Queen Mary University of London
Science and Engineering

Scintillator simulations for LhARA test stand
(summary of work to date)

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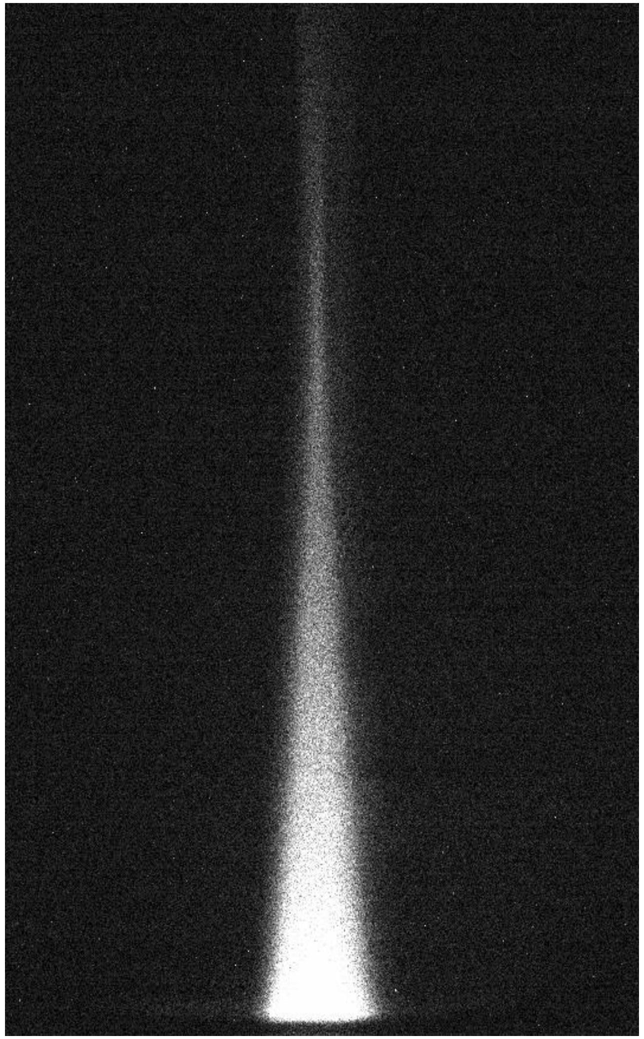
Context

How do we validate the predictions of the Monte Carlo simulations that lead to a predicted spatially varying deposit of Energy in a phantom?

I have been considering a liquid scintillator, as the phantom, and then imaging the scintillation light. The idea has been tested with UV excited violet-emitting dye (Coumarin 440).

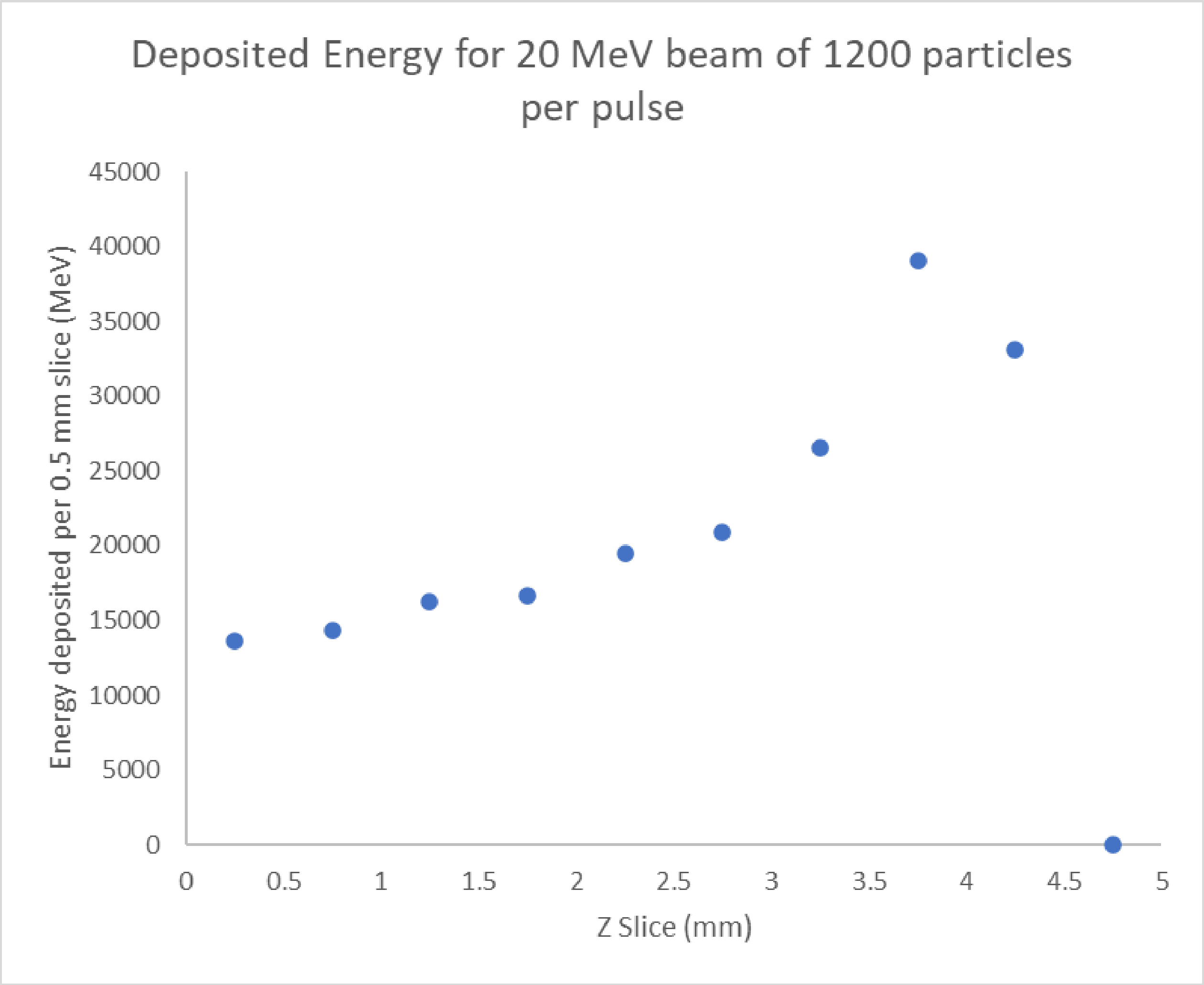
Some commercially available liquid scintillators have a density very close to water and can be mixed 50/50 with water (e.g. Perkin Elmer Ultima Gold XR).



Initial Modelling for LhARA (historic)

1. Volume is assumed to be **water** contained within a cylinder in air;
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 **not optimised for imaging an object in water**;
4. The **detector is perfect** (no noise, no pixel gaps);
5. The scintillation yield is assumed to be 10000 photons per MeV (typical of Eljen liquid organic scintillators);
6. The beam is modelled as a cylinder of 10 mm diameter sub-divided into 0.5 mm thick slices. Each slice can have a different intensity and rays are emitted isotropically in each slice;
7. All rays have a single wavelength of 400 nm;
8. Simulations were carried out using ZEMAX OpticStudio Professional V22.2 on my home PC (i5 6/12 core @4.6 GHz peak, 32 Gbytes of 3200 MHz DDR4 memory).

Beam Data (early data from Maria, Feb 2023)

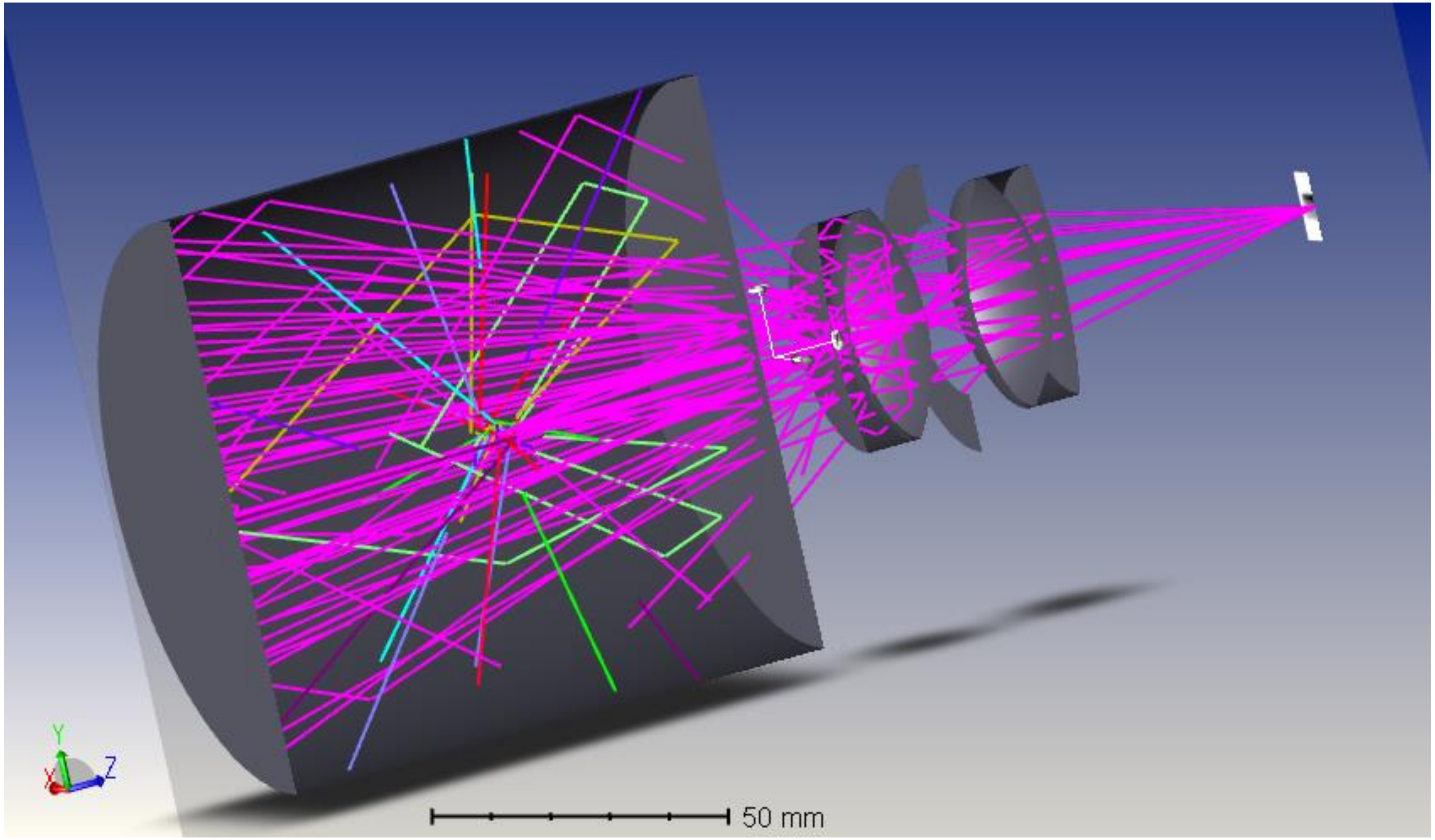


Parameters:
Beam Energy = 20 MeV (+/- 0.3 MeV)

Number of particles per pulse: = 1200

Nominal width of energy deposit in transverse plane = 10 mm

Geometry View 3D cut section render

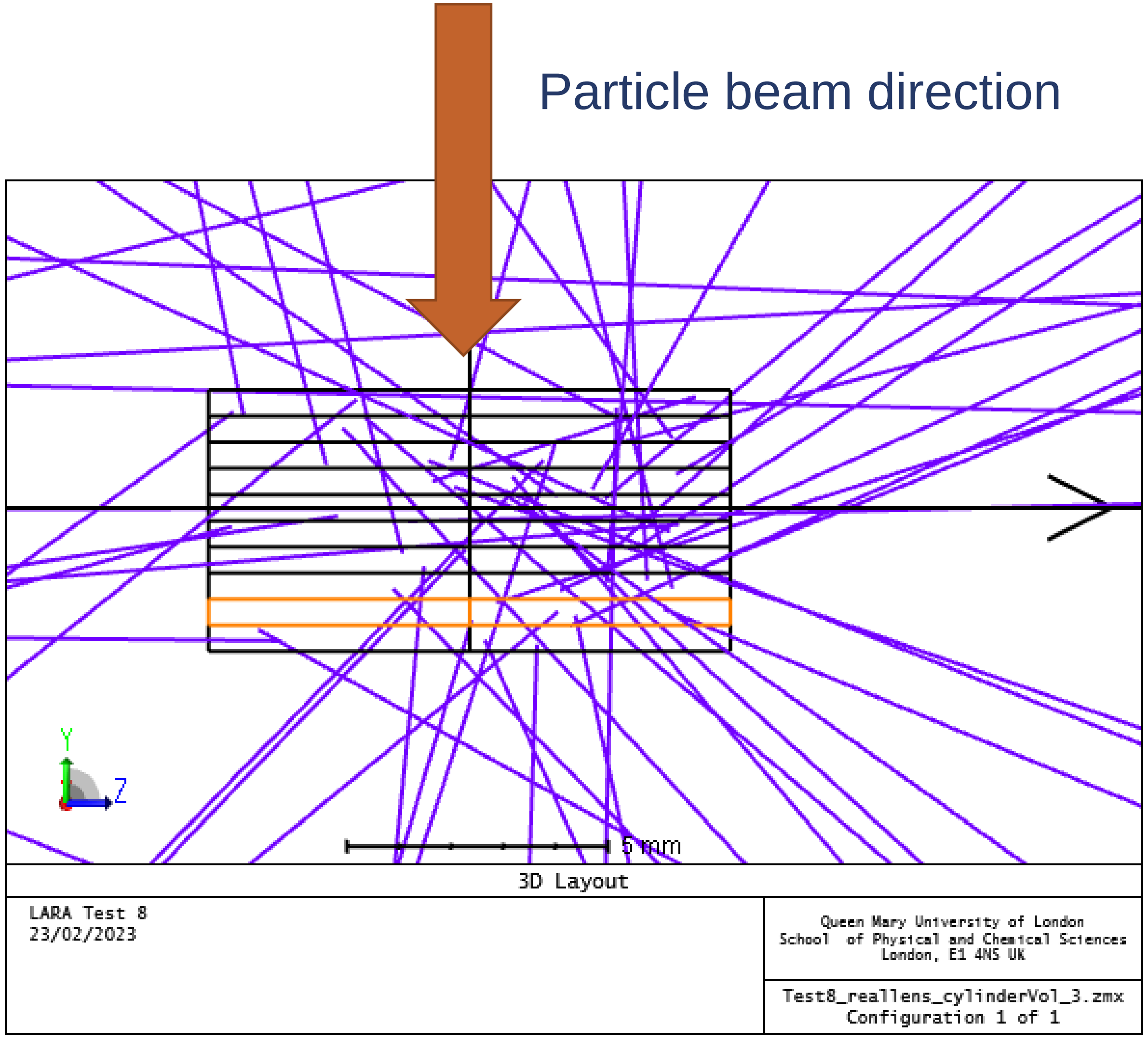


Ray splitting ON, purple rays are from a point source, at the centre of the water volume, and are only used for lens position optimisation.

Note the reflections from the lens surfaces, no AR coating in model yet.

Cylindrical and back face of water volume modelled as 100% absorbing

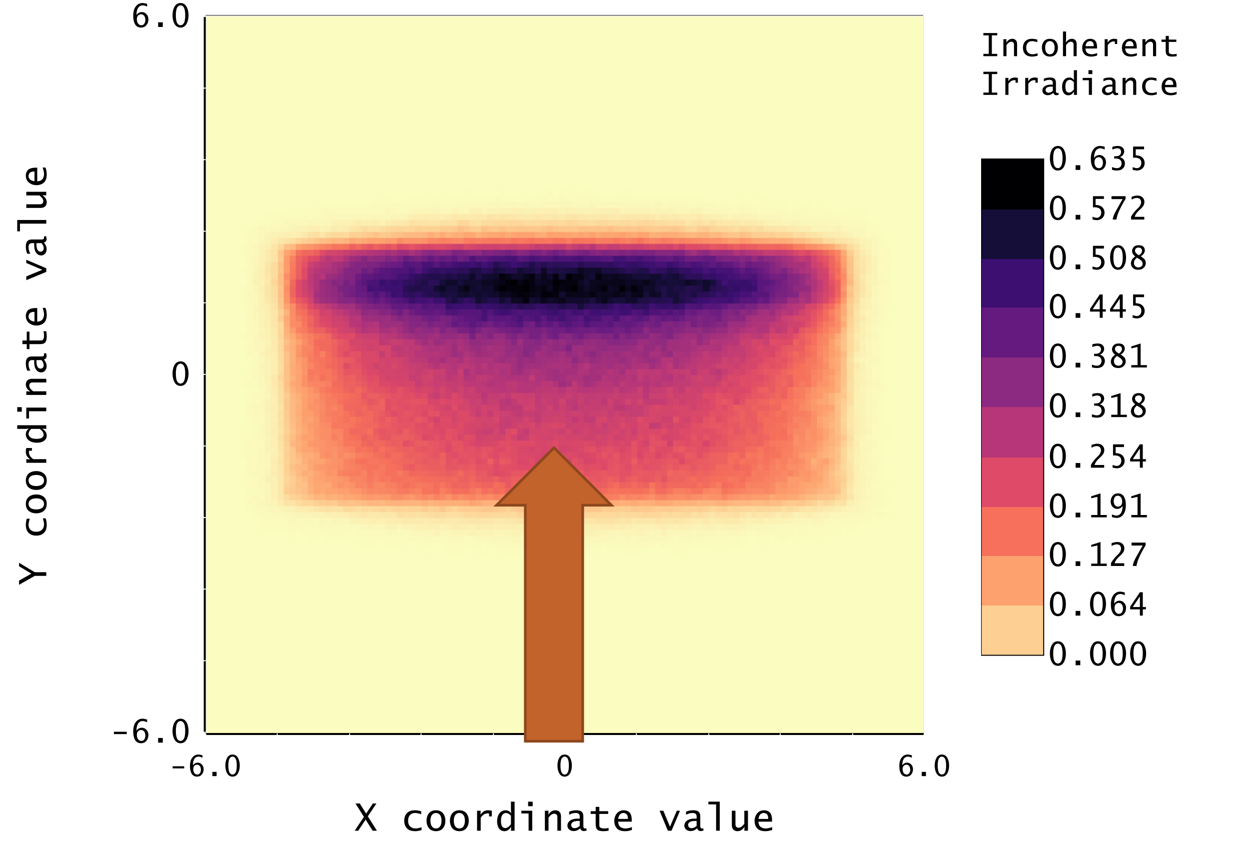
Geometry View (wireframe) at centre of water



Particle beam is assumed to come down from the +Y direction, 10 beam cylinder slices of 10 mm diameter are modelled here, the one coloured orange is in the position of the “Bragg” peak. Each slice is 0.5 mm thick.

Ray splitting is off for clarity.

Preliminary Result

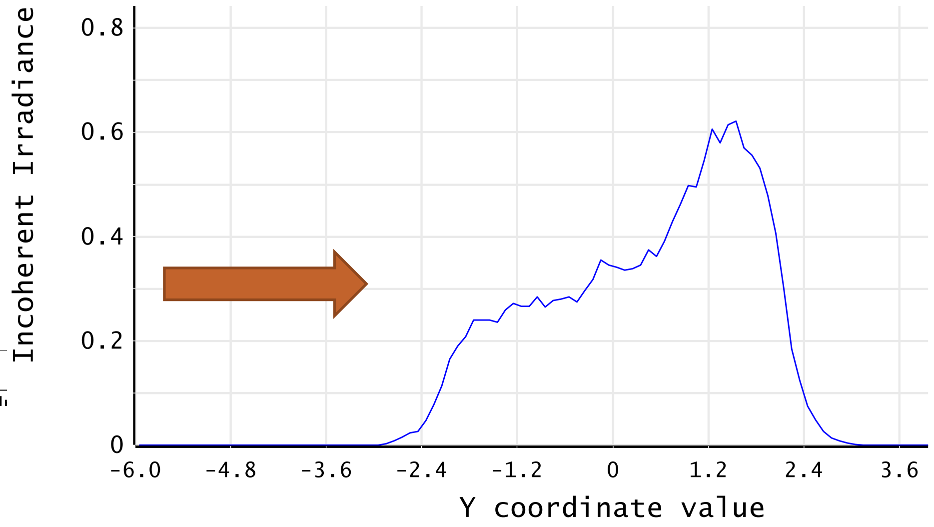


Particle beam direction

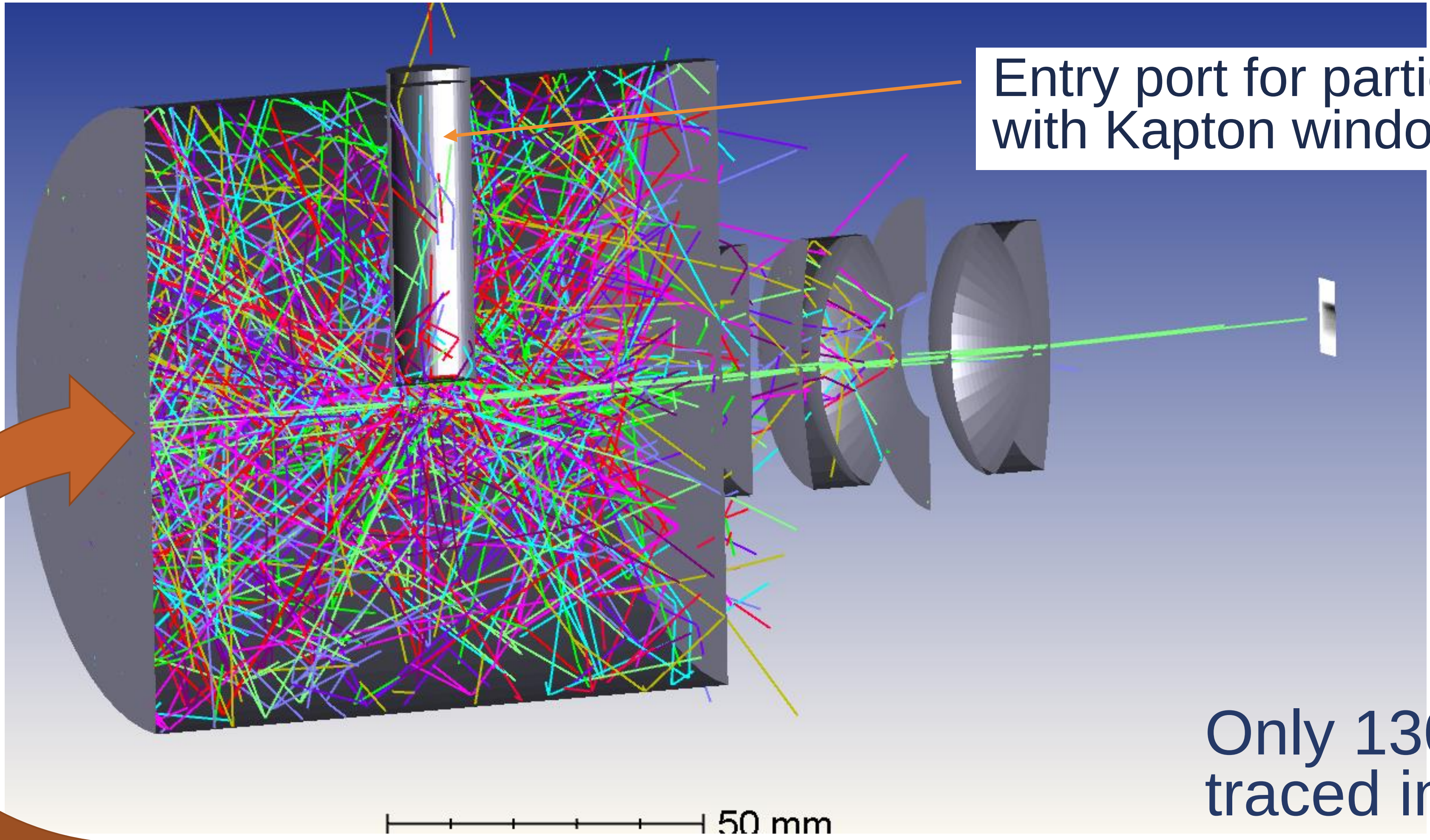
200 **million** primary rays traced (equivalent to a beam with 120 particles per pulse). Each slice has an intensity in the proportional to the energy deposition data provided by Maria. **Remember that the lens system inverts the image**!

No ray is traced after it has dropped below 1% of its original intensity

Detector has 120x120 100x100 μm^2 pixels, below is the column at X=0.



A more realistic simulation



Entry port for particle beam (in air) with Kapton window

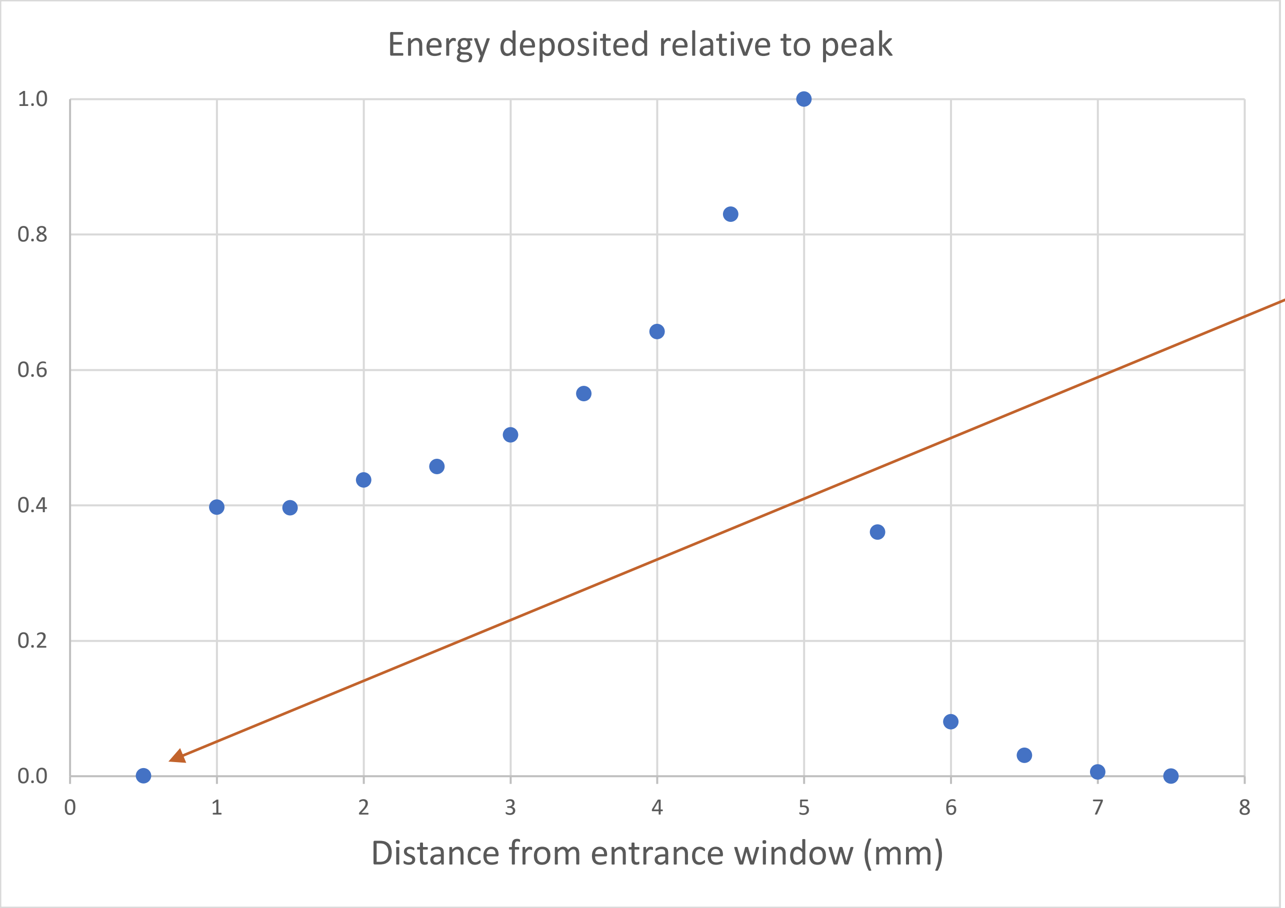
Only 130 primary rays traced in this plot

“Black” surfaces are 5% reflective: split 80% Lambertian scatter and 20% specular reflection.

Current modelling of whole system

1. Using non-sequential ray tracing;
2. **Latest energy profile** with narrow **elliptical** beam in water;
3. Beam has 1000000 particles per pulse. **I have rescaled to 10000**;
4. All rays have a single wavelength of 400 nm, **1000 photons per MeV** assumed;
5. Detector (unless noted otherwise) has 100 µm square pixels (no gaps);
6. “Black” surfaces are 5% reflective, split into 80% Lambertian scatter and 20% specular;
7. Simulations were carried out using ZEMAX OpticStudio Professional V22.2 on my home PC (Gen 11 i5 6/12 core @4.3 GHz sustained average, 32 Gbytes of 3200 MHz DDR4 memory).

Deposited energy spectrum (latest data from Maria)

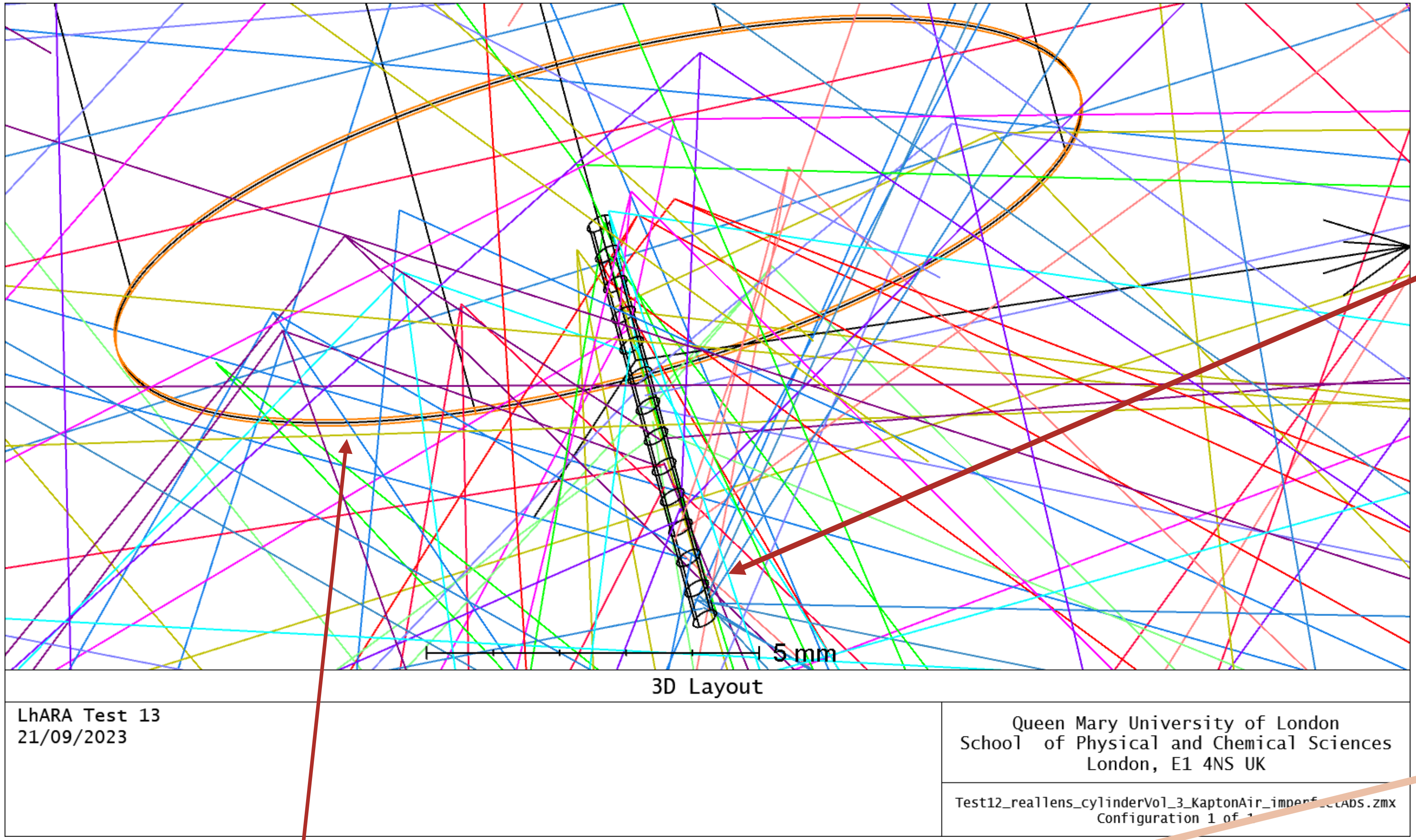


Beam FWHM = 0.67 mm (*x*), 0.37 mm (*y*)

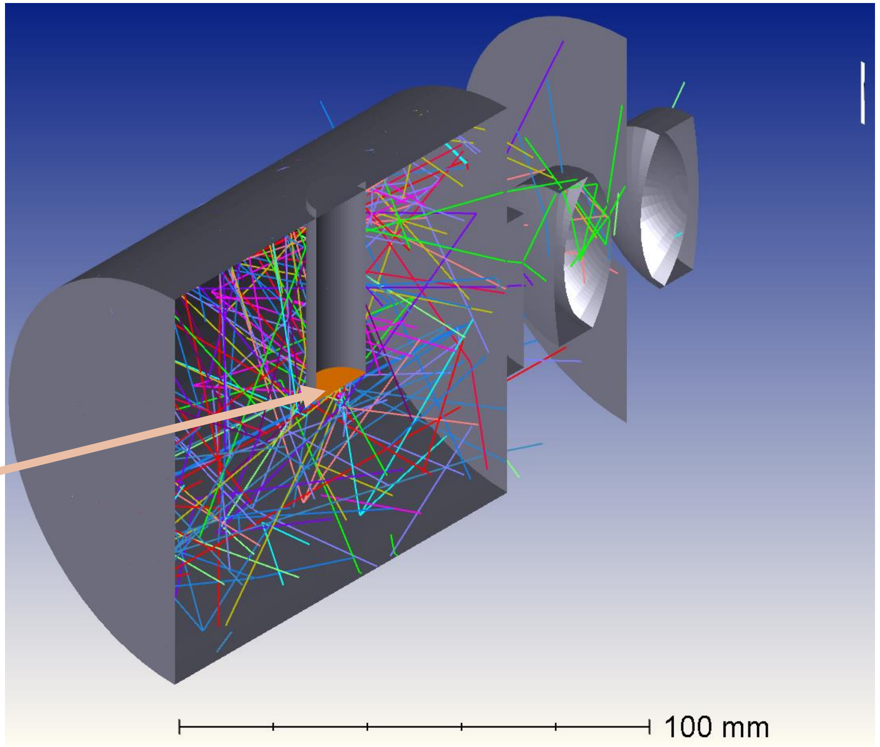
Data from Maria on **16/09/2023**

NOTE The first point on the graph is actually in air **before** the Kapton window.

Overall view of simulated system (1)

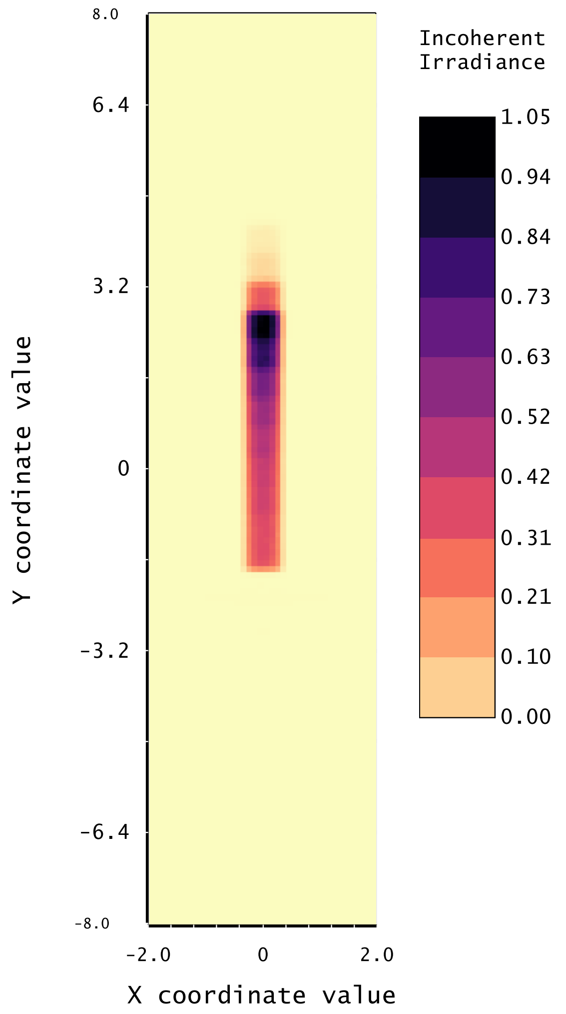


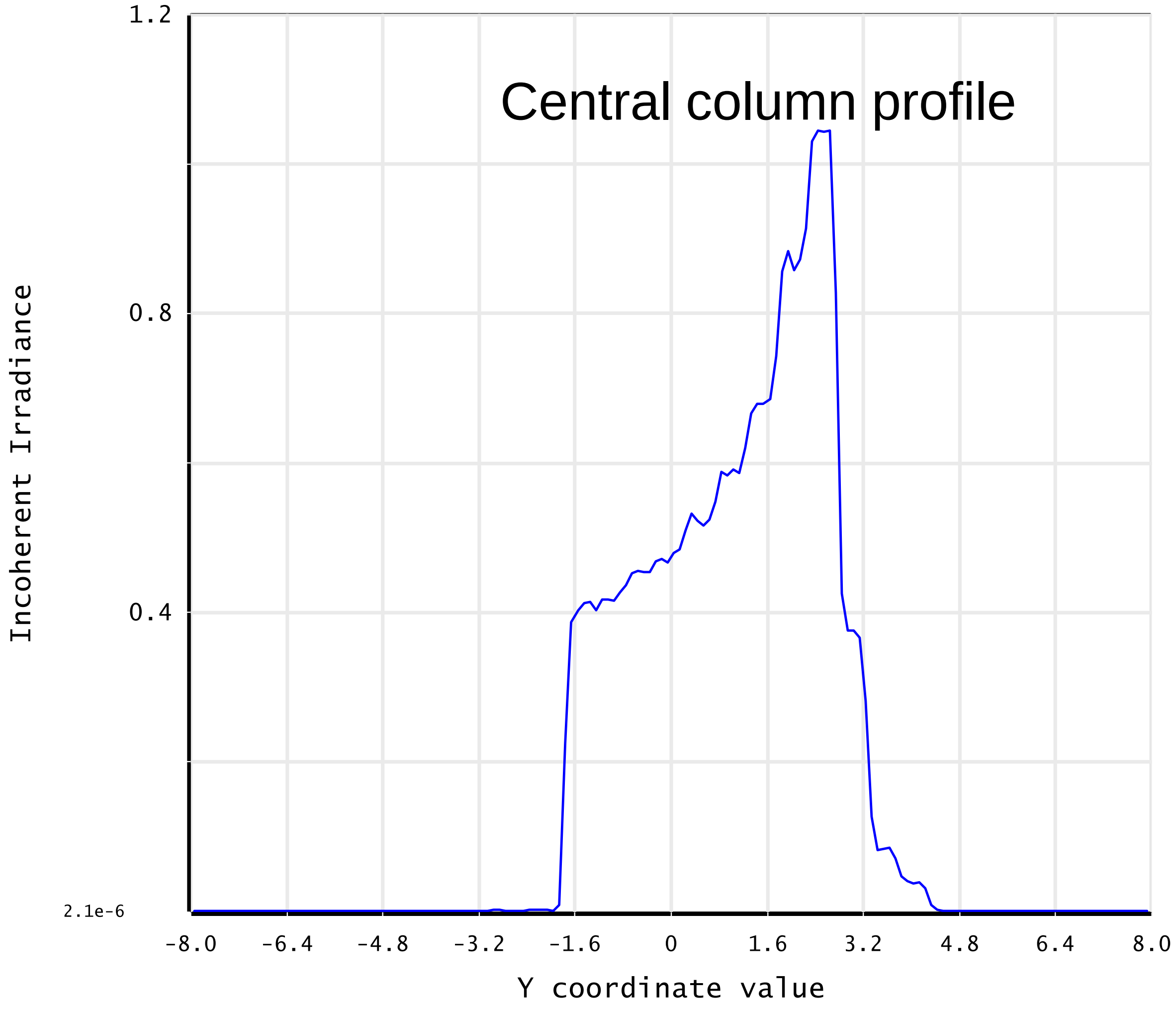
0.5 mm thick elliptical slices simulate the energy deposited by the beam.



“Black” Kapton disc

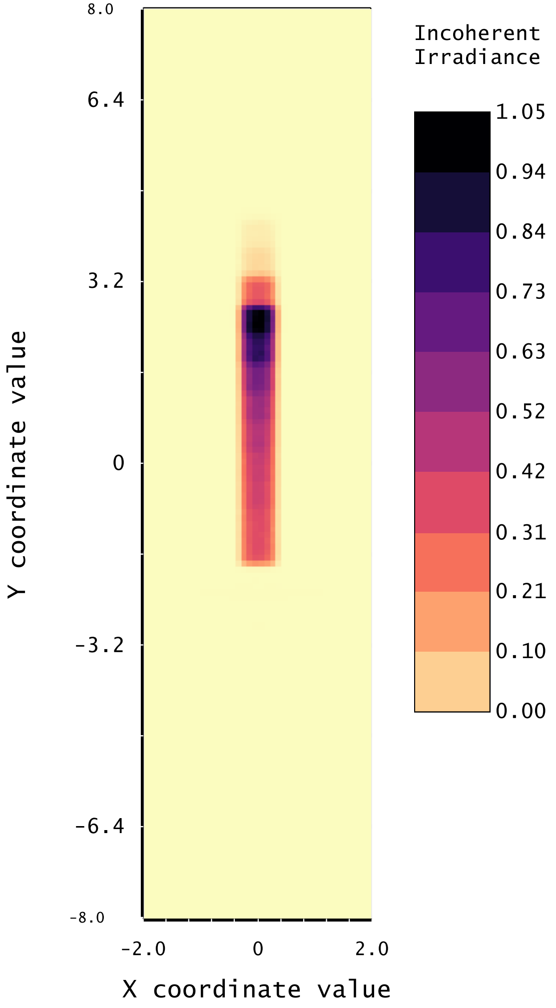
0.67 × 0.37 mm^2 FWHM elliptical beam (current data)



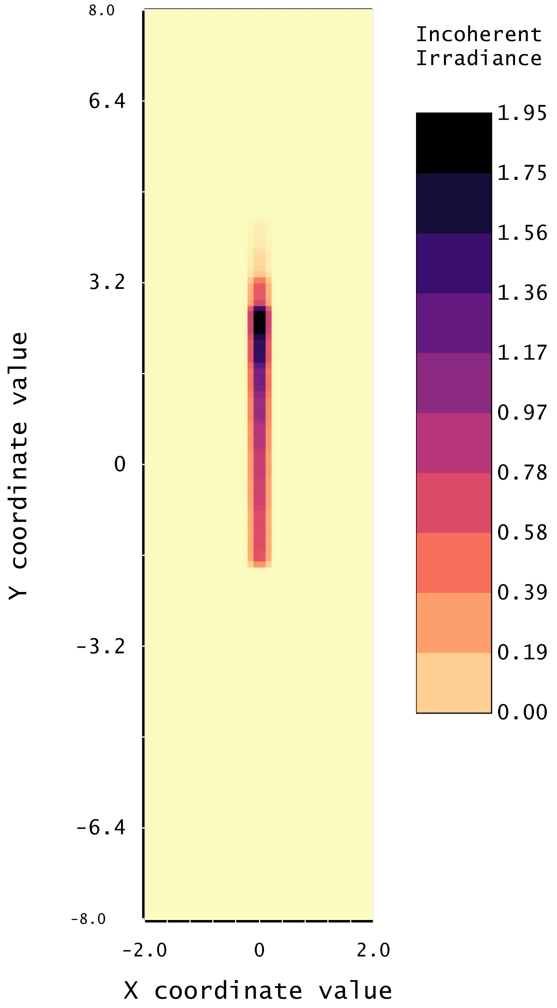


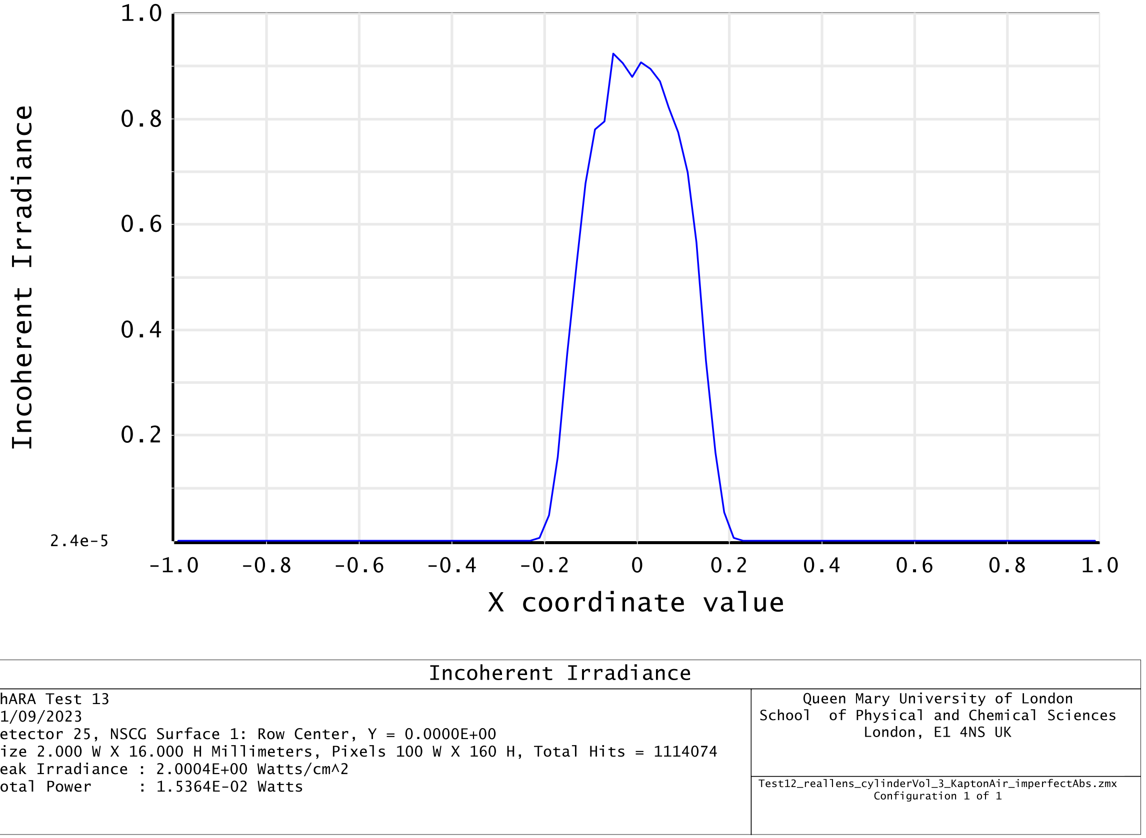
Elliptical beam (current data)

0.67 × 0.37 mm² FWHM



0.37 × 0.67 mm² FWHM





Y = 0 row with **20 µm** pixels in *X*

To do list!

1. Compare simulated image quantitatively with deposited energy profile;
2. Incorporate the actual Smart Phantom design (see next talk by Oliver Jeremy);
3. Incorporate the measured attenuation length of the liquid scintillator proposed;
4. Design custom optics for imaging object in water to improve the optical resolution.
5. Etc.