# IonAcoustic: Optical Simulations

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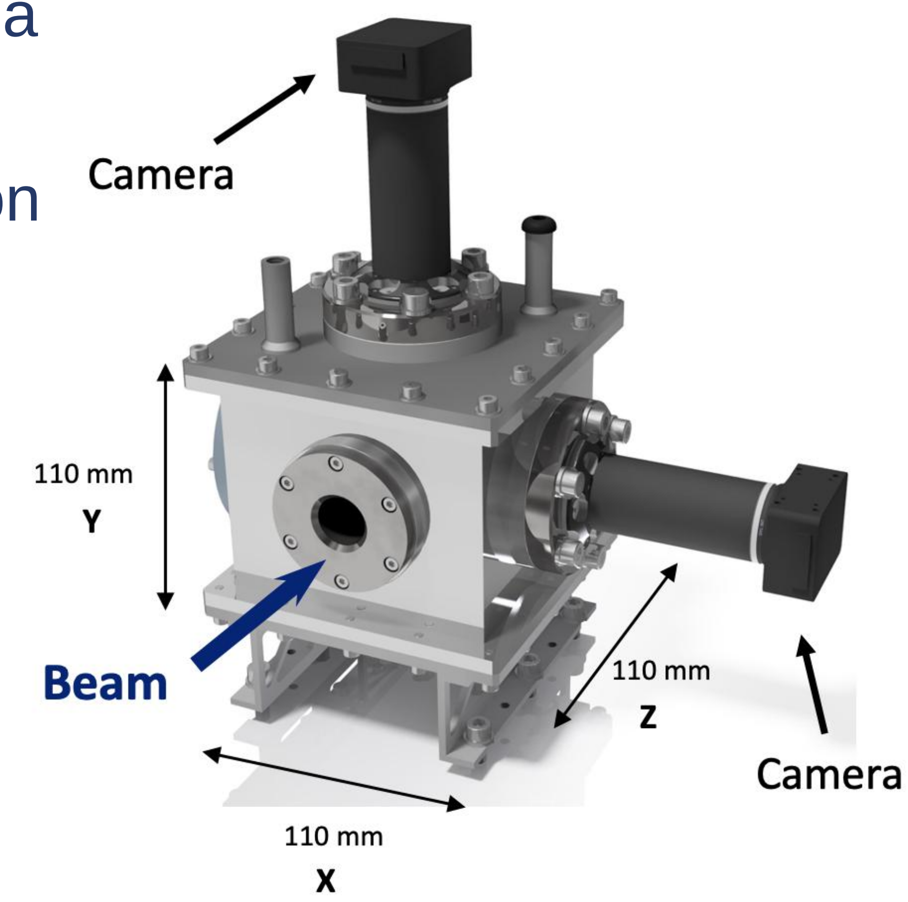
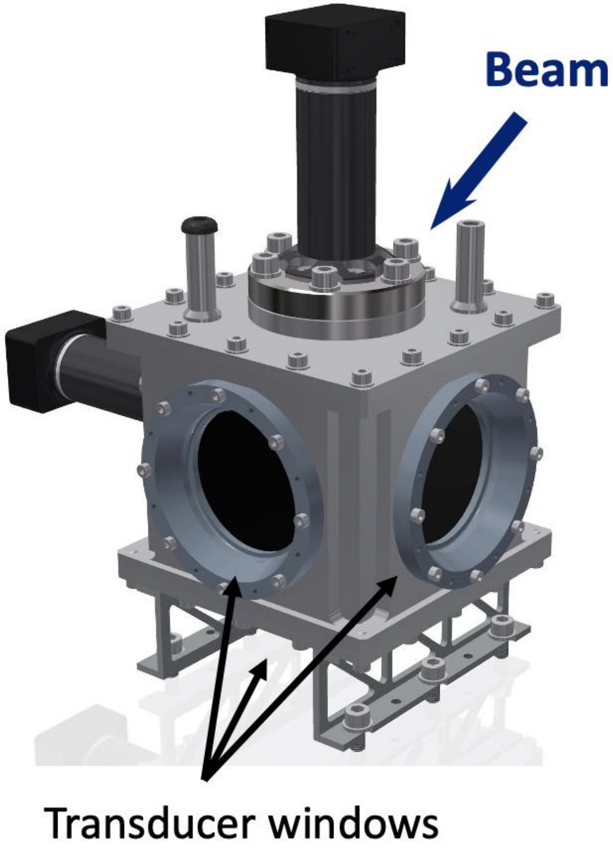
# Scintillator-based approach to dose mapping

Here we image the light arising from the proton beam, using a liquid scintillator contained within a 1000 mL volume.

This will be a cross-check on our ion-acoustic image and simulations.

The “Smart Phantom” with ports for optical cameras and external ultrasonic transducer arrays.



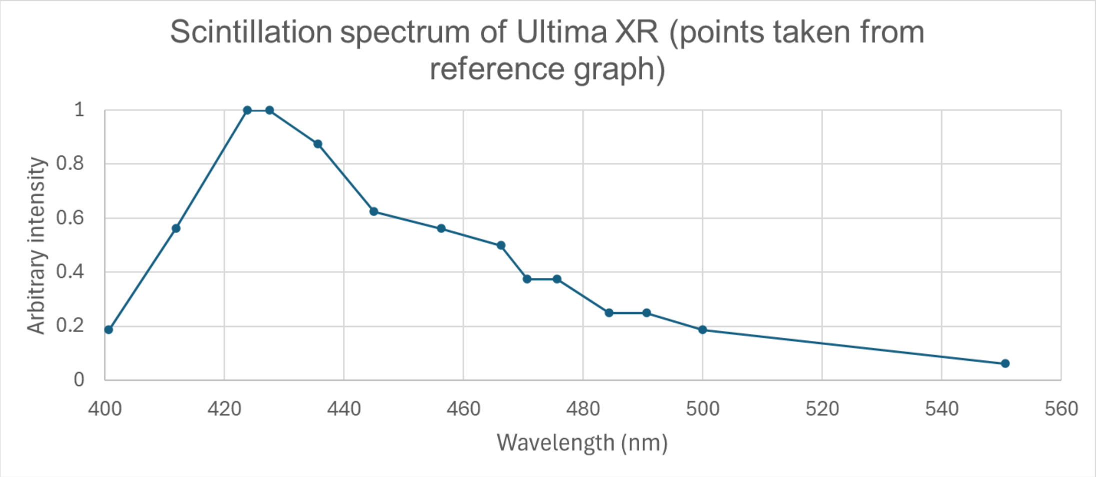



# Simulating the scintillator-based approach

1. Scintillator is **UltimaGold™ XR** contained within the 100×100×100 $mm^3$ cube;
2. The scintillation yield is assumed to be 11200 photons per MeV deposited;
3. Non-sequential rays are traced with "ray-splitting" enabled (i.e. Fresnel reflection and polarization is accounted for);
4. Imaging optics are a combination of two identical commercial achromatic lenses;
5. "Black" surfaces (Kapton™ and anodized aluminium) use **measured reflectance** (diffuse and specular);
6. The particle beam is modelled as an elliptical or circular cylinder sub-divided into 0.5 mm thick slices and rays are emitted isotropically in each slice;
7. Simulations use **Ansys ZEMAX OpticStudio 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. Peak emission wavelength: 427 nm




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).

| Liquid | Wavelength (nm) | | | | | | | | | 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 |

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



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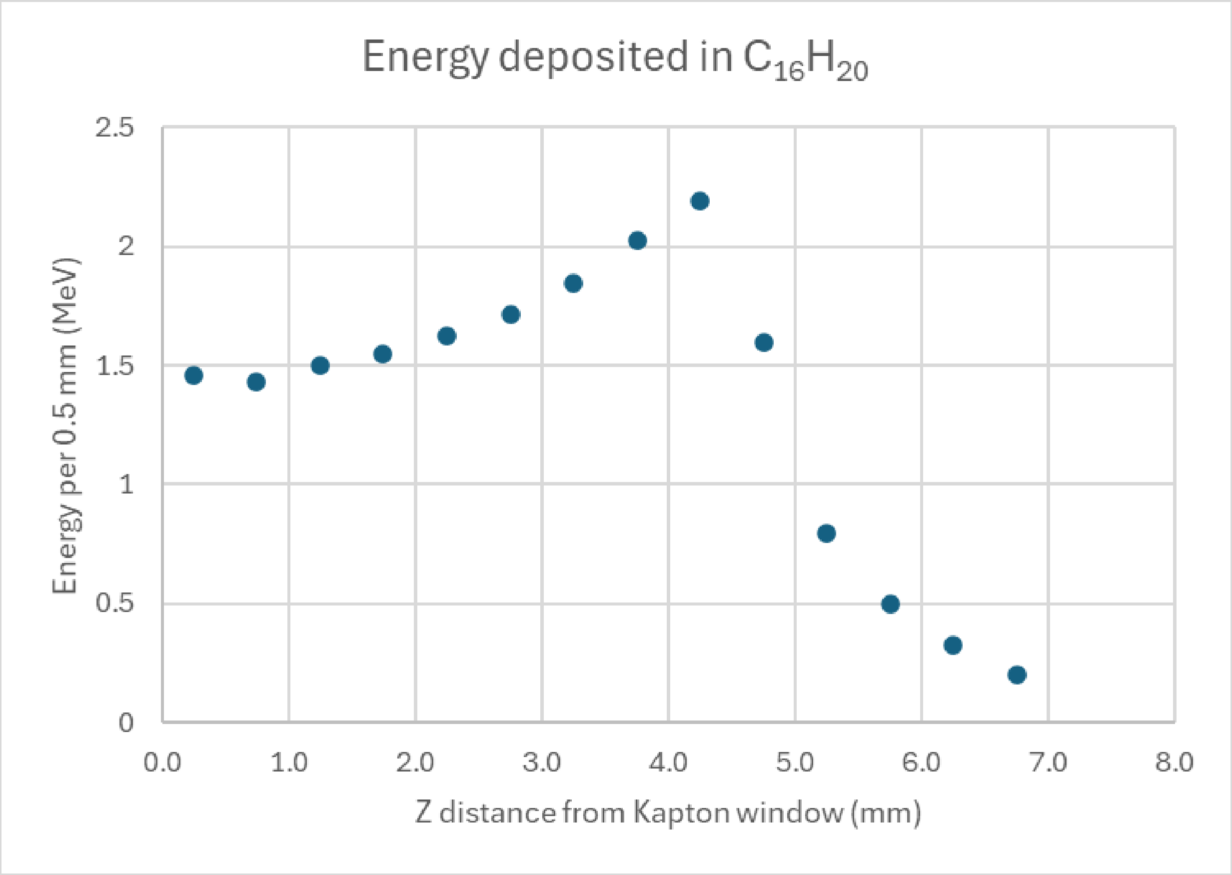
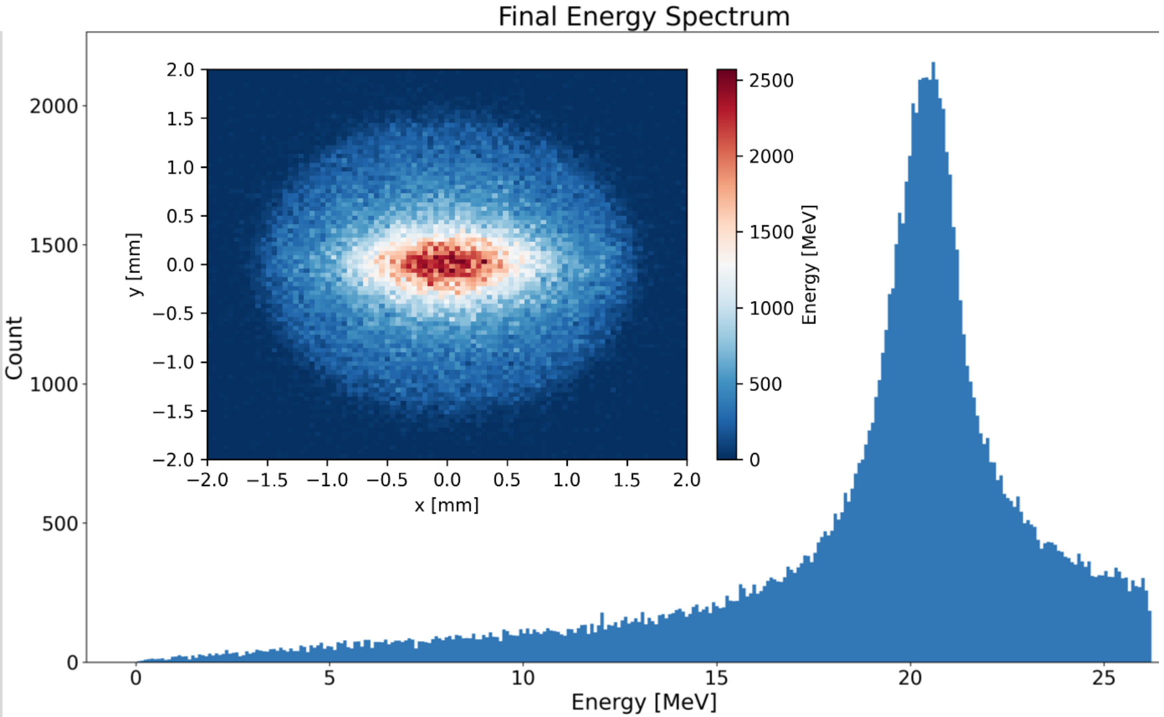
*Radiation Physics and Chemistry* **84** (2013) 59–65

# Deposited Energy from protons at 20 MeV nominal

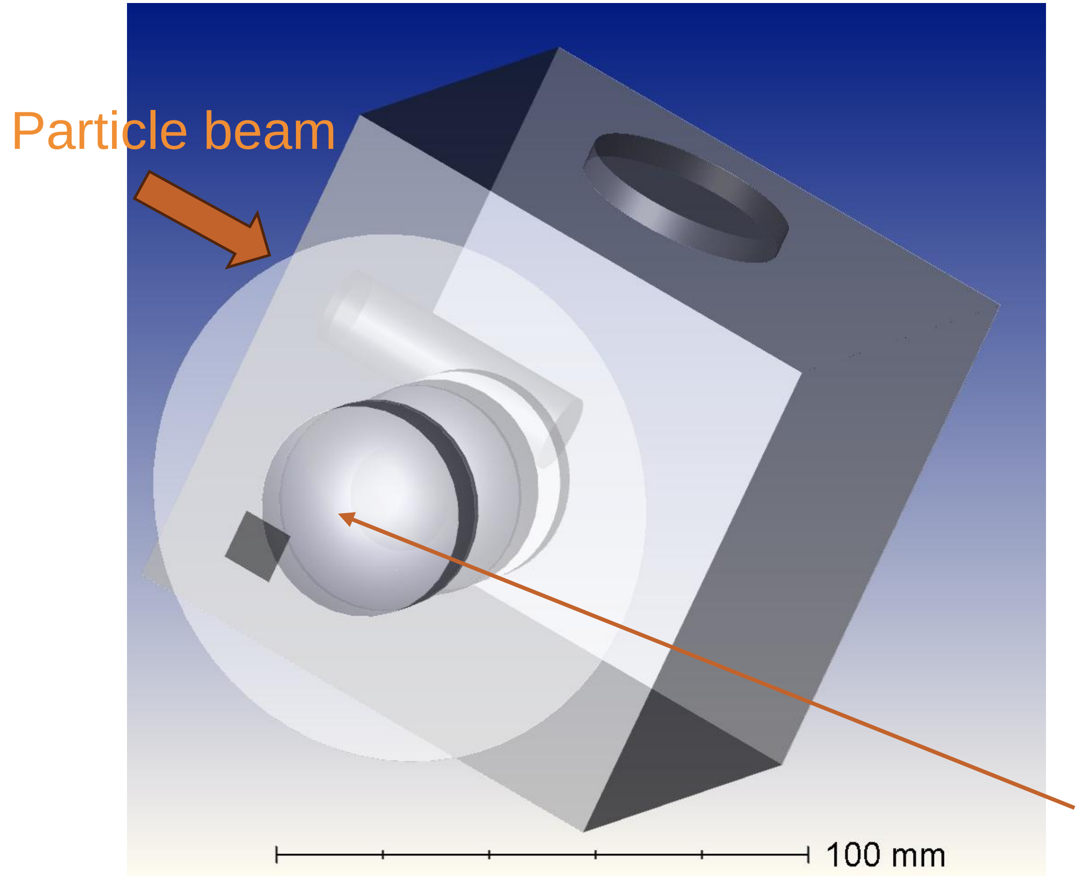
The figure shows the average energy deposited per proton in the simulated DIPN. The simulation is for the **ideal** LION beam at LMU Munich.



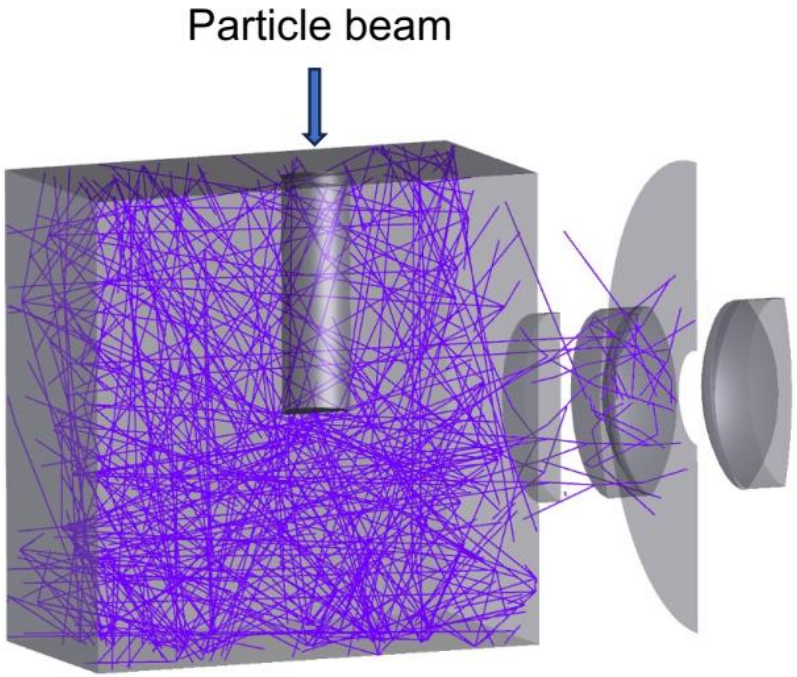

LION proton beam energy spectrum and (inset) beam profile

# Modelled Smart Phantom



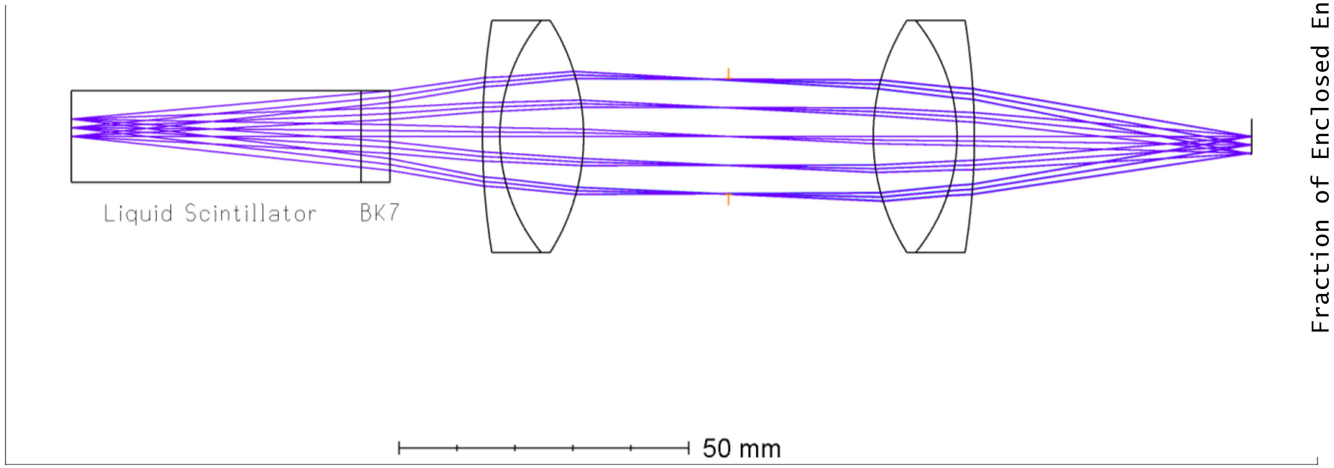

Optical window, lens, diaphragm and sensor (1 of 2 sets)

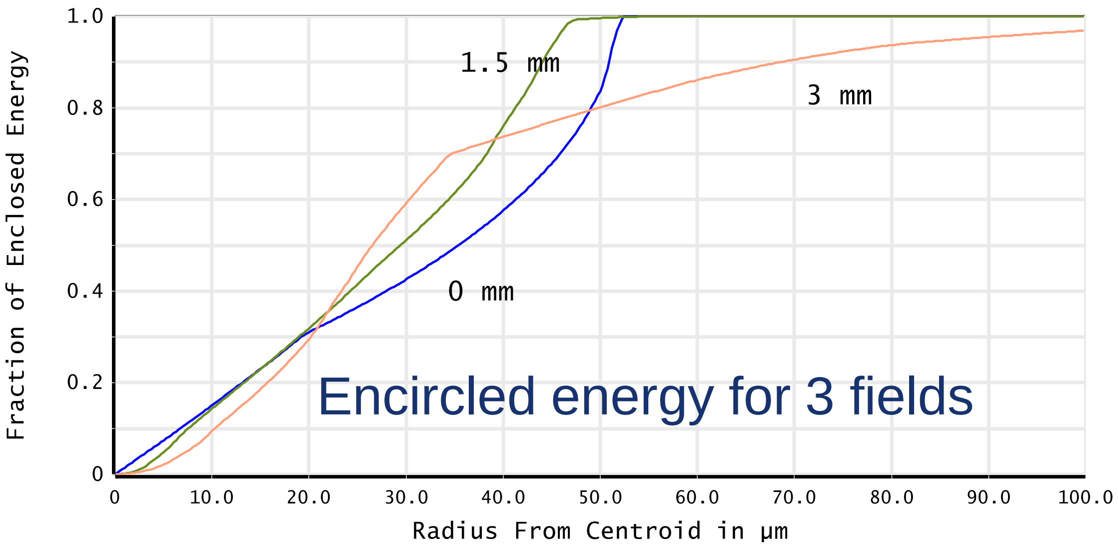
3D view of modelled volume. The second optical window is shown upper right.

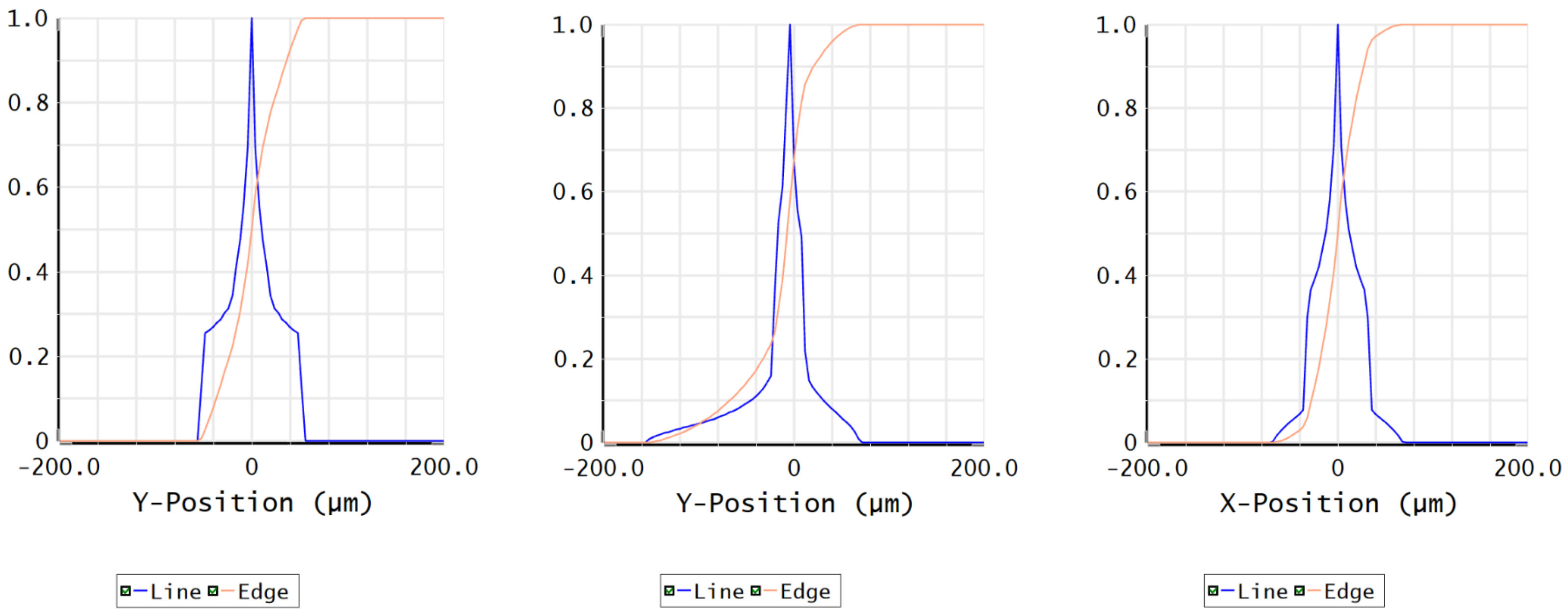



Zemax optical simulation of the phantom with liquid scintillator

# Optical imaging system

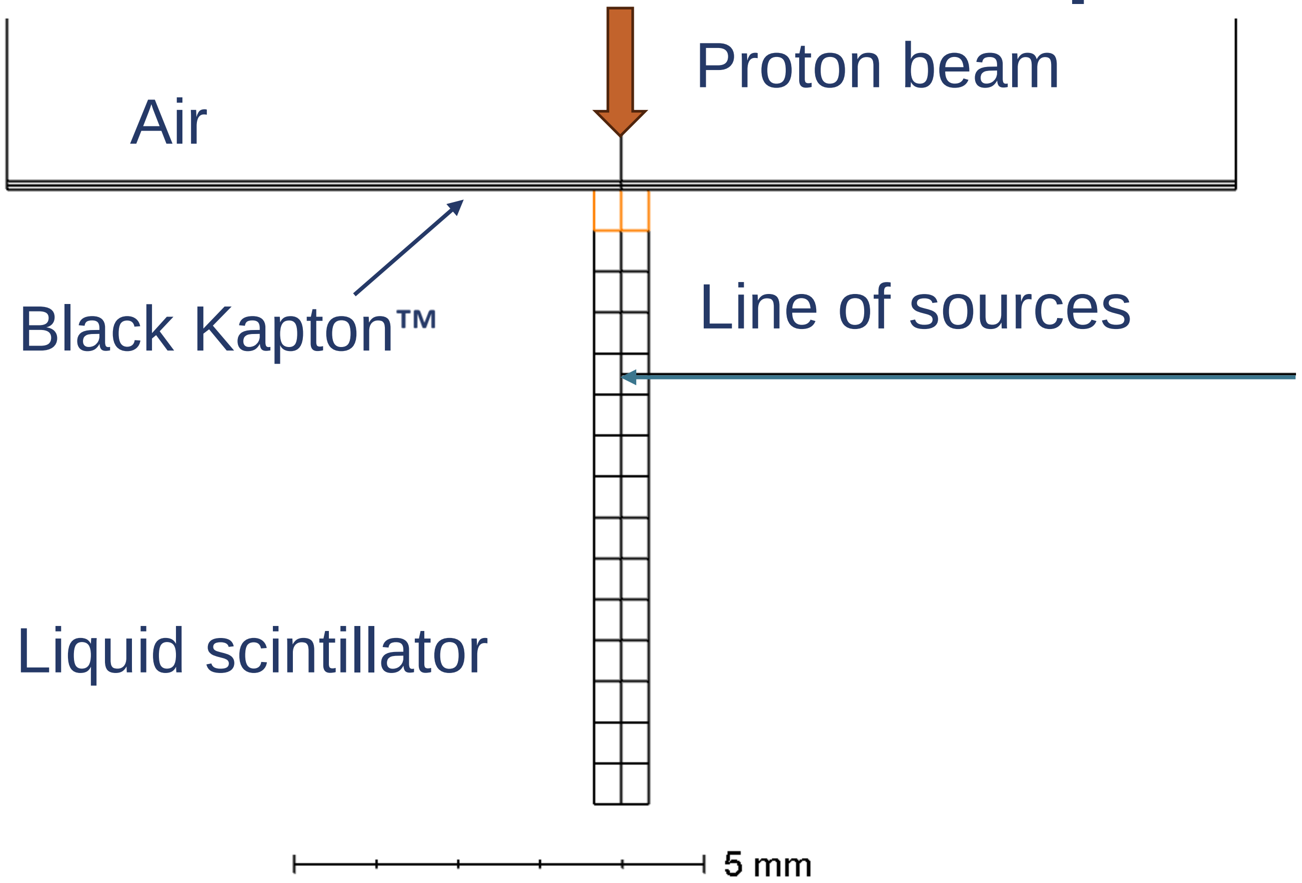


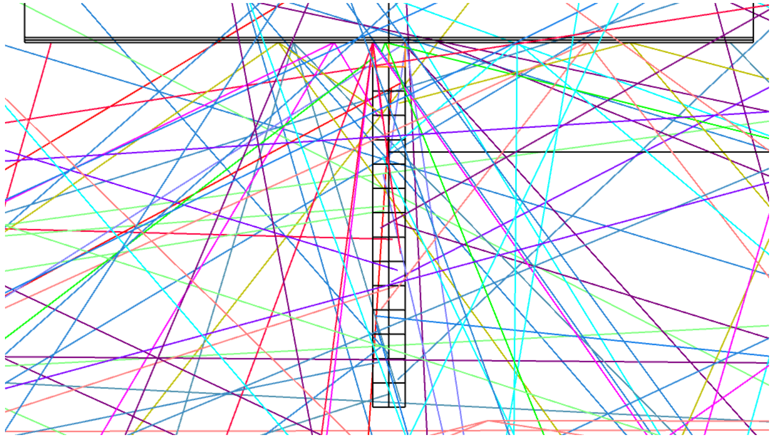



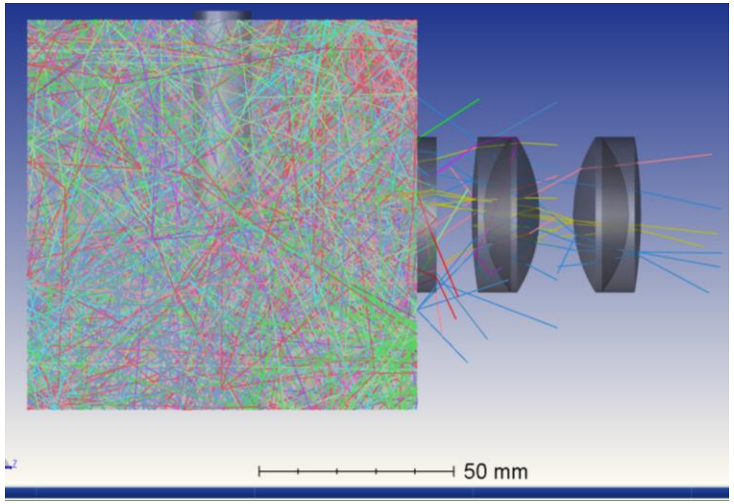

Geometric Line/Edge shown for on-axis (L) and for the 3 mm off-axis fields (C & R). (λ = 447 nm)

# Source model in ZEMAX Optic Studio



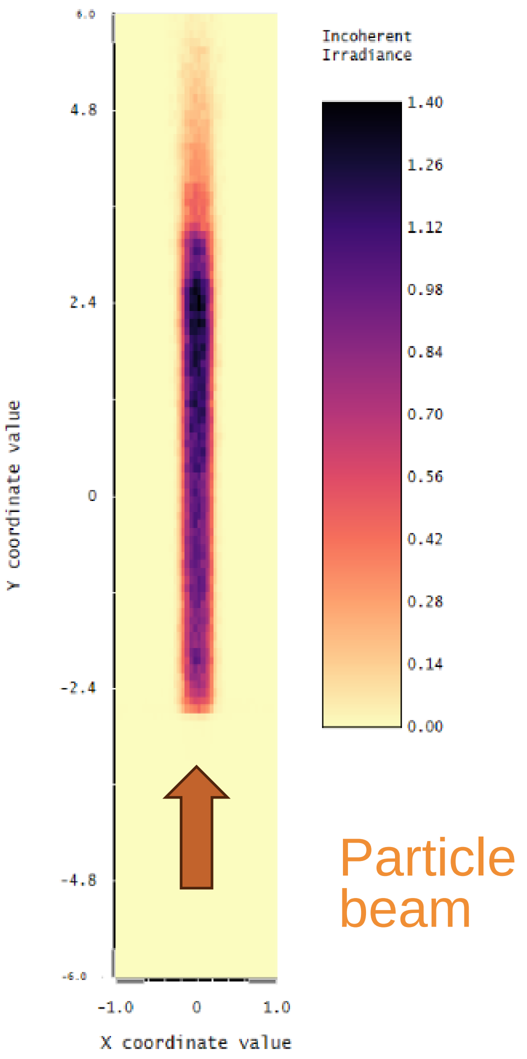

Source of scintillation photons is modelled as a line of elliptical elements each emitting isotropically. Intensity and # of photons are weighted by the simulated energy deposited in each 0.5 mm long elliptical cylinder.

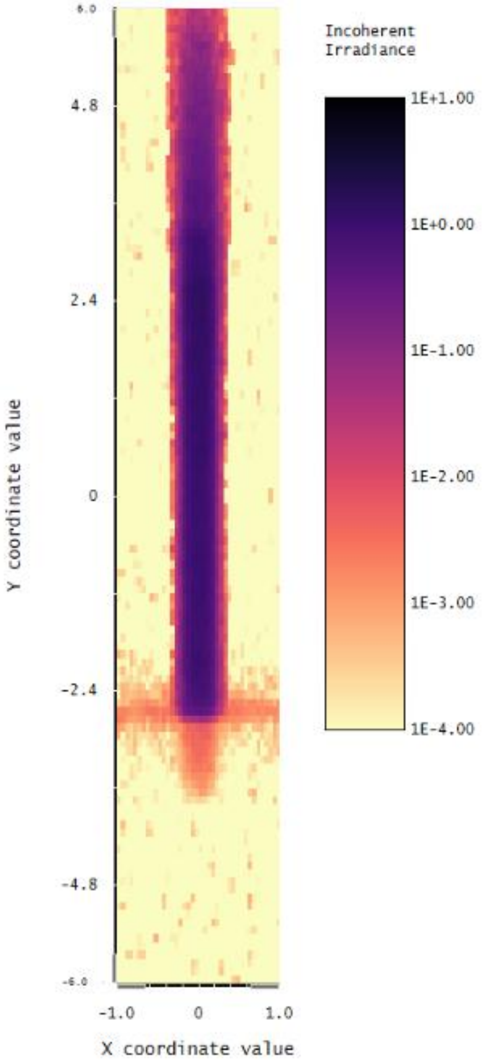





Only 2 primary rays per source are generated in this ray trace. Ray splitting and scattering are switched on.

# Simulated image on camera




NOTES

50 µm × 100 µm pixels

21 million *primary* rays, have been generated to produce this image.

3 rays generated per Lambertian scatter event from "black" surfaces.

Optical collection efficiency is 0.3%

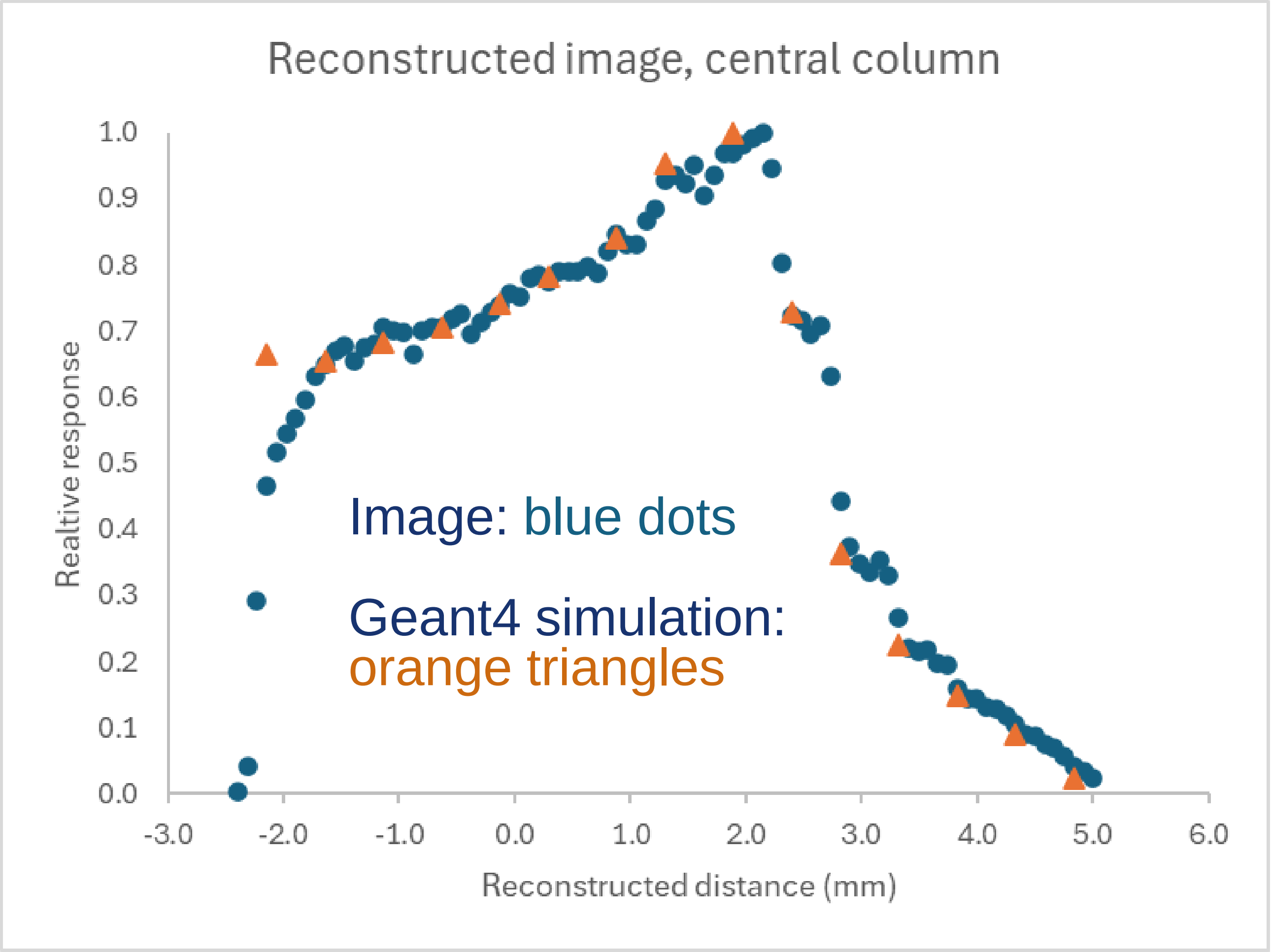
X, Y coordinates are in mm

Left figure is linear irradiance, right figure is logarithmic plot of the same data

# Simulated image on camera

Cross-section along column centre of image on previous slide.

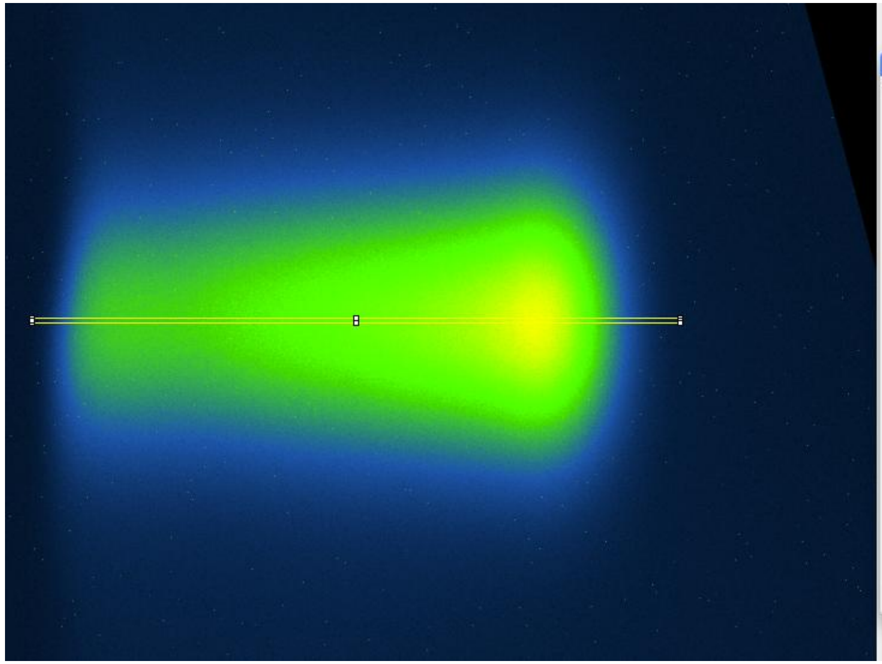
Both data sets, image and predicted energy deposit from the proton beam were normalised to total area and then to unity at the respective peaks.

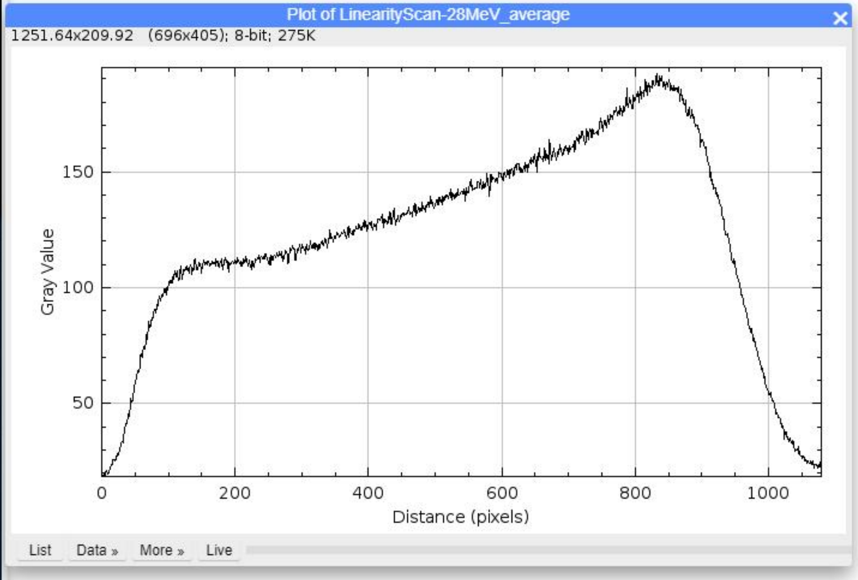



NOTE

50 µm × 100 µm pixels

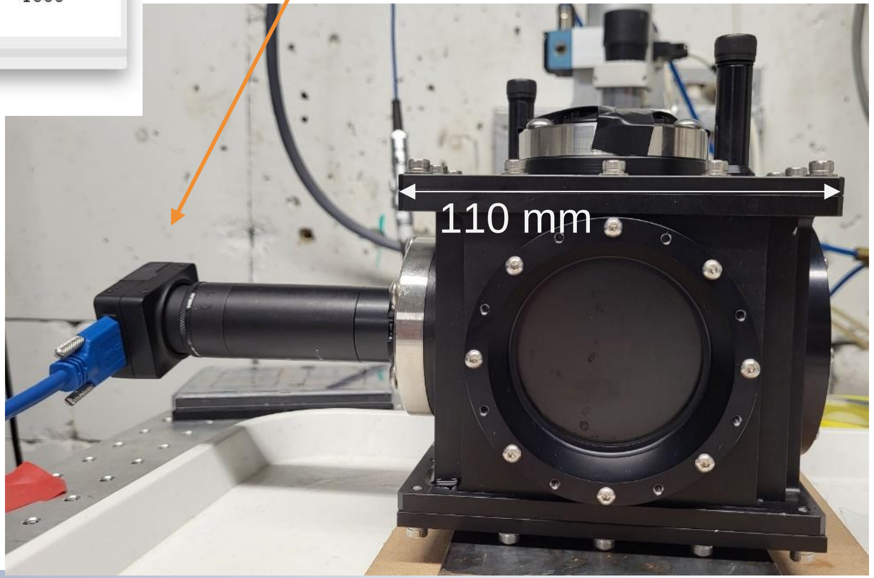
# Actual image on camera from cyclotron proton beam






## Camera

3.5 µm × 3.5 µm pixels




**Data** from the UK Birmingham cyclotron (~20 MeV protons, 2 mm diameter beam collimator).

Average of 60 frames, dark frame subtracted. Profile plot is along the yellow rectangle.

# Presented at the OPTICA Optical Imaging Conference, Toulouse, July 2024

Queen Mary University of London Science and Engineering

IMPERIAL

ICR The Institute of Cancer Research in partnership with The ROYAL MARSDEN NHS Foundation Trust

LhARA Laser-hybrid Accelerator for Radiobiological Applications

## Imaging the Energy Deposited by a 20 MeV Proton Beam Using a Commercial Liquid Scintillator

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[1]Queen Mary University of London, [2]Imperial College London, [3]Institute of Cancer Research and Royal Marsden NHS Foundation Trust

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# Revisiting optical simulations for the real LION beamline experimental conditions

What is the effect of real lens tolerances?

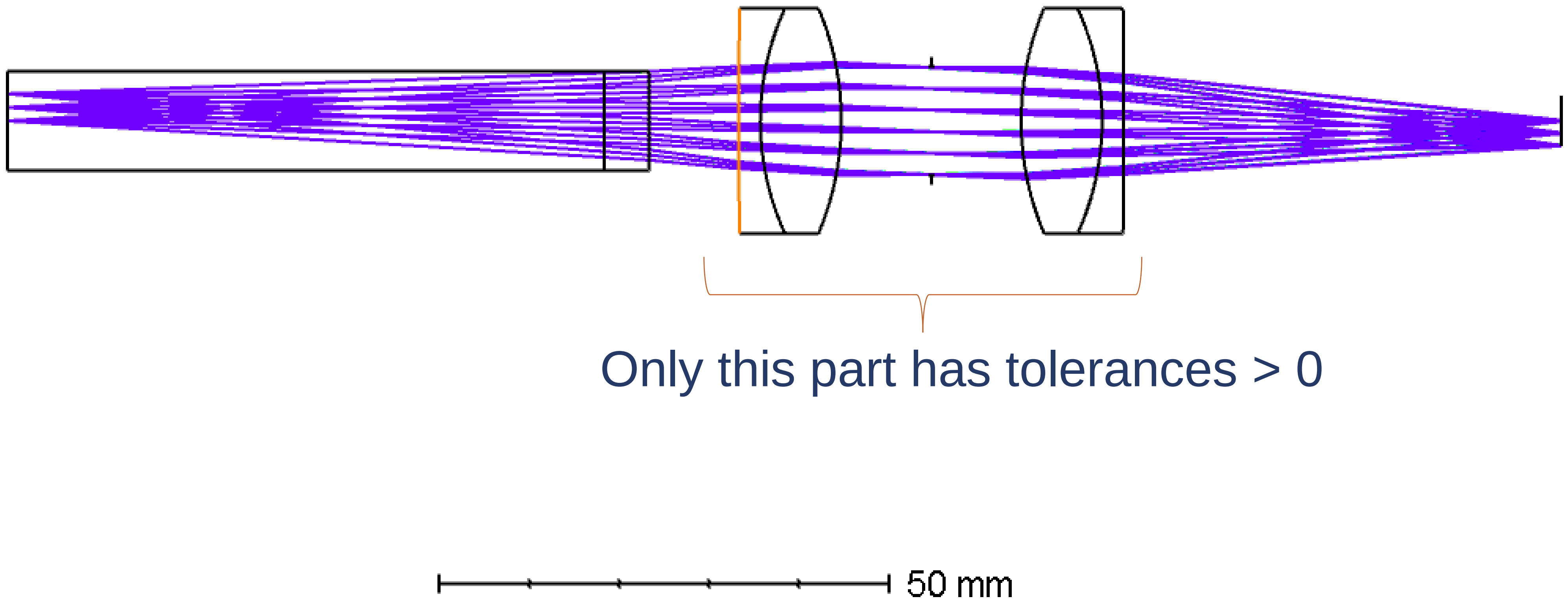
What is the sensitivity of the liquid scintillator imaging system to proton beam offsets from the nominal centre?

What is the effect on the first ~ 1.5 mm of beam due to the "occluding ring"?

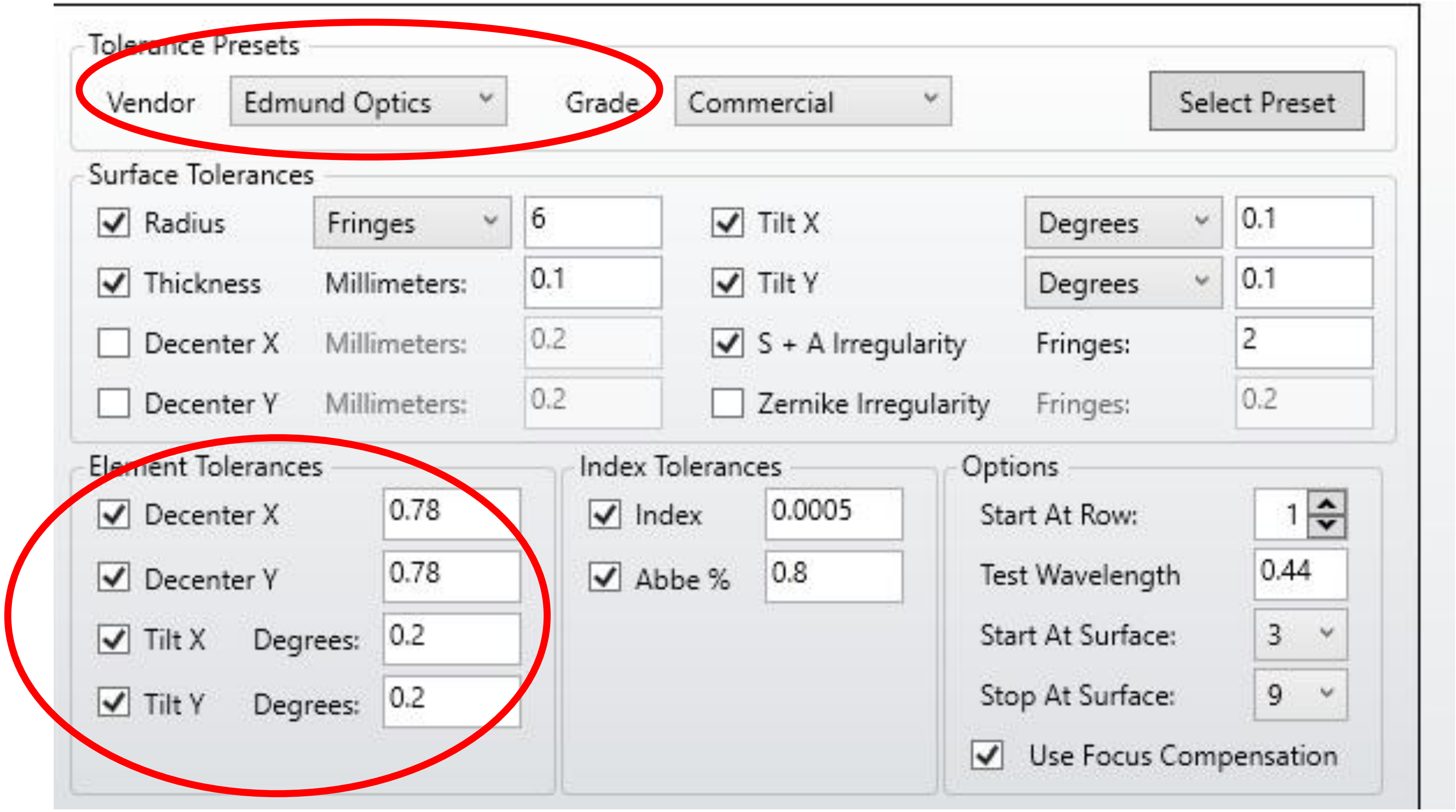
# Tolerance analysis

Minimise rms spot radius, use paraxial focus as compensator;

Made **50 MC runs** and assumed a normal distribution of deviations.



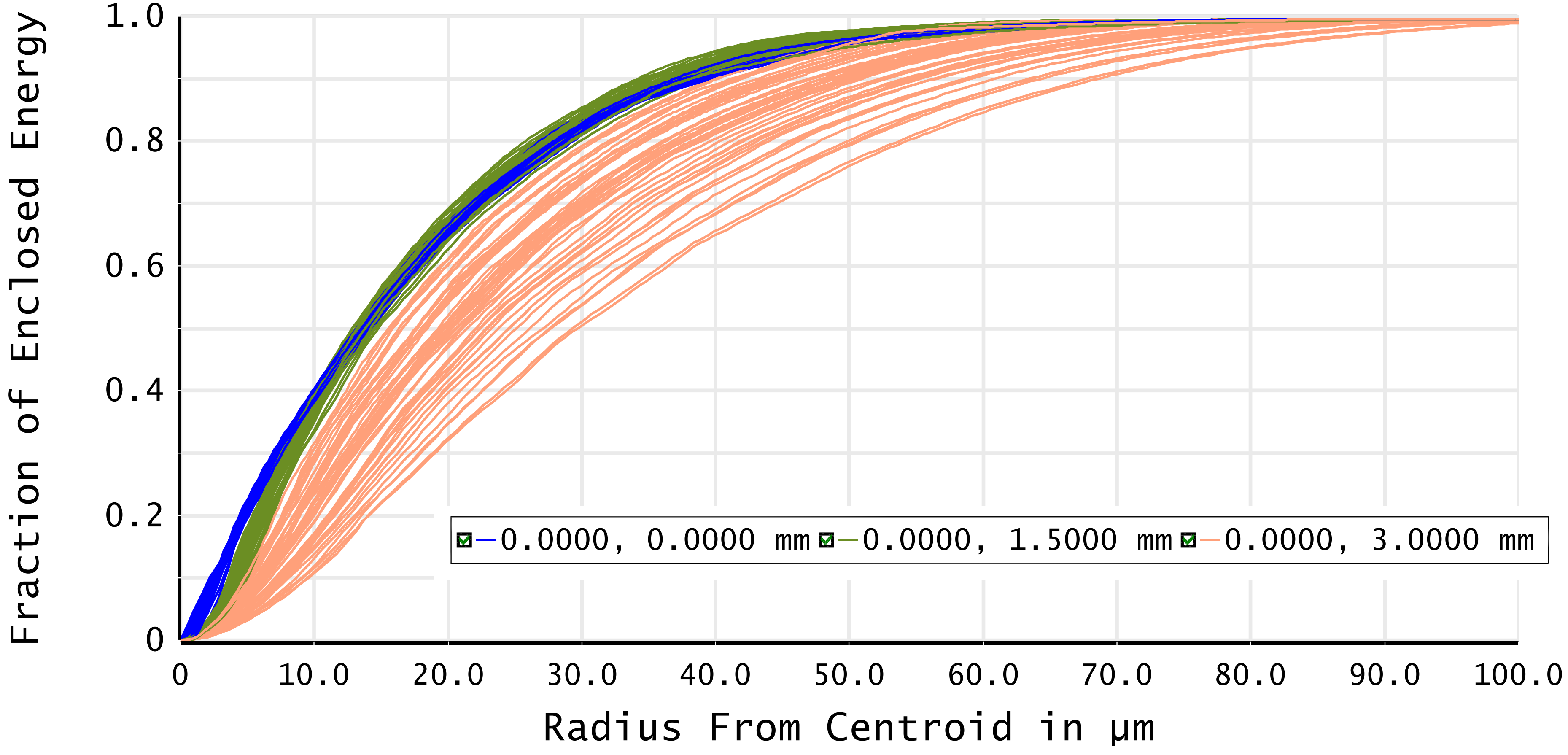
# Zemax lens tolerances




Worst case tolerance of lateral fit of lens to tube = 0.78 mm

# Zemax tolerance analysis – encircled energy

Wavelength = polychromatic

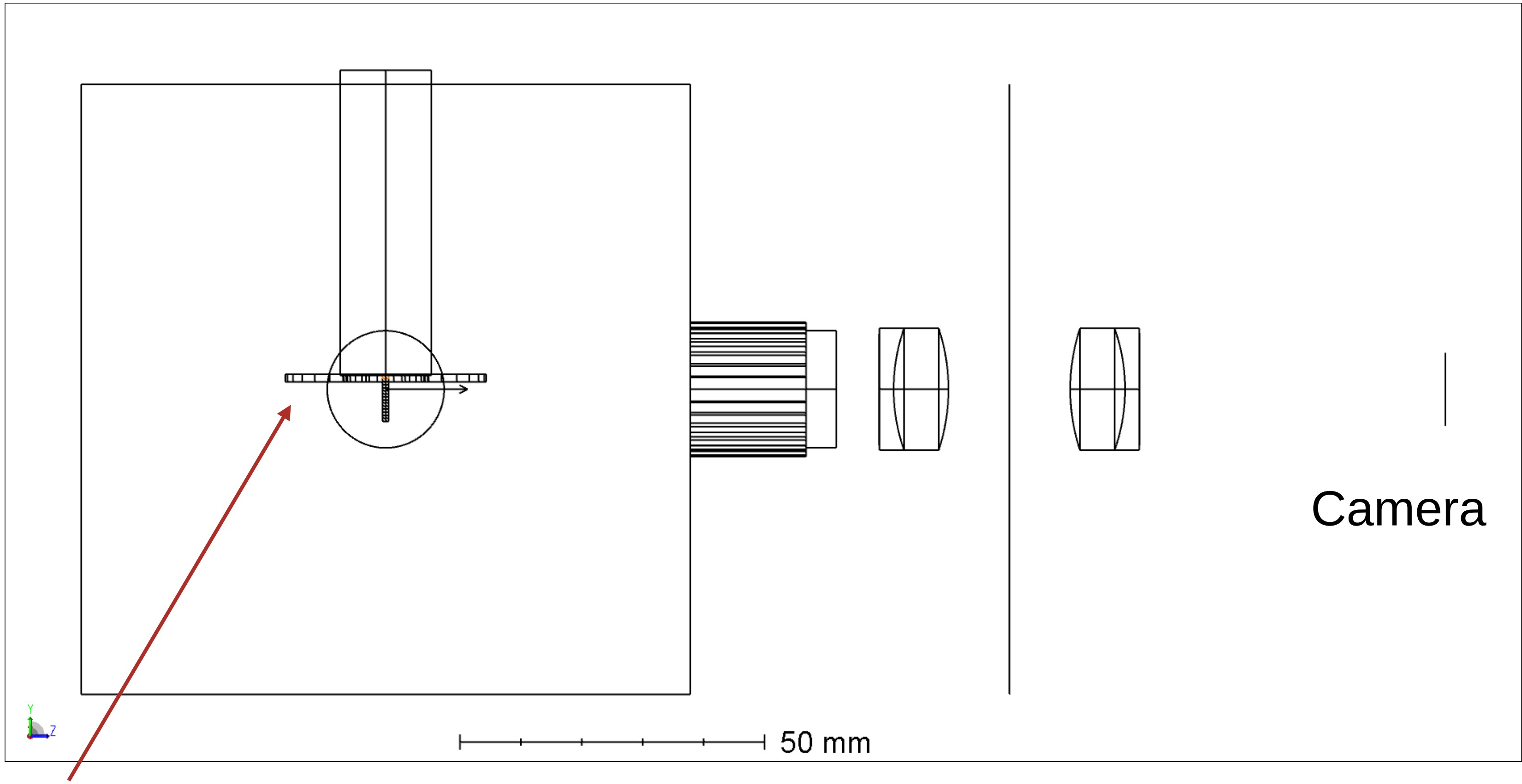


# SmartPhantom optical arrangement with occluding ring

Wavelength = 440 nm

Fluorescent beam is circular and 1 mm in diameter;

A total of 300 million primary photons were generated. Ray splitting and scattering were enabled (this accounts correctly for Fresnel reflection).




Occluding ring (Kapton™ retaining and scintillator plane support)

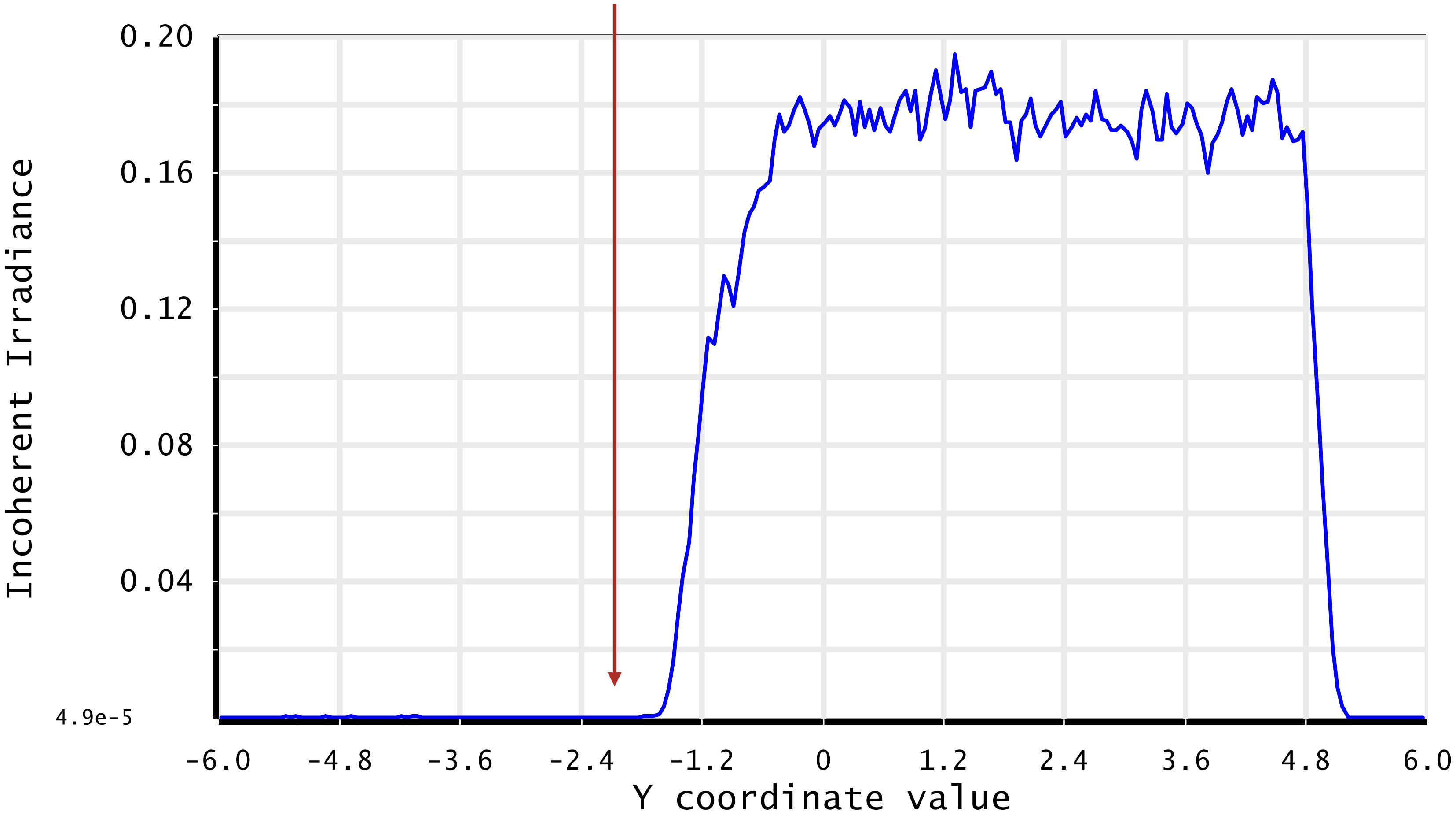
# Beam on axis

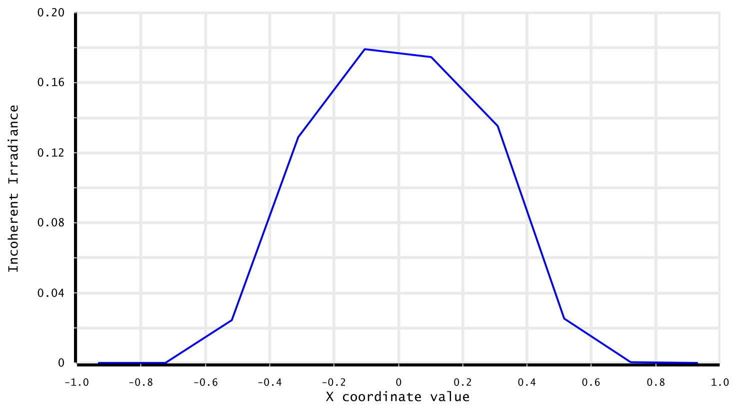
Wavelength = 440 nm

Fluorescent beam is circular, uniform and 1 mm in diameter;

Central 60 rows are summed.

Fluorescent light starts here




Cross-section at y = 0

# Beam on axis vs +5 mm towards lenses

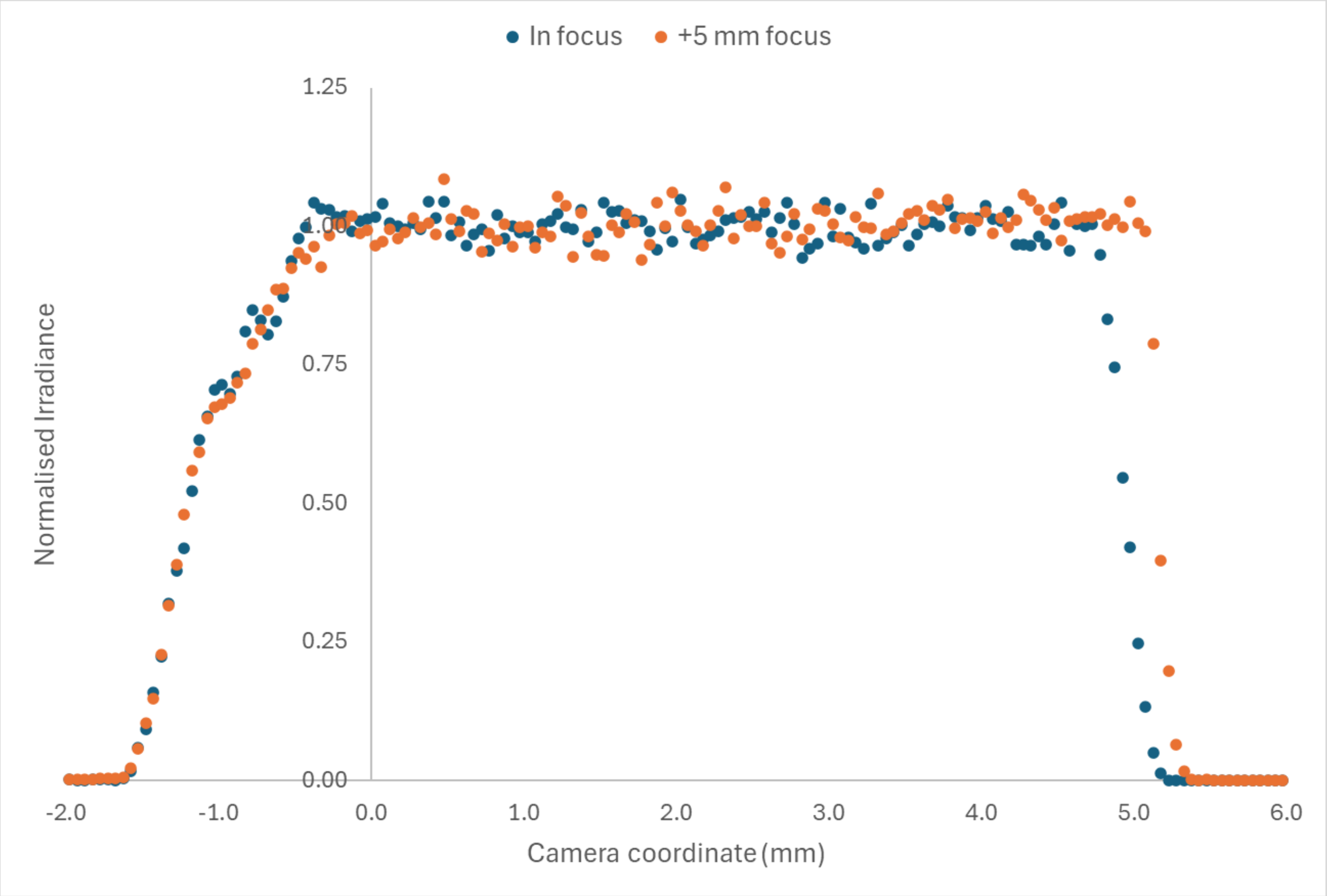
Wavelength = 440 nm

Fluorescent beam is circular, uniform and 1 mm in diameter;

Central 60 rows are summed.

Data normalised to the average intensity from 0.0 to 3.6 mm

Some magnification change, this has not been corrected for – camera coordinate is plotted.



# Where next with IonAcoustic dose cross-check?

Can we design an improved SmartPhantom for accelerator beam evaluation?

Can we design a new phantom which is as close as possible to a commercial cell culture plate?

What role should the detection of liquid (or solid) scintillation light play?

How do we get this funded?