U.S. DEPARTMENT OF ENERGY
Office of Science

Electron Compton polarimetry R&D

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The University of Kansas

ePIC

Joint EICUG/ePIC Collaboration Meeting - July 27, 2024

Compton electron polarimetry at the EIC

$$\sigma(\overrightarrow{e} + \gamma \rightarrow e' + \gamma') \neq \sigma(\overleftarrow{e} + \gamma \rightarrow e' + \gamma')$$

$$FOM \propto \frac{1}{\langle A_N^2 \rangle}$$

Impacts the time to achieve desired precision in the measurement

…a 1% precision in the measurement is faster (or the time required is shorter) if the analyzing power is high.

The Compton scattering process depends on the initial beam polarization

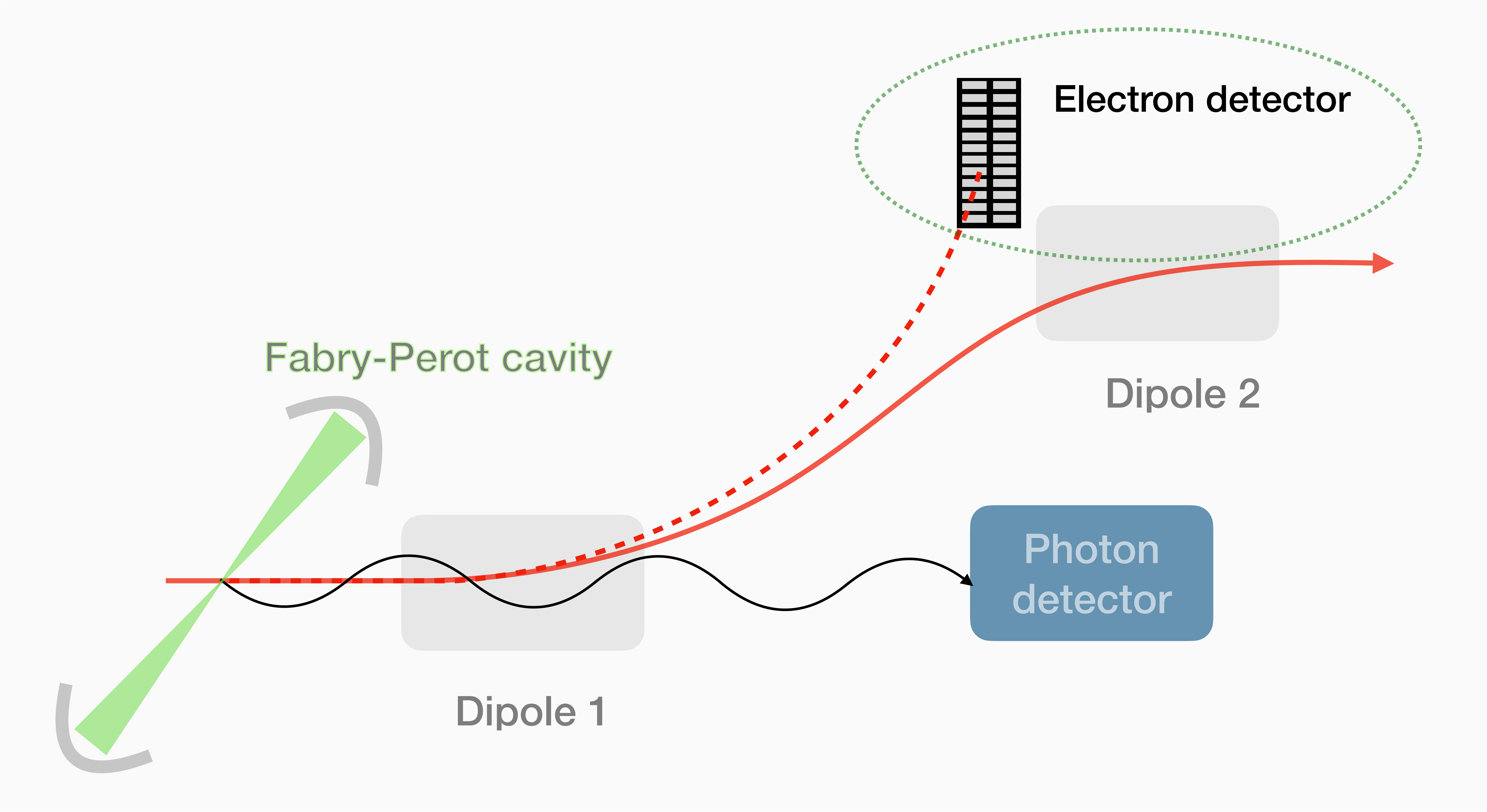
$$\frac{d\sigma}{d\Omega} \propto (1 + P_e \cdot A_{exp} \cdot cos\theta)$$

Measurement: polarization asymmetry

$$A_{exp} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{N_+ - N_-}{N_+ + N_-}$$

Observable: electron counting on detector section

$$N_i = N_0(1 + P_e \cdot A_{exp} \cdot cos\theta_i)$$



Compton electron polarimetry at the EIC

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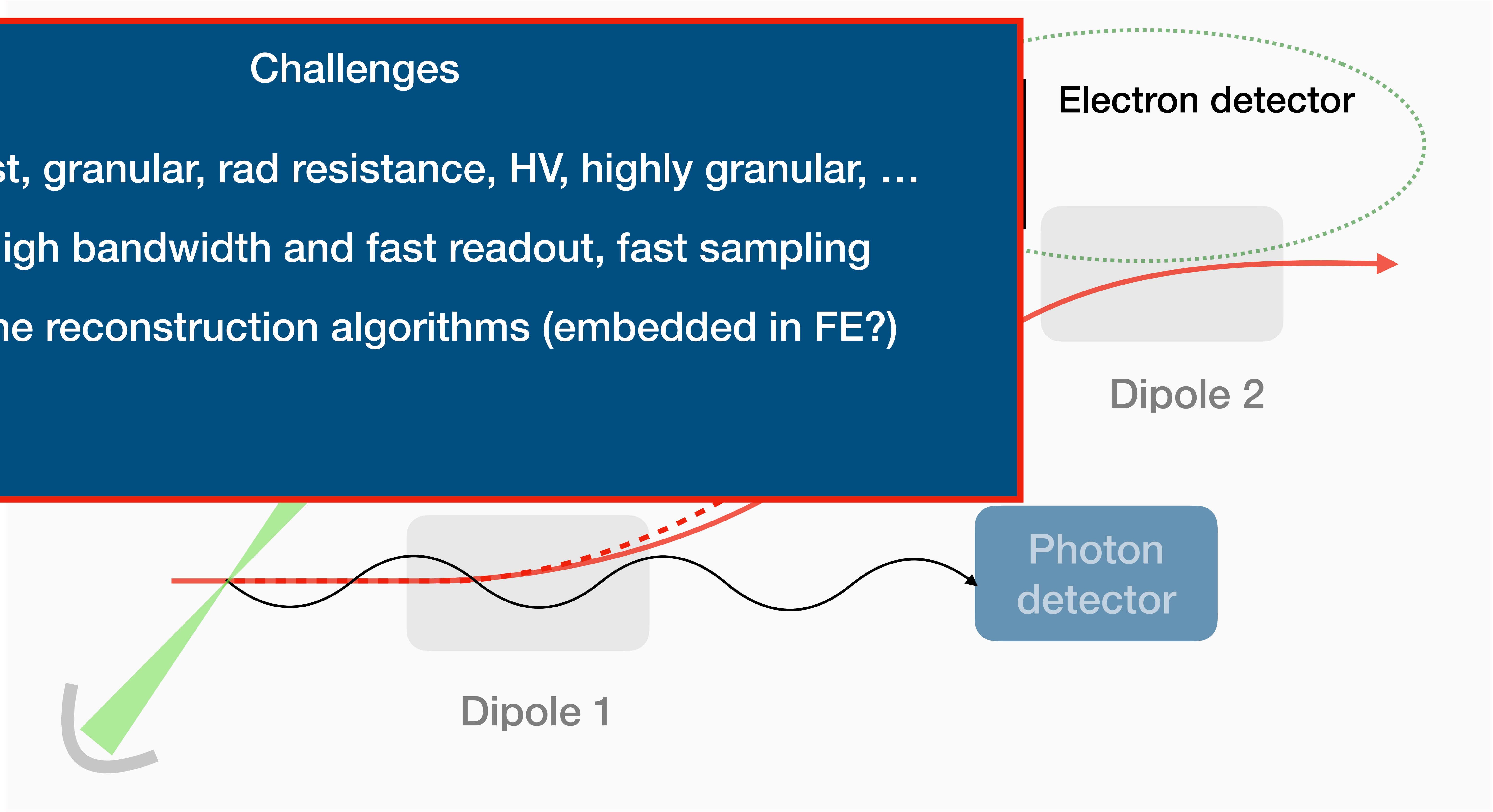


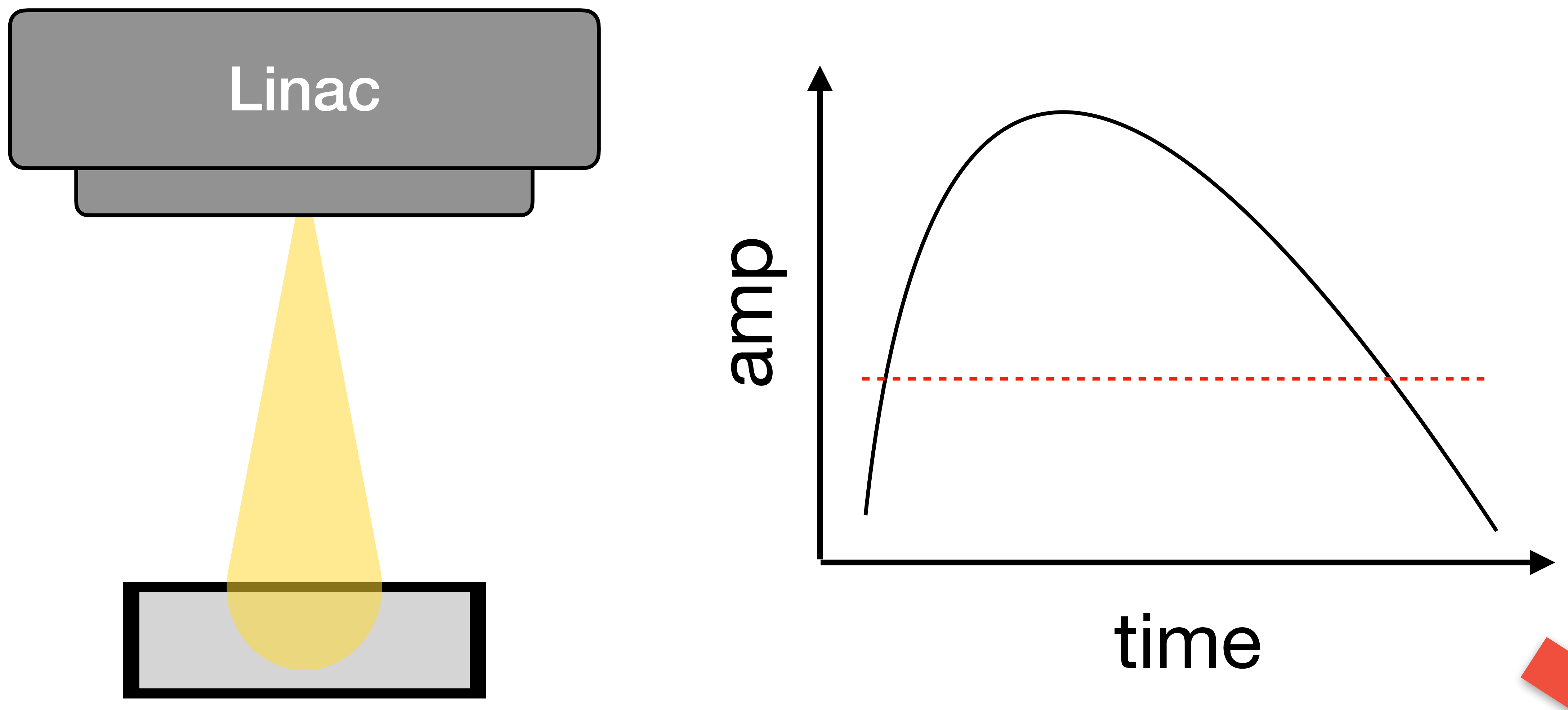
Challenges

Sensor: fast, granular, rad resistance, HV, highly granular, …

Readout: high bandwidth and fast readout, fast sampling

DAQ: on-line reconstruction algorithms (embedded in FE?)

Fast detectors - principles of operation



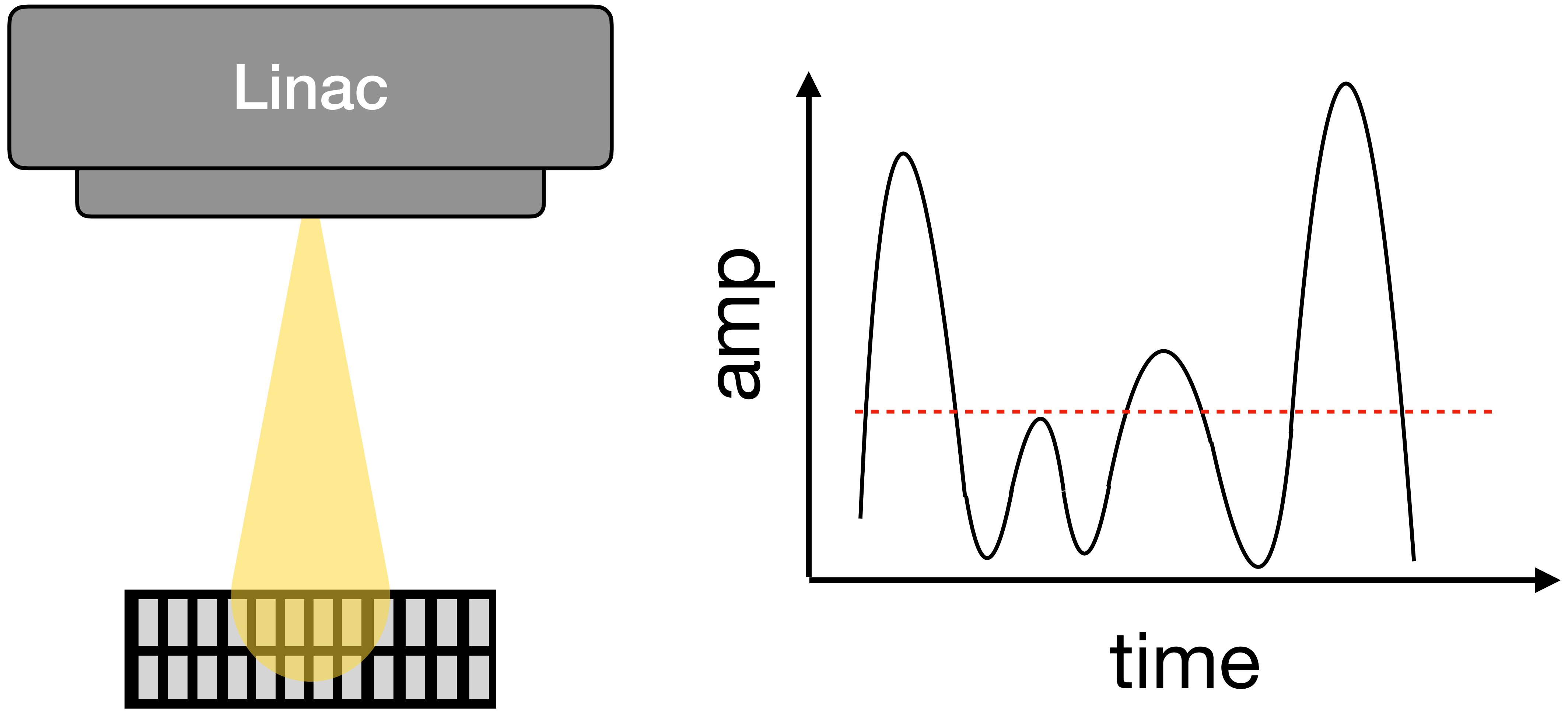
Integrating devices (e.g. ion chamber)

Fast Detectors for high-rate measurements

- Single particle resolution at high rate
- Online dose evaluation
- Precise beam characterization
- In-beam instrumentation
- …

The EIC scenario

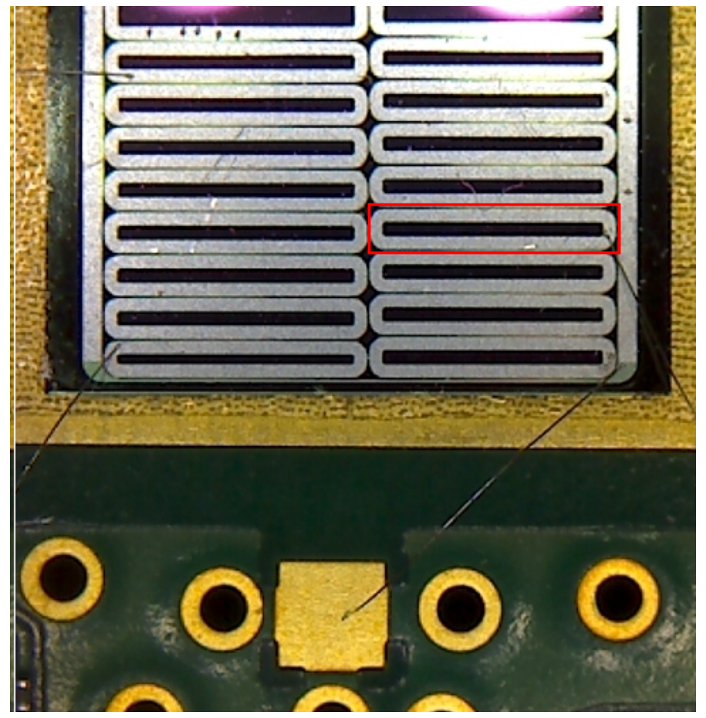
- Possibility to perform integrated measurement
- chance to pefrom bunch-by-bunch feedback measurements:
  - Reduces the integration time
  - Increases the accuracy of the individual measurement



Fast, highly granular detector (e.g. LGAD, pCVD, AC-LGAD…)

R&D on dosimetry and medical physics

Readout system v1 used to prove single particle counting capabilities at medical facilities



LGAD

intrinsic gain = 5-20

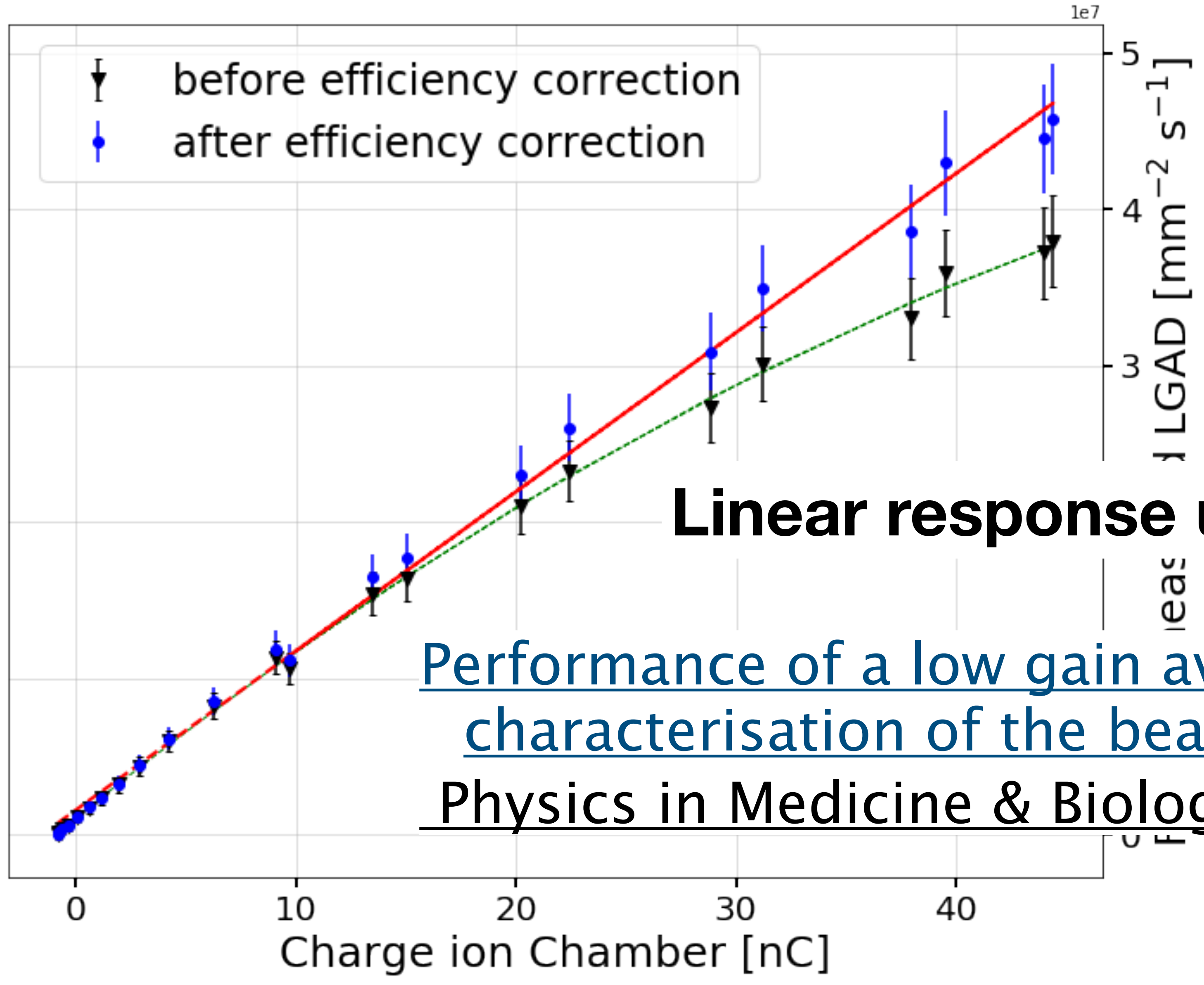
thickness = 50 μm

pixel active area = 2.9 × 0.5 mm^2

time resolution ~ 50 ps

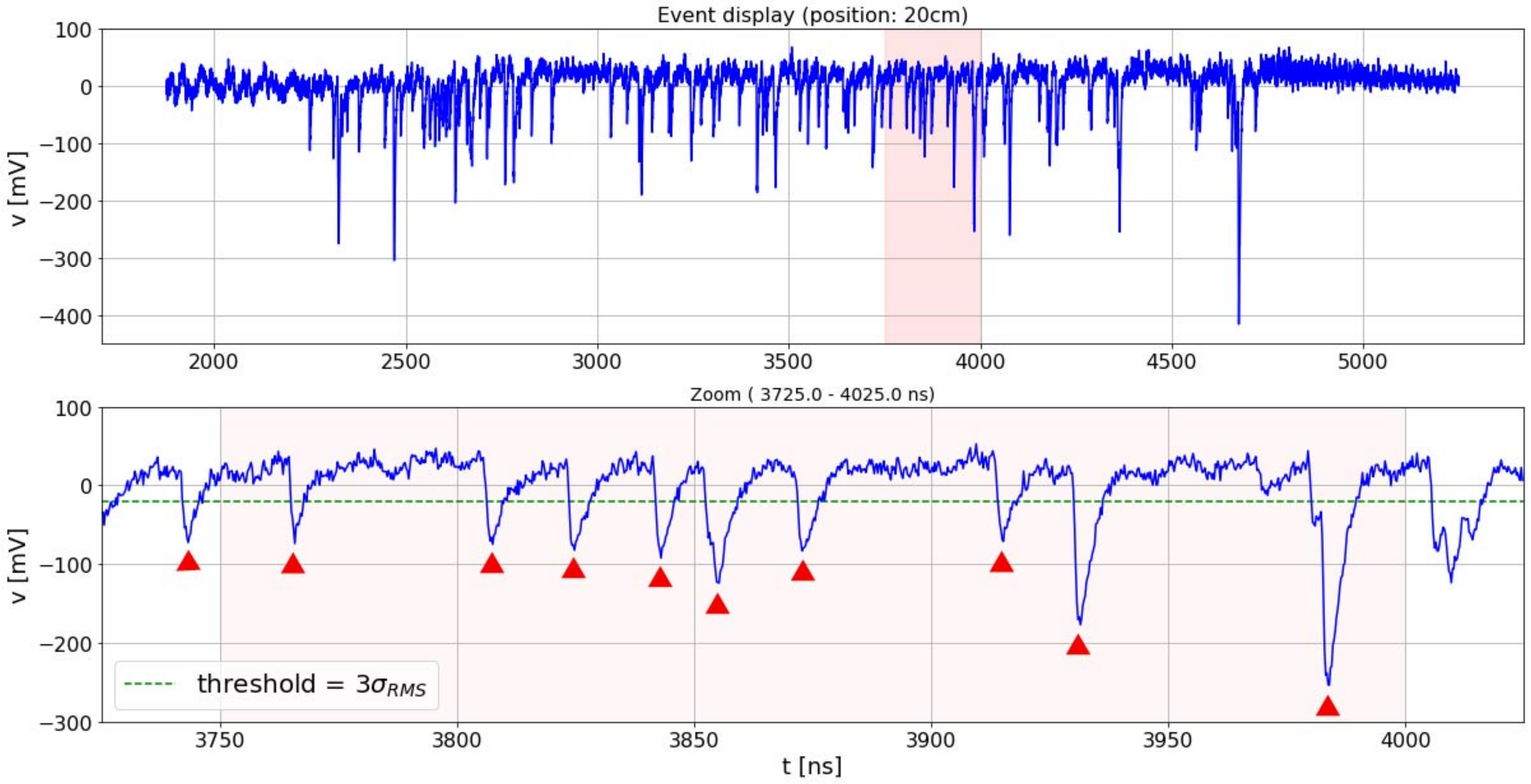
signal rise time ~ 600 ps

signal width = 5 − 10 ns



Linear response up to ~200 MHz/mm2

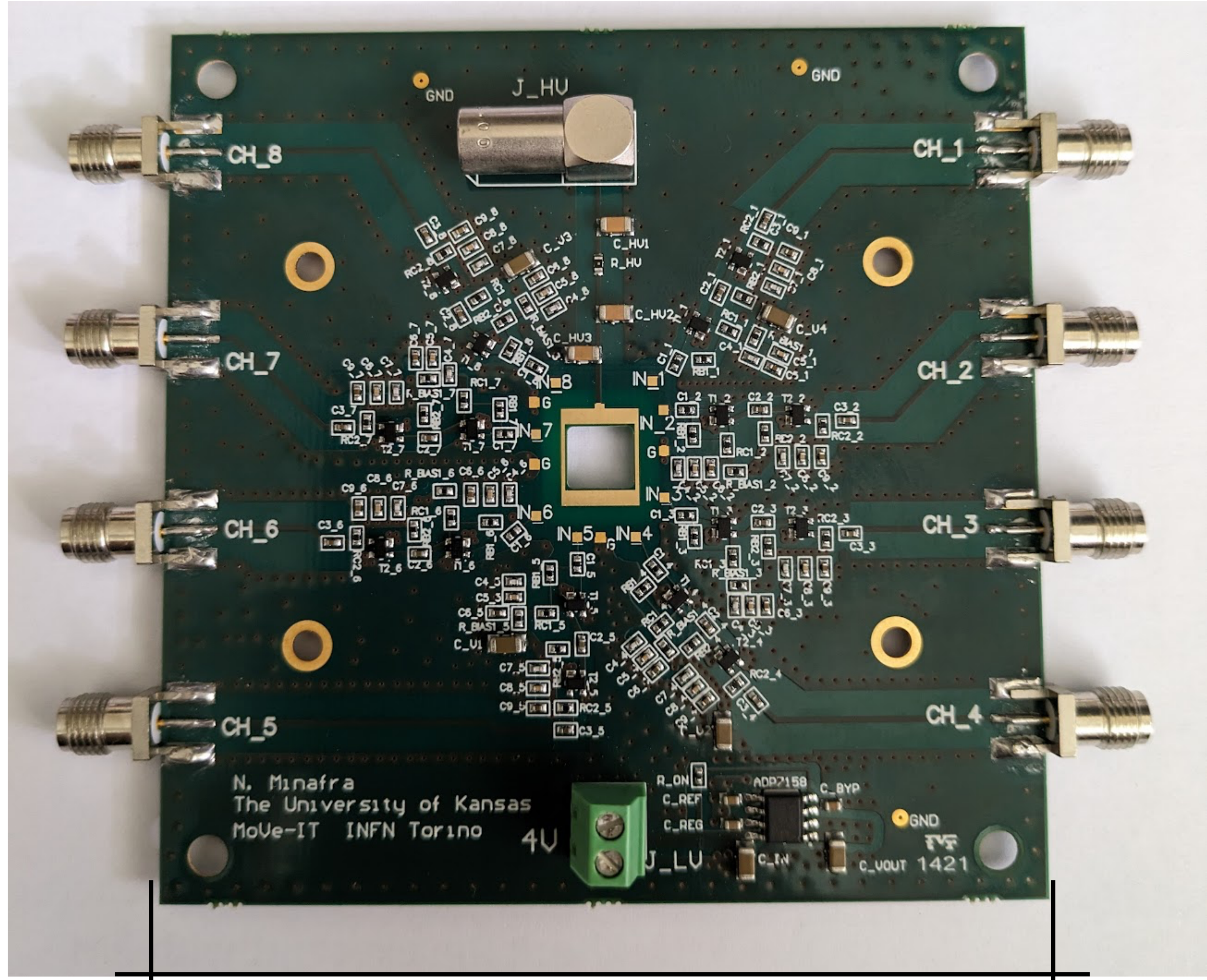
Performance of a low gain avalanche detector in a medical linac and characterisation of the beam profile, Physics in Medicine & Biology, T.Isidori et al.



EIC electron beamline (high-lumi)

- energy up to 18 GeV
- 560 MHz RF
- 1320 bunches
- 10 ns between bunches
- Electron current up to 2.4 A

First results with new readout

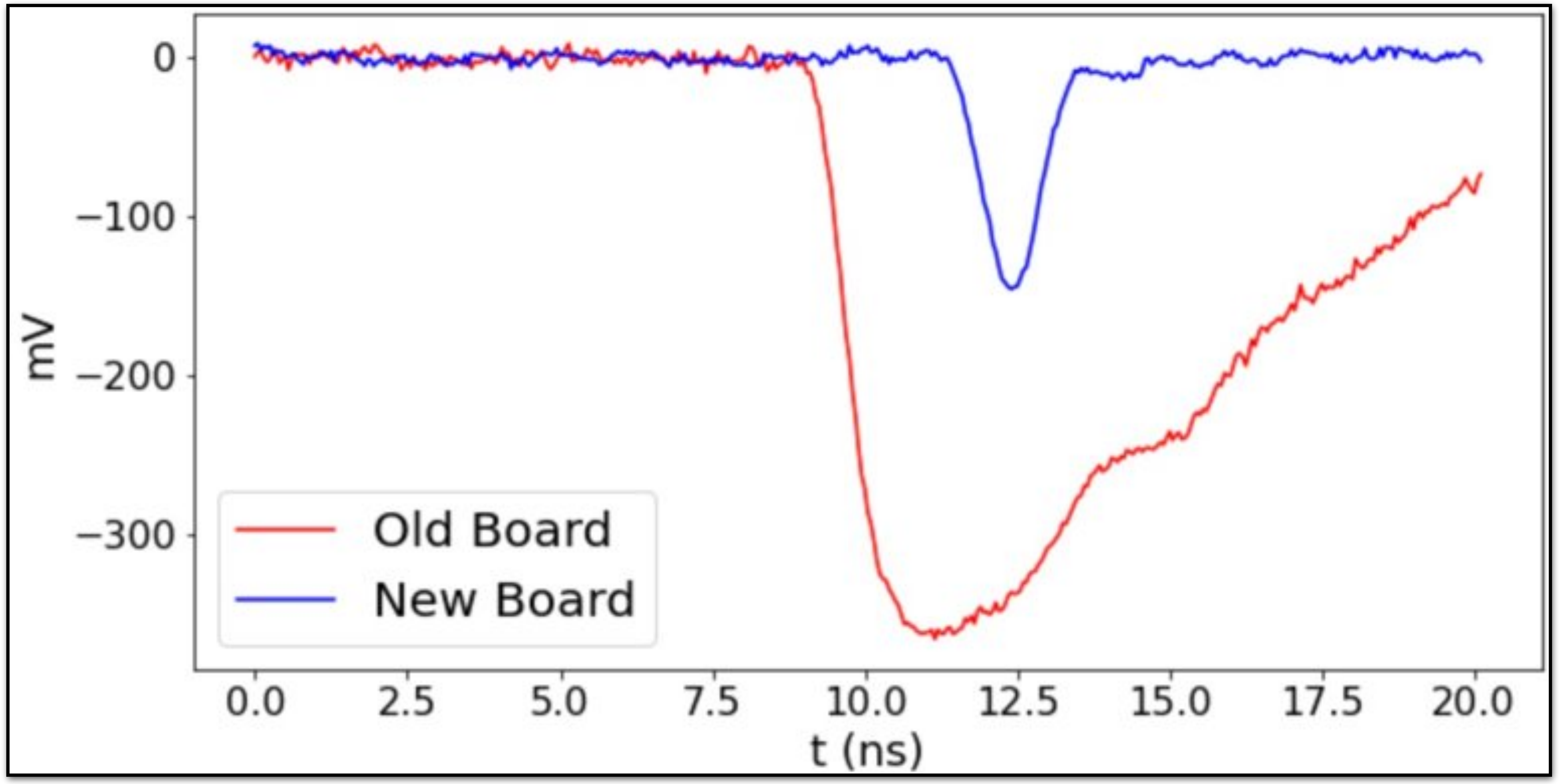


90 mm

New KU readout board

- 2 stages (transimpedance) amplification chain
- Discrete components for easy simulation/customization
- Holed design for reduced material budget

- T_{len}(readout v1) ~10ns
- T_{len}(new readout) ~ 2ns

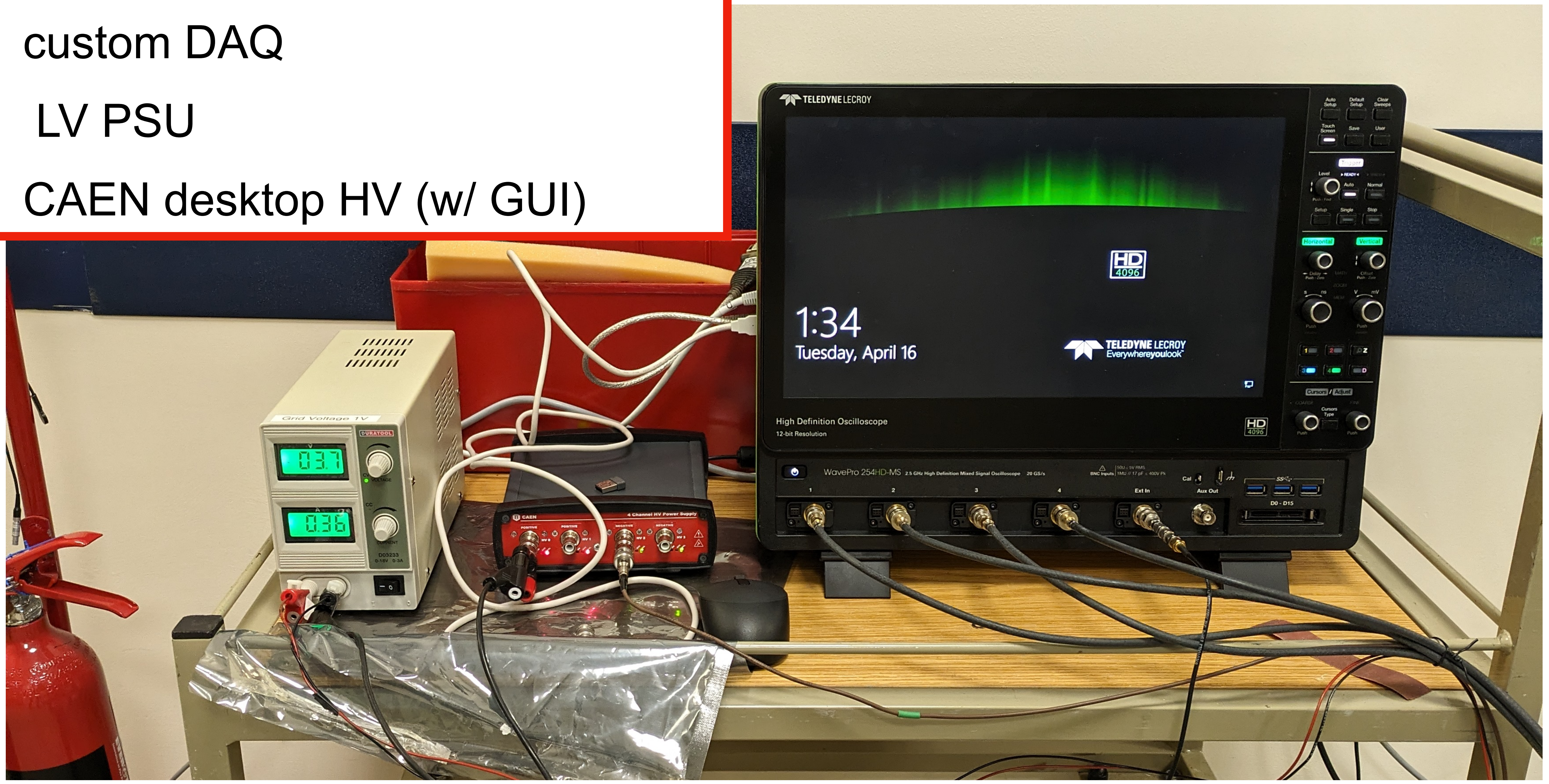


- Optimized readout for single particle counting
- Improved cluster finding algorithms

May 2024 test beam - Survey on fast detctor technologies

Acquisition setup:

- Oscilloscope (10G Sa/s, 2.5 GHz)
- custom DAQ
- LV PSU
- CAEN desktop HV (w/ GUI)



Survey of fast detector technologies for single particle resolution:

pCVD *A.Camsonne, JLab.*

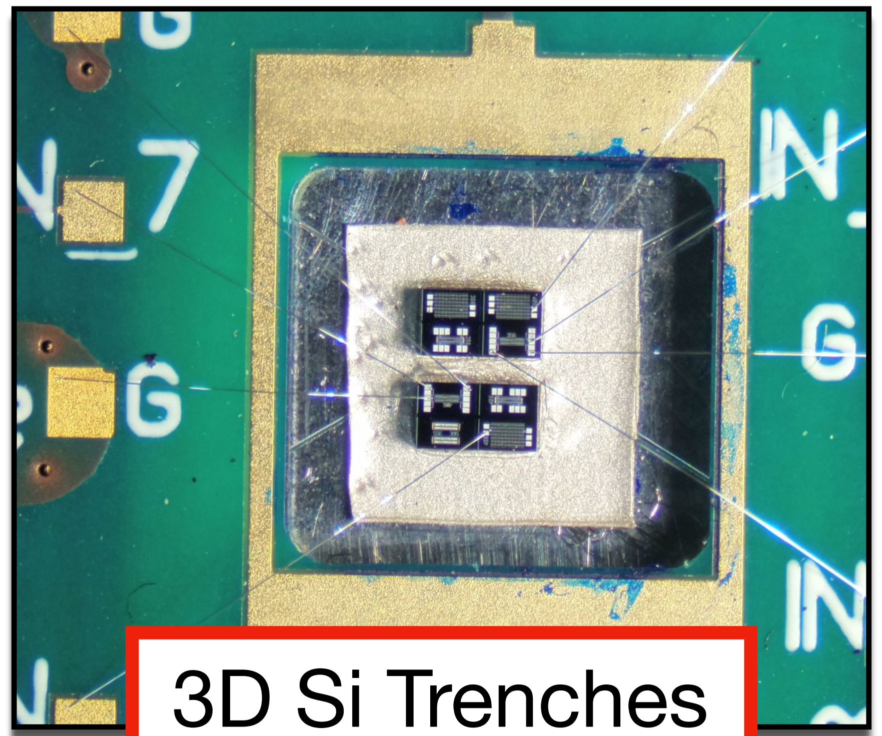
LGAD *R. Sacchi et al, University and INFN Torino*

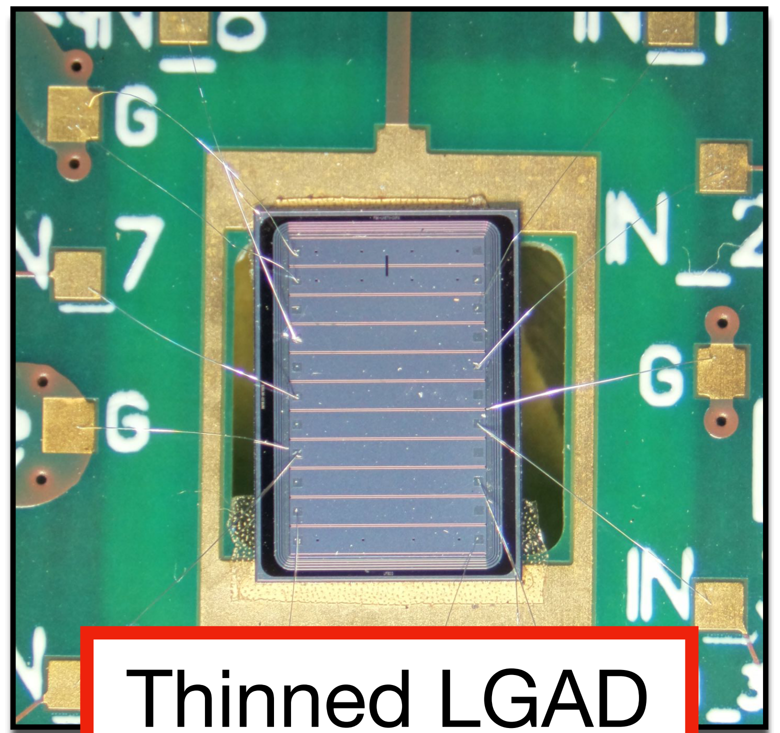
AC-LGAD *A.Tricoli, G.Giacomini, BNL*

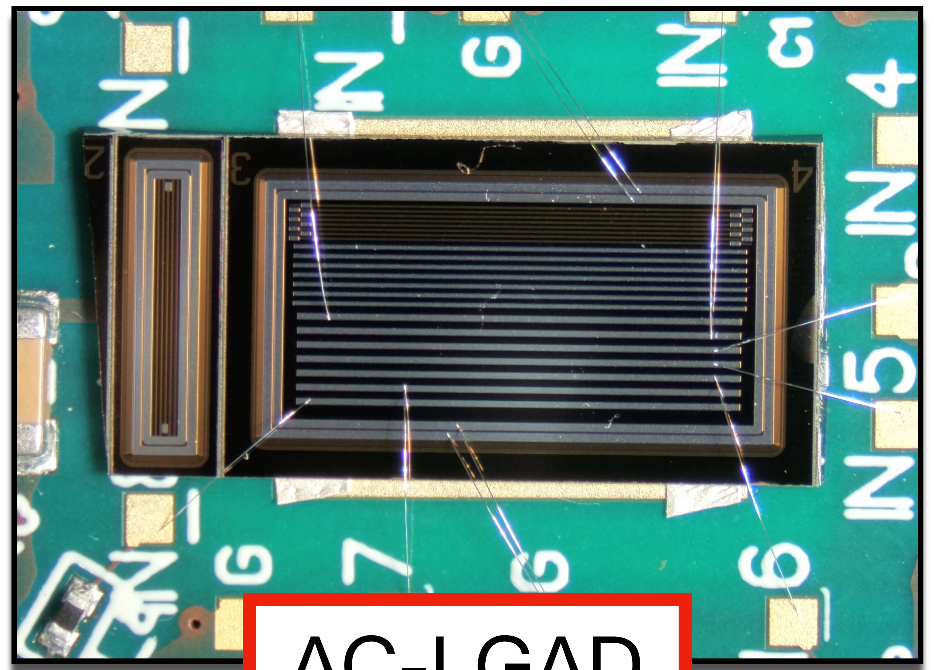
3D diamond *G. Passaleva, INFN Firenze*

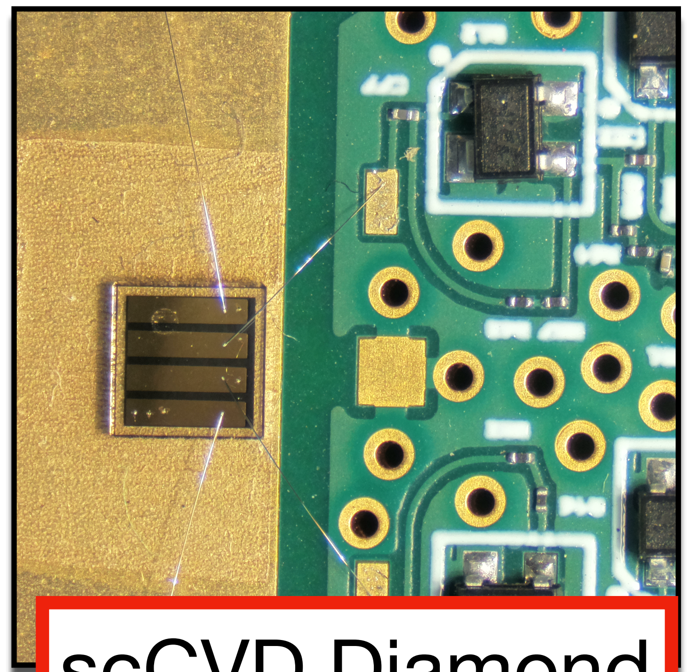
3D Si Trenches *A.Lai, A.Cardini, INFN Cagliari*

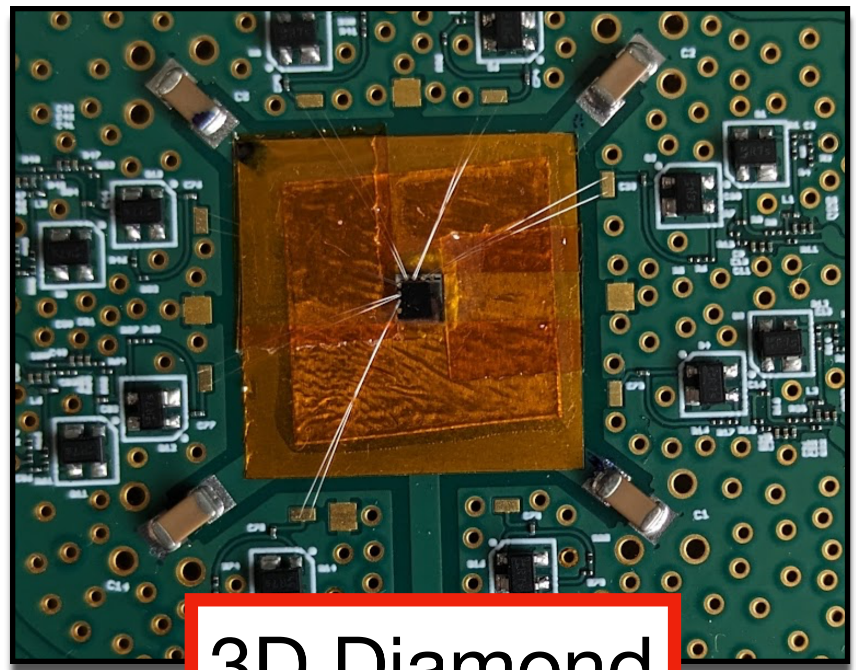
Detectors still in R&D phase:
3DSi trenches, 3d diamond, AC-LGAD


3D Si Trenches


Thinned LGAD

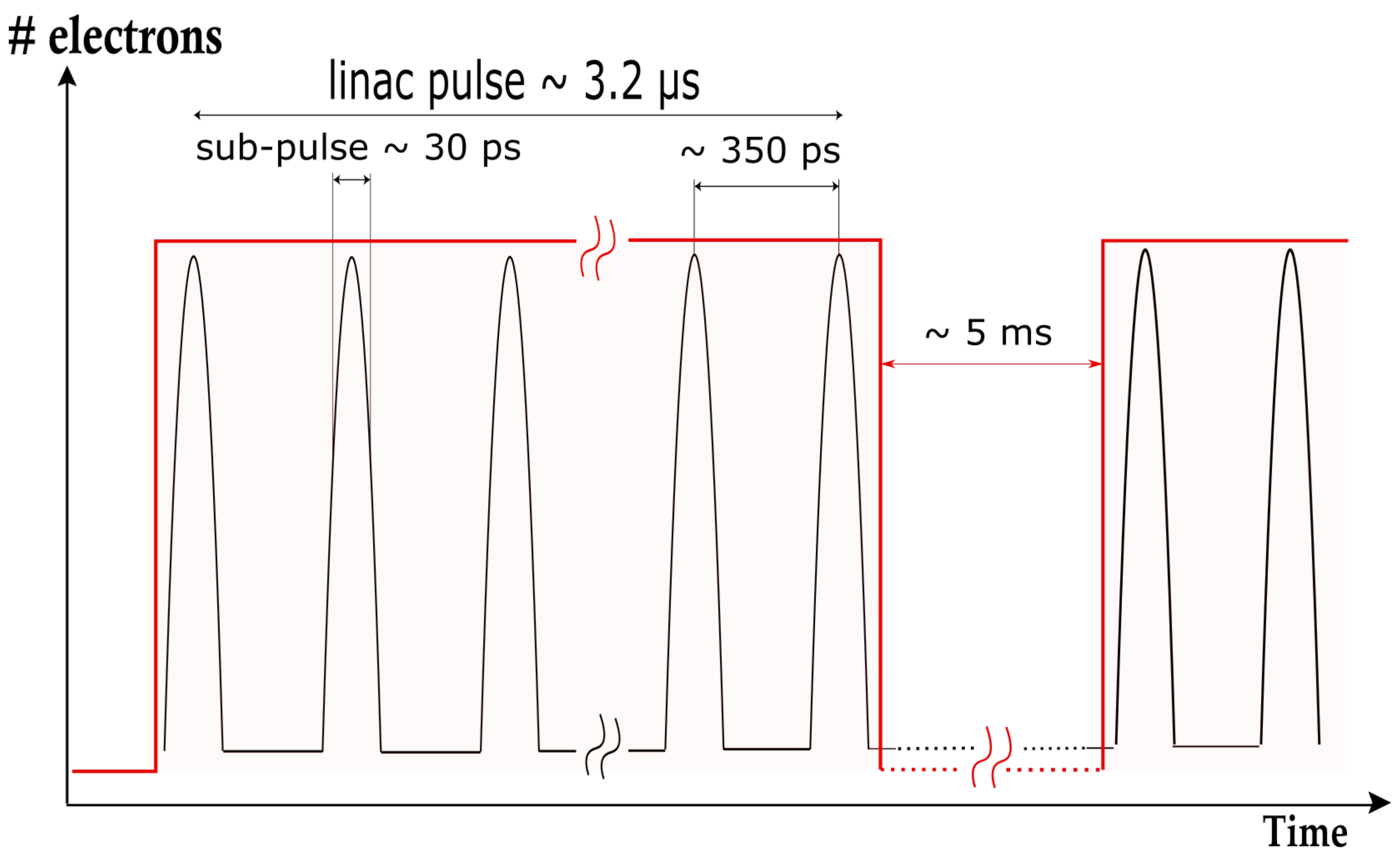

AC-LGAD


scCVD Diamond

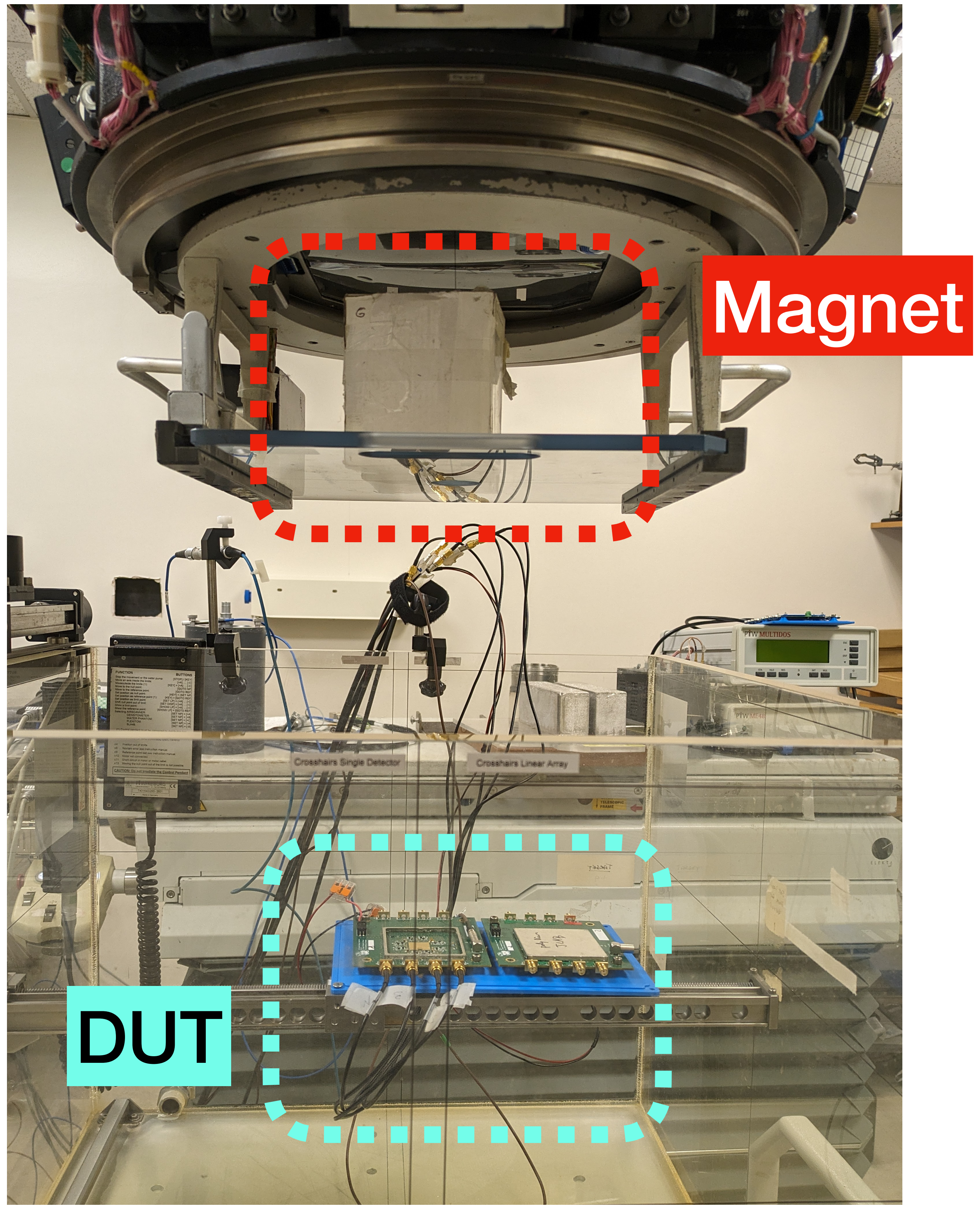

3D Diamond

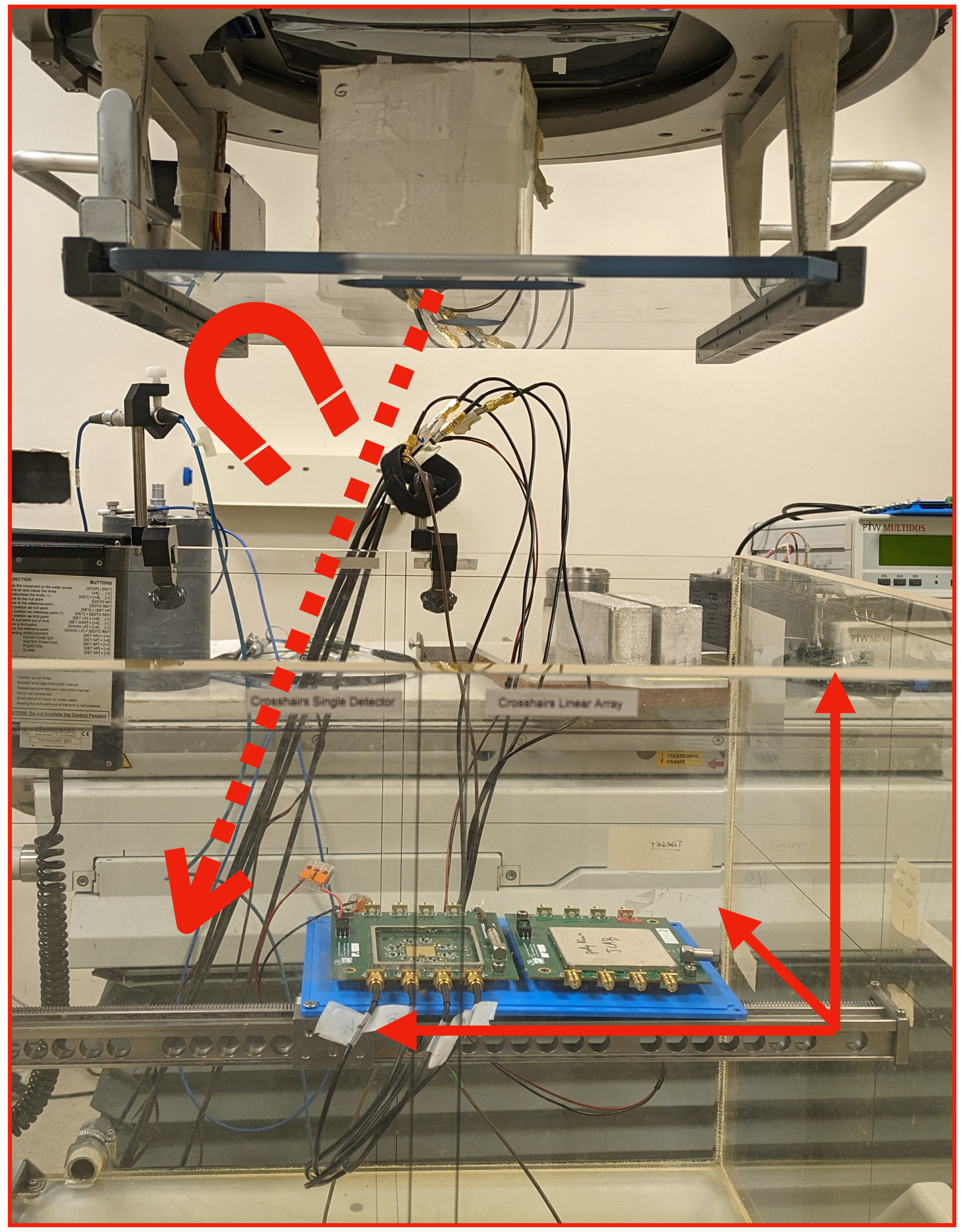

pCVD Diamond

Electron Linac at the St.Luke's Hospital of Dublin



- Spills of ~ 3 μs
- Substructure of ~350 ps (~2.8 GHz)
- ~ 5 ms between spills





Permanent magnet bends the electrons trajectory

DUT moves on the 3 axes for alignment

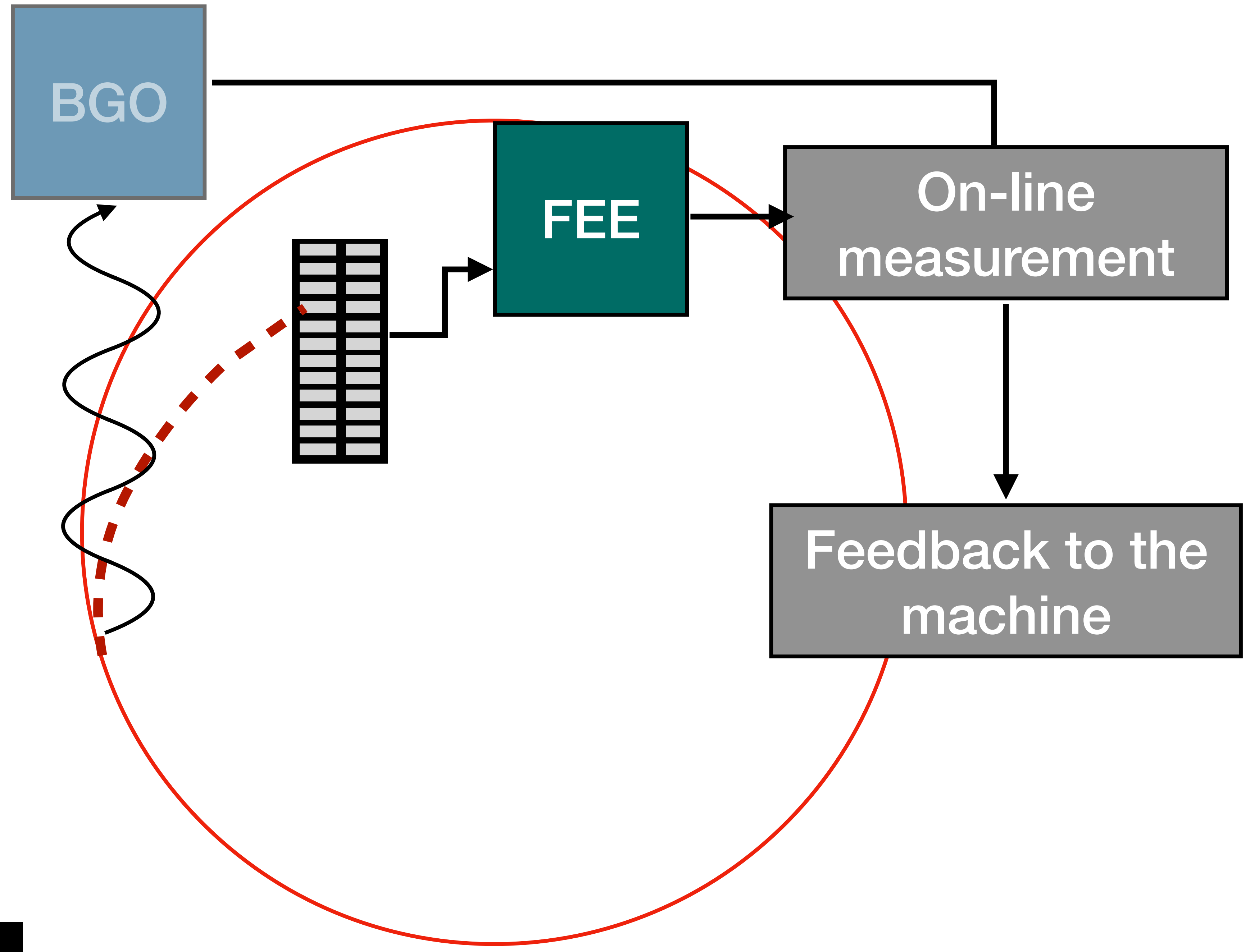
Remote acquisition with scilloscope

Thanks to **R.McNulty's** group, **P.McNavana** and the St. Luke's Hospital staff

Analysis strategy - fast peak detection algorithm

- Oscilloscope .h5 data
- Dataframe building
- QA and automatic bpm
- Data filtering
- Peak finding
- Data plotter

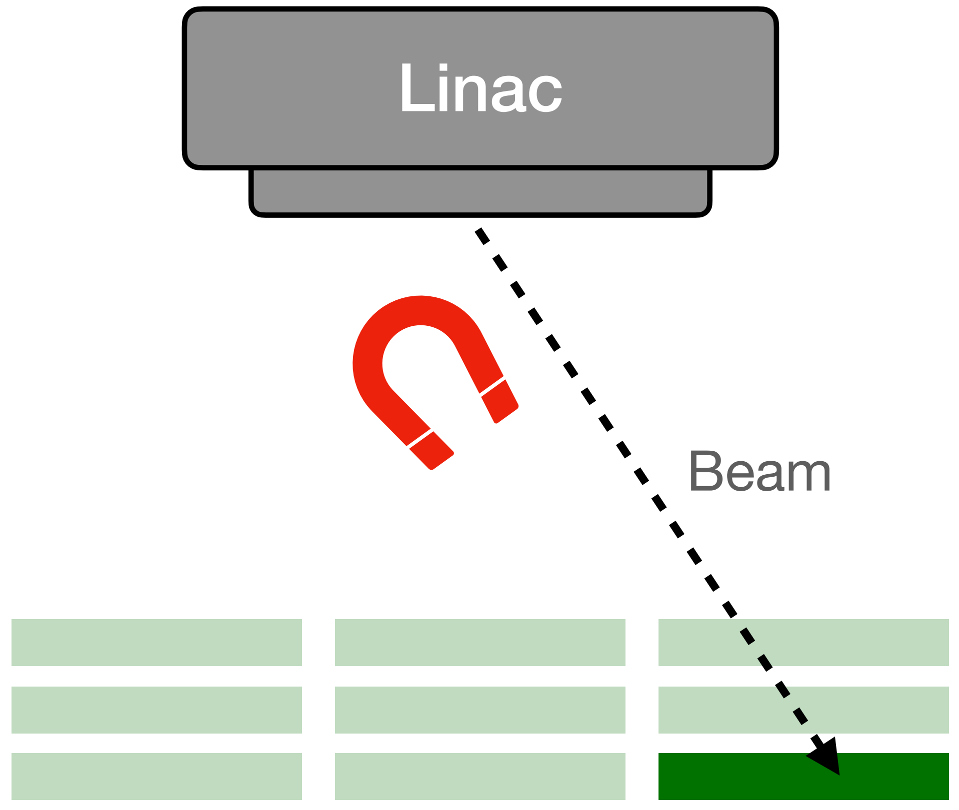
The EIC scenario

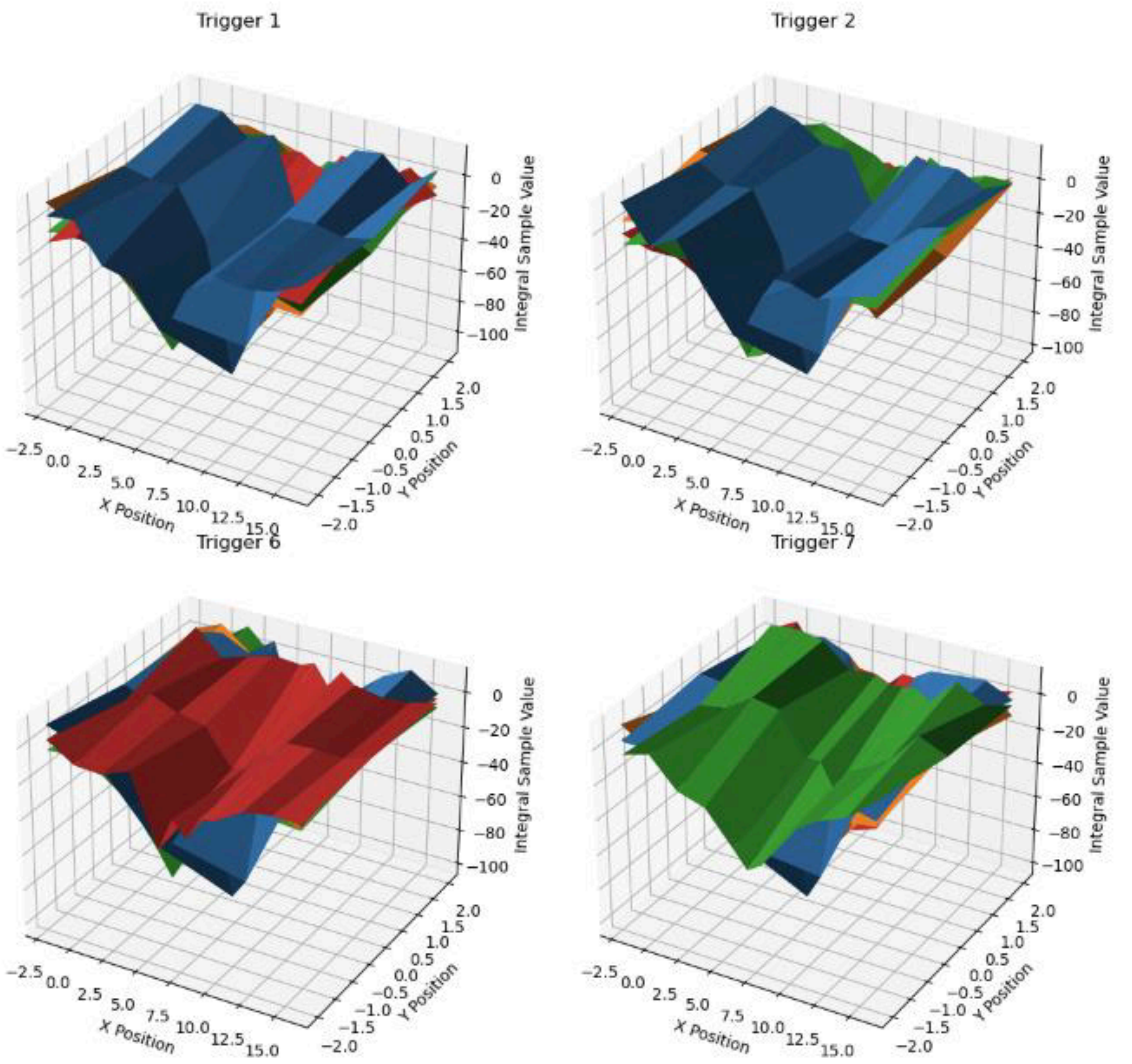


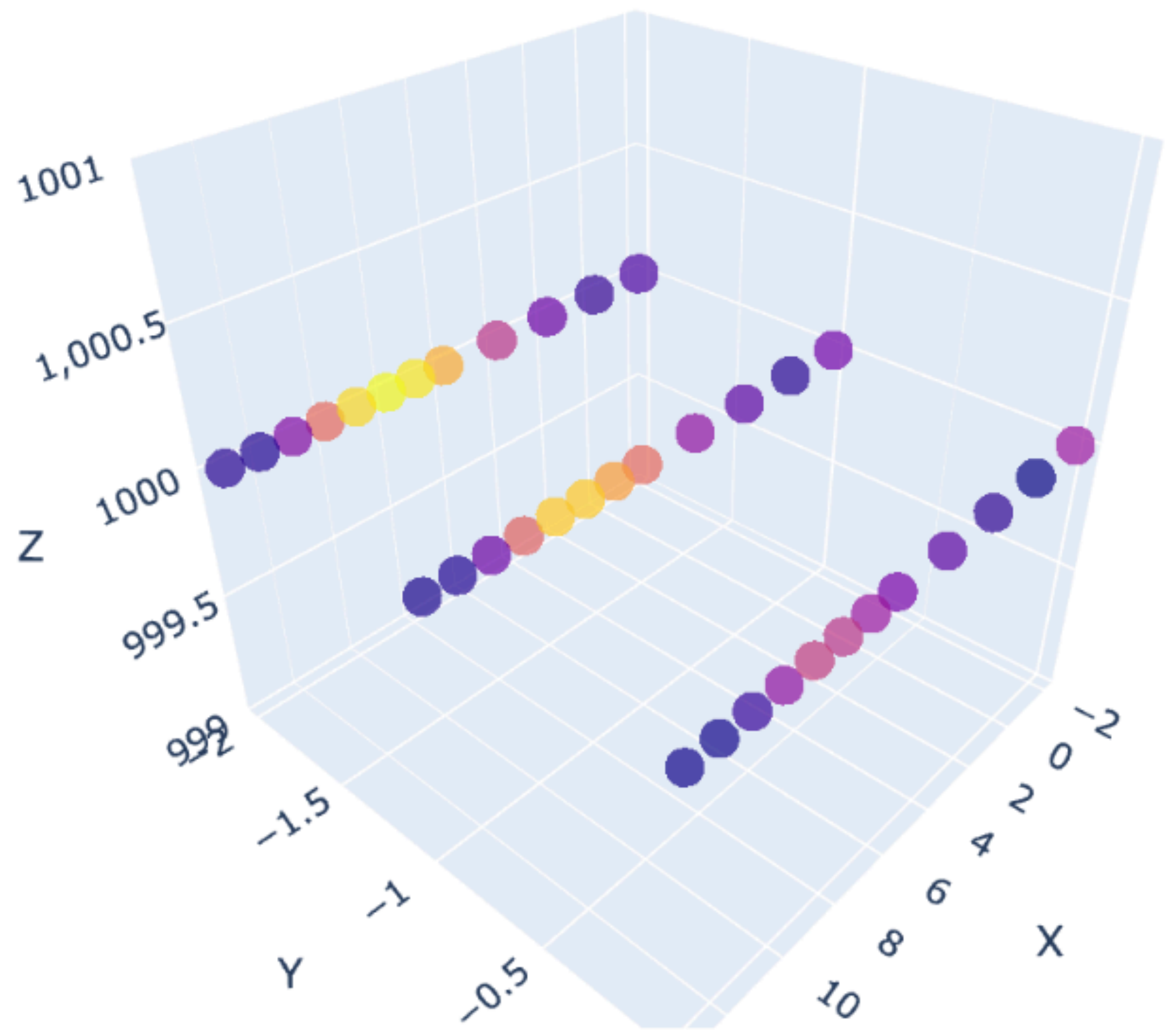
Analysis strategy - beam position

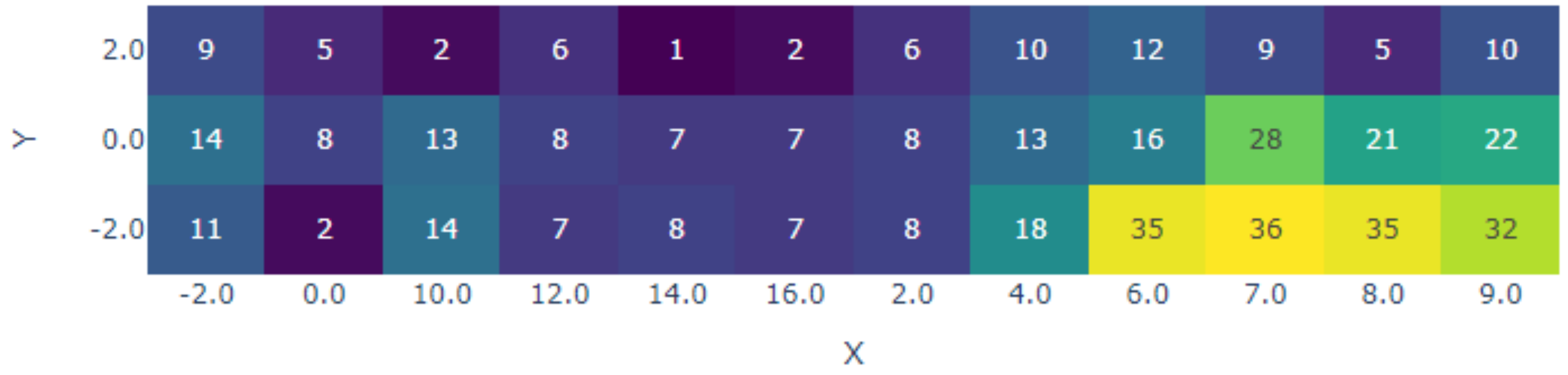
Beam position measurement

- Data are stored in .h5 dataframes
- Custom class to extract the beam position
- displays the observable (rms, peak-to-peak, std, intergal, counts …) as a function of the detector position







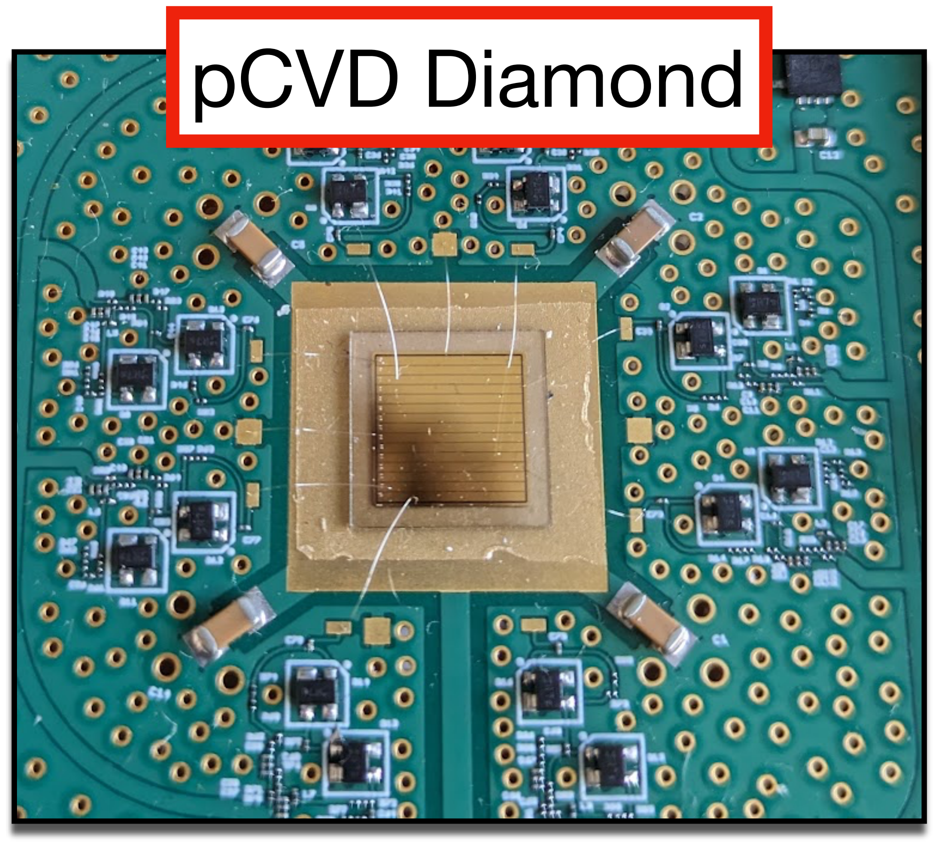


Automatic beam position detection

Interactive GUI to check the expected beam propagation

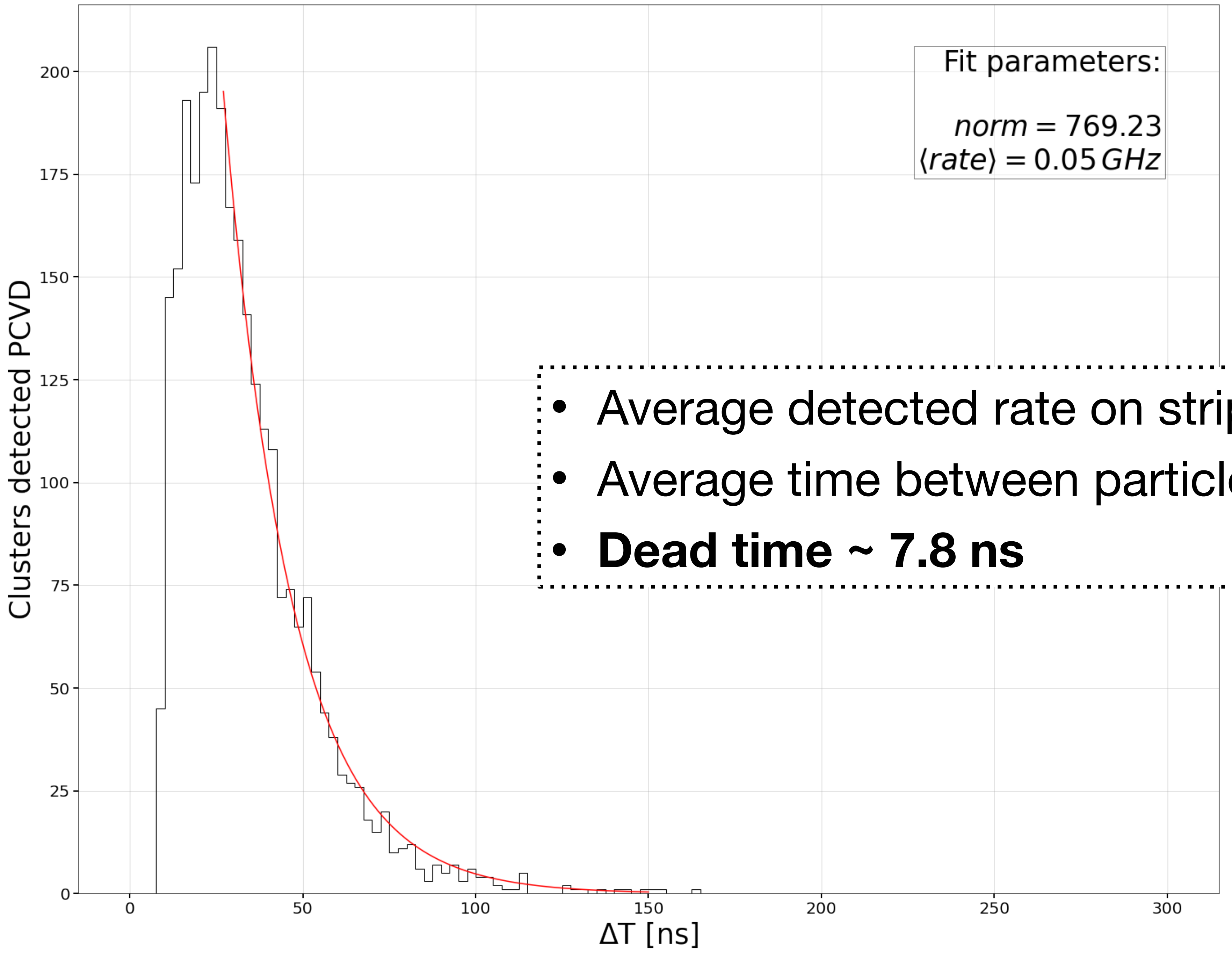
QA to assess algorithm stability

Preliminary results - pCVD

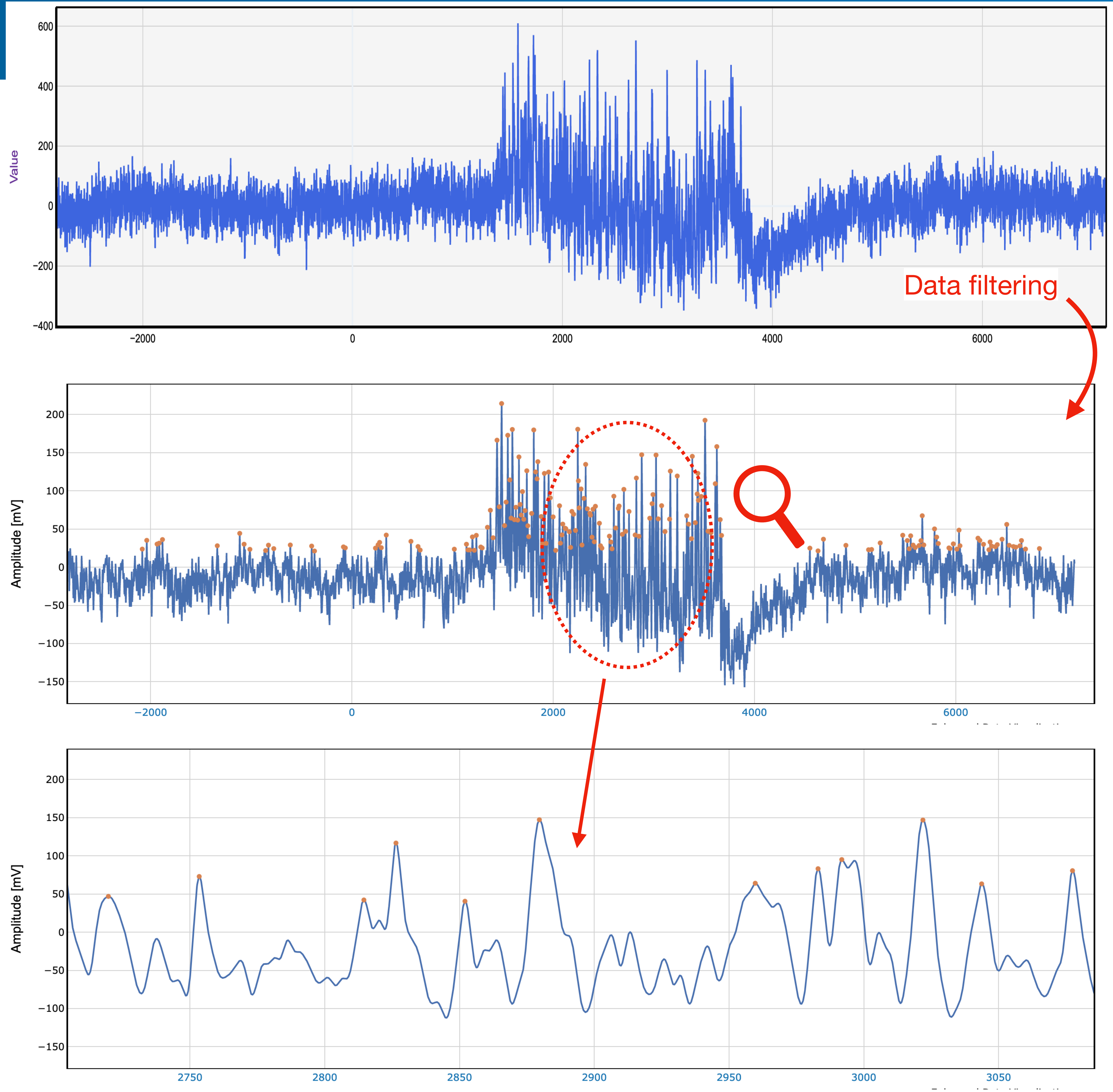


JLAB HALL-C Poli-crystal CVD

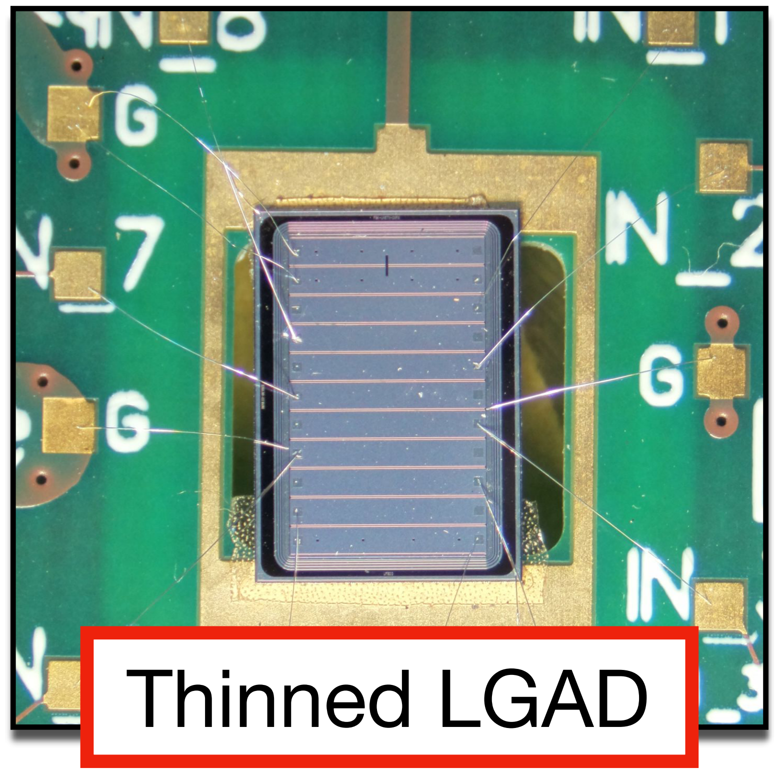
- Good radiation resistance
- Pulses width ~ 6 - 10 ns
- Good SNR
- High voltage bias required (~ 800 V)
- Large production costs
- CCE scales with irradiation (~ 10^{14} neq)



- Average detected rate on strip ~ 50 MHz
- Average time between particles ~ 20 ns
- **Dead time ~ 7.8 ns**

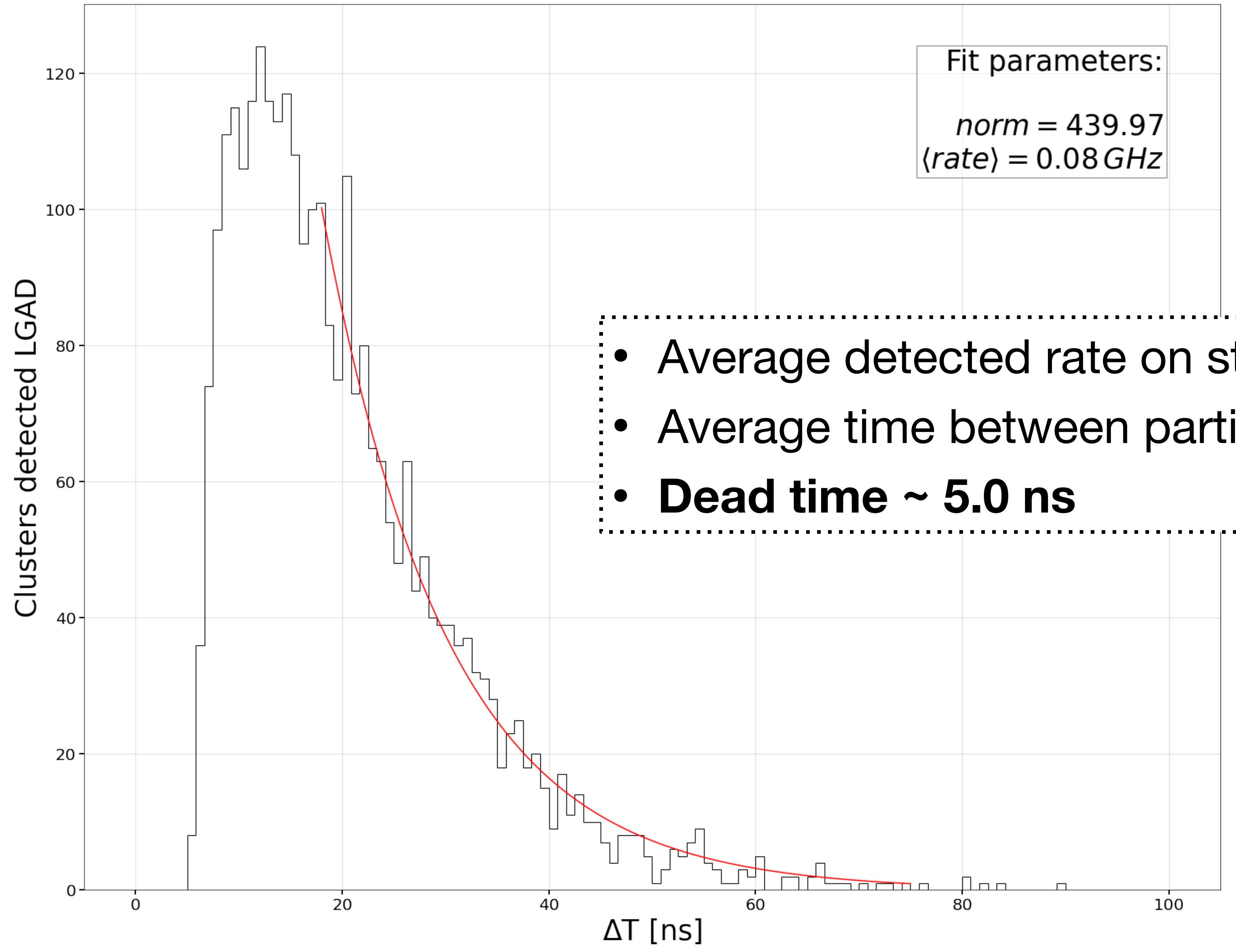


Preliminary results - LGAD

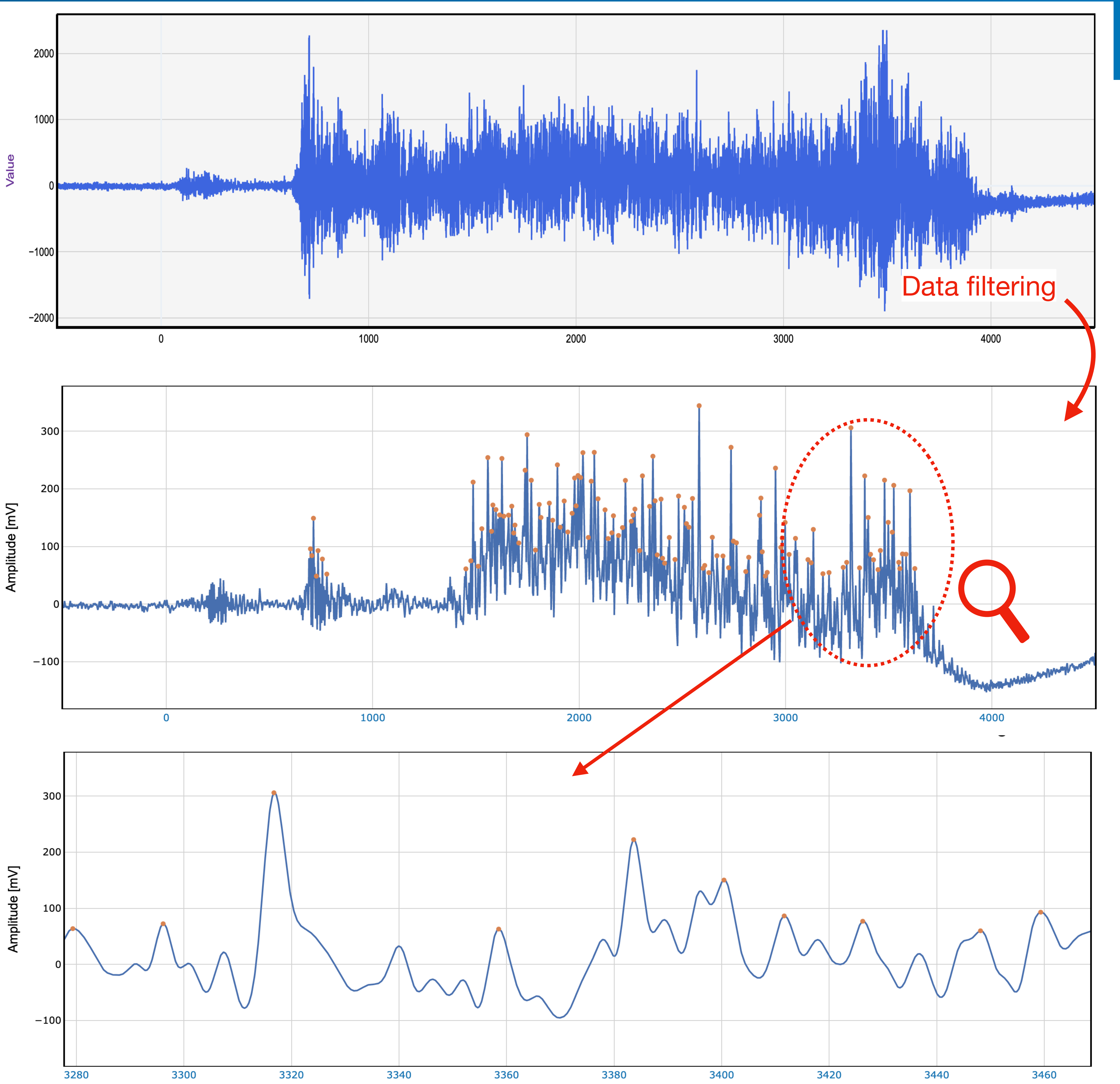


Low Gain Avalanche Diode

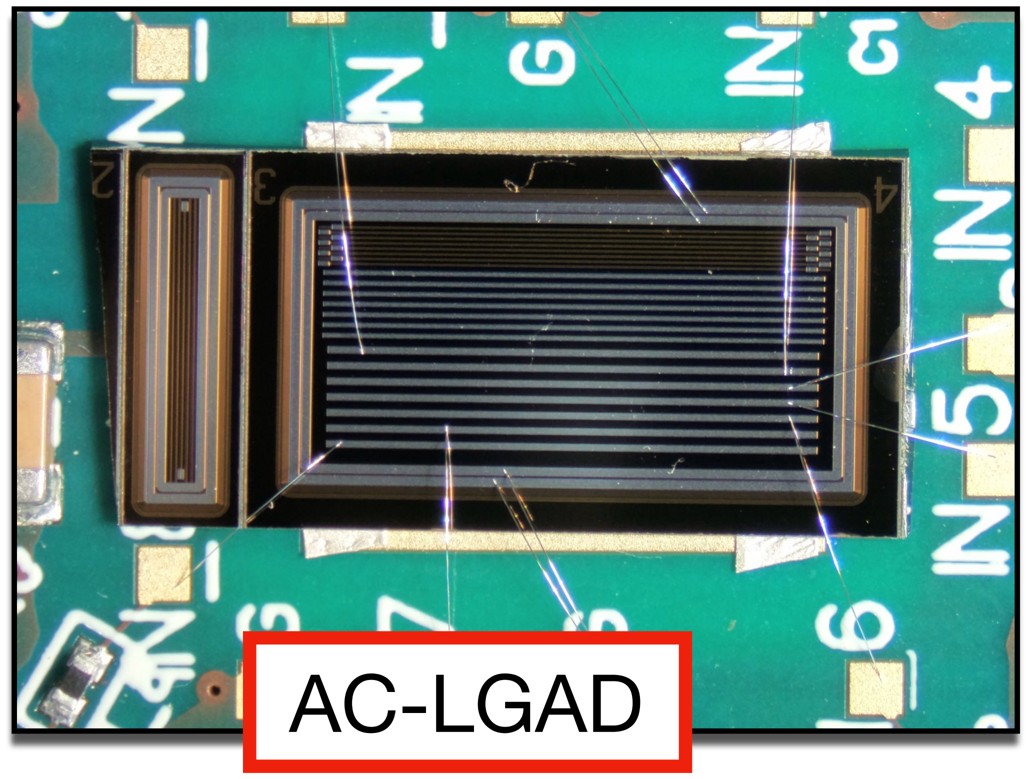
- Prototype for MoVeIT
- Active thickness = 45 um
- Tot thickness = 616 um
- linearity up to 10 MIPs and for rates ~ 200 MHz
- Improved single particle ID
- Time resolution < 50 ps up to 1.5 x 10^{15} neq
- Radiation hardness under study



- Average detected rate on strip ~ 80 MHz
- Average time between particles ~ 12.5 ns
- **Dead time ~ 5.0 ns**

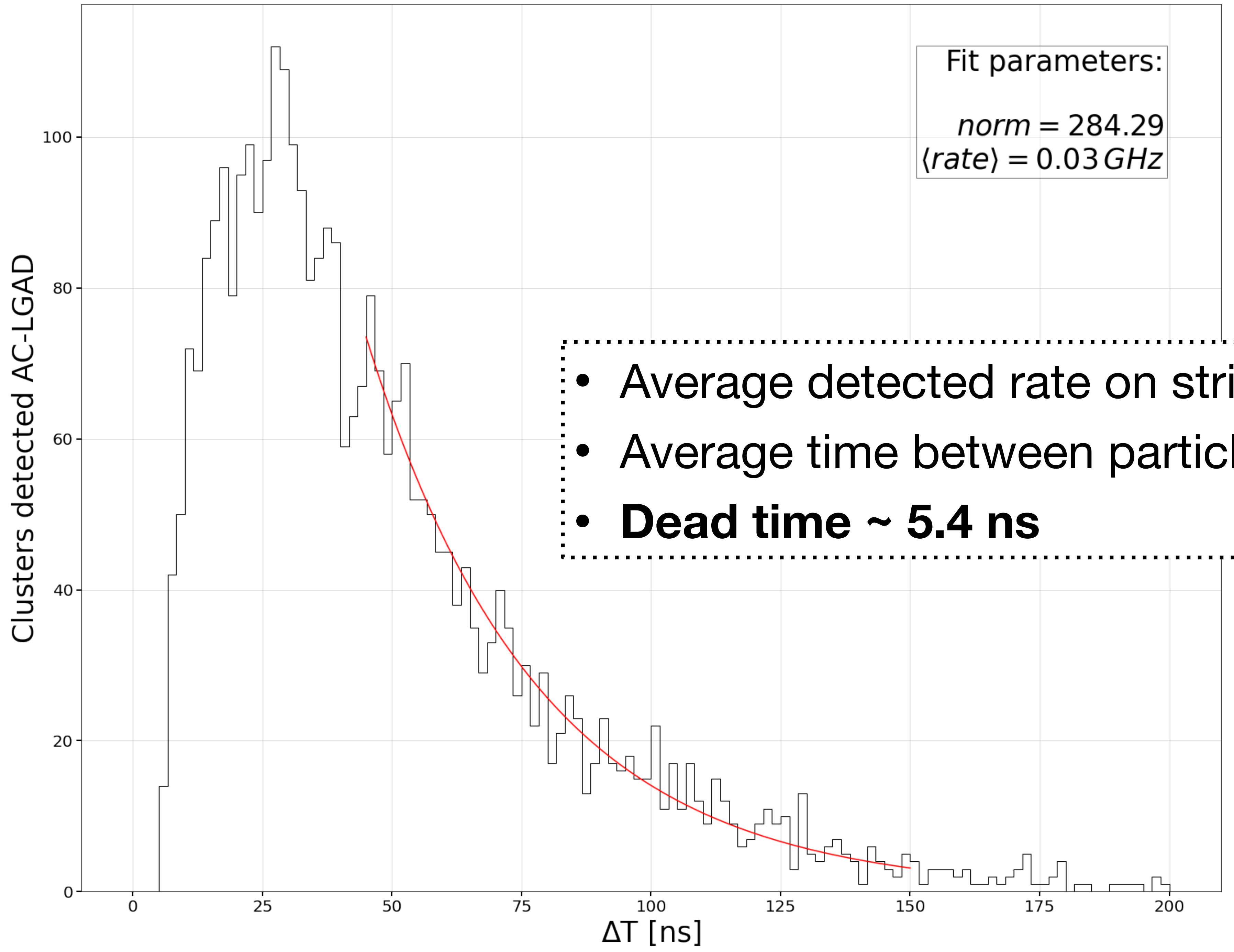


Preliminary results - AC-LGAD

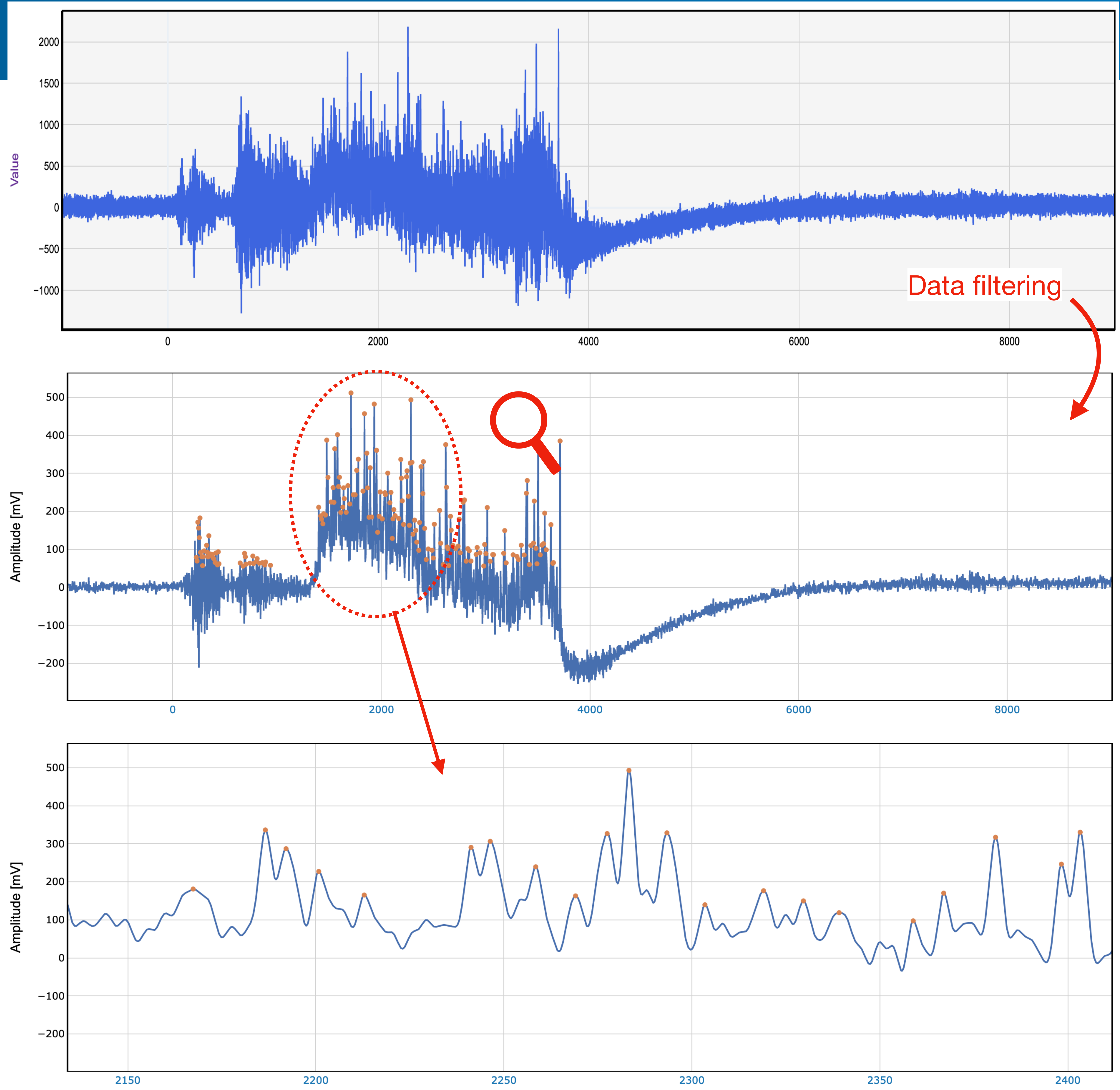


AC-LGAD

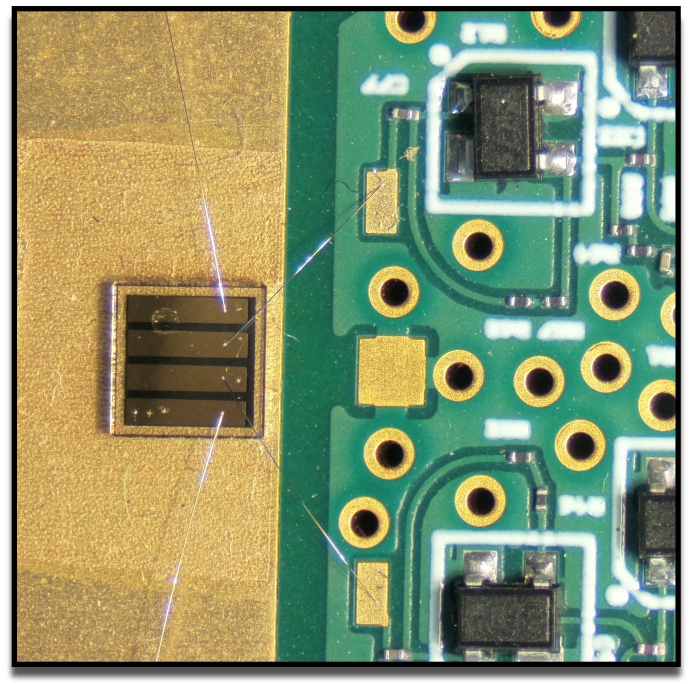
- Prototype from BNL
- 100% fill factor
- Many possible electrode geometries
- Use already planned for the EIC
- Still in R&D phase
- Signal integration at high rates



- Average detected rate on strip ~ 30 MHz
- Average time between particles ~ 33.3 ns
- **Dead time ~ 5.4 ns**



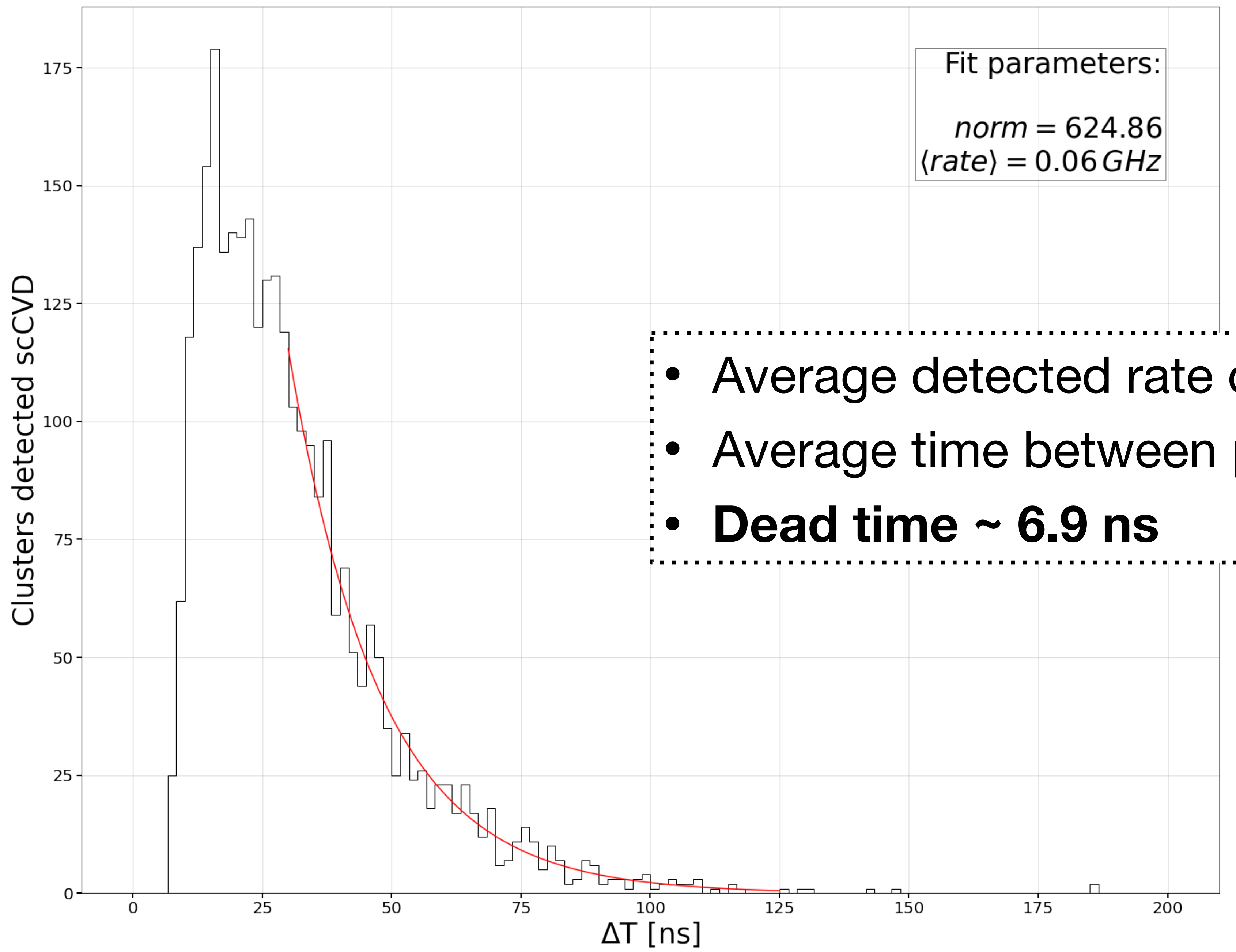
Preliminary results - scCVD



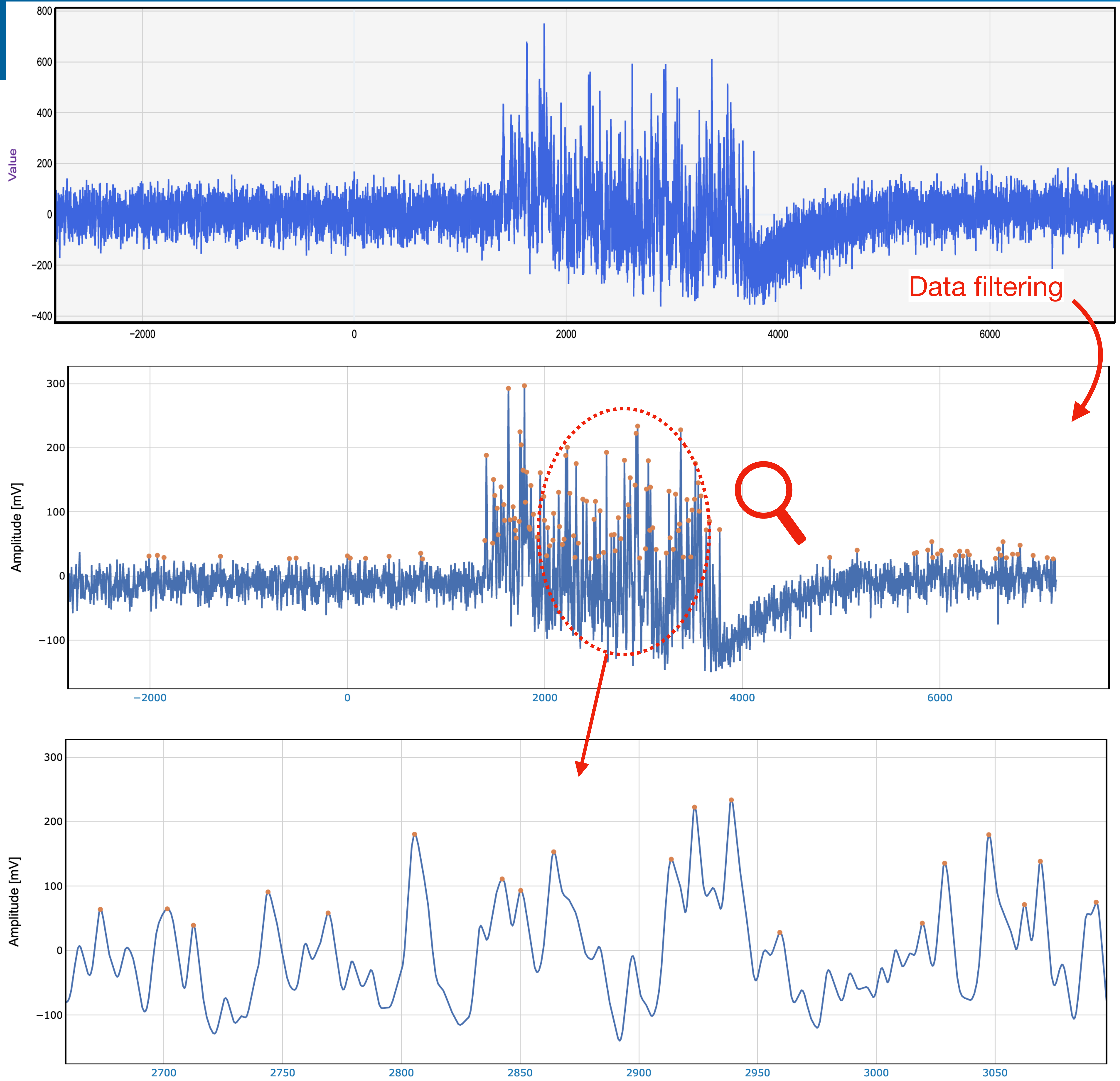
scCVD Diamond

Single crystal CVD

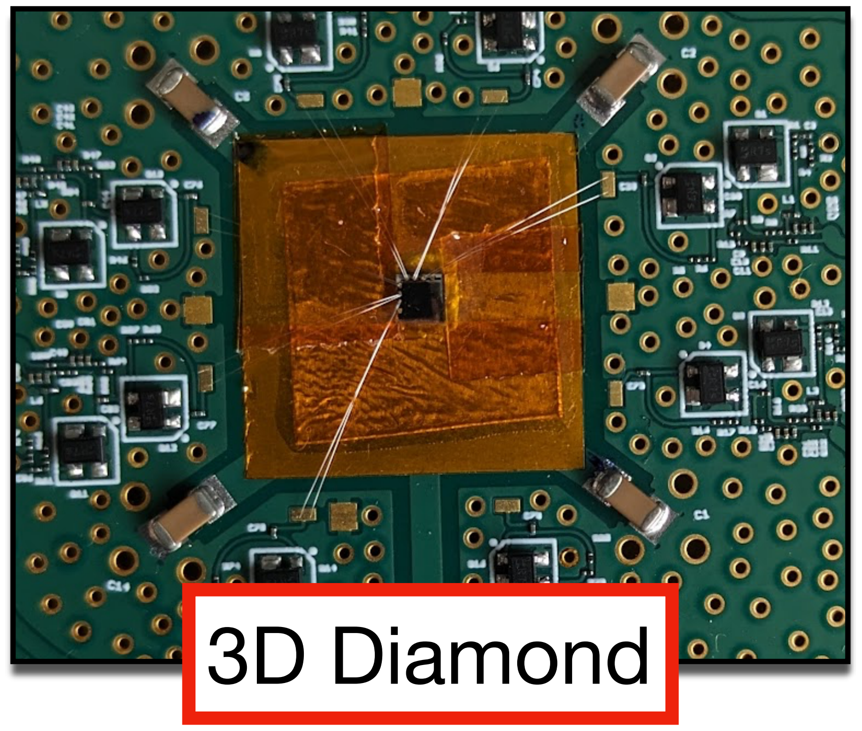
- Good radiation resistance
- Already used at High rate
- CCE scales with irradiation (~ 10^{15} neq)
- High voltage bias required (~ 1kV)
- Large production costs
- Small areas



- Average detected rate on strip ~ 60 MHz
- Average time between particles ~ 16.7 ns
- **Dead time ~ 6.9 ns**

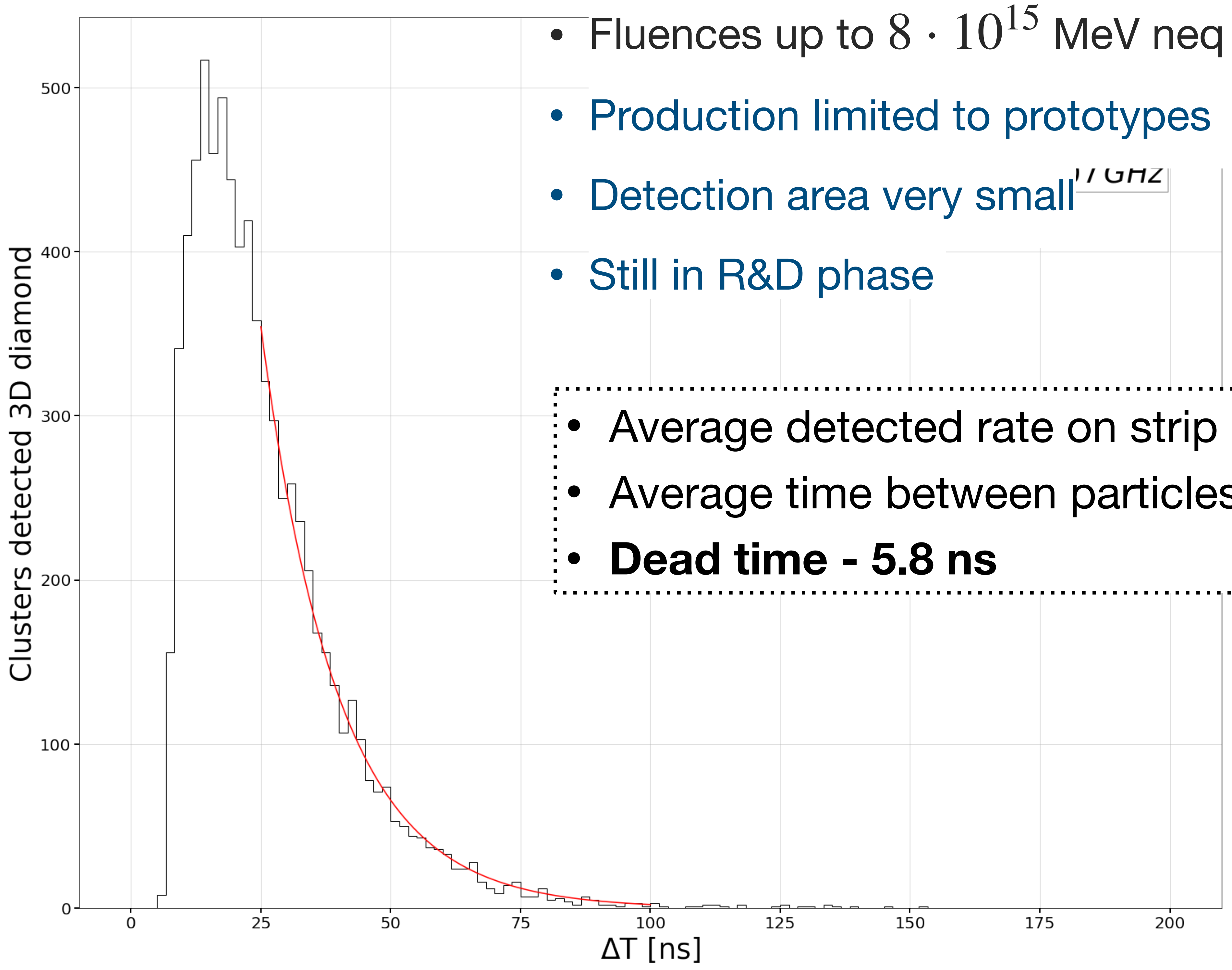


Preliminary results - 3D Diamond

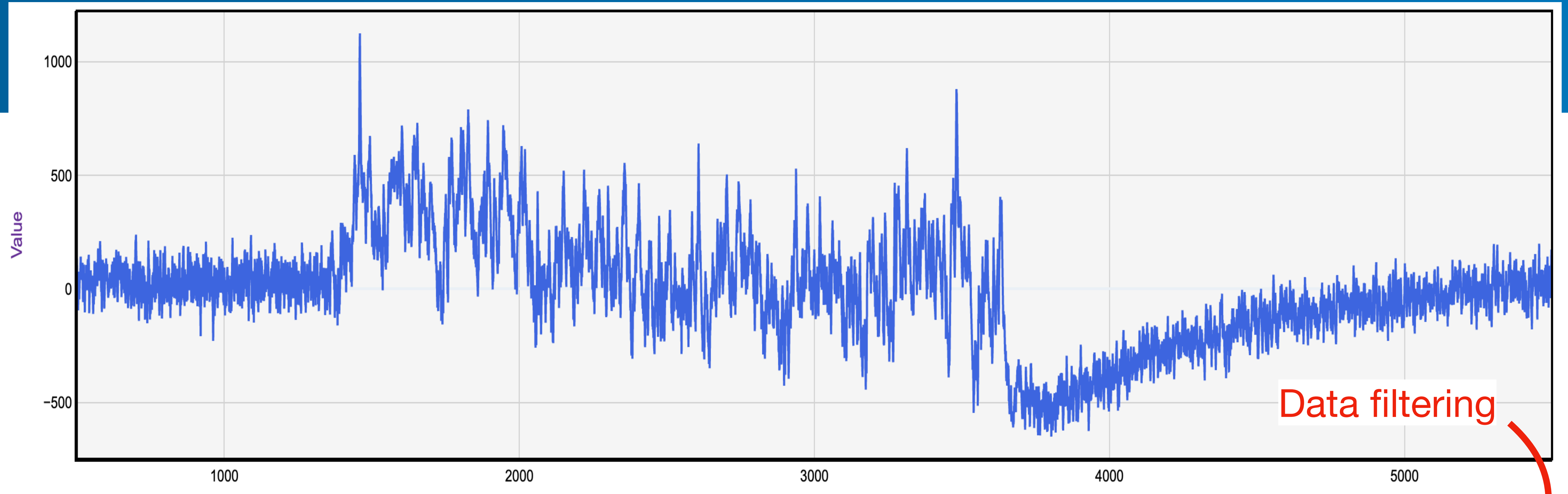


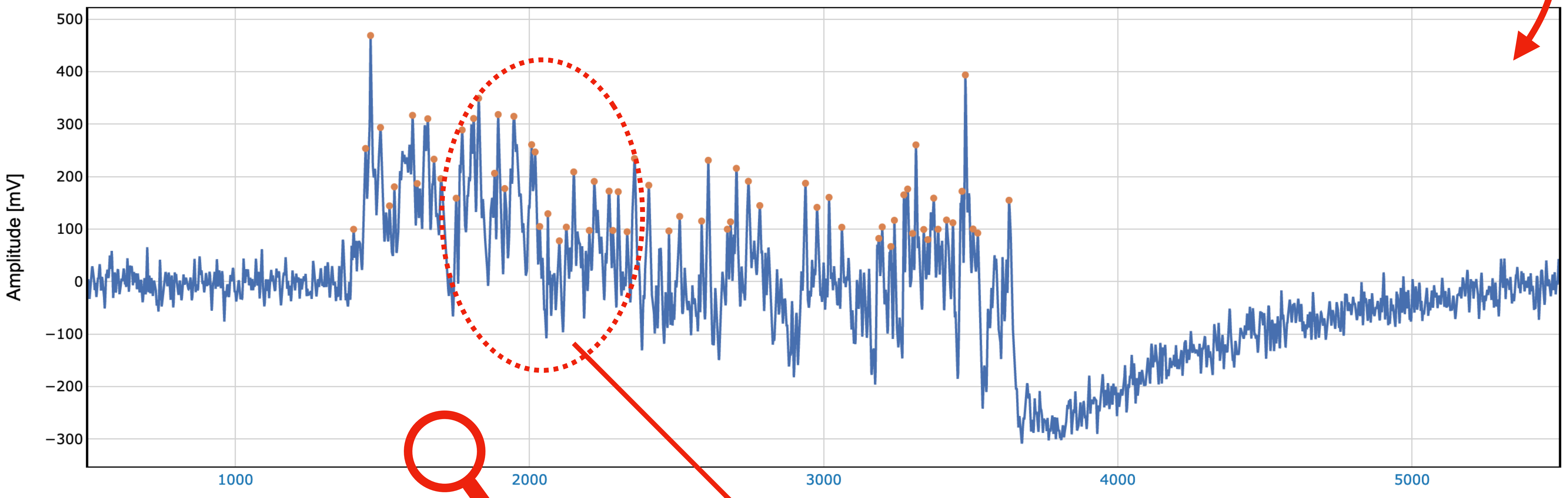
3D synthetic diamond

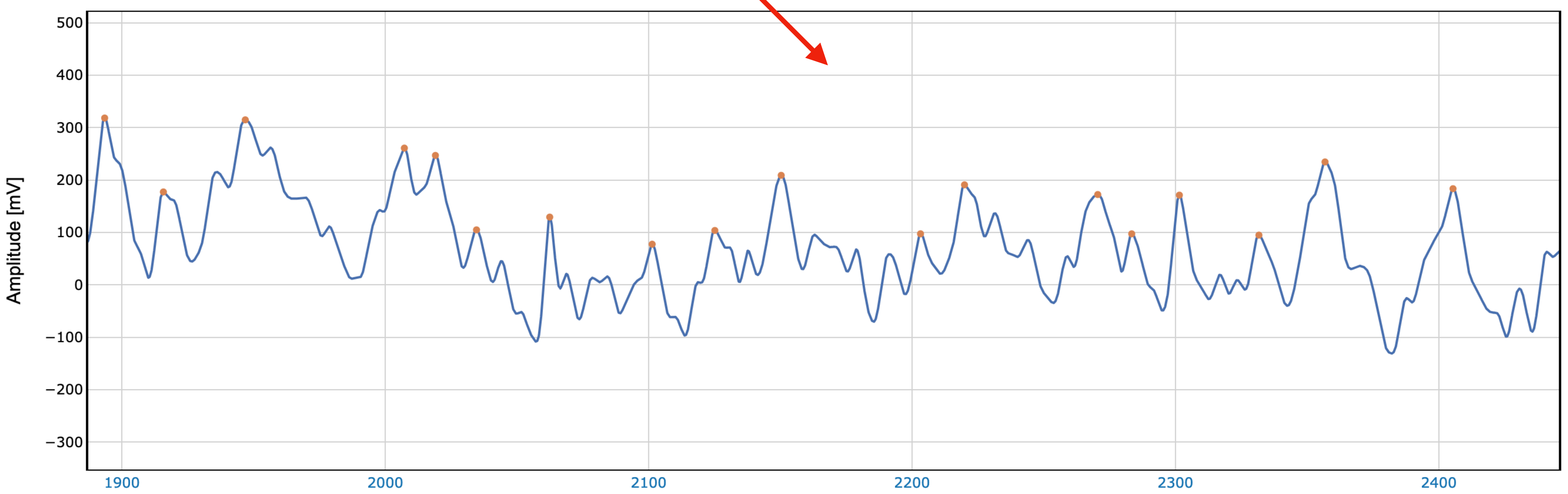
- Tot active area 1.5mm x 1.5mm
- Min Pixel pitch 55 µm × 55 µm
- Bias voltage: –100 to +125
- best time resolution $\sigma_t \sim 35\,ps$
- Single hit efficiency up to 20 MHz/cm^2
- Fluences up to $8 \cdot 10^{15}$ MeV neq cm^{-1}
- Production limited to prototypes
- Detection area very small
- Still in R&D phase



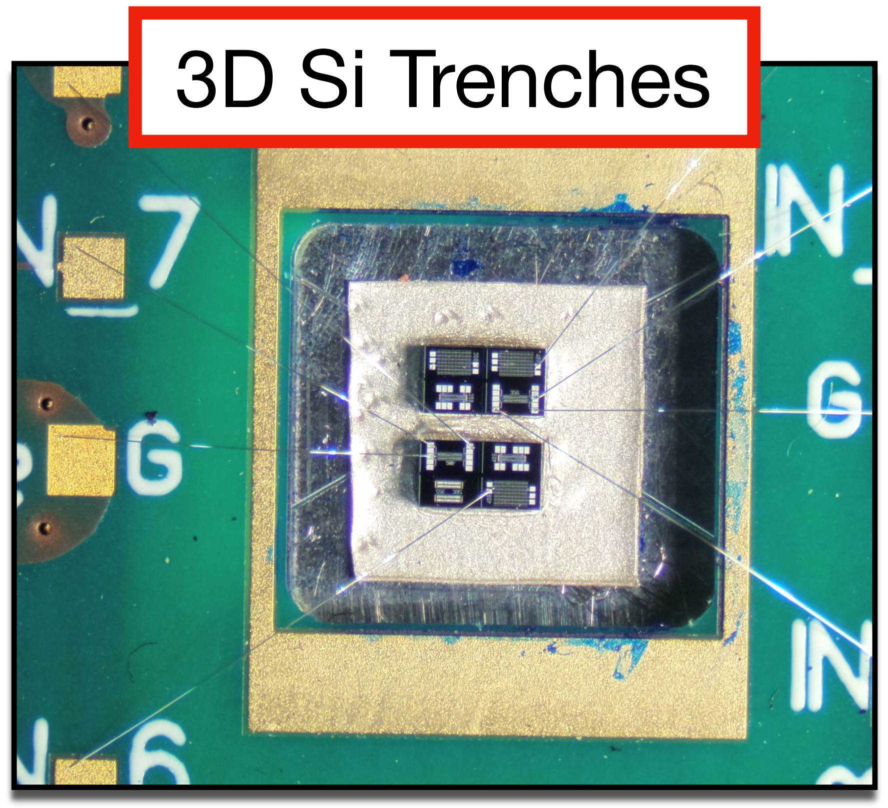
- Average detected rate on strip ~ 70 MHz
- Average time between particles ~ 14.2 ns
- **Dead time - 5.8 ns**





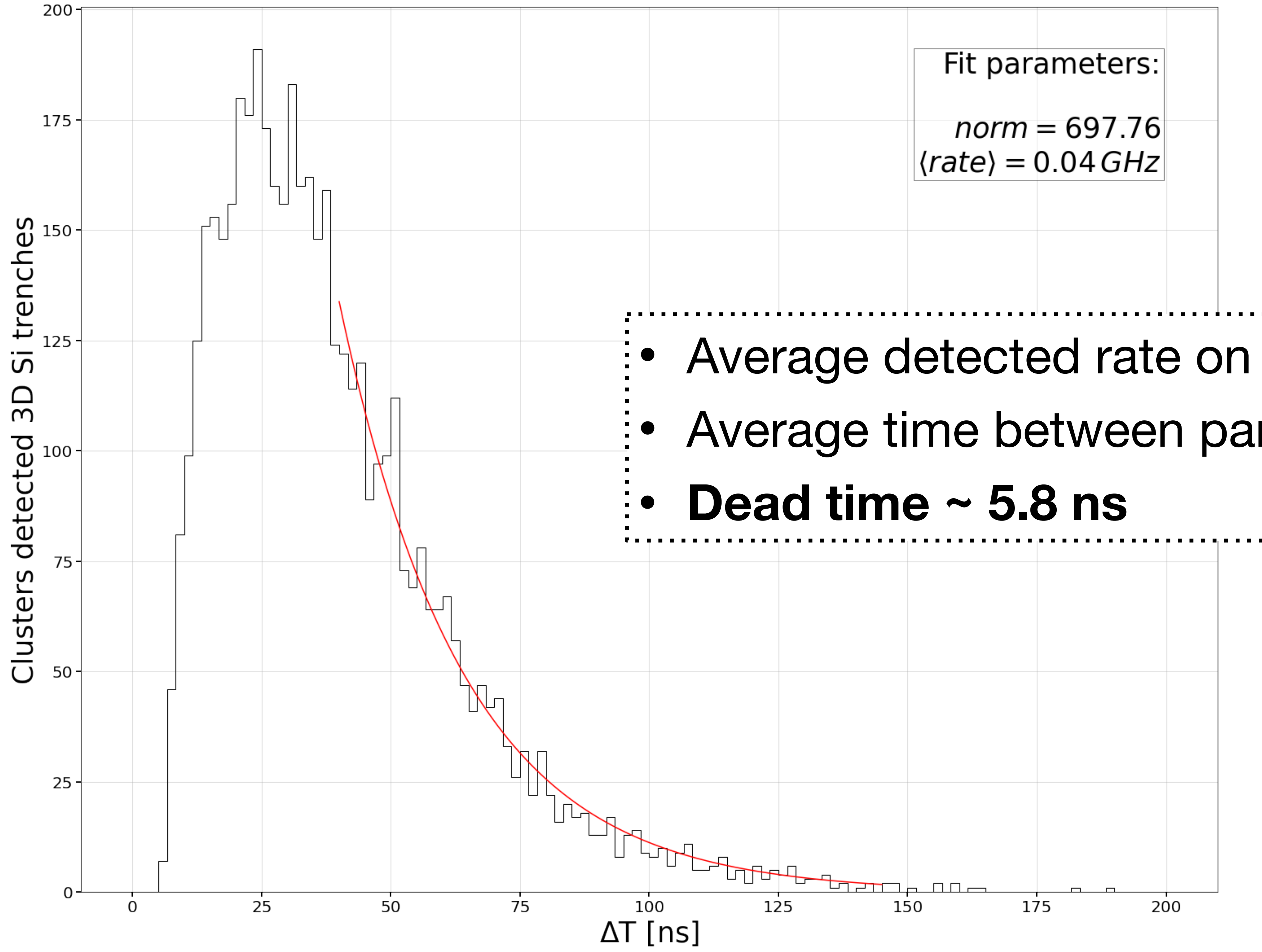


Preliminary results - 3D Si trenches

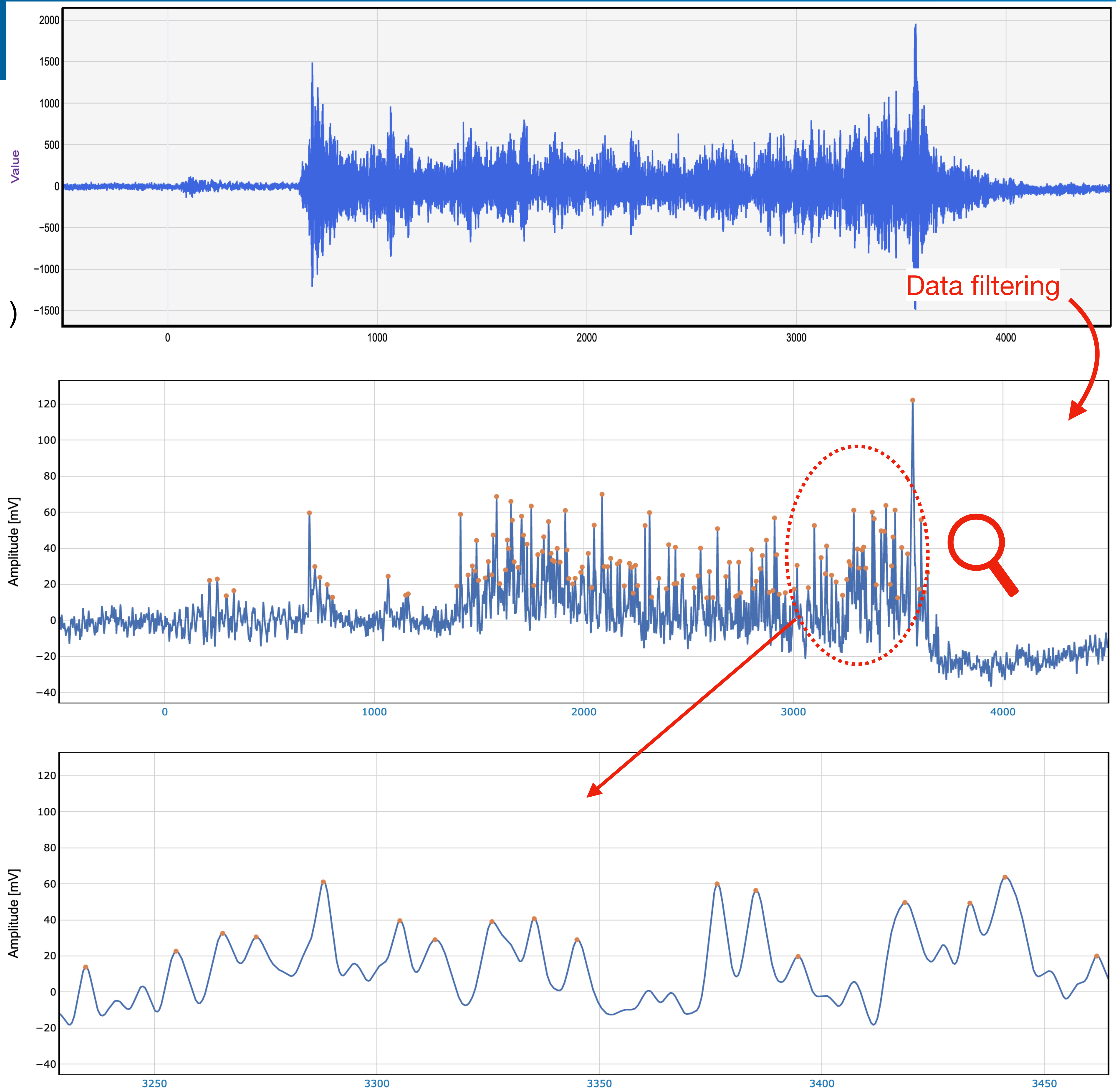


3D Si trenches

- Pixels ~ 55 mum x 55 mum
- Sensors biased down to -85V
- Very short pulses < 1 ns
- Radiation resistance (2.5×10^{16} 1MeV n_{eq} cm^{-2})
- Production complexity
- Limited availability
- Early development stage



- Average detected rate on strip ~ 45 MHz
- Average time between particles ~ 22.2 ns
- **Dead time ~ 5.8 ns**



Summary

- Good preliminary performance for single particle counting. **All detector integration time under 10 ns**
- Noise and backgrounds reduced through iterative filtering methods
- Data under study to extract final distributions

ToDo list:

- Finalizing filtering procedures and assesing systematics
- Finalize detectors comparison
- Exploring unsupervised ML techniques for fast oscillation detection
- Paper in preparation

The University of Kansas

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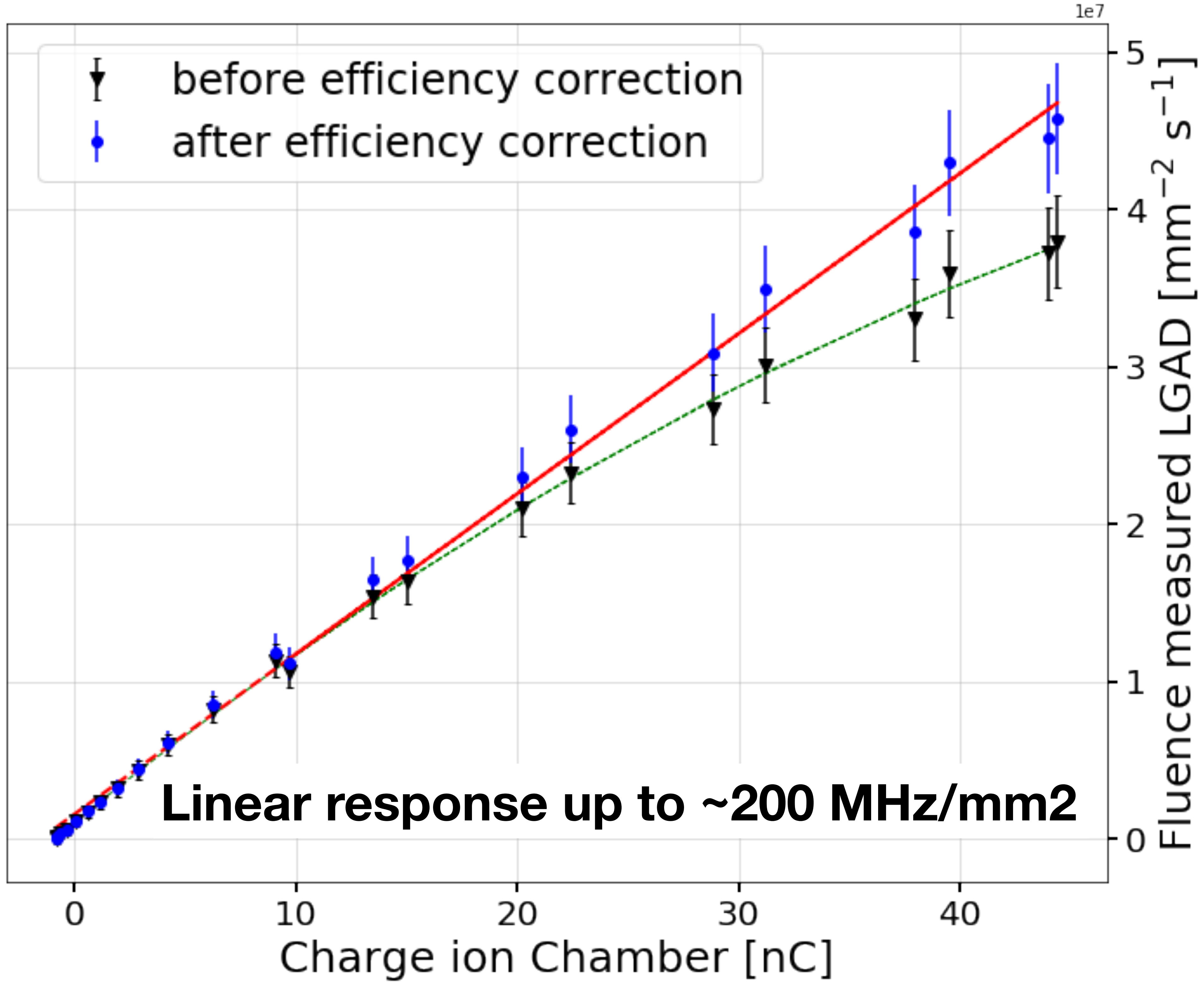
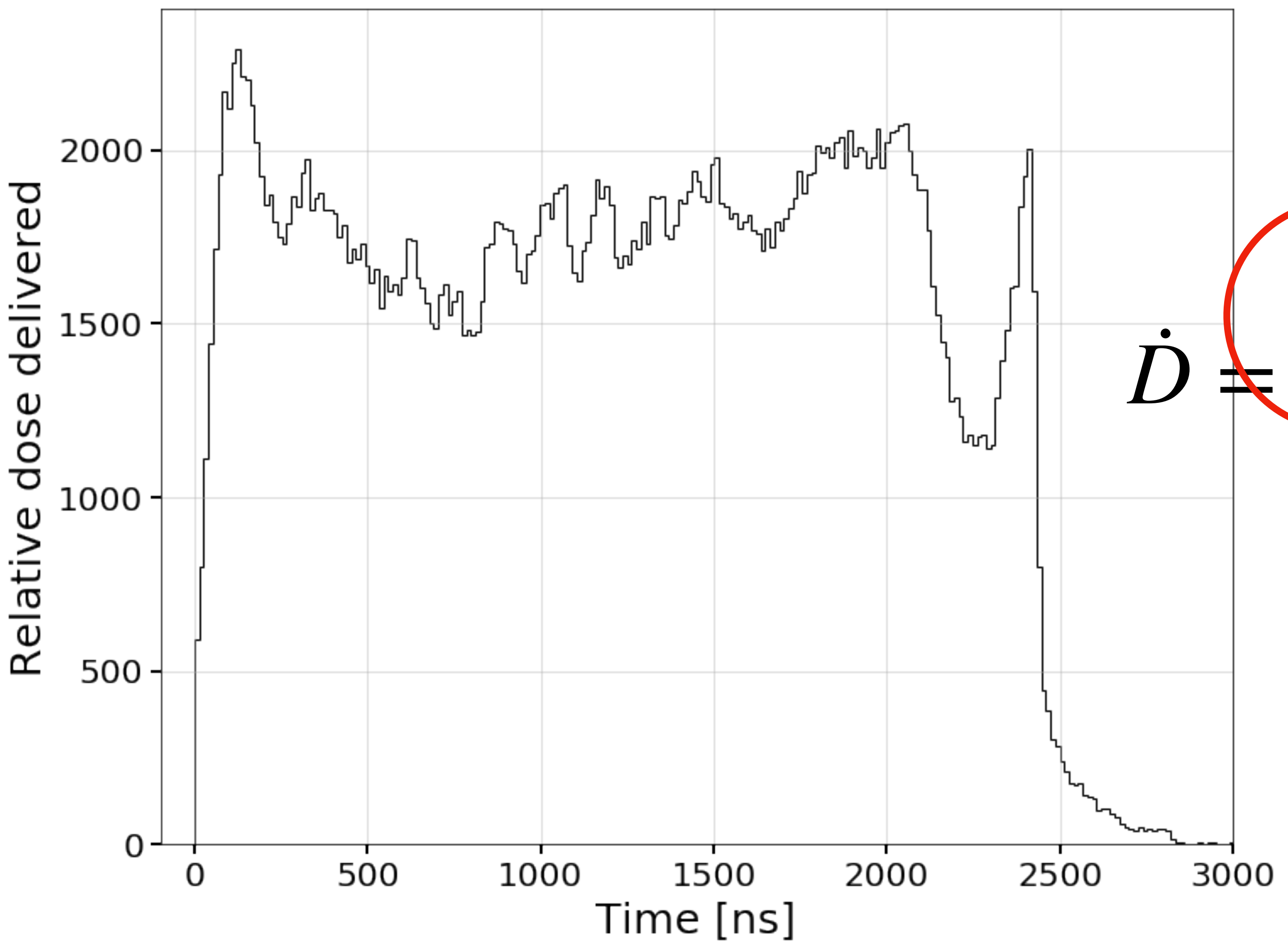
Backup slides

R&D on dosimetry and medical physics

Single particle resolution at high rate:

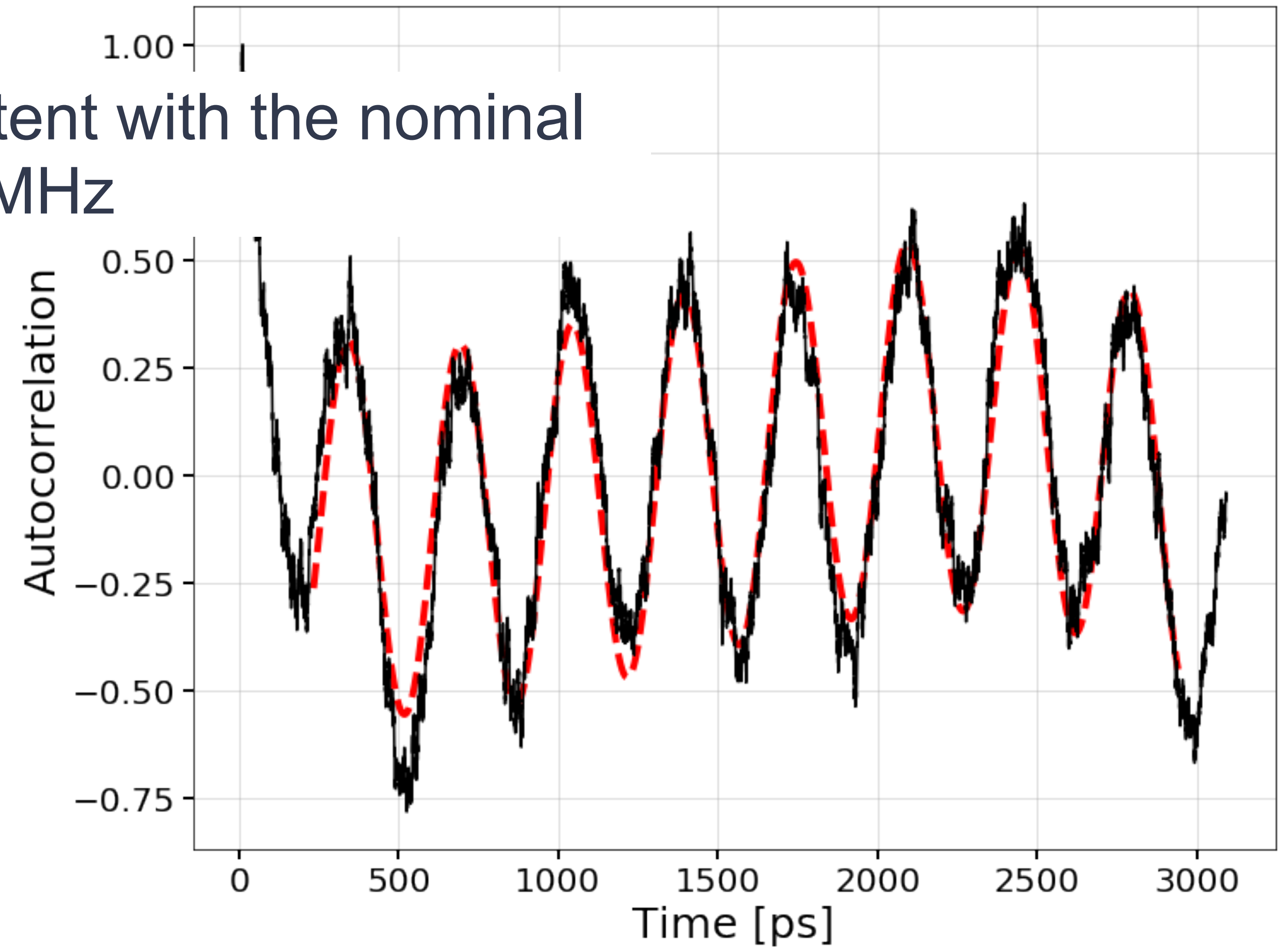




$$\dot{D} = \frac{\dot{\phi}(-dE/dx)\Delta x}{\rho\, A\, \Delta x} = \dot{\phi} \cdot \left(\frac{-dE}{\rho\, dx} \right)$$

Dosimetry w/single particle resolution (σ_t ~ 50 ps)

Period = 346 ± 3 ps, consistent with the nominal frequency of the linac 2856 MHz

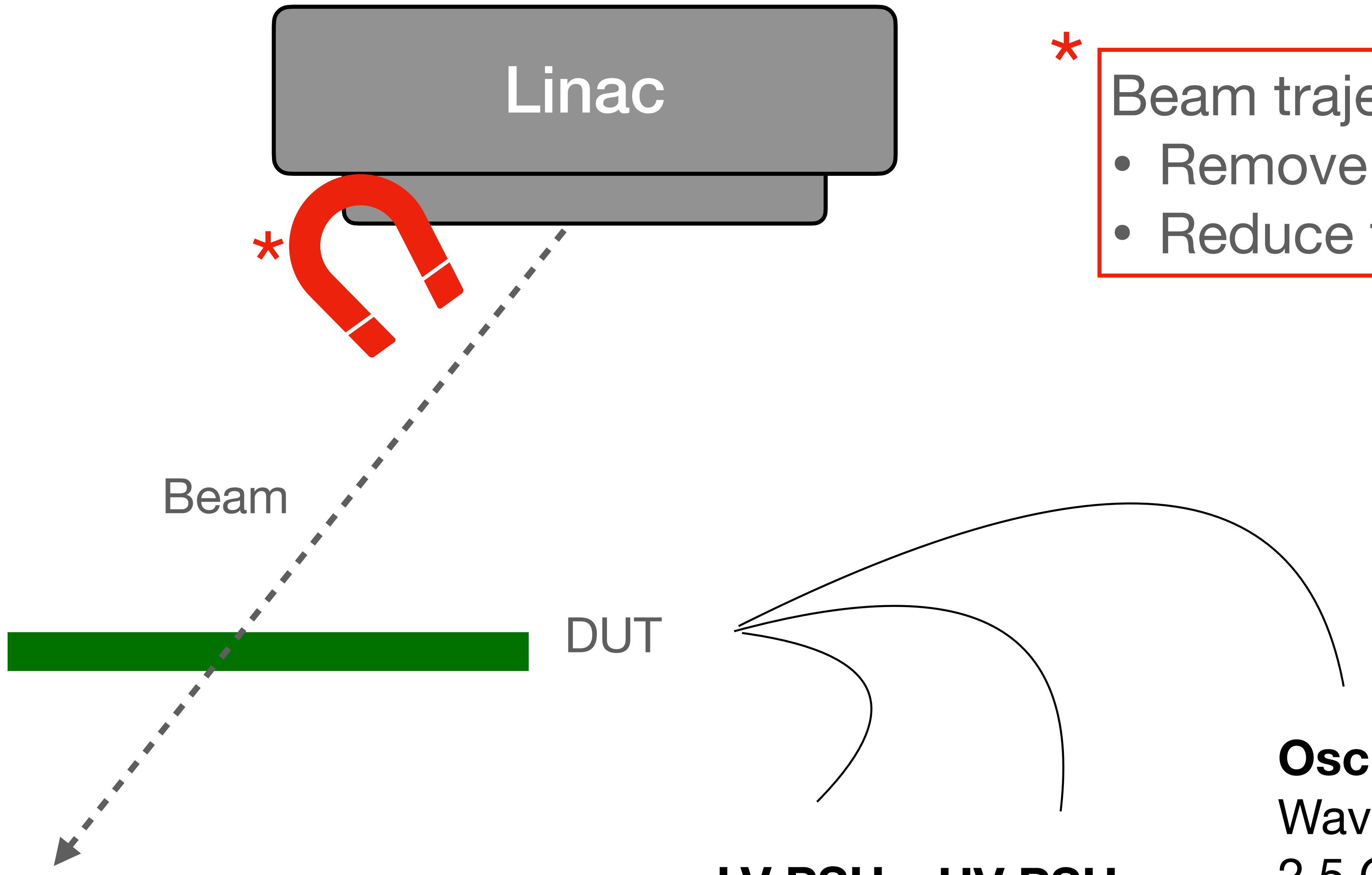


[Performance of a low gain avalanche detector in a medical linac and characterisation of the beam profile](#)

Journal and that's it

Journal: T Isidori, P McCavana, B McClean, R McNulty, N Minafra, N Raab, L Rock, and C Royon

May 2024 test beam - Survey on fast detctor technologies



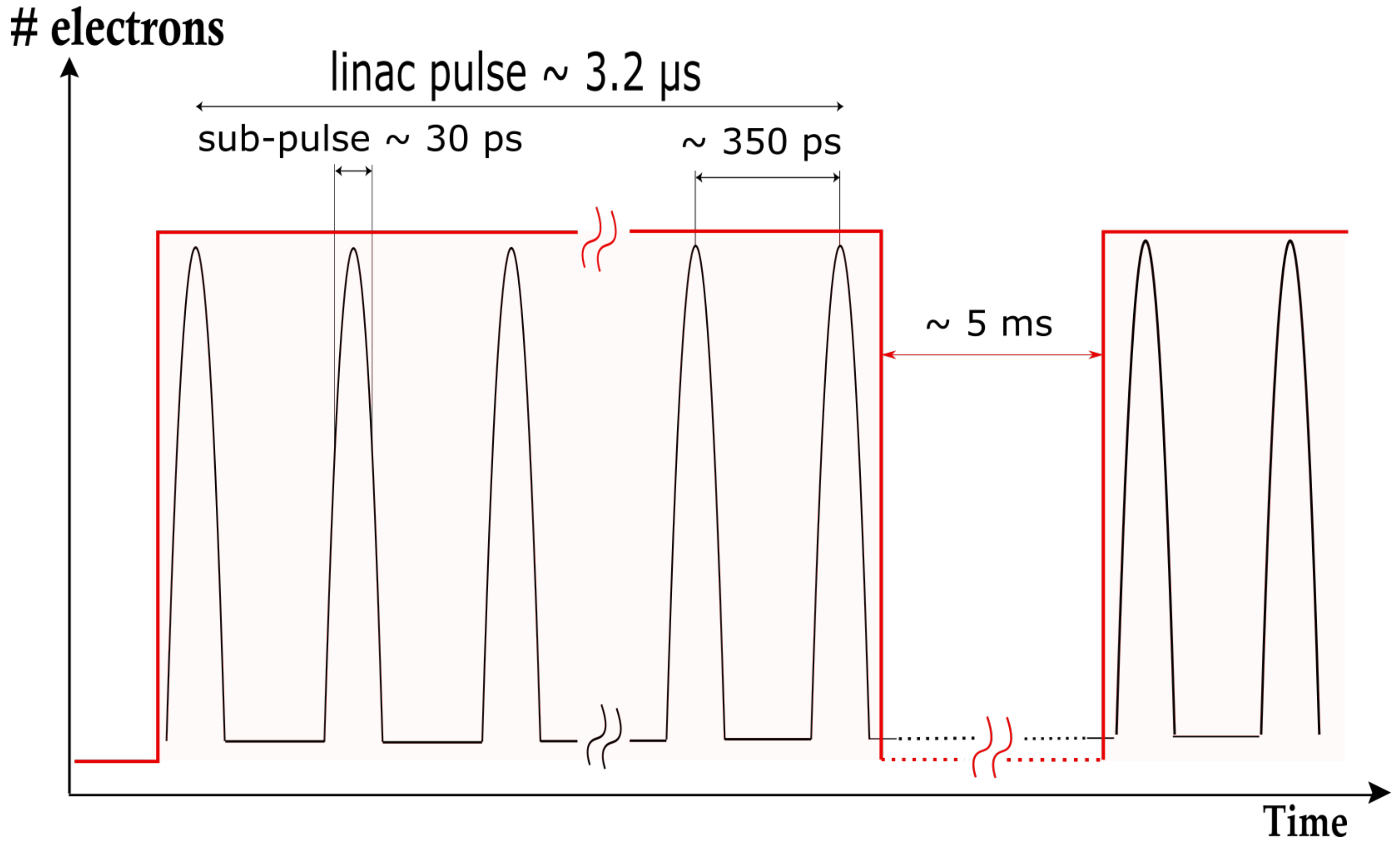
*Beam trajectory bent to:
- Remove the contamination of neutrals
- Reduce the elctrons energy spread

LV PSU

HV PSU
- Bias setting
- I-V monitoring

Oscilloscope (4ch)
WavePro 254HD-MS
2.5 GHz, 4 Ch, 12 bits, 10 GS/s, 100 Mpts/Ch

St. Luke's Hospital LINAC beam structure
- Spills of ~ 3 mus
- Substructure of ~350 ps (~2.8 GHz)
- ~ 5 ms between spills



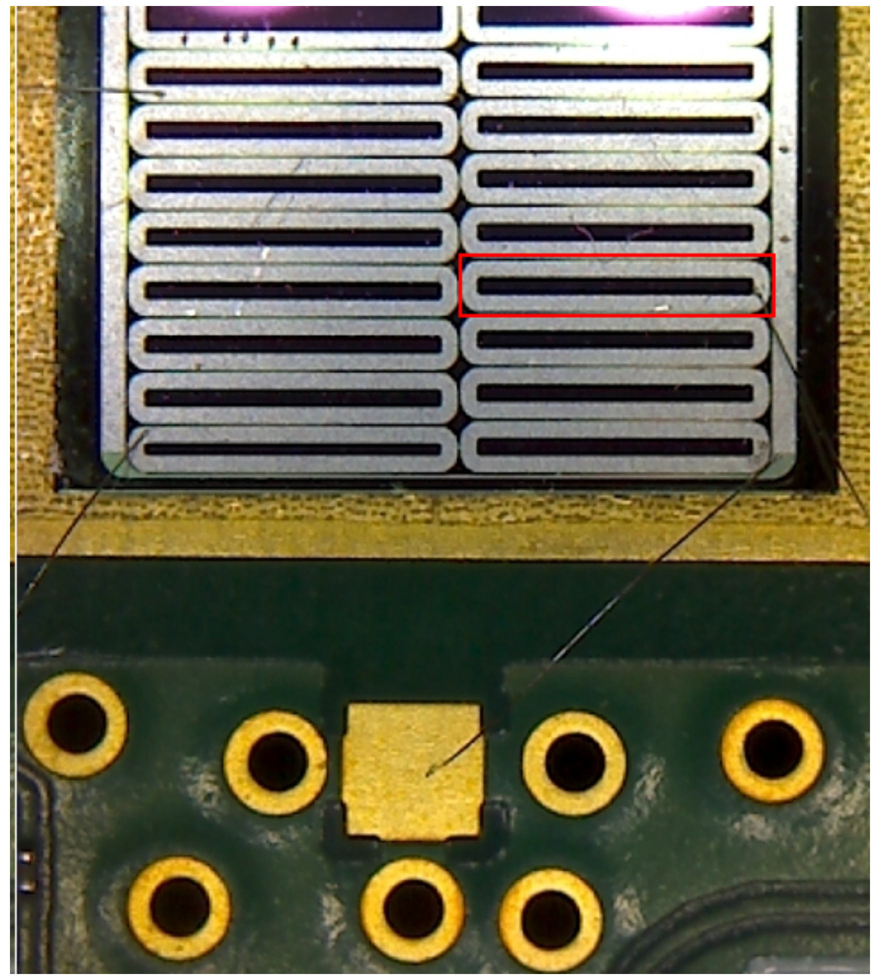
Not many options for electron facilities at high rate and intensity!

Medical Linac at the St.Luke's hospital of Dublin:
- Previous experience
- Knowledge of the beam characteristics

Many thanks to Prof. **R.McNulty** and his UCD group, **P.McNavana** and the St. Luke's Hospital staff (Dublin) !!

R&D on dosimetry and medical physics

Readout system v1 used to prove single particle counting capabilities at medical facilities



LGAD

intrinsic gain = 5-20

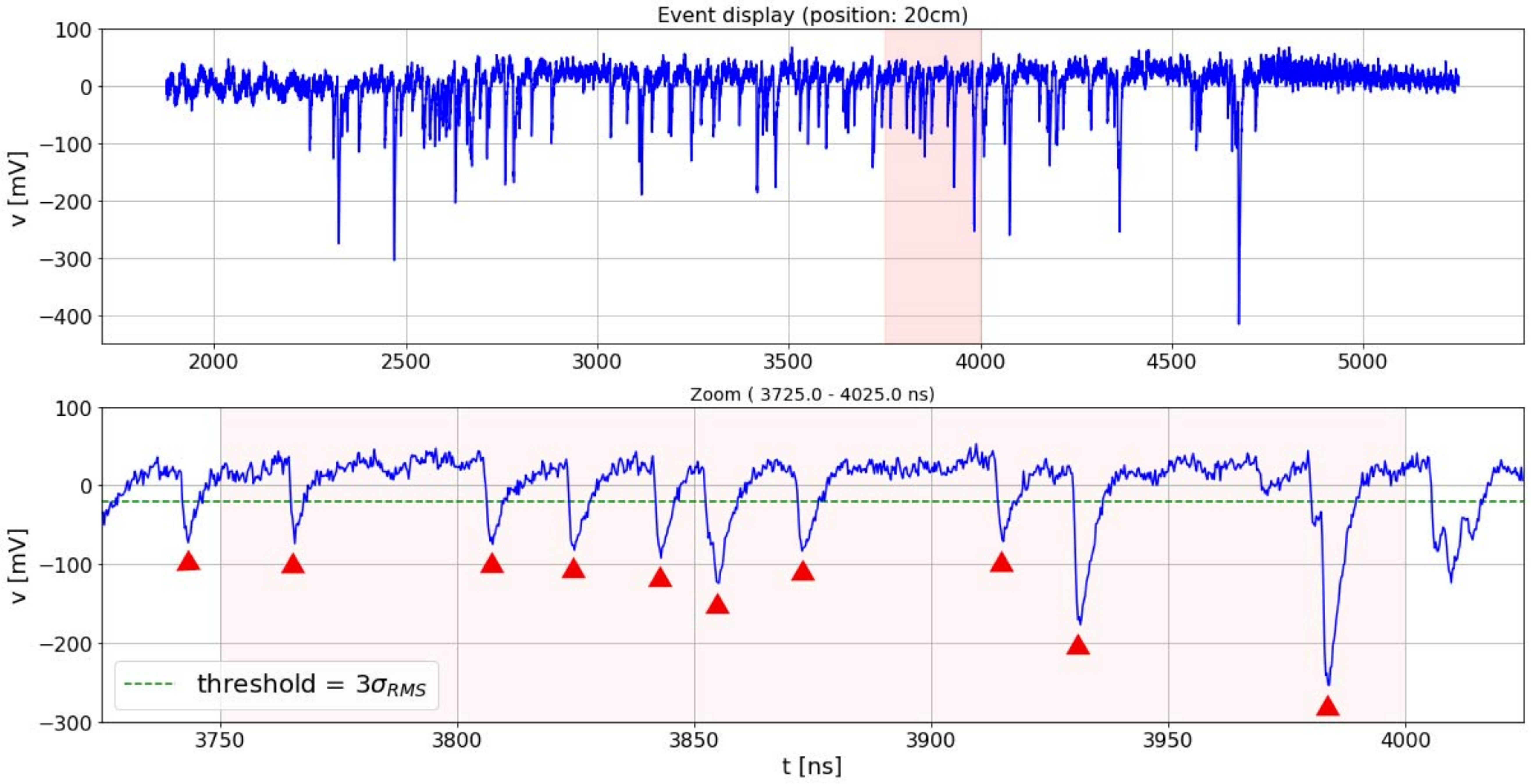
thickness = 50 micron

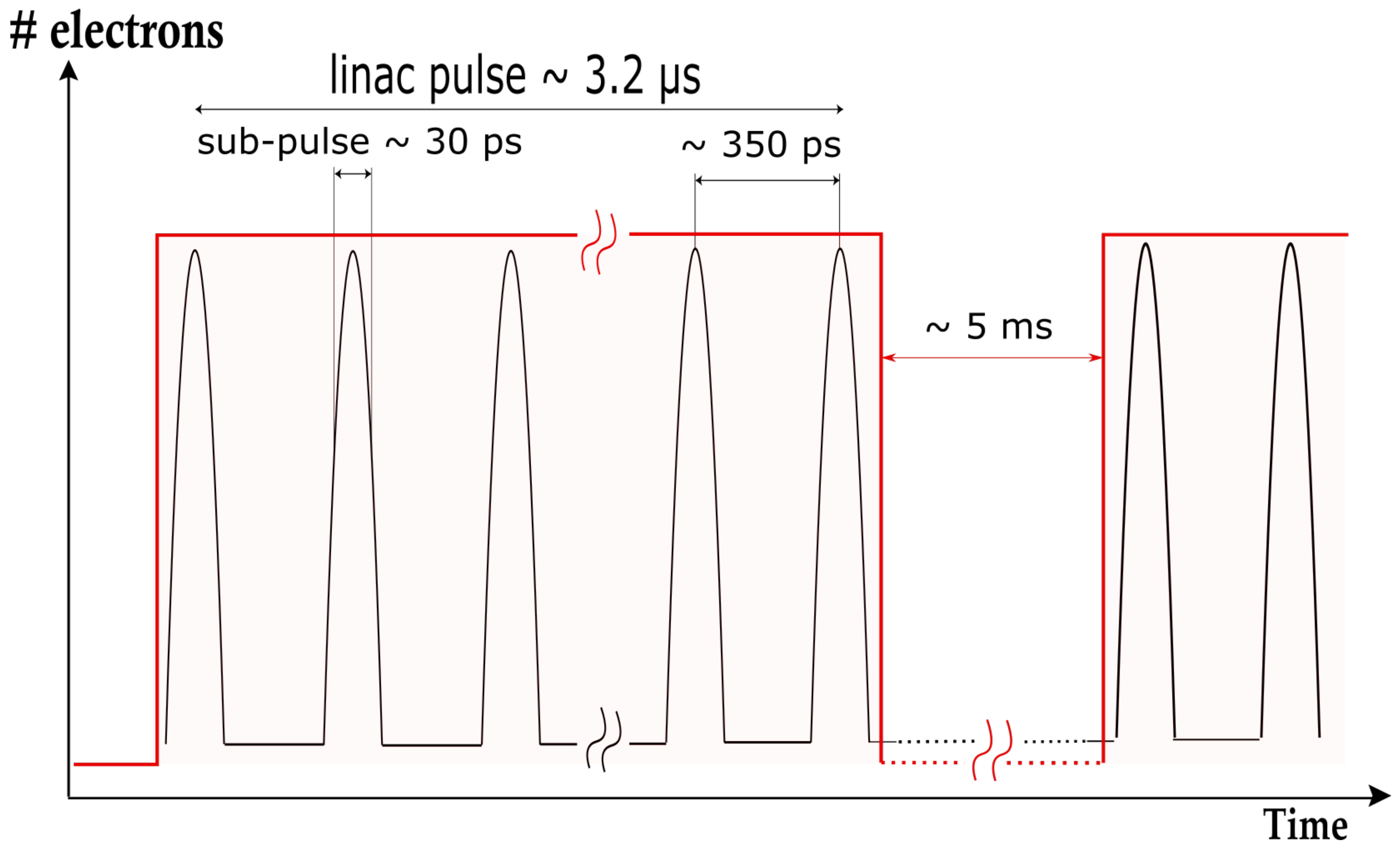
pixel active area = 2.9×0.5 mm2

time resolution ~ 50ps

signal rise time ~ 600 ps

signal width = 5 − 10 ns





Linac electron beam

energy 4-18 MeV

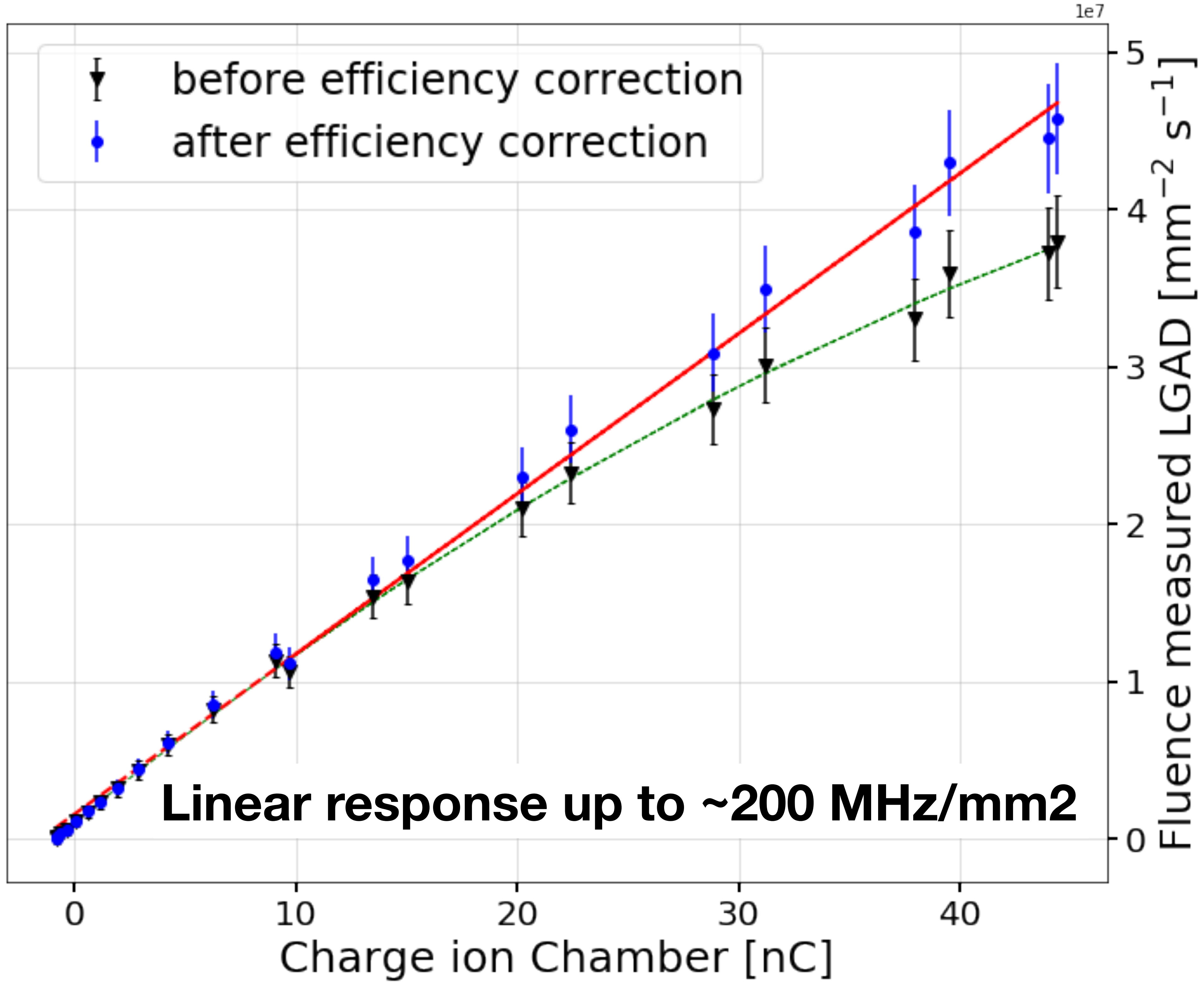
pulse repetition frequency of 200 Hz

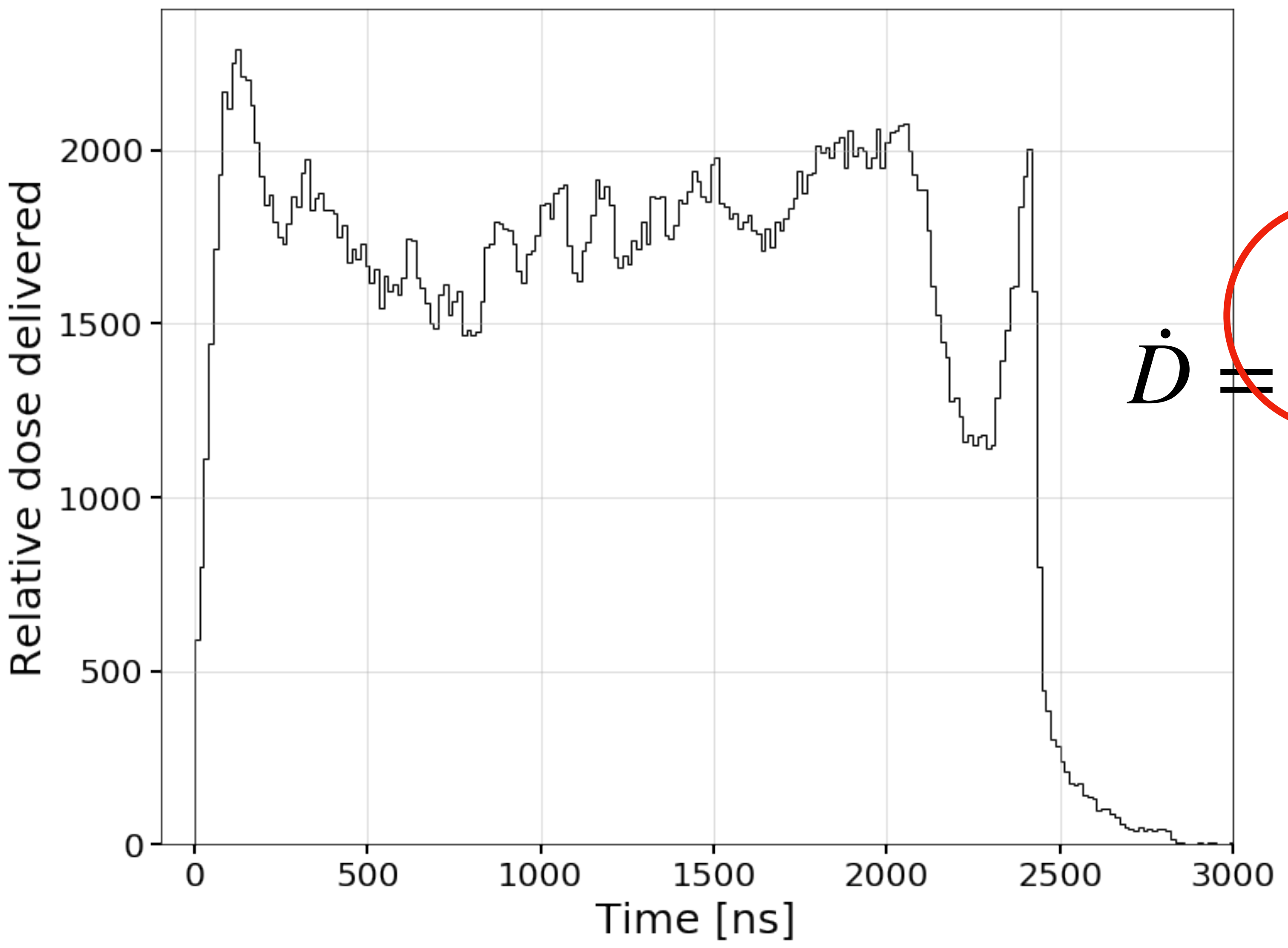
EIC electron beamline (high-lumi)

- energy up to 18 GeV
- 560 MHz RF
- 1320 bunches
- 10 ns between bunches
- Electron current up to 2.4 A

R&D on dosimetry and medical physics

Single particle resolution at high rate:

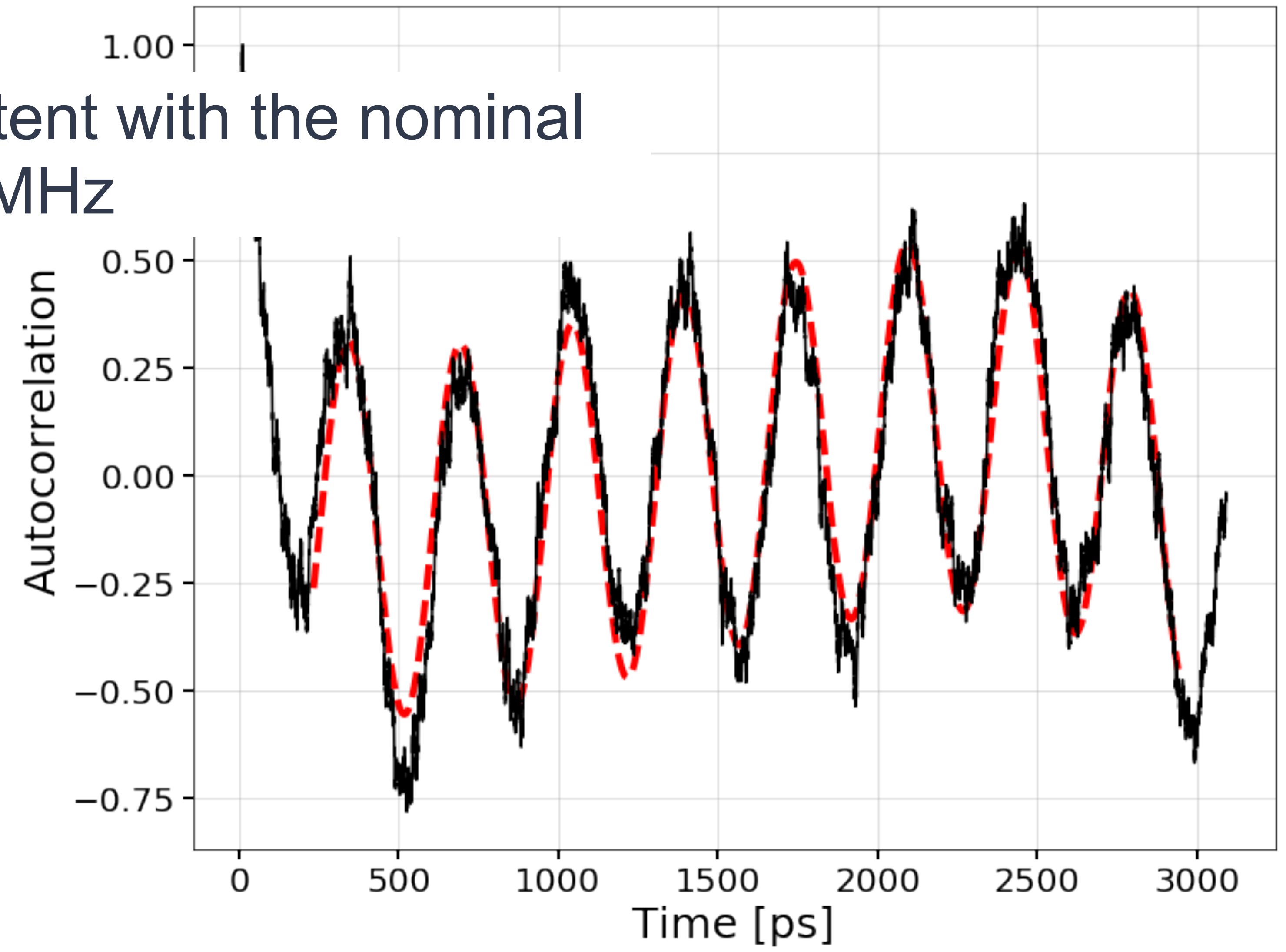




$$\dot{D} = \frac{\dot{\phi}(-dE/dx)\Delta x}{\rho\, A\, \Delta x} = \dot{\phi} \cdot \left(\frac{-dE}{\rho\, dx}\right)$$

Dosimetry w/single particle resolution (σ_t ~ 50 ps)

Period = 346 ± 3 ps, consistent with the nominal frequency of the linac 2856 MHz



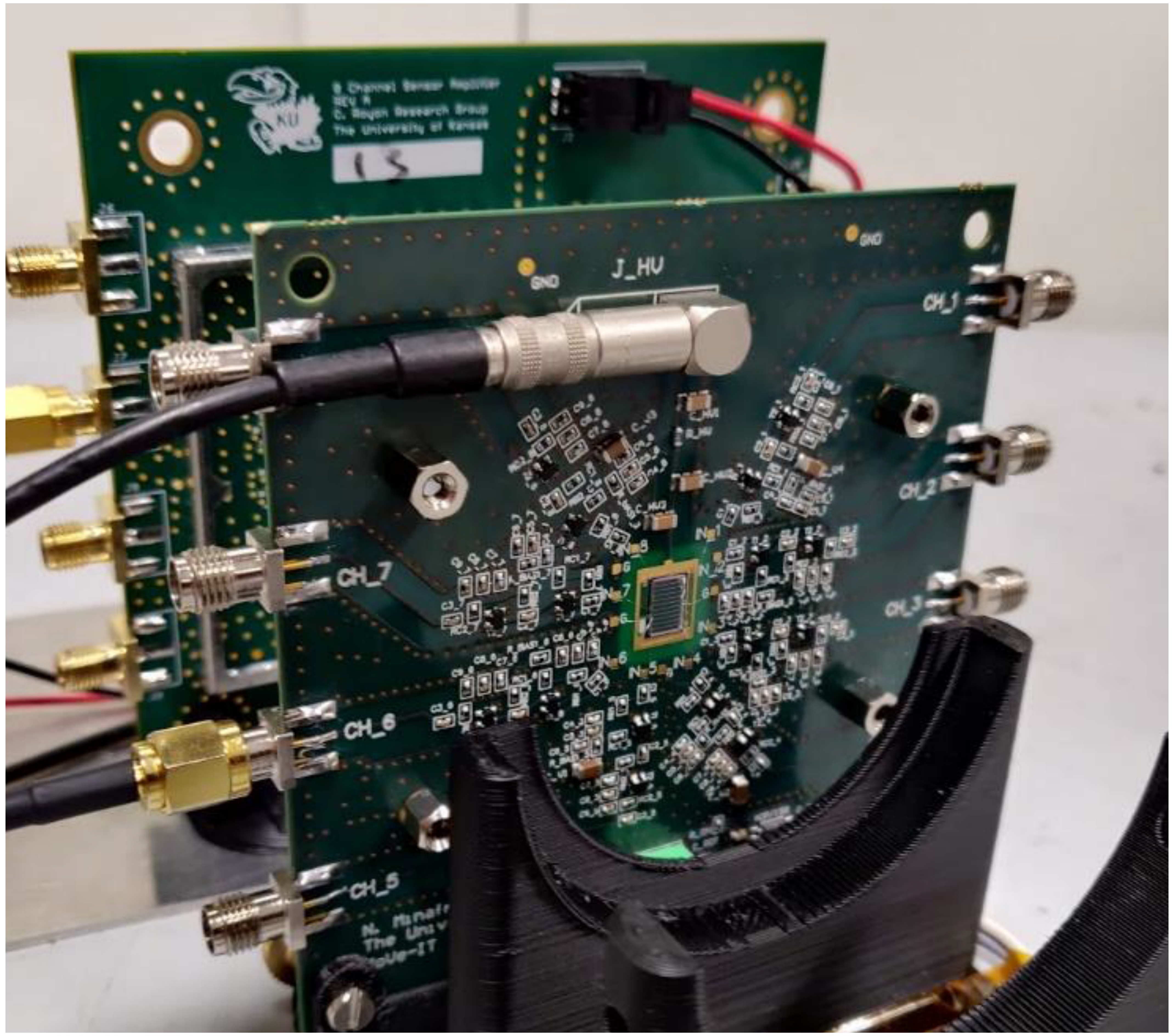
[Performance of a low gain avalanche detector in a medical linac and characterisation of the beam profile]

Journal and thesis.it

Journal: T Isidori, P McCavana, B McClean, R McNulty, N Minafra, N Raab, L Rock, and C Royon

First results with v2 readout

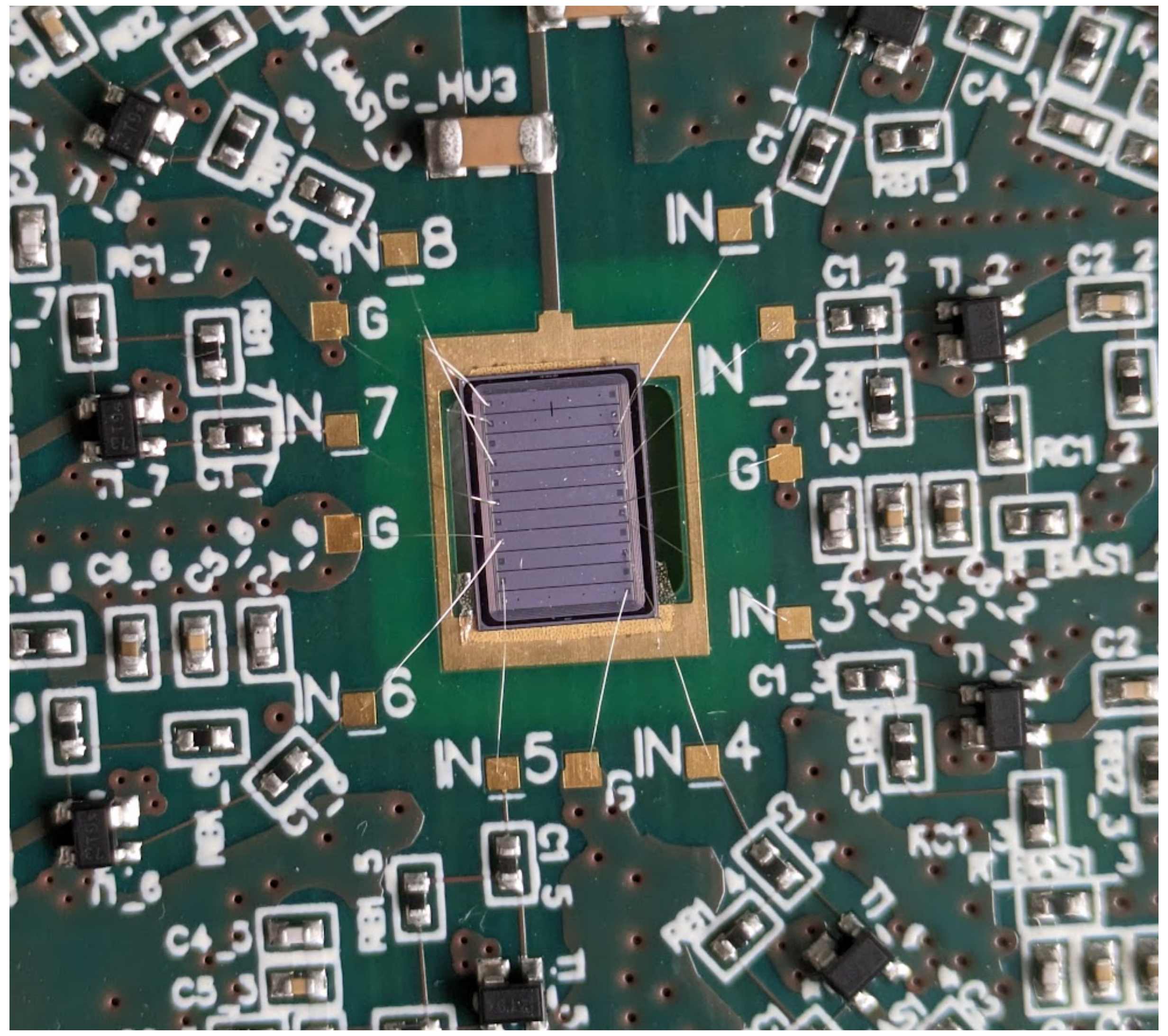
New boards are optimized for fast response (sacrificing some time resolution)



N.Minafra, Test Platform for Automated Scan of Multiple Sensors

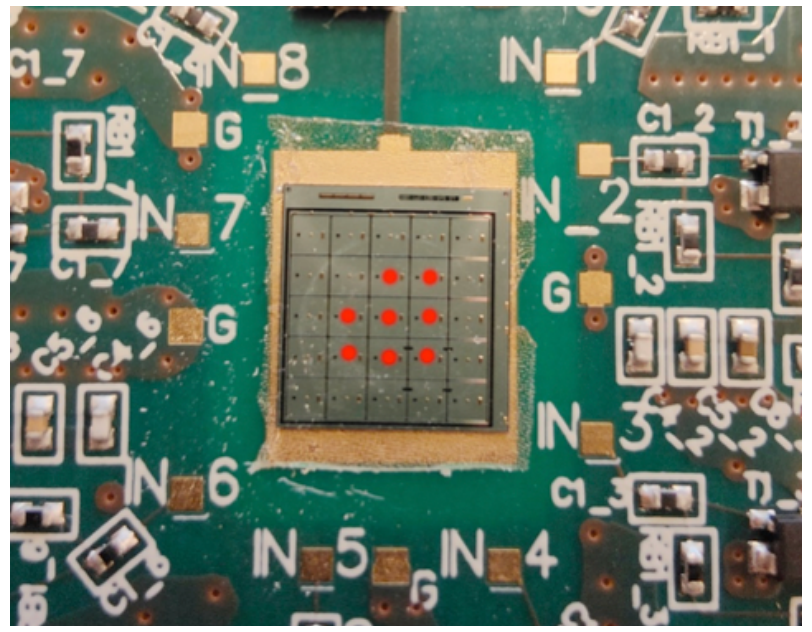
Reference detector: thin LGADS for CMS ETL

- Thickness ~150 um (tot)
- linearity up to 10 MIPs and for high rates (>200MHz)
- Improved single particle ID
- Time resolution < 50ps up to 1.5 x 10^15



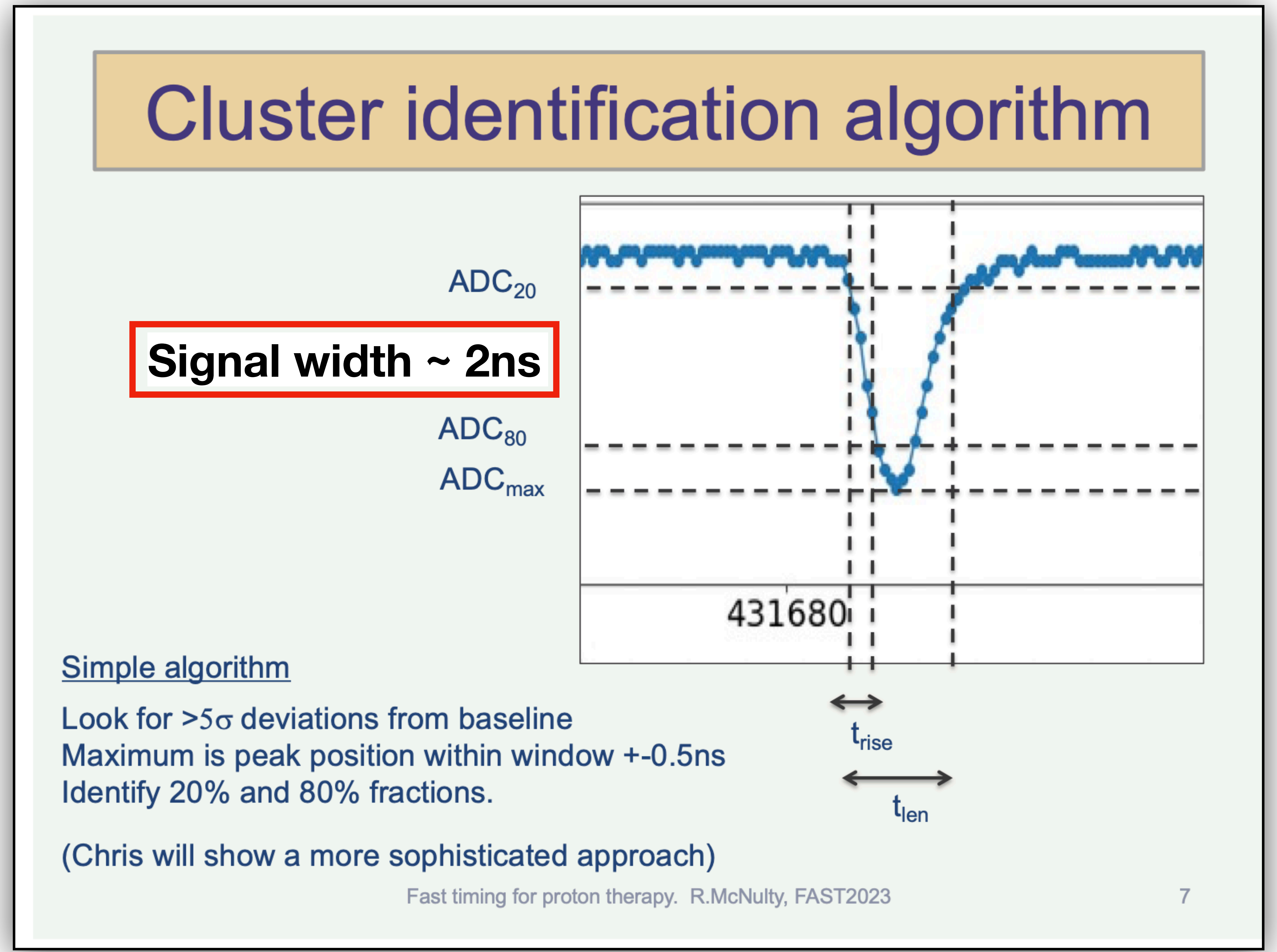
Proton beam at the AIC144 cyclotron (Crakow)

- 60 MeV protons (58 MeV in treatment room)
- Intensity up to 100 Gy/s.
- $4x10^6$ - $4x10^8$ protons/sec
- Nominal pulse structure RF = 26.26 MHz



Thin LGAD

- Pixels 1.3mm x 1.3 mm
- Sensors biased to 180 or 200V
- Gain of ~20
- Short pulses ~ 2.5ns
- precise time of arrival of ~ 50 ps



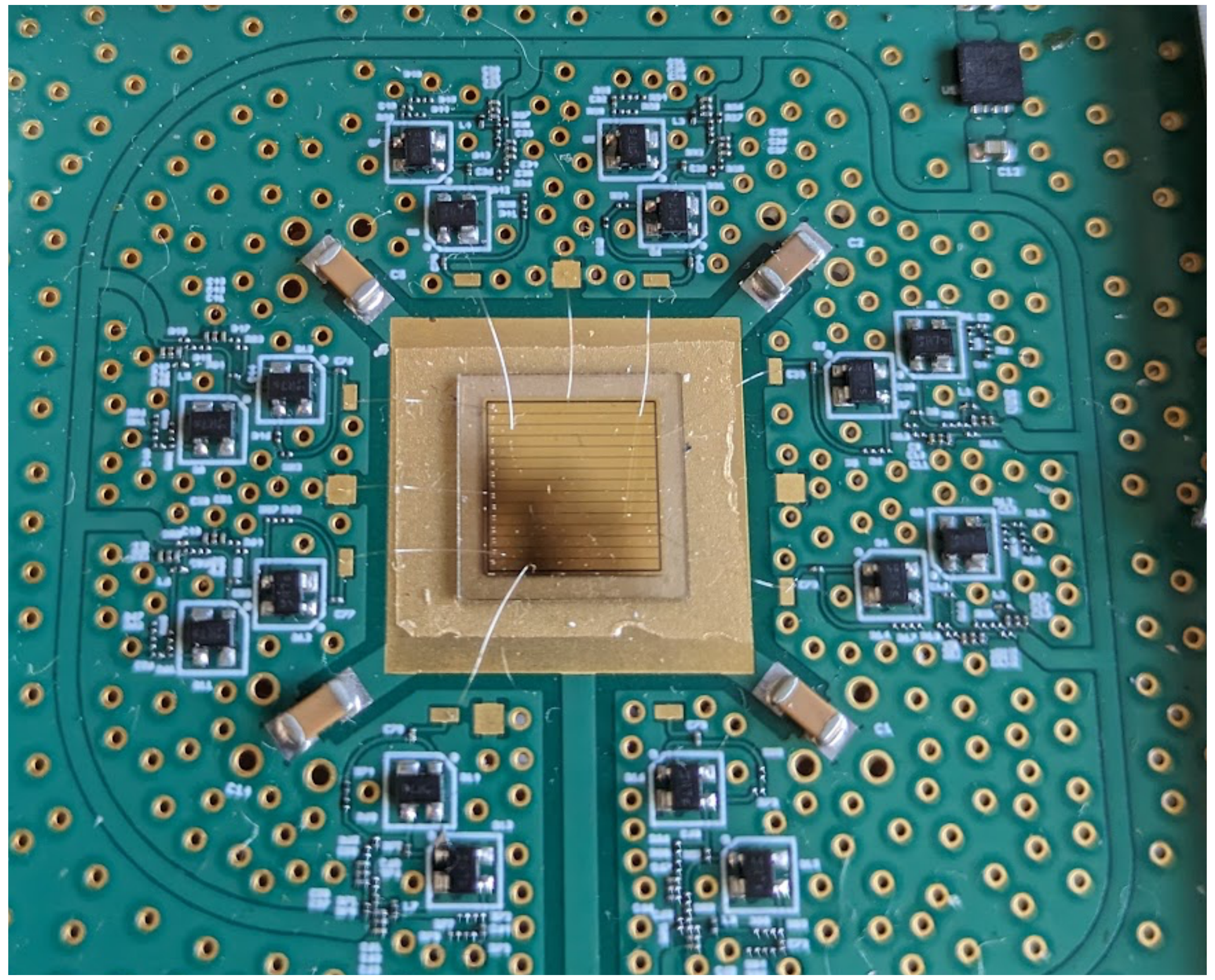
- Optimized readout for single particle counting
- Improved cluster finding algorithms

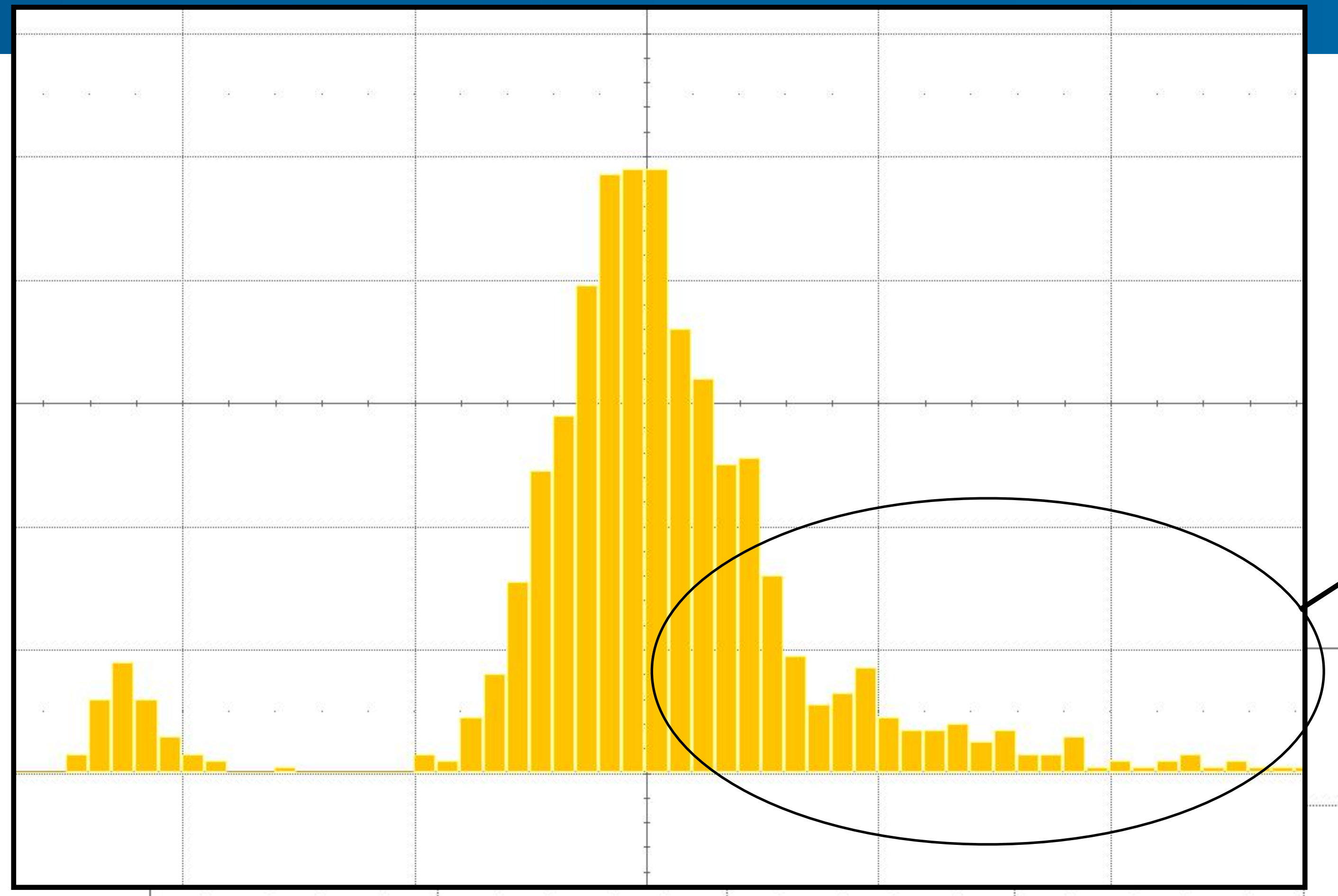
Machine Learning for Analysis of Fast Particle Detector Data for Proton Therapy Application

Fast timing for proton therapy

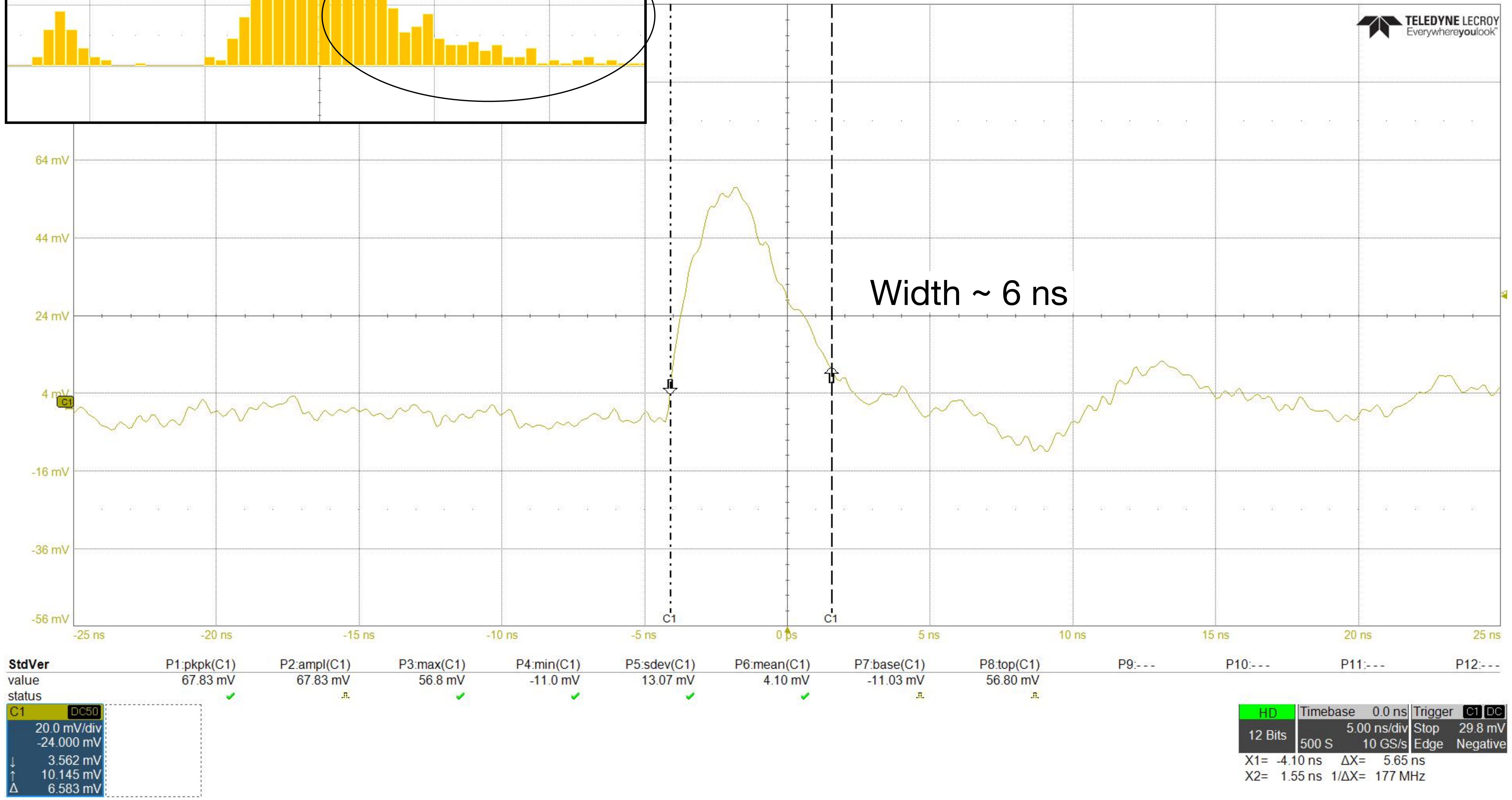
Survey on fast detctor technologies - pCVD

Baseline pCVD detector





- Signal swamped by relatively high background (@ 800V)
- <$V_{pedestal}$> ~ 50 mV

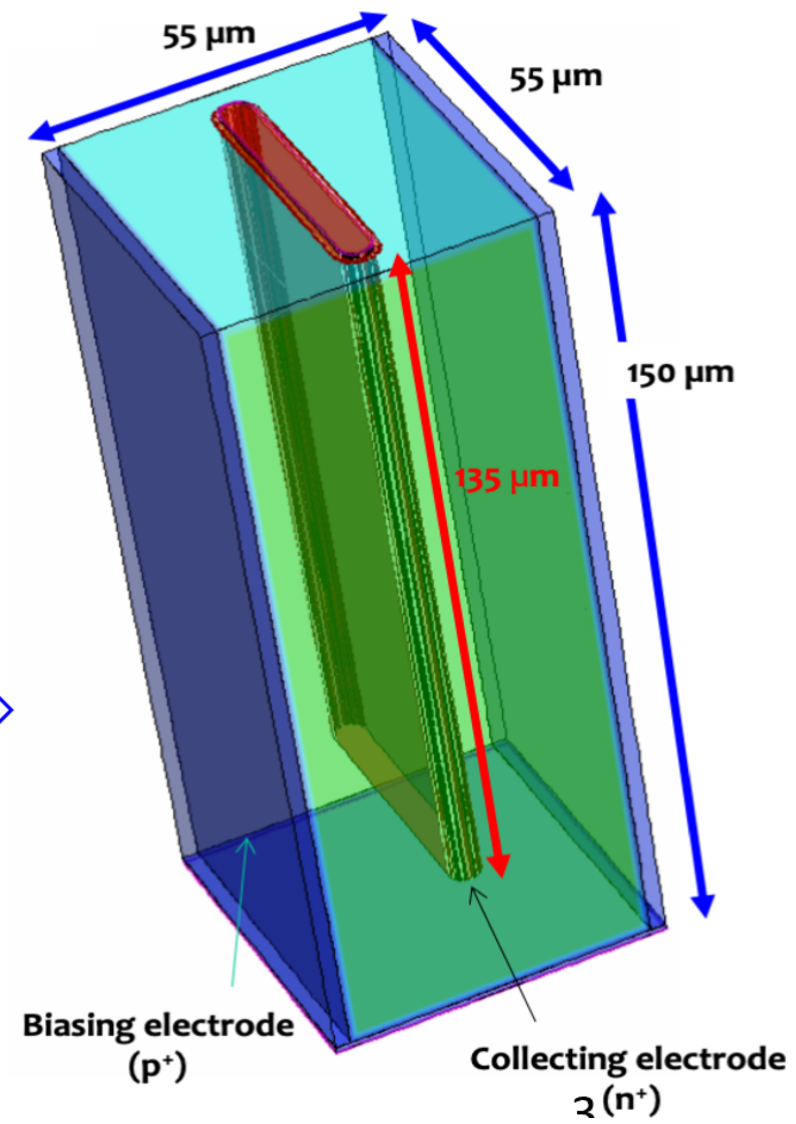


JLAB Poli-crystal CVD

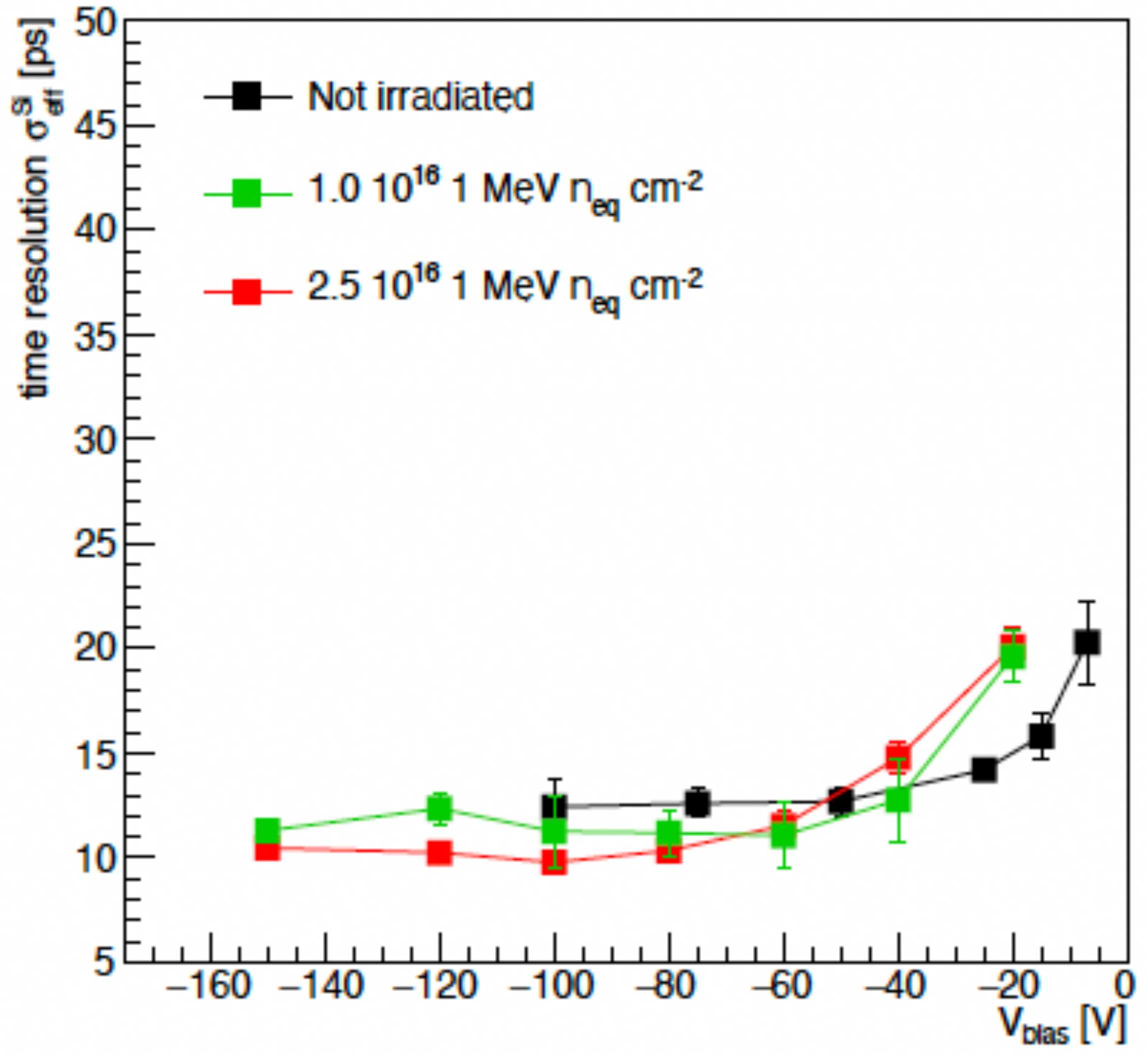
- Good radiation resistance
- CCE quickly deteriorates with irradiation (~ 10^{14} neq)
- Pulses width ~ 5 - 10 ns
- To be tested at high rate and electron beams

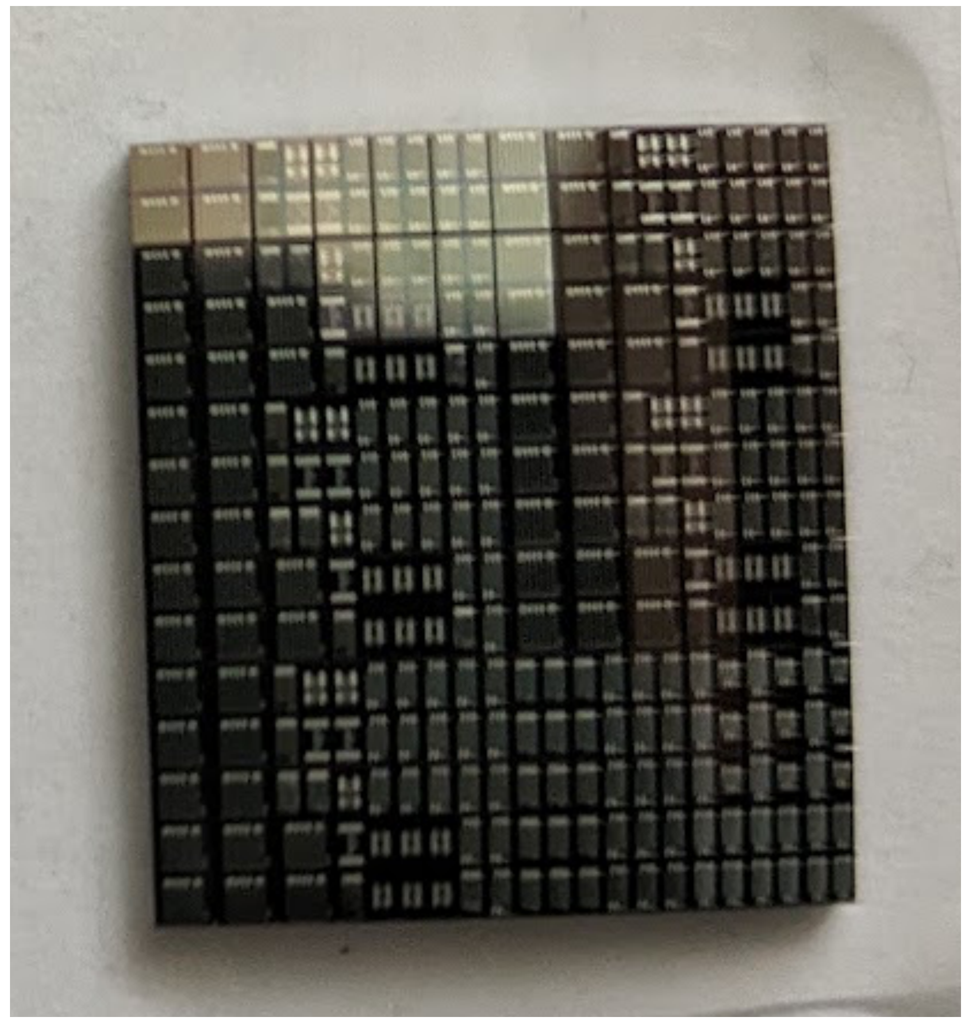
Survey on fast detctor technologies - Si3D trenches

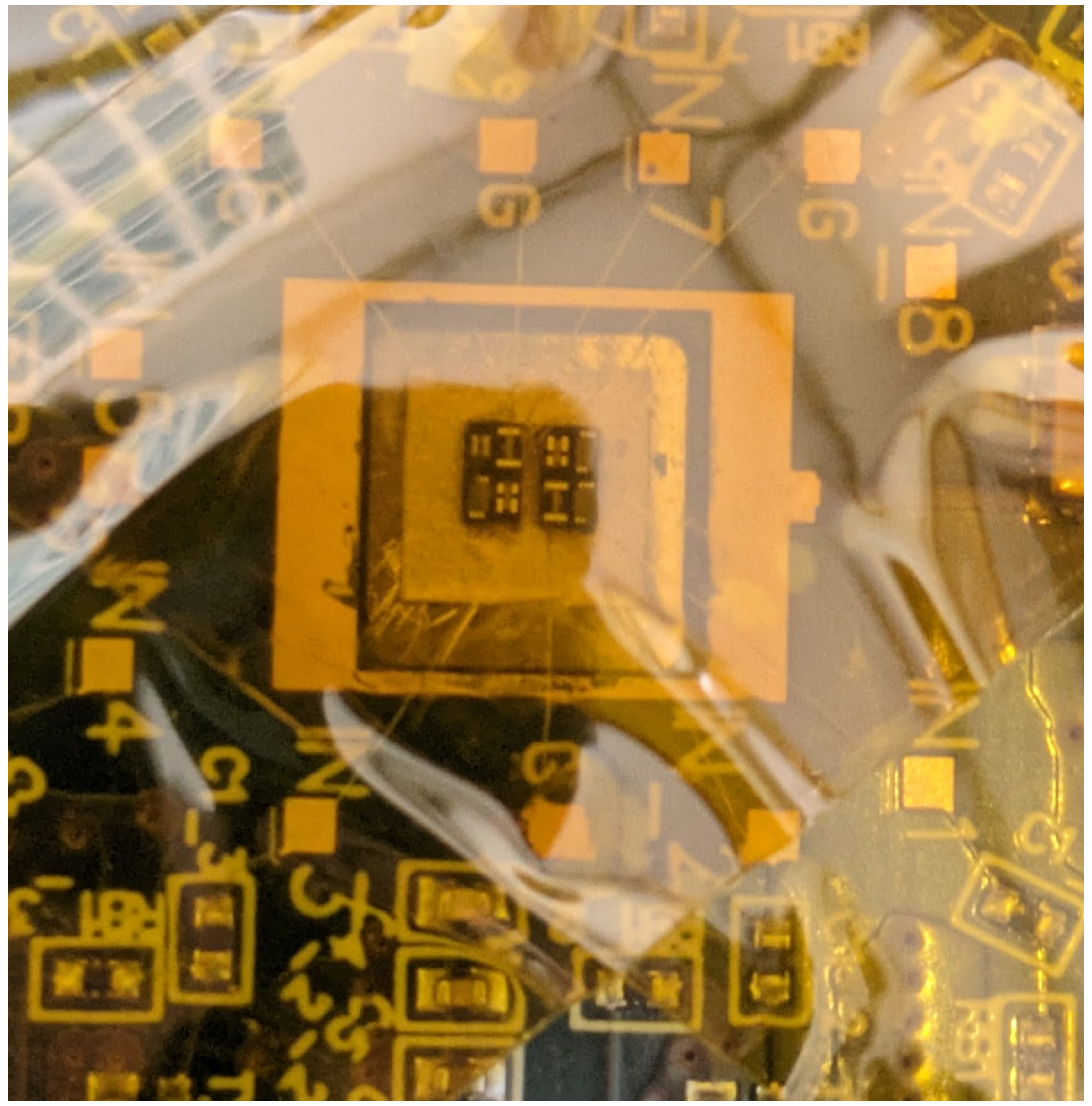
Si 3D trenches detector

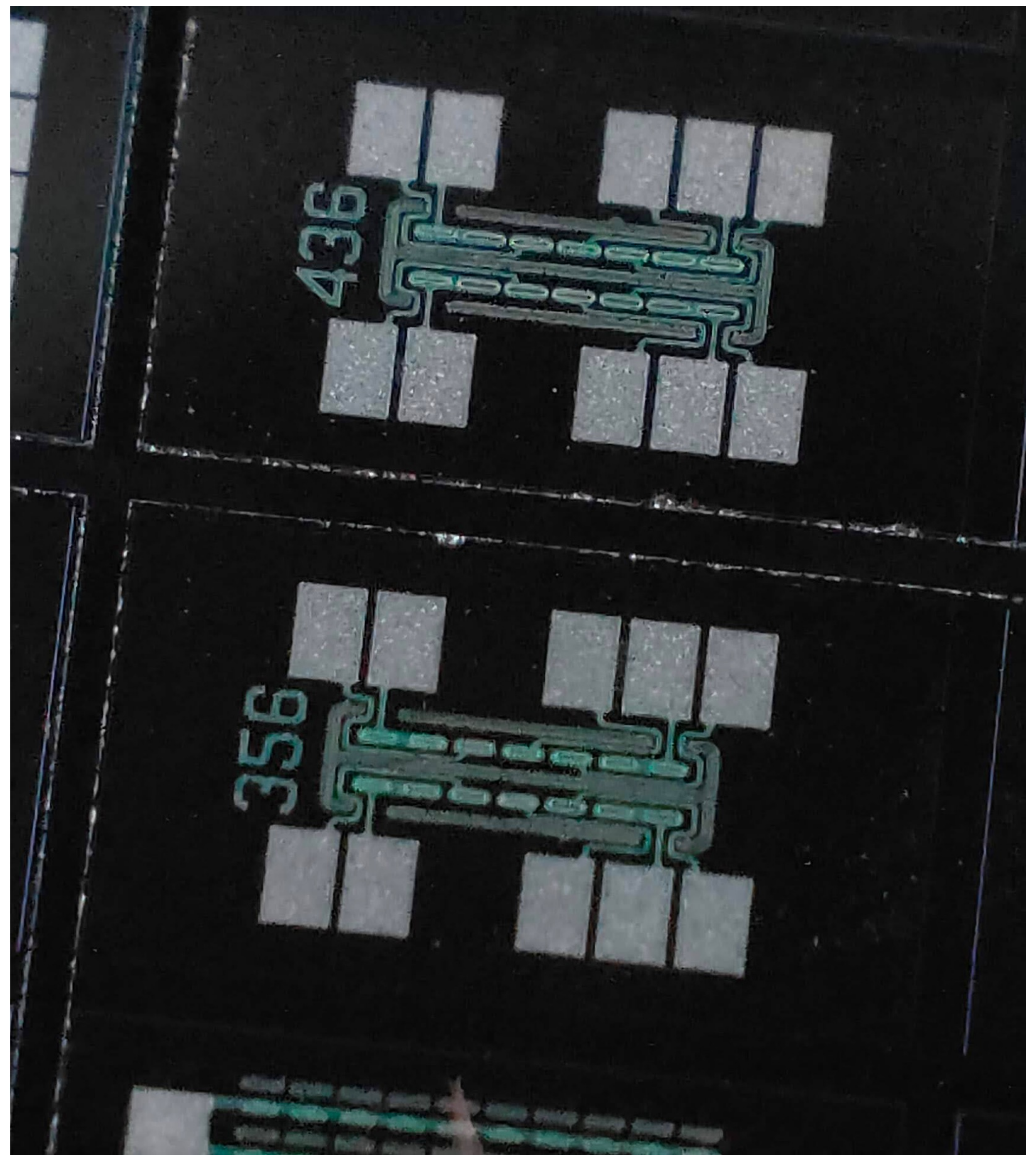


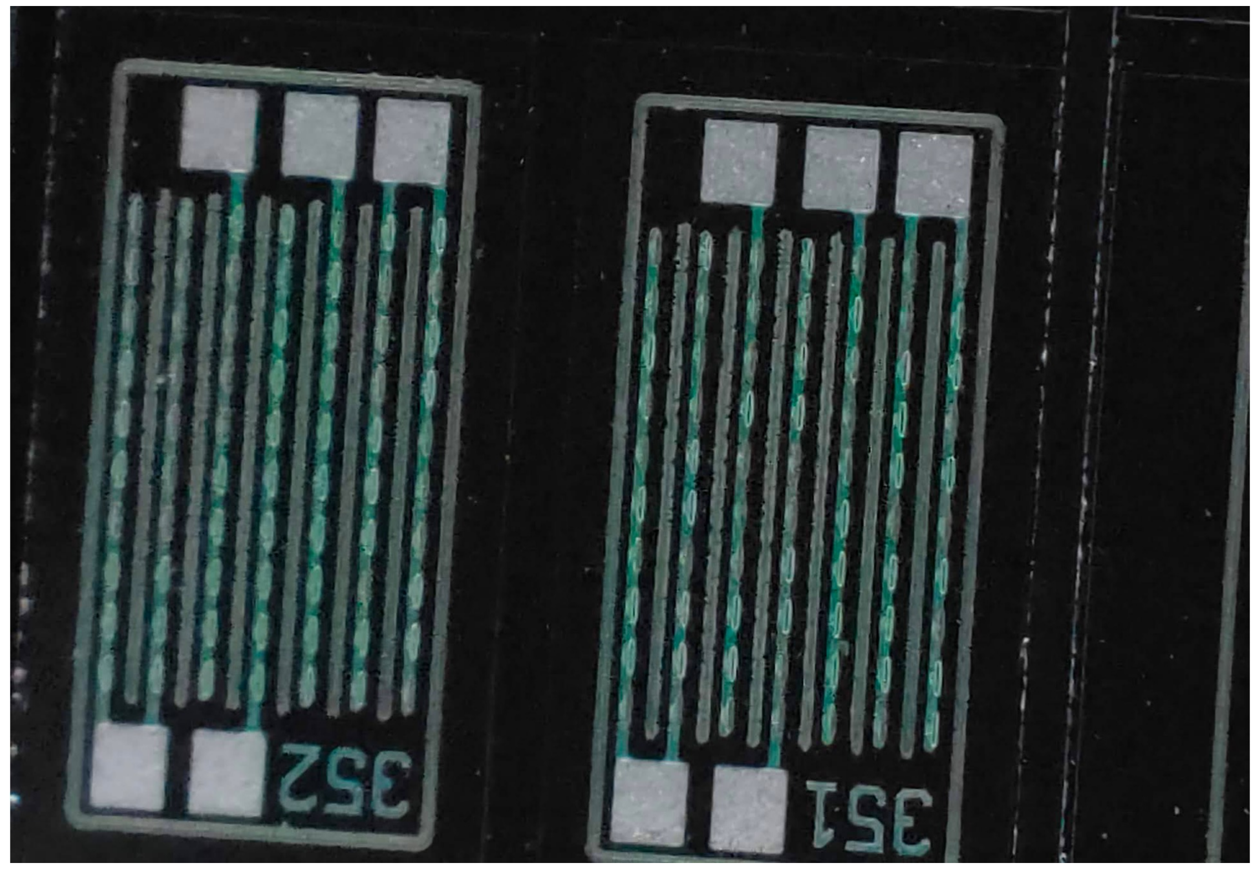
- Pixels ~ 55 mum x 55 mum
- Sensors biased down to -150V
- Very short pulses < 1 ns
- Very promising radiation resistance
  (2.5 x 10^{16} 1MeV n_{eq} cm^{-2})







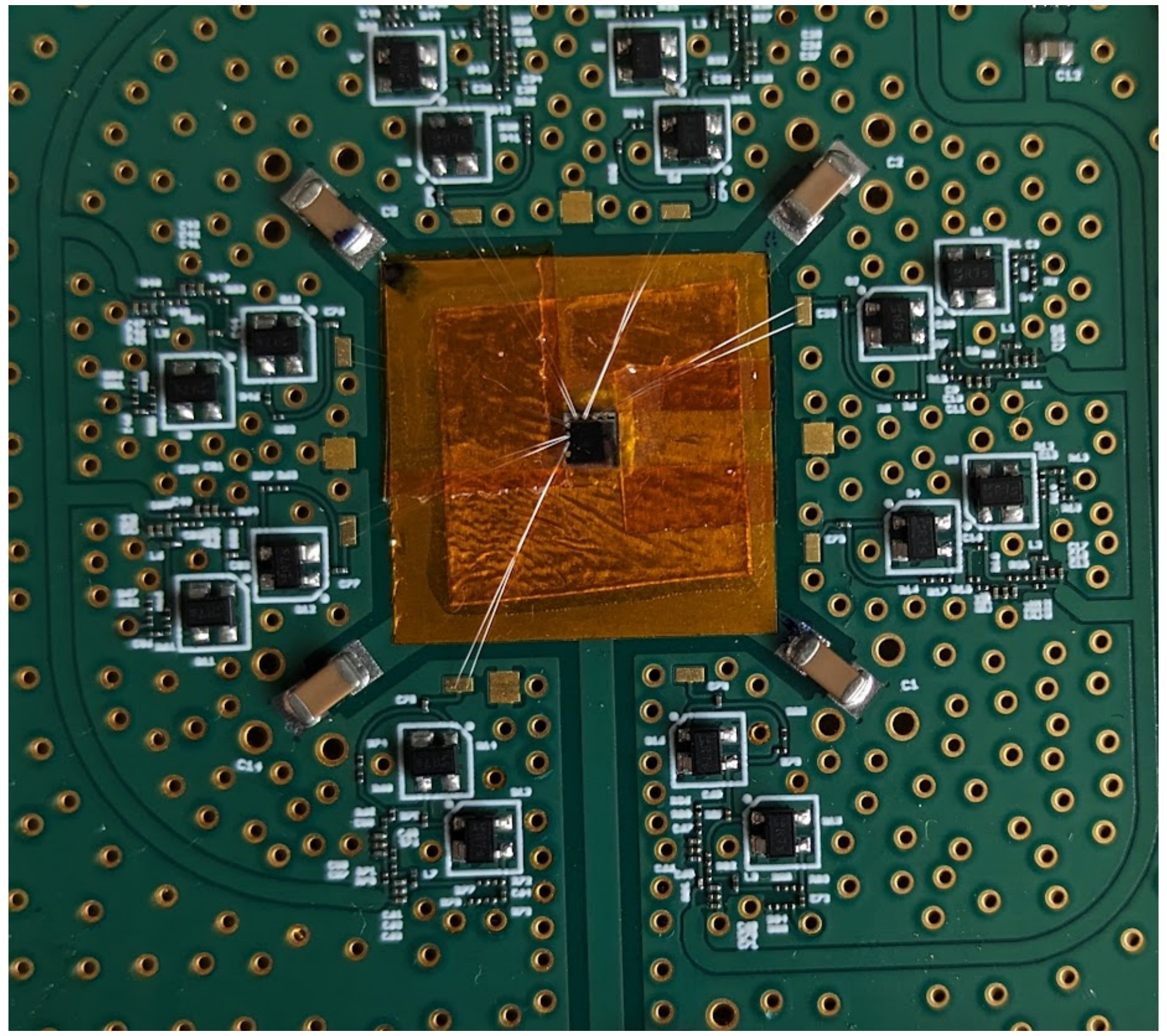


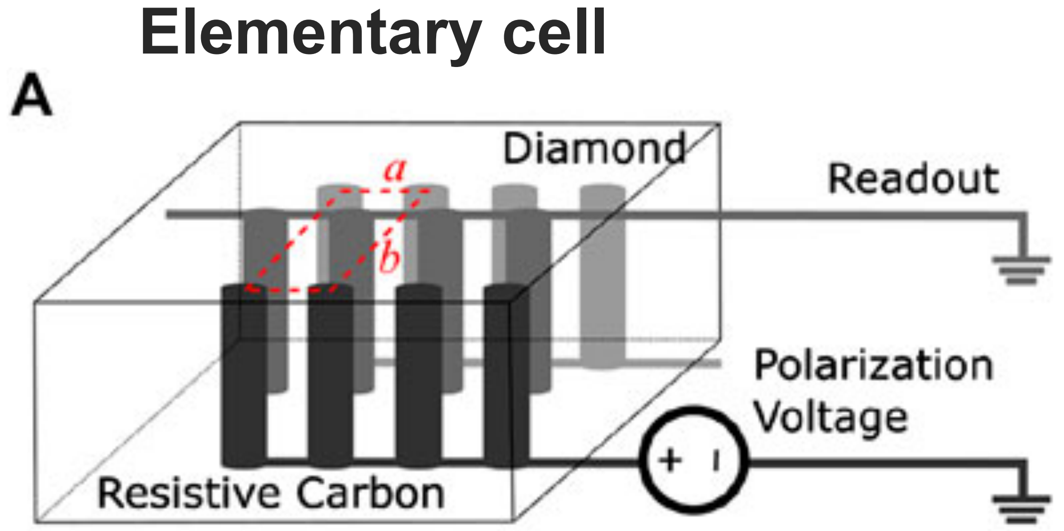


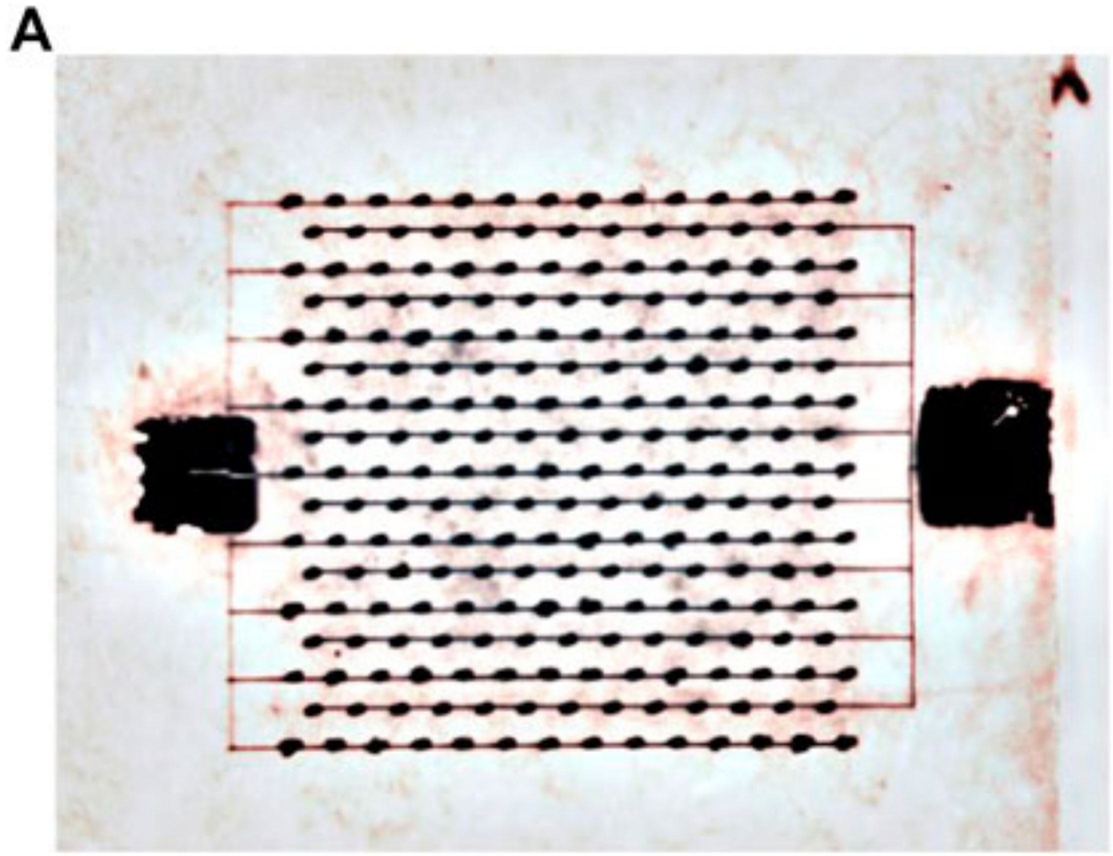
Innovative silicon pixel sensors for a 4D VErtex LOcator detector for the LHCb high luminosity upgrade

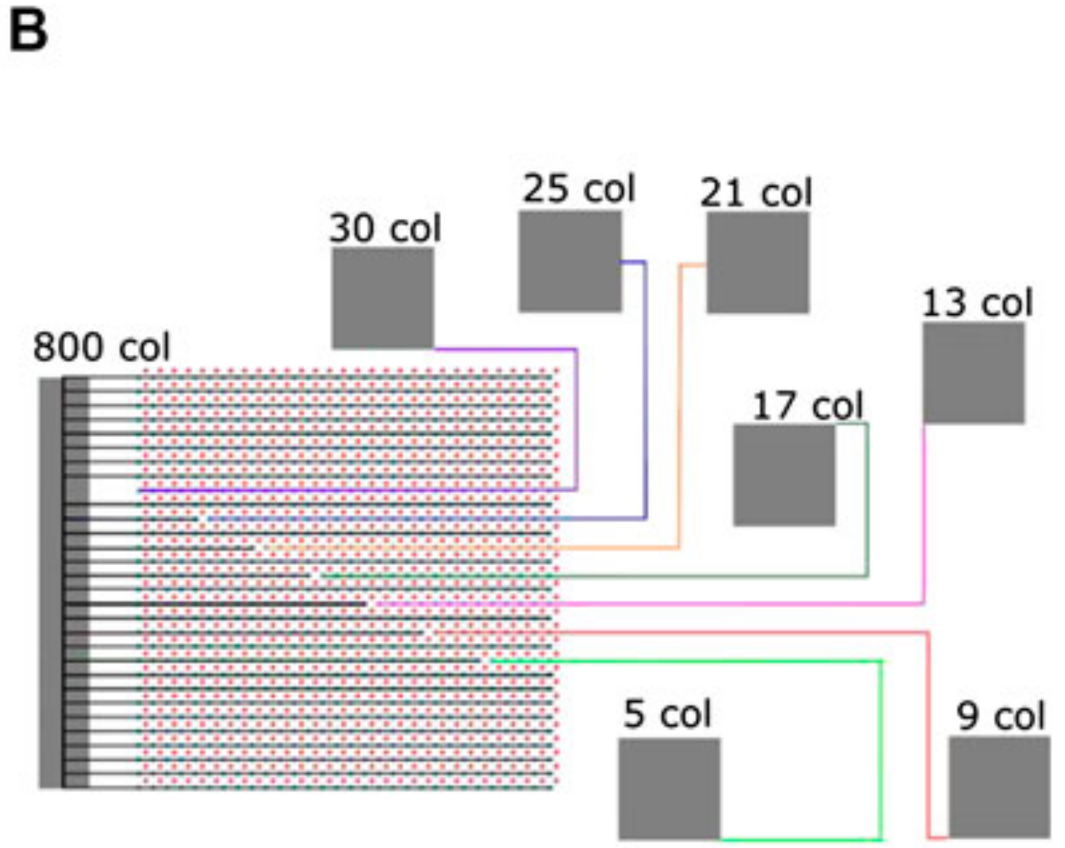
Survey on fast detctor technologies - 3D diamond

3D synthetic diamond

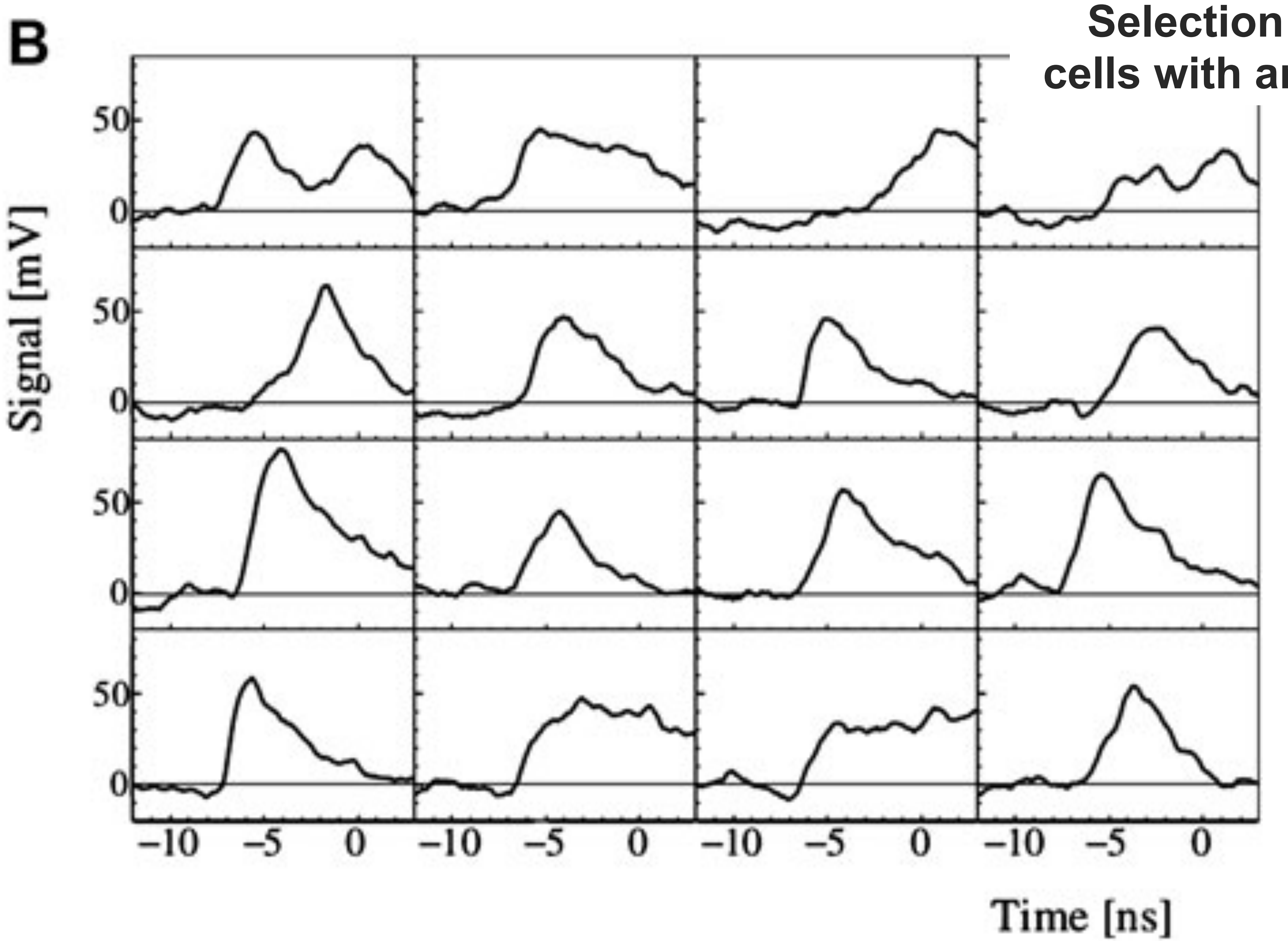








Selection of signals with 30 elementary cells with an amplitude larger than 40 mV

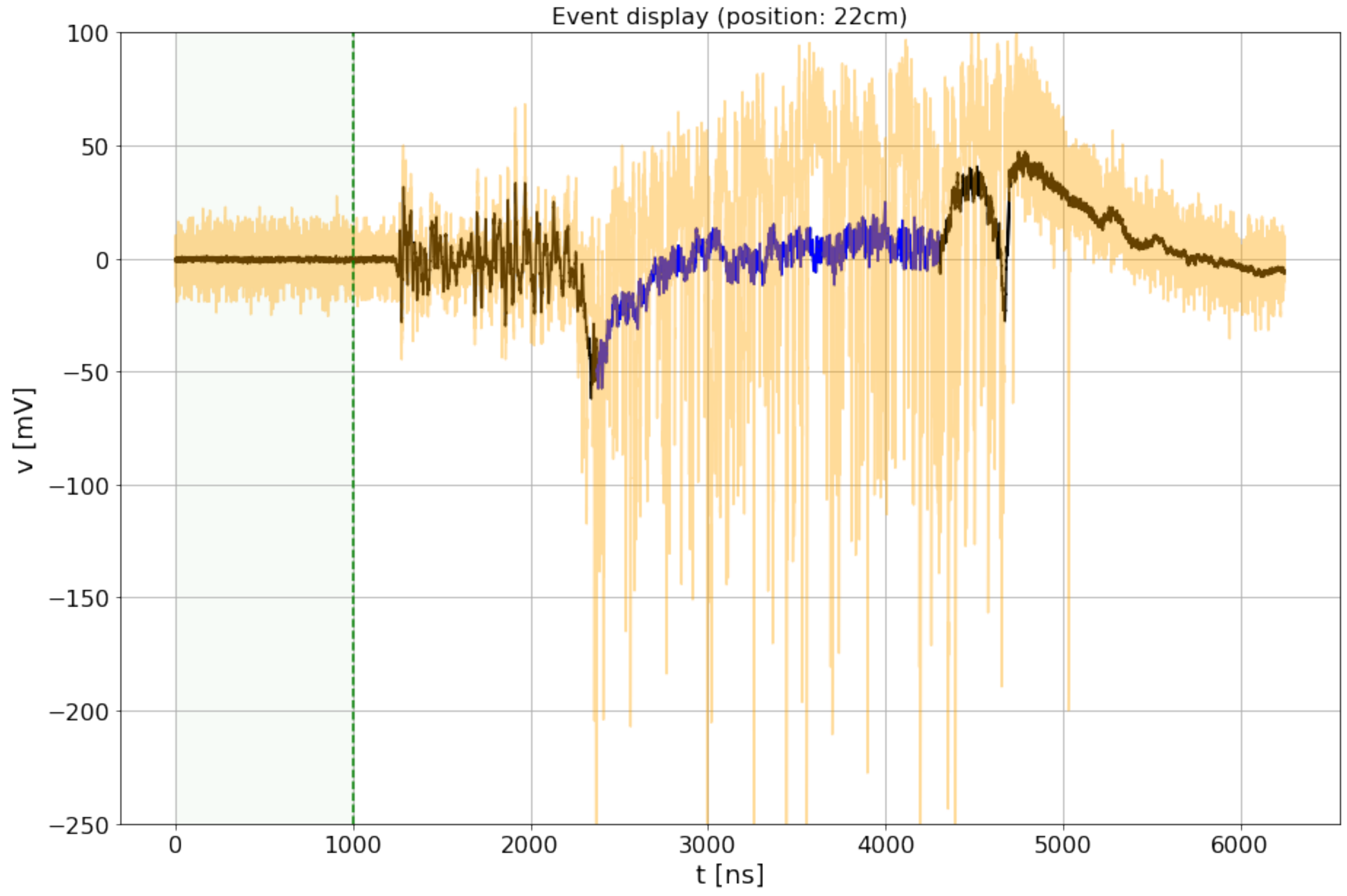


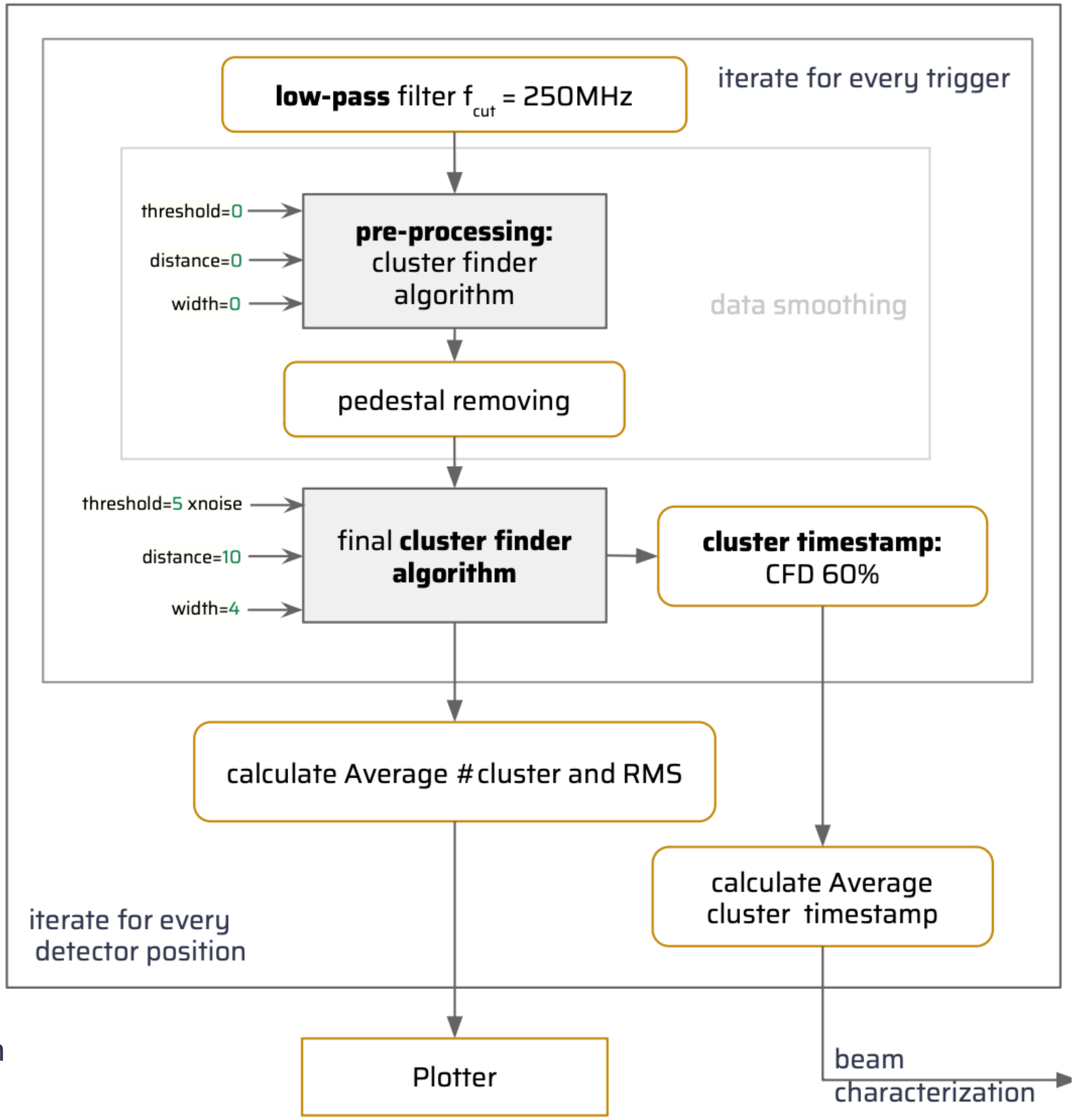
Tested @ PSI with pion beam

- p_{π} = 270 MeV/c
- Tot active area 1.5mm x 1.5mm
- Pixel pitch 55 μm × 55 μm (or 100 mum x 160 mum)
- Bias voltage: −100 to +125

Fabrication and Characterisation of 3D Diamond Pixel Detectors With Timing Capabilities

Previous results - R&D on Dosimetry and medical physics





data smoothing:

average of the data from 0.5 to 1.5 ns before every pulse for each one of the waveforms.

data filtering:

remove from the data the high frequency fluctuations, reducing the uncertainty on the threshold crossing definition

Cluster finder algorithm:

Select the isolated candidate particles

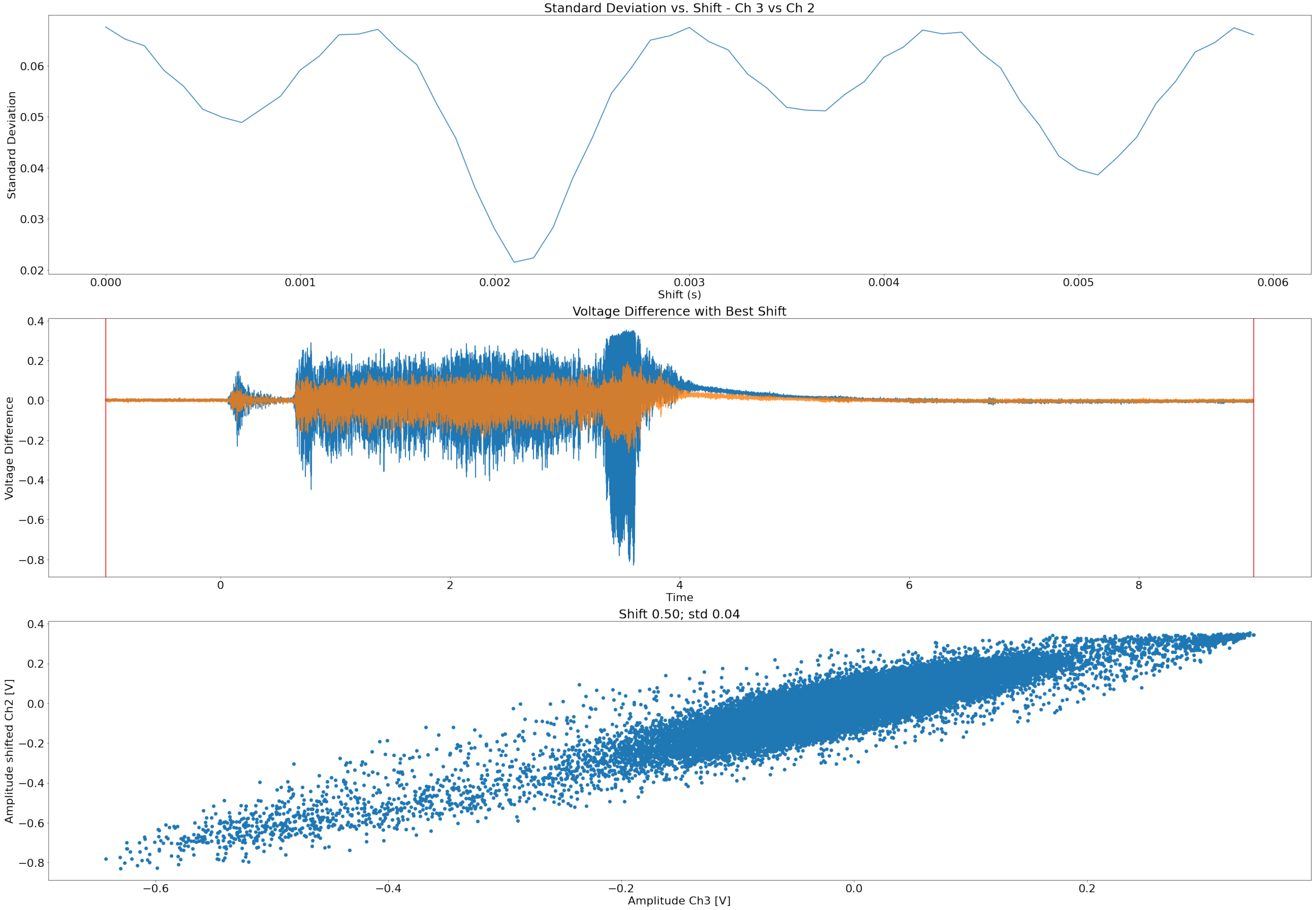
Constant Fraction Discrimination:

Offline algorithms to correct the ToA reconstruction

Preliminary results - noise analysi

Noise Analysis

- Custom python class to:
  - **Iteration Over Shifts:** iterates over a range of shifts, shifting one waveform relative to the other by a set amount of time
  - **Waveform Interpolation:** for each shift, it interpolates one of the waveforms to align with the other
  - **Linear Regression:** It performs a linear regression between the two waveforms to find the best-fit line
  - **Calculation of Standard Deviation:** after finding the best-fit line, it calculates the std of the difference between the interpolated waveform and the waveform under analysis
  - **Minimization of Standard Deviation:** identifies the shift that minimizes the std, indicating the best alignment between the two



The Jlab Hall-C electron detector

> set of four diamond planes each with 96 “microstrips”

> Each strip is 0.180 mm wide separated by 0.02 mm.