Target Fiber Monitor (TFM) using cerium-doped silica fibers for medical isotope production

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Background

The TR13 medical cyclotron located at TRIUMF in Vancouver, Canada, provides radioisotopes for research, medical diagnostics and therapy. To maximize radiological yield, the beam position must be optimized on the target material. However, typical target monitoring options either do not provide real time information, or only provide 2D solutions. Here we present a real-time, potentially 3D monitoring solution by measuring the secondary neutron and gamma radiation from the target material instead of directly intercepting the high-power density proton beam. Previously, several scintillating doped fibers were tested [1], and initial experiments showed a light signal response linearly proportional to beam current for 200 µm diameter, 30 mm long cerium-doped silica fibers. These initial tests prompted the Target Fiber Monitor (TFM) design, which holds the four fibers tightly around the target and aims to provide real-time beam diagnostic information for beam steering and alignment.

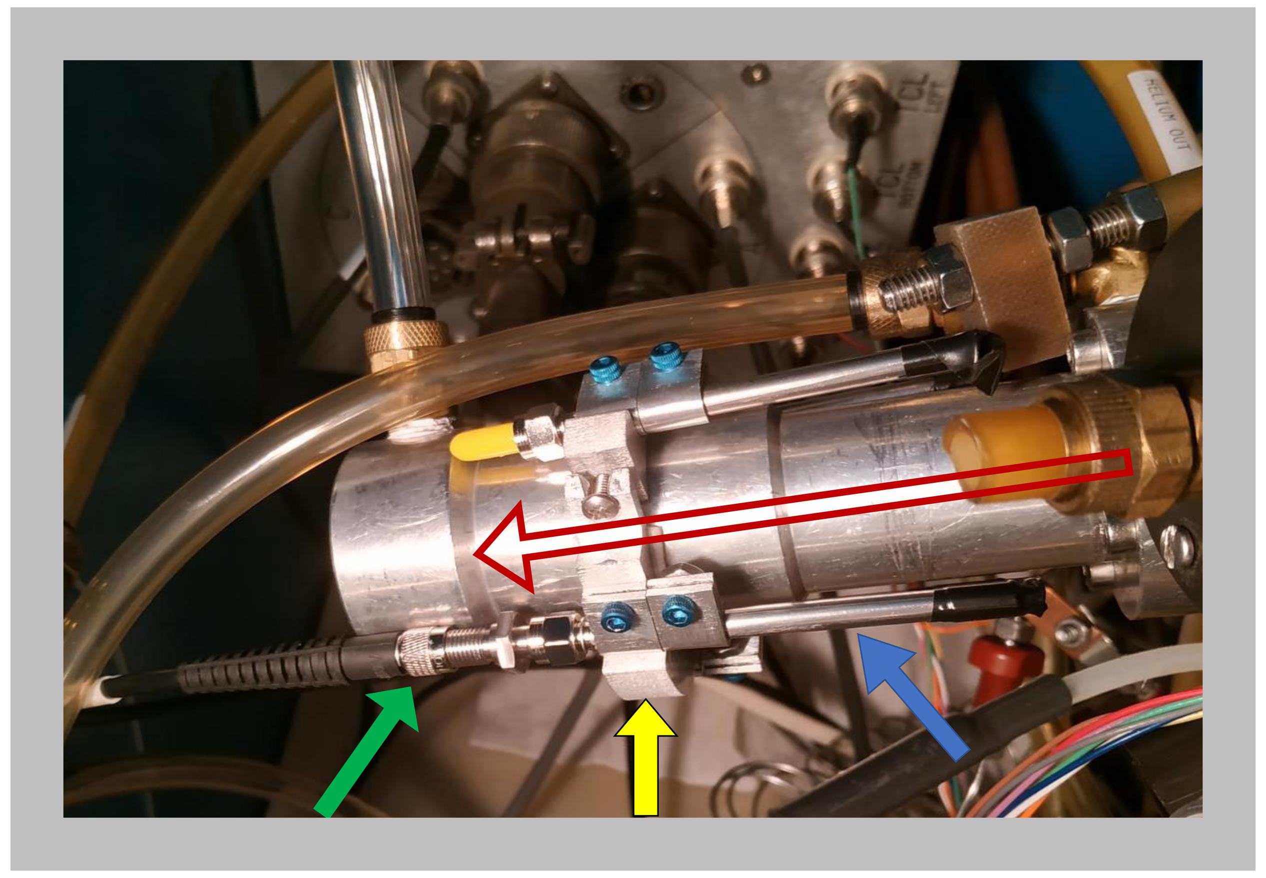

Fig 1: TFM installed on the F-18 gas target; red arrow indicates direction of proton beam on target; blue shows location of the doped fiber; green shows the transport fiber; yellow shows the collar

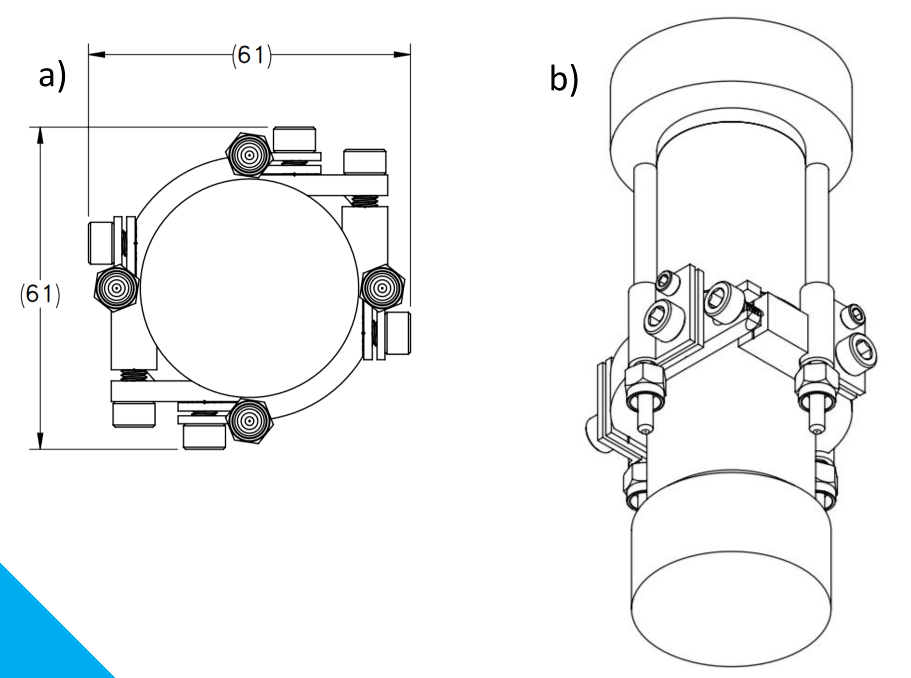

Fig 2: TFM design on F-18 gas target

Design and installation

Hardware (Fig. 1-3)

- Four Ce-doped fibers are mounted on a collar (see Fig. 1). The doped fibers are connected to 15 m transport fibers that guide the light to a 16 channel SiPM based light collection module from Hamamatsu (model: Hamamatsu C13369-3050ED-04).
- 3D printed face plate attaches the fibers to the MPPC (see Fig. 3c).
- The two-collar, four-fiber design (see Fig. 2) is waterjet cut from a .375" thick aluminum plate.
- Each fiber is placed in a light-tight steel inner tube to protect the fiber from physical damage.
- Fiber and inner steel tube are clamped by an outer aluminum tube, which is screwed into the collars.
- The TFM is mounted on the F-18 gas target. This target is in position D on the target plate (see Fig. 3a).

Software (Fig. 4)

- A Python script takes the CSV file output by the Hamamatsu software and plots the instantaneous light yield for each fiber overlayed with target and collimator current data (see Fig. 4).
- Summed light yield for each channel is plotted in a bar graph, representing overall dose (see Fig. 3d, 5b)
- A complete bar graph with all 16 channels of the MPPC can show the background light/electronic cross-talk levels within the MPPC (see Fig 5b).

Initial experimental results

Scintillation can be seen in the fibers when a target in the area is irradiated, either in position D or in position B. So far, only the bottom fiber (green solid circle in Fig. 3a) is being read out.

F-18 gas target (position D) irradiation (Fig. 3d & 4)

- Signal to background ratio > 250.
- Clear correlation between on-target current measurements and light output by the fiber.

Solid Calcium target (position B) irradiation (Fig. 5)

- Signal from the solid target in slot B above the background noise levels of the MPPC.
- Less light yield (LY) than for the gas target, consistent with the increased distance from the fiber to the target, and smaller volume of material irradiated.
- Signal to background ratio of around 14.

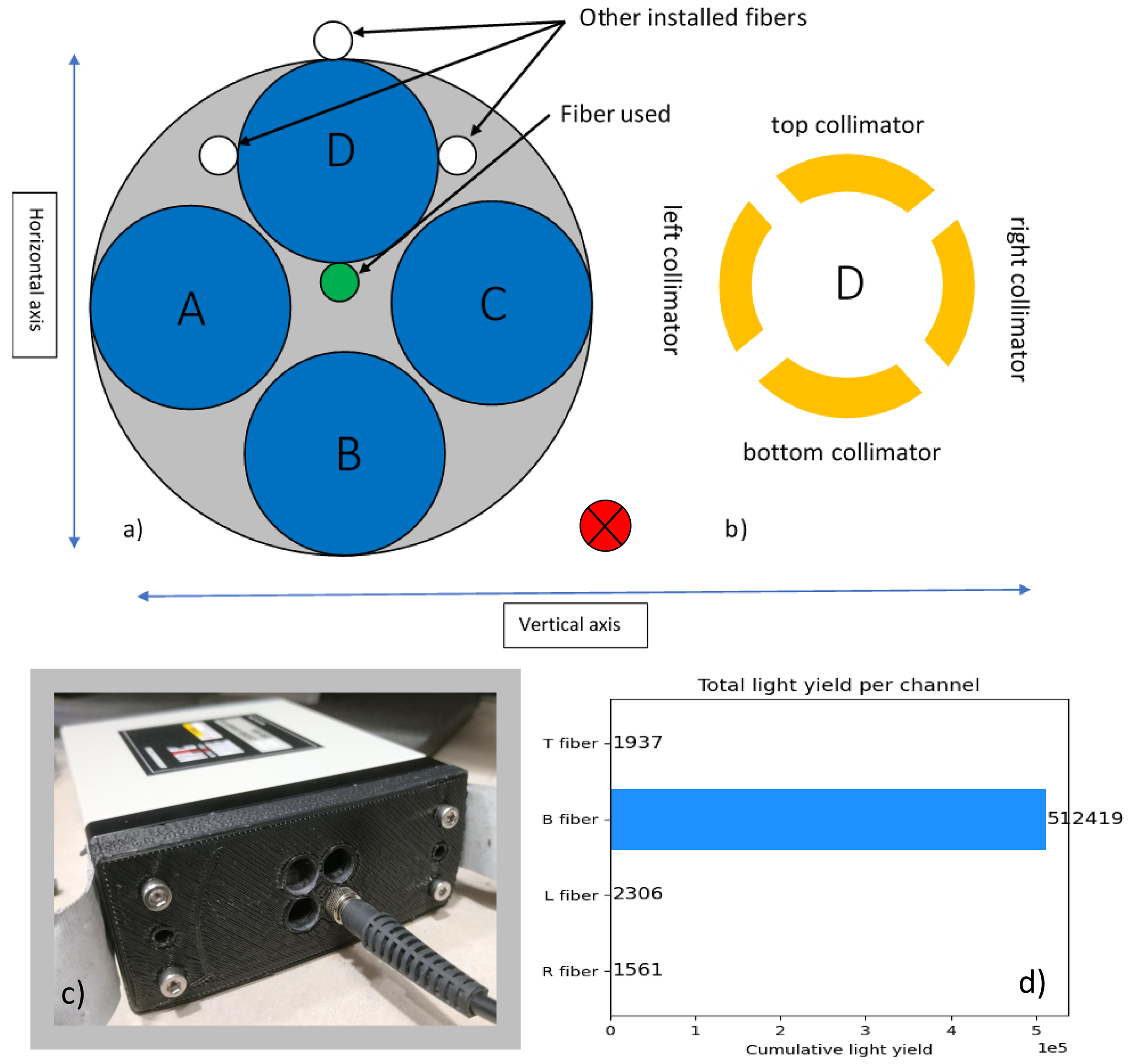

Fig 3: Collimator arrangement with target positions, fiber positions, MPPC, and F-18 target (position D) overall light yield (LY)

a) Diagram of TR13 target locations with installed fiber. Beam direction going towards the page, indicated by red circle with cross.
b) Diagram showing collimators in front of each target.
c) Hamamatsu SiPM MPPC with bottom fiber connected to the 3D printed face plate.
d) Total light yield for F-18 run. Bottom fiber was connected to the MPPC, other channels show non-radiation induced backgrounds.

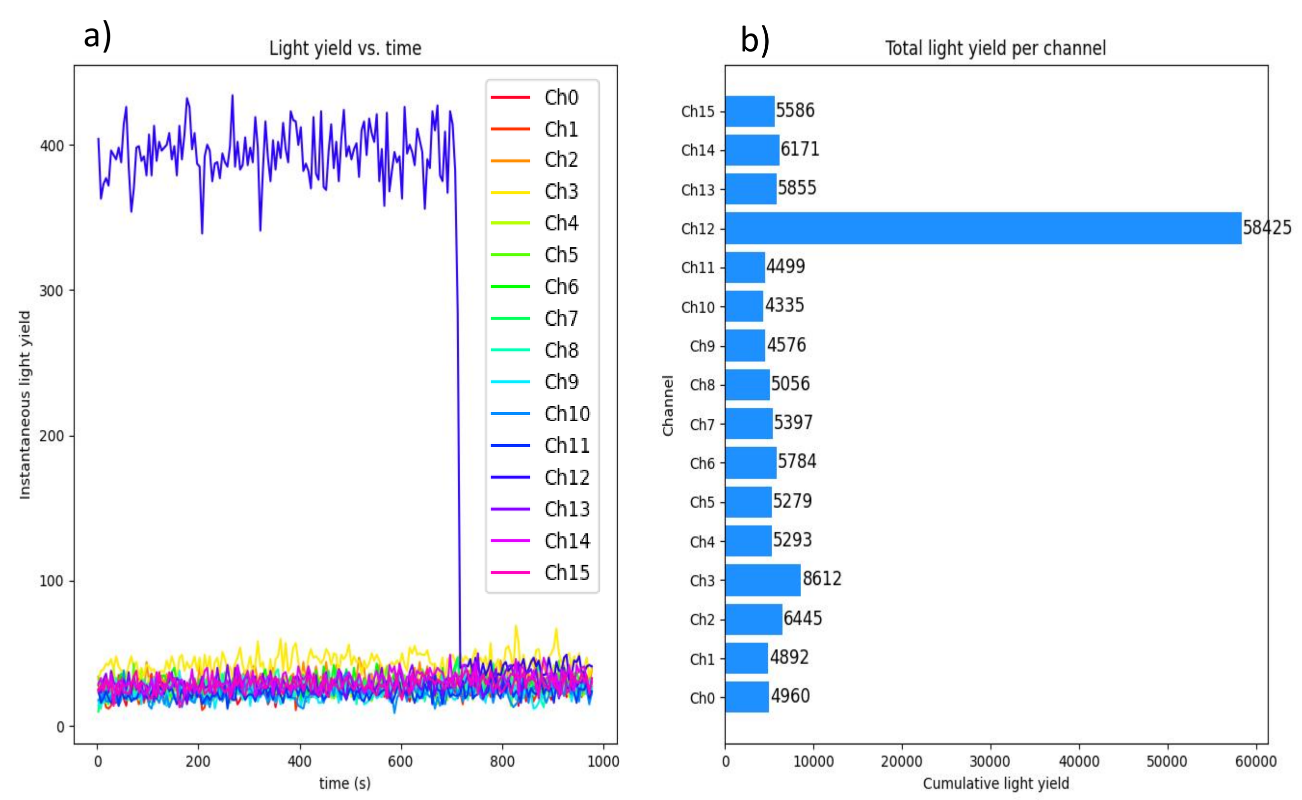

Fig 5: Calcium target (position B) light yield. Taken May 5, 2021
a) Light yield vs. time for all 16 channels, during the last minutes of irradiation. Ch12 bar is the bottom fiber.
b) Total light yield per channel, only Ch12 is radiation induced.

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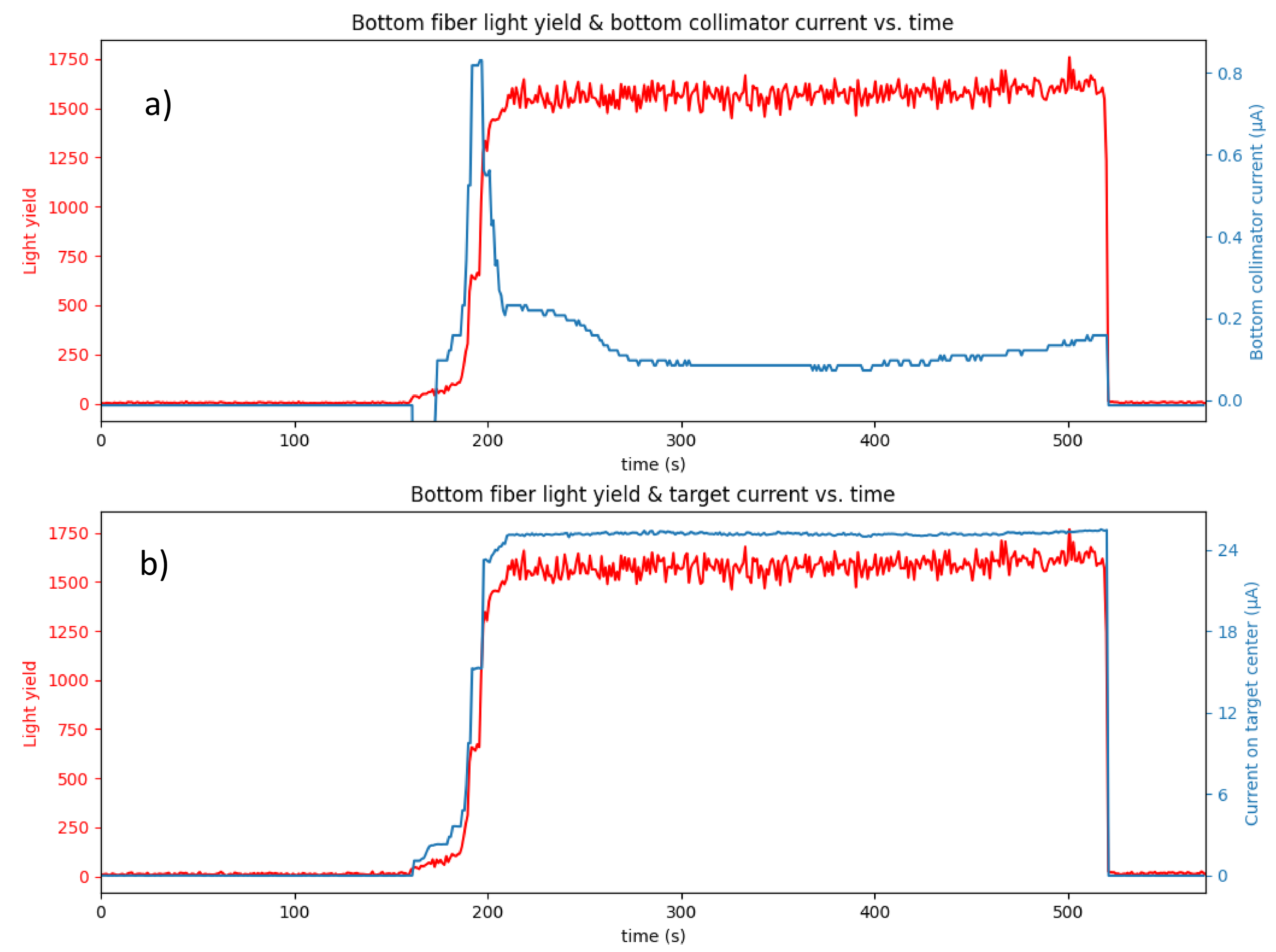

Fig 4: F-18 target (position D) data. Taken May 6, 2021
a) Light yield (red) vs. time for F-18 gas target run, overlayed with corresponding bottom collimator current in μA (blue).
b) Light yield (red) vs. time for F-18 gas target run, overlayed with target current in μA (blue).

Summary and outlook

The TFM data closely follows the current detected on the target center. First tests show promising results with a strong signal to noise ratio. More tests need to be done with all 4 fibers connected, then compared with collimator current data in order to better understand the behavior of the fibers. The full capabilities of the TFM should be carefully tested to confirm that full beam power target monitoring can occur, which is not possible with traditional methods that directly intercept the high-power density proton beam upstream of the target.

Acknowledgement

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References

1. Hoehr, C.; Hanna, M.; Zeisler, S.; Penner, C.; Stokely, M.; Dehnel, M. Ce- and B-Doped Silica Fibers for Monitoring Low-Energy Proton Beams on a Medical Cyclotron. *Appl. Sci.* **2020**, *10*, 4488. https://doi.org/10.3390/app10134488

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