16TH TOPICAL SEMINAR ON INNOVATIVE PARTICLE AND RADIATION DETECTORS (IPRD23)
Siena, 25 - 29 September 2023

SILICON CARBIDE DETECTORS FOR DOSIMETRY AND MONITORING OF ULTRA-HIGH DOSE RATE BEAMS

Presented by

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Introduction

CONVENTIONAL RADIOTHERAPY

Dose: ~2 Gy/fract. (x 30 fractions)

Average Dose Rate: **~ 0.5-10 Gy/mins**

Irradiation Time: few minutes

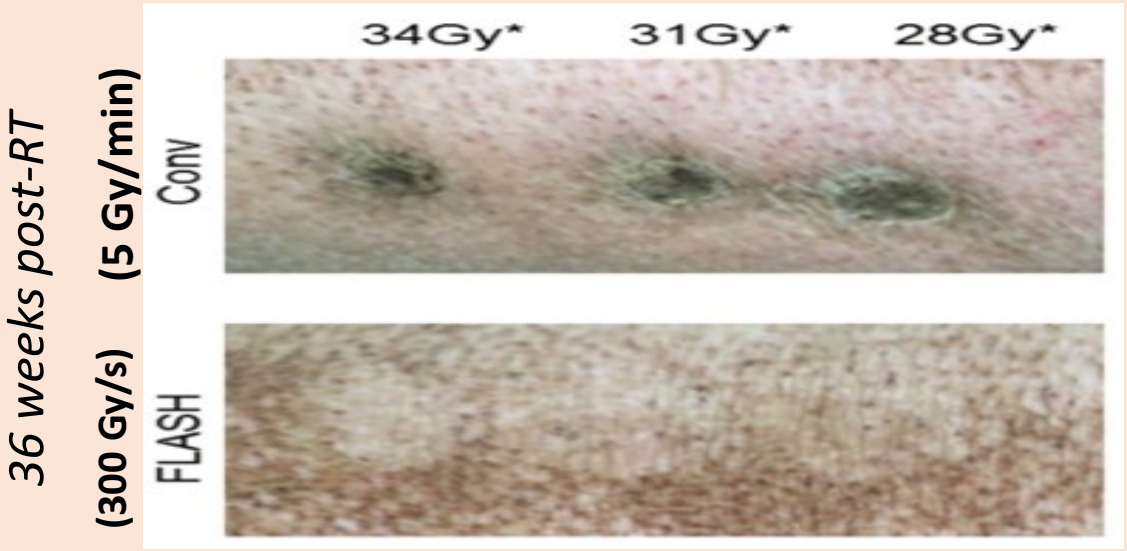
FLASH RADIOTHERAPY

Dose: >8 Gy x 1 fraction

Average Dose Rate: **>40 Gy/s**

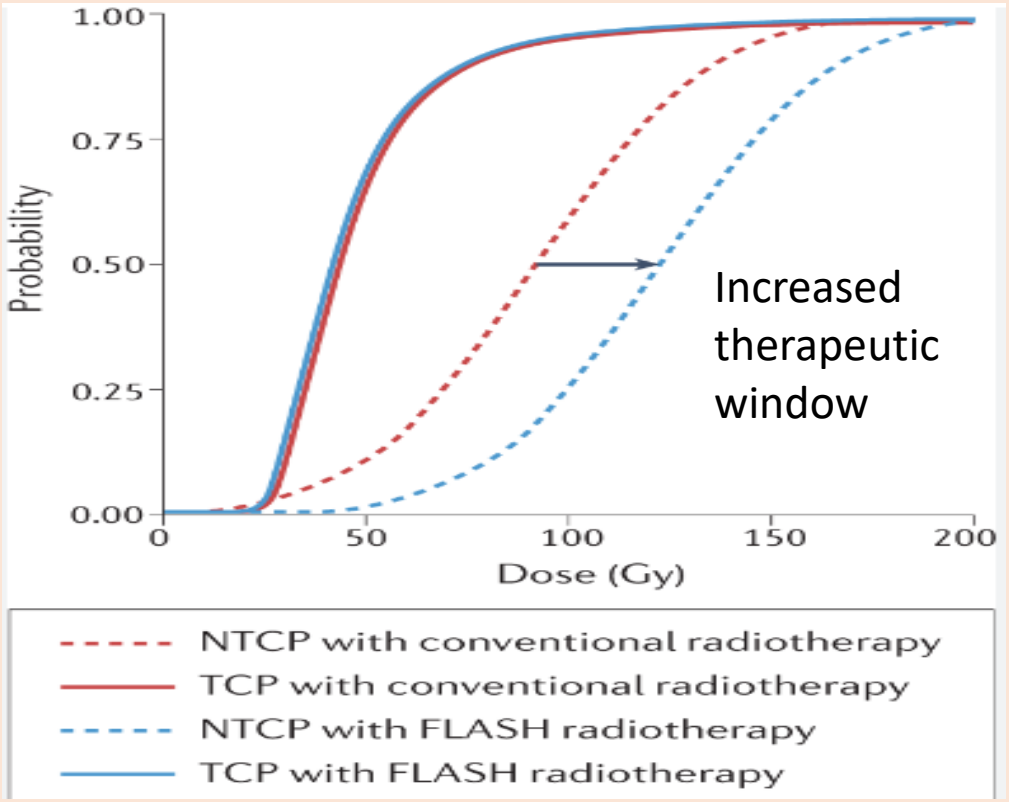
Irradiation Time: <200 ms

The FLASH effect



Vozenin et al., Clinical Cancer Research 25 (2019) 35

Mini-pig's skin irradiated at 300 Gy/s and 5 Gy/mins.

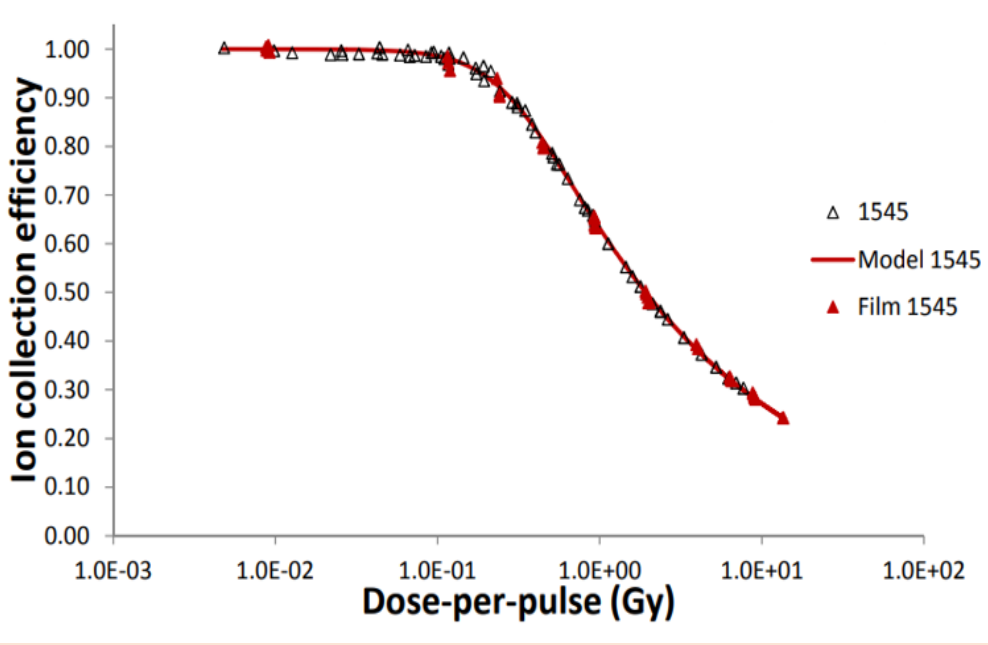


Dosimetry challenges for FLASH radiotherapy

Challenges

- **Saturation effect** on the standard dosimeters, like the **ionization chamber (IC).**

Ion recombination



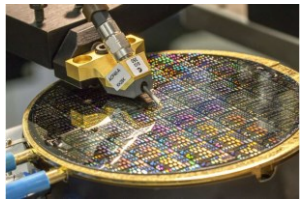
Petersson et al., Medical Physics 44 (2017) 1157

Solutions

- modifying the geometry of the existing IC, and calculation of the correction factor of the ion recombination.
- Use of passive detectors, like Alanine.
- Identifying new technologies. E.g., solid state detectors, like diamond detectors, **SiC**.

The Developed SiC detectors

Silicon



\+

Diamond

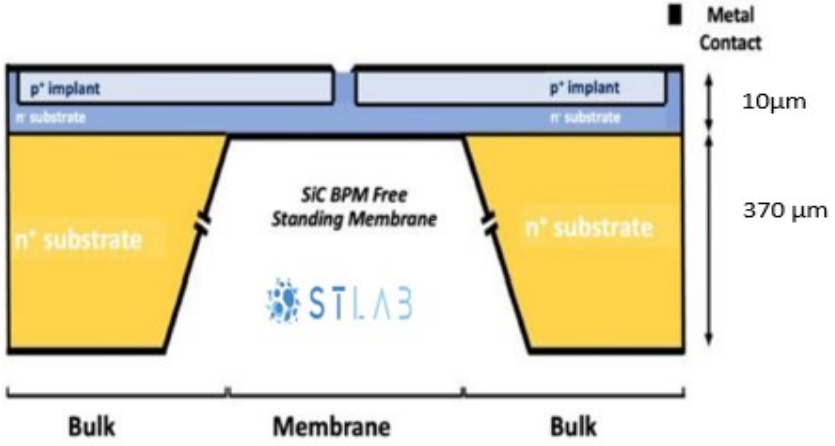
SiC

High radiation hardness

High signal to noise ratio

High **time resolution (ns)** and fast collection time

- e-h pair creation energy: 7.6 - 8.4 eV
- p^+ doped layer ($N_A = 1 \times 10^{19}$ cm^{-3})
- n^- doped layer ($N_D = 8 \times 10^{-13}$ cm^{-3})
- n^+ substrate (370 µm, $N_D = 5 \times 10^{18}$ cm^{-3})



- Active thicknesses: **0.2 µm** to **100 µm**.
- Active areas: **1 x 1 mm²** to **10 x 10 mm²**
- **370 µm** substrate.
- **Free-standing membrane**: minimize beam perturbation

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The Developed SiC detectors

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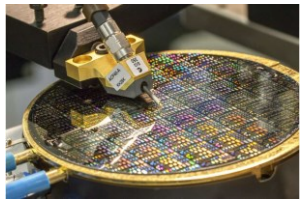

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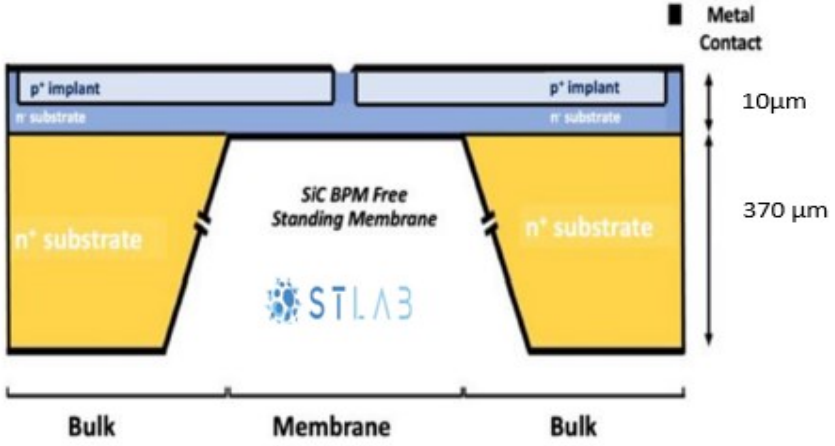

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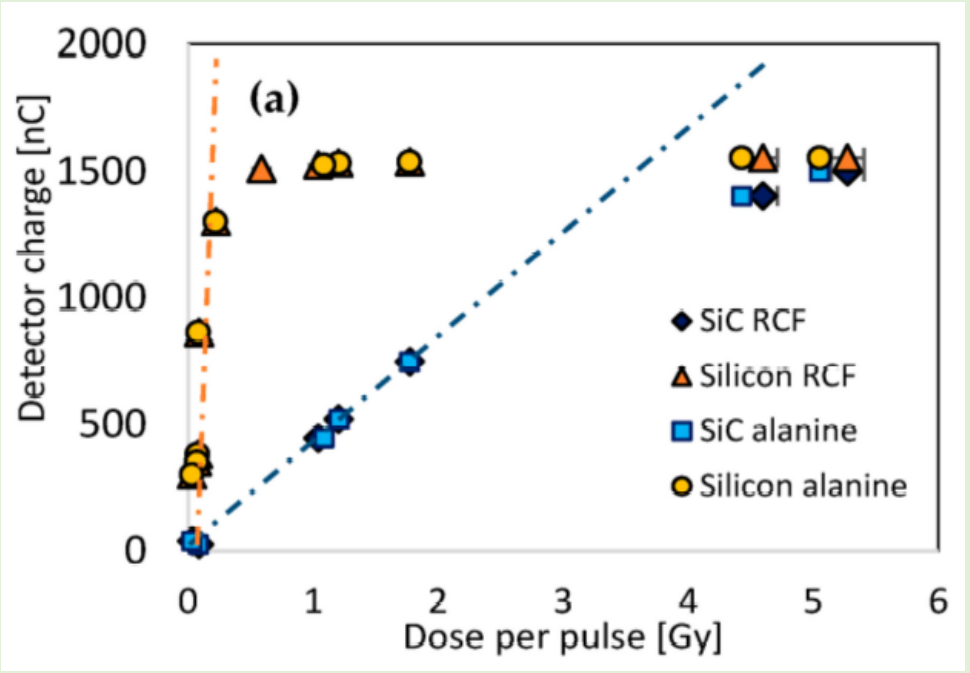
First Characterization

- **10x10 mm²** area**, 10µm** thick SiC detector.
- Varying DPP; **9 MeV electron** beam from ElectronFlash (EF)
- Pulse width = **2 µs,** V= **480 V**,
- The electrometer, Keithley 6517A (**maximum current = 20 mA**).



(F. *Romano, G. Milluzzo et al., Applied science (2023)* 13, 2986)

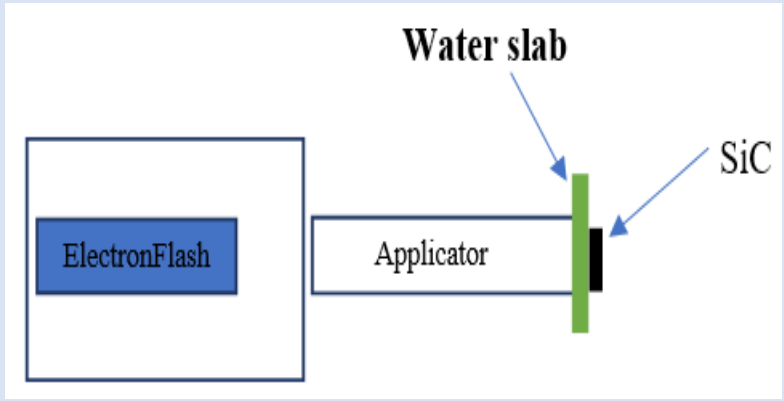
Experimental Setup

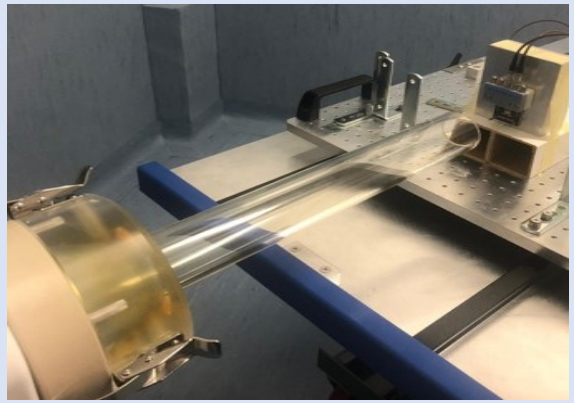
Purpose and Schematic

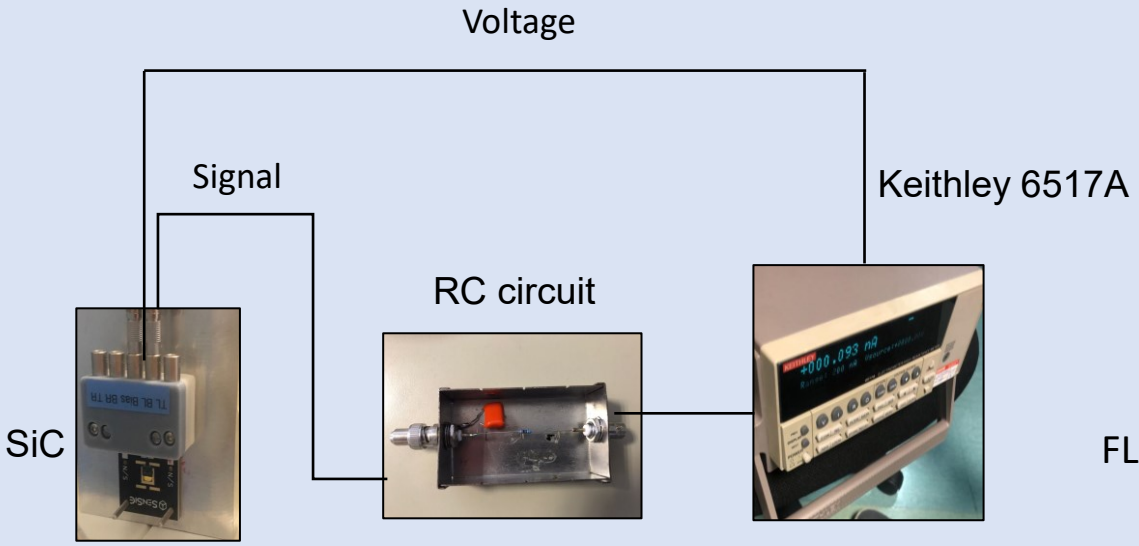
@CPFR Pisa

- **9 MeV electron** beam from EF.
- Varying **beam current**.
- **10x10 mm², 5x5 mm²** , and **3 mm²** area; 10 µm thick SiC detectors.
- SiC placed after a 13 mm thick water slab.
- Polymethylmethacrylate (PMMA) cylindrical applicators of 40 mm diameter.
- Alanine dosimeters for reference.

- Study the linearity of the charge response with DPP.





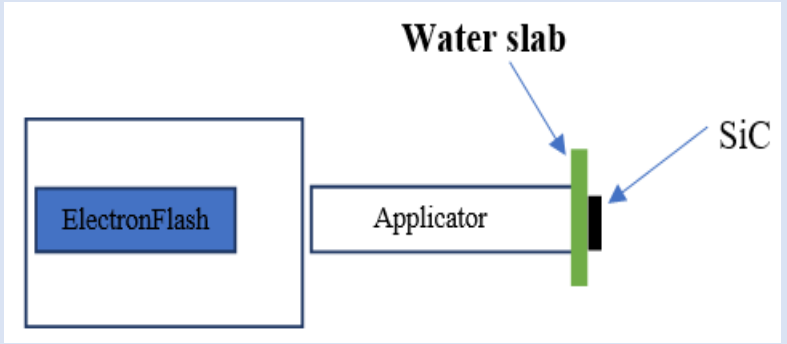


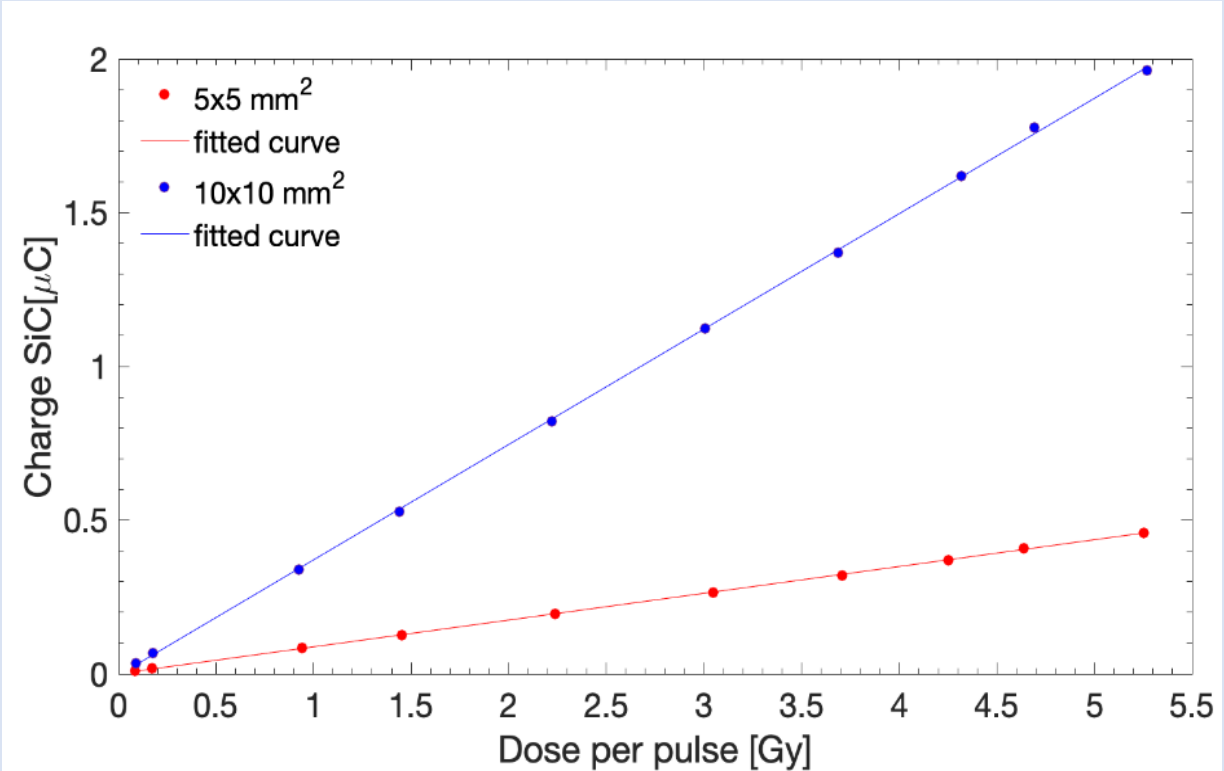
- Electrometer, Keithley 6517A **(bias voltage + recording response)**
- **RC circuit (2 kΩ, 1 µF)**

FLASH Radiotherapy with hIgh Dose-rate particle beAms **(FRIDA**) project of INFN

Dose rate Independence

- **9 MeV electron** beam from EF.
- Varying **beam current,** instantaneous dose rate up to ≈ **1 MGy/s**
- **4 µs** pulse width
- **10x10 mm², 5x5 mm²** area; **10 µm** thick SiC detector.
- SiC placed after a 13 mm thick water slab.
- 200 V





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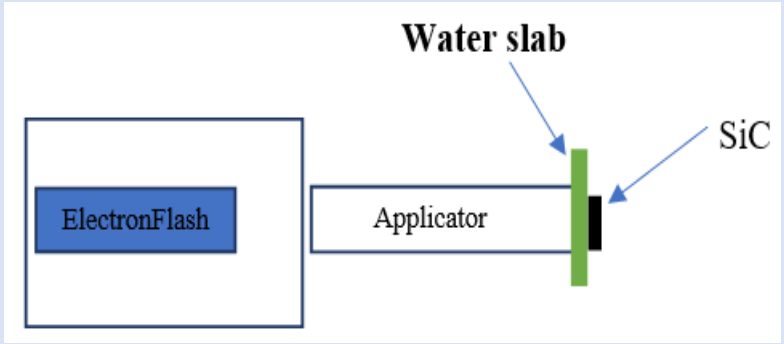
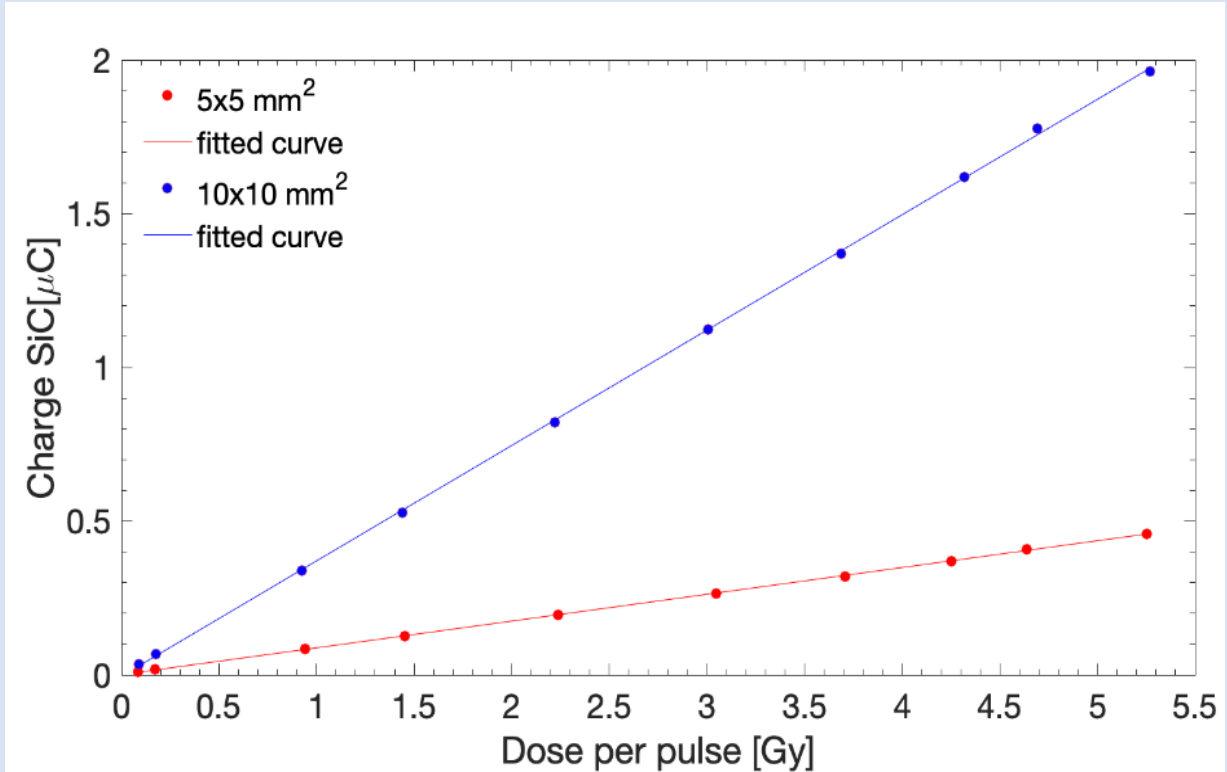
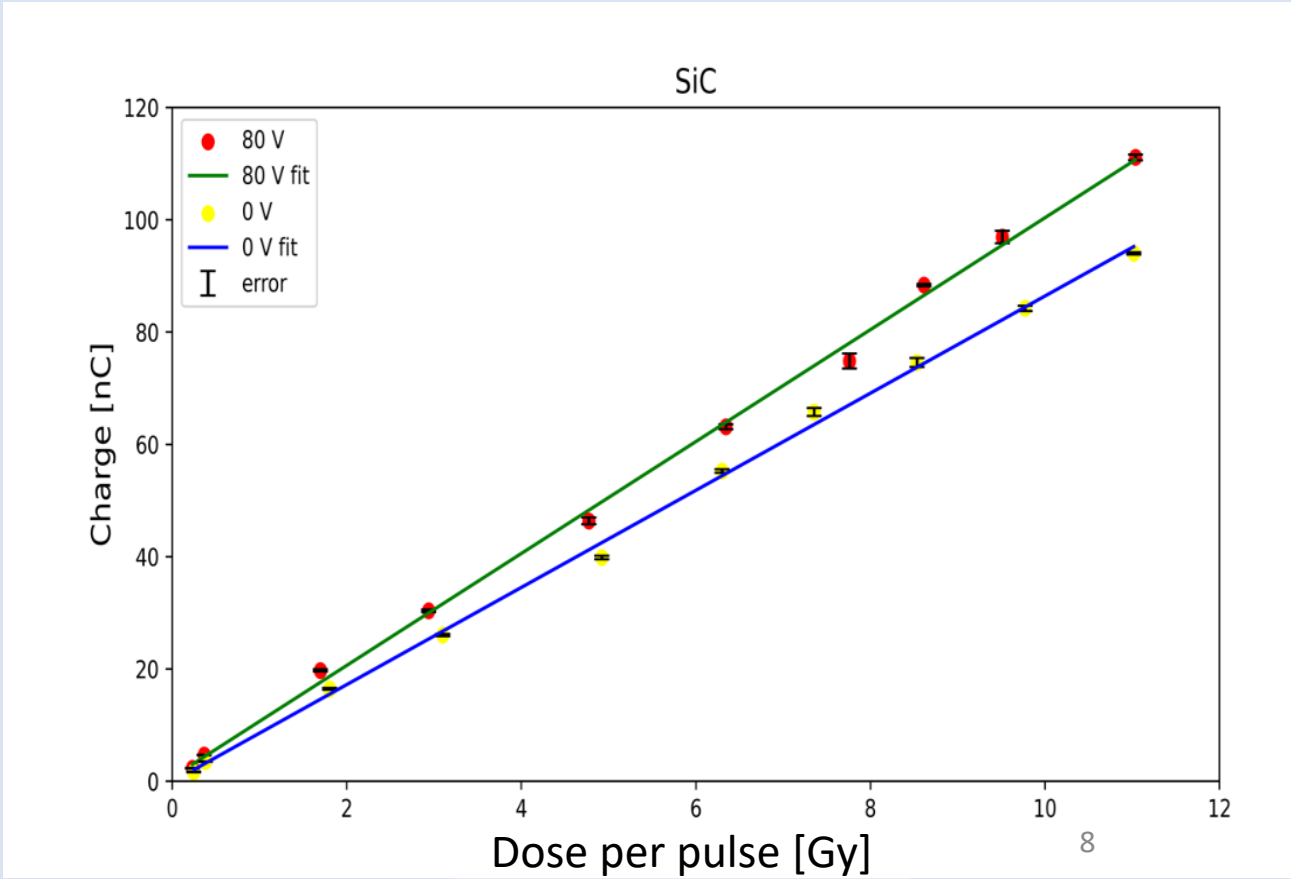
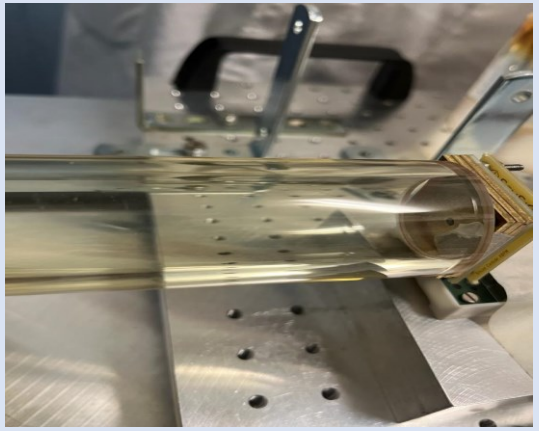


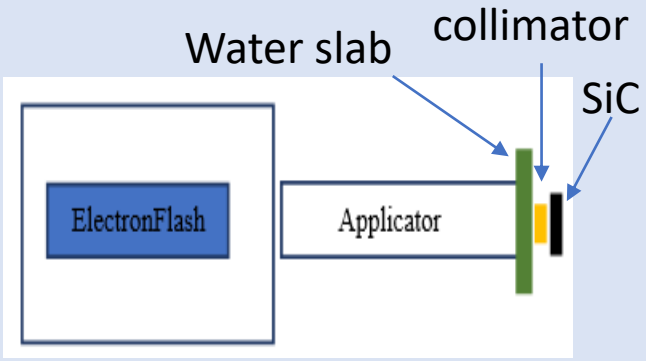
- 3 **mm²** area, **10 µm thick** SiC
- **0 V** and **80 V**
- DPP (0.23 to 11.0 Gy), instantaneous dose rate up to ≈3MGy/s
- **4µs** pulse width



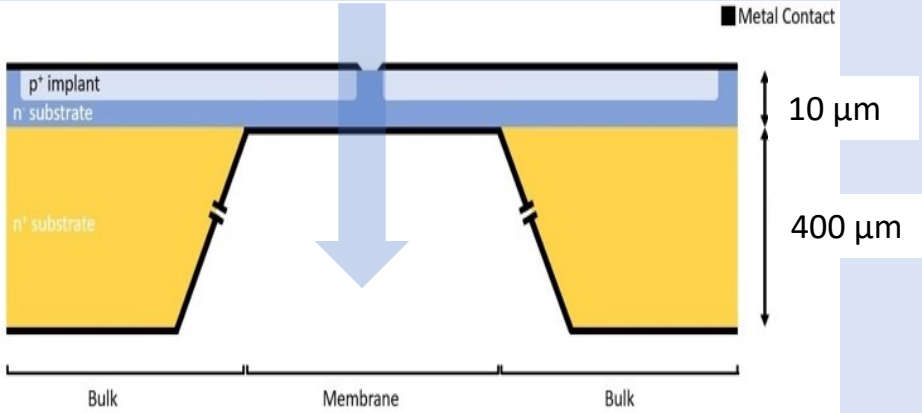


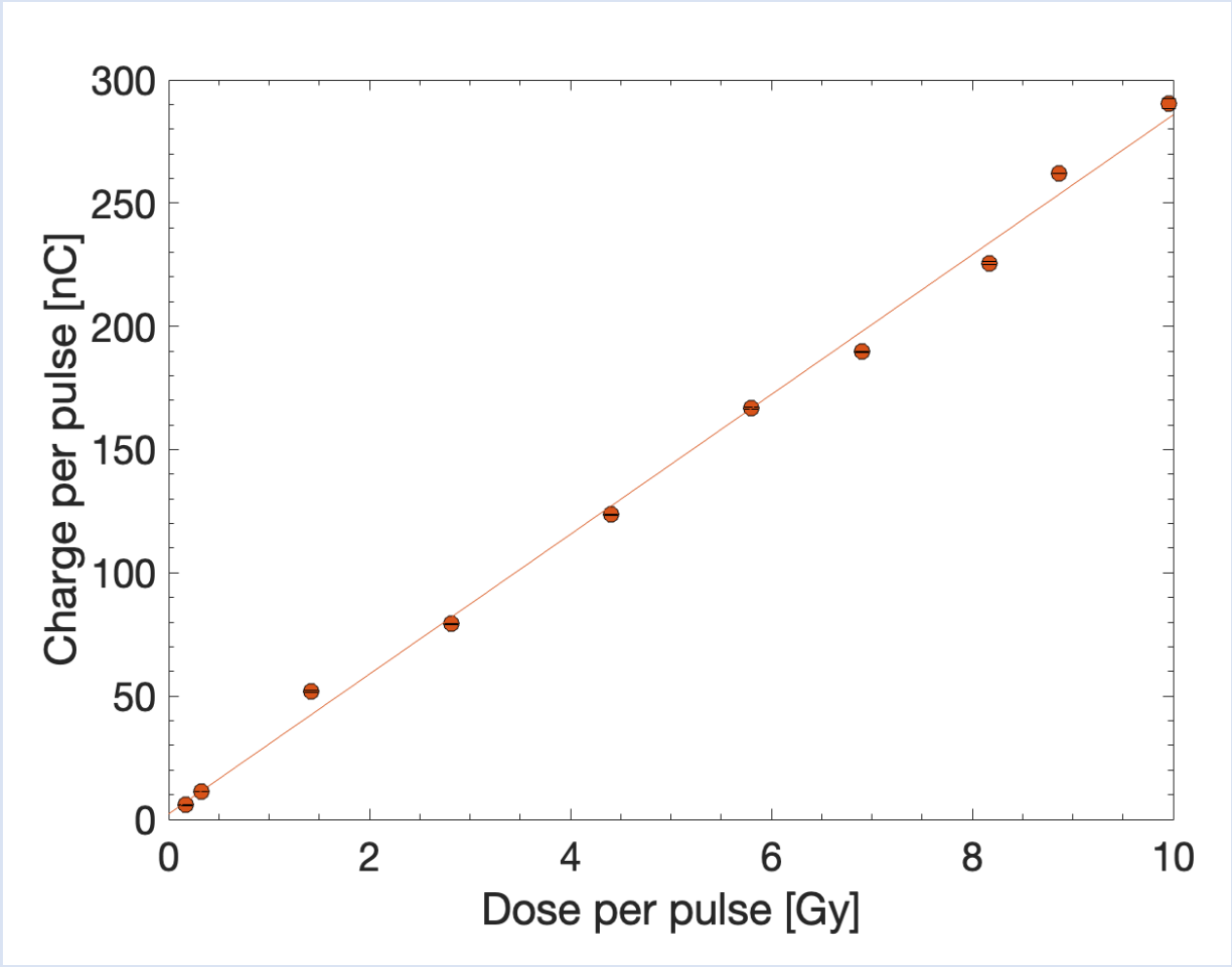
Free-standing membrane



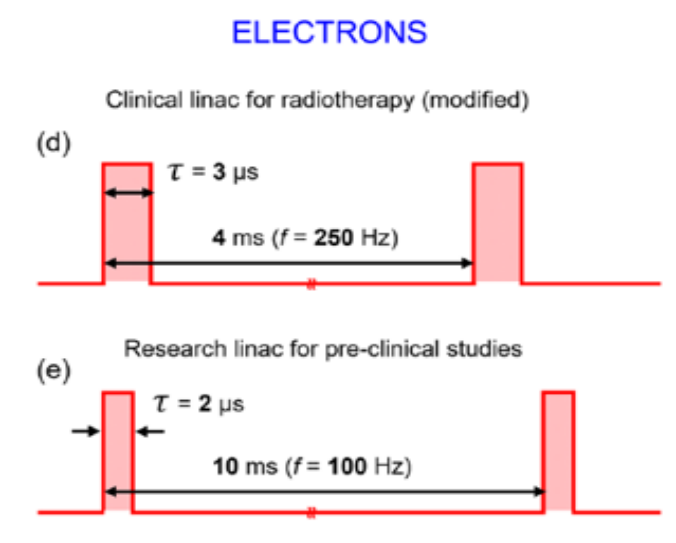


- 10 µm thick **10x10 mm²** area SiC
- Brass collimator: 3 mm diameter 6 mm thick





Time structure of the FLASH beams

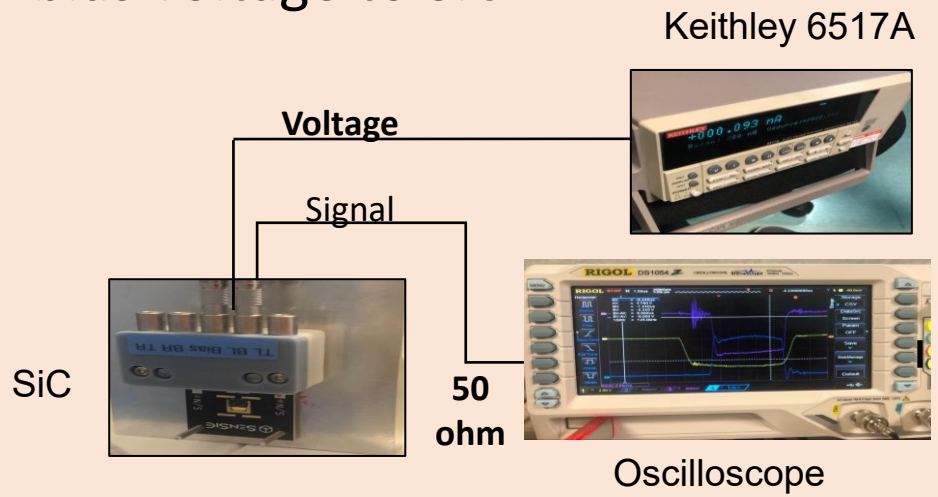


F. Romano *et al*. Med. Phys. (2022)

Dose per pulse D_p

Instantaneous dose rate $\dot{D}_p = \frac{D_p}{\tau}$

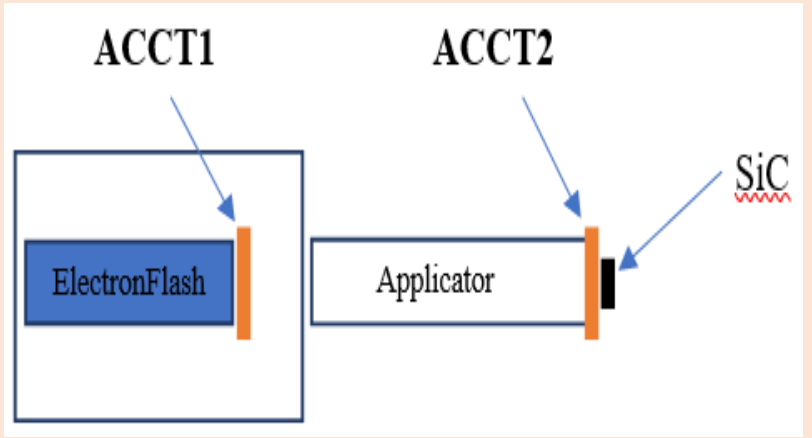
- Oscilloscope (RIGOL, 100 MHz, 8 GS/s)
- Electrometer (Keithley 6517A): to apply bias voltage to SiC



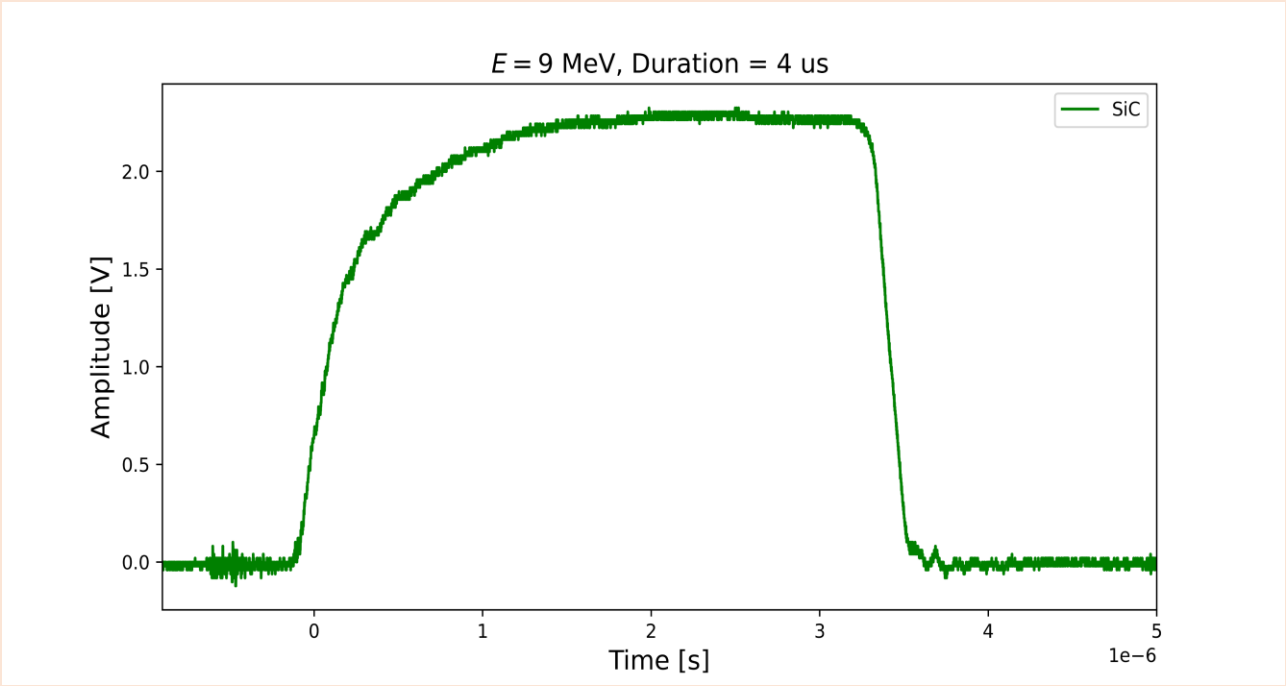
@SIT Sordina, Aprilia

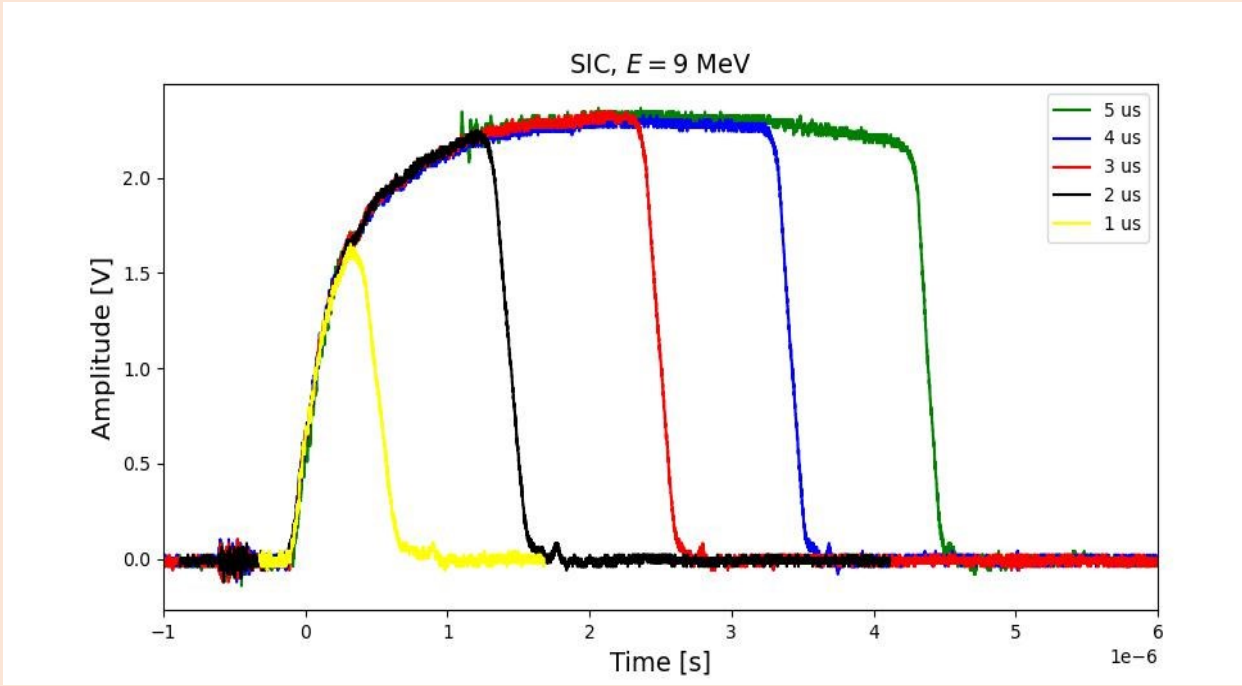
- **7 and 9 MeV electron** beam from the EF.
- **Pulse widths (1-4 μs)** .
- ACCT1 as its monitoring detector in the EF.
- PMMA cylindrical applicator (40 cm length, 40 mm diameter).
- ACCT2 placed at the end of the applicator with the **3 mm²** SiC.

- Study the time shape of single pulse and instantaneous dose rate



Time shape of single pulse





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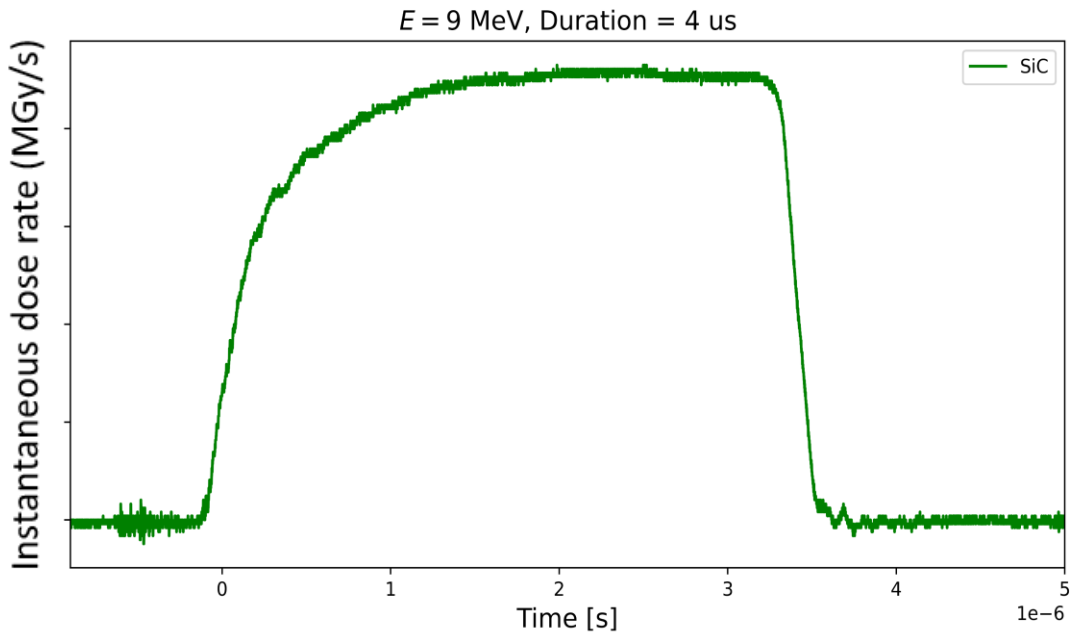
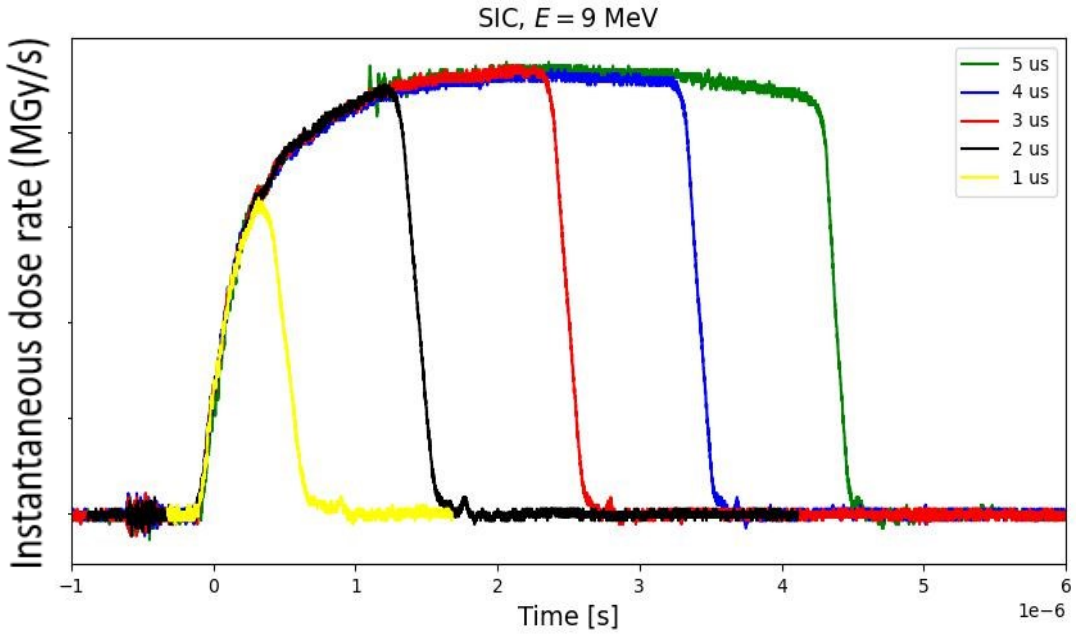
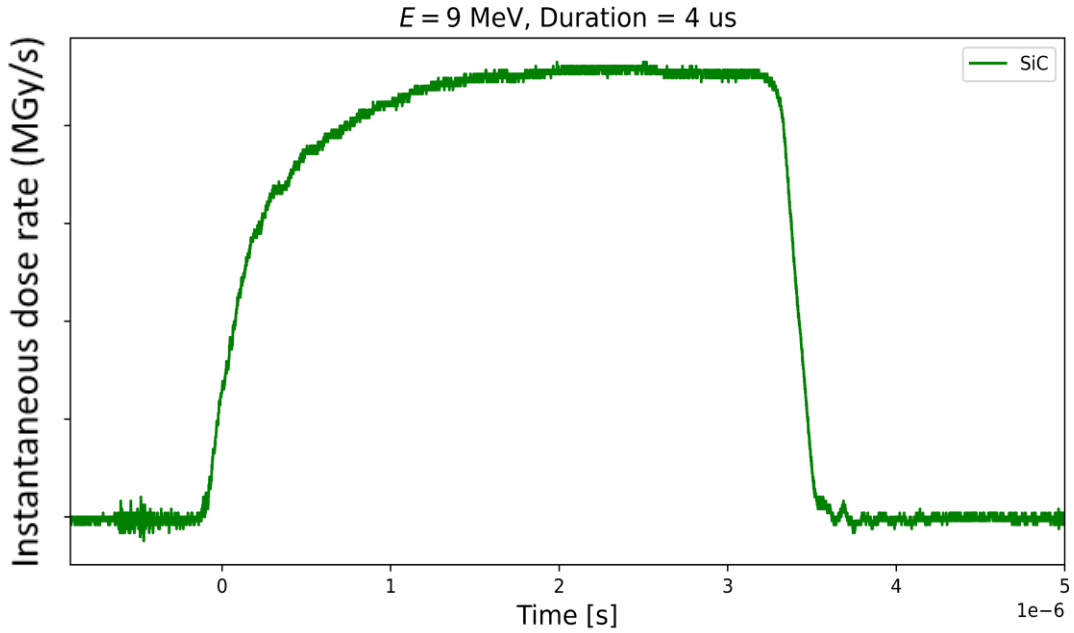
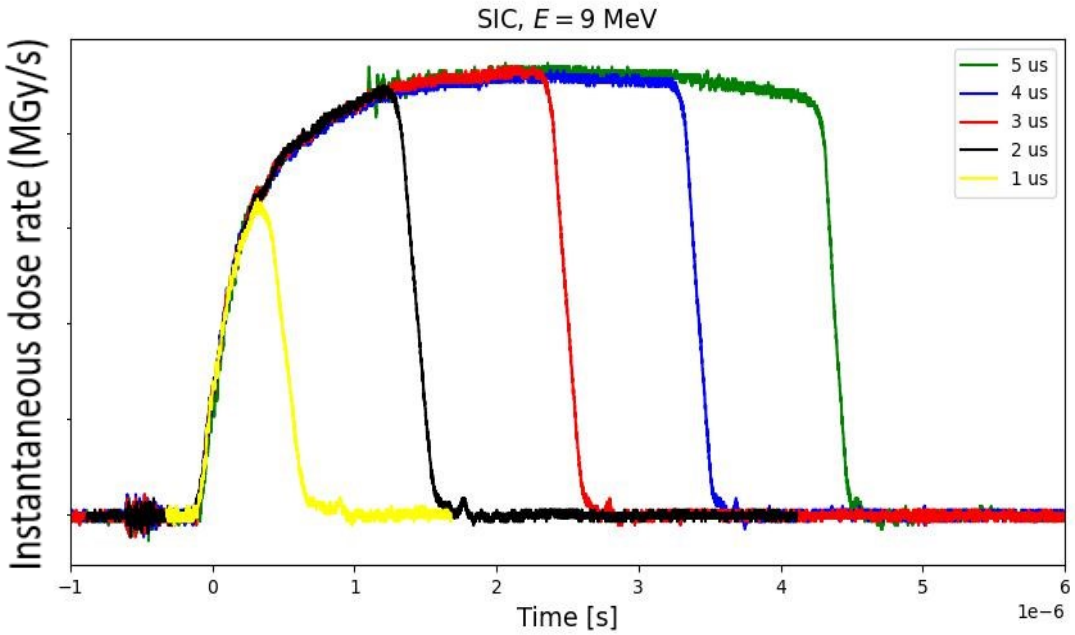
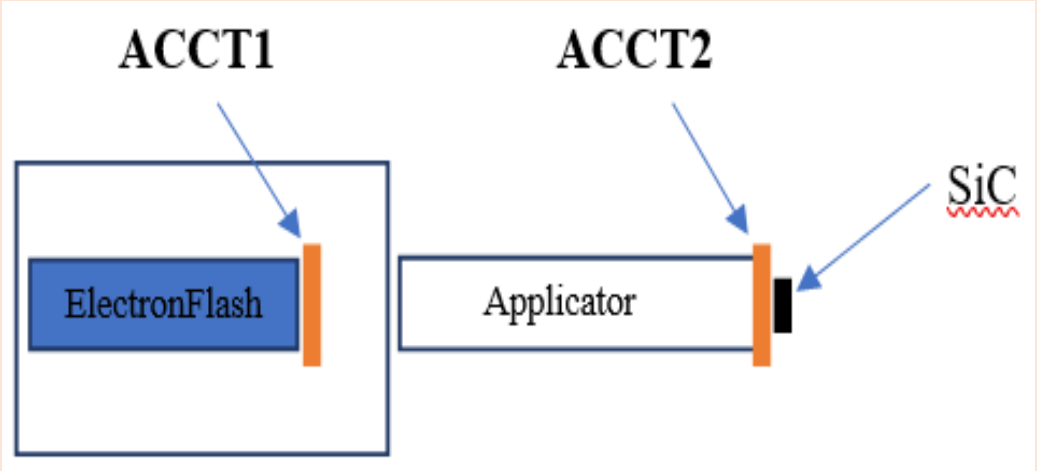


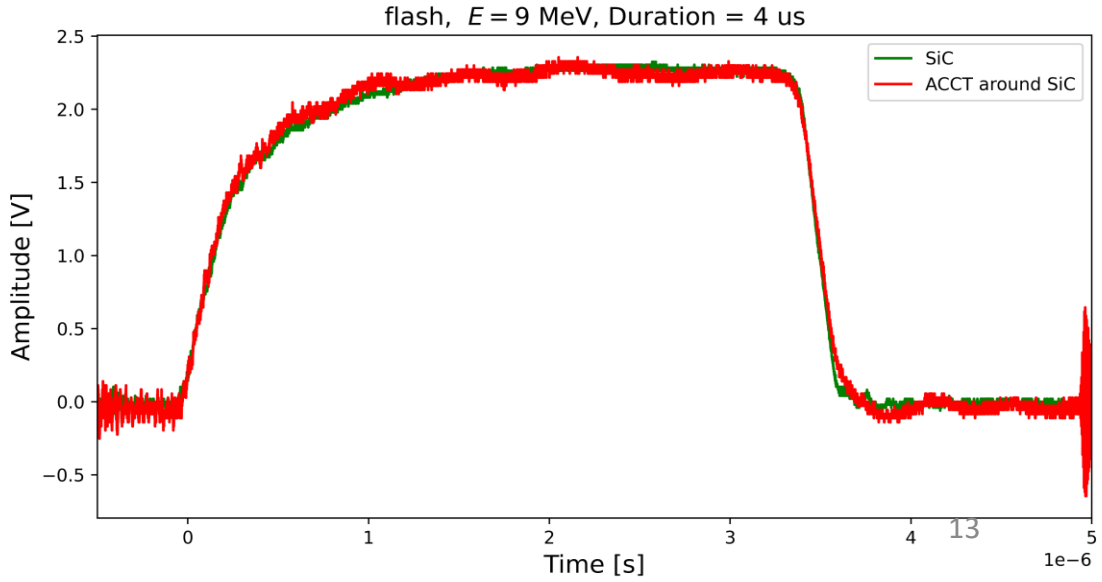


Time shape of single pulse









Conclusion

- SiC detectors have been characterized using low energy UHDR electron beams.
- Linear response up to DPP of 11.0 Gy (instantaneous dose rate of ≈3 MGy/s). Indicating dose rate independence within this dose range.
- Linear response, with and without bias voltage.
- The time shapes of the pulses were accurately obtained, showing that the SiC detector can accurately measure intra-pulse instantaneous dose rate

Future activities

- Characterize for higher dose per pulse (up to 20 Gy).
- Characterize using UHDR proton beams.
- Design of a 2D array of SiC for obtaining the single shot lateral beam profile.

C. Okpuwe (1,2,3), A. Amato (4,5), S. Capaccioli (6, 7), I. D'Amico (8), V. De Liso (8), D. Del Sarto D (6,9), M. De Napoli (1), F. Di Martino (6,9,10), M.C D'Oca (1, 11), G. Felici (8), L. Galluzzo (8), M. Marrale (1,11), L. Masturzo (6,8,9), E. Medina (12,13), F. Paiar (6,10, 14), J.H Pensavalle (6,8,9), E Sangregorio (15), A. Vignati (12,13), M. Camarda (4), F. Romano (1), G. Milluzzo (1)

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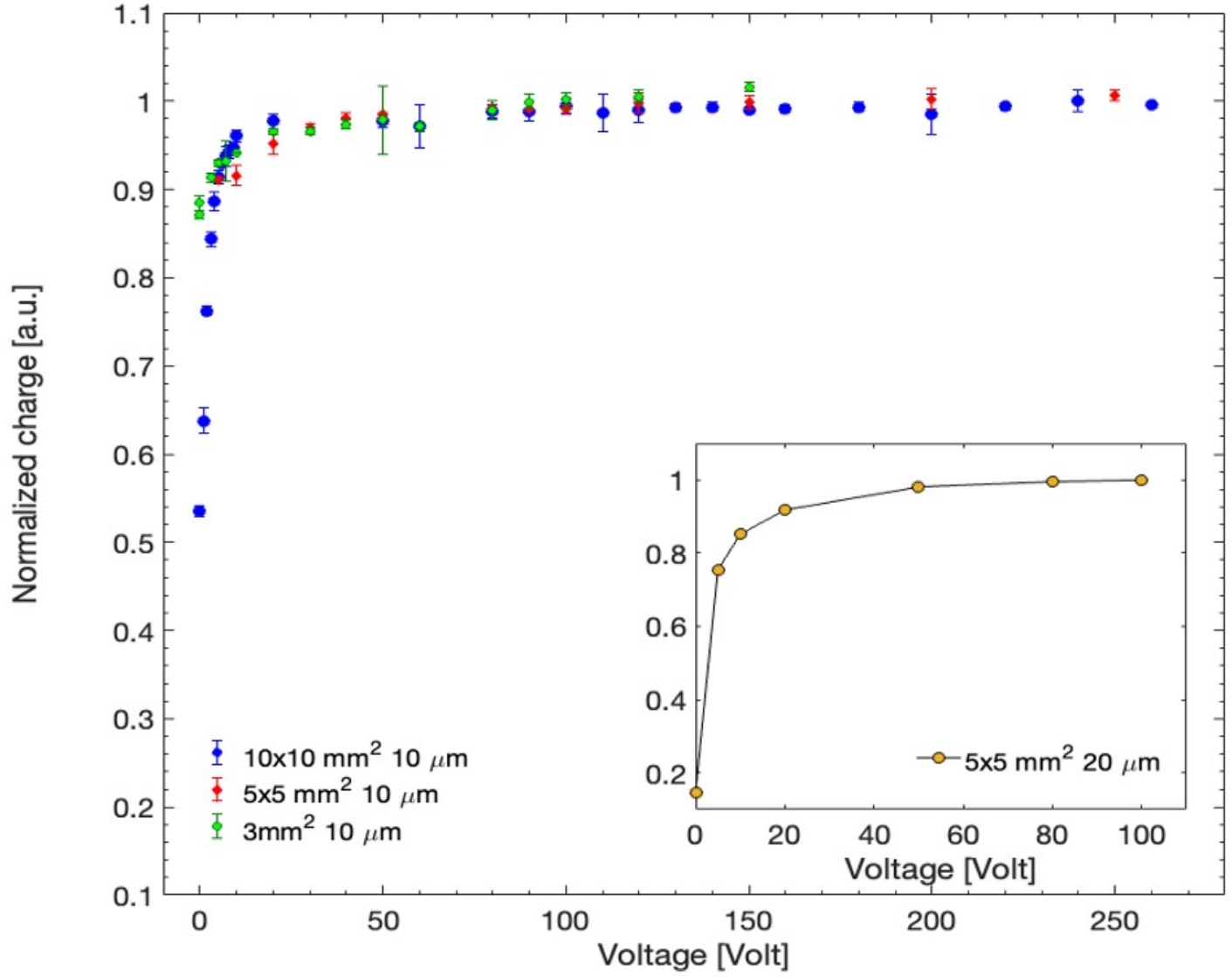
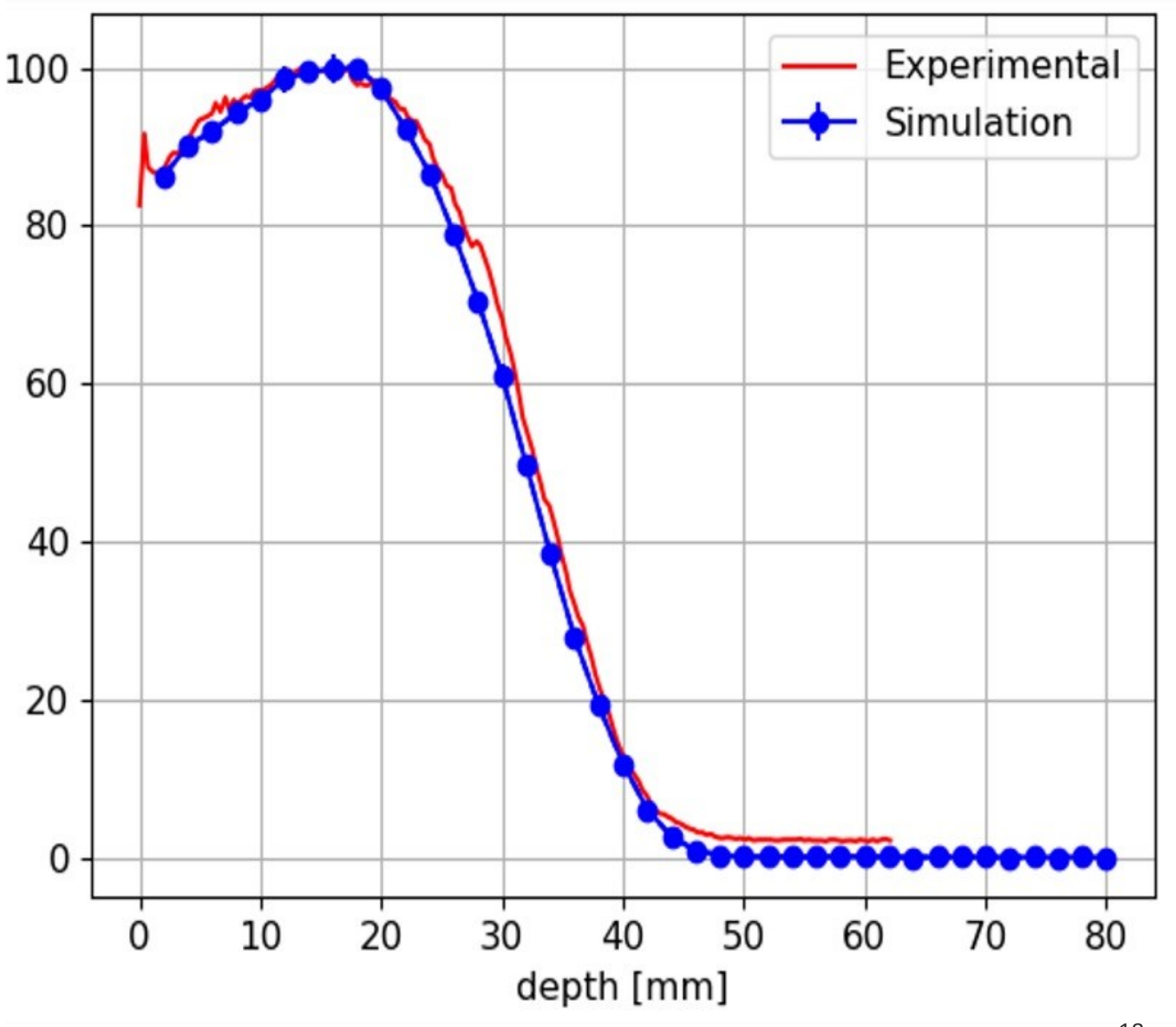
THANK YOU

Back up

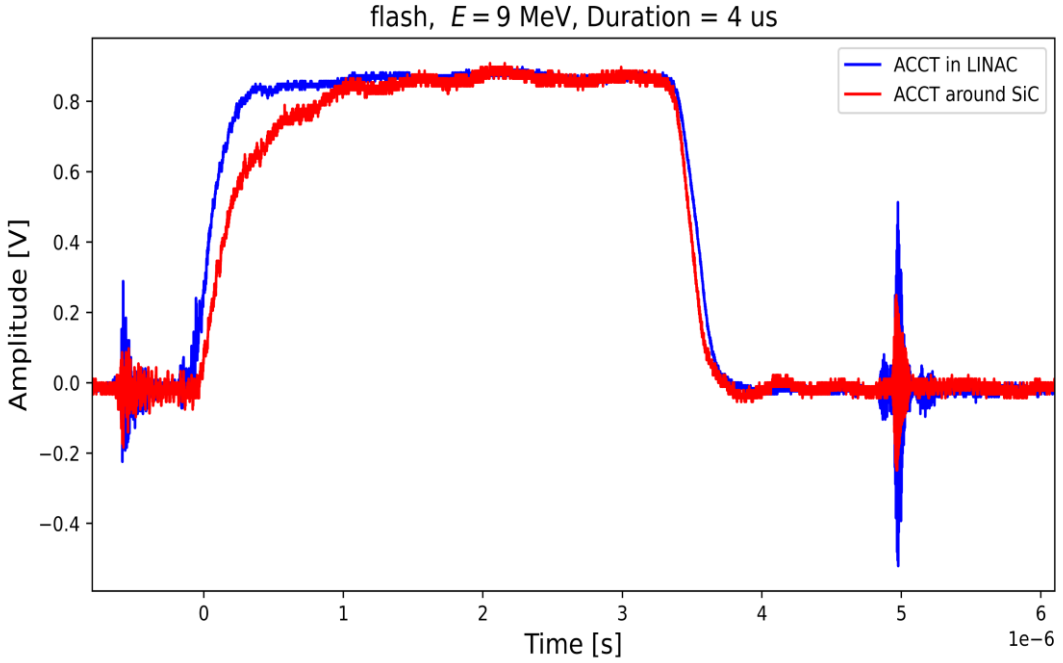
Variation of the charge with respect to applied bias voltage for the SiC detector

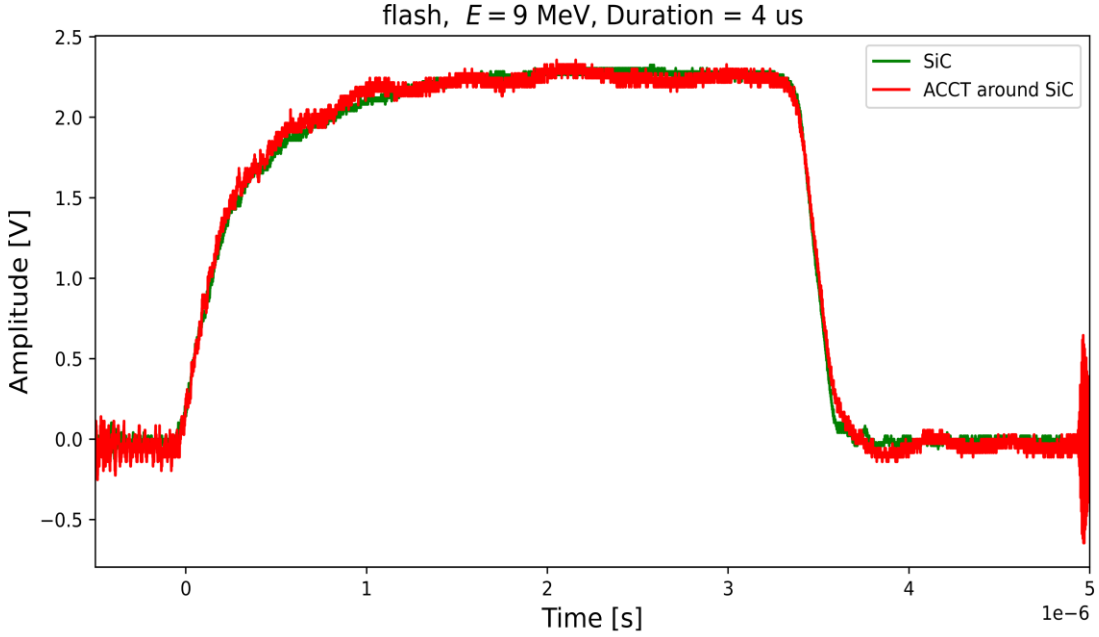


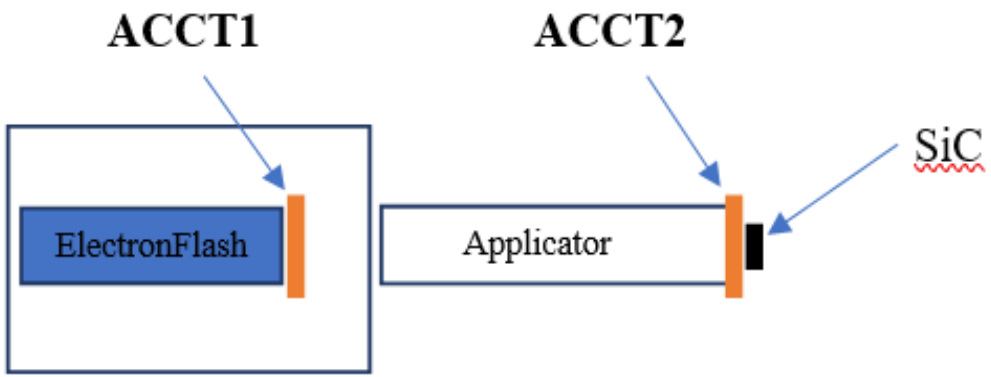
Depth dose distribution of 9 MeV electron in water



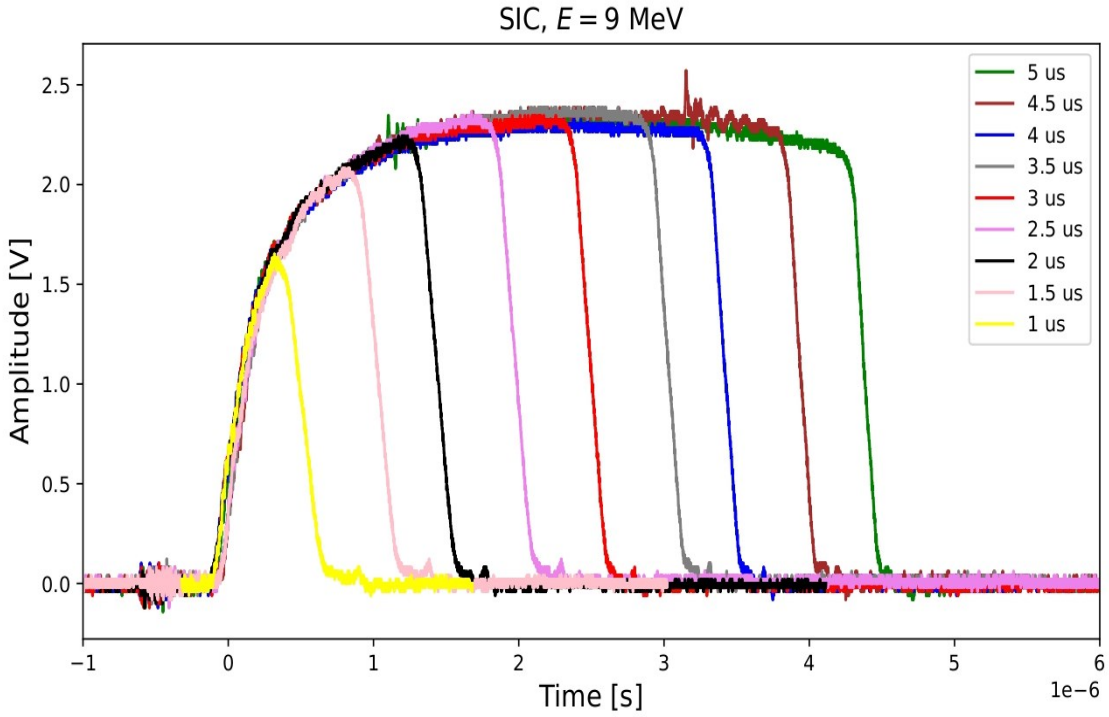
Comparison of the signals

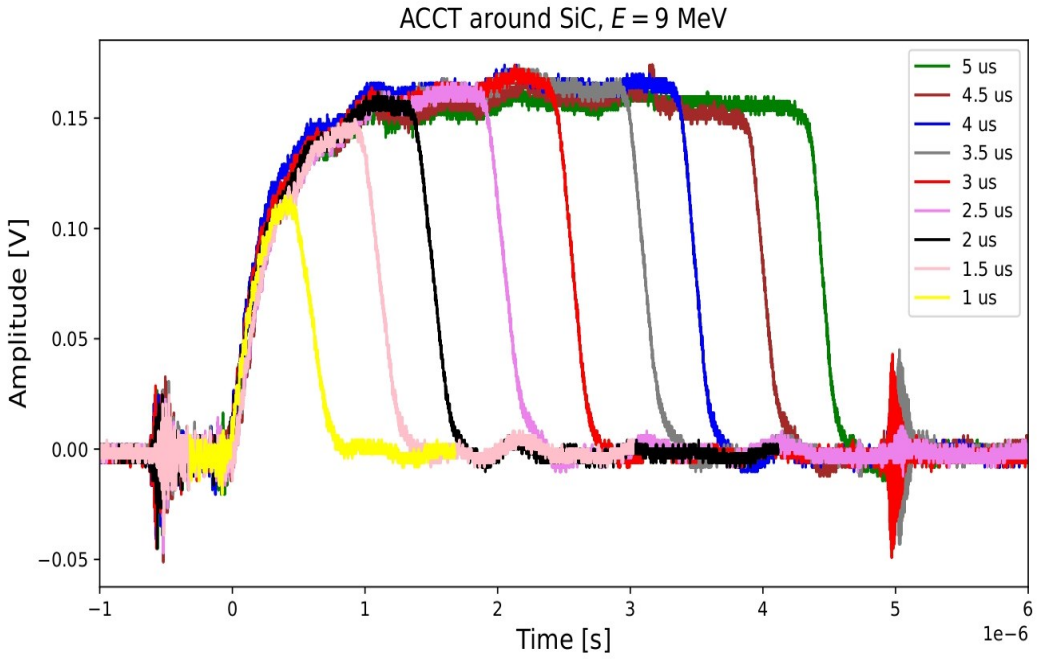


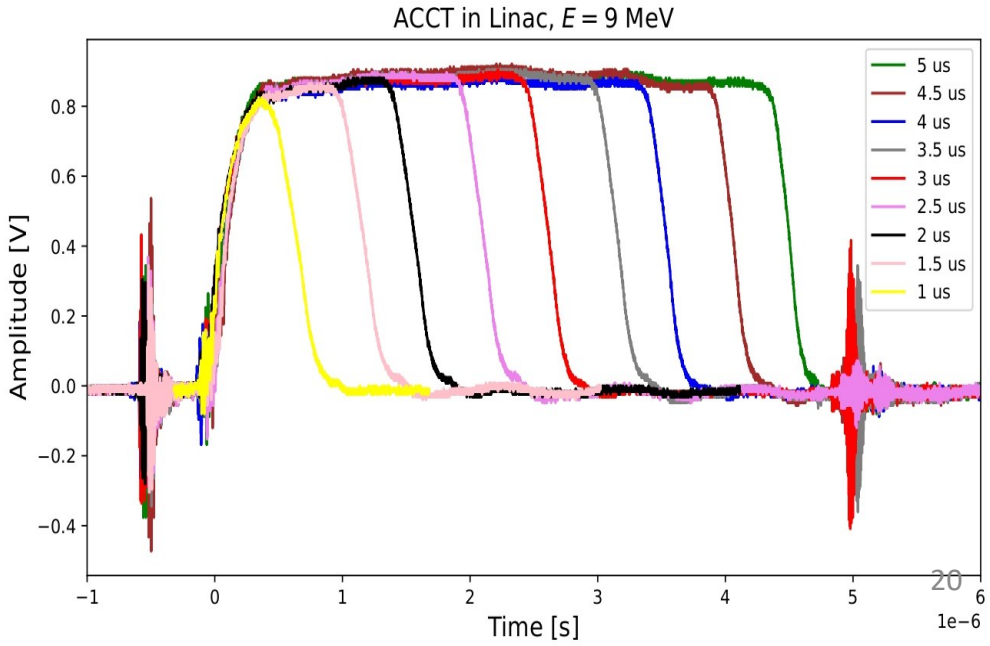




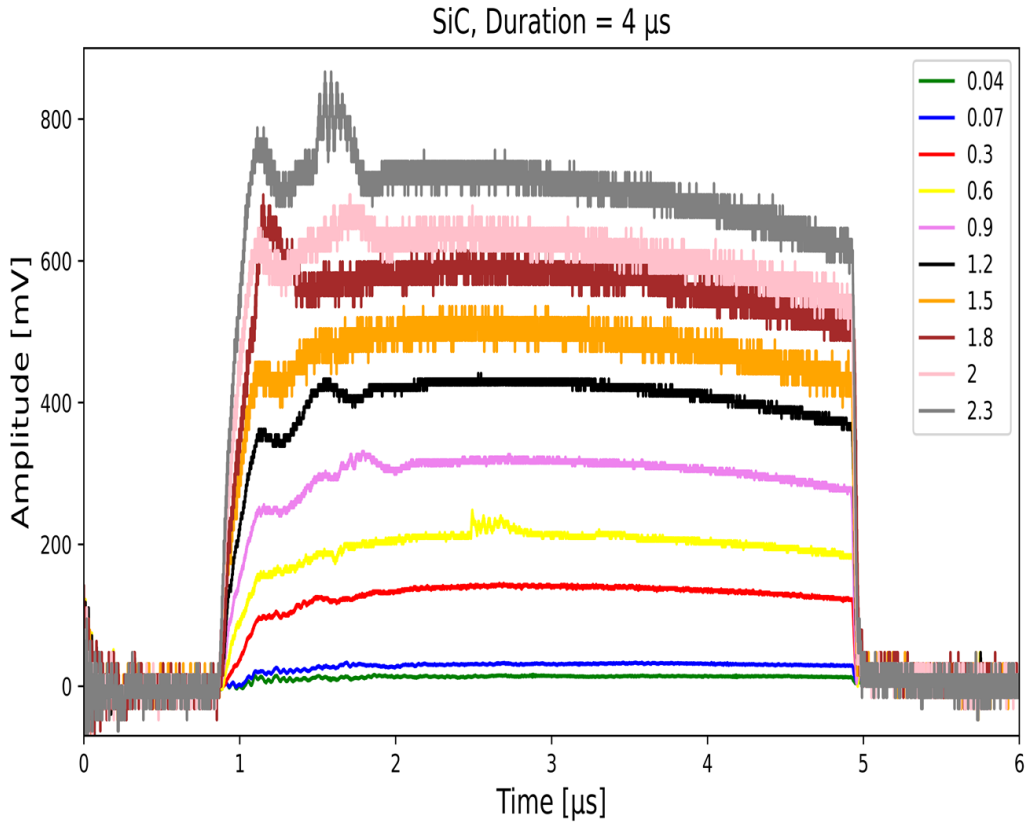
Signals from the detectors

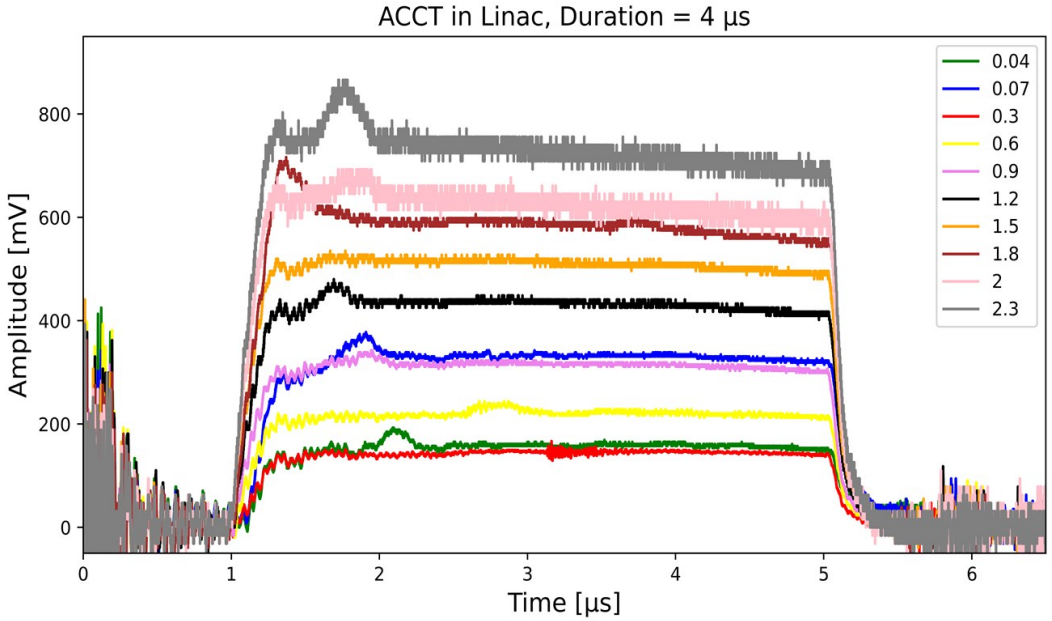


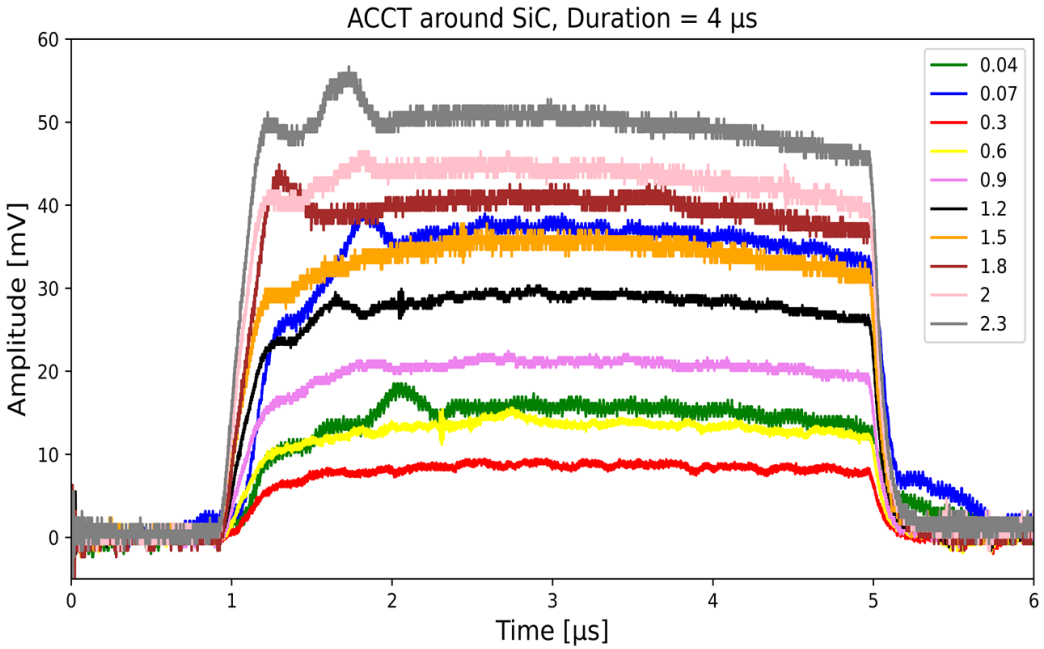




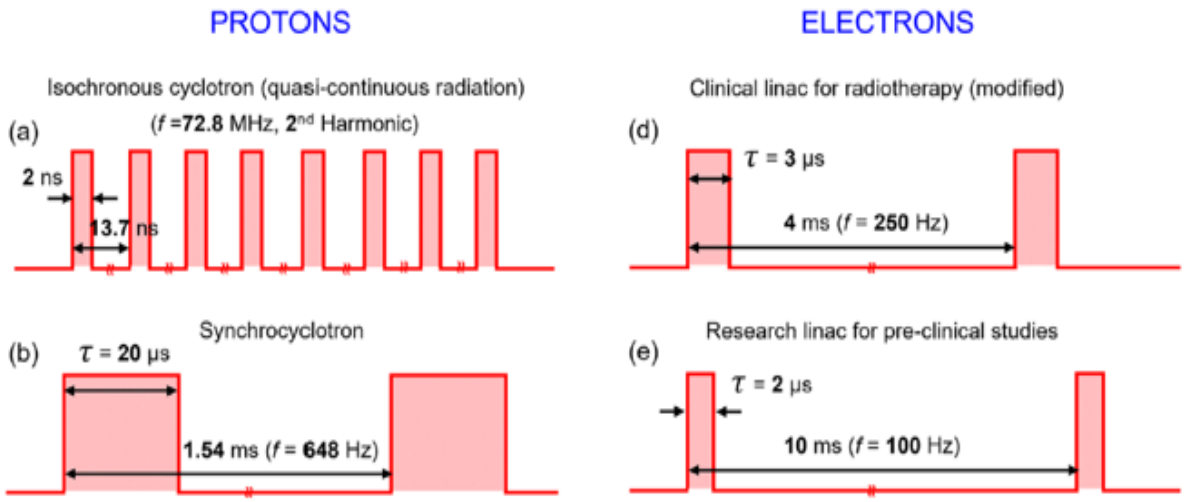
Different beam Currents for 4 µs







Time structure of FLASH beams



F. Romano *et al*. Med. Phys. (2022)

- The average dose rate for a (quasi)continuous beam:

$$\dot{D} = \frac{D}{t}$$

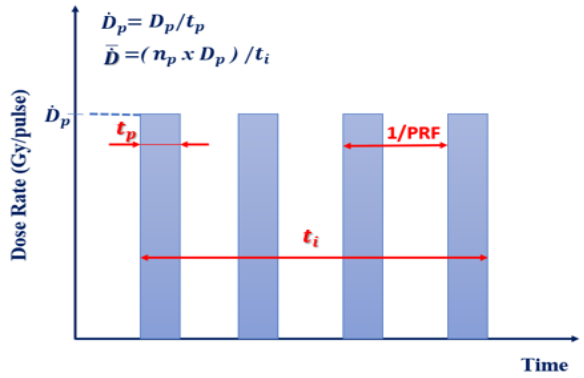
- For pulsed beams, the average dose rate is:

$$\dot{D} = \frac{Df}{N}$$

- The instantaneous dose rate for a pulsed beam is:

$$\dot{D}_p = \frac{D}{N\tau}$$

ElectronFLASH



PRF: 245 Hz
Beam current up to 100 nA
Pulse width: 0.5-4 μs