Improving the Resolution of MLFCs used for Low-energy Beams

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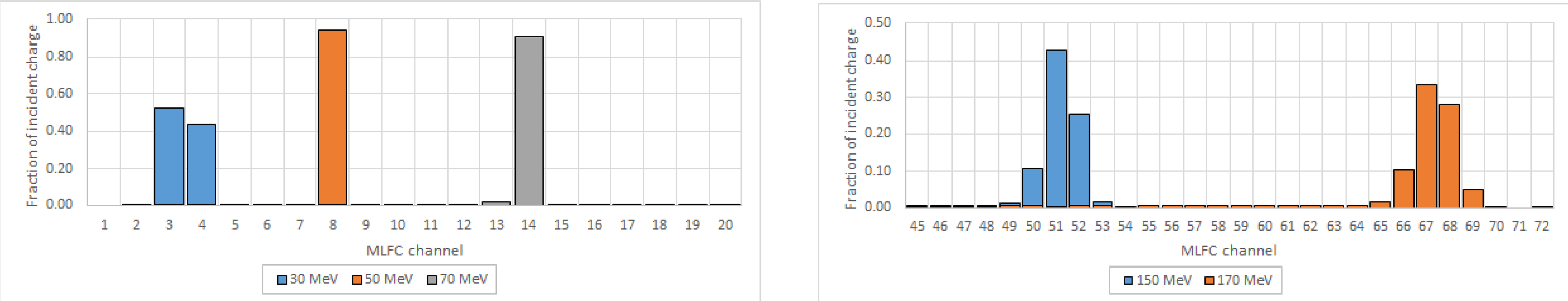
Background and Aims

The multi-layer Faraday collector (MLFC) was developed for use in proton therapy at the Harvard Cyclotron laboratory by Bernie Gottschalk [1]. Commercial versions designed for in-air measurement of proton energies up to 250 MeV have proved convenient and precise for routine machine QA [2] and system commissioning [3,4,5]. There has been increasing interest in using MLFCs to measure relatively low energies, down to 30 MeV and lower [6]. Such low energy protons have a very sharp end of range peak in the MLFC structure which prevents robust peak fitting and so degrades energy resolution.

The aim of this work has been to overcome this limitation while maintaining the convenience, accuracy and stability of the MLFC. A particular requirement is to resolve to 0.3 MeV or better at 30 MeV for beam quality control in cyclotron-based boron neutron therapy, and more generally to provide a diagnostic device for research and isotope generation systems working at energies up to 65 MeV .

Energy resolution limitation

Measurements and simulations show that the MLFC128-250 used for proton therapy measurements up to 250 MeV has very narrow end of range peaks at low energies [7]. If the useful signal in the peak falls in four or more channels, a regression fit to a Gaussian curve allows centroid determination to one-tenth of a channel or better. Less than this and the available resolution drops to +/- 0.5 channels in the worst case.



Comparison of peaks typical from a 128-layer MLFC designed for protons up to 250 MeV. Low proton energy (left) and higher proton energy (right). Energy resolution is lost when the end of range peak does not have enough channels be fitted with a Gaussian curve.

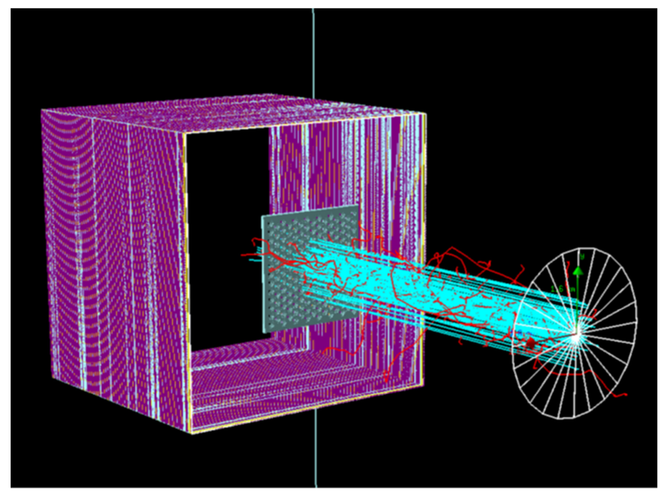
Available solutions

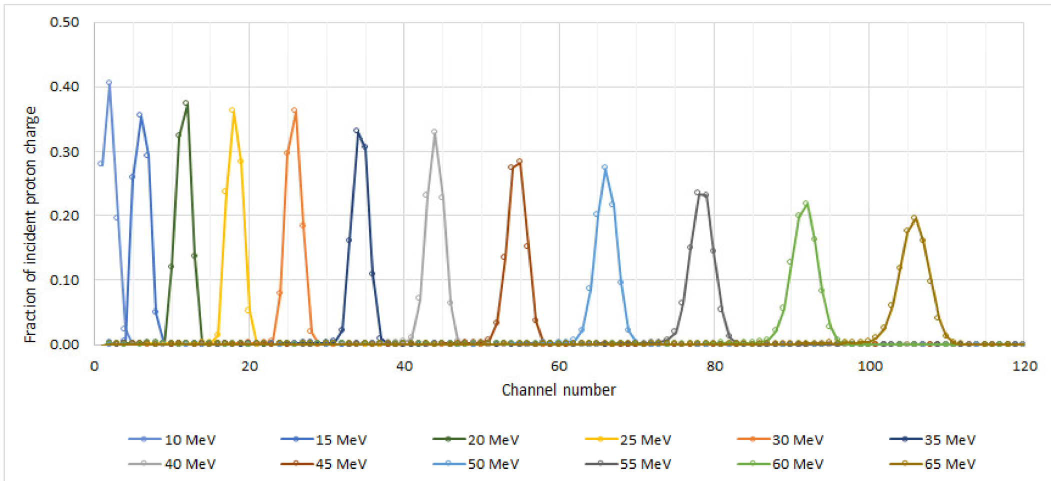
The objective of the current work was to maintain the convenience of a robust and portable in-air measurement device while working with good resolution for protons at 30 MeV and below. Some options for improving low energy resolution are:

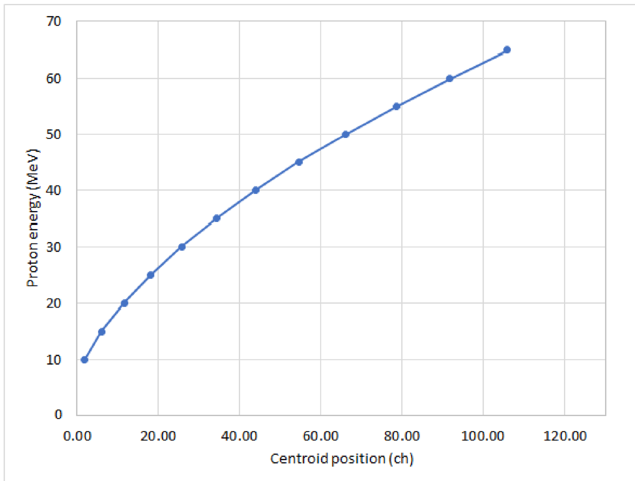
1. Reduce the stopping power of the layers by choice of materials and layer thickness.
2. Change the thickness of the layers in steps along the MLFC. This complicates the construction and data handling, and was not taken to practice after modeling showed it was not of sufficient benefit on its own.
3. Introduce some deliberate range straggling to spread the peak over more layers [8].

A copper range spreading filter had already been developed to allow the 250 MeV MLFC version to give good resolution down to 70 MeV. A similar filter using layered polyimide was developed and integrated into the low energy MLFC.

Monte-Carlo modeling using TOPAS [9] showed that a combination of (1) and (3) provided the required performance at 30 MeV.

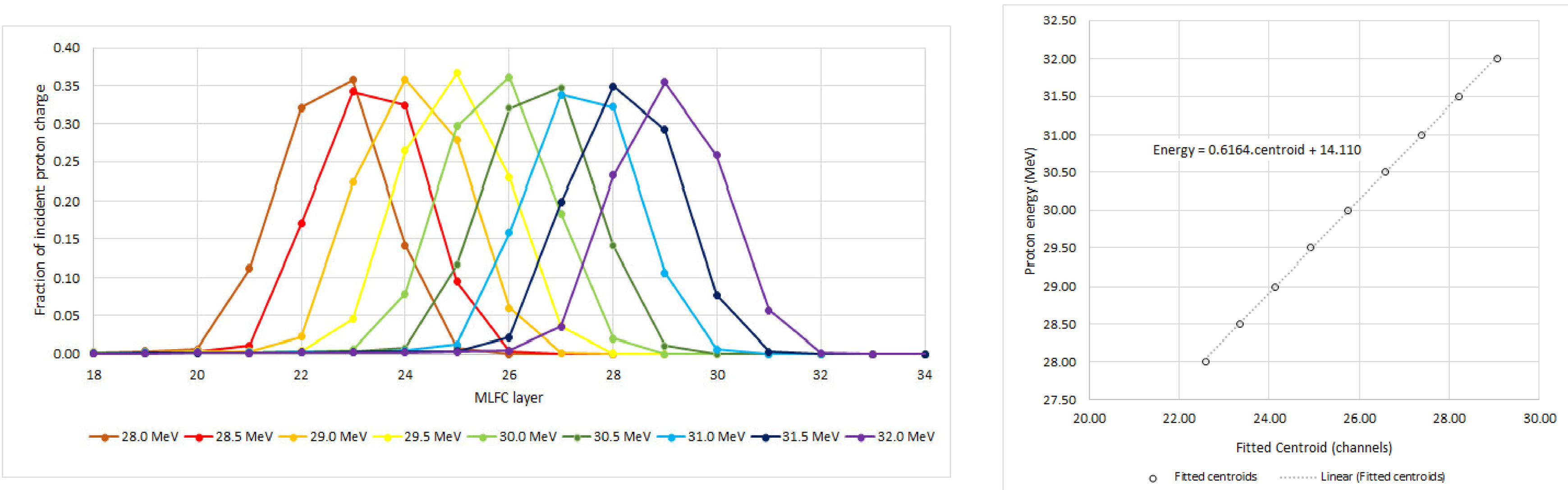






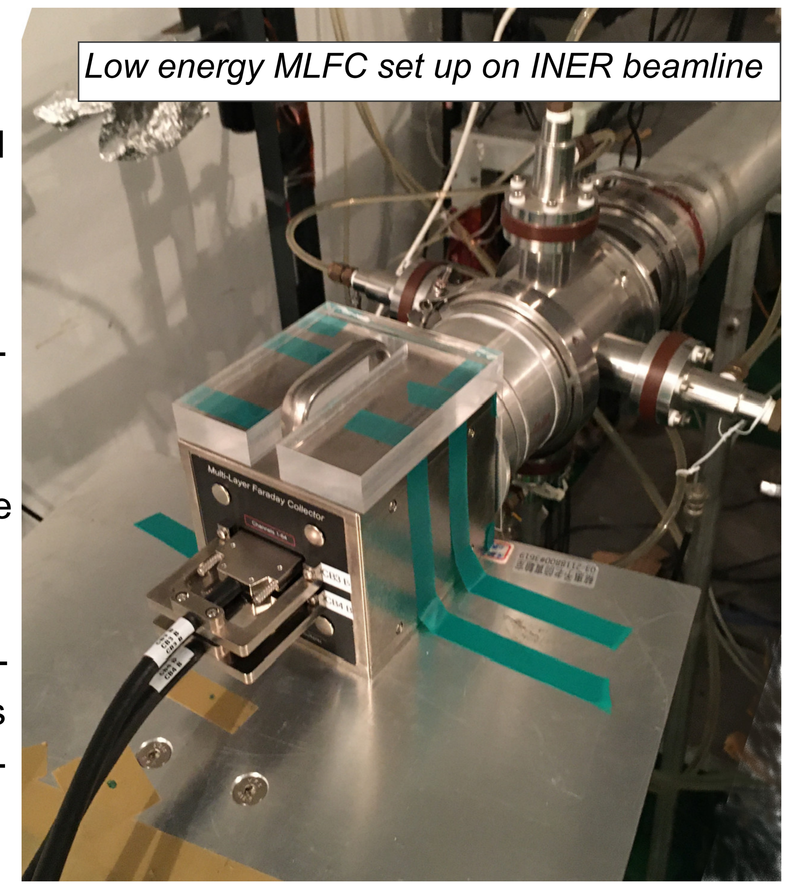
Resolution at 30 MeV

Over a small energy range the MLFC response is very close to linear. The slope of the model data in the range 28 to 32 MeV is 0.616 MeV per channel. Since centroid finding to one-tenth of a channel is straightforward using a fit to a Gaussian, the limiting energy resolution in this range is forecast to be around 0.062 MeV, which meets the requirement.



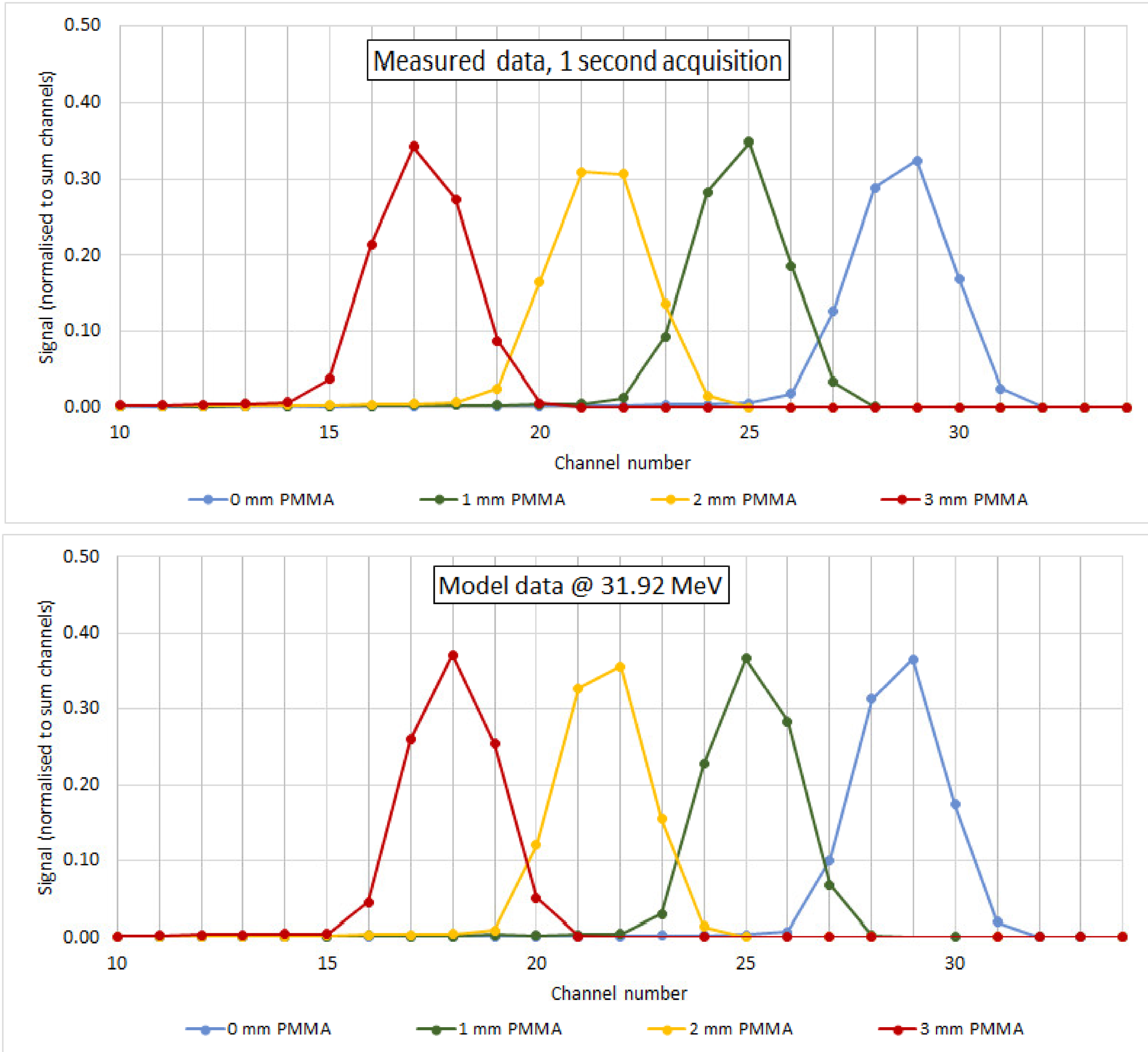
End of range peaks and corresponding energy response function for proton beams around 30 MeV

Initial beam tests

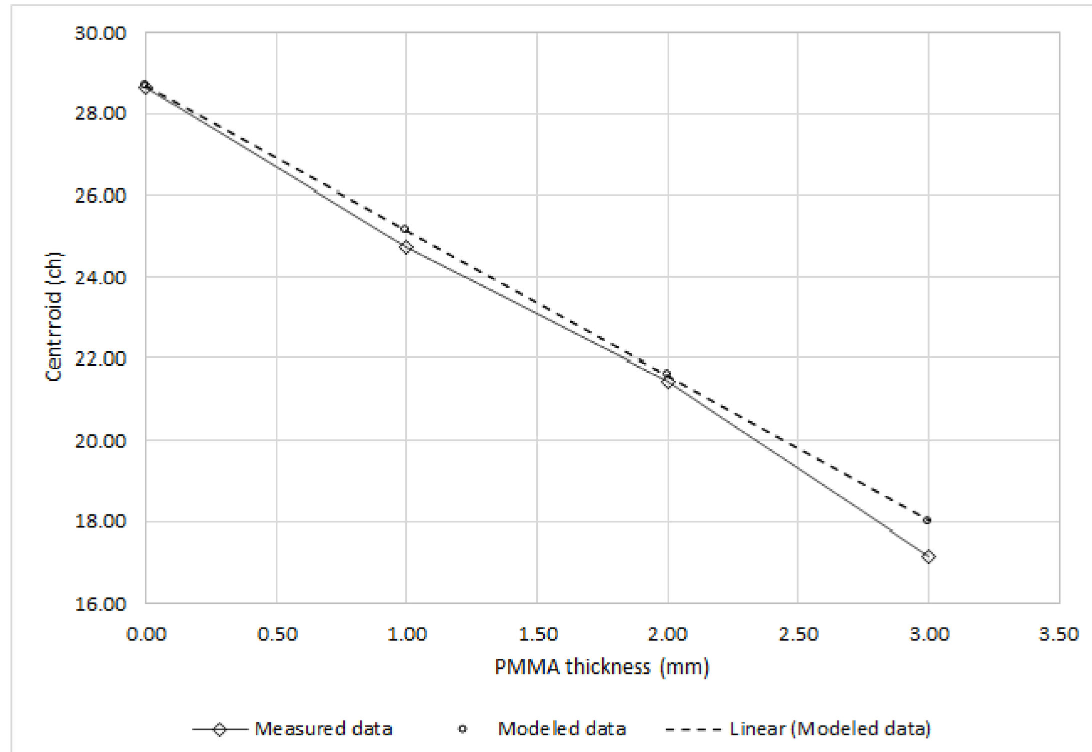


Low energy MLFC set up on INER beamline

The first example of the filtered low-energy MLFC was tested on a beamline at the Institute of Nuclear Energy Research in Taiwan. The beam left vacuum through a 40 µm havar window and 1.0, 2.0 and 3.0 mm sheets of PMMA were used to produce small reductions in the beam energy. Proton beam currents were between 0.5 and 1.0 µA, which allowed good quality data to be collected in 250 msec. The experimental configuration was reproduced in a TOPAS model which matched the measured MLFC end of range centroid at an energy of 31.92 keV. The modeled and measured energy change due to the PMMA can be compared by assuming in the absence of other information that this was the actual beam energy.

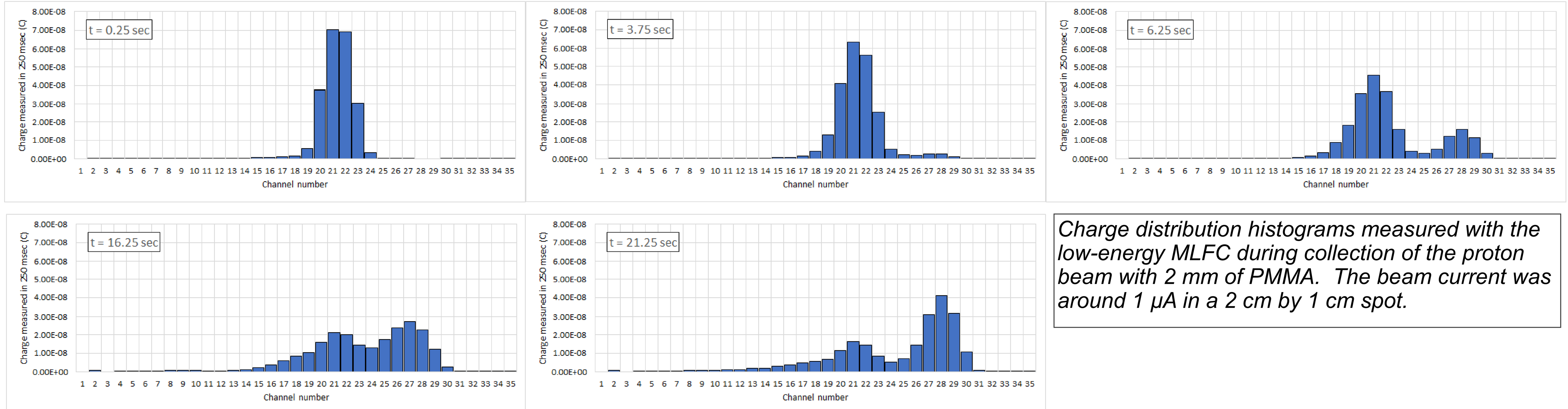


Measured and modelled peaks assuming 31.92 MeV proton energy



Time resolution

Extended beam exposure allowed the MLFC to track changes in the beam energy with 250 millisecond time resolution. This revealed interesting behaviour during the runs with PMMA degraders. Ask the author if you can't guess what was happening!



Charge distribution histograms measured with the low-energy MLFC during collection of the proton beam with 2 mm of PMMA. The beam current was around 1 µA in a 2 cm by 1 cm spot.

References

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