Performance of a low gain avalanche detector in a medical linac and characterisation of the beam profile

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Ronan McNulty.

Workshop on pico-second timing detectors for physics.

Zurich, Sept 11th 2021

Motivation

Linac creates electrons and photons for radiotherapy

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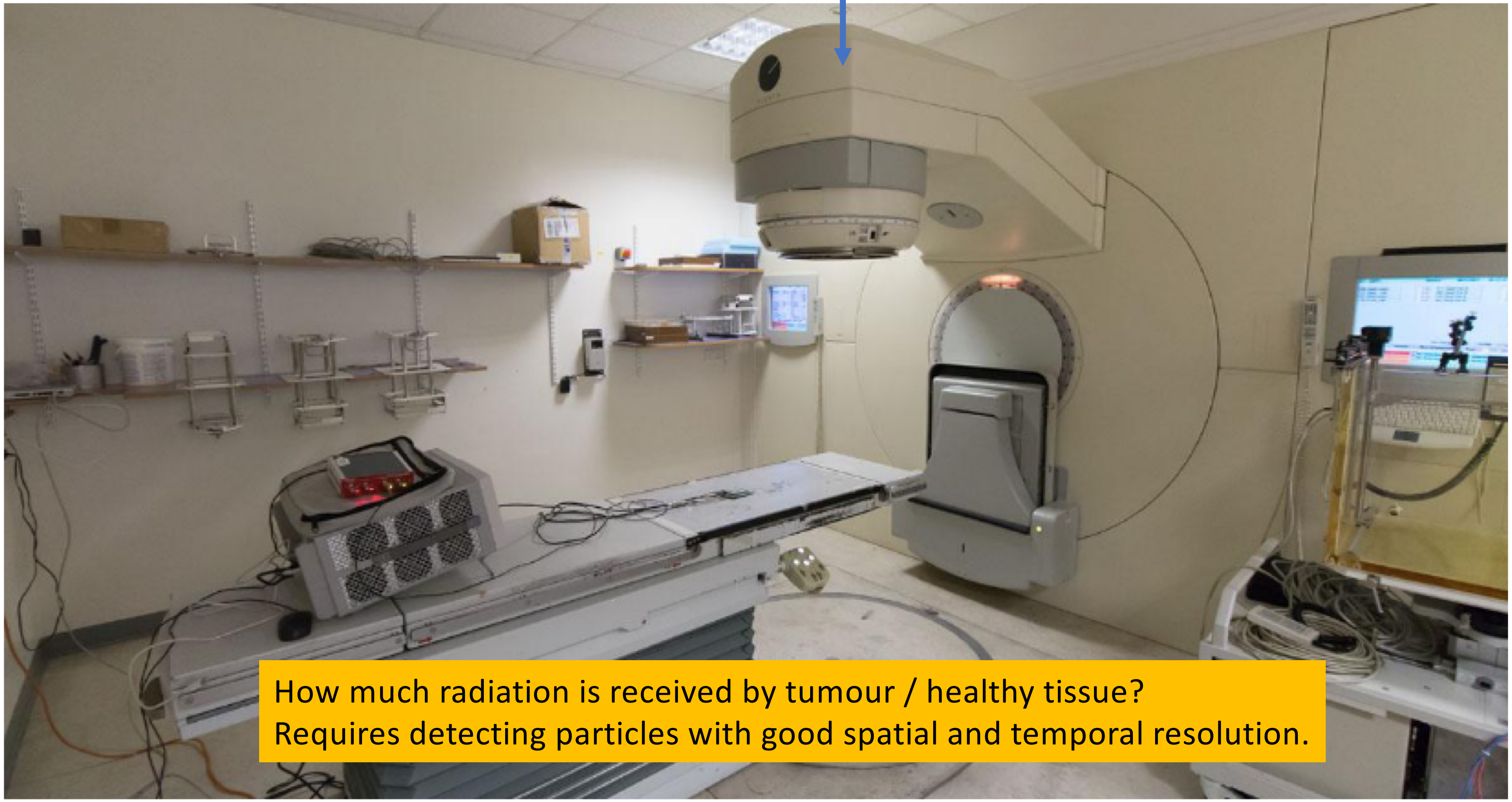
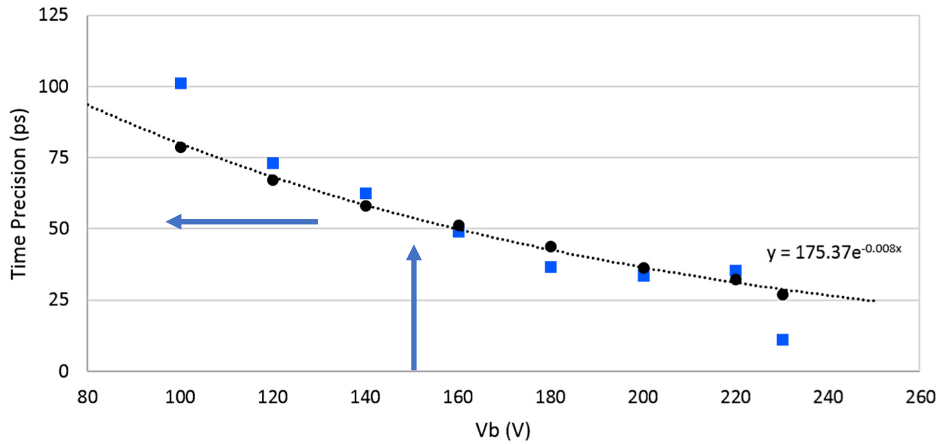


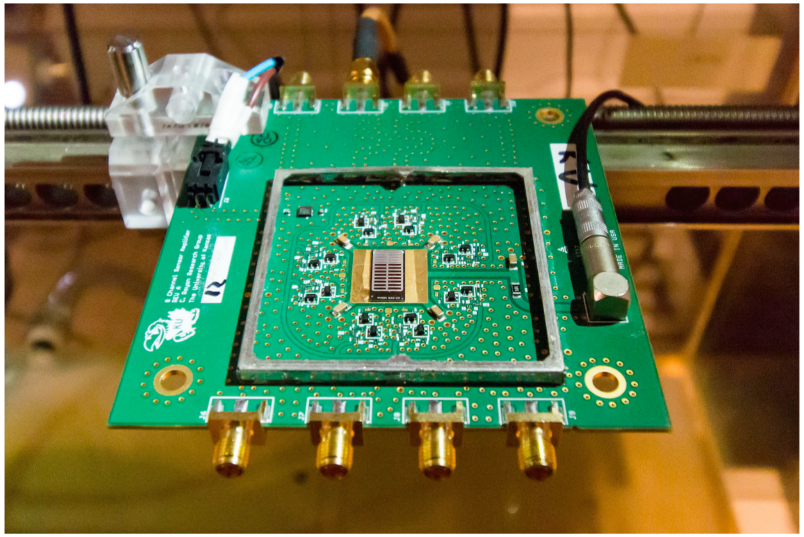
Dosimetry challenges

- High spatial resolution (few μm) desirable in:
  - intensity modulated radiation therapy
  - microbeam therapy
- Time resolution required:
  - if subject is in motion
  - if dose varies with time
  - for FLASH therapy (emergent technology with ultra-high doses in fractions of a second)
- Currently used:
  - Ion chamber: time resolution typically ¼ second.
  - 2D pixel or ion chamber arrays. (e.g. Medipix)

Low Gain Avalanche Detector

Single pixel 2.9 x 0.5 mm^2
Kansas university readout board
Trade-off between integration time and SNR. Potential problems with high occupancies.

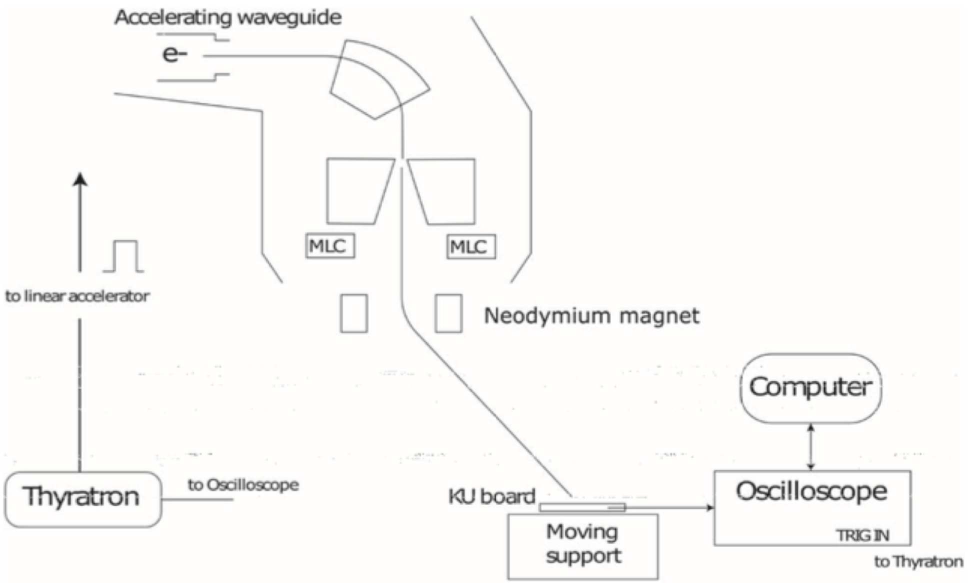


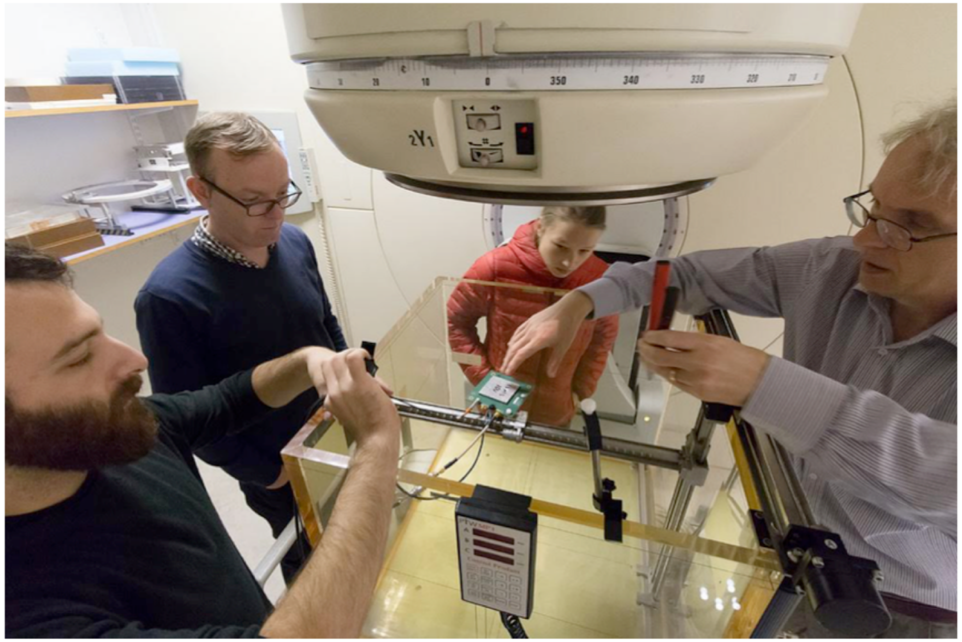


Minafra N et al., NIM A 867 88–92

Test-beam set-up

6 MeV electron beam





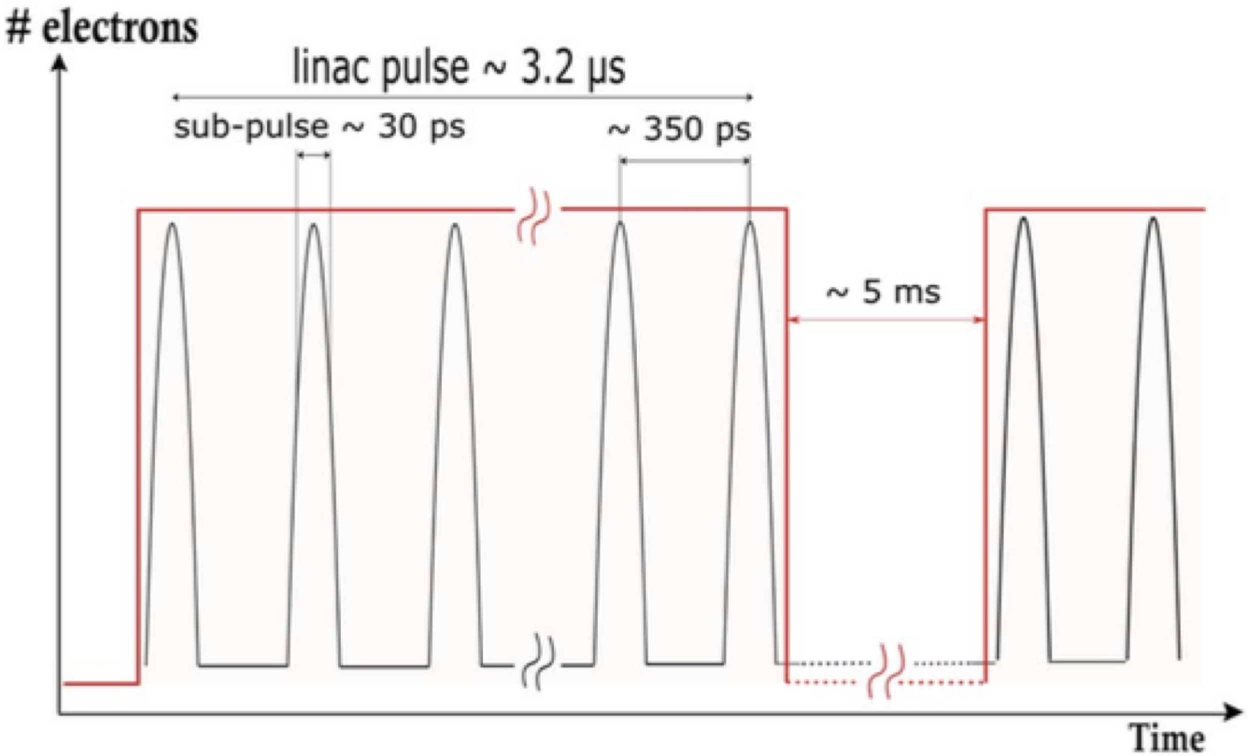
Magnet separates photons from electrons and spreads the beam by energy.
Spatial dimension scanned with xy-table.
We took 200 linac pulses at each detector position.

Nominal beam profile

This is what the text-book tells you the beam looks like.

Each pulse is 3.2 μs long.

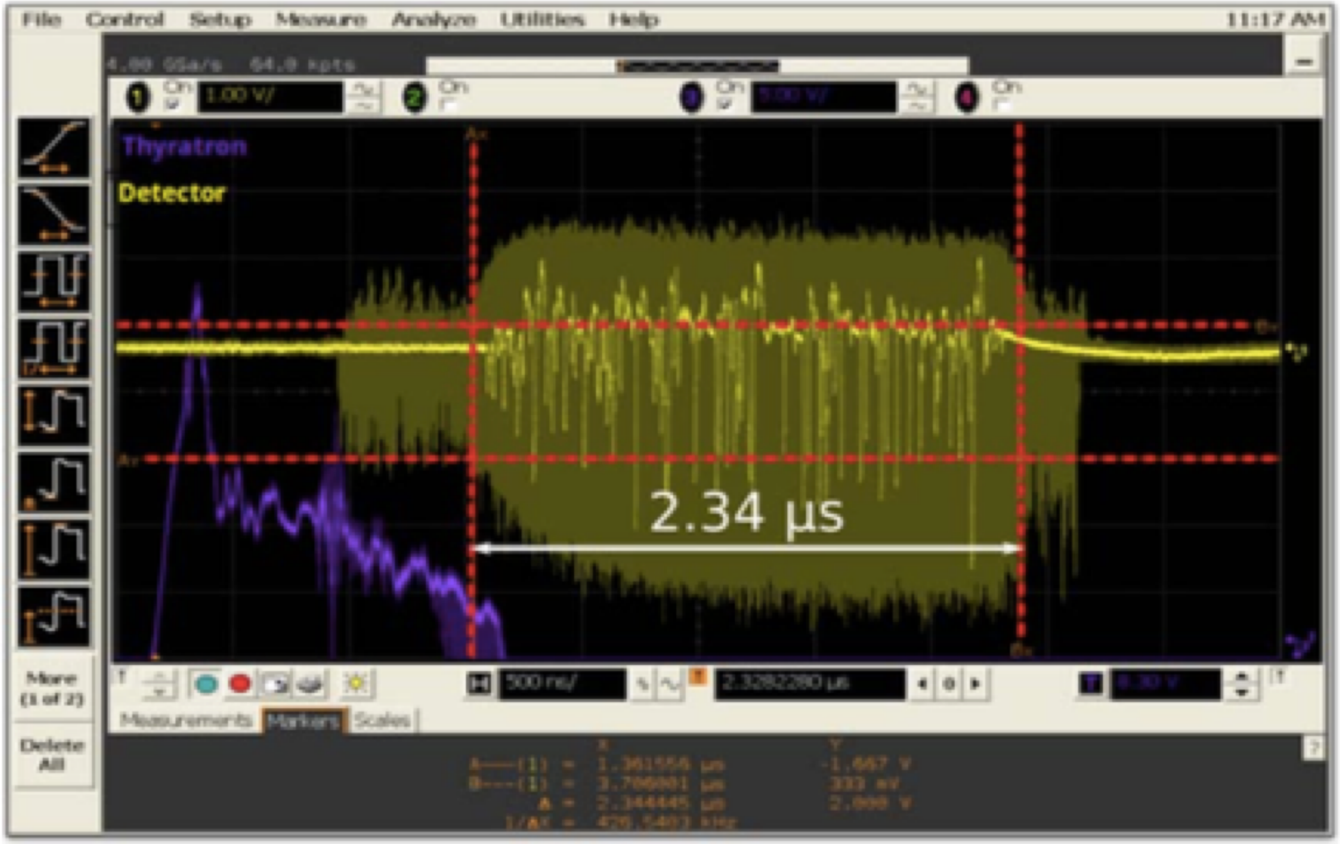
These are made up of a series of pico-pulses produced at 2856 MHz, the RF of the linac



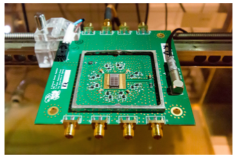
LGAD response

Triggered by linac thyratron

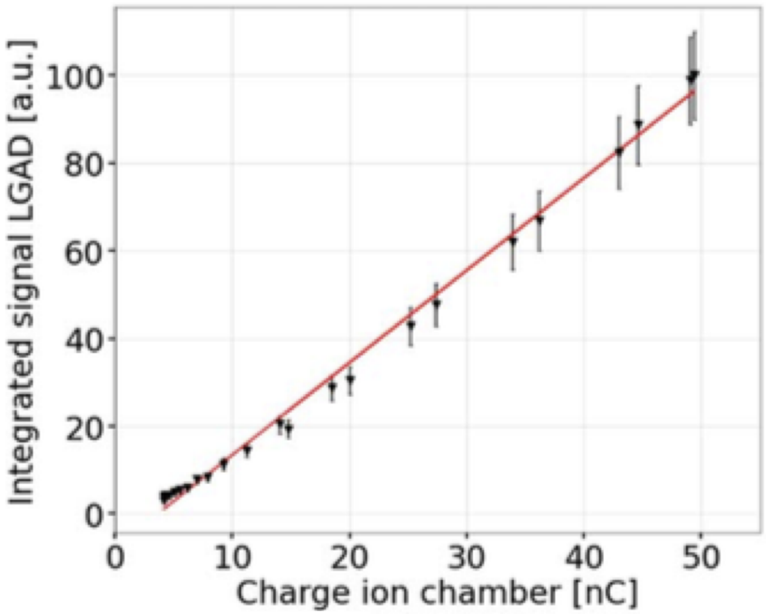
Detector has little activity before electrons emitted.
Mean and rms define baseline and typical noise.

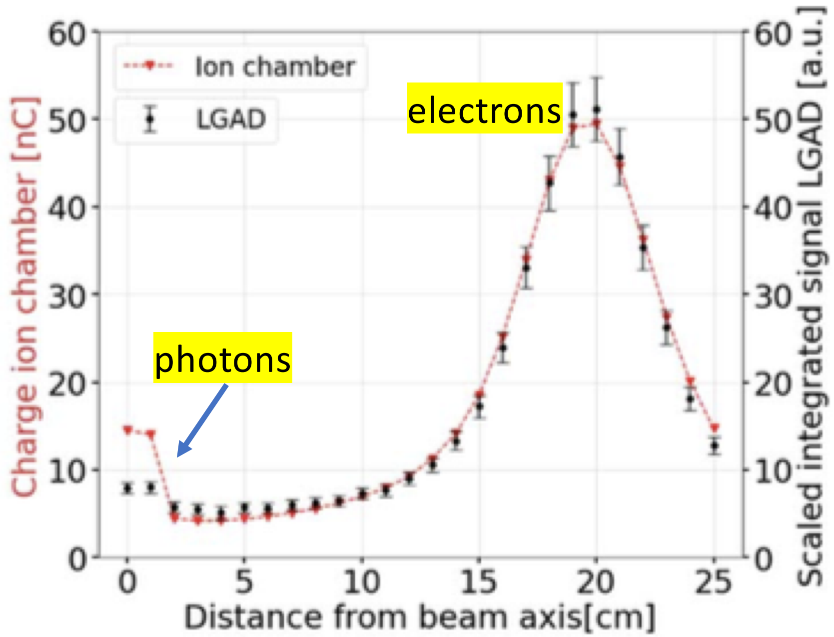


Calibration:
how does it compare to standard dosimetry?



Integration time
2.5 μs





Integration time
250,000 μs

Unsurprisingly, can use a diode rather than an ion chamber.
Important though to relate to medical standard.

250,000 → 2.5 → 0.01 → 0.00005 μs

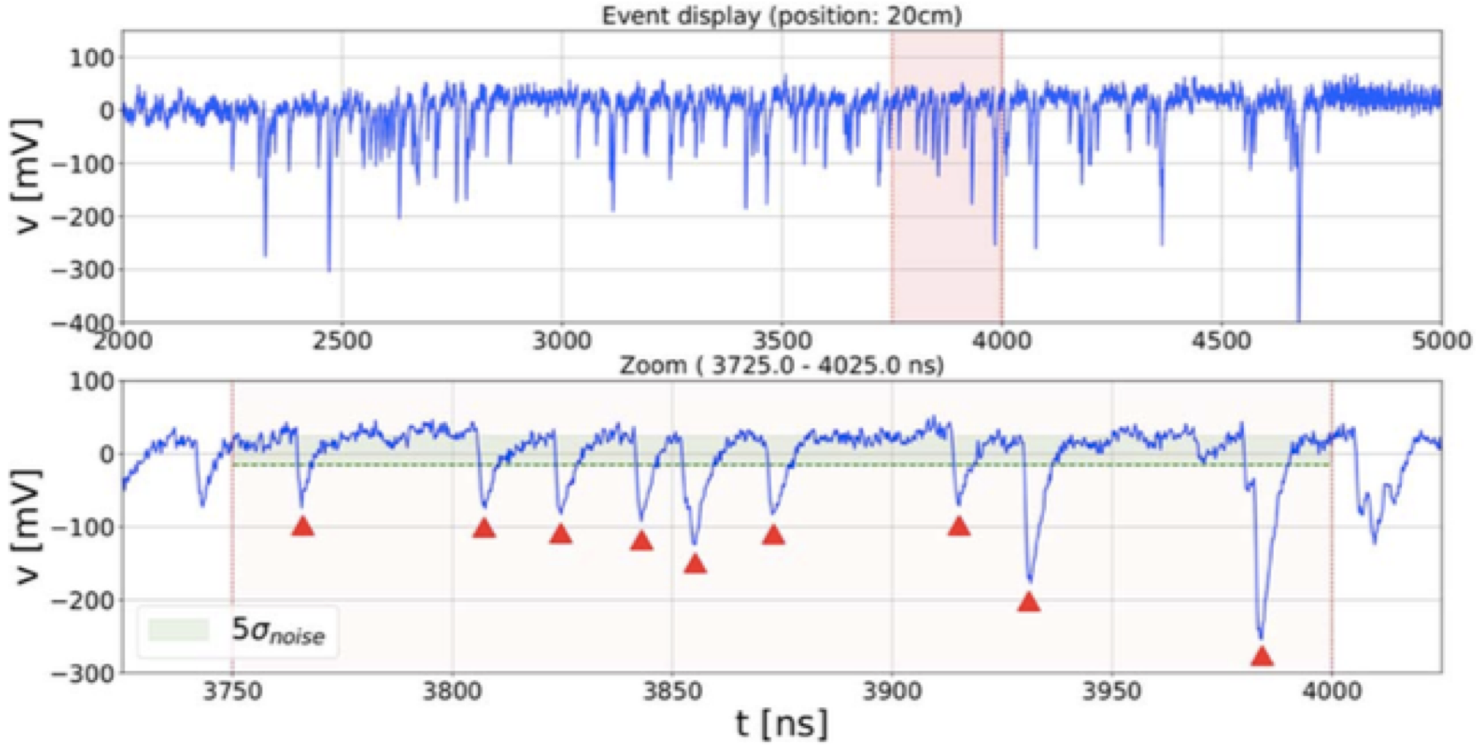
Zoom of data shows detection of **single charged particles** in LGAD

Offline algorithm selects individual particles:

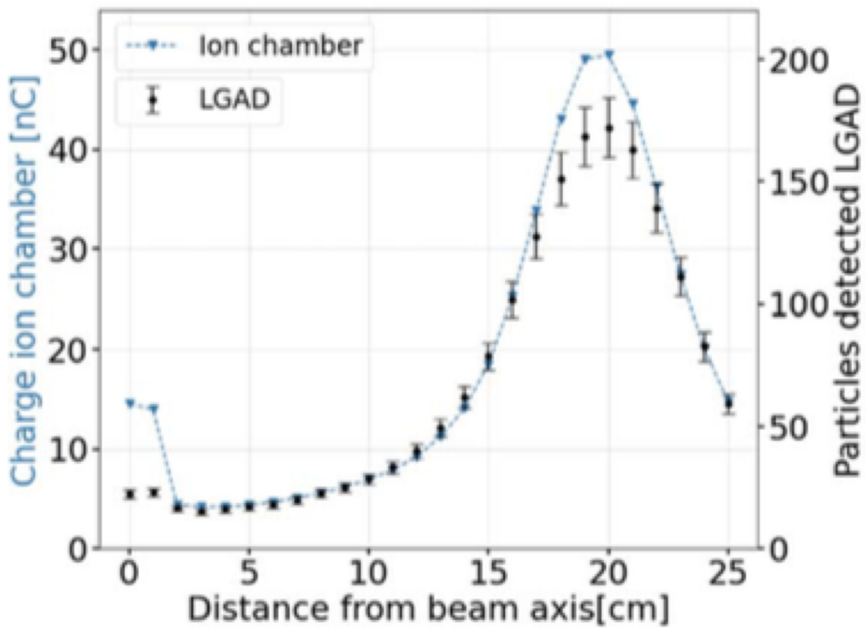
- Baseline defined as 2 to 4.5 ns before signal
- Signal channel > 5 rms.
- Signal channel largest in +- 3 ns.

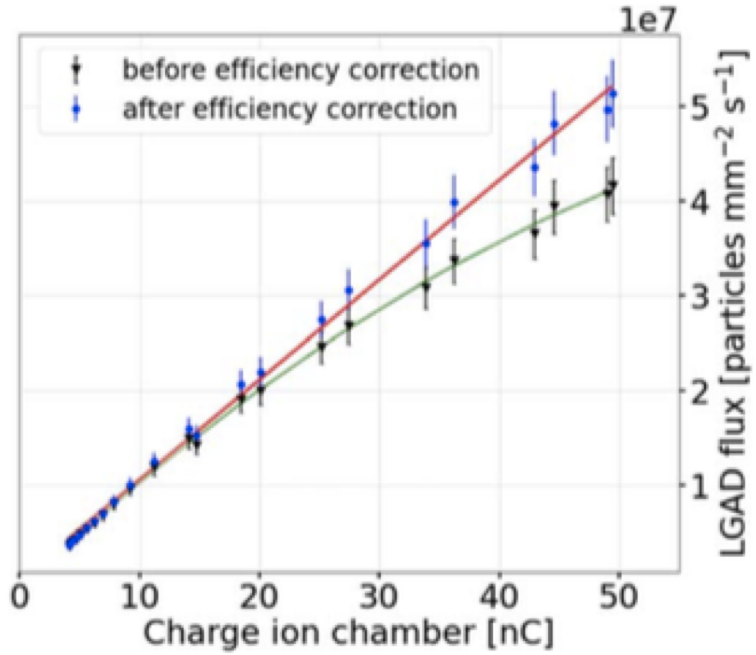
Note this is a Poisson process and algorithm partially fails if two particles pass within 3 ns.

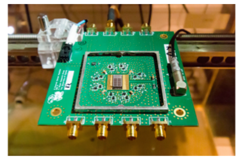
Intense rates also affect baseline.



Individual particles compared to medical standard







Particle counting
In 2.5 μs

Particle counting is a little different to charge deposited, particularly for photons.

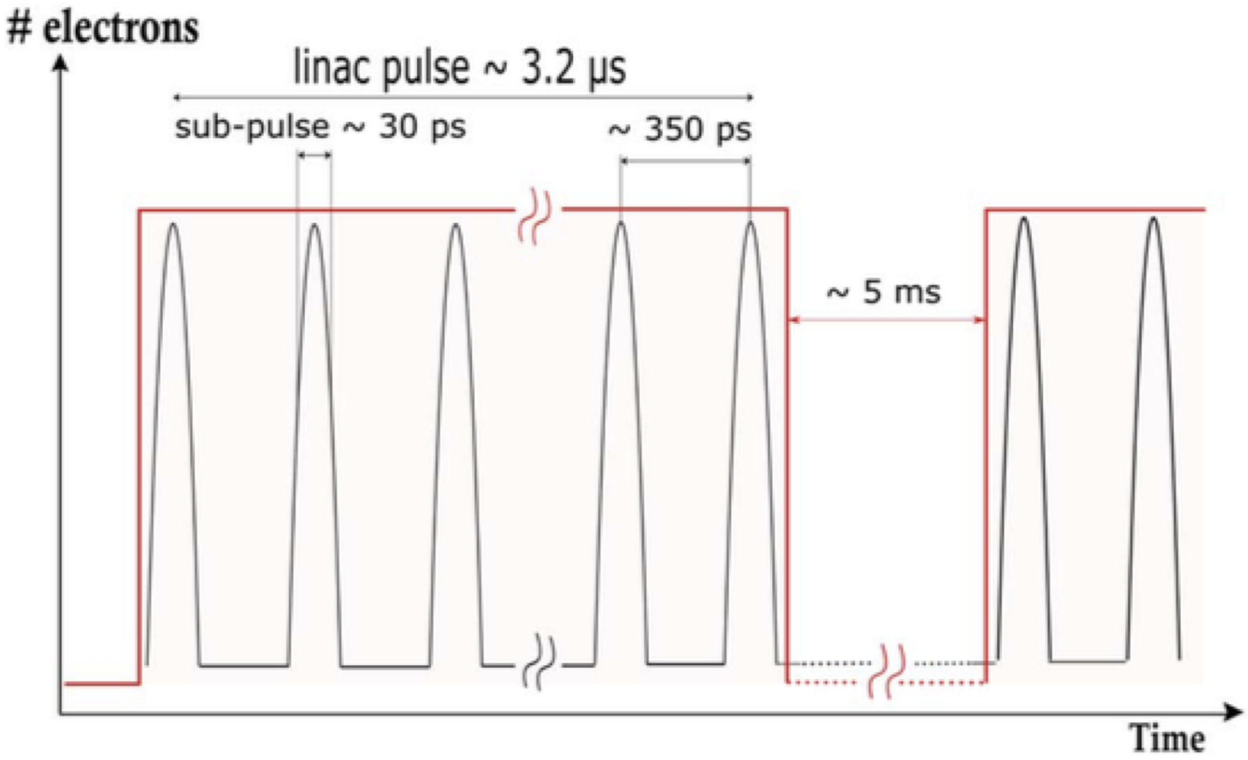
Integration time
250,000 μs

Potential of LGAD of medical physics

	Spatial resolution	Temporal resolution
Standard technique (ion chamber)	5 mm x 5 mm	250 ms
LGAD	50 μm. x. 50 μm	50 ps
Order of magnitude improvement	4	8

Applications abound for small-field dosimetry, IMRT, micro-beam, and FLASH radiotherapy as well as hadron therapy.

Application #1:
What does a linac beam really look like?



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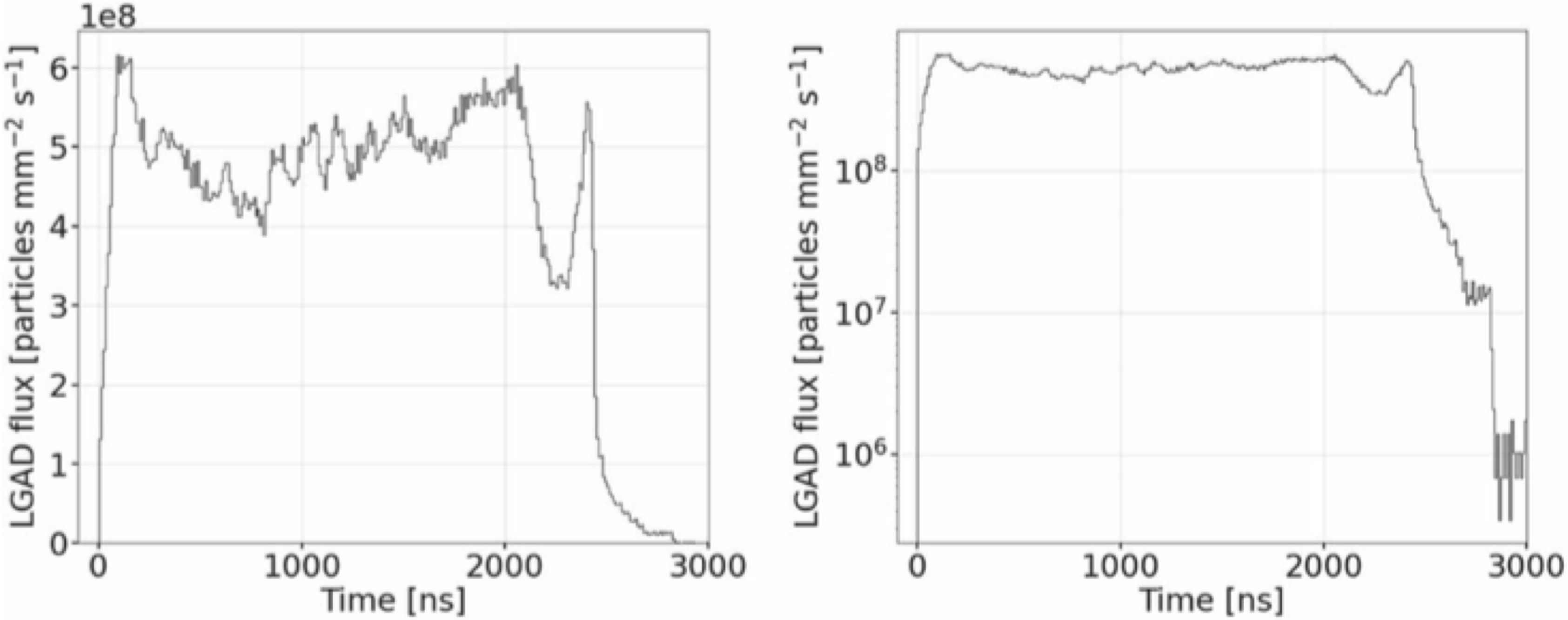
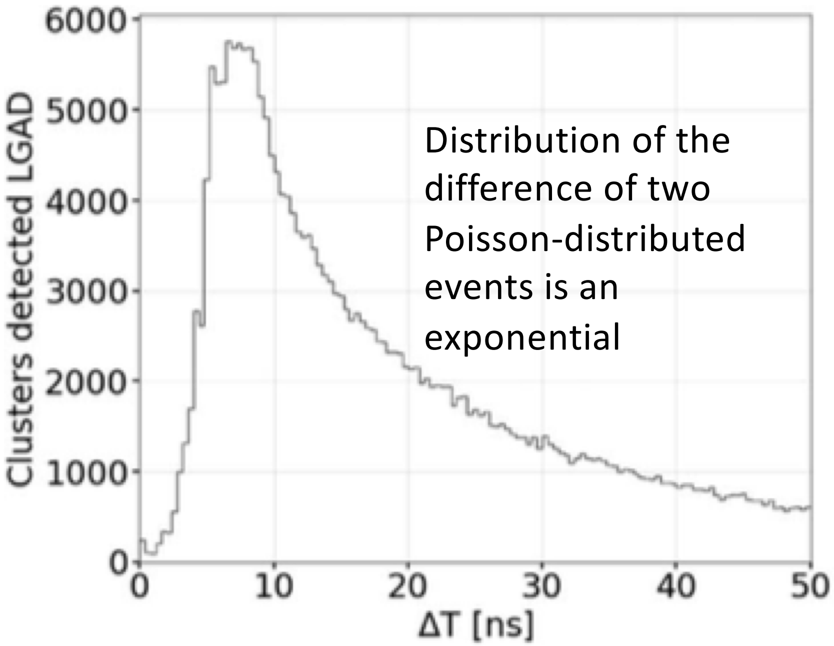


Not quite a square wave!
Also quite a bit shorter than nominal. (Probably not that important for therapy.)

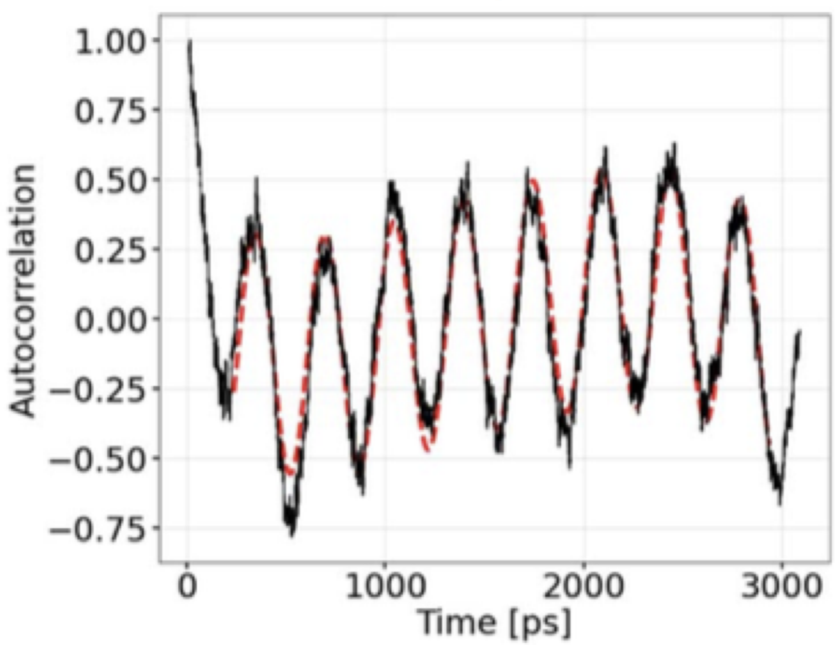
Application #1:
What does a linac beam really look like?

Can we see the pico-structure at 2856 MHz ?

$$R(\tau) = \frac{1}{N-\tau}\sum_{i=1}^{N-\tau} y_i y_{i+\tau}$$



Distribution of the difference of two Poisson-distributed events is an exponential



Impressive detector performance.
346 +- 3 ps measured.

Conclusions and outlook

- Proof of concept for the use of new generation fast detectors for medical applications
- LGAD can be used for dosimetry but with a precision many orders of magnitude better than conventional techniques
- First time the beam time-profile and sub-structure have been observed
- Can provide the dosimetry and beam-monitoring required by emergent technique for radiotherapy (e.g. FLASH, hadron therapy)