Advanced examples: eFlash_radiotherapy and radioprotection

AdvaNced Technologies for Human-centrEd Medicine

Giuliana Milluzzo

28th Geant4 Collaboration Meeting
25-29 September 2023 Hokkaido University

Outline

- **eFLASH_radiotherapy**

Current authors: J. Pensavalle (University of Pisa, Italy) G. Milluzzo (INFN Catania, Italy), F. Romano (INFN Catania, Italy)

- **radioprotection**

D. Bolst and S. Guatelli (UOW, Australia), J. Magini (PARTREC, NL), G. Parisi (University of Surrey, UK) and F. Romano (INFN Catania, Italy and PARTREC, NL)

Advanced example: eFLASH_radiotherapy

Included in Nov 2022 Geant4 release

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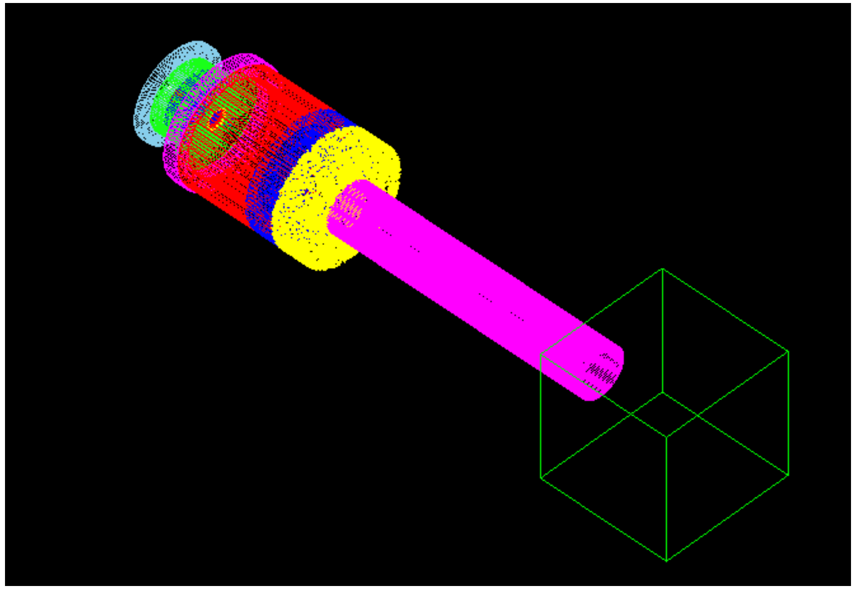
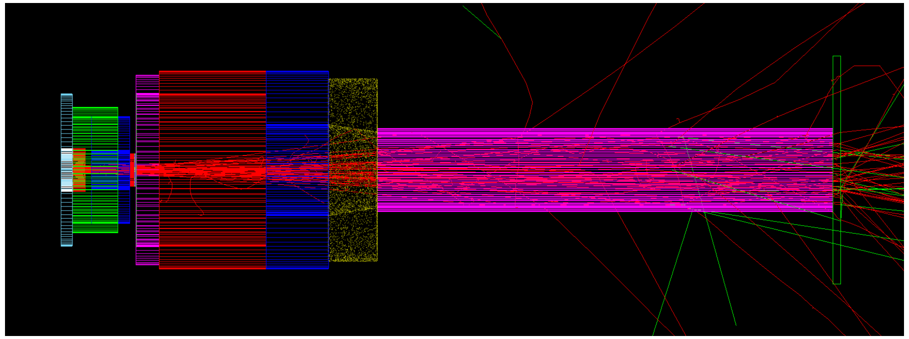
- Implementation of the ElectronFLASH LINAC installed at the Centro Pisano for FLASH Radiotherapy CPRF by following the manufacturing specifications provided by Sordina Iort Technologies S.p.A
- Used for preclinical studies of the FLASH effect, radiobiological experiments and in-vivo experiments
- Needs to predict the dose distributions (lateral and in depth) for irradiation optimization
- Capability of vary the dose delivered per pulse by changing the field size through variable applicator dimensions for different dose per pulse set-up (diameter 1cm to 10cm)
- Simulation of a water phantom and detectors placed within the phantom to predict dose distributions and scattering



Advanced example: eFLASH_radiotherapy
Validation with experimental data



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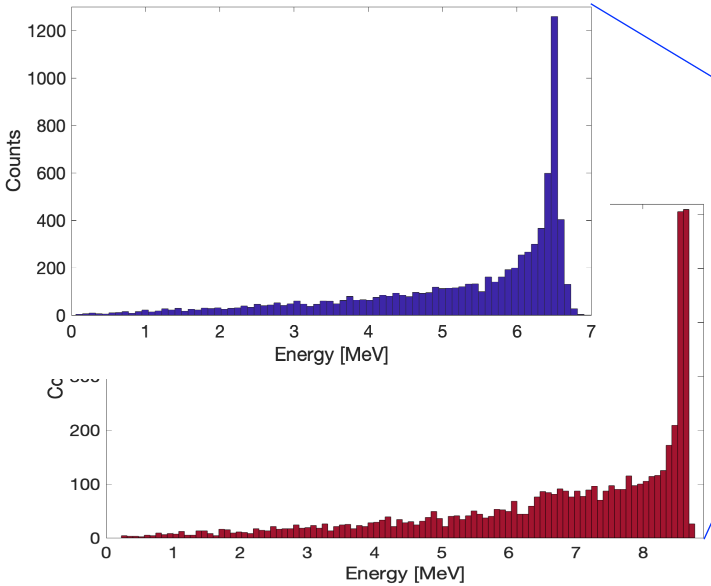
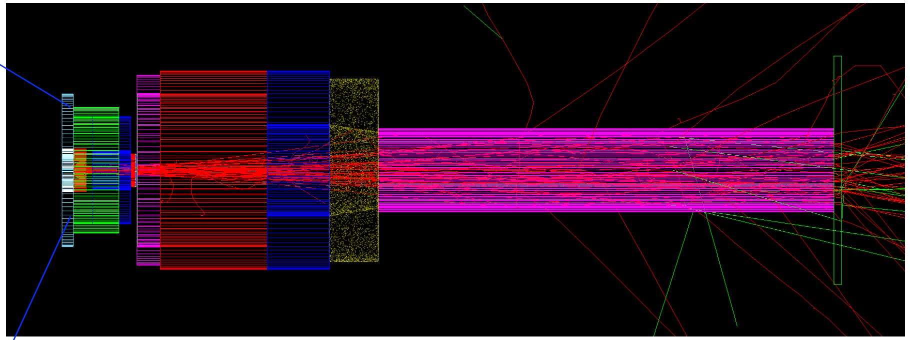
Validation with experimental data

Energy spectra





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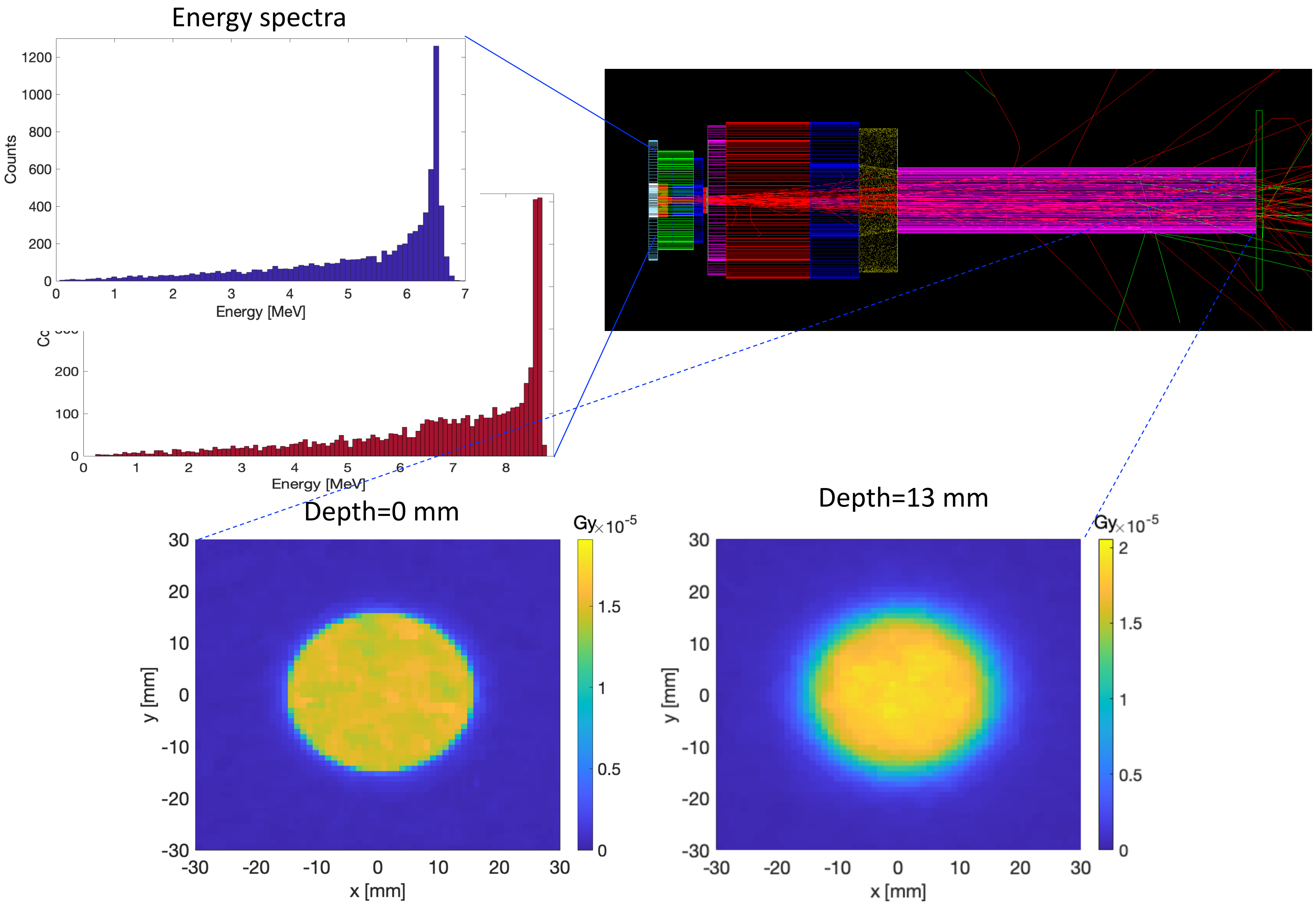

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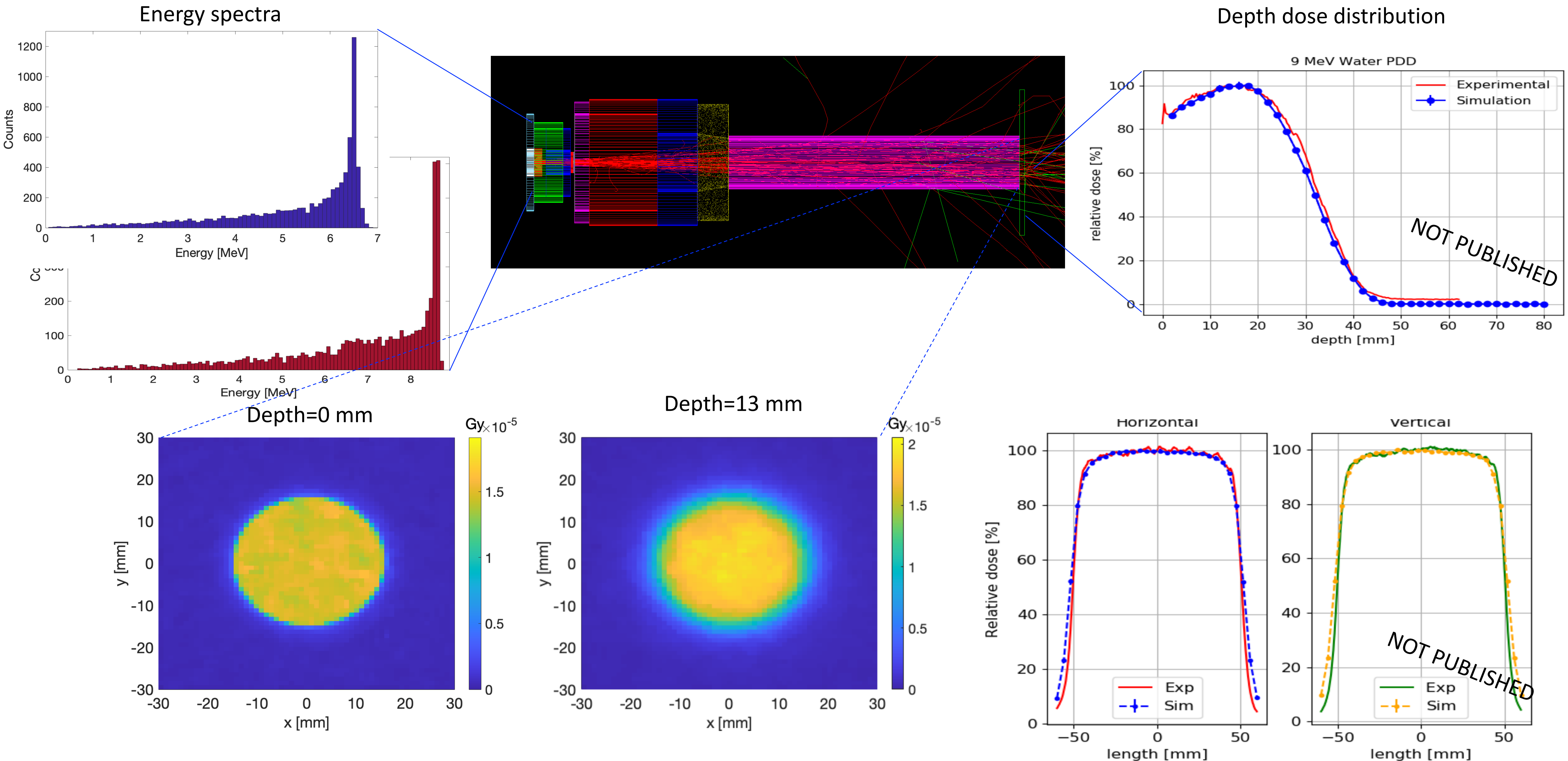
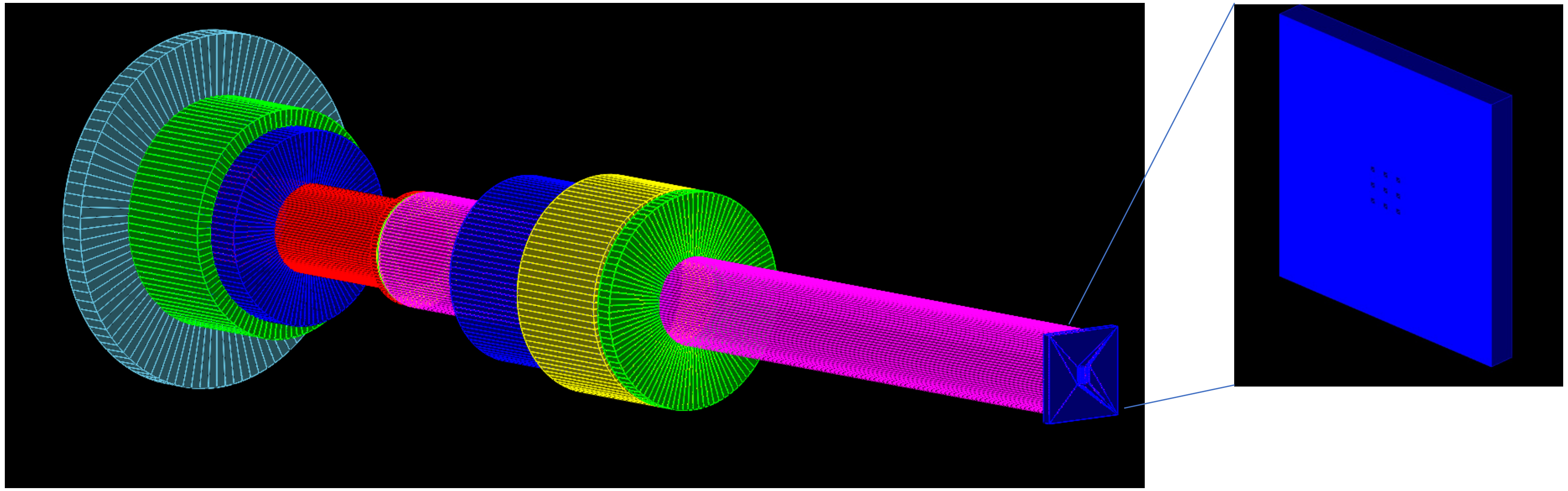


Advanced example: eFLASH_radiotherapy

Collimator implementation for minibeam applications



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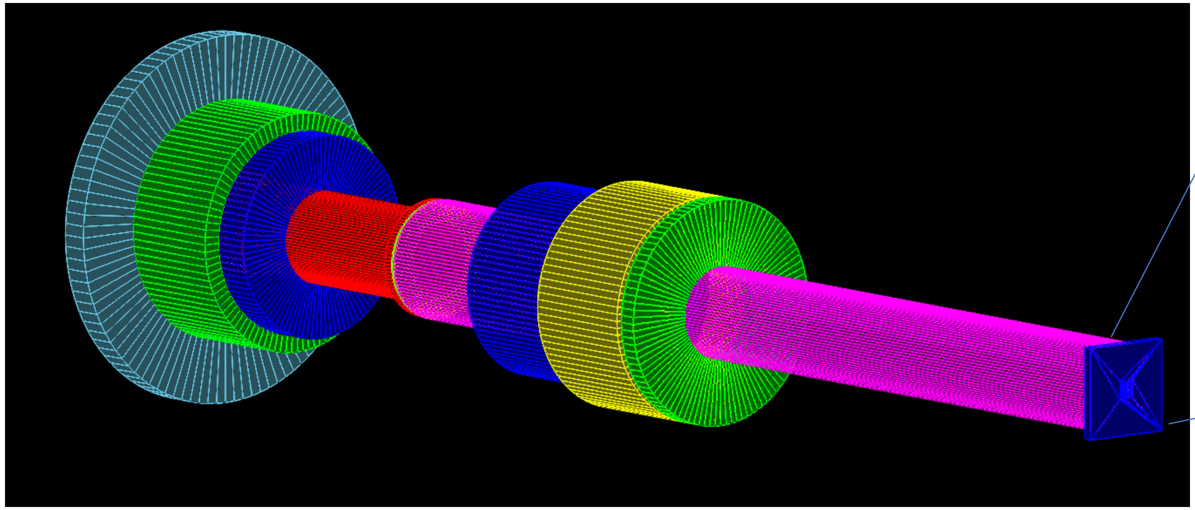
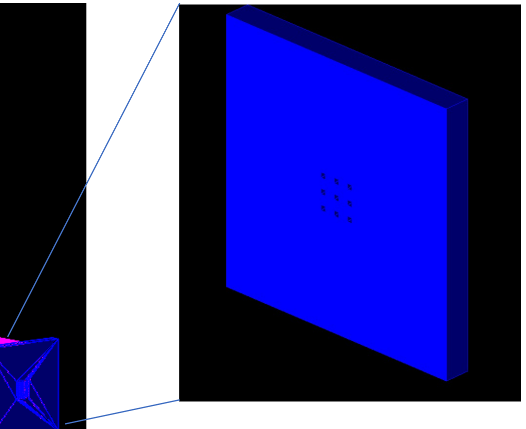
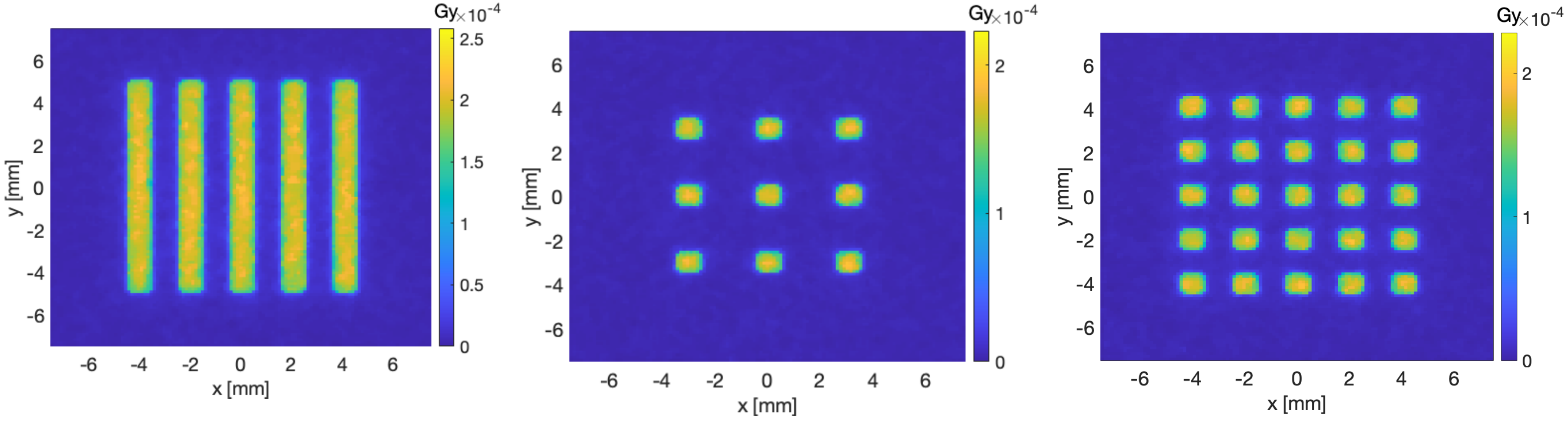




Different minibeam collimators



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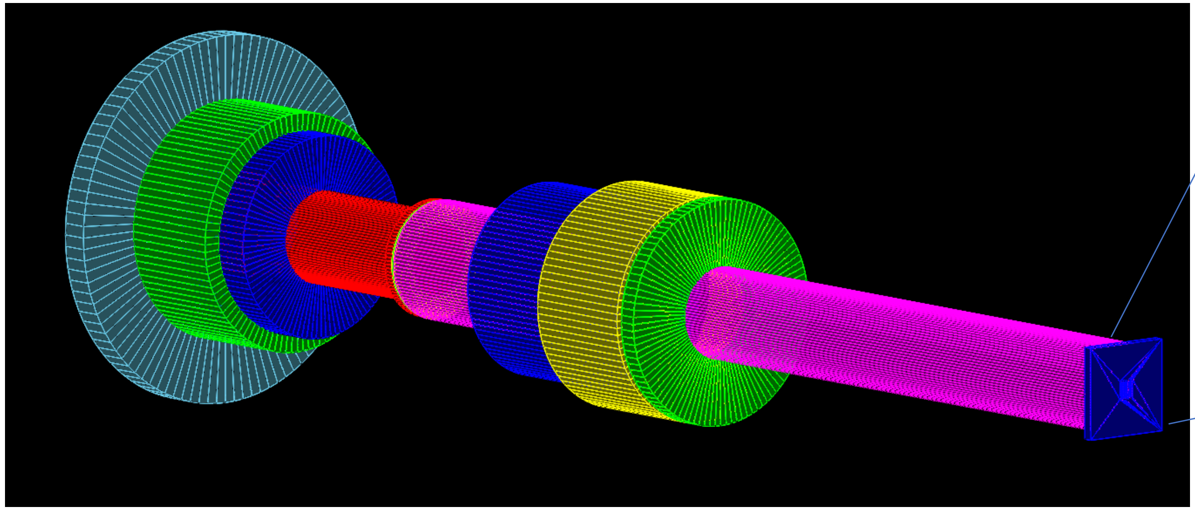

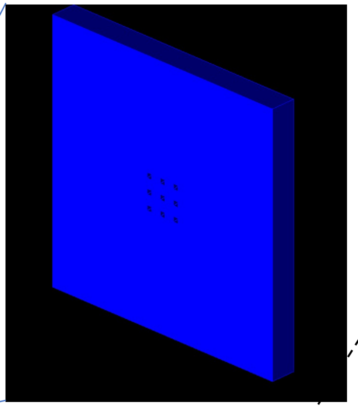

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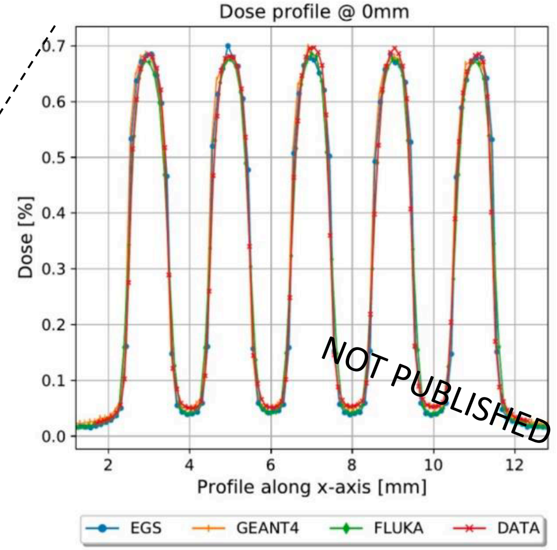

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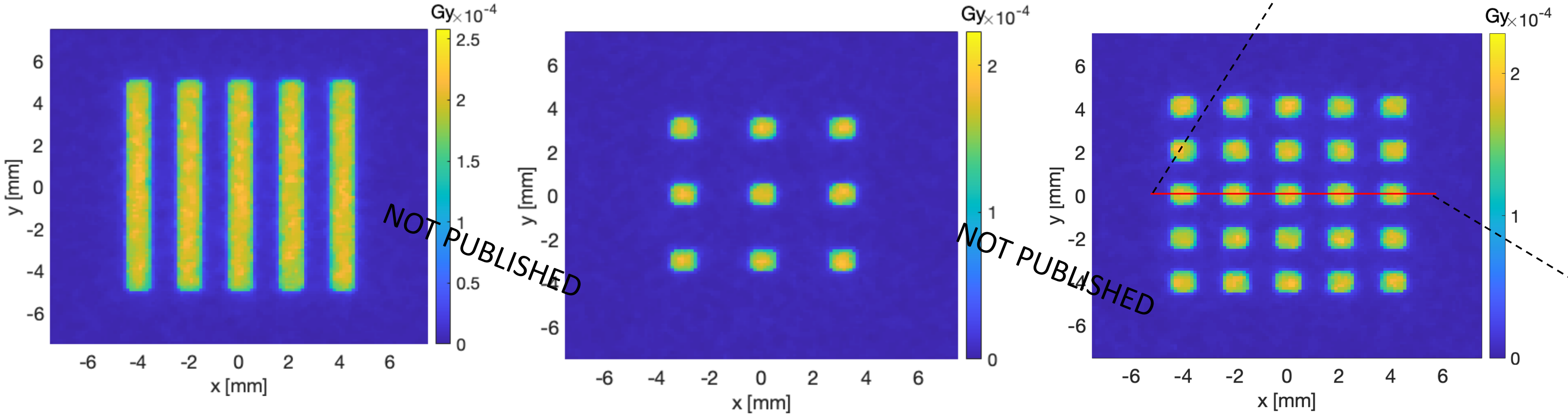

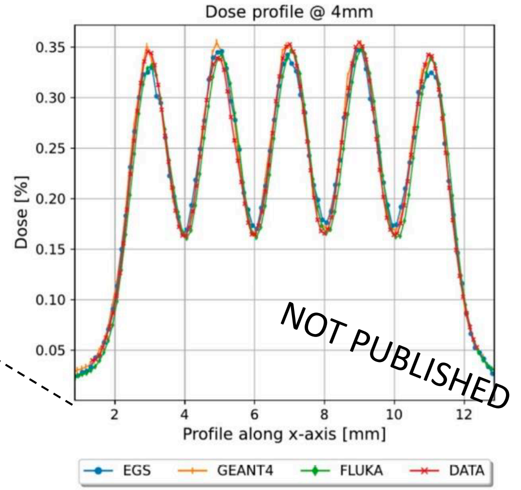

J. Pensavalle et al., submitted in Appl. Science

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Advanced example: Radioprotection

→ experimental_microdosimetry (*simulation of detectors for microdosimetry)*

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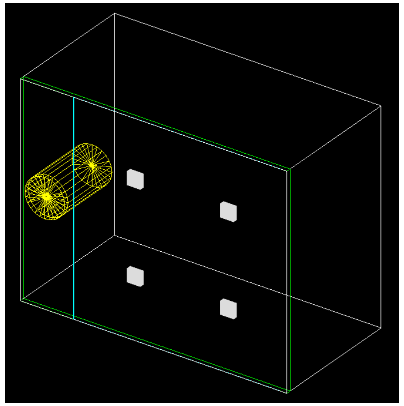
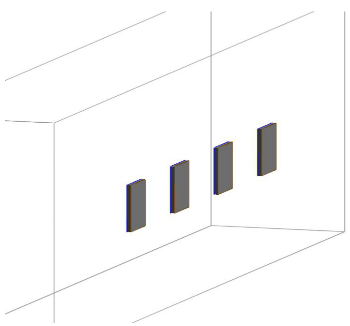
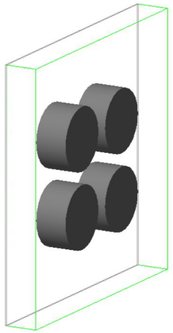


- Originally developed for radioprotection studies in space missions (here is the name….)
- In the last years extended to clinical microdosimetric applications (proton and ion therapy)
- Now a **general-purpose versatile example** for the simulation of several microdododosimeters:
    - Silicon microdosimeters
    - diamond microdosimeters
    - TEPC (in progress)

Diamond microdosimeters





Silicon microdosimeters

Advanced example: Radioprotection

→ experimental_microdosimetry (*simulation of detectors for microdosimetry)*

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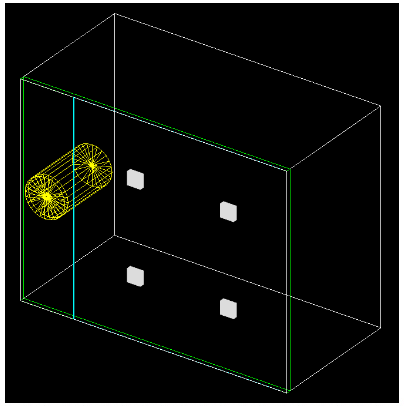
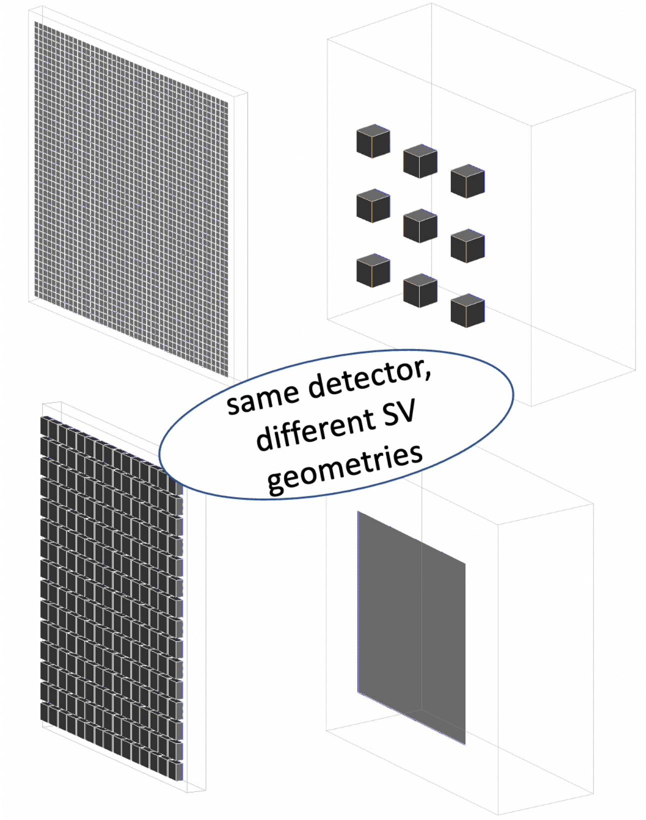
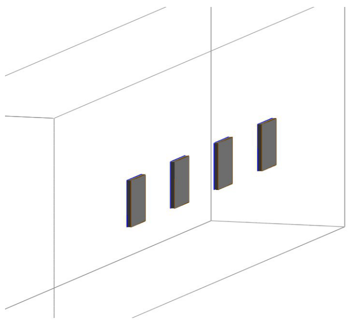
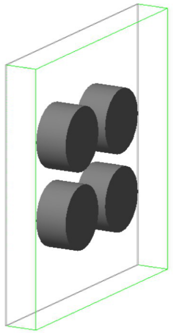


- Originally developed for radioprotection studies in space missions (here is the name….)
- In the last years extended to clinical microdosimetric applications (proton and ion therapy)
- Now a **general-purpose versatile example** for the simulation of several micrododosimeters:
  - Silicon microdosimeters
  - diamond microdosimeters
  - TEPC (in progress)
- Several functionalities available also for a novice User
  - Implementation of simple macro commands for easily changing the different geometrical configurations and parameters
  - **Python scripts** for microdosimetric spectra and data analysis (first version)
  - Simulation of **double-stage geometries** for particle identification



Diamond microdosimeters



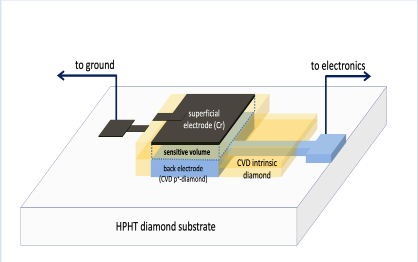


Silicon microdosimeters

Advanced example: Radioprotection

Microdosimeters

Semplified diamond microdosimeter developed at the Centre For Medical Radiation Physics, CMRP, University of Wollongong, NSW, Australia IEEE Transactions on Nuclear Science, Vol. 59, pp. 3110-3116, 2012

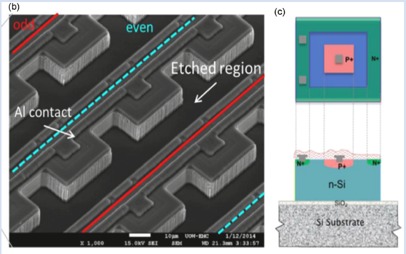


- *p-i-n* junction structure
- **1 to 10 µm** thick
- **Single SV** 10/500 µm diameter (or side)
- Manufacturing by Chemical Vapour Deposition (**CVD**) **growing**
- Possibility to grow **independent detectors** on the **same substrate** with different area or **different thickness**
- ~10-100 keV low energy cut-off
- Well defined SV
- Low CCE regions surrounding SV

Journal of Applied Physics, vol. 118, 2015

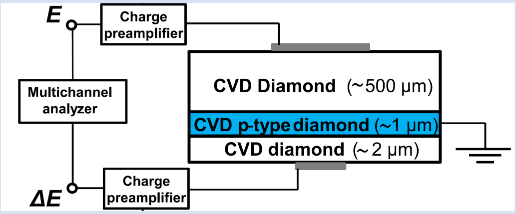
The microdiamond detector based on the detectors developed by the Research Group of The University of Rome "Tor Vergata". The design

Silicon microdosimeters based on the "Bridge" microdosimeter, developed by the Centre For Medical Radiation physics, University of Wollongong (simplified geometry with only four sensitive volumes and the complete design)



- ***p-n*** junction structure
- **Silicon On Insulator (SOI)** → insulates SV to avoid Field Funnelling effect
- **1-10µm thick**
- Arrays of 10x10 / 100x100 μm^2 SVs
- Manufactured by **etching and ion-implantation**
- Dedicated front-end electronics
- **~1/10 keV low energy cut-off**
- Low CCE regions surrounding SVs / lateral charge collection from outside SV

The diamond telescope is based on the detector developed by University of Rome "Tor Vergata".

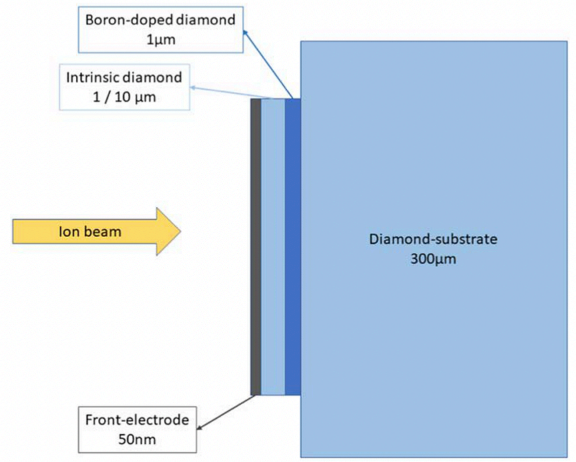


Cesaroni et al., "", Nucl. Instrum. Methods. Phys. Res. A, vol.947, 2019

Advanced example: Radioprotection

→ ***(simulation of detectors for microdosimetry)***

Microdosimetric characterization of nuclear interaction events, and assessment of their effect on the dose-mean lineal energy uncertainty (G. Parisi's PhD thesis)



Follow-up analysis: code upgrade

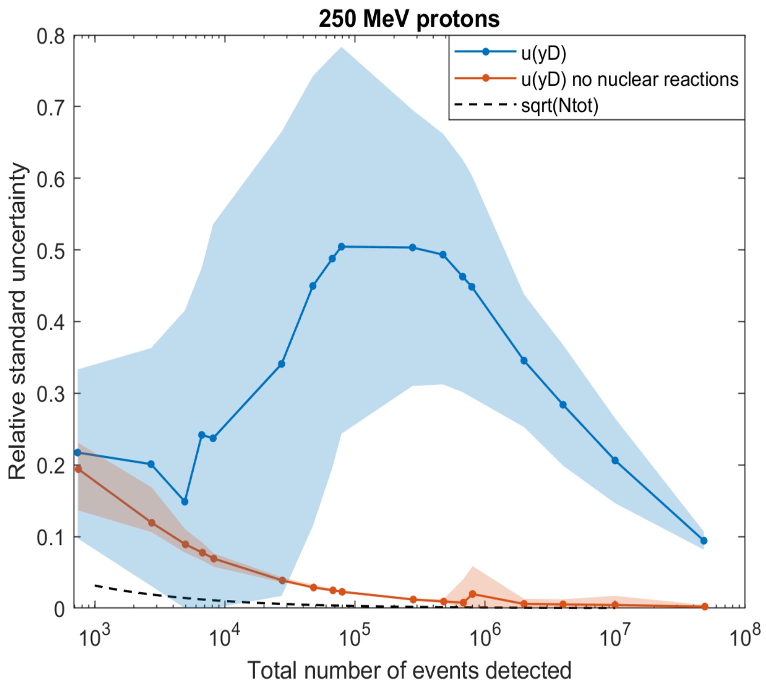
Each detected event → G4Step() -> GetTrack() -> GetCreatorProcess() -> GetProcessName(); IF generated by Nuclear Interaction → Nuclear interaction event

- Event ID (history #)
- Depostied energy
- Primary path length
- Particle Z

- Event ID
- Fragment Z
- Fragment A
- Deposited energy by the fragment
- Path length of the fragment
- Volume in which it was generated

➢ Contributions from each fragment:
- Microdosimetry spectrum
- Mean values

Uncertainty analysis: counting statistics contribution



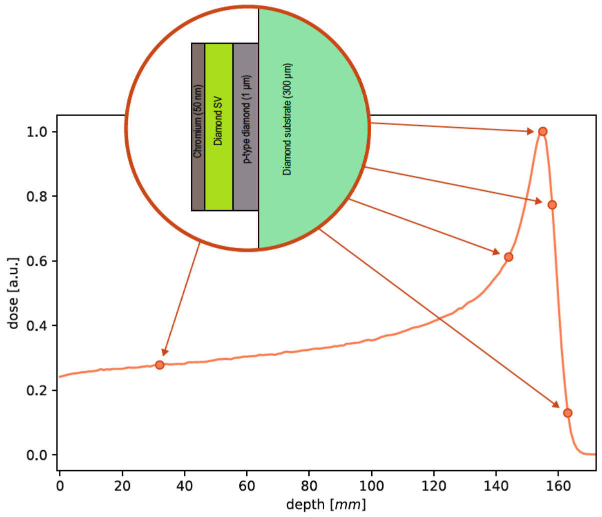
- About $5 \cdot 10^7$ events for $u\left(\bar{y}_D\right) < 10\%$ in proton entrance region
- Strong impact of nuclear interaction events
- Effect of rare events at low "total number of counts

G. Parisi, G. Schettino and F. Romano, "*A systematic study of the contribution of counting statistics to the final lineal energy uncertainty in microdosimetry*", PMB 2022

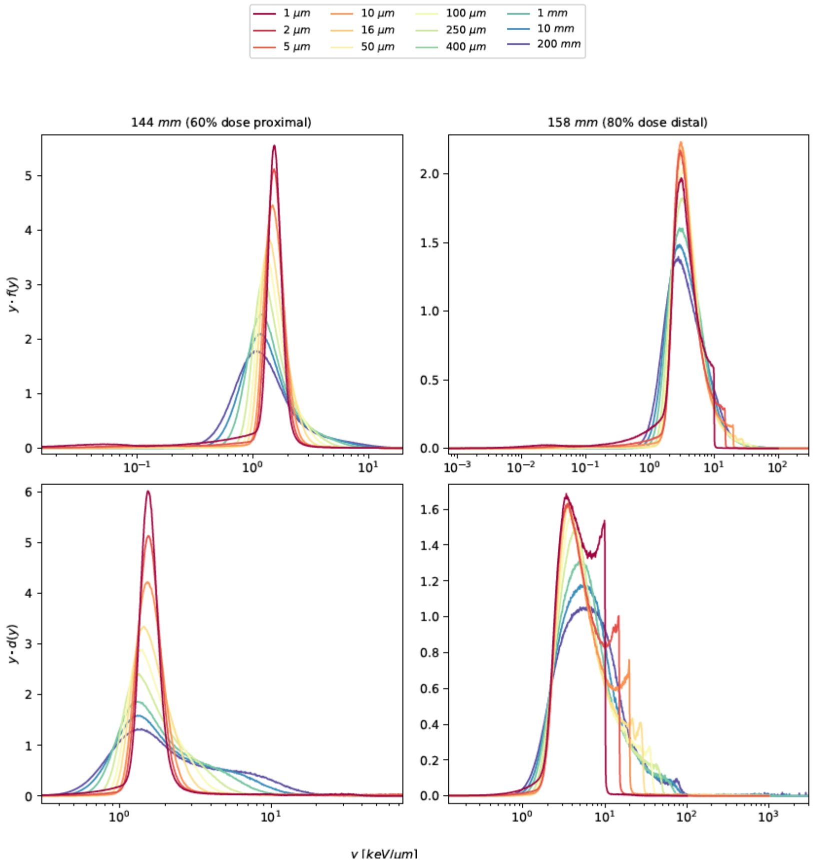
Advanced example: Radioprotection

Systematic uncertainty budget assessment (J. Magini's thesis)

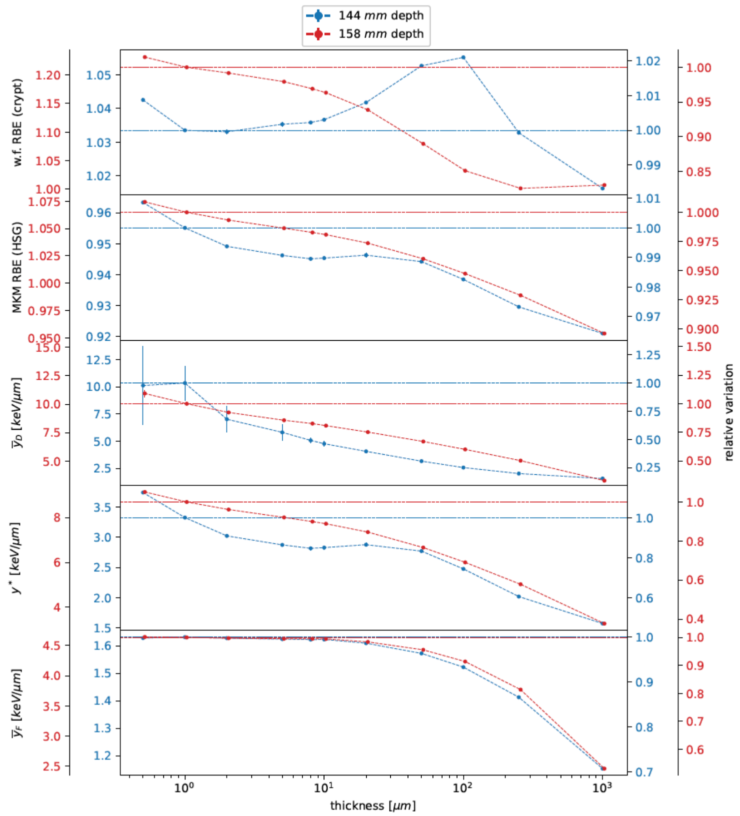
Effect of the sensitive volume thickness



Effect on the microdosimetric spectra



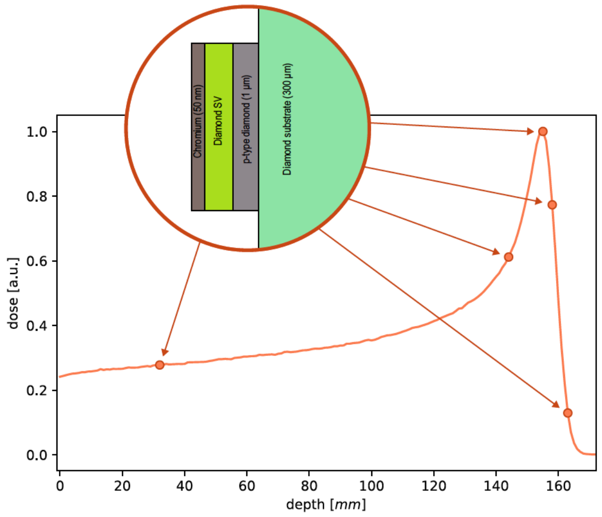
Effect on the microdosimetric means



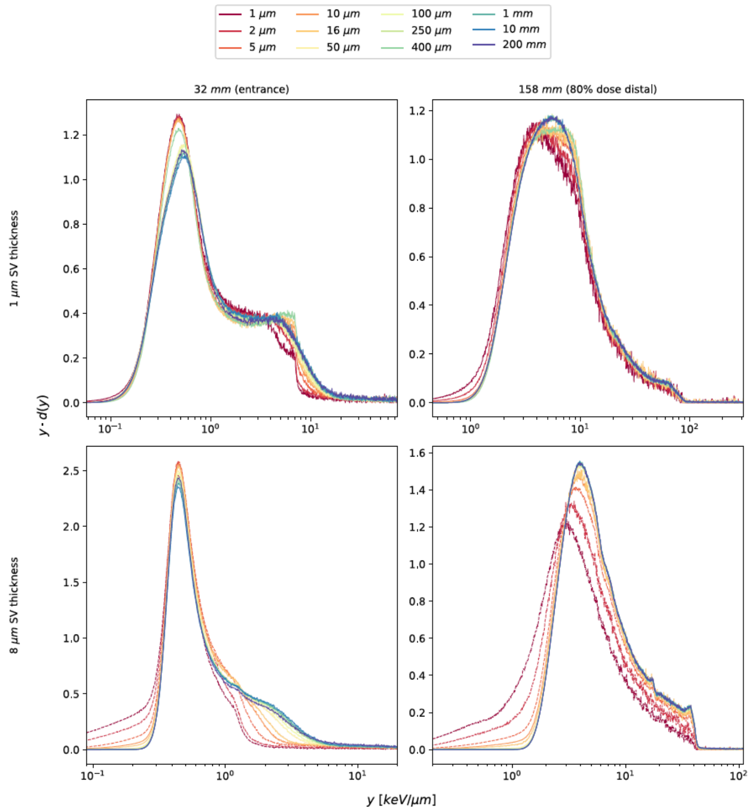
Advanced example: Radioprotection

Systematic uncertainty budget assessment (J. Magini's thesis)

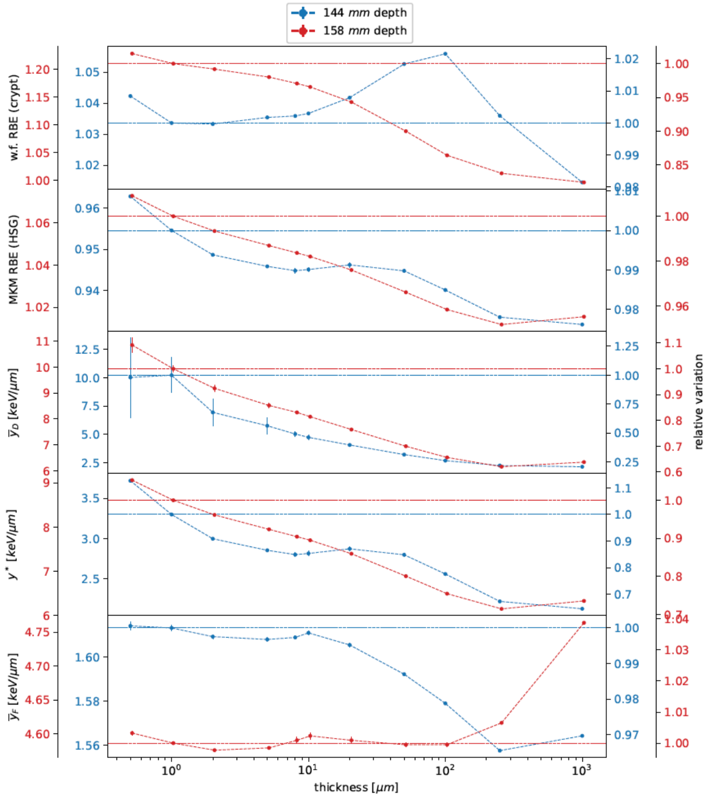
Effect of the sensitive volume width



Effect on the microdosimetric spectra



Effect on the microdosimetric means



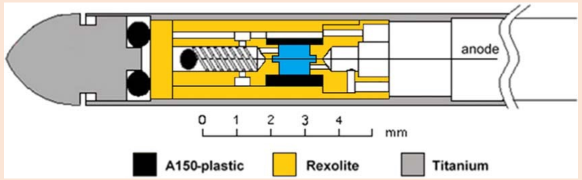
New developments

eFLASH_radiotherapy

- Messanger commands to modify the geometry and the reproduce the experimental configurations (end of 2023)
- New geometry implementation: reference dosimeters (ionization chamber, SiC detector) (2024)
- Implementation of new collomator for mini-beams and energy deposited distributions (peak and valley)

Radioprotection

- New geometry implementation: mini TEPC (Tissue Equivalent Proportional Counter) and Silicon Carbide microdosimeter (2024)



Radiation Physics and Chemistry 202 (2023) 110567

Collaboration with INFN divisions in Italy in the framework of a new proposed project (LNL-INFN, LNS-INFN)

Thanks for the attention