Monte Carlo calculated correction factors for a proton calorimeter in clinical proton beams

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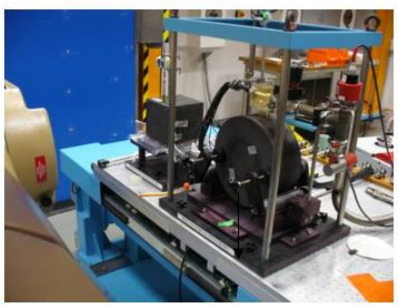
Background

- Quantity of interest in clinical proton beams is **absorbed dose to water** but…
- … to date, no primary standards laboratory has a proton or ion beam in which to conduct calibrations
- Current standard methods typically involve the use of an ionization chamber calibrated in a ^{60}Co beam – so a **beam quality correction factor** is needed to account for the difference between the chamber response in the proton/ion and the calibration beams.

^{60}**Co** NPL primary standard → NPL reference chambers → Hospital secondary standard



Calibrated secondary standard returned to hospital

Hospital secondary standard → Hospital field instrument →

Background

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- Current standard methods typically involve the use of an ionization chamber calibrated in a ^{60}Co beam – so a **beam quality correction factor** is needed to account for the difference between the chamber response in the proton/ion and the calibration beams.
- This approach gives rise to uncertainties (at 68% confidence level) on the reference dosimetry of 2.3% for proton beams and 3.4% for carbon ion beams when using a plane-parallel ionization chamber (ref TRS-398).
- It has long been recognised and indeed stated in TRS 398 that the preferred method of calibration is to calibrate chambers in a similar beam to that which is being used therapeutically.
- A **new UK code of practice** is being written to facilitate calibration in proton beams primarily for scanned but also for scattered beam delivery modes.
- The aim is to deliver an uncertainty on reference dosimetry for protons of approximately 2% (at 95% CL) and will utilise a **primary standard graphite calorimeter** that is robust and portable enough to be used in the end-user facility.

Formalism based on the new CoP

- Water and graphite calorimeters have been developed & demonstrated in p beams
- **Graphite calorimetry**:
  - lots of benefits *however* largest uncertainty in absorbed dose-to-water determination is conversion of dose-to-graphite to dose-to-water

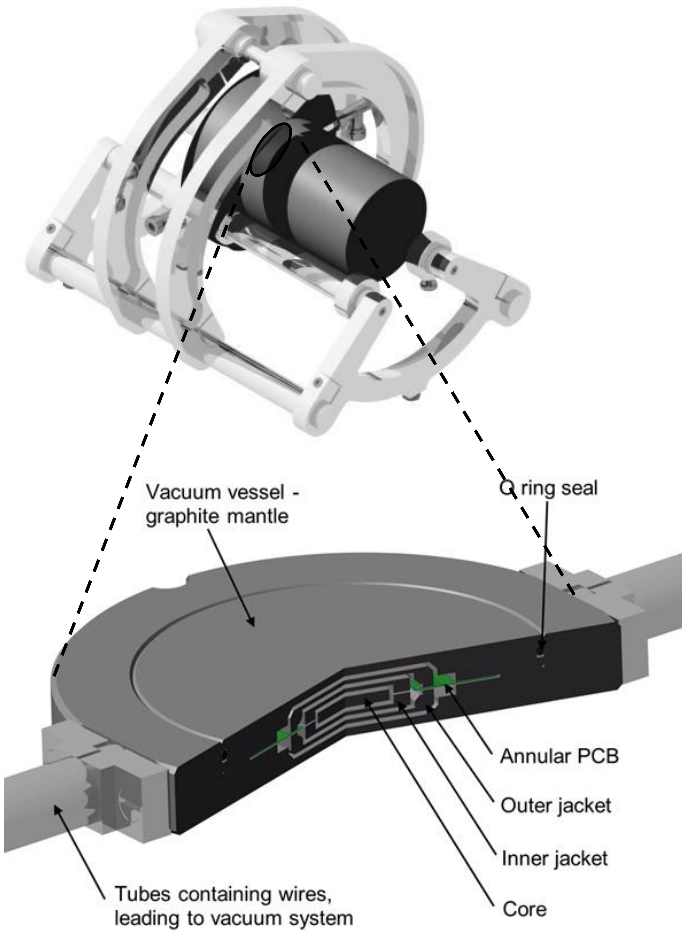
$$N_{D,\mathrm{w}} = \frac{D_\mathrm{g}}{M_\mathrm{g}} \frac{s_{\mathrm{w,air}}}{s_{\mathrm{g,air}}} \frac{p_\mathrm{w}}{p_\mathrm{g}} \qquad z_{\mathrm{ref},g} = z_{ref,w} \frac{r_{\mathrm{g},80}}{r_{w,80}}$$

$$D_\mathrm{g} = \left(\frac{E_{\mathrm{core}}^{\mathrm{rad}}}{m_{\mathrm{core}}}\right) \cdot k_{\mathrm{imp}} \cdot k_{\mathrm{non-g}} \cdot k_{\mathrm{gap}} \cdot k_{\mathrm{vol}}$$

k_{gap} → *gap correction factor*

k_{vol} → *volume averaging correction*

- Aim: determine k_{gap} *and* k_{vol} with Monte Carlo simulations using TOPAS (framework based on Geant4) for:
  - monoenergetic pencil beams
  - reference clinical SOBP beams (scanning/passive)



How do we calculate k_{gap} and k_{vol} ?

Representative drawings
Not to scale !

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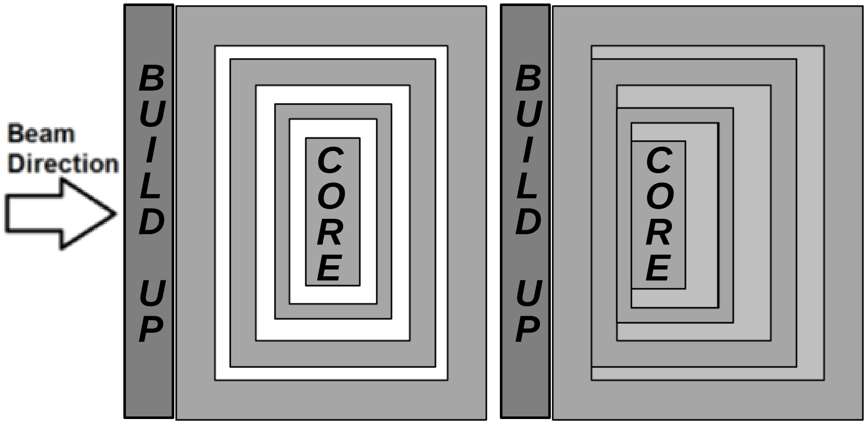
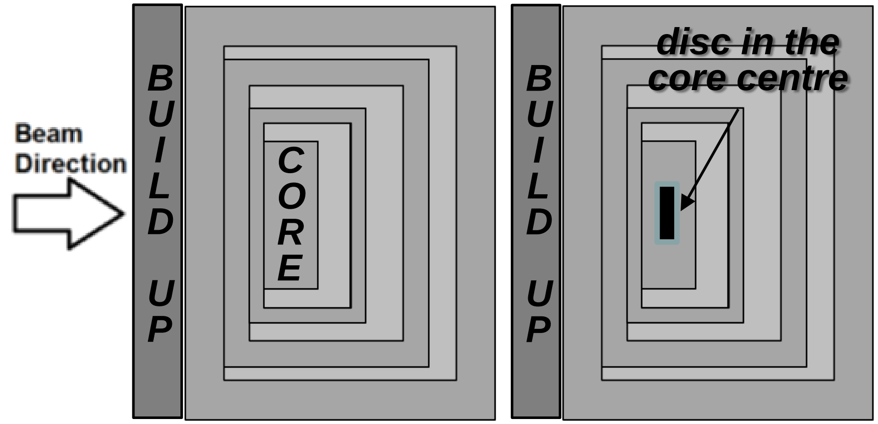
$$k_{gap} = D_{core\_comp} / D_{core\_full}$$



Full geometry | *Compensated* geometry

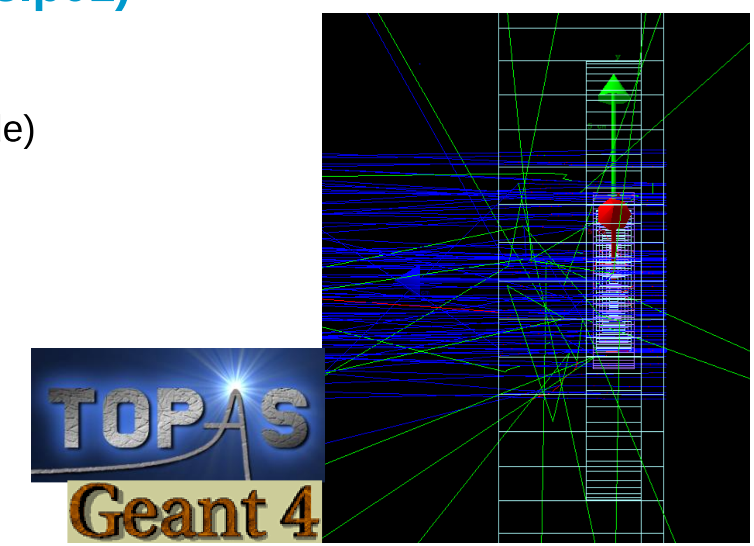
$$k_{vol} = D_{disk\_comp} / D_{core\_comp}$$



Compensated geometry | *Compensated + disc*

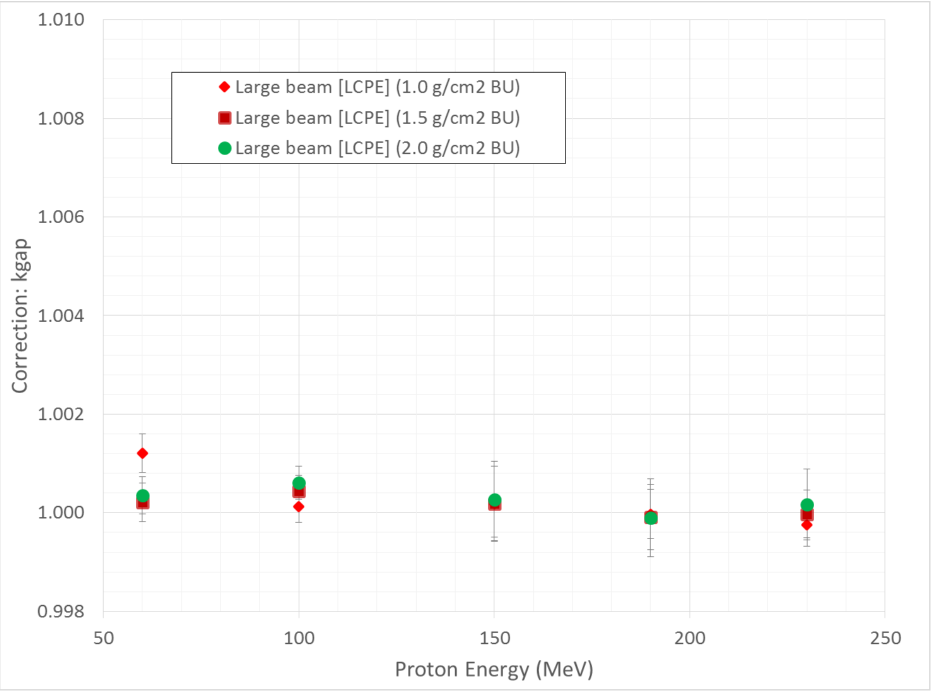
TOPAS application (based on Geant4 v10.3.p01)

- **Default modular physics list:**
  - *Hadronic:* **QGSP_BIC_HP** (Binary Intra.Cascade)
  - *EM:* emstandard_opt4
  - ICRU90 material definitions
  - Production cuts 0.05mm
- **Scoring/tracking: TOPAS**
  - Total dose deposited per event
  - Standard deviation → SDOM

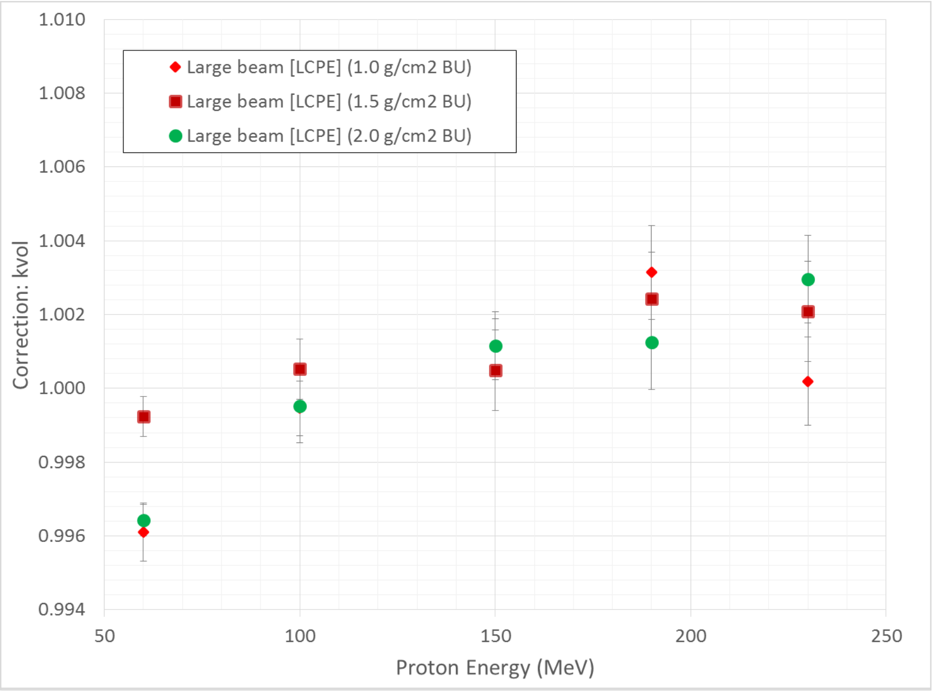


Correction factors for mono energetic protons

k_{gap}



k_{vol}

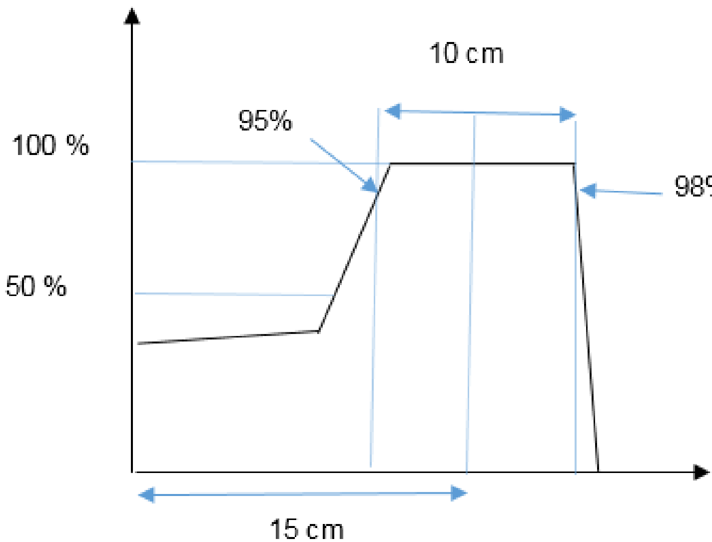


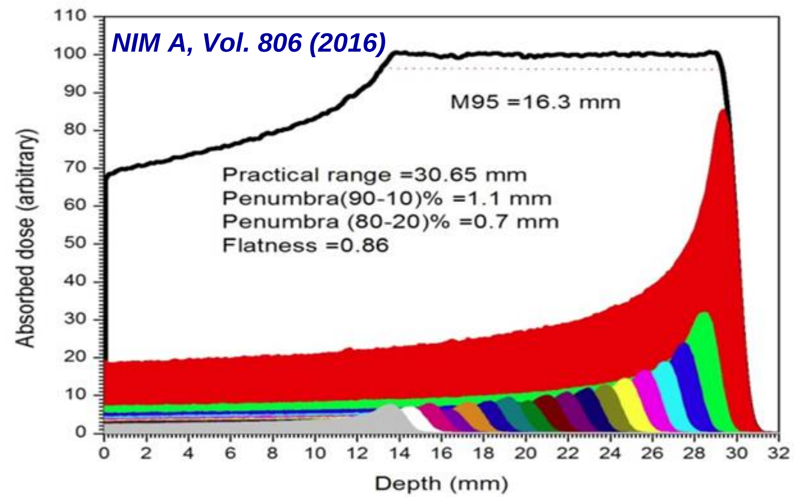
- **3 cm** beam diam & **NO BU**: **k_{gap} upto 1.004** (230 MeV)
- **3 cm** beam diam & **2.0 g/cm² BU**: **k_{gap} upto 1.008** (230 MeV)
- **consistency** with previous work (Petrie *et al.* 2016)
- **no** significant **dependence** of k_{gap} **on I** (78 vs 81 eV)
- **Large beam diam** (LSCPE), **k_{gap} within 0.1% of unity** for all the energies
- **Large beam diam** (LSCPE) and changing **BU**, no significant change

- Various disk thickness investigated
- **k_{vol} ~ 0.997** at 60 MeV up to **~ 1.003** at 230 MeV
- **Large beam diam** & changing **BU,** no significant change

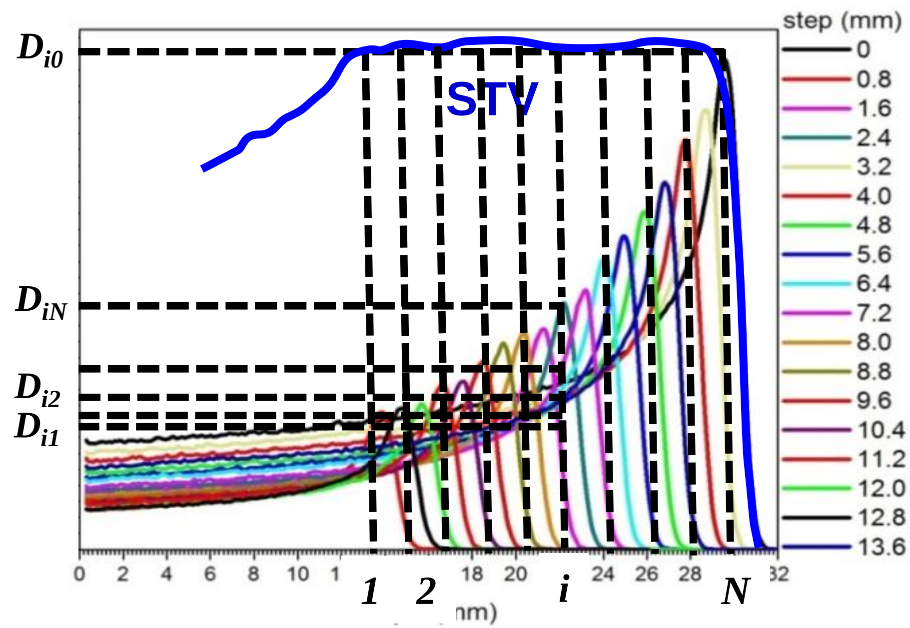
Clinical relevant SOBPs

- According to the new UK Code of Practice (*still in draft*), reference dosimetry has to be carried out in a **STV** (Standard Test Volume) centred at *15 cm depth in water* (box *10 x 10 x 10 cm³*)



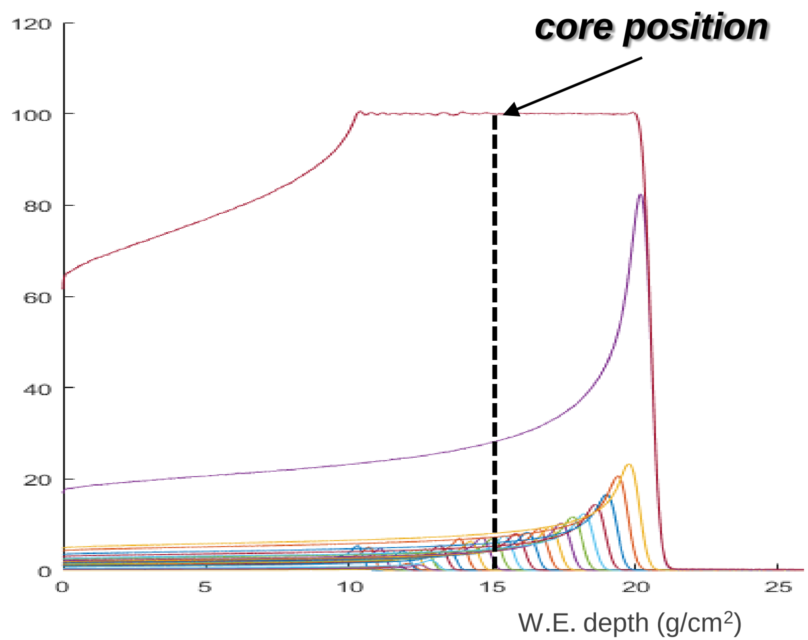


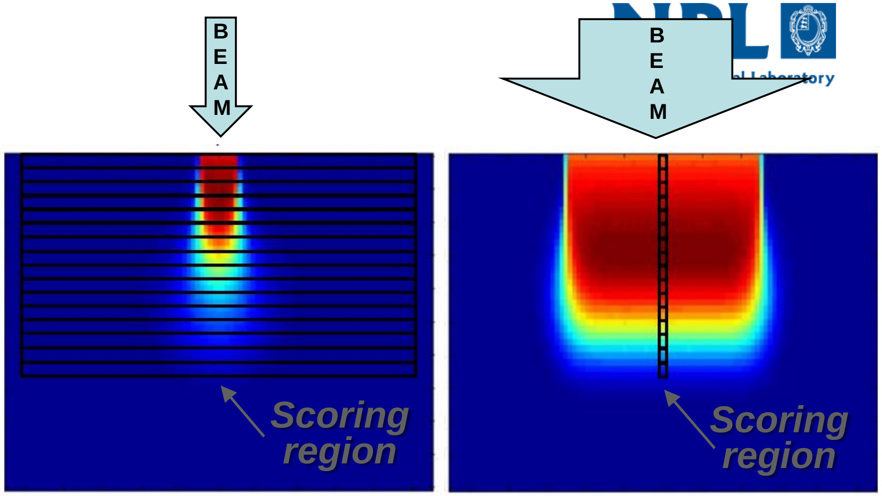
$$\begin{cases} w_1 D_{i1} + w_2 D_{i2} + \cdots w_N D_{iN} = D_{i0} \qquad i = 1,2,\dots,N \\ \cdots \\ \cdots \\ \cdots \end{cases}$$

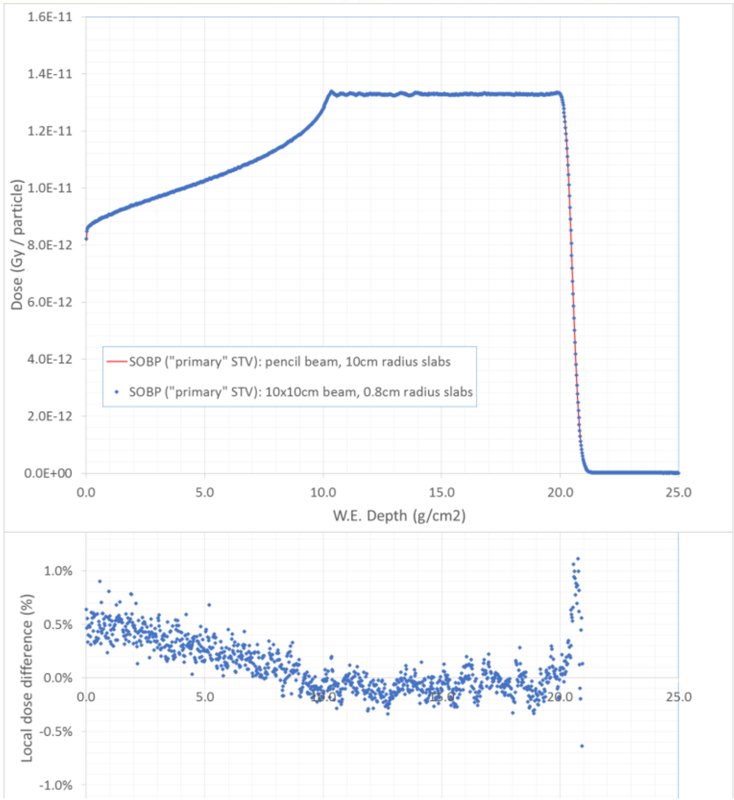


- Compromise between number of peaks and complexity of solving it!
- Positive suitable solutions

Correction factors for SOBP





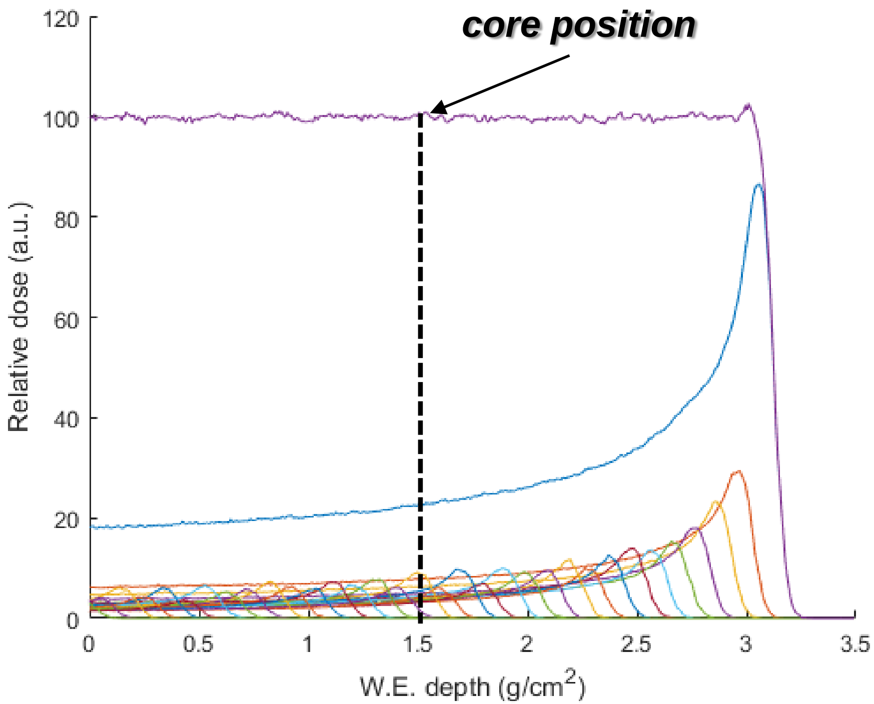


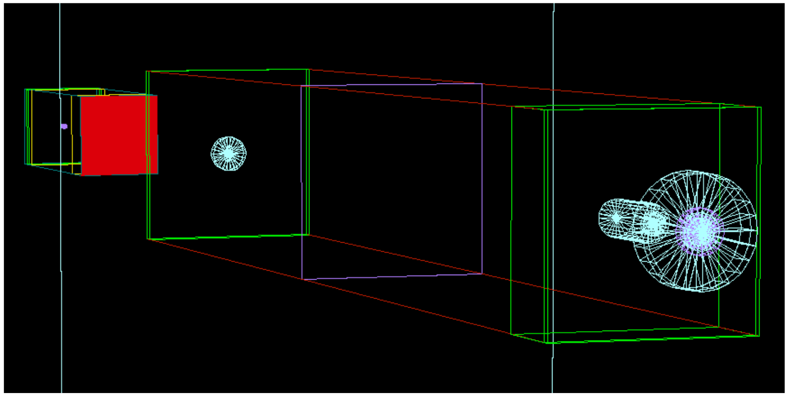
- *Weighted using pencil beams on large slabs*
- *10x10 cm² beam required by CoP*
- *Reciprocity theorem to be demonstrated*
- *32 peaks in total → uniformity within 0.5%*
- *Weights converted to numbers of events per peak in TOPAS*

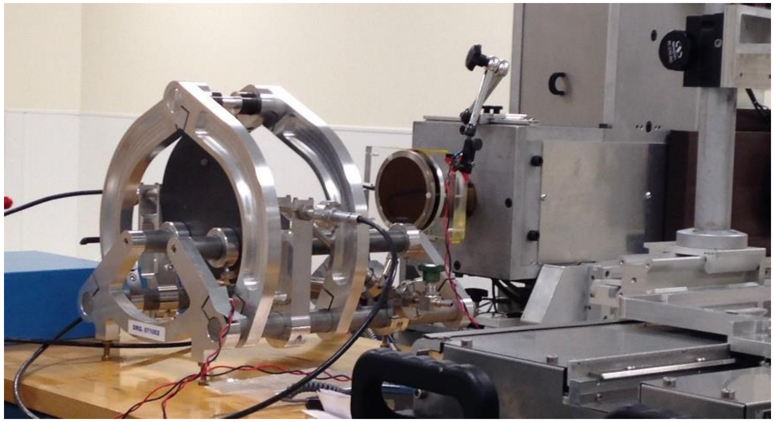
k_{gap}	k_{vol}
1.0006 ± 0.0005	1.0003 ± 0.0011

Correction factors for a passive beamline (CCC)

- *Passive beam line for eye melanoma treatment with 62 MeV proton beams at the Clatterbridge Cancer Centre*







- *Weighted using pencil beams on large slabs*
- *33 peaks in total → uniformity within 0.5%*

k_{gap}	k_{vol}
1.0024 ± 0.0015	?? $\pm$??

(still in progress!!!)

Summary and future work

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Summary

- Overview of the **formalism** for determining absorbed dose to water in proton beams based on a new UK code of practice using a **portable primary standard graphite calorimeter**
- Description of methods for determining the $\boldsymbol{k_{gap}}$ and $\boldsymbol{k_{vol}}$ corrections with TOPAS (Geant4) for mono-energetic and clinical relevant beams
- For mono-energetic beams (LSCPE):
  k_{gap} within 0.1% of unity, k_{vol} ~ 0.997 at 60 MeV to ~ 1.003 at 230 MeV with no significant change with energy and build-up
- For the STV volume:
  $k_{gap} = 1.0006 \pm 0.0005$ $k_{vol} = 1.0003 \pm 0.0011$
- CCC
  $k_{gap} = 1.0024 \pm 0.0015$ k_{vol} = ?? ± ?? (in progress!)

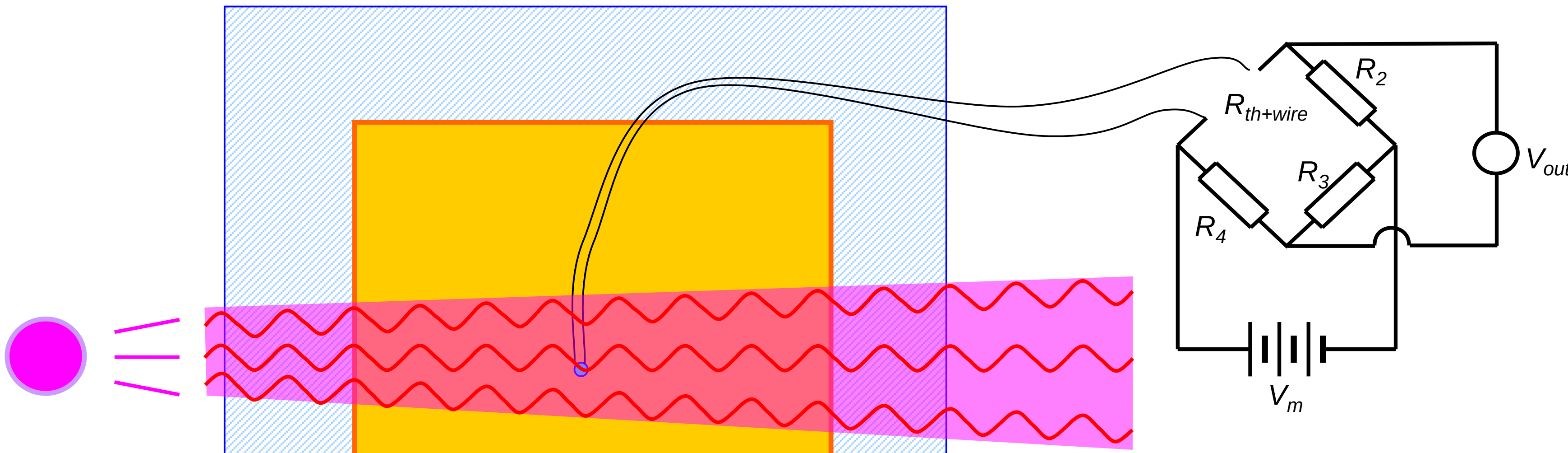
Future work

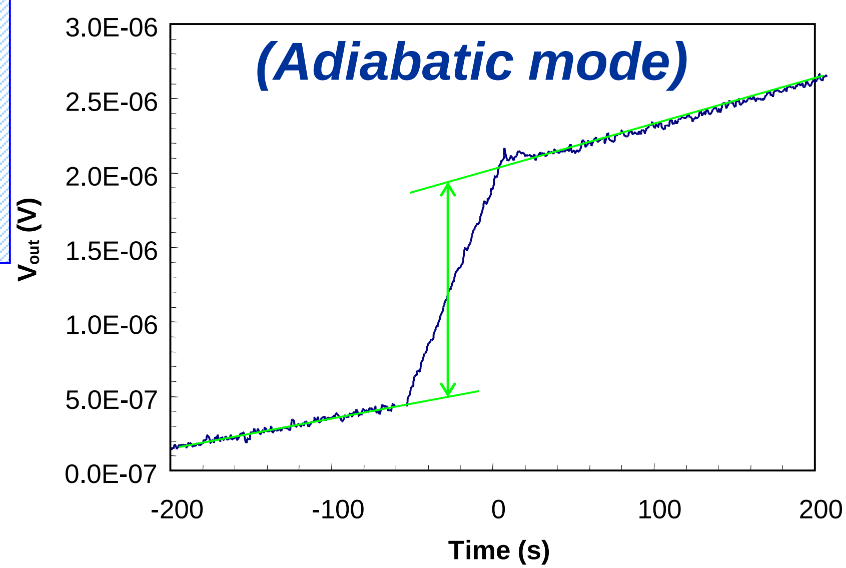
- Improve the procedure for SOBP potentially decreasing the ripple and including more peaks
- Secondary STVs according to the new code of practice
- We want to establish a primary standard for reference proton dosimetry in preparation for the new proton centres in the UK in 2018

Thank you

Calorimetry

our primary standard for radiation dosimetry are calorimeters





…heat is tiny, but measurable