Simulating dynamic irradiation of complex systems using RayXpert®'s built-in energy-angle spectrum

- *Nicolas MARY (TRAD), with L. EYCHENNE, C. DOSSAT, S. ROBIN-CHABANNE, N. CHATRY (TRAD), and D. PRIEELS (IBA), F. STICHELBAUT (IBA)*

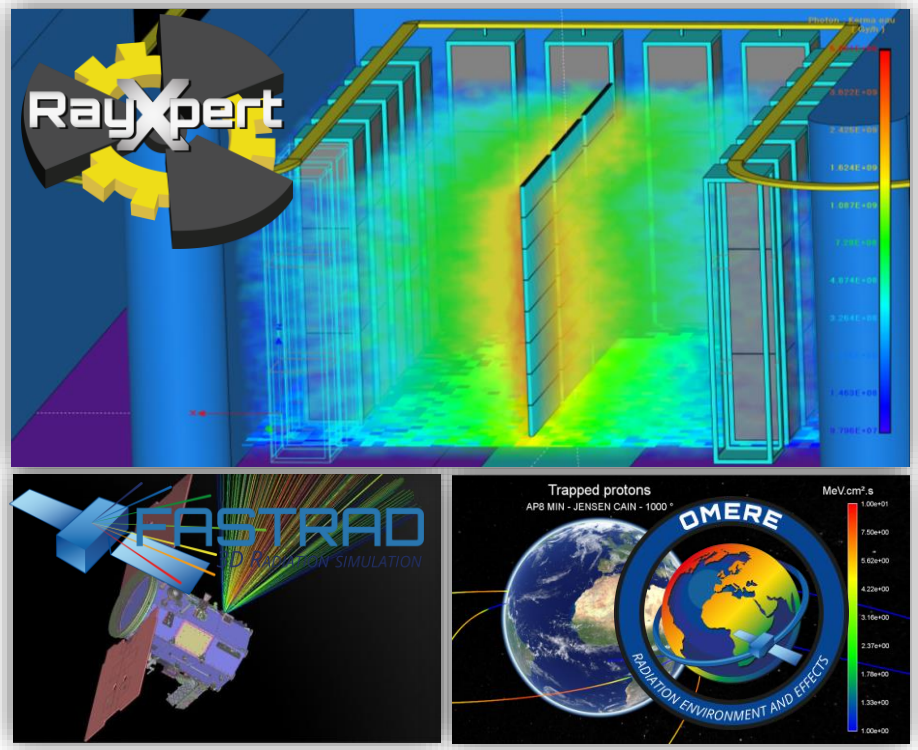
Summary

- TRAD, Tests & Radiation
- RayXpert®
- Introduction
- Reference setup for the dynamic irradiation
- First approximation of the dynamic irradiation
- The energy-angle spectra
- Definition of mapping and quantity of interest
- Comparison between the simplified source and the dynamic calculation
- Comparison between the Energy Angle spectrum and the dynamic calculation
- Conclusion

TRAD, Tests & Radiations

- Since 1994, we have been helping our customers with their projects involving radiation issues. From Space to Earth, with simulation & radiation processing

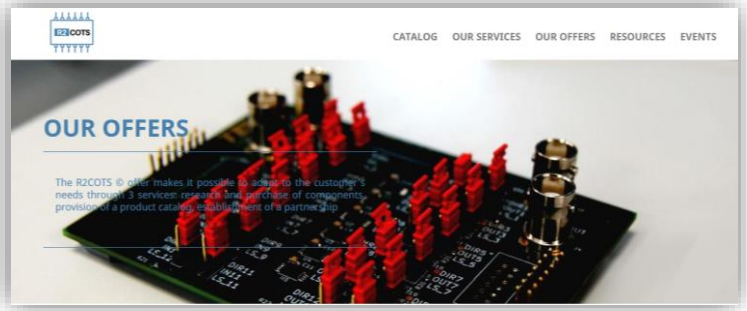
SOFTWARES EDITORS & ENGENIERING



RADIATION TESTS

RADIATION QUALIFIED ELECTRICAL COMPONENT

R2 COTS

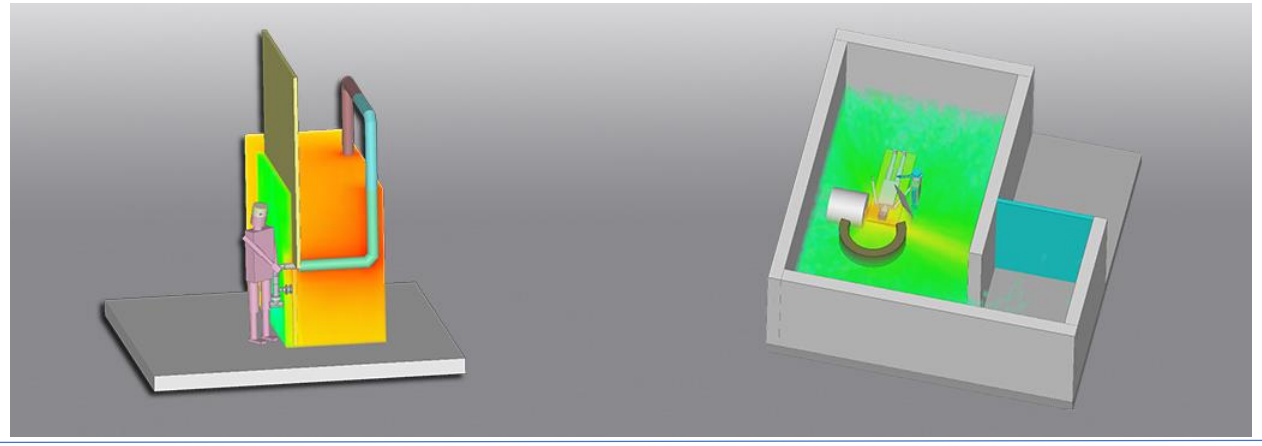


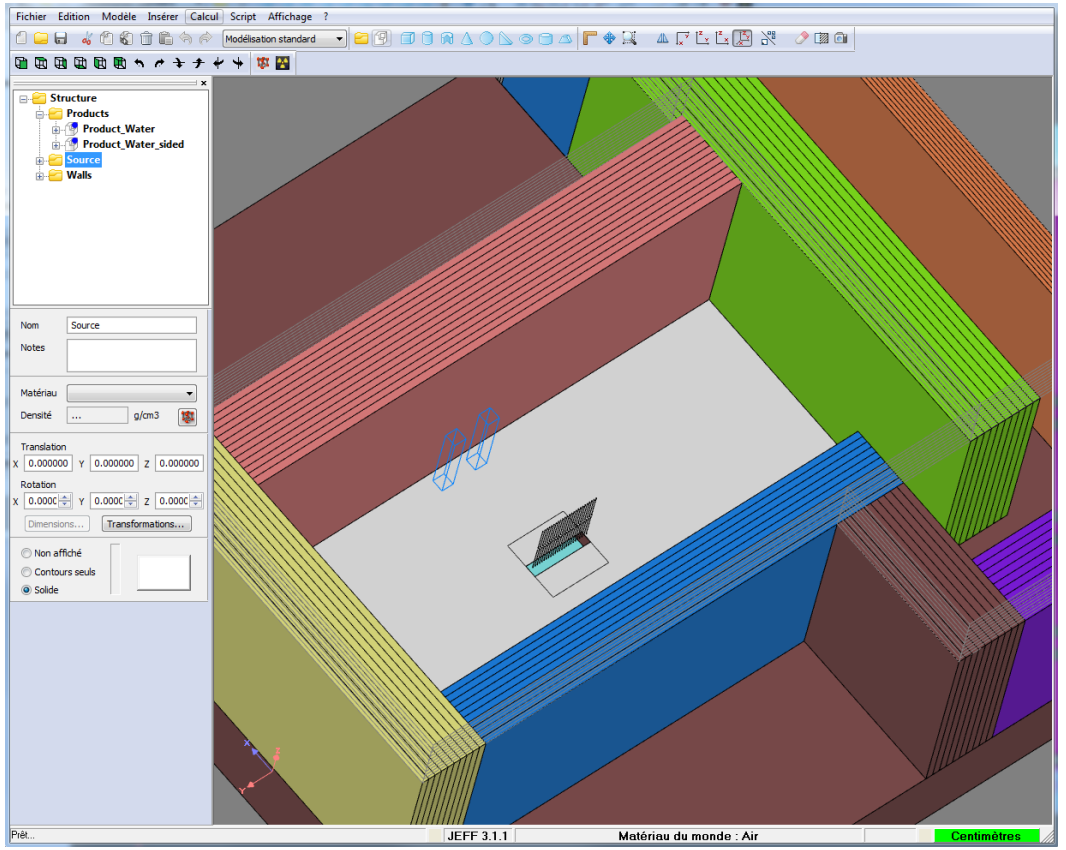
For more information :

rayxpert.com
trad.fr
r2cots.com
fastrad.net

RayXpert®

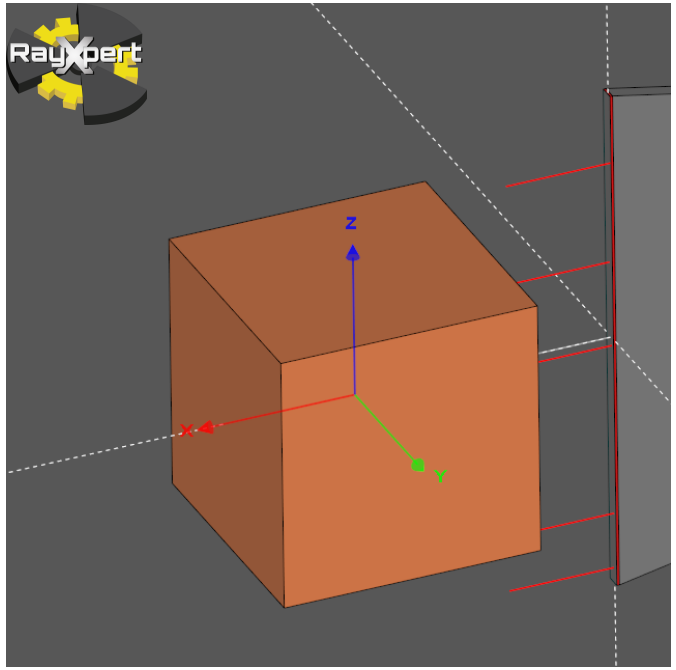
- Based on GEANT4® physics, with some tweaks since 2014
- Uses 3D engine and user friendly interface to interact with the model
- Photon, electron, positron (neutron as an add-on)
- Continuously updated



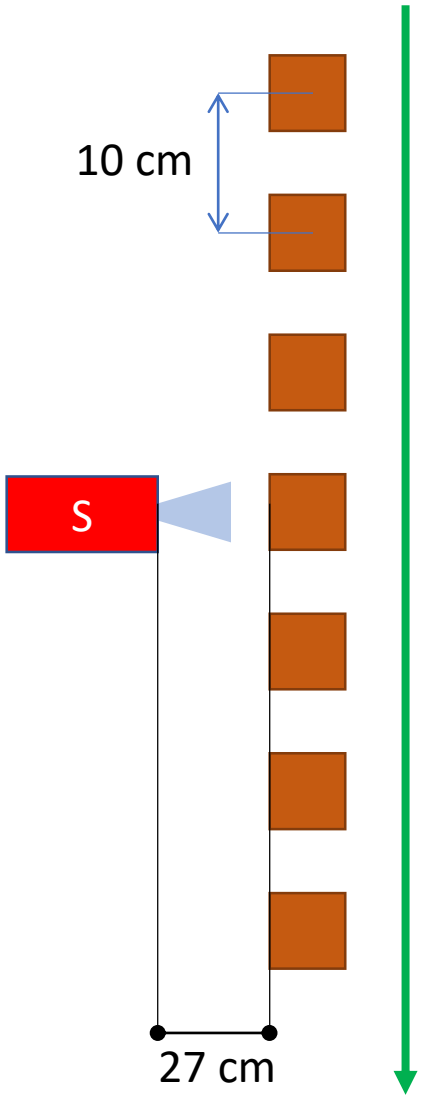


Introduction

- Irradiation facilities often involve moving trolleys passing in front of a x-ray source
- Proper modelling of this situation involves discretization of the motion and running high number of calculation
- One way to get faster results is to use a simplification of the initial source
- This simplification is often done one of two way:
  - Simplification of the geometry using equivalent thickness
  - Using an energy-angle spectrum



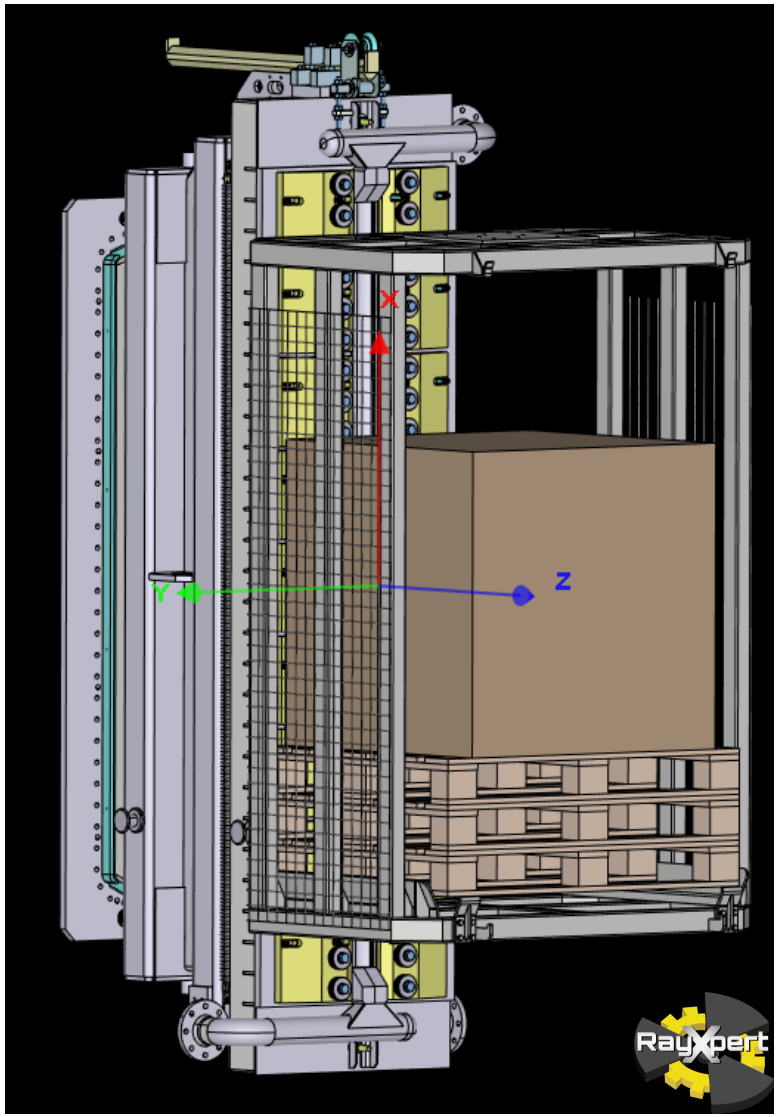
Reference setup for the dynamic irradiation



- The reference setup for the dynamic irradiation is as follow:

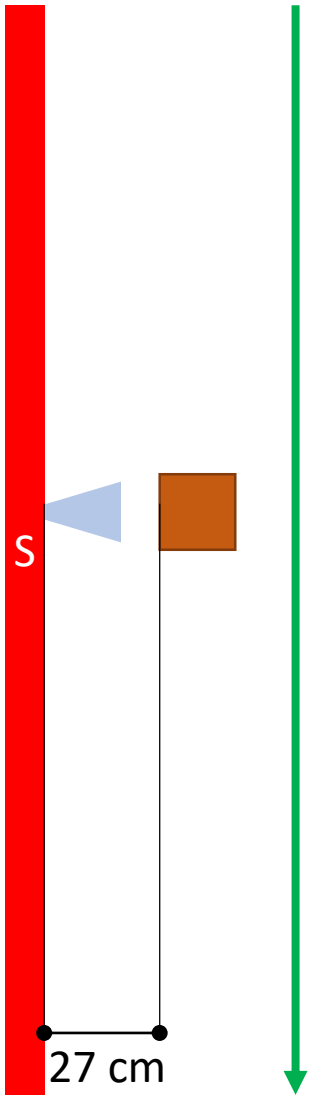
- **Product: Box of water (brown)**
  - Density: 0.15 g.cm^{-3}
  - Dimensions: 100 cm x 100 cm x 100 cm
- **Moving 310 centimeters in front of the beam**
  - 31 steps with 10 cm translation each

- Distance between the source (S) and the product is fixed at 27 cm
- Partnership with **IBA** for source information
- Source emits **electron**, conversion is simulated inside RayXpert®

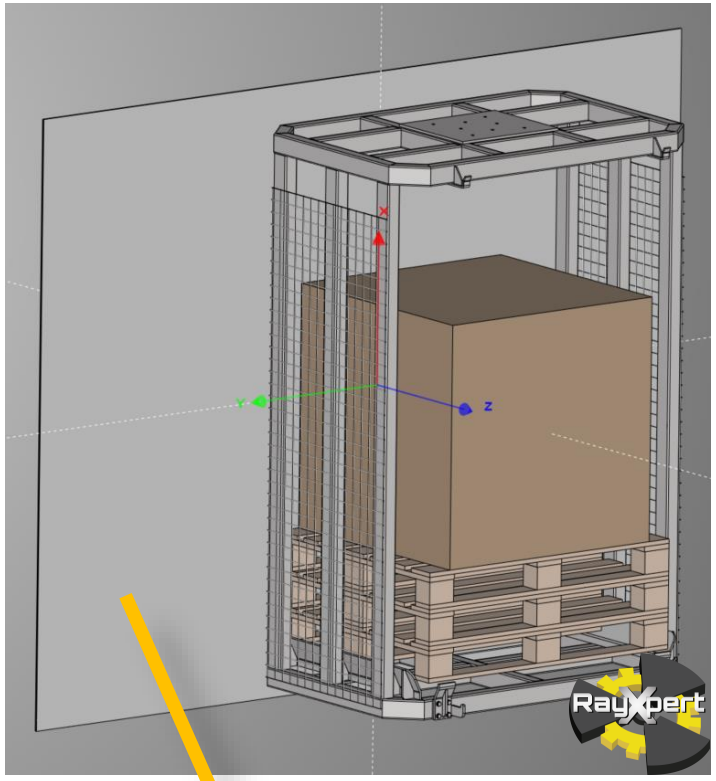


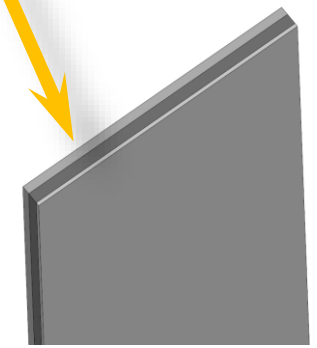
Courtesy of Aerial and IBA

First approximation of the dynamic irradiation



- The first approximation is based on **equivalent thickness of material**
- **Same product: Box of water**
- **310 centimeters long source, using the same materials as the real device**
- Distance between the source (S) and the product is fixed at 27 cm
- Source emits **electron**, conversion is simulated inside RayXpert®





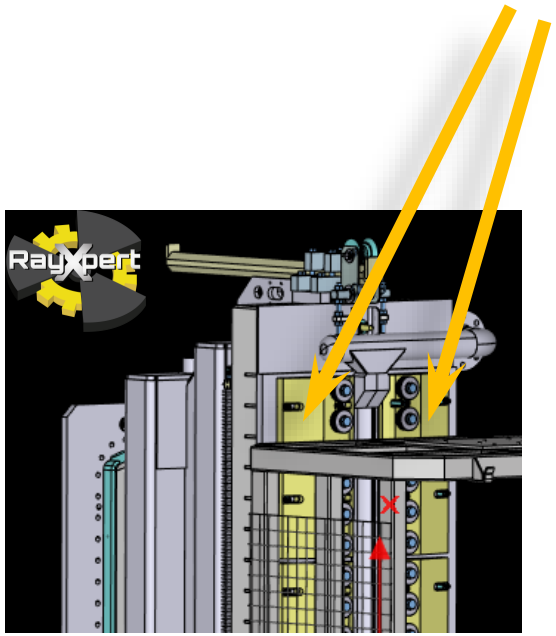
Courtesy of Aerial and IBA

Difference between first approximation and real life source

- Real life geometry is more complex than the simplification

- Elements not in the direct line between source and target product may have an impact (flanges) and can't be reproduced in the simplified model

➔ a more subtle approach is required that can incorporate the effect of the flanges and the specific of complex systems

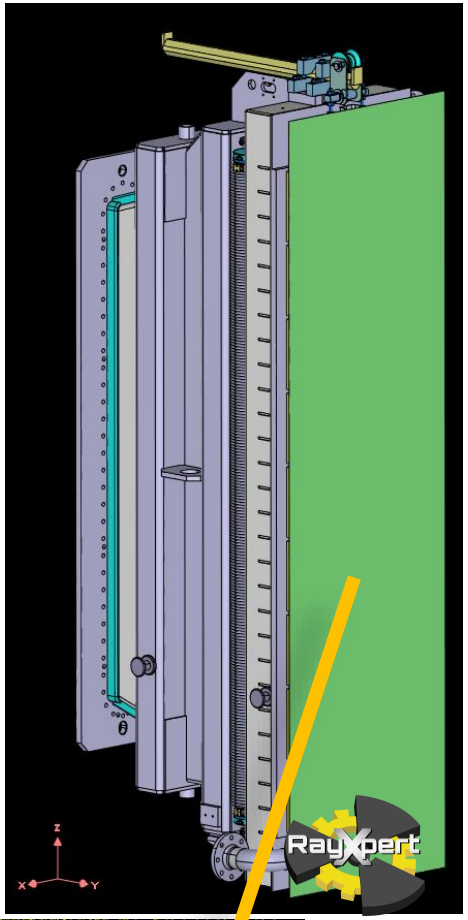


The energy-angle spectrum (1/4)

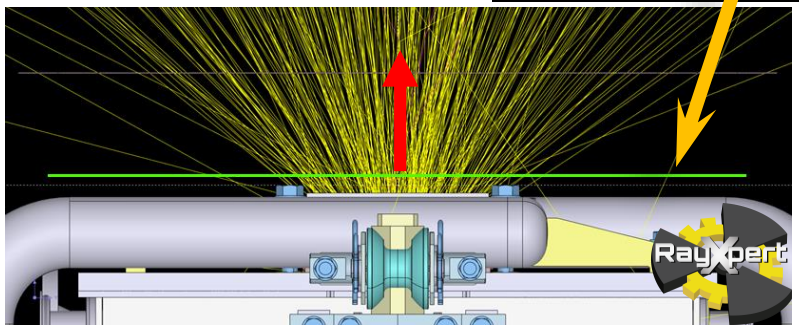
- Require two distinct calculations (akin to particle storage)

EA storage volume

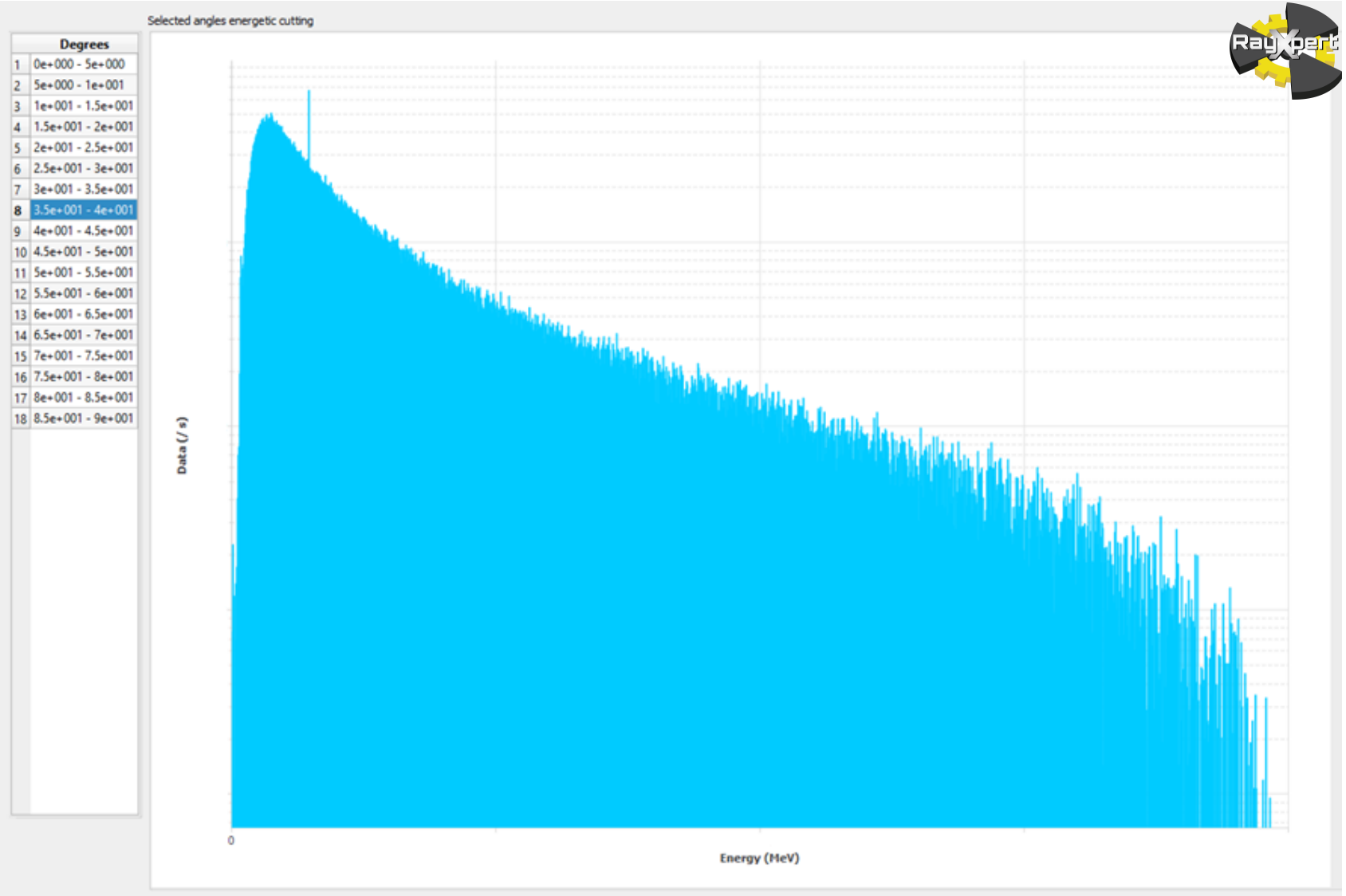
- **First calculation: store the particles and create the energy angle spectra**
  - **Particles stored: photon**
  - **18 angles for θ**
  - **Revolution regarding ϕ**
  - **1400 energetic groups ranging from 1 keV to Emax**



- **Output a .dat file that can be loaded as a source in RayXpert®**



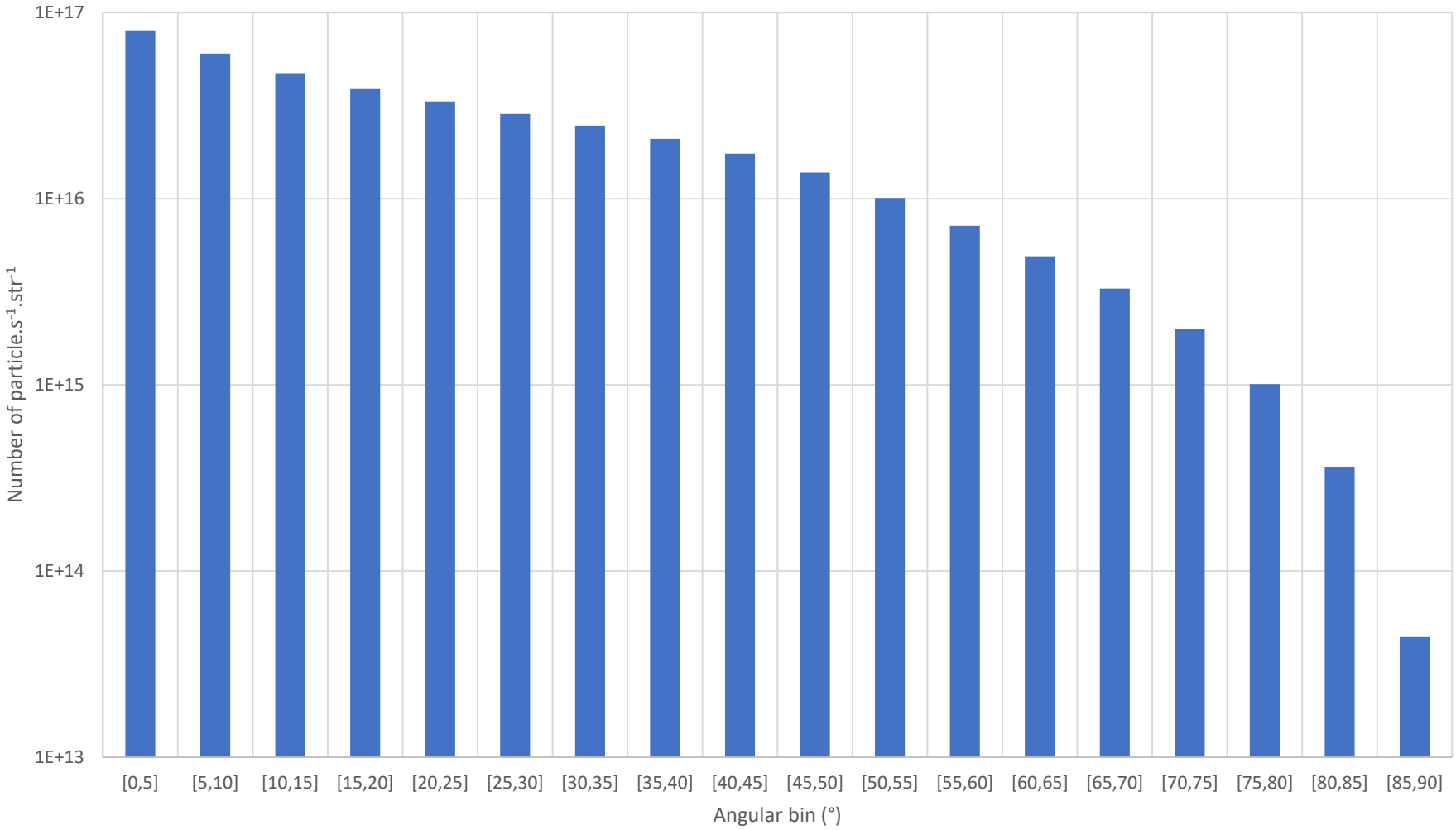
The energy-angle spectrum (2/4)



Resulting energy-angle spectrum (photon)

For the angle bin 35°-40°

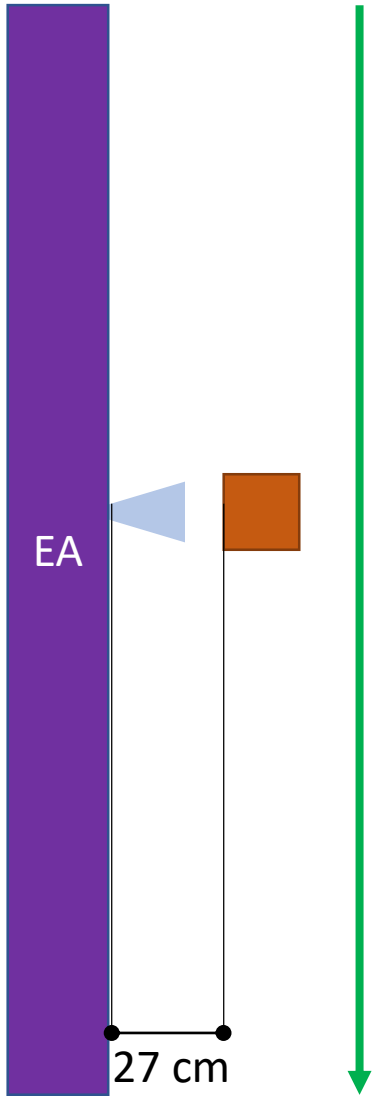
The energy-angle spectrum (3/4)



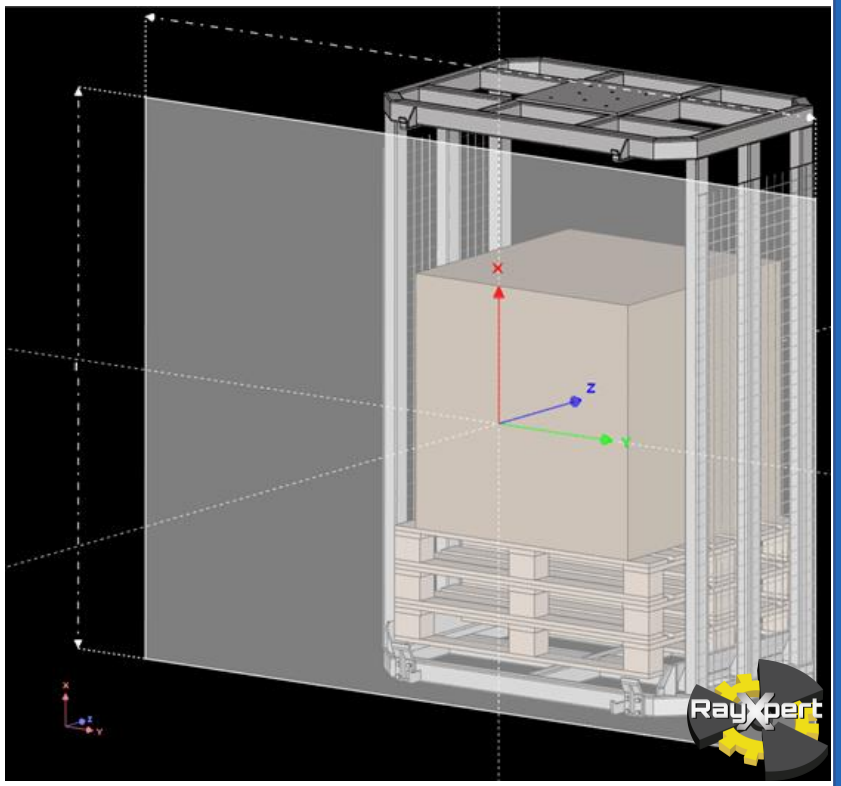
Resulting energy-angle spectrum (photon)

Total number of particle/steradian

The energy-angle spectrum (4/4)



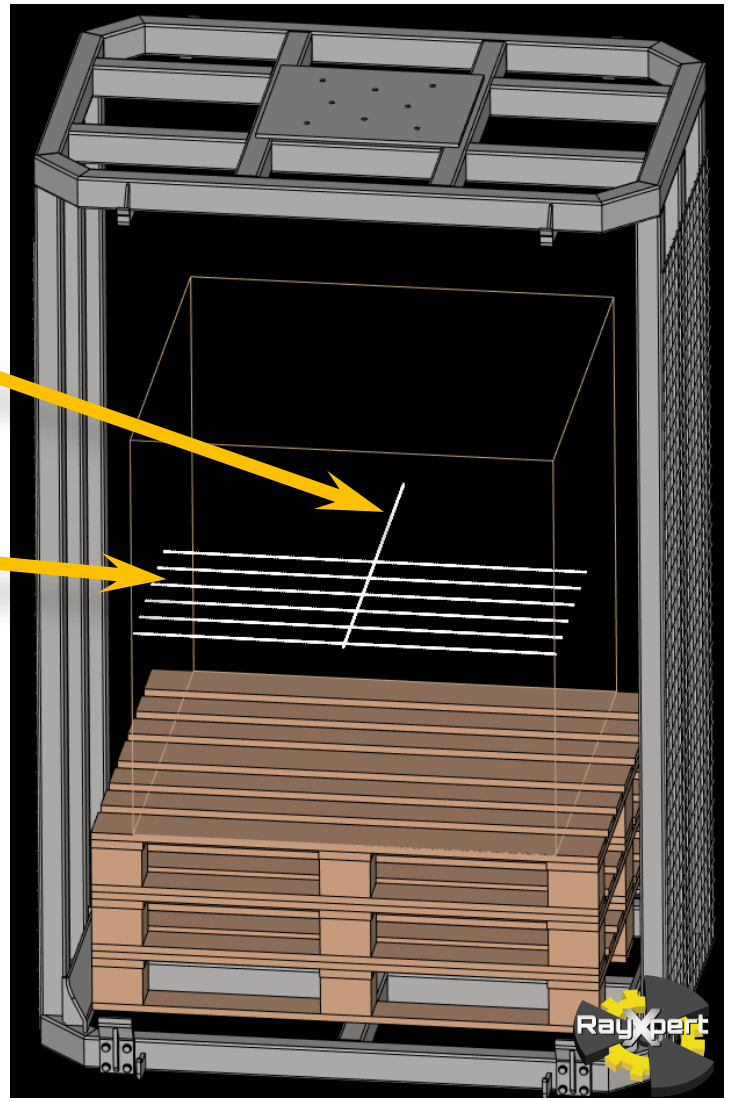
- Using the same kind of source as the first approximation
- **Same product : Box of water**
- **310 centimeters long source, no material (virtual source)**
- Distance between the source (S) and the product is fixed at 27 cm
- **Emits photon & electrons based on the various bins in the EA spectrum**



Courtesy of Aerial and IBA

Definition of mappings and quantities of interest

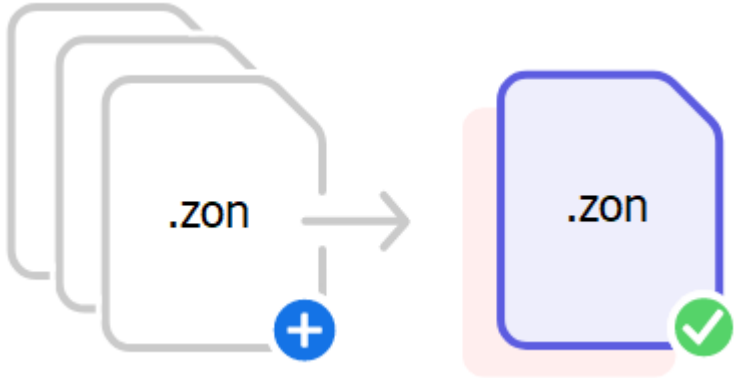
- **Depth dose profile**
  - Along Z axis, centered
  - Dimension of voxels : 5 cm x 5 cm x 0.5 cm
- **Slices along Y axis**
  - Each 10 cm along the Z axis
  - Dimension of voxels : 5 cm x 0.5 cm x 5 cm
- **Quantities**
  - Kerma water (Gy/h) from photons
  - Deposited energy (MeV/h) converted to absorbed dose (Gy/h) from electrons



Courtesy of Aerial and IBA

Data and post-processing of results

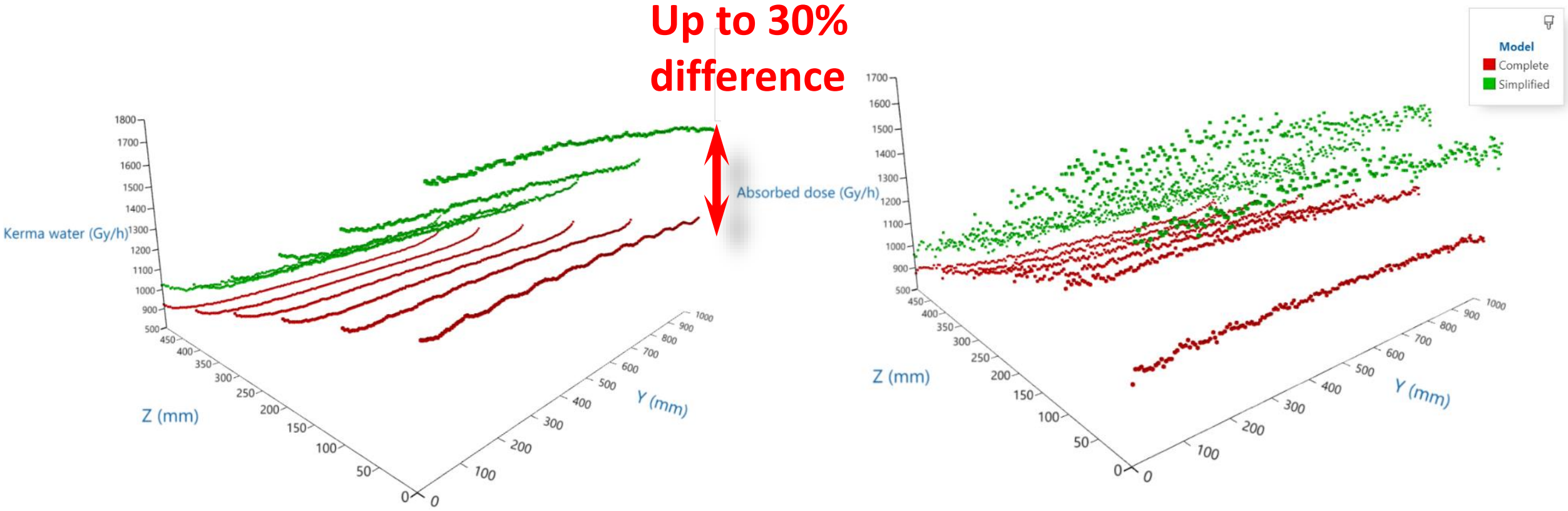
- The reference case used 31 calculations. The results from each calculation was summed



- The simplified and energy angle cases were treated as such: contribution from everywhere in the spatial distribution already taken into account
- Time integration would permit absolute dose comparison
- 3D graph were plotted using PowerBI

Power BI

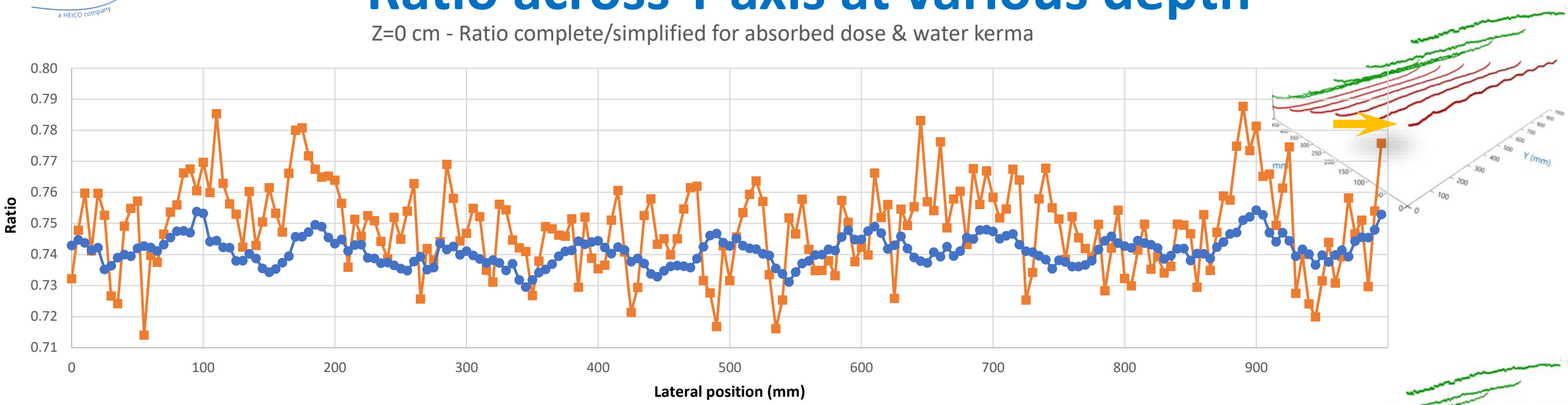
Comparison of simplified and reference case



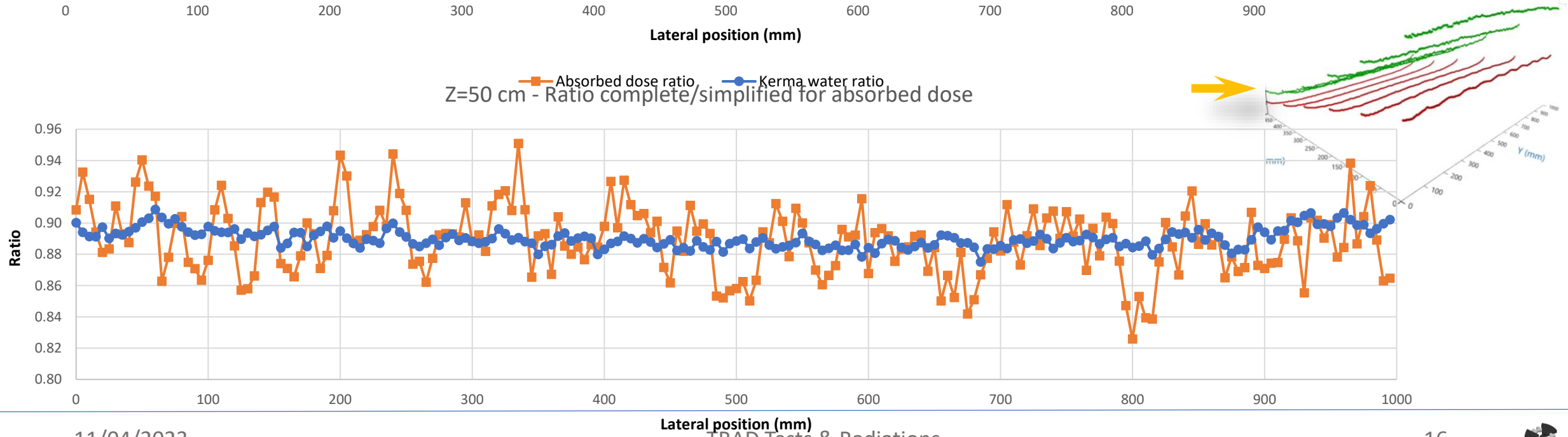
Higher dose rate with the equivalent thickness model, **up to 30% difference**

Ratio across Y axis at various depth

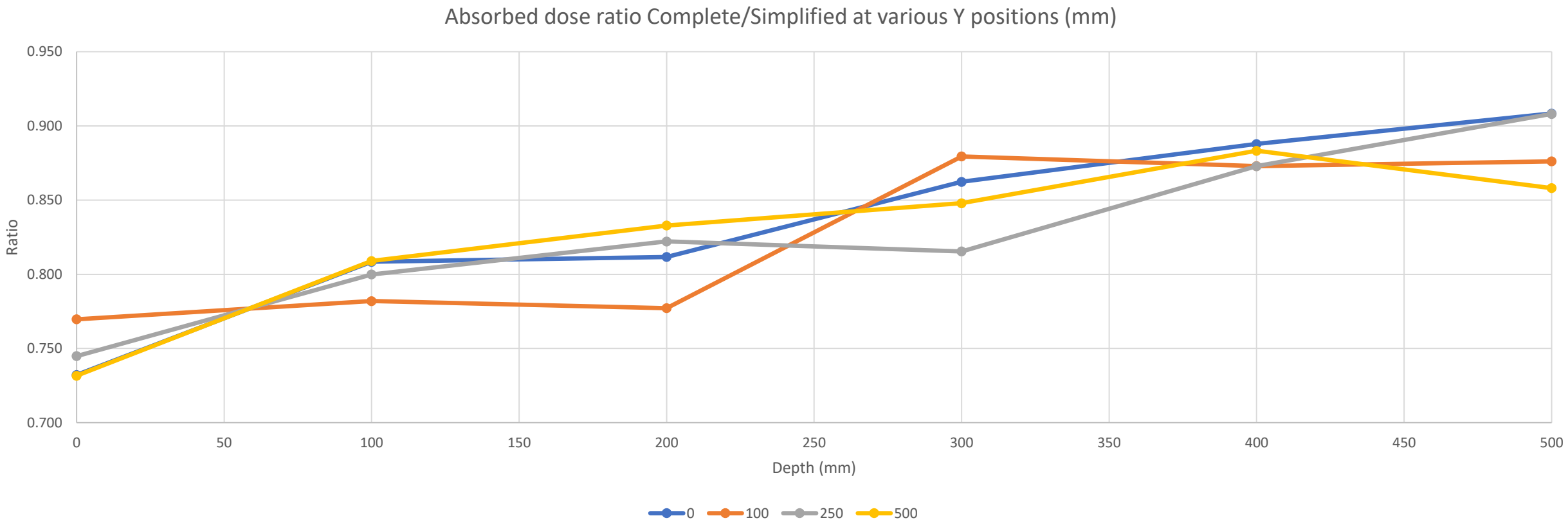
Z=0 cm - Ratio complete/simplified for absorbed dose & water kerma



Z=50 cm - Ratio complete/simplified for absorbed dose

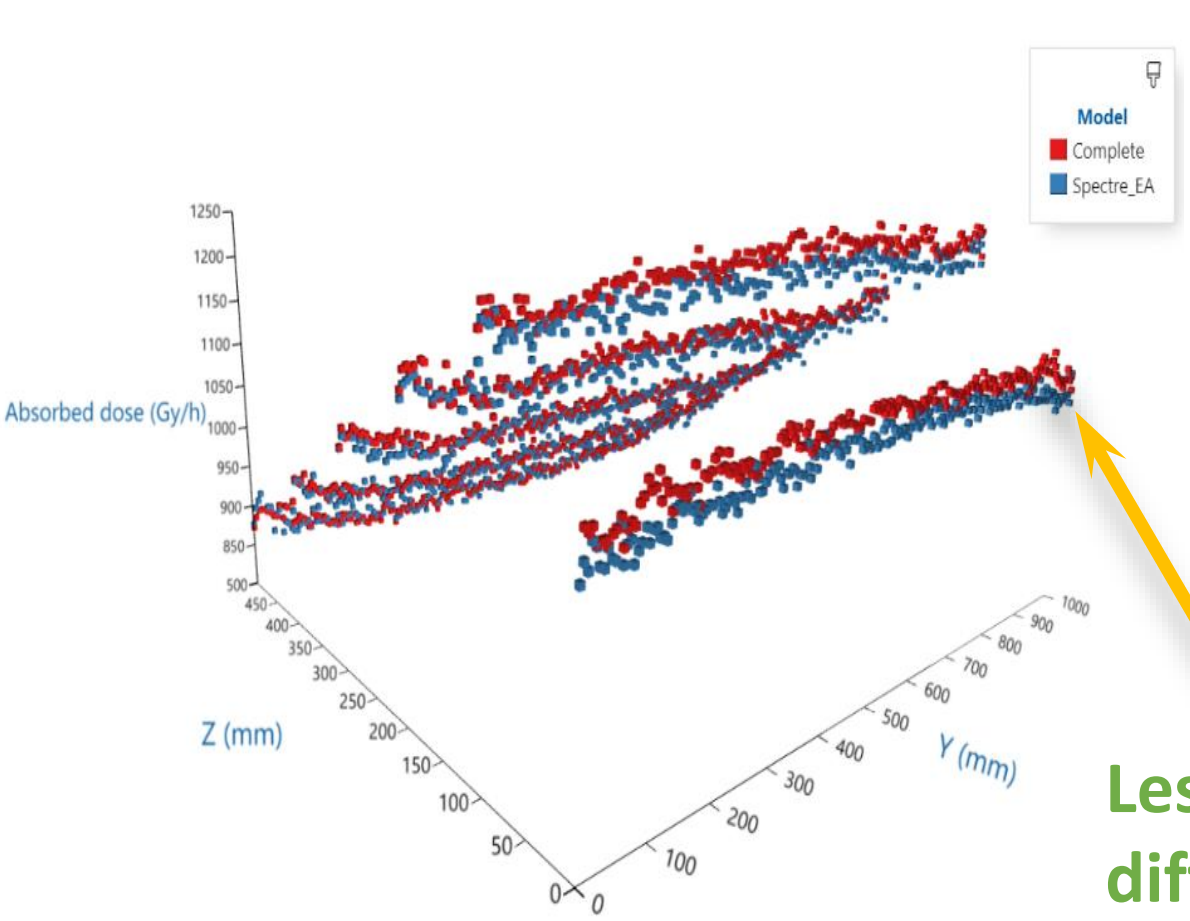


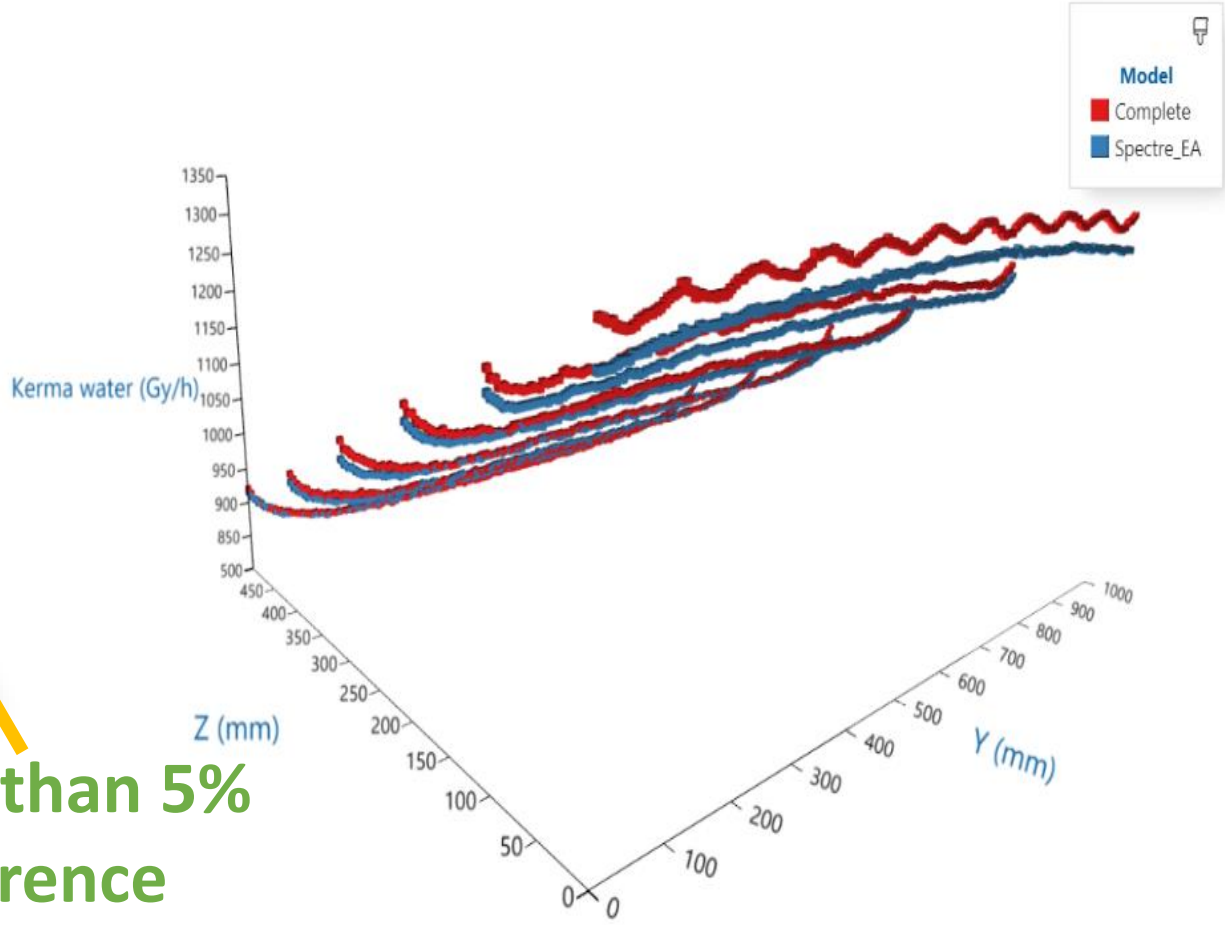
Depth evolution of the ratio



Difference between the two models are evening out (<15% difference at the end of the product)

Comparison of EA spectrum and reference case



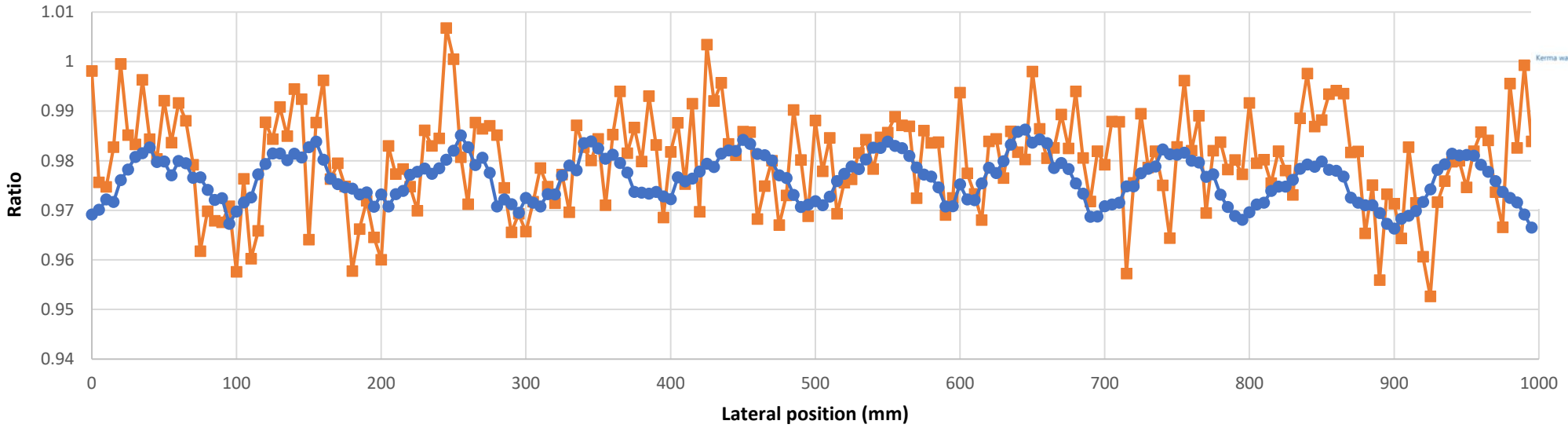


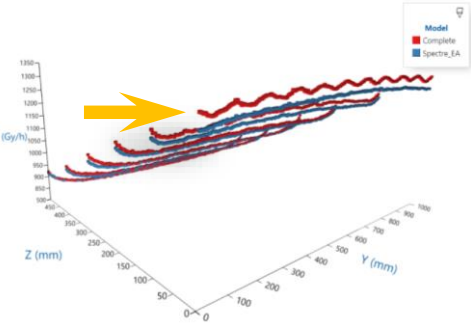
Less than 5% difference

Close to the dynamic calculation: **<5% difference**

Ratio across Y axis at various depth

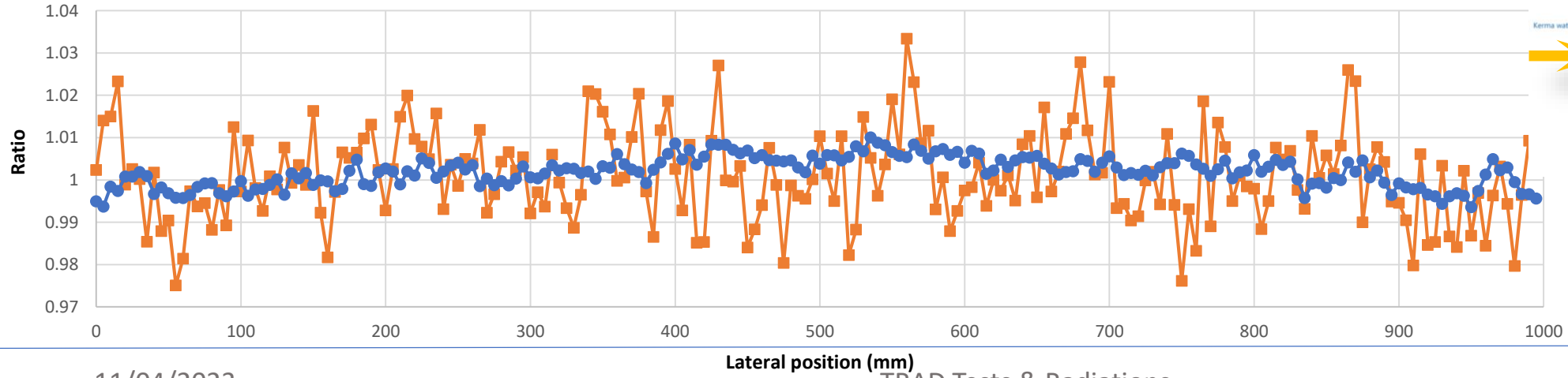
Z=0 cm - Ratio EA spectrum/complete for absorbed dose & water kerma

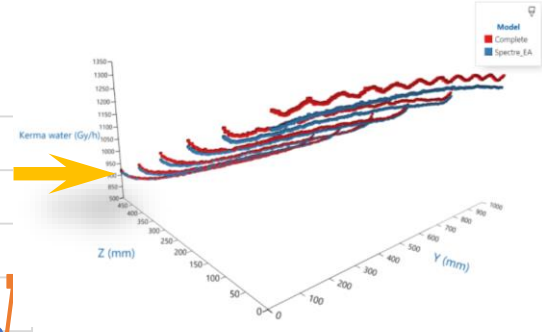




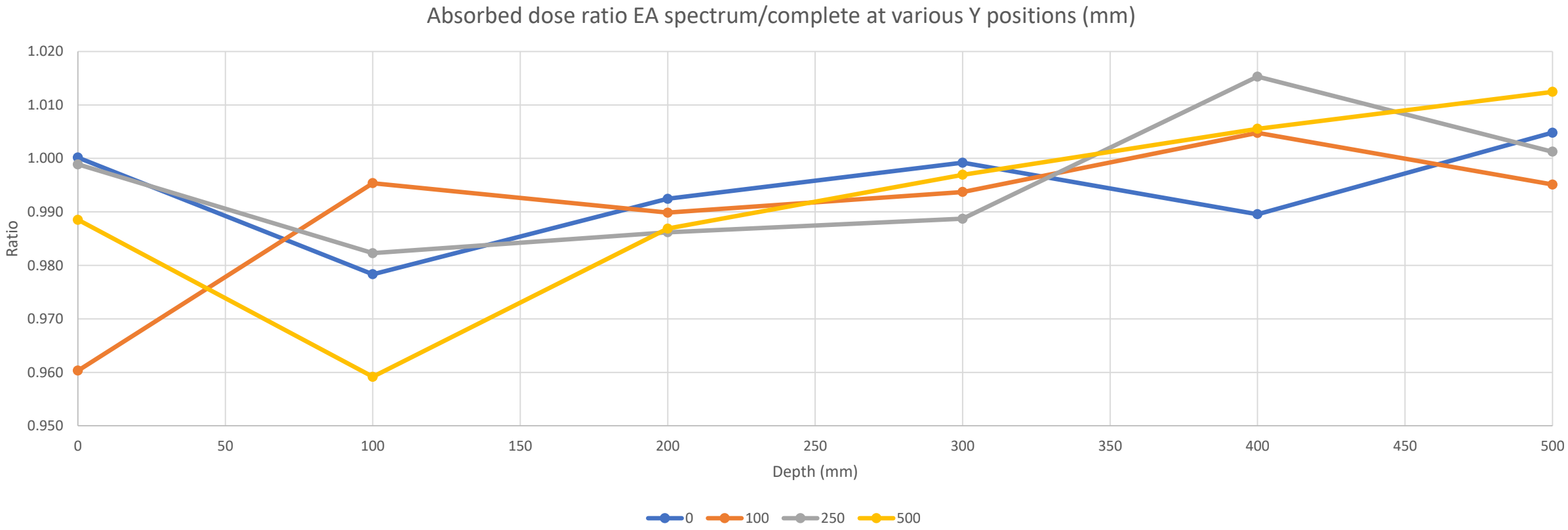
Absorbed dose ratio Kerma water ratio

Z=50 cm - Ratio EA spectrum/complete for absorbed dose & water kerma





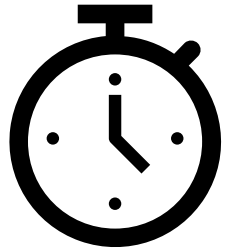
Depth evolution of the ratio



Less than **5% difference** in absorbed dose between EA spectrum and complete simulation

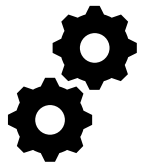
Runtime comparison

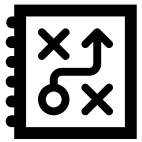
- 31 models for the dynamic irradiation were run for 87 to 180 day.CPU
  - 10.7 year.CPU total
- Simplified model was run for 3.6 year.CPU total
- Energy angle spectrum:
  - Creation : 40 day.CPU (<u>one time only</u>)
  - Use: 11 h.CPU



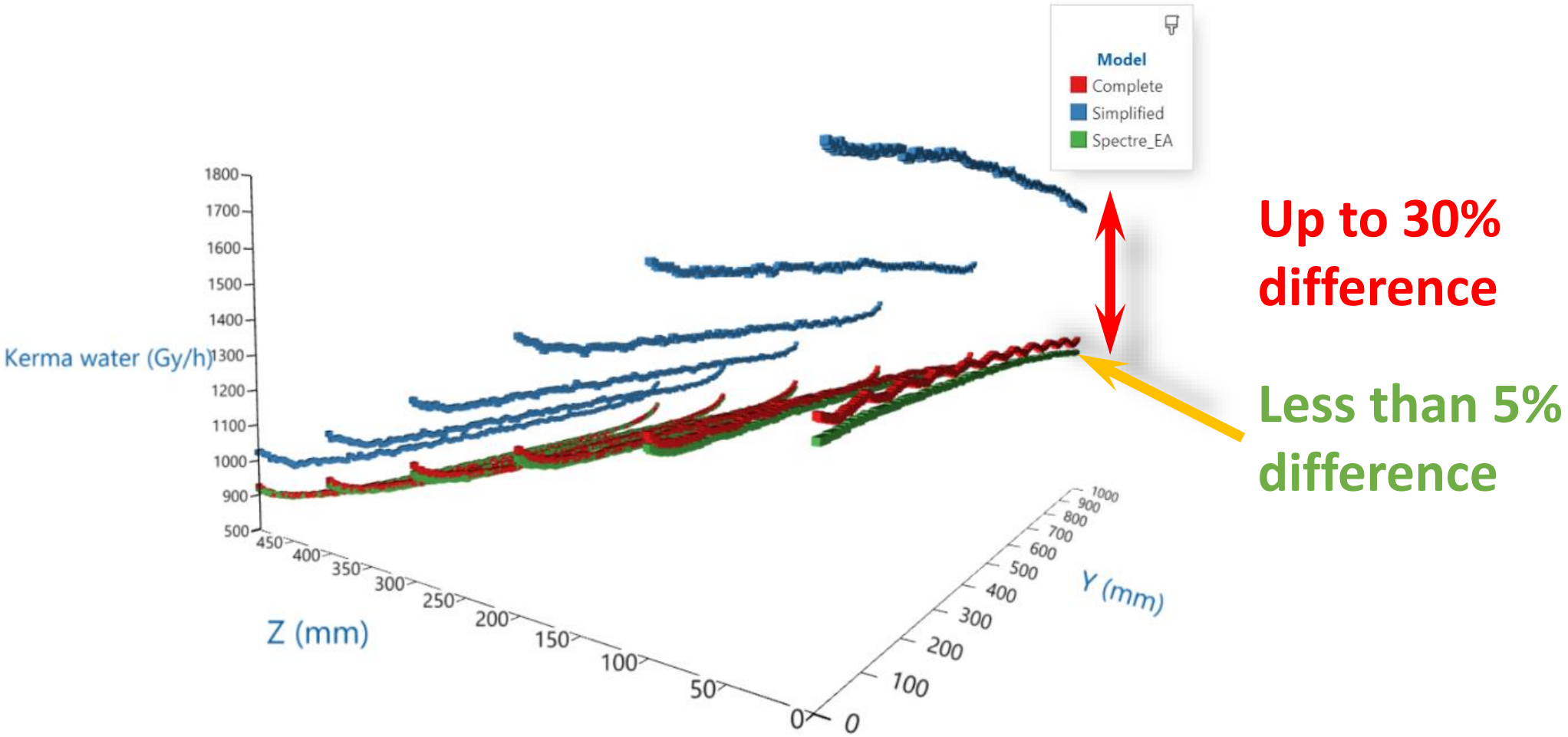
- Reduce runtime by **100** (including generation) or up to **7800** for subsequent run

- Allows for easy iteration over a product design, or optimization of the irradiation setup





Comparison of the three models

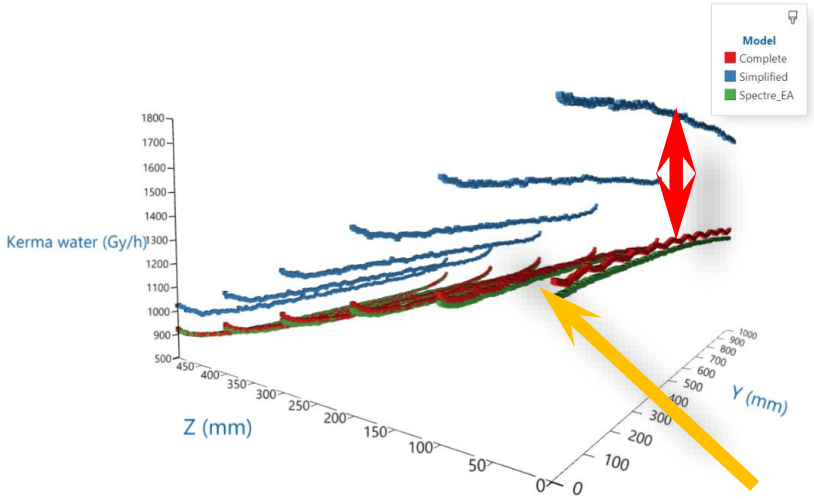


Up to 30% difference

Less than 5% difference

Conclusion

- Discretization of moving target is a time-consuming process
- Equivalent thickness approximation yields up to 30% difference and an acceleration factor of 3
- New energy-angle spectrum functionality in RayXpert® yields less than 5% difference and an acceleration factor of up to 7800
- Can be used for quick assessment of new design



Up to 30% difference

Less than 5% difference

Thank you for your attention

For further information on:

www.trad.fr – www.fastrad.net
www.rayxpert.com – www.r2cots.com

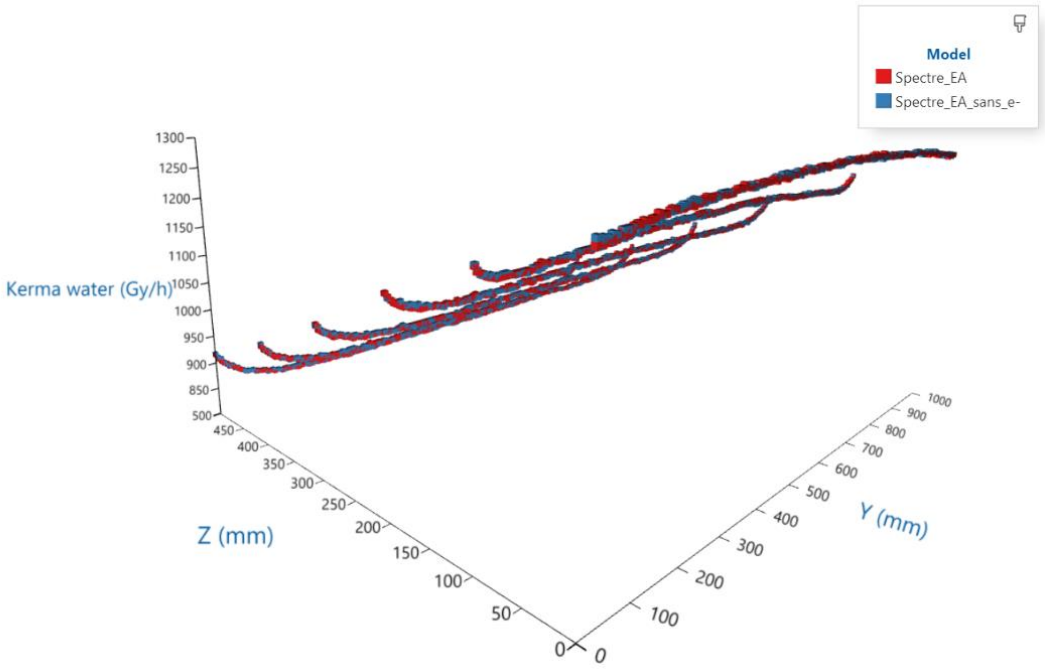
See you at Booth #4!

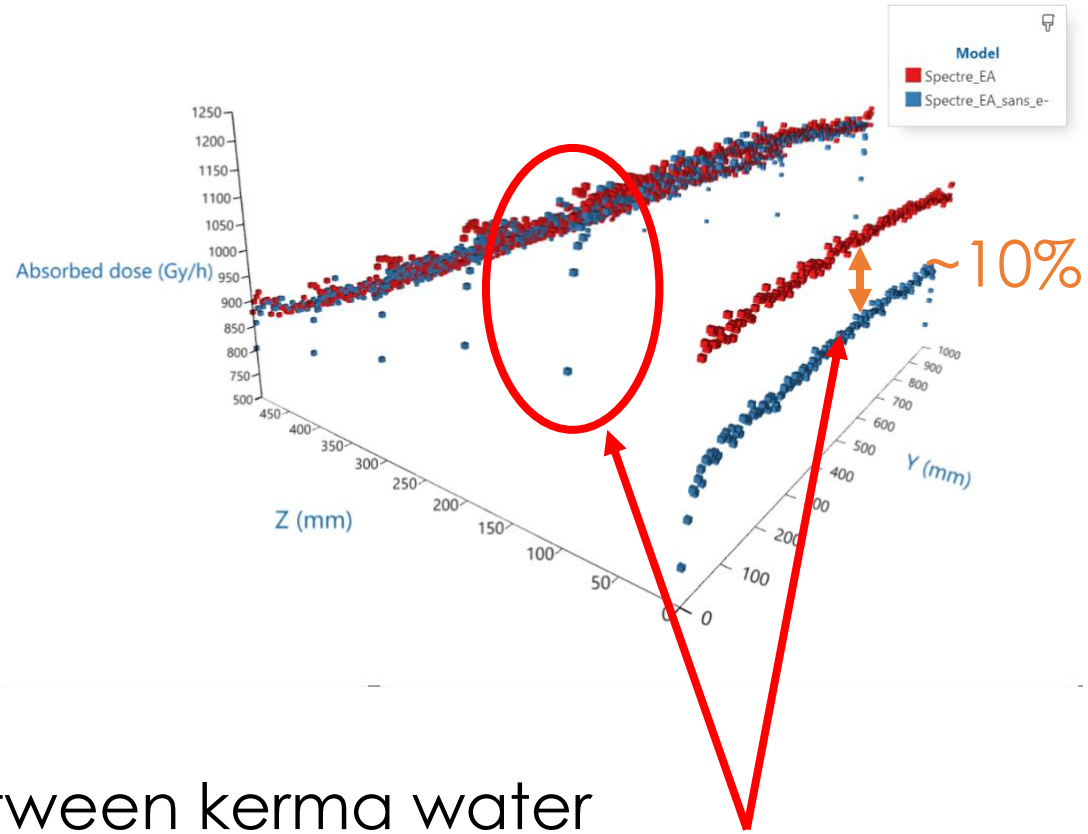
TRAD Tests & Radiations
@TRAD_Officiel

trad@trad.fr

+33 (0)5 61 00 95 60

Effect of the electron source in the EA spectrum





Very good agreement between kerma water

/!\ Not so much with absorbed dose due to surface electrons