SmartPhantom

3rd CCAP Plenary Meeting

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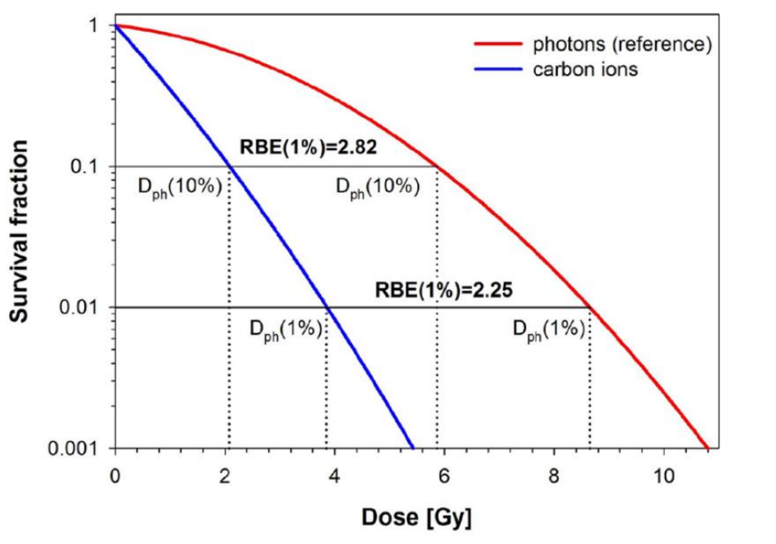
Imperial College London

Introduction

- Cell sample irradiation in a water phantom studies at MedAustron.
  - Investigate RBE for protons and carbon ions.
  - Look at effect of equivalent dose before and after Bragg peak.



Karger and Peschke 2018 *Phys. Med. Biol.* ***63***

- Previous water phantom studies at MedAustron.
  - Cell irradiation and dosimetry done separately.

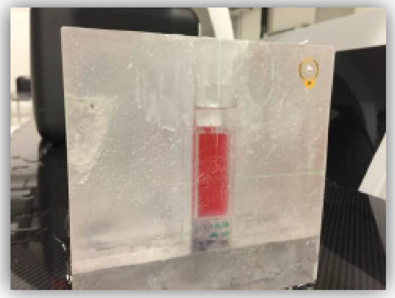
- The SmartPhantom is an instrumented phantom that can measure dose profile shot-by-shot (up to 10Hz) delivered to the cell sample.

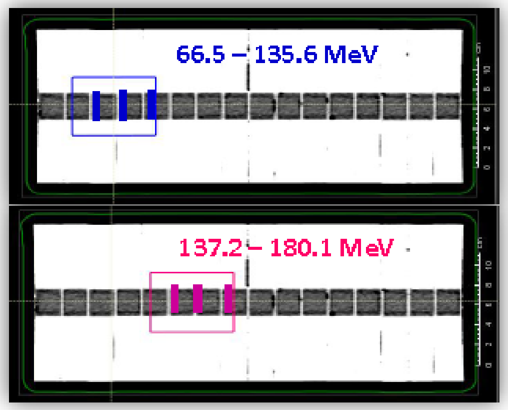
Previous Studies

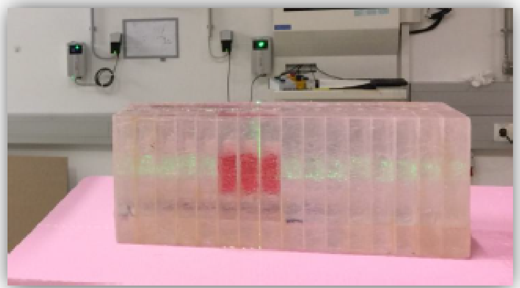
MedAustron

RBE Dependencies: Target Coverage Energy and LET

- Development and implementation of a dedicated irradiation setup in cooperation with Medical Radiation Physics
- Key requirement 1:
  - Simultaneous irradiation of multiple samples
    - investigation of end-of-range effects (LET)
- Key Requirement 2:
  - Variation of target depth
    - investigation of target coverage energy effects



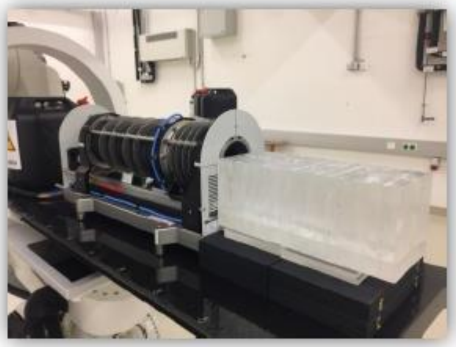


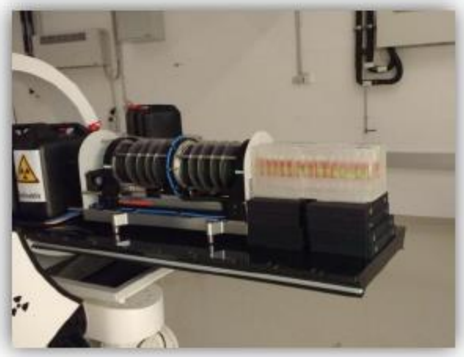


From Sylvia Gruber

Previous Studies

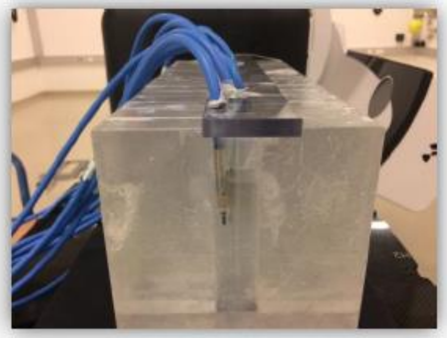
Dosimetry Aspects





Range measurements

Dosimetry: films



Dosimetry: Ionisation chambers

MEDICAL UNIVERSITY OF VIENNA

Radiobiology Research at MedAustron
HEPS / 27.06.2018

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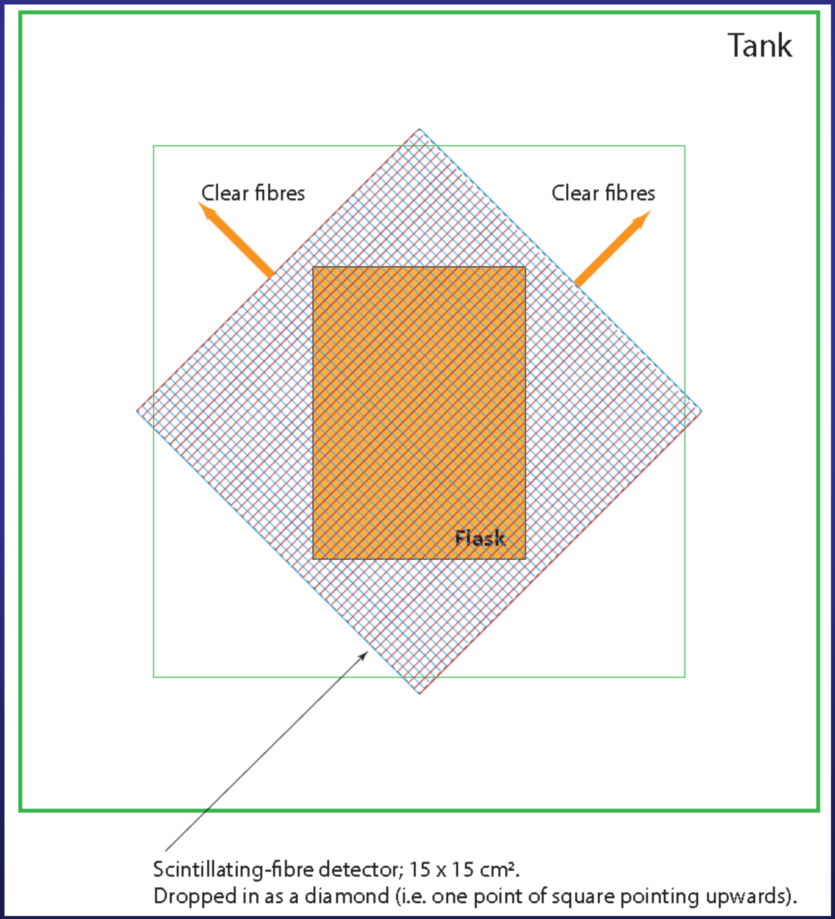
From Sylvia Gruber

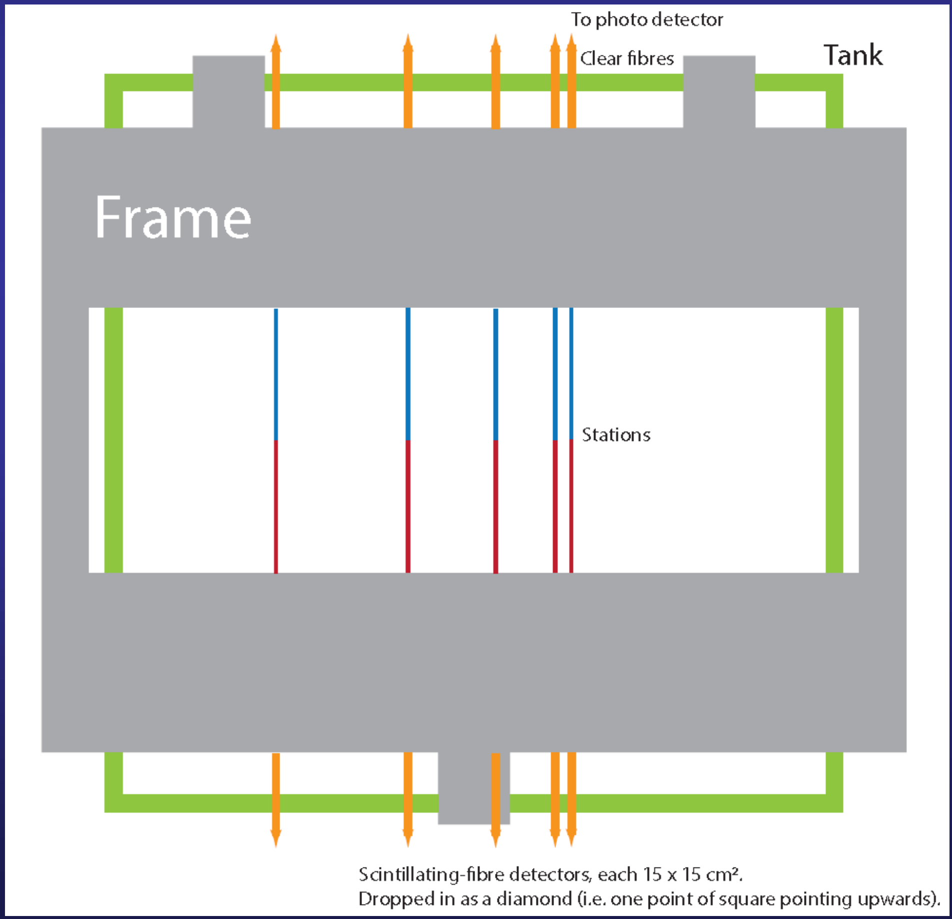
New Phantom Requirements

- Water phantom that is instrumented very close to the cell layer to measure the dose profile delivered to the cells shot-by-shot.
- Measure the energy loss as a function of range and transverse position before the Bragg peak.
- Observe the rapid increase in the rate of energy deposition and the beam profile just before the Bragg peak.
- Measure the energy-loss distribution and transverse beam profile within the Bragg peak (in the absence of a biological sample).
- Characterise the rapidly-falling distal edge of the Bragg peak.

SmartPhantom Concept

- Box filled with water in which a sample flask is suspended.
- Scintillating fibre layers with photo-diode read-out positioned just before the sample flask.

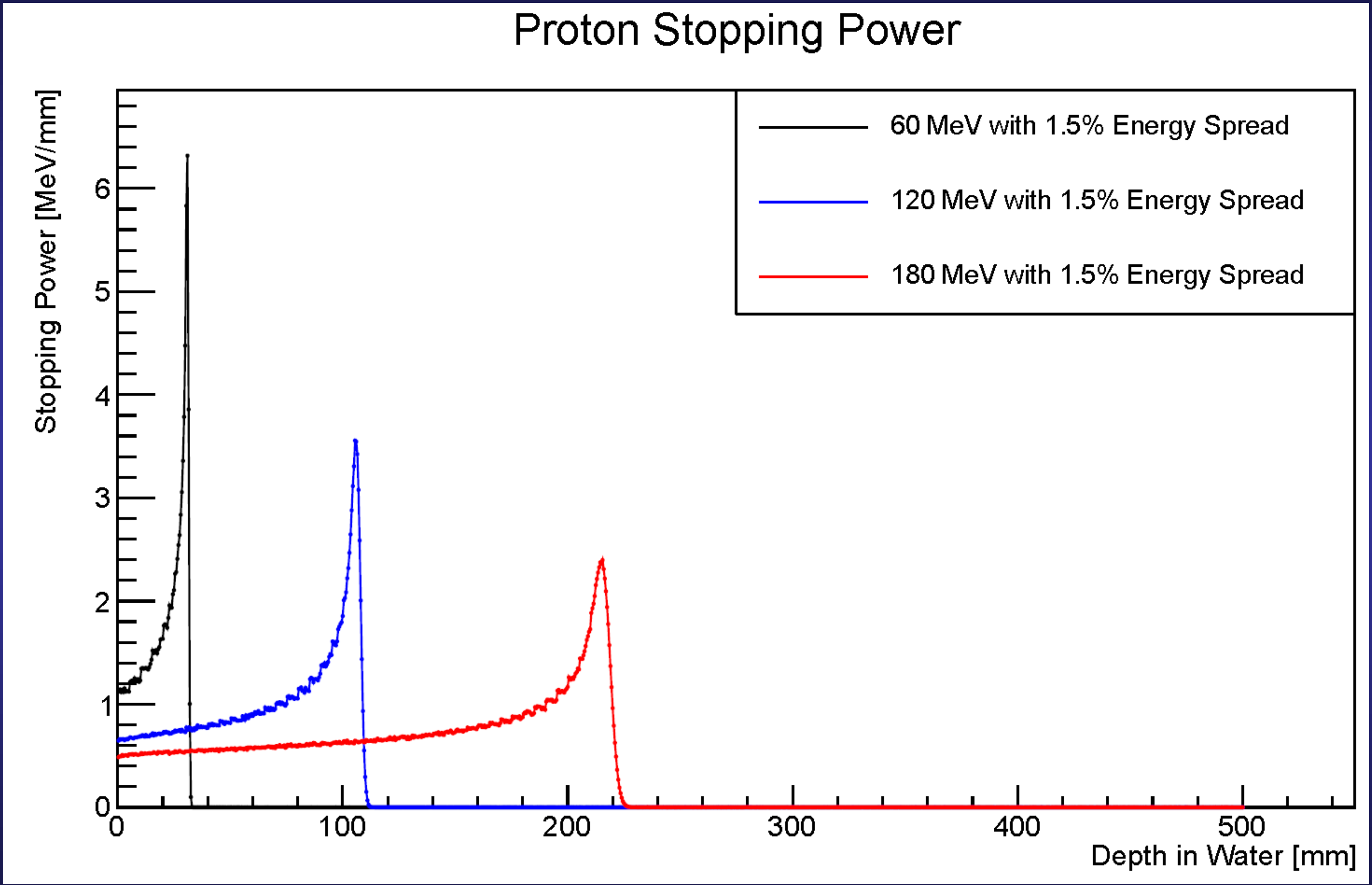




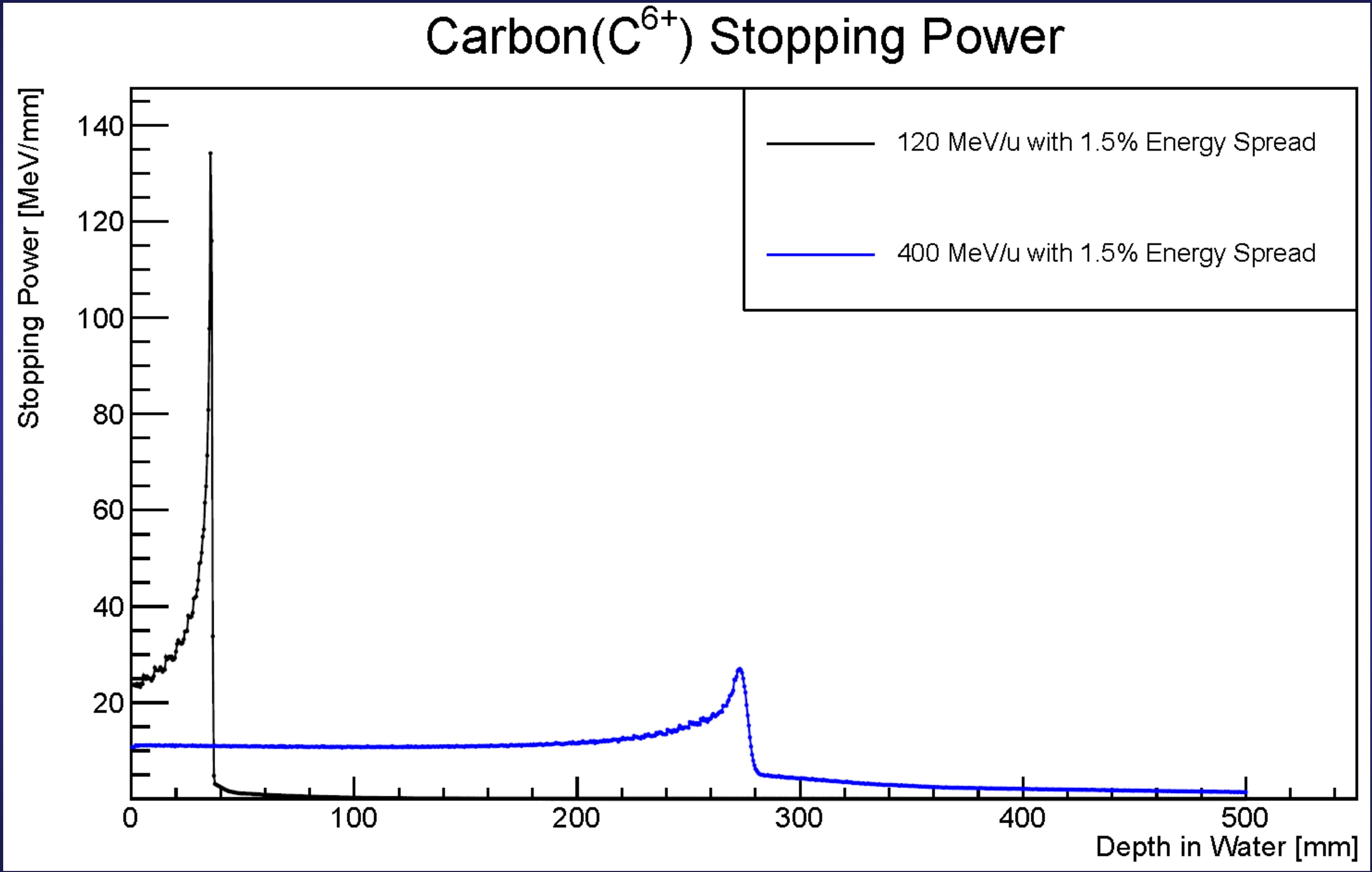
Simulations

- Initial simulations using BDSIM by HT Lau.
- Block of water 300x300x500mm.
- Look at stopping distance in water for MedAustron proton and carbon beam.
  - Proton kinetic energies between 60 and 250 MeV.
  - C^{6+} ions with kinetic energies between 120MeV/u and 400MeV/u.
  - FWHM of the beam is approximately $6\text{x}6\text{mm}^2$.
  - Typical spill length is 5 s for protons and 4 s for C^{6+}. There are approximately $1.8\text{ x}10^{10}$ protons ($4.5\text{x}10^8$ C^{6+} ions) in a typical spill.
  - Length of a full cycle ranges from 9 s to 14 s.
- For the simulations
  - Gaussian beam $\sigma_x = \sigma_y =$ 1.2mm, $\sigma_{x'} = \sigma_{y'} = 1 \times 10^{-5}$.
  - Beam kinetic energy spread is 1.5%.

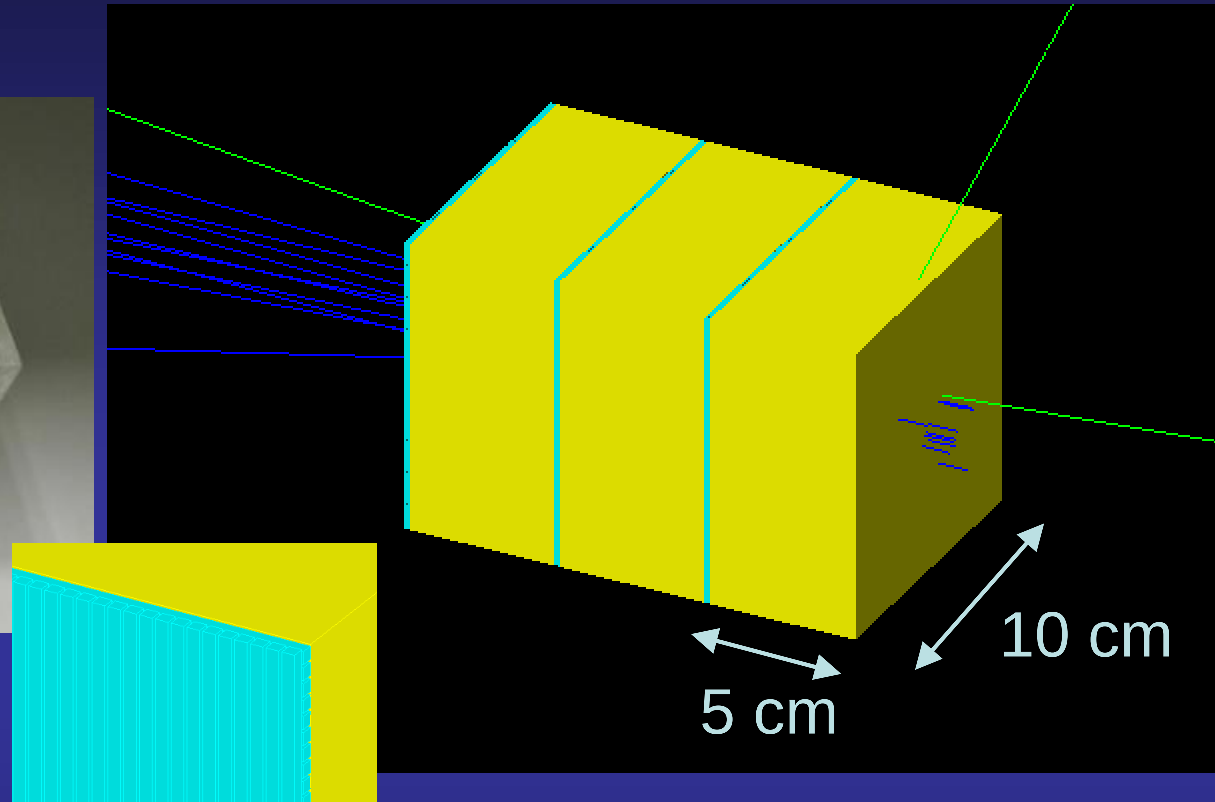
Proton Stopping Power



Carbon Stopping Power

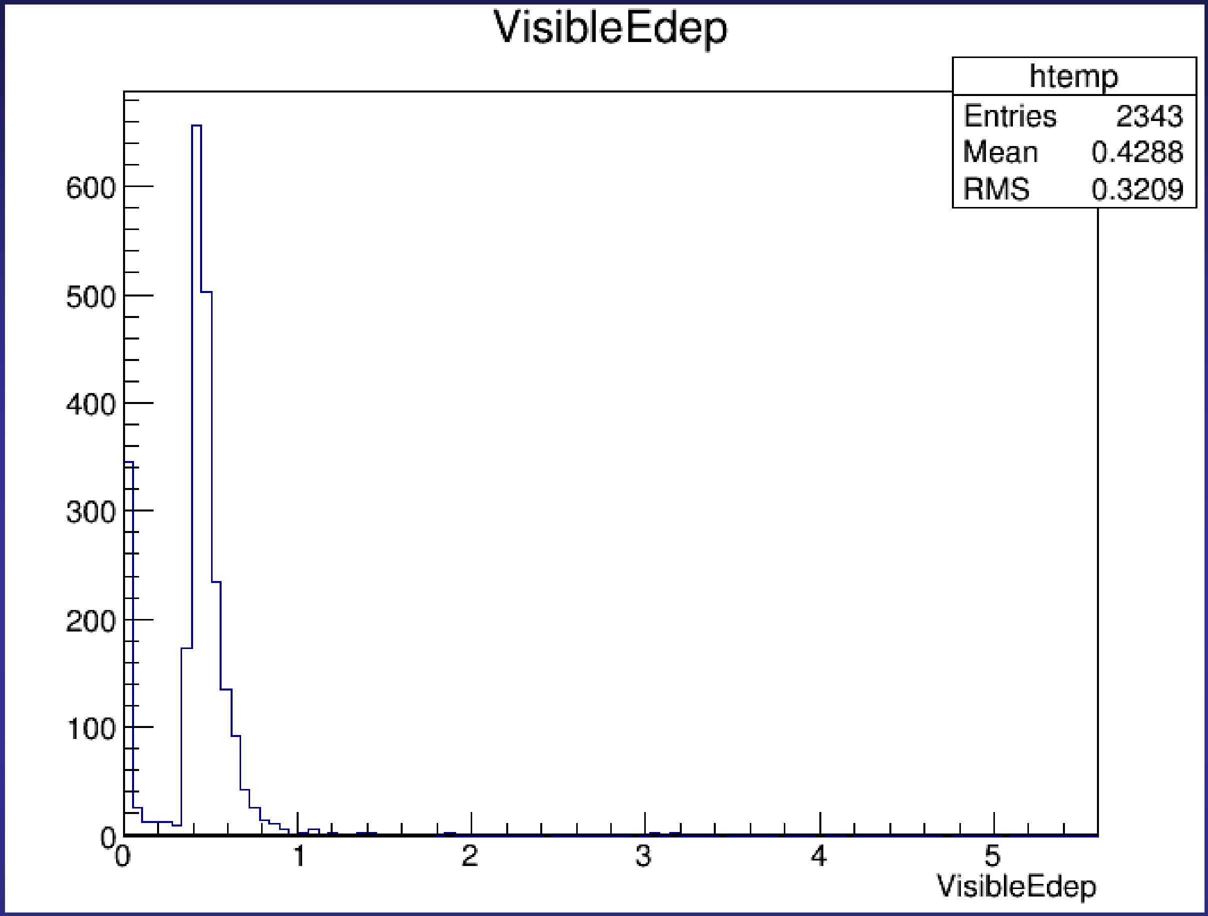


Light Yield Simulations



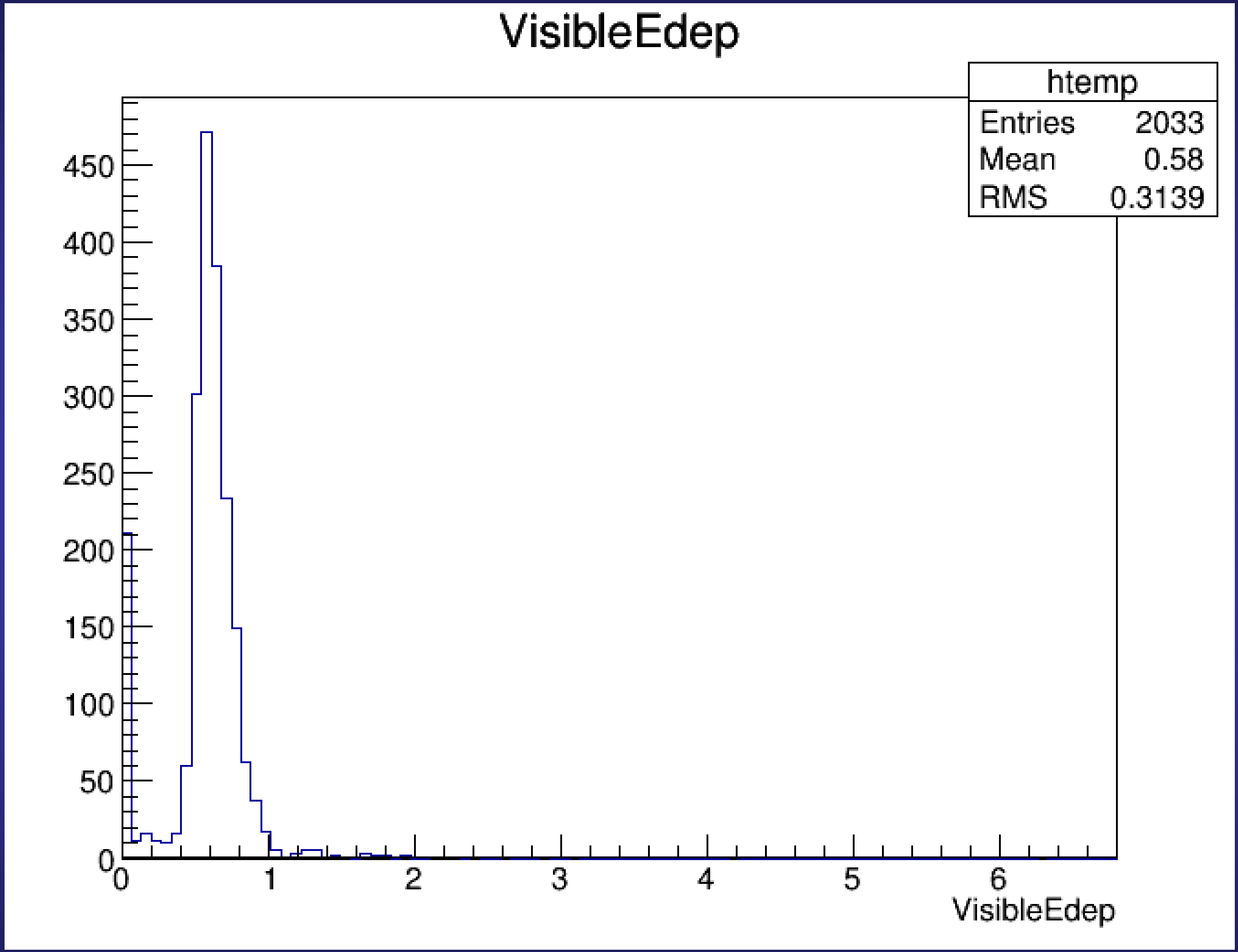
- 1mm square fibres, 2 planes x and y.
- Yellow is water.
- 200 MeV protons.
- Following results for 1x10^5 protons, gaussian with 1cm width in x and y, 0.005 x' and y', Gaussian momentum spread width 20MeV.

Scintillation light yield in one fibre



- Visible energy deposits (MeV) in one fibre in the middle of the detector.

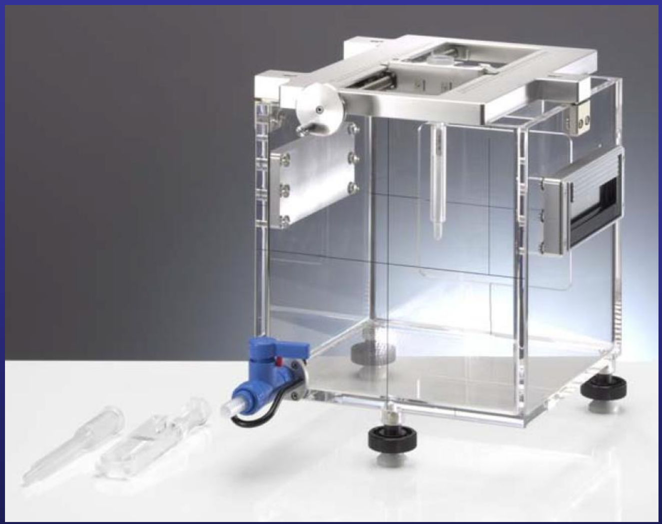
Scintillation light yield in one fibre in layer 3



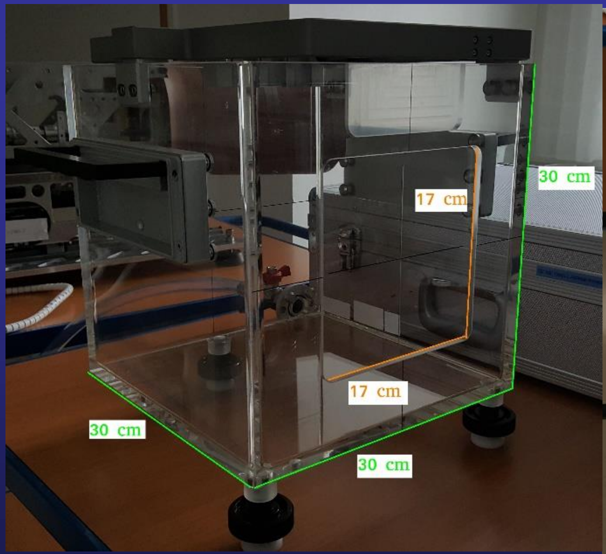
Water Phantoms

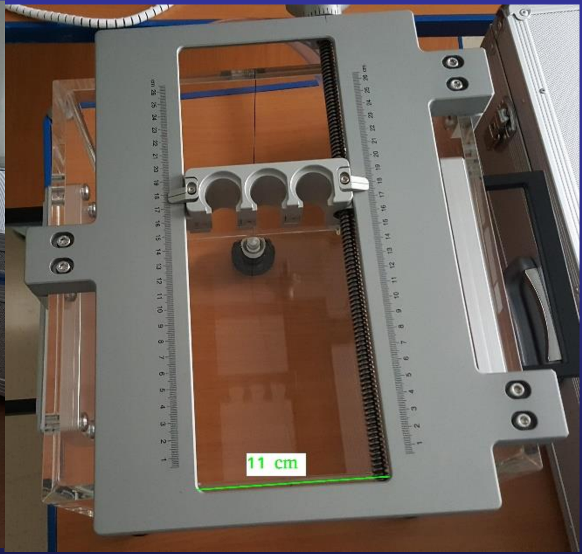
- Inhomogeneous materials in the beam path.
  - Sample holders, support frame, joins between water equivalent plastic.
  - Comparison of linear energy transfer more complicated.

- Water bath and mechanism for moving the sample.
  - Commercially available.



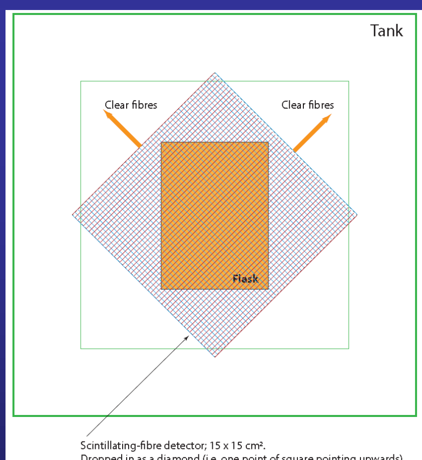
T41023 from PTW





Fibre Planes

- 5 stations consisting of two 'doublet layers' of 250μm diameter scintillating fibres glued on a carbon-fibre station body.
- Doublet layers are arranged such that the fibres in one layer run at an angle of 90° to the fibres in the other layer.
- Clear-fibre light guides transport the scintillation light to the photo-sensors.



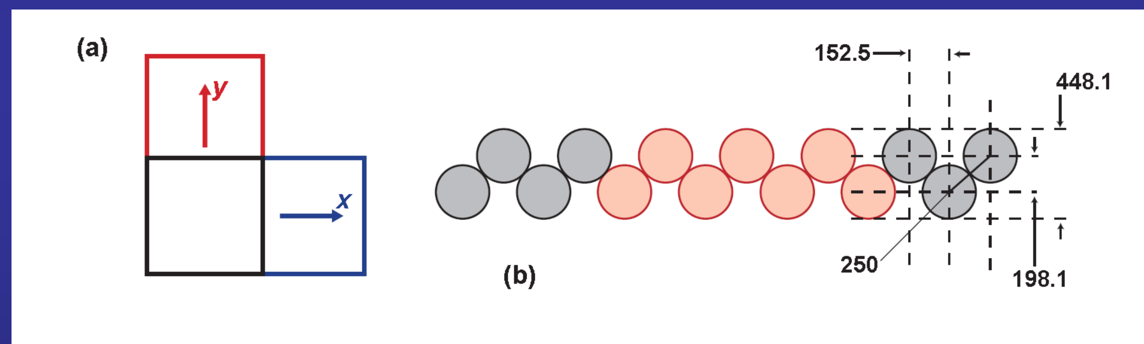
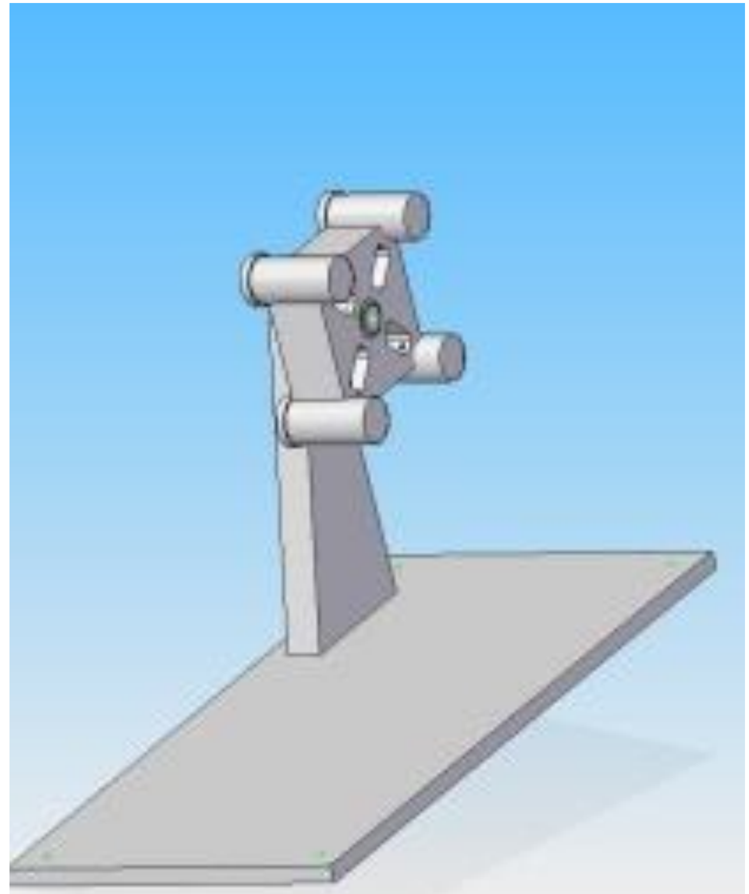


Figure 4: (a) Arrangement of the doublet layers in the scintillating-fibre stations. The square bounded by the solid black line shows the limit of the active area. The regions bounded by the solid blue and green lines indicate the direction that the individual 250 μm fibres run (moving outward from the centre) in the x and y directions respectively. (b) Detail of the arrangement of the scintillating fibres in a doublet layer. The fibre spacing and the fibre pitch are indicated on the right-hand end of the figure in mm.

- Engineering input from Geoff Barber on construction of the fibre planes.

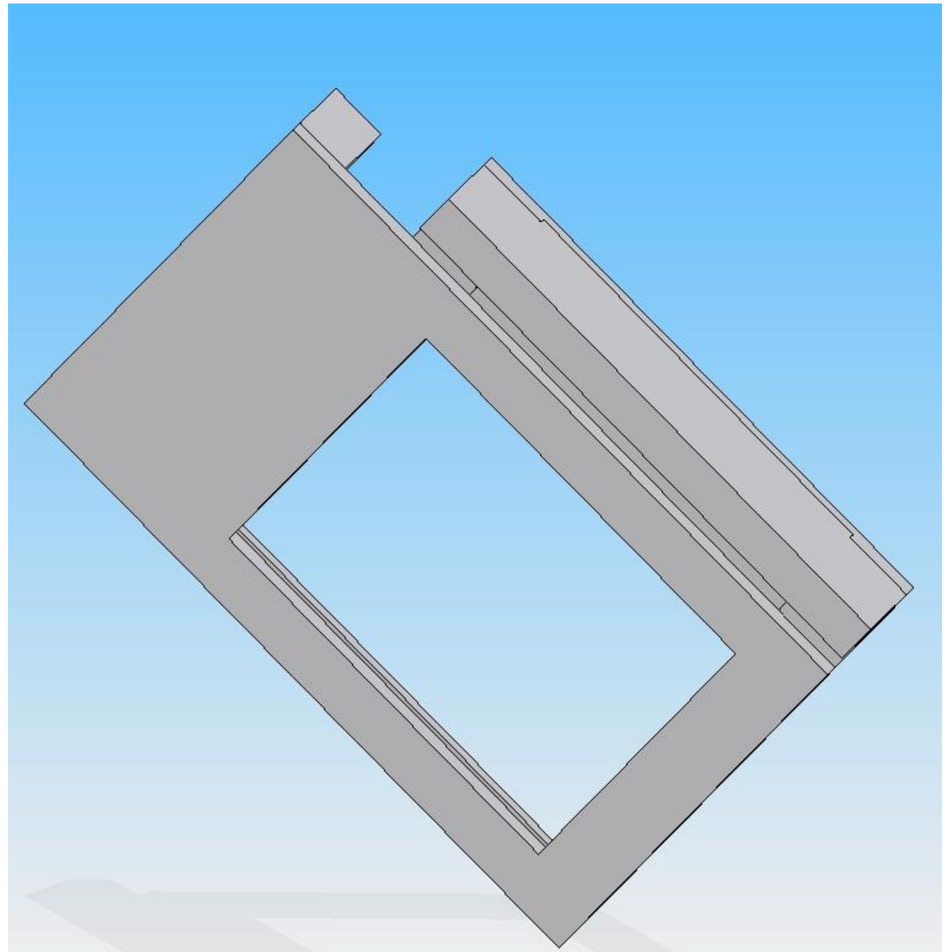
Idea for the Manufacture of Planes

The model shows a rotating boss with 4 PTFE Lobes.
The idea is to wind the fibre straight from the bobbin
Around the 4 lobes ensuring that it is tight against the
preceding fibre. This will give 4 straight sections on
Which the plans can be fabricated. The gap below
the newly formed plane will allow for a support frame
to be inserted and the fibres and any potting block
can be inserted. If we only want the plane (no tails to
take into a plug) then one can imagine making 4 planes
at a time. If however tails are required then this could be
reduced to 2. Jigs and fixings could be attached to the
central boss to hold the frame in place whilst
bonding/curing of adhesives take place.



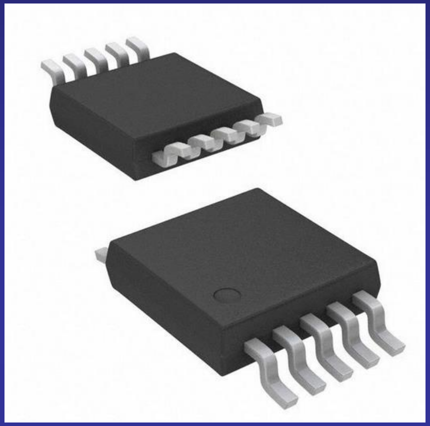
Possible means of making a double plane

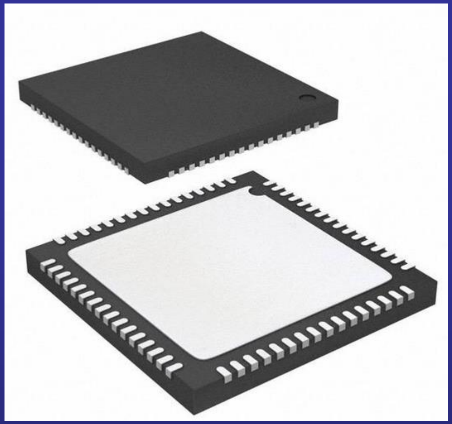
A single plane could be made with the fibres on one face all going into a header which could have a second header attached using plain transmission fibres to minimise ‘noise. This is similar to the Mice scintillating tracker.



Fibre Readout

- Photodiode.
  - Opto Diode Corp ODD-1B.
- Low-noise amplifier.
  - Texas Instruments LMP7712.
- Digitiser.
  - Analogue Devices Inc. AD7779
- PCB mounted readout backend.
- Option for better time resolution by using SiPMs.





Summary

- Concept of an instrumented phantom using scintillating fibre planes to measure shot-by-shot dose in real time.

- Initial simulations started.

- Next steps
  - More details in the simulation.
  - Design and build the fibre plane construction mechanism.
  - Proposal in preparation.