Optical simulations of SmartPhantom

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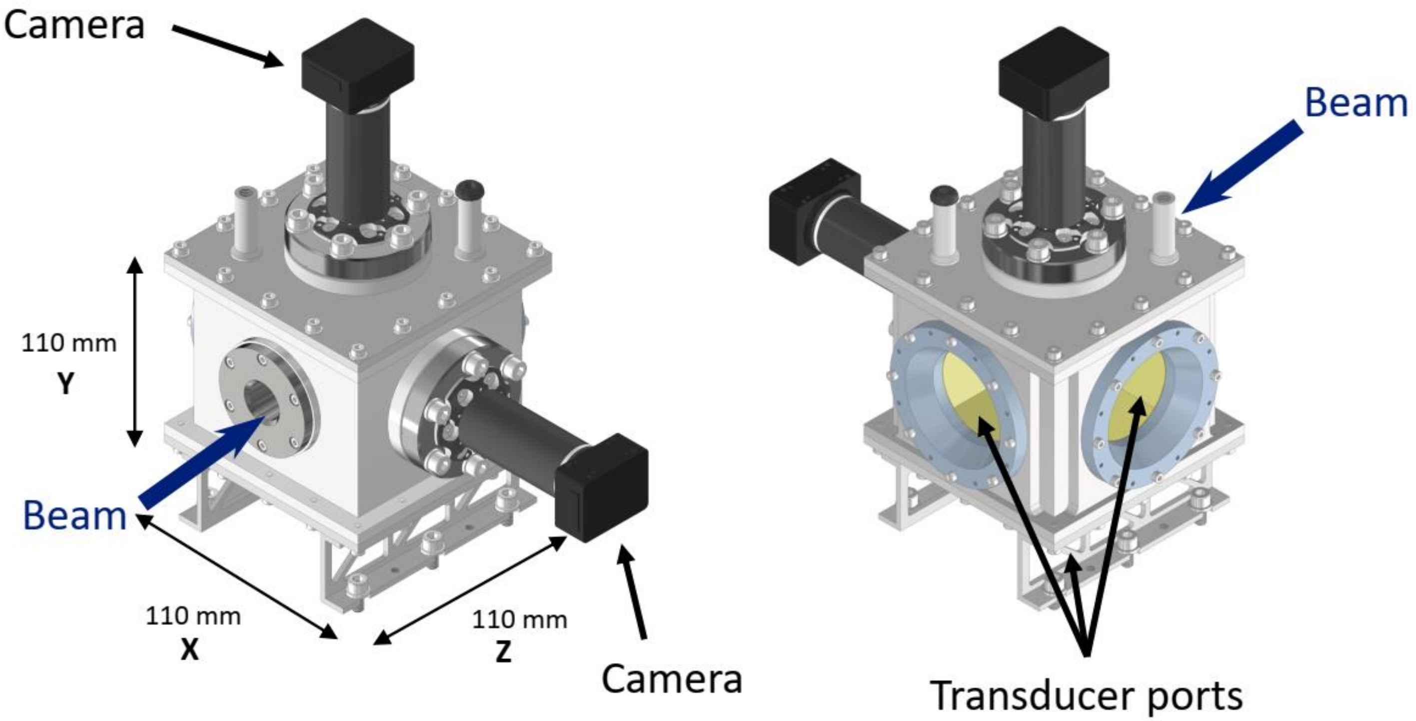
Scintillator-based approach to dose mapping

Here we aim to image the light from a liquid scintillator contained within the volume.

This can act as a cross-check on the ion-acoustic image and the simulations.

This is our proposed “Smart Phantom” with ports for optical cameras and external ultrasonic transducer arrays.



Simulating the scintillator-based approach

1. Scintillator is **UltimaGold XR** contained within the 100×100×100 mm^3 cube;
2. Non-sequential rays are traced with “ray-splitting” enabled (i.e. Fresnel reflection and polarization is accounted for);
3. F#2 imaging optics are a plausible combination of two identical commercial achromatic lenses but have not been in any way optimised;
4. “Black” surfaces use **measured reflectance** (diffuse and specular);
5. The scintillation yield is assumed to be 11200 photons per MeV;
6. The beam is modelled as an elliptical cylinder sub-divided into 0.5 mm thick slices. Each slice has a different intensity and rays are emitted isotropically in each slice;
7. All scintillation light rays have a single wavelength of 427 nm;
8. Image sensor is ideal (no noise).
9. Simulations use **Ansys ZEMAX OpticStudio 2023 R2.01 Pro** (PC is an i5 6/12 core @4.6 GHz peak with 32 Gbytes of 3200 MHz DDR4 memory).

Scintillator properties

Scintillator is UltimaGold XR.

A commercial “cocktail” so some important details are not readily available.

Major component is Diisopropylnaphthalenes (DIPN), we model this in Geant4 as $C_{16}H_{20}$ with a density of 0.96 $g.cm^{-3}$ (real scintillator density).

				Wavelength (nm)								
Liquid											Temperature (C)	
	404.7	435.8	486.1	546.1	587.6	589.3	632.8	656.3	706.5			
Water	1.3432	1.3403	1.3372	1.3345	1.3335	1.3334	1.3321	1.3314	1.3301		20.0	
UltimaGold XR	1.5652	1.5553	1.5445	1.5362	1.5321	1.5320	1.5287	1.5272	1.5245		16.0	

Peak emission wavelength: 427 nm

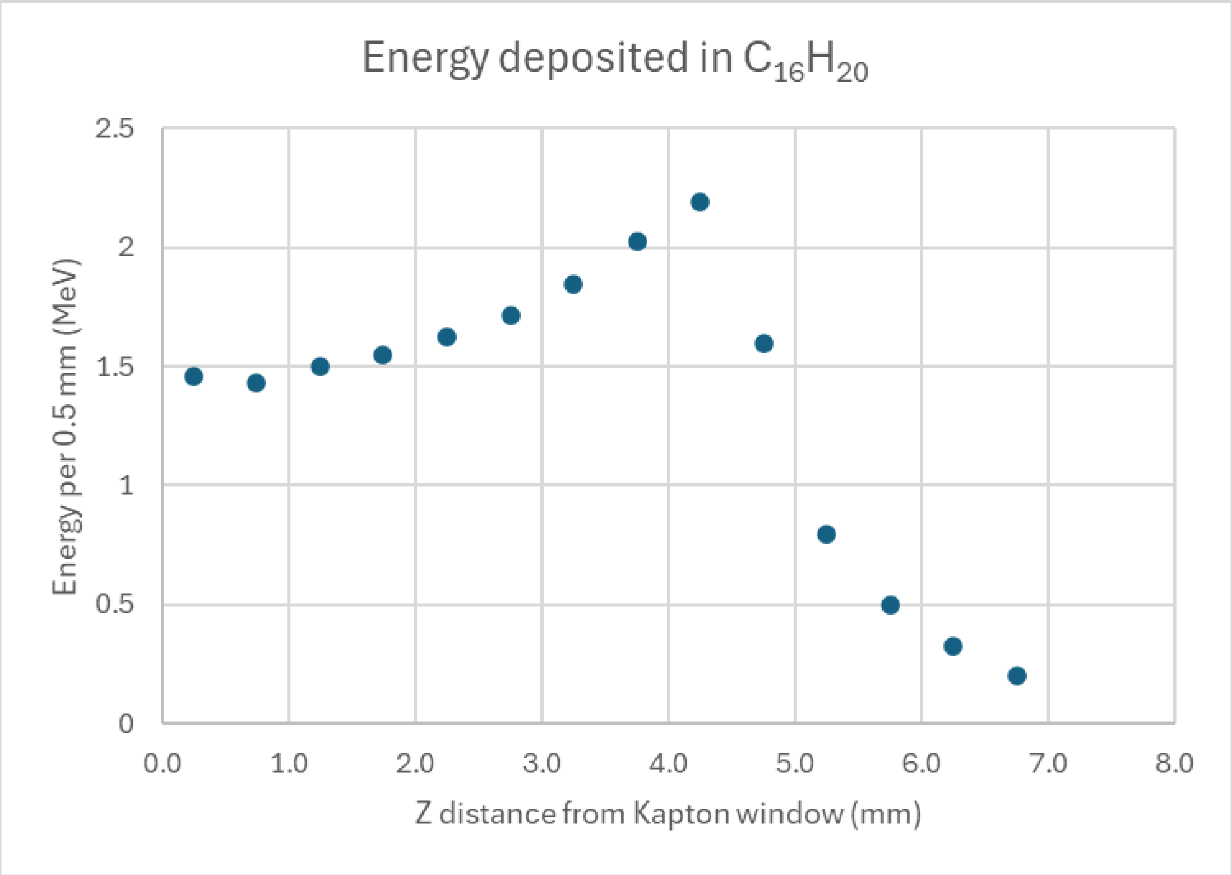
Scintillation yield (photons/MeV) ~ 70% of anthracene. Anthracene yield is 16000 photons/MeV

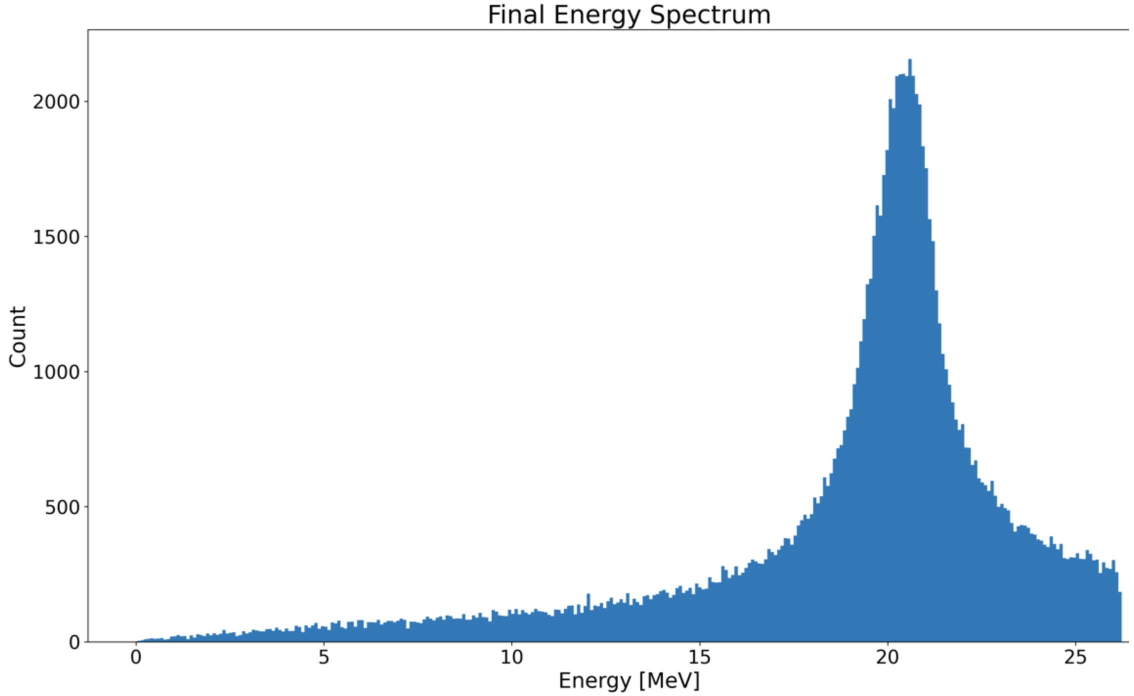
Applied Radiation and Isotopes **82** (2013) 382–388
Radiation Physics and Chemistry **84** (2013) 59–65

Deposited Energy in DIPN

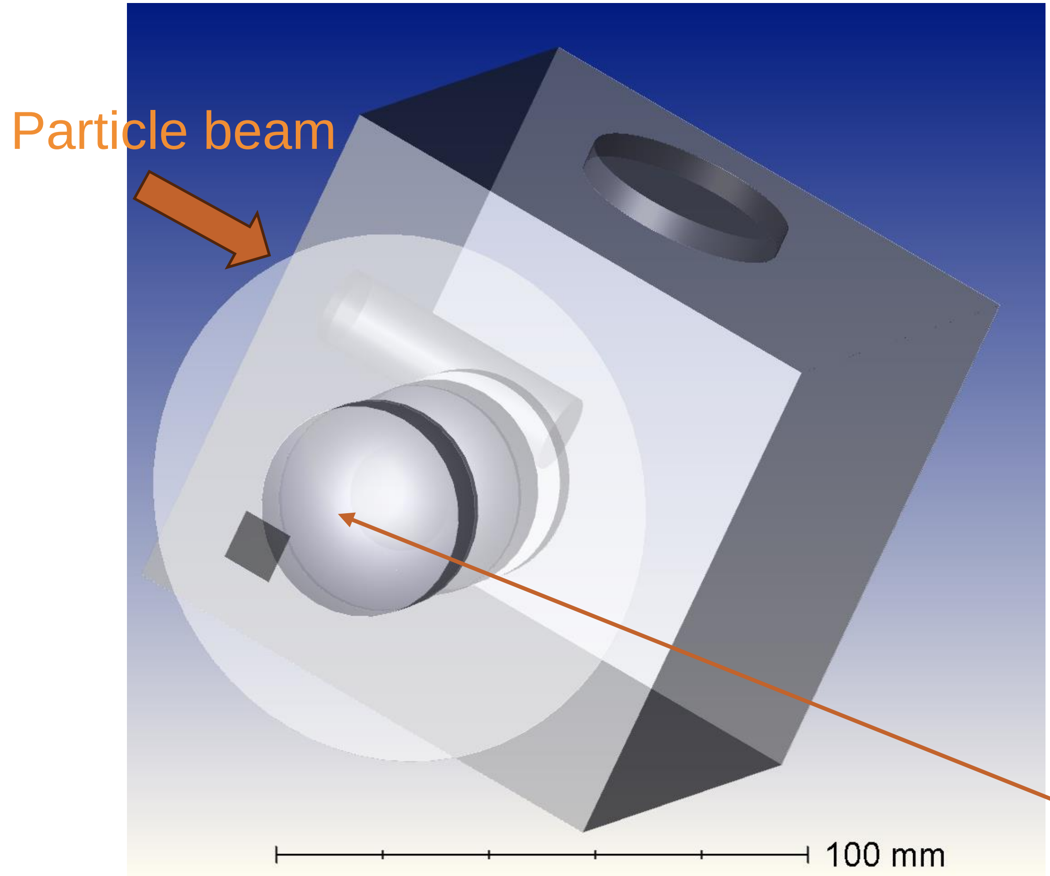
Simulations by Maria Maxouti (IC)

The figure shows the average energy deposited in the simulated DIPN. Peak Beam energy (just before air and Kapton window) is 19.1 MeV.



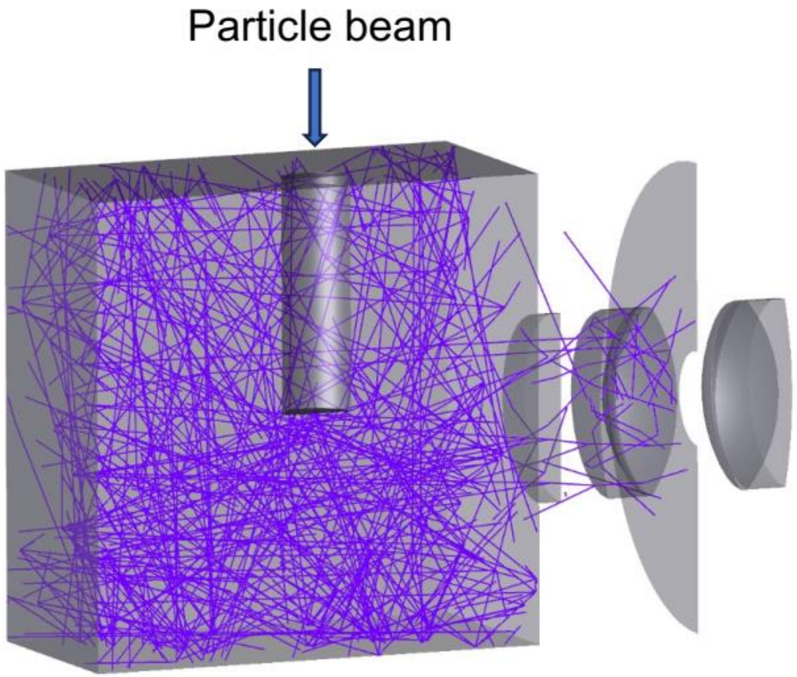


Modelled System



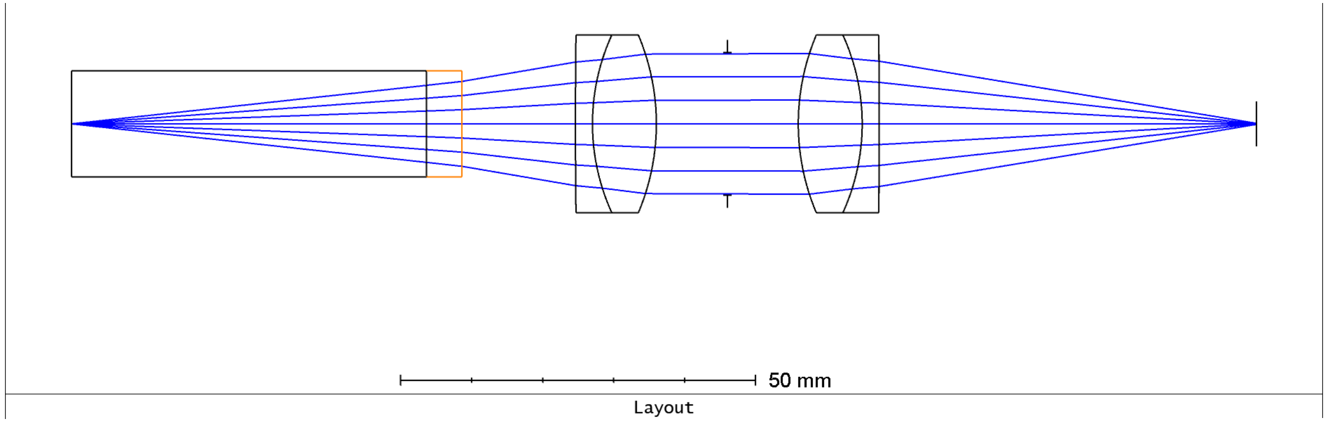
Optical window, lens, diaphragm and sensor (1 of 2 sets)

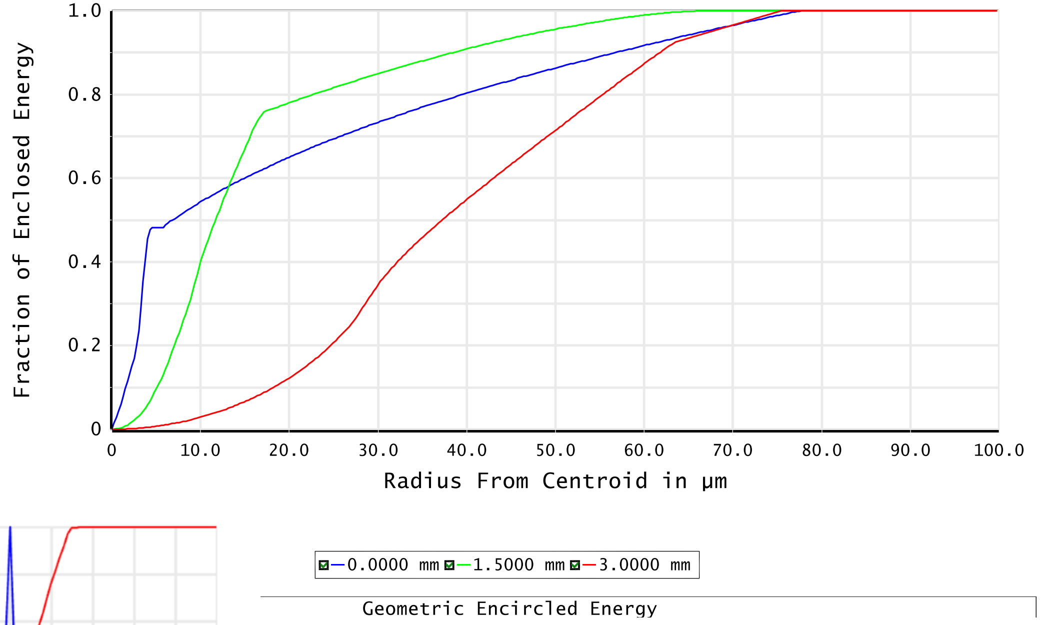
3D view of modelled volume. The second optical window is shown upper right.

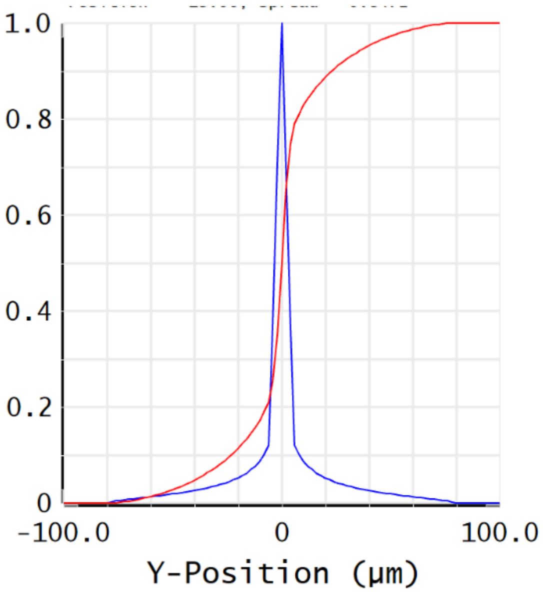


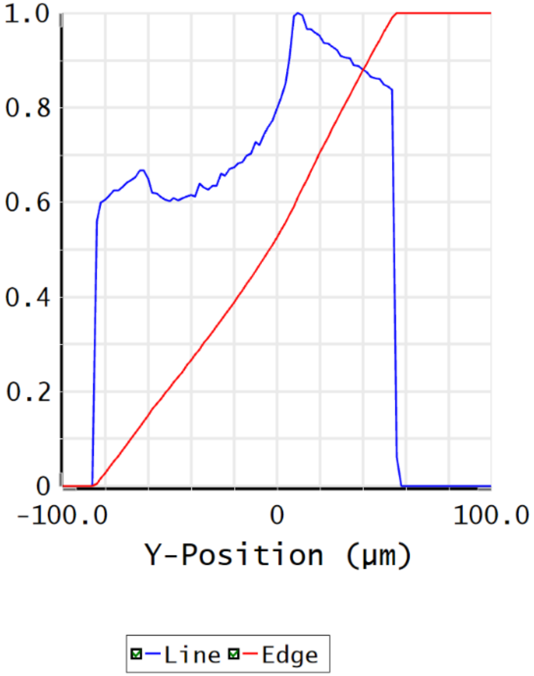
Zemax optical simulation of the phantom with liquid scintillator

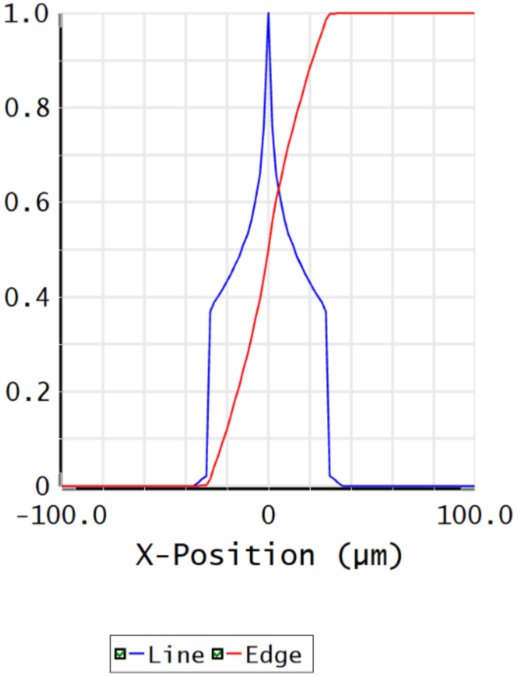
Optical imaging system





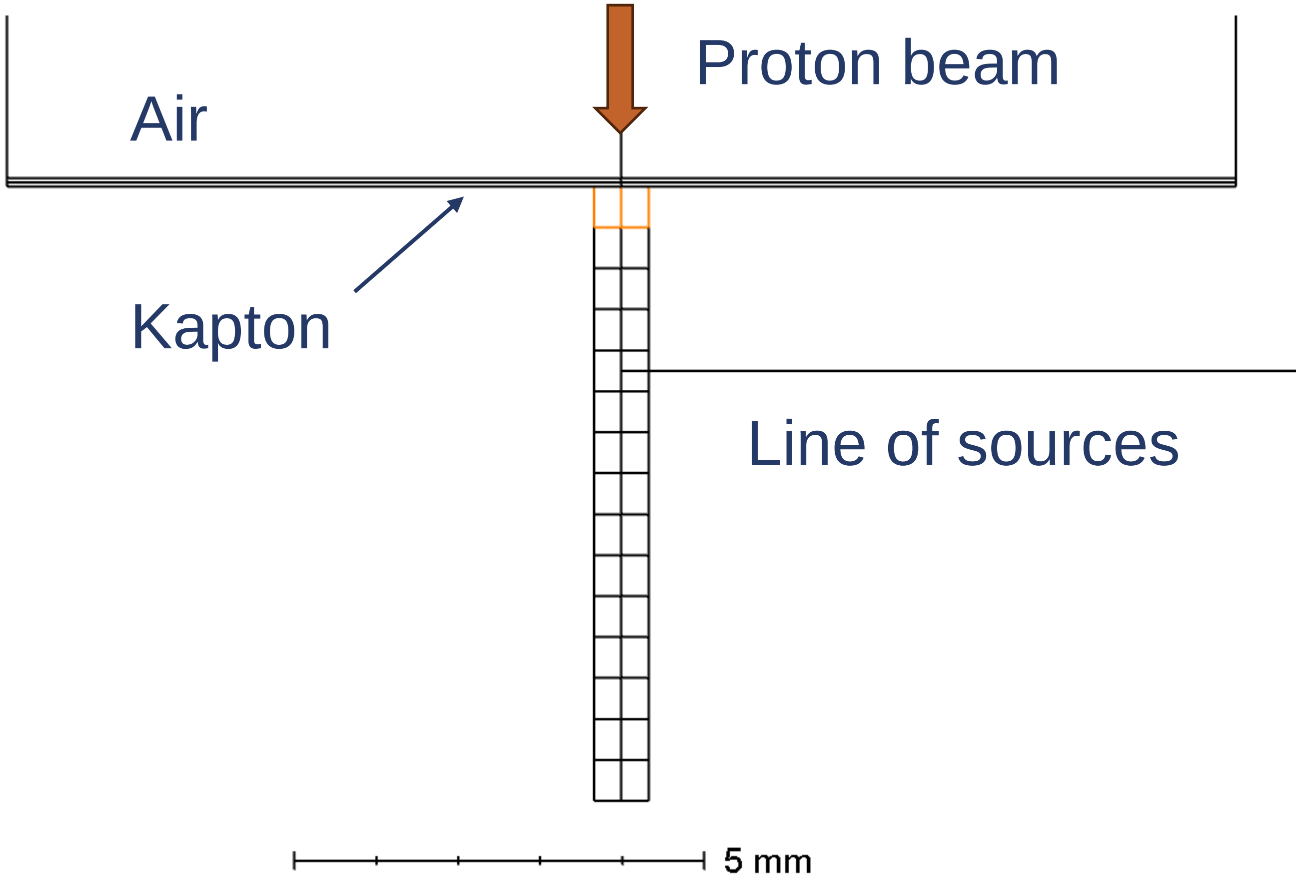


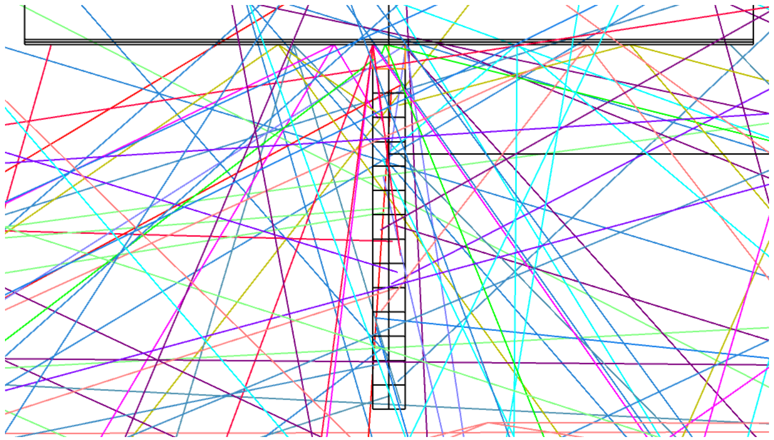


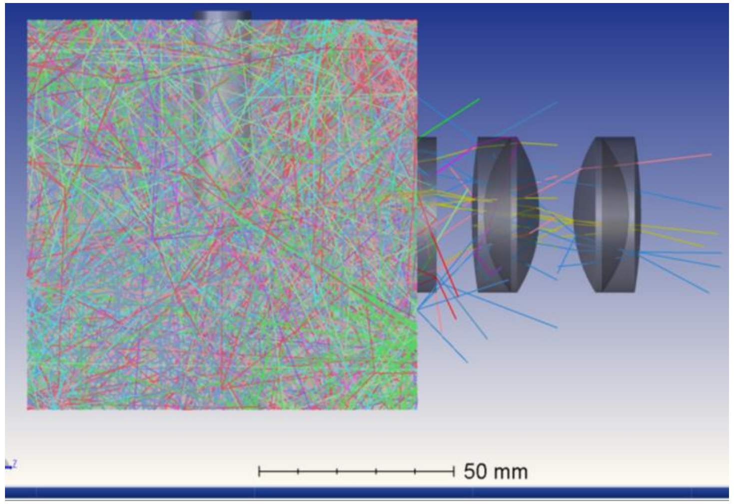


Line/Edge shown for on-axis and for the 3 mm off-axis fields.

Source model



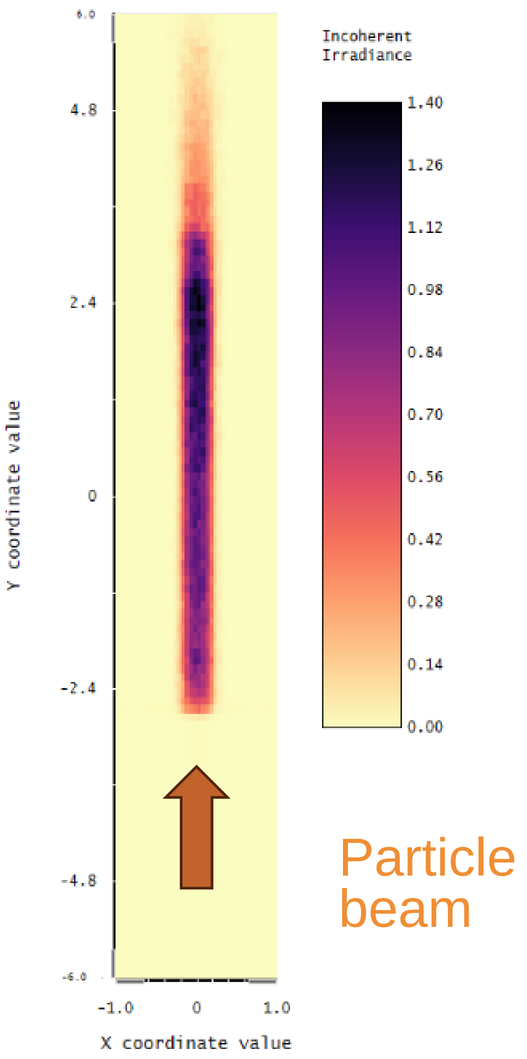


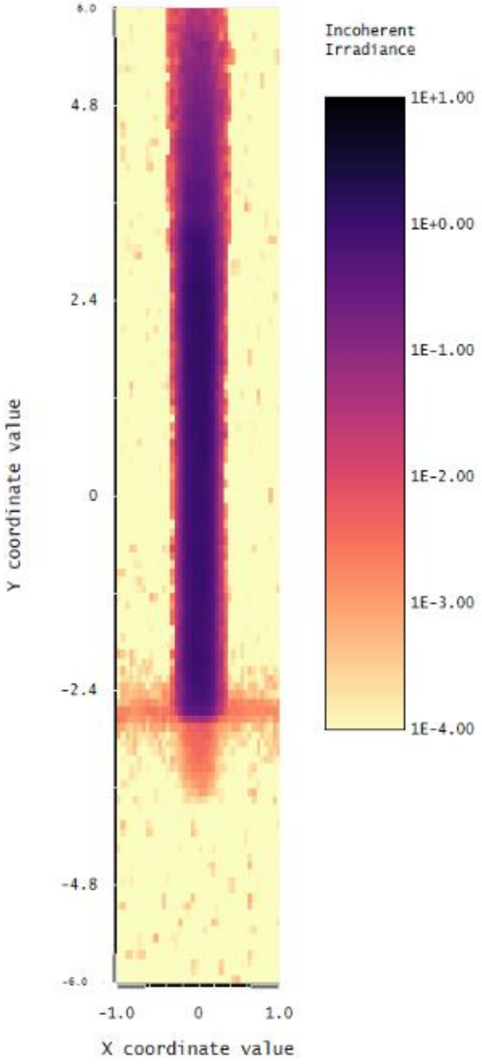


Source of scintillation photons is modelled as a line of elliptical elements each emitting isotropically. Intensity and # of photons are weighted by the Geant4 energy deposited in each 0.5 mm long elliptical cylinder.

Only 2 primary rays per source are generated in this ray trace. Ray splitting and scattering are switched on.

Simulated image on camera





NOTES

50 µm × 100 µm pixels

3 rays generated per scatter event from “black” surfaces.

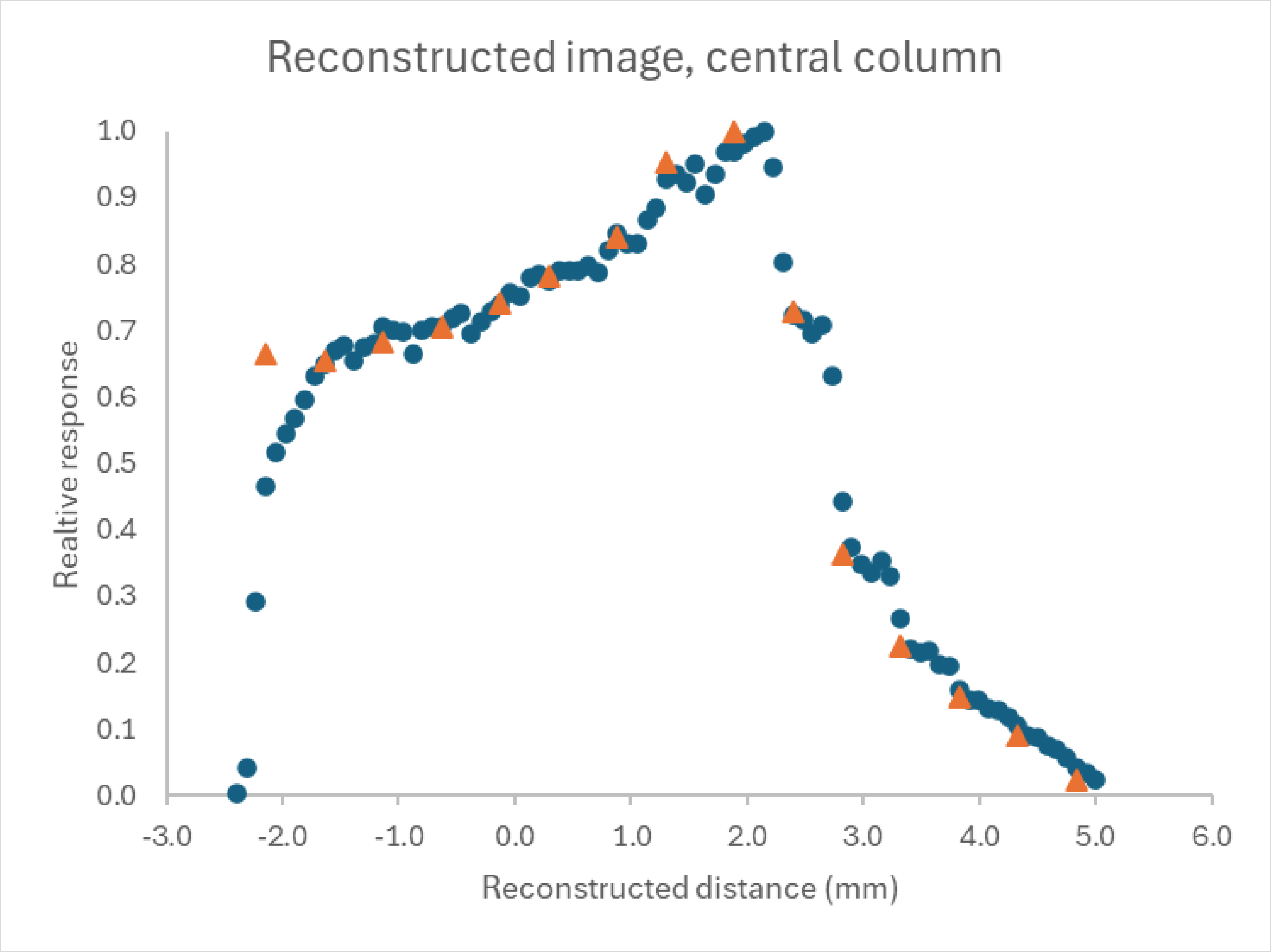
21 million primary rays, equivalent to 100 protons per pulse, have been simulated.

Optical collection efficiency is 0.3%

Simulated image on camera – corrected for magnification

Cross-section along column centre. Image is shown as blue dots, Maria's Geant4 simulation as orange triangles.

Both data sets were normalised to area and then normalised to unity at the respective peaks.



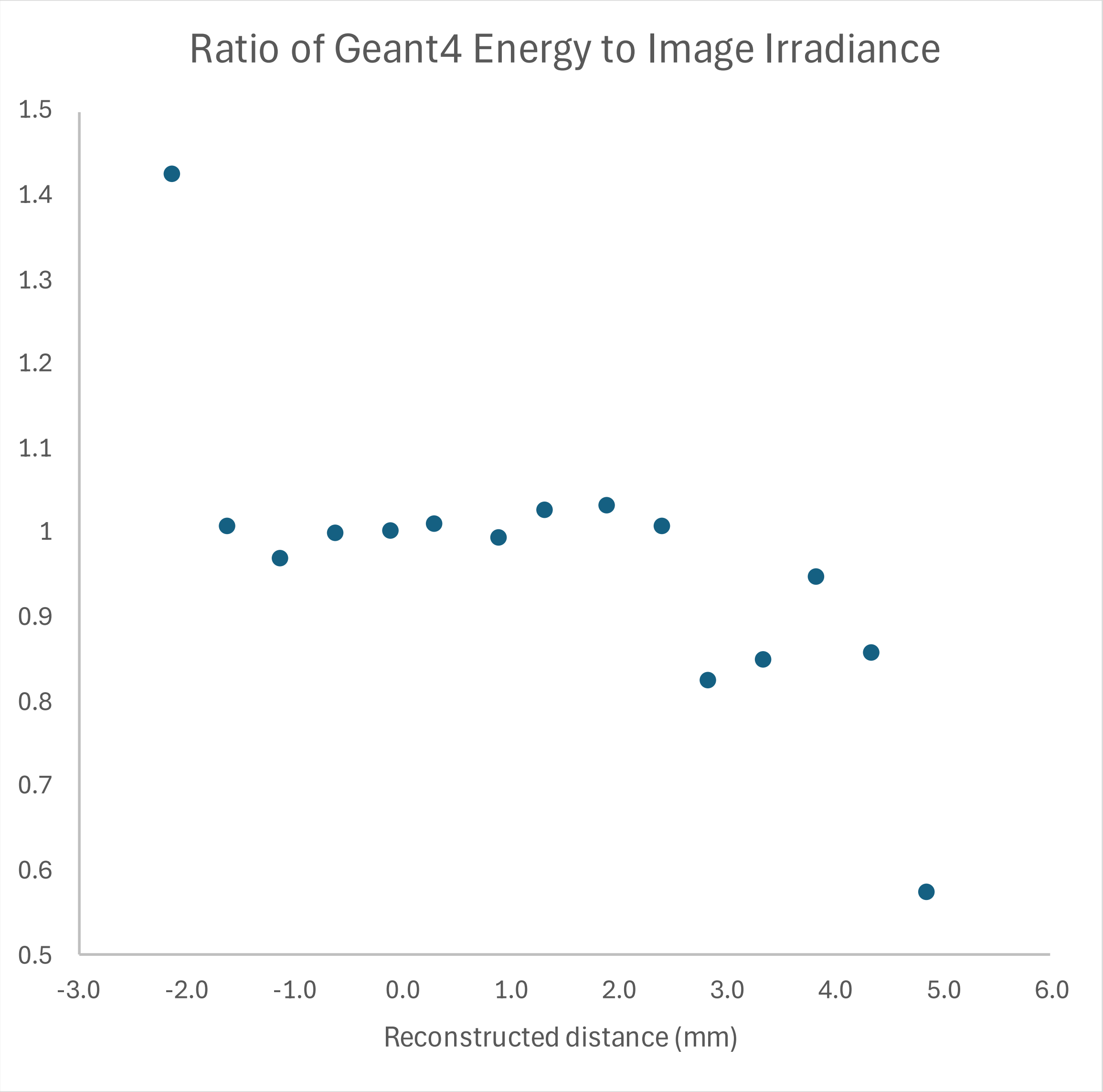
NOTES

50 µm × 100 µm pixels

Simulated image on camera – corrected for magnification

Figure shows the ration of the Geant4 predicted energy to the reconstructed image irradiance after normalisation (see previous slide).

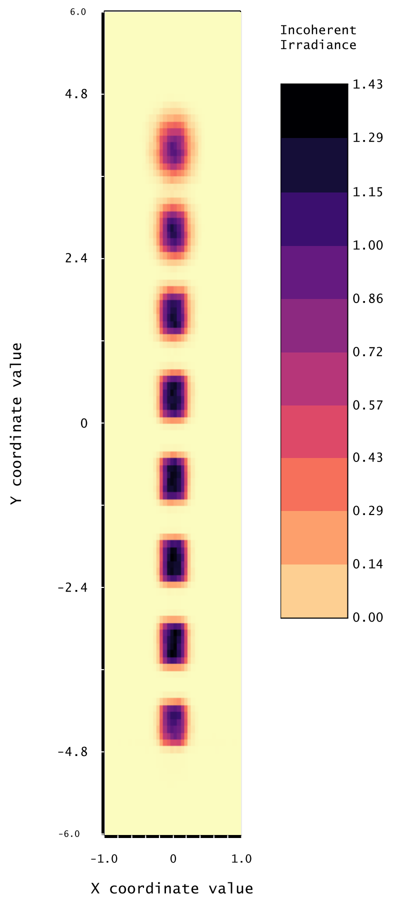
Image data corrected for optical magnification

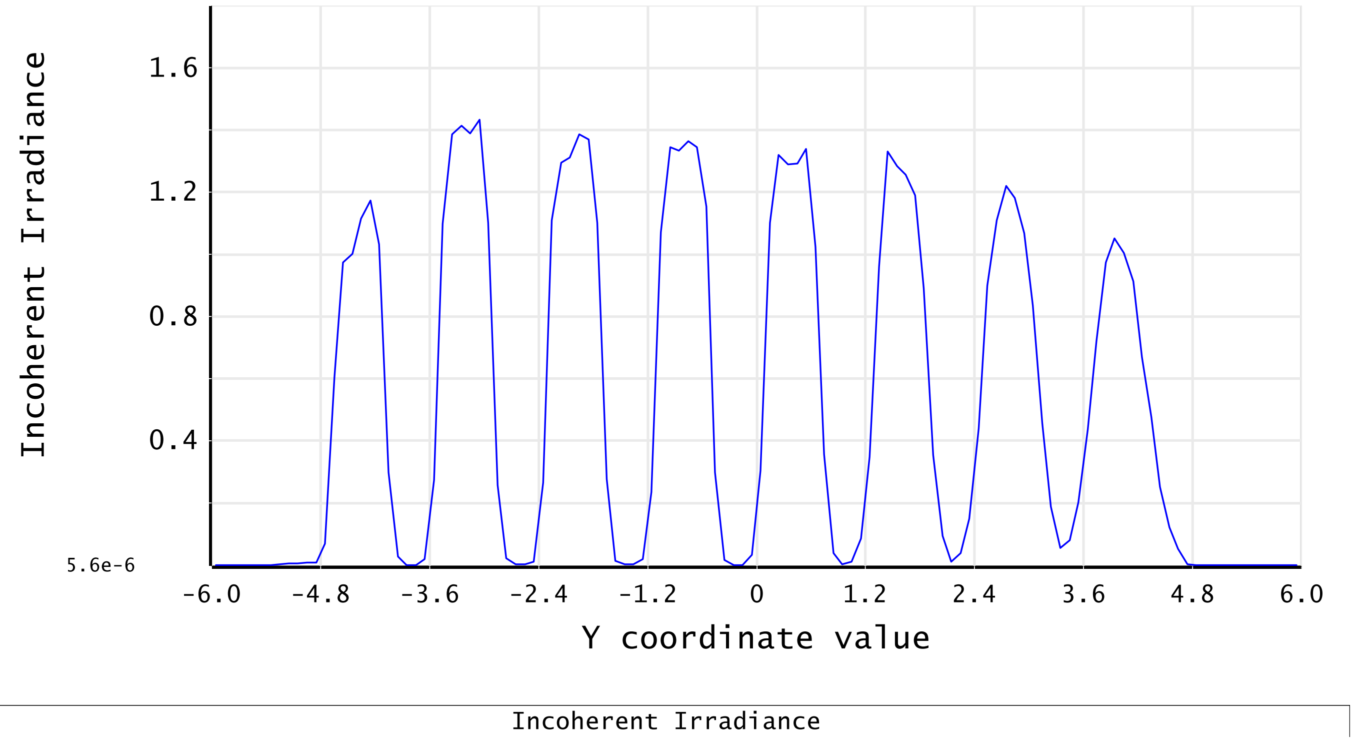


NOTES

50 µm × 100 µm pixels

Simulated image on camera – alternating segments





Cross-section along column centre.

Alternating segments were set to 1 W and 10^{-6} W
Each 1W segment generates 2×10^{7} primary rays

NOTES

50 µm × 100 µm pixels

Further Zemax work

Develop image correction procedure based on synthetic sources;

Include realistic sensor pixel size and noise;

Investigate the optical effect of including an acoustic sensor within the scintillator volume;

Determine the sensitivity of the simulation to intensity cut-off (0.1 % relative at present);

Determine the sensitivity of the simulation to scintillation wavelength (chromatic aberration);

See if any further optimisation of the imaging optics is helpful;

Develop a system to help us focus the imaging optics