Target Material tests at MAMI for the FCC-ee positron source
Ferrara-IJCLab Beam Tests in November 2021

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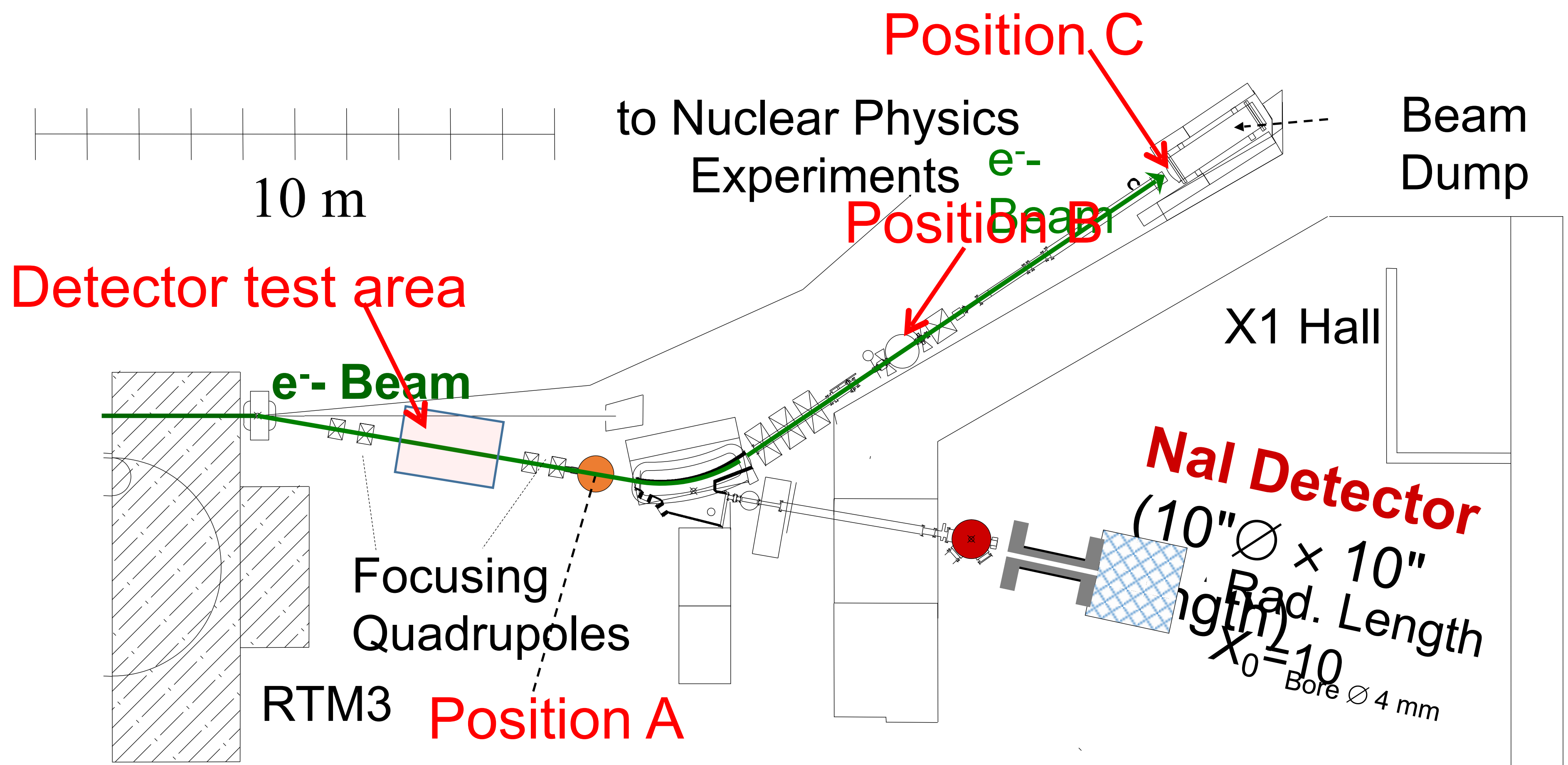
+ Werner Lauth

MAMI Experiment



Vacuum chamber with 3 axis
-Goniometer
Diameter 600 mm
Windows under different angles
Beamsize < 10 µm in both directions
Max. current depending on target
For thick targets (1mm Tungsten) I < ~nA

Outline

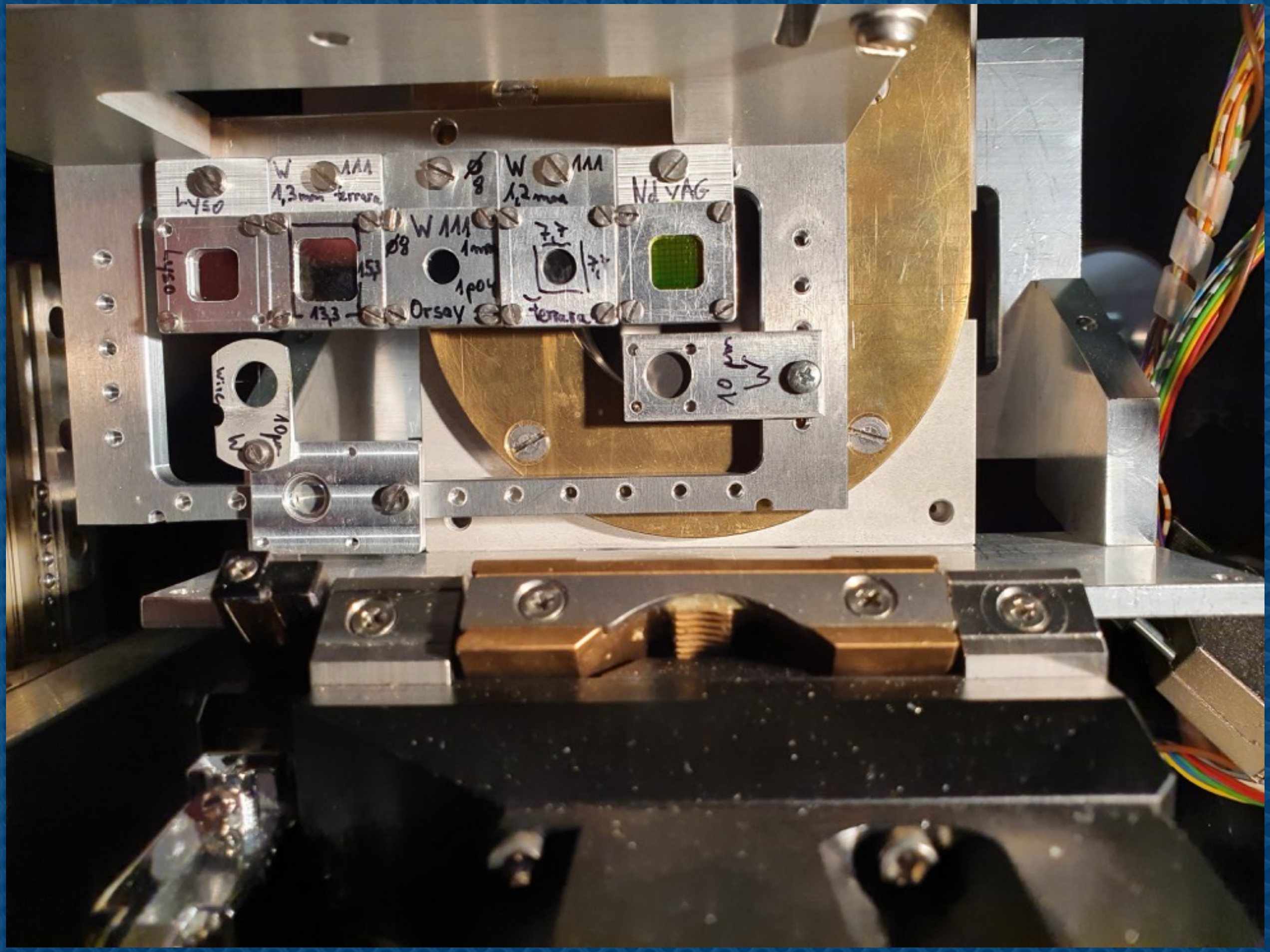
1) Position A

2) Position C

1- Position A (the Crystals)

❖ Werner put 2 W(1,1,1) targets of Ferrara and 1 W(1,1,1) crystal of IJCLab on a Goniometer at Position A which is under vacuum before we come.

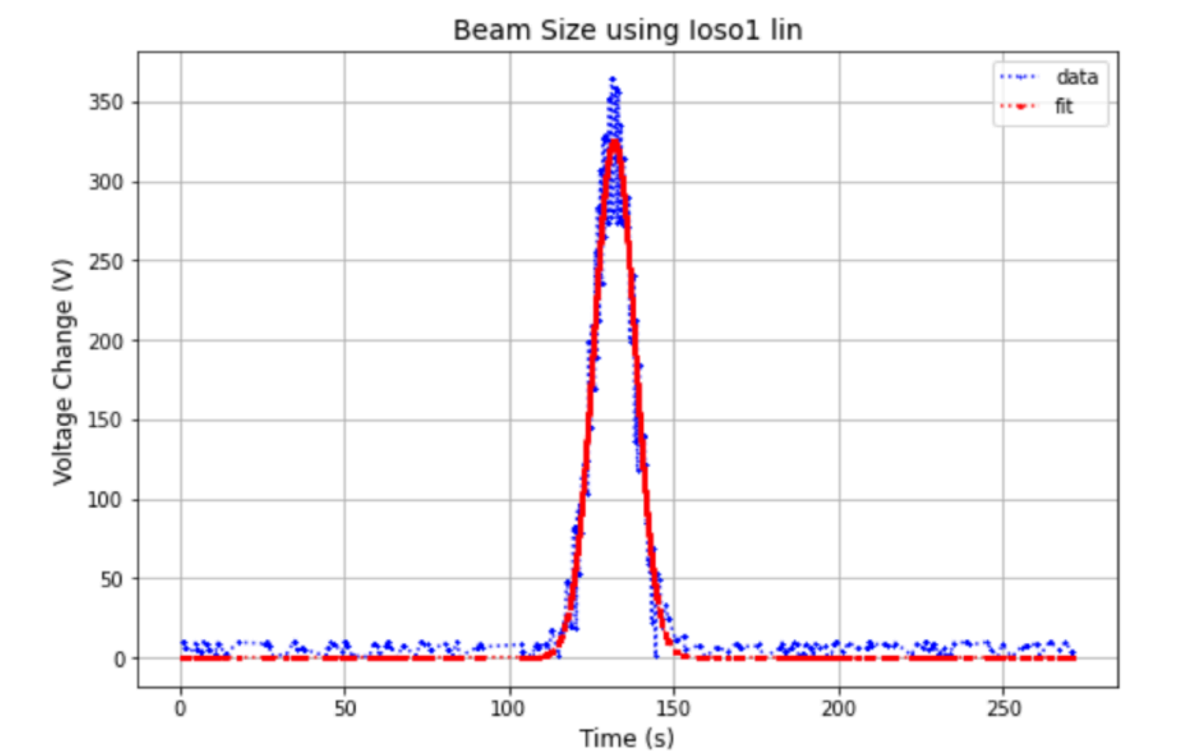
❖ We determine the positions of our targets and scan PHI and CRAD to find the orientation of our crystals.



❖Notice the additional diagnostic elements: YAG, LYSO screens as well as h/v wires for beam size and profile measurements.

1- Position A (the Crystals)

- Using the wire scanner, we can determine the beam size 46/30 um (h/v), preliminary.

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the horizontal rms beam size 6.283218778451794 seconds
the horizontal rms beam size 0.046331467346425306 mm
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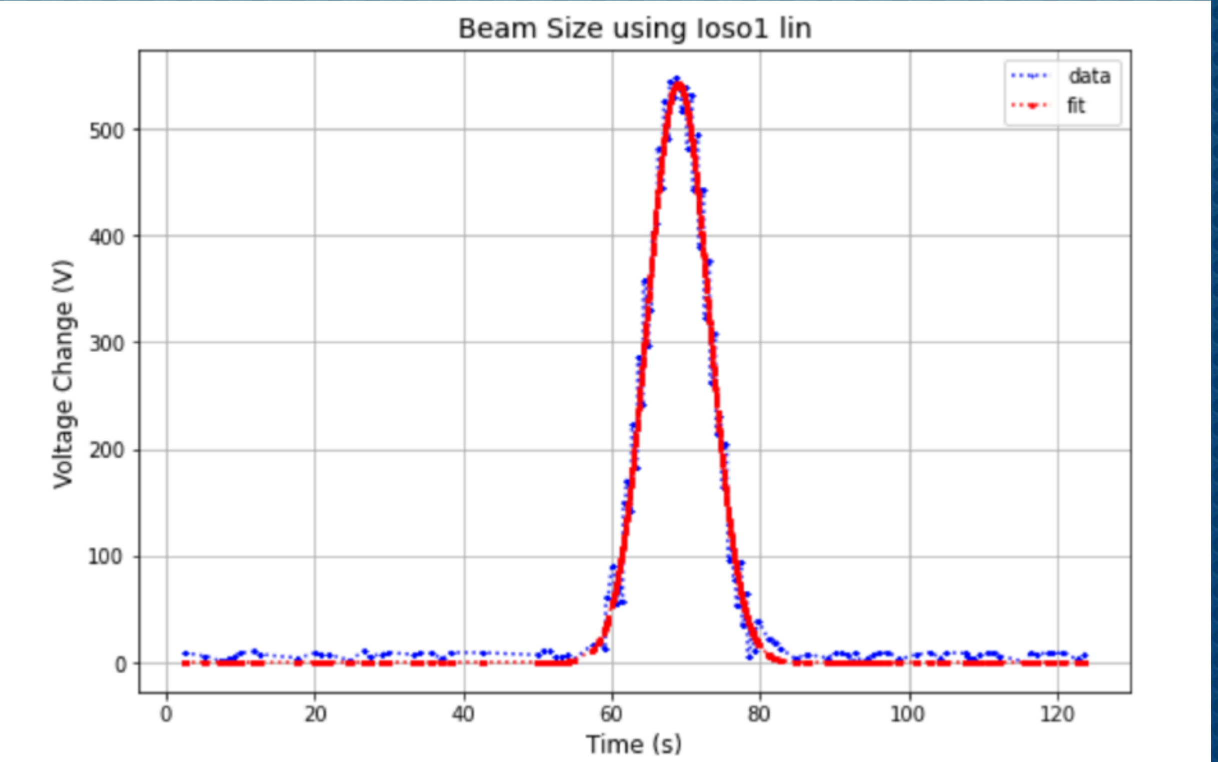


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the vertical rms beam size 4.128921067732017 seconds
the vertical rms beam size 0.030446014753O8332 mm
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- Voltage of the gun = -9 V which corresponds to 1 nA of current.

- Measurements were performed on 04 Nov at 14h30.

1- Position A (the Crystals)

- IJCLab 1 mm thick W crystal is radiated with 10.3 nA for 08h27m plus with 7.7 nC for 7h07m with the rms beam size 46/30 um (h/v).

- Equivalent to say 15h of 9.5 nC

$$Fluence_{achieved} = \frac{9.5x10^{-9}}{1.6x10^{-19}} \times \frac{1}{\pi \; 46x10^{-3} \; 30x10^{-3}} \times 15 \times 3600 \times 0.25 = 1.8x10^{17}$$

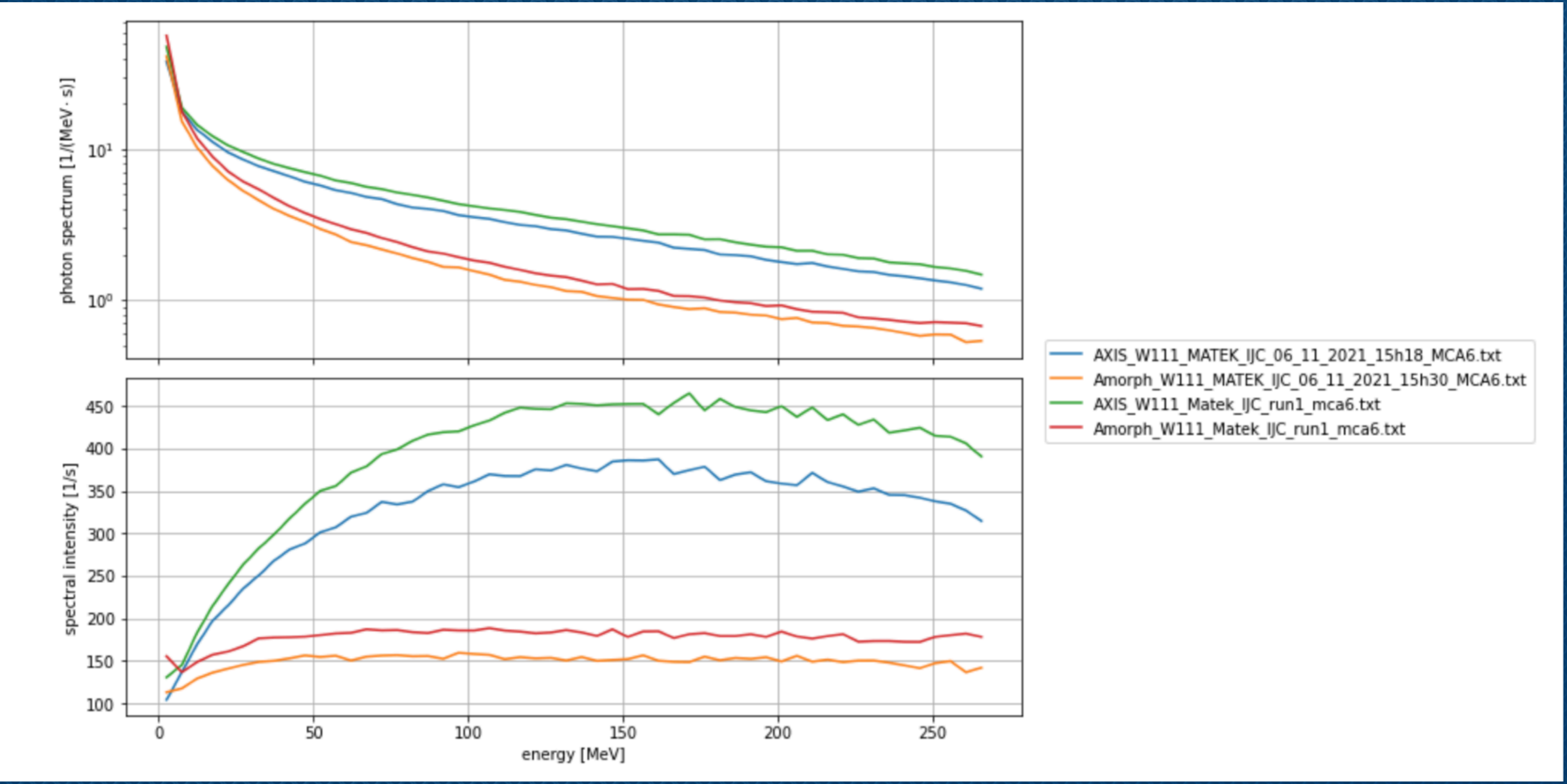
Assuming the 2-sigma contains ~the beam

- SLC achieved fluency on crystal is $2x10^{18}$; considering the radiation during the alignments and so on we can say we are at 1/10th of what has been achieved (a thorough calculation to be done.)

1- Position A (the Crystals)

- SLC achieved fluency on crystal is $2x10^{18}$; considering the radiation during the alignments and so on we can say we are at 1/5th of what has been achieved (a thorough calculation to be done.)

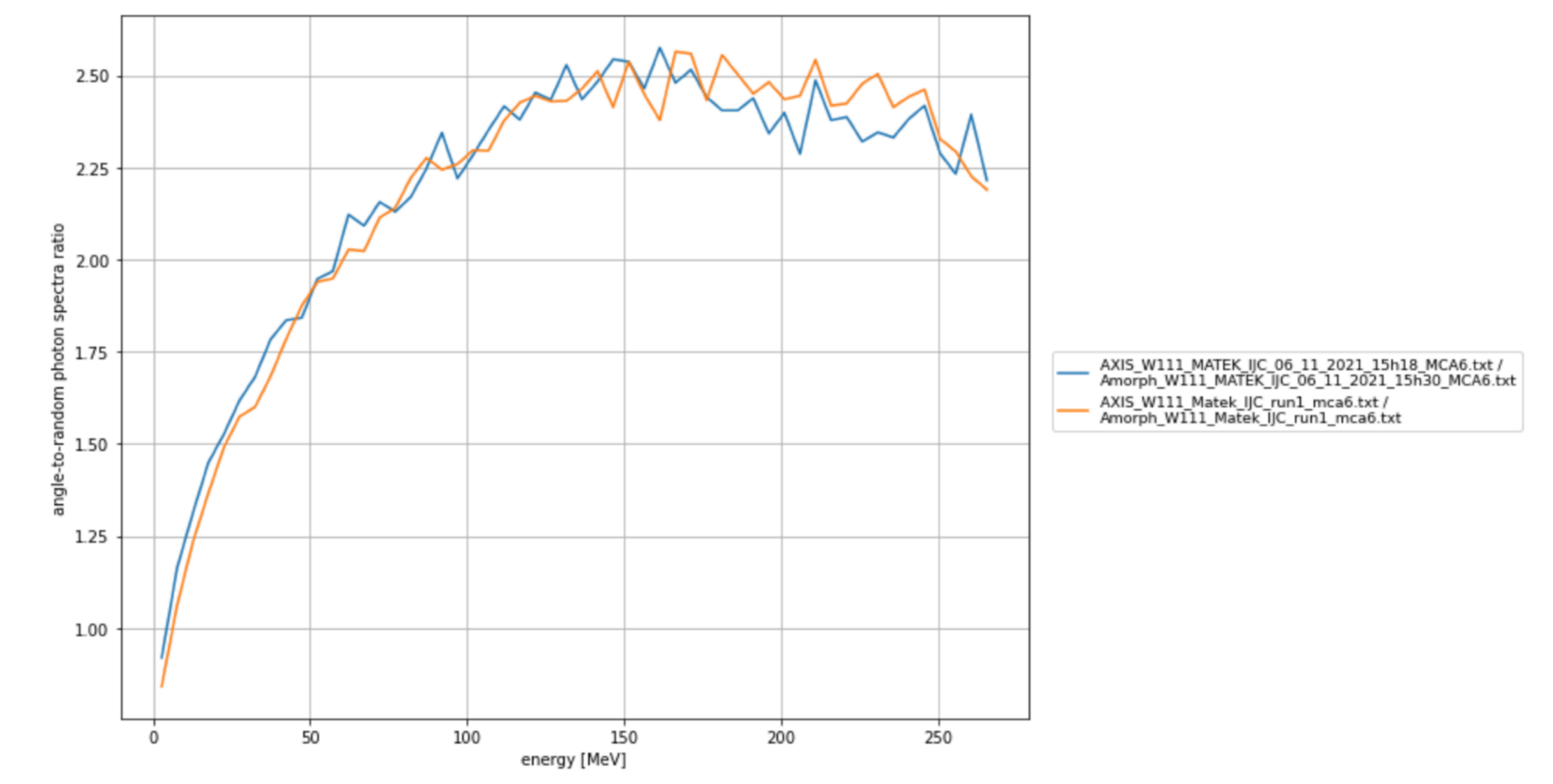
- Under this total dose our crystal should kept its crystal structure for channeling radiation, and it did:



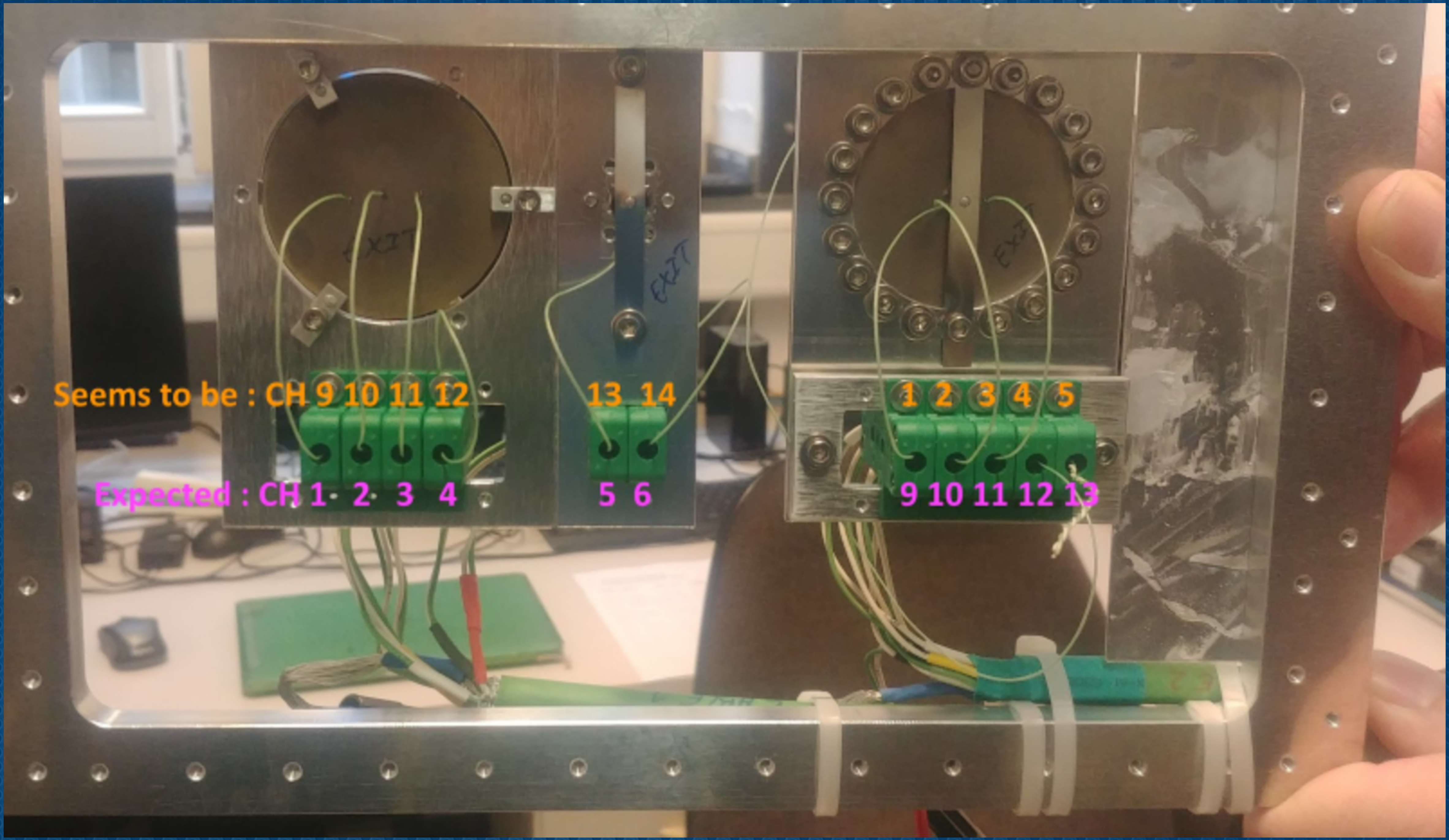
1- Position A (the Crystals)

❖ Under this total dose our crystal should kept its crystal structure for channeling radiation, and it did.

❖ Relative (AXIS/Amorphous, associate BACKGROUNDs subtracted!) plot shows the before and after 27h radiation spectral ratio.



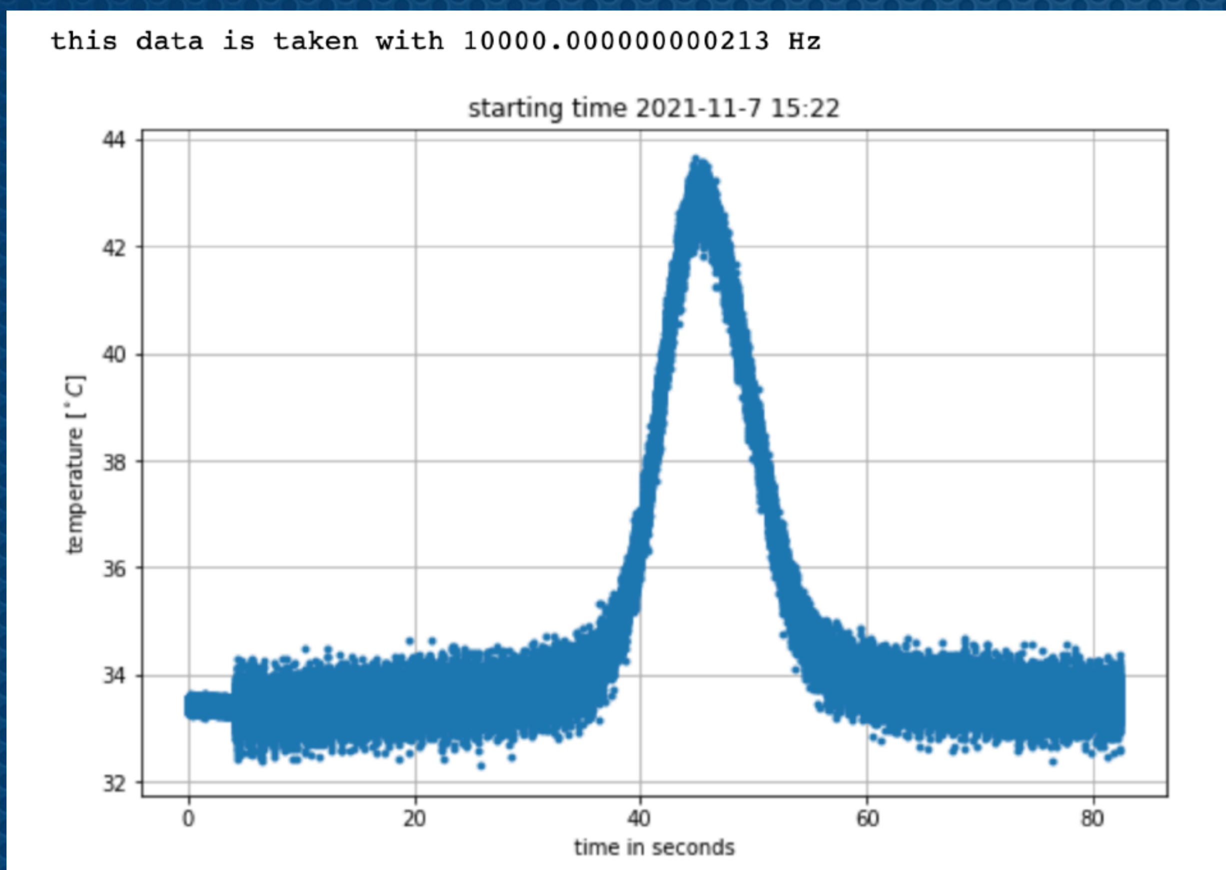
2. Position C (Thermo Couples)



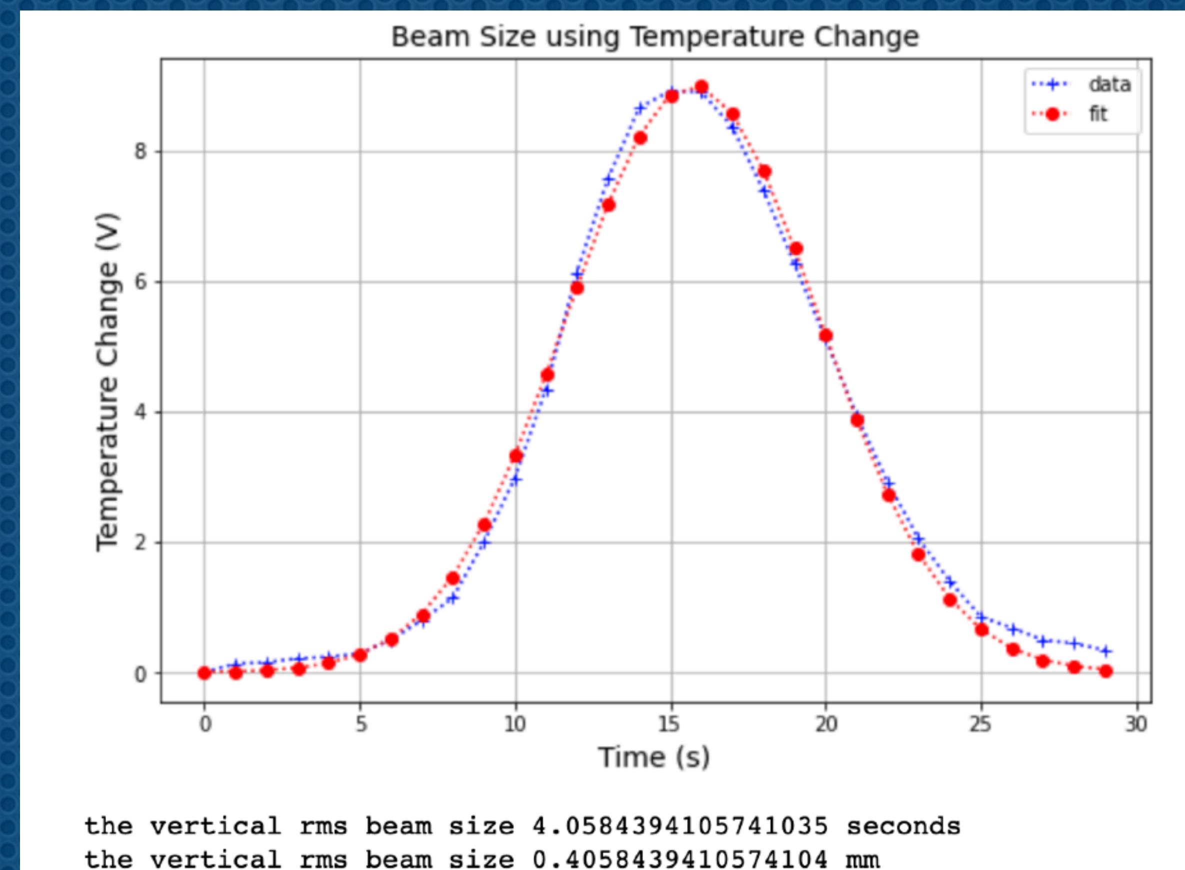
- Back side (w.r.t. beam) of the target holder at Position C. Left 50 mm diameter thermally isolated amorphous, then crystal, and left most contacted target and a phosphor screen.

2. Position C (Thermo Couples)

- Measuring the beam size cleverly using the thermocouples and stepper motors, as Werner suggested. Upper limit for the beam size.



Raw Data



Baseline subtracted, Gaussian Fit

2. Position C (Thermo Couples)

Material	Diameter	Thickness	Avg. power at 10.5 J/g	Temp. Max	Avg. power at 35 J/g	Temp. Max
W	25 mm	2 mm	5.1 W	239 °C	17.1 W	510 °C

❖ Our temperature simulation was for ϕ=25 mm for 0.1 mm rms beam size with current avg. current 0.6 uA.

❖ But we end up ϕ=50 mm disk and 0.4 mm rms beam size and various beam current.

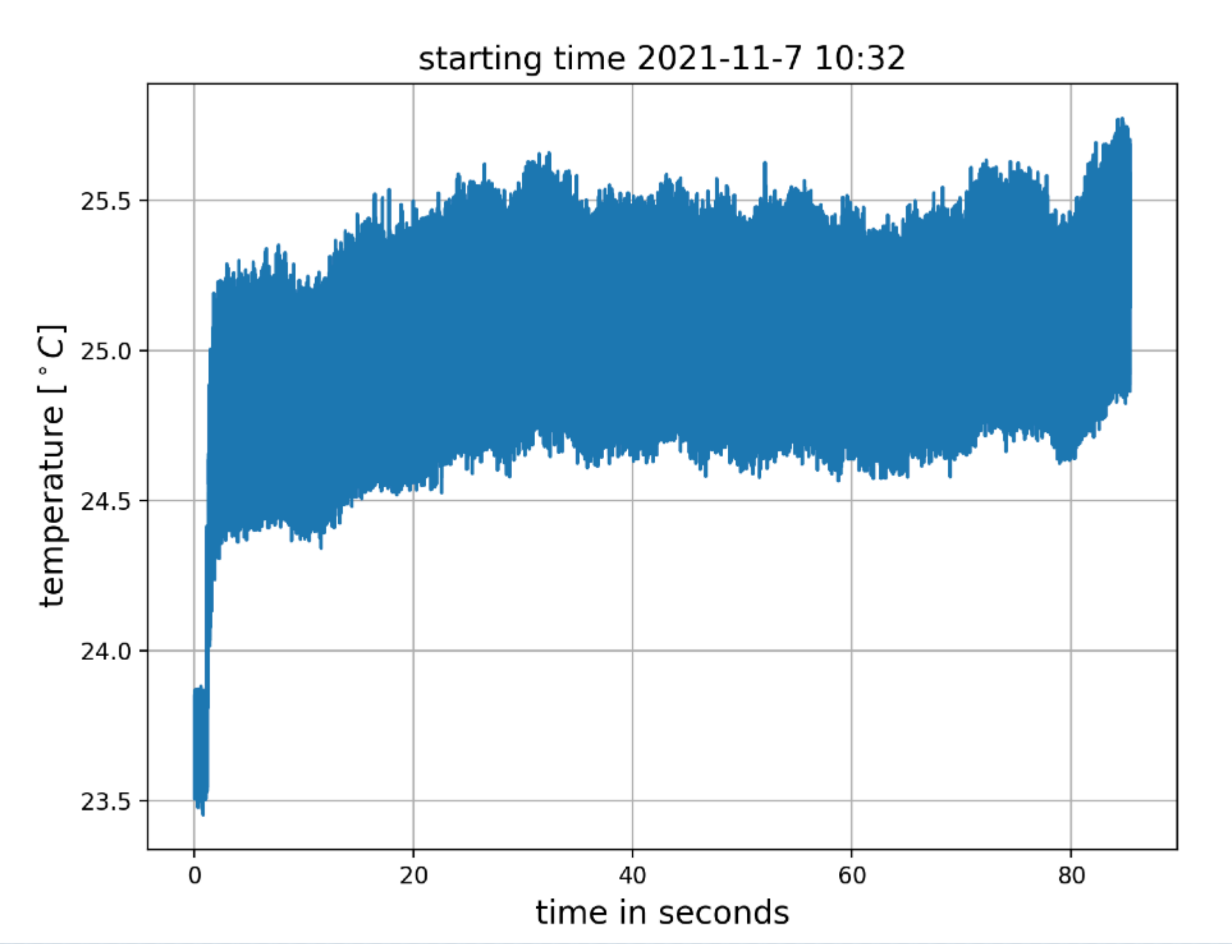
Rms beam size	E_{dep}^{mean} [MeV]	E_{cell}^{max} [MeV]	$PEDD^{e-}$ [J/g]	Pulse Duration	Current (@200 Hz)	Power for 10.5 J/g	Power for 35 J/g
0.1 mm	7.02	68.42	4.6×10^{-10}	60 μs	0.6 μA	5.1 W	17.1 W
0.2 mm	7.02	22.58	1.5×10^{-10}	182 μs	1.8 μA	15.8 W	52.5 W
0.3 mm	7.13	13.05	8.7×10^{-11}	315 μs	3.2 μA	27.6 W	92.0 W
0.4 mm	7.08	9.54	6.4×10^{-11}	418 μs	4.3 μA	37.1 W	124 W
0.5 mm	7.08	7.15	4.8×10^{-11}	571 μs	5.7 μA	49.6 W	165 W

2. Position C (Thermo Couples)

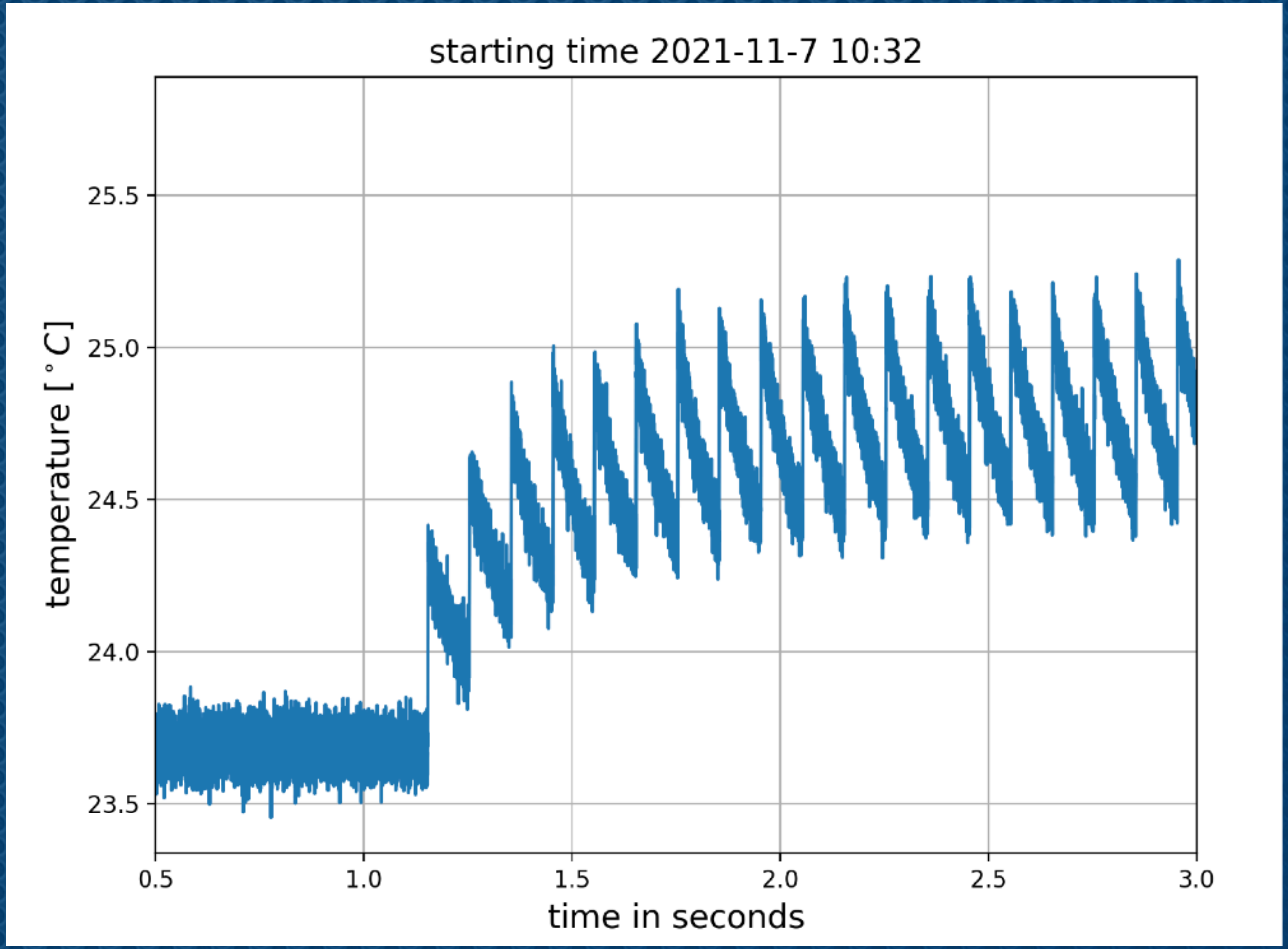
❖ But we end up ϕ=50 mm W disk and 0.4 mm rms beam size and various beam current.

❖ Below, data taken with thermally isolated target for 10 Hz, 1 ms pulse duration 1uA/100 = 10 nA average current.

❖ We can resolve the pulse structure:



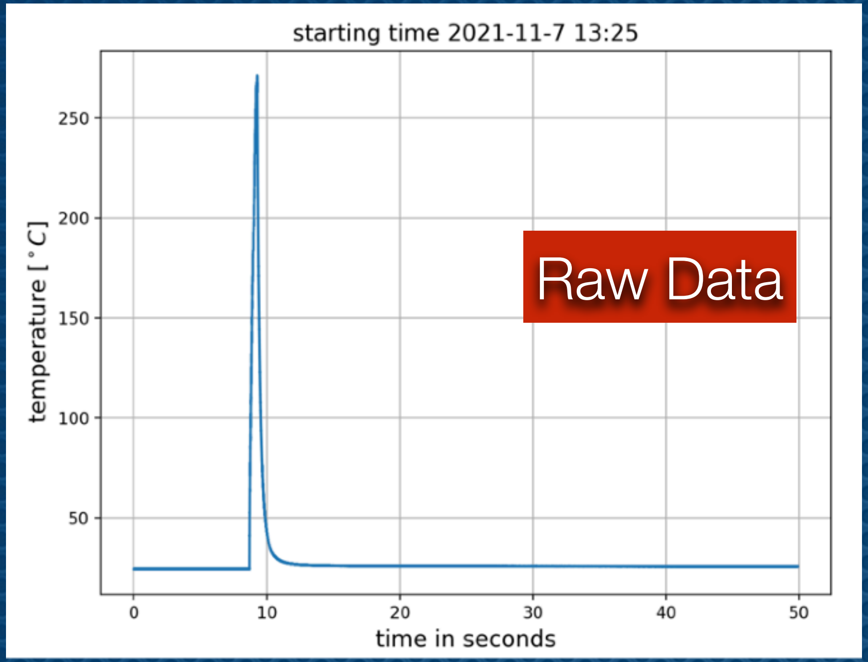
Raw Data

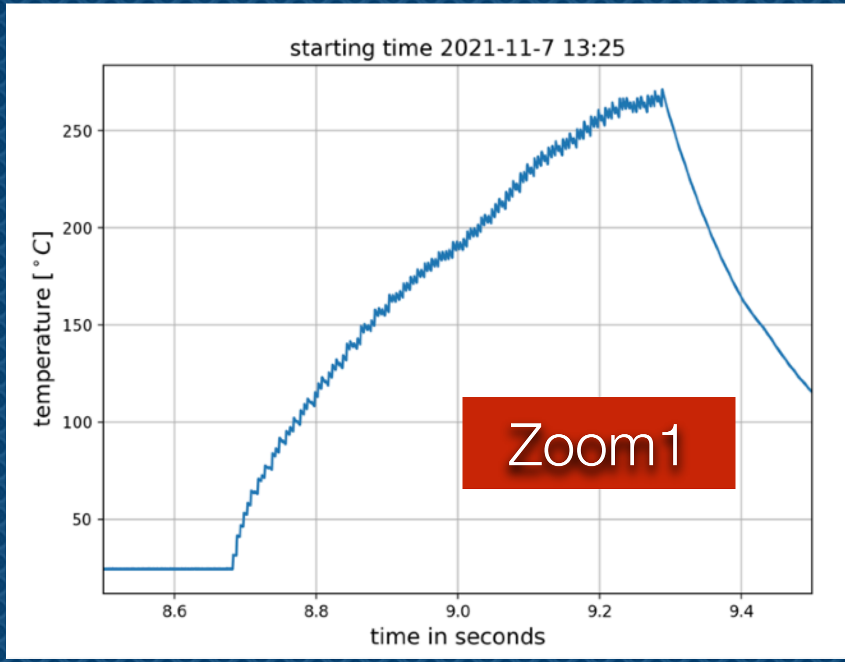


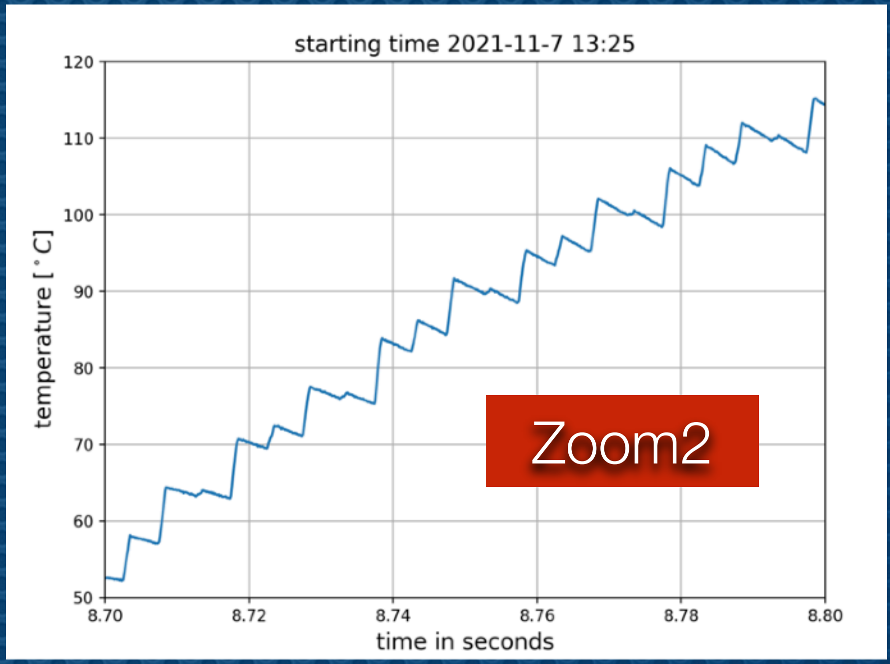
Zoom in

2. Position C (Thermo Couples)

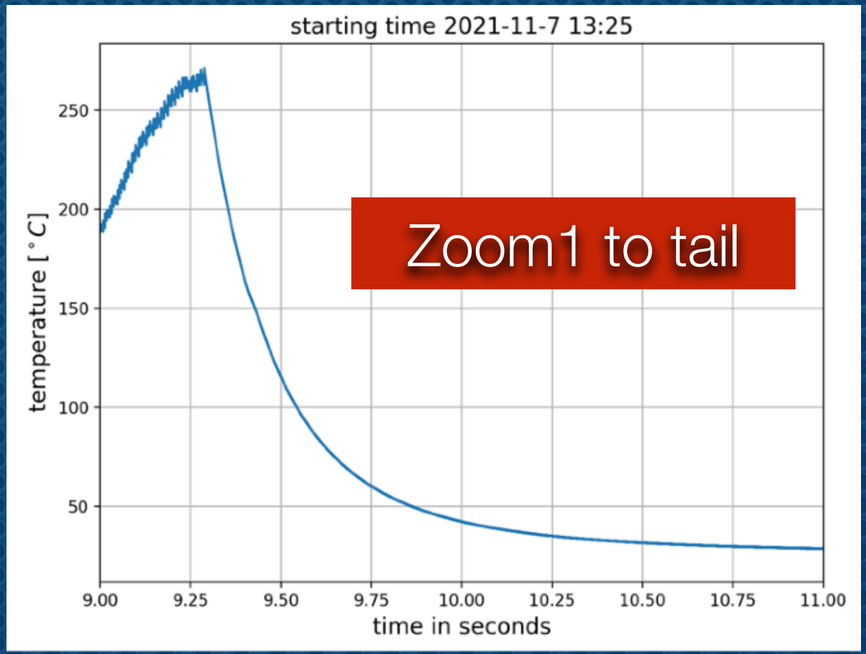
❖ Below, data taken with thermally isolated target for 200 Hz, 1 ms pulse duration 2uA average current.





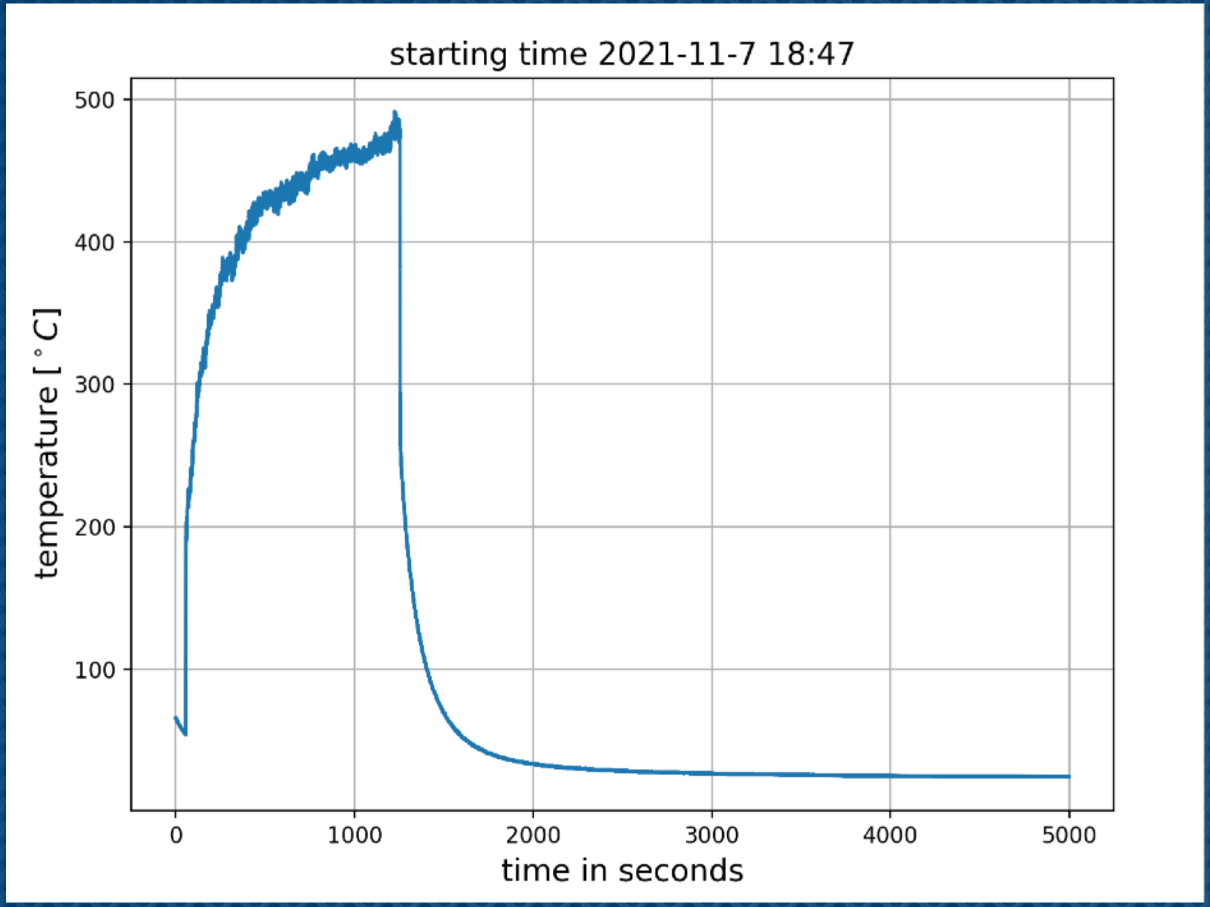


❖ Beam is lost just after the switch but still contains useful data .

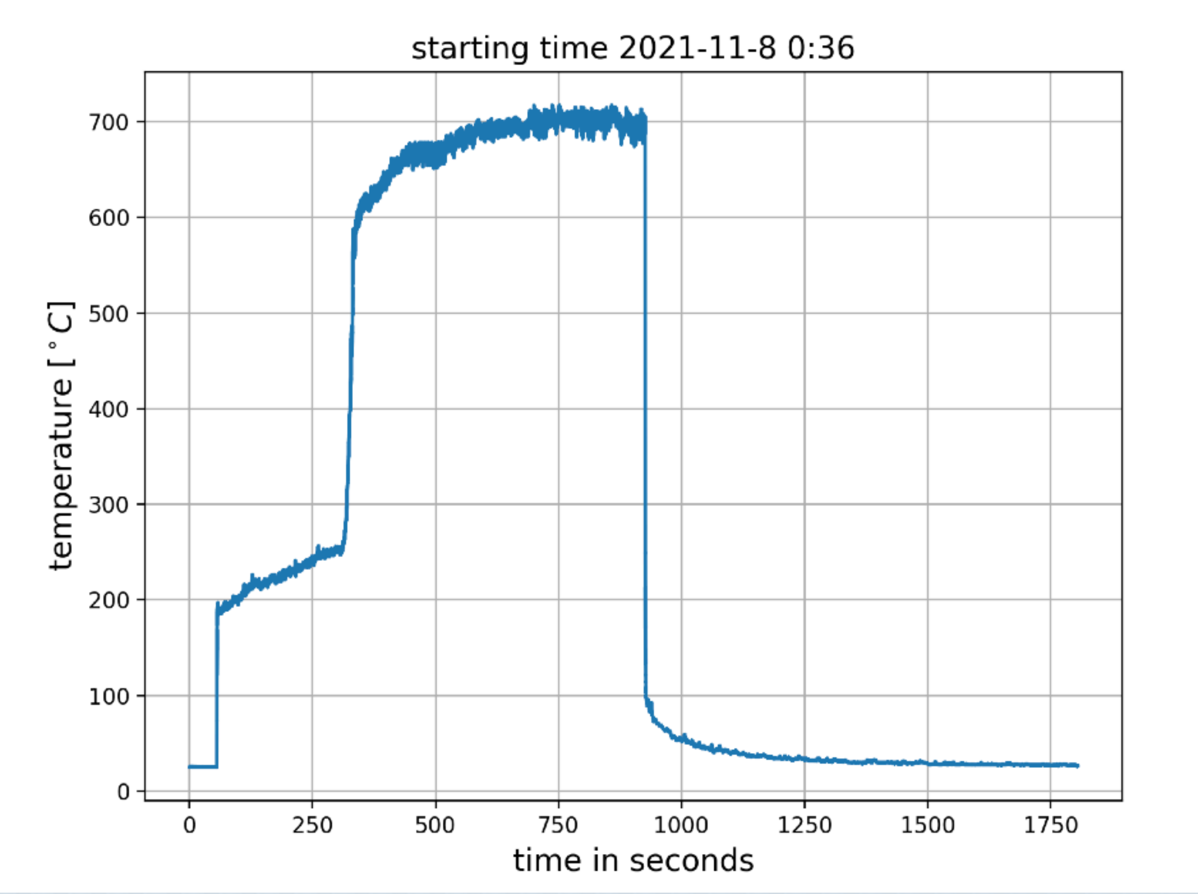


2. Position C (Thermo Couples)

❖ Below, data taken with thermally isolated target for 200 Hz, 0.6 ms pulse duration, 4 uA (?) average current. Different times, more importantly re-aligned with the dipoles (h/v).



4 uA average, but seems not well-aligned, 10k Sampling (run31)



1uA beginning, switch (jump can be seen) to 4 uA average, well-aligned, 20k Sampling (run37)

Outline

0) Target Holder

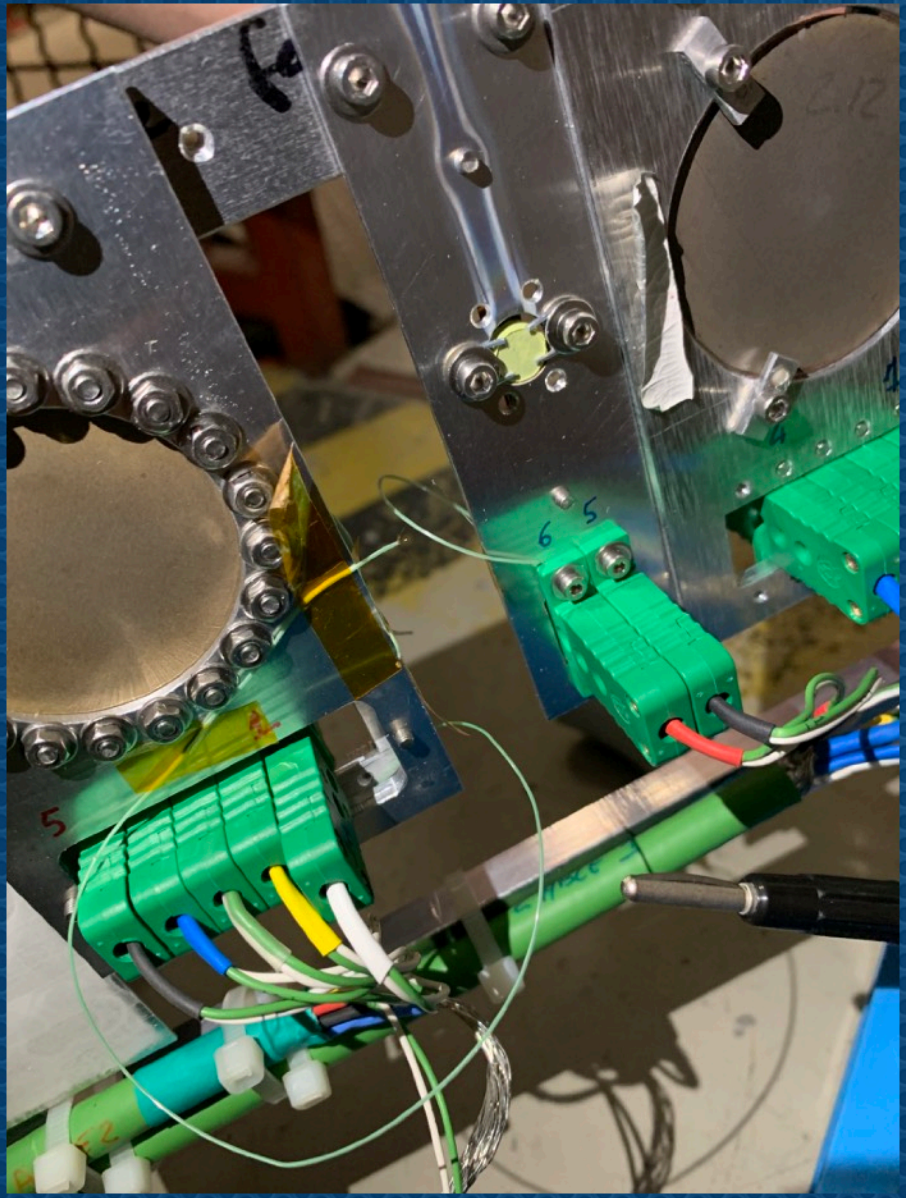
1) Thermocouples in the Air

2) Amorphous at Position C

3) Crystal at Position C

0- Target Holder

❖ As requested by IJC Lab, we remove the frame at Position C, for the thermocouple (TC) manipulation. TCs measuring the ambient air as well as broken-glued TCs are taped with capton, to measure directly the beam hitting TCs.



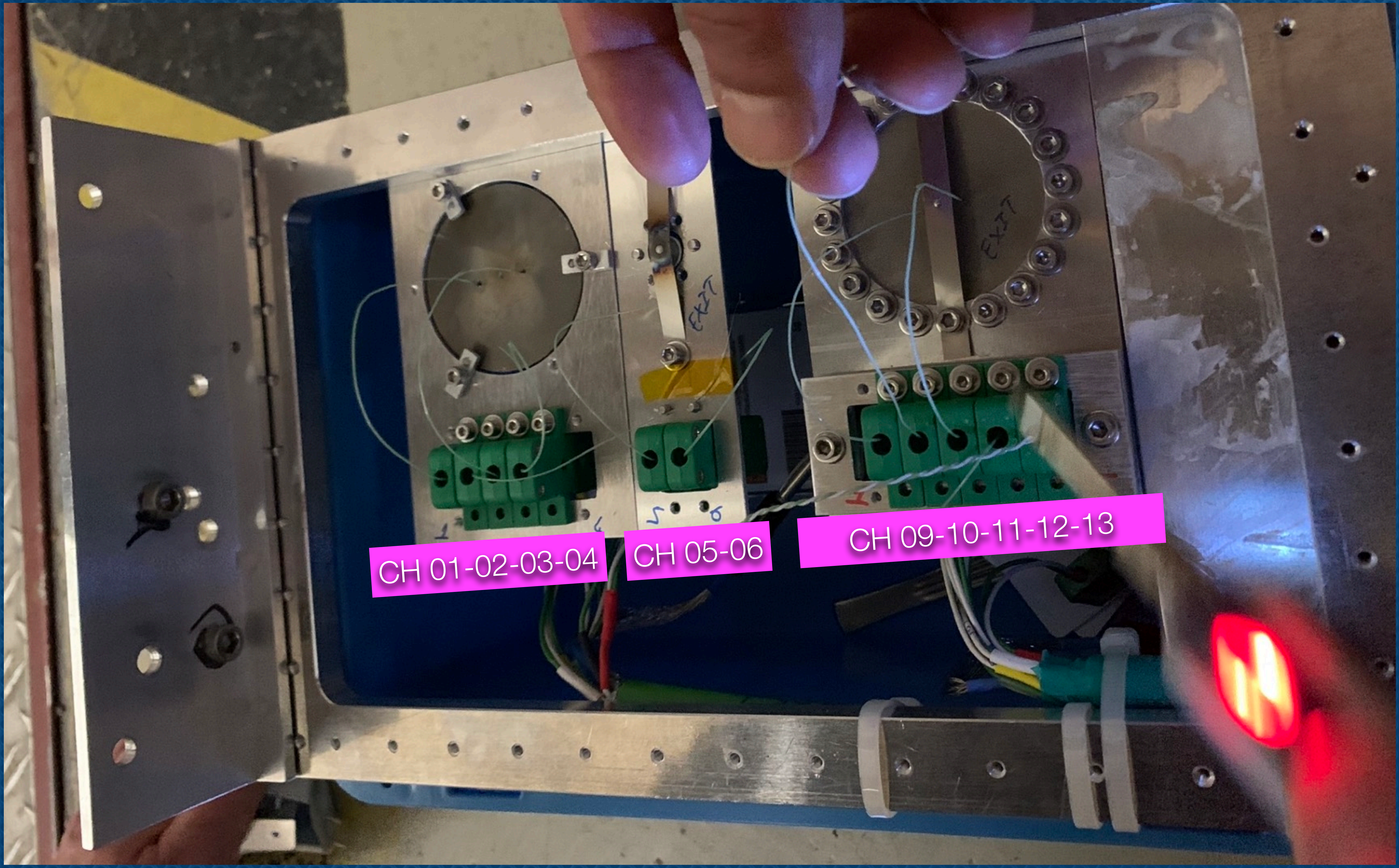
❖ One can clearly see the horizontal wire taped near the thermally contacted amorphous.

❖ We put also vertical wire, and one wire facing the beam.

0- Target Holder

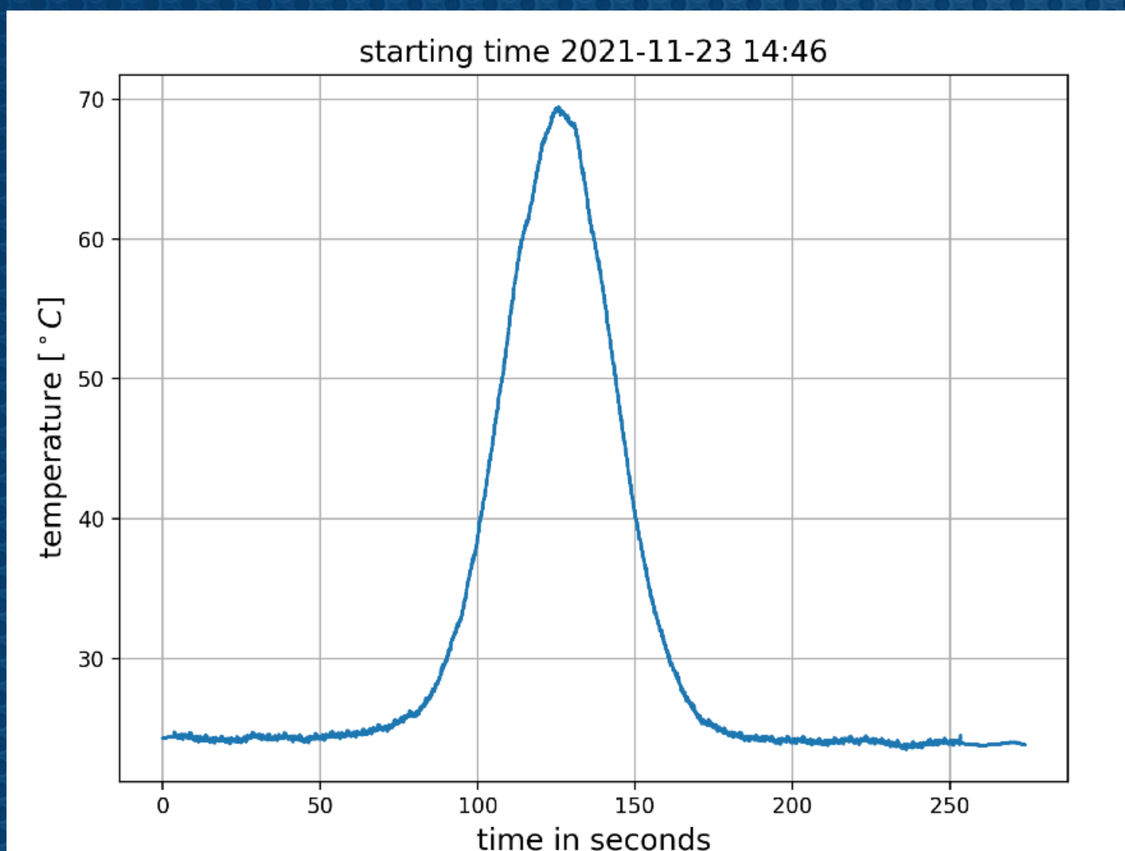
❖ The cabling has been done starting with the thermally contacted amorphous being CH01-05. However, CH02 at the center of amorphous was free. We decided use this one as the horizontal one. One can see the cabling for this beam test session below.

❖ Note that, CH02 the horizontal TC in the air, CH12 vertical, CH10 facing the beam TCs in the air!



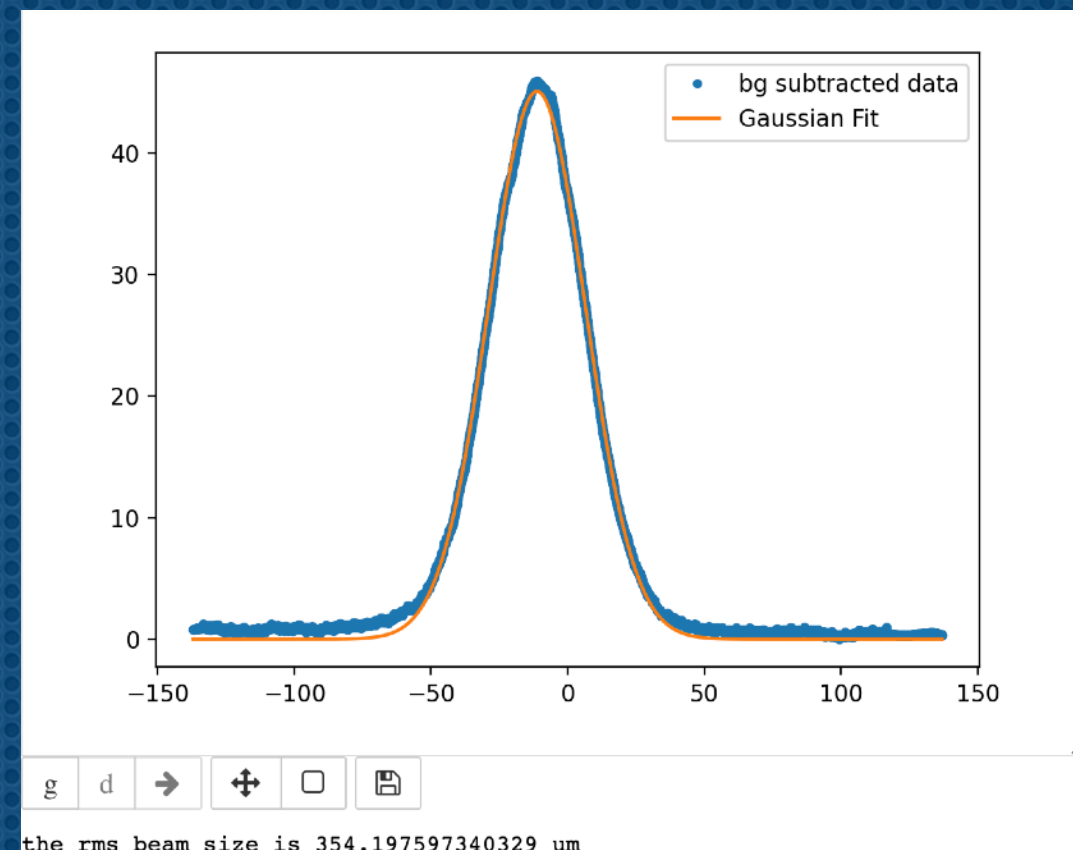
1- Thermocouples in the Air

❖ Beam size measurement before Werner used stronger quad(s) using horizontal wire connected to the CH12, vertical scan with 20 um/second.



Raw Data 100 Samples/second

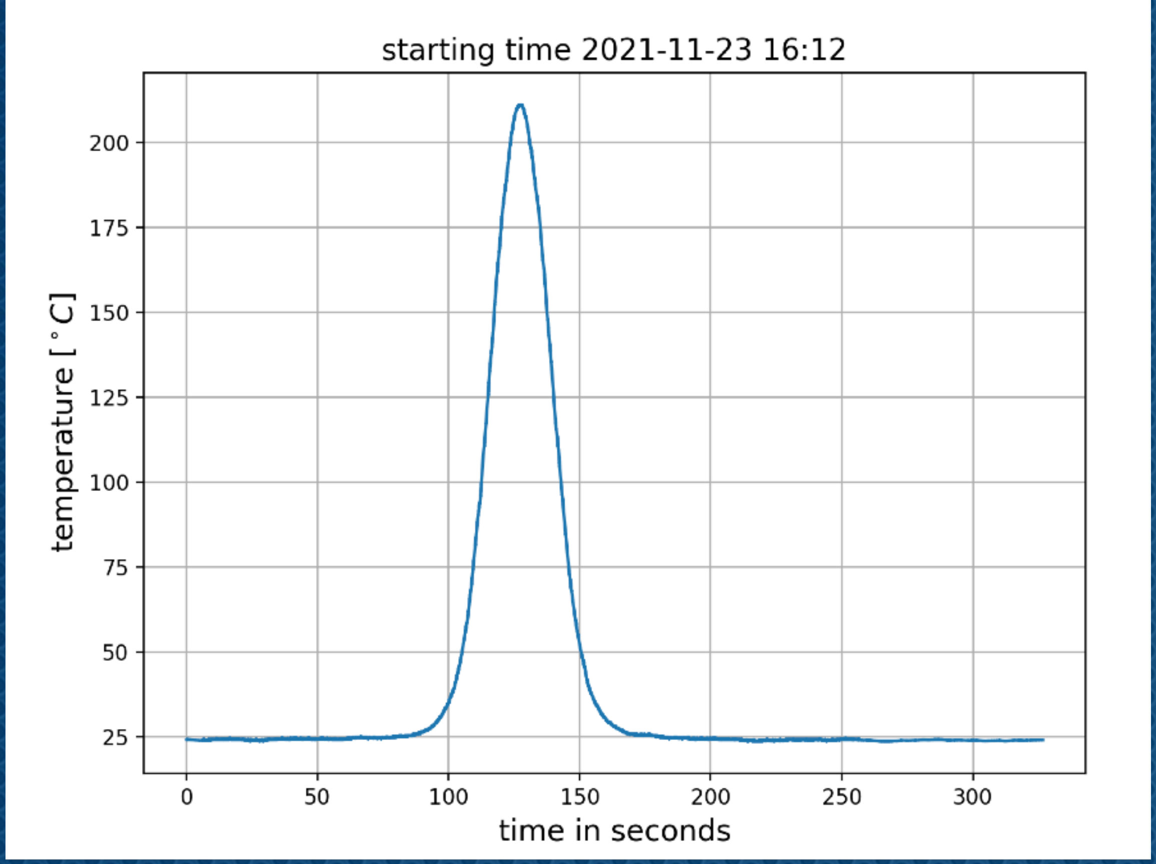
PS: One can see the movement of the motor (i.e. 5 mm) when it stops temperature has less noise



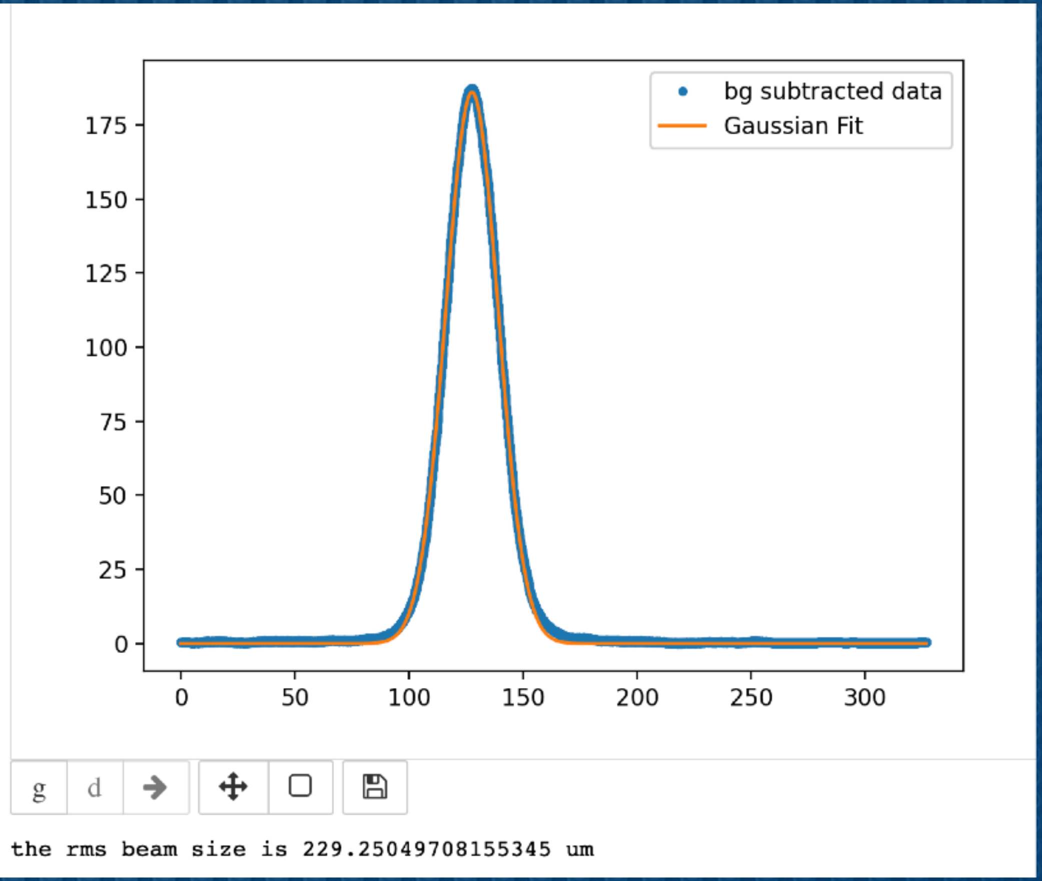
vertical RMS beam size before beam squeeze: 354 μm
0.6 μA CW current

1- Thermocouples in the Air

❖ Beam size measurement AFTER Werner used stronger quad(s) using horizontal wire connected to the CH12, vertical scan with 20 um/second.



Raw Data 100 Samples/second

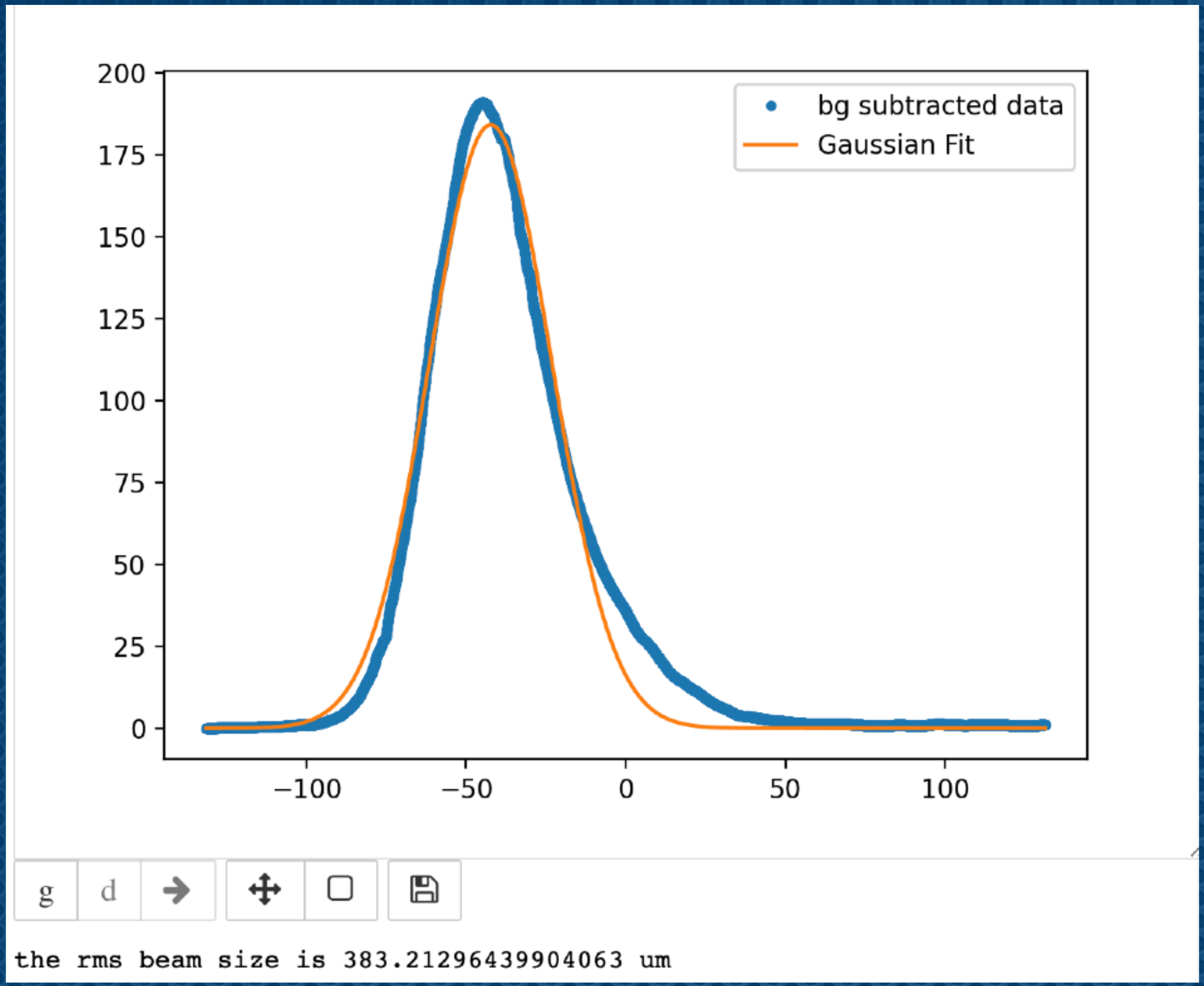


vertical RMS beam size before beam squeeze: 229 μm

0.6 μA CW current

1- Thermocouples in the Air

❖ Beam size measurement AFTER Werner used stronger quad(s) using horizontal wire connected to the CH12, horizontal scan with 20 um/second. 0.6 μA CW current.



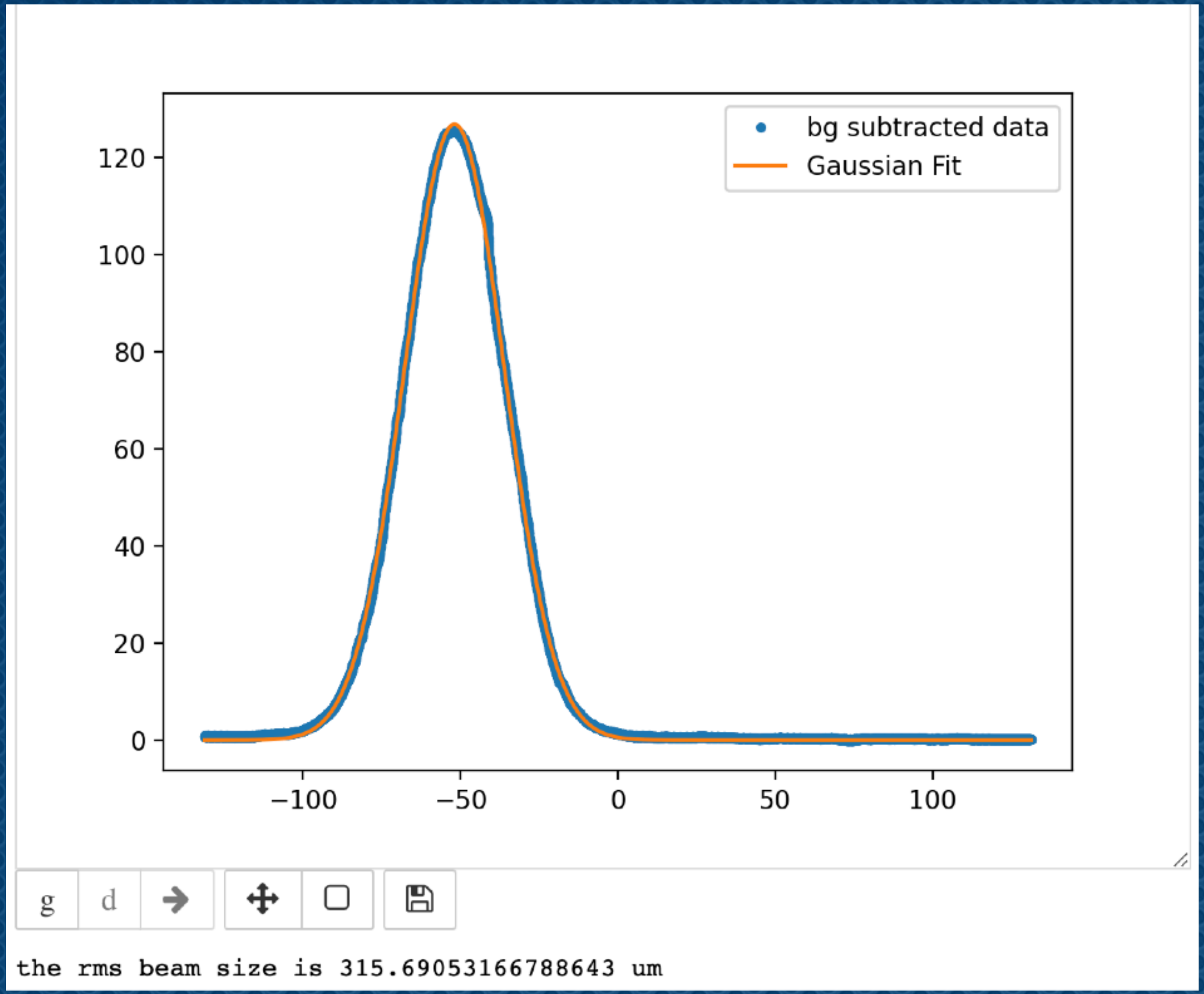
horizontal wire horizontal scan RMS beam size before beam squeeze: 383 μm

➡ One should notice that during the scan the cable holding the TC is intercepting the beam, as more cable hit by the beam, the temperature is measured more than it is (right hand side of the fit)!

➡ Immediate conclusion: Use horizontal wire for the vertical measurement or vice versa.

1- Thermocouples in the Air

❖ Beam size measurement AFTER Werner used stronger quad(s) using vertical wire connected to the CH02, horizontal scan with 20 um/second. 0.6 μA CW current.



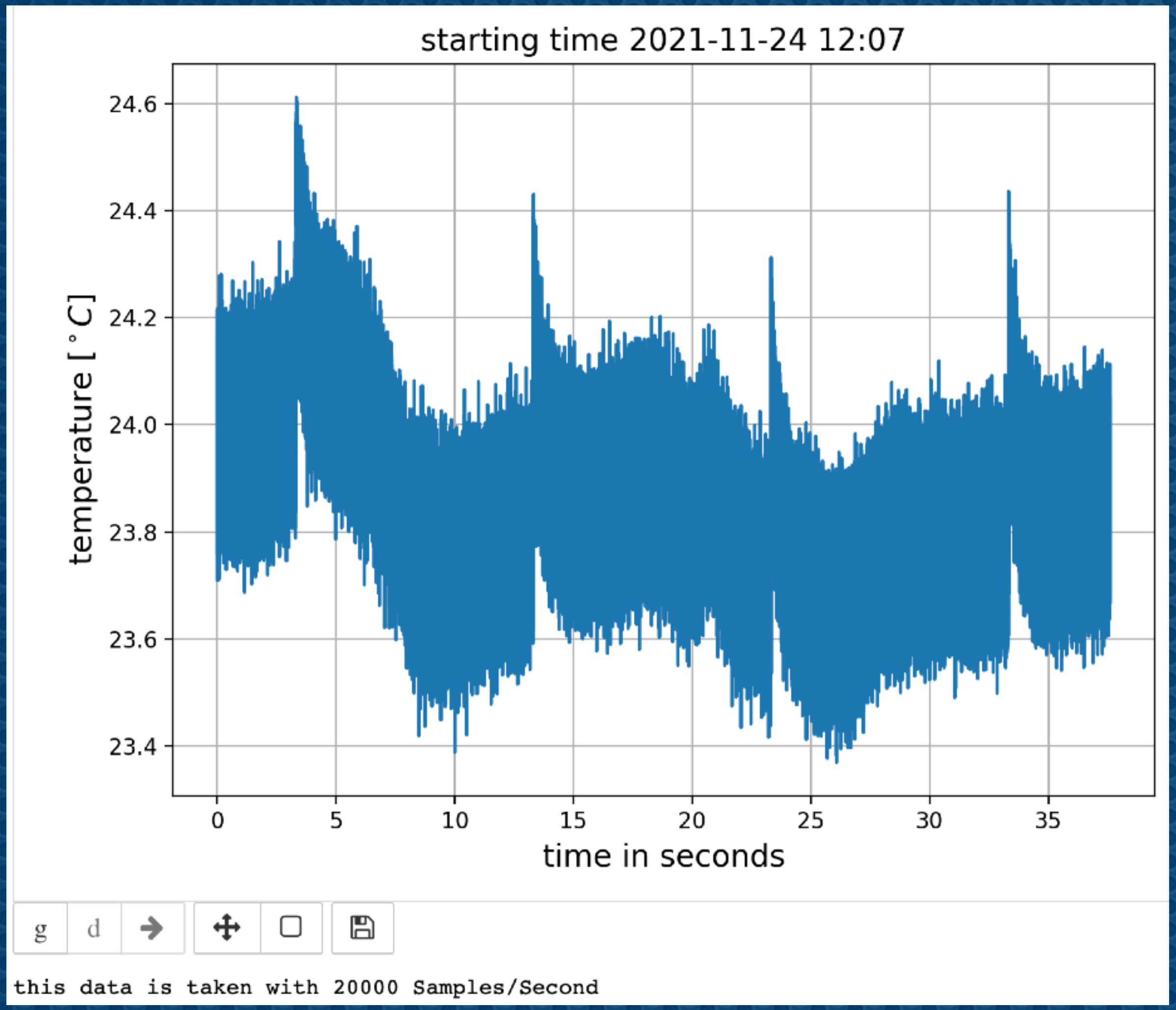
➡ Transverse beam size = 315/229 μm (x/y)

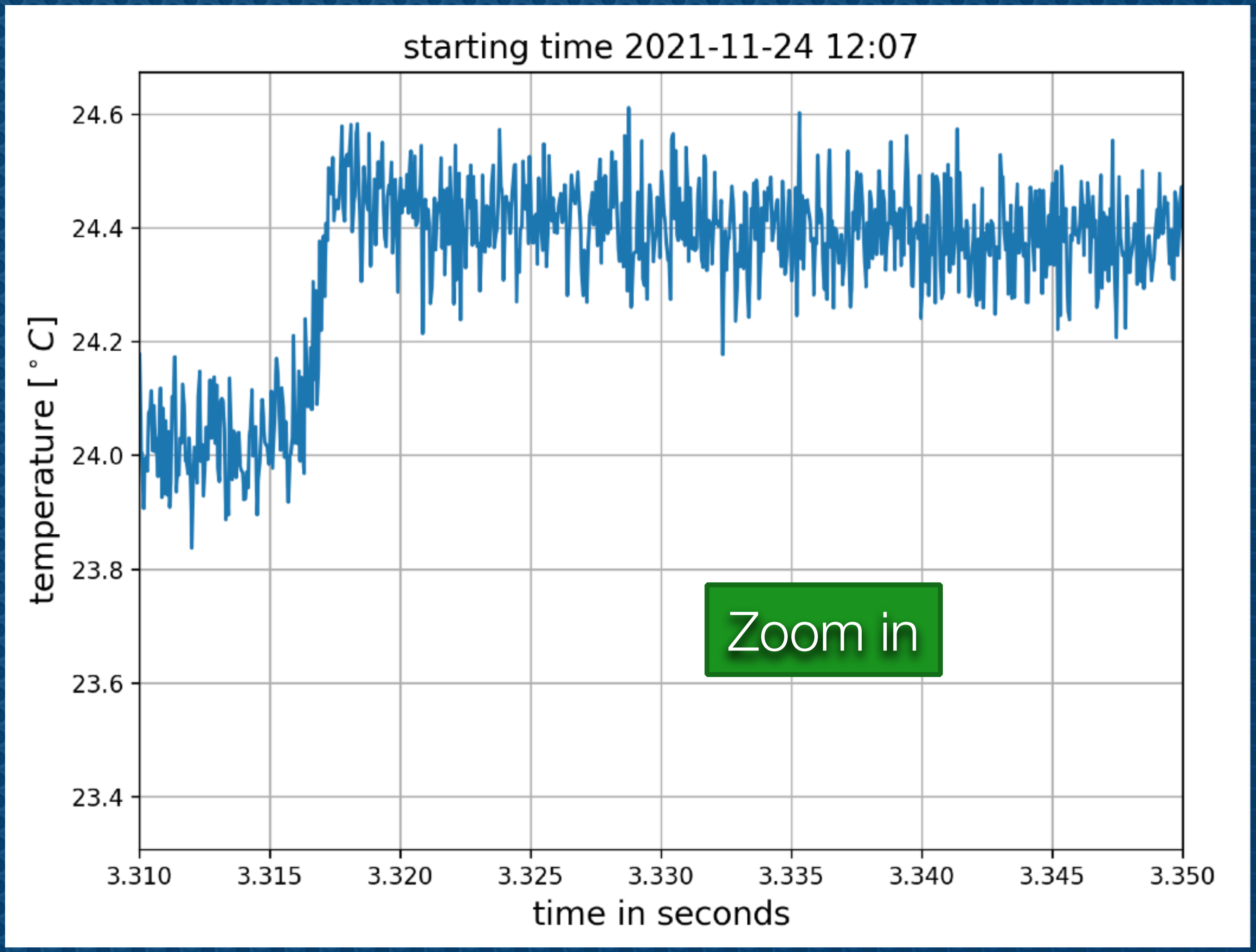
vertical wire horizontal scan RMS beam size before beam squeeze: 315 μm

1- Thermocouples in the Air

❖ We did some pulsed beam tests to study the time resolution of the thermocouples.

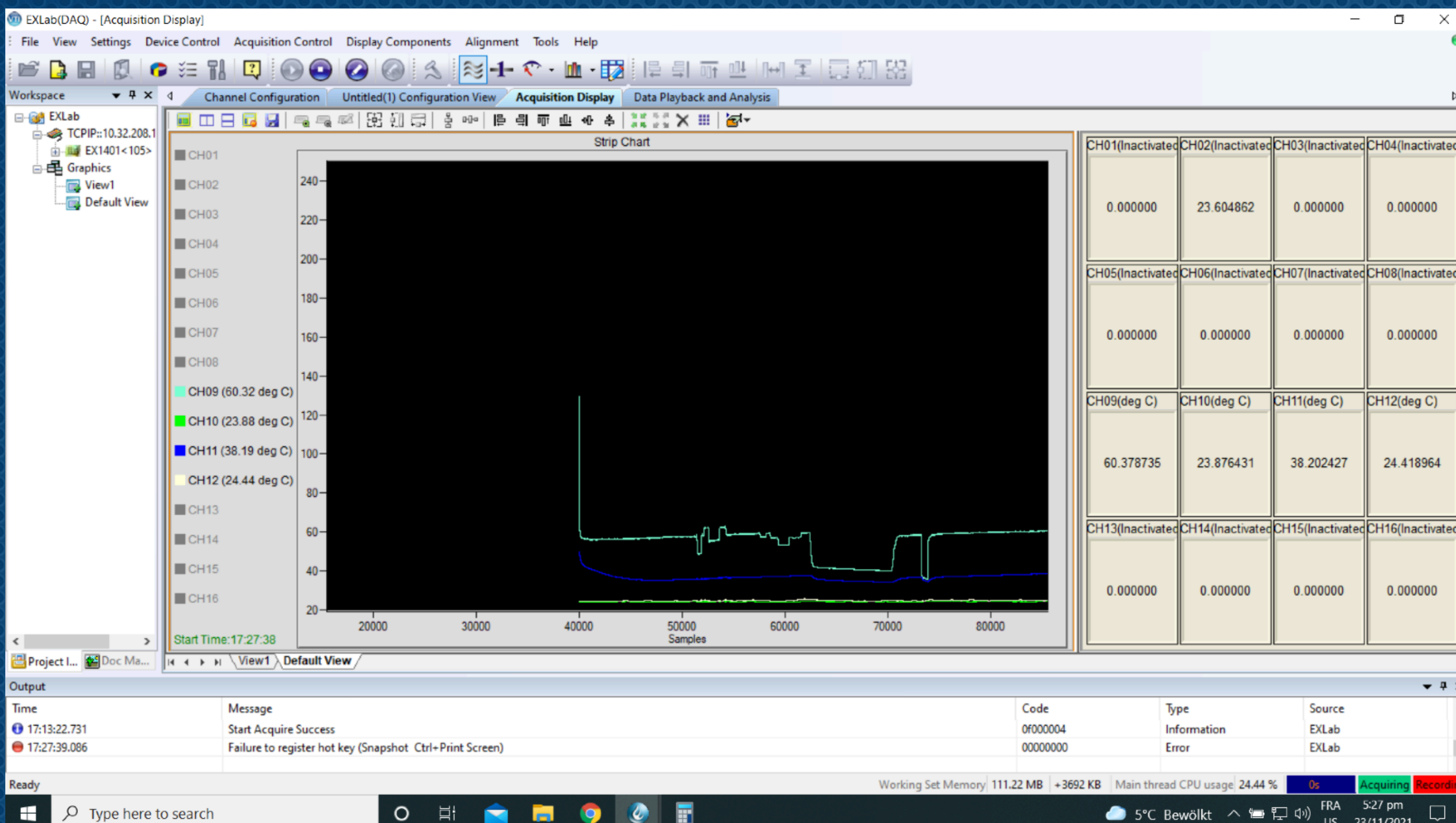
❖ For instance, beam was sent with 0.1 Hz repetition (1 pulse per 10 seconds) with a pulse duration of 1 ms. The average current can be estimated to be 0.1 nA.





2- Amorphous at Position C

❖ We chose the thermally contacted amorphous, because it had the mechanically contacted TC at its center i.e. CH09. However, during beam tuning on it, TC lost the contact with the amorphous, but TC was still working:



❖ We keep recording CH09, because it was still measuring a temperature proportional to the current, incident date and time: 23 Nov at 17h27.

2- Amorphous at Position C

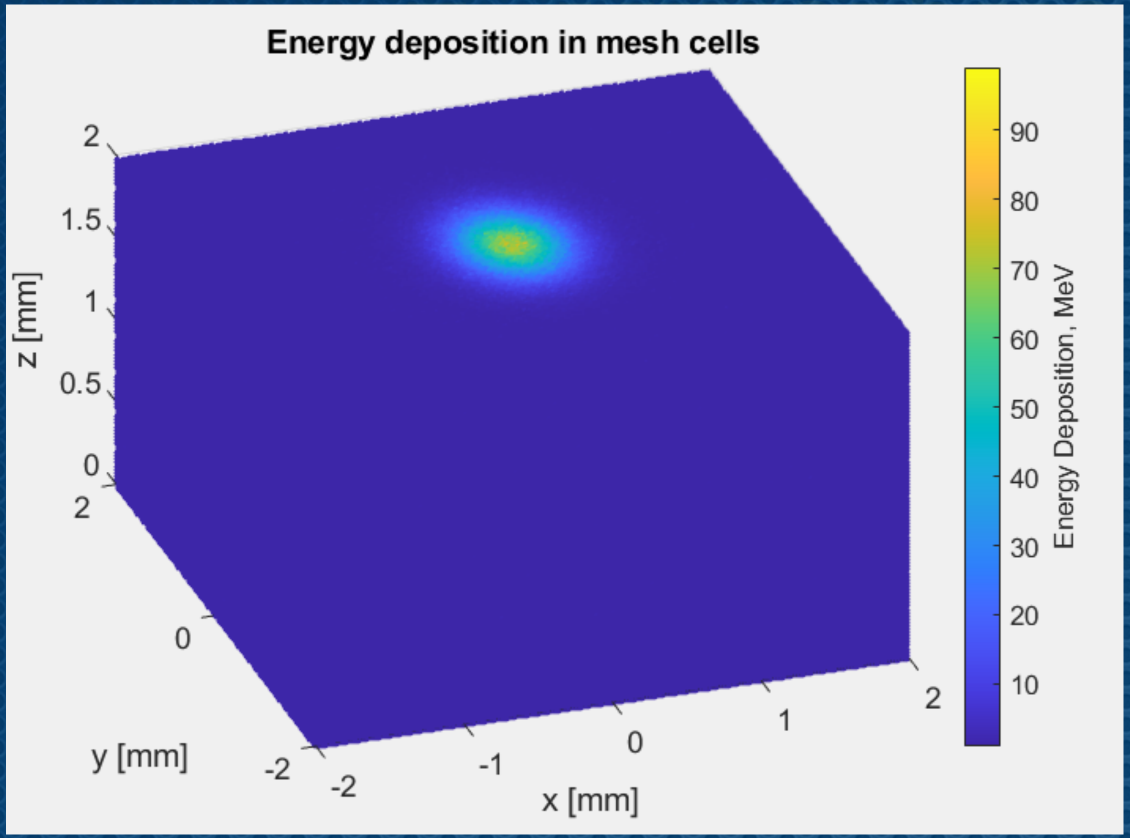
- We used 200 Hz, 300 μs pulse duration with average current of 2 μA (max we get from MAMI with this orientation). This will result in approximately 7 J/g for the beam size of 315/229 μm (x/y). Exact calculations to be performed at IJCLab.

- We radiate for a total time of ~ 27 hours, this would refer to total number of 19.4 Million hits similar to FCC-ee primary beam.

- This would mean 1168 fills of FCC-ee collider from scratch. If we consider 185 days of run, this would refer to ~6 fills from scratch per day.

- After x and γ ray diffractometry, if the target is fine, we can say that the amorphous can bear 1 year operation. Of course, real calculation on Geant4 for the corresponding PEDD is necessary. Also, FCC-ee annual hits with the appropriate charge during a day has to be studied.

2- Amorphous on Geant4

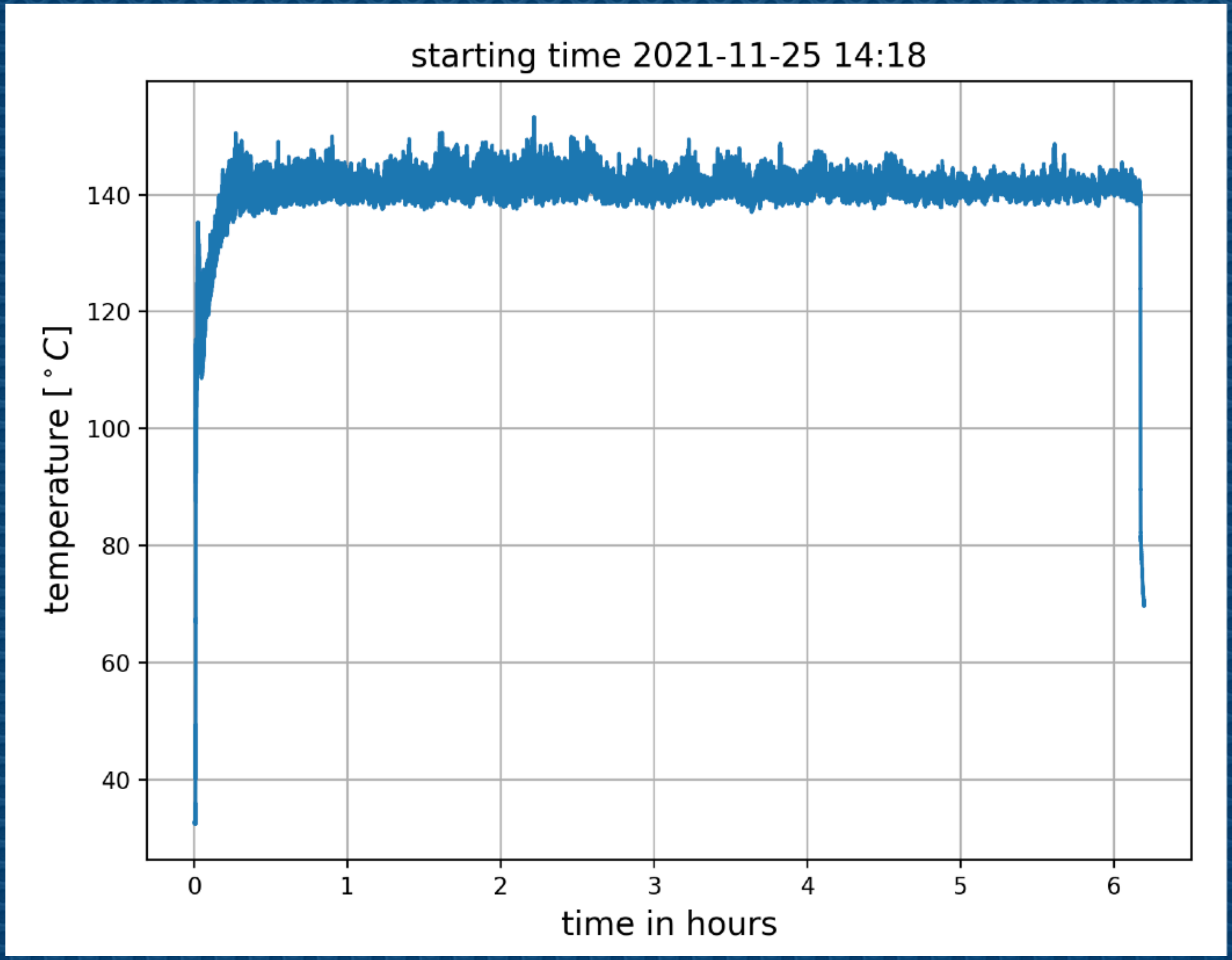


- We used 200 Hz, 300 μs pulse duration with average current of 2 μA for the beam size of 315/229 μm (x/y).

E_{dep}^{mean} [MeV]	E_{cell}^{max} [MeV]	$PEDD^{e-}$ [J/g]	Current (@200 Hz)	Bunch Population in a pulse	PEDD due to beam
7.03	98.06	1.0×10^{-10}	2 μA	6.7E+10	6.7 J/g

2- Amorphous at Position C

❖ We used 200 Hz, 300 μs pulse duration with average current of 2 μA (max we get from MAMI with this orientation). Beam size of 315/229 μm (x/y). Temperature of the **center but contactless CH09 Thermocouple** during irradiation:



3- Crystal at Position C

❖ 2 mm W Crystal with 8 mm diameter was irradiated for a total time 18h30 with ~ 2.38 μA CW beam with rms beam size 315/229 μm. Assuming $\pi\ \sigma_x \sigma_y$ contains the 40% of the whole beam, the accumulated fluence:

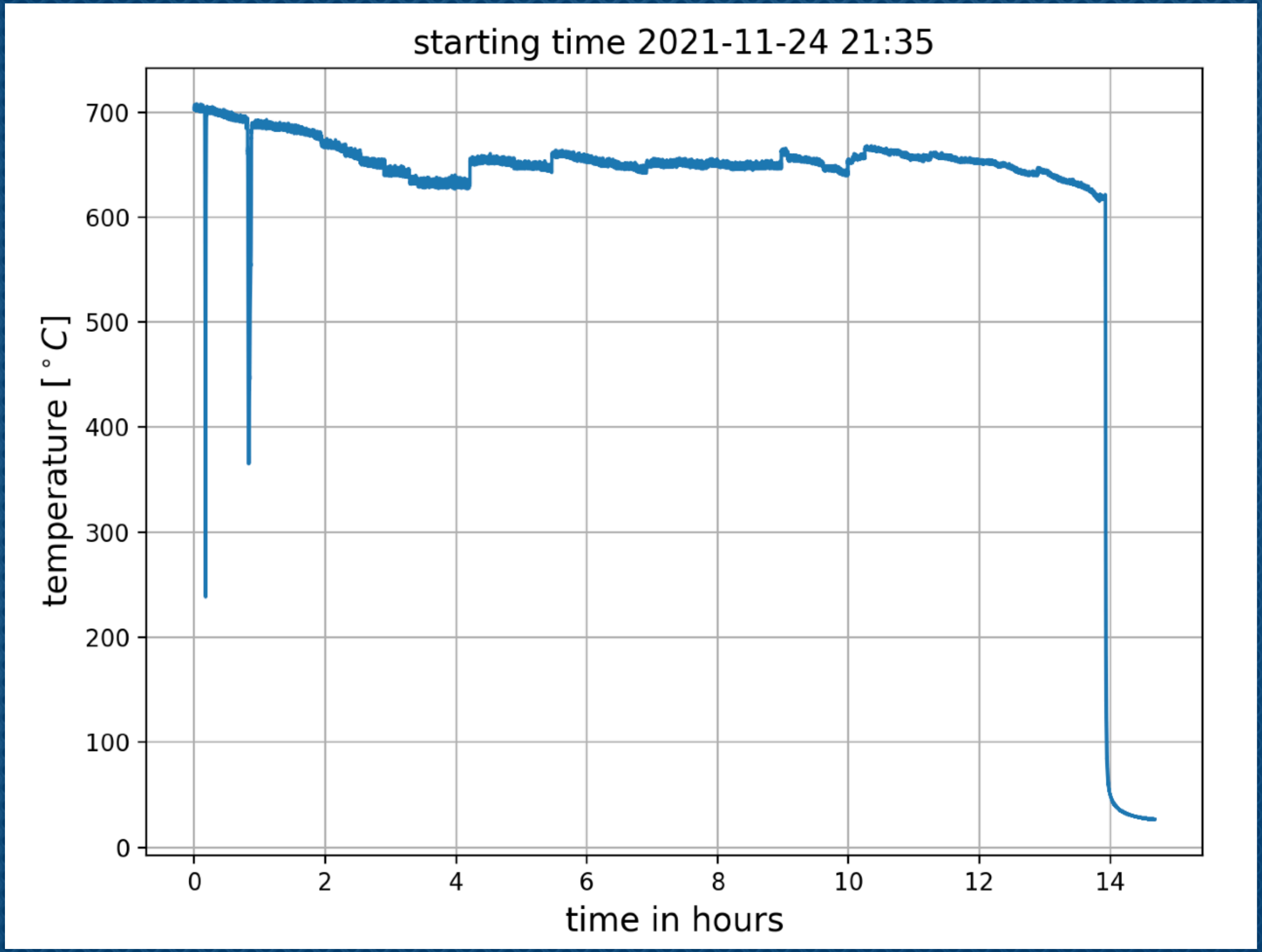
$$Fluence = \frac{2.38 \times 10^{-6}}{1.6 \times 10^{-19}} \frac{1}{\pi 0.315\ 0.229} \times 0.4 = 6.6 \times 10^{13}\ \frac{e^-}{mm^2\ sec}$$

❖ 18h30m (2.4 uA) 1h 3 uA would refer to 6.6e13 x 3600 x 20 = 4.75 x 10^{18} e-/mm^2

❖ Which is more than twice of the what SLC achieved UNDER this assumptions exact calculations to be done.

3- Crystal at Position C

❖ 2 mm W Crystal with 8 mm diameter was irradiated for a total time 18h30 with ~ 2.38 μA CW beam with rms beam size 315/229 μm. The temperature recorded by the CH05 center thermocouple on the crystal:



Conclusions

- ❖ We performed some study on the TCs for the time resolution, and also we used TCs in the air for the beam size measurement.
- ❖ We irradiated the amorphous like FCC-ee fills from scratch for a year.
- ❖ We HOPE we have exceeded the SLC crystal fluency.
- ❖ Exact calculations, and crystal channeling enhancement and targets x-ray and γ-ray diffractometry will be performed in a laboratory after the targets are COOL.

We are sorry for all the radiation we caused, thanks 😇