

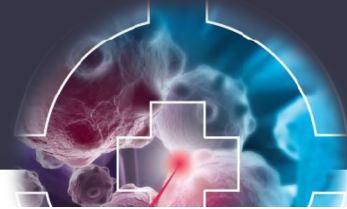


Beam characterisation and modelling for novel beam diagnostics development for particle therapy

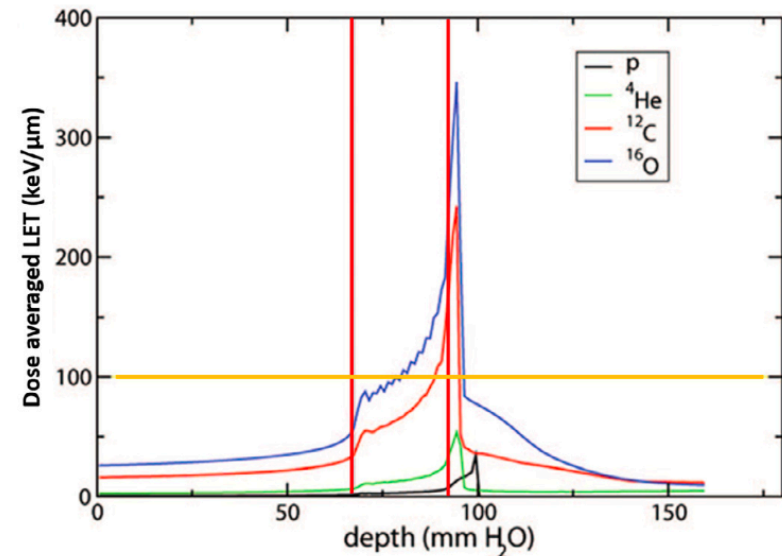
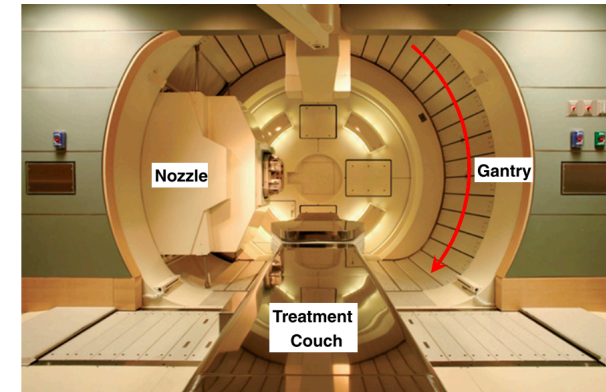


Jacinta Yap
Research Fellow
Medical Accelerator Physics Group
University of Melbourne

Radiotherapy

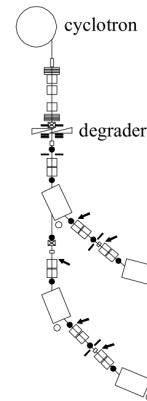
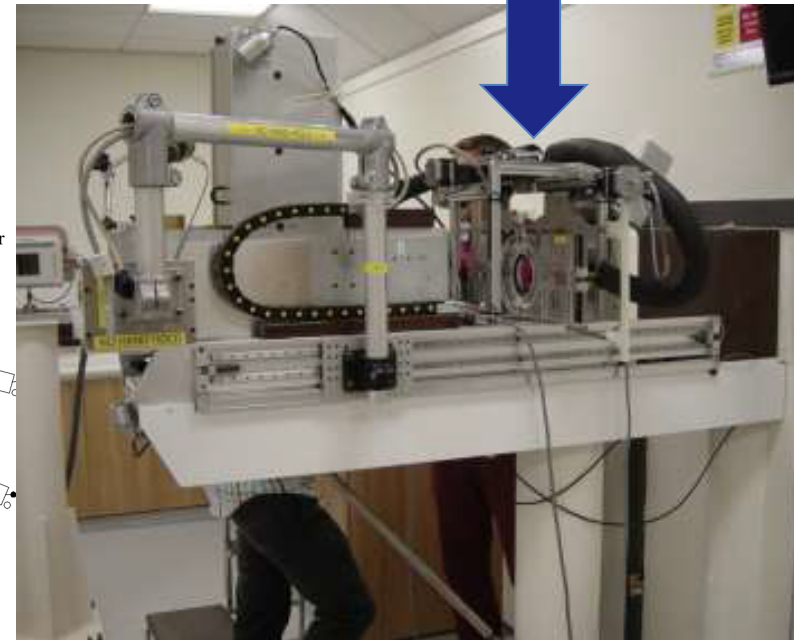
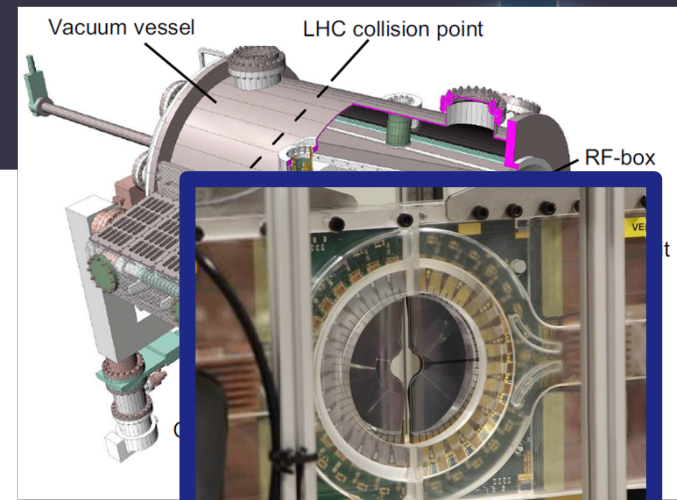


- X-ray photons
 - Conventional external beam radiotherapy
- Particle therapy
 - Advantageous dosimetric characteristics
 - Bragg Peak
 - Finite range
 - Higher LET & RBE
 - Globally increasing modality
 - >100 centres worldwide, ~40 under construction, ~30 planned
 - 12 C-ion, all others protons
 - >220k patients treated

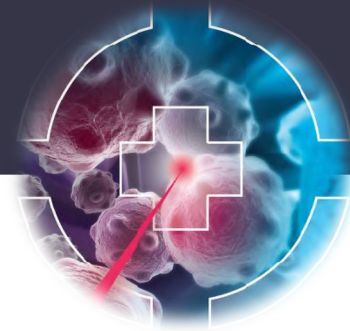


PhD Project

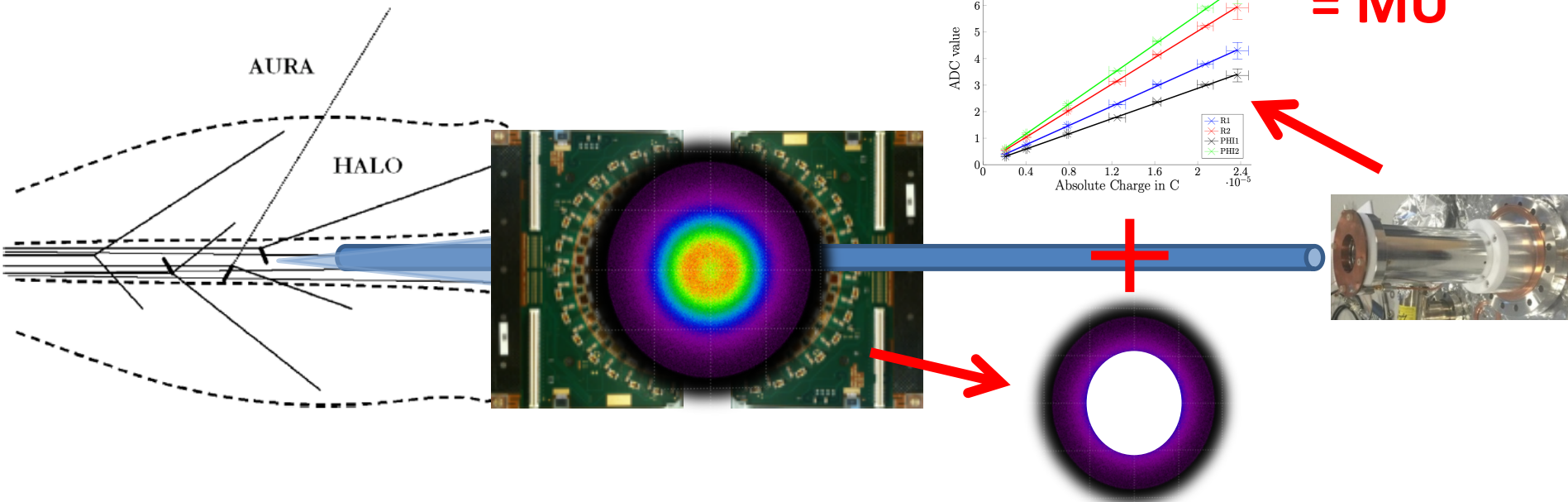
- Beam diagnostics
 - Measure beam properties: current, position, profile, emittance, energy
- LHCb **VER**tex **LO**cator detectors
 - Novel beam monitoring system
 - Online measurements
 - Non-destructive
- Gold standard: Ionisation chambers
 - Interceptive
- Treatment beam measurements:
 - Dose delivered
 - Beam intensity
 - Beam profile
 - Beam position



Concept – novel beam measurements

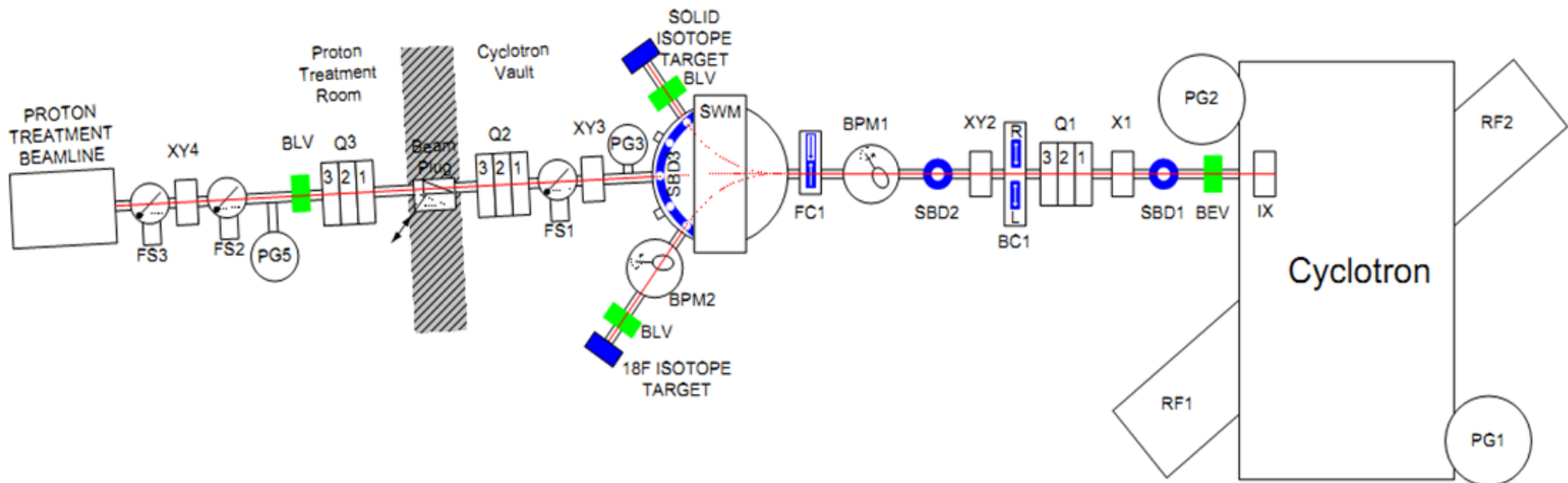


- Beam halo generated from scattering components
 - Surrounding protons which are collimated prior to exit
- Correlate halo region to dose delivered
 - Online monitoring of dose delivery



Clatterbridge Cancer Centre (CCC)

- First hospital based proton therapy facility in the world
 - 60 MeV protons
 - Passive delivery system
 - Ocular treatments



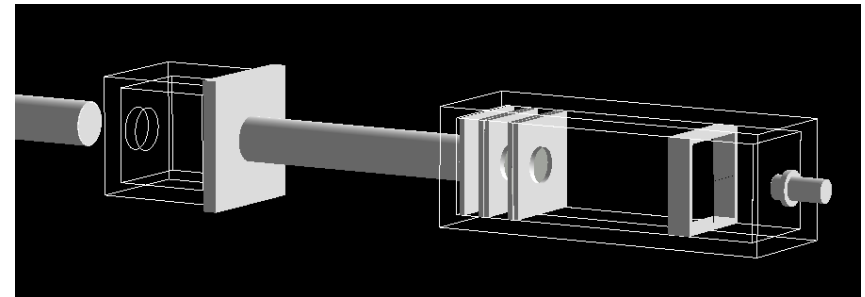
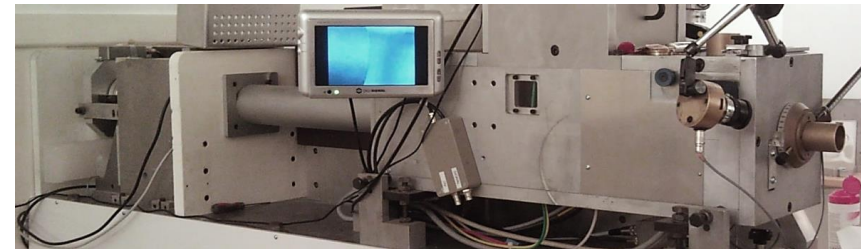
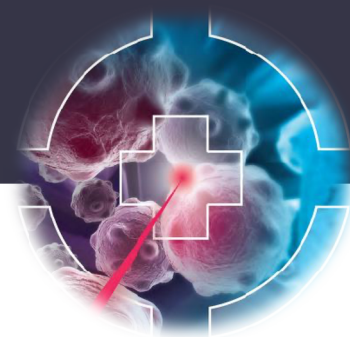
Clatterbridge Cancer Centre (CCC)

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Simulation studies

- Modelling to investigate beam behaviour, transverse profiles
 - Database of halo maps, correlation
- Integration of detector in beamline
 - Benchmark experimental data
- Monte Carlo toolkit: **Geant4**
- Model of CCC delivery system
 - Historical beam parameters
 - Realistic geometry



A: Scattering tube; tungsten foils, brass beam stopper

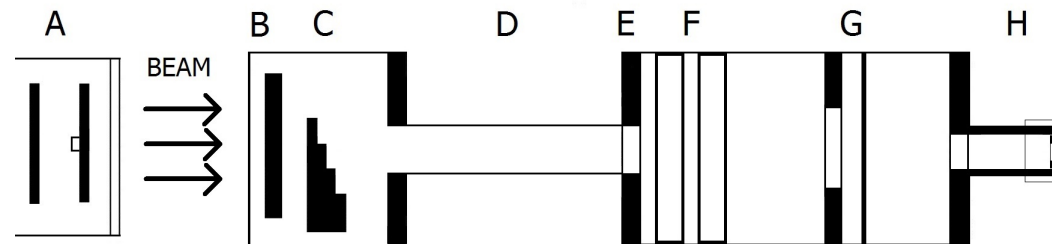
B/C: Absorbers & modulators

D: Integration zone

F: Dose monitors

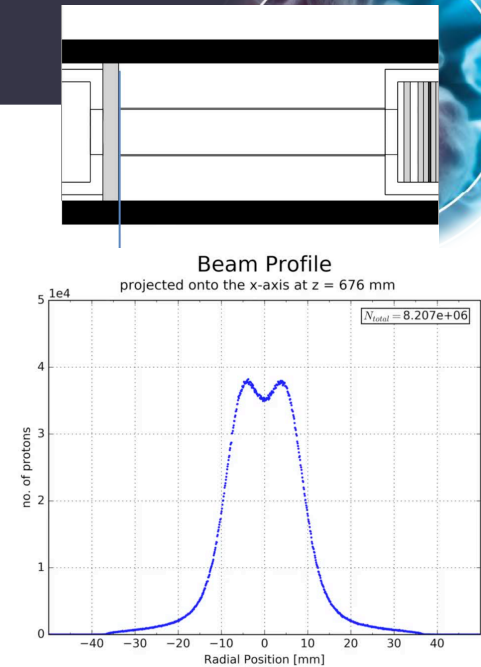
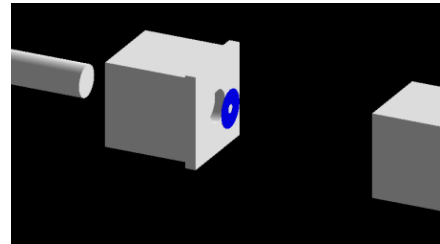
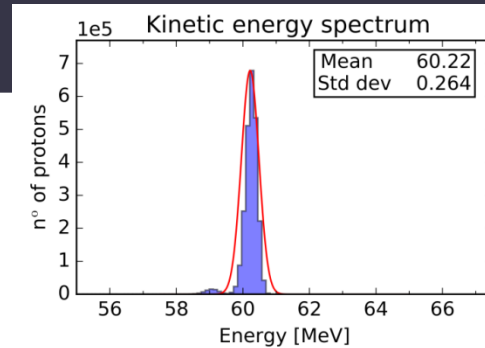
G: Cross-wires

H: Treatment nozzle



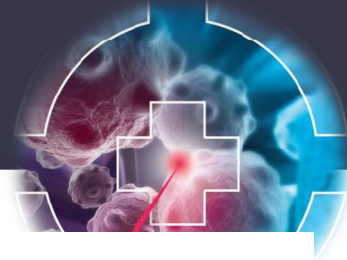
Study outcomes

- **Beam profiles**
 - Beam propagation
- **System Integration**
 - Effects of sensor on beam
- **Beam parameters**
 - Impact on results

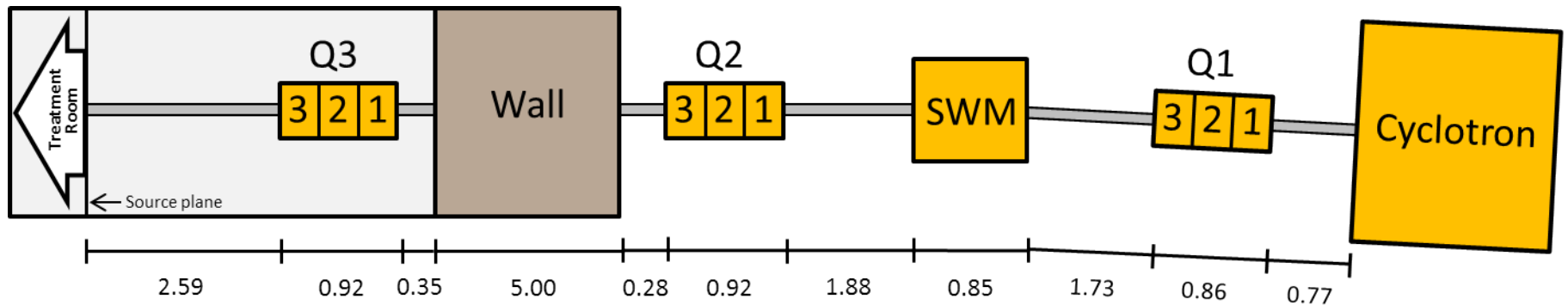
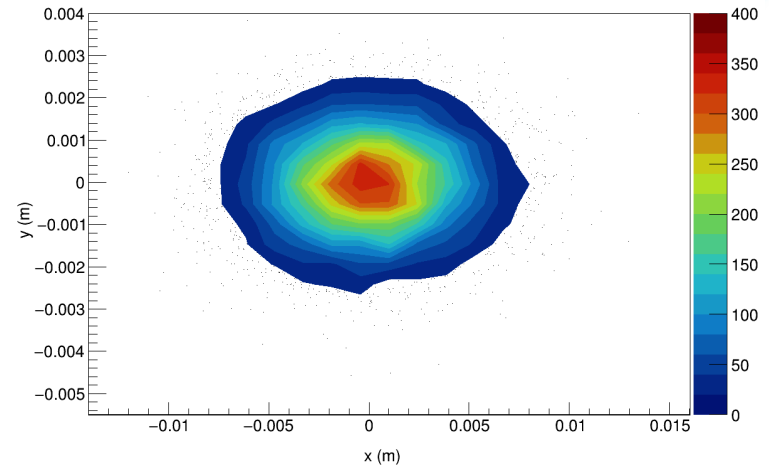


- **Main findings:** Our halo dose correlation relies on accurate beam information but there are no diagnostics in beam transport line
 - Dependence of transverse profiles on our input beam parameters
 - Differences will scale for different beam settings
 - Assumed beam parameters due to accelerator & transport line unknowns
- **Need to investigate beam optics & validate models**

1. Beam dynamics



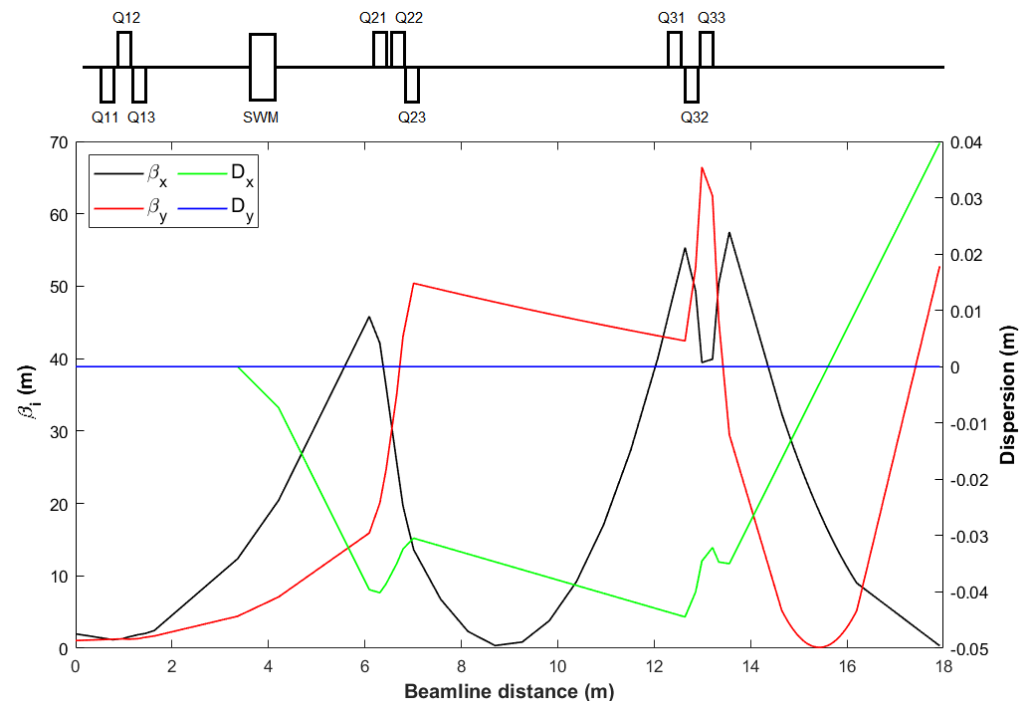
- **CCC beamline optics study**
 - Accelerator design code: MAD-X
 - Geant4 toolkit wrap around: BDSIM
 - Determine beam distributions, Twiss parameters
 - beam sigma size
 - distribution at simulation source



Optical lattice

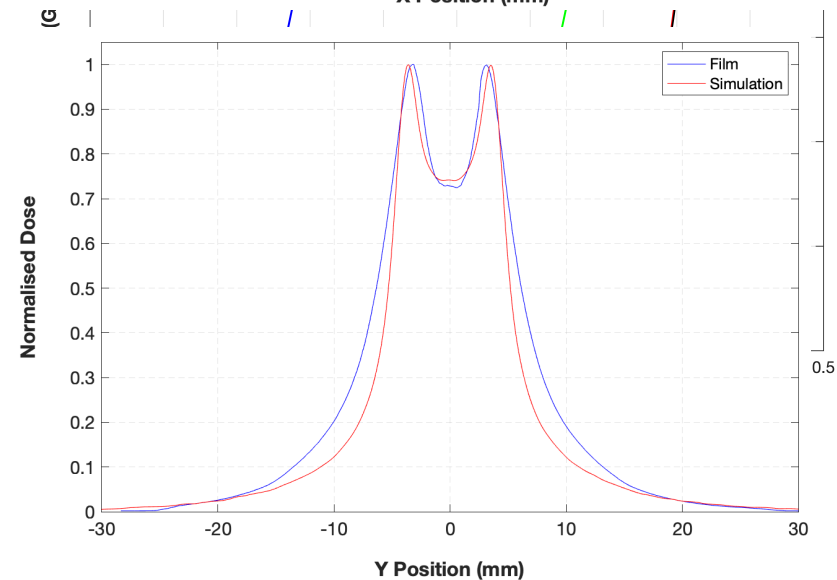
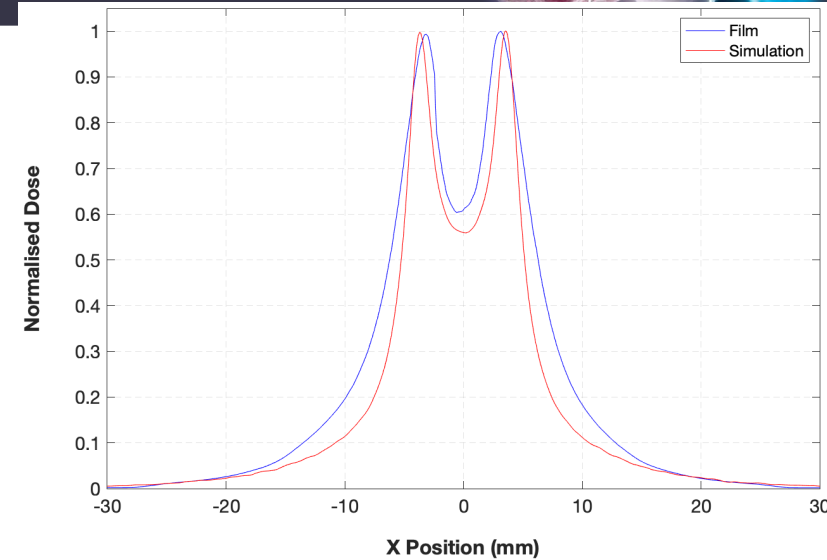
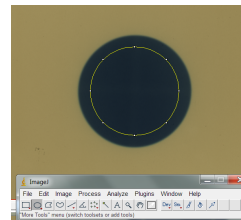
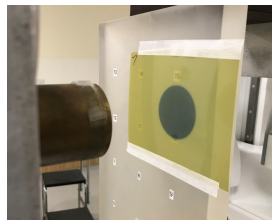
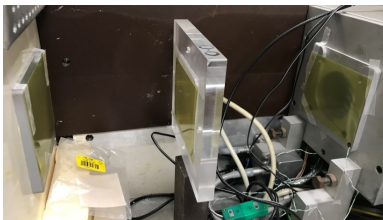
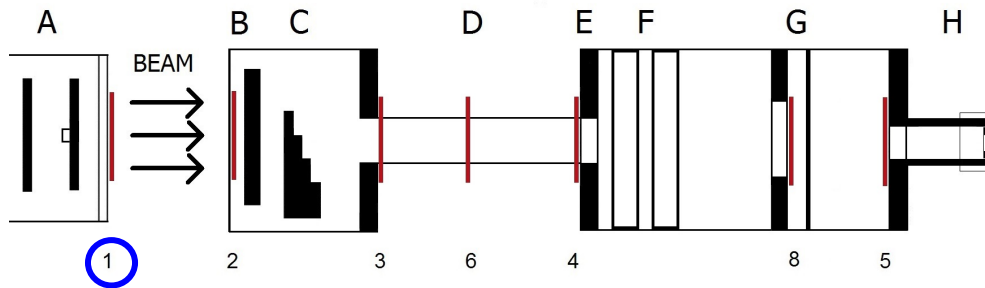


- Many challenges
 - No diagnostics
 - Limited documentation
 - Unknown parameters
 - Inaccessible components
 - Legacy/historical numbers
- Solution: Optimised lattice
 - Geometrical measurements
 - Convert control system data
 - Estimate quadrupole parameters
 - Nominal case
 - Optimise for facility and treatment conditions (transmission, beam parameters)
 - Design experiment & measurements => Match lattice



2. Experimental measurements

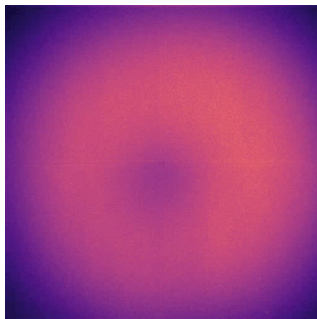
- EBT3 Gafchromic film
 - 8 different locations in the treatment beamline
- Pixel values correlate to absorbed dose
 - Net OD is a function of the dose
 - Calibration set to generate exponential fits
- Plot dose against lateral position



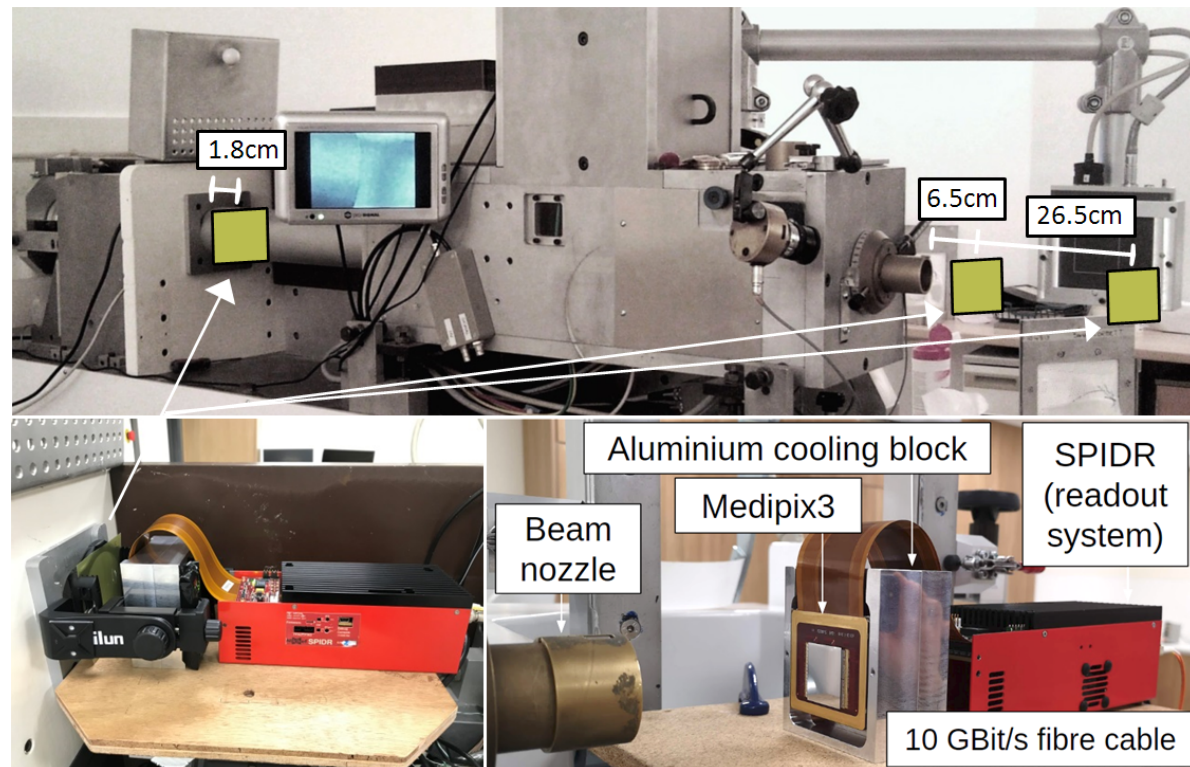
Medipix3 measurements



- Collaboration with ASI & Nikhef, Netherlands
- Medipix3 & EBT3 film comparisons
 - Possibilities for verification with VELO
- First tests with Medipix3 detector in a clinical proton therapy environment
 - High proton flux ($\sim 10^{10}$ ions/s)



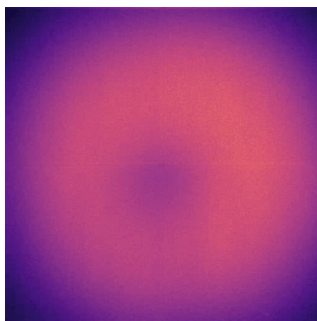
Courtesy of N. Bal



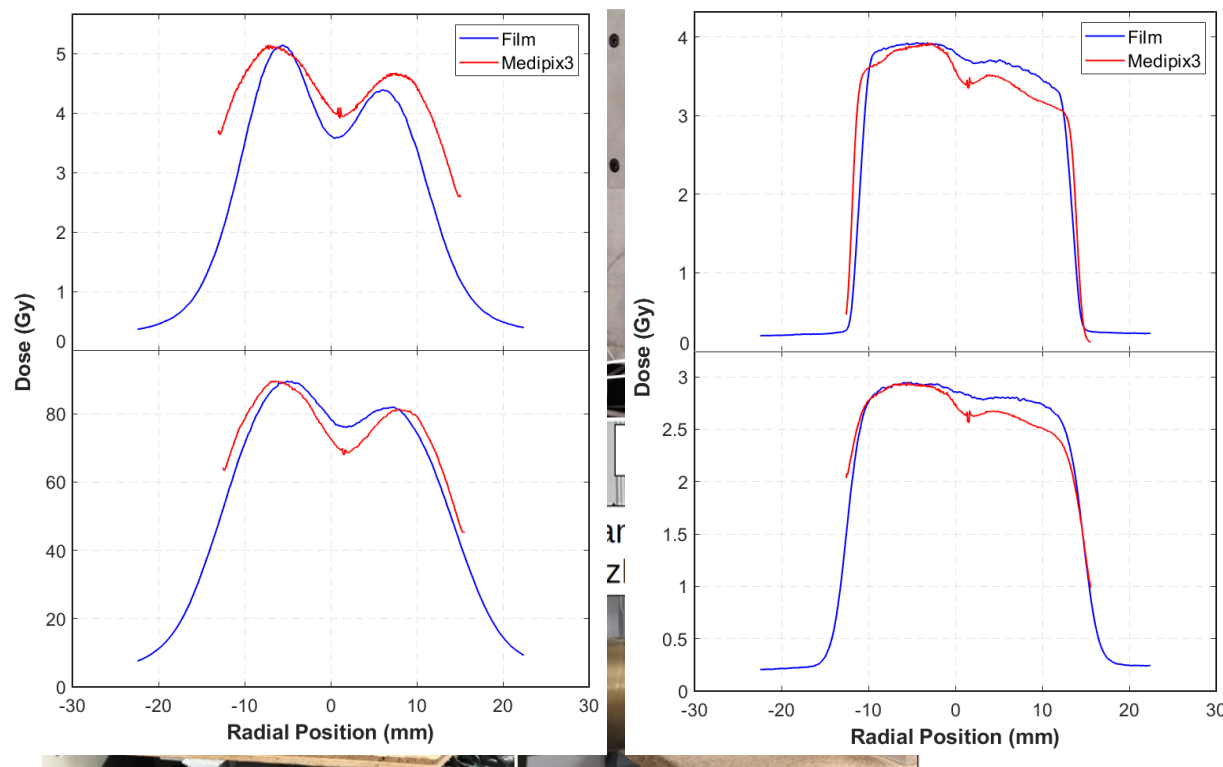
Medipix3 measurements



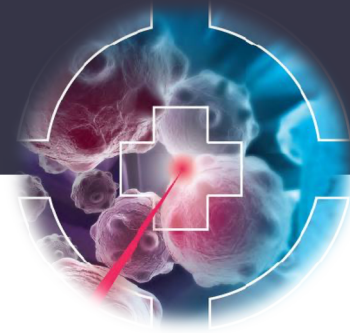
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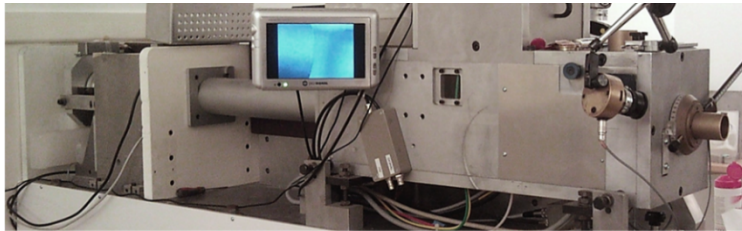
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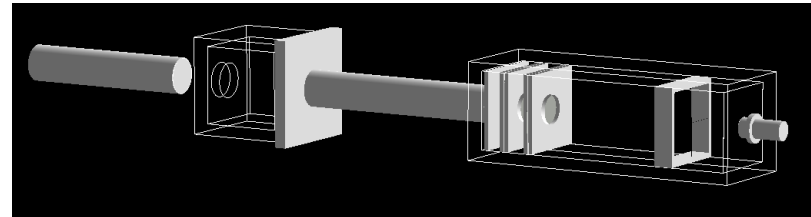
CCC TOPAS model



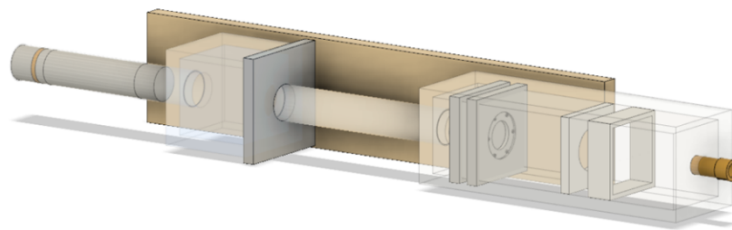
- TOPAS: TOOl for PArticle Simulation
 - Geant4 wrap around/extension specific for proton therapy
 - Time dependency & radiobiological scoring features
- Implemented all components of the updated CCC beamline
 - Combination of CAD imports (individually by material) & user defined geometries
- Documented & open source simulation model for future beamline users



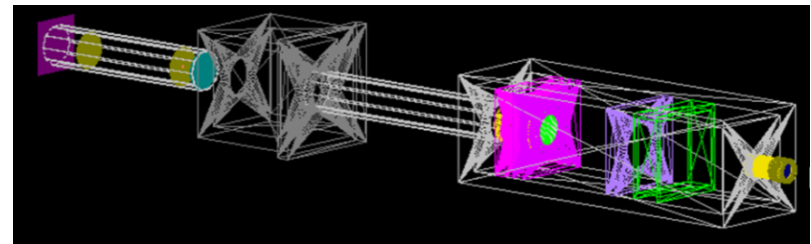
Reality



Geant4

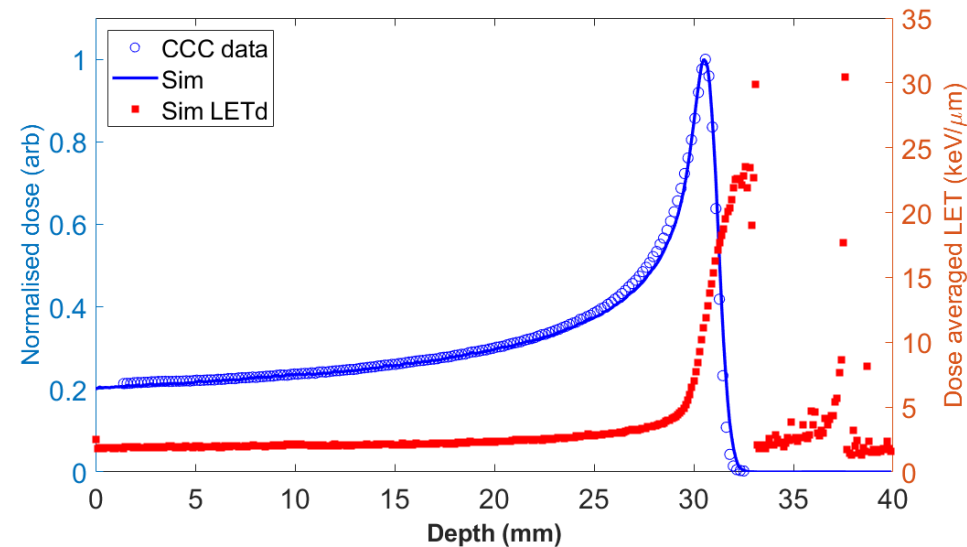
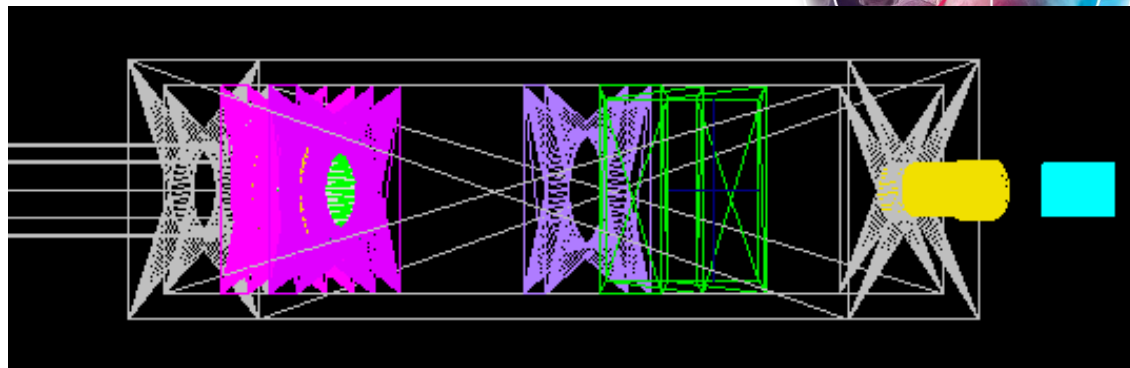
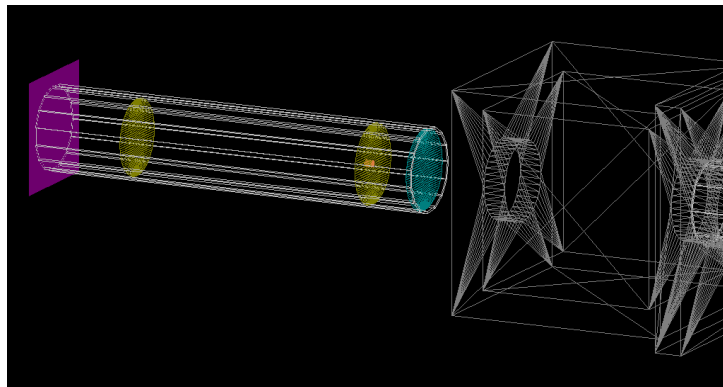


CAD



TOPAS

Performance

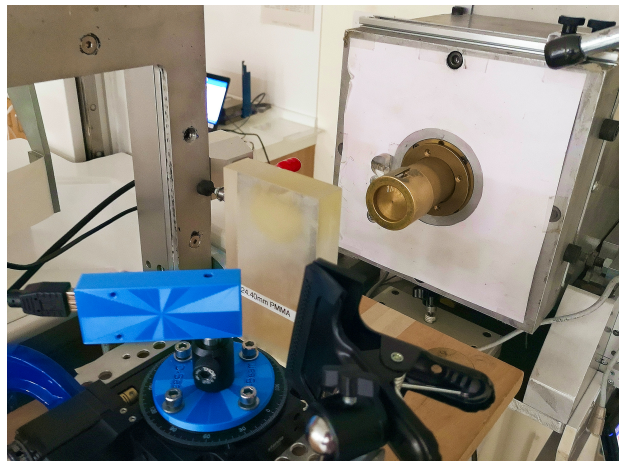
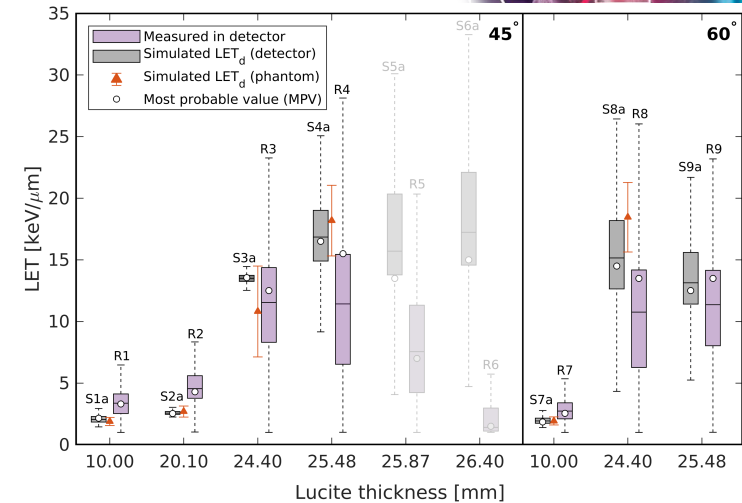


- Linear energy transfer (LET)
 - Energy loss (keV) over a path length (μm)
 - Correlated with biological damage
- Measurements
 - MiniPIX-Timepix detector
 - Pristine BP, comparisons with TOPAS
 - To match & validate our simulation models with experimentally obtained data (high-LET vs low-LET irradiation)

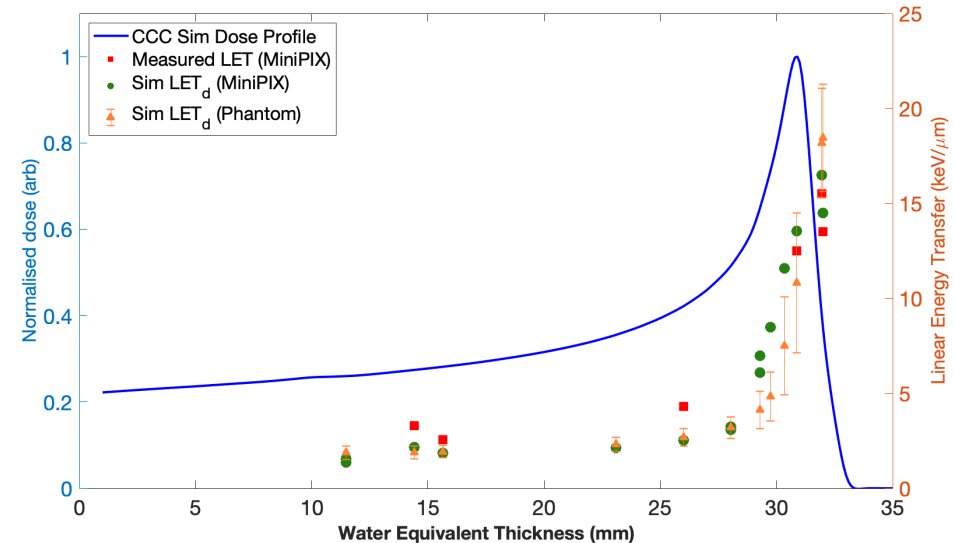
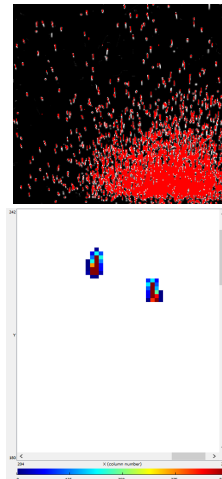
MiniPIX-Timepix measurements

- Beam to $<10^5$ protons/s
- Different thickness PMMA blocks
 - Varies WET along BP
- Determined LET spectra
 - Cluster volume (energy dep) & size (track lengths)
- Energy spectra for radiobio applications
 - Oxford: DSBs, RBE factors for TPS

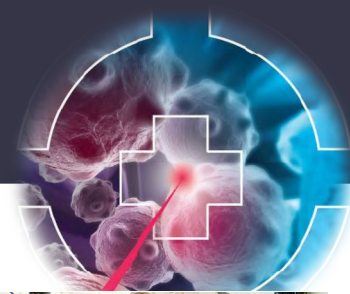
Courtesy of M. Brooke



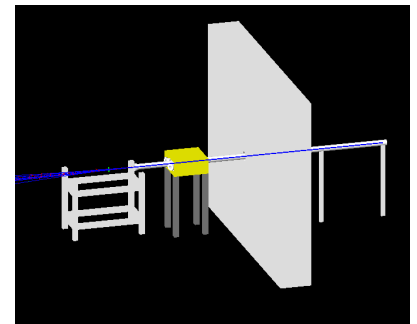
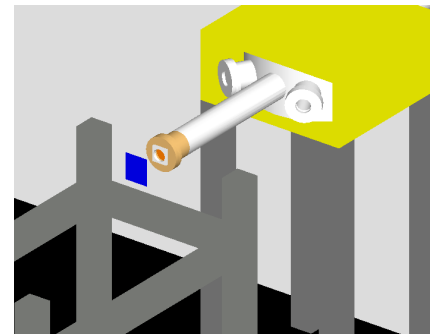
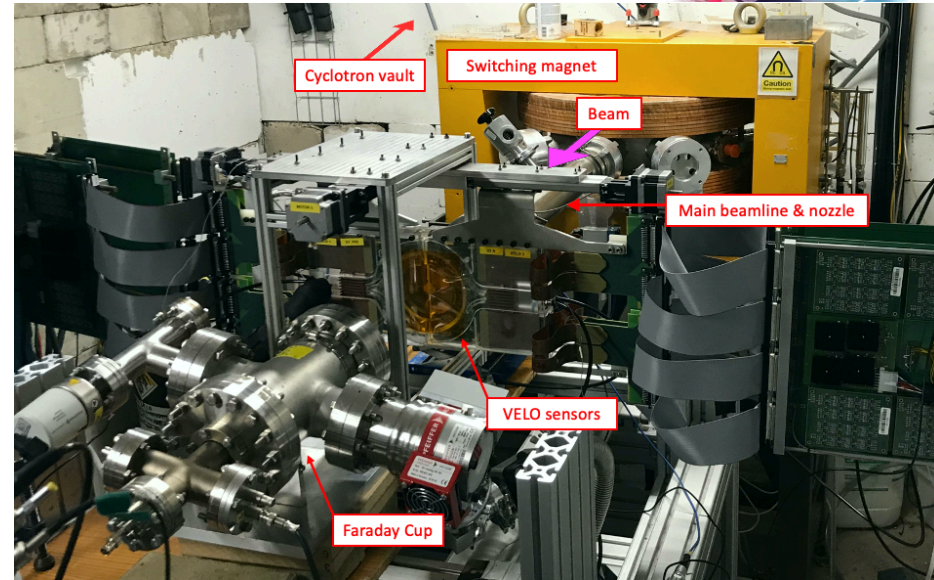
ADVACAM
Imaging the Unseen



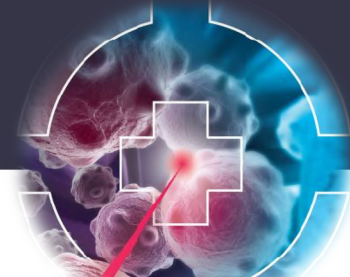
VELO proof-of-concept measurements



- 3 days of beam time at a proton beamline, University of Birmingham (MC40, 35 MeV cyclotron)
 - Verification of system operation at a proton facility
 - Characterisation of VELO with differing beam currents and beam sizes
 - First tests of the VELO monitoring system after upgrades (hardware, mostly software – triggering & synchronisation)
- Main outcomes:
 - Linearity between beam current and VELO hits
 - Agreement between VELO, film and simulation profiles



VELO proof-of-concept measurements

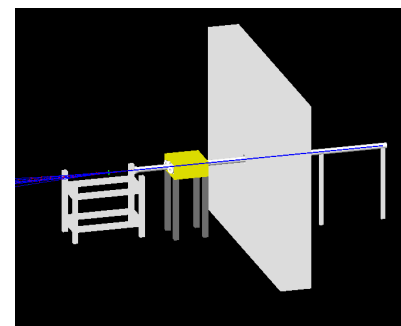
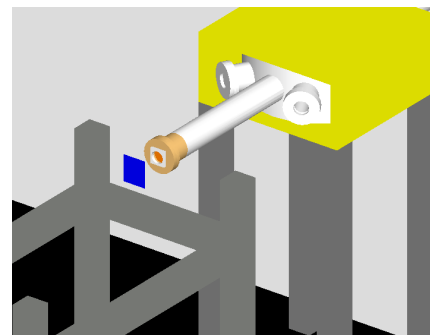
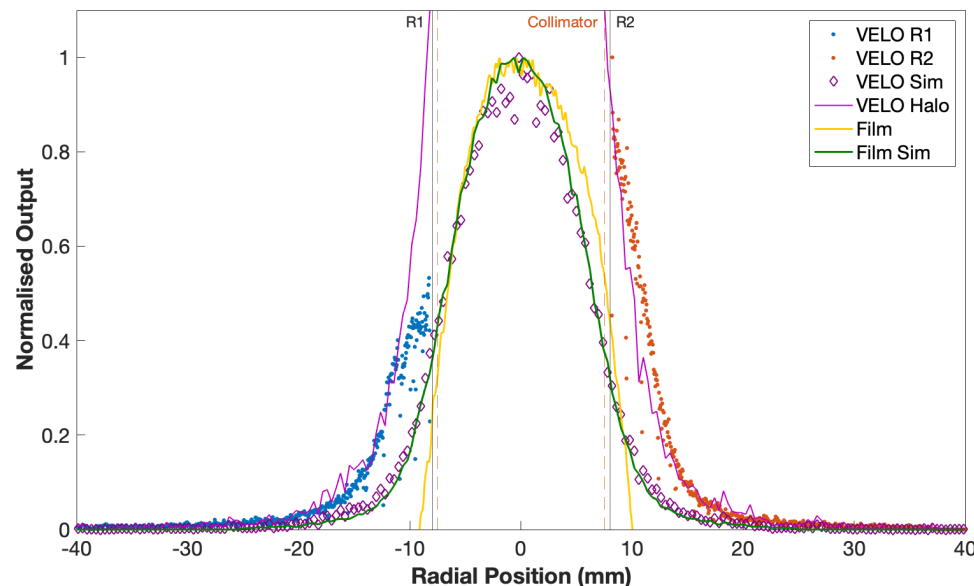


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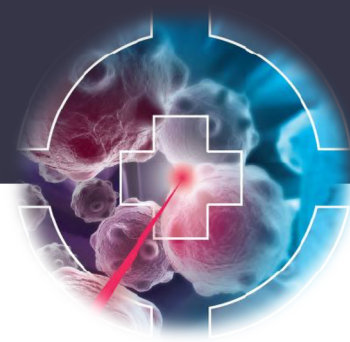
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Summary



- Novel diagnostics: LHCb VELO beam halo monitor
- Simulations, beam dynamics study & experimental measurements
- Complete end-to-end characterisation for the integration & development of novel beam diagnostics for particle therapy facilities

Acknowledgements to collaborators & contributors:

A Kacperek, S Jolly, S Boogert, J Resta-López, C P Welsch,
R Schnuerer, M Brooke, N Bal, M Hentz.

PhD work was undertaken with the QUASAR Group, Accelerator Physics,
University of Liverpool & Cockcroft Institute, United Kingdom



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Additional images:

Durante, M. & Flanz, J. (2019), "Charged particle beams to cure cancer: Strengths and challenges", *Seminars in Oncology*, vol. 46, pp. 219-225.

Mohan, R. & Grosshans, D. (2017), "Proton Therapy – Present and Future", *Adv. Drug Deliv. Rev.* 109.

Dölling, R. et al. (2004), "Profile, Current, and Halo Monitors of the PROSCAN Beam Lines", *Proc. of BIW04*.

Gottschalk, B. et al. (2015), "On the nuclear halo of a proton pencil beam stopping in water", *Physics in Medicine & Biology*, no. 60, July, pp. 5627-5654.

Kacperek, A. et al. (2012), "Ocular Proton Therapy Centers", *Ion Beam Therapy: Fundamentals, Technology, Clinical Applications*, pp. 149-177.

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<http://www.oma-project.eu/>