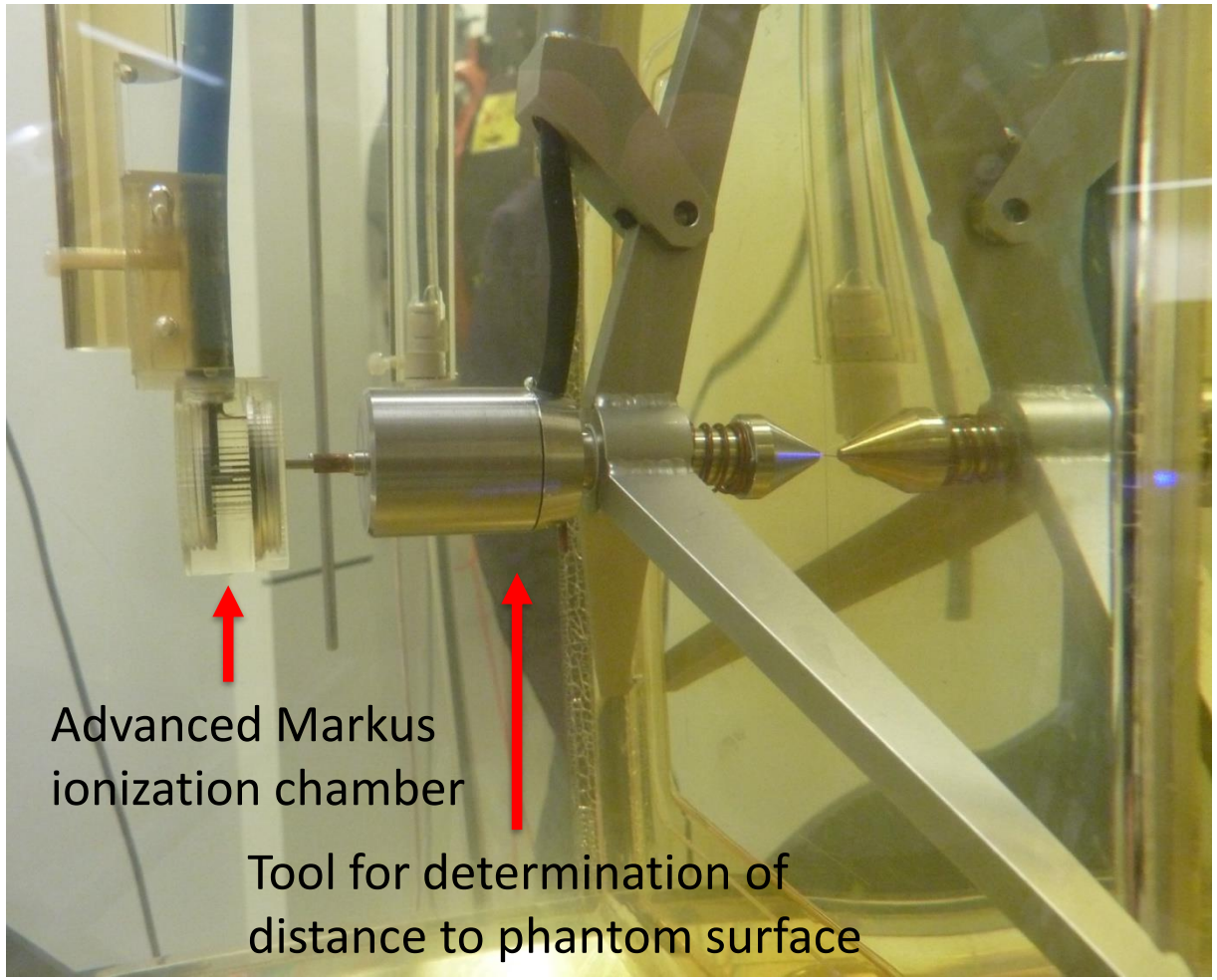
x, y, z - motorized positioning system

water phantom (30 x 30 x 30 cm)



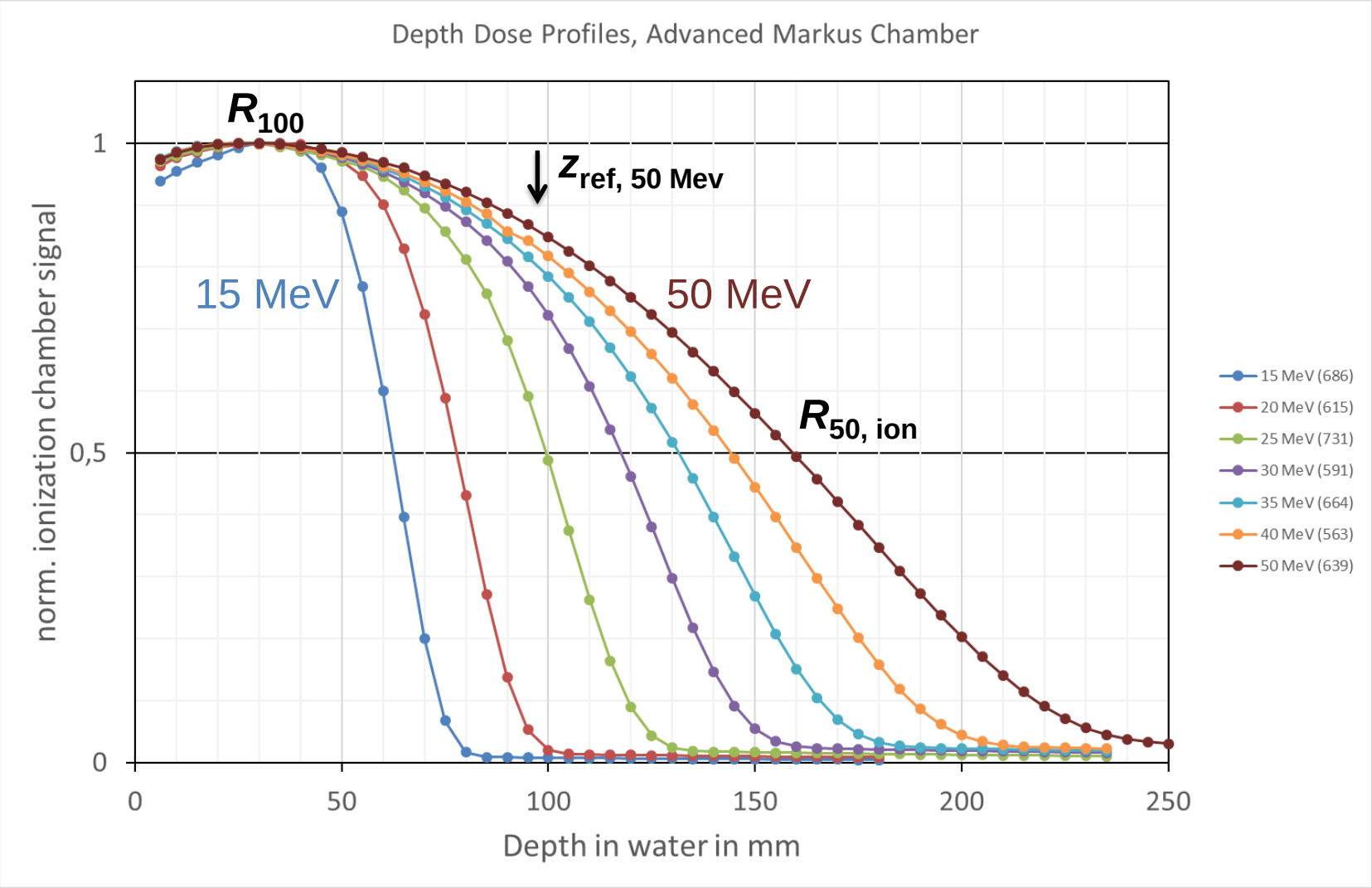
Dosimetry procedure for up to 50 MeV





precise determination of the depth in water

Dosimetry procedure for up to 50 MeV



Dosimetry protocols (electrons with 3 – 50 MeV):

- TRS 398 (IAEA)
- DIN 6800-2 (in German)

  "Ionization chamber dosimetry of high energy photon and electron radiation"

Reference depth:
(after correction due to ion recombination)

$z_{ref} = 0.6\ R_{50} - 0.1$ (in cm)

$R_{50} = 1.059\ R_{50,\ ion} - 0.37$ cm

($R_{50,\ ion} > 10$ cm)

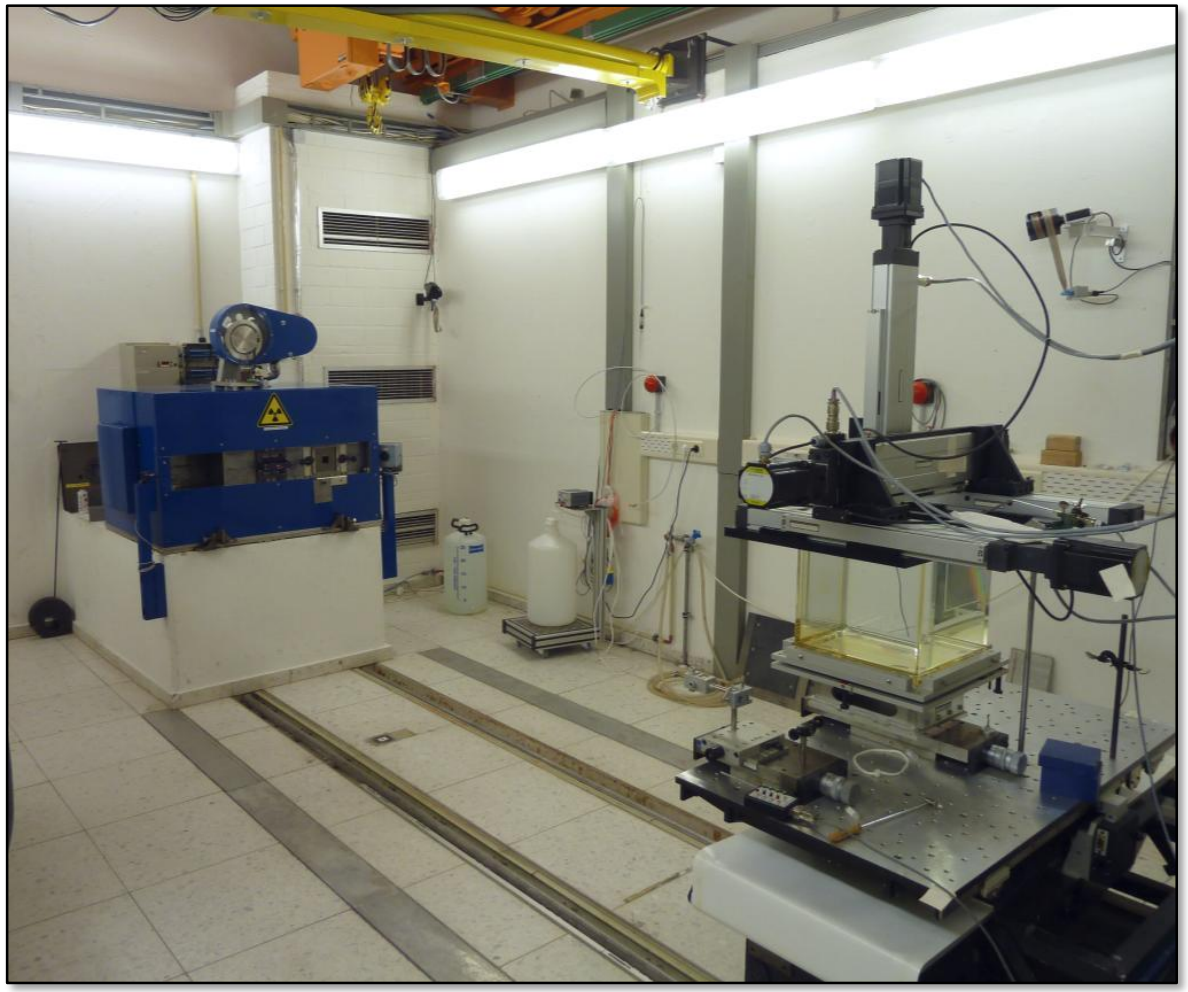
Dosimetry procedure for up to 50 MeV

$$D = (M\text{-}M_0)\, N\, k_\rho k_h k_s k_p k_E$$

D	absorbed dose (at $\boldsymbol{z_{ref}}$)
M	reading
M_0	zero reading
$\boldsymbol{N}$	**calibration factor (Co-60)**
	correction due to
k_ρ	air density
k_h	humidity
k_s	ion recombination
k_p	polarity
$\boldsymbol{k_E}$	**radiation quality (electrons)**

$k_E = 1.106 - 0.1312\,(R_{50})^{0.214}\; k_E$“

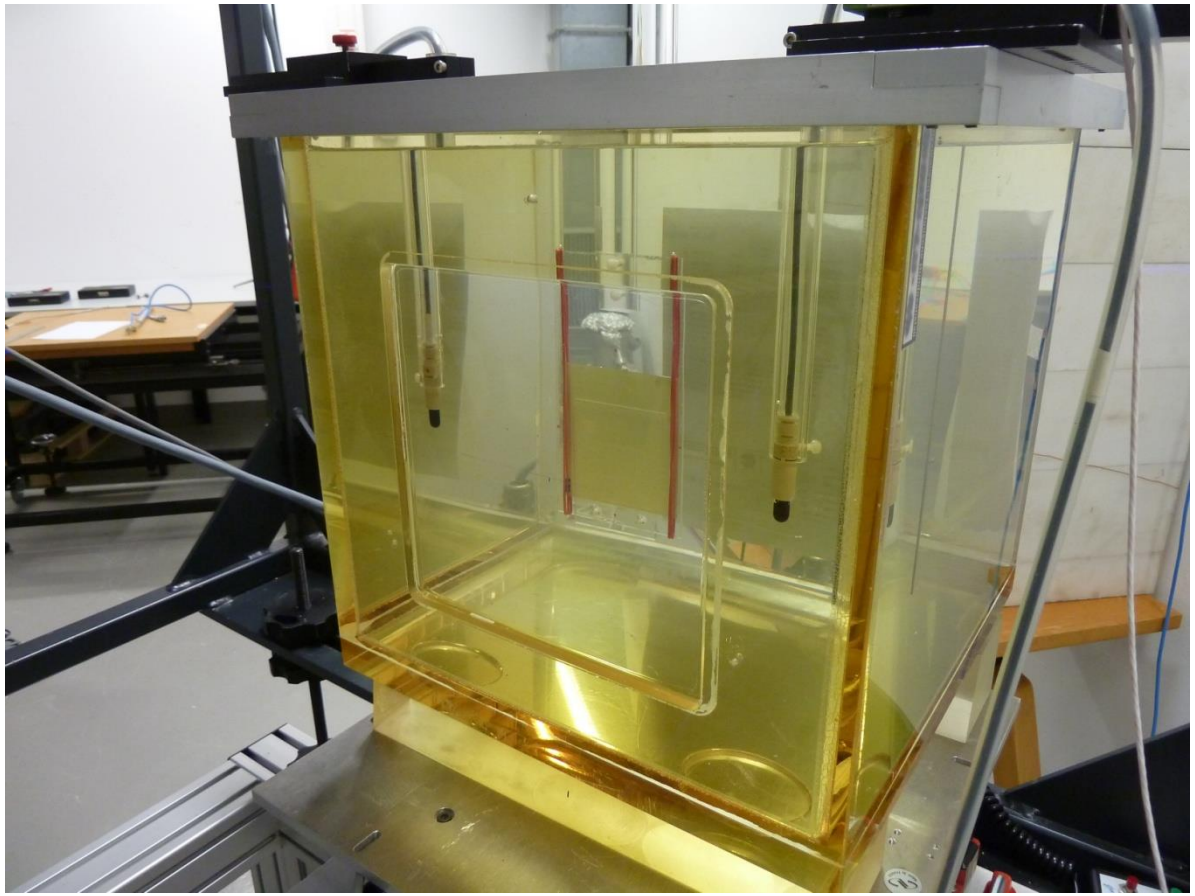
k_E“(Advanced Markus)=0.985

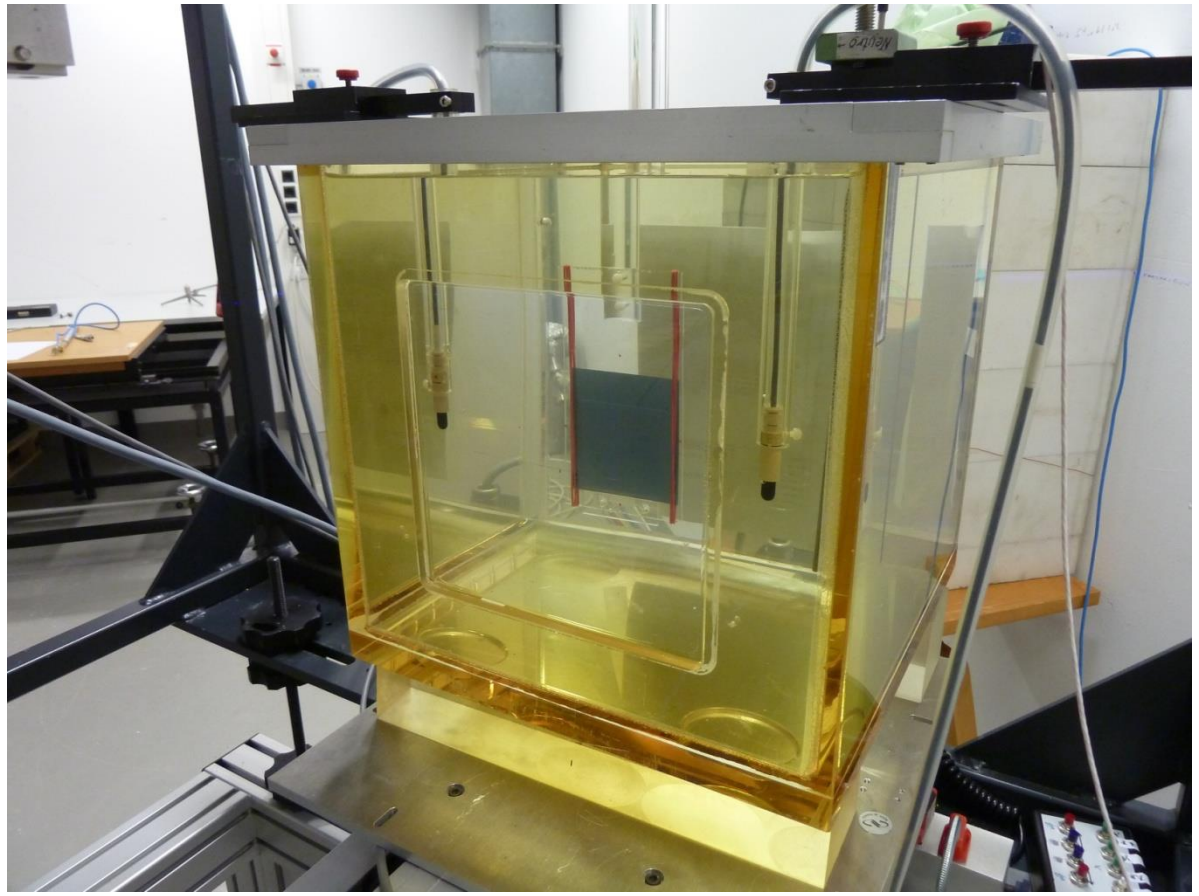


^{60}Co Source of PTB’s calibration service

Outlook - radiochromic film dosimeter

Investigation of the response of radiochromic films (EBT3) on high-energy electrons (15 – 50 MeV) in collaboration with the University of Strathclyde

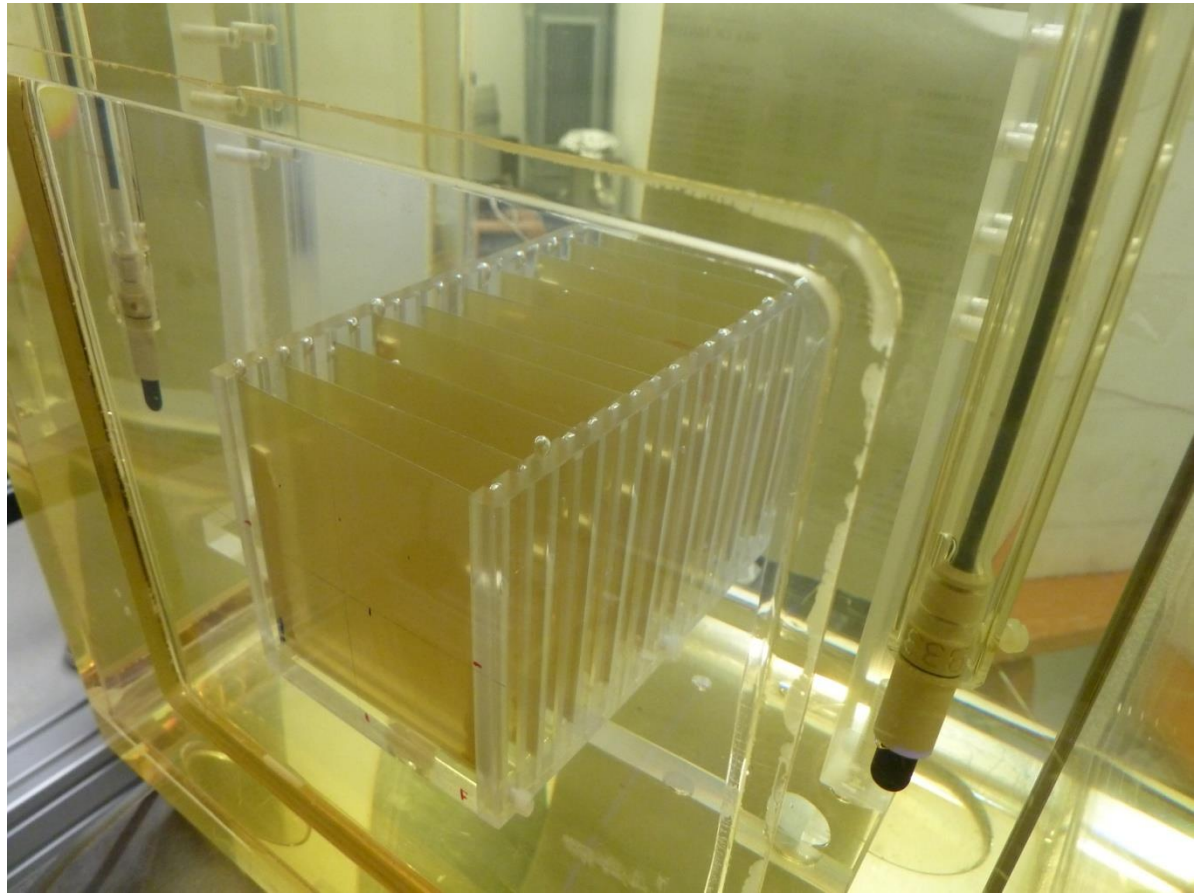


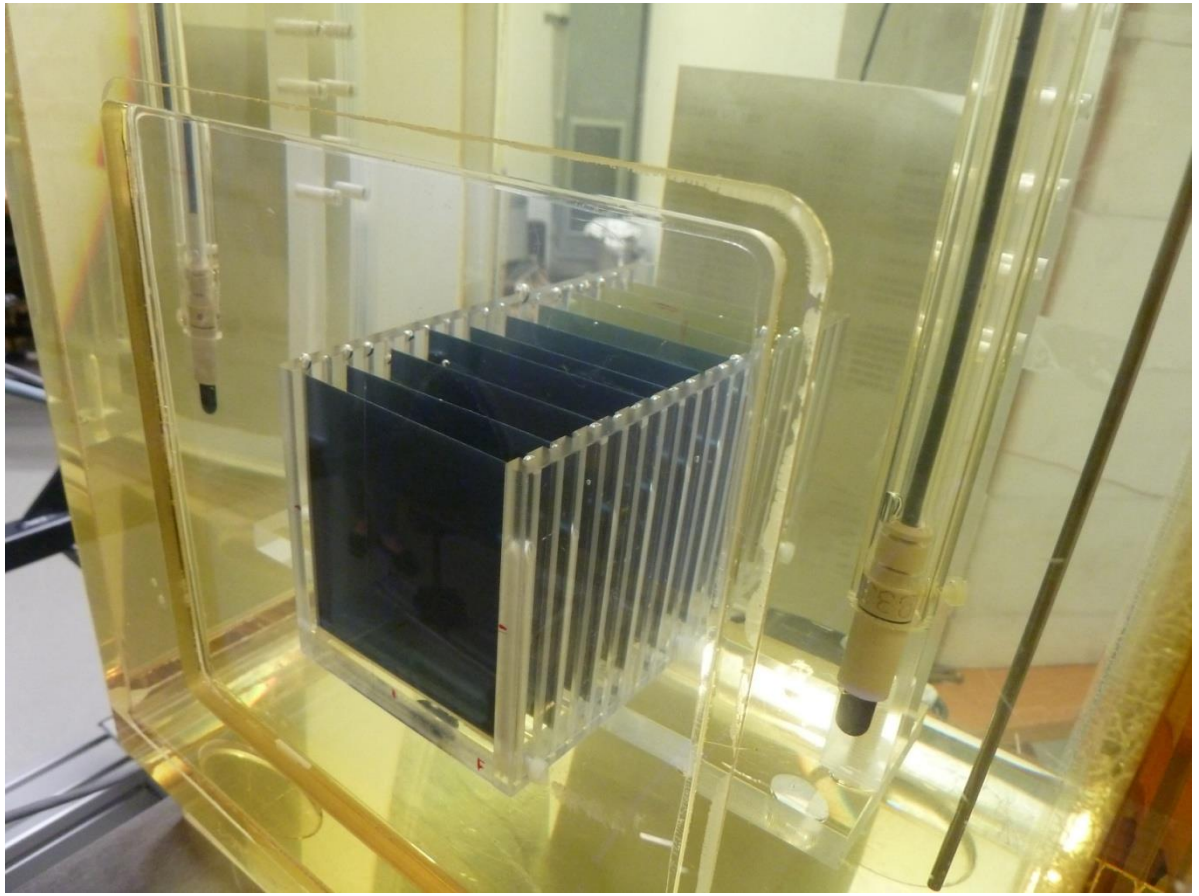


before and after irradiation with 50 MeV electrons, EBT3 film at z_{ref}

Outlook - radiochromic film dosimeter

Investigation of the response of radiochromic films (EBT3) on high-energy electrons (15 – 50 MeV) in collaboration with the University of Strathclyde

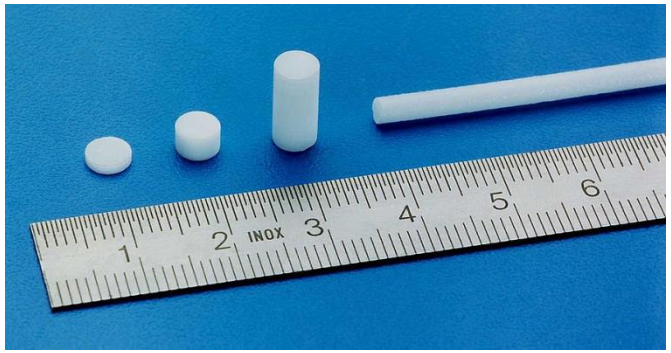


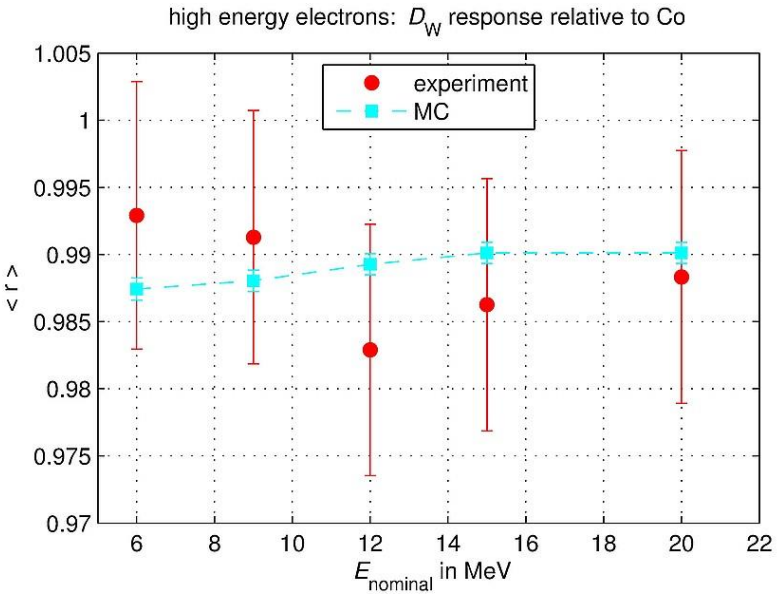


before and after irradiation with 50 MeV electrons, depth dose profile by means of EBT3 films

Outlook - alanine dosimeter

Investigation of the response of PTB's **secondary standard dosimetry system** based on alanine/ESR in high-energy electron fields (15 – 50 MeV)

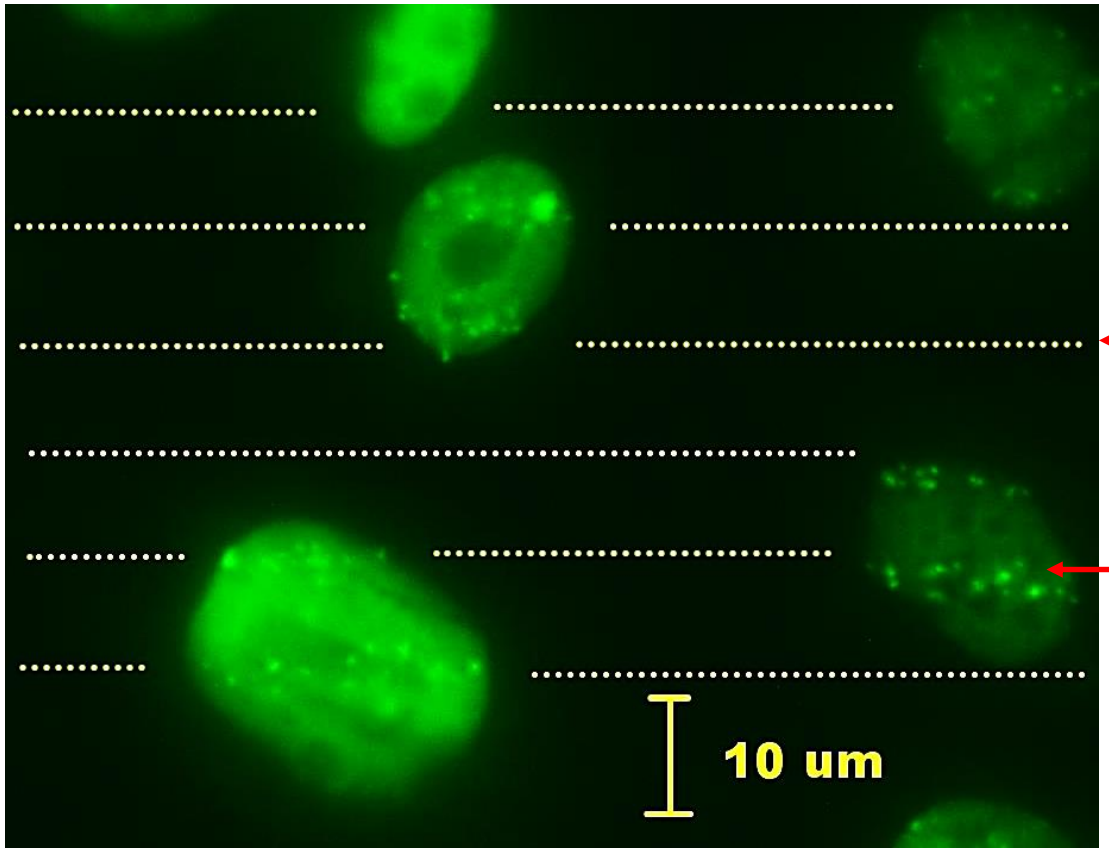




alanine at z_{ref}

Outlook - cell irradiation

PTB provides onsite an S1 laboratory for cell culture and microbiological preparations with qualification for genetically modified cells (at PTB's ion micro beam facility close to MELAF).



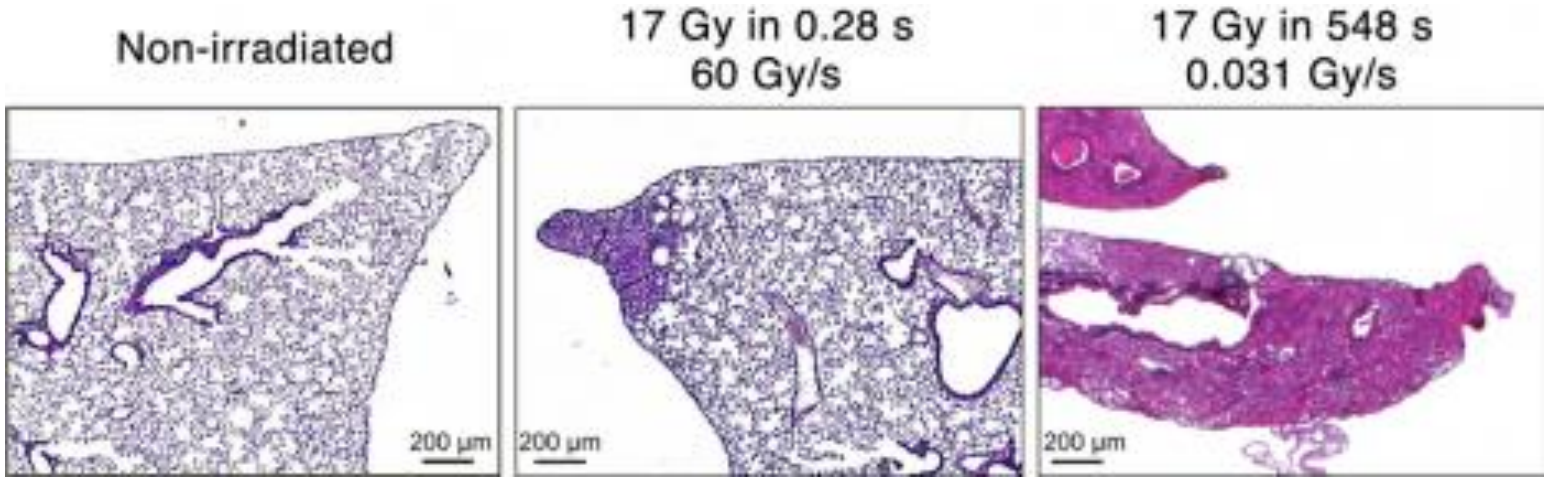
positions of α-particle hits

fluorescence-marked repair proteins at DNA double-strand breaks

Irradiated human cells at PTB's ion micro beam (up to 20 MeV He^{2+})

Outlook – dosimetry for FLASH irradiations

EU project (proposal):
“Metrology for advanced radiotherapy using particle beams with ultra-high pulse dose rates”



Tissue irradiated with a very high dose-rate looks the same as non-irradiated tissue, while tissue irradiated at conventional dose-rate is completely altered.

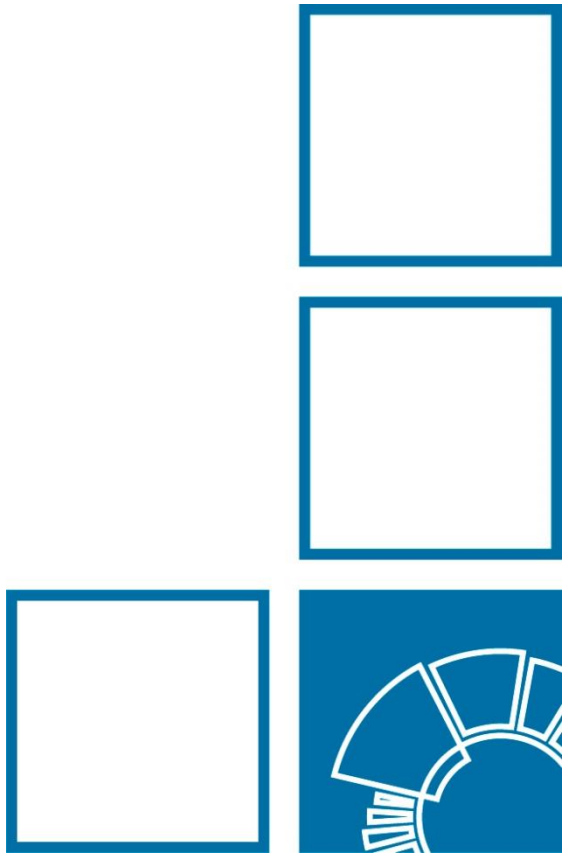
See talk of Vincent Favaudon in this session:
„Dose, dose-rate, beam-on time: what requisites for the FLASH effect”

Conclusion

A **reliable radiation dosimetry** is **needed** for reliable radiobiological experiments and to carry out preclinical radiobiological studies to test the efficacy of the electron beams at PRAE for future radiotherapy applications.

PTB's mission: **Provision** of an innovative, **reliable measurement** infrastructure and to support internationally leading science. PTB is a capable partner in research for **dosimetry** for radiotherapy of high-energy electron radiation.

Future **cooperations** between PTB and researchers of or at PRAE could be beneficial.



Physikalisch-Technische Bundesanstalt
Braunschweig and Berlin
Bundesallee 100
38116 Braunschweig

Andreas Schüller
Telefon: 0531 592-6209
E-Mail: andreas.schueller@ptb.de
www.ptb.de

Stand: 10/18