A. Dittwald, J. Bundesmann, A. Denker, T. Fanselow, G. Kourkafas

S. Dillenardt

HZB Helmholtz Zentrum Berlin

BHT Berliner Hochschule für Technik

real time determination of the range and Bragg-peak of protons with a depth profile camera at HZB

HZB accelerator complex

camera system

LabVIEW – readout and visualization

results

conclusion

patent pending

23rd International Conference on Cyclotrons and their Application

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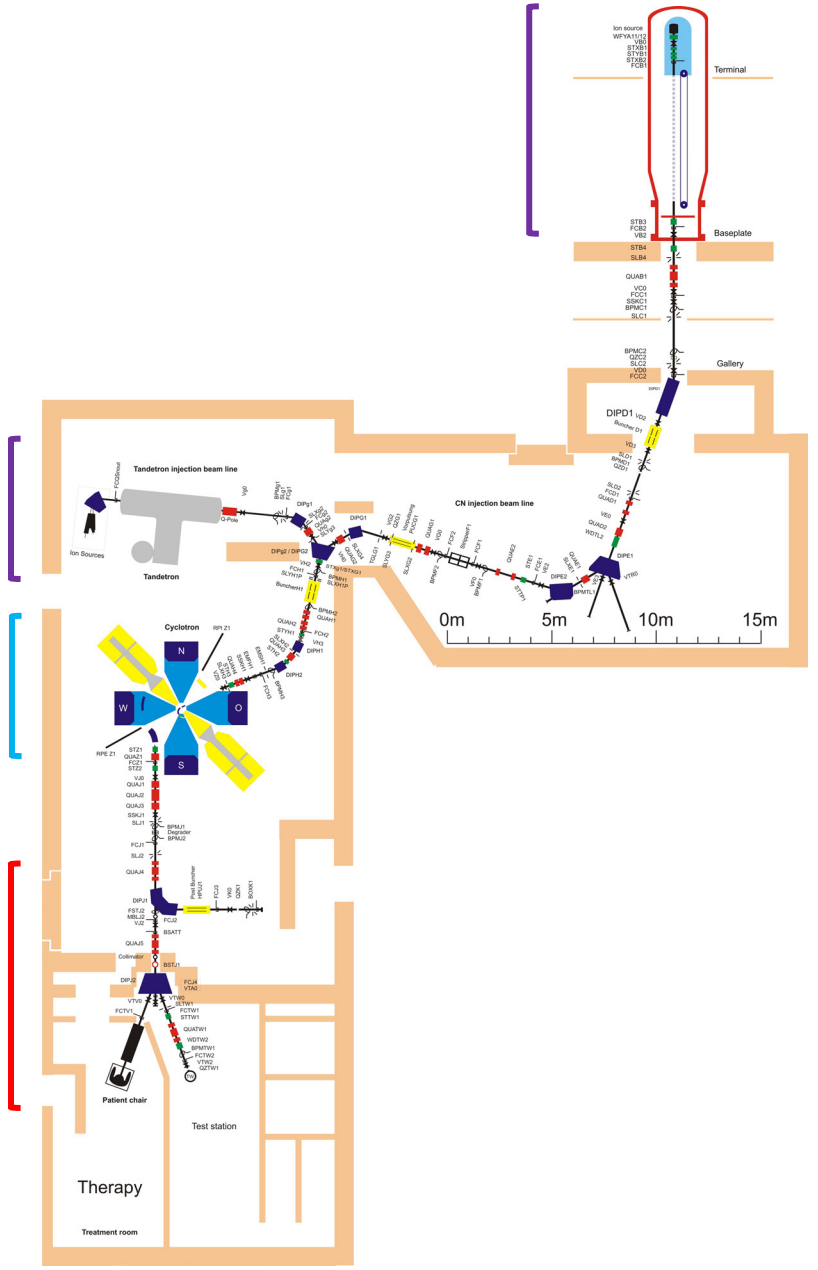
HZB accelerator complex

- two injector
  - 2 MV Tandetron
  - 6 MV Van-de-Graaff
- isochronous sector cyclotron as main accelerator
- three target stations
  - treatment room
  - experimental station
  - beam line end for tests in cyclotron vault
- eye tumour therapy since 1998 with over 4300 patients
- normal determination of the Bragg curve with a water bath phantom
- problem: long measuring times



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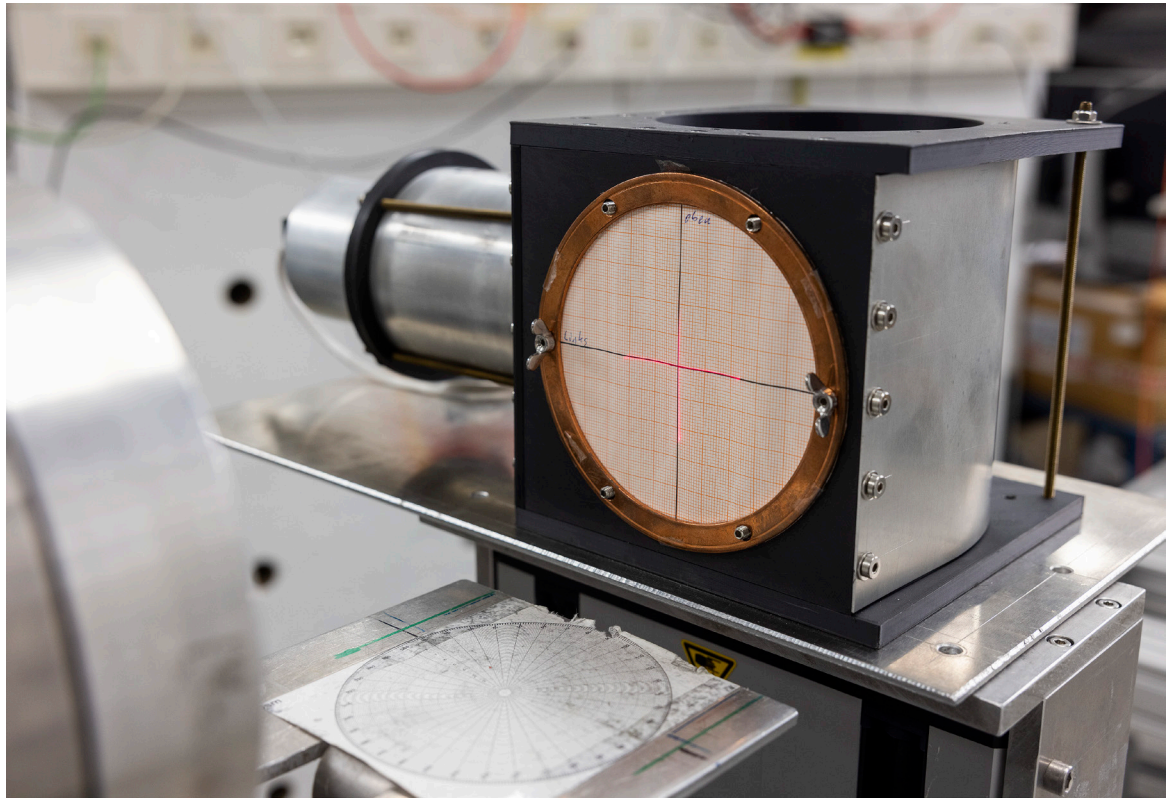
camera system – compact data

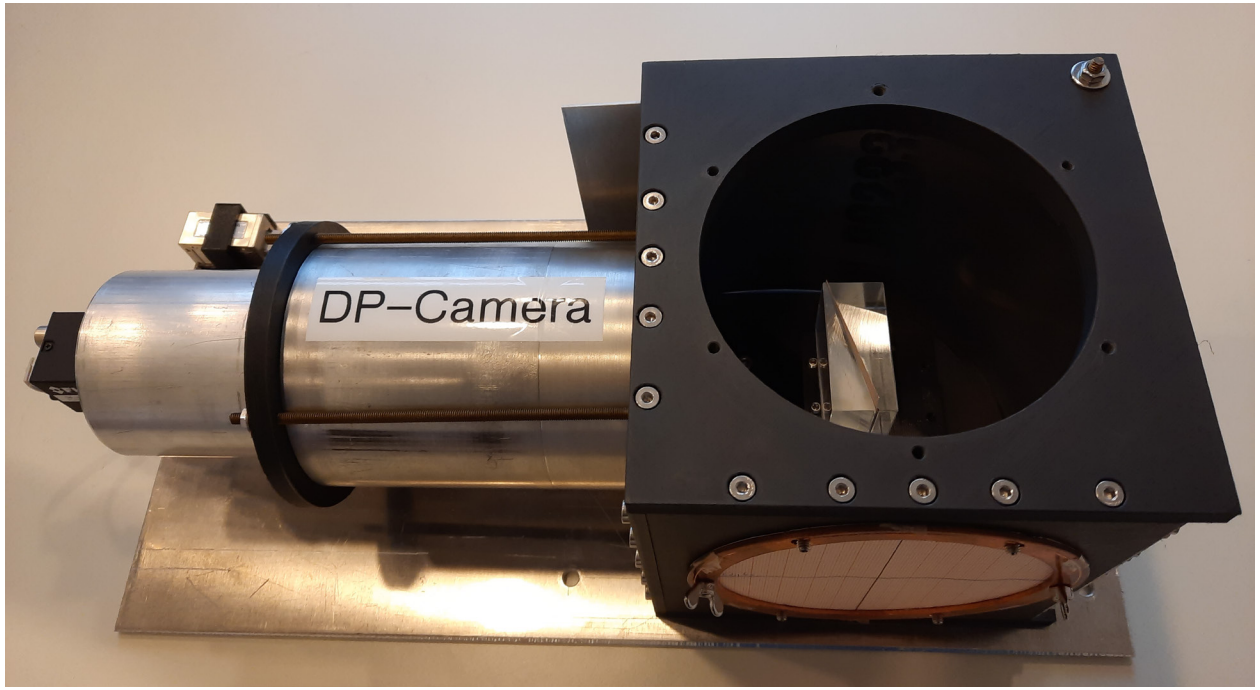
- patent pending
- consists of a phantom, a luminescent layer, a housing and a camera (FLIR, monochrome)
- low proton beam intensity of 10 pA/cm^2 (scattered beam is needed)
- small size of 35 cm x 20 cm x 20 cm
- very light with only 1.5 kg
- millimetre paper in front is for alignment of the system



- photo is taken in beam direction and laser crosshair for alignment is shown

camera system – view inside

- phantom consists of two plastic blocks with the luminous layer in between -> shows Bragg-curve
- camera detects the signals of the luminescent layer and is readout by a LabVIEW code
- camera system is placed in a light-tight housing
- camera itself is located outside of the proton field



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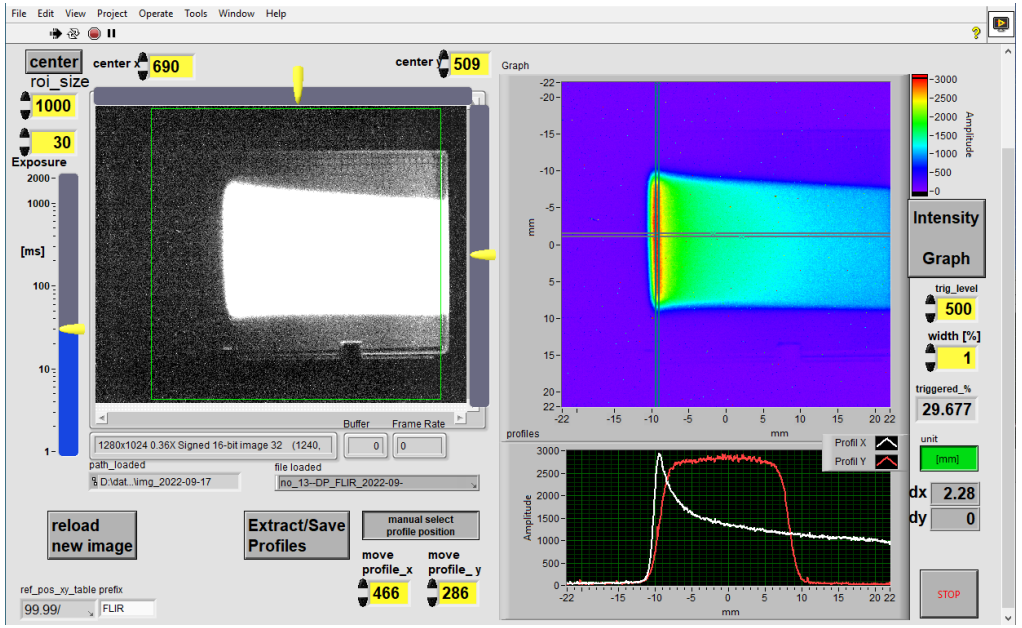
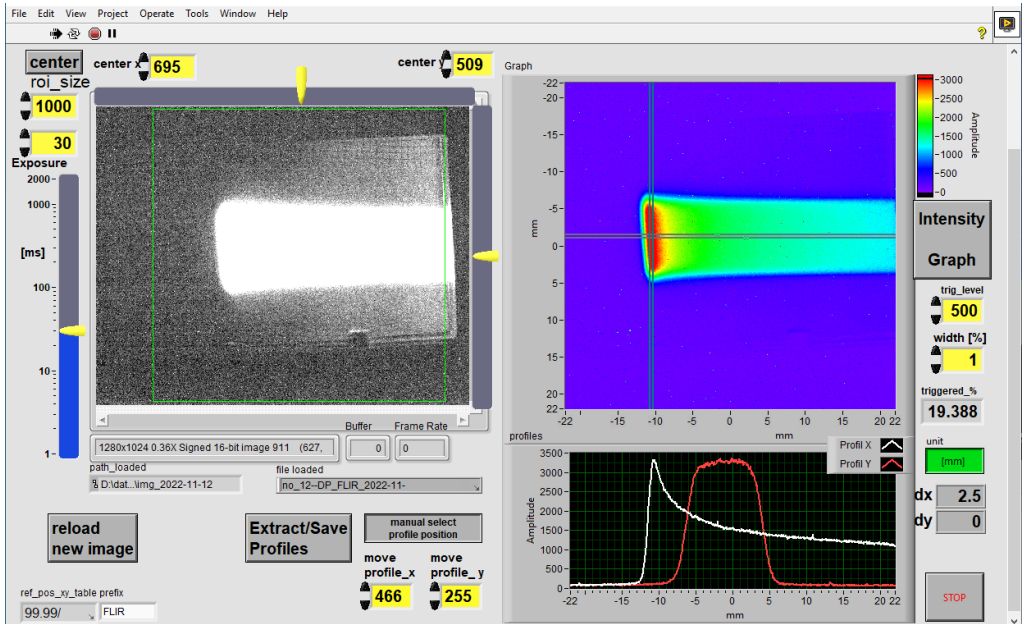
LabVIEW code: visualization of camera image

- left side:
  - live image with monochrome intensity
  - ROI area (region of interest) can be selected on the image (green box)
- right side:
  - ROI area is shown with coloured coded intensities
  - profiles in beam and lateral to beam direction
- profiles:
  - shown below the coloured coded intensities
  - live feedback of the Bragg-curve (white) and the lateral profile (red)
- e.g. different apertures visible
  upper image: 20 mm x 20 mm,
  lower image: 10 mm x 10 mm





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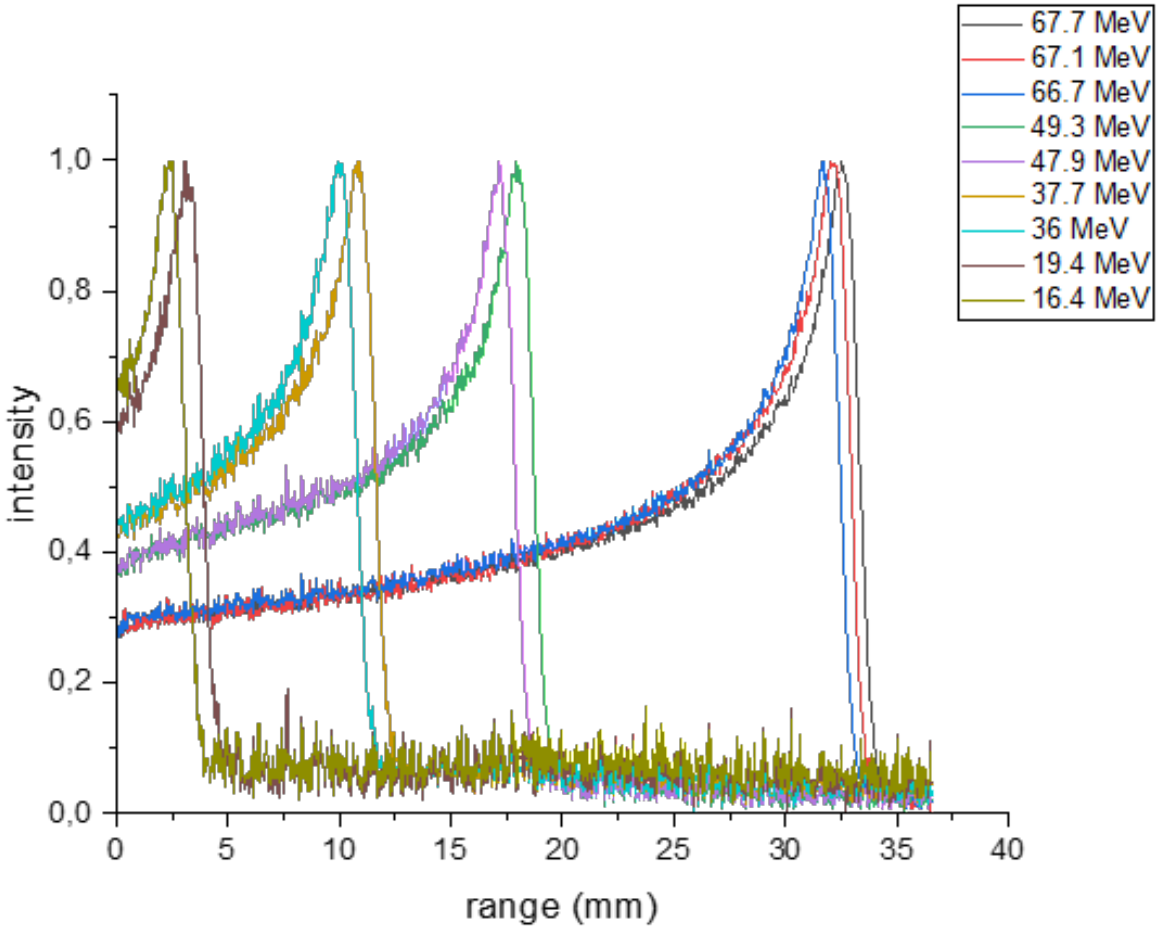
different energies of the proton beam

- proton beam energies from 68 MeV down to 16 MeV, achieved with absorber plates
- Bragg-peak of beam with different energies directly visible
- small steps of 400 keV are clearly discernible
- differences between measured and theoretical values are larger at lower energies

energy	camera range [mm]	PSTAR range [mm]
67.1	32.96	32.61
66.7	32.46	32.20
19.4	3.86	3.45
16.4	3.02	2.57



- ranges are taken at 80% of the Bragg-peak

- PSTAR: https://physics.nist.gov/PhysRefData/Star/Text/PSTAR.html

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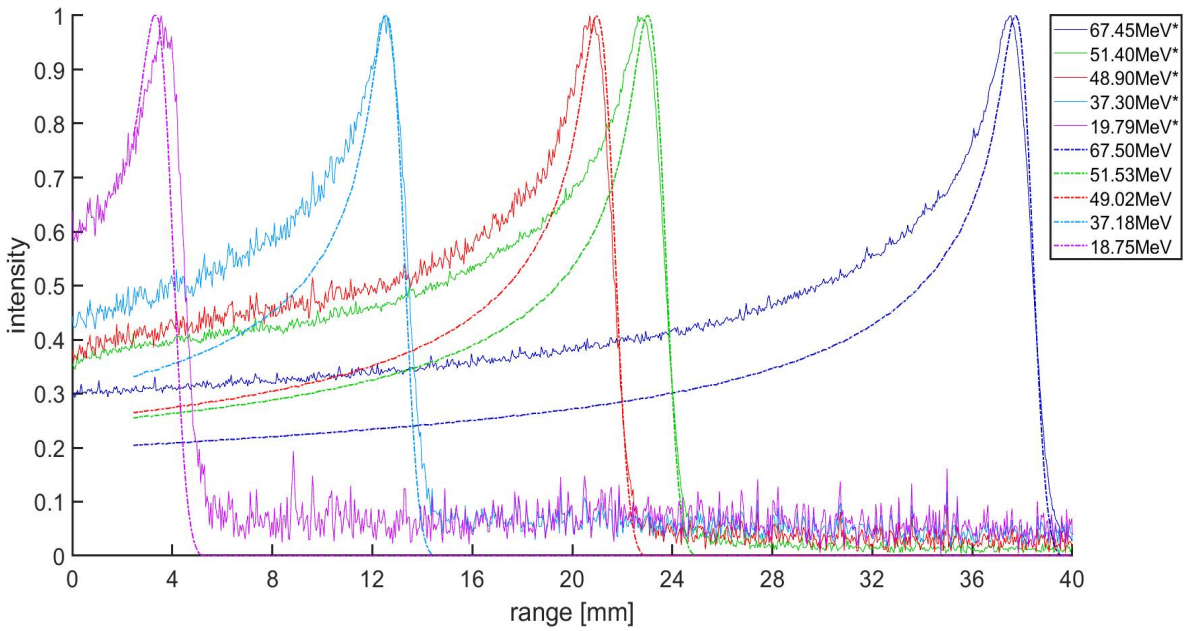
camera system vs. water phantom

- measured ranges of the camera system were converted to water ranges
- in direct comparison the Bragg-curves are very similar
- less noisiness of the camera graphs when using scattering system close to the camera -> influence of the beam scattering system (neutrons)
- Difference explained by:
  - uncertainties for phantom and absorber materials or interaction layers
  - geometry of camera lenses



- measurements with the camera system (solid line)
- measurements with the water bath (dashed line)

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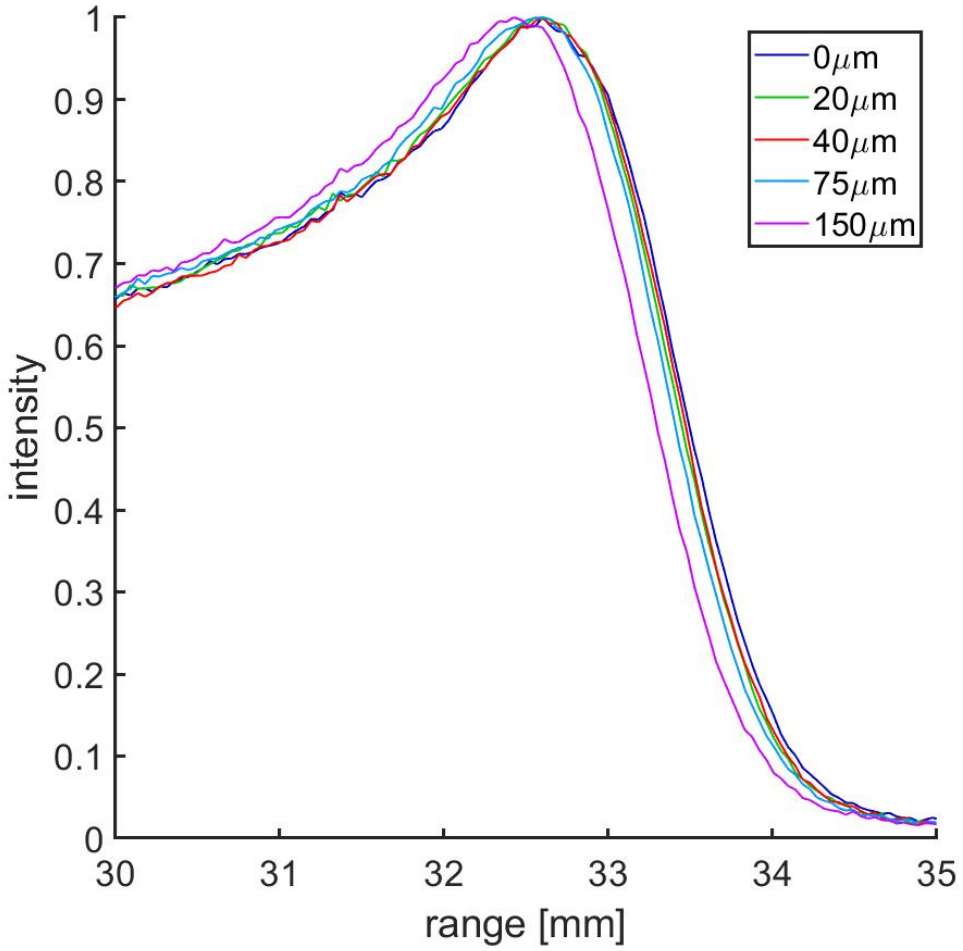
minimum energy resolution

- single pixel resolution of 40 keV feasible?
- thin aluminium foils
- ranges are given for phantom material
- -> energy loss of 100 keV is measurable

foil thickness [µm]	measured ranges [mm]	calculated energy [MeV]
0	33.20	67.90
20	33.16	67.84
40	33.13	67.81
75	33.08	67.75
150	33.96	67.61



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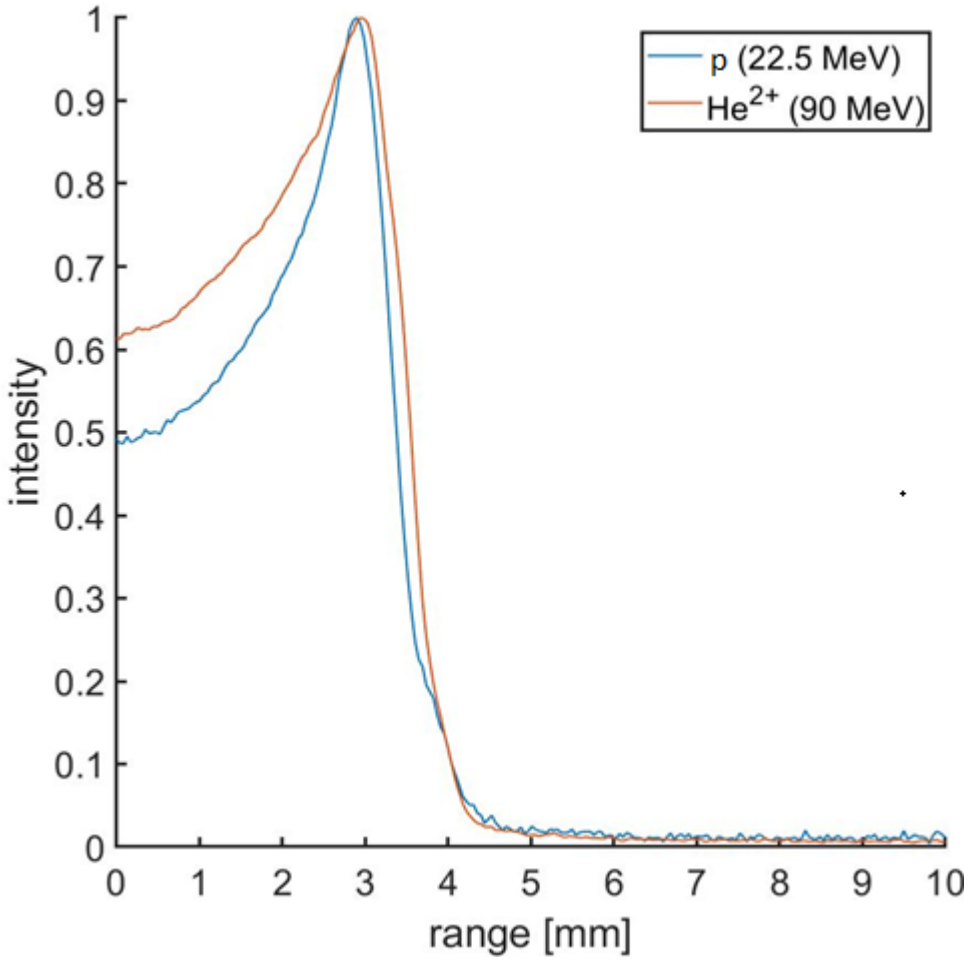
different ion species

- different ions chosen: p (22.5 MeV), $^{4}He^{2+}$ (90 MeV)
- same range for both ions
- calculate energies taking to account exit foil and air pass
- good agreement for calculated and measured values
- difference between calculated energy and measured energy is less than 2%

ion	nominal energy [MeV]	calculate energy [MeV]	measured range [mm]	measured energy [MeV]
p	22.5	19.43	3.40	19.18
He^{2+}	90	78.48	3.37	76.02



conclusion

- inexpensive, lightweight camera system
- camera system shows excellent results
- works for different ions and energies
- minimal energy resolution 100 keV
- very good agreement with water phantom
- small differences in the measurements