This activity is synergetic to the EIC-SVT work and
it is independently funded by STFC Nat Labs internal funds.

Dosimetry in SiO2: update on Geant4

20251008

L.Godfrey, M.Borri

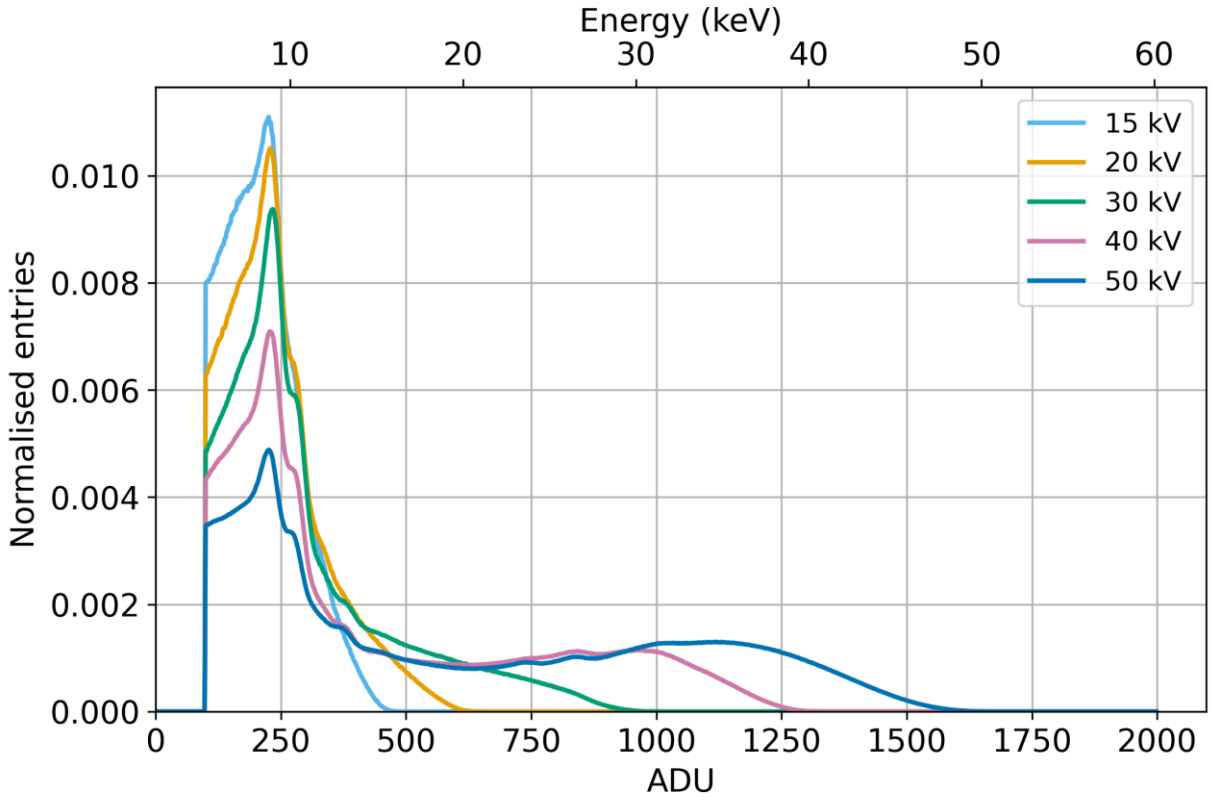
UKRI Science and Technology Facilities Council

Introduction

- X-ray generators are useful tools to test TID effects on ICs.
  - Quicker than Co60…
  - … particularly useful at high integrated dose.
  - See the exploratory irradiations up to ~3 Grad of the ER1 RAL IC. (~28 days, 24/7 at ~100krad/min).

- Calibration of X-ray generator at DL is based on calibration procedure from CERN:
  - This lacks transparency and requires a leap of faith;
  - **Liam** submitted an **internal proposal** to improve our understanding of dosimetry (~5k GBP i.e. only consumables). Proposal in **collaboration with RAL** (F.Wilson, C.Sawyer).

- Three things in this project:
  - **Simulate the physics of energy deposition in matter**;
  - Perform half value layer measurements with an ionisation chamber;
  - Perform dose measurements with radio chromic foils;

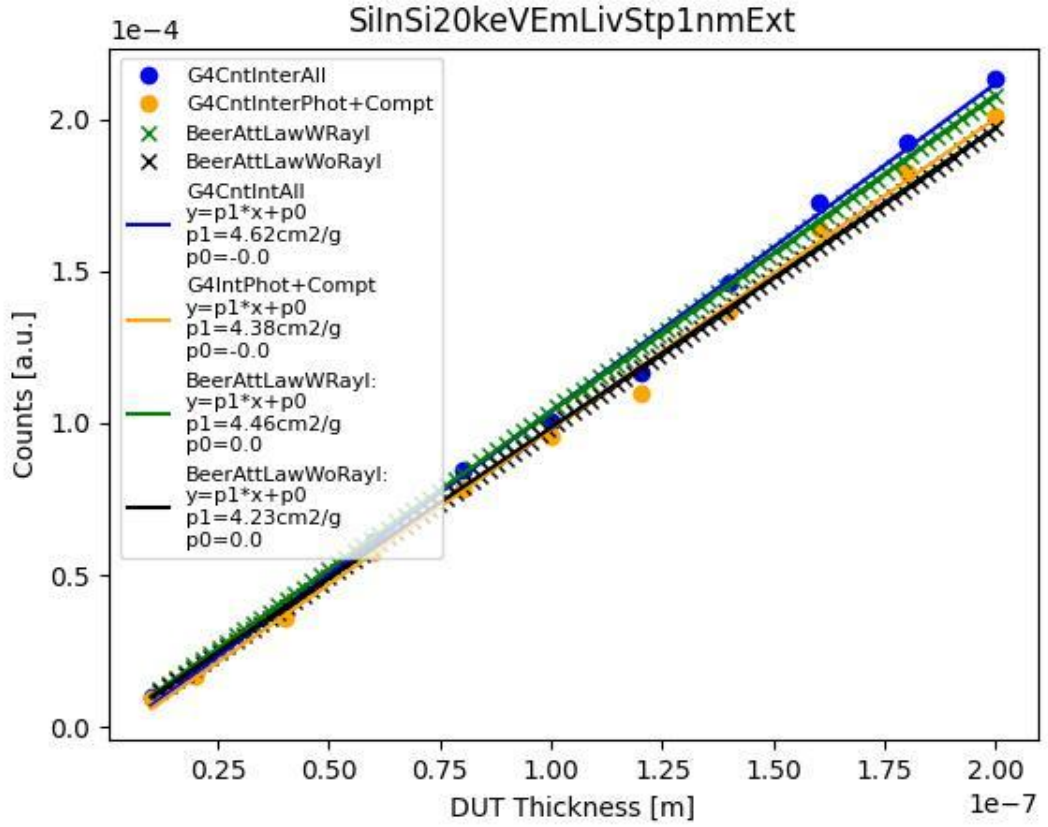


CERN target dose rate : 100krad/min (recommended)
DL measured dose rate : 104krad/min at **20kV** 20mA

Science and Technology Facilities Council

Update about Geant4 simulations - attenuation

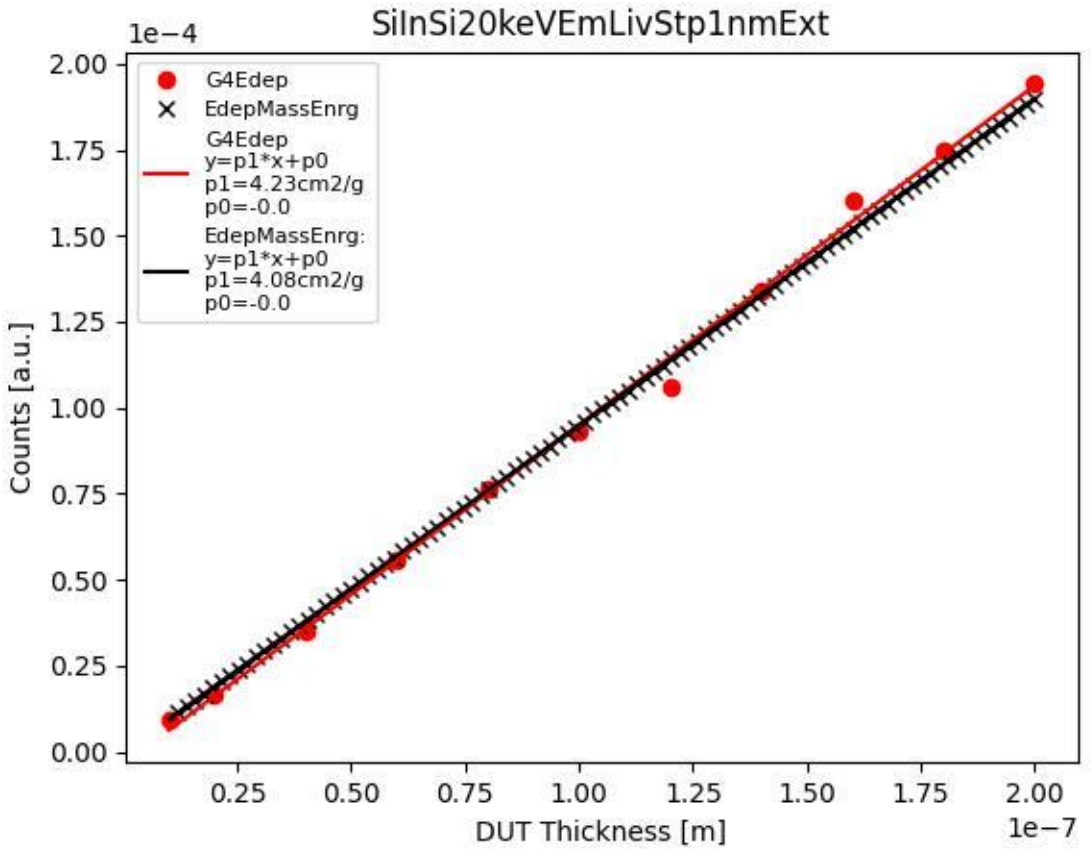
- Selected Geant4 as simulation framework
- Geometry: thin sheet (10's -100's nm)
- Beam: monochromatic X-rays
  - Sampled 4 energies: [5keV, 10keV, 15keV, 20keV]
- Physics list:
  - Livermore Electromagnetic (only);
- Successfully replicated the reciprocal to 1 of the Beer-Lambert law in thin sheet (d~0).
  - f(x) = 1 – (I/I0) **= 1 – e^(-d*mu)**
  - mu = mass attenuation coefficient;



Science and Technology Facilities Council

Update about Geant4 simulations – Mass Energy Absorption

- Validated a key formula for dose evaluation:
- **D = phi*E*mu_en**
  - D= dose [Energy/Mass];
  - phi=flux/area [#/area]; (Dependent on Bee-Lamber law)
  - E=energy [Energy];
  - mu_en = mass-energy absorption coeff. [Area/Mass];
- Valid for thickness ~0 and in charge particle equilibrium etc…
- i.e. **Edep increases linearly with thickness, when thickness ~0**.
- i.e. dose is independent of thickness when thickness ~0.

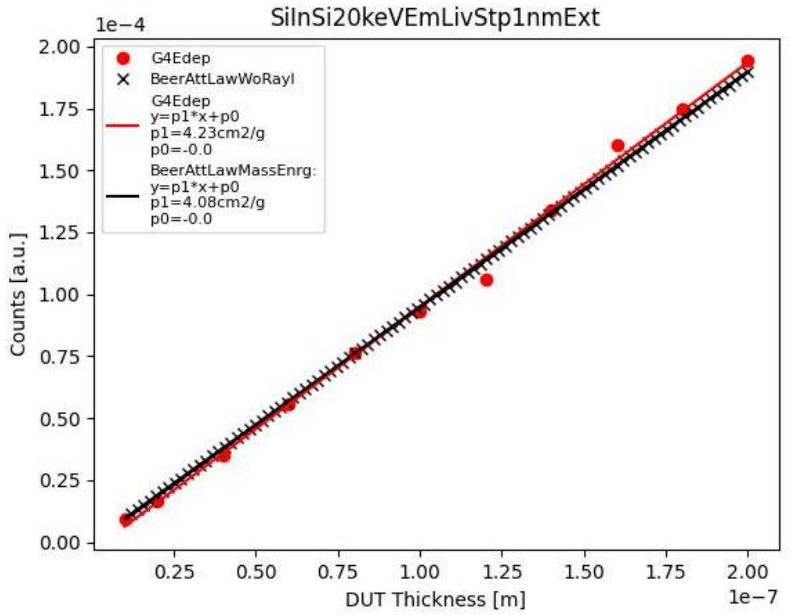


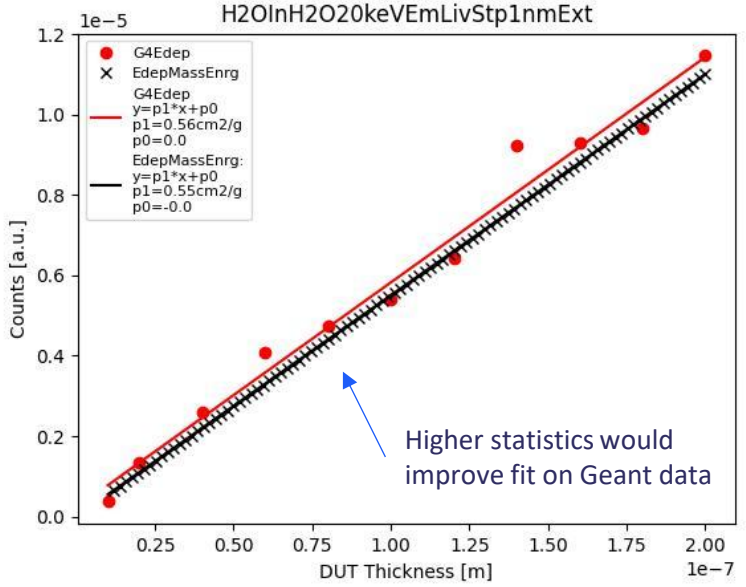
Science and Technology Facilities Council

Update about Geant4 simulations – Energy conversion

- Energy conversion validation between Si and H2O.
- **Si: D1 = phi1*E1*mu_en1**
- **H2O: D2 = phi2*E2*mu_en2**
- Samples irradiated under the same conditions:
  - phi1 = ph1; E1 = E2;
- **D1/D2 = mu_en1/mu_en2;**
- **D1 = D2 * (mu_en1/mu_en2);**
- Dose ratio comparison at 20keV: (mu_en1/mu_en2)
- **NIST db:**
  - **4.076E+00 [cm2/g] / 5.503E-01 [cm2/g] = 7.4 ;**
- **G4:**
  - **4.23E+00 [cm2/g] / 5.6E-01 [cm2/g] = 7.55 ;**

~2% discrepancy from NIST





Science and Technology Facilities Council

Conclusion

- We successfully validated Geant4 against theory/experimental data.
- Setting up Geant4 and running qualitative examples was (fairly) straight forward; (well documented)
- It was hard to achieve quantitatively reliable results for our specific application [5 months Liam and Marcello]:
  - Lack of directly applicable literature
    - Micro dosimetry in medical applications focusses on H2O;
    - Micro dosimetry in micro-electronics focusses on e-, p+, and ions;
  - Bugs in G4 NIST database; [SiO2 material has wrong density]
  - Selecting correct physics list and processes;
  - Setting correct max step parameters;
  - Setting correct particle production threshold;
  - Not to use function “GetTotalEnergyDeposit()” in “Step”;
- Next: to model the real beam shape in Geant4 (inc. HVL measurements), and to practice conversion H2O to SiO2

Science and Technology Facilities Council