EAC 2019
4th European Advanced Accelerator Concepts Workshop
15-21 September 2019
Hotel Hermitage, La Biodola Bay, Isola d'Elba, Italy
Europe/Rome timezone

Dosimetry of laser-accelerated carbon ions for cell irradiation at ultra-high dose rate

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QUEEN'S UNIVERSITY BELFAST
EST 1845

A-SAIL
ADVANCED STRATEGIES FOR ACCELERATING IONS WITH LASERS

Laser-acceleration of ions for biomedical applications

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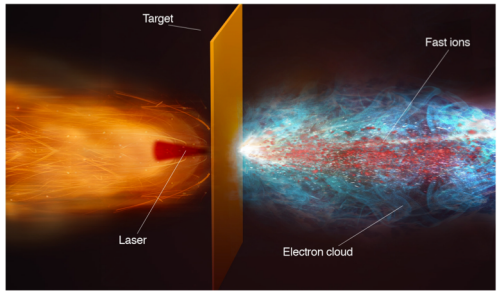


A-SAIL's vision

All-optical delivery of dense, high-repetition ion beams at energies above the threshold for deep-seated tumour treatment and diagnosis

Activities:

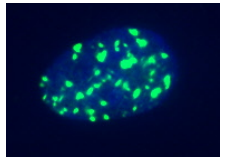
WP1: Exploration of different acceleration regimes
WP2: Investigation of the extreme interaction physics underlying the acceleration processes
WP3: Development of enabling technology (targetry, advanced optics, diagnostics)
WP4: Investigation of highly pulsed ion radiobiology

Science & Technology Facilities Council Central Laser Facility
University of Strathclyde
QUEEN'S UNIVERSITY BELFAST
Imperial College London

Novel regime of radiobiology

Short pulse irradiation

High dose rates> 10^9 Gy/s (cfr 10 Gy/min with conventional beams)

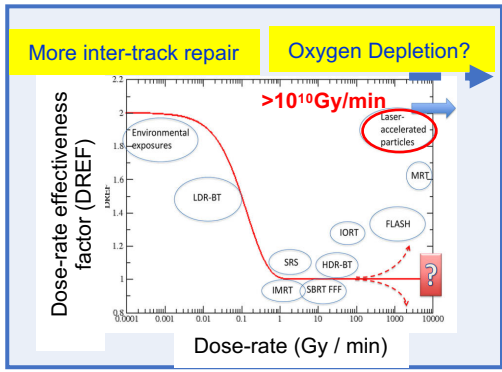


Possible effects

- Spatio-temporal overlap of independent tracks
- Local depletion of oxygen
- Lack of interaction between prompt DNA lesions and indirect lesions

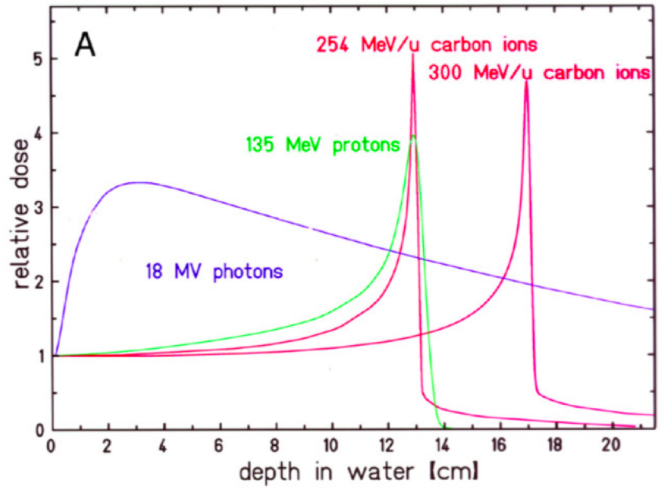
Studies

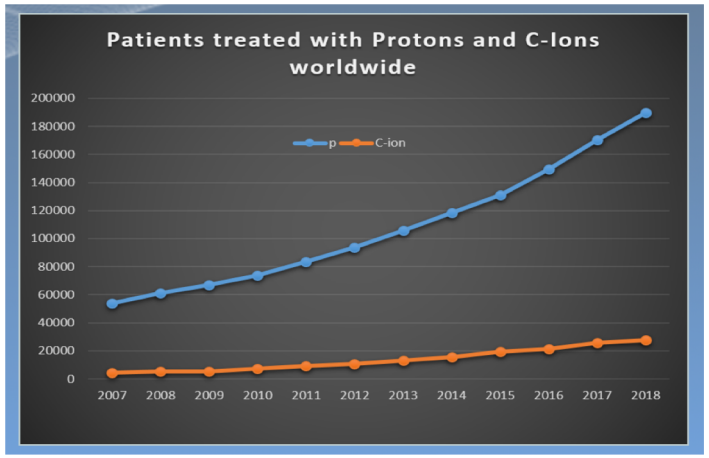
- Investigations of DNA damage and repair dynamics
- Survival studies
- Sub-lethal damage investigations



Hadrontherapy VS Protontherapy

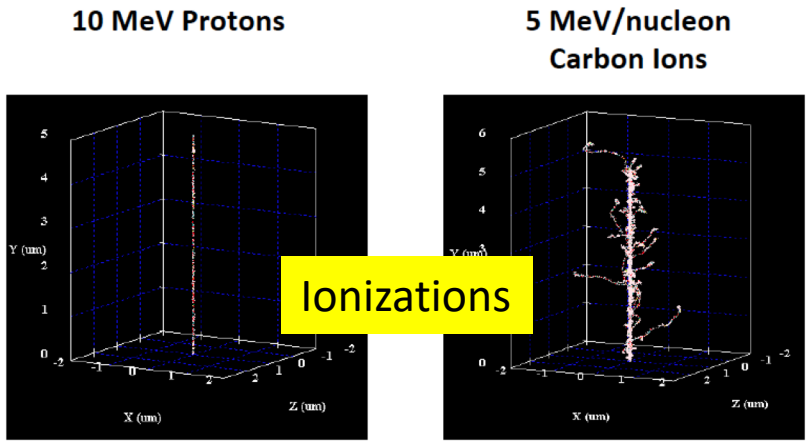
Proton and Carbons from RF accelerators such as cyclotrons are currently used for treating a number of tumours

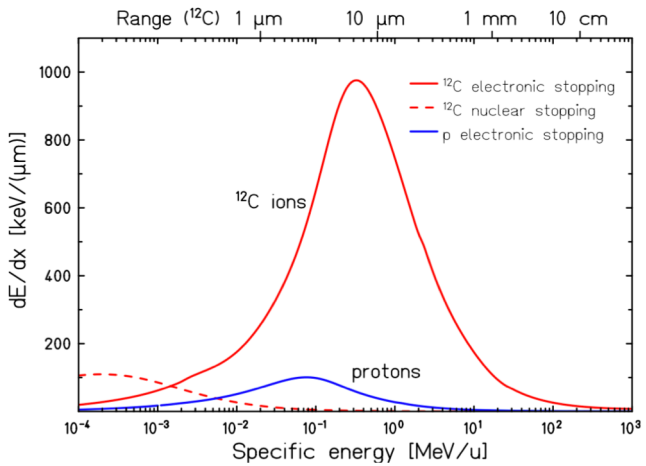




Radiation quality index for cell response

Linear Energy transfer (LET)
Relative Biological Effectiveness (RBE)
Medium ionization





Advantages of carbon ions

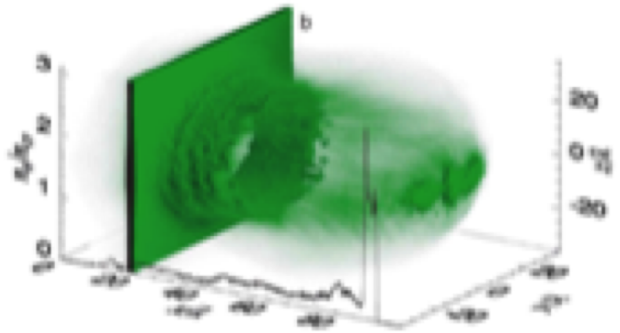
- ✓ More complex damages to the cell DNA
- ✓ Higher LET > 100 KeV/um
- ✓ Higher biological efficiency
- ✓ Higher efficiency for the treatment of radioresistent tumours

Recent results for carbon ion acceleration @ ASTRA GEMINI (RAL)

Laser characteristics

- **Pulse duration ~ 40 fs**
- **Energy on target up to 15 J**
- **I~ 0.5 - 1.0 10^{21} W/cm^2 (f/2 focusing)**

Energy dependence from target thickness and laser polarization for carbon ions and protons



Efficient Radiation Pressure Acceleration of Carbon ions (up to 400 MeV) achieved by polarization control
C. Scullion et al, PRL, **119**, 054801 (2017)

See talk Aodhan McIlvenny
WG2 Thursday h 17:00

17:00 **Bulk ion acceleration from ultrathin foils in PW-class interactions on the ASTRA GEMINI laser** 20m

During the interaction of ultra-intense laser pulses with ultrathin foils, advanced mechanisms of ion acceleration take place which can be controlled and optimized in view of further progress towards high energy ranges of medical relevance on upcoming multi-PW facilities.
In the framework of the activities of the UK-wide A-SAIL project, recent campaigns at the ASTRA GEMINI laser facility (Rutherford Appleton Laboratory) have investigated and characterised ion acceleration from 2-100 nm thick Carbon foils irradiated by 40 fs laser pulses at intensities of 1020-1021 W/cm2. The experiments have highlighted a strong dependence of the ion energy from the target thickness and the laser polarisation, and suggested the onset of Light Sail Radiation Pressure acceleration from the bulk of the target when using circularly polarized pulses.
Following initial results (published in PRL, 119, 054801, 2017), following campaigns have led to an enhancement of the ion energies (up to ~35 MeV/n for Carbon 6+) and to observations of an intensity-dependent optimal thickness, consistently with analytical predictions. Comparison with extensive Particle-in-Cell simulations clarifies the complex interplay of multispecies dynamics during the acceleration, as well as the role of relativistically-induced transparency, and allows predictions of future performance at increased laser power and intensity.

Speaker: Mr McIlvenny Aodhan (Queen's Univesrity Belfast)

Experimetal setup @ ASTRA GEMINI (RAL)

Science & Technology Facilities Council
Central Laser Facility

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ADVANCED STRATEGIES FOR ACCELERATING IONS WITH LASERS

PURPOSE

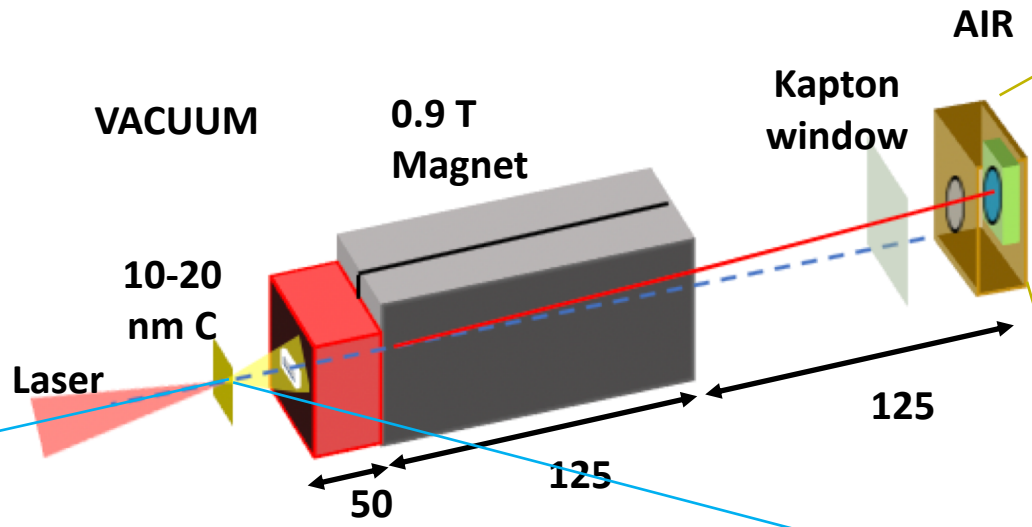
GBM stem cells irradiation with 10 MeV/u carbon ions

REQUIREMENTS

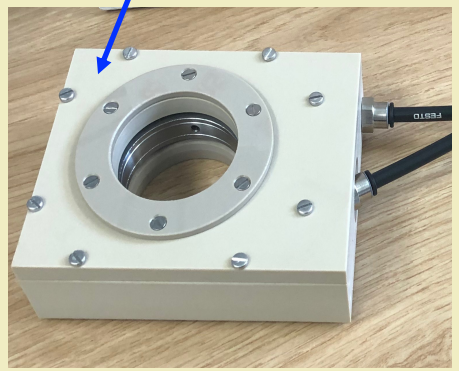
Separation of carbon from proton contribution for a pure carbon irradiaton

CHALLENGES

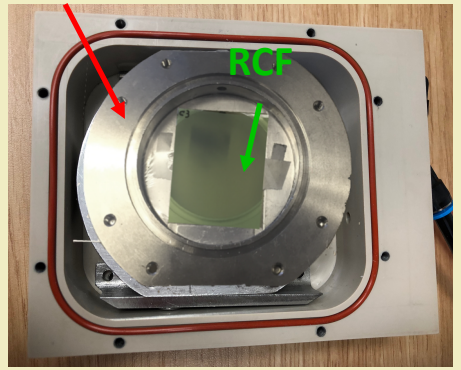
Dosimetry at low-energy high LET carbon ions



HOLDER CHAMBER



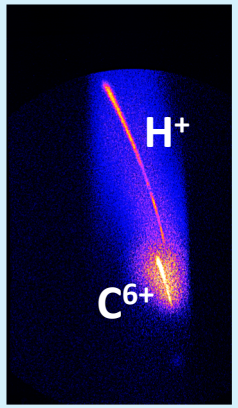
CELL DISH

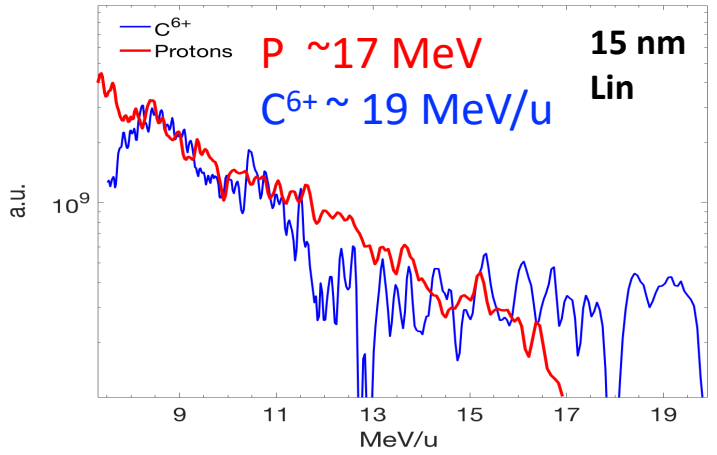


Monolayer 2D cells : Glioblastoma (GBM) stem cells

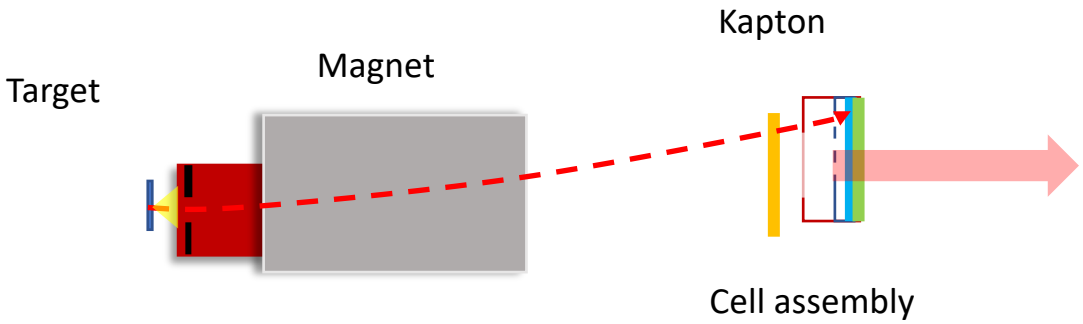
Input ion beam characteristics

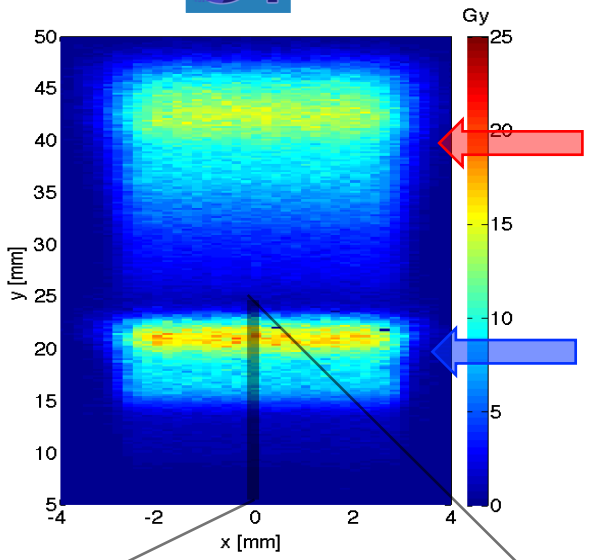
- **Thomson Parabola Spectrometer**
- **RadioChromic film stacks**

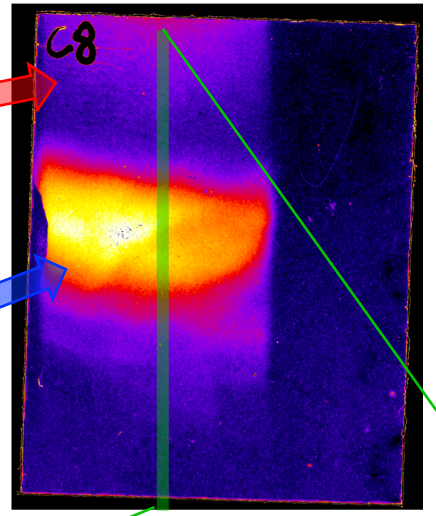




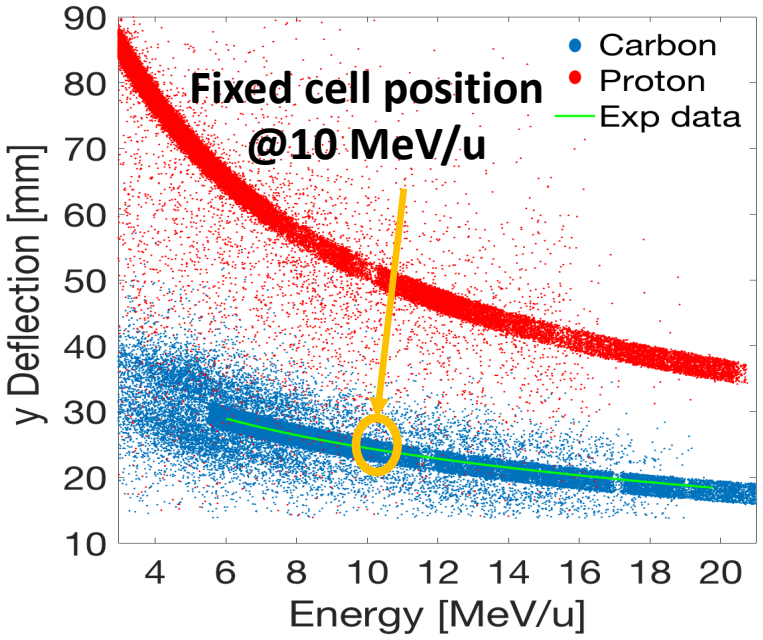
Proton & Carbon dose and energy transversal distribution at the cell plane

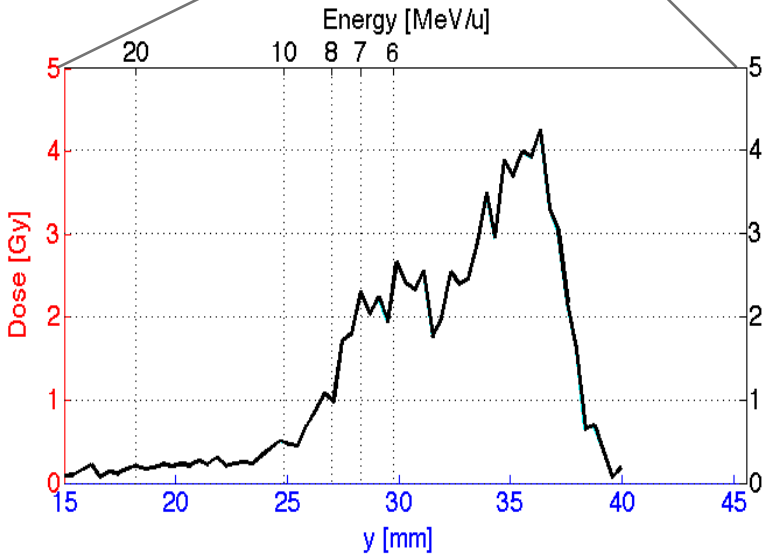


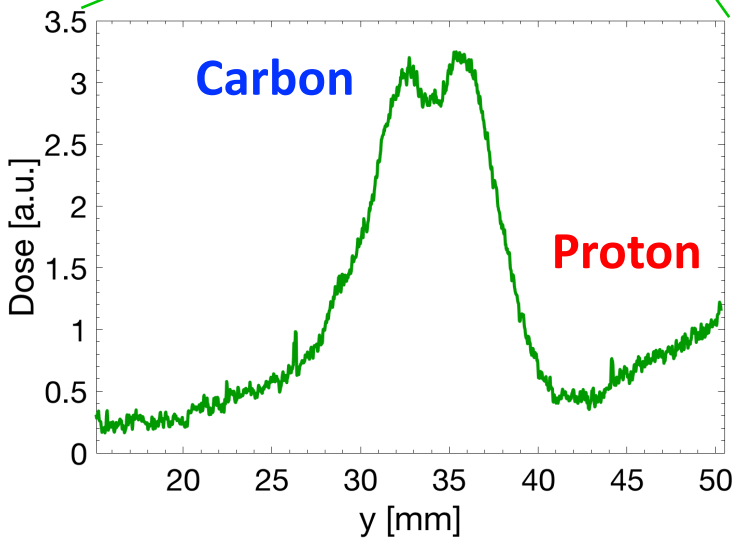




RCF@ Cell position

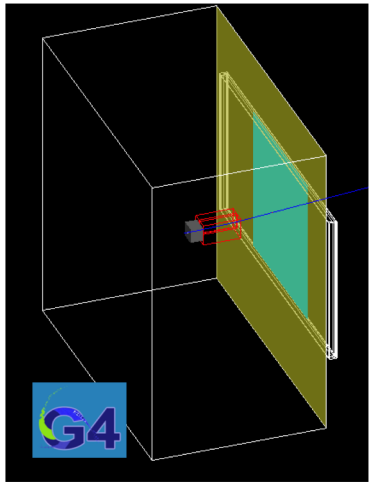






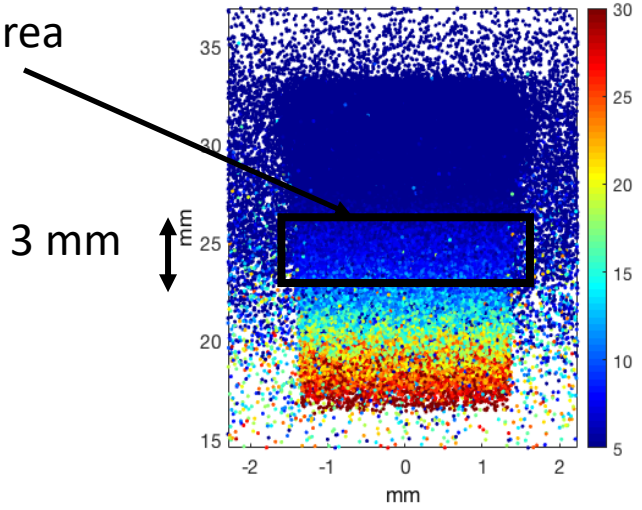
Carbon energy and LET distribution at the cell plane-MC simulation

MC simulations to estimate the energy and the LET distribution on the cell plane



Irradiation area

3 mm

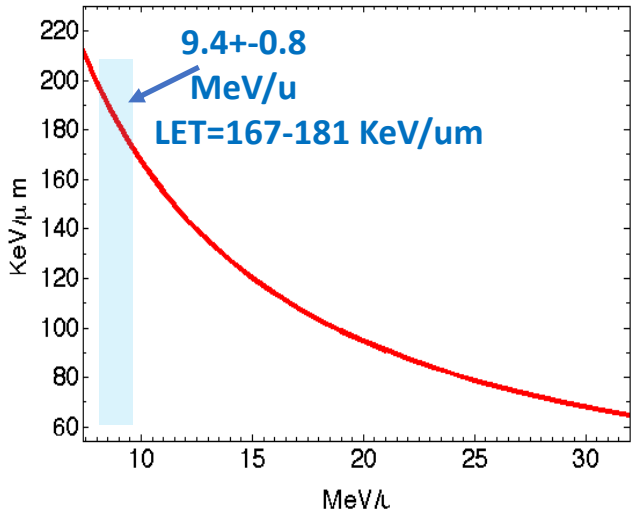


REQUIREMENT FOR CELL IRRADIATION

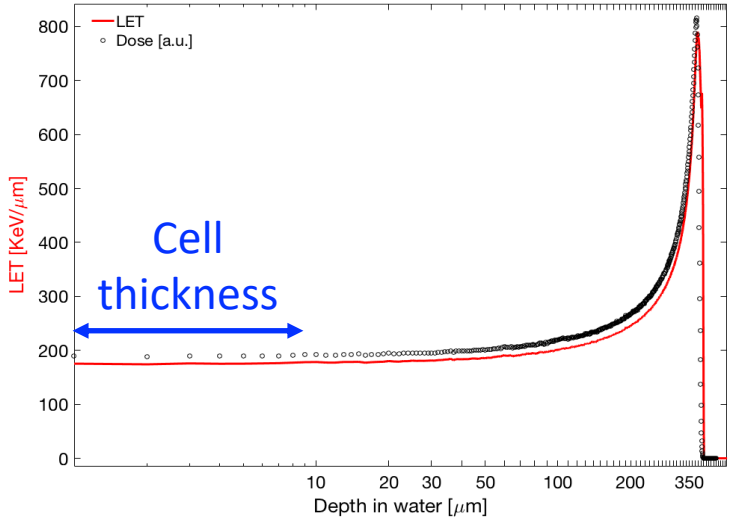
- Reduced energy spread at the cell plane
- Reduced Dose and LET variation in the transverse and longitudinal plane

8% energy and LET variation

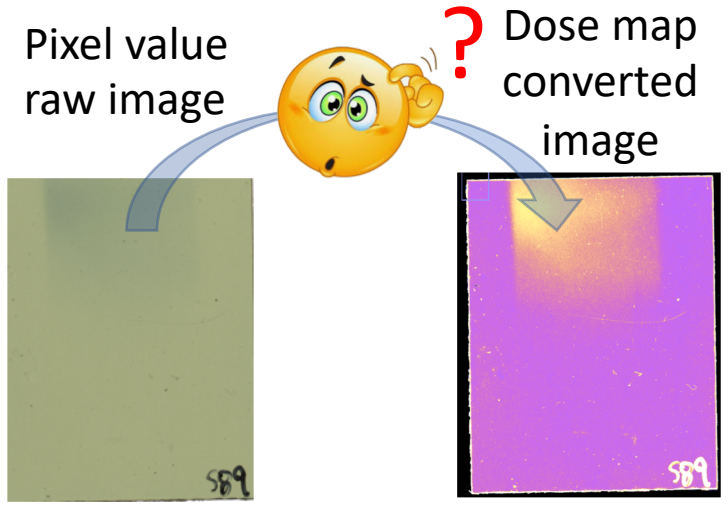
LET VS Energy



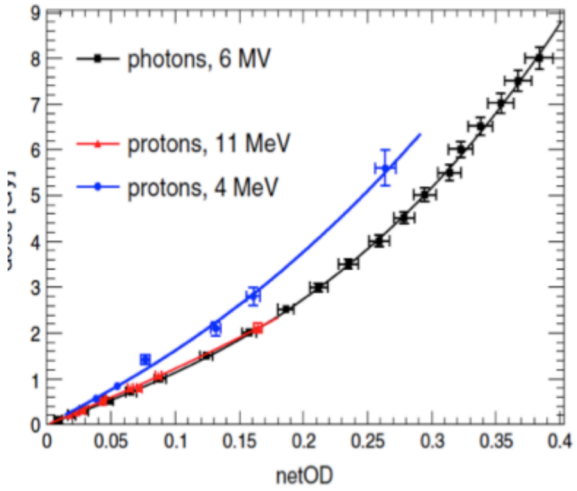
Depth LET & Dose profile in water

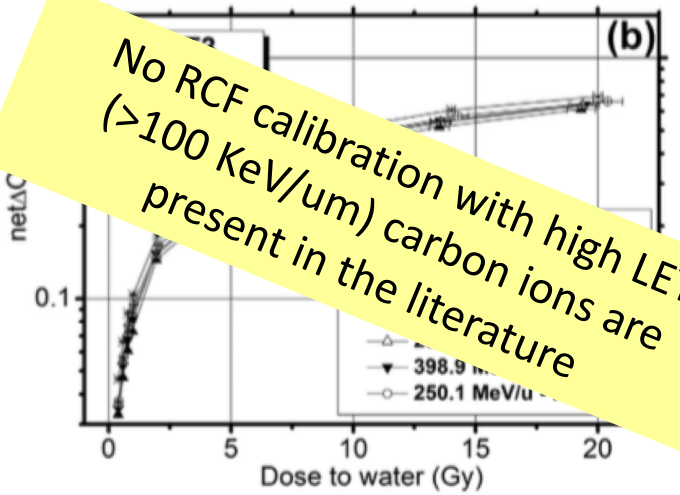


Dosimetry with EBT3 RadioChromic films: low energy carbon ions



OD dependence from LET for protons and carbon ions





No RCF calibration with high LET (>100 KeV/um) carbon ions are present in the literature

[1] S. Reinhardt et al, Radiat. Environ. BioPhys, 29, 569 (2002)

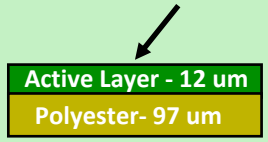
Phys. Med. Biol. **62** (2017) 377–393

Issues

- Low energy carbon ions (10 MeV/u) do not traverse the polyester layer
- High LET value 200 KeV/um
- OD dependence from LET

Solution

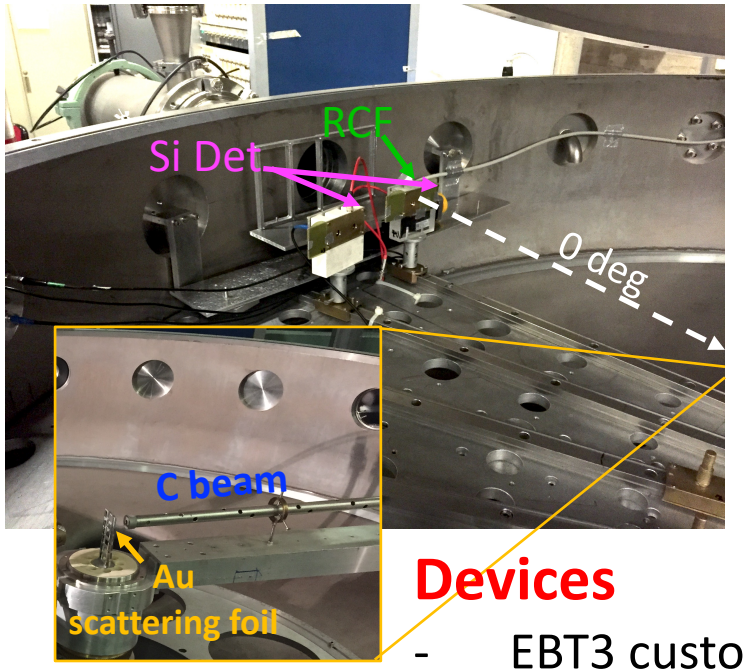
Unlaminated EBT3: active layer+1 polyester dead layer

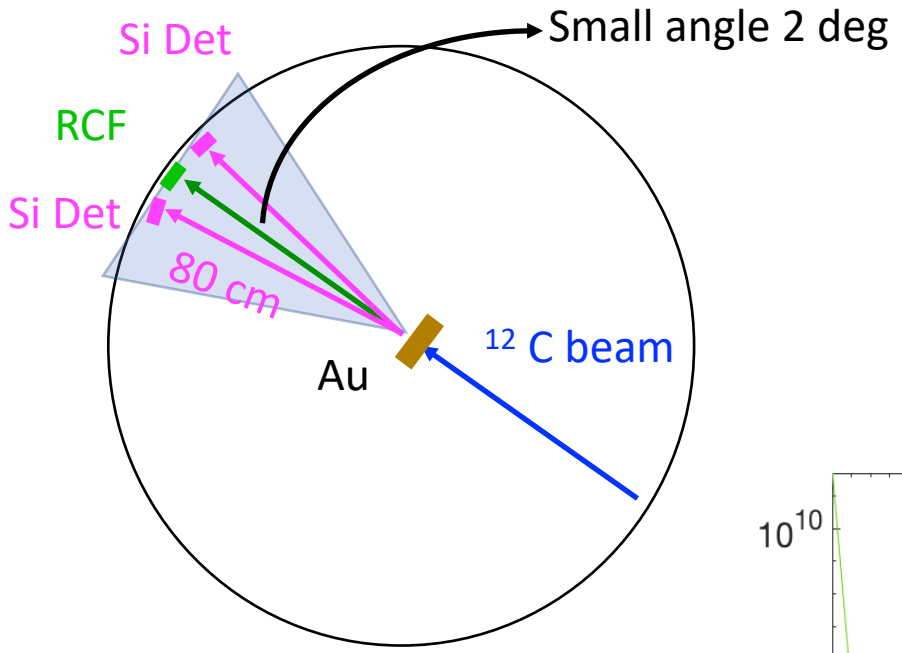


New procedure for EBT3 unlaminated calibration at low energy

EBT3 customized calibration with 6 MeV/u C @ LNS-INFN

EXPERIMENTAL SETUP





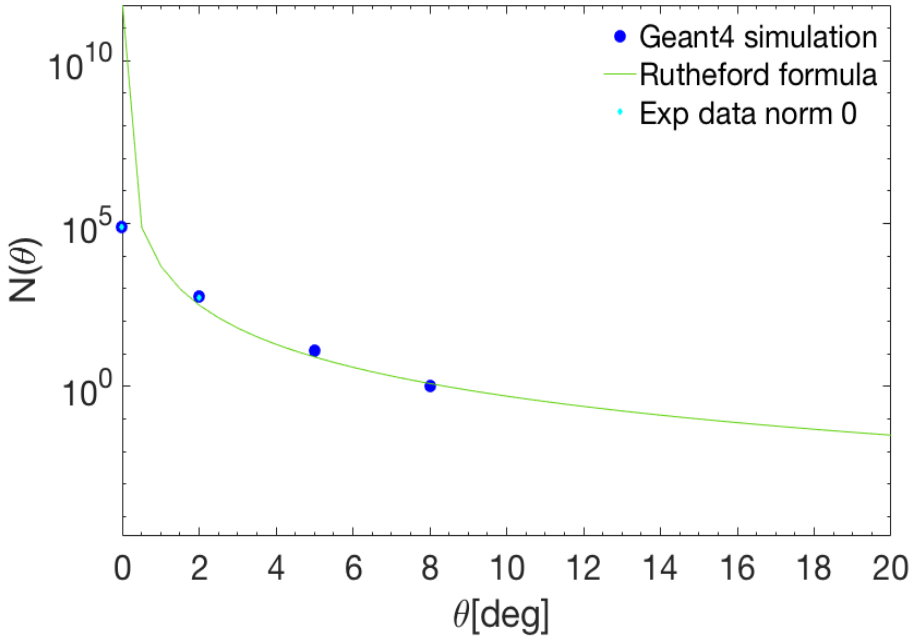
Beam characteristics

-6 MeV/u C beam from Tandem accelerator (1% E spread)
- Tunable incident current

Devices

- EBT3 customized
- CR39
- 100/500 um thick Si detector acting as monitor for the beam current at small angles

Rutherford scattering



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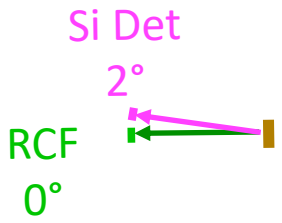
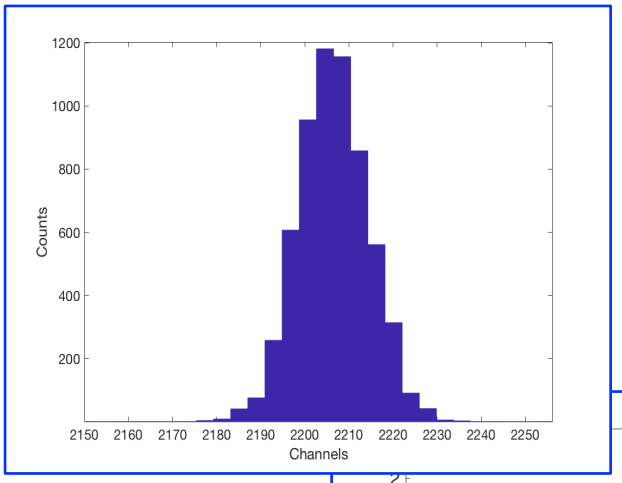
EBT3 customized calibration with 6 MeV/u C @ LNS-INFN

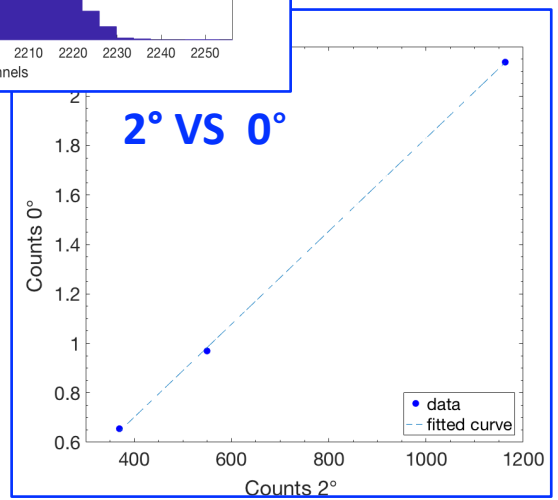


netOD VS Dose calibration curve

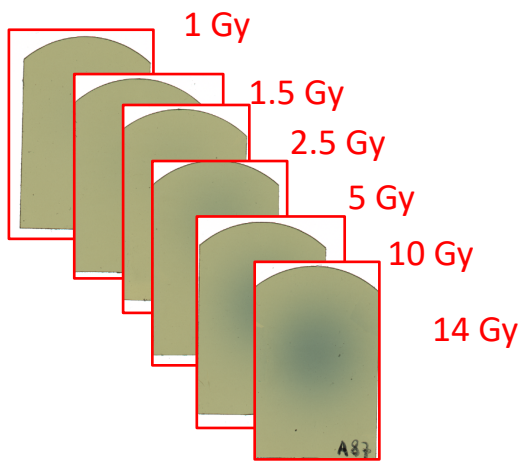
Lower RCF response to dose for carbon ions than protons

Si counts @ 2°

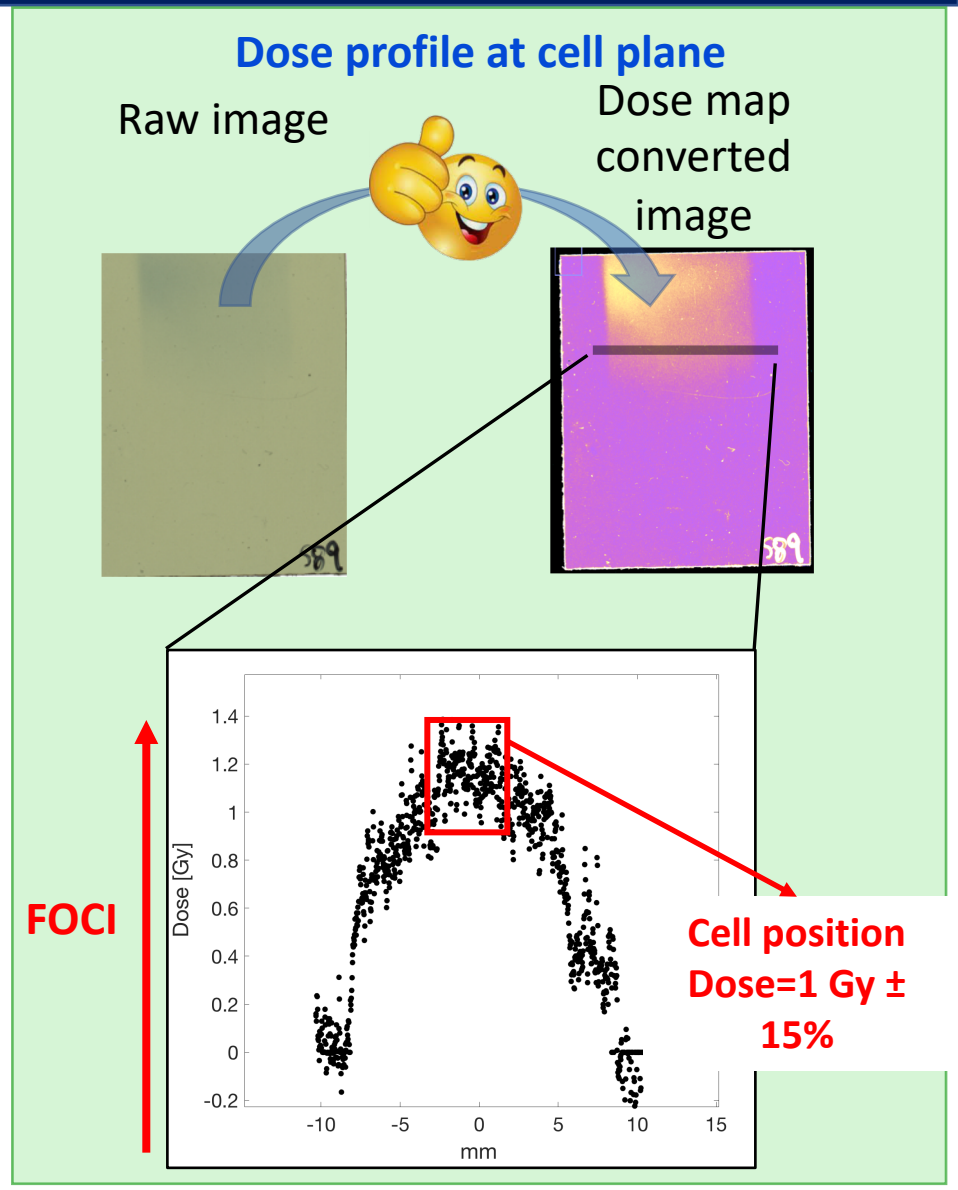




OD conversion



Dose profile at cell plane



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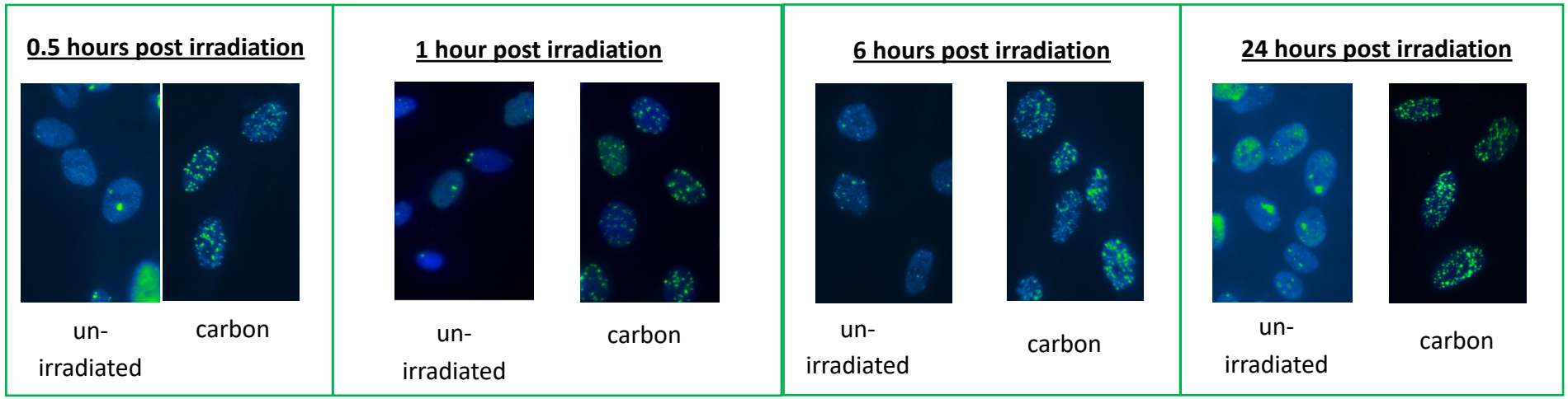
More complex, unreparable damage is inflicted by the Carbon ions

DNA damage and repair (53BP1 immunofluorescence):

Foci (regions of accumulation of the agent) are highlighted , e.g. by fluorescence



GBM stem cells

Conventional comparator data needs to be generated

See talk Dr. Pankaj Chaudhary Plenary session Tuesday h 12:10

Contributors

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Summary

- **Dosimetry of laser-driven carbon beams @ 10 MeV/u**
  - New approaches for dose measurement with high LET and low energy carbon ions
  - New procedure for RCF-EBT3 calibration

- **Radiobiology investigations using laser-driven carbon beams @ 10 MeV/u with GEMINI laser**
  - Test unexplored regimes of ultrahigh dose rates
  - Cell irradiation with high-LET carbon ions
  - may provide a flexible, unique source for novel biological studies

Future perspectives

- Careful comparison with dedicated “conventional “ data ongoing to assess any variation in biological effectiveness associated to the peculiar nature of the source

Thanks for the attention