Fast timing for proton therapy

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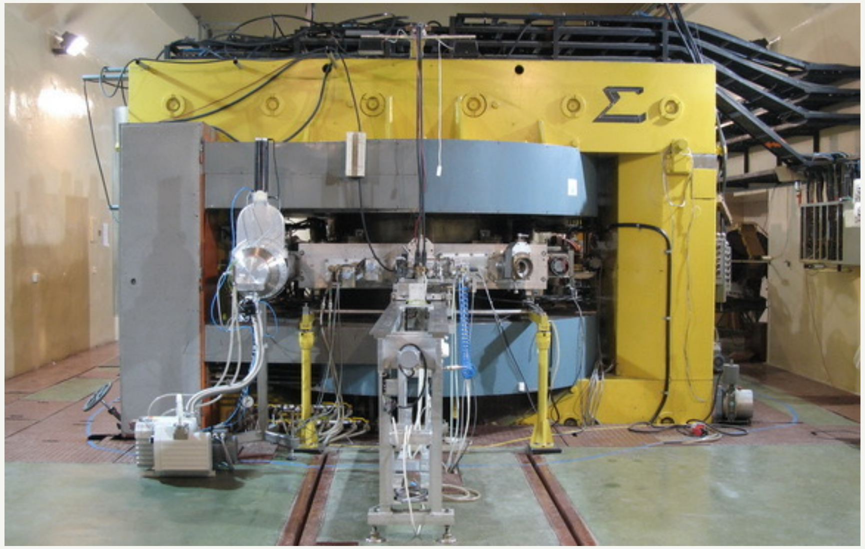
FAST 2023, Elba, 28/5-1/6.

This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101057511

Overview

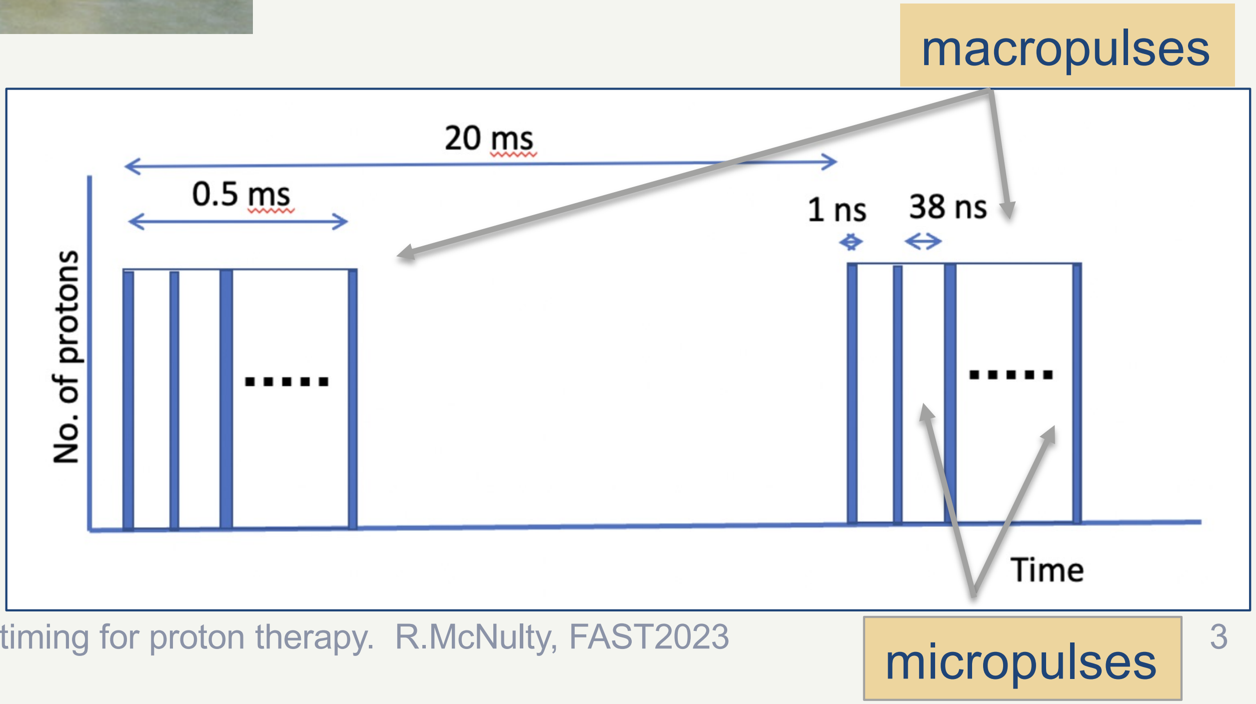
- AIC144 cyclotron and LGAD sensors
- Timing resolution
- Cyclotron pulses
- Dosimetry
- Identifying the Bragg peak

AIC144 cyclotron

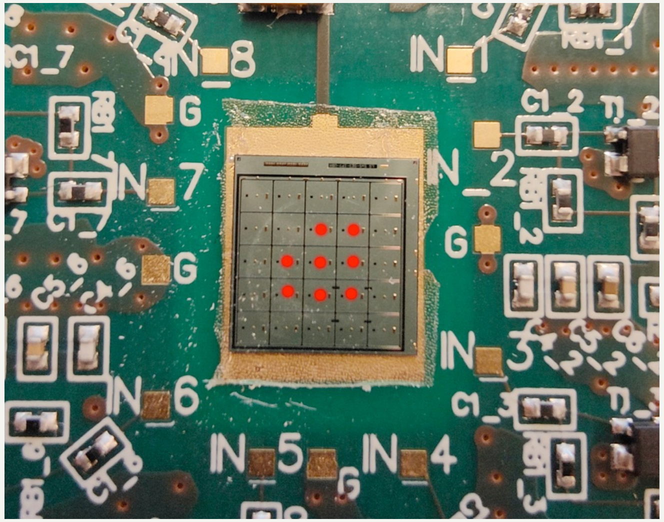


- 60 MeV protons (58 MeV in treatment room)
- Used to treat ocular melanoma
- Intensity up to 100 Gy/s.
- Intensity for treatment: 0.005 Gy/s–0.5 Gy/s
- 4×10^6-4×10^8 protons/sec

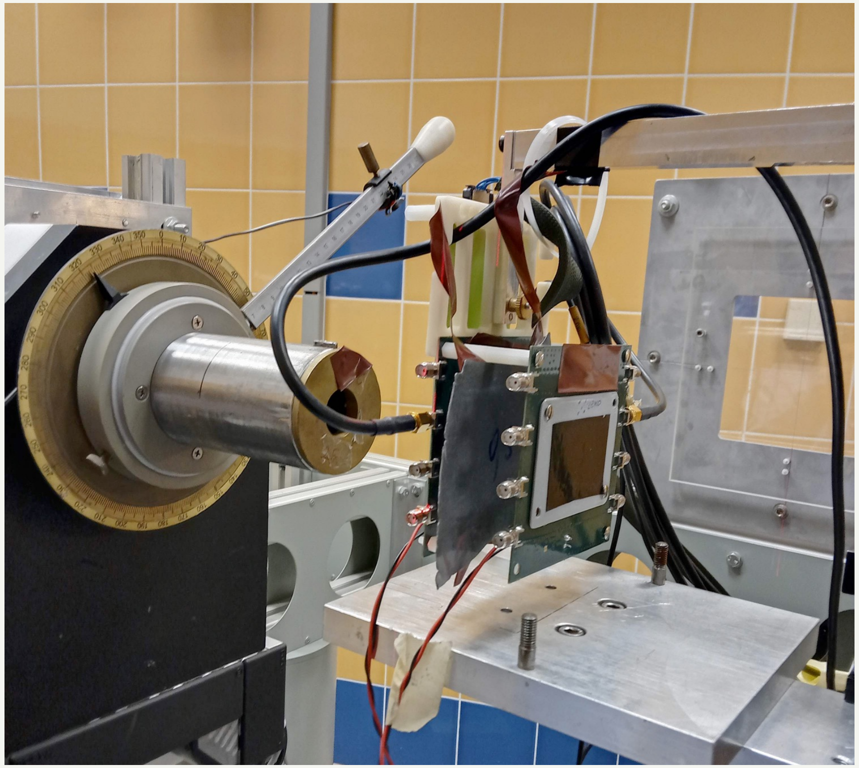
Nominal pulse structure
RF=26.26 MHz



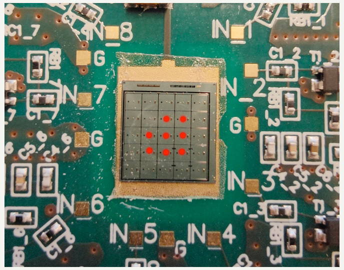
LGAD sensor



- 25 pixels 1.3mm x 1.3 mm
- 8 pixels bonded to PCB
- Two boards used for AIC144 beam-test



- Sensors biased to 180 or 200V
- Gain of ~20
- Short pulses ~ 2.5ns
- Fast rise time allowing precise time of arrival of ~ 50 ps



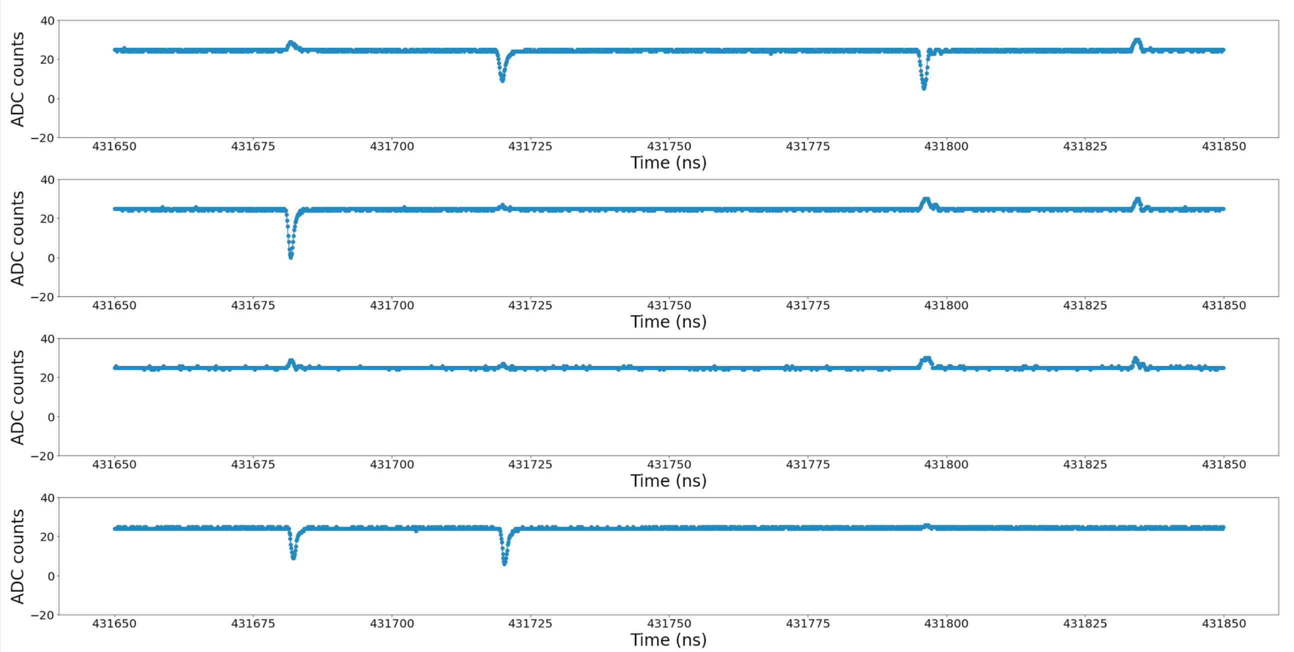
Signals (during 200 ns)

Sensor 1: Left

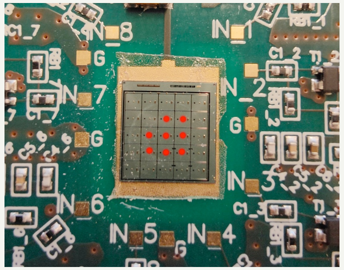
Sensor 1: Centre

Sensor 1: Right

Sensor 2: Centre



LGAD signals have width of ~2.5 ns and rise time of ~0.5 ns
Regular structure indicates <u>micro-pulse</u> modality
Negative pulses are signal
Positive pulses are cross-talk from other bonded pixels.



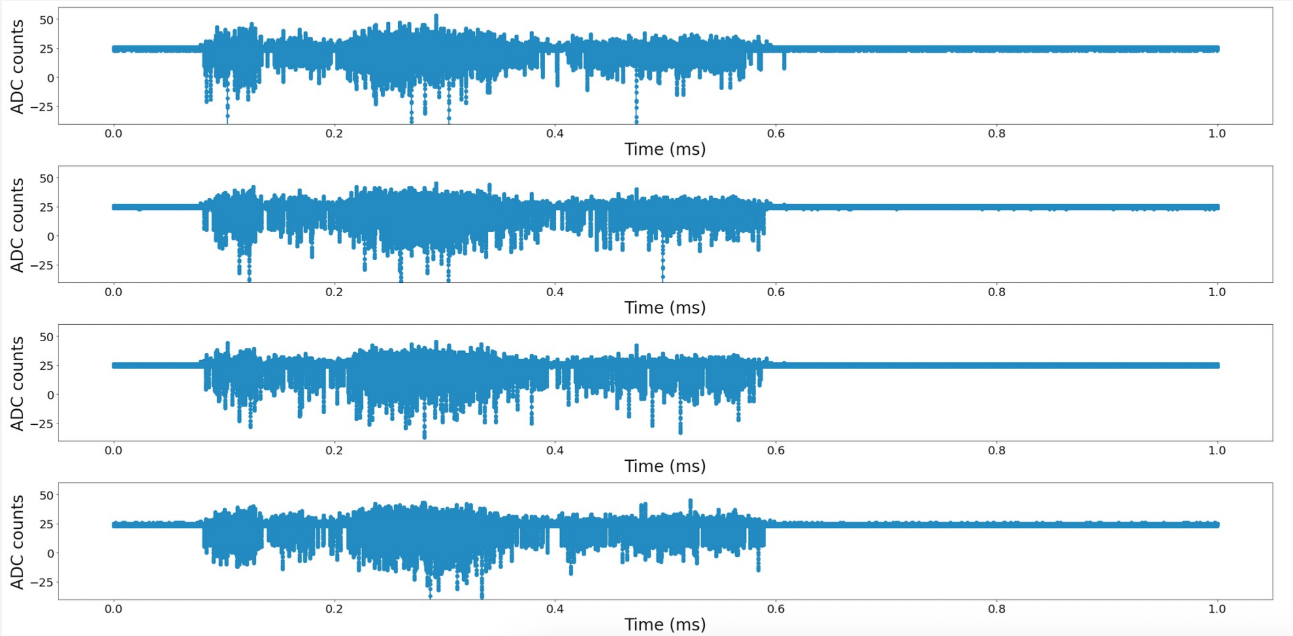
Signals (during 1 ms)

Sensor 1: Left

Sensor 1: Centre

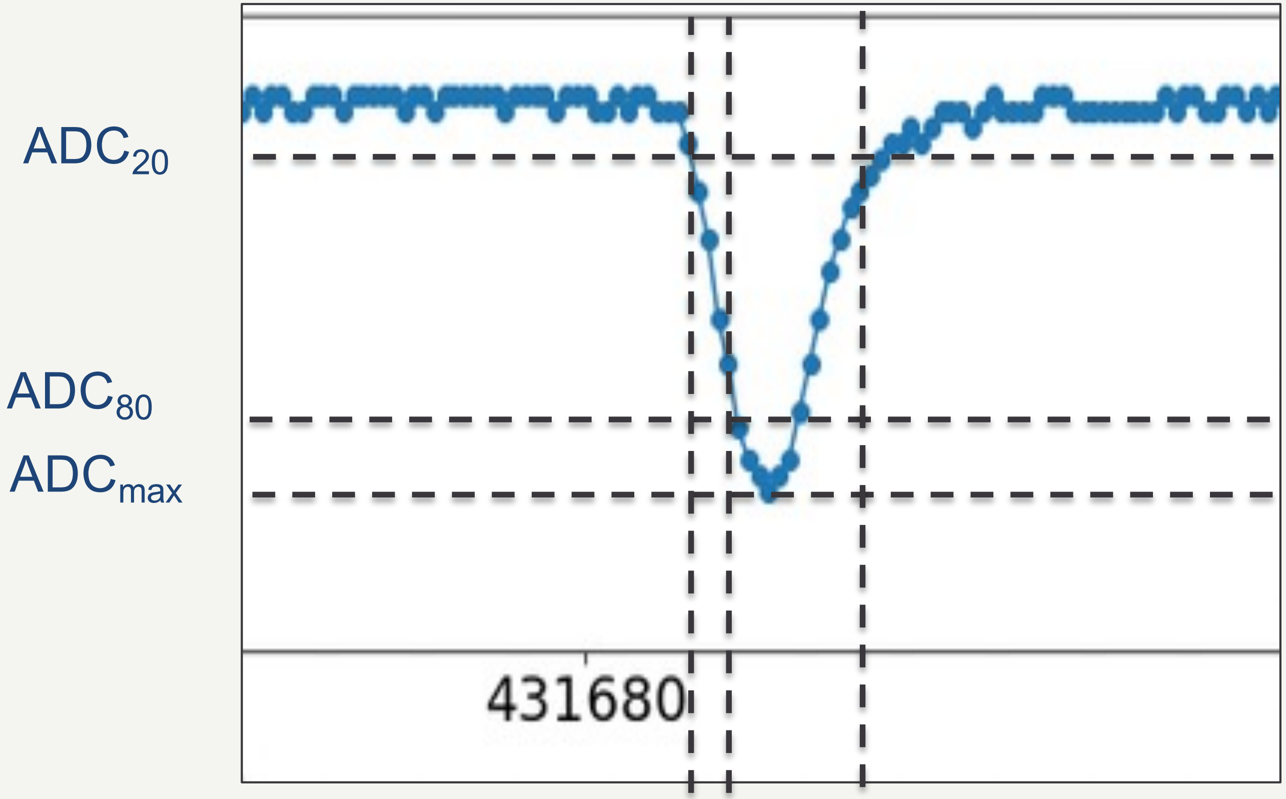
Sensor 1: Right

Sensor 2: Centre



Shows macro-pulse modality
Occupancy of micro-pulses varies as function of time in macro-pulse

Cluster identification algorithm



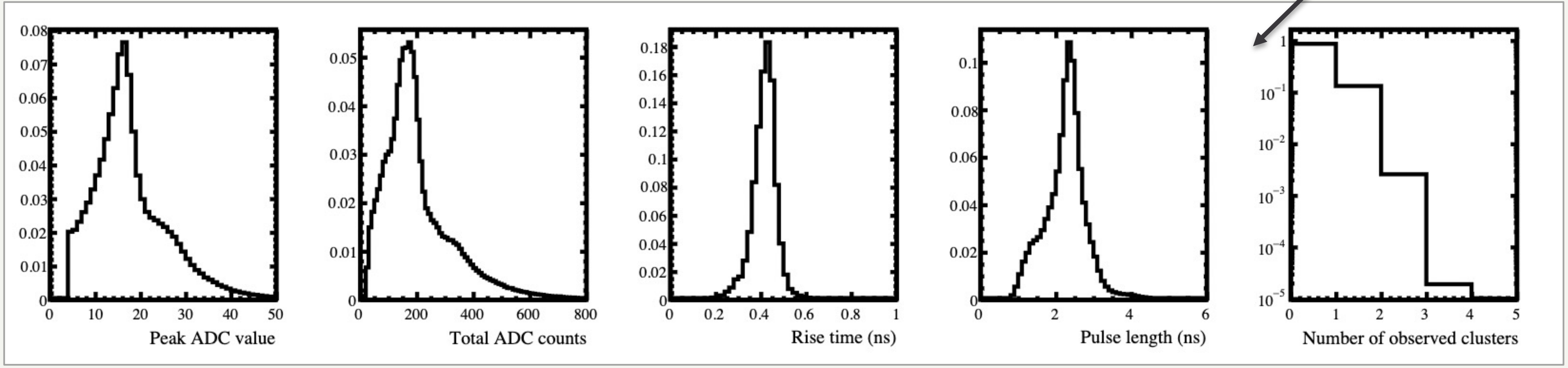
Simple algorithm

Look for >5σ deviations from baseline
Maximum is peak position within window +-0.5ns
Identify 20% and 80% fractions.

(Chris will show a more sophisticated approach)

Some signal characteristics (clusters)

(log scale)

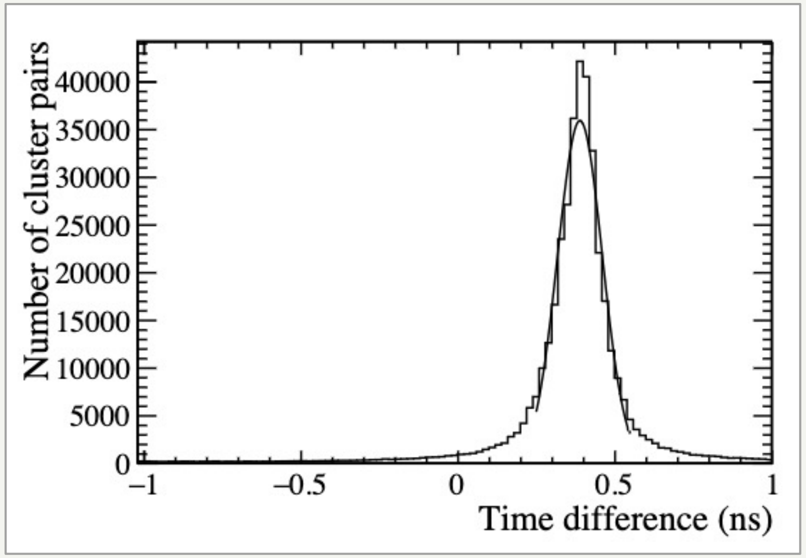


- Peak ADC is maximum deviation from zero
- Total ADC is integral from 20% of max on leading and trailing edges
- Rise time measured from 20% to 80% of max on leading edge
- Pulse length measured from 20% of max on leading and trailing edges
- Number of clusters is counted in window of +-10 ns around nominal position.

For the lowest machine currents, little pile-up.

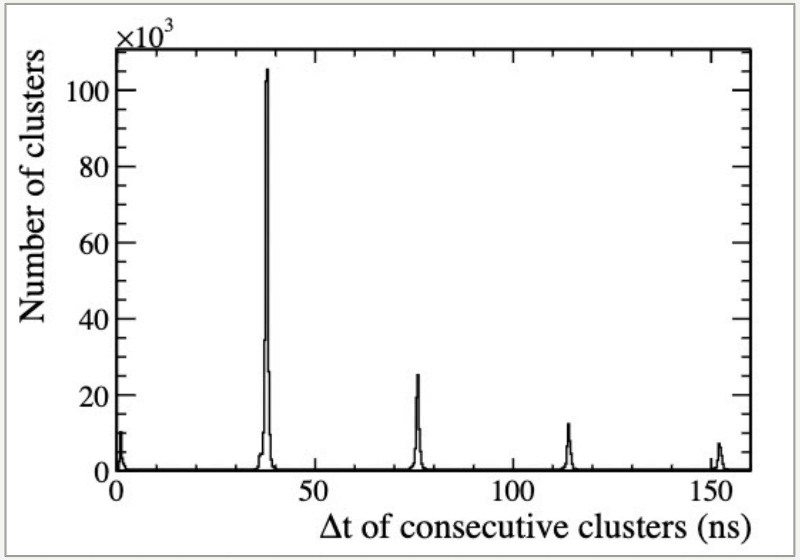
Time resolution

- Plot shows time difference in signals in central pixels on <u>different</u> sensors.
- Offset = 4 cm / (c/3) ~ 400 ps
- Width=70ps
- => Time resolution = 50 ps



Time difference between signals in the <u>same</u> sensor.

Width gives size of micro-pulse = 0.3 ns
Separation of 38 ns gives cyclotron RF.



Cyclotron RF

Micro-pulses in the bunch-train occur at

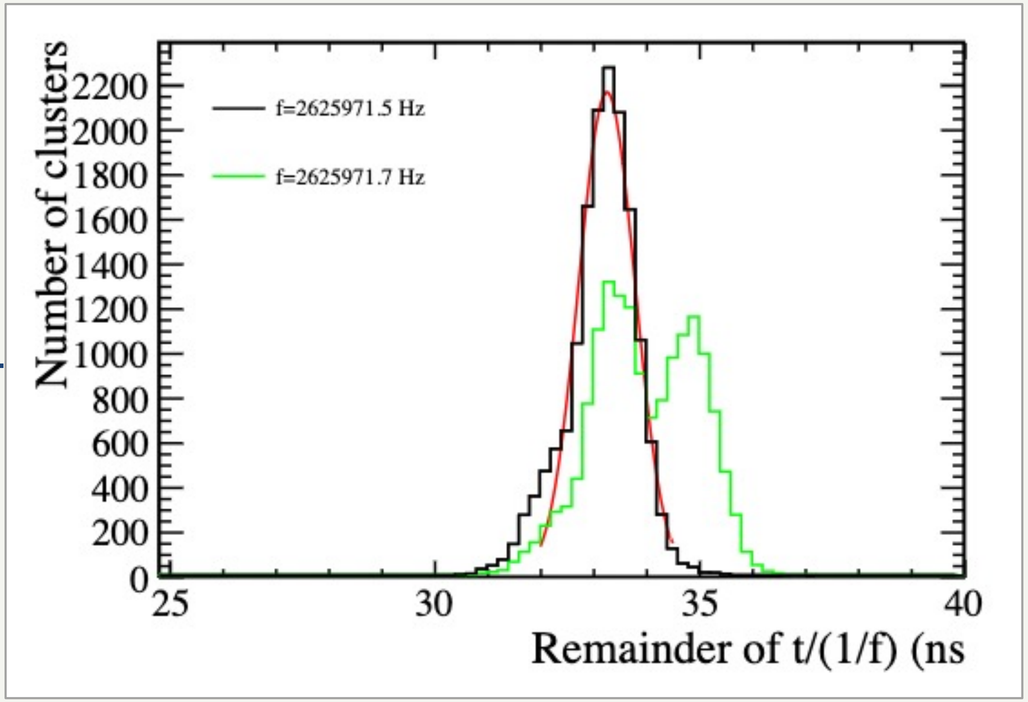
$t=t_0+n\delta t$.

If you know δt:

- Remainder of t/δ determines t_0.
- Width of t_0 = average width of micro-pulses.

Turn logic around:

Minimise width to determine δt

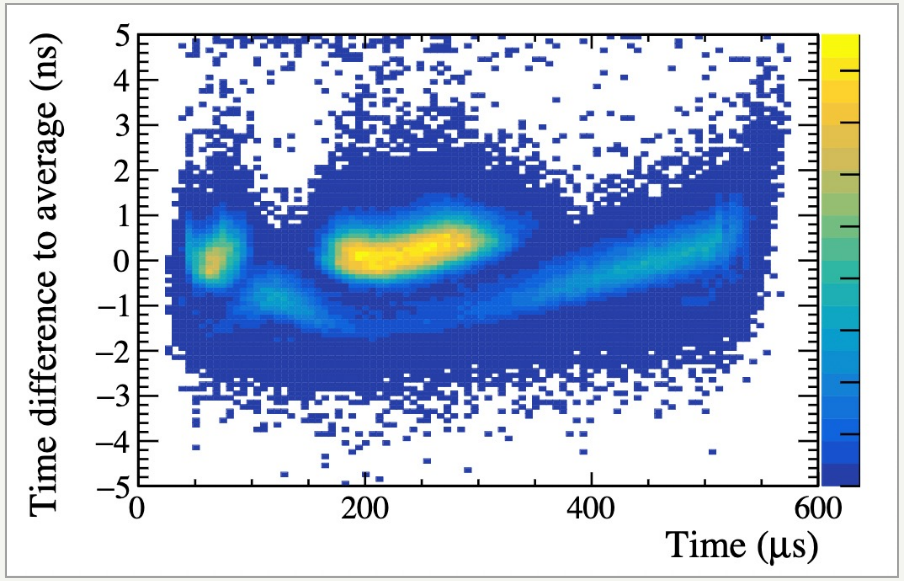


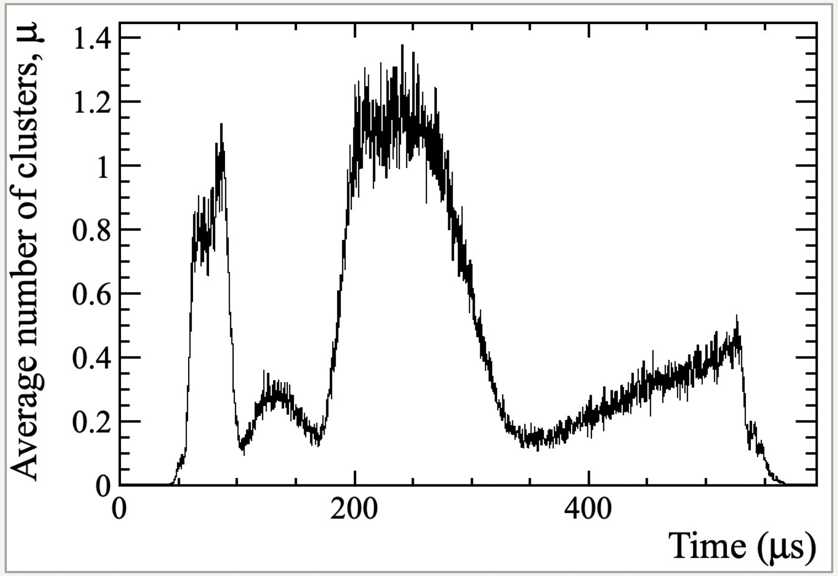
RF = 2625971.508 +- 0.001 Hz.

(Measurement with a precision better than 1 part in a billion!)

Macro-pulse structure

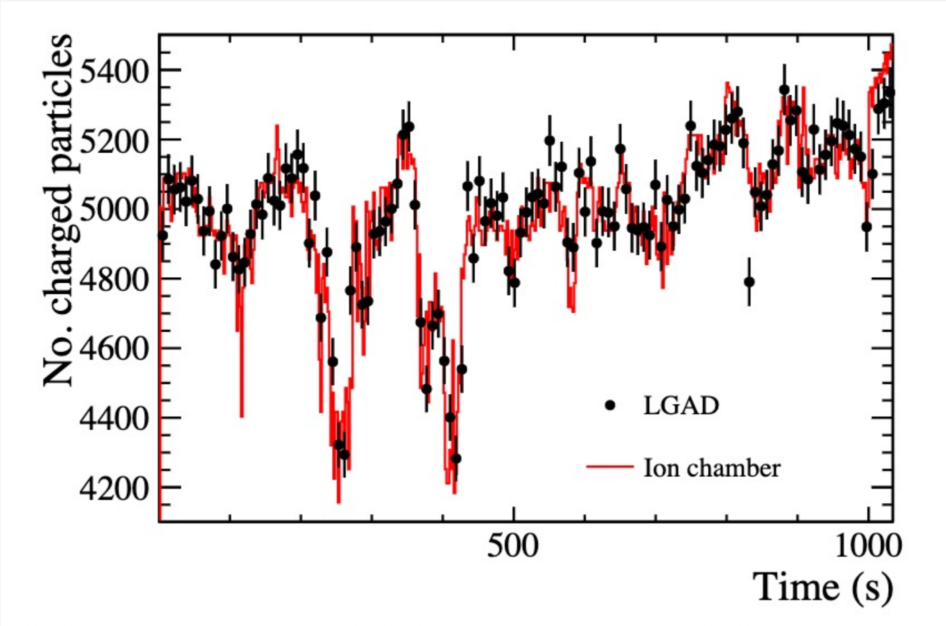
- Average micro-pulse width = 0.5 ns. Δt adjacent pulses width = 0.3 ns.
- Structure of macro-pulse investigated plotting number of clusters and time difference to nominal. (Data shown is for 250 macro-pulses.)





Probes details of the machine injection and acceleration

Dosimetry



The number of clusters tracks the beam current as measured by monitoring ion chambers.

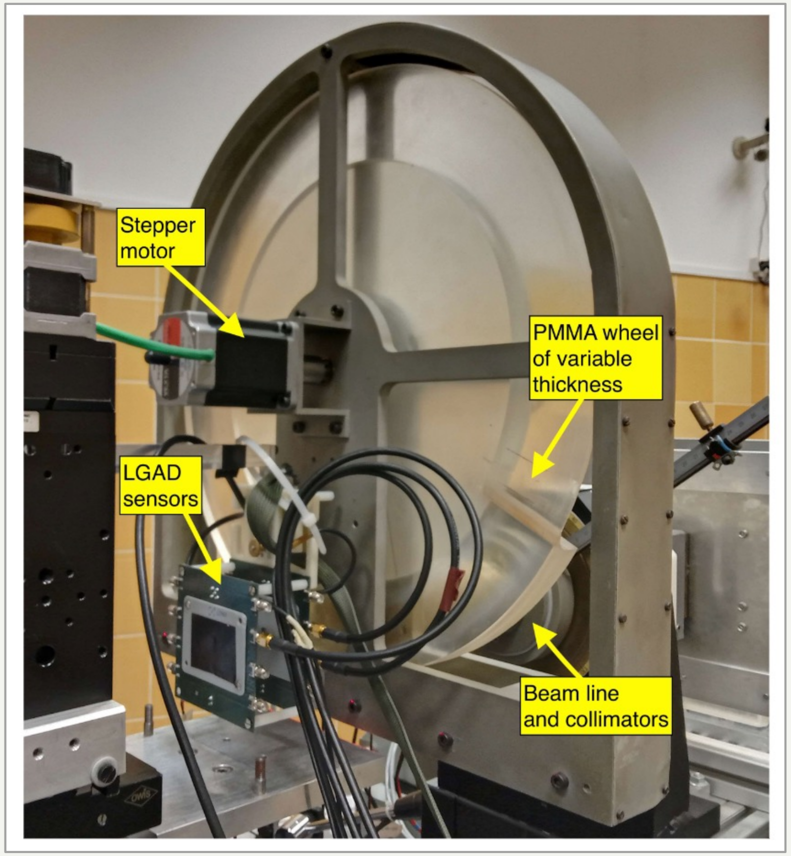
In principle therefore, LGAD can be used as a dosimeter.

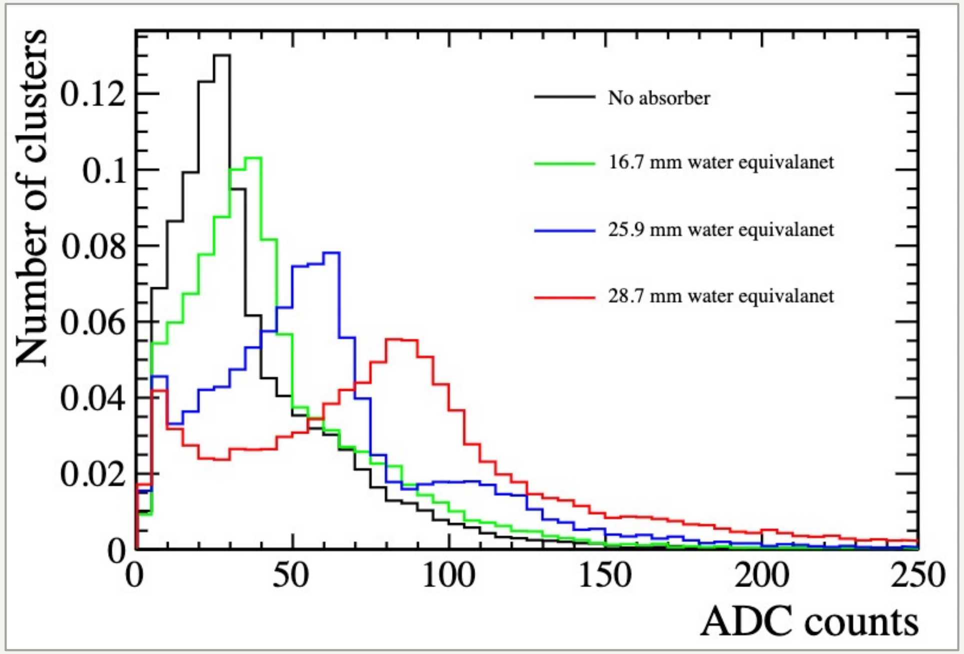
Advantage of super-fast response.

Promising detector for FLASH therapy, given time resolution and radiation hardness.

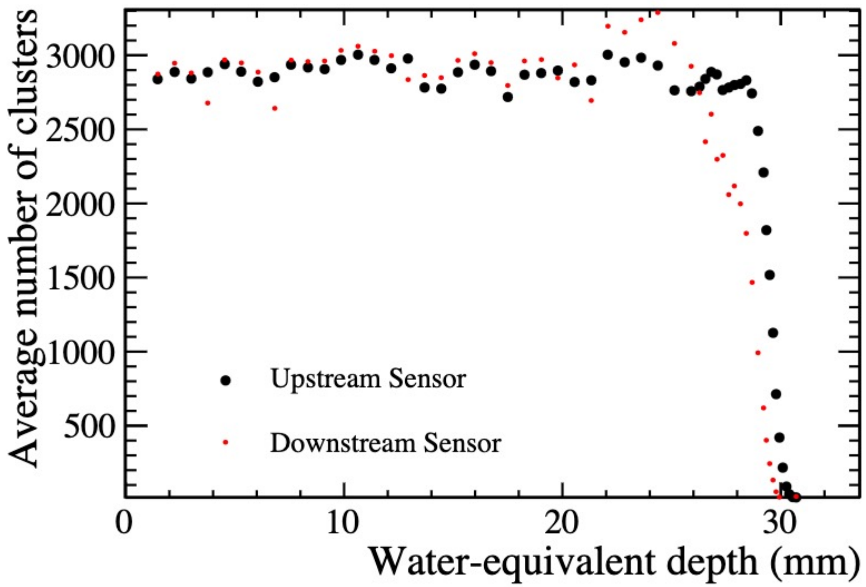
The Bragg Peak

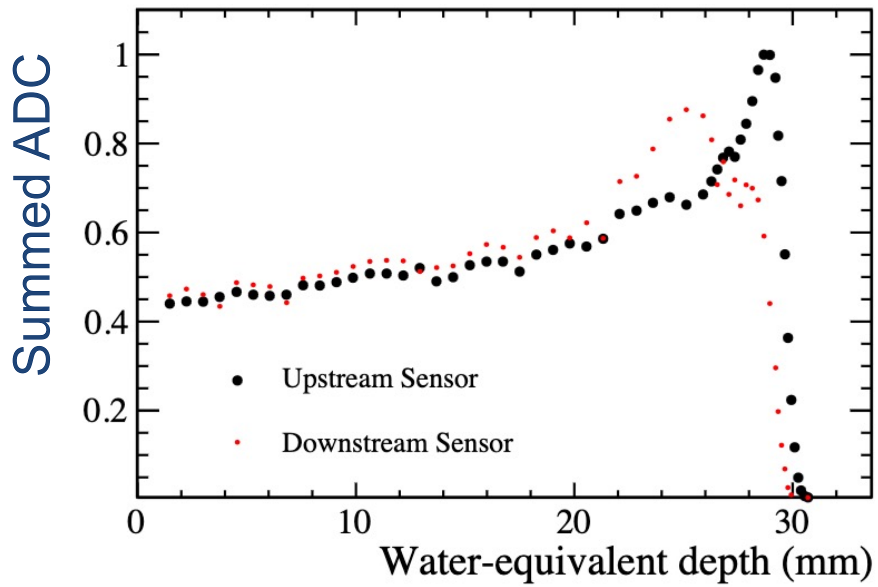
- Reason for using protons in oncology is the high energy deposits for low energy protons. Protons lose energy passing through the body (water) and this energy loss accelerates towards the end point.
- For 58 MeV protons, this occurs at 28.7 mm in water.

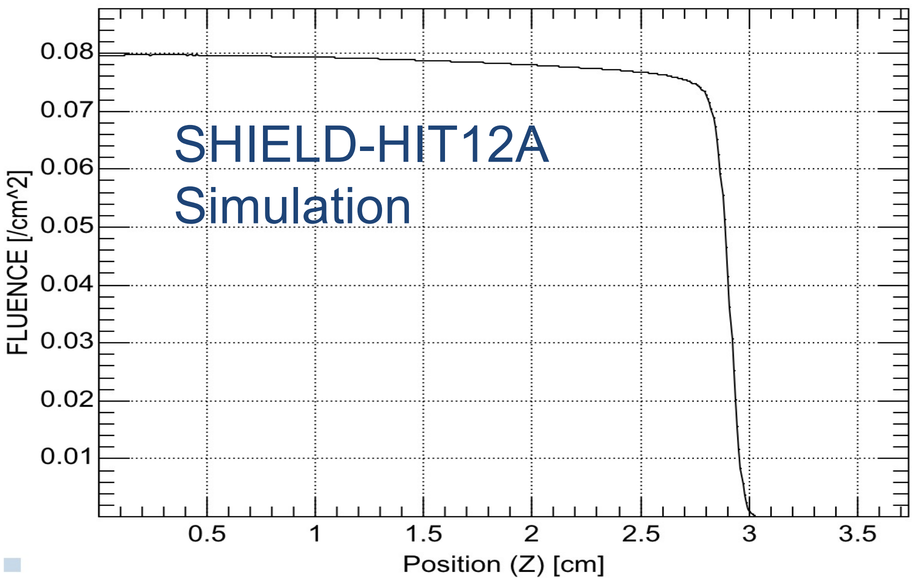


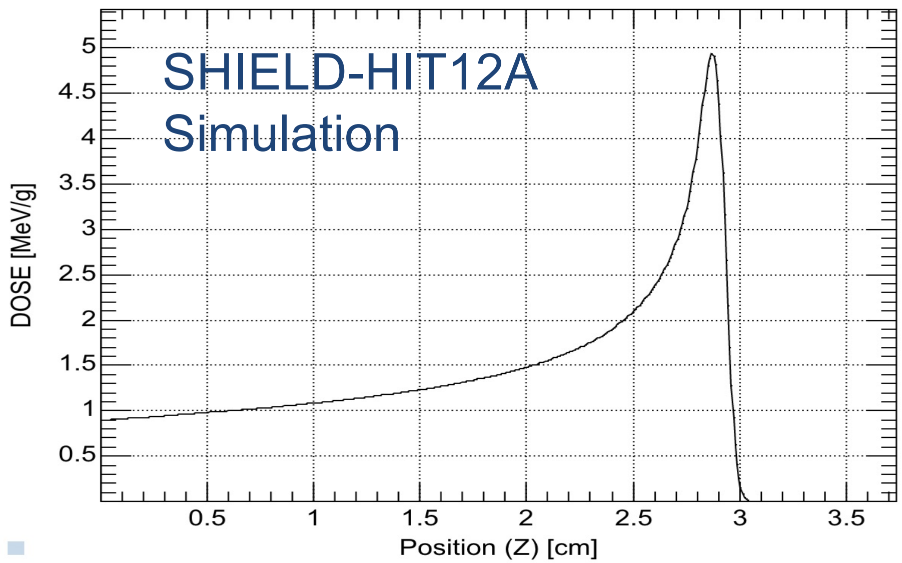


The Bragg Peak



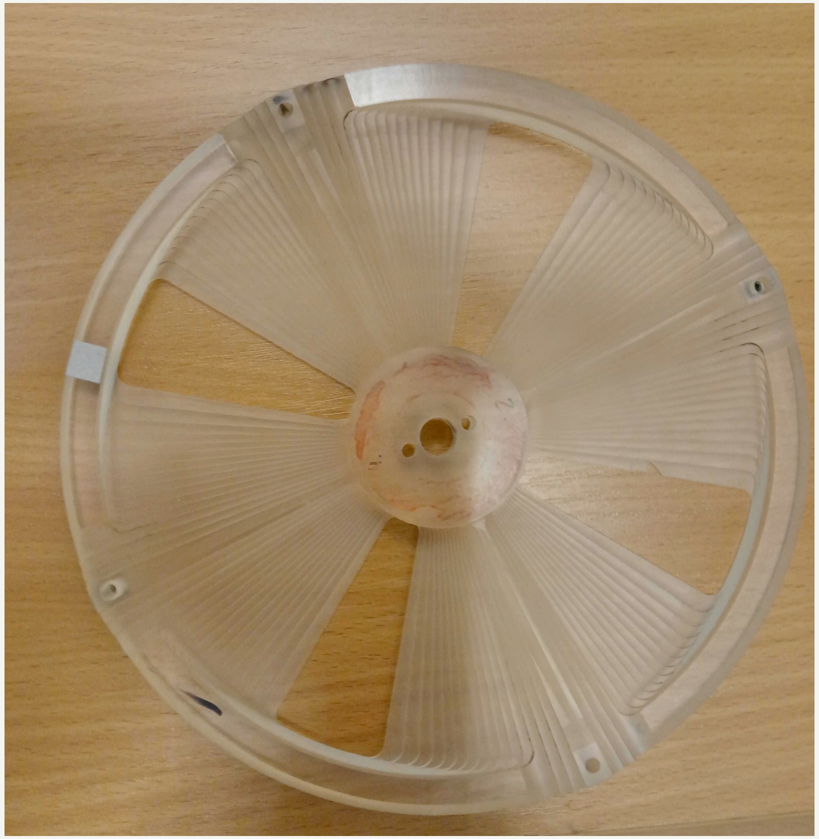


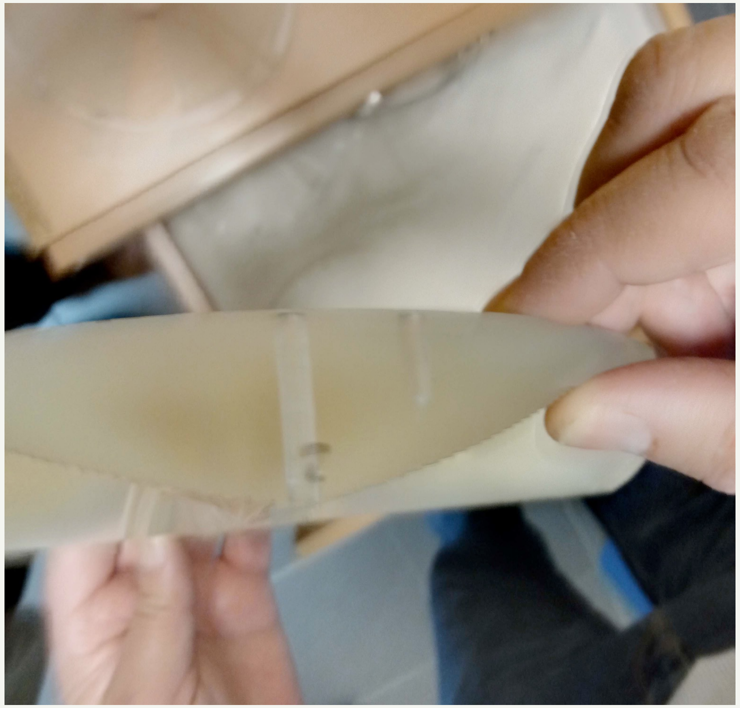




Spread-Out Bragg Peak

For 58 MeV protons most energy deposited after 28.5 mm of tissue. To tackle tumours at varying depth, increase energy spread of beam using propeller.

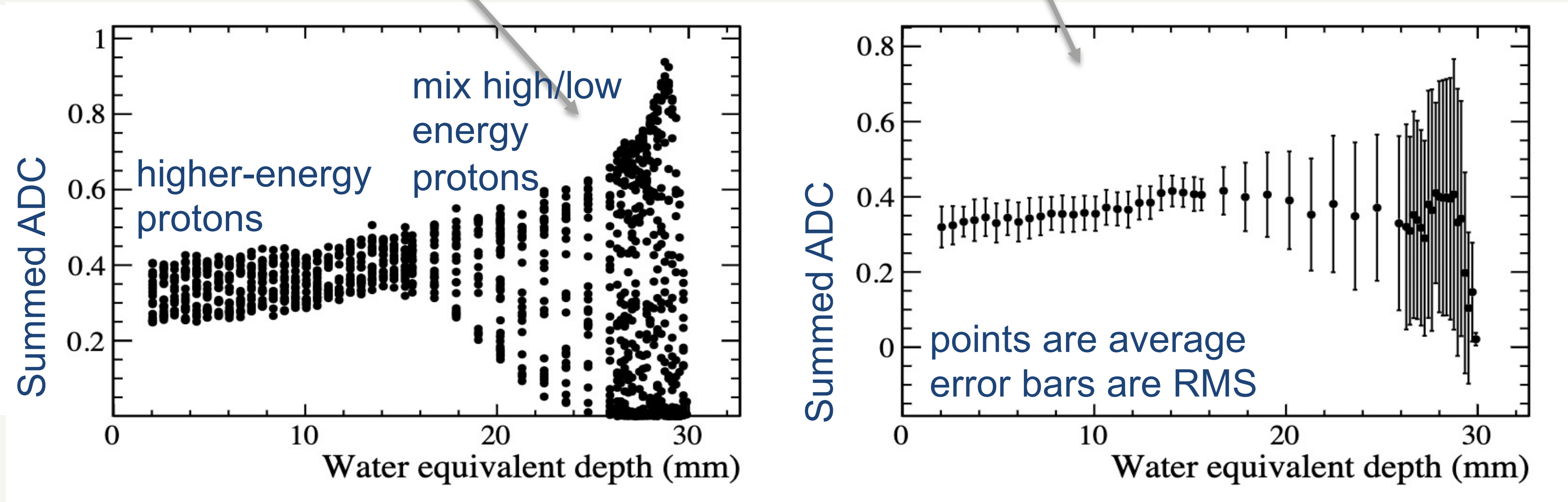




Spread-out Bragg Peak

upper limit is Bragg curve corresponding to gap in propeller

Radiation delivered to patient, by design, is more uniform with depth



Wheel rotates at 33.1 Hz, but LGAD is so fast that it captures snapshot of a particular thickness.

Conclusions

- LGAD can be used as a dosimeter
- The fast response allows details of the radiation delivery to be seen with precision
  – structure of the beam
  – motion of propeller
- Could be of particular importance in FLASH therapy where treatment times can be <0.1 s, inaccessible to standard technology.