WP1 – FRIDA – Torino
Linac Upgrade

UNIVERSITÀ DI TORINO

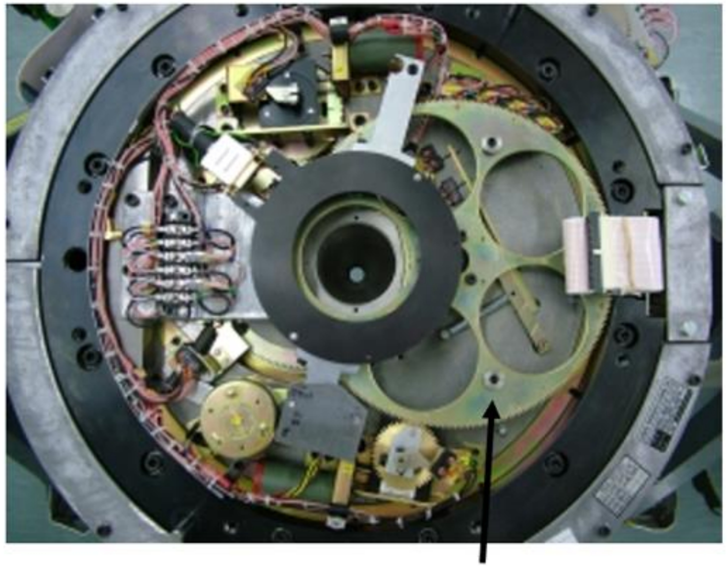
INFN Istituto Nazionale di Fisica Nucleare

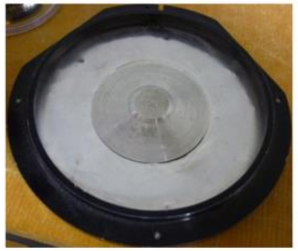
Prime modifiche del LINAC

Preparation of the 10 MeV FLASH pre-set working modality:

- Magnetron power and electron bunches transportation set as for 10 MV X-ray beam production → electron beam extraction
- Complete remotion of the secondary filters (hole in the carousel)
- Forced increase of the gun current (from 5.7 A up to 8.5 A)

Collimator assembly looking into the target





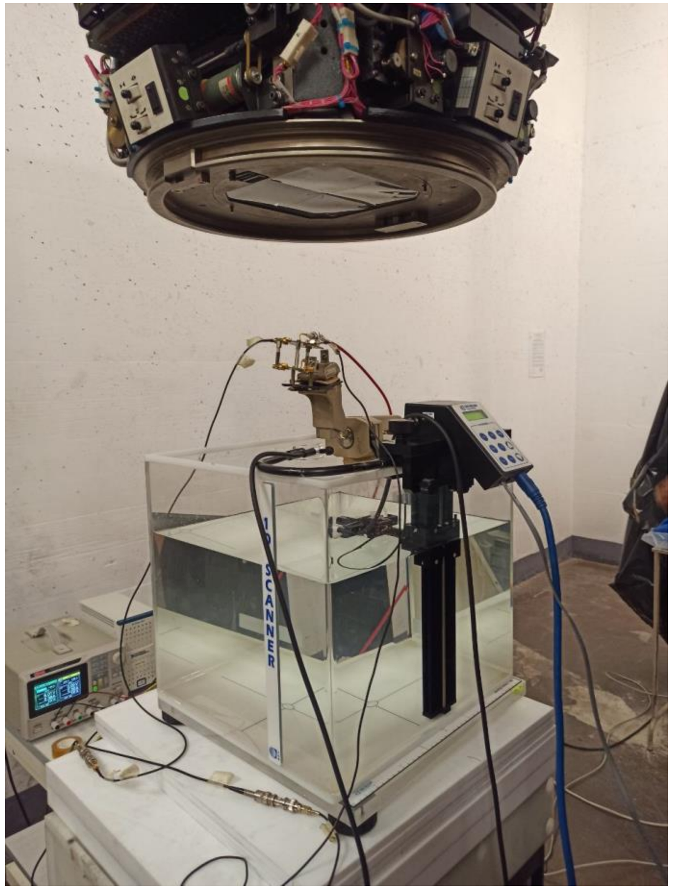
Electron secondary scatter filter

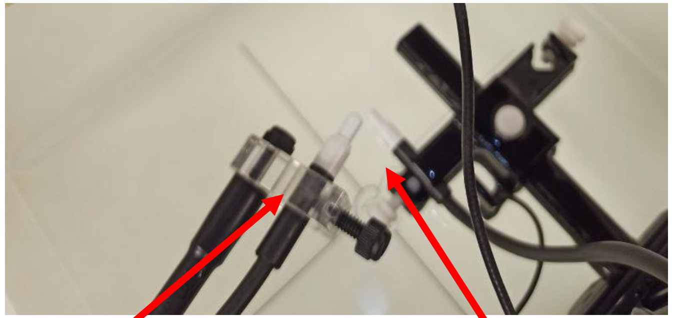
Experimental setup - 1

15/07/22 - 14/09/22

- **10MeV** electron beams
- **Flash vs normal** mode
- IC
- Different **gun currents**
    - 5.7A in *normal* mode
    - 7.6A in *flash* mode
- **Frequency 12 Hz**

- **<u>To verify the beam energy</u>**



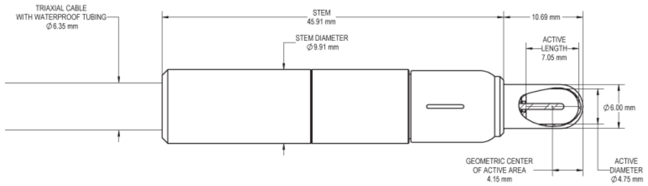


$IC_{(2)}$ in the field border

$IC_{(1)}$ in the water

<u>Cylindrical IC</u>

SNC125c (Sun Nuclear Corporation)

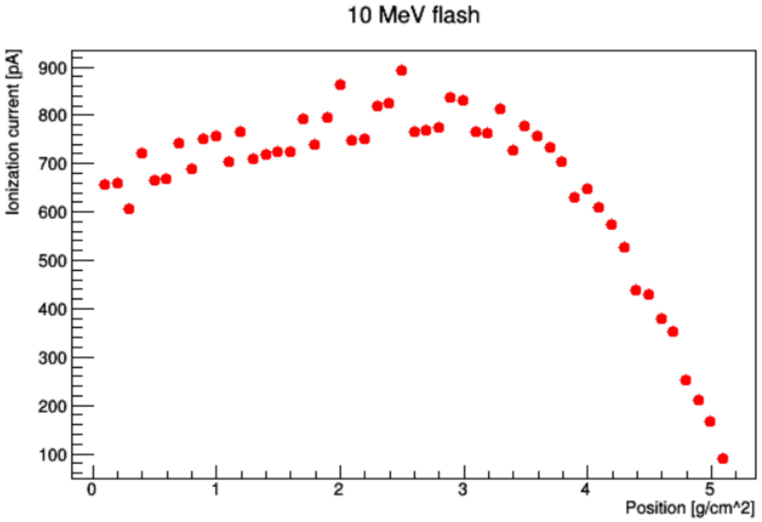


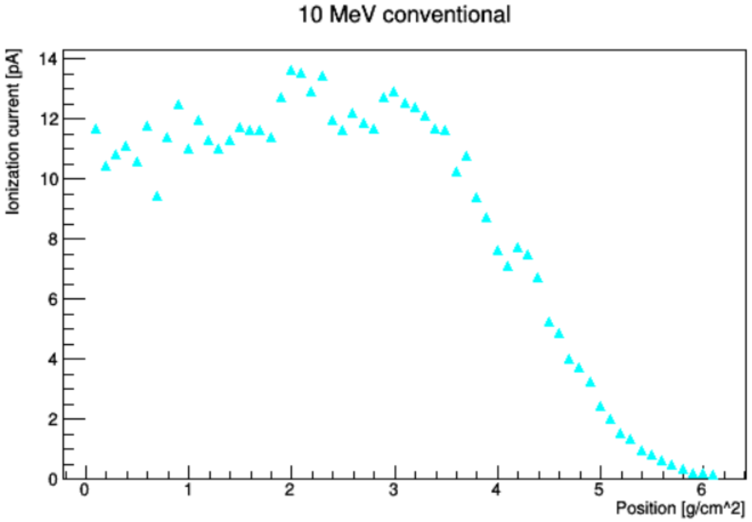
PDD: flash vs conventional

14/09/22

PDD flash measurements:

- 10 MeV electrons
- Gun current: 7.6 A
- Frequency: 12 Hz

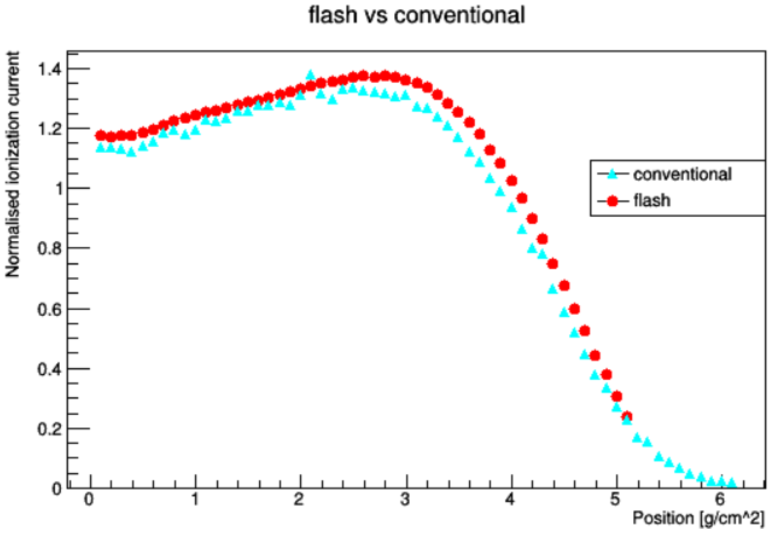




PDD conventional measurements:

- 10 MeV electrons
- Gun current: 5.7 A
- Frequency: 12 Hz

Normalising with the IC in the border of the beam field



$$\frac{R_{80}}{2} = (1.90 \pm 0.09)\ {}^{g}/_{cm^2}$$

Stima della dose con IC – z_{ref} (2,5 cm)

- Convenzionale (5.7 A, 12 Hz, 500 pulses)
  D tot = 0.13 Gy
  D/pulse = 0.26 mGy (ottenuta dividendo per i 500 impulsi)
  Average Dose rate = 2.89 mGy/s (ottenuto dividendo per il tempo di irraggiamento 45 s)

- Flash (7.6 A, 12 Hz, 500 pulses)
  D tot = 10.4 Gy
  D/pulse = 20.7 mGy
  Average Dose rate = 230 mGy/s

(Seguendo step del TRS-398)

Stima della dose con IC – z_{ref} (2,5 cm)

- Convenzionale (5.7 A, 12 Hz, 500 pulses)
  D tot = 0.13 Gy
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- Flash (7.6 A, 12 Hz, 500 pulses)
  D tot = 10.4 Gy
  D/pulse = 20.7 mGy
  Average Dose rate = 230 mGy/s

(Seguendo step del TRS-398)

0,02 Gy/p

@ 7.6 A gun current → increase?
@ isocenter → go closer?

Dose per pulse di riferimento

Beam Characteristics	CONV	FLASH
Dose Per Pulse D_p	~0.4 mGy	~1 Gy
Dose Rate: Single Pulse $\dot{D}_p$	~100 Gy/s	~10^5 Gy/s
Mean Dose Rate: Single Fraction $\dot{D}_m$	~0.1 Gy/s	~ 100 Gy/s
Total Treatment Time T	~days/minutes	< 500 ms

Ashraf paper

	Conventional RT		FLASH RT
Dose rate	≈10^{-1} Gy/s	↔	40-10^7 Gy/s
Dose/pulse	≈10^{-4} Gy	↔	1–10^1 Gy
Time for 10 Gy delivery	10^2 s	↔	10^{-6}–10^{-1} s

Dartmouth lecture - Petersson

For electron beams, the data on critical FLASH parameters are genuinely scarce, with only a few beams having reproduced the FE in vivo. The trends observed from the literature on pulsed electron FLASH beams indicate the irradiation time and the D_{pulse} as two beam properties that are critical for reducing the radiation toxicity in normal tissues. Irradiation times shorter than 0.4 s and D_{pulse} higher than 0.2 Gy are required to achieve the FE with electron linacs. The individual contribution of these two properties to the biological response is yet to be resolved.

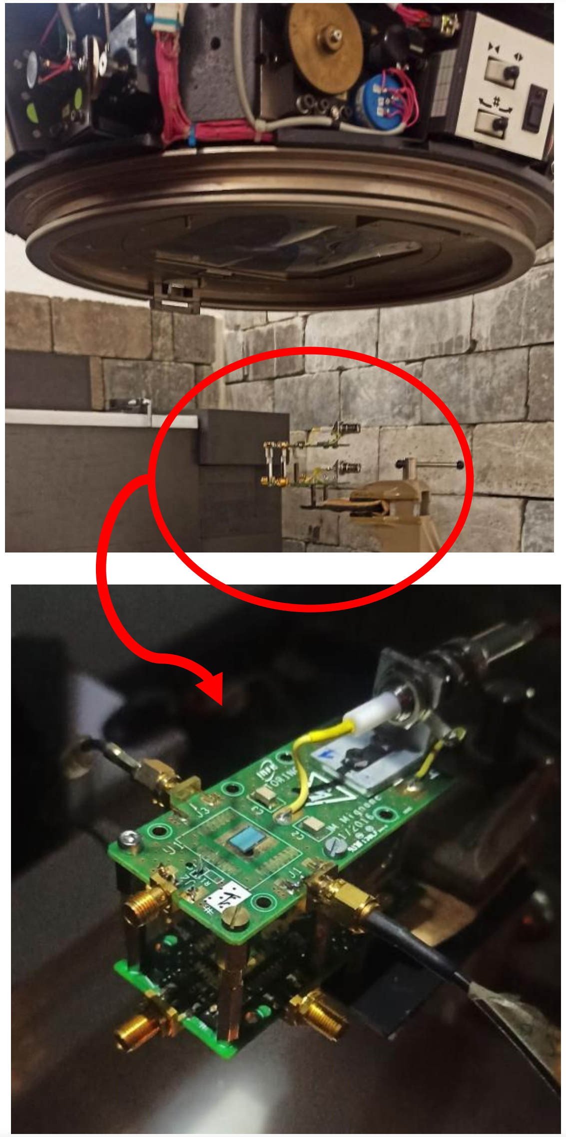
Farr – Med Phys 2022

Experimental setup - 2

6/07/22

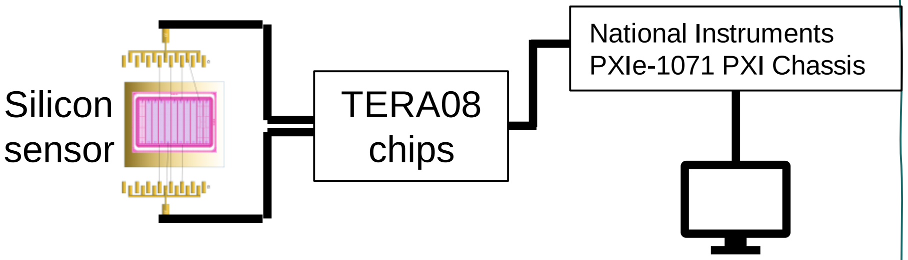
- **10MeV** electron beams
- **Flash vs normal** mode
- Different **gun currents**
  - 5.7A in *normal* mode
  - Up to 8.5A in *flash* mode
- Different **frequencies**
  - 6, 12.5, 25, 50, 200, 400 Hz
- Fixed number of pulses
  - To anticipate LINAC interlock
- Different **distances** (100 - 80 - 58cm)
- x 5 each condition

→
- Stability of the pulses
- Reproducibility
- Gain in charge per pulse

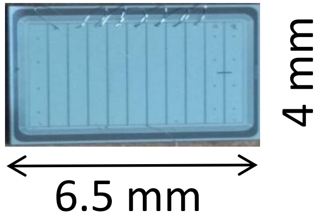


TERA08

Readout electronics for our silicon sensor
(chip based on *recycling integrator* principle)

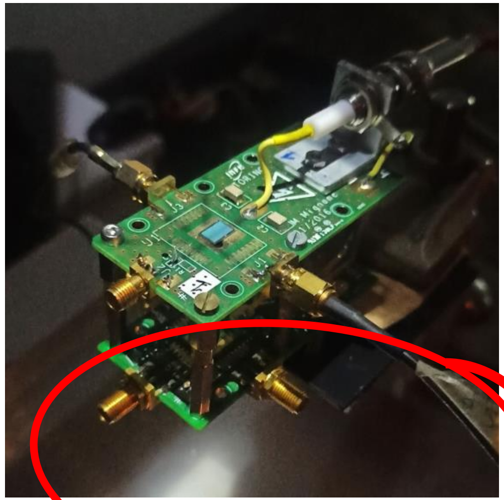


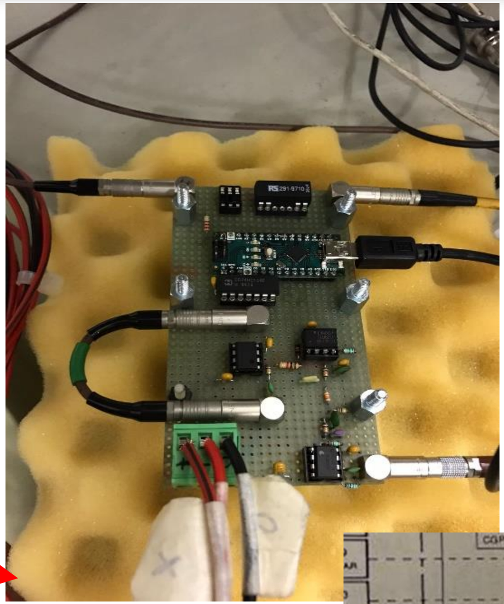
Silicon sensor



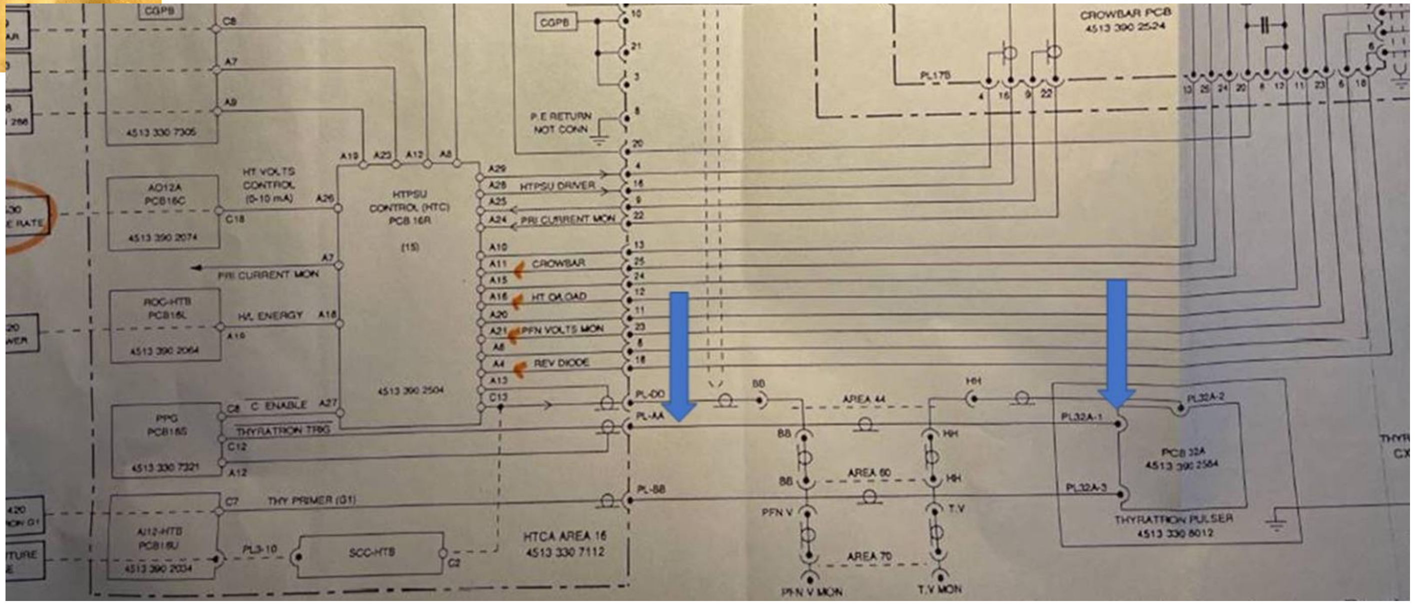
11 strips,
pitch 590 µm
50 µm active thickness

Pulse counter





il circuito riceve in input il segnale del trigger del thyratron e lo trasmette al thyratron fino a quando non è stato raggiunto il numero definito di impulsi. Quando il numero di impulsi definito è stato raggiuntoil circuito interrompe il trigger del thyratron, tramite un relay, e quindi ferma l'erogazione del fascio del linac

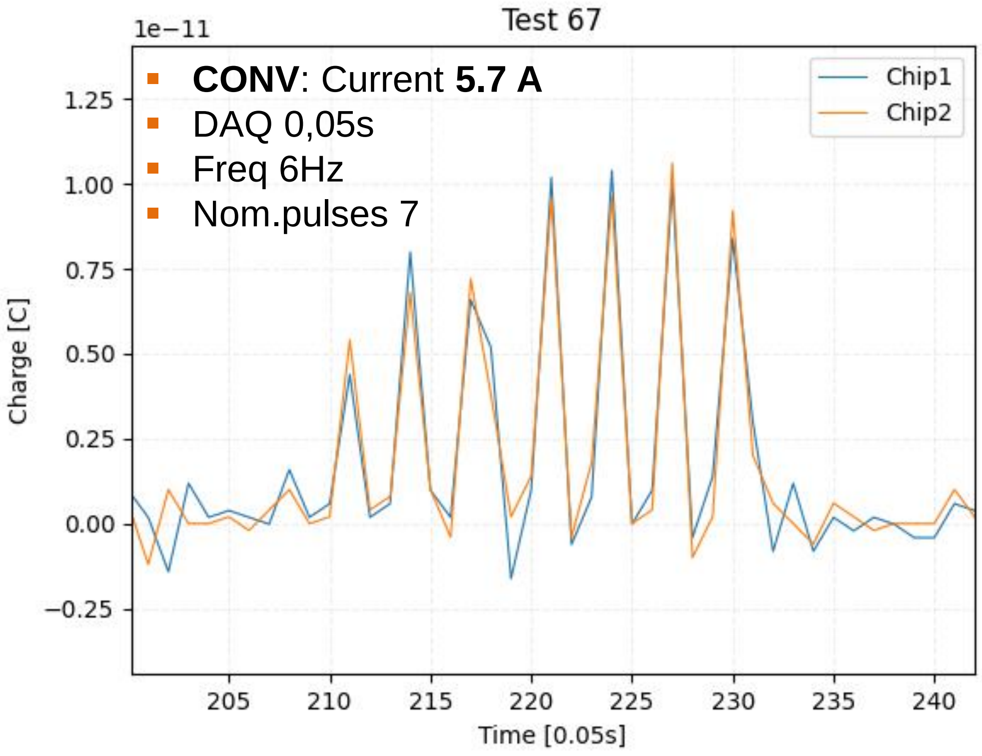


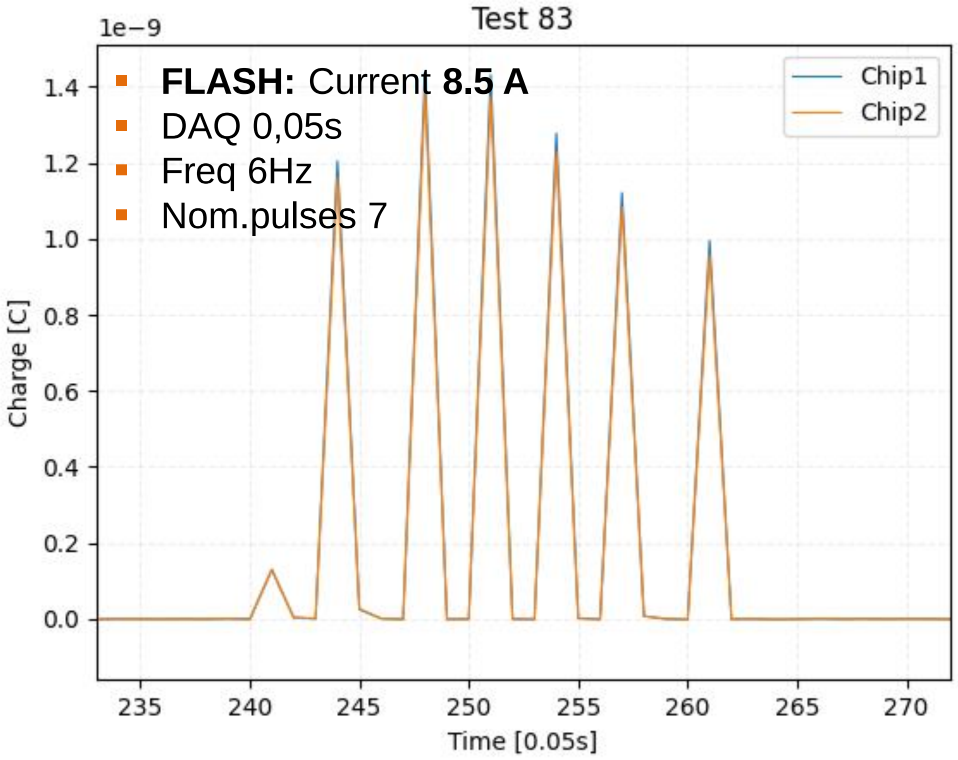
$Q_{/pulse}$CONV vs FLASH (isocenter) TERA08

→CONV **5.7A** VS FLASH **8.5A**

$$\frac{Q_{/pulse(Flash)}}{Q_{/pulse(Normal)}} = \frac{\mathbf{1.20e{-}9\ C}}{\mathbf{1.04e{-}11C}} = 115.4 \sim 120$$

We can reach higher gain: for gun current **8.3A** we observed **higher charge per pulse than with 8.5A**! (*Slide 9-10-11)





Number of pulses set to <u>anticipate the LINAC interlock.</u>

Charge per pulse is computed as: $Q_{/pulse} = \frac{Q_1+Q_2+\ldots+Q_7}{7}$

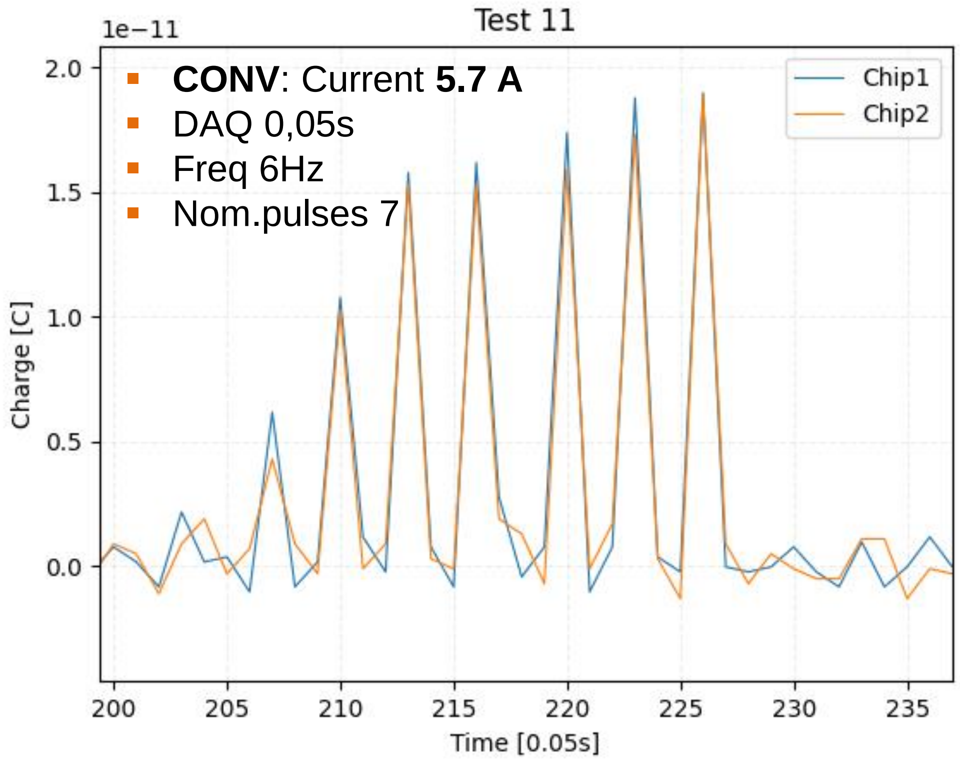
$Q_{/pulse}$CONV vs FLASH (80cm)

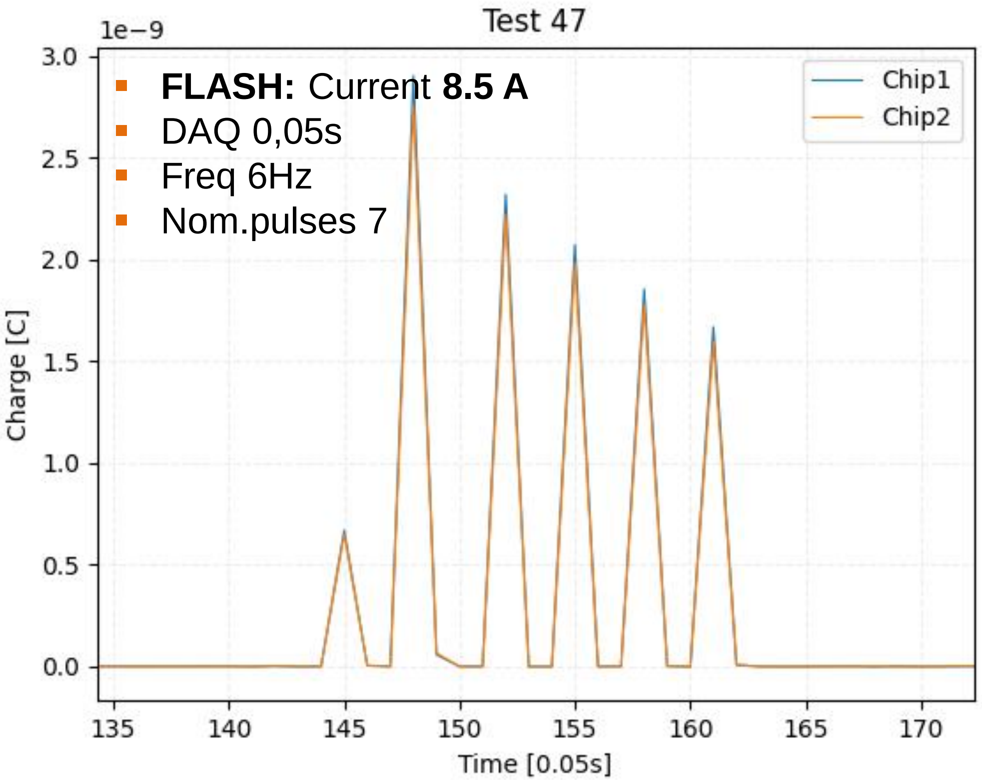
TERA08

→CONV **5.7A** VS FLASH **8.5A**

$$\frac{Q_{/pulse(Flash)}}{Q_{/pulse(Normal)}} = \frac{1.91e{-}9\ C}{1.64e{-}11C} = 116.4 \sim 120$$

We can reach higher gain: for gun current **8.3A** we observed **higher charge per pulse than with 8.5A**! (*Slide 9-10-11)





Charge per pulse is computed as: $Q_{/pulse} = \frac{Q_1+Q_2+\ldots+Q_7}{7}$

Number of pulses set to anticipate the LINAC interlock.

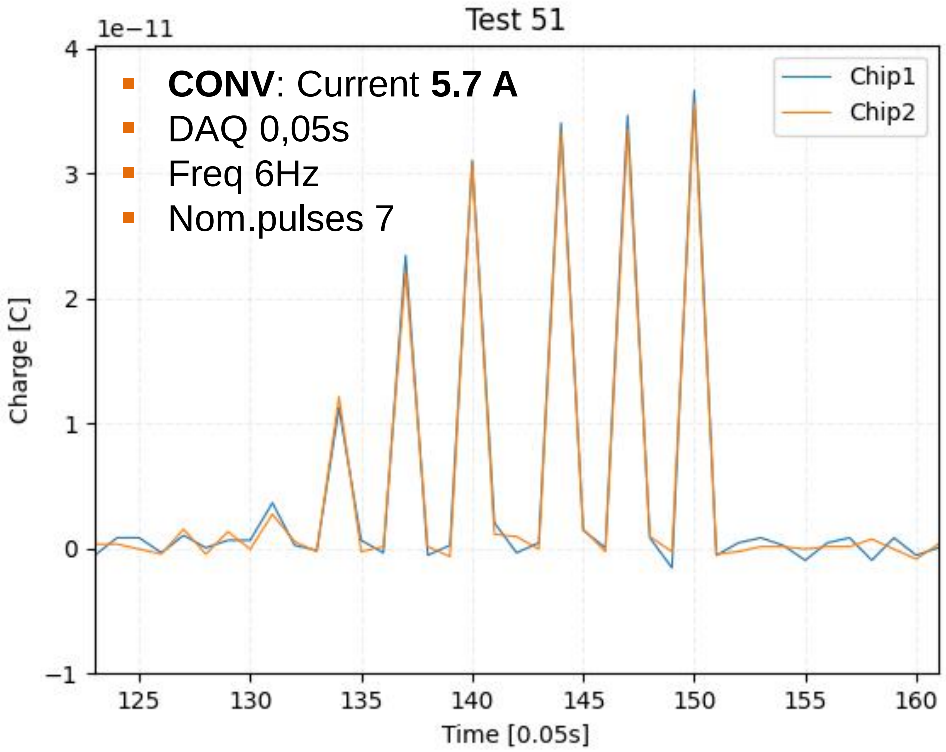
$Q_{/pulse}$ CONV vs FLASH (58cm)

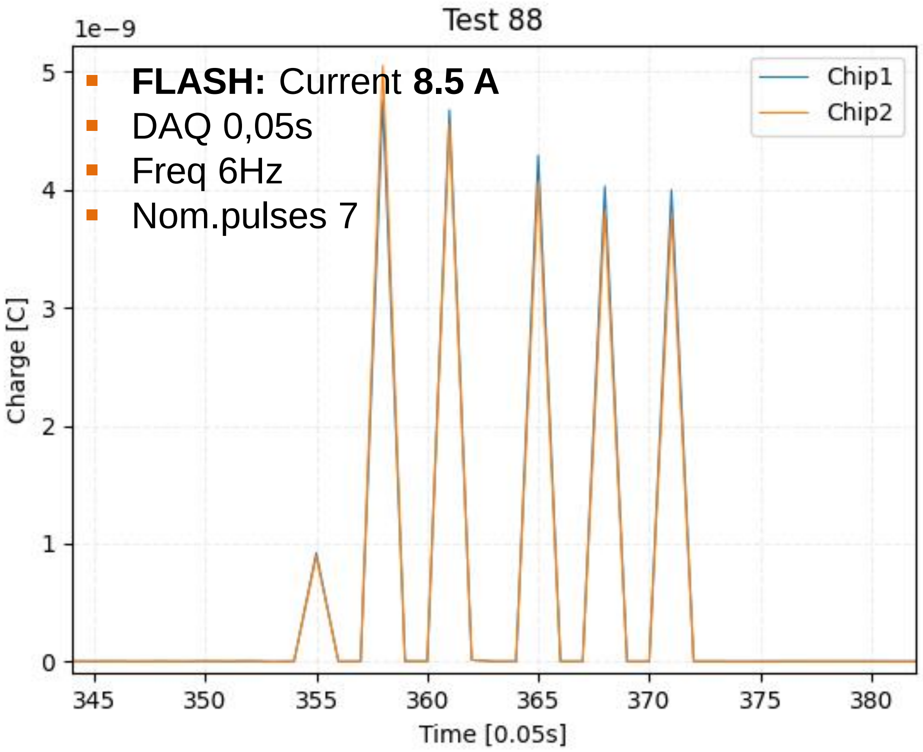
TERA08

→CONV **5.7A** VS FLASH **8.5A**

$$\frac{Q_{/pulse(Flash)}}{Q_{/pulse(Normal)}} = \frac{3.78e{-}9C}{2.83e{-}11C} = 133.6 \sim 130$$

We can reach higher gain: for gun current **8.3A** we observed **higher charge per pulse than with 8.5A**! (*Slide 9-10-11)





Charge per pulse is computed as: $Q_{/pulse} = \frac{Q_1+Q_2+\ldots+Q_7}{7}$

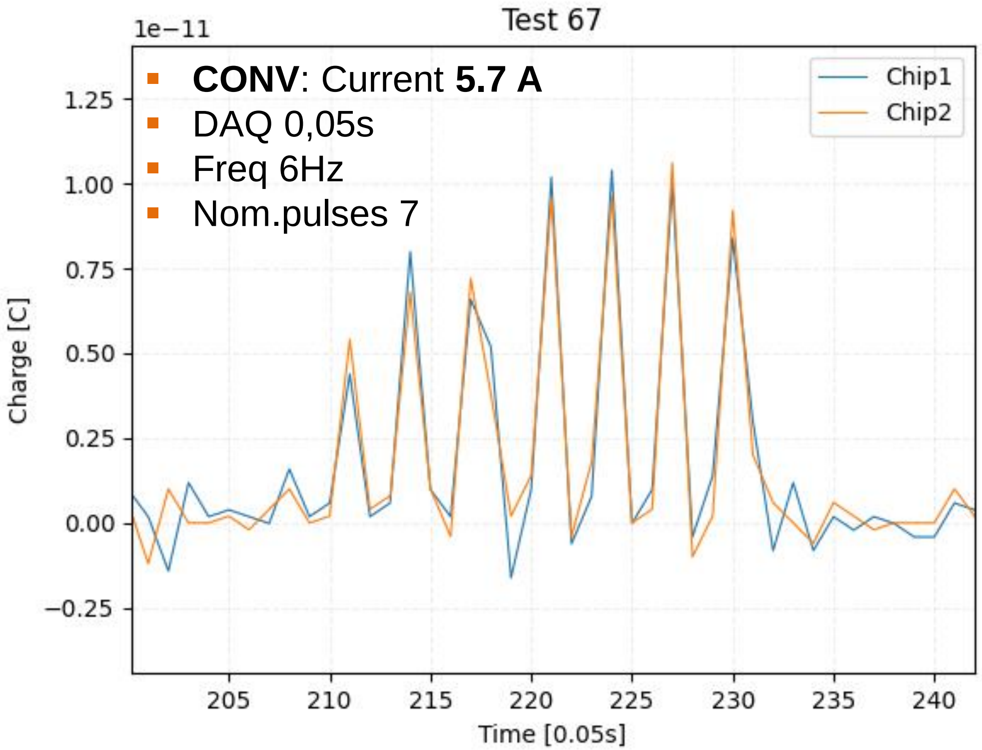
Number of pulses set to <u>anticipate the LINAC interlock.</u>

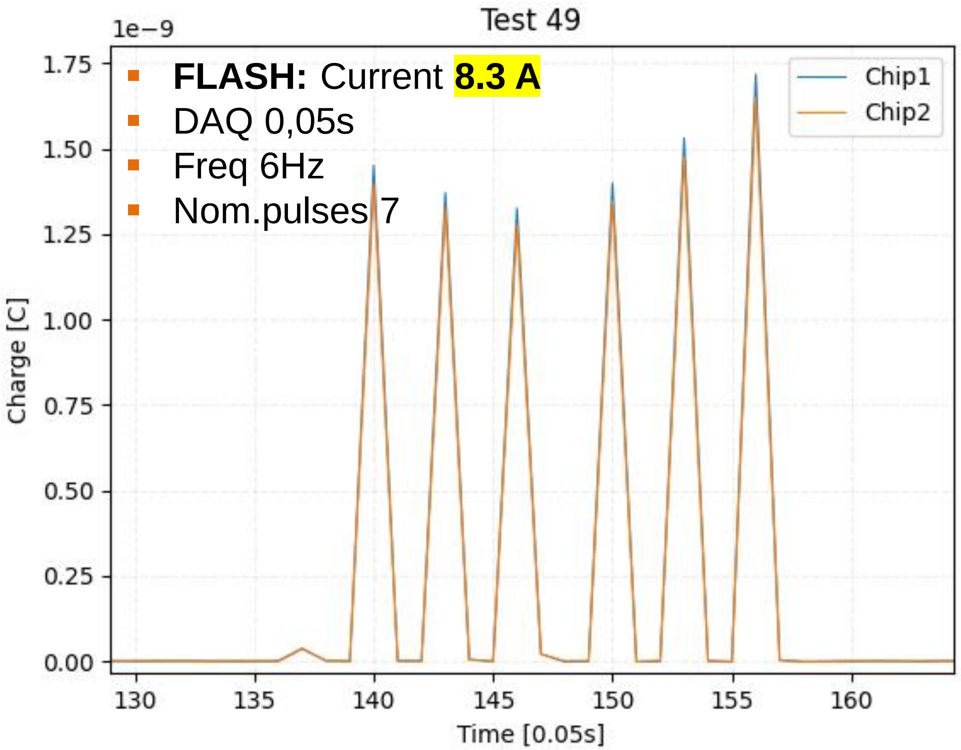
$Q_{/pulse}$CONV vs FLASH (isocenter)

TERA08

→CONV **5.7A** VS FLASH **8.3A**

$$\frac{Q_{/pulse(Flash)}}{Q_{/pulse(Normal)}} = \frac{1.27e{-}9\ C}{1.04e{-}11C} = 122.1\ \sim 120$$





Number of pulses set to <u>anticipate the LINAC interlock.</u>

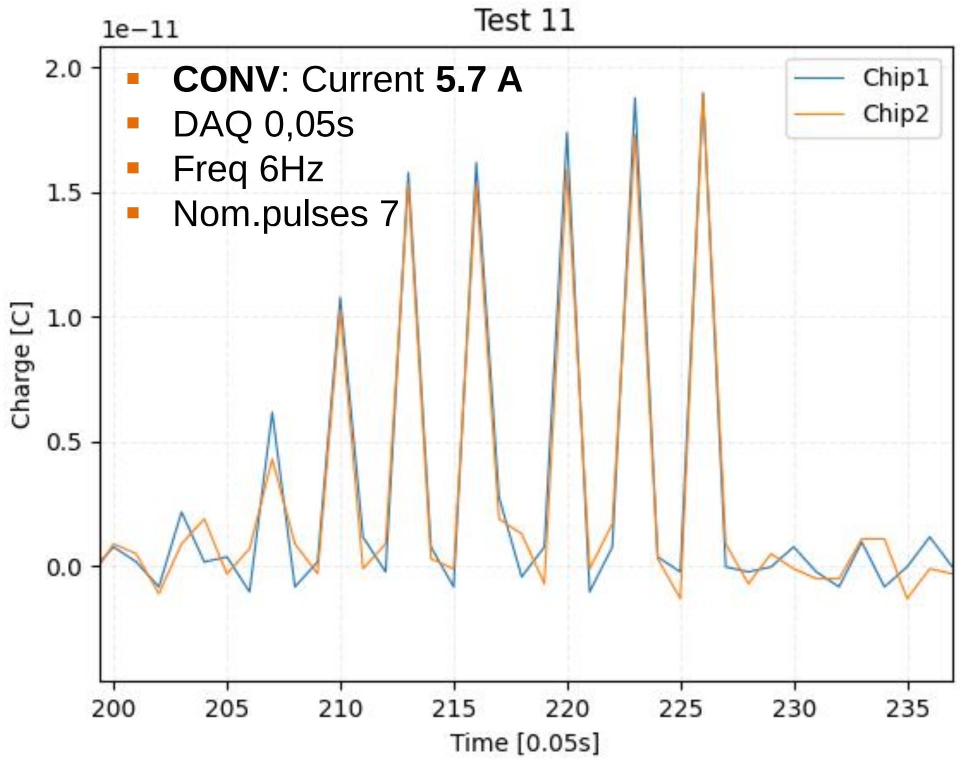
Charge per pulse is computed as: $Q_{/pulse} = \frac{Q_1 + Q_2 + \ldots + Q_7}{7}$

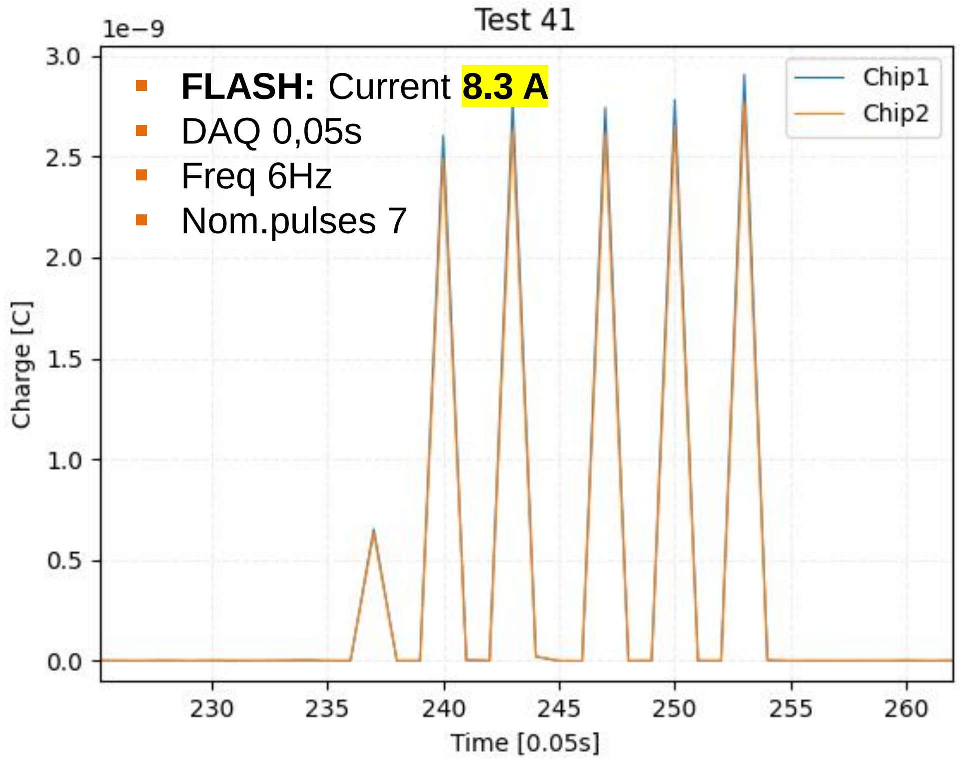
$Q_{/pulse}$CONV vs FLASH (80cm)

TERA08

→CONV **5.7A** VS FLASH **8.3A**

$$\frac{Q_{/pulse(Flash)}}{Q_{/pulse(Normal)}} = \frac{2.414e{-}9\ C}{1.64e{-}11C} = 147.2 \ \sim 150$$





Number of pulses set to anticipate the LINAC interlock.

Charge per pulse is computed as: $Q_{/pulse} = \frac{Q_1+Q_2+\ldots+Q_7}{7}$

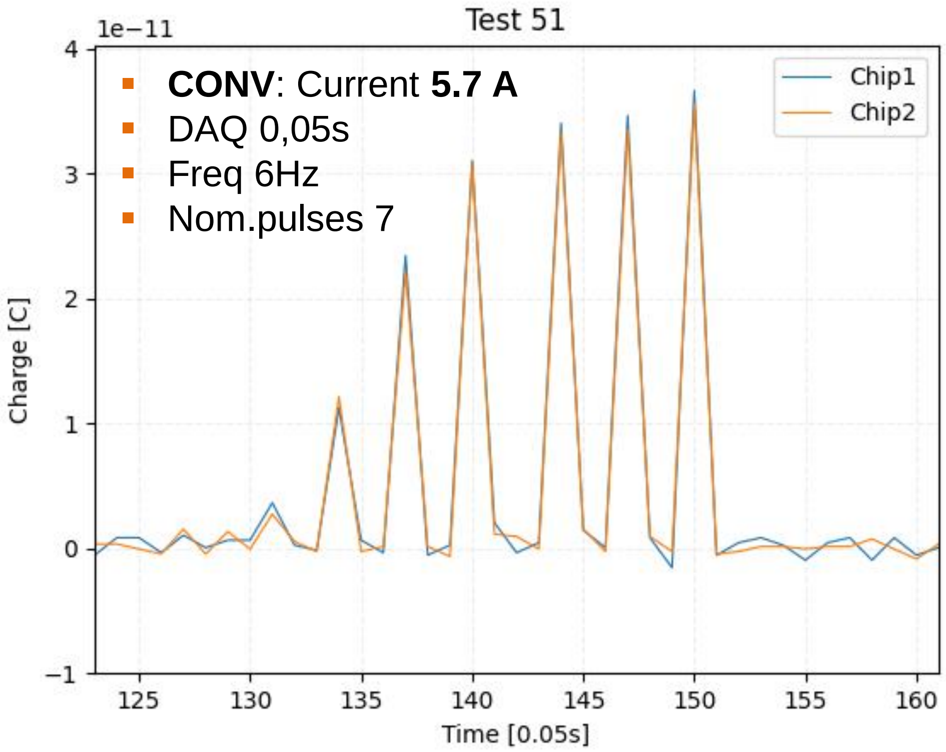
$Q_{/pulse}$CONV vs FLASH (58cm)

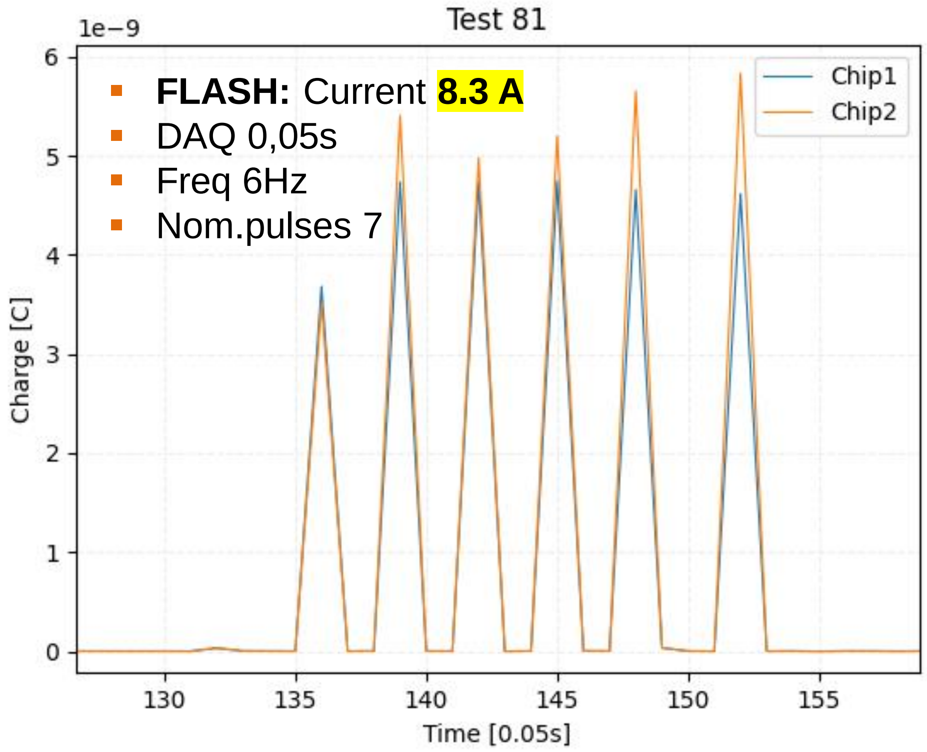
TERA08

→CONV **5.7A** VS FLASH **8.3A**

→CONV **5.7A** VS FLASH **8.3A**

$$\frac{Q_{/pulse(Flash)}}{Q_{/pulse(Normal)}} = \frac{3.890e{-}9C}{2.83e{-}11C} = 137.5 \sim 140$$





Charge per pulse is computed as: $Q_{/pulse} = \frac{Q_1+Q_2+\ldots+Q_7}{7}$

Number of pulses set to <u>anticipate the LINAC interlock.</u>

Stability of the pulses

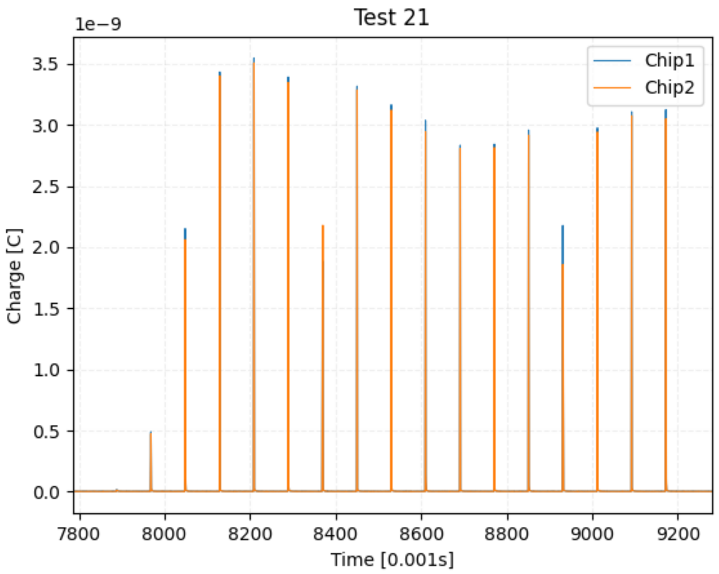
TERA08

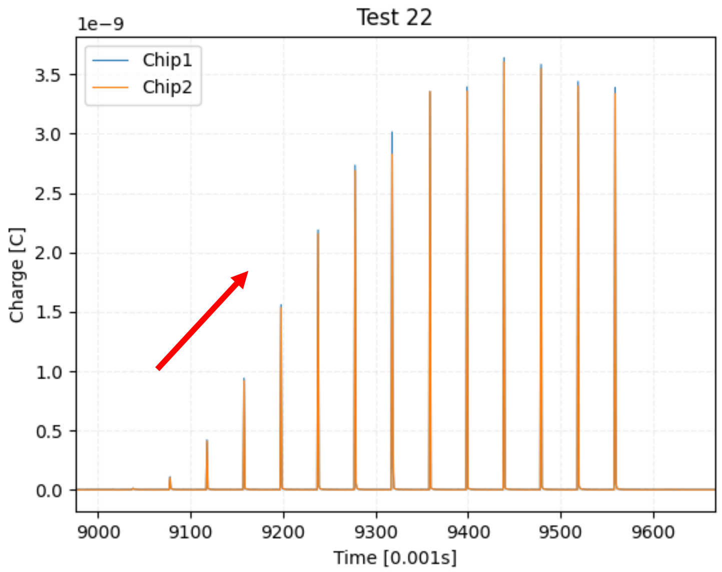
- Current 8.5 A
- DAQ 0,001s
- Freq **12.5Hz**
- Counted pulses 18

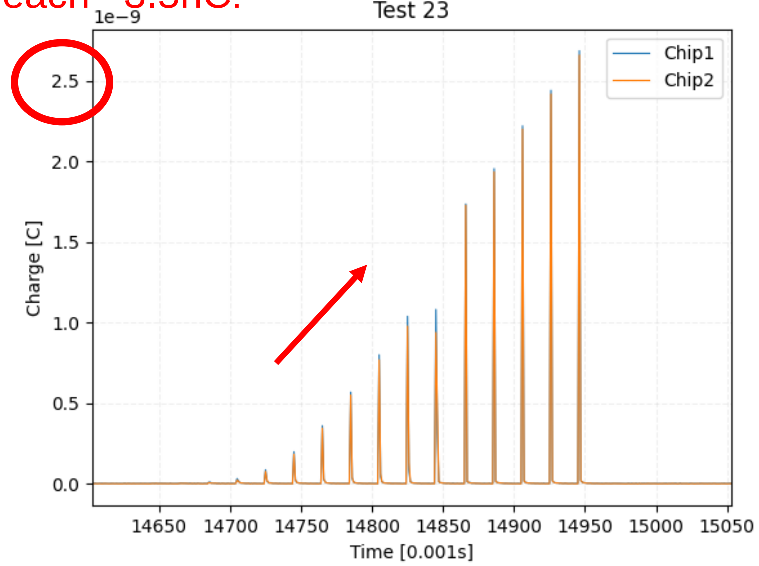
- Current 8.5 A
- DAQ 0,001s
- Freq **25Hz**
- Counted pulses 16

- Current 8.5 A
- DAQ 0,001s
- Freq **50Hz**
- Counted pulses 17

For 8.5A we don't reach ~3.5nC!

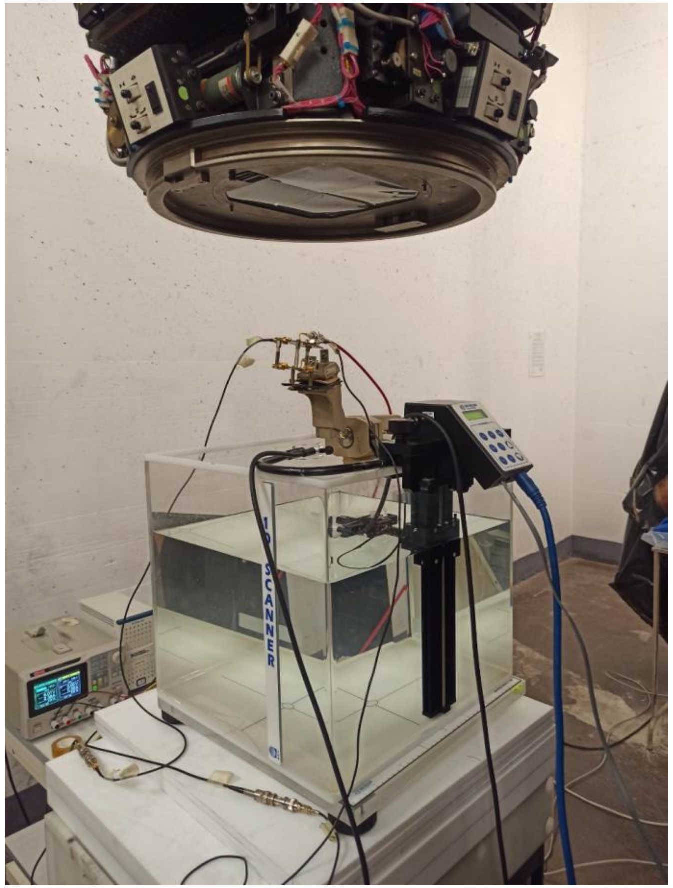






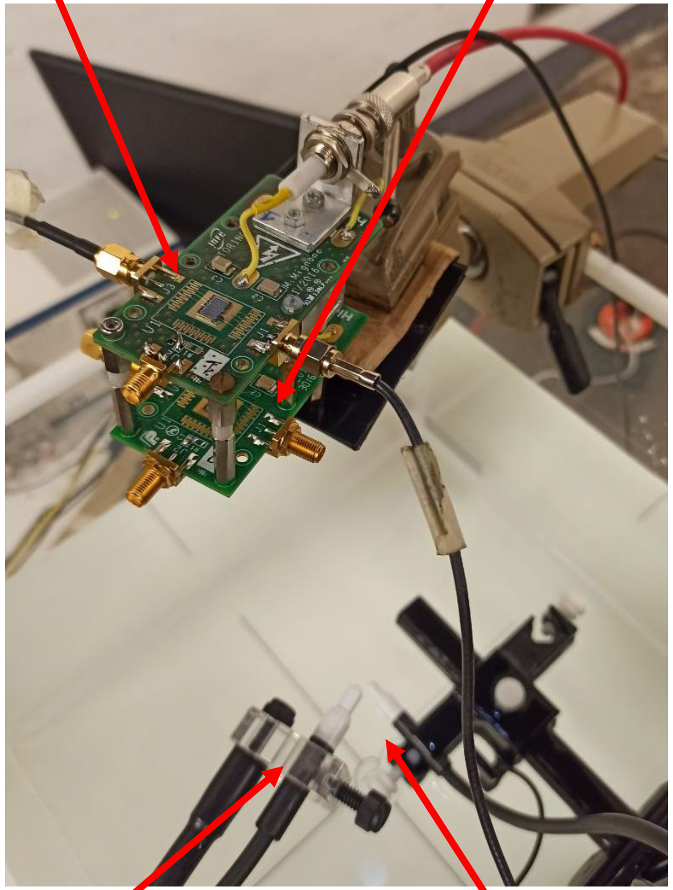
Experimental setup - 3

- **10MeV** electron beams
- **Flash vs normal** mode
- TERA08 and IC
- Different **gun currents**
  - 5.7A, 6.7A, 7.6A in *normal* mode
  - 6.7A, 7.6A, 8.3A , 8.5A in *flash* mode
- Different **frequencies**
  - 6, 50, 100, 400 Hz in *normal* mode
  - 6, 12, 25, 50, 100, 200, 400 Hz in *flash* mode
- Fixed number of pulses (**500 pulses**)
- x3 each condition



Sensor for TERA08 (field border)

Sensor for pulse counting (field border)

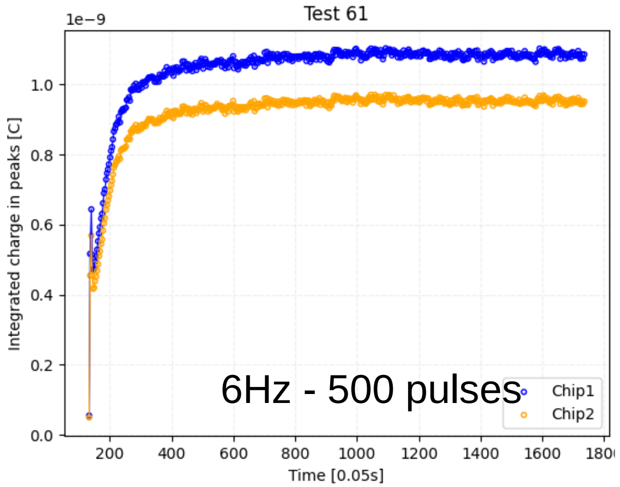


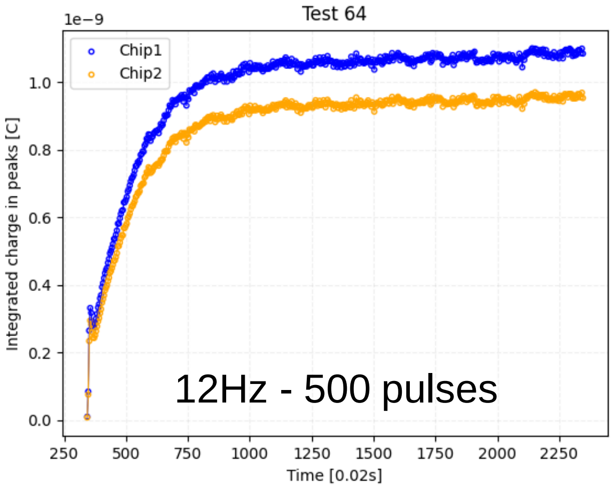
$IC_{(2)}$ in the field border

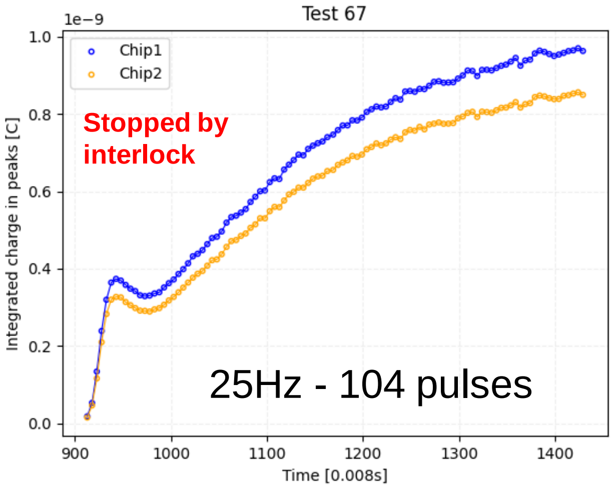
$IC_{(1)}$ in the water

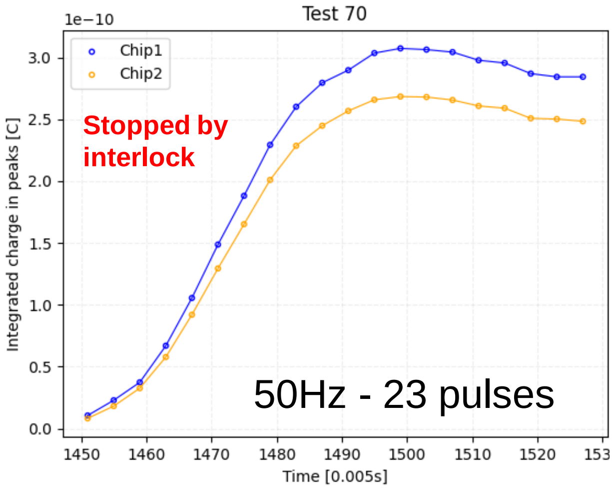
FLASH: 7.6A – Charge per pulse

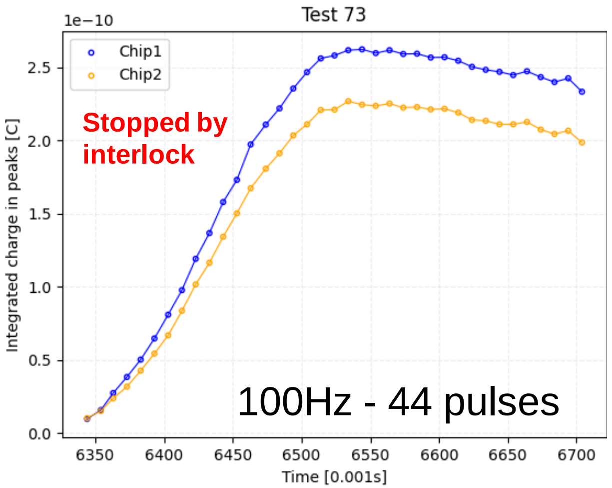
TERA08

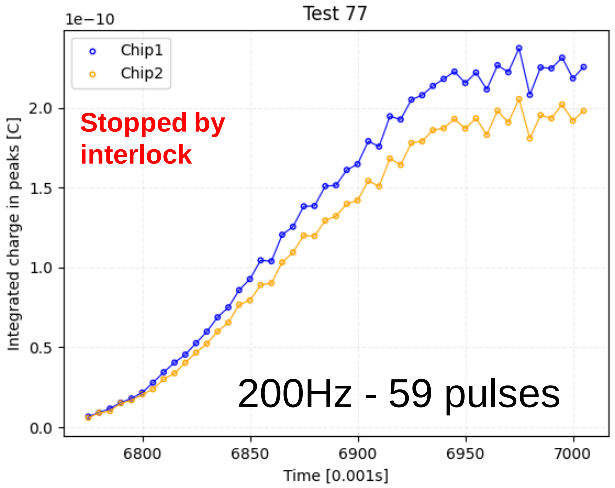


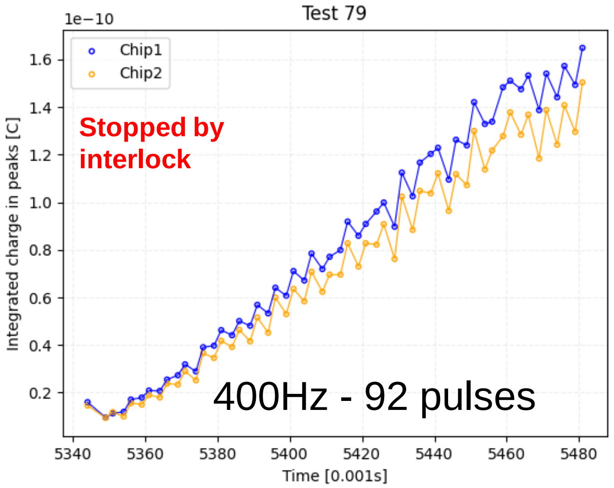






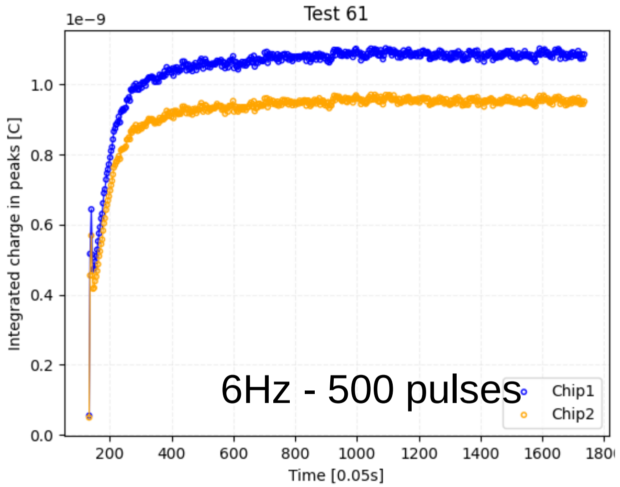


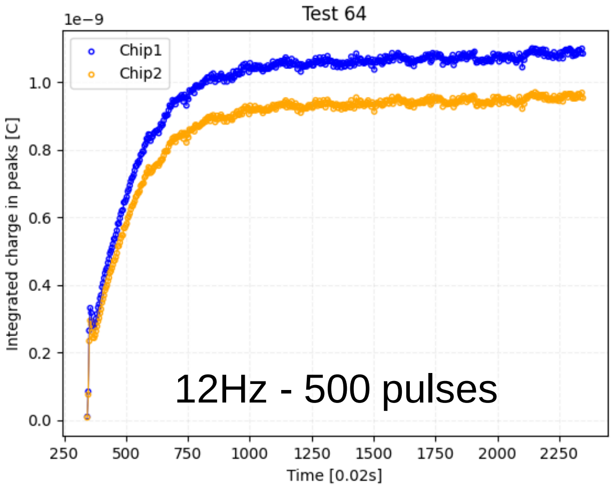


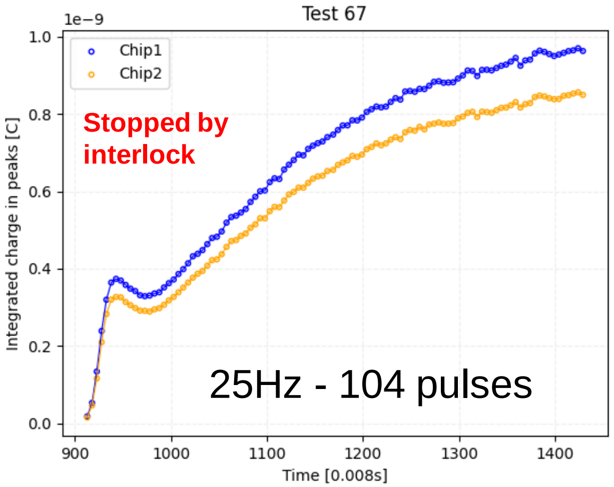


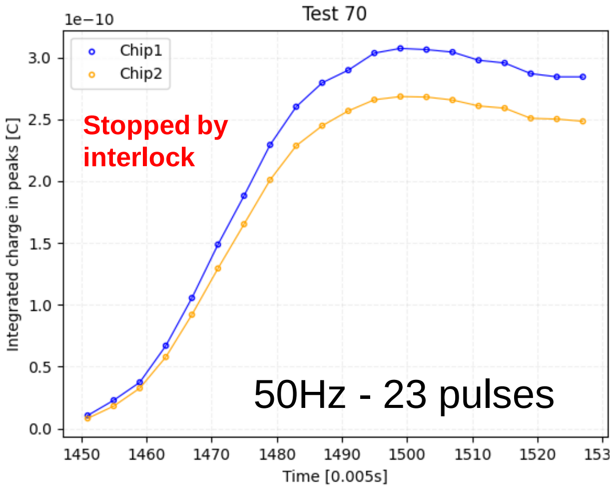
FLASH: 7.6A – Charge per pulse

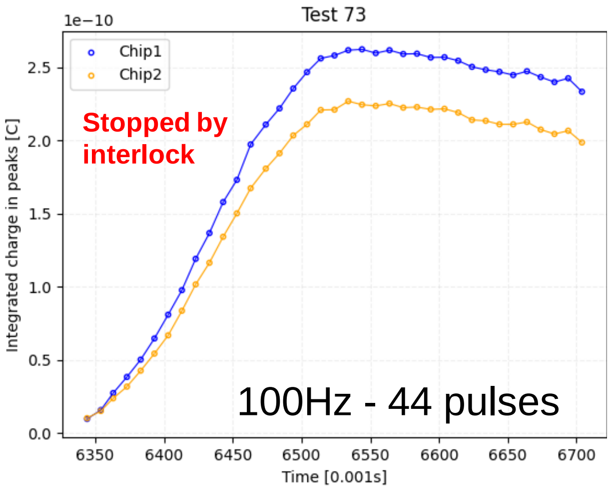
TERA08

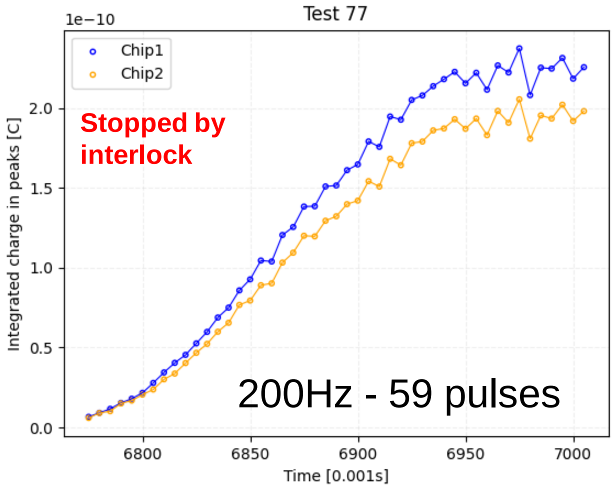


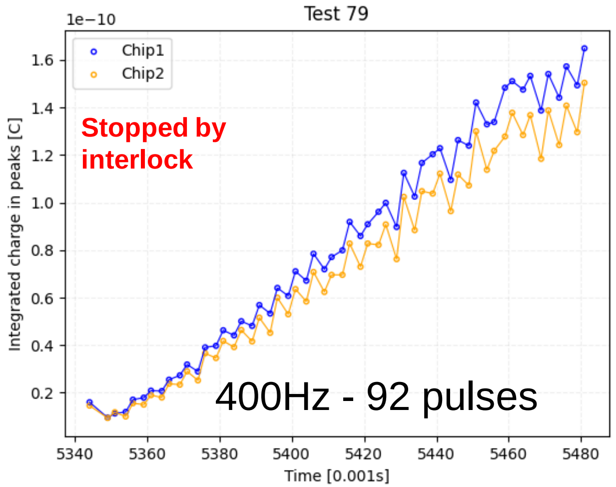








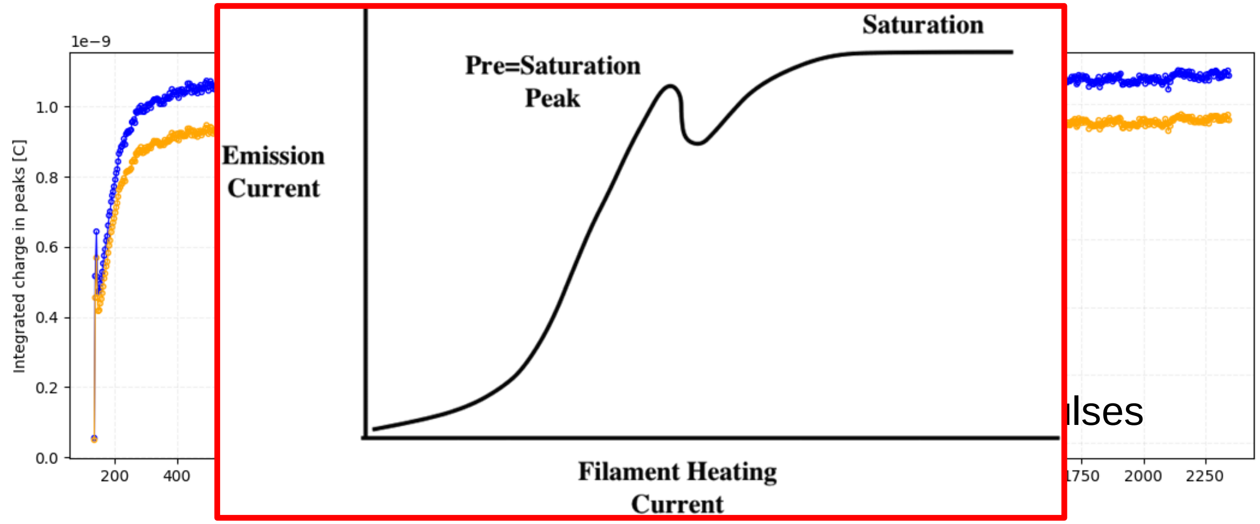


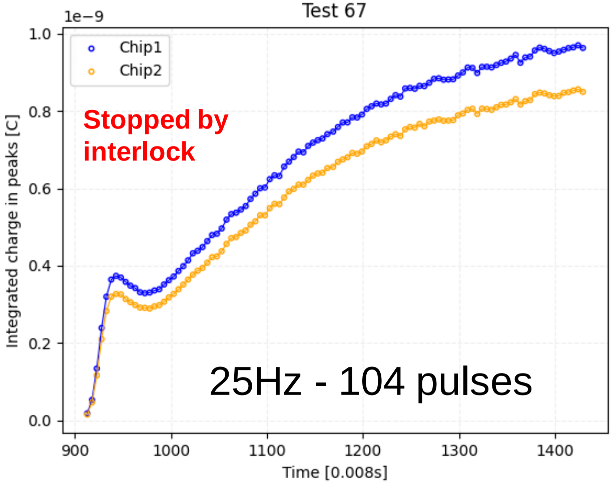


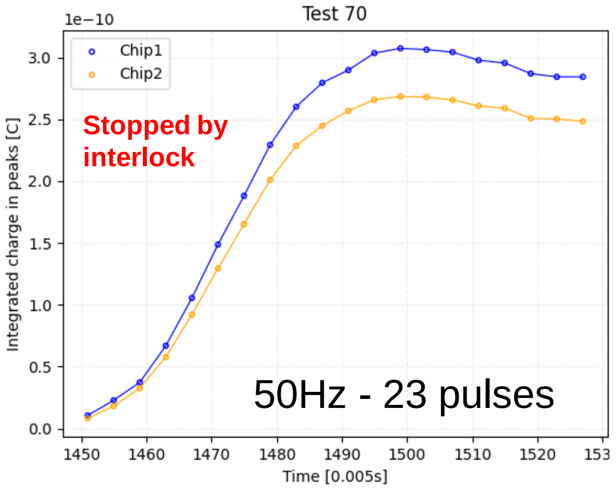
Similar behaviour for 8,3 – 8,5 A

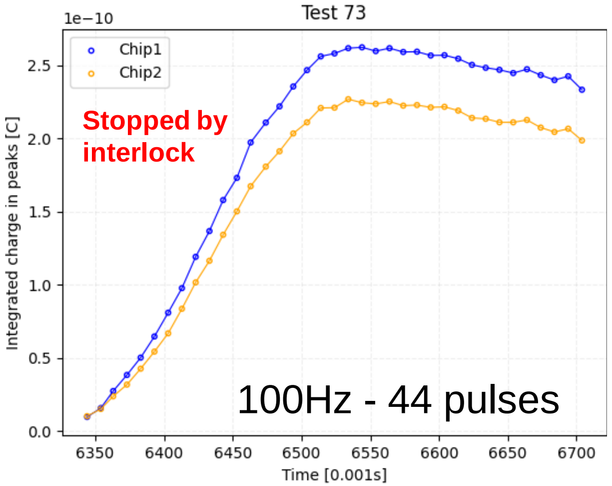
FLASH: 7.6A – Charge per pulse

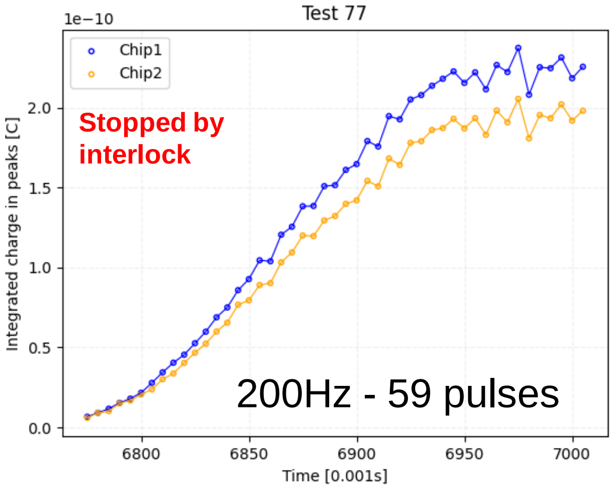
TERA08

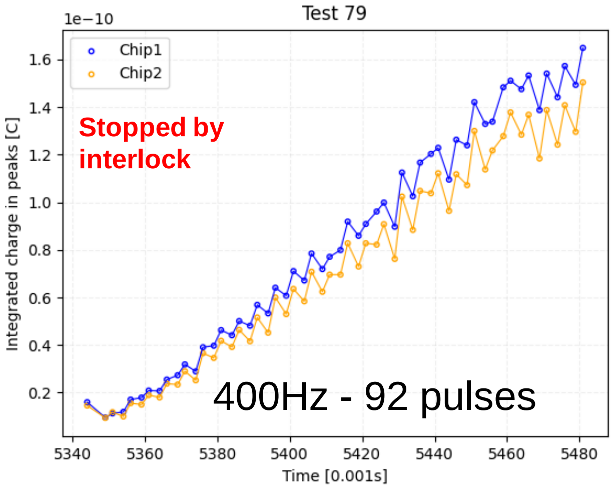








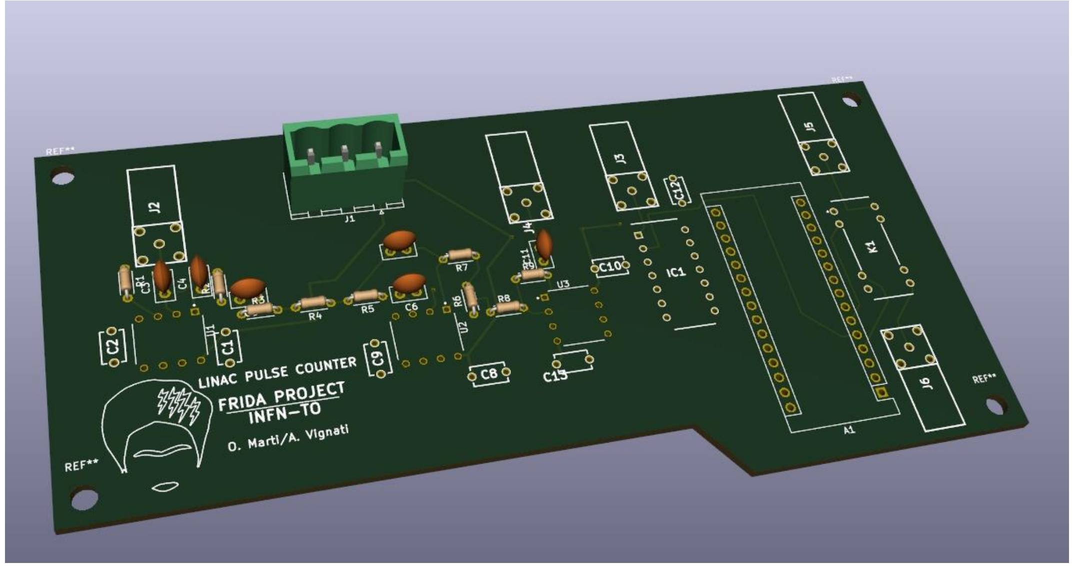




Similar behaviour for 8,3 – 8,5 A

What's next

- Optimization of the pulse counter



- Agreement with Elekta
- Delay of the interlock activation
- Further optimization of the gun current and RF phase optimization