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Dosimetry of Ultra-Short High Dose-Per-Pulse Very High Energy Electron Beams

Michael McManus[1,2], Anna Subiel[1], Francesco Romano[1,4], Hugo Palmans[1,3], Gary Royle[2]

[1]National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW
[2]University College London, Gower Street, London, WC1E 6BT
[3]MedAustron, Marie Curie-Strasse 5, 2700 Wiener Neustadt, Austria
[4]Instituto Nazionale di Fisica Nucleare, Sezione di Catania, Catania, Italy

Background

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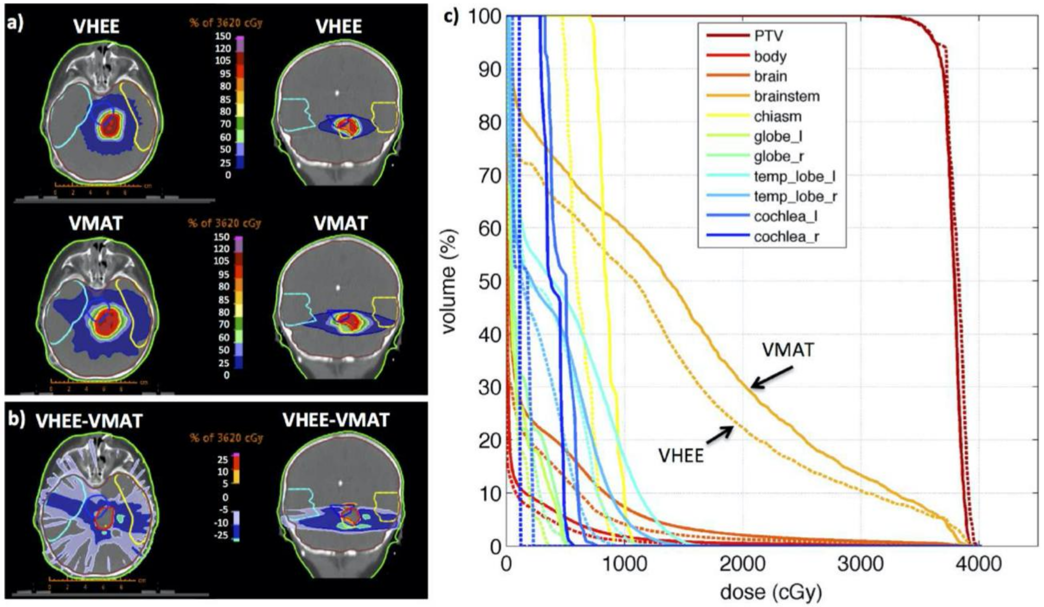
- Monte Carlo treatment planning studies have shown that Very High Energy Electrons (VHEEs) can provide a **more conformal dose distributions** and **reduced integral and organ-at-risk doses**(*C. DesRosiers 1999, Schuler et al. 2017, Bazalova-Carter et al. 2015*).

- 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

- FLASH radiotherapy promises reduced healthy tissue toxicity by increasing significantly the dose-rate of delivery. Combining this technique with VHEEs would allow for the benefits of the **FLASH effect to be realised for deep-seated and complex tumour sites** (*Vozenin et al. 2019*).

Ion Recombination

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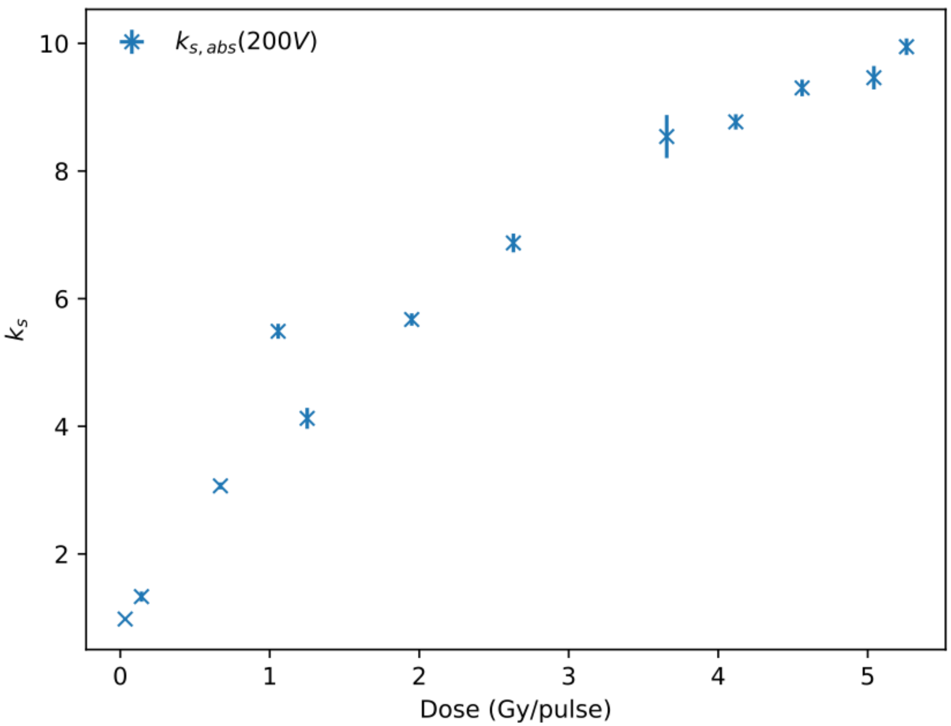
- **Difficulties arise** however when one attempts to perform **traceable dosimetry** measurements using VHEEs and FLASH.
- Our recent study using VHEEs with dose-per-pulse **up-to 5.26 Gy/pulse and instantaneous dose-rates up-to approx. 3 x 10^8 Gy/s** can cause the collection efficiency to fall to as low as 4% (*McManus et al. 2020*).
- Large ion recombination effects in secondary standard ion chamber leads to **underestimations in the measured dose**.
- Currently available **recombination correction models show varied success**.



Ion Recombination

- Models compared include *Boag et al. 1996, Di Martino et al. 2005* and *Petersson et al. 2017.*

- The logistic model used by ***Petersson et al.* shows the best fit to data.**

- All analytical models from Boag and Di Martino give a general qualitative fit, however, show discrepancy throughout the dose-per-pulse range.

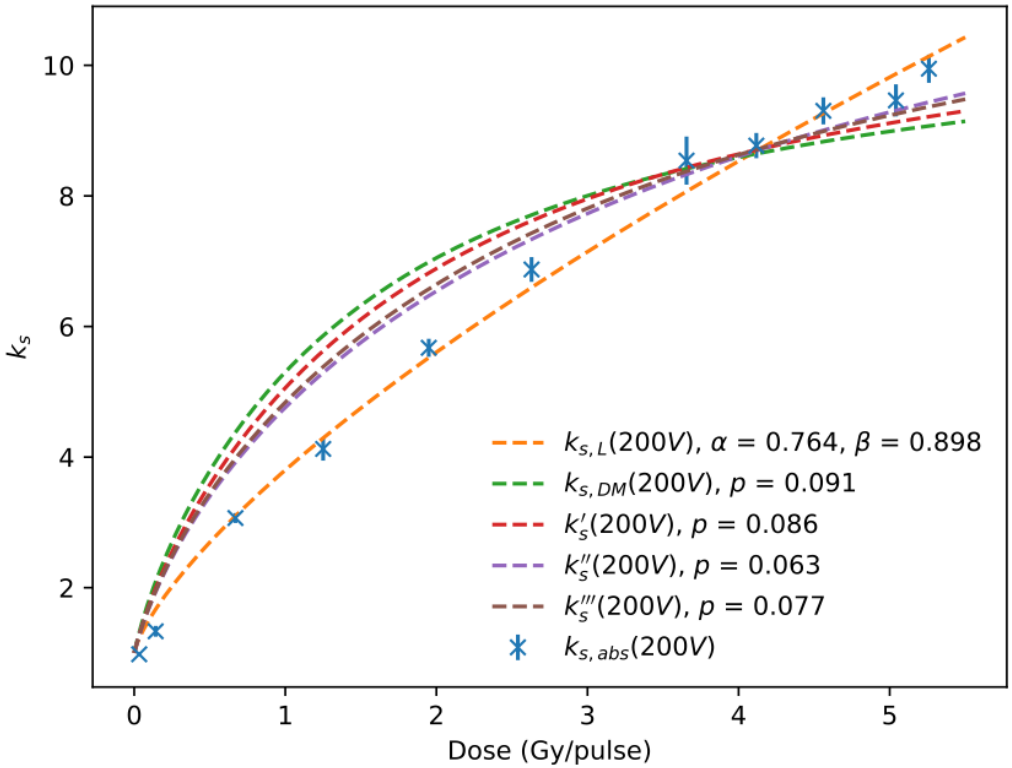


Figure 1: Recombination factor, k_s, as a function of dose-per-pulse with multiple models fitted. $k_{s,abs}$ ***was found to increase close-to-linearly with dose-per-pulse.***

Uncertainty Budget and Fano Test

- In order to fully appreciate these preliminary findings, a complete **uncertainty budget must be completed**.
- This includes the dissemination of correction factors such as the **ionisation chamber perturbation factors and beam quality correction factor.**
- These require detailed Monte Carlo simulations to be conducted and the accuracy of **transport algorithm to be determined**.
- A thorough **Fano test of the Geant4 general purpose code** for various physics lists was performed.
- Provided one is in a region of charged particle equilibrium, the Fano test should show a consistent dose across a geometry of constant material composition but varying density.

Results

- The plot here shows the ratio of dose to the entrance wall and cavity of a Roos ionisation chamber.
- In theory, this ratio should be equal to 1 provided the physics transport algorithm is correctly implemented.
- Two transport parameters required were the ***finalRange*, which is step size of a particle at the boundary** between two regions, and the ***dR/R* parameter, which is the fractional decrease in step size per-step as the particle approaches a boundary**.

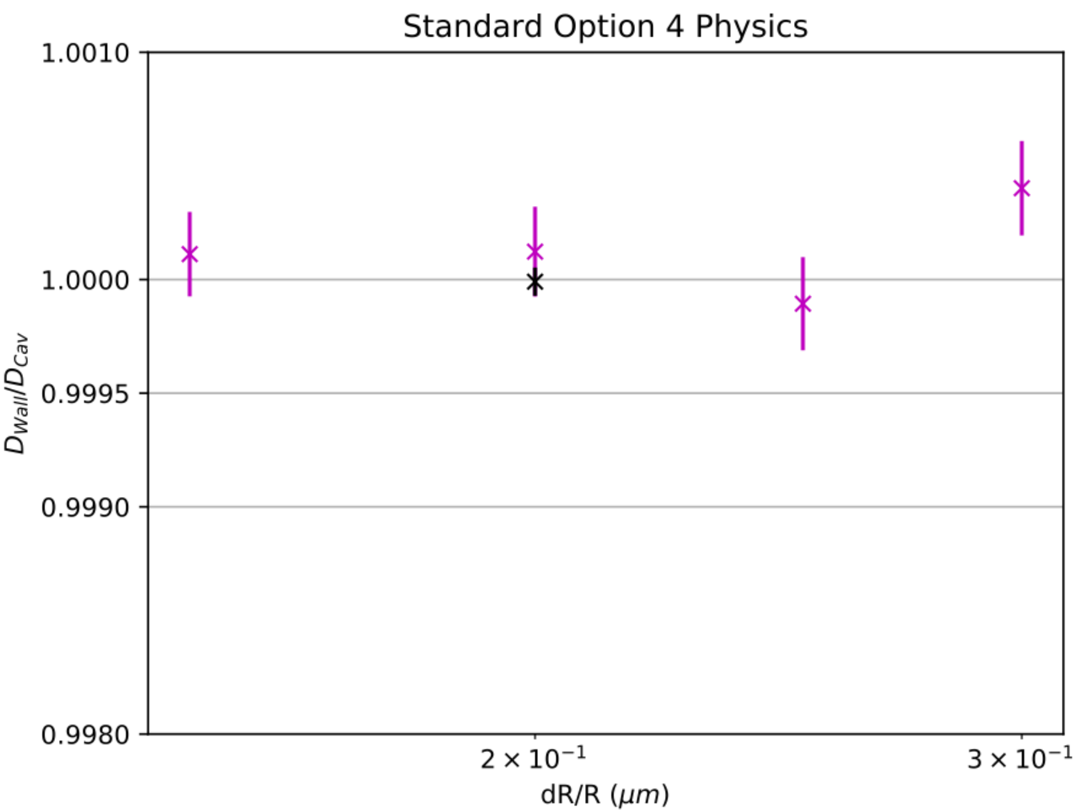


*Figure 2: Dose-to-wall/dose-to-cavity ratio. Constant **finalRange = 1um** with varying dR/R. All but one purple point passes Fano test with **uncertainty ~0.02% (k=1)**. The black point shows a pass with 10 times more histories and **uncertainty ~0.006% (k=1)**.*

Conclusions and Outlook

- Our study has shown a significant dose-per-pulse dependence on ion recombination, making **traceable dosimetry difficult** with high dose-per-pulse and dose-rate radiotherapy techniques.

- With the success of the Fano test in Geant4, the next stage is to calculate the ion chamber perturbation factors using the same physics as with the Fano test.

- From this it is possible to **derive an accurate value for the beam quality correction factor and calibration factor** for non-standard beams such as VHEEs.

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

Thank You!

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