Calorimetry For Ultra-High-Dose-Rate Very High Energy Electron Beams

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Background

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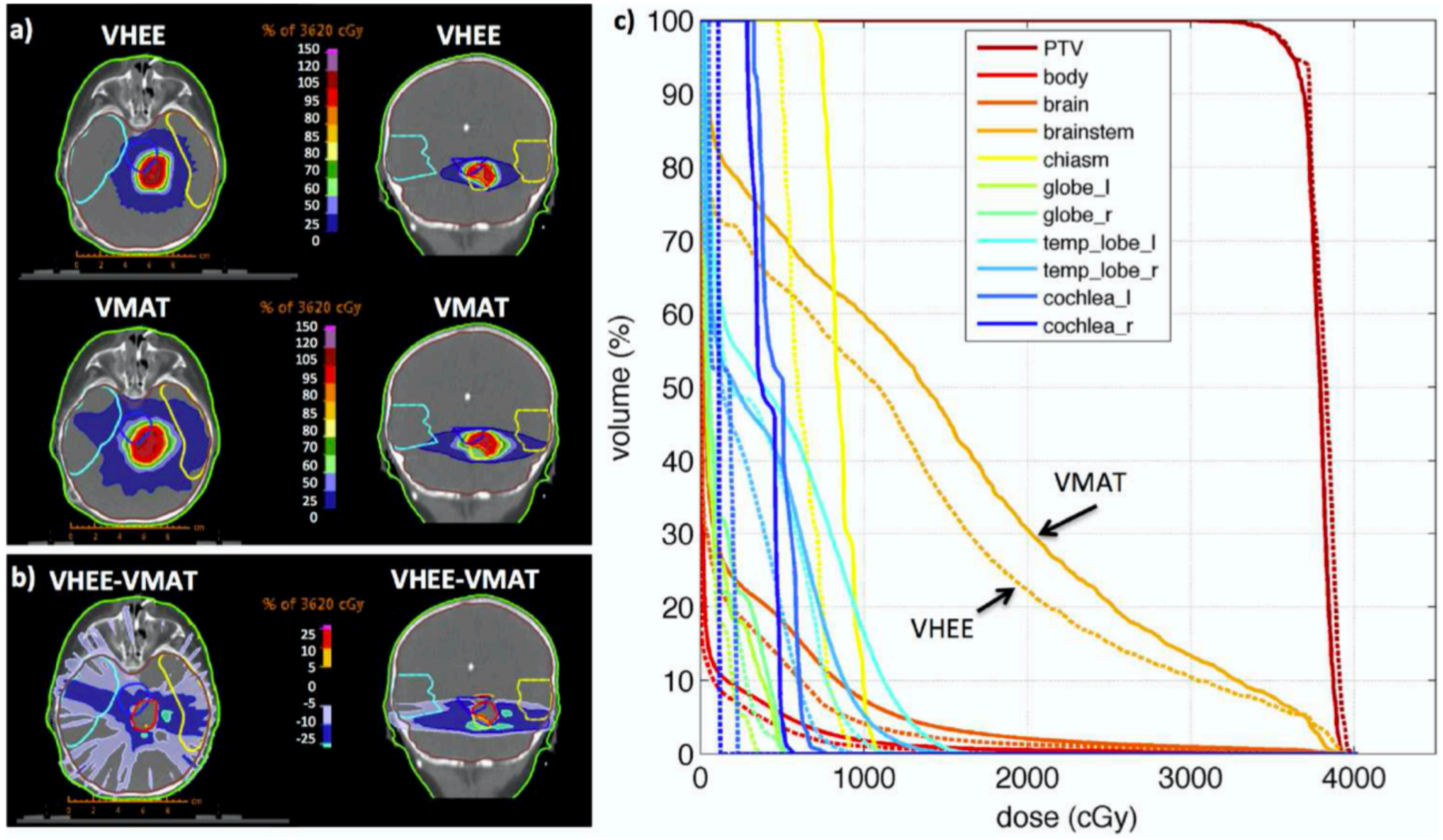
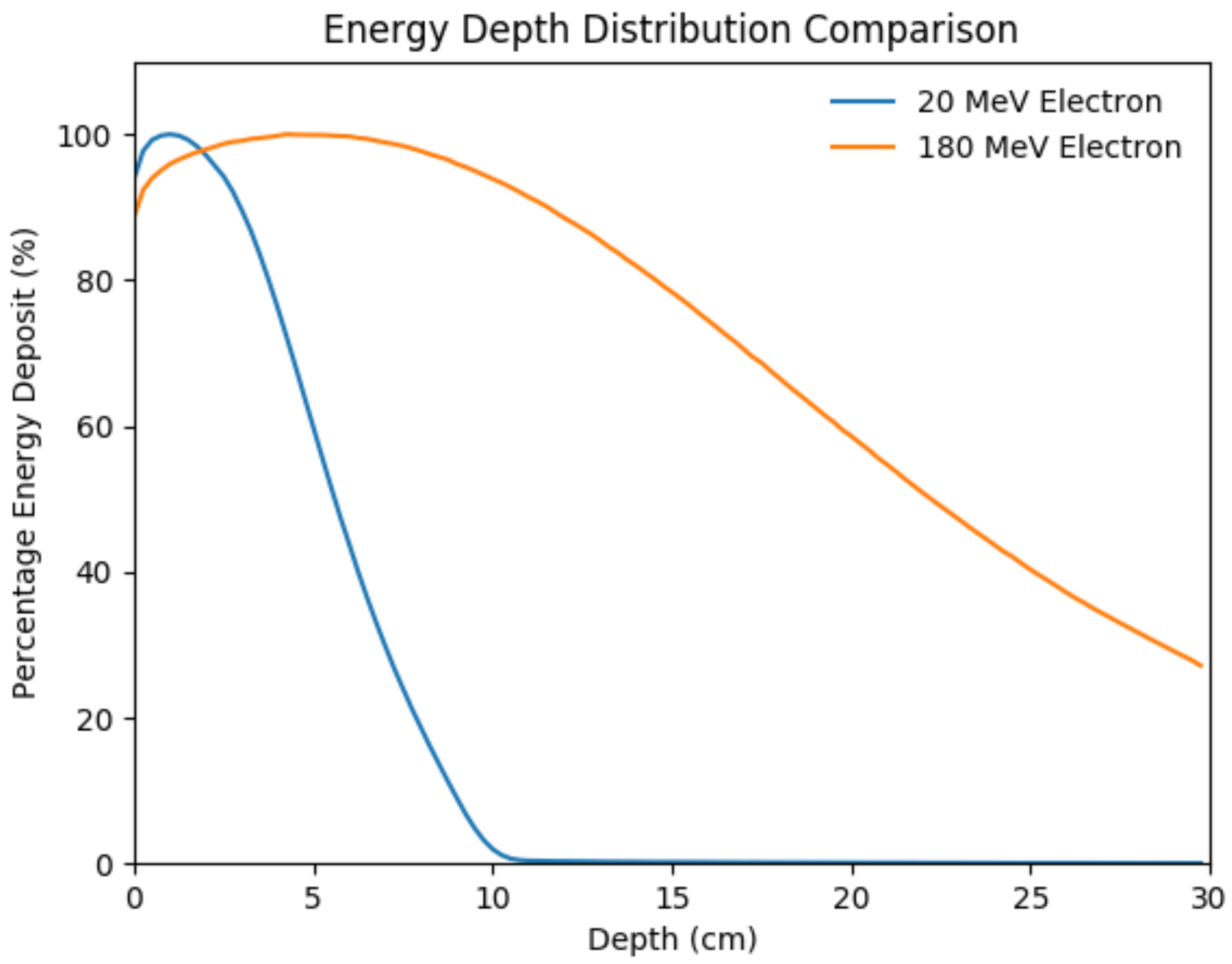
- Monte Carlo treatment planning studies have shown that Very High Energy Electrons (VHEEs) can provide a **more conformal dose distributions** and **reduced integral and organ-at-risk doses**(*C. DesRosiers 1999, Schuler et al. 2017, Bazalova-Carter et al. 2015*).
- VHEEs can also be **electromagnetically scanned and focused, reducing excess irradiation** of surrounding healthy tissue (*K. Kokurewicz et al. 2019*).



Bazalova-Carter et al. 2015

VHEE Dose Distribution in Water



- Along the central axis, depth of maximum dose for 20 MeV clinical beam is approximately 1 cm.
- 180 MeV VHEE beam delivers maximum dose at around 5 cm.
- Reduction in lateral scattering and divergence at higher energies.

Calorimeter Experimental Setup

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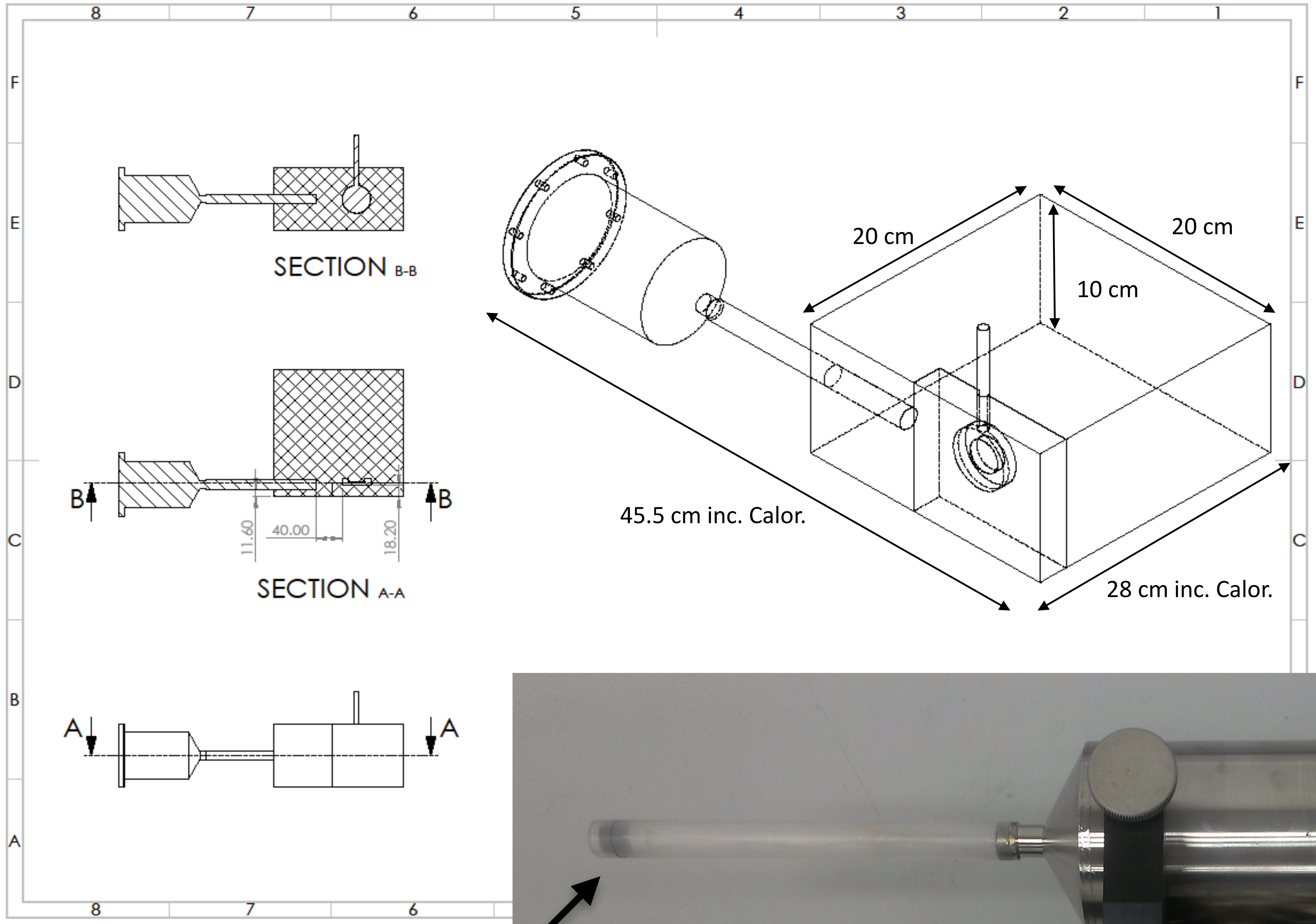
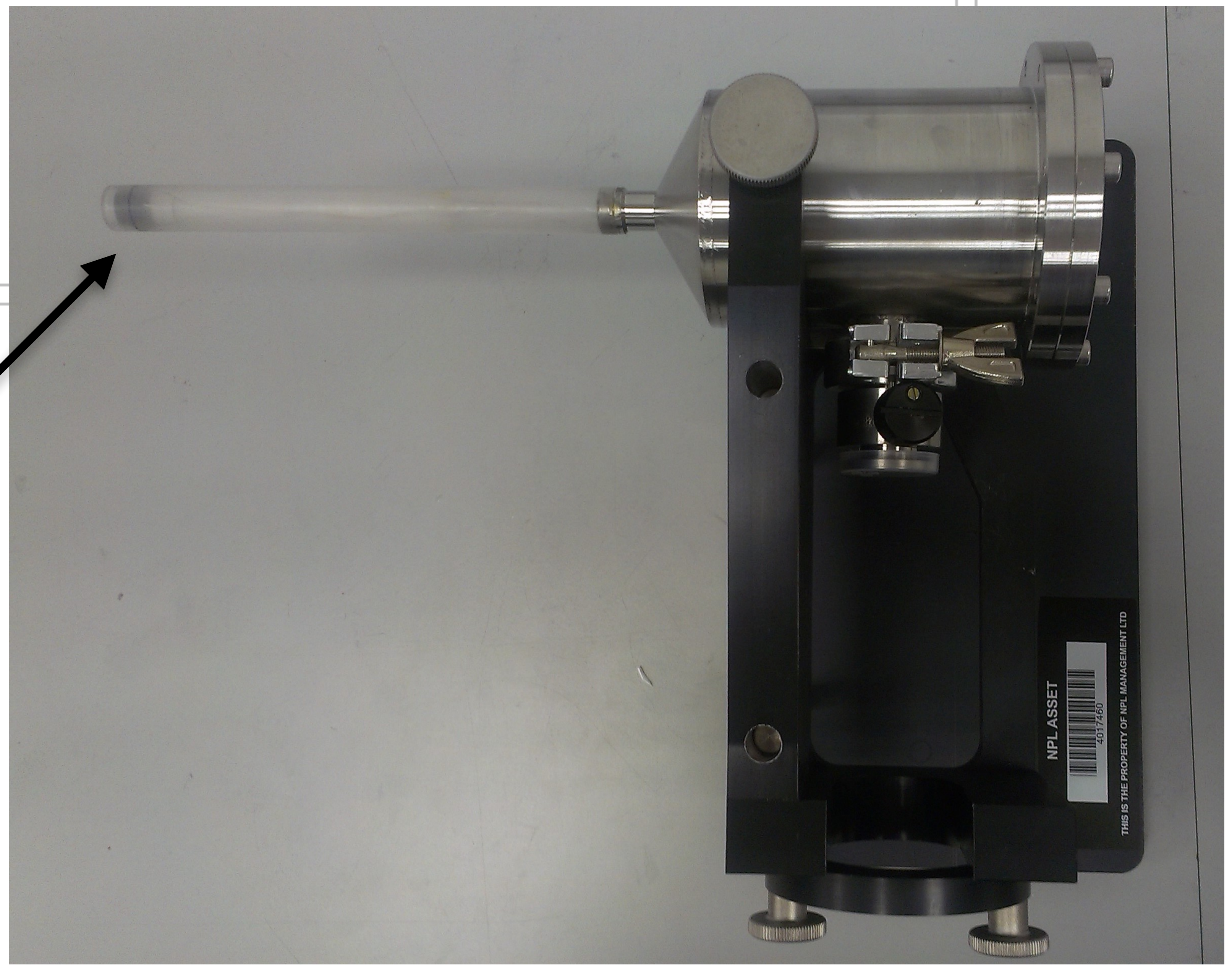
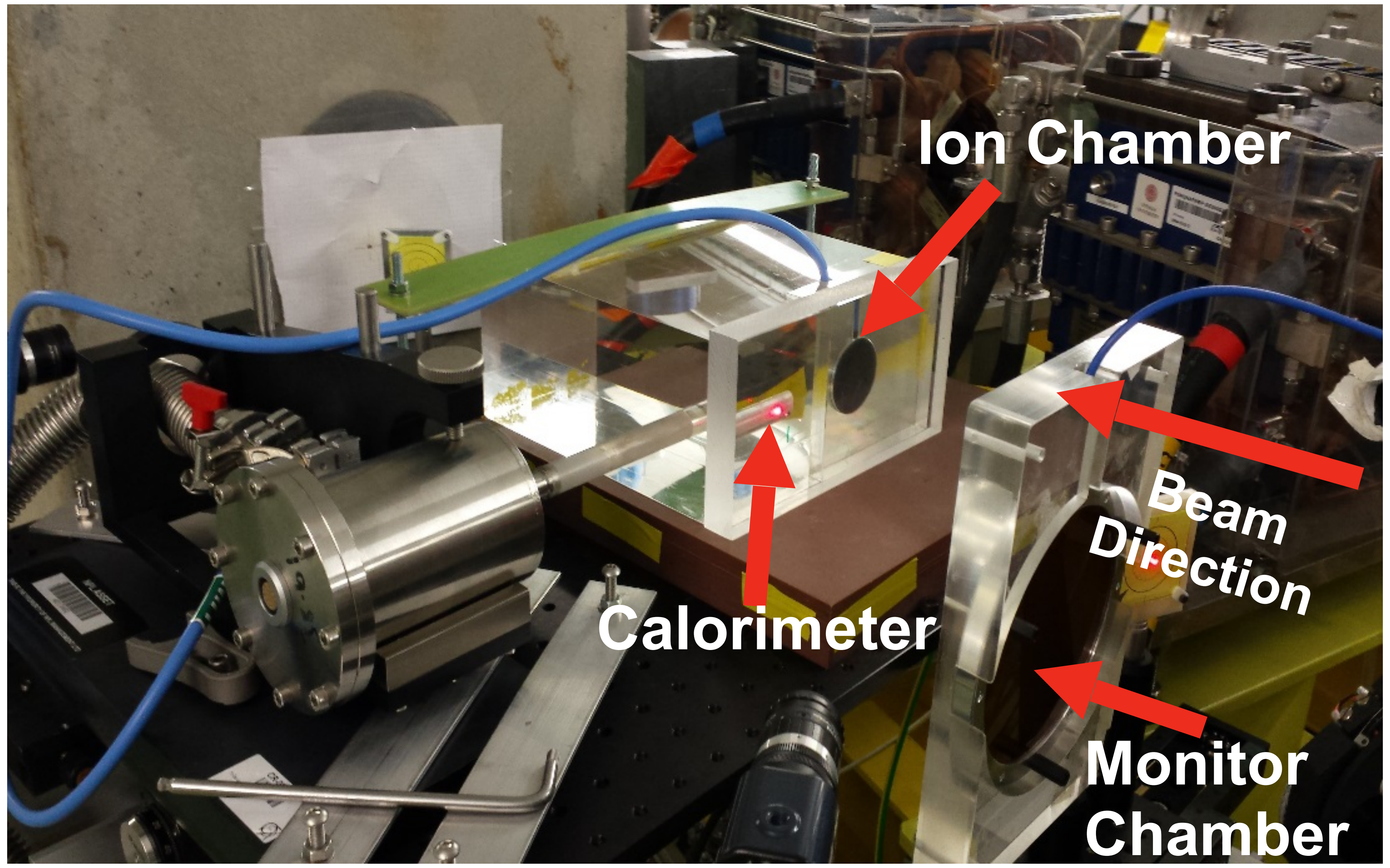
- Absolute graphite calorimeter designed by the NPL for IMRT radiation.
- Core is cylindrical with diameter 7mm and length 7mm.
- Calorimeter placed inside custom PMMA phantom next to ionisation chamber.
- Vacuum created inside calorimeter body and housing.

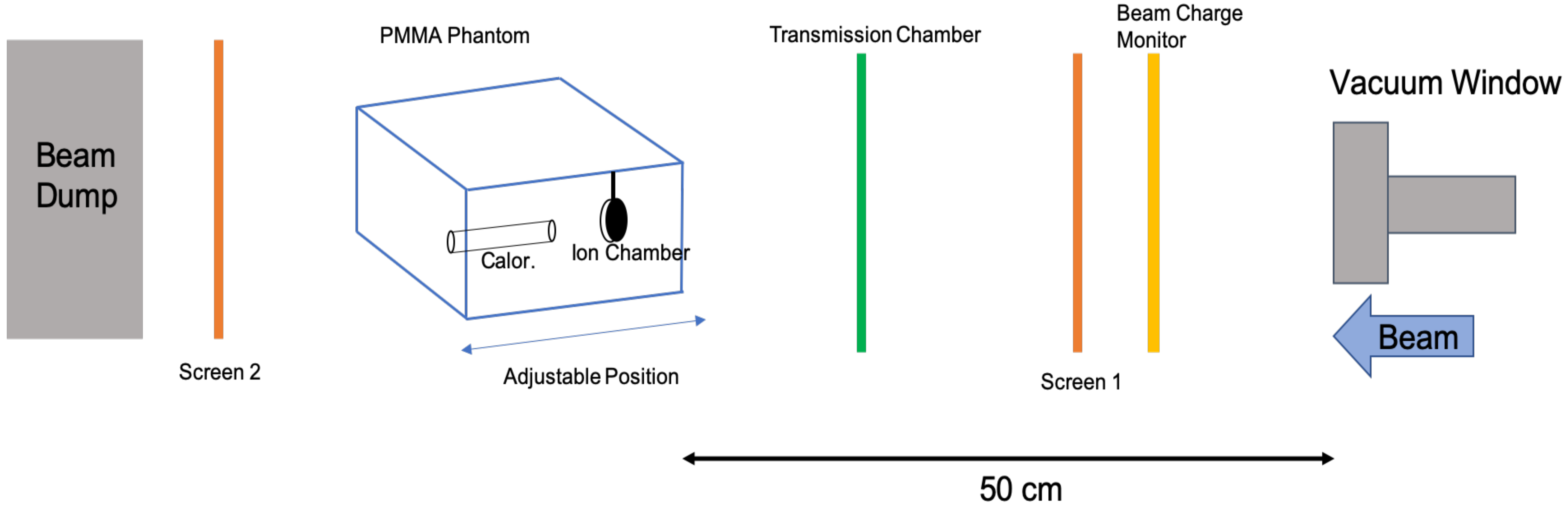




Calorimeter core

Calorimeter Experiments at CERN CLEAR





- CLEAR facility provided quasi-monoenergetic electron beam at approx. constant 200 MeV with energy spread between 0.25% and 6.5% (Gamba et al. 2017) .
- Circular field with x and y σ of approximately 5 mm.
- Instantaneous dose rates investigated ranged between 5×10^6 Gy/s and 3.1×10^8 Gy/s.
- Pulse widths ranged between 666ps and 133.2ns.

Calculation of Dose from Calorimeter

- The dose to the calorimeter is calculated by measuring the temperature rise when exposed to ionising radiation:
- $$D_{g,cal} = \frac{E_{dep}}{m_{core}} = c_g \Delta T$$
- The dose-to-water is calculated as follows:
- $$D_{w,cal} = D_{g,cal} C_{g,w} k_{gap} k_{imp} k_{non-g} k_{vol}$$
- At present for this work k_{vol}, k_{imp}, k_{non-g} are all taken to be unity.

Dose-to-water Conversion Factor

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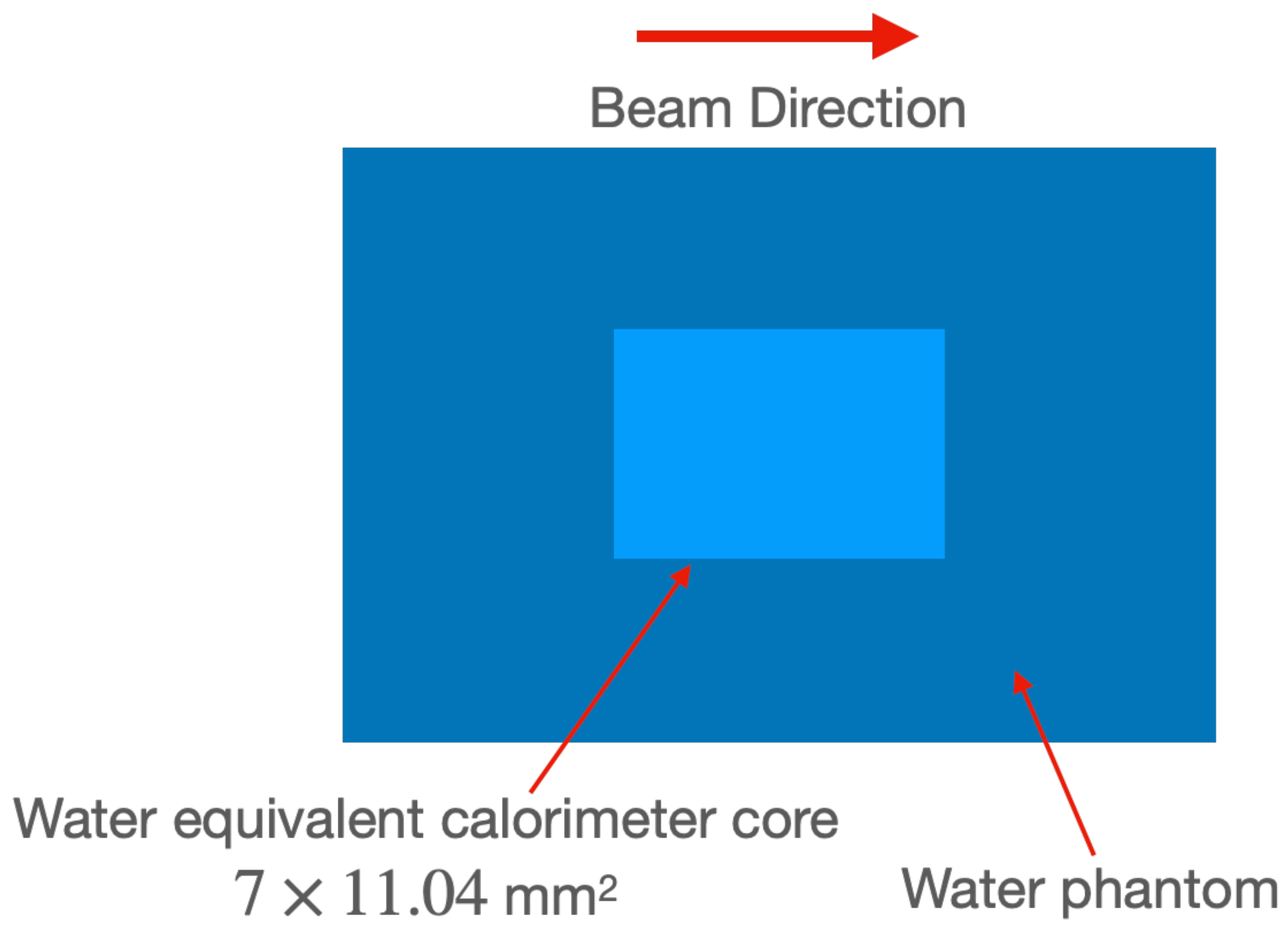
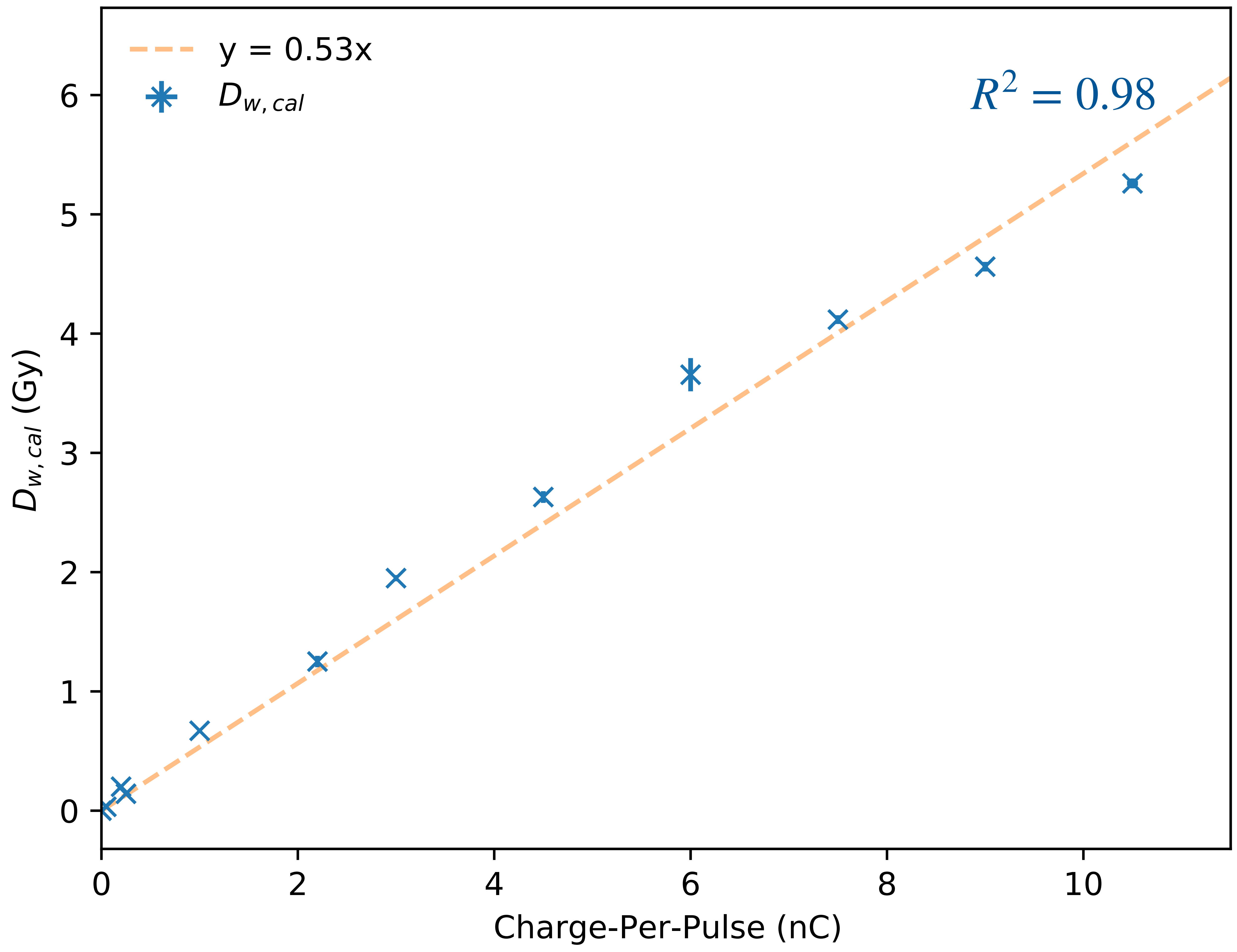
- Calorimeter volume was scaled to WET along the beam direction.
- Diameter of core increased from 7mm to 11.04mm.
- PMMA phantom build-up was also scaled to WET.
- Dose scored again in WET calorimeter core.

- $C_{g,w} = 1.103$ with $0.063\ \%$ relative uncertainty.



Measured Dose

- As expected, dose-to-water per-pulse increases with increasing charge-per-pulse of beam.
- Trend is close to linear across charge-per-pulse range.
- Charge-per-pulse ranged from ~0.05nC/pulse to 11nC/pulse.
- Dose-per-pulse measured was between 0.03Gy/pulse and ~5.27Gy/pulse.

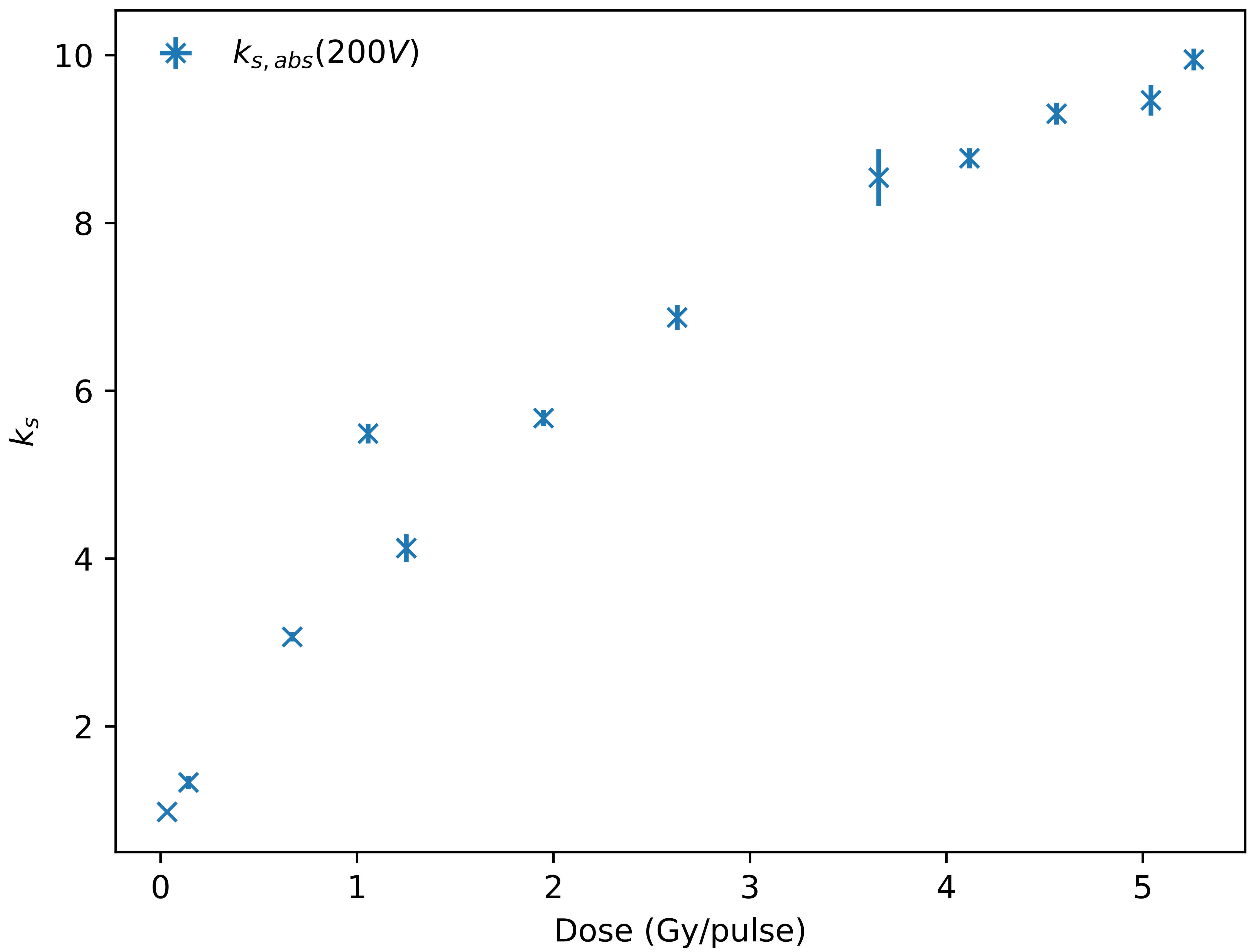


Ion Recombination

- Significant ion recombination was found when comparing calorimeter dose with that of ionisation chamber.

$$k_s = \frac{D_{w,cal}}{M \mathbf{N}_{\mathbf{D,w,Q_0}} k_{TP} k_{elec}}$$

- Large ion recombination effects in secondary standard ion chamber leads to underestimations in the measured dose.
- Collection efficiency of chamber was found to be as low as 4% in some beam configurations.



Recombination factor, k_s, as a function of dose-per-pulse. ***$k_{s,abs}$ was found to increase close-to-linearly with dose-per-pulse.***

Conclusions and Outlook

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- This work aims to develop a traceable dosimetry protocol for high dose-rate VHEEs which could be applied to future VHEE radiotherapy development.

- Monte Carlo calorimeter correction factors have been determined and the dose-to-water inferred from the calorimeter measurements.

- Dose-to-water was found to increase linearly with charge-per-pulse in the beam ranging from 0.03Gy/pulse to 5.27Gy/pulse.

- When comparing calorimeter dose to that of an ion chamber, significant ion recombination was found.

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