Calorimetry techniques for absolute dosimetry of laser-driven ion beams

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Faculty Disclosure

	No, nothing to disclose
✔	**Yes, please specify;**

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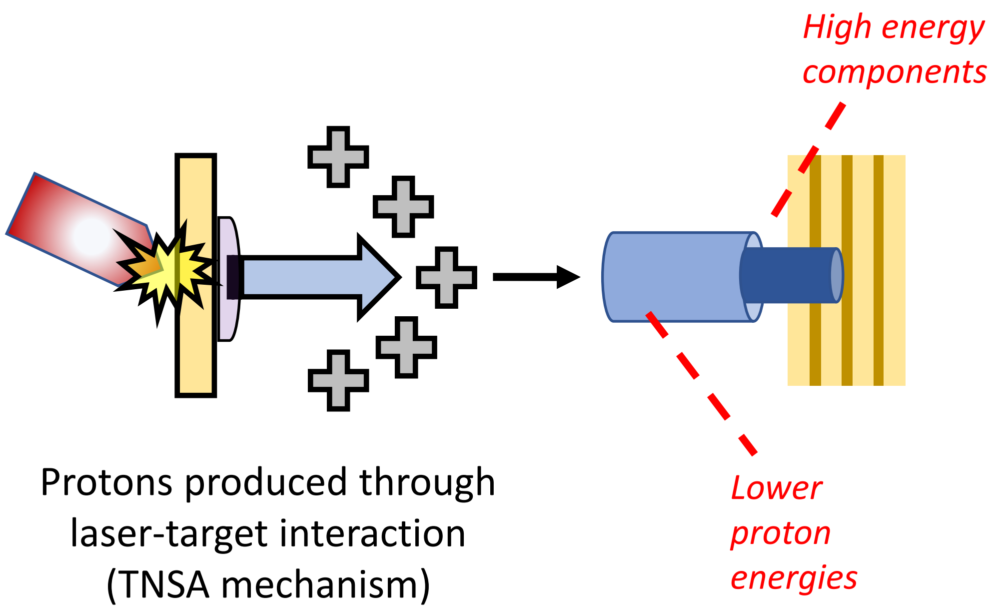
Ultra-High Pulse Dose Rate Laser-Driven Beams

Maximum deliverable radiation dose limited by normal tissue toxicities

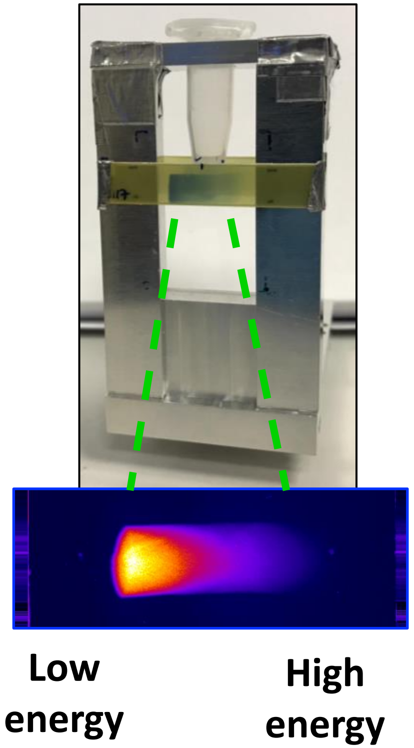
Studies using ultra-high pulse dose rates (UHPDR) decreased undesired effects

- *In vivo* studies of so-called **FLASH effect**
- Even higher dose-rates produced by **laser-matter interaction**

  Possibility to accelerate at more extreme regimes than RF accelerators – **potentiality promising**



Protons produced through laser-target interaction (TNSA mechanism)



Ultrashort durations (~ 10 fs)
High dose rate per pulse (10^9 Gy/min)
Up to 100% energy distribution

Necessary to characterize these polyenergetic beams through accurate spectra measurements – **vital for clinical applications requiring precise energy selection**

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Dosimetry Challenges at Ultra-High Dose Rates

Accurate dosimetry of high dose-rate particle beams is challenging

- Response of established active detectors **influenced by high dose rates**

Laser-driven beams can be even more technically challenging than conventionally accelerated ones

- Larger instantaneous dose rates & generation of electromagnetic pulse during target interaction

The big picture with radiation dosimetry – **understanding the biological response**

Conventional source:
Controlled delivery

Laser-driven approach:
Particle burst

Revision of current dosimetry protocols and framework for dose measurements required

- UHDpulse EMPIR project

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Dosimetry through Calorimetry Techniques

Bulky, complex devices typically maintained at National Standards Labs to calibrate other dosimeters

Bulky & complex ***but very accurate***

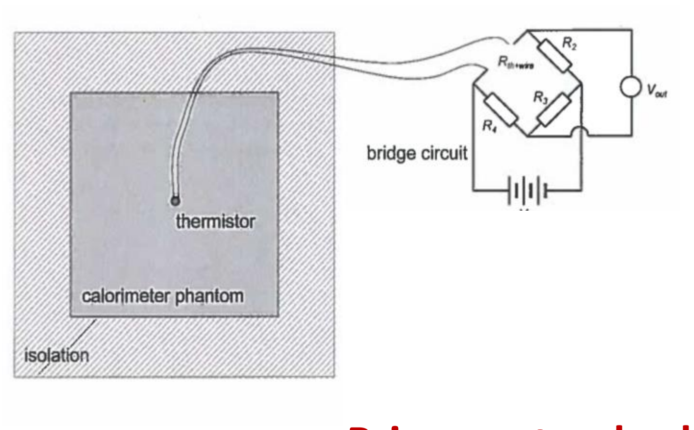
Innovative approach developed by National Physical Laboratory (NPL)

- Dosimetry of laser-driven beams through **calorimeters** thus far **unexploited**

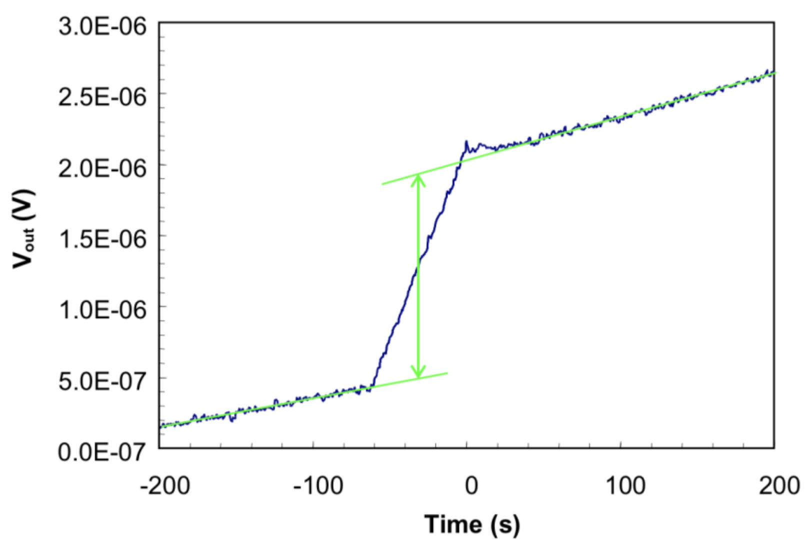
R. Thomas, (2016)

Calorimetry measures radiation induced temperature rise

- Rise in T converted to absorbed dose; $\boldsymbol{D_W = c_x \Delta T f_{w,x}}$
- **Absolute dosimeter** – calibrated radiation field not required



Use of water and graphite calorimeters have been demonstrated with proton beams
Graphite preferred at **NPL** due to **higher sensitivity**



Primary standard for absorbed dose measurements in clinical proton beams based on graphite calorimeter at NPL

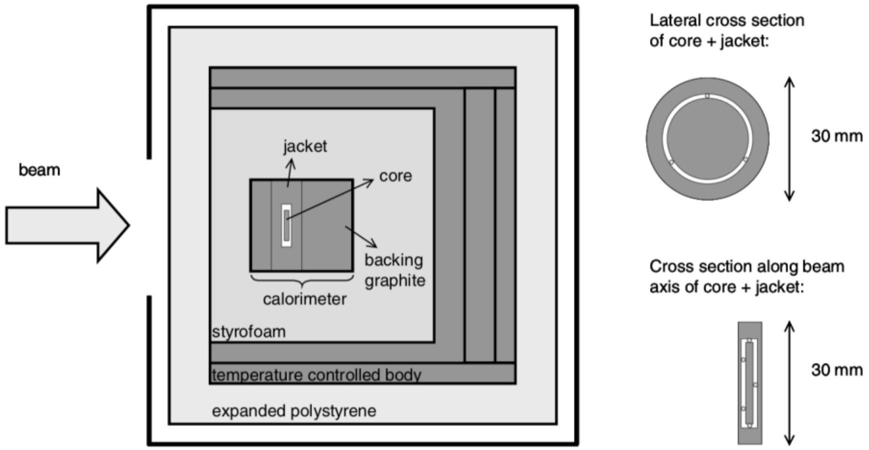
Development of the Small Portable Graphite Calorimeter

Small portable graphite calorimeter (SPGC) completely refurbished at NPL

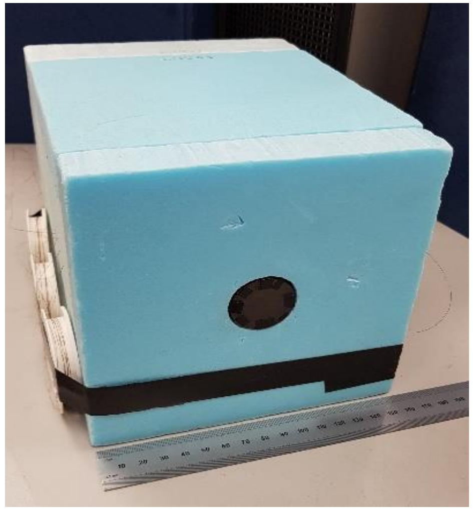
- Original use in measurement of low energy proton beams

Cylindrical arrangement of graphite components

- Core enclosed within graphite jacket, plus additional graphite slabs
- Styrofoam added to provide thermal isolation



H. Palmans, et al., (2004)



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SPGC Features

SPGC core contains **four thermistors** (**mK** sensitivity)

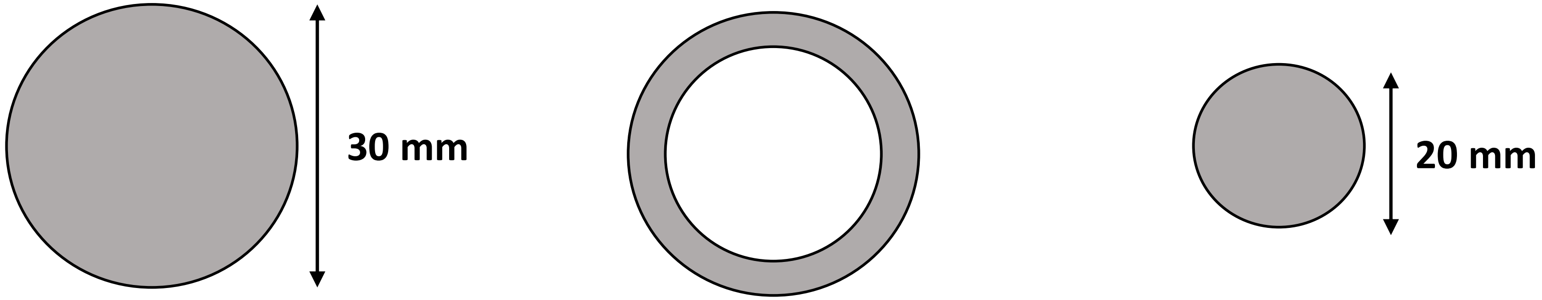
Two jacket thermistors added allowing jacket temperature measurements

- Assessments of jacket-core heat transfer
- Possibility to operate in **constant temperature** mode

One additional thermistor added to monitor the ambient temperature

Functional tests successfully performed at NPL using conventional photon beams

Small temperature increases involved **(~ 1.4 mK for a dose of 1 Gy**)
→ sensitive measuring equipment and excellent temperature control required



Jacket (base) | Jacket (body) | Core

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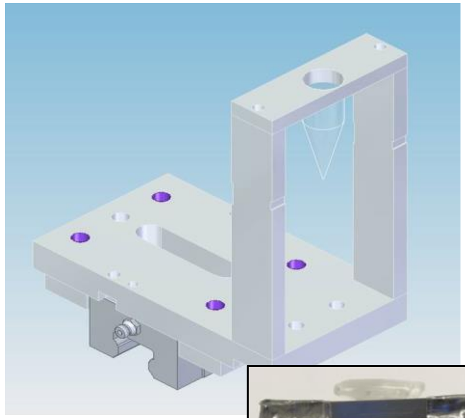
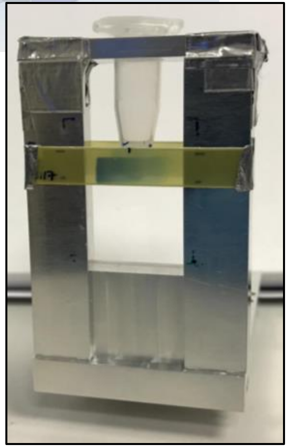
Calorimetry for Dose Measurements of Laser-Driven Beams

First **ever** recorded absorbed dose measurement using calorimetry



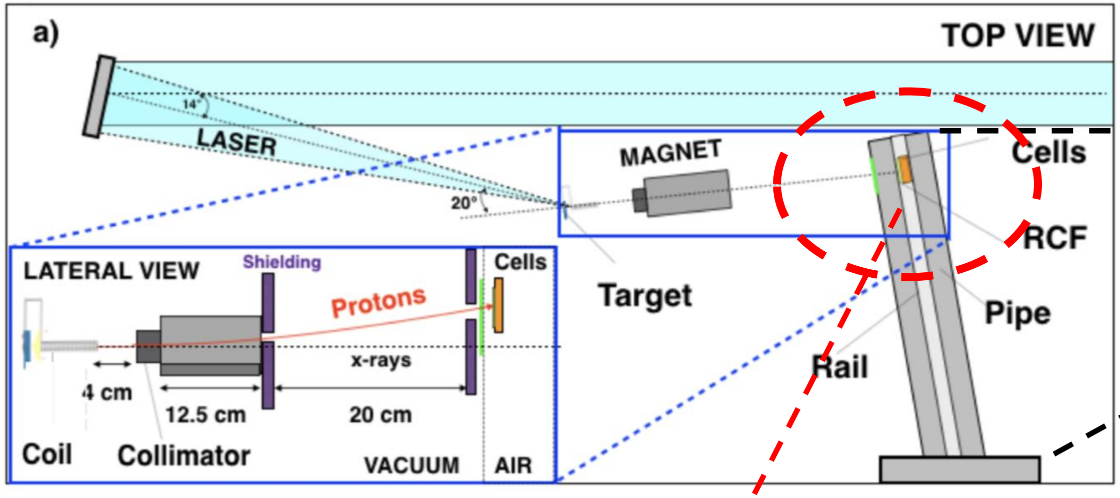
Measurements conducted using VULCAN PW laser of CLF (RAL)

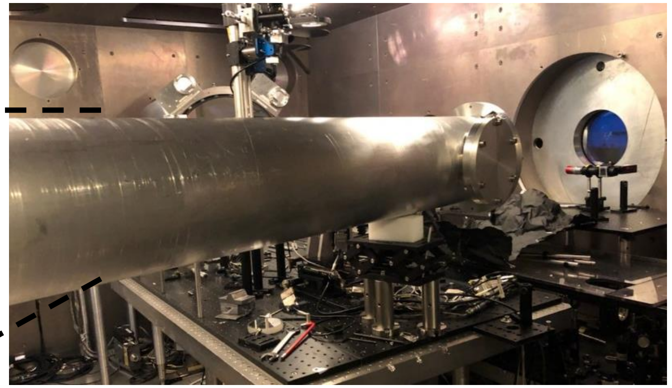
- Using setup for radiobiology experiment of 3D tumor cell irradiation
- Holder designed to be placed in re-entrance pipe
- Focused Intensities > $\mathbf{10^{20}}$ **W/cm²**, Energy separation using **0.9 T** dipole magnet



Monte Carlo simulations performed prior (working in TOPAS/Geant4 codes)

- Simulation of SPGC for dose prediction using laser-driven proton parameters





Site of SPGC in beamline

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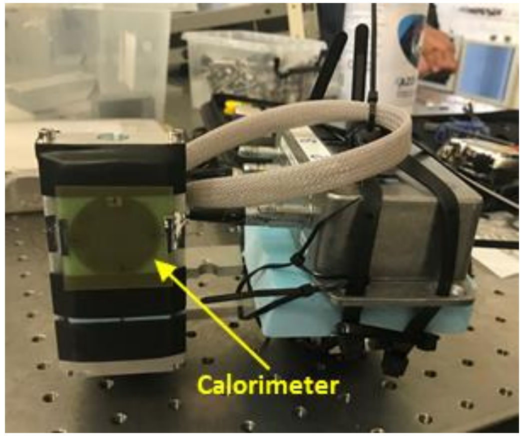
Proof of Principle Measurement – July 2019

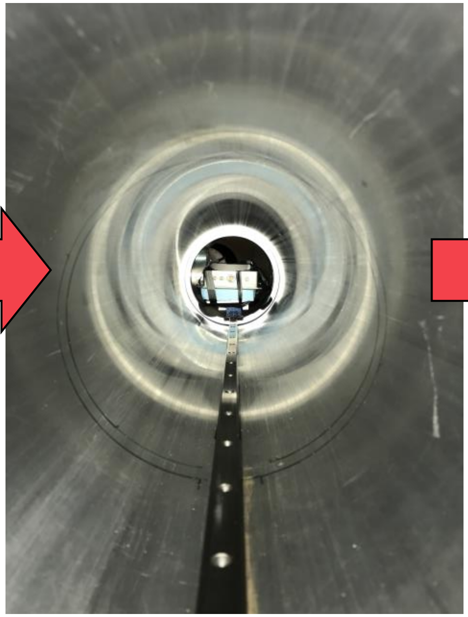
First test of calorimetry techniques using laser system:

Requirement: laser-driven protons of ≥15 MeV needed

- In order to penetrate graphite jacket and reach core
- Thin walled to minimize beam divergence/absorption

- **VULCAN PW** pulses of **600 J** and **~500 fs**
- Protons between **20 – 45 MeV** produced
- Doses from **1-3 Gy per pulse**





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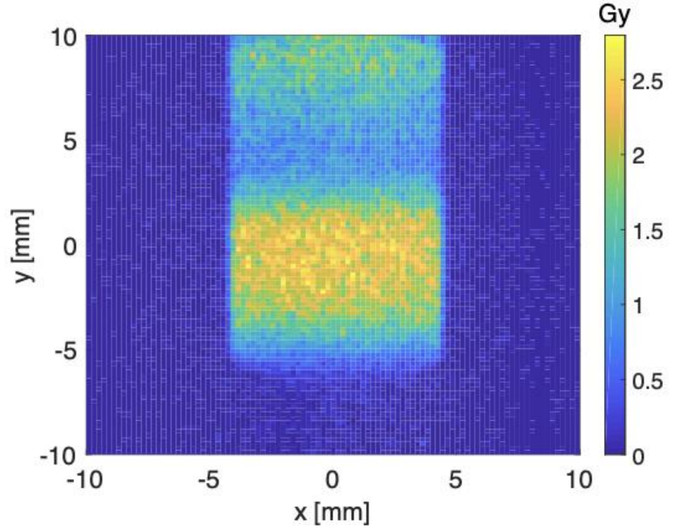
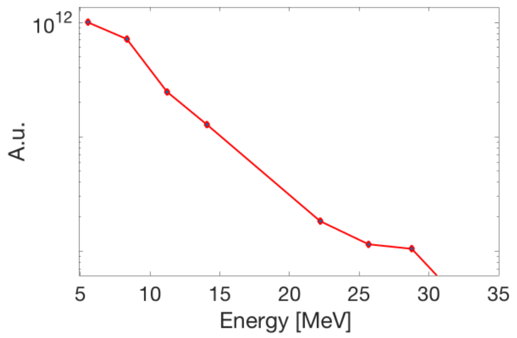
Proof of Principle Measurement – July 2019

Total of **five** shots performed with this setup
- Four at full power (~600 J) directly onto calorimeter
- One with calorimeter taken from re-entrance pipe (assess EMP)

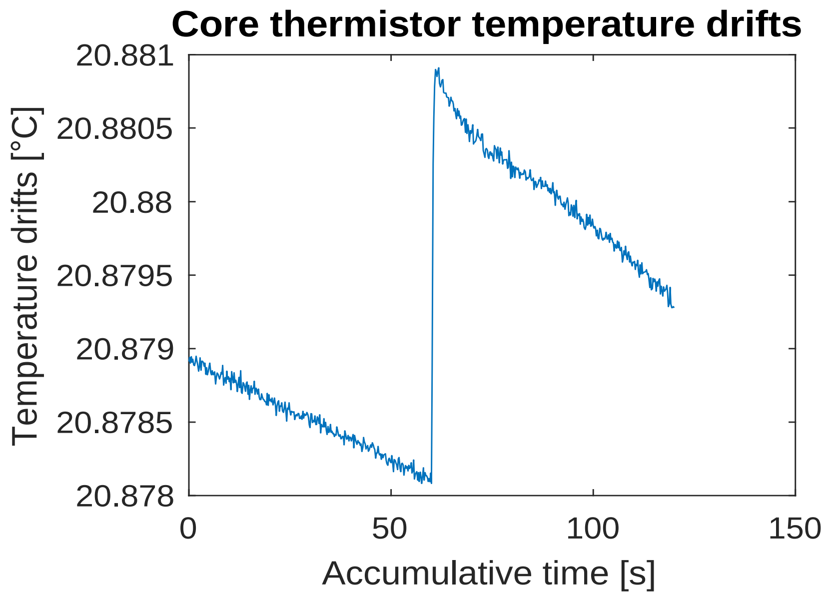
Analyzing the temperature drifts for each shot, and converting to absorbed dose:
1) 2.2 Gy, 2) **1.2 Gy**, 3) **1.7 Gy**, 4) **0.413 Gy**



Expected dose map obtained from Monte Carlo simulations



Simulated energy spectrum



Radiation induced temperature rises of one of the core thermistors for first laser shot

- **Feasibility** of calorimetry in laser environment demonstrated
- As shown, **good signal to noise ratio retrieved** for ~2 Gy dose values
- Large EMP managed – final result **not** affected

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Summary and Outlook

- Laser-driven regime potentially promising for generation of UHPDR beams

- Challenges associated with dosimetry at these high dose rates

- Feasible absorbed dose measurement of laser-driven beams demonstrated with promising results
  Good signal/noise ratio, EMP properly managed, at decreased doses w.r.t FLASH irradiations

- Dedicated campaign for calorimetry measurements of laser-driven protons required

- Results will serve as a tool to aid potential clinical applications of these beams

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Thank you for your attention!

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Acknowledgements & References

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