# Analytical modeling of a broad Very-High Energy Electron (VHEE) beam and its implementation in matRad for dose calculation

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**Résumé**

**Modélisation analytique d'un faisceau large d'électrons de très haute énergie (VHEE) et implémentation dans matRad pour des calculs de dose**

Introduction: Very high-energy electrons (VHEE, 50-200 MeV) are being investigated as a promising modality for deep-seated tumors. VHEE beams could potentially combine ultra-high dose rate irradiation (FLASH), which confers increased robustness to motion, with deep tissue penetration (Vozenin, 2019), reduced lateral scattering and improved robustness to tissue heterogeneity, compared with conventional electron beams (6-20 MeV) (Sitarz, 2025). Recent developments in accelerator and beam delivery technologies are exploring electromagnetic scattering and passive beam-flattening approaches to generate broad and spatially homogeneous VHEE fields. This work aims at proposing a robust analytical dose engine for broad VHEE beams (FLASHDEEP project). The calculations are performed through the open-source software matRad and are validated by GATE Monte-Carlo simulations.

*Material and Methods:* The analytical dose calculation model is based on the Hong pencil-beam algorithm (Hong, 1996), in which the broad beam is decomposed into elementary beamlets. The investigated 145 MeV VHEE source and beam delivery shaping system were simulated with GATE10.0 using proprietary confidential data, to generate the dose deposition of 1) the broad beam and 2) an elementary Gaussian beamlet ($\sigma$ = 5 mm). These two steps enabled to build a database containing 1) the contribution of each elementary beamlet to the broad beam through fluence deconvolution weights at the phantom surface and 2) the beamlet parametrization in water, including central-axis depth-dose curves and single/multiple lateral scattering components (from double Gaussian fits). The total dose distribution was reconstructed by weighting the contribution of each beamlet from the matRad Hong dose engine. For model validation, analytical dose calculations are compared to the GATE simulation results in several geometries, including a water and TG119 phantoms.

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***Results:*** Characterization of the FLASHDEEP VHEE beam in a water phantom enabled a rigorous comparison of lateral dose profiles and percentage depth-dose distributions at different depths. Ongoing results show that the field size (50% of the dose along the axis) was about 16.6 cm with matRad (M) and 16.4 cm with GATE (G) at 10 cm. The penumbra was equal to 1.7 cm (M) and 0.9 cm (G) respectively at the same depth, while the flat region, defined as within ±3% of the maximum dose was measured 12.8cm (M) and 14.0cm (G). R100, R80 and R50 were also compared.

*Conclusion:* The broad VHEE beam configuration was successfully implemented in matRad through GATE simulations of VHEE beamlets database. GATE simulations of the broad beam allowed us to evaluate the validity of the matRad analytical model. Further improvements are expected from current work including photon contamination generated by Bremsstrahlung from the elements of the beamline. Perspectives include retrospective clinical investigation of potential VHEE treatments regarding VMAT glioblastoma treatments.

**Mots-Clés:** Radiotherapy, VHEE beams, Monte Carlo simulations, matRad, GATE