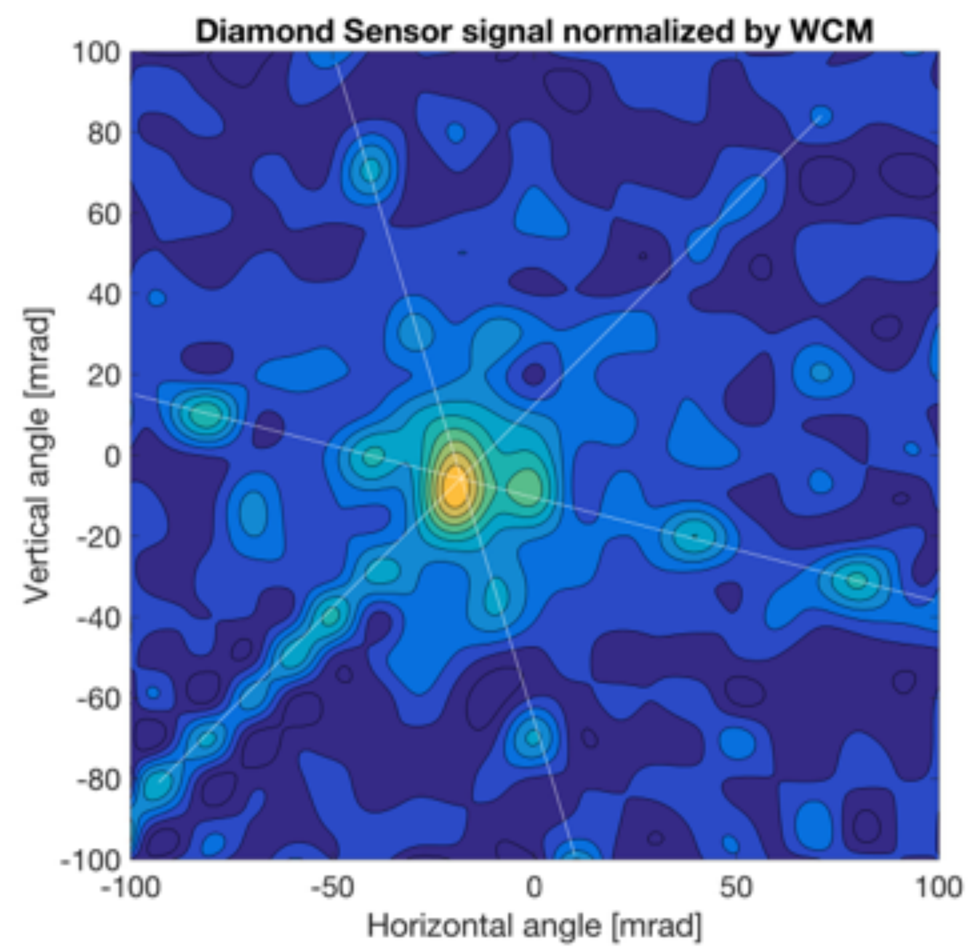
KEK Experiment



Hybrid e+ source studies

X. Artru, I. Chaikovska, R. Chehab, K. Furukawa, H. Guler, T. Kamitani, V. Kubytskyi, F. Miyahara, M. Satoh, Y. Seimiya, V. Rodin, P. Sievers, T. Suwada, K. Umemori

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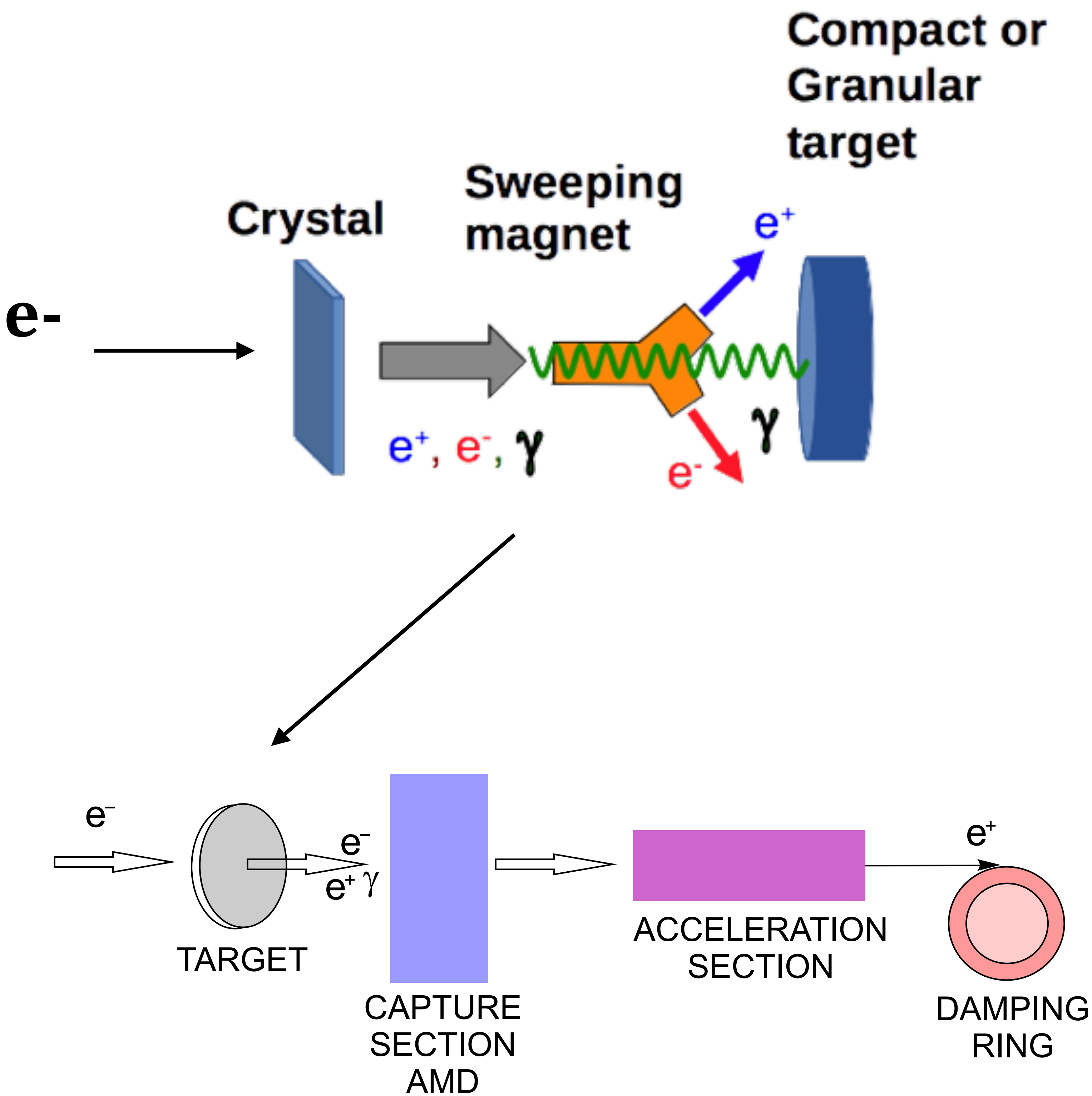
18-20 January 2017

Introduction

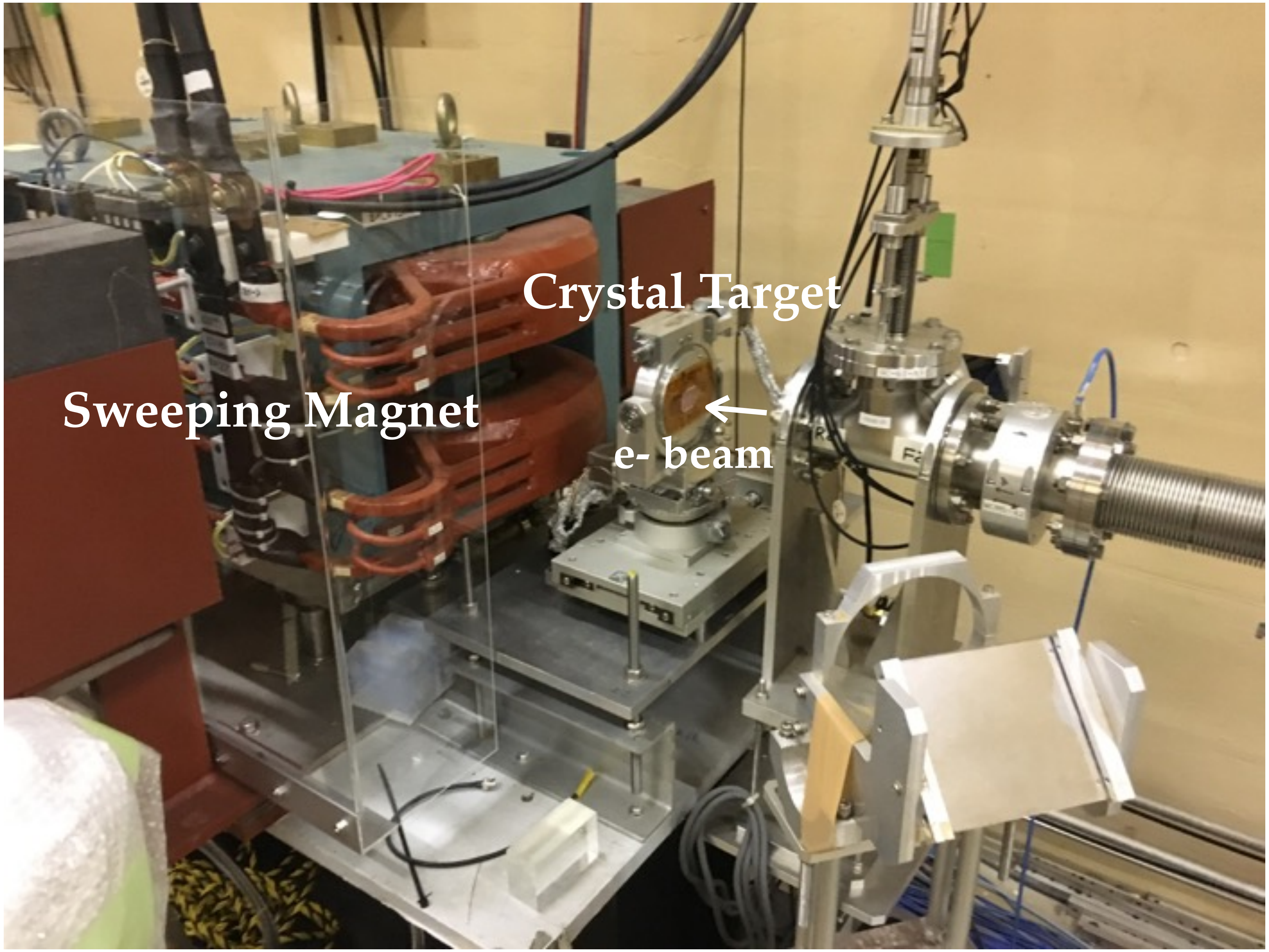
- Experimental studies on the hybrid positron source at KEK-B injector linac started in 2000s.
  - Proof-of-principle experiment in Orsay (observing radiation enhancement in a tungsten crystal oriented along the ⟨111⟩ axis submitted to a 2 GeV electron beam). X. Artru et al., *NIM Section B,* 119.1 (1996): 246-252.
  - Experiment at CERN (4 mm and 8 mm thick tungsten crystals and a compound target made of a 4 mm crystal followed by a 4 mm amorphous disk were used. The gain was about 3 for the 4 mm target and about 2 for the 8 mm and the compound targets.). X. Artru et al., NIM Section B, 201.1 (2003): 243-252.
  - Experiment at KEK (tungsten crystal target has been successfully employed at the e+ source of the KEKB injector linac. The crystal thickness was 10.5 mm, primary e- beam 4 GeV. The e+ yield increased by ~25% compared to that for a conventional tungsten plate with a thickness of 14 mm. The steady-state heat load on the crystal target decreased by ~20%. After a two-month operation, no degradation of the e+ production efficiency was observed). T. Suwada et al., *Physical Review Special Topics-Accelerators and Beams* 10.7 (2007): 073501.
- The experimental activities have restarted in 2015: beam test on ***10-12 October 2015*** and ***21-22 October 2016***.
- Goals: e+ yield and temperature measurements to compare different targets (Bulk & Granular) => e+ source performances.

Hybrid e+ source



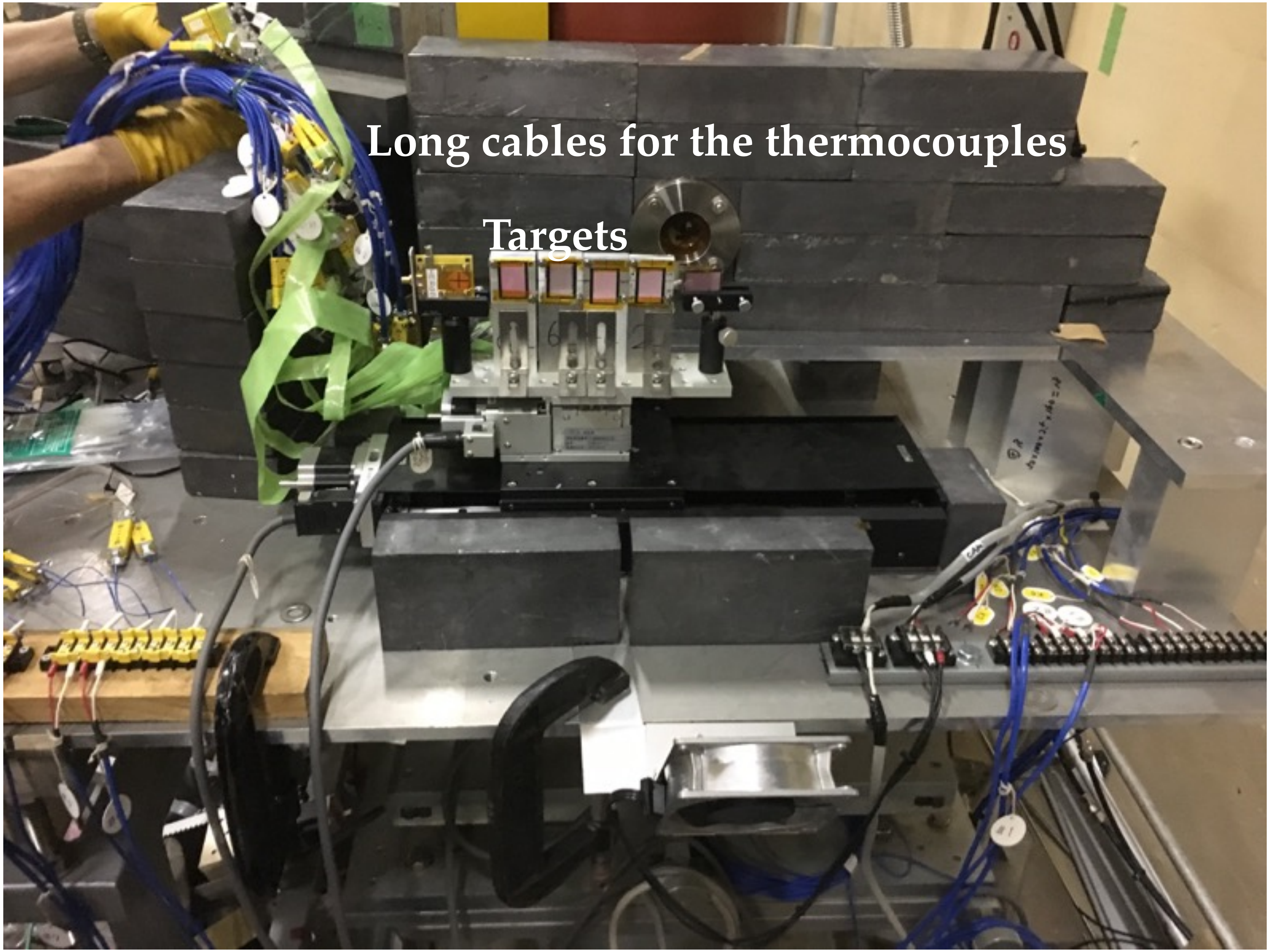
Experiment layout

KEK B injector linac

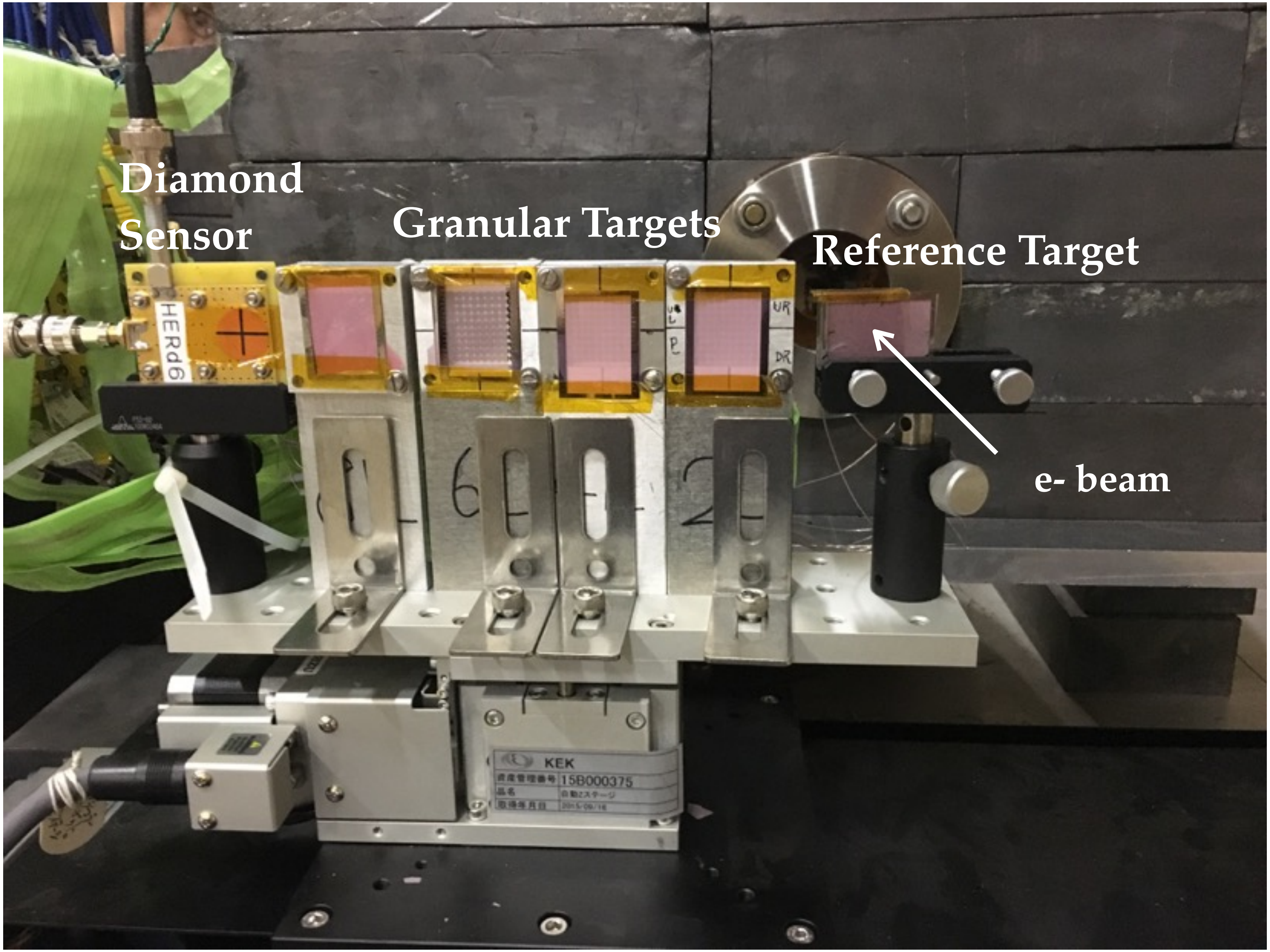


Experiment layout

Experiment layout

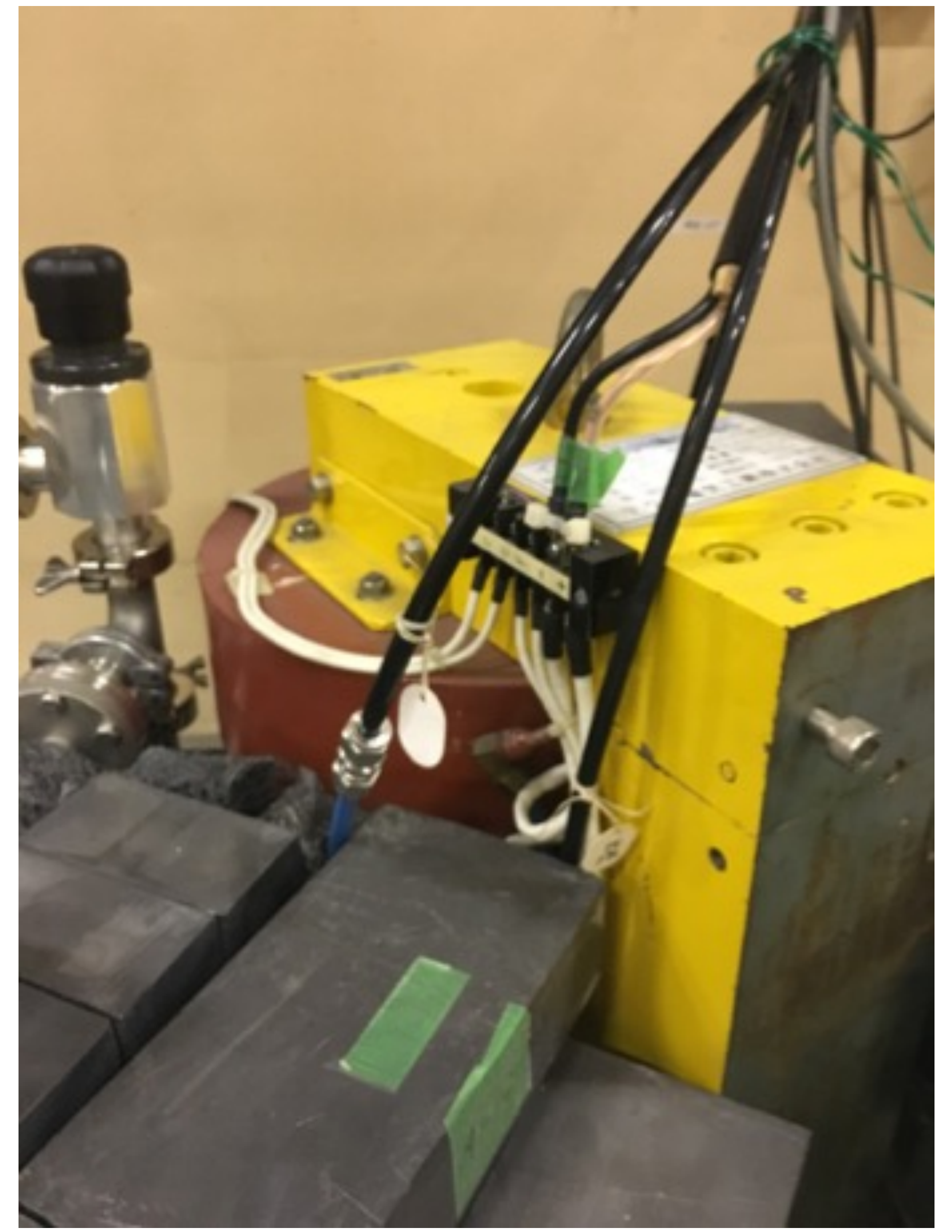


Target installation



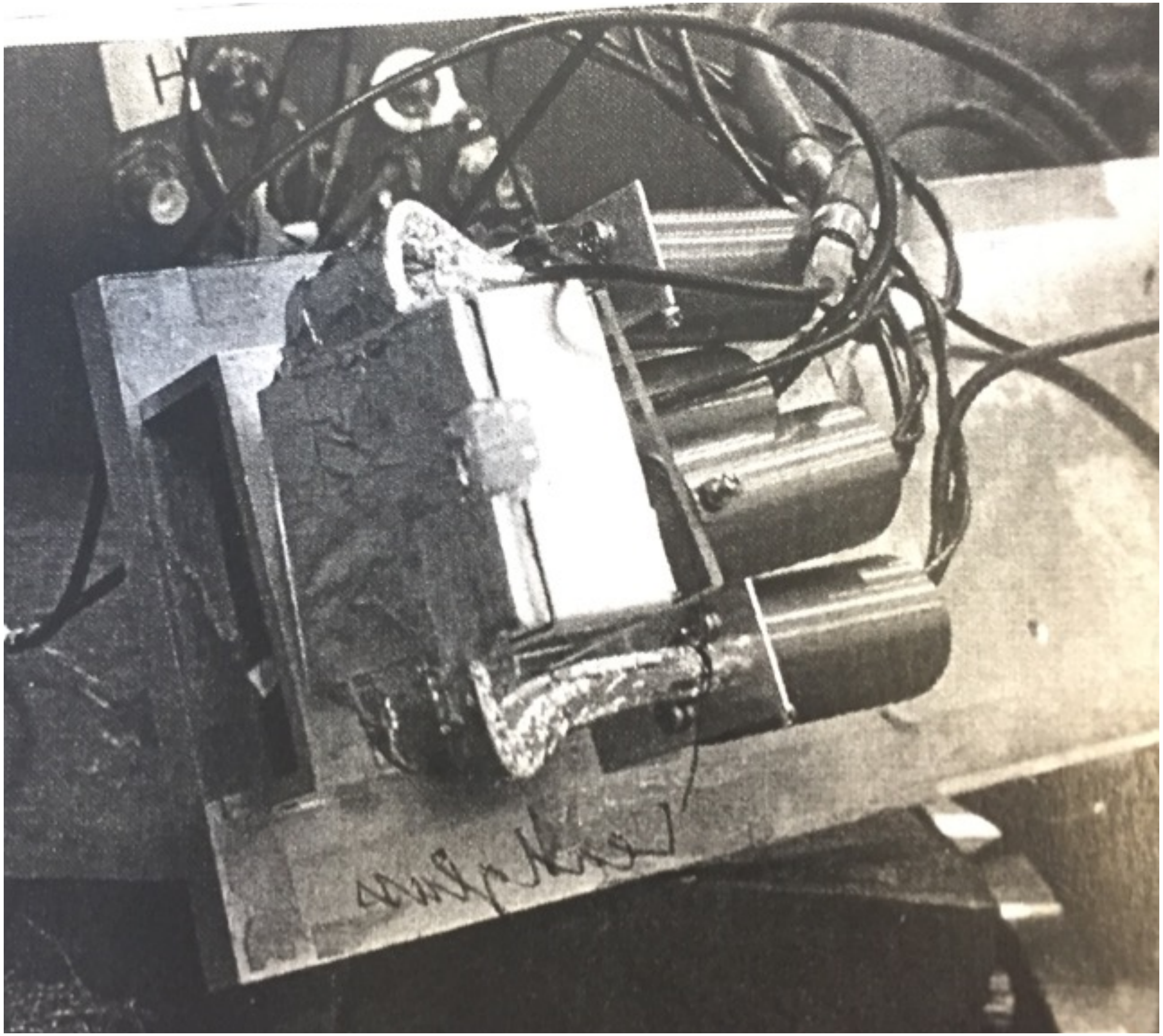
Experiment layout

Analysing Magnet settings: 5, 10, 15 and 20 MeV



Experiment layout

Lucite counter (2 PMT) + Lead glass (2 PMT)



Electron beam parameters

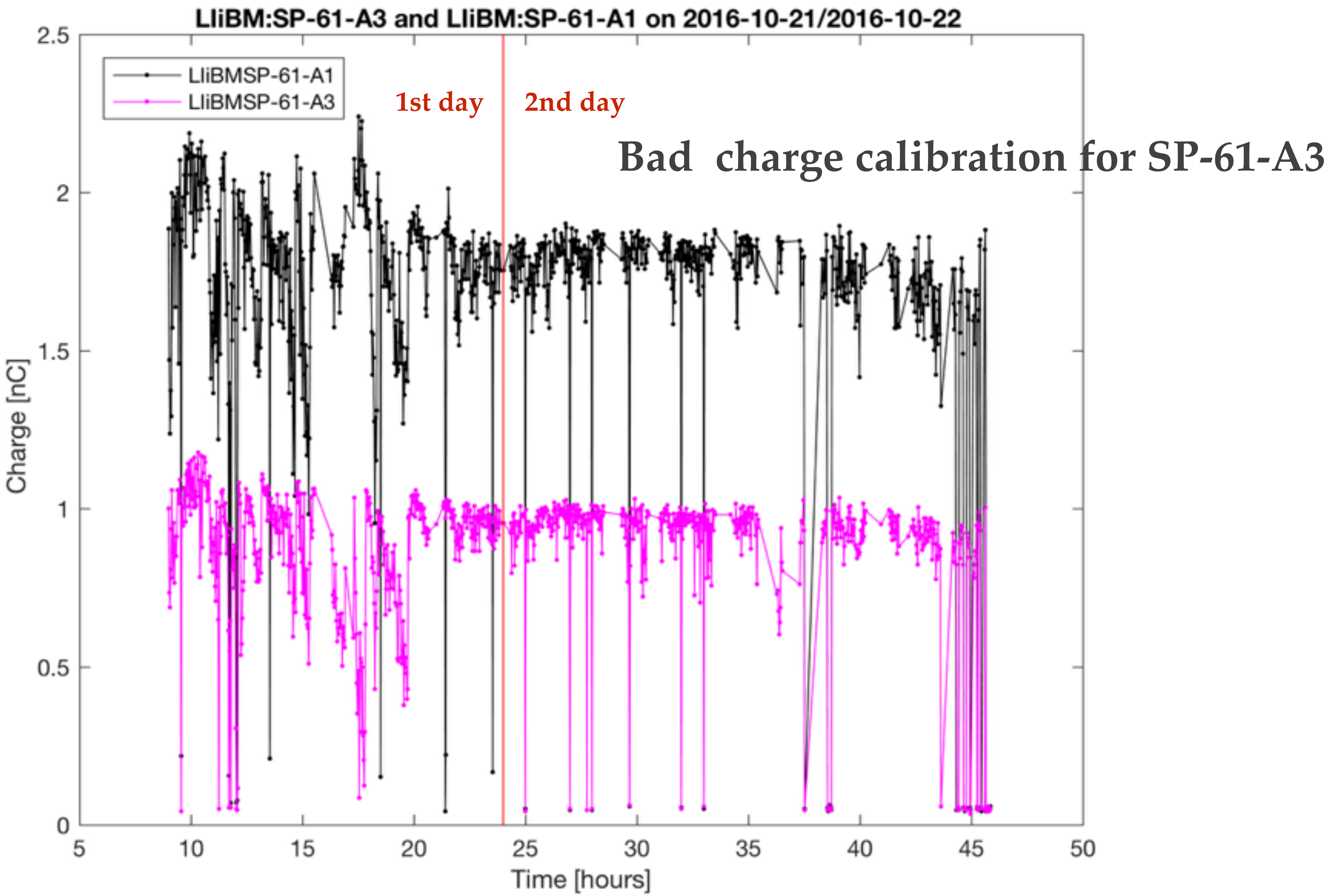
<u>KEKB beam for the test:</u>

- Energy = 7 GeV,
- Beam size @Crystal (e- beam) 1.44 /0.79 mm, @Amorph (e- beam) 1.05 /1.4 mm (different beam conditions).
- Charge ~1.5 - 2 nC.
- Frep 1 - 50 Hz.

<u>Available beam diagnostics:</u>

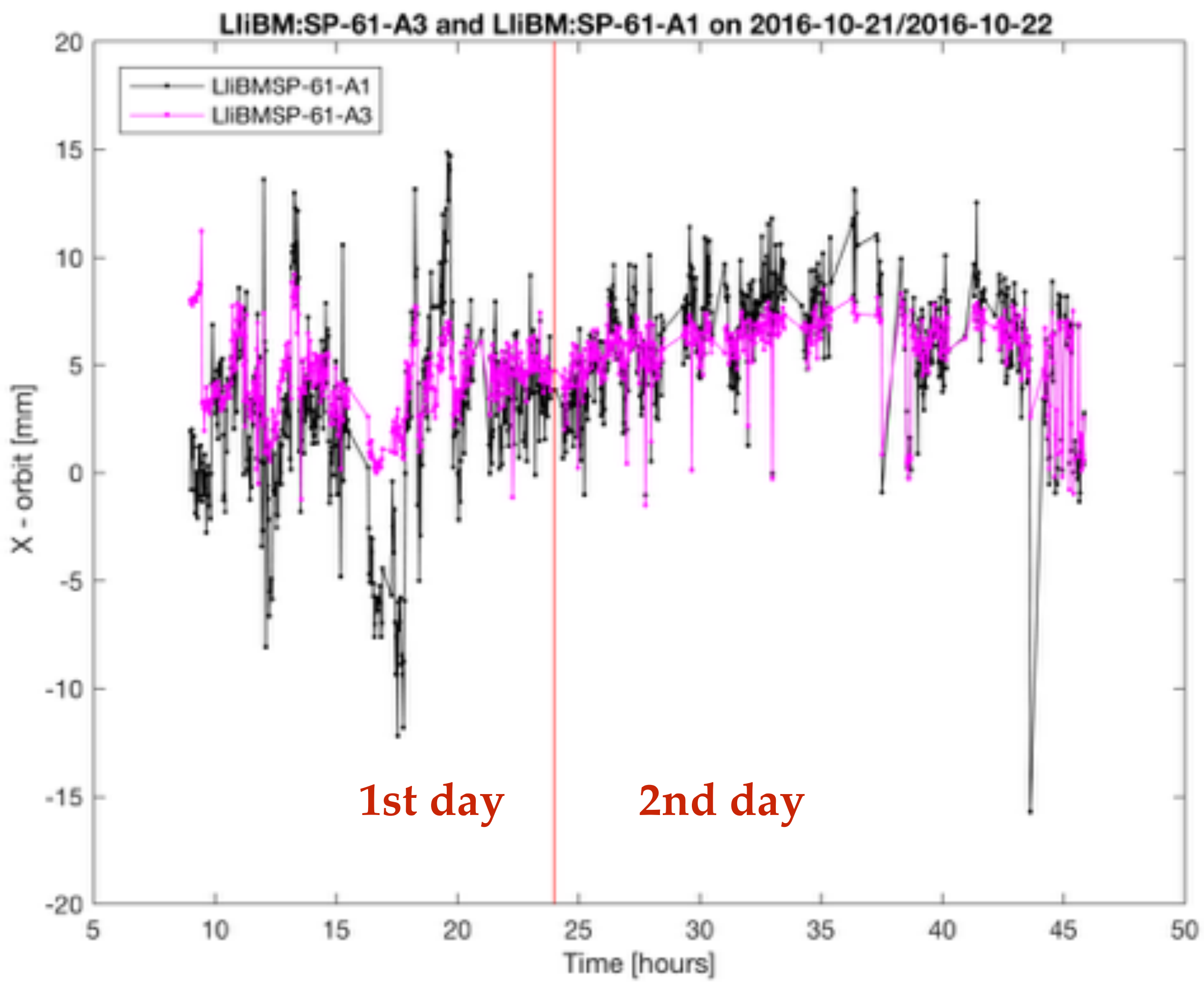
- Two nearest BPMs: BPM SP_61_A3 (closest) and BPM SP_61_A1 (next upstream).
- Wall Current Monitor (relative measurements of beam charge).
- 2 CCD cameras (beam size on the crystal and amorphous targets).
- Wire Scanner => norm. emittance = 149.9/63.1 pi. mm.mrad

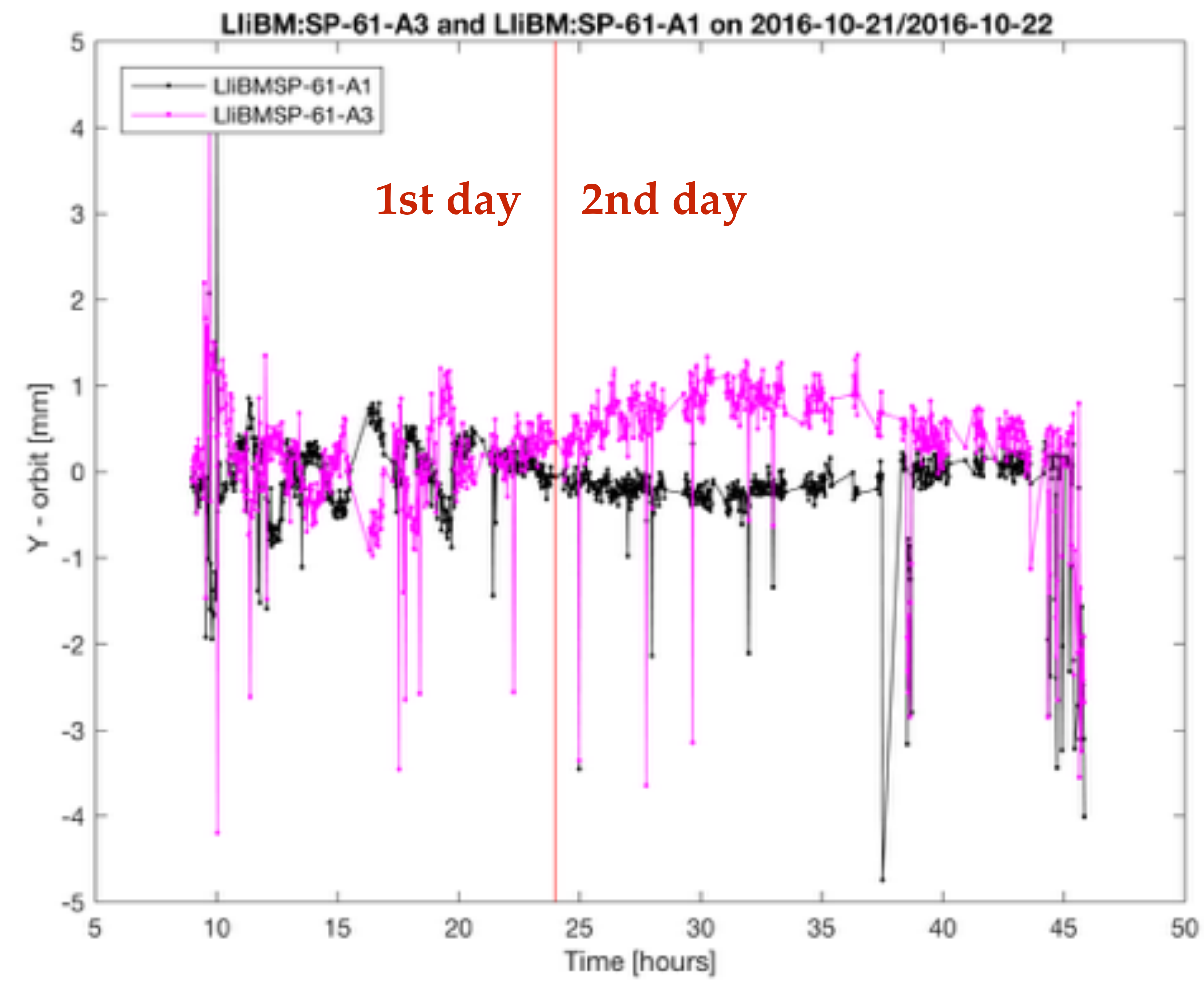
Electron beam parameters



Beam charge distribution measured by the BPMs for two days of the experiment.

Electron beam parameters





Beam orbit measured by the BPMs for two days of the experiment.

Positron yield measurements

Positron yield measurement

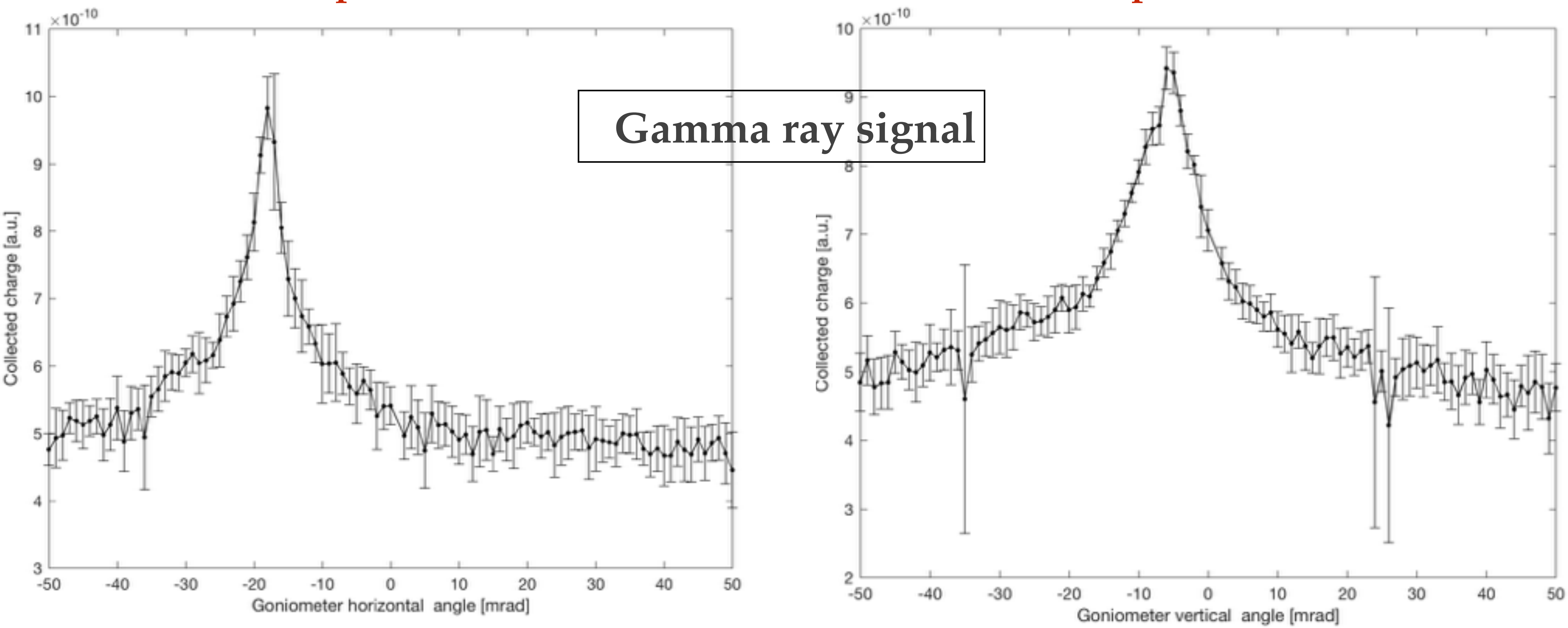
- The e+ yield was measured by the Lucite Cherenkov counter.
- Two PMT are coupled to the Lucite detector through two lightguides.
- The electron beam intensity was measured by the WCM.
- The signals (e+ yield: CH1 and CH3; WCM: CH2) are acquired by the Leroy oscilloscope.
- The data are taken with the beam trigger (synchronisation signal 1-50 Hz).

Angular scan: channeling regime

During this experimental campaign, we have used the Diamond Detector to perform the angular scan and measure the flux of the gamma rays.

Horizontal position: -18.3 mad

Vertical position: -5.4 mad

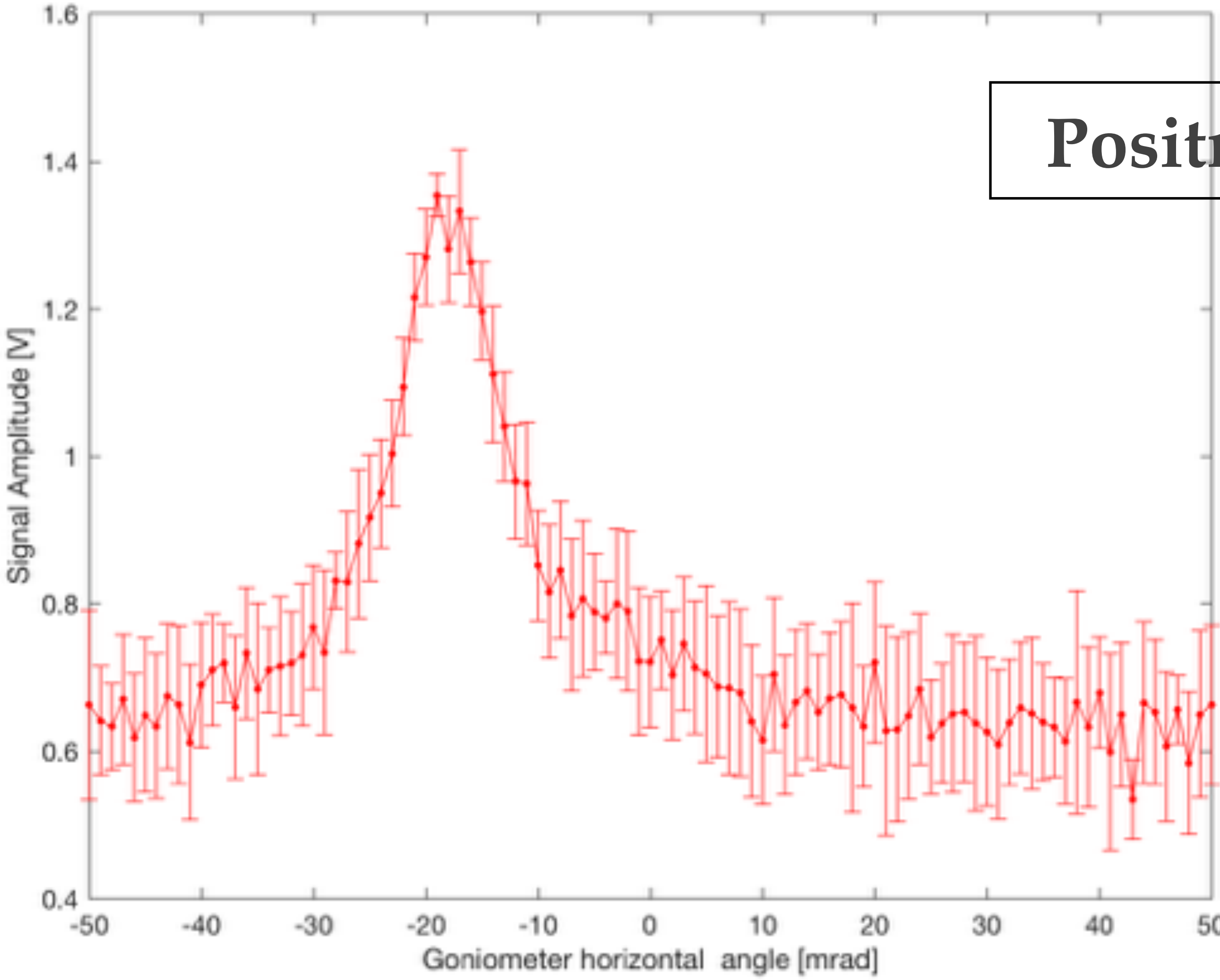


Rocking curve shows the flux of the gamma rays measured while changing relative angle between the crystal axis and the electron beam direction.

Angular scan: channeling regime

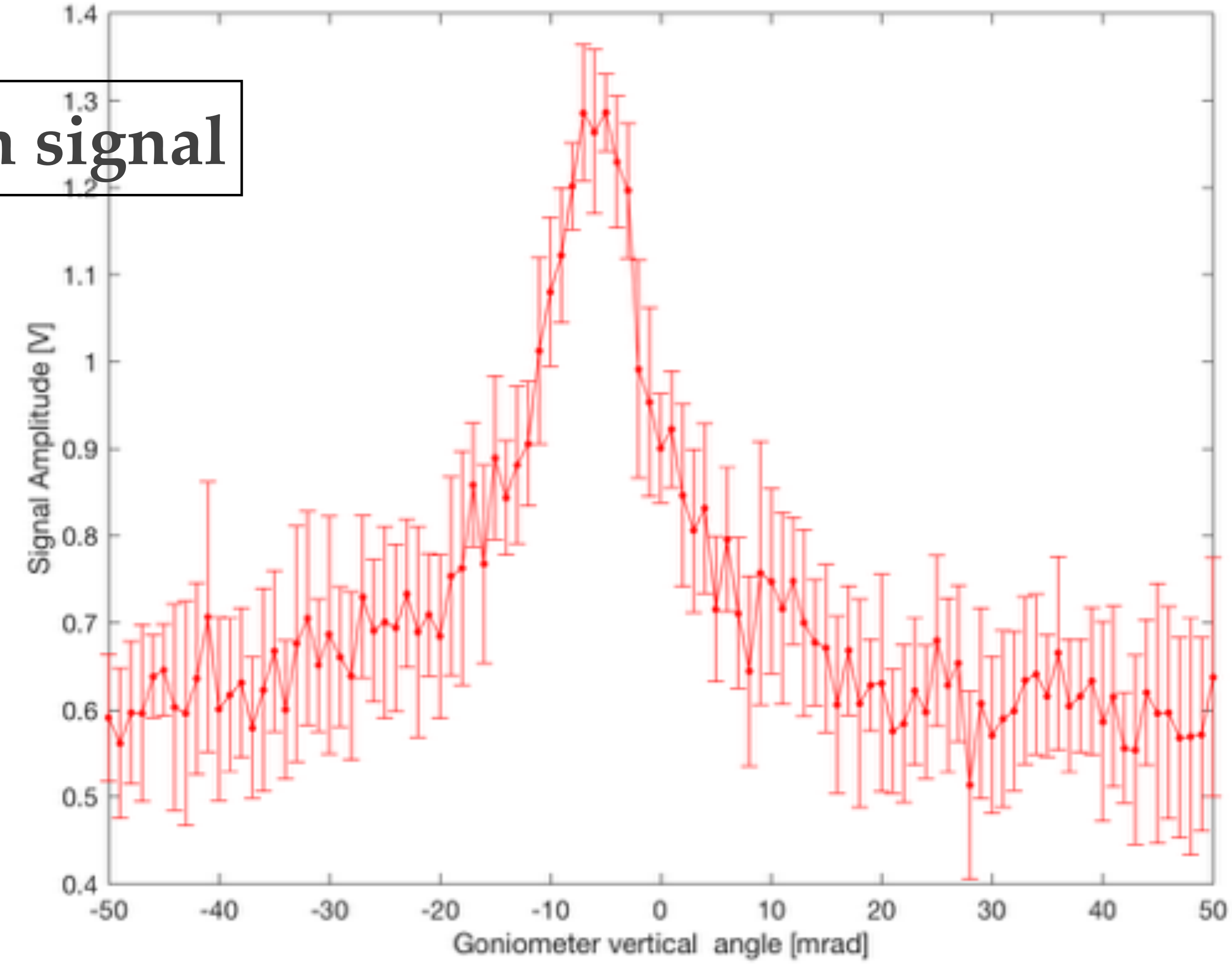
Angular scan made by using the positron detector (AM set to 20 MeV) and 6-Layers granular target for the positron production.

Horizontal position: -18.3 mad



Positron signal

Vertical position: -5.4 mad



Rocking curve shows the e+ yield measured while changing relative angle between the crystal axis and the electron beam direction.

Positron yield measurement

We took the data under the following conditions:

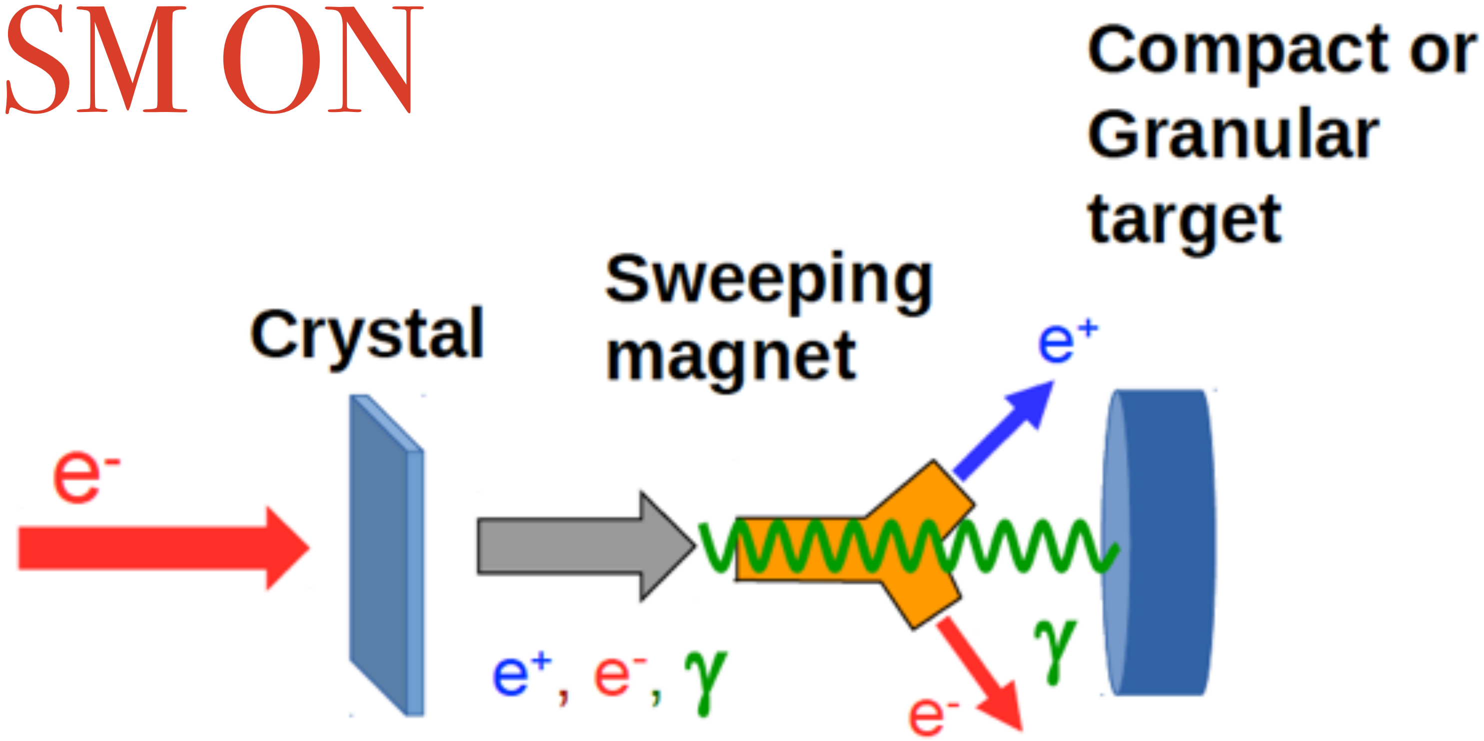
- Momentum scan under crystal the Axis ON/OFF (crystal is aligned to satisfy the channeling conditions/ crystal axis is offset by ~50 mrad).

- Momentum scan under the Sweeping Magnet (SM) ON/OFF (only the gamma rays impinge on the amorphous target/all particles exiting the crystal target impinge on the amorphous target). /@ Axis ON/

Hybrid scheme: Ref. target

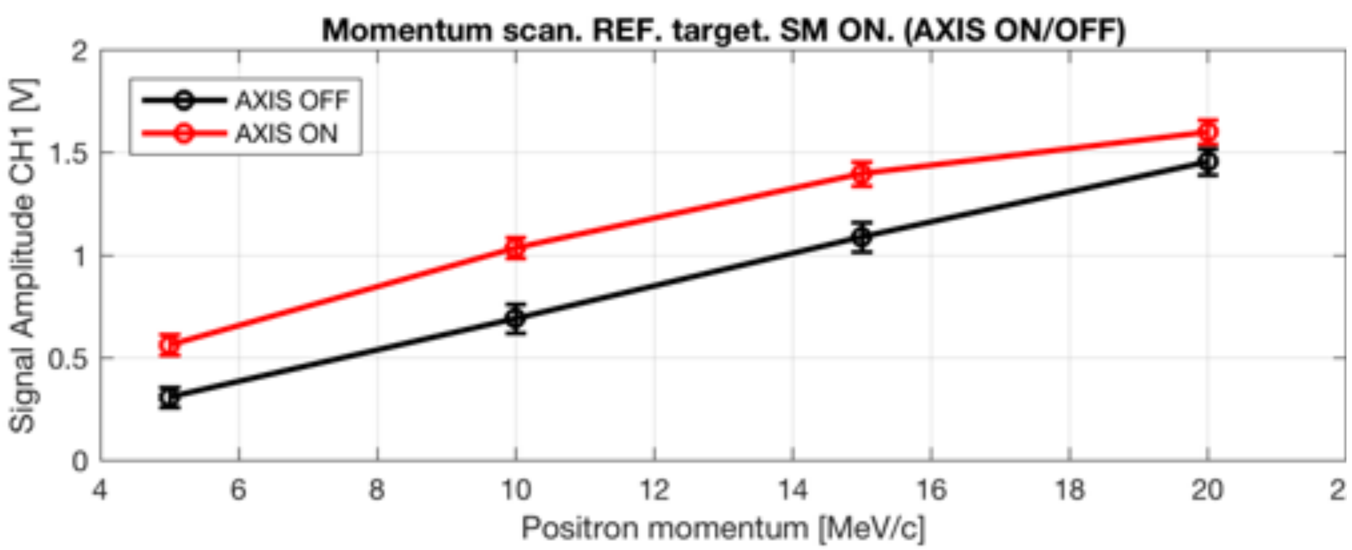
Axis ON/OFF

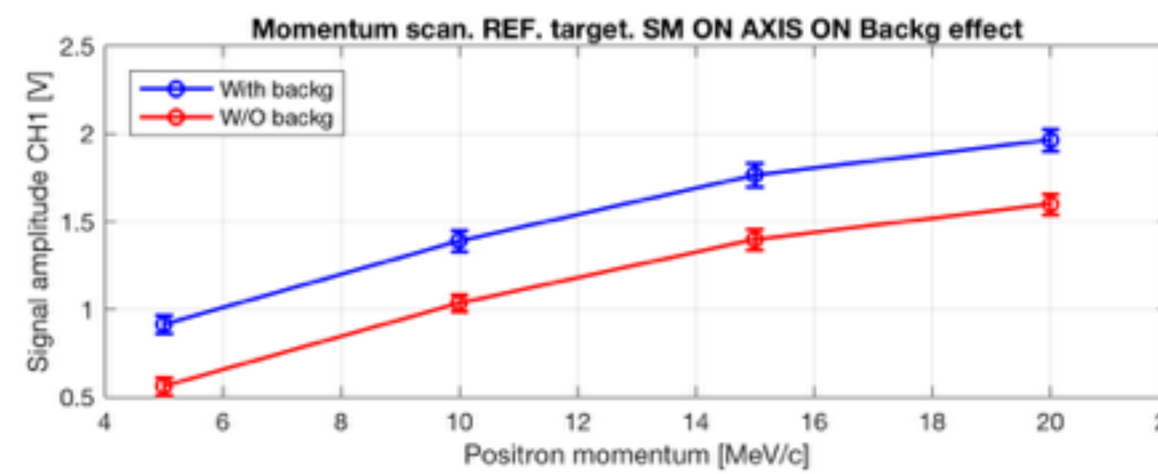
SM ON

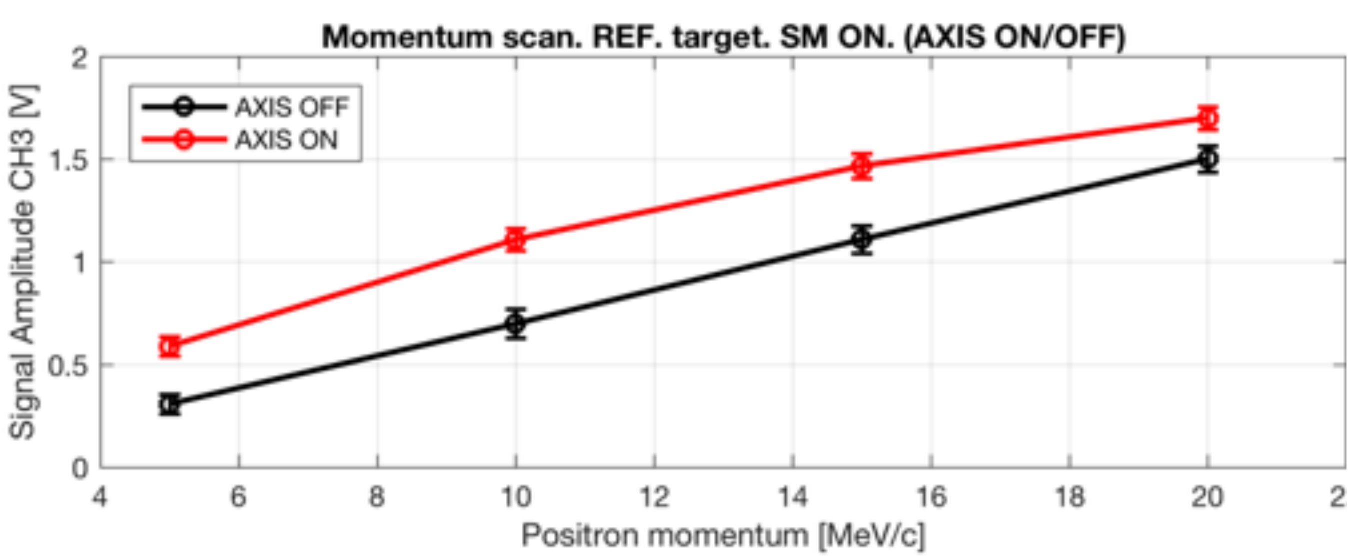


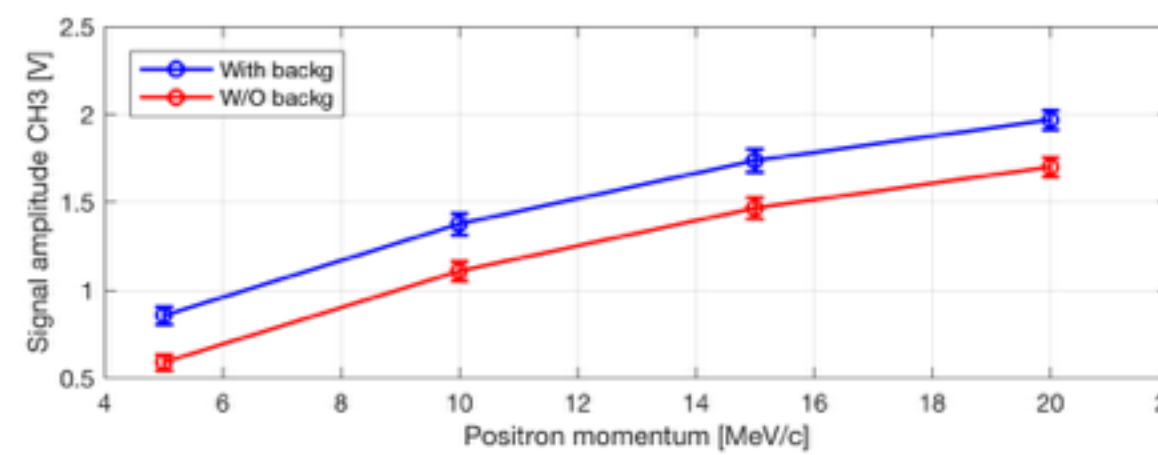
Reference target: hybrid scheme

- The positron production is measured at different positron momenta (5, 10, 15, 20 MeV) by the Lucite Cherenkov detector.
- There are two PMTs attached to different sides of the Lucite detector. On figures, it corresponds to the signals acquired on CH1 and CH3. Signal amplitude is directly proportional to the number of positrons produced.

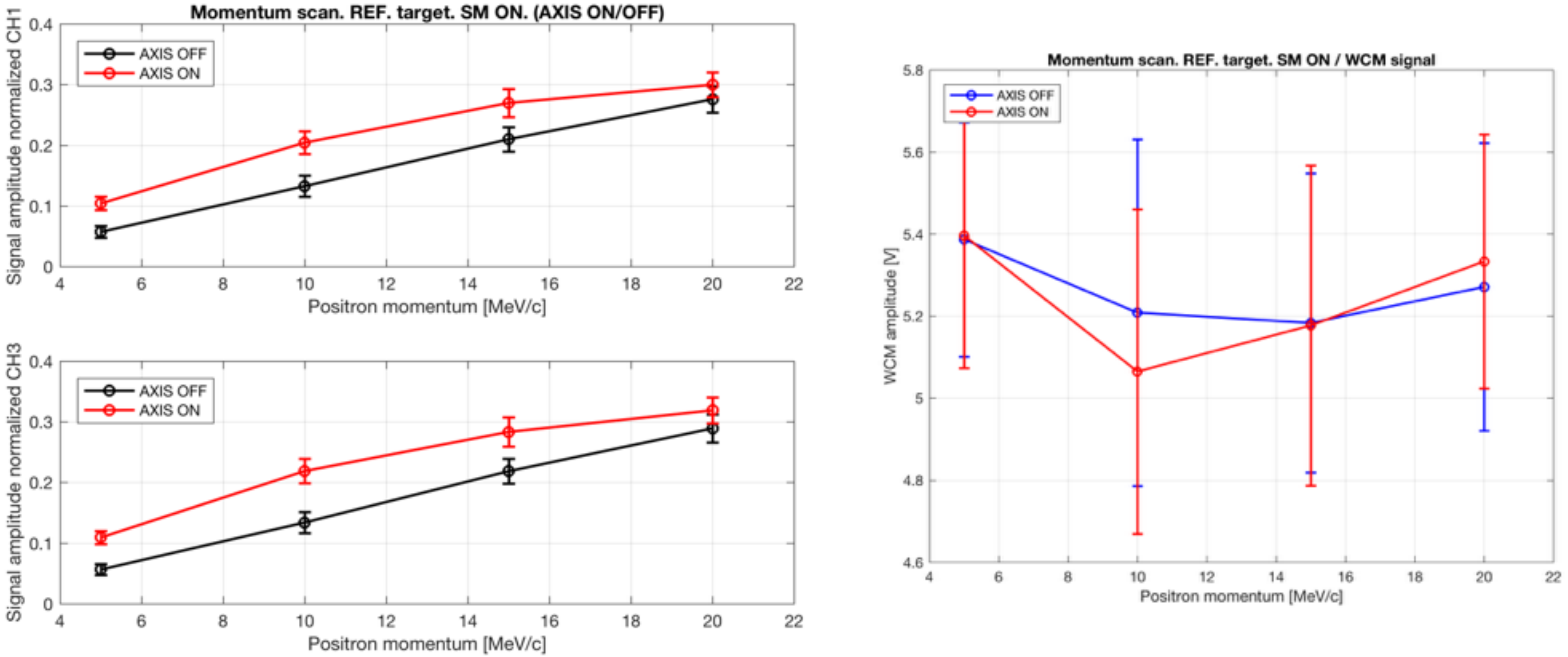






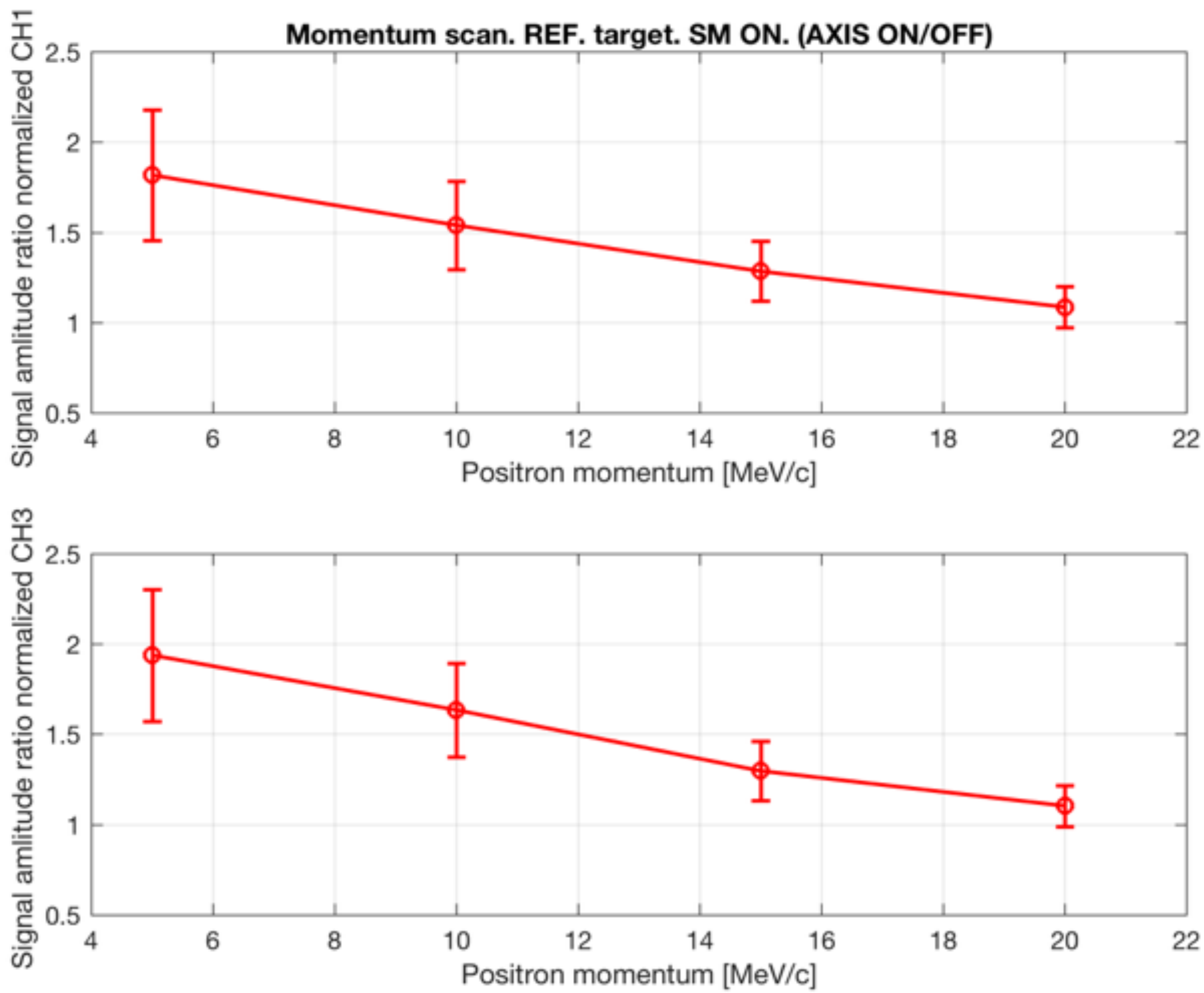


Reference target: hybrid scheme



The e+ signal acquired has been normalised by the electron beam intensity (WCM signal).

Reference target: hybrid scheme

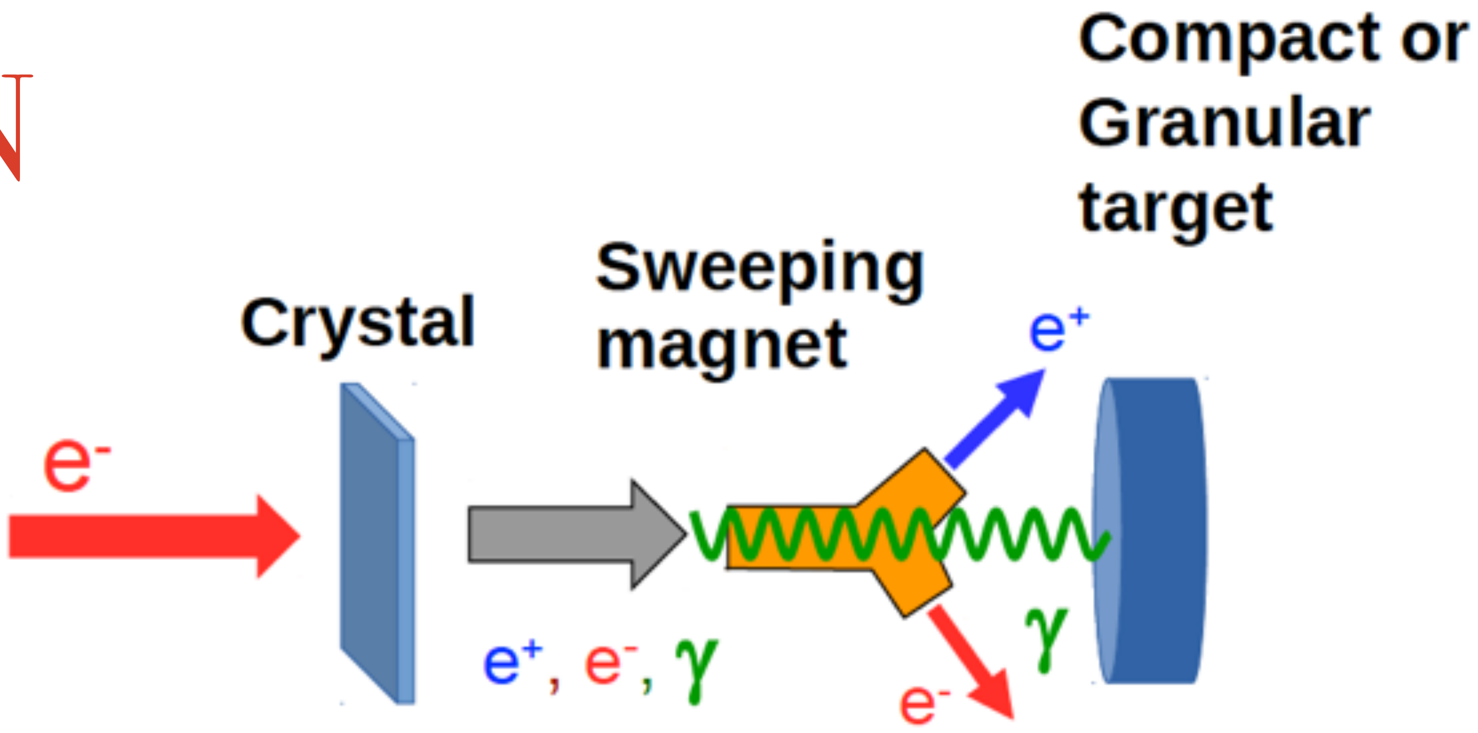


Enhancement factor related to the crystal AXIS ON/OFF conditions.

Hybrid scheme: Gran. 6L target

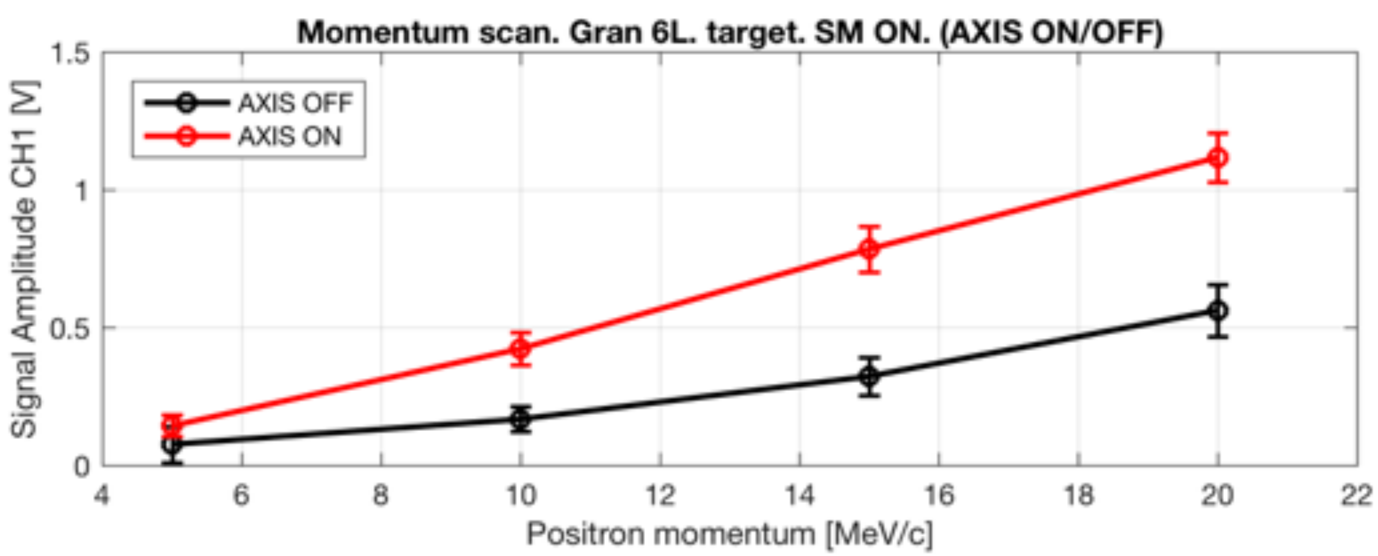
Axis ON/OFF

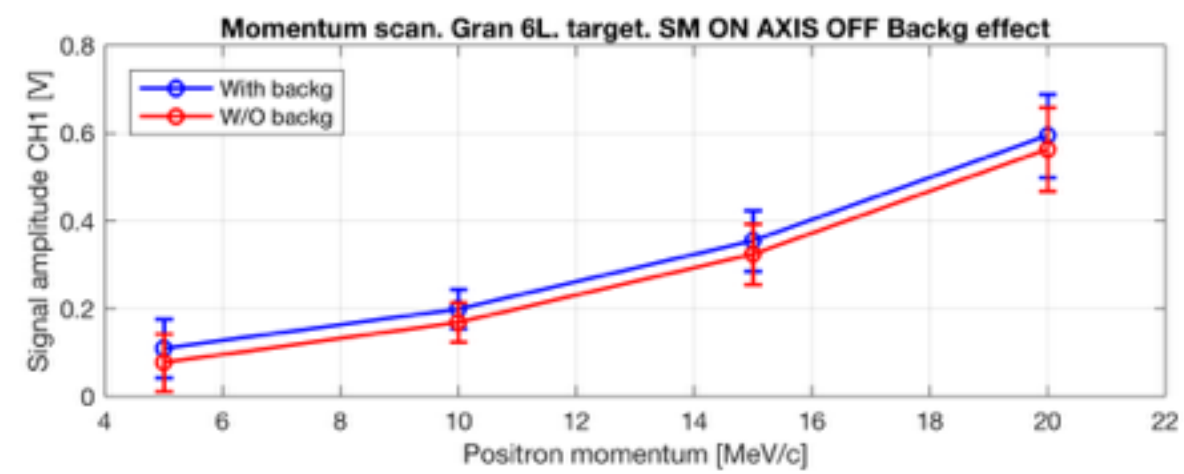
SM ON

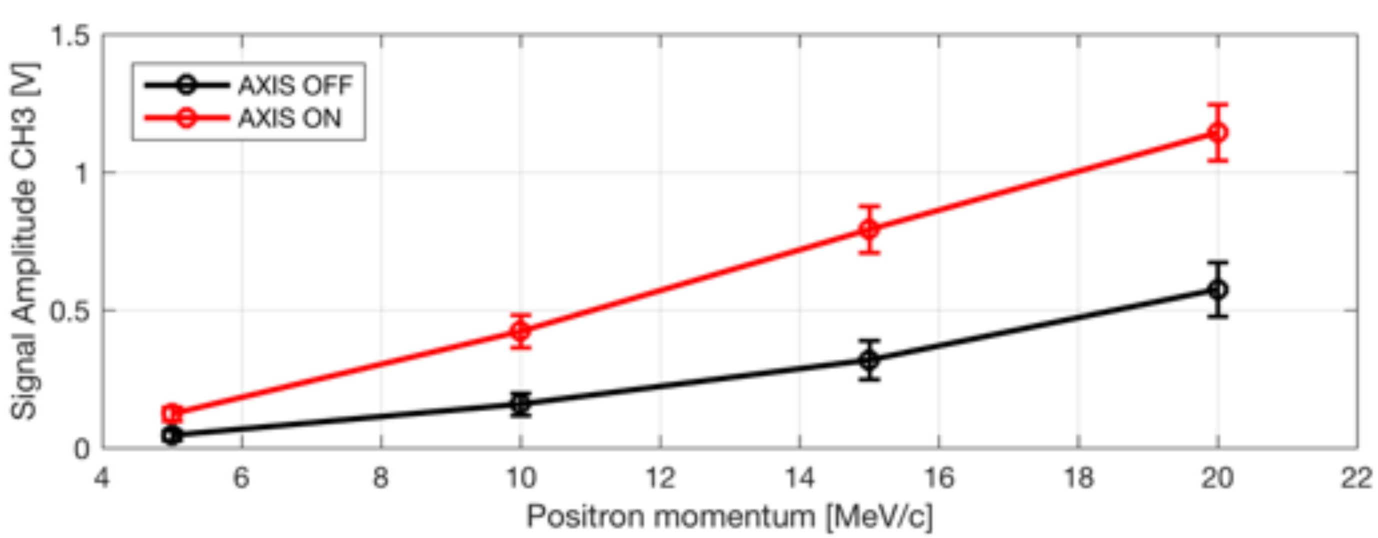


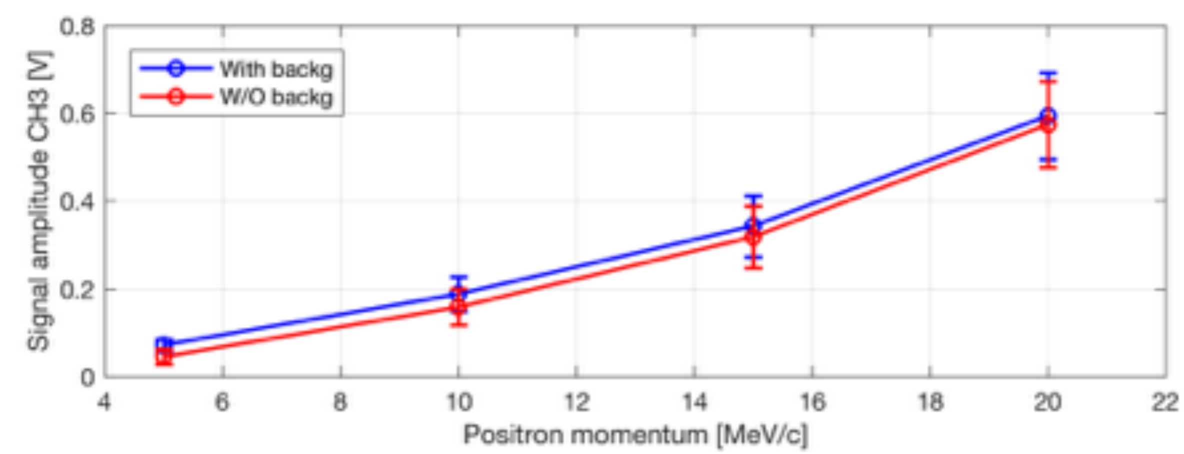
6L Granular target: hybrid scheme

- The positron production is measured at different positron momenta (5, 10, 15, 20 MeV) by the Lucite Cherenkov detector.
- There are two PMTs attached to different sides of the Lucite detector. On figures, it corresponds to the signals acquired on CH1 and CH3. Signal amplitude is directly proportional to the number of positrons produced.

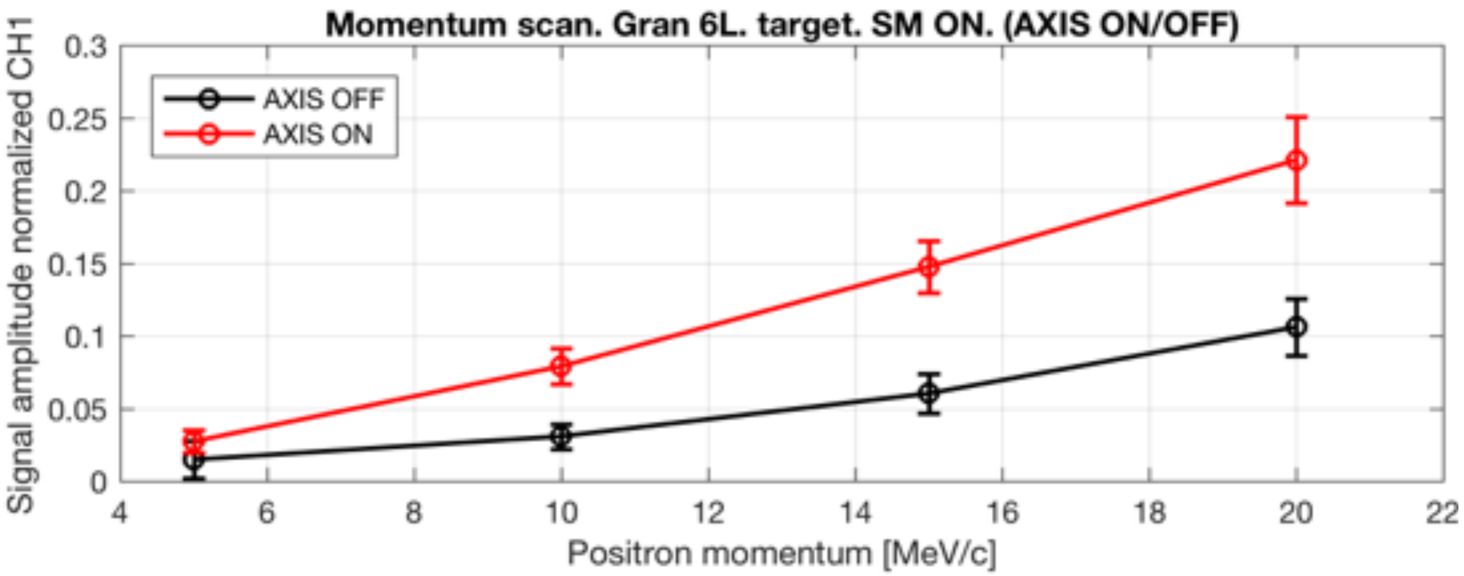


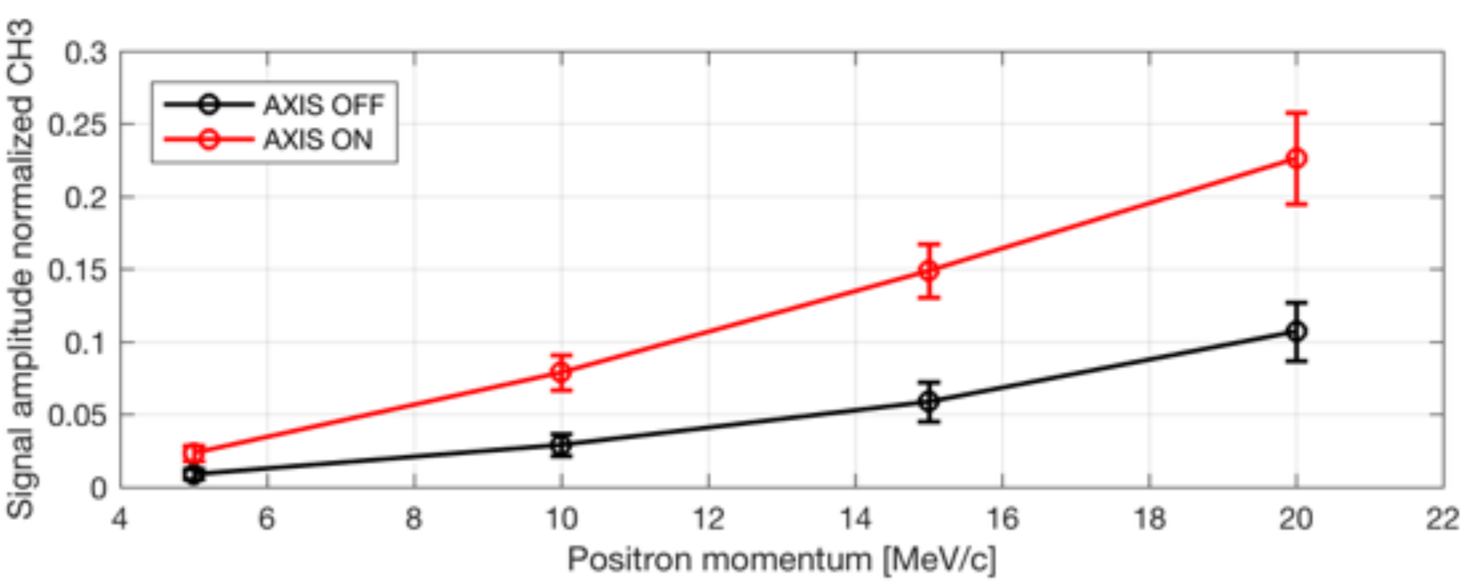


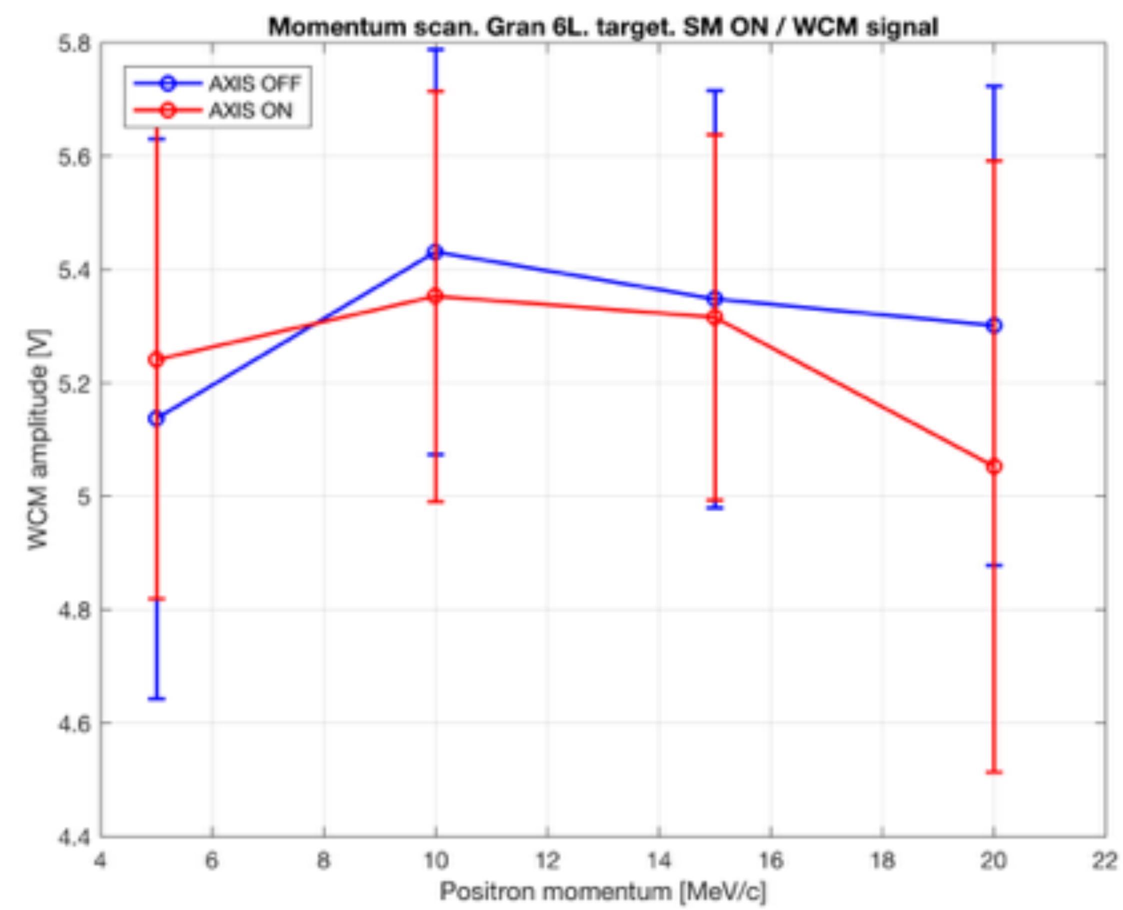




6L Granular target: hybrid scheme

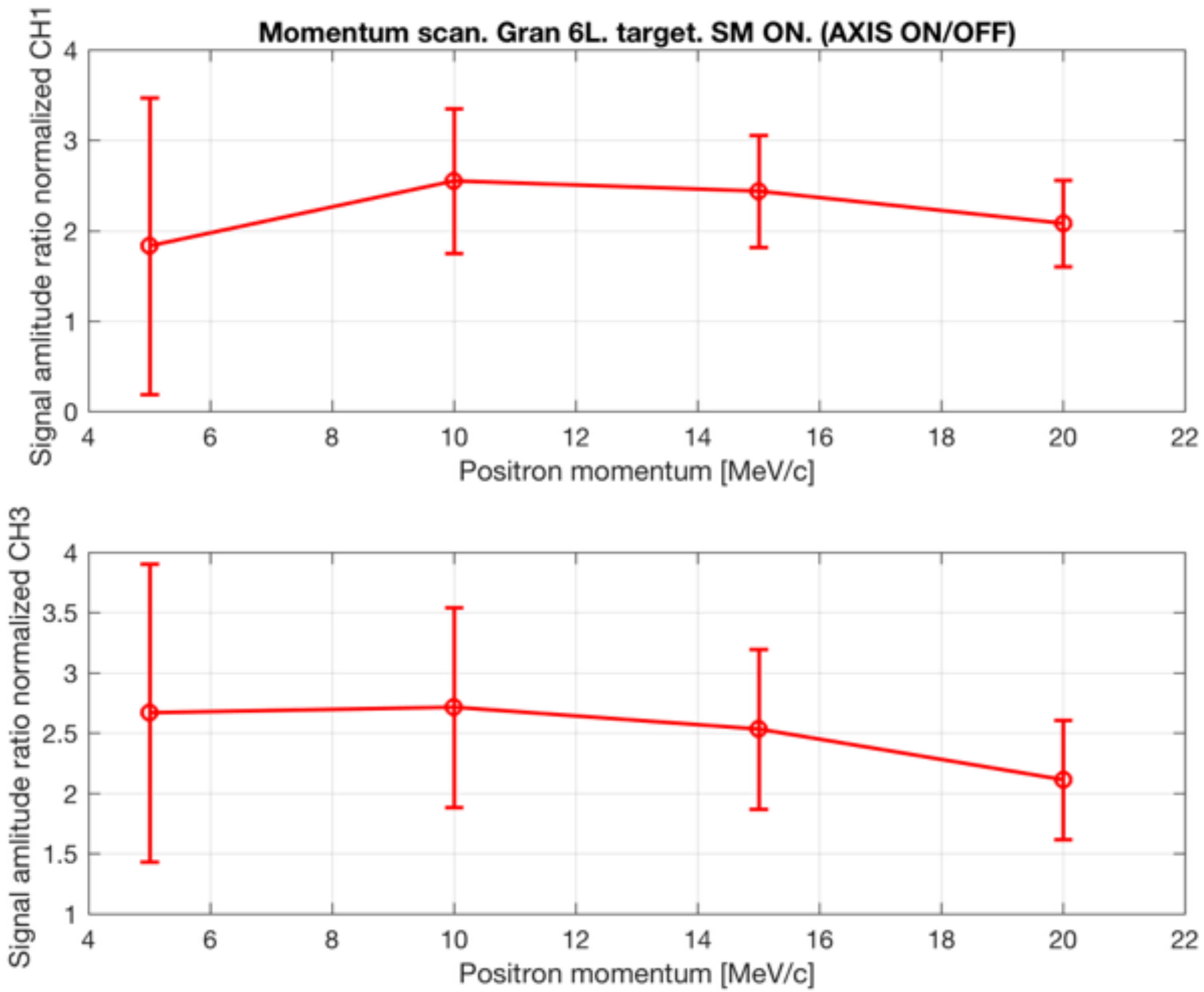






The e+ signal acquired has been normalised by the electron beam intensity (WCM signal).

6L Granular target: hybrid scheme

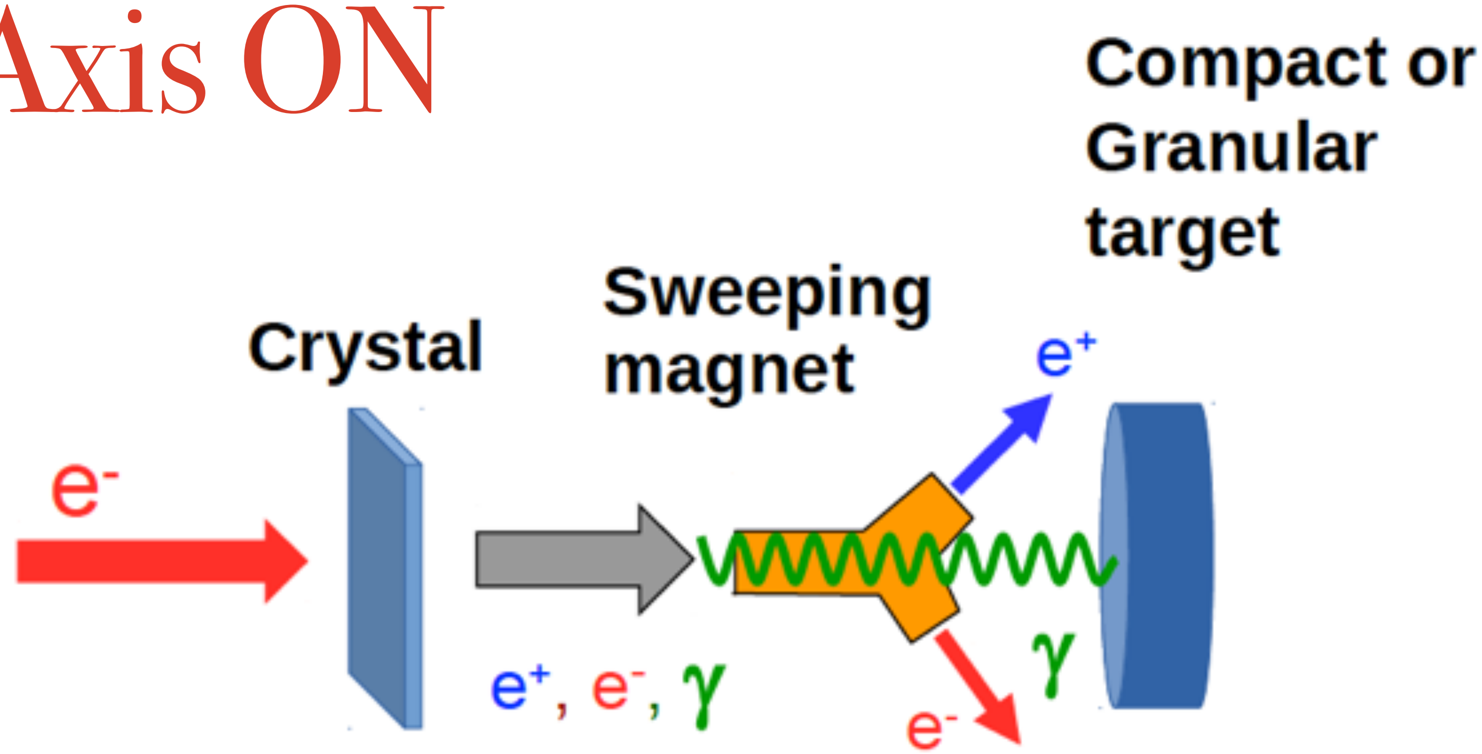


Enhancement factor related to the crystal AXIS ON/OFF conditions.

Hybrid scheme: 6L Gran. target

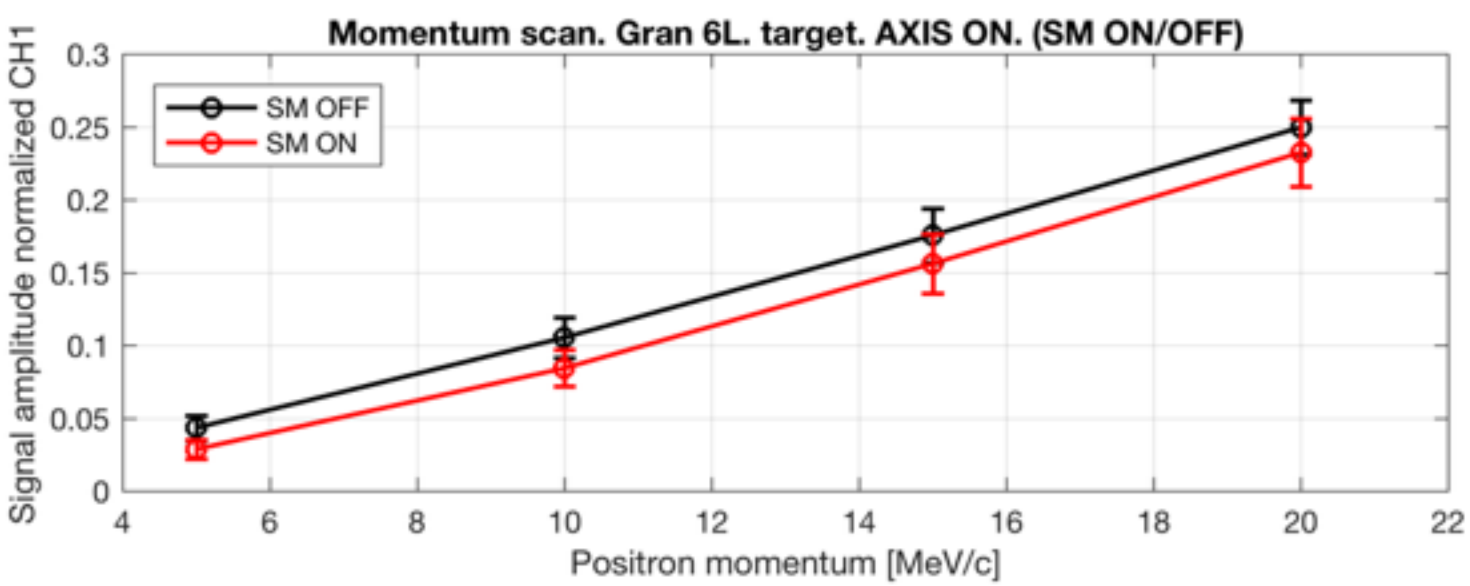
SM ON/OFF

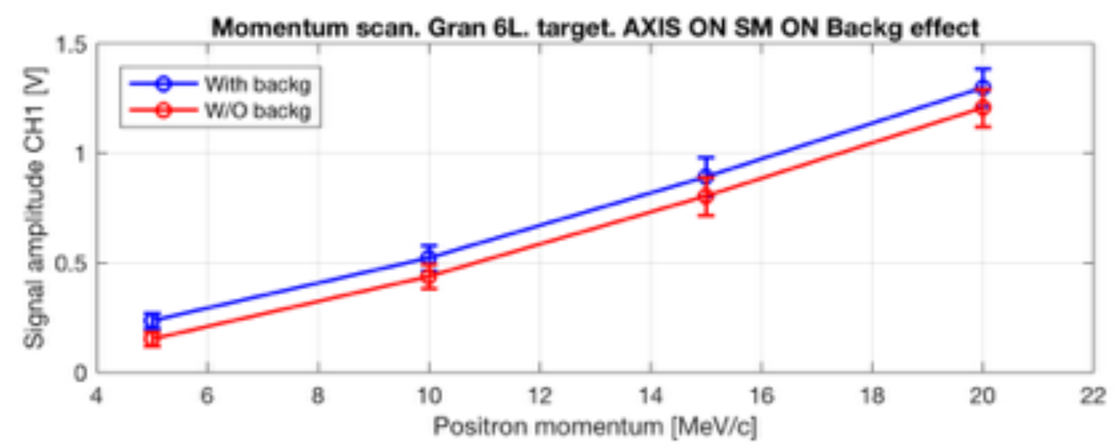
Axis ON

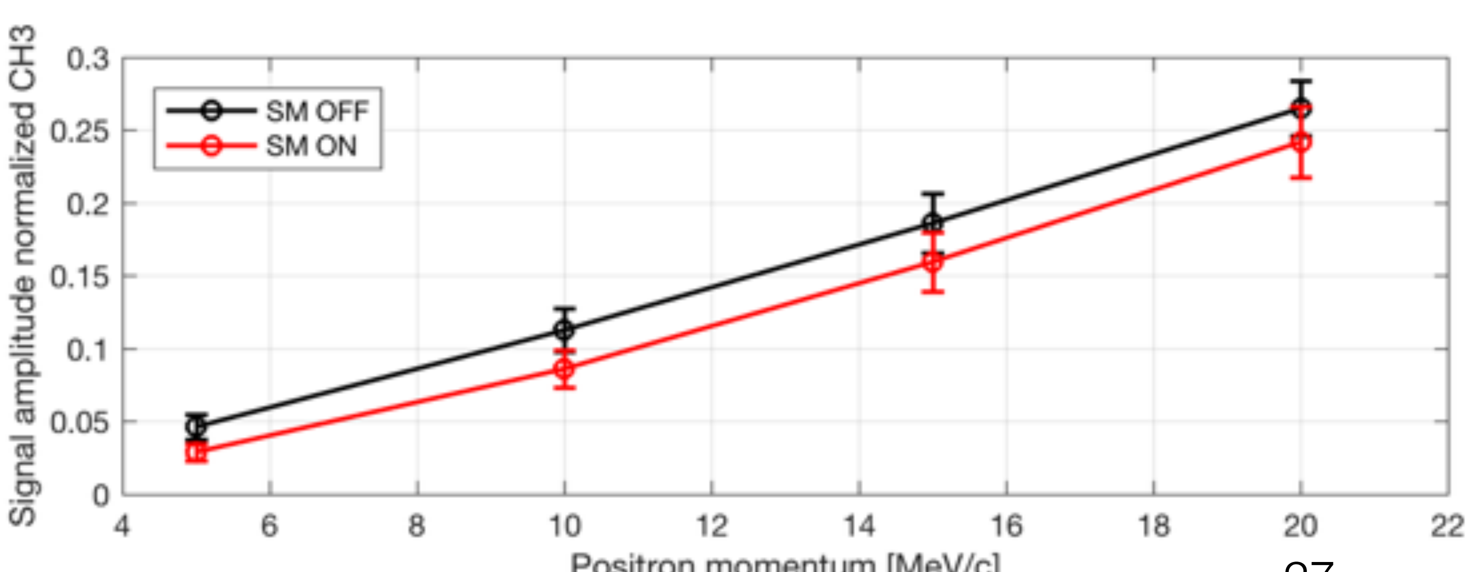


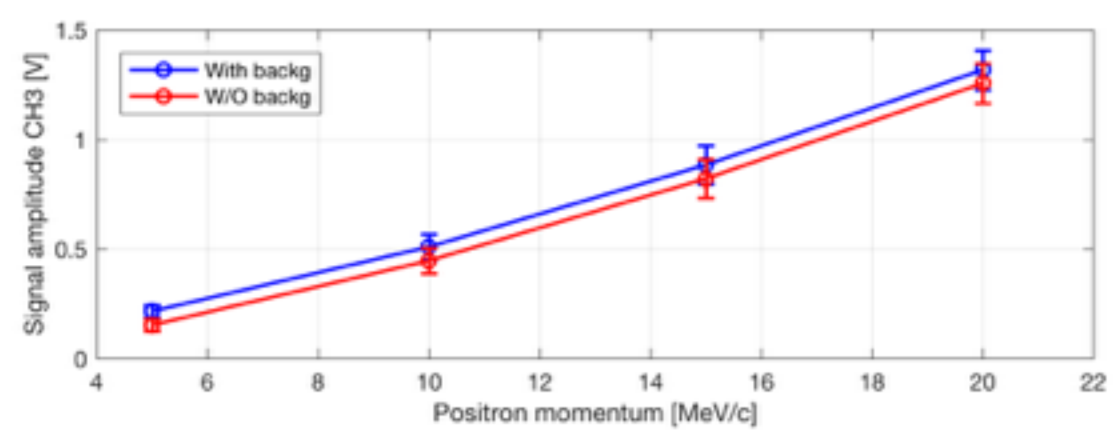
6L Granular target: hybrid scheme

- The positron production is measured at different positron momenta (5, 10, 15, 20 MeV) by the Lucite Cherenkov detector.
- There are two PMTs attached to different sides of the Lucite detector. On figures, it corresponds to the signals acquired on CH1 and CH3. Signal amplitude is directly proportional to the number of positrons produced.

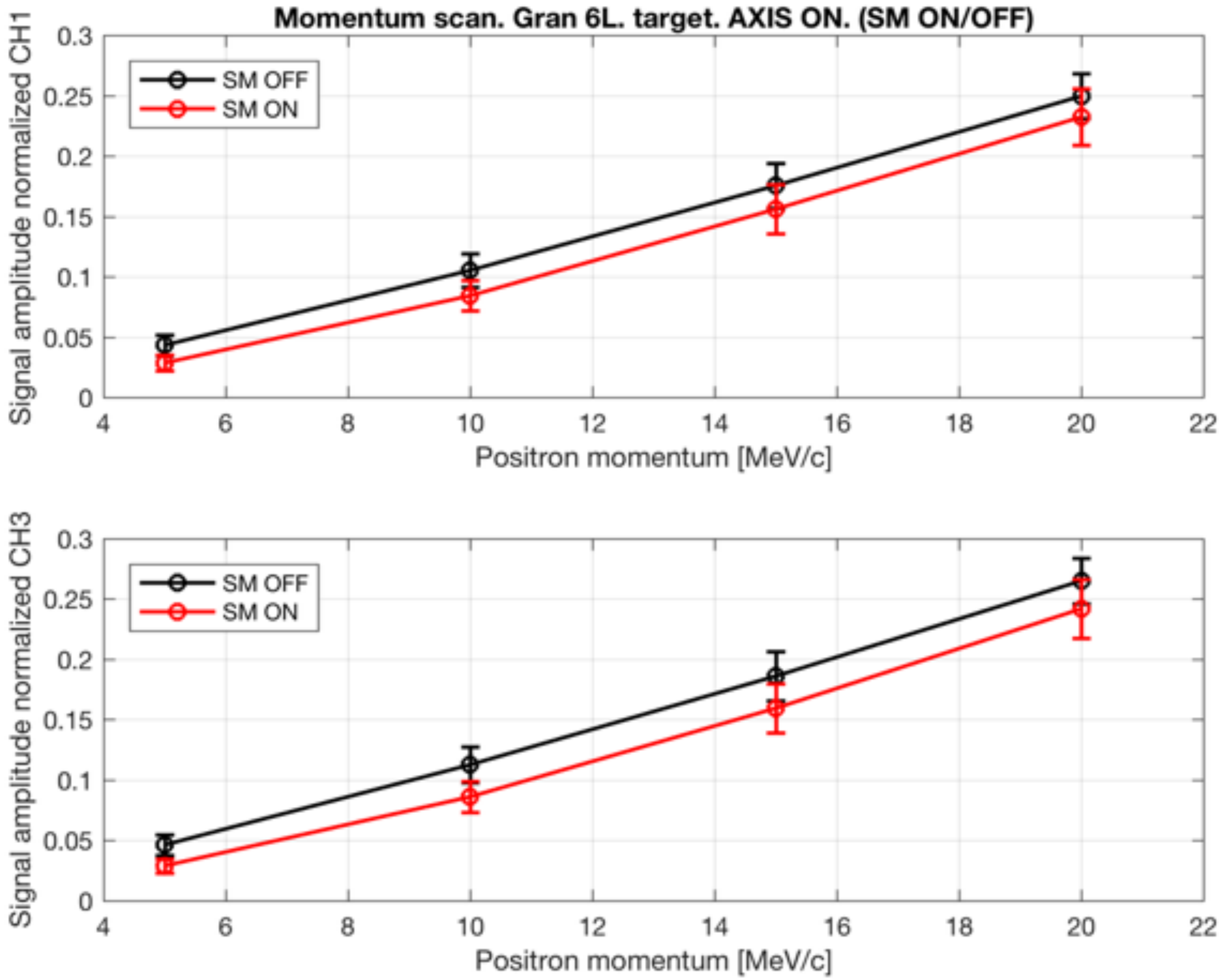


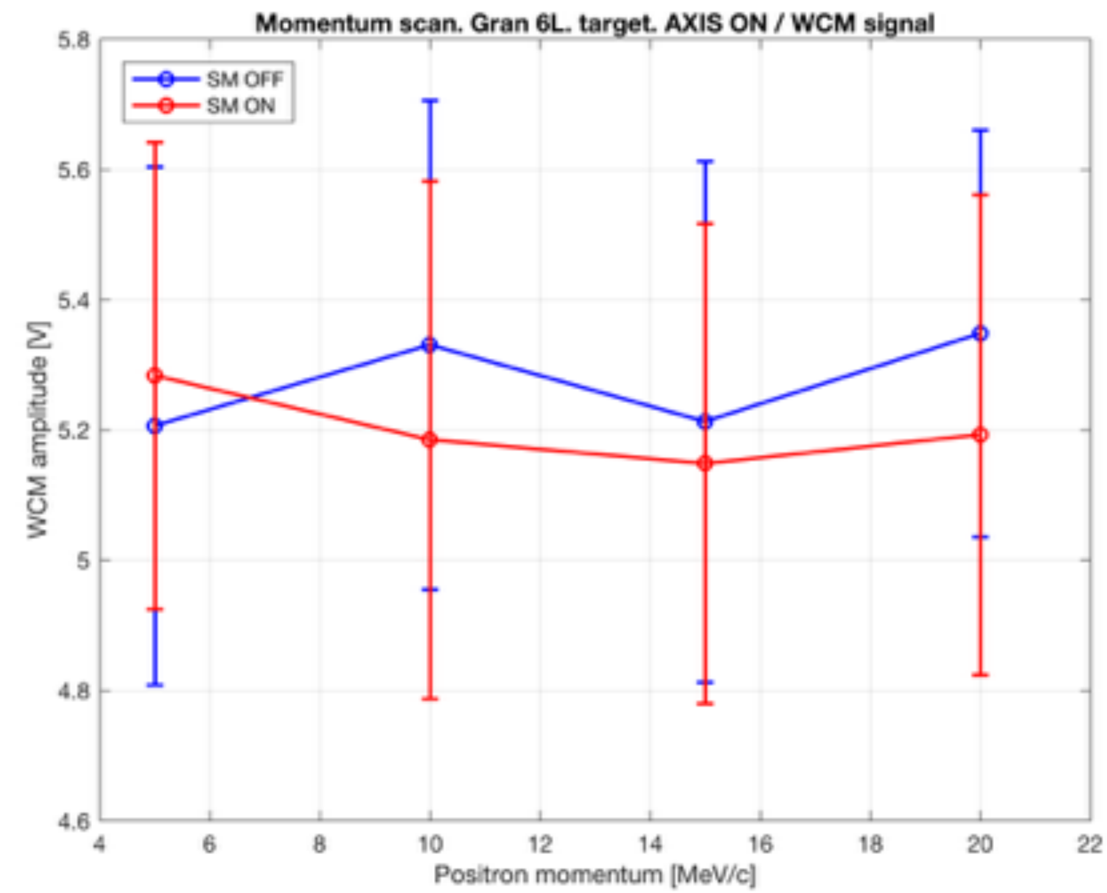






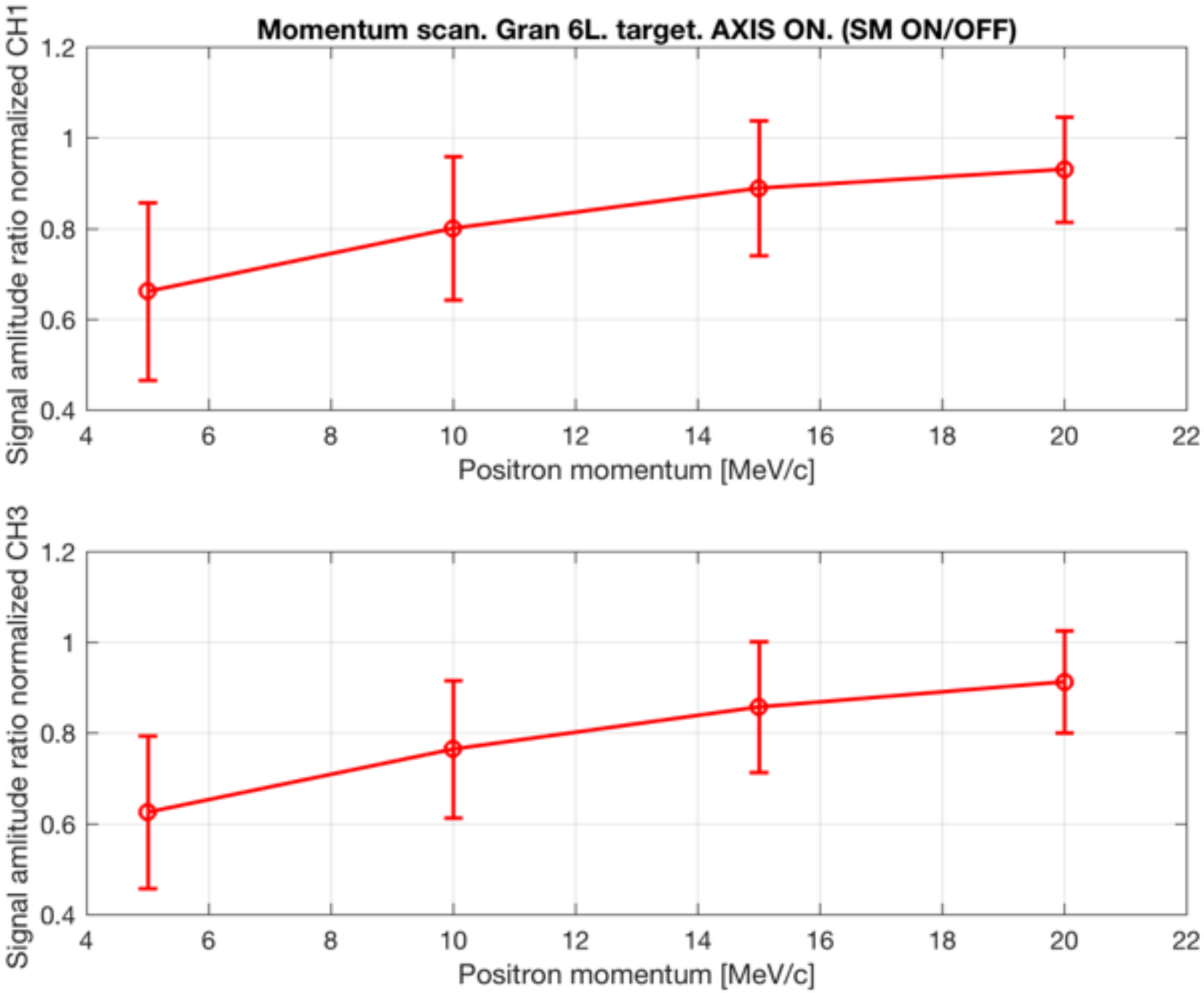
6L Granular target: hybrid scheme





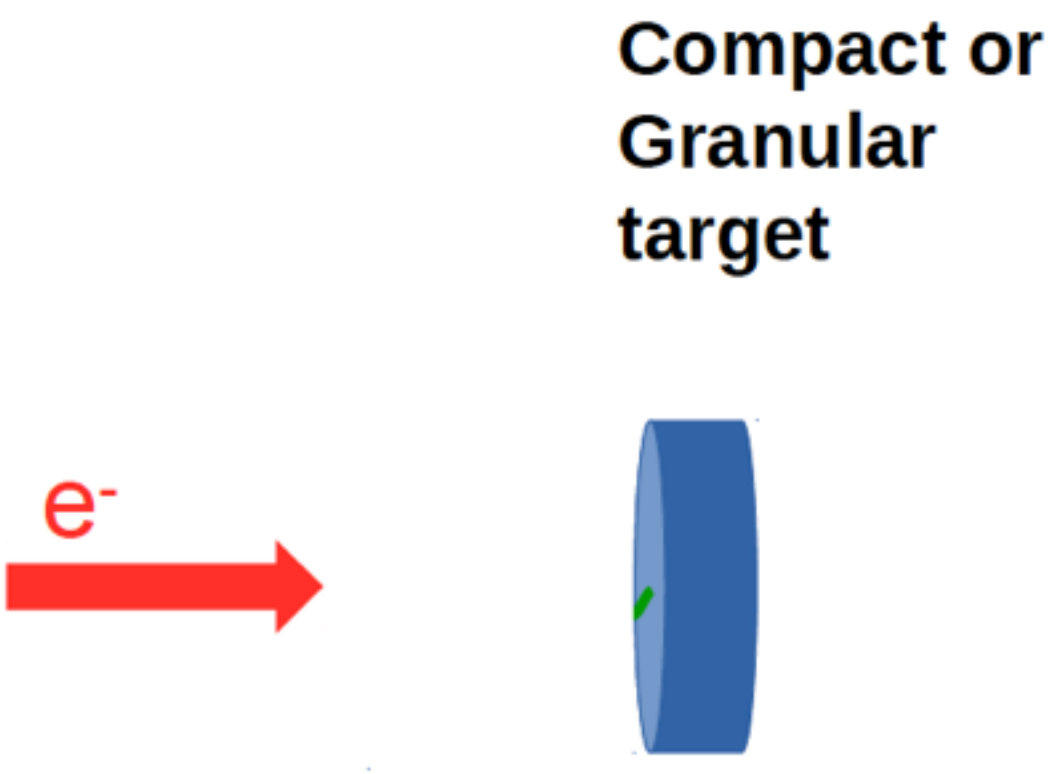
The e+ signal acquired has been normalised by the electron beam intensity (WCM signal).

6L Granular target: hybrid scheme



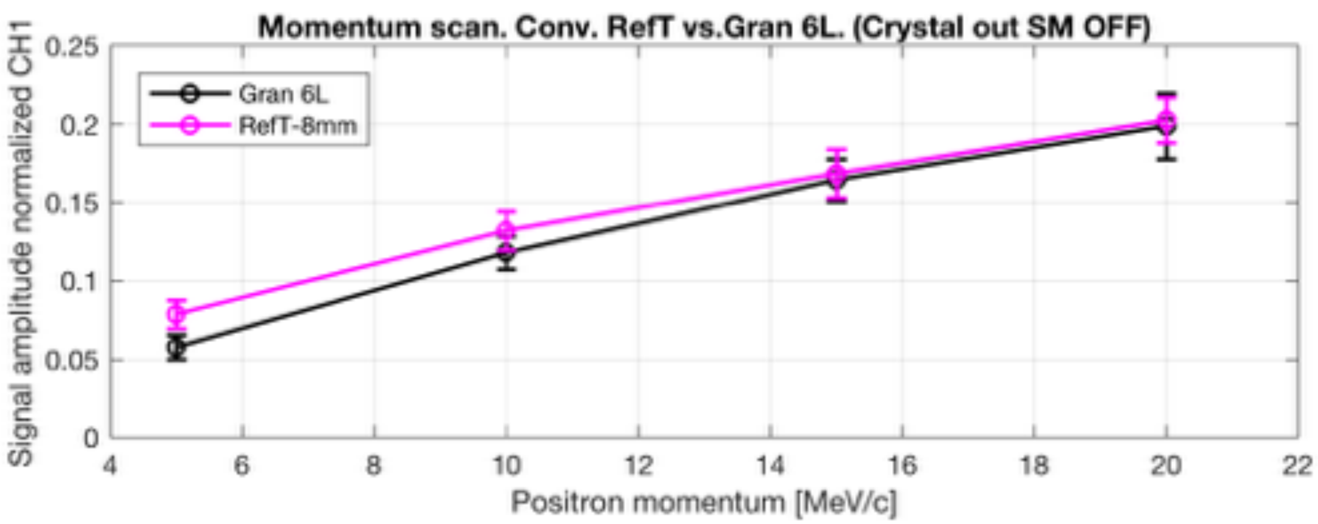
Contribution of the charged particles to the e+ production.

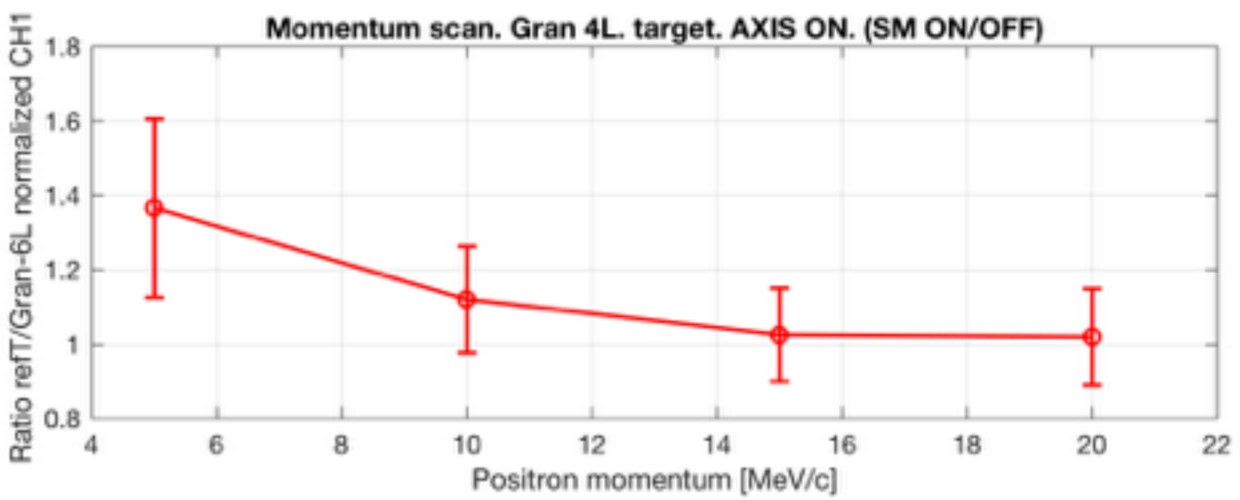
Ref. target vs. Granular target

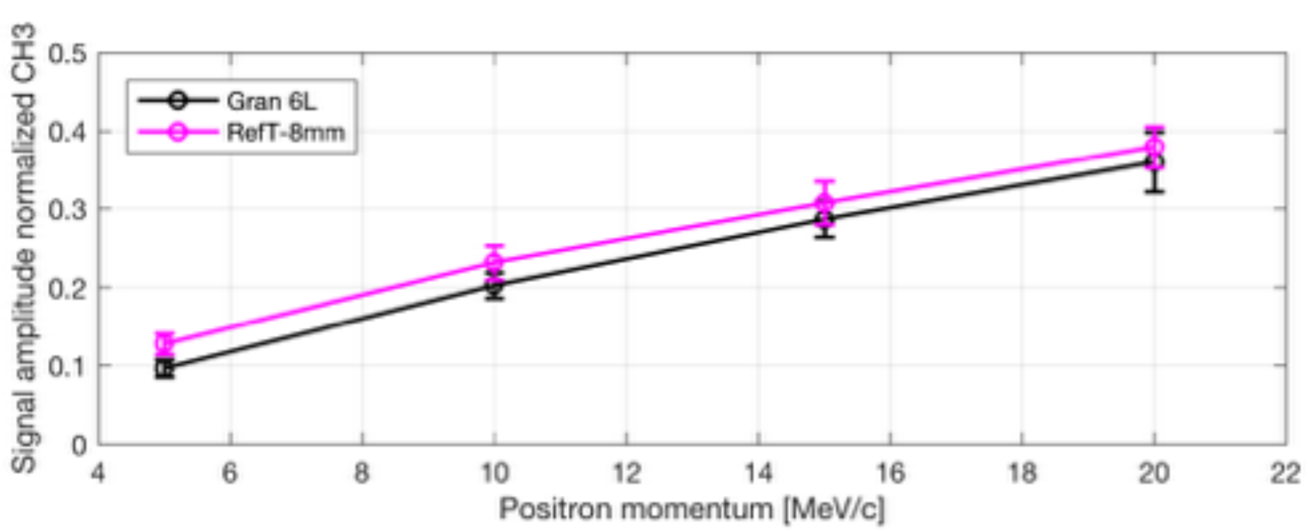


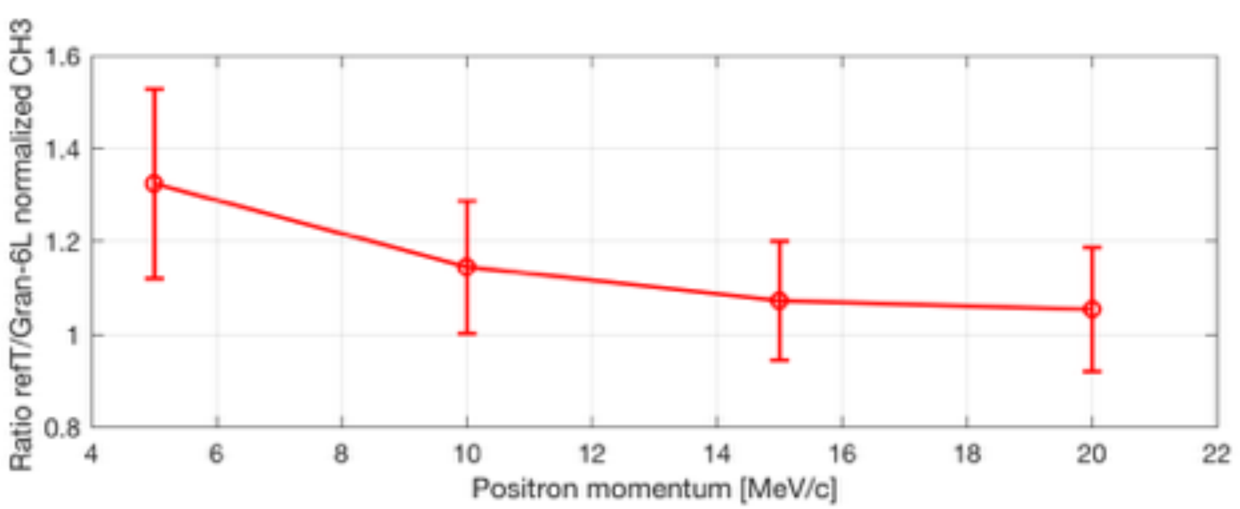
Positron production measured

- The positron production in the case of the Reference and Granular targets are measured at different positron momenta (5, 10, 15, 20 MeV) by the Lucite Cherenkov detector.
- There are two PMTs attached to different sides of the Lucite detector. On figures, it corresponds to the signals acquired on CH1 and CH3. Signal amplitude is directly proportional to the number of positrons produced.









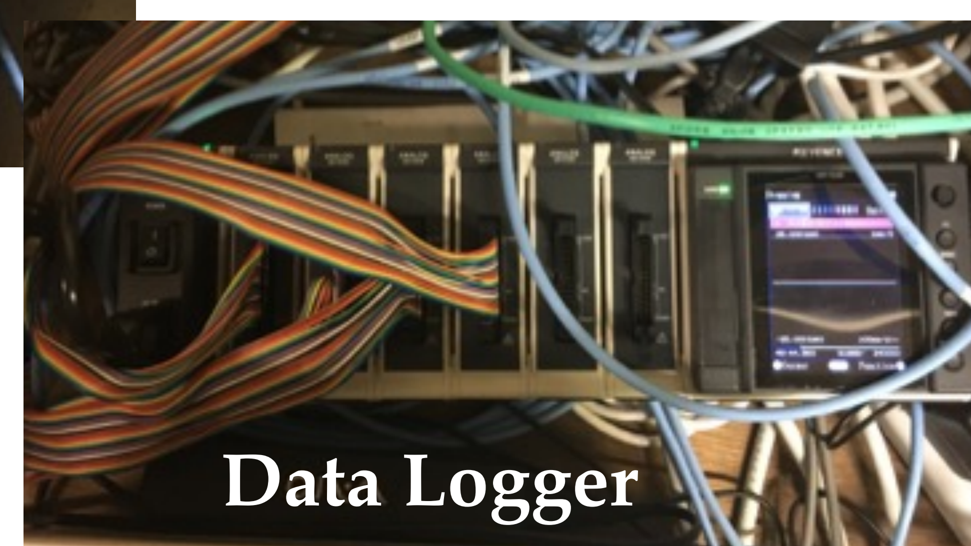
Temperature measurements

Temperature measurement

- The temperature is measured by the type K thermocouples attached to the backside of the targets. (wrt to the beam direction) in current mode. Calibration: 20 mA => 100 °C.
- Dynamic range of the signal transformers used is limited to the following range: 0 - 100 °C.
- To measure the ambient temperature in the tunnel, a dedicated thermocouple is employed. It is measured by the signal transformer working in the range 0 - 300 °C (calibration: 20 mA => 300 °C).
- The average temperature maintained in the tunnel ~25 °C.
- The temperature is acquired by the data logger Keyence NR-HA08 (control unit NR-600).
- The data are taken continuously without any beam trigger (synchronisation by time later on if needed).

Temperature measurement

Signal transformers


Data Logger

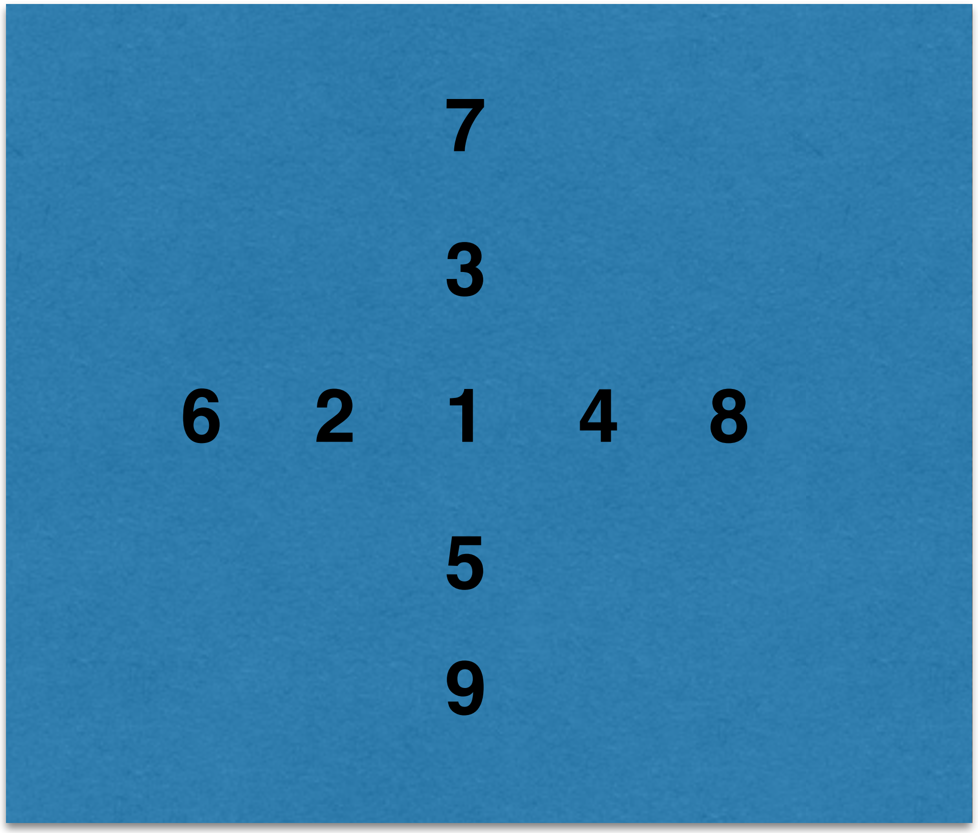
Installation of the temperature measurement in the data taking hall (not far from the tunnel).

Thermocouples configuration

Reference target

Target size: 23 x 23 x 8 mm

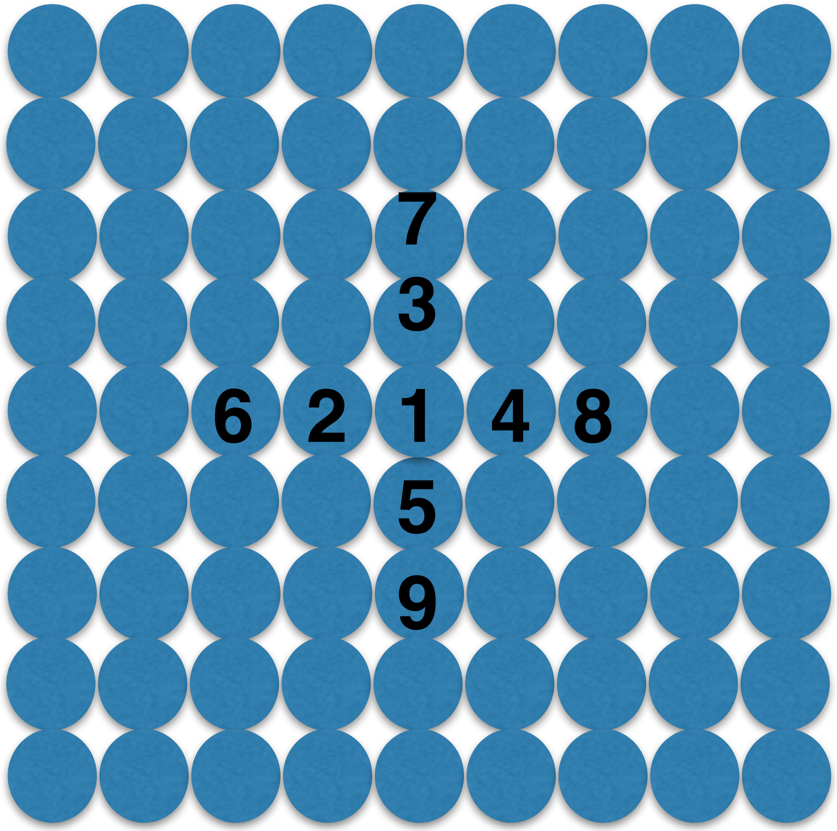
Distance between the thermocouples: 2 mm

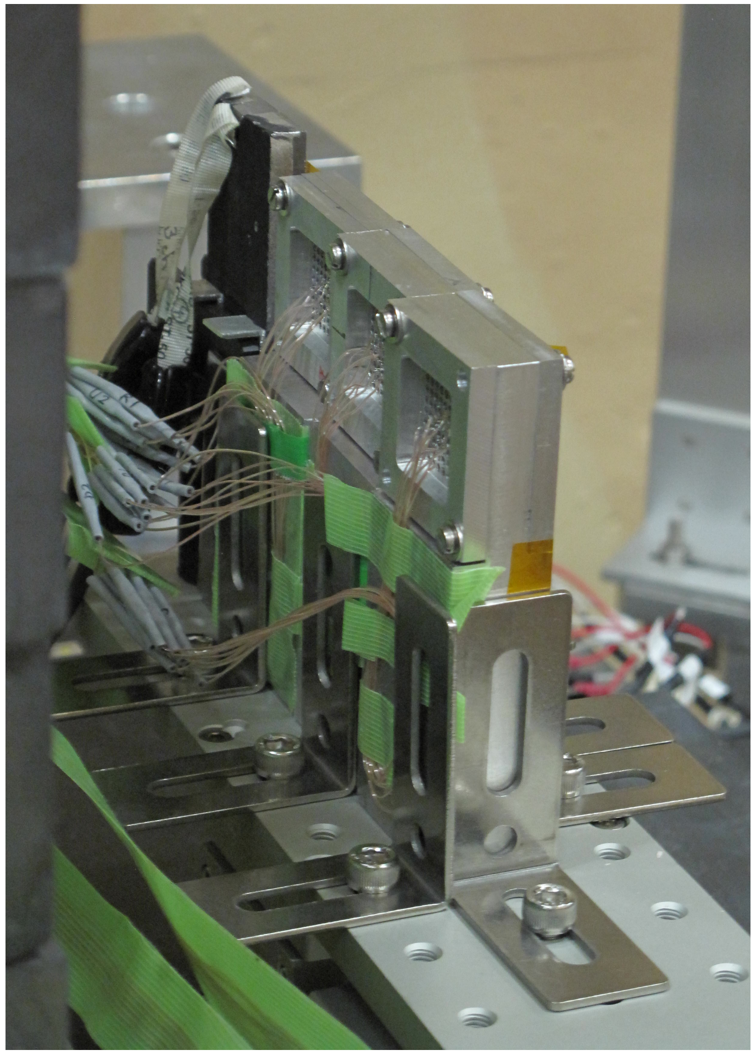


Granular target (4L and 6L)

Target size: 23 x 23 x 8 mm + Al frame

Distance between the thermocouples: 2.2 mm



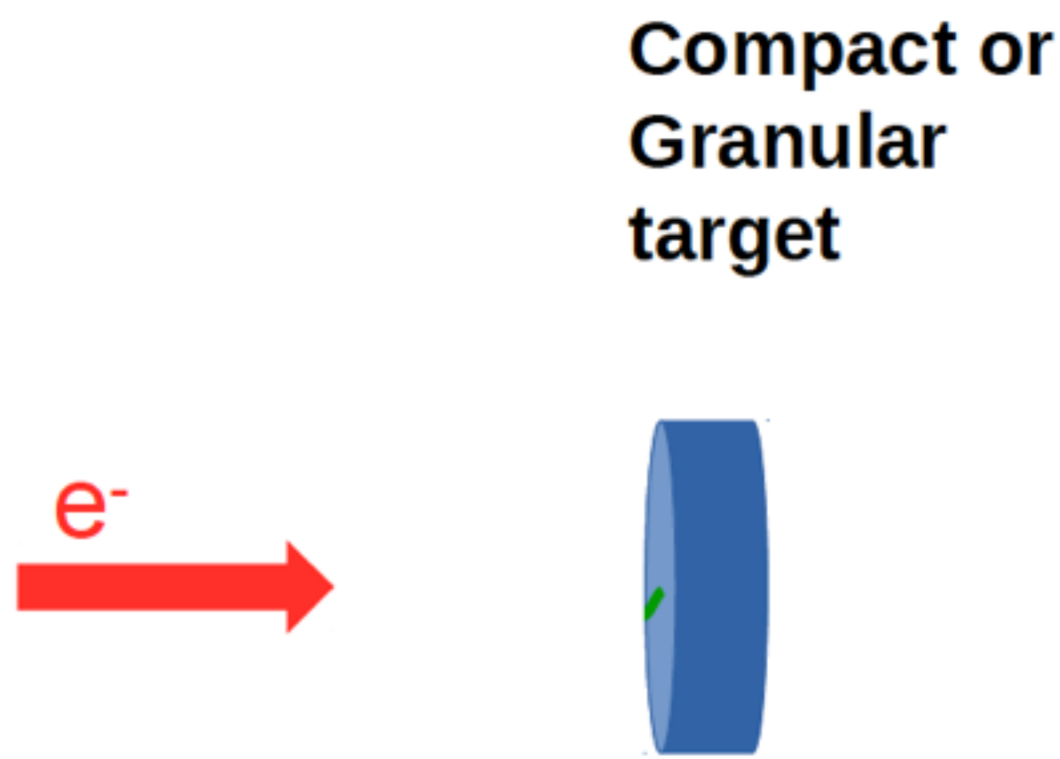


Temperature measurement

We took the data under the following conditions:

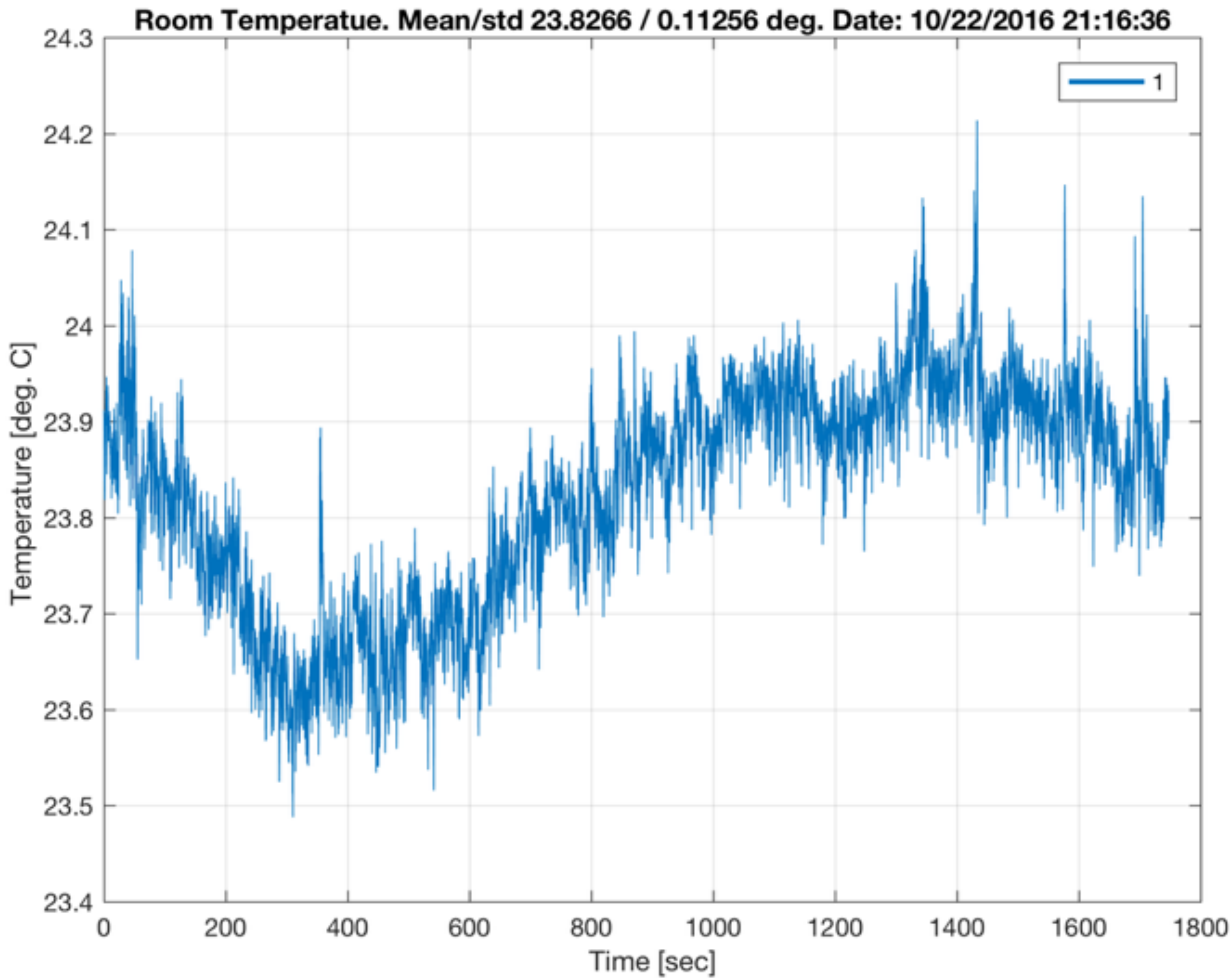
- Crystal Axis ON/OFF (crystal is aligned to satisfy the channeling conditions/ crystal axis is offset by ~50 mrad).
- Different Frep: 1 Hz, 5 Hz, 25 Hz.
- Sweeping Magnet (SM) ON/OFF (only the gamma rays impinge on the amorphous target/all particles exiting the crystal target impinge on the amorphous target). /@ Axis ON/

Conventional scheme: Ref. target



Reference target: conv. scheme

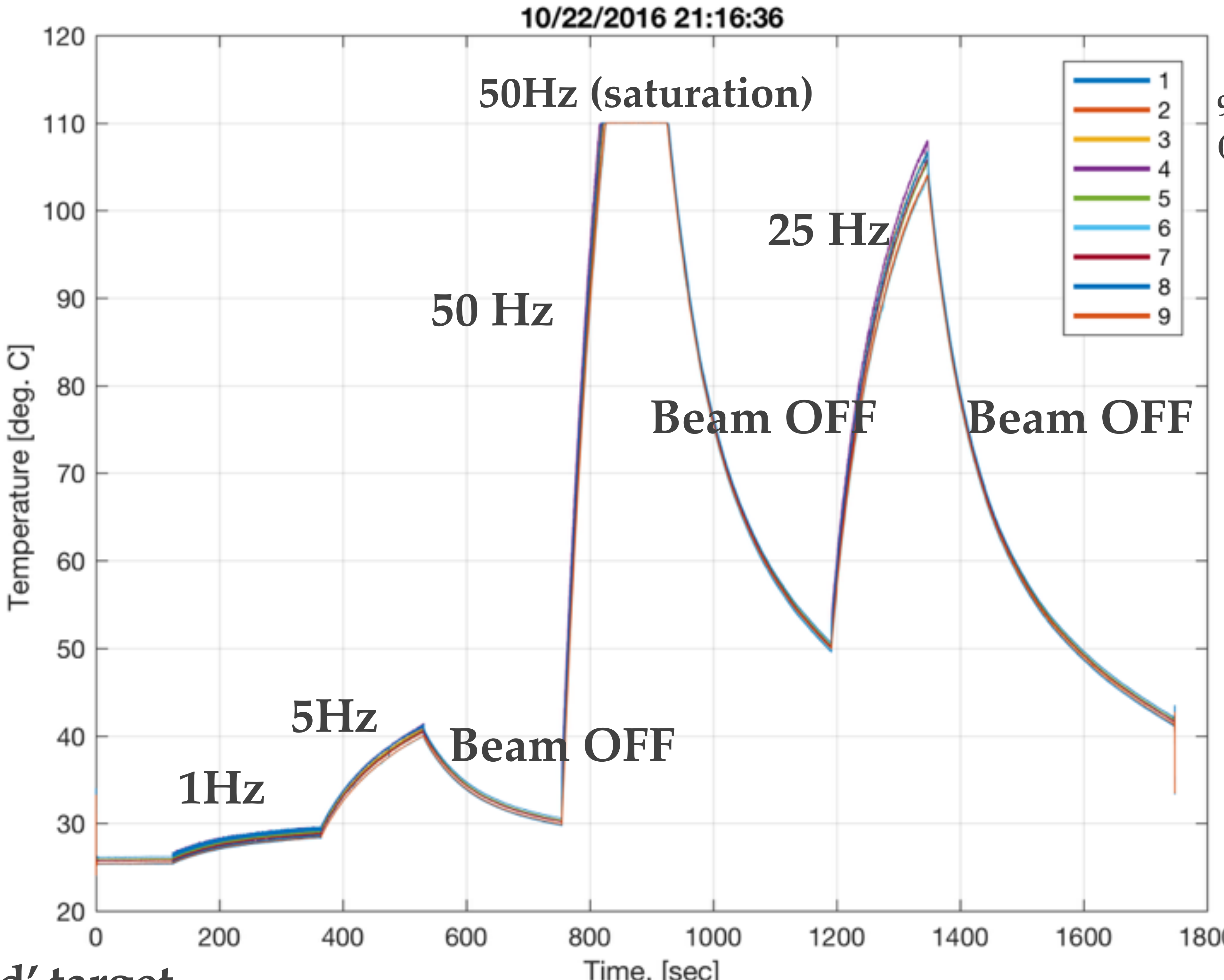
Raw data: 30 min RUN



Ambient temperature measured during the Run. Mean T = 23.8 ± 0.1 °C.

Reference target: conv. scheme

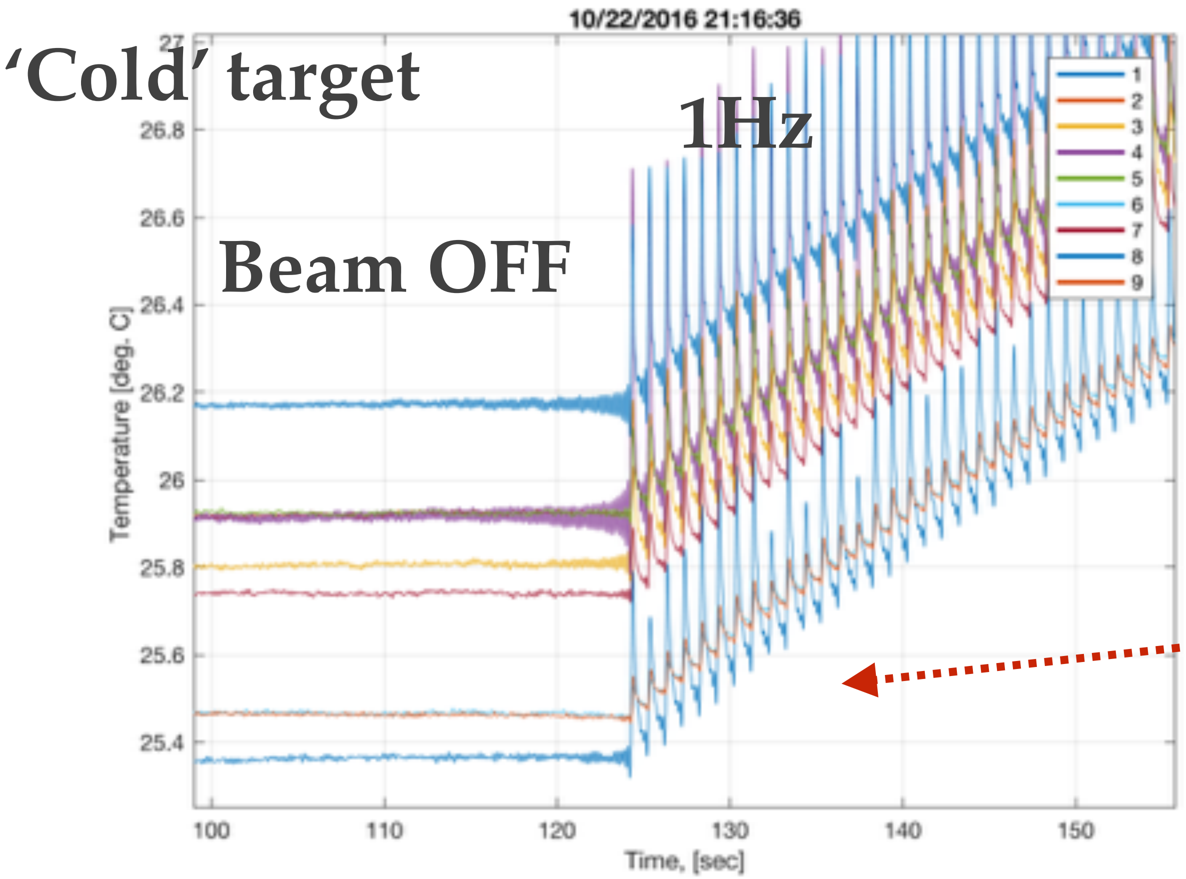
Raw data: 30 min RUN

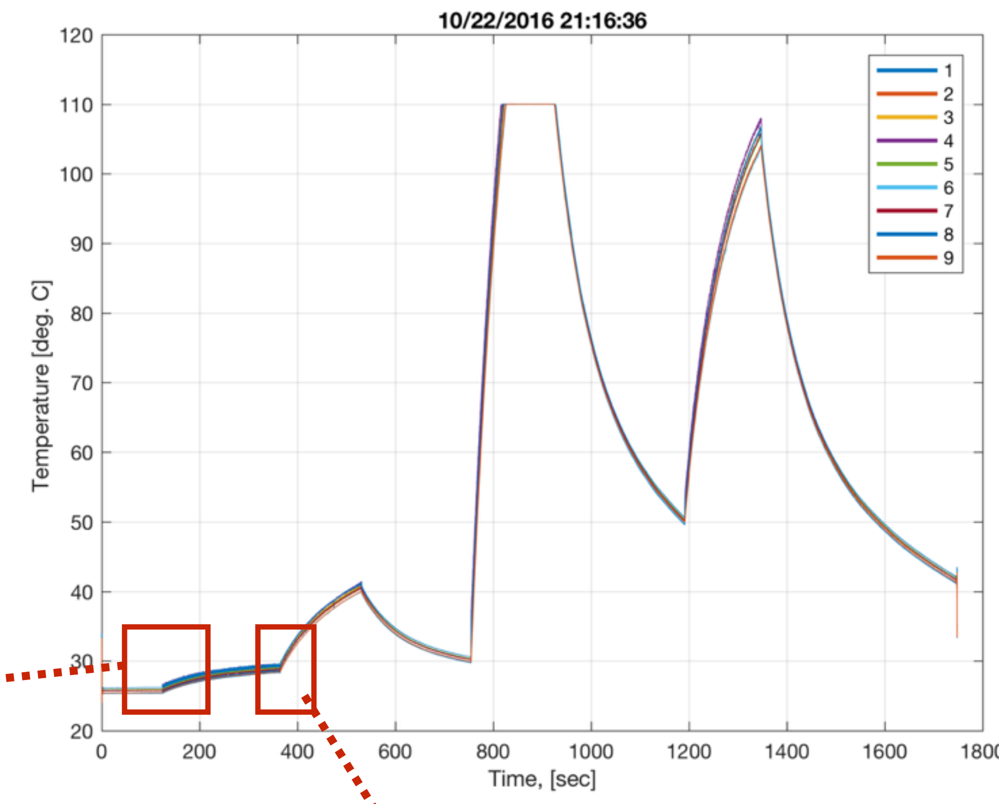


9 thermocouples (sensors) are shown

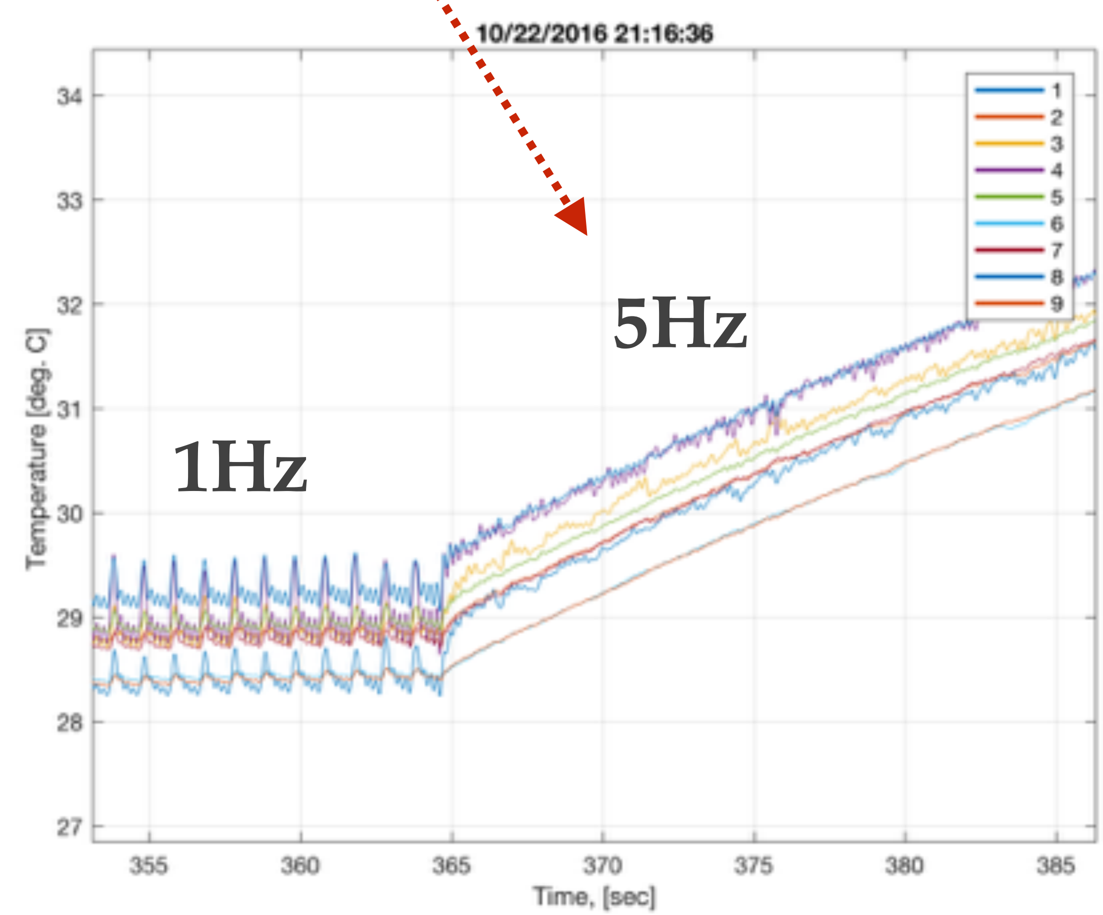
'Cold' target

Reference target: conv. scheme





Raw data zoomed in.



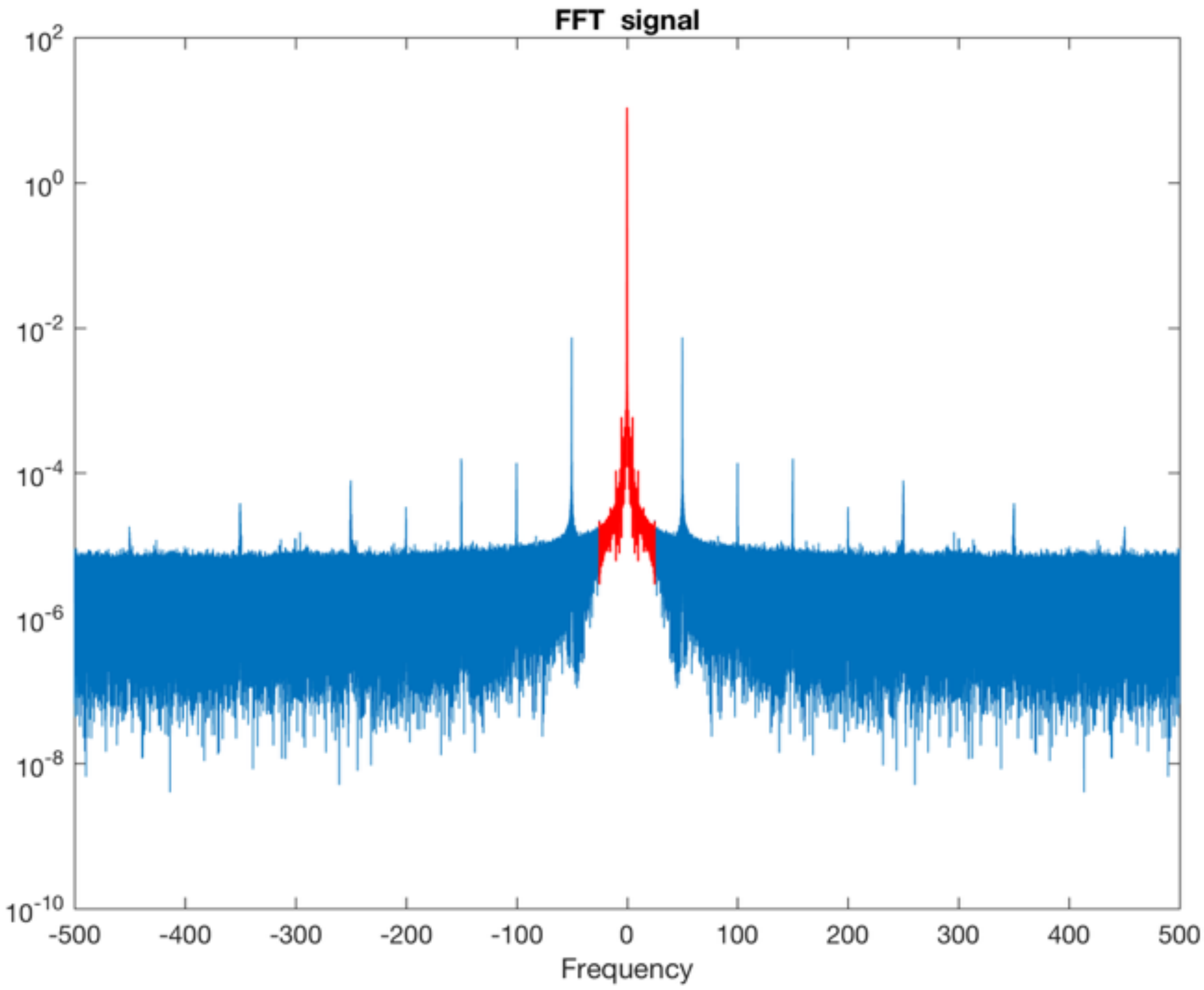
Data manipulation

- As the first step, a very simple FFT analysis is made on the data to see the frequency content.

- To be fast at the beginning, a simple filter is also applied with different cut-off frequencies depending on the beam repetition rate used.

- Next step: apply a proper filter (to clean the data from picked-up noise) and see the effect of different frequency cut-offs. Them extract the useful information from the data.

Reference target: conv. scheme

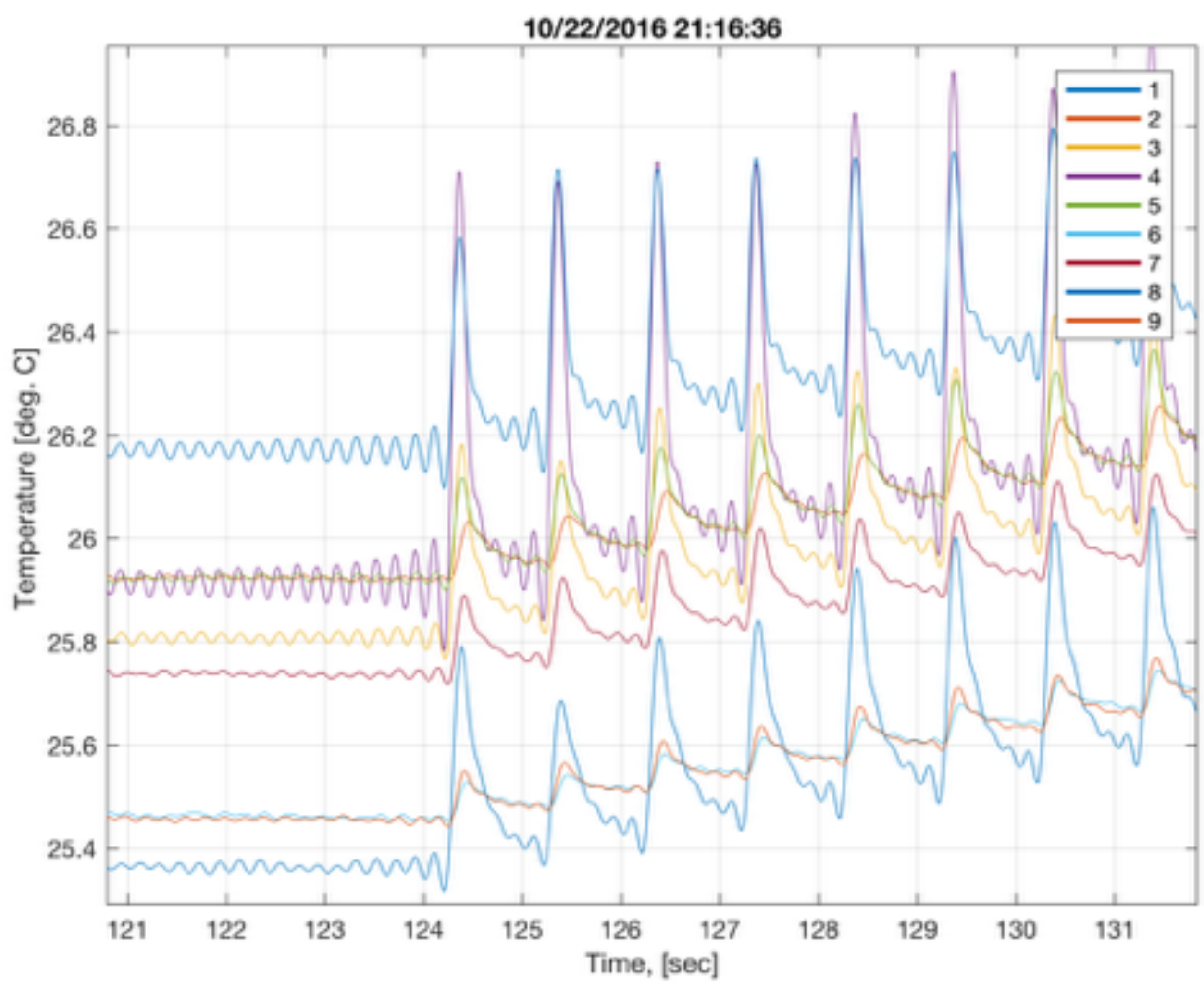


The klystrons are operated at 50 Hz.

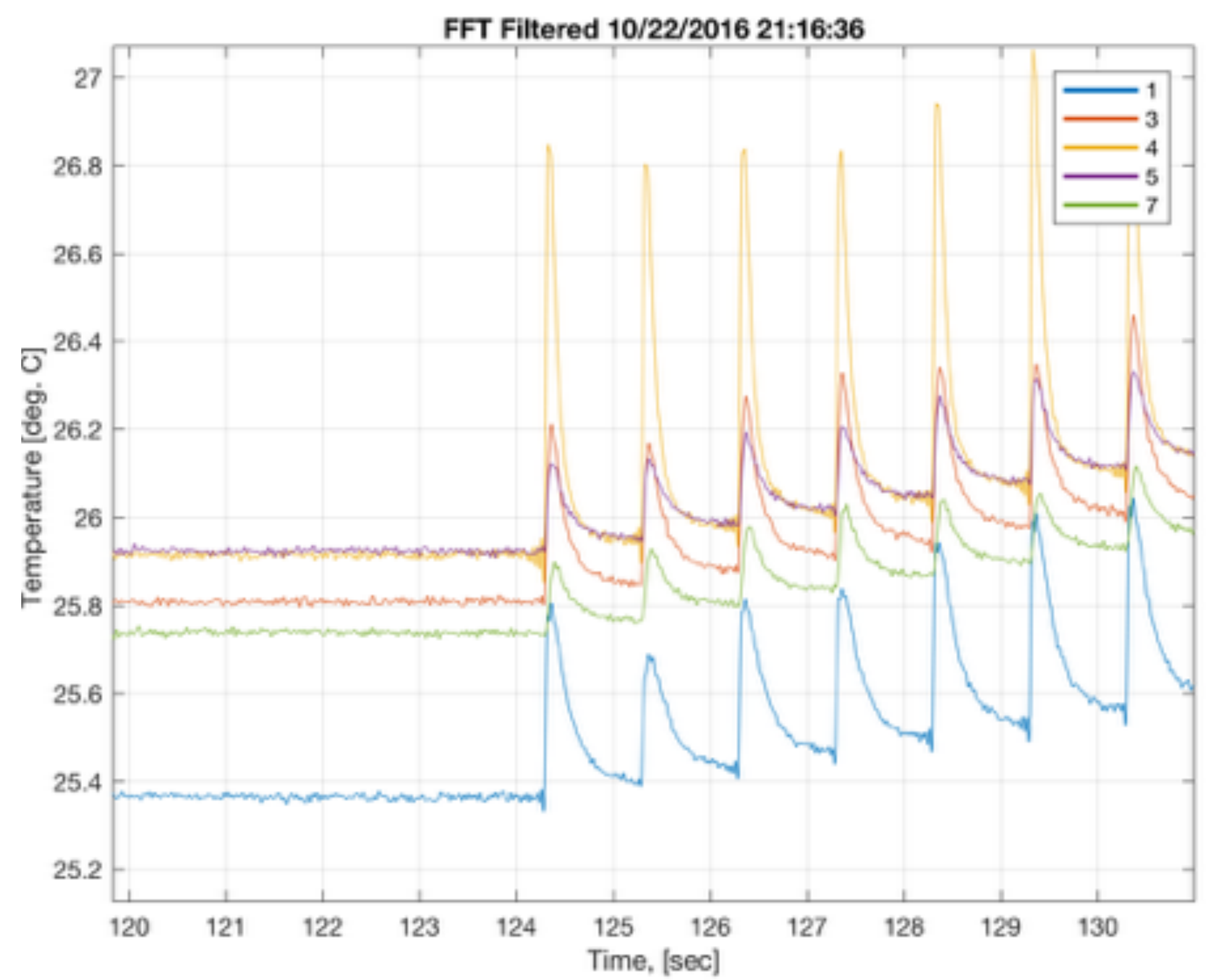
Reference target: conv. scheme

Effect of the filter

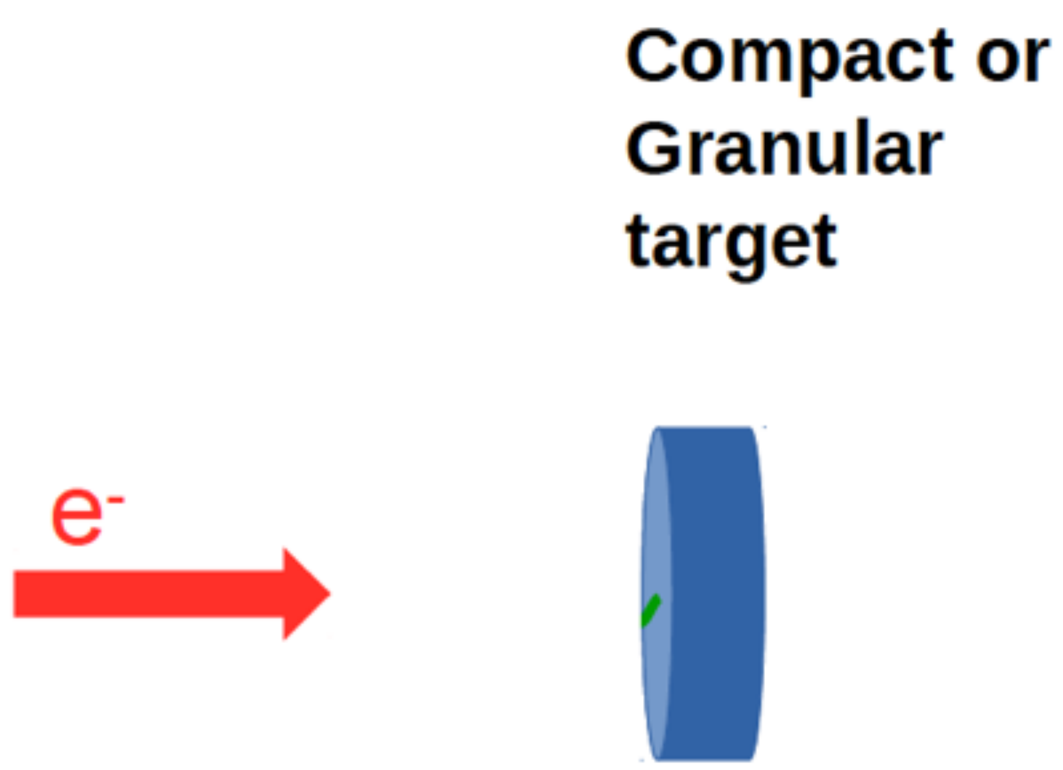
Raw data



Raw data + filter with Cutoff 25 Hz

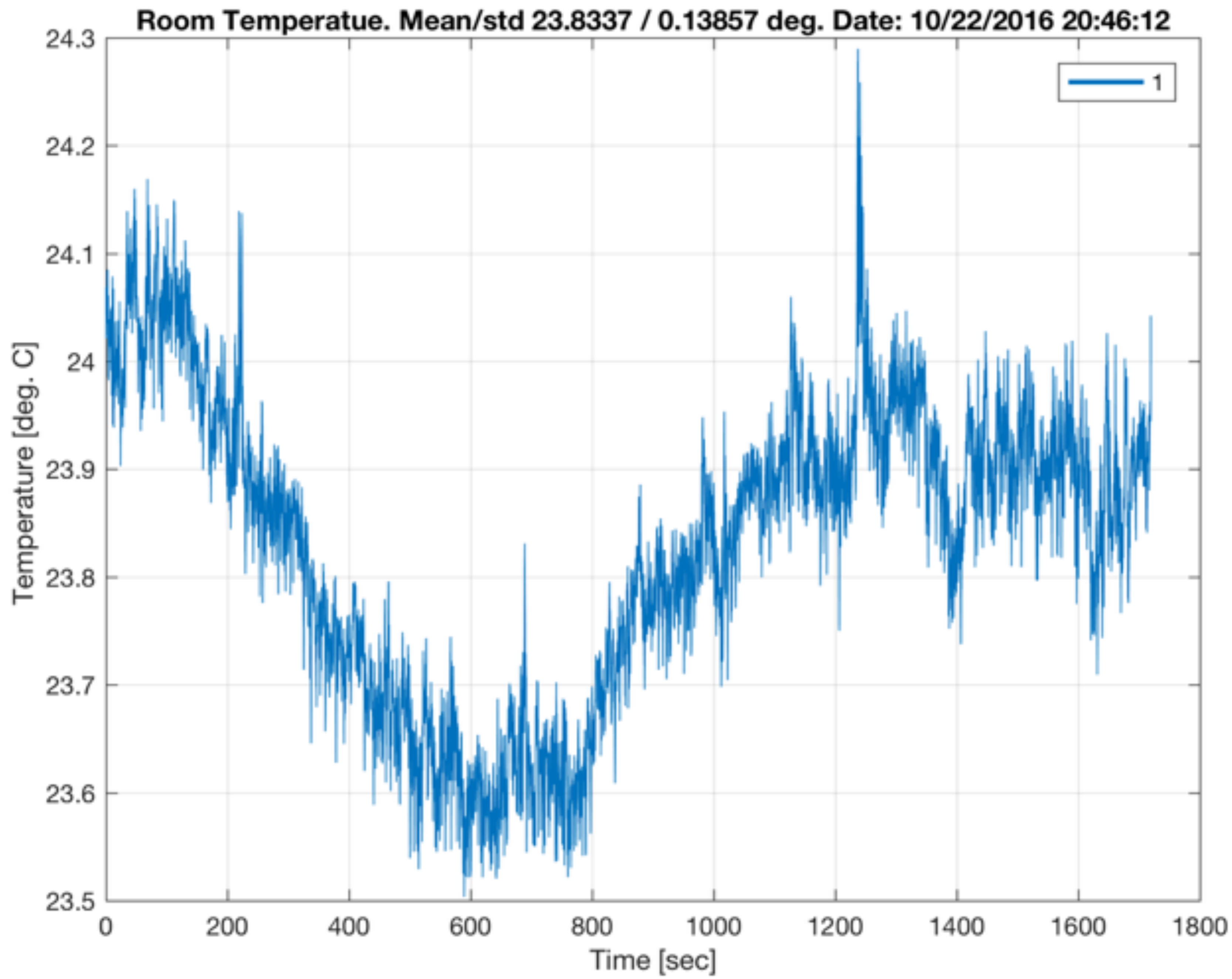


Conventional scheme: Gran. 6L target



6L granular target: conv. scheme

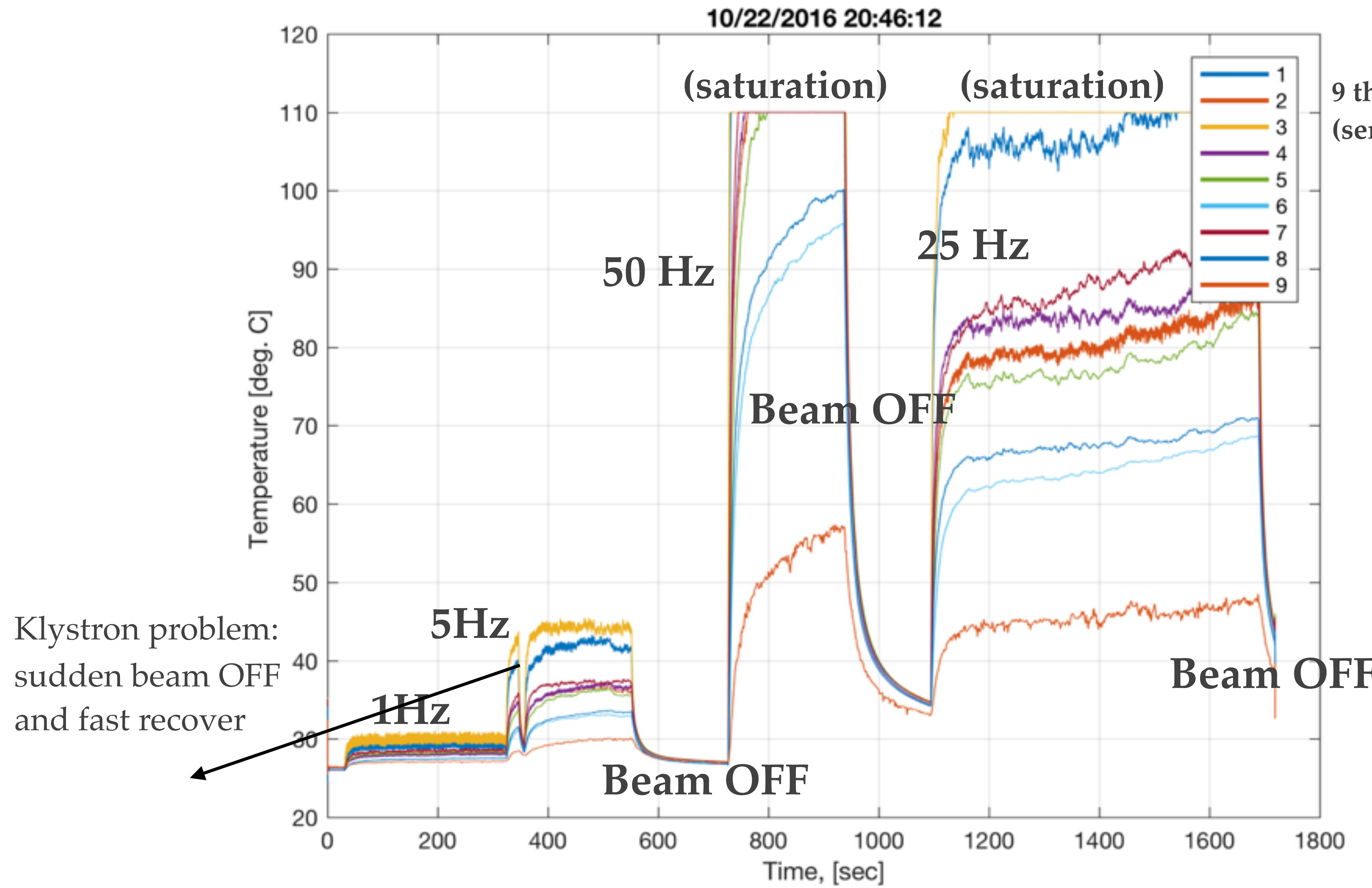
Raw data: 30 min RUN



Ambient temperature measured during the Run. Mean T = 23.8 ± 0.1 °C.

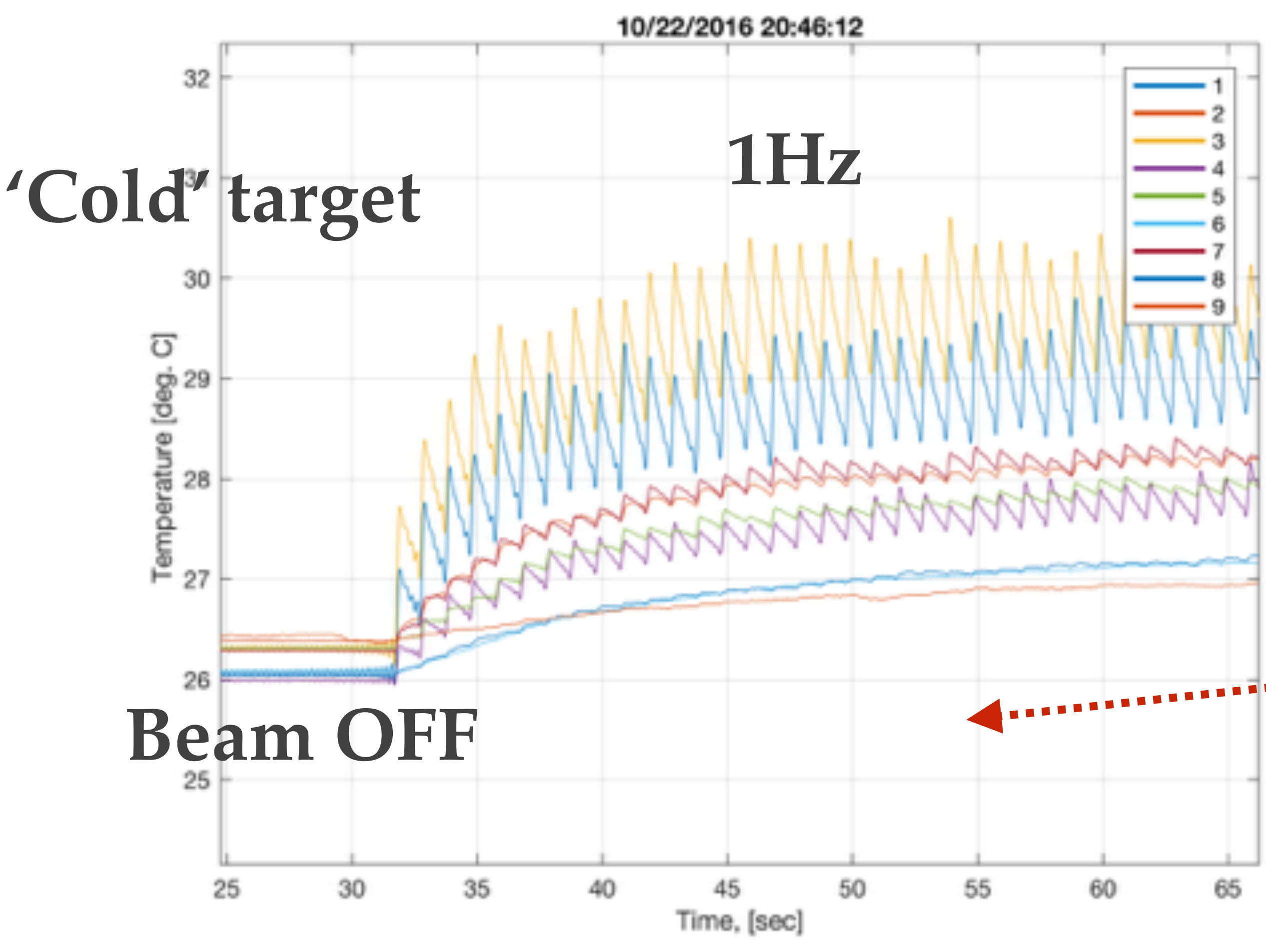
6L Granular target: Conv. scheme

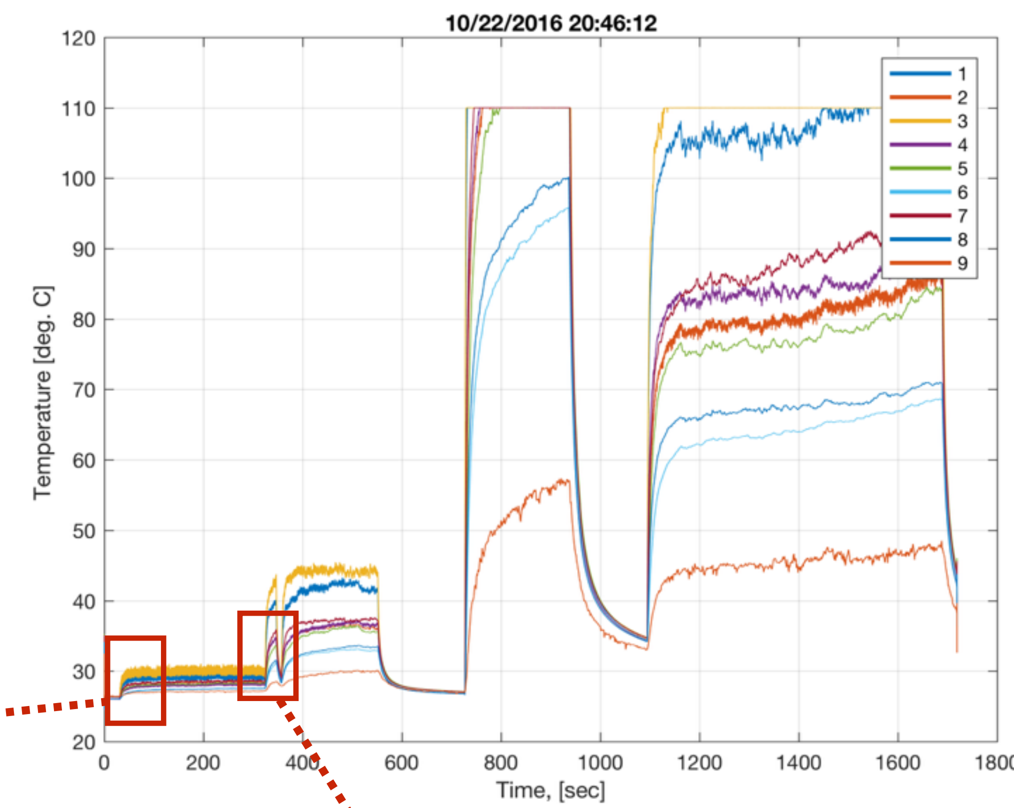
Raw data: 30 min RUN

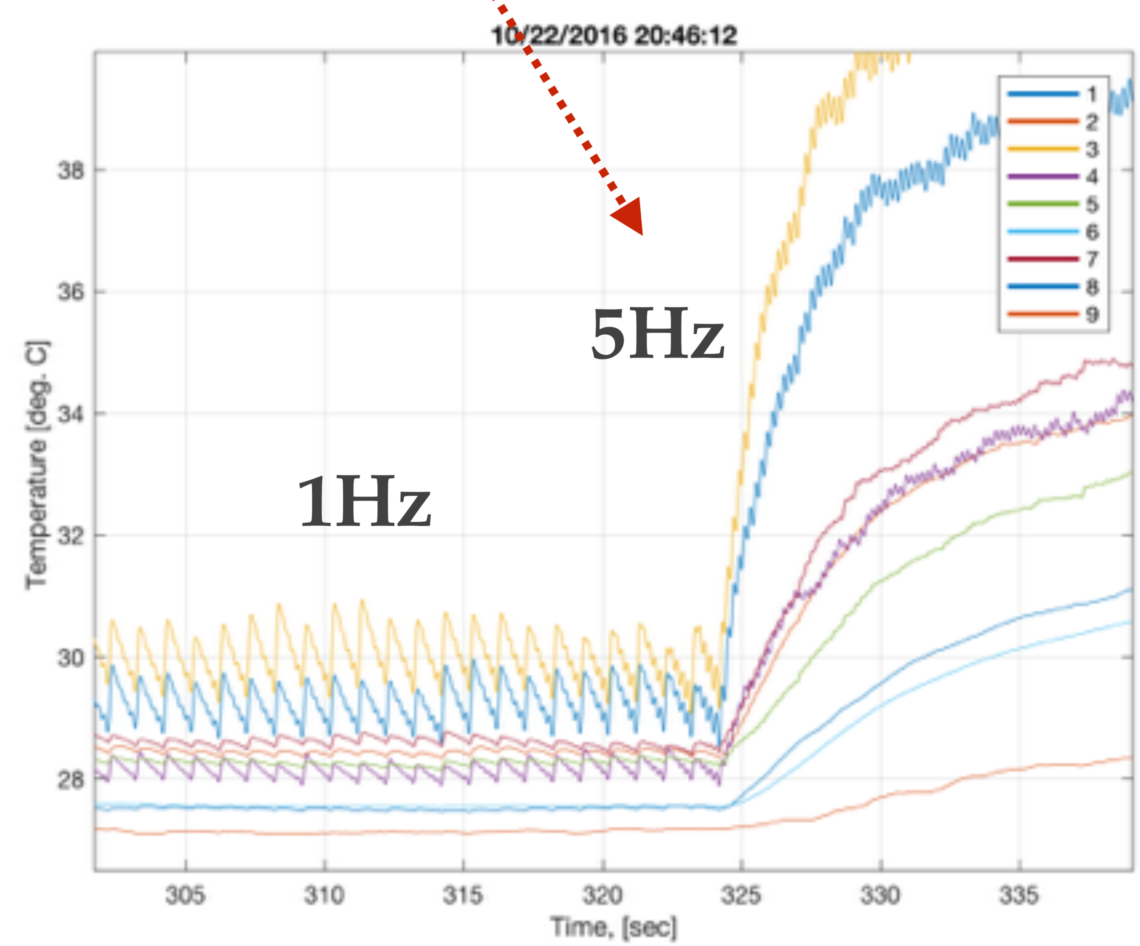


9 thermocouples (sensors) are shown

6L Granular target: conv. scheme

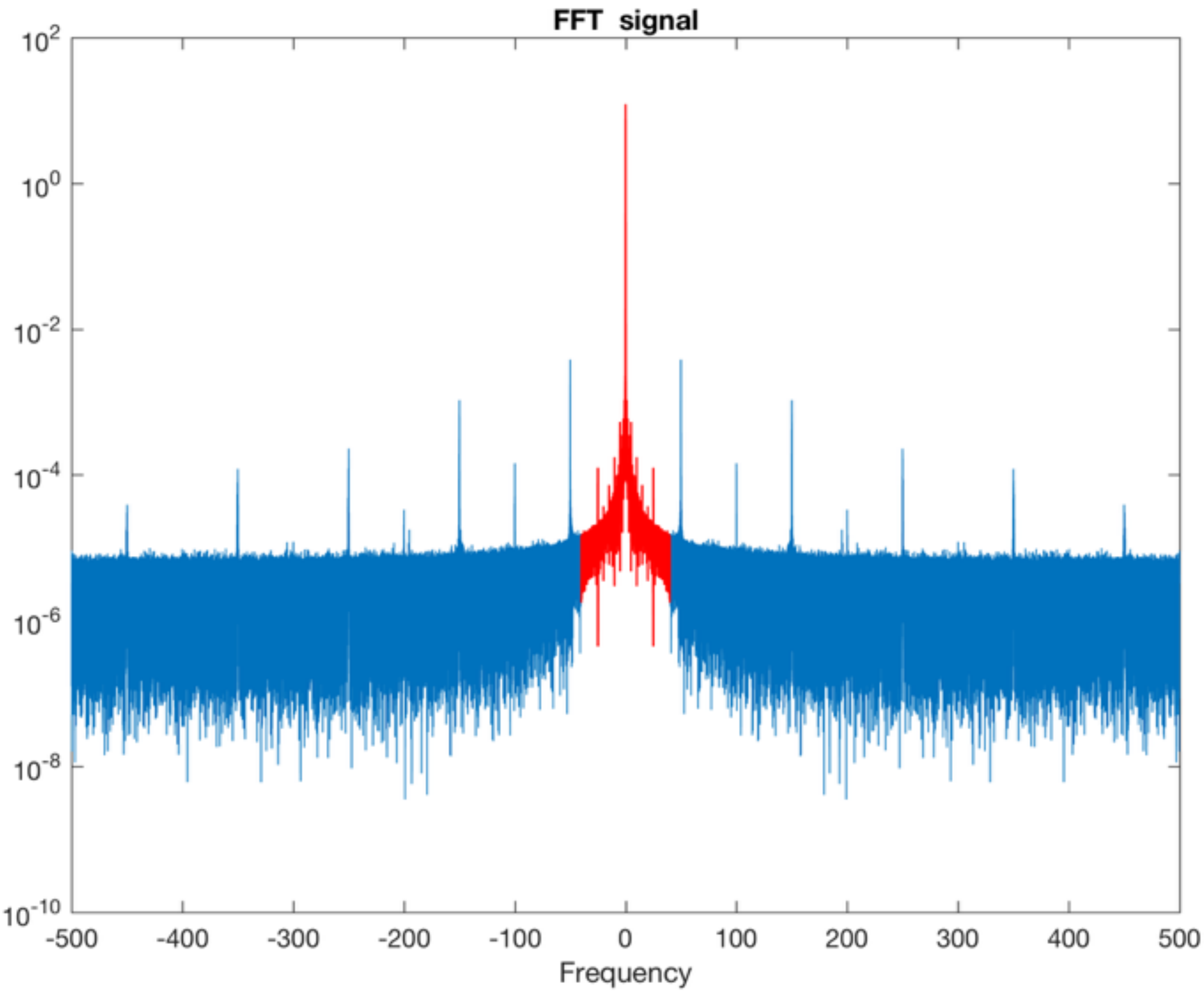






Raw data zoomed in.

6L Granular target: conv. scheme

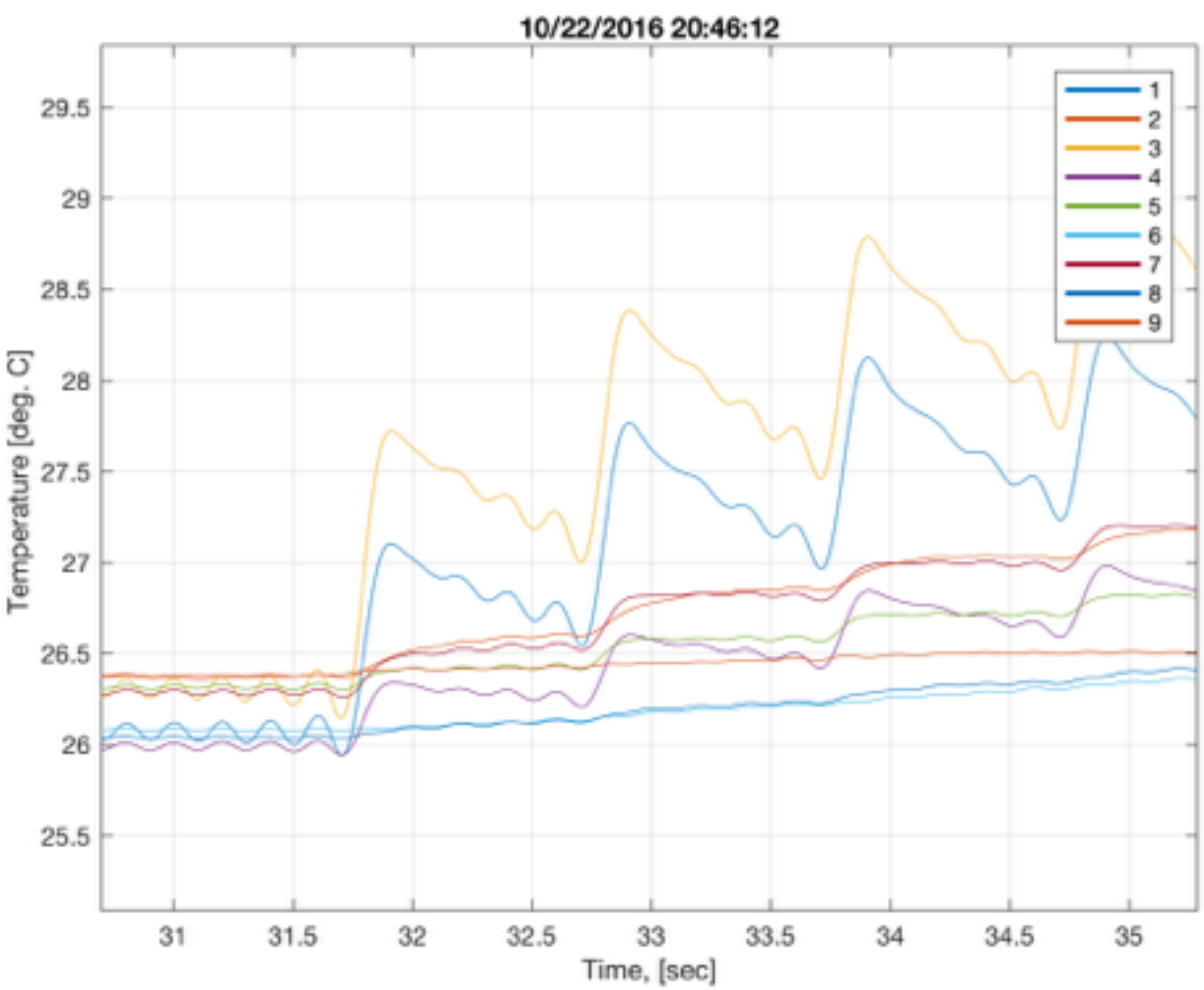


The klystrons are operated at 50 Hz.

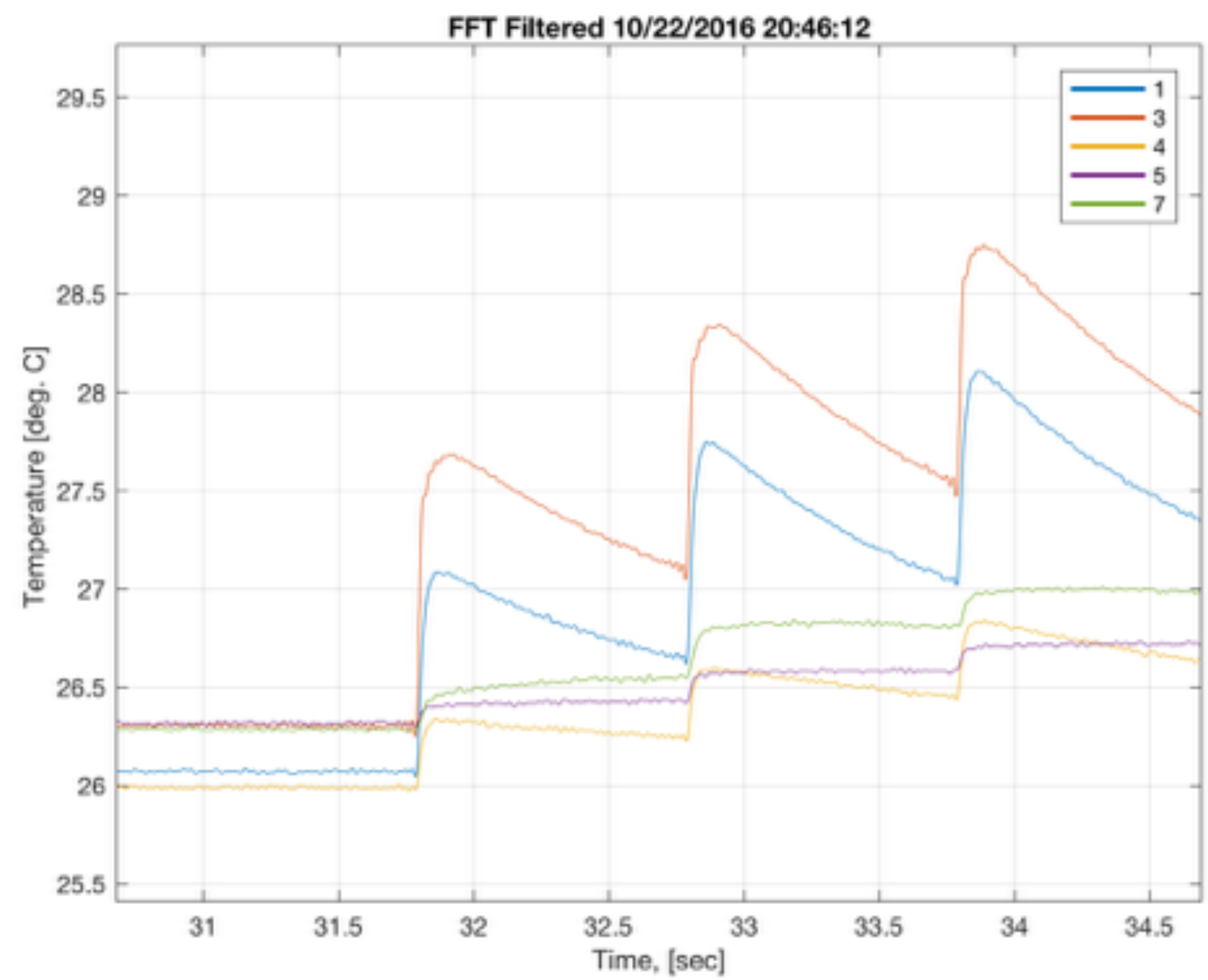
6L granular target: conv. scheme

Effect of the filter

Raw data



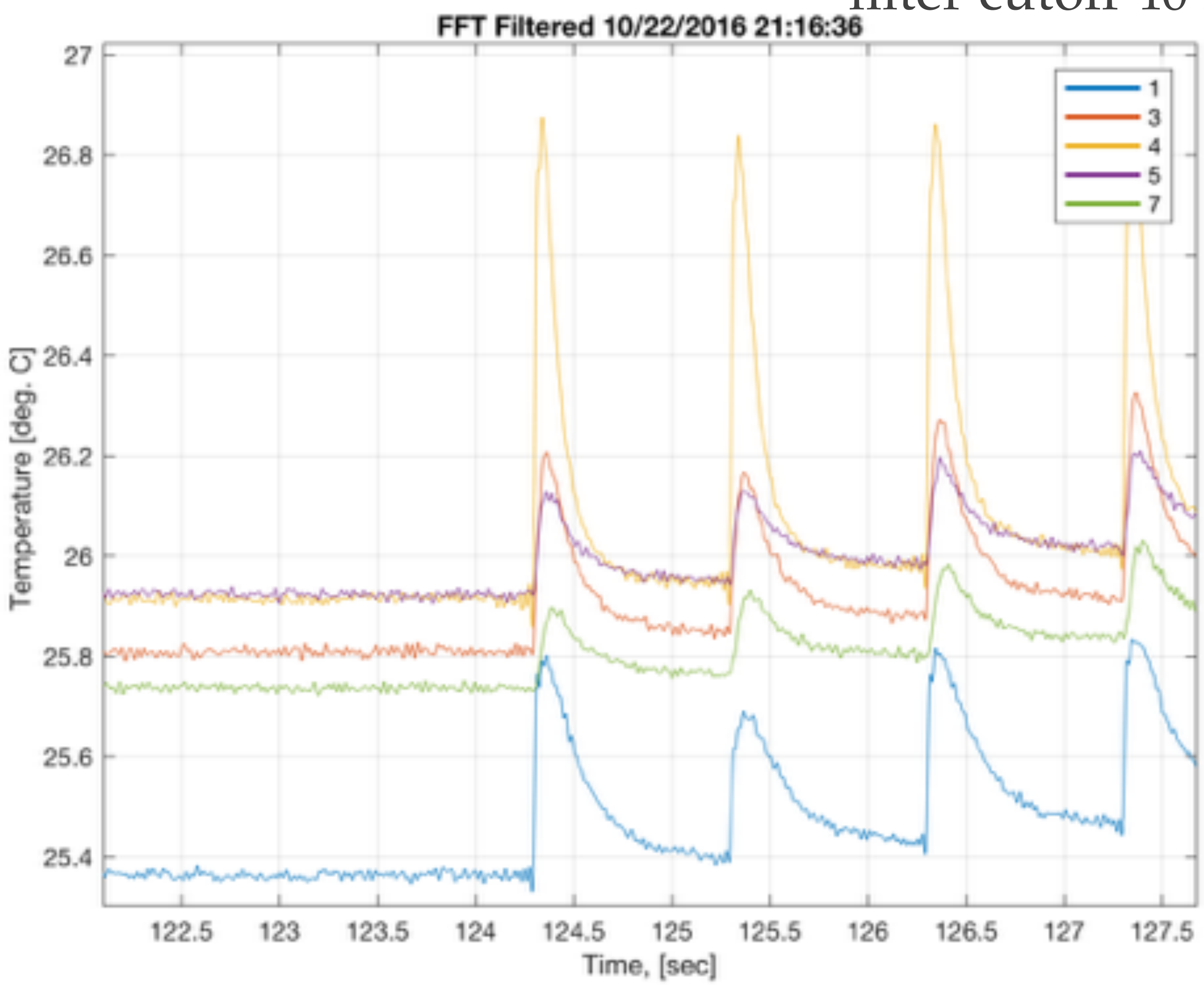
Raw data + filter with Cutoff 40 Hz



Bunch-by-Bunch operation (1 Hz)

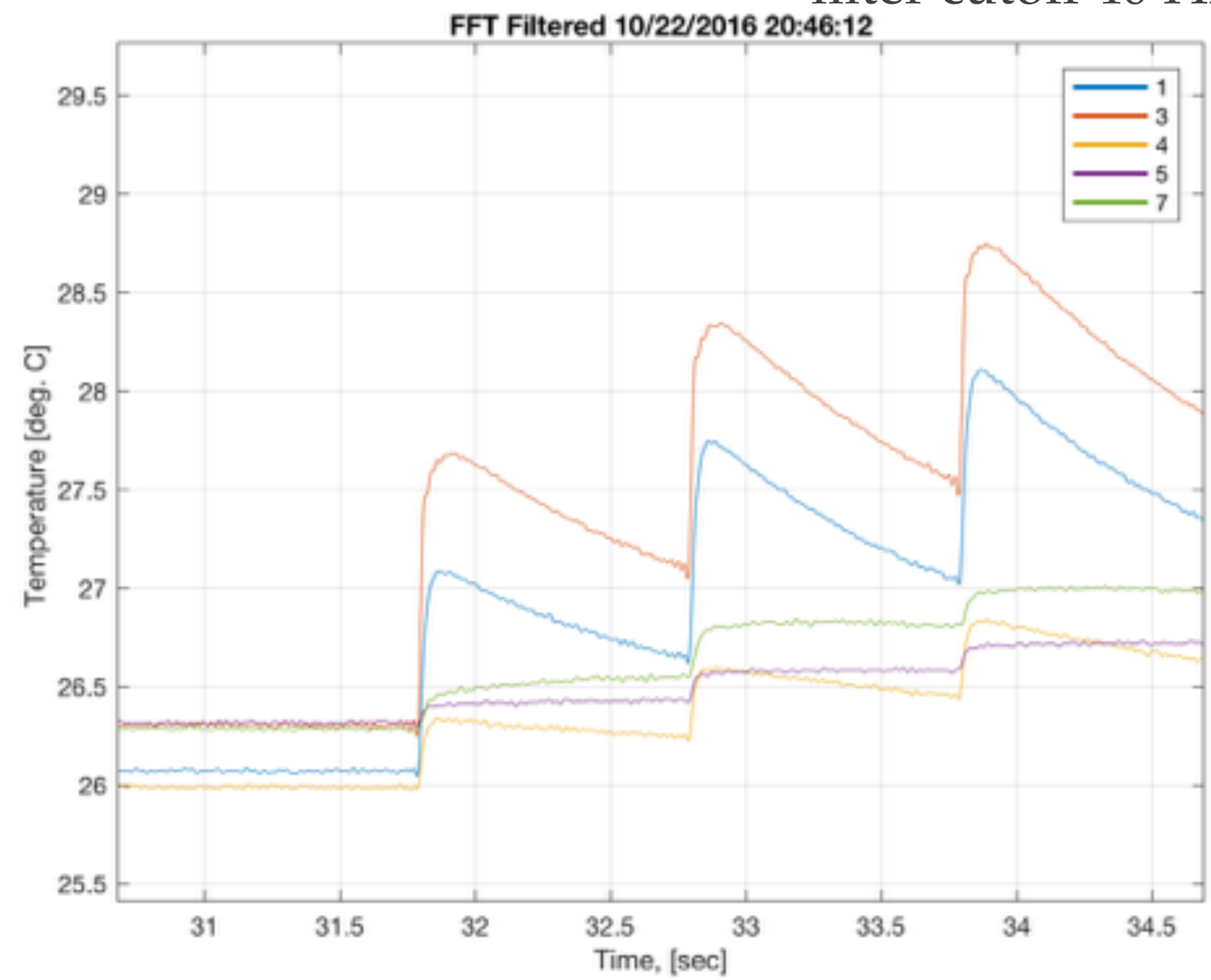
Reference target

filter cutoff 40 Hz



Granular 6L target

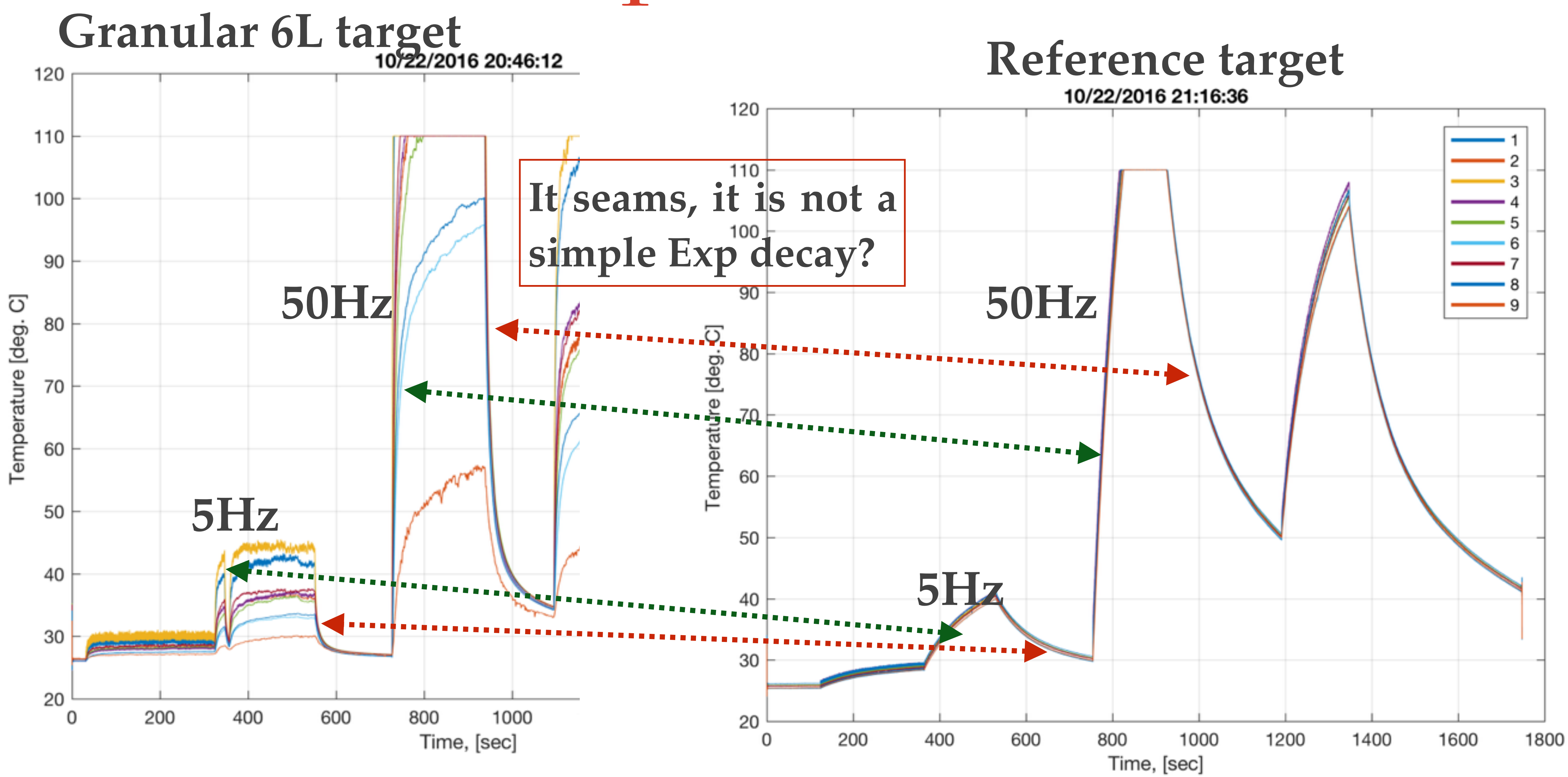
filter cutoff 40 Hz



Observation: as we can see, the main difference is the heat dissipation. It occurs much faster in the case of Reference (bulk) target. For the Granular target, due to the limited contact with the surrounding spheres, it takes more time to evacuate the heat.

Certainly, there is a difference in temperature rise as well. 'By eye', it seems that T-rise is larger for the Granular target if we compare sensors having the T-rise max: sensor 4 (RefT) vs. sensor 3 (GranT). However, for a real comparison, the e- beam parameters should be taken into account.

‘Continuous’ operation (5, 25, 50 Hz)

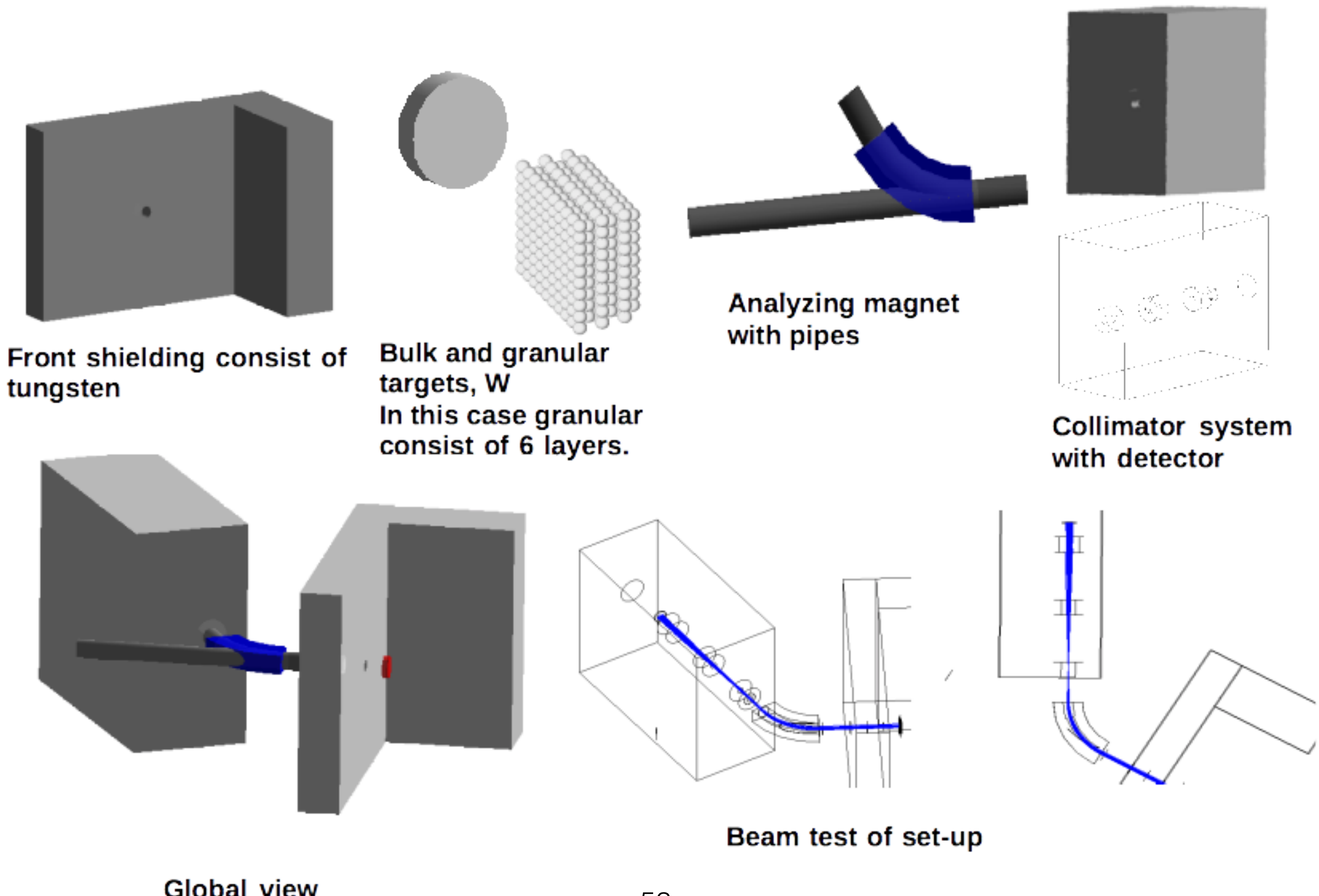


Observation: there is a big difference in the rise (adiabatic heating) and decay (cooling) time if we compare RefT and GranT. Perhaps, the time to reach the equilibrium temperature at ‘high’ Frep is larger for the RefT due to the reason explained on previous slide. For the GranT, there is no time to dissipate much the heat after every bunch (see previous slide) and the temperature grows and reach equilibrium faster than in case of the RefT. Concerning the decay time (cooling): sphere evacuates the heat through its surface to air as a cooling medium (faster than a bulk target).

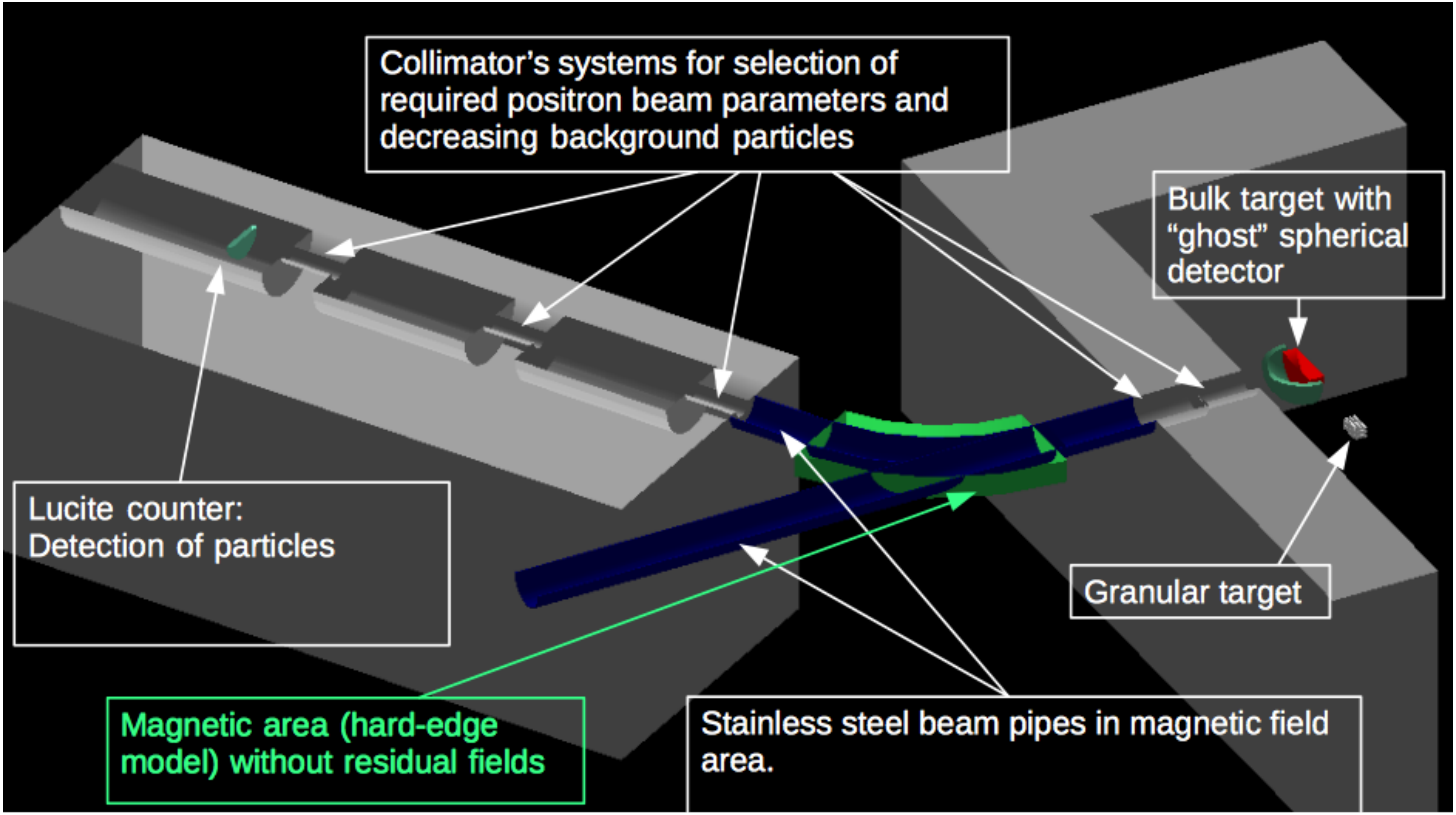
Simulations

Experimental set-up simulated in Geant4

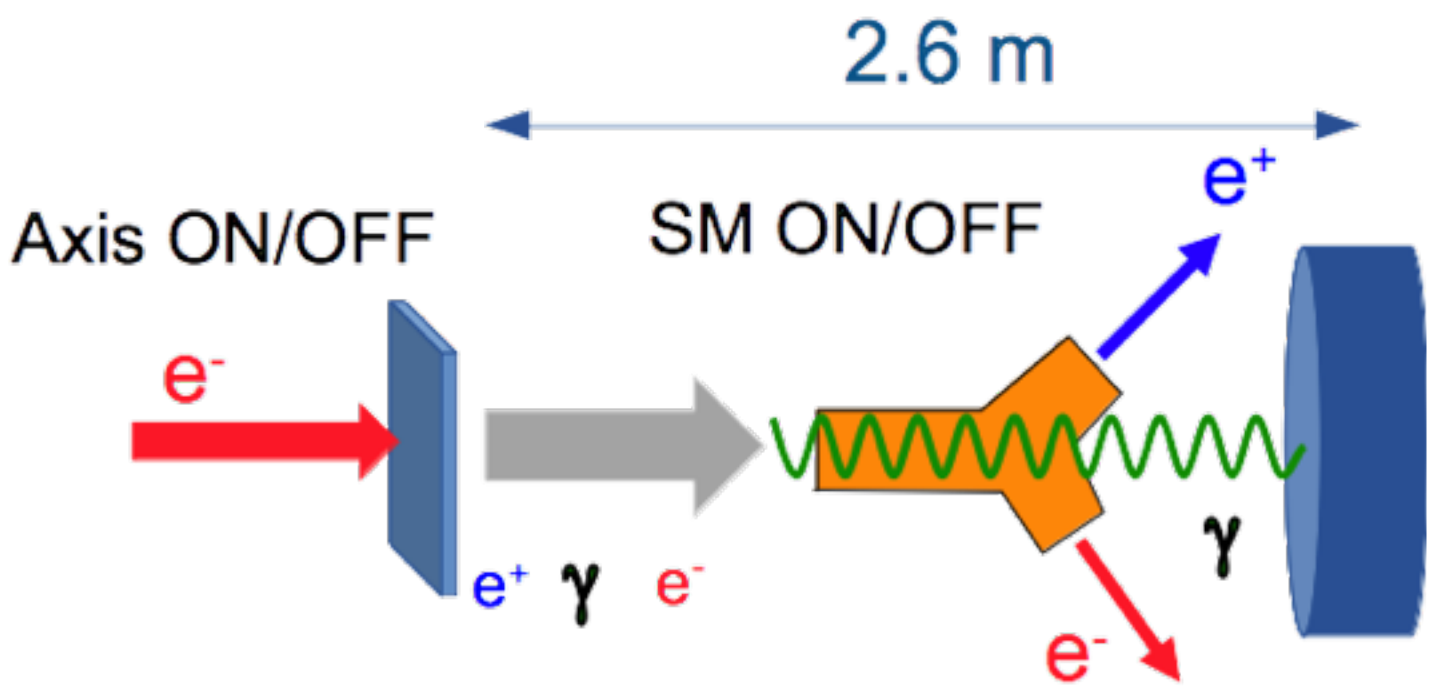
For better understanding of the already obtained results the detailed simulations of the experimental set-up are of great importance.



Experimental set-up simulated in Geant4



Geant4 model description



Target-radiator => 1 mm thick W crystal, Target-convertor => 8 mm compact (bulk) or granular W targets (4, 6 and 8-Layers).

<u>Possible configurations:</u>

- Hybrid scheme: alignment of the crystal: Axis ON/OFF
    - Axis OFF state is the ordinary bremsstrahlung radiation (no photon enhancement given by the channeling).
- Hybrid scheme: status of the Sweeping Magnet (SM) ON/OFF
    - SM OFF state allows the charged particles reach the target-converter.
- Conventional scheme (without crystal)

Simulations: next steps

- The Geant4 simulations require channeling modelling in the crystal (at least distribution of the photons).
    1. Program of V. Strakovenko => input for 3, 4, 5, 8, 10 GeV (all particles after the crystal) => program not available.
    2. Program of X. Artru FOT (fortran), FOTPP (C++) => distribution of photons => benchmark is needed.
- Currently, the results of the simulations show a good agreement with the original simulations (old Geant3 simulations) concerning detector acceptance and describe fairly well the main behaviour of the experimental data (first beam test) concerning the bulk target-converter.
- Continue the experimental data/simulation comparison for the bulk and granular target (data of the second beam test).

Summary and Perspectives

- Choosing a hybrid e+ source using channeling already meets the requirements of the ILC and CLIC.
- Replacing the compact converter with a granular one made of small spheres improves the heat dissipation, decreases the PEDD and provides better resistance to the shocks.
- New option of the hybrid source with a granular converter => Experimental tests are mandatory => Recent beam tests at KEK.
- The experimental data have been acquired. The analysis is ongoing.
- We have started the Geant4 simulations of the experimental set-up to estimate the target energy deposition, e+ and gamma ray yield and detection acceptance. Work is ongoing.
- The simulations of the thermal load in the target-converter and evaluations of the shocks are of great importance.