Carl von Ossietzky
Universität
Oldenburg

University of Oldenburg Contribution

Vanessa Wyrwoll

20.04.2023

Carl von Ossietzky Universität Oldenburg

Outline

- Our Background and Expertise

Outline

- Our Background and Expertise
- The Detector Array

Outline

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- The Detector Array
- Other Dosimetry Options

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- Possible Contribution

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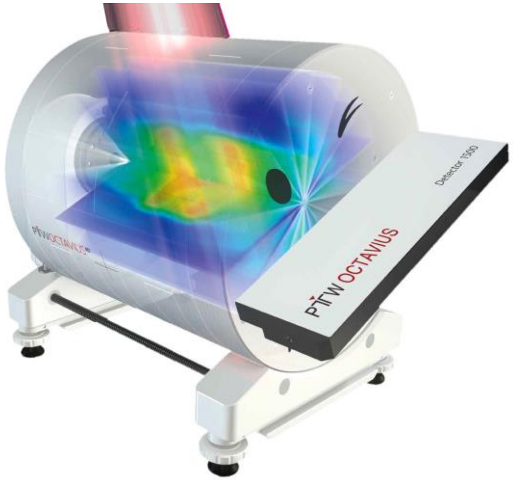
Background

- Experience in using detector arrays for treatment plan verification in radiotherapy
- Different types of detector arrays are in use at linear accelerators for radiation therapy, suitable for photon and heavy ion radiation
- Monte Carlo simulations of correction factors on a chamber level accuracy
- Effects of target fragmetation on water equivalent tissue / dose to water



Current projects FLASH/R2E -> New Working Group R2E (V. Wyrwoll)

UHDpulse

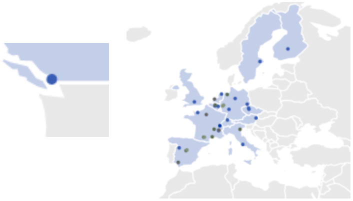
EU: H2020 EMPIR

...

Flash Beams

2 PhD Students

Schüller et al, 2020 Physica Medica
Kranzer et al, 2020, Medical Physics

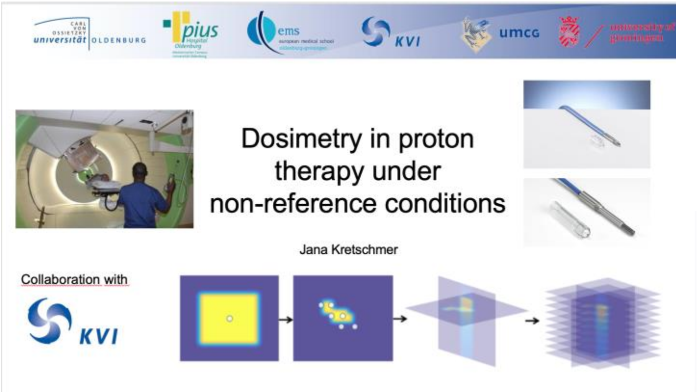


EU: H2020 INFRAIA-02-2020

R2E

4 PhD students

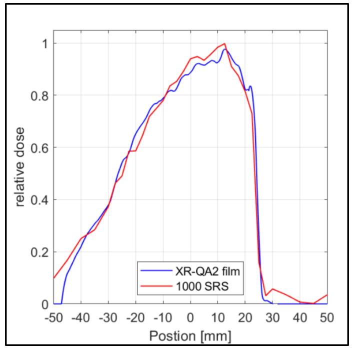
Wyrwoll, V et al 2020 *IEEE Transactions on Nuclear Science*
Wyrwoll, V., 2020 *IEEE Transactions on Nuclear Science*.
Wyrwoll, V. et al 2020, *NUCL INSTRUM METH A*
Poppinga, D et al 2020, Biomed Phys Eng

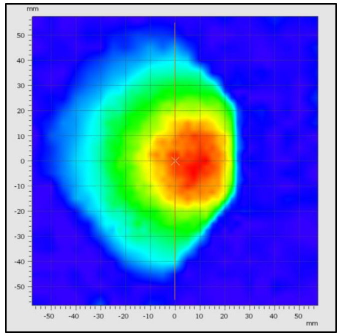


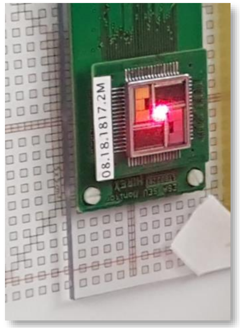
Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research, A
journal homepage: www.elsevier.com/locate/nima

On-line beam monitoring and dose profile measurements of a ^{208}Pb beam of 150 GeV/n with a liquid-filled ionization chamber array

V. Wyrwoll[a,b,*], B. Delfs[c], M. Lapp[d], D. Poppinga[d], P. Fernandéz Martinéz[a], M. Kastriotou[e], R. García Alía[a], K. Røed[b], A. Gerbershagen[a], H.K. Looe[c], B. Poppe[c]
[a] CERN, CH 1211, Genève, Switzerland
[b] University of Oslo, Problemveien 7, 0315 Oslo, Norway
[c] University Clinic for Medical Radiation Physics, Medical Campus Pius Hospital, Carl von Ossietzky University, Oldenburg, Germany
[d] PTW Freiburg, Lörracher Str. 7, 79115 Freiburg im Breisgau, Germany
[e] ISIS Facility, UKRI-STFC, Rutherford Appleton Laboratory, Didcot OX11 0QX, UK







$$D = (M - M_0) \cdot N \cdot k_Q \cdot k_h \cdot k_s \cdot k_p \cdot k_r \cdot k_T \cdot k_Q \cdot k_{NR}$$

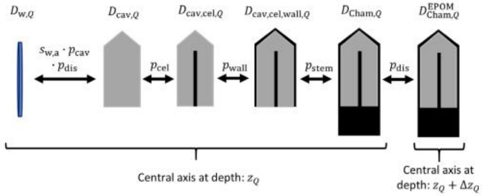
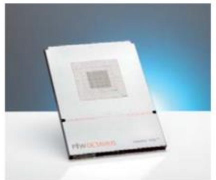


FIG. 1. Illustration of simulated quantities to determine the individual perturbation correction factors for cylindrical ionization chambers.

OD1500XDR

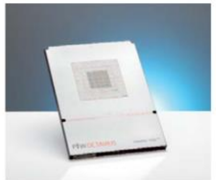
- Detector array for protons and heavy ions
- Chamber size: 4.4 x 4.4 x 3 mm³
- Detector spacing: 7.1 mm

OD1600XDR



- Detector array for protons and heavy ions (Prototype)
- Chamber size: 2.3 x 2.3 x 2 mm³
- Detector spacing: 2.5 mm

OD1600SRS



- Detector array for photons
- Chamber size: 2.3 x 2.3 x 0.5 mm³
- Detector spacing: 2.5 mm

MC-Simulations: Geant4, Fluka, EGSnrc

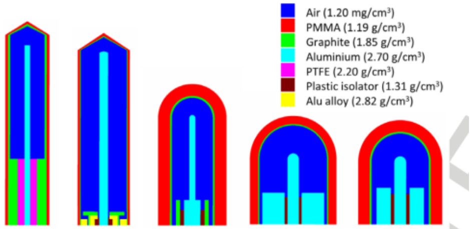


FIG. 2. Geometries (not true to scale) and materials with density given in parenthesis of all cylindrical chambers investigated in this study visualized with egs_view from EGSnrc.[18,19] Geometries from left to right: Farmer chamber NE 2571, PTW Farmer chamber 30013, PTW PinPoint 31014, PTW Semiflex 3D 31021, and PTW PinPoint 3D 31022.

PAPER

VHEE beam dosimetry at CERN Linear Electron Accelerator for Research under ultra-high dose rate conditions

Daniela Poppinga[1], Rafael Kranzer[1,5], Wilfrid Farabolini[3,4], Antonio Gilardi[2,4,6], Roberto Corsini[4], Vanessa Wyrwoll[4], Hui Khee Looe[5], Björn Delfs[5], Lukas Gabrisch[5] and Björn Poppe[5]
[1] PTW Freiburg, Freiburg, Germany

IAEA.TRS398 etc.

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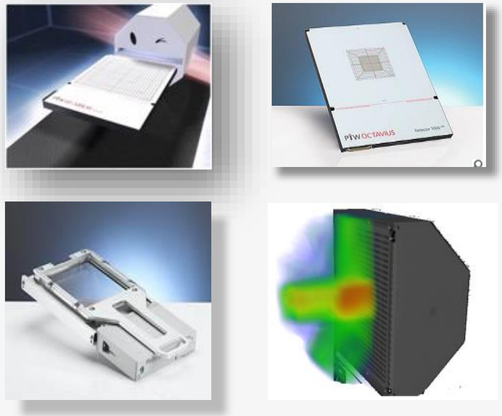
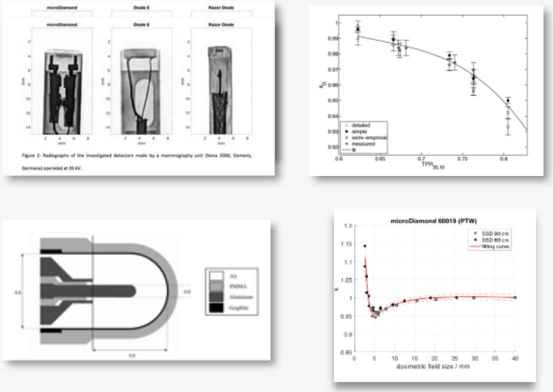
Detector Development

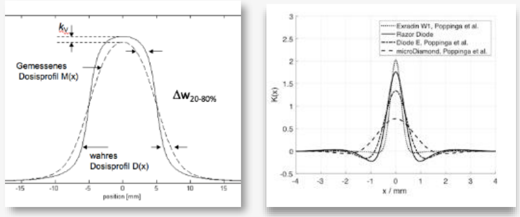
1. 2D Ion-Chamber Arrays



2. 1D-Detectors



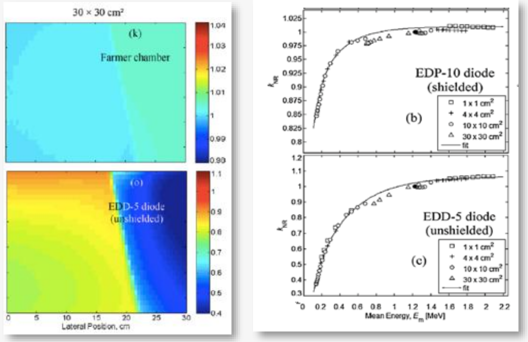
3. Signal - Theory



$$D(x) = R(x) * K_H(x) = \frac{1}{\sum_{i=1}^{N} A_i \mathrm{erf}\left(\frac{a}{\sqrt{2}\sigma_i}\right)} \sum_{i=1}^{N} \frac{A_i}{2}\left[erf\left(\frac{a+x}{\sqrt{2}\sigma_i}\right) + erf\left(\frac{a-x}{\sqrt{2}\sigma_i}\right)\right]$$

$$M(x) = D(x) * K(x) = \frac{1}{\sum_{i=1}^{N} A_i \mathrm{erf}\left(\frac{a}{\sqrt{2}\sigma_{i,eff}}\right)} \sum_{i=1}^{N} \frac{A_i}{2}\left[erf\left(\frac{a+x}{\sqrt{2}\sigma_{i,eff}}\right) + erf\left(\frac{a-x}{\sqrt{2}\sigma_{i,eff}}\right)\right]$$

4. Non-Reference Conditions



1.
Stelljes et al Medical Physics (2018)
Stelljes T *et al.* Medical Physics (2017)
Blank *et al.* Physica Medica (2016)
Stelljes *et al.* Medical Physics (2015)
Poppe *et al.* Medical Physics (2014)
Poppe *et al.* „Green Journal“ (2010)
Poppe *et al*. Medical Physics (2007)
Heilemann *et al.* Medical Physics (2013)
Poppe *et al*. Medical Physics (2006)
Poppe *et al.* ZMP (2006)
...

2.
Schönfeld et al (2019)
Poppinga et al Med Phys (2019)
Büsing. Z Med Phys (2019)
Poppinga et al Med Phys (2018)
Looe et al Med. Phys (2019)
Delfs et al Med. Phys (2018)
Poppinga *et al.* (ZMP 2017)
Burke *et al.* ZMP (2016)
Poppinga *et al* (2014)
Looe *et al.* PMB (2011)
Djouguela *et a.l* ZMP (2008)
Djouguela *et al.* ZMP (2006)
...

3.
Looe *et a*l PMB (2019)
Looe *et al* PMB (2018)
Looe *et al.* PMB (2016)
Looe *et al.* PMB (2016)
Looe *et al.* PMB (2015)
Looe *et al.* Mecia Physics (2013)
Poppe *et al.* Medical Physics (2007)
...

4.
Chofor *et al.* ZMP (2015)
Chofor *et al.* ZMP (2014)
Chofor *et al.* ZMP (2014)
Looe *et al.* PMB (2013)
Chofor *et al.* PMB (2012)
...

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vesper clear

VESPER

The Very energetic Electron facility for Space Planetary Exploration missions in harsh Radiative environments

Dosimetry with Very High Energy Electrons at CERN

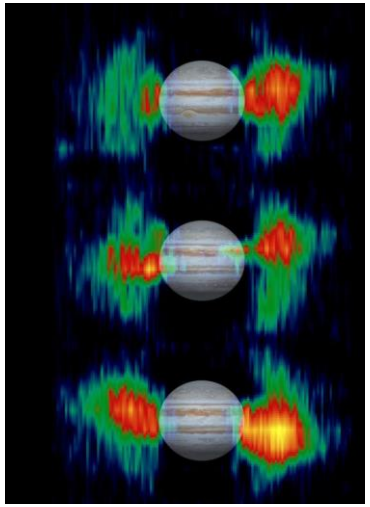
60MeV – 200 MeV Electrons

Dose Rates up to **nearly 2 kGy/s**

Simulation of Jupiter Radiation Belts

Built for testing missions to Jupiter

Dose rate in radiation belts ca. 6Gy/min (Equivalent to clinical linac)!!



Ion collection efficiency of ionization chambers in ultra-high dose-per-pulse electron beams

Rafael Kranzer[a)]
PTW-Freiburg, Freiburg 79115, Germany
University Clinic for Medical Radiation Physics, Medical Campus Pius Hospital, Carl von Ossietzky University, Oldenburg 26121, Germany

Daniela Poppinga and Jan Weidner
PTW-Freiburg, Freiburg 79115, Germany

Andreas Schüller and Thomas Hackel
Physikalisch-Technische Bundesanstalt, Braunschweig 38116, Germany

Hui Khee Looe and Björn Poppe
University Clinic for Medical Radiation Physics, Medical Campus Pius Hospital, Carl von Ossietzky University, Oldenburg 26121, Germany

Kranzer et al 2020

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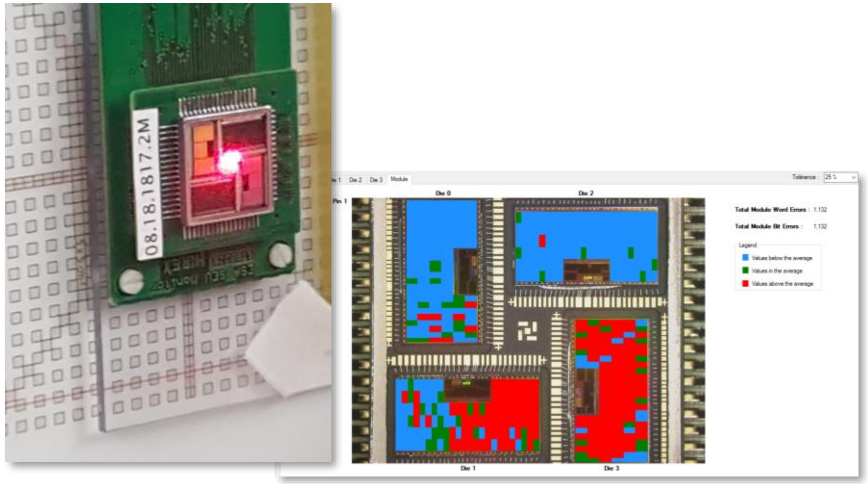
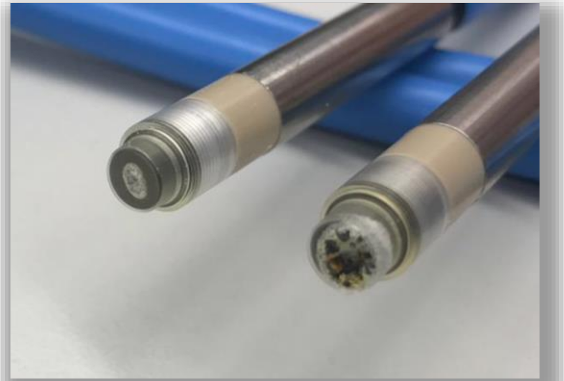
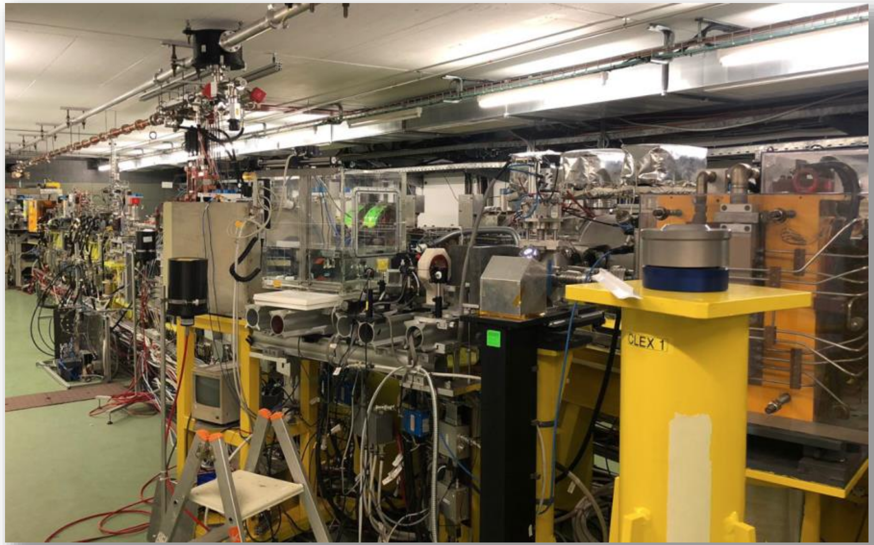
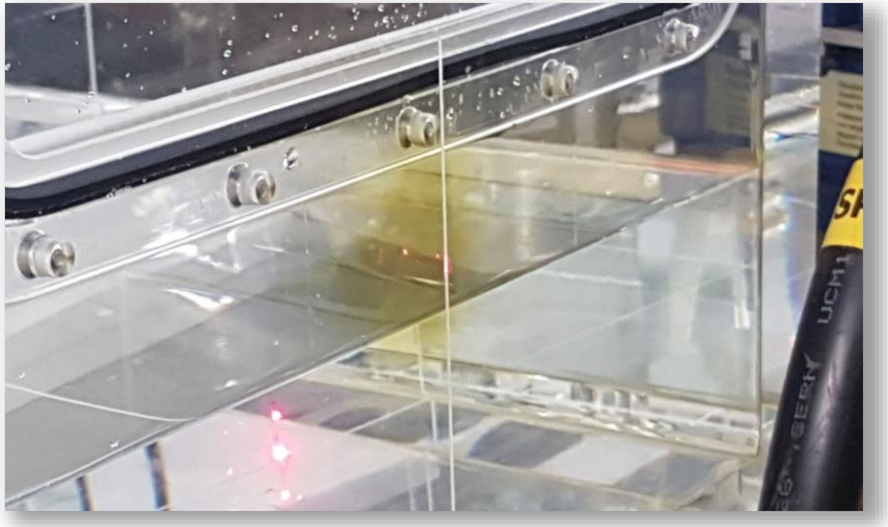
Oldenburg: Flash-Activities



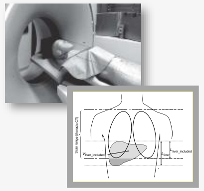






Radiation/Particle Detection and Transport Calculations

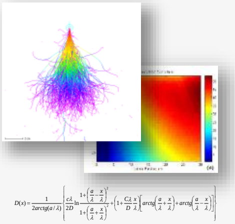
Radiology



Dose Optimization and Calculation

H. von Boetticher

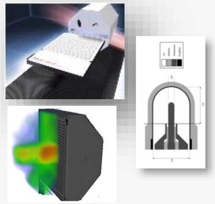
Modelling



Monte Carlo and Analytical Methods

H.K. Looe

Radiation Detection



Detectors, Flux, Dose, Activity, Signal-Theory

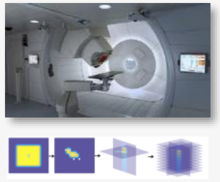
B. Poppe

Space Environment

Radiation, Small Bodies, Instrumentation

G. Drolshagen

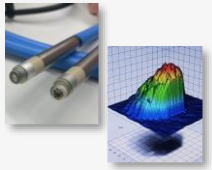
Particles and Protons



2D Dosimetry, Non Reference Dosimetry

B. Poppe + T. Stelljes

Extreme Beams



2D Dosimetry,

Non Reference Dosimetry

V. Wyrwoll

all areas strongly connected

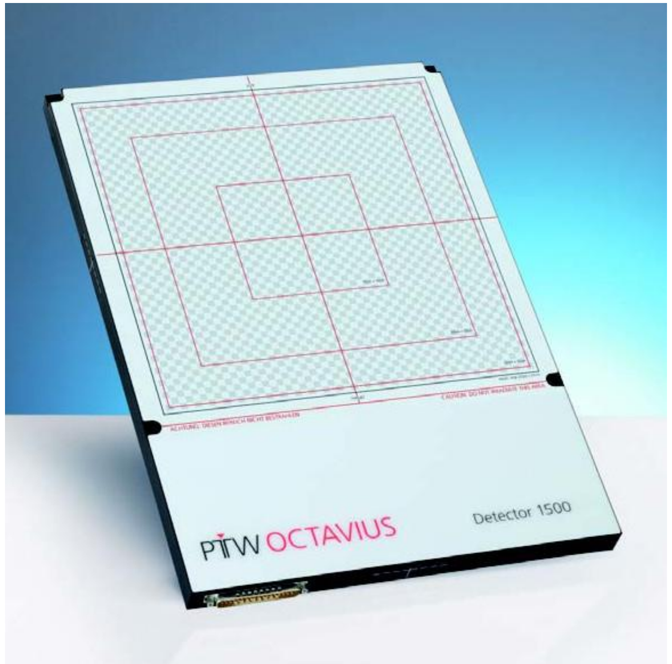
- > members app 40: (4 Habil/PI, 4 physicists, 18 Phd students,…)
- > 100 Peer Reviewed papers
- DIN norms, AAPM –TGs, UN-group

Outline

- Our Background and Expertise
- The Detector Array
- Other Dosimetry Options
- Possible Contribution

One of the Possible Experiments The Detector Array

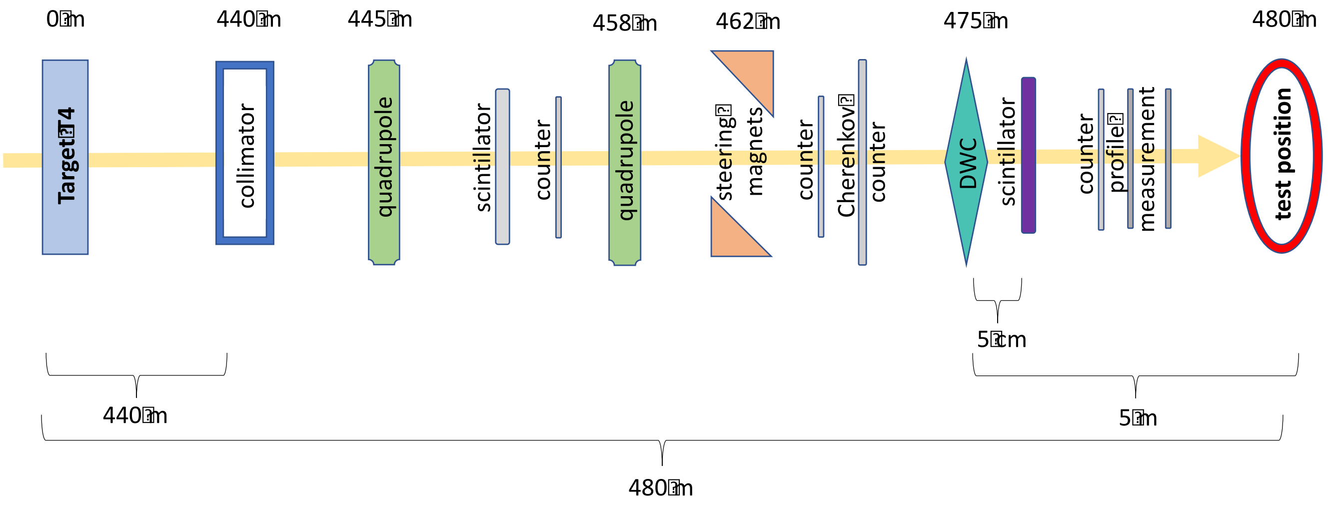
- Easy-to-use opportunity to put a measurement device into the beam
- Array with detector matrix suitable for measurements of heavy ions and beam characterization
- Device is already in use for QA in treatment plan verification for radiotherapy
- Different types available



Previous Experiment with the Array:

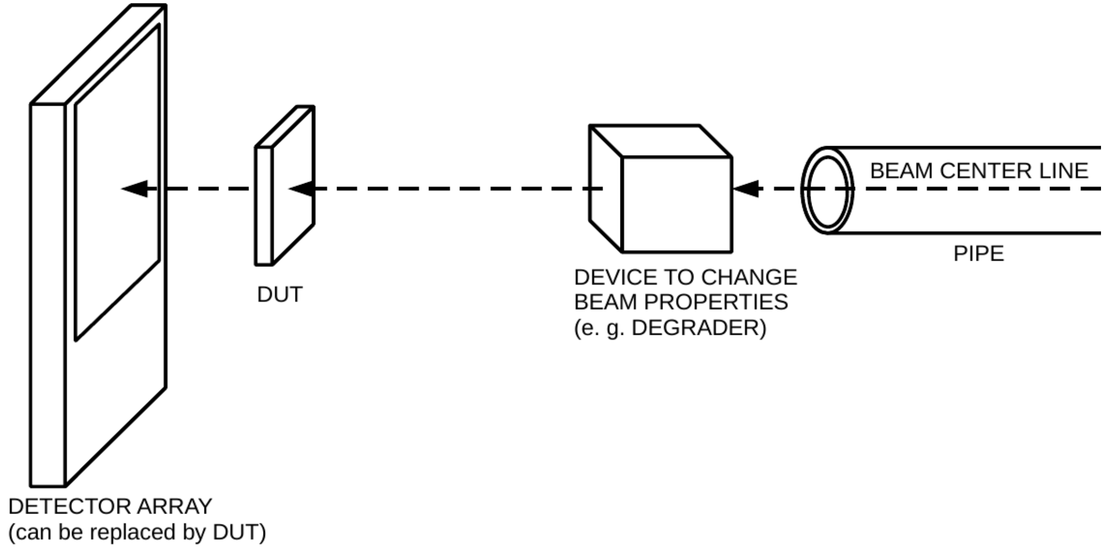
North Area CERN 2018 with 150 GeV/n lead

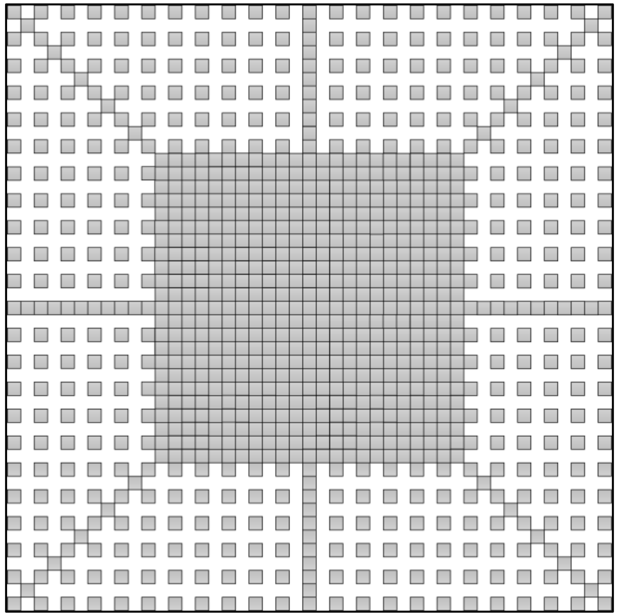
H8 North Area 150 GeV/n ^{208}Pb



All grey elements have been removed during the tests in Nov. 2018

Experimental Set-Up





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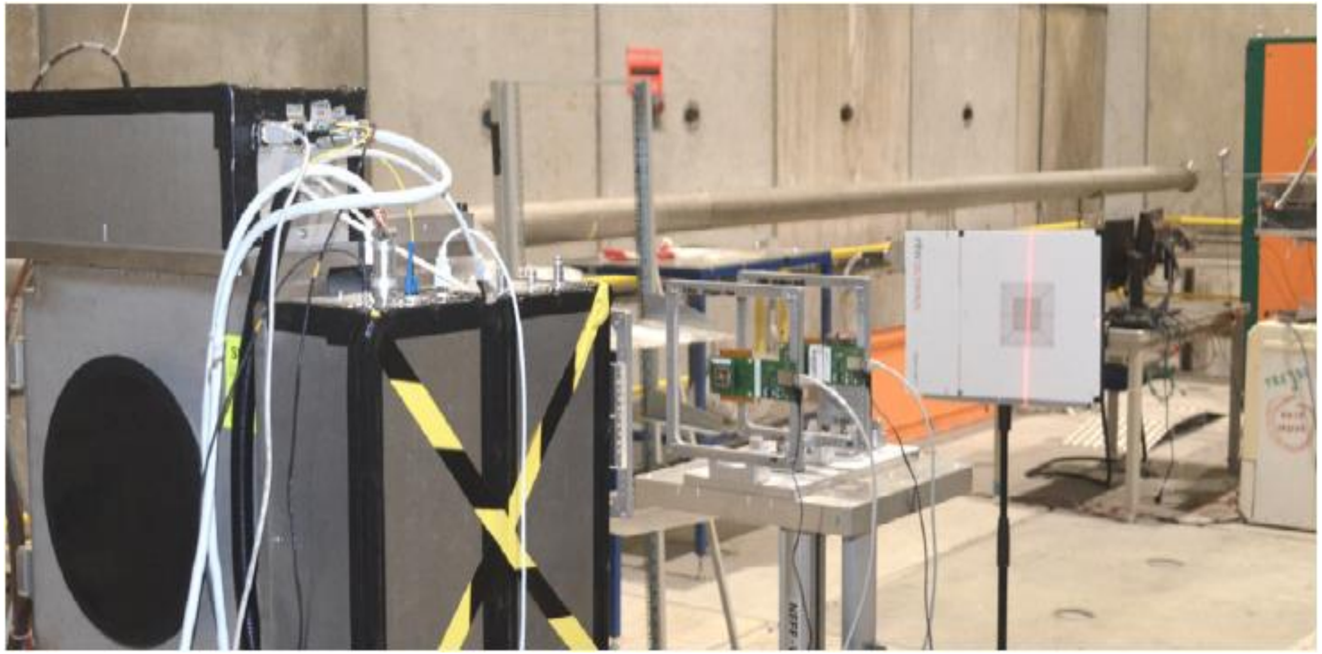
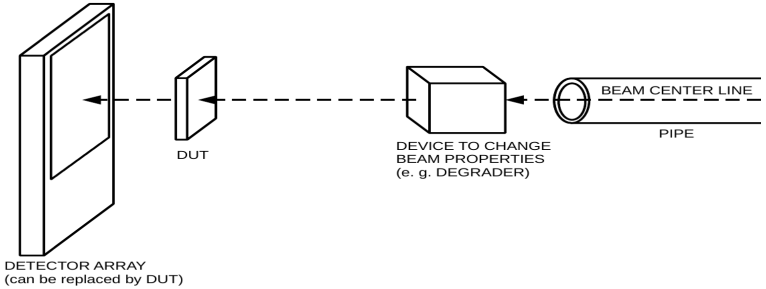
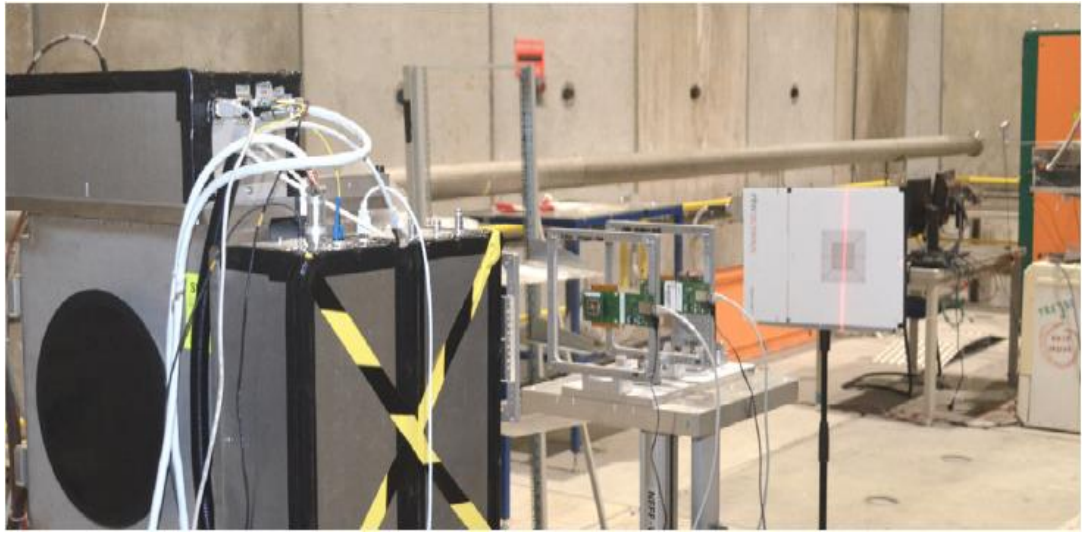
1000SRS set-up in the North Area CERN 2018





1000SRS set-up in the North Area CERN 2018



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Previous Results with the Array

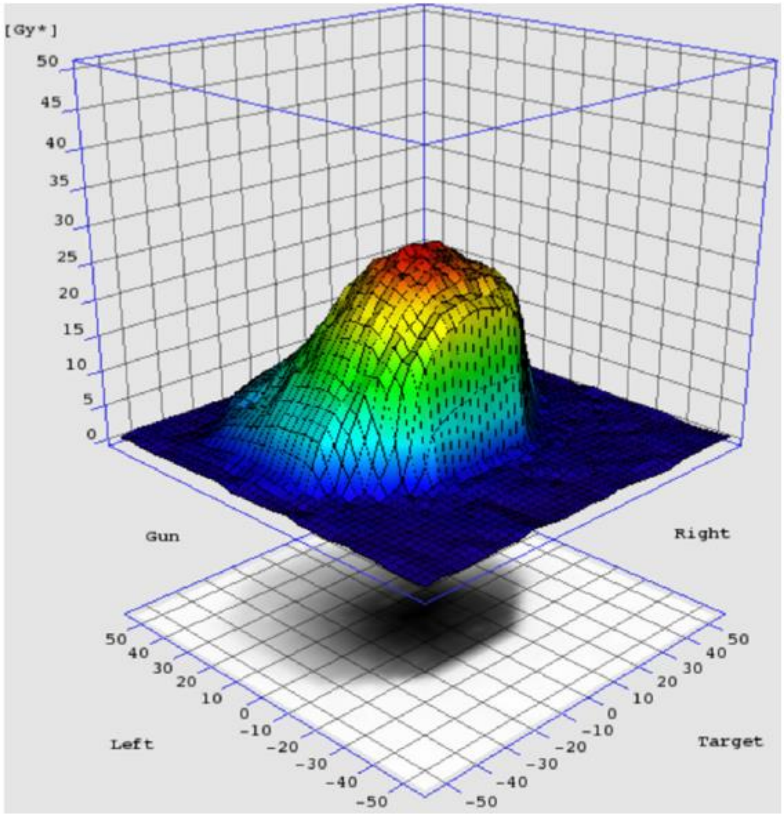


Fig. 5. Illustration of on-line beam monitoring during exposure to the 150 GeV/n ^{208}Pb beam in H8 of the SPS-NA using the OCTAVIUS 1000SRS liquid ionization chamber array.

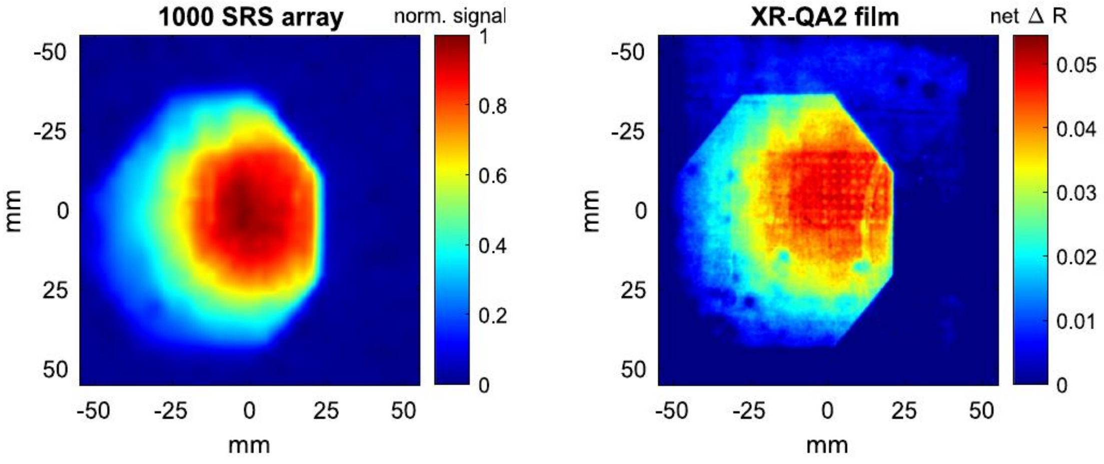
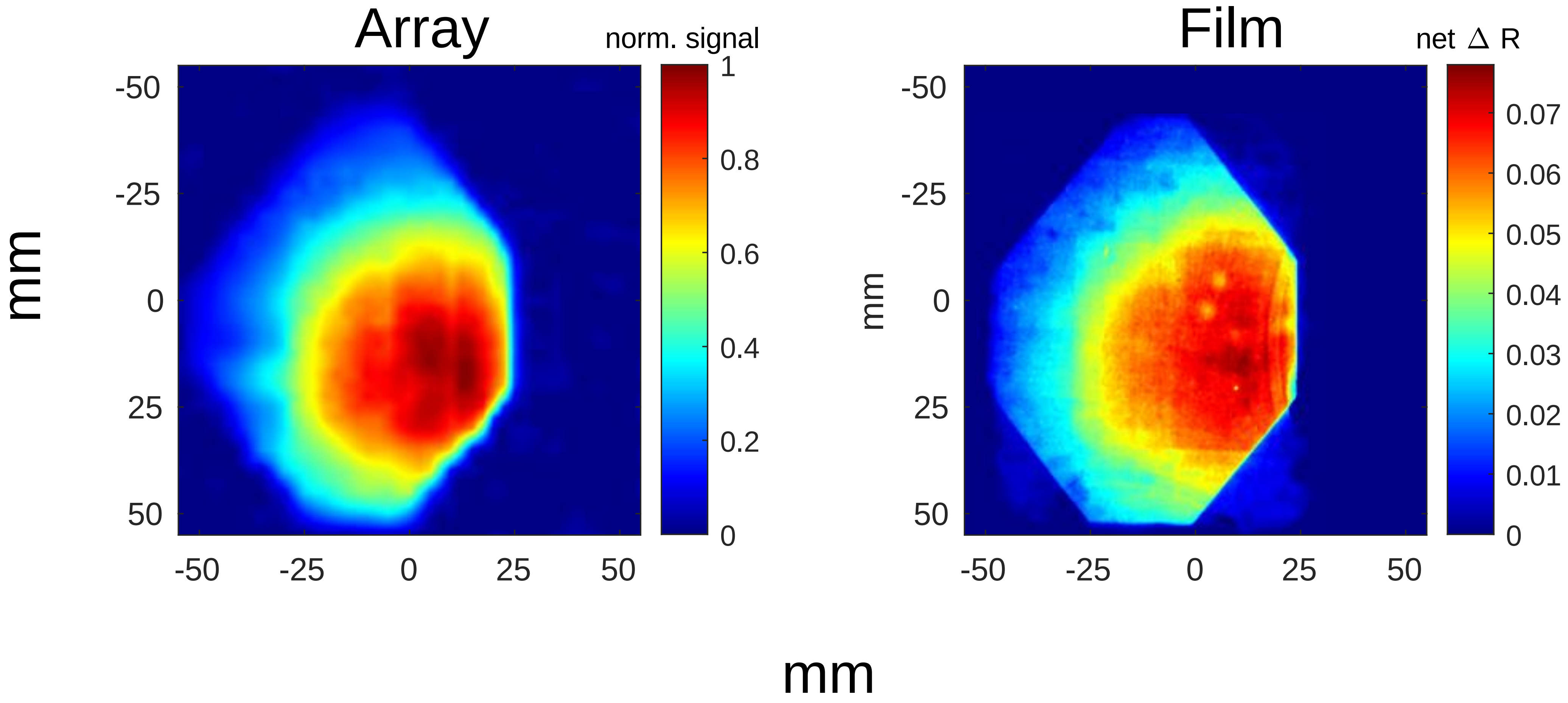
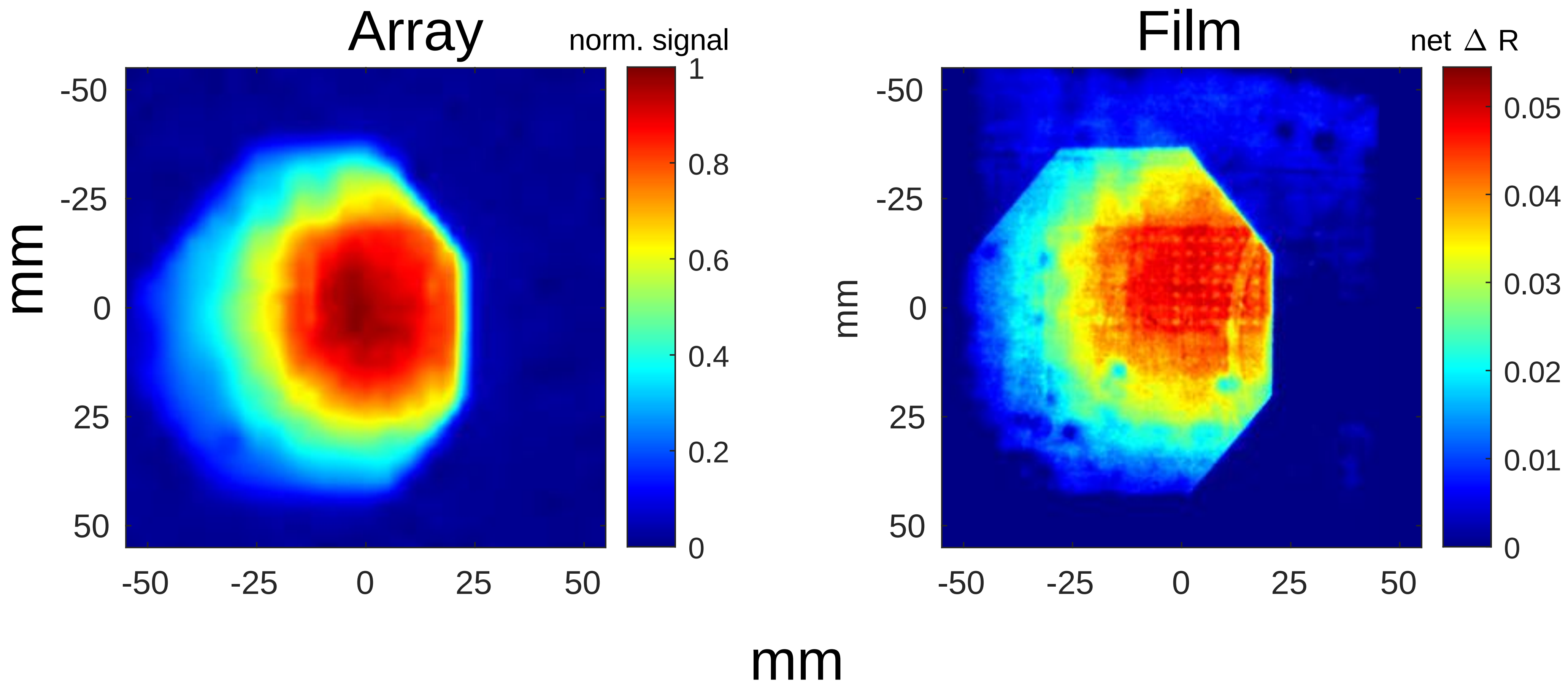


Fig. 10. 2D illustration of the measurement with the film attached behind the array (right) and recorded by the array (left).

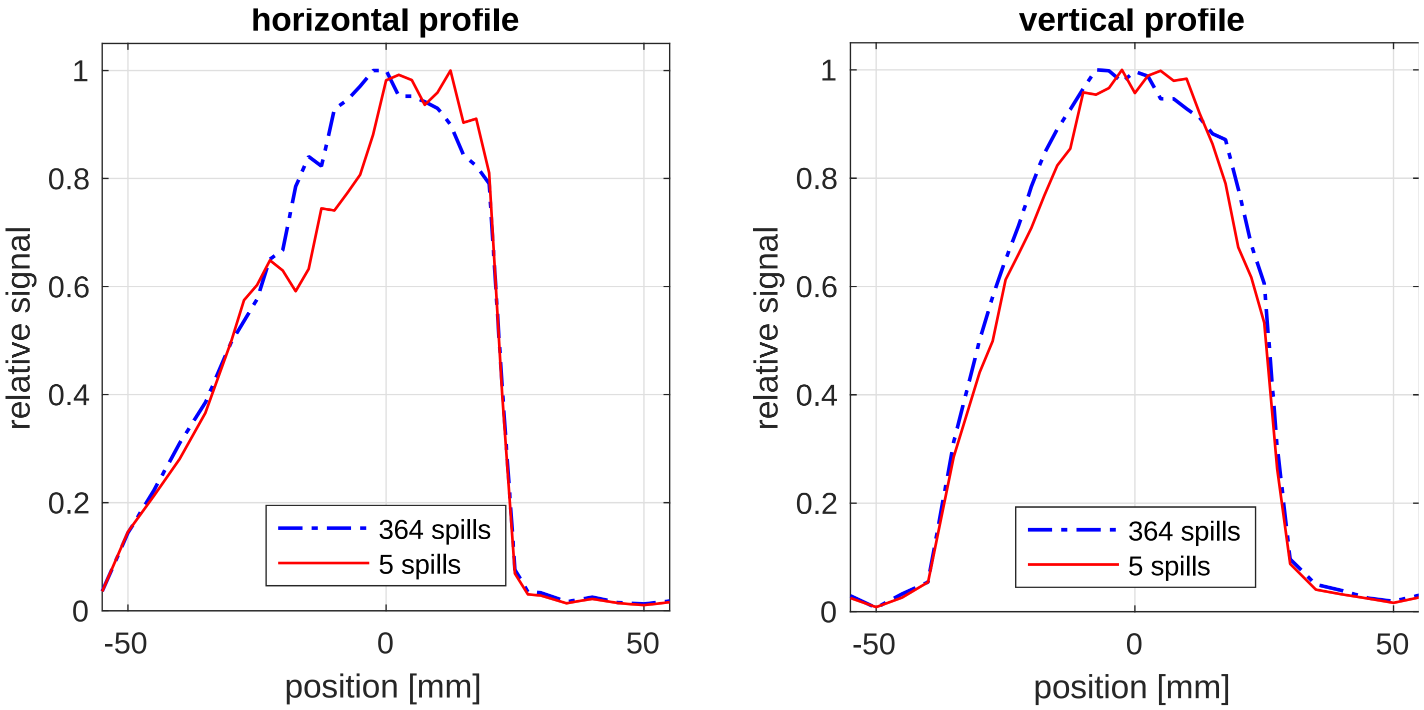
Octavius 1000SRS and Films in front of array



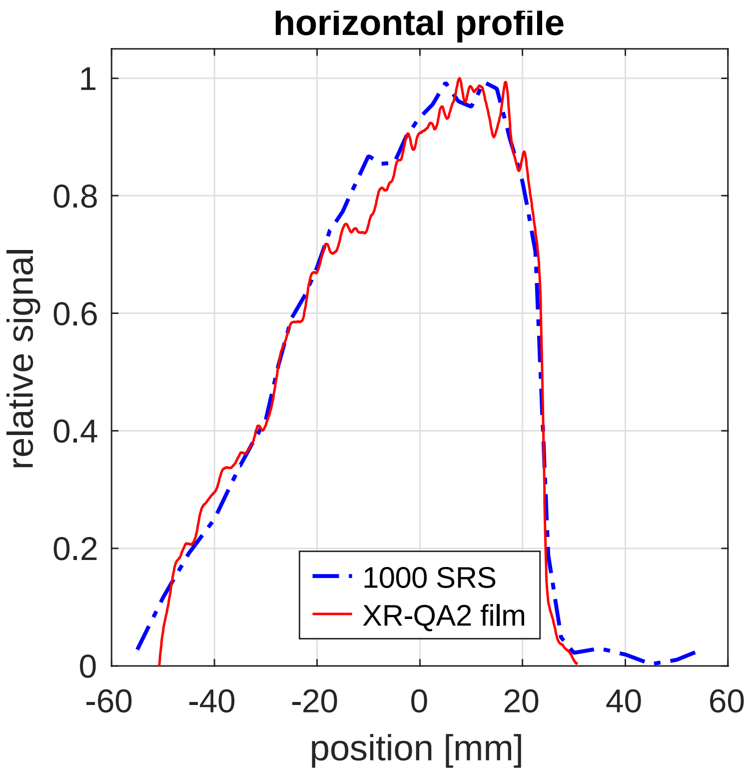
Octavius 1000SRS and Films behind array

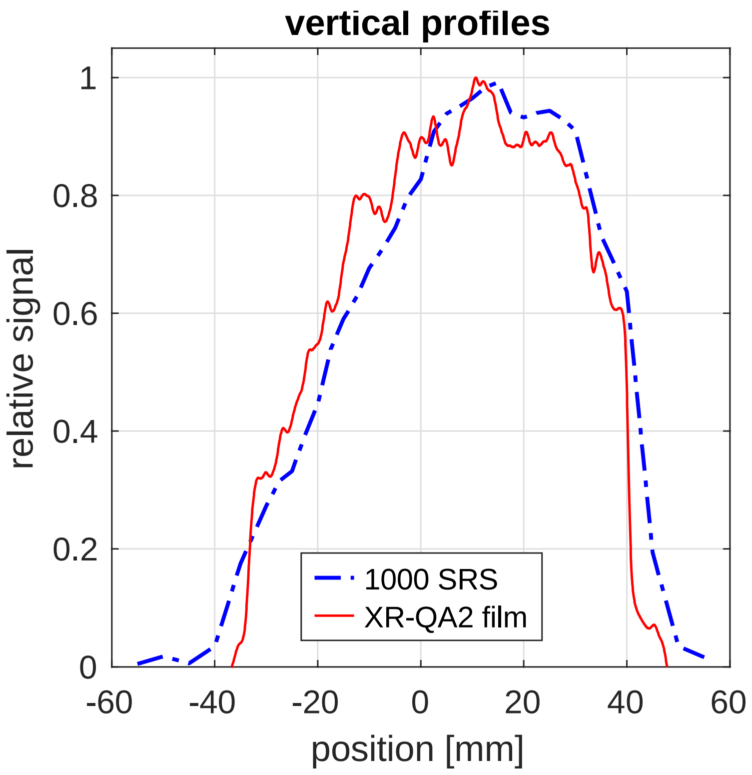


Horizontal and vertical line profiles measured with the 1000 SRS array integrated over 5 and 364 ion spills



Comparison of horizontal and vertical beam profiles of the array and Gafchromic film attached **in front of** the array





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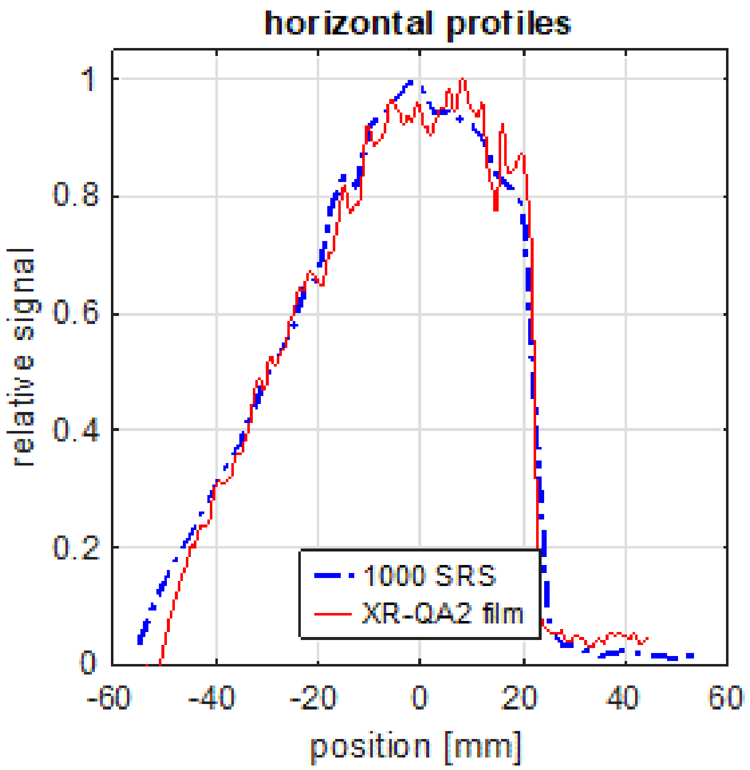
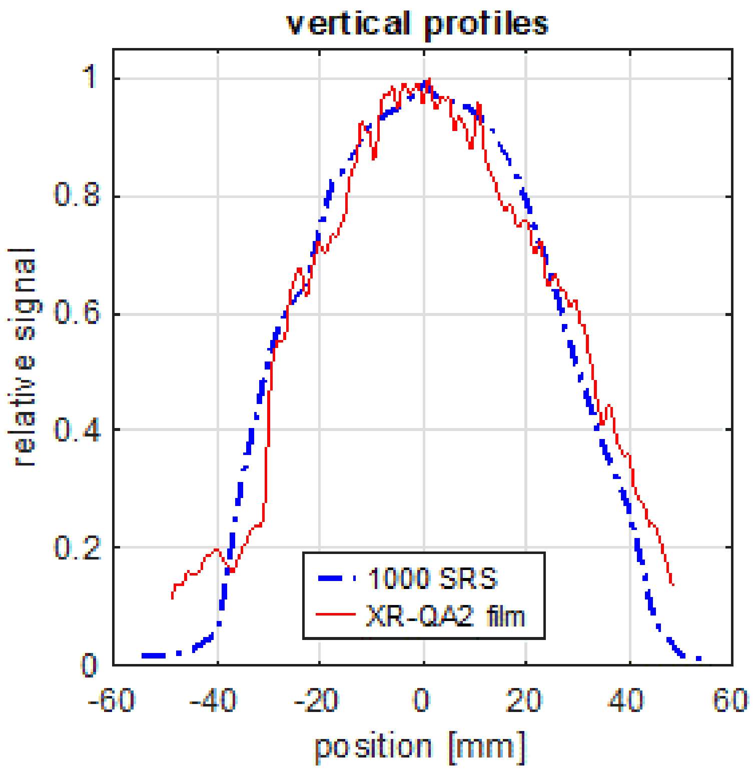
Comparison of horizontal and vertical beam profiles of the array and Gafchromic film attached **behind** the array





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Calculation of dose to water

$$D_w = (M - M_0)\, {}^{60\mathrm{Co}}\mathrm{N}_{\mathrm{D,W}}\, k_Q$$

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Calculation of dose to water

$$D_w = (M - M_0)\ {}^{60\mathrm{Co}}\mathrm{N}_{\mathrm{D,W}} k_Q$$

Measured value

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Calculation of dose to water

Calibration factor of the array

$$D_w = (M - M_0)\ {}^{60\text{Co}}\mathrm{N}_{\mathrm{D,W}} k_Q$$

Measured value

Calculation of dose to water

Calibration factor of the array

$$D_w = (M - M_0)\ {}^{60\text{Co}}\text{N}_{\text{D,W}} k_Q$$

Correctionfactor
for the beam quality

Measured value

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Calculation of correction factor k_Q calculated with FLUKA

$$k_Q = \frac{\left(\frac{D_{water}}{D_{chamber}}\right)_{^{208}Pb}}{\left(\frac{D_{water}}{D_{chamber}}\right)_{^{60}Co}}$$

Stopping Power calculation

In general, restricted LET:

$$S/\rho = \frac{E_{deposited}}{(voxel\ length\ in\ z\ direction\ *\ density_{water})}$$

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Stopping Power calculation

In general, restricted LET:

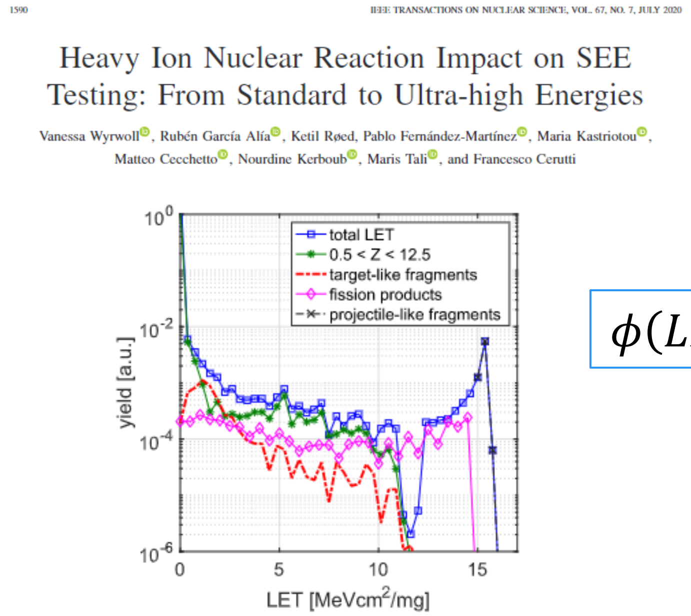
$$S/\rho = \frac{E_{deposited}}{(voxel\ length\ in\ z\ direction\ *\ density_{water})}$$

However, here a weighted calculation was needed, due to a lead percentage of 70%

$$\bar{S}/\rho = \frac{\int_0^{(LET)_{max}} \phi(LET) \cdot S/\rho\,(LET)\ d(LET)}{\int_0^{(LET)_{max}} \phi(LET)\ d(LET)}$$

Weighted Stopping Power calculation

$$\bar{S}/\rho = \frac{\int_0^{(LET)_{max}} \phi(LET) \cdot S/\rho\,(LET)\; d(LET)}{\int_0^{(LET)_{max}} \phi(LET)\; d(LET)}$$


1590 IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 67, NO. 7, JULY 2020

Heavy Ion Nuclear Reaction Impact on SEE Testing: From Standard to Ultra-high Energies

Vanessa Wyrwoll, Rubén García Alía, Ketil Røed, Pablo Fernández-Martínez, Maria Kastriotou, Matteo Cecchetto, Nourdine Kerboub, Maris Tali, and Francesco Cerutti

$\phi(LET)$ is the LET distribution of the beam

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Calculation of particle fluence distribution and convert to counts

$$\Phi(x, y)[cm^{-2}] = \frac{D_W(x,y)\left[\frac{J}{kg}\right]}{S/\rho\left[\frac{MeV\ cm^2}{mg}\right]} \frac{10^{-6}\frac{kg}{mg}}{1 \cdot 10^6 \cdot 1.6 \cdot 10^{-19}\frac{J}{MeV}}$$

→

$$counts = \iint \Phi(x,y)dxdy$$

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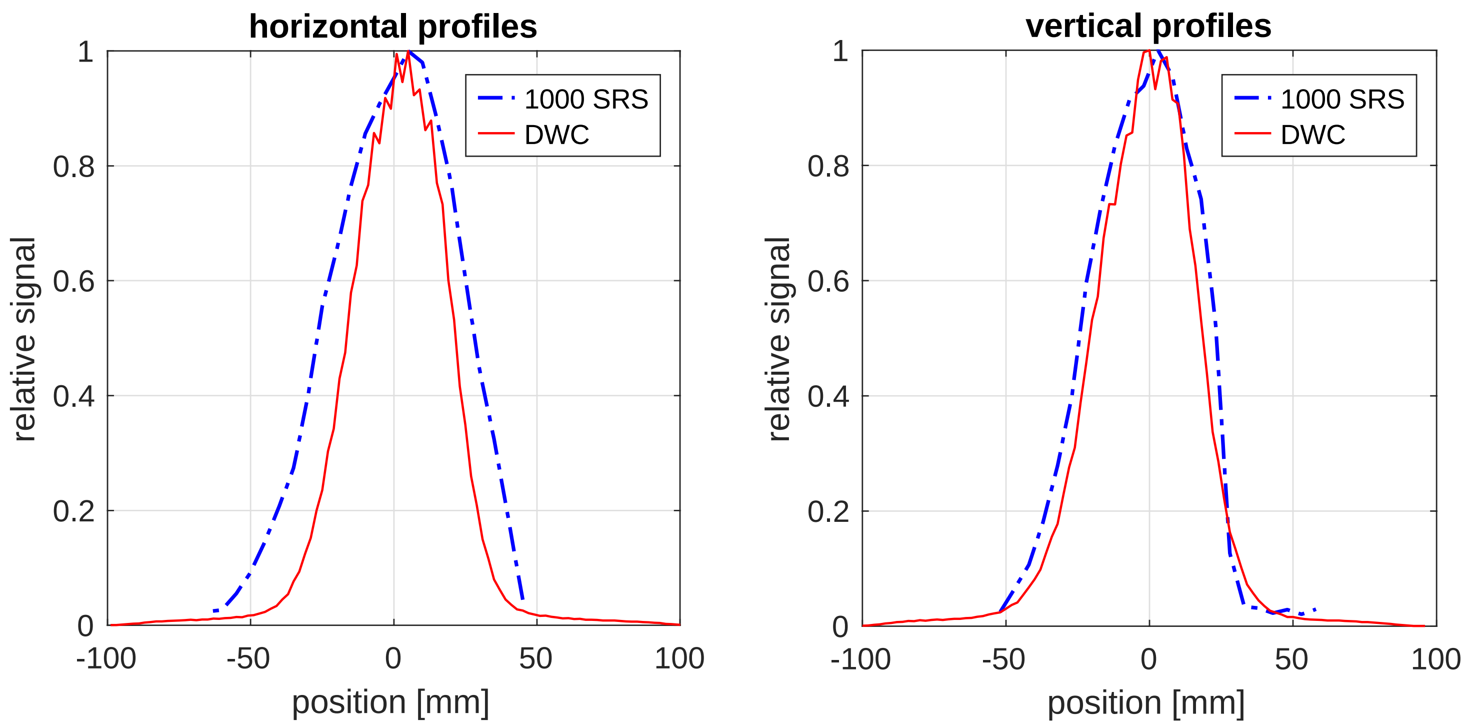
Comparison between DWC signals and the line integrals of the 1000 SRS array



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For more Details in the Paper

Contents lists available at ScienceDirect

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On-line beam monitoring and dose profile measurements of a ^{208}Pb beam of 150 GeV/n with a liquid-filled ionization chamber array

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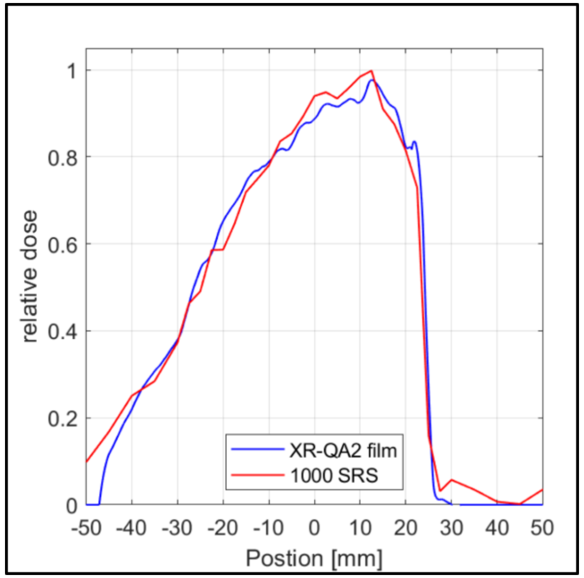
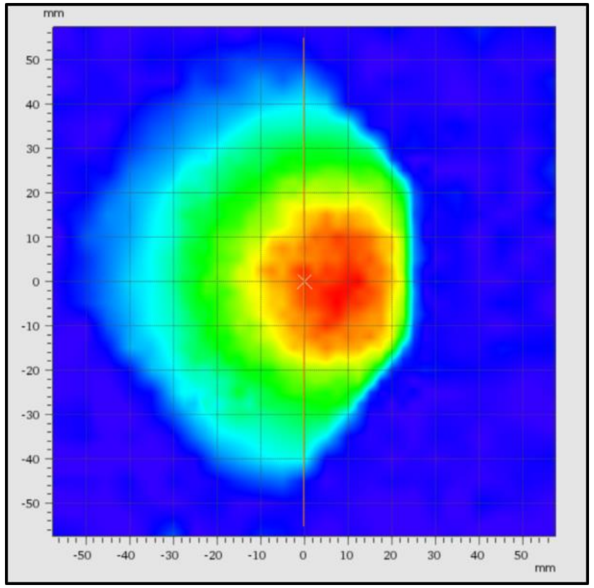


1000SRS and Film



First online image of a 120 GeV Lead Beam

Carl von Ossietzky Universität Oldenburg

Summary
Previous Results with the Array in an UHE Lead Beam

- Knowledge of beam properties at the position of the experiment is important for the user
- Beam shape has been examined and compared with dosimetry films
- Particle flux and dose to water has been examined at the position of the experiment

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Outline

- Our Background and Expertise
- The Detector Array
- Other dosimetry Options
- Conclusion - Possible Contribution

Other possible ways of dosimetry in VHE and UHE heavy ion beams

- Different array available (including possible modifications depending on the beam properties)
- Farmer chamber
- Gafchromic Films
- Advances Markus Chamber
- Measurements in a water phantom or solid water



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Farmer Chamber

Farmer® Chamber Type 30013

Waterproof therapy chamber for reference dosimetry in high-energy photon, electron and proton beams

- Acrylic wall, graphited
- Aluminum central electrode
- Waterproof
- Sensitive volume 0.6 cm³, vented
- Reference class in accordance with IEC 60731 and AAPM TG-51 Addendum

The 30013 Farmer chamber is the standard ionization chamber for reference dose measurements in radiation therapy. Correction factors needed to determine absorbed dose to water or air kerma are published in the pertinent dosimetry protocols. Its waterproof design allows the chamber to be used in water or solid state phantoms. The acrylic chamber wall ensures the ruggedness of the chamber.

General

Type of product	vented cylindrical ionization chamber
Application	reference dosimetry in radiotherapy beams
Measuring quantities	absorbed dose to water, air kerma, exposure
Reference radiation quality	^{60}Co
Design	waterproof, vented, guarded
Direction of incidence	radial

Specification

Materials and measures

Wall of sensitive volume	0.335 mm PMMA, 1.19 g/cm³ 0.09 mm graphite, 1.85 g/cm³
Total wall area density	56.5 mg/cm²
Dimensions of sensitive volume	radius 3.05 mm length 23.0 mm
Central electrode	Al 99.98, diameter 1.15 mm
Build-up cap	PMMA, thickness 4.55 mm

Ion collection efficiency at nominal voltage

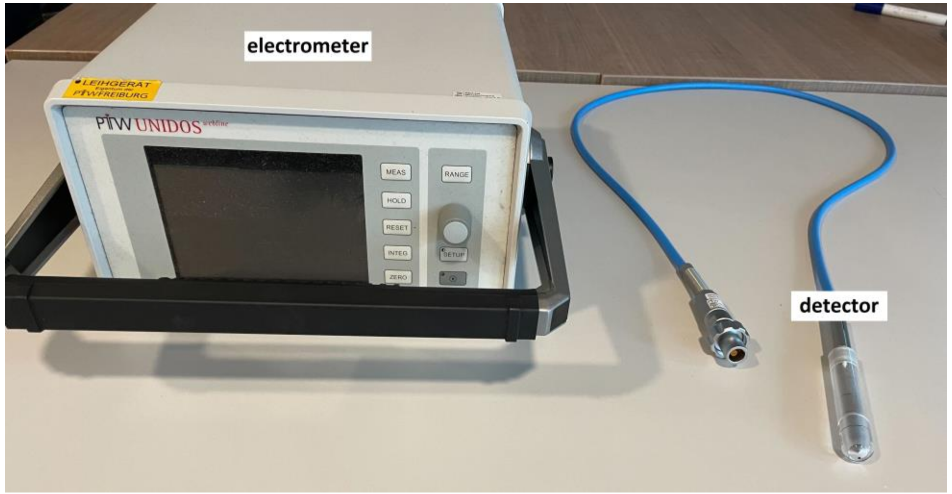
Ion collection time	140 µs
Max. dose rate for	
≥ 99.5 % saturation	5 Gy/s
≥ 99.0 % saturation	10 Gy/s
Max. dose per pulse for	
≥ 99.5 % saturation	0.46 mGy
≥ 99.0 % saturation	0.91 mGy

Ranges of use

Chamber voltage	± (100 ... 400) V
Radiation quality	30 kV ... 50 MV photons (10 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(5 x 5) cm² ... (40 x 40) cm²
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m³

Farmer Chamber

- Farmer chamber



Advanced Markus

- Well-guarded in accordance with TRS-398
- Thin entrance window and waterproof protection cap
- Small-sized for high spatial resolution
- Sensitive volume 0.02 cm³, vented

The 34045 Advanced Markus chamber is the successor of the well-known classic Markus electron chamber, equipped with a wide guard ring for perturbation-free measurements. The thin entrance window allows measurements in solid state phantoms up to the surface. The protection cap makes the chamber waterproof for measurements in water phantoms.

General

Type of product	vented plane-parallel ionization chamber
Application	reference dosimetry in high-energy electron beams
Measuring quantities	absorbed dose to water, air kerma
Reference radiation quality	^{60}Co
Design	waterproof with protection cap, vented, guarded
Direction of incidence	perpendicular to chamber plane

Specification

Nominal sensitive volume	0.02 cm³
Nominal response	0.67 nC/Gy
Long-term stability	≤ 1 % per year
Chamber voltage	300 V nominal ± 400 V maximal
Polarity effect	≤ 1 % for electrons > 9 MeV

Materials and measures

Entrance foil	0.03 mm PE (polyethylene CH_2), 2.76 mg/cm²
Protection cap	0.87 mm PMMA, 1.19 g/cm³, 0.4 mm air
Total window area density	106 mg/cm², 1.3 mm (protection cap included)
Water-equivalent window thickness	1.04 mm (protection cap included)
Dimensions of sensitive volume	radius 2.5 mm depth 1 mm
Guard ring width	2 mm

Ion collection efficiency at nominal voltage

Ion collection time	22 µs
Max. dose rate for	
≥ 99.5 % saturation	187 Gy/s
≥ 99.0 % saturation	375 Gy/s
Max. dose per pulse for	
≥ 99.5 % saturation	2.78 mGy
≥ 99.0 % saturation	5.56 mGy

Ranges of use

Chamber voltage	± (50 ... 300) V
Radiation quality	(2 ... 45) MeV electrons (50 ... 270) MeV protons
Field size	(3 x 3) cm² ... (40 x 40) cm²
Temperature	(10 ... 40) °C (50 ... 104) °F
Humidity	(10 ... 80) %, max 20 g/m³
Air pressure	(700 ... 1060) hPa

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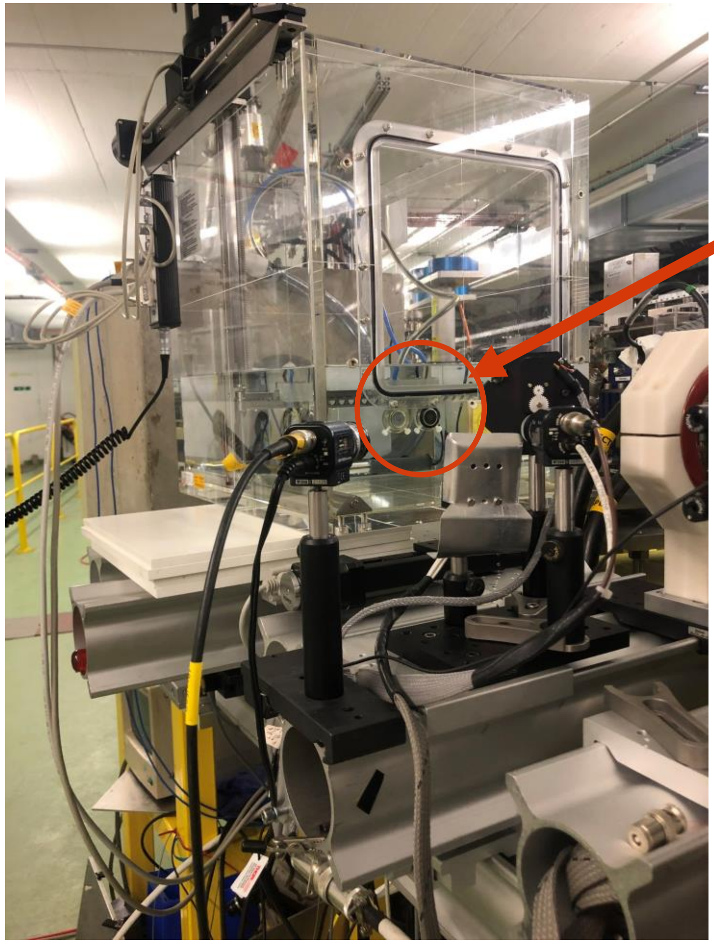
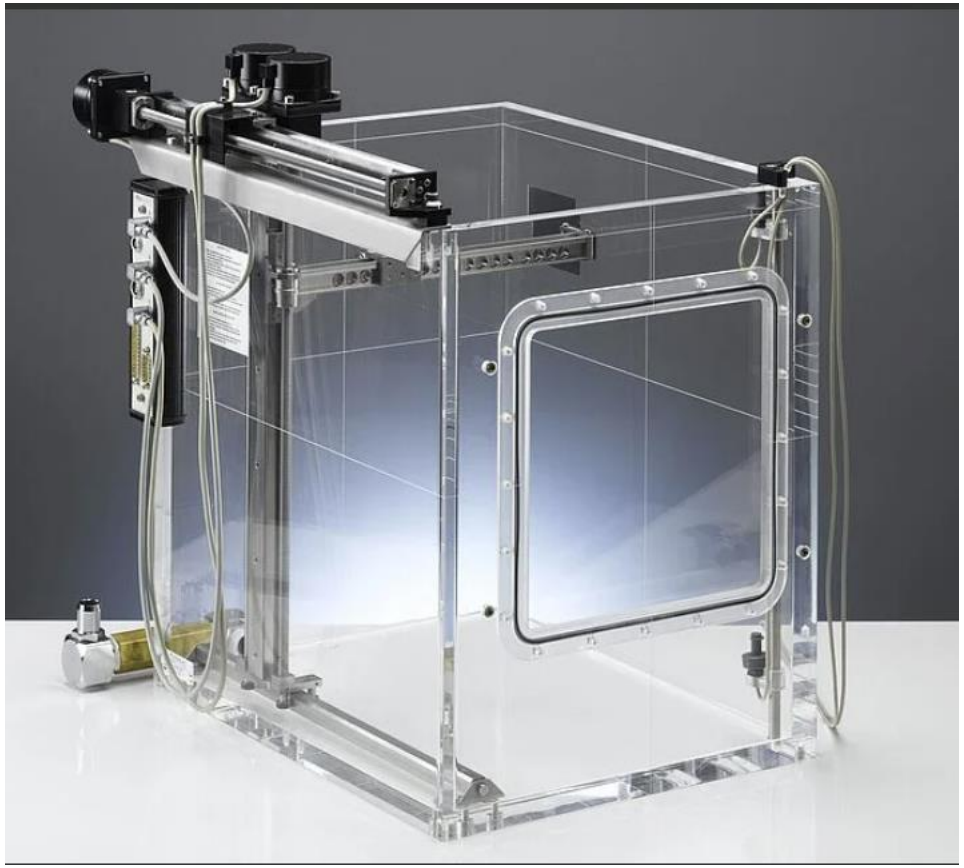
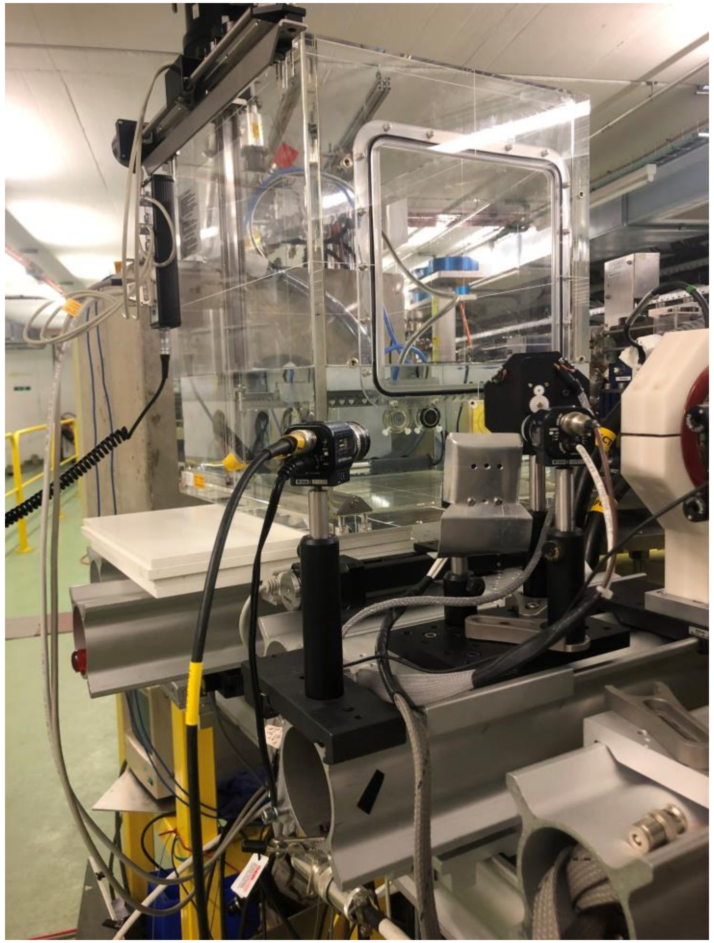
Advanced Markus



Water Phantom





Water Phantom

- Versatile, application-specific solution
- Appropriately sized, fully automatic 3D water tank with up to 38 cm (MP3-P; vertical)/50 cm (MP3-PL; horizontal) scanning depth
- parallel walls and a thin exchangeable entrance window for precise horizontal beam measurements
- Detector positioning accuracy true to 0.1 mm
- Electrometer with extended measurement range also suitable for reference dose measurements

Outline

- Our Background and Expertise
- The Detector Array
- Other Dosimetry Options
- Conclusion - Possible Contribution

Conclusion - Possible Contribution

- Expertise in the field of Monte Carlo simulation on a chamber level of details
- Expertise in characterization of detectors and correction factors
- Already performed dosimetry in a UHE lead beam at CERN 2028 using a 1000SRS detector array
- Possible changes and modifications of available PTW detectors
- Access to a variety of PTW detectors