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Interstitial Detectors for Synchronized Radiation Quality and Range Verification in Ion-Beam Therapy

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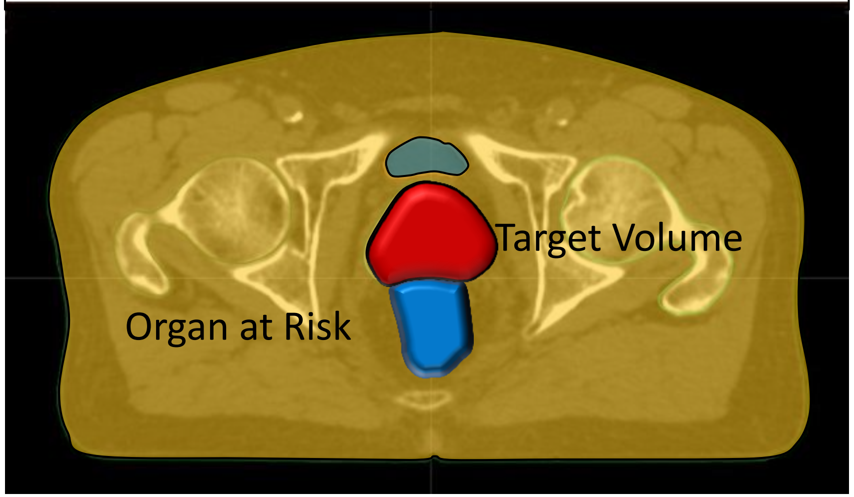
Internal measurements in ion-beam therapy

Possibilities and challenges of internal measurements **during the patient irradiation** are not discussed here

No doubts that it would be useful in ion-beam therapy where the uncertainties on the range prohibit some beam directions

Prostate cancer are the most treated with **protons** (60% of total at LLU) and **carbon ion** (23% of total at Chiba)



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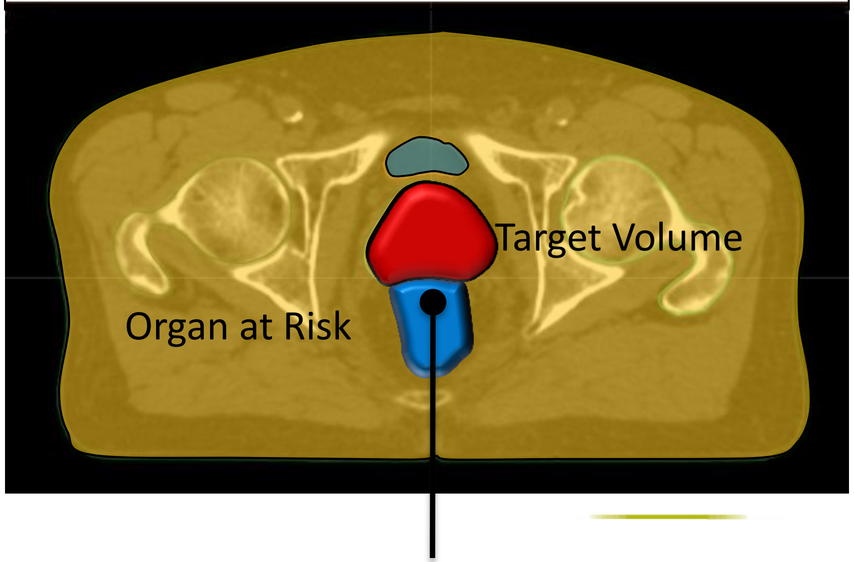
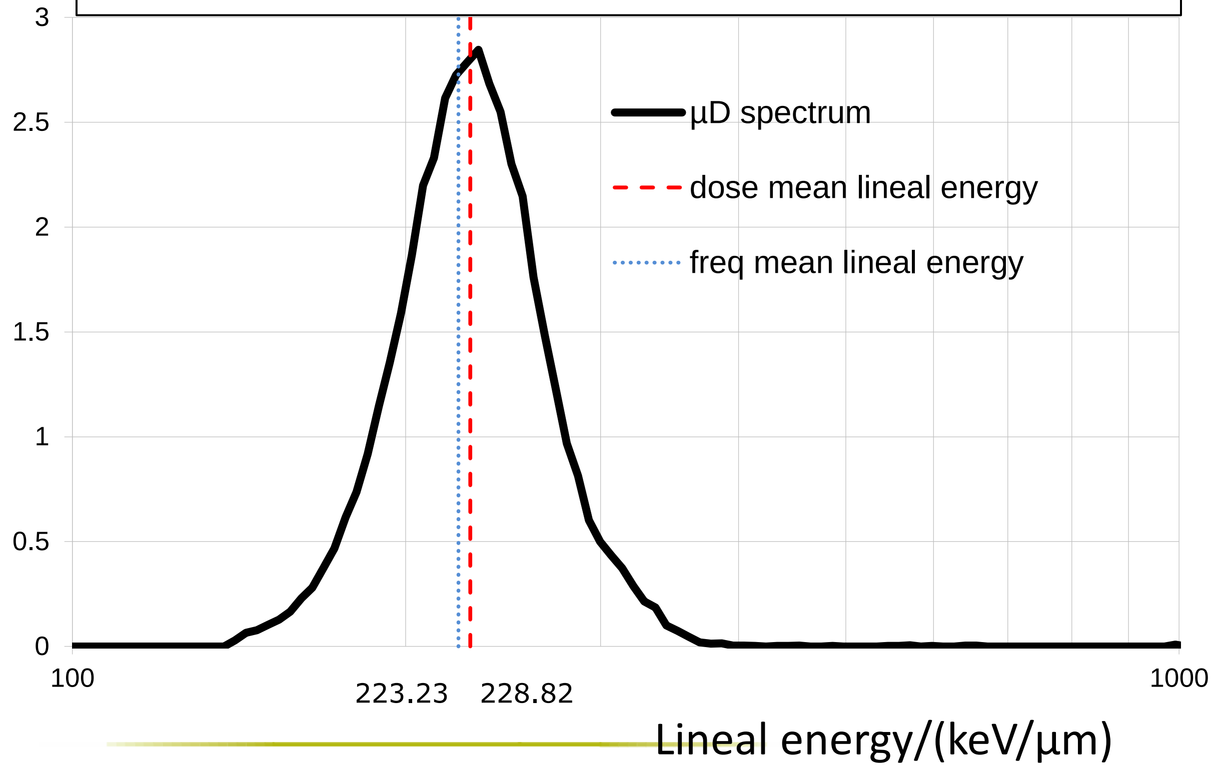


Dose and radiation quality

The preferred candidate
(Rollet, IEEE Transactions on Nuclear Science, VOL. 59, NO. 5, 2012):
The microdosimeter collects the energy of each single particle independently and represents it in a distribution.
This spectrum is the response of a Chemical Vapor Deposition Diamond µ-spectrometer to 110 000 alpha particles (241-Am)



Simultaneously
dose, *D*
area of the spectrum
in this case, 1.51Gy (factor 3.47)

radiation quality, y^*_D
mean value of the spectrum
In this case 229keV/µm

Radiation quality defined by y^*_D instead ***LET***

CVD-diamond µdosimeter:
~ 1µm in thickness
~ 10µm in cross diameter
~ 100µm total detector size

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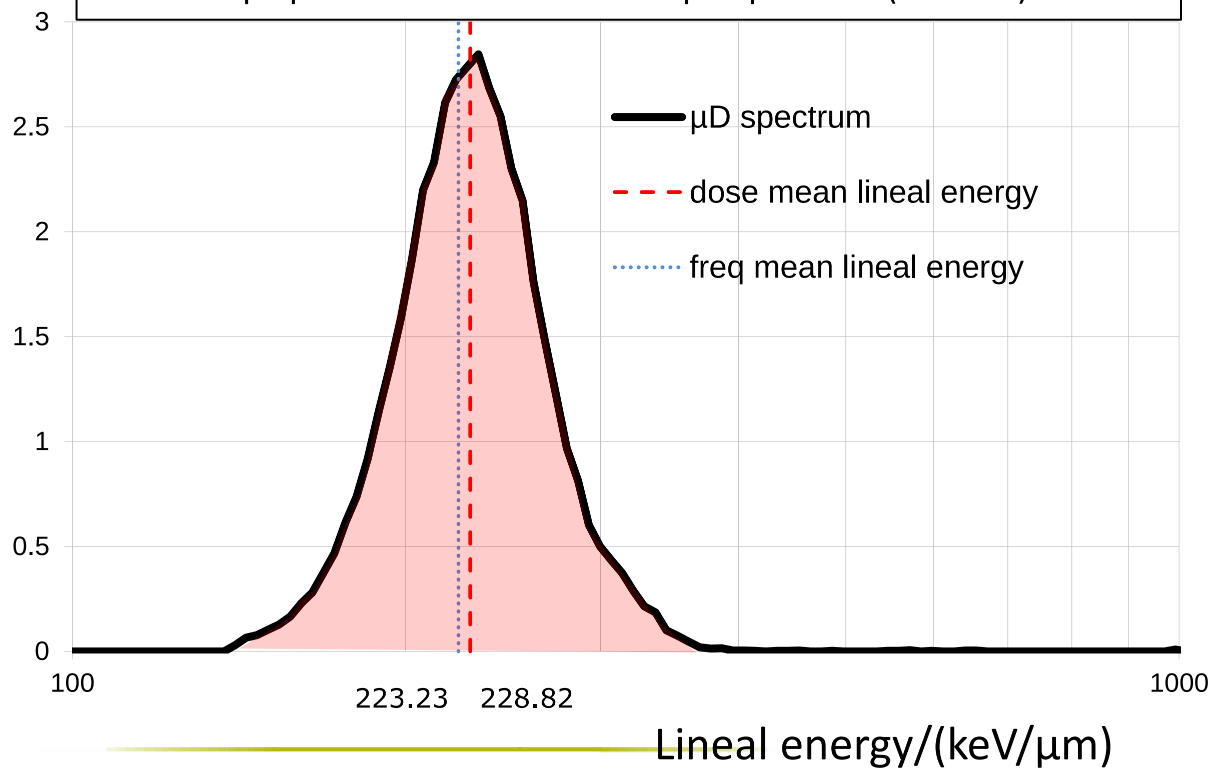

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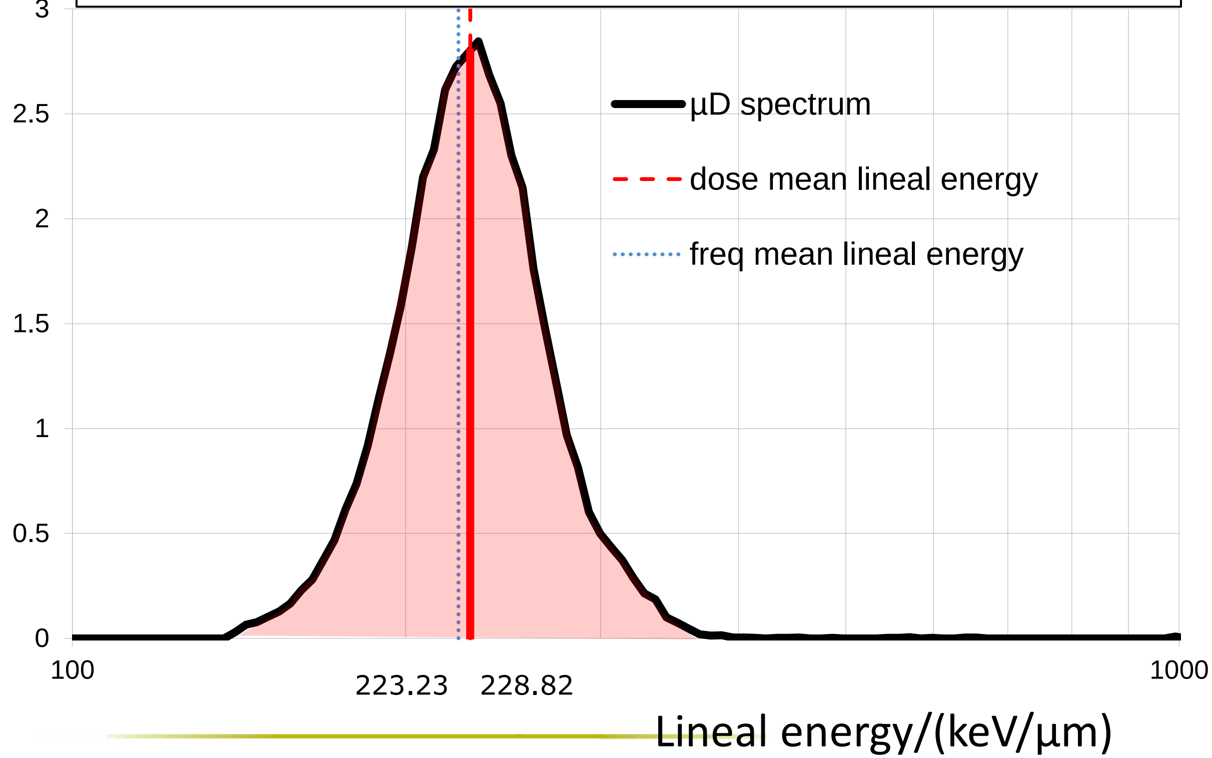

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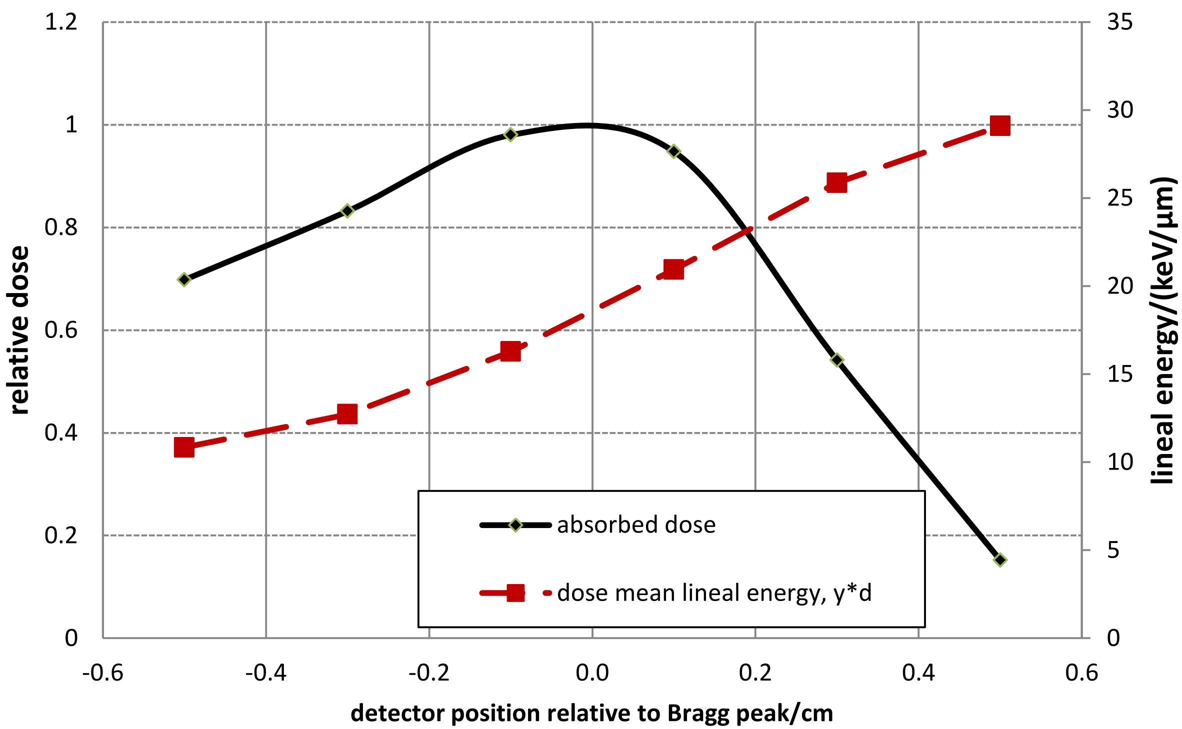
Radiation range



Simulation (Gate-Geant4) of proton beam on a 2µm thick carbon detector in water phantom

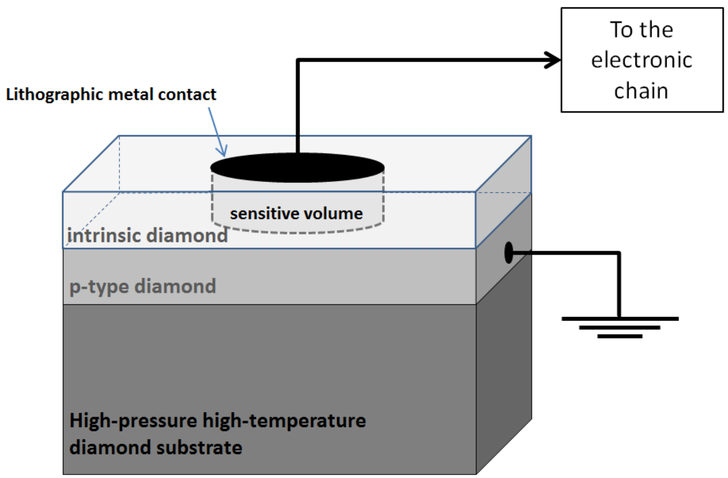
Dose and radiation quality have independent correlation to range:

Bragg peak

Radiation quality increase at end of the path

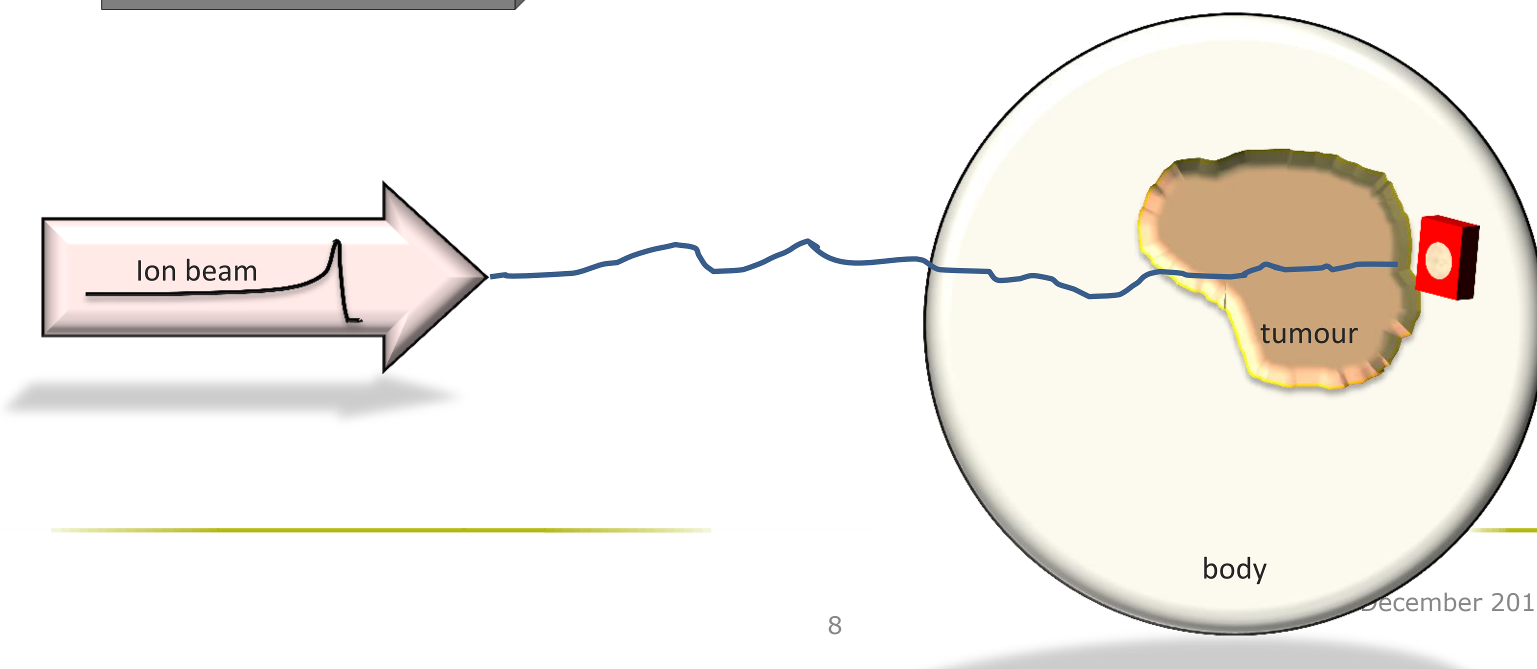
Two good variables for a robust determination of the range.

Detector shape

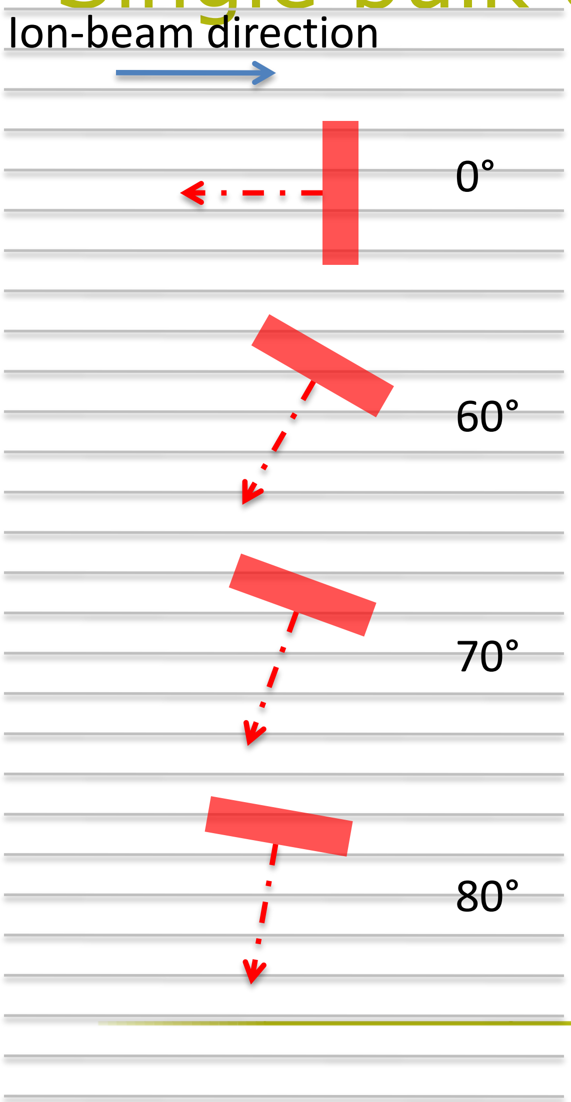


The sensitive volume is **non-spherical** and therefore the response depend on the orientation of the detector surface to the beam direction

Not easy to know the orientation when the detector is inside the patient

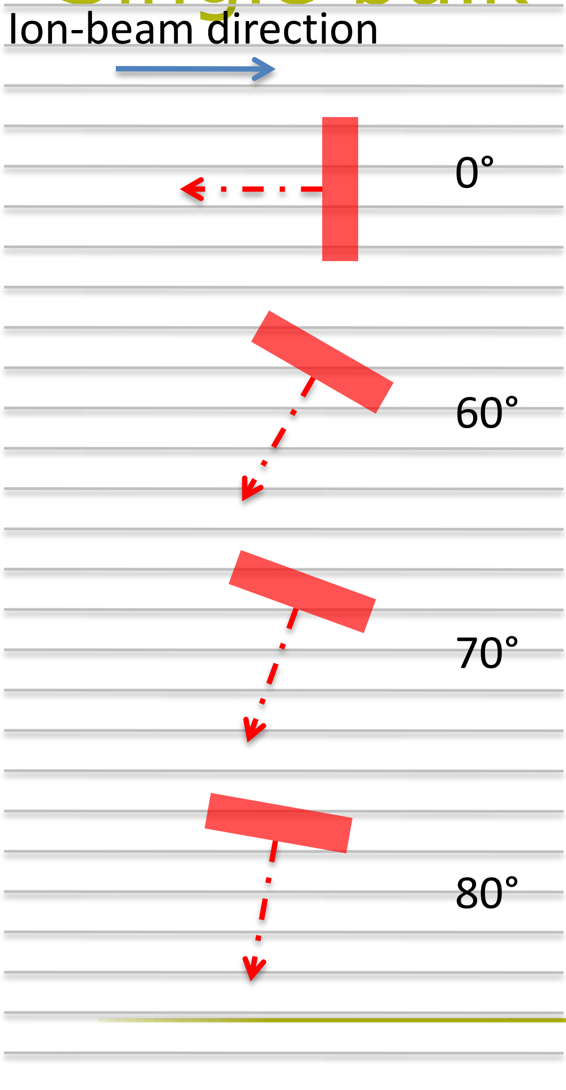


Single bulk detectors



2 dimensional example

Single bulk detectors



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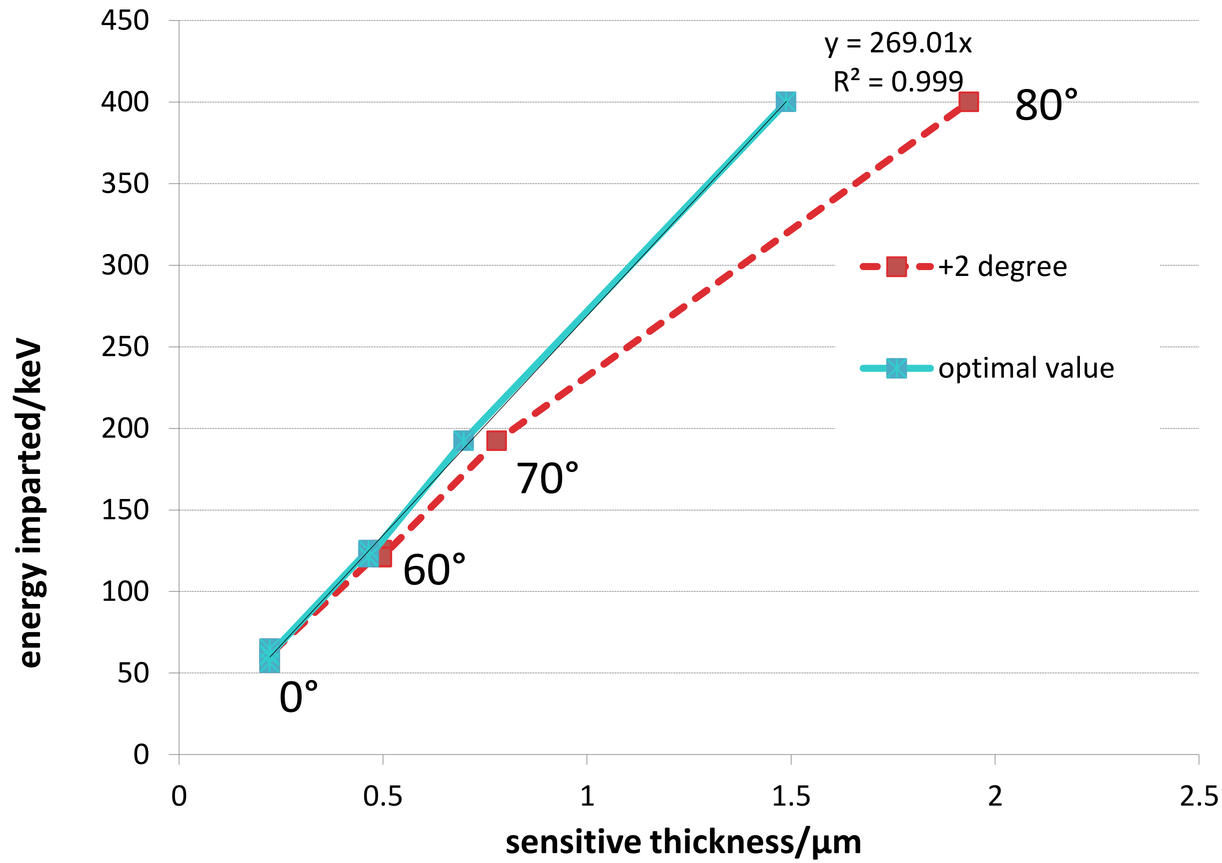
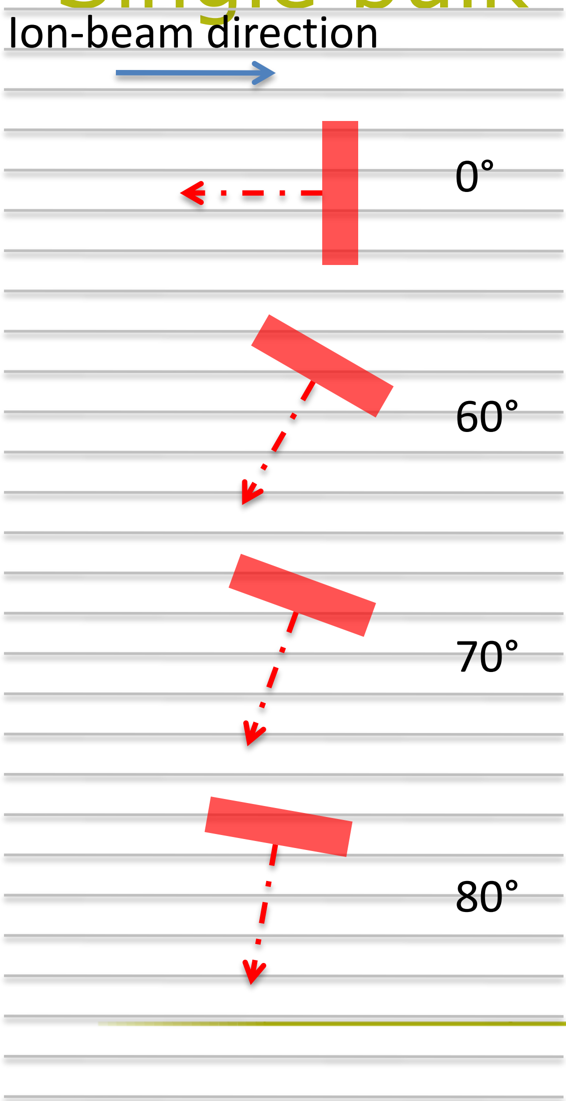


Tor Vergata University-MedAustron tests in diamond

Single bulk detectors



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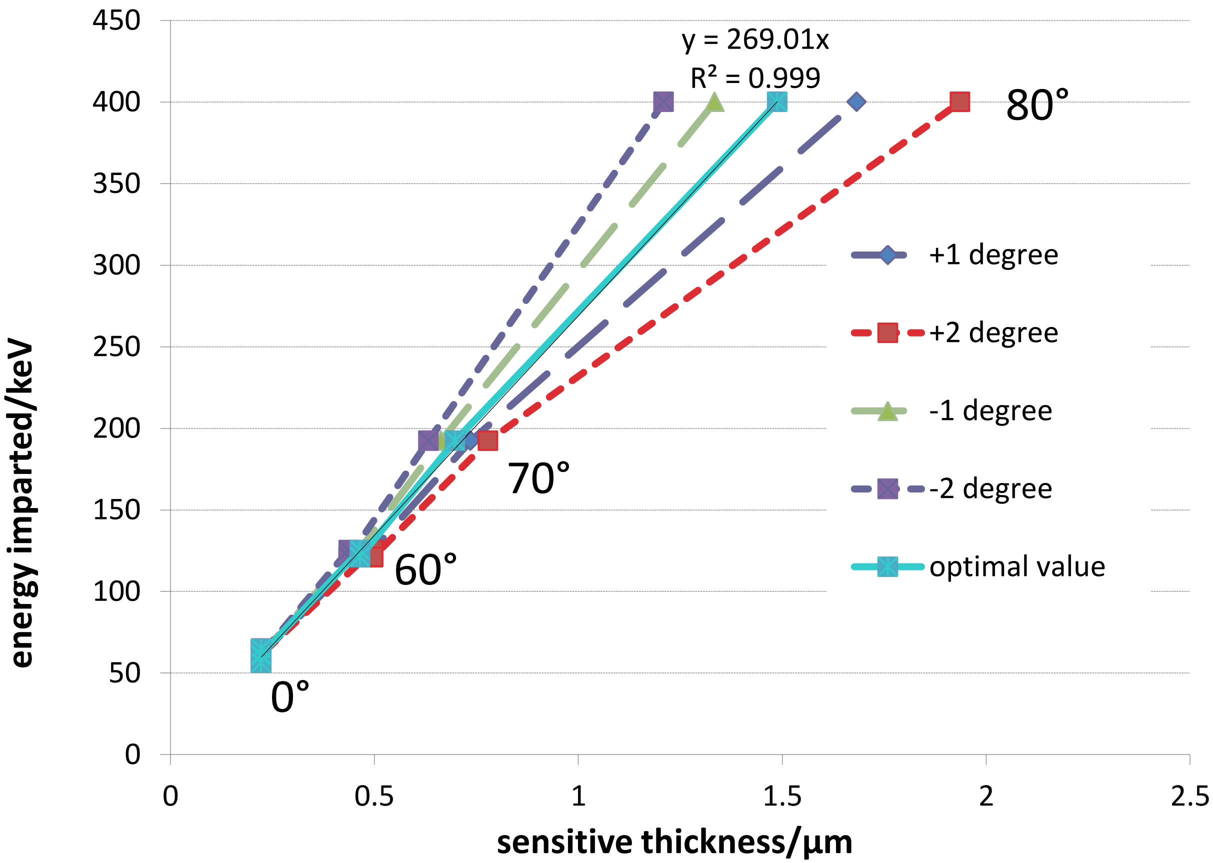

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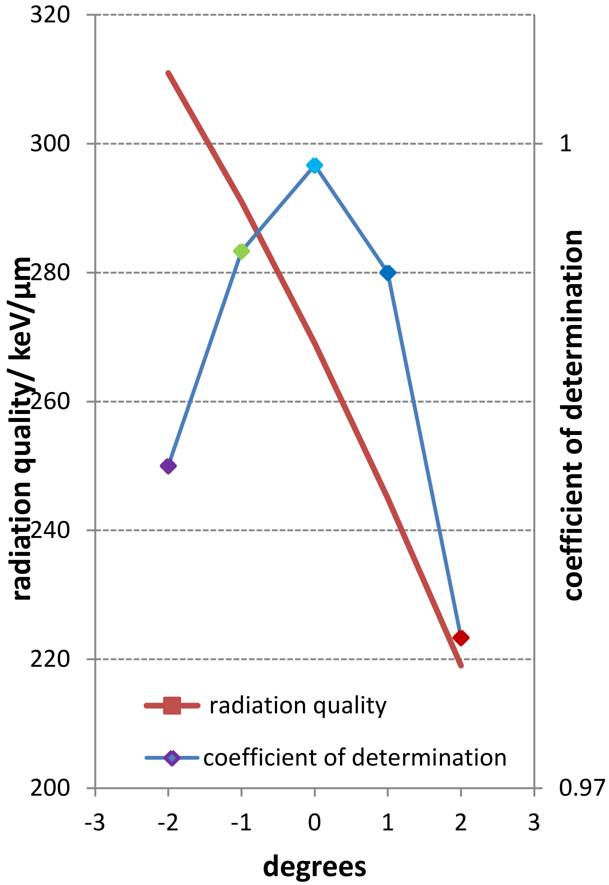
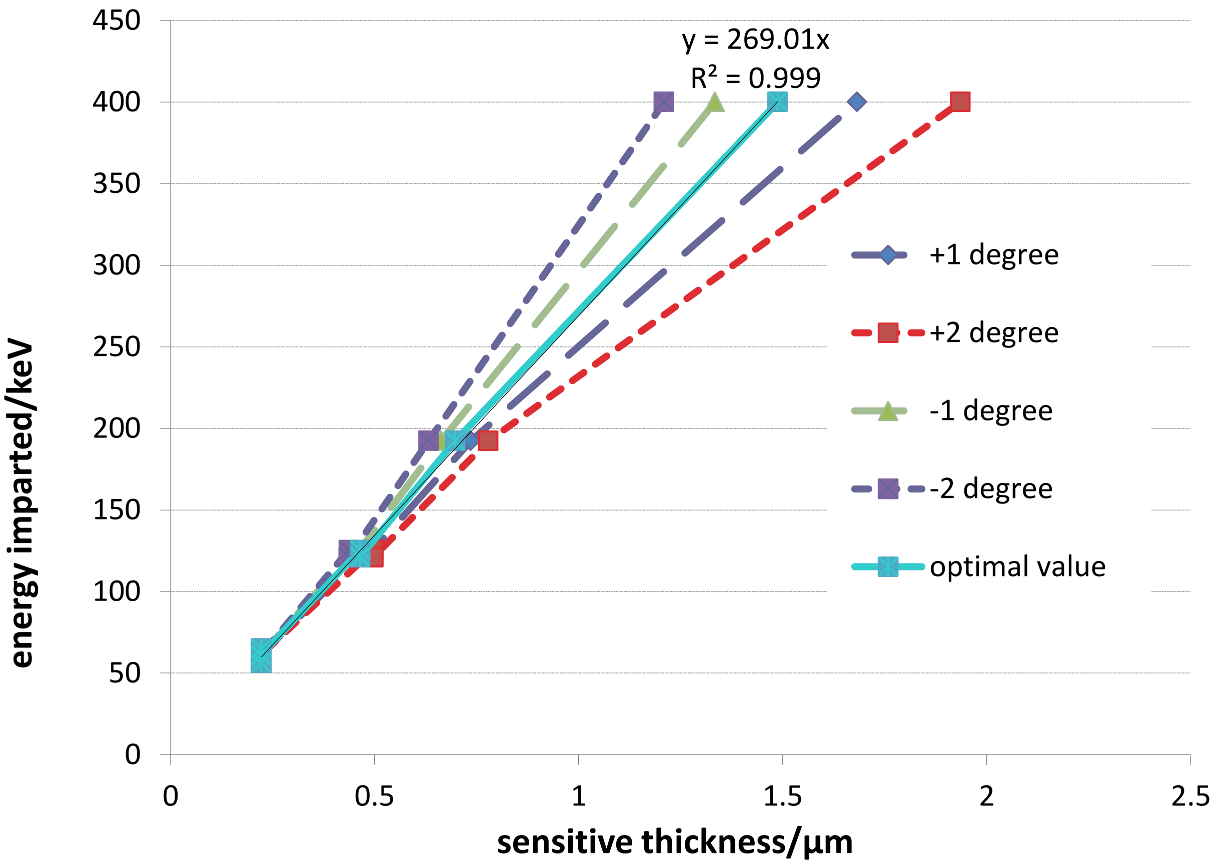


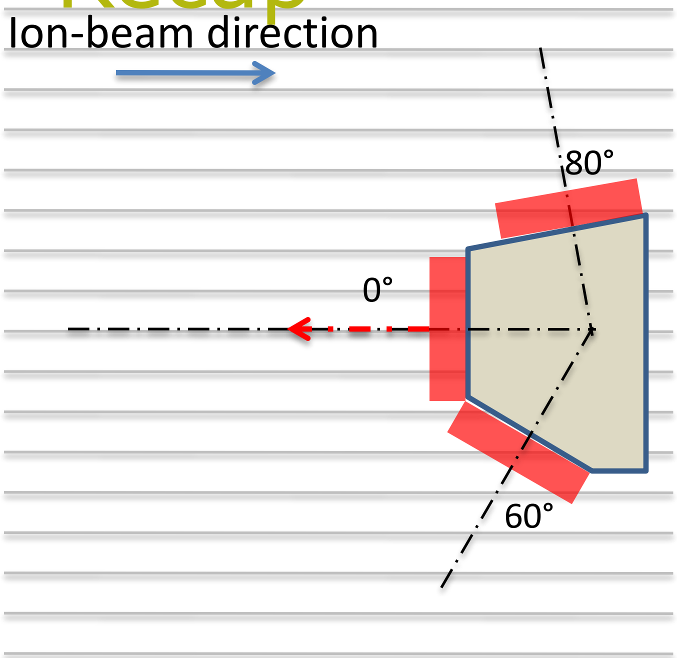


The highest linearity* provides the experimental radiation quality 269 keV/µm, 266 from literature

* Linear response within the approximation of thin detector

2 dimensional example

Recap



The assemble of several detectors well defined in thickness and orientation may provide simultaneously:

Dose

(the dose is in first approximation independent on the angle of incidence)

Radiation quality

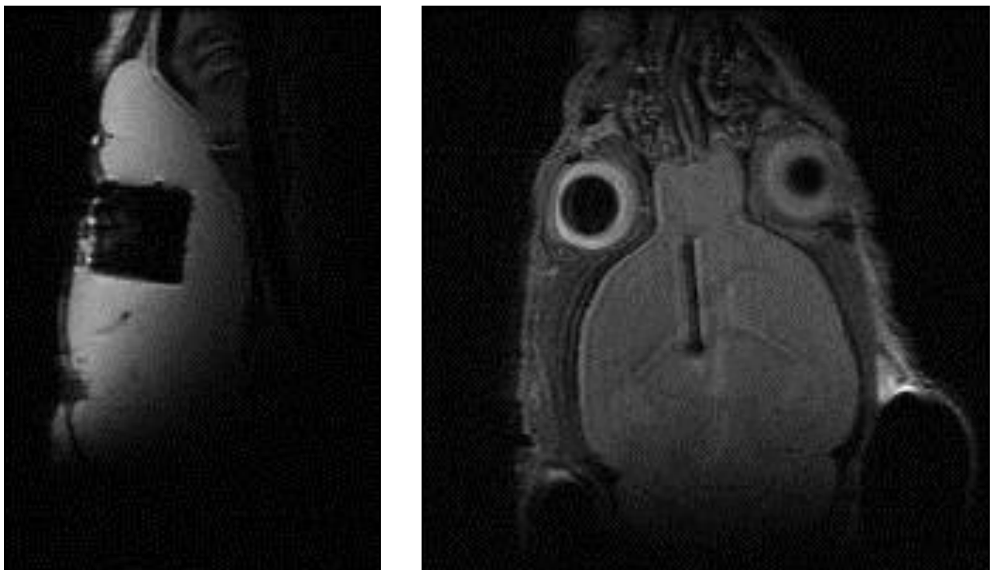
$y^*_{D\ \mathrm{corrected}} = y^*_{D\ \mathrm{measured}} \cdot \cos\phi$

with an accuracy on angle of ± 1°

Optimization of the number and orientation of the diamonds is in process to optimize detector orientation in 3D. The simplest: Tetrahedral

Future

The primary goal of microdosimetric measurements:
correlate radiation quality and biological effectiveness



Sagittal and coronal T1-weighted MR image of a 3.1x3.1x0.5 mm^3 diamond microdosimeter in a mouse's brain

ETH/MedAustron studies on compatibility of the detector with biological tissue and imaging techniques.

Future studies in correlating radiation quality measurements and molecular-imaging-based assessments of the radiation biological effectiveness

The presence of metallic electrodes did not produce artefacts in the MR image.

Thank you