CERN Linear Electron Accelerator for Research

U.S. DEPARTMENT OF ENERGY
Office of Science

Timing detectors tests

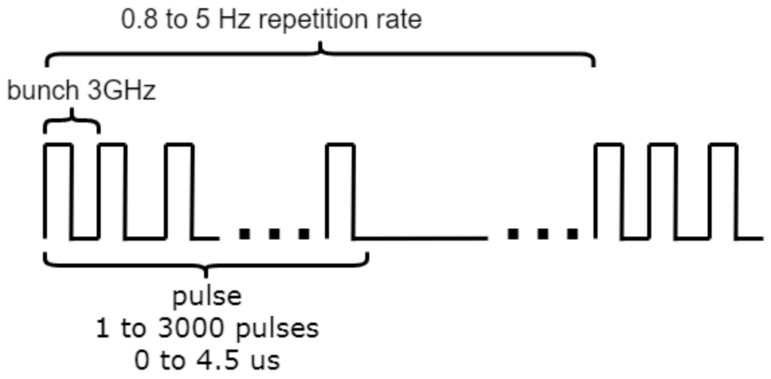
at the CLEAR beam line

Tommaso Isidori - Nov 8th 2023

Timing detectors tests at the CLEAR beam line

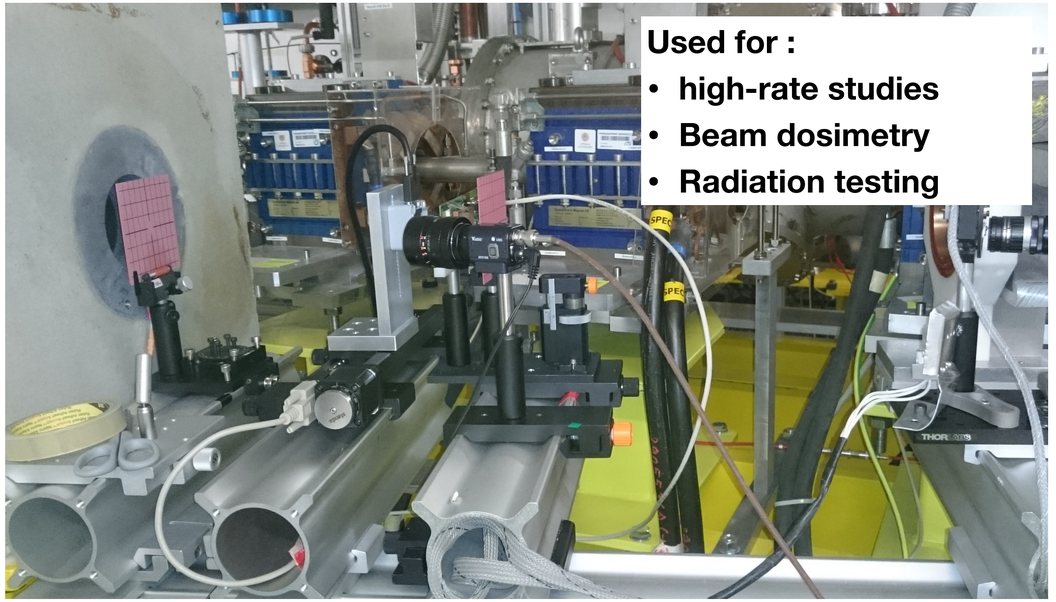
the Vesper facility

VESPER (Very energetic Electron facility for Space Planetary Exploration missions in harsh Radiative environments



High rate Electron Beam

Energy: 60 - 220 MeV
Pulse Rep Frequency (on DUT): 0.8 - 5Hz
Pulse structure: 1 - 3000 bunches
Pulse duration: 0 - 4.5 mus
Frequency: 3GHz frequency (15’000 bunches/5mus)
Bunch population: ~ 4170 electrons (~ 30ps)

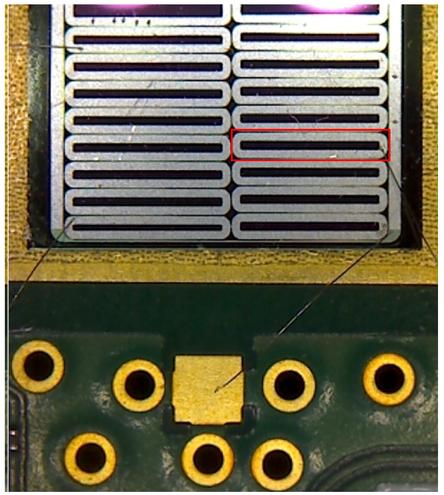


Supports for in-beam alignment
Control room ~ 20 m
Low radiation around the setup can be used for hosting PSU and DAQ

http://vesper.web.cern.ch/

Timing detectors tests at the CLEAR beam line

Previous readout designed used to prove single particle counting capabilities at Medical facilities



LGAD

intrinsic gain = 5-20

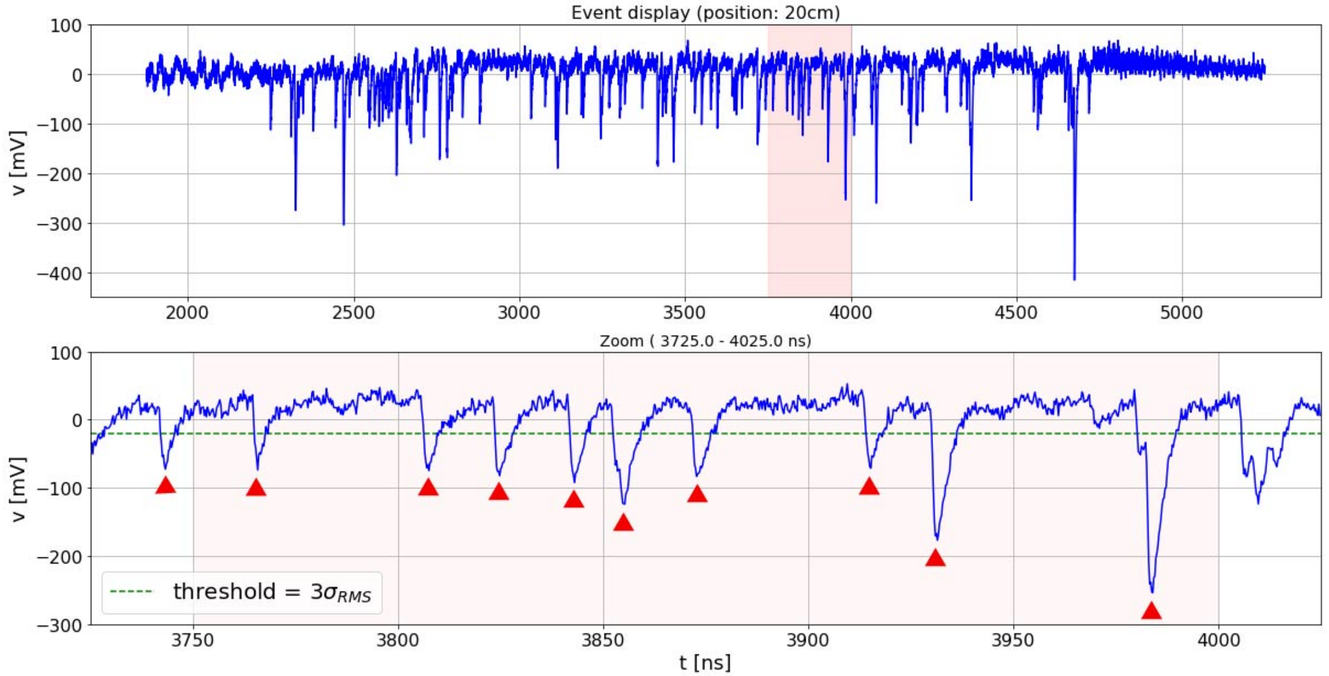
thickness = 50 micron

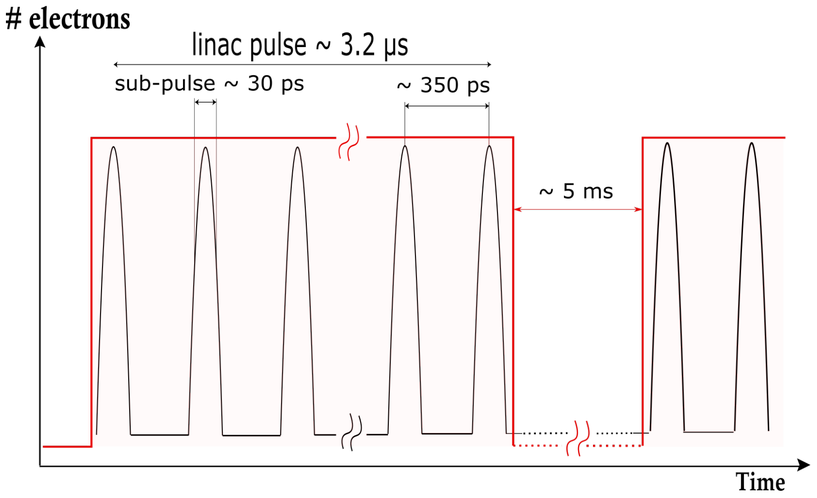
pixel active area = 2.9×0.5 mm2

time resolution ~ 50ps

signal rise time ~ 600 ps

signal width = 5 − 10 ns





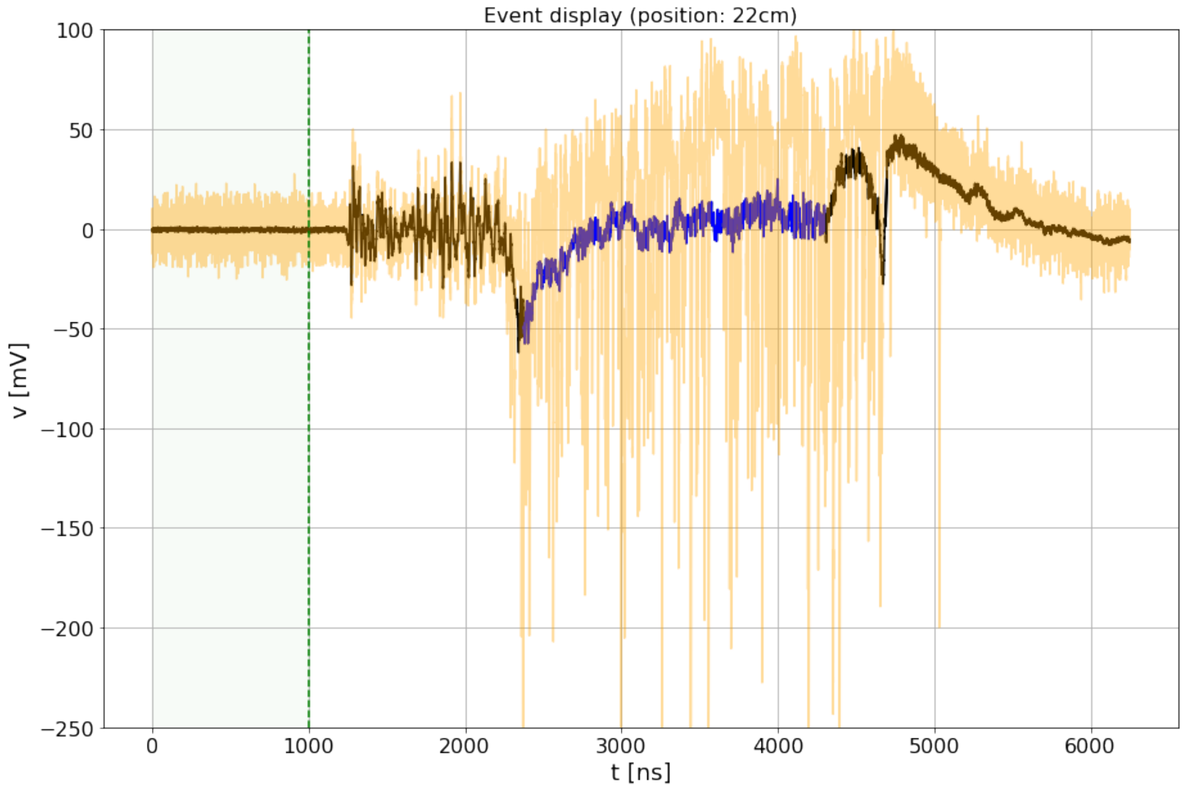
electron beam

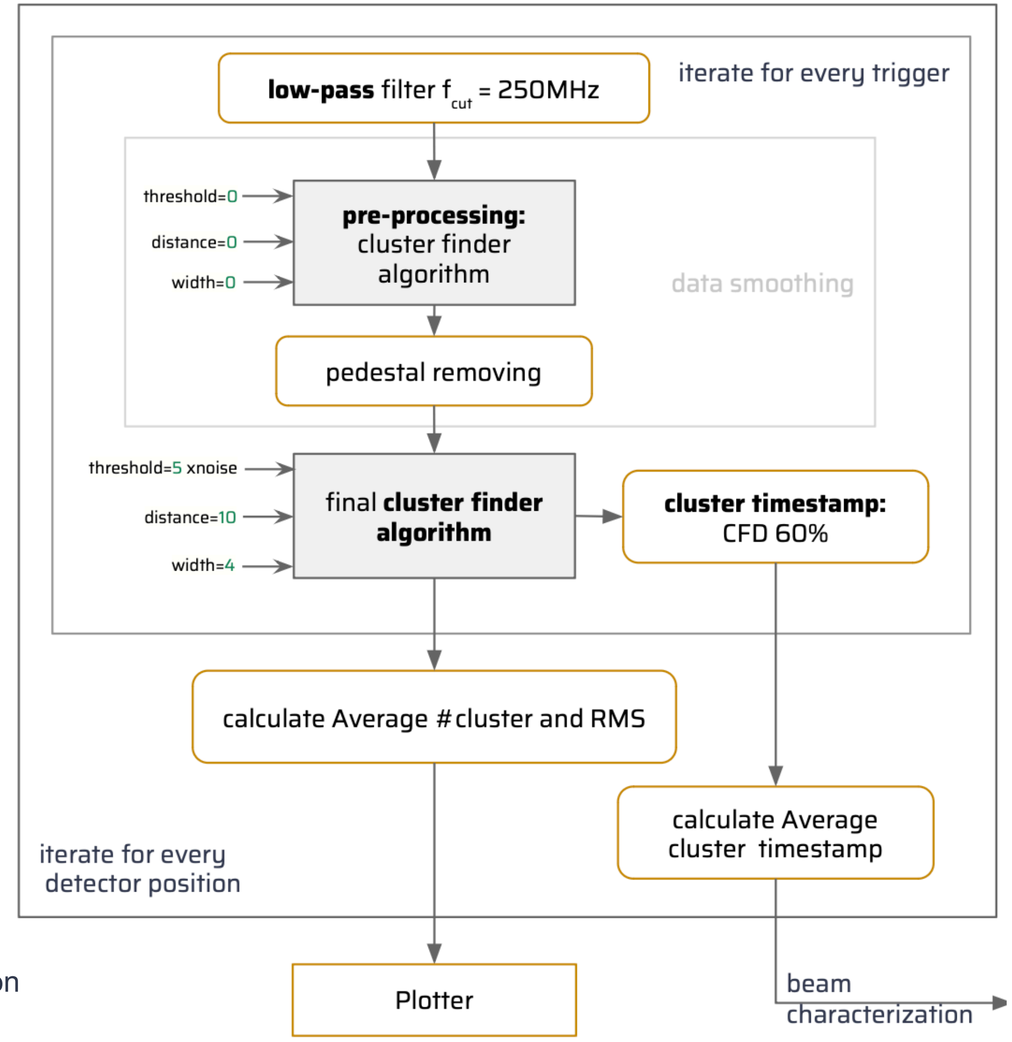
energy 4-18 MeV

dose rates up to 600 MU/min

pulse repetition frequency of 200 Hz

Timing detectors tests at the CLEAR beam line





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

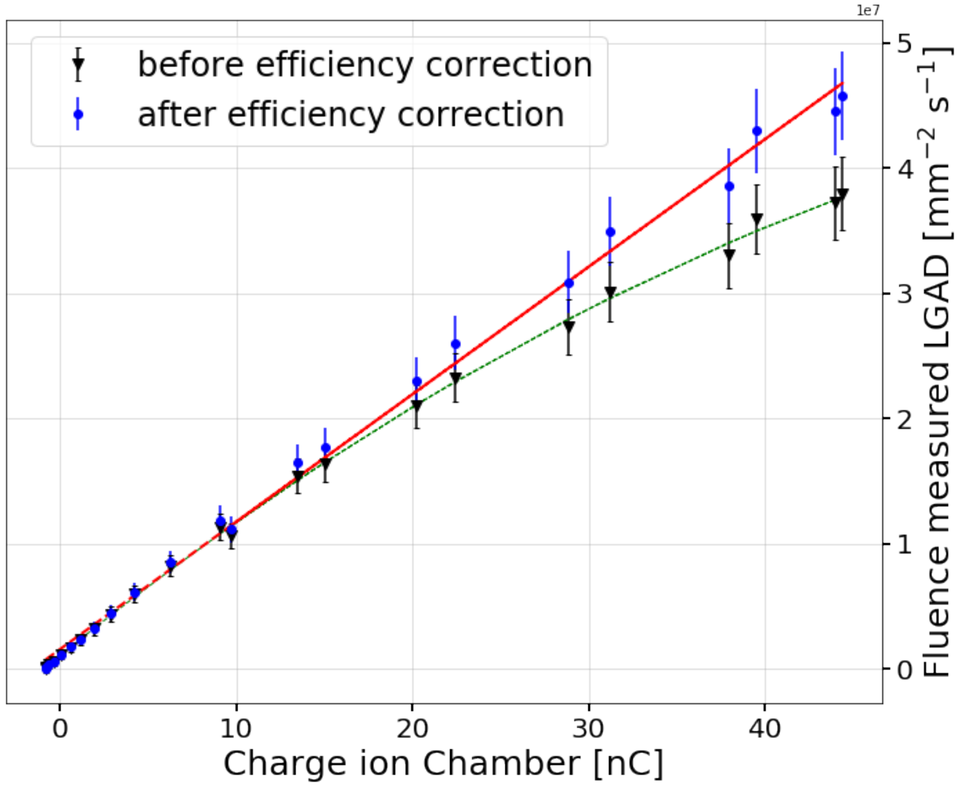
Constant Fraction Discrimination:

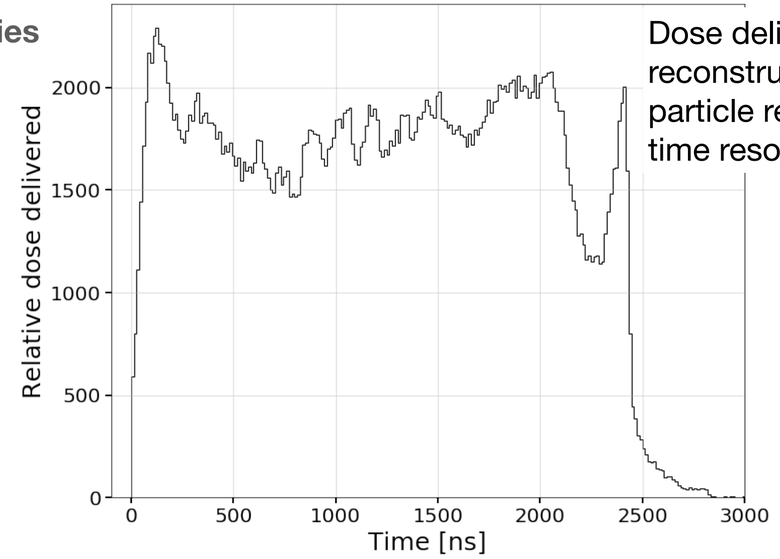
Offline algorithms to correct the ToA reconstruction

Timing detectors tests at the CLEAR beam line

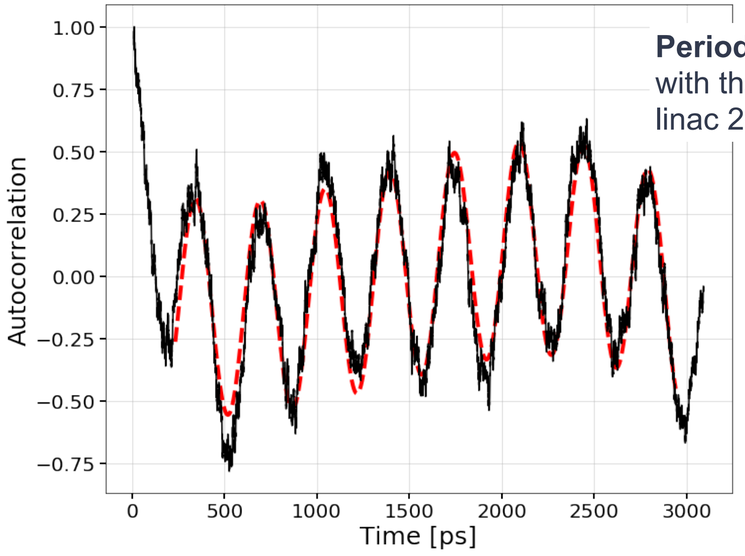
Previous readout designed used to prove single particle counting capabilities at Medical facilities

Timing detector response calibrated using medical Ion chamber





Dose delivered over time reconstructed w/single particle resolution and ~50 ps time resolution

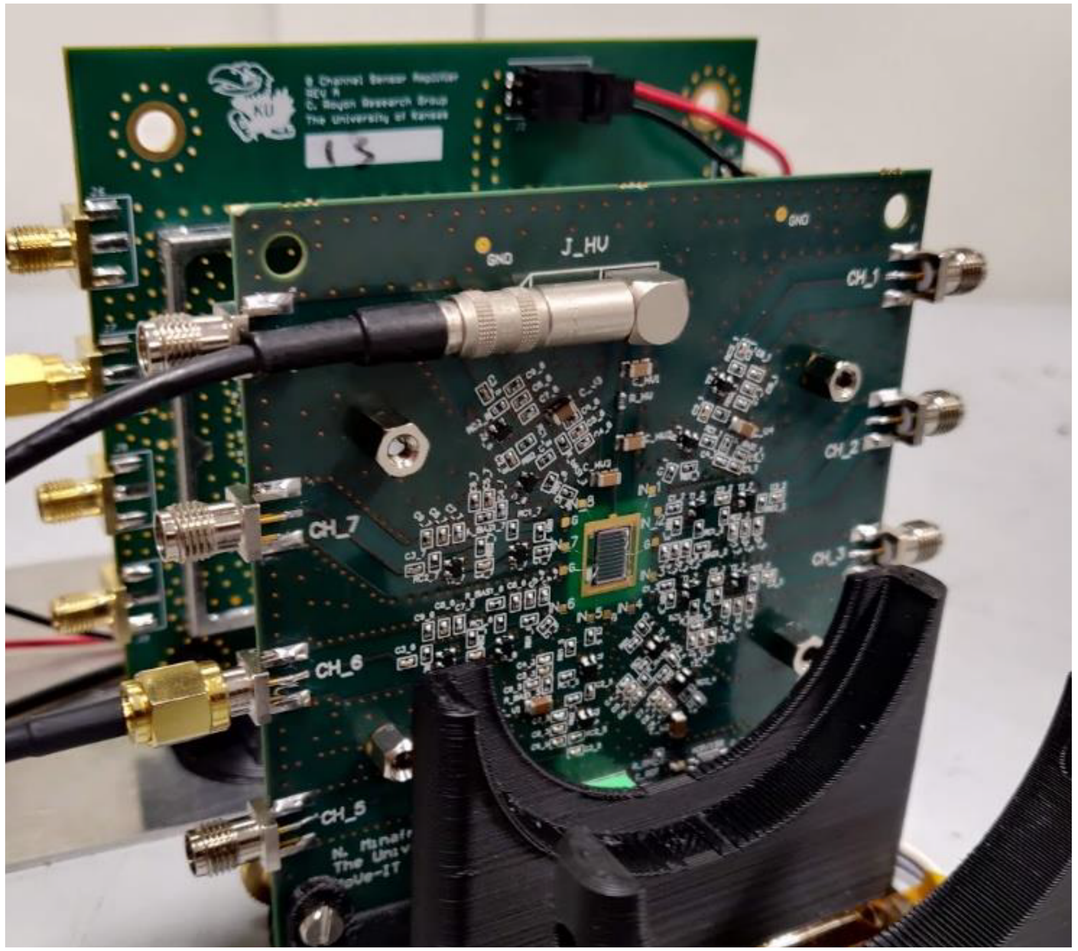


Period = 346 ± 3 ps, consistent with the nominal frequency of the linac 2856 MHz

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

Timing detectors tests at the CLEAR beam line

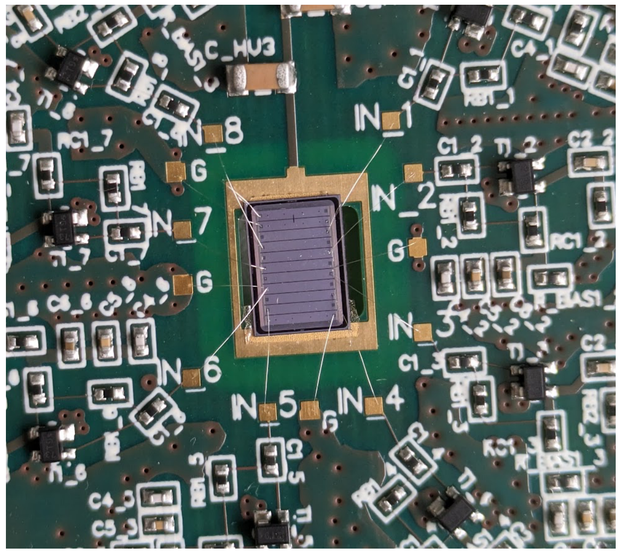
New boards are optimized for fast response (sacrificing some time resolution)



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

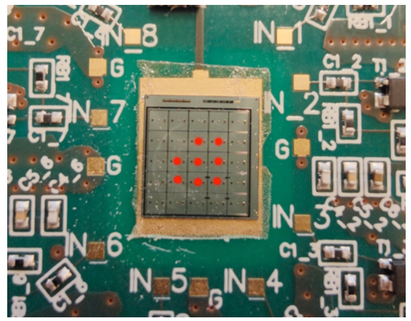


Timing detectors tests at the CLEAR beam line

Results with new boards

Proton beam at the 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
- $4x10^6$ - $4x10^8$ protons/sec
- Nominal pulse structure RF=26.26 MHz



Thin LGAD

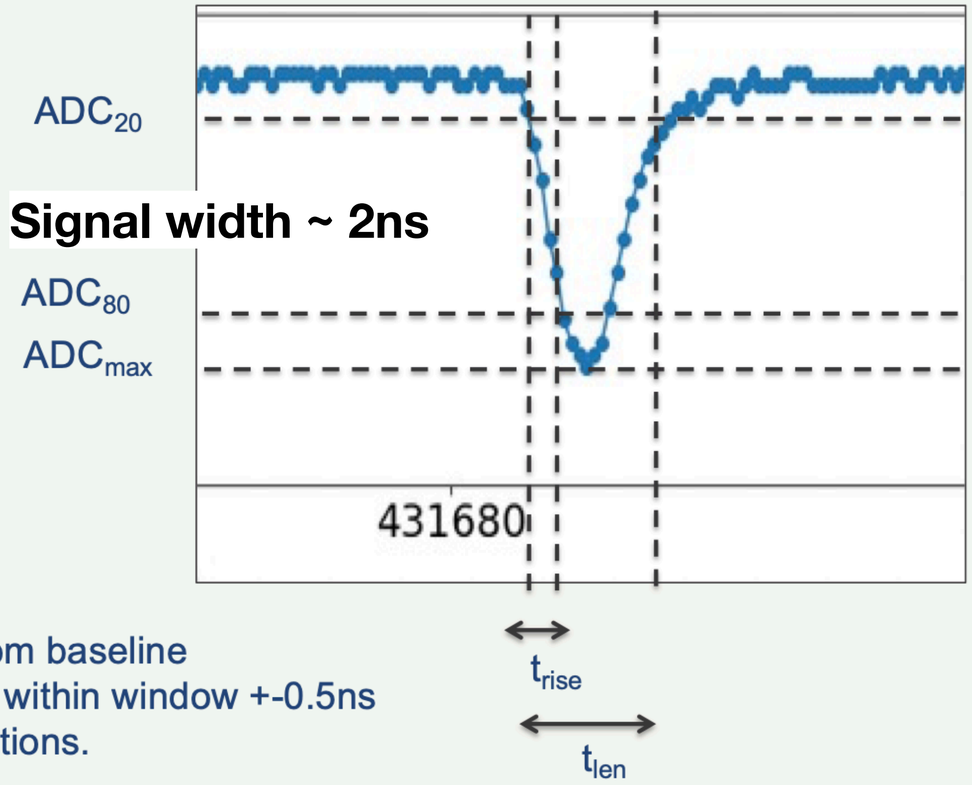
- Pixels 1.3mm x 1.3 mm
- Sensors biased to 180 or 200V
- Gain of ~20
- Short pulses ~ 2.5ns
- Fast rise time allowing precise time of arrival of ~ 50 ps

- Improved detectors
- Improved cluster finding algorithms

Fast timing for proton therapy

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

Cluster identification algorithm



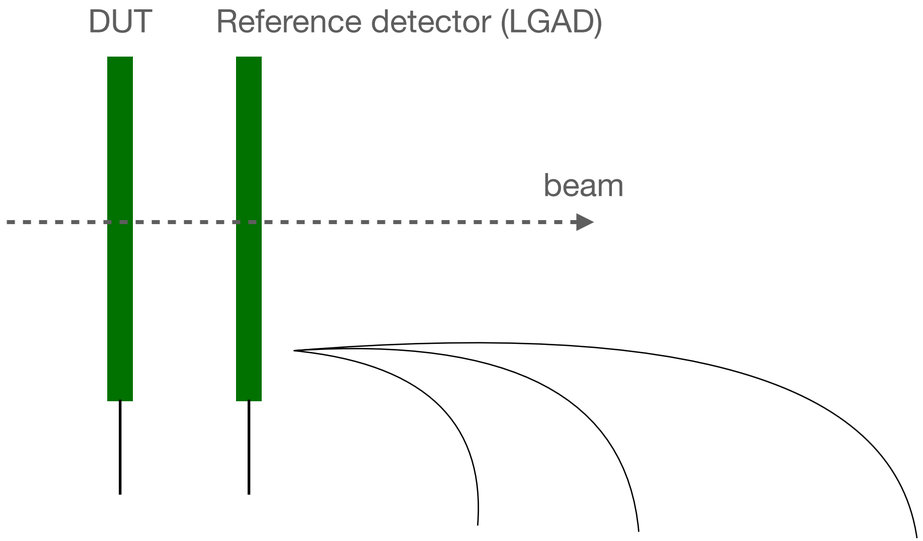
Simple algorithm

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)

Fast timing for proton therapy. R.McNulty, FAST2023 7

Timing detectors tests at the CLEAR beam line

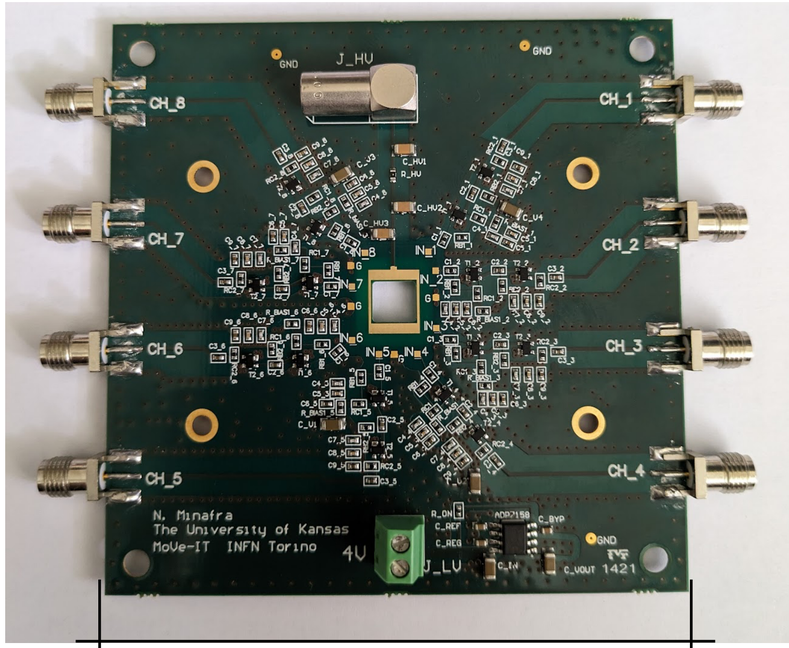


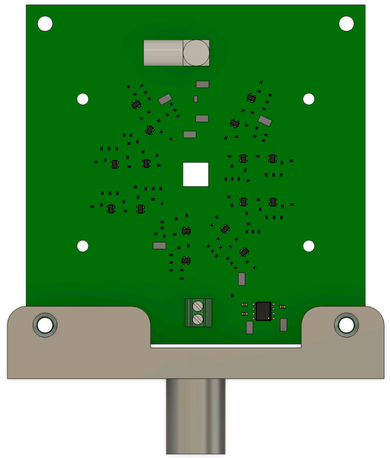
LV PSU

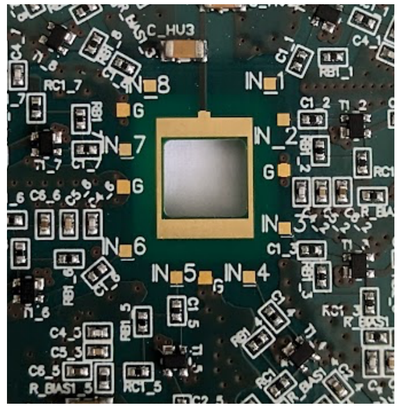
HV PSU
- Bias setting
- I-V monitoring

Oscilloscope
WavePro 254HD-MS
2.5 GHz, 4 Ch, 12 bits, 20 GS/s, 100 Mpts/Ch

KU Custom readout board (N.Minafra)



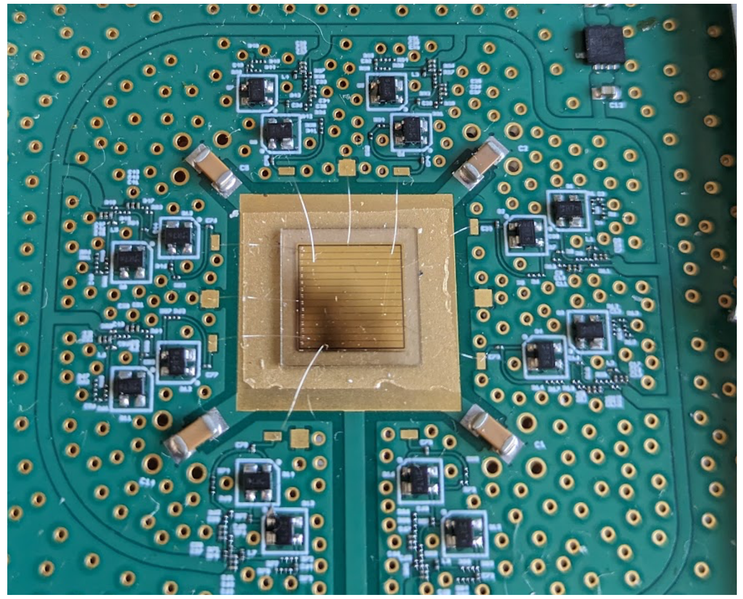


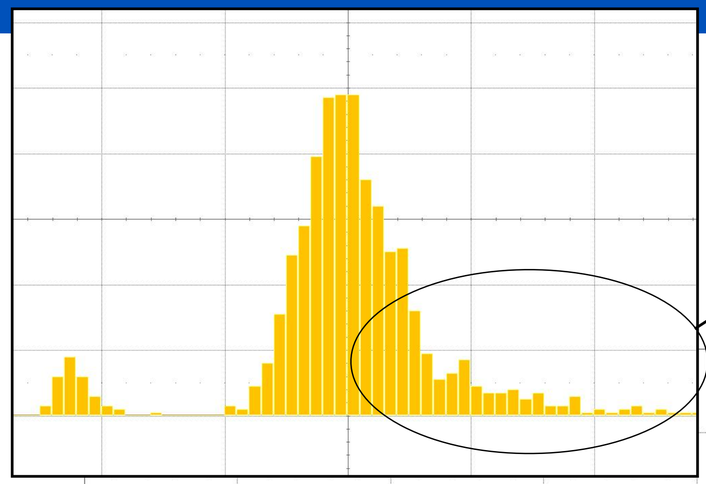


KU Custom readout board (N.Minafra)
- 2 stages (transimpedance) amplification chain
- Discrete components for easy simulation/customization of the performance
- Holed design for reduced material budget

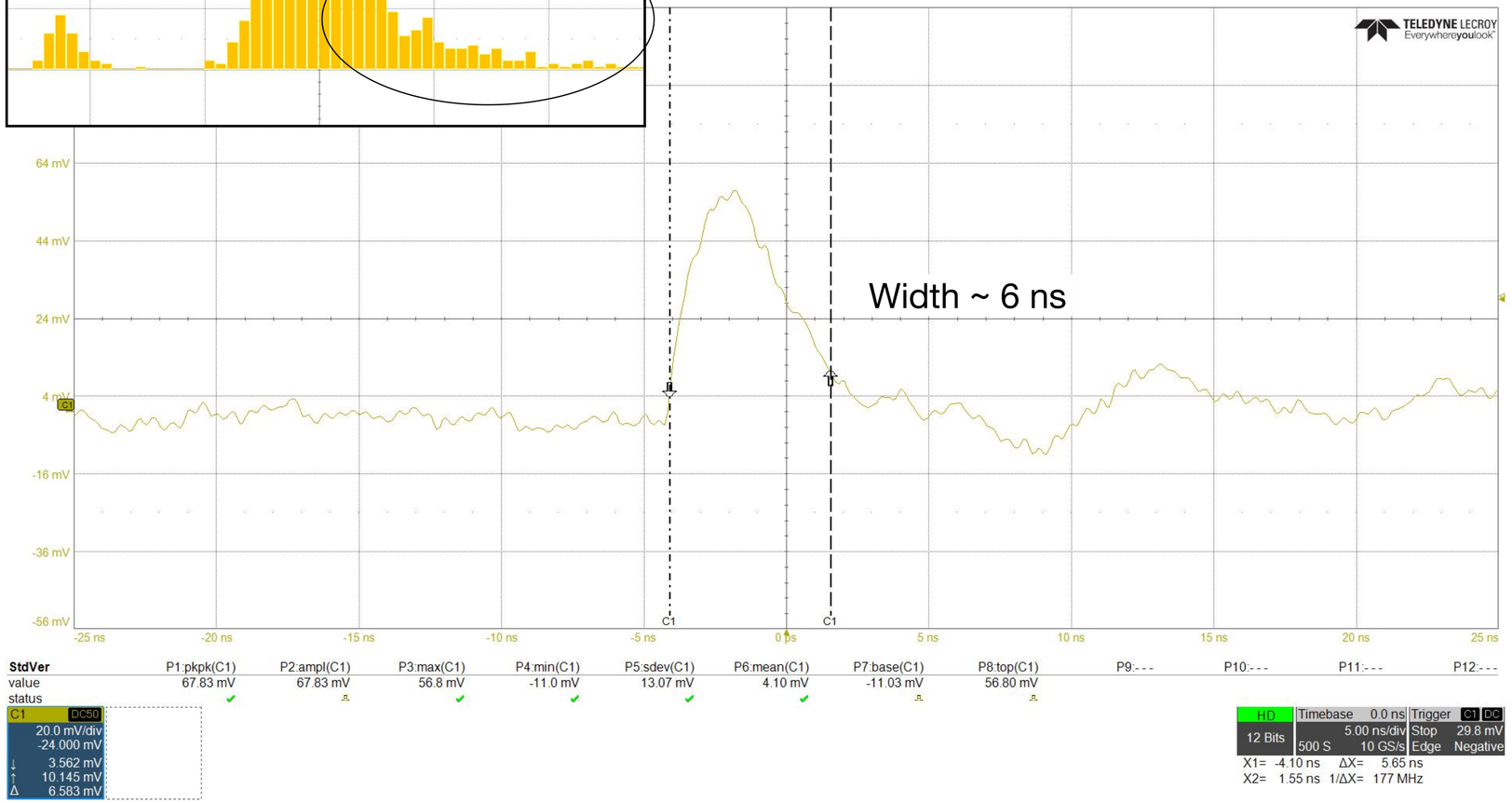
Timing detectors tests at the CLEAR beam line

Baseline pCVD detector





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

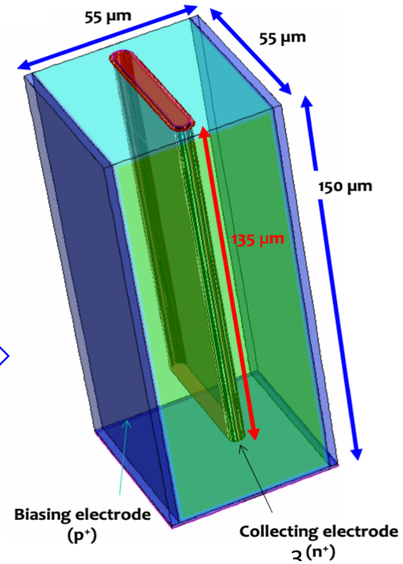


JLAB Poli-crystal CVD

- 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

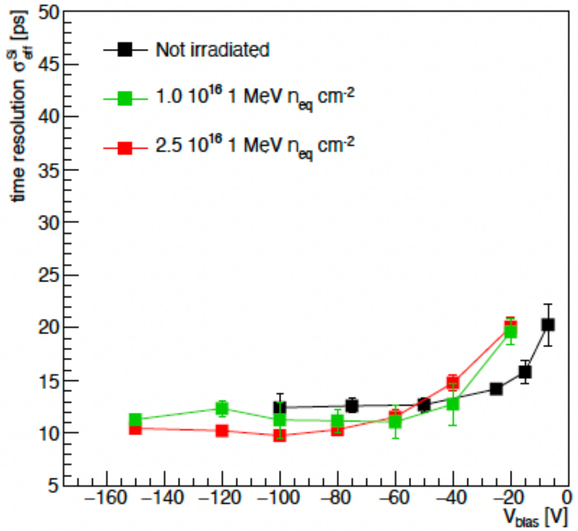
Timing detectors tests at the CLEAR beam line

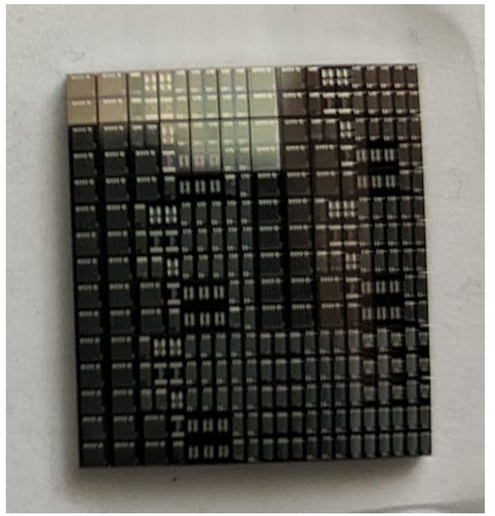
Si 3D trenches detector

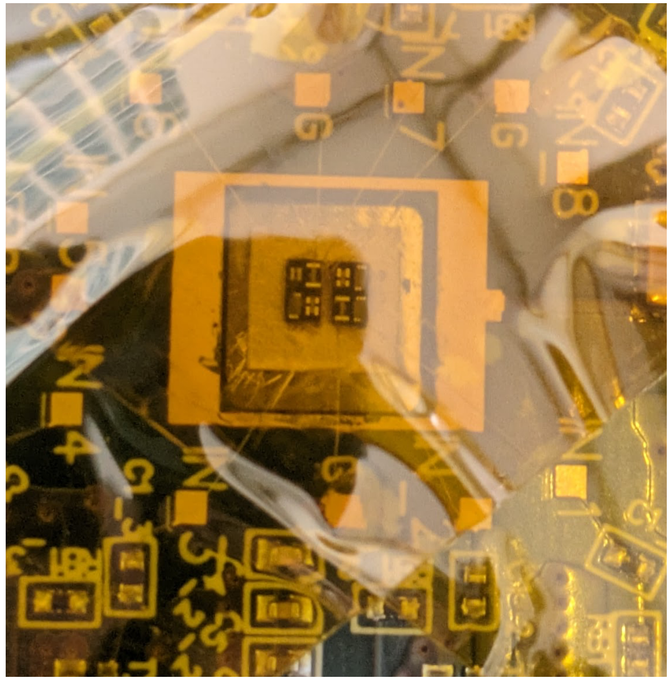


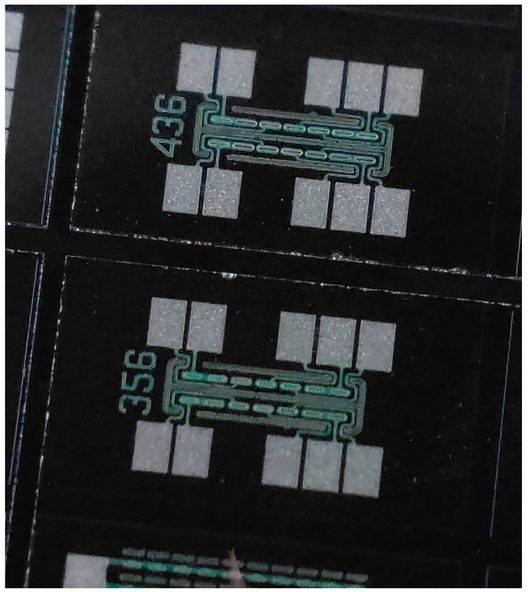
- Pixels ~ 55 mum x 55 mum
- Sensors biased down to -150V
- Very short pulses < 1 ns
- Very promising radiation resistance

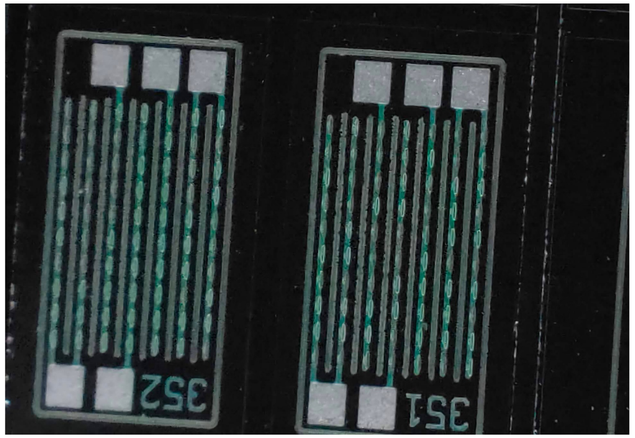
  (2.5 x 10^{16} 1MeV n_{eq} cm^{-2})







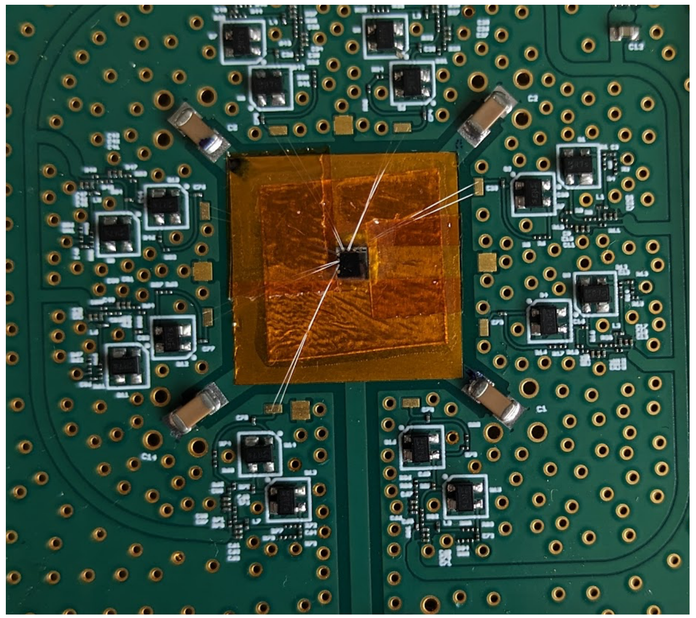




Innovative silicon pixel sensors for a 4D VErtex LOcator detector for the LHCb high luminosity upgrade

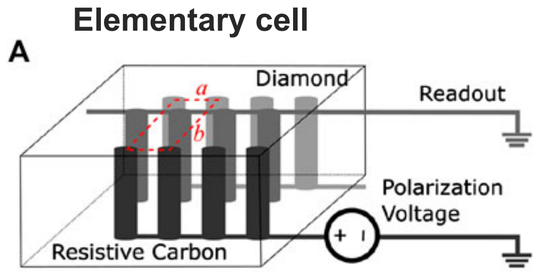
Timing detectors tests at the CLEAR beam line

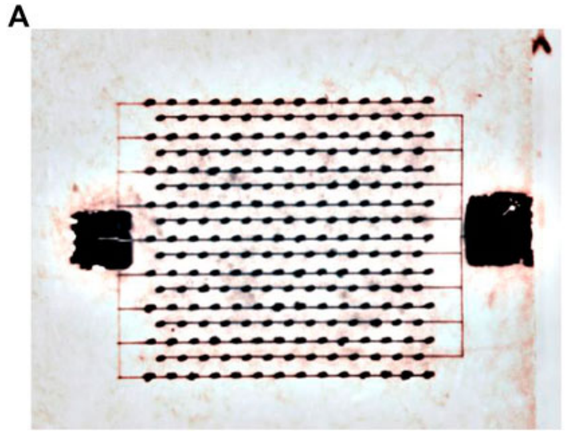
3D synthetic diamond

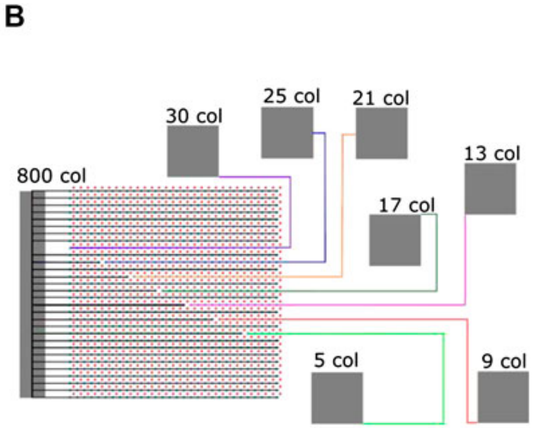


Tested @ PSI with pion beam

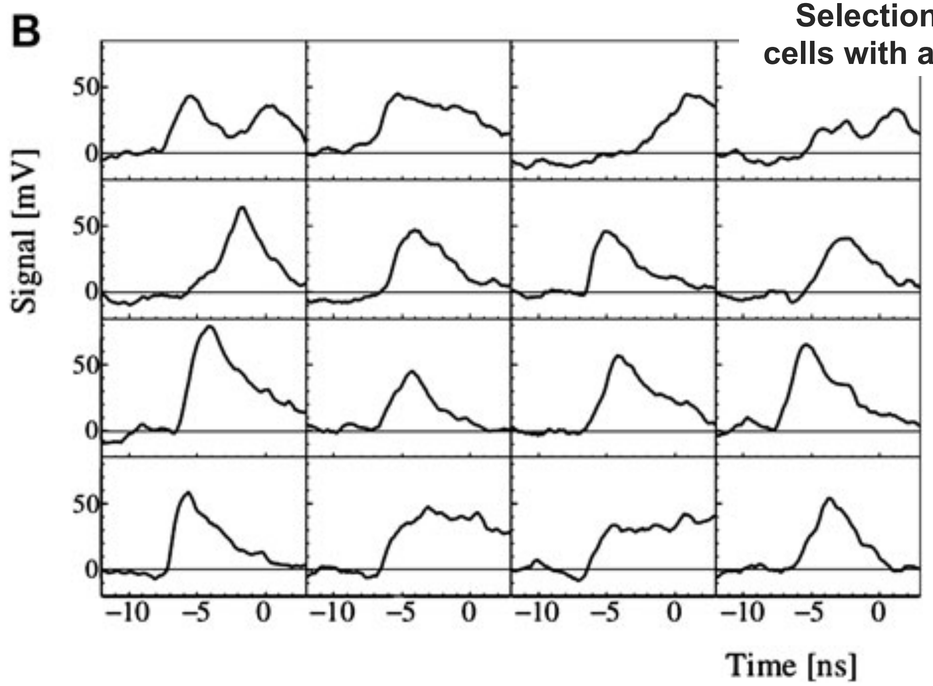
- p_π = 270 MeV/c
- Tot active area 1.5mm x 1.5mm
- Pixel pitch 55 μm × 55 μm (or 100 mum x 160 mum)
- Bias voltage: −100 to +125







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



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

Timing detectors tests at the CLEAR beam line

Summary and Beam plan

- 2 days of High rate tests at the CLEAR facility scheduled for Nov 13th -Nov 14th
- Beam parameters to be agreed with the facility team
- Pool of timing detector with promising (spatial and timing) performance to be tested with high rate electron beam
- Sensors choice criteria: radiation hardness, fast signal integration, optimal space resolution, segmented structure
- Tests results could be of interests for the EIC Compton polarimetry community
- The optimized readout design and reconstruction algorithms can help in the development of the polarimeter

Todo list

- Interests in testing 3D Si with columnar geometry
- Interest in testing AC-LGADs
- Few additional tests at high rate facilities scheduled for the end of 2023