Imaging of prompt gamma emissions during proton cancer therapy for geometric and dosimetric verification

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UCL

The Clatterbridge Cancer Centre NHS

NHS Foundation Trust

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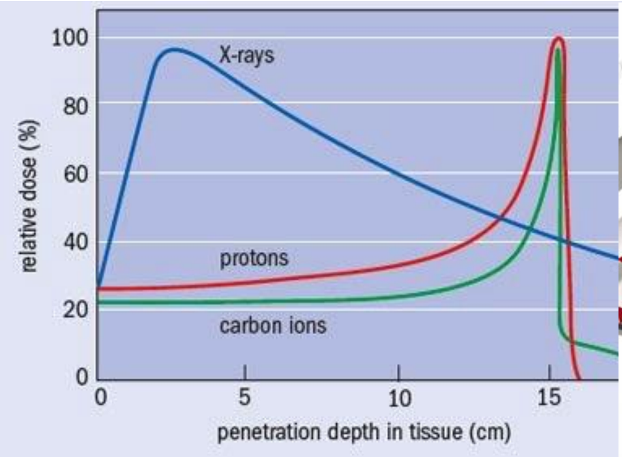
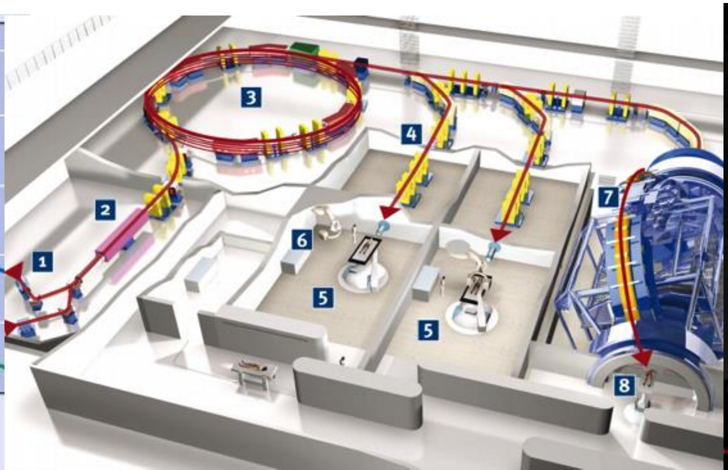
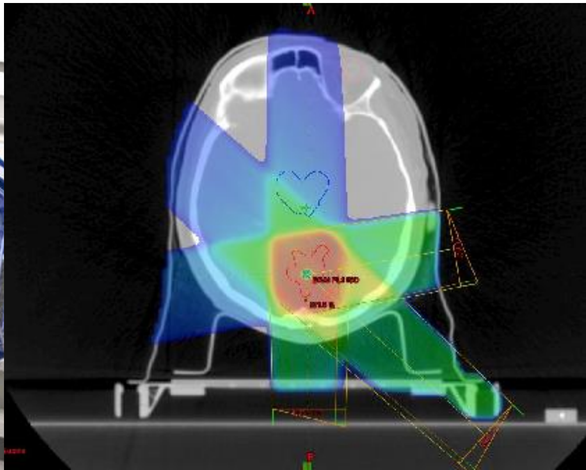
Proton Beam Therapy

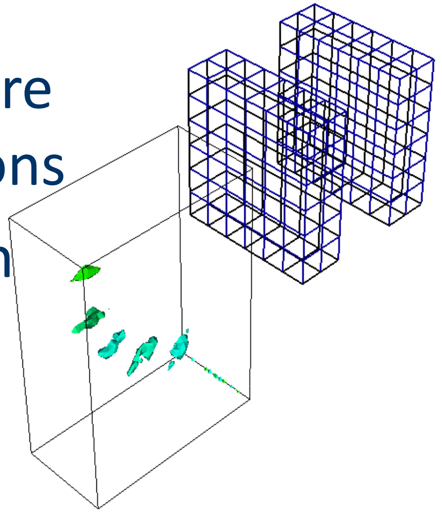
- Benefits over other radiotherapy techniques
- The treatment is particularly suitable for complex childhood cancers, increasing success rates and reducing side effects
- Used to treat brain cancers and head and neck cancers.
- The UK is in the process of building two new high-energy proton therapy centres in London (UCLH) and Manchester (Christie) - in addition to existing Clatterbridge facility.





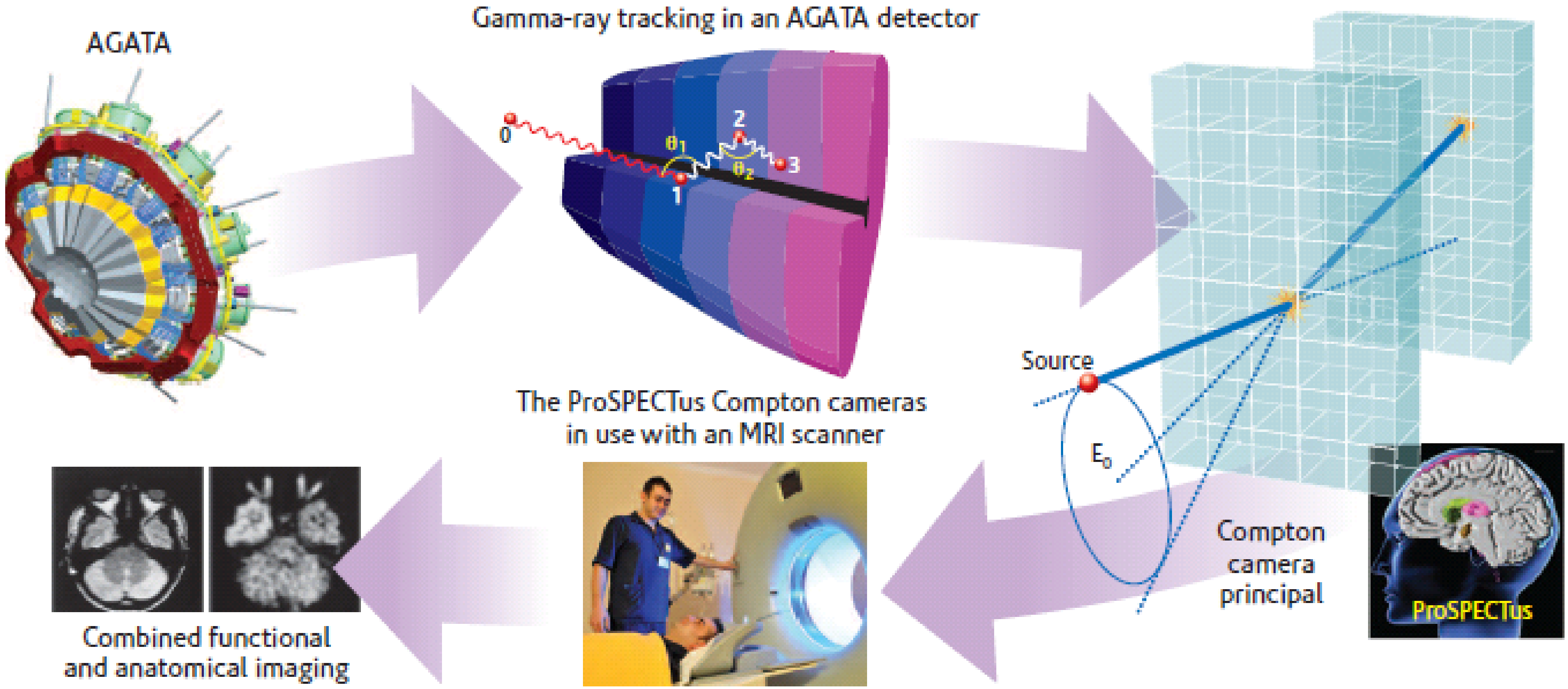


What is new?



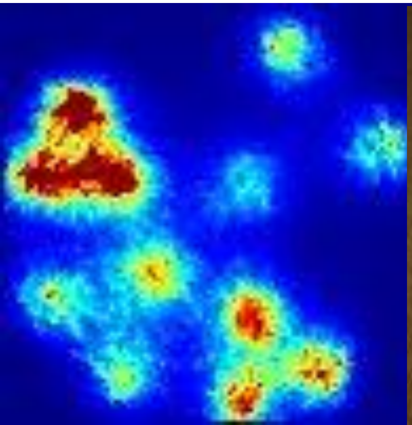
- Verification of radiation delivery is significantly more challenging for protons than for high-energy photons
- Real-time verification via prompt gamma detection
  - Utilise existing ProSPECTus Compton Imager with 3rd detector element
  - Position resolution 2-3mm
  - Sensitivity factor 10 larger
- Imaging allows for verification of the intended proton treatment delivery:
  - In terms of geometrical placement of beams (range verification)
  - Ideally the more challenging ultimate aim of deriving and hence verifying both (3D) beam placement and delivered radiation dose

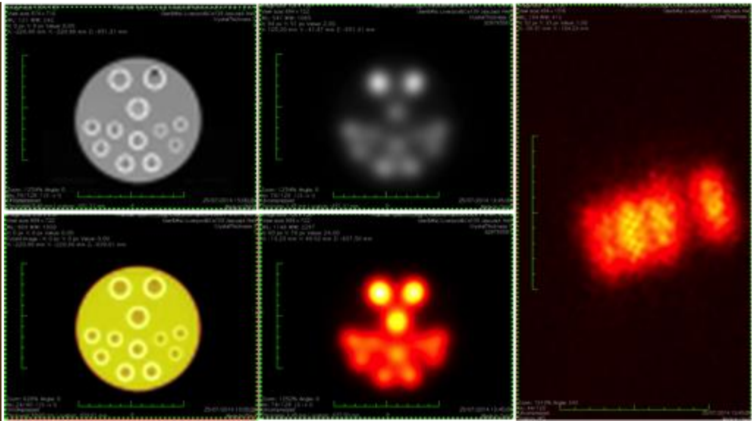
From AGATA to ProSPECTus



ProSPECTus: Next generation SPECT

- Detector head sensitivity maximised for ^{99m}Tc 141 keV gamma rays (also works at higher energies e.g. ^{131}I 364keV).
- Sensitivity is a factor of 10 improvement over LEHR collimated SPECT detector heads.
- Multi-isotope imaging in single acquisition
- Wide energy range with one system
- 2 semiconductor detectors housed in 1 cryostat
- MRI-compatible



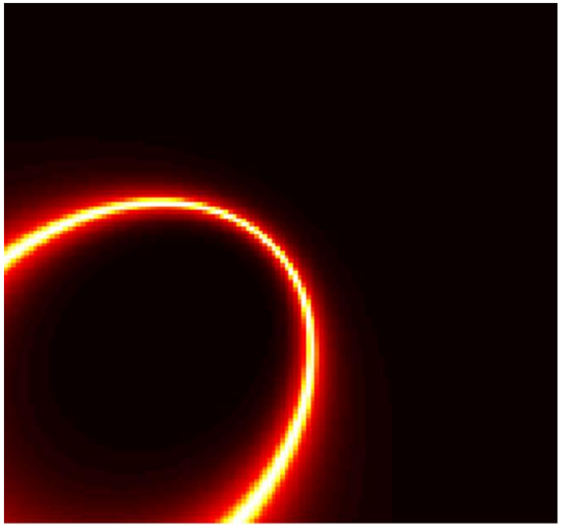


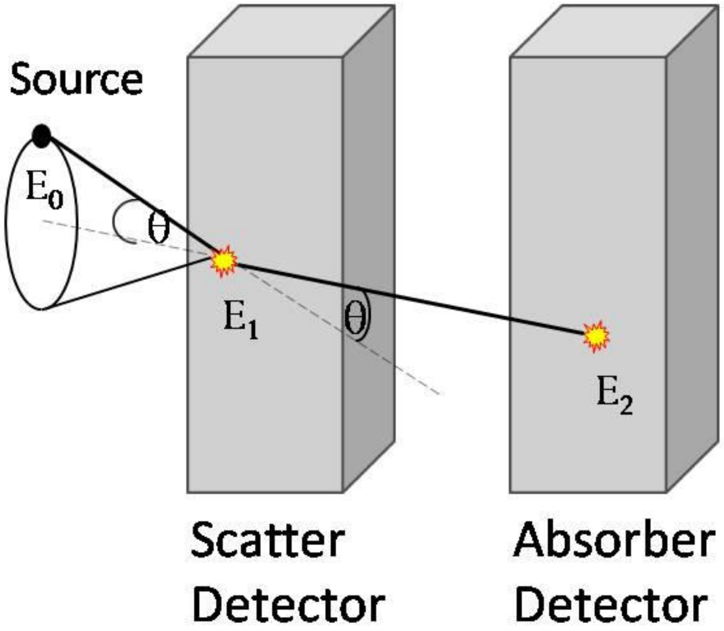
Reconstruction code

- Reconstruction code (Dr. D.Judson, University of Liverpool)

$$\cos(\theta) = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

from presentation L. Harkness ProSPECTus





From Uni. Liverpool Nuclear physics website

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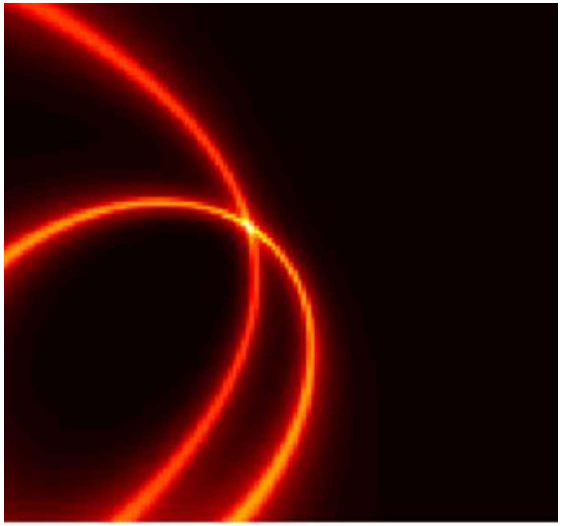

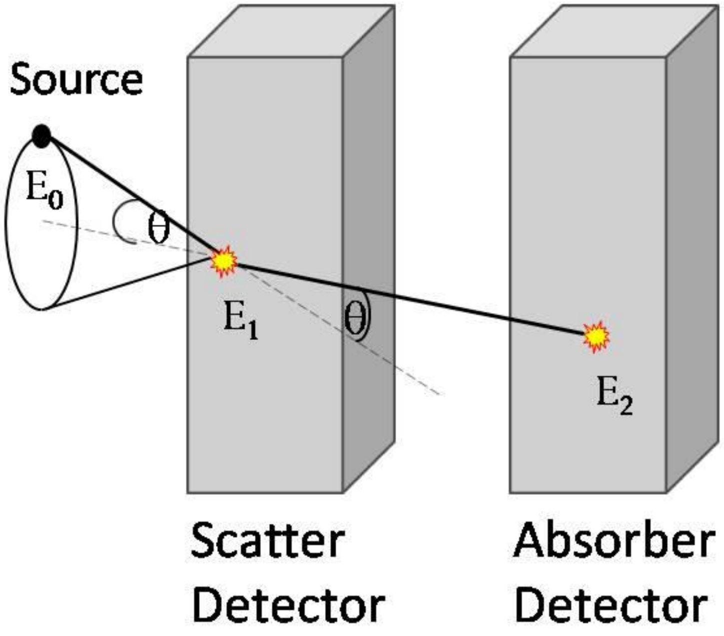

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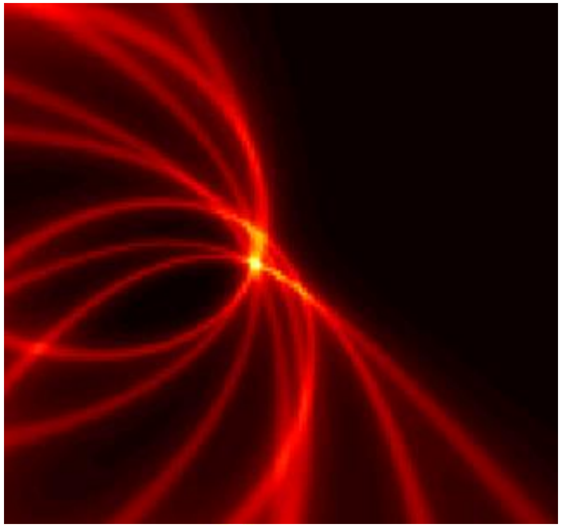
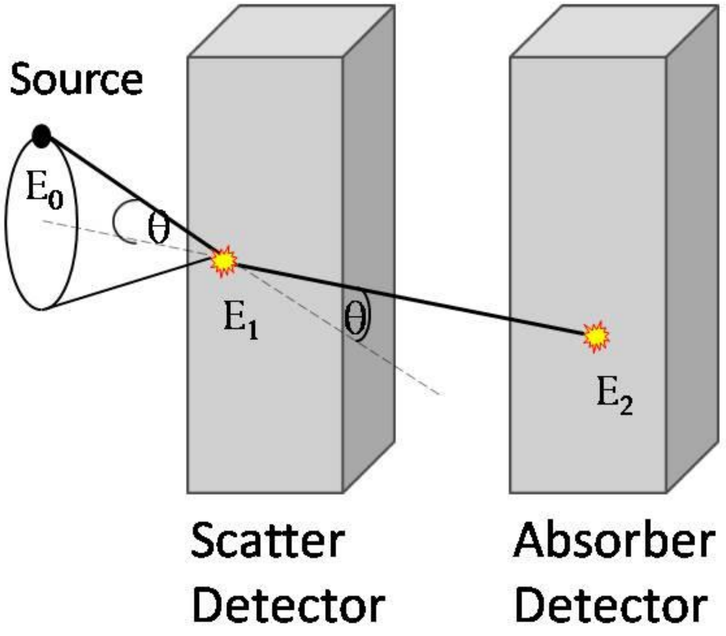
ProSPECTus

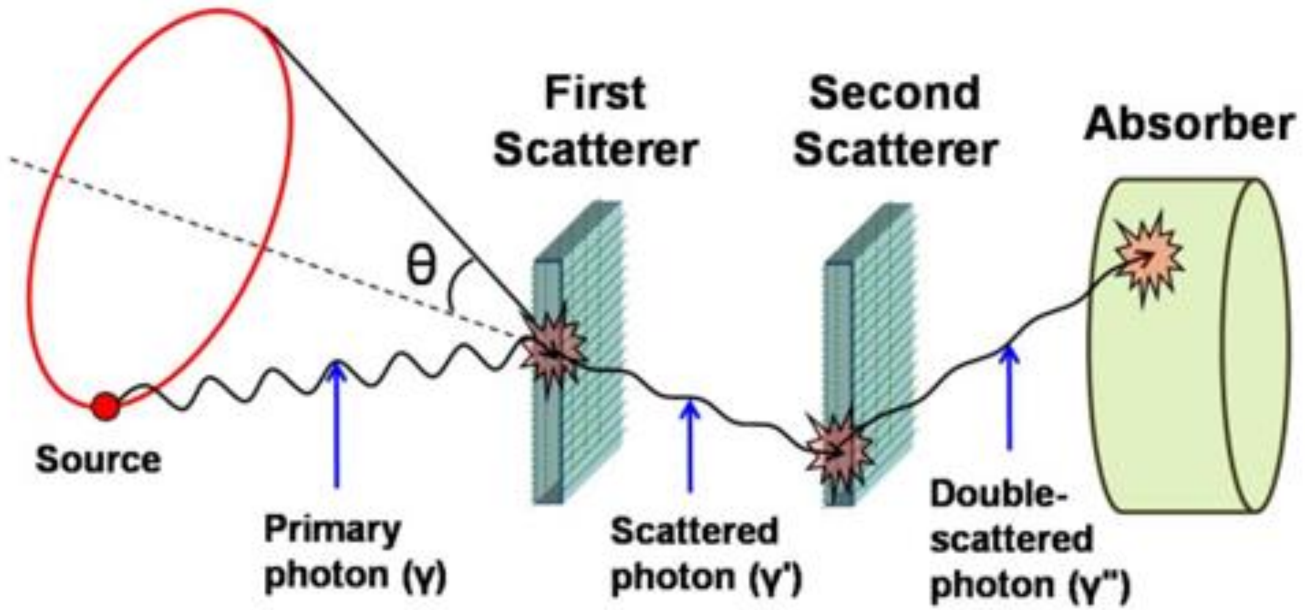




From Uni. Liverpool
Nuclear physics website

Triple Compton imaging

Prompt Gammas Energies: 2.2 MeV, 4.4 MeV



Increased efficiency for high-energy gamma rays

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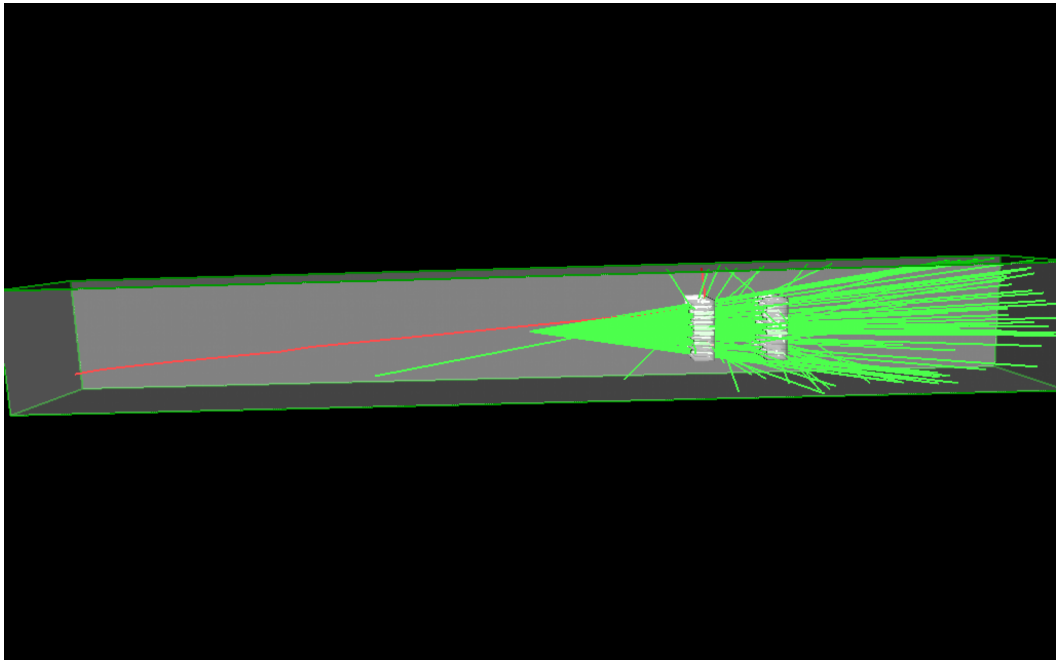
Simulation using GAMOS

Geant4-based **A**rchitecture for **M**edicine-**O**riented **S**imulations

P. Arce et al. NIM A 735(2014)304-313

L.J. Harkness et al. NIM A 671(2012)29-39 (Compton Camera part)

2 HPGe
60x60x20 mm^3
12X – 12Y
5mm strips



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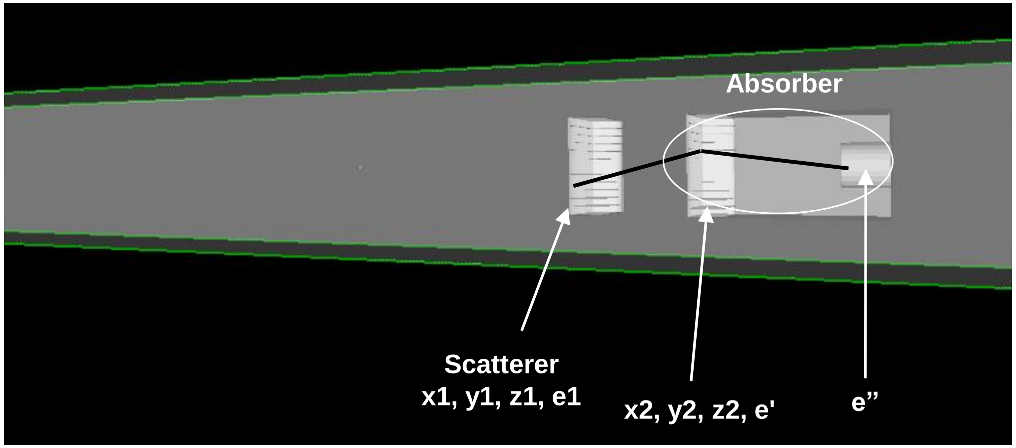
2 HPGe
60x60x20 mm^3
12X – 12Y
5mm strips

Ge
Cylinder

Separation 70mm



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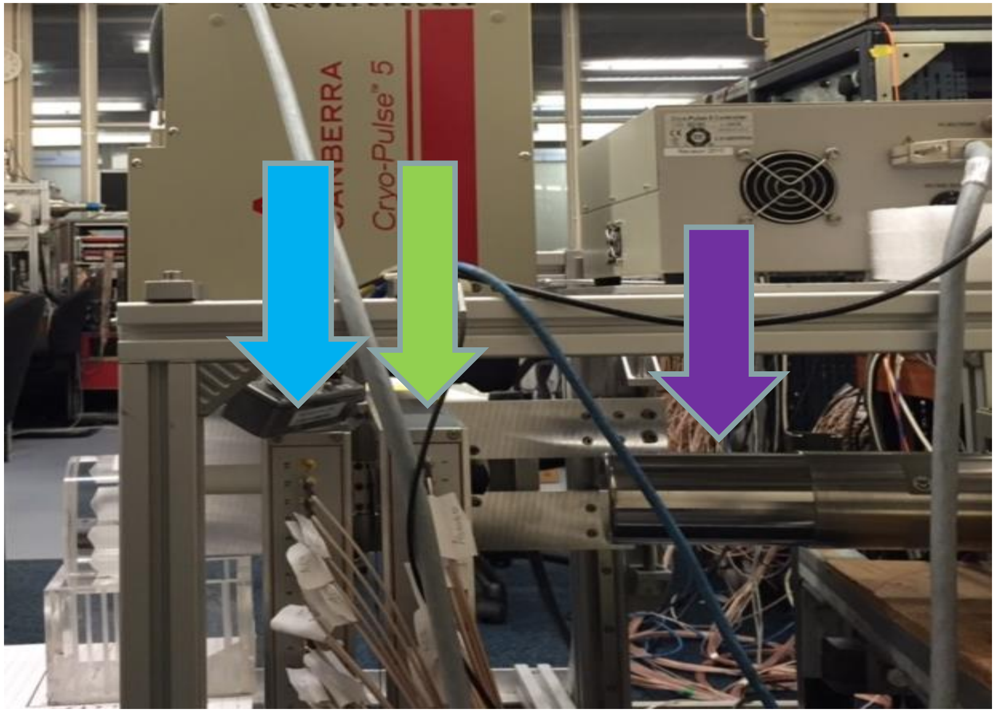
Triple Compton imaging



- Three tier Compton system:
- i) First layer scatter detector is Si(Li) detector
- ii) Second layer absorber detector is HpGe detector
- iii) Third layer Coaxial germanium detector

- A full triple layer Canberra Compton Camera

The implication

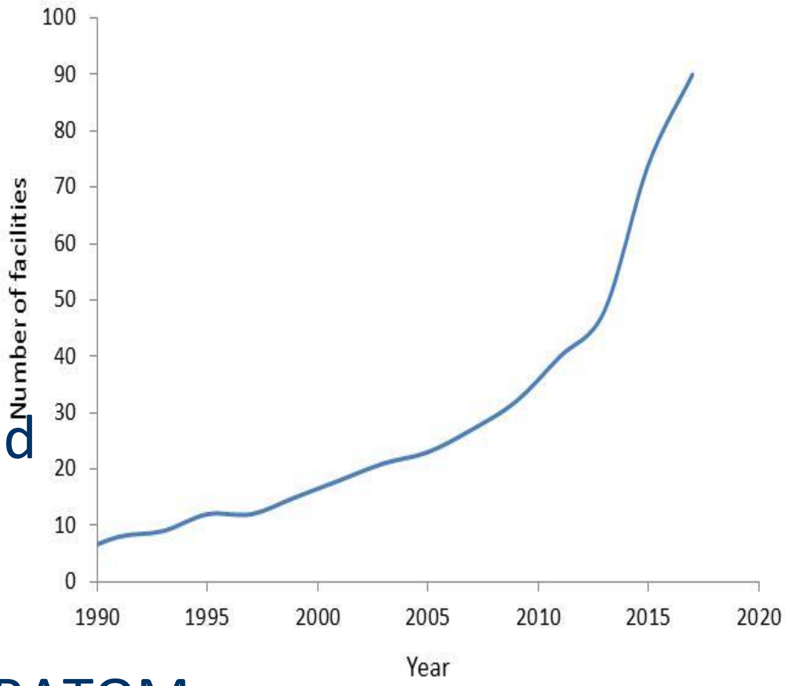
- Outcome will be a proof-of-concept demonstration of real time geometric and dosimetric verification of treatment delivery.
- The project will provide a specification for a system that can be taken forward to market.
- Clinical trials follow a successful demonstration of the system.
- The proposal offers excellent potential for economic impact, but also societal impact through the delivery of better healthcare provision
- Metrology for molecular radiation therapy JRP

MetroMRT
Metrology for Molecular Radiotherapy

NPL
National Physical Laboratory

What is the need?

- Increasing number of facilities world-wide, including the two new UK centres, a trend which is expected to increase as the cost of proton therapy reduces.
- Reliable and accurate methods for proton treatment verification are urgently required.
- Evidence-based knowledge of the radiation dose required and delivered to a patient during treatment



- EU COUNCIL DIRECTIVE 2013/59/EURATOM
- "For all medical exposure of patients for radiotherapeutic purposes, exposures of target volumes shall be individually planned and their delivery appropriately verified " – 6 February 2018 timescale

Imaging of prompt gamma emissions during proton cancer therapy for geometric and dosimetric verification

- Proof-of-concept demonstration of real time geometric and dosimetric verification of treatment delivery
- Offers economic & societal impact through the delivery of better healthcare provision
- Large and growing market size
- Addresses EU Council Directive 2013/59/EURATOM

- Simulation tools for geometry optimisation
- Compton camera system available in the laboratory

Nuclear Physics Group, Dept of Physics, University of Liverpool;

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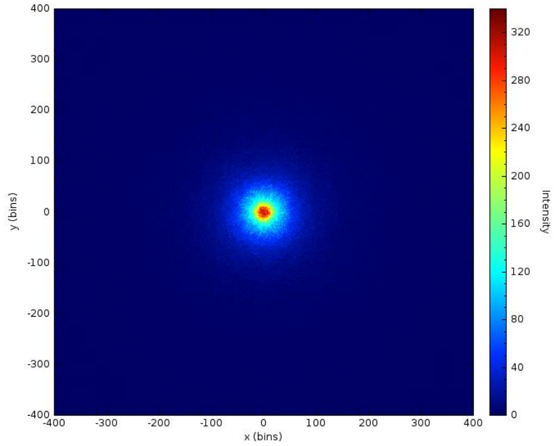
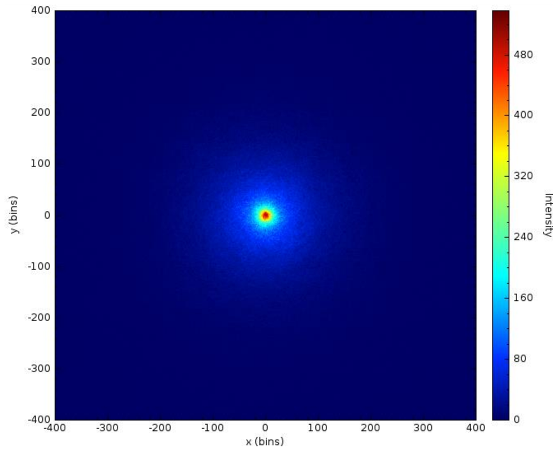
Thank you for your attention

2 Layers or 3 Layers ?

2 HPGe (60x60x20 mm^3)
Scatterer + Absorber

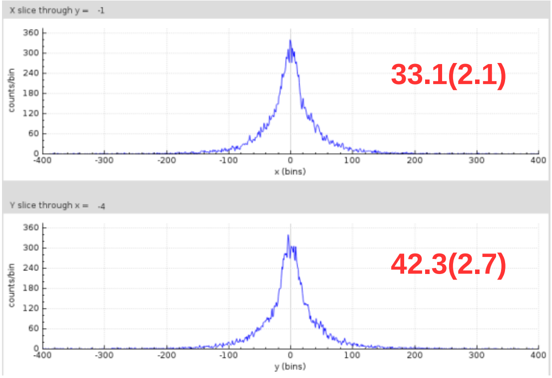


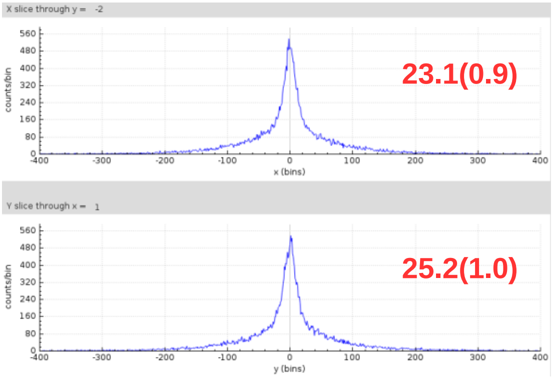
3 HPGe (60x60x20 mm^3)
Scatterer + 2 Absorbers



FWHM x (mm)

FWHM y (mm)





We need to use three layers

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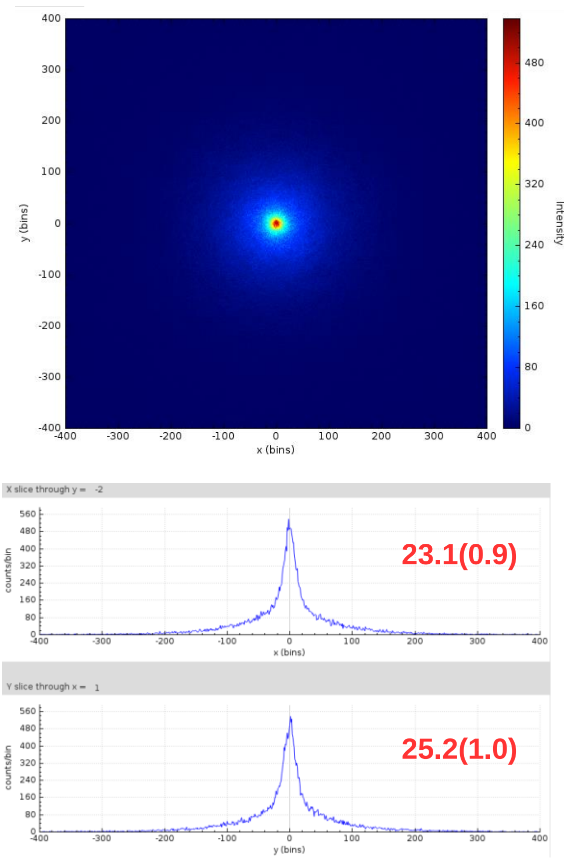
Importance of Pulse Shape Analysis

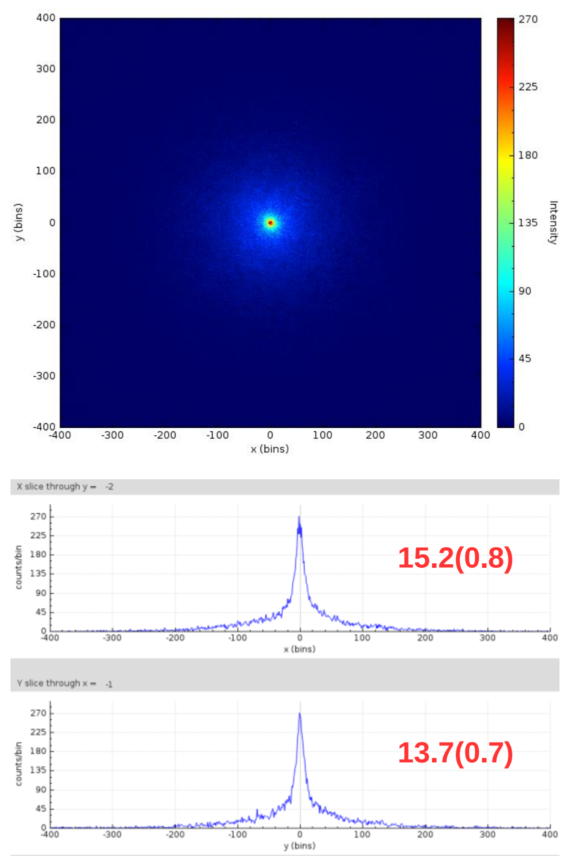
- **Without Pulse Shape Analysis: Precision 5x5x20 mm^3**
- **Use of Pulse Shape Analysis for better precision**

R.J. Cooper et al. NIM A 573(2007) 72-75 → ***Perfect situation: Precision 1x1x1 mm^3***

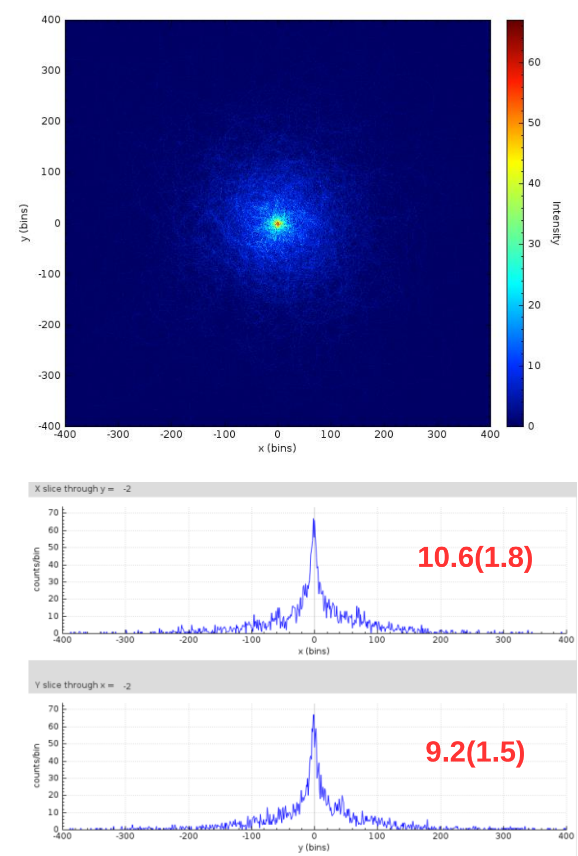
3 HPGe (precision 5x5x20 mm^3)



3 HPGe (precision 2.5x2.5x10 mm^3)



3 HPGe (precision 1.25x1.25x5 mm^3)



It takes a lot of times and we loss statistics

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