AC-LGAD Readout using ALTIROC 0V2B ASIC

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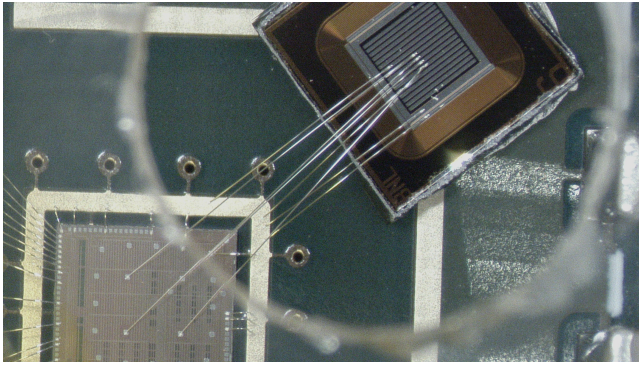
Readout with Altiroc ASIC

Device Under Test

Linear strip BNL AC-LGAD 1x16

- Area: 2×2 mm^2
- 16 strips, pitch 100 μm, gap 44 μm
- Wafer 2003
- V_{bias} = -170 V
- 4 strips bonded to 4 input channels of ALTIROC 0V2B ASIC
- Digital channel DAC = 2020

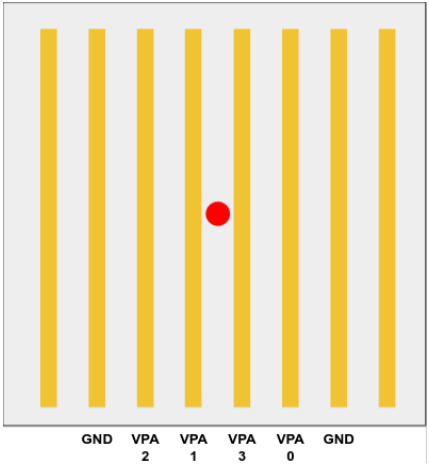


Betas from ^{90}Sr and IR Laser from TCT used to characterize ALTIROC response to AC-coupled signals

Readout with Altiroc ASIC

Device Under Test wirebonding

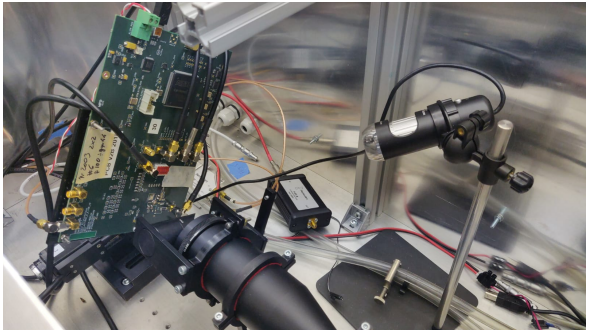
- **Central neighbouring strips** wire bonded to the four input channels on the ALTIROC ASIC
- Strips chosen to be **far from the the device guard-ring** in order to minimize border effects
- Lateral strips on their left and right are wire-bonded to the same ground as the ASIC to keep them to remain floating
- Guard-ring signal sharing should be minimized



[1] [1]Only central strips are shown

Readout with Altiroc ASIC

Altiroc Setup



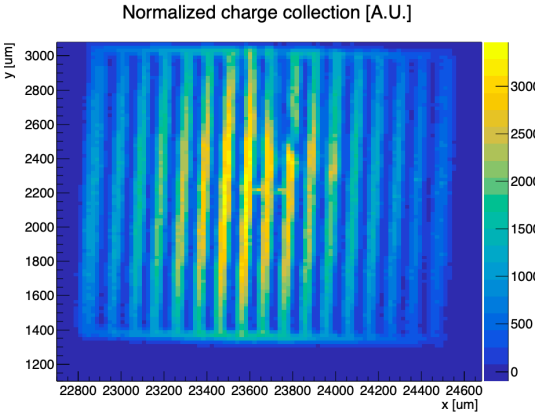
- ASIC ALTIROC 0V2B bonded to ALTIROC Testing PCB V2B (2018, **ver. 1807**)
- **Software Version:** 19072018
- **Firmware Version:** v4
- **IR scans**: conducted using **Particulars Scanning-TCT** apparatus mounting IR laser (1064 nm)
- ALTIROC PCB mounted on a 3-axis computer-controlled mechanical stage with position resolution of less than 1 μm
- **Beta tests:** ^{90}Sr source used for beta tests

Signals from IR laser

Readout with Altiroc ASIC

TCT characterization

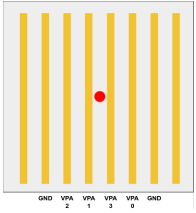
- Characterization of the signal sharing, time and space resolution using ALTIROC 0V2B
- **ALTIROC setup adapted to TCT station**; characterization performed by using an IR laser with 10 kHz frequency
- Colour indicates **integral charge of the signal peak** from the ALTIROC analog output



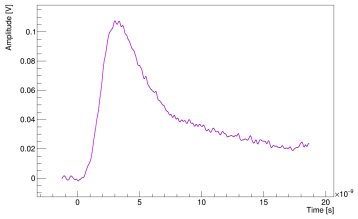
[2] "Wave" effect is due to mechanical vibration in the board support. Will be addressed with a new support in the near future

Waveforms TCT - IR Laser

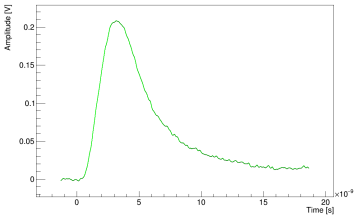
- Signals from IR laser interacting at the center of the sensor (between strip 1 and 3, as shown by **red dot**)
- **Analog output** of the ALTIROC shaper
- Signals from channel 3 and 1 (closest to laser focus) have higher amplitude



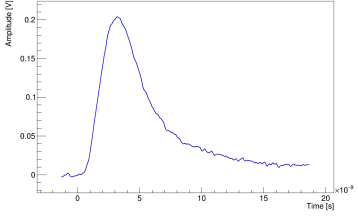
Channel 2



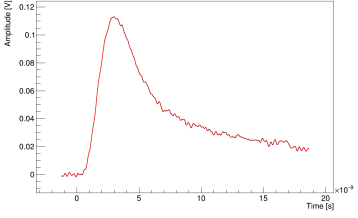
Channel 3



Channel 1

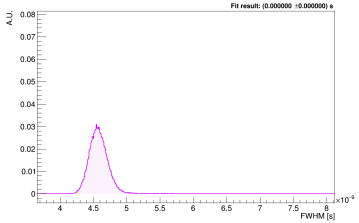


Channel 0



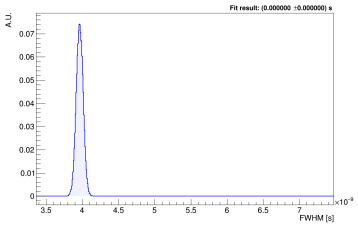
FWHM distributions - IR Laser

Channel 2

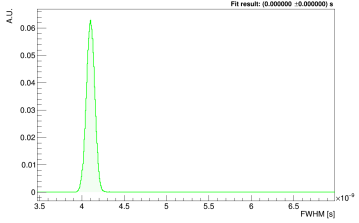


- FWHM of signals acquired from **analog output** of the ALTIROC shaper for all 4 channels
- Fast ($\sim$5 ns) signal **compatible with published results for (DC-)LGAD sensors** read-out via ALTIROC0

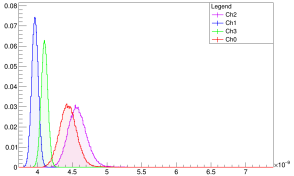
Channel 1



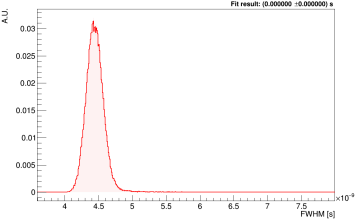
Channel 3



Superimposed distributions

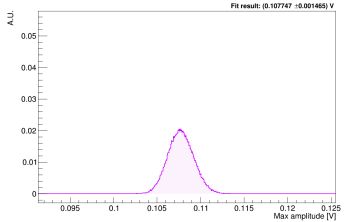


Channel 0



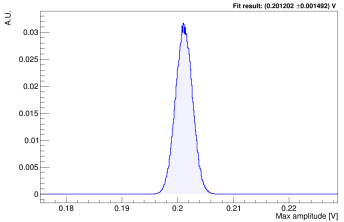
Maximum distributions - IR Laser

Channel 2

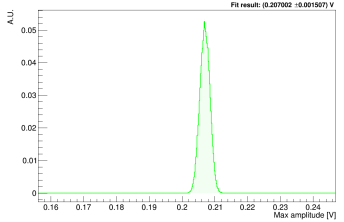


- Amplitude of signals acquired from **analog output** of the ALTIROC shaper for all 4 channels
- Amplitudes of channels 1 and 3 slightly different due to difficulty to focus laser on precise center between two strips caused by setup oscillations (details later)

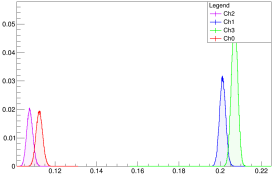
Channel 1



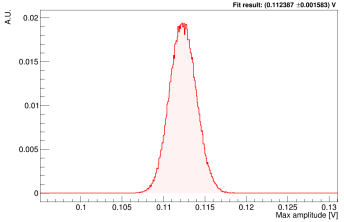
Channel 3



Superimposed distributions

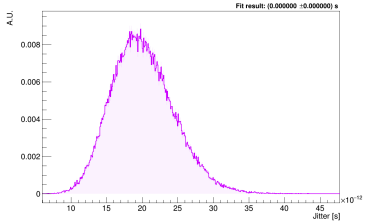


Channel 0



Jitter distributions - IR Laser

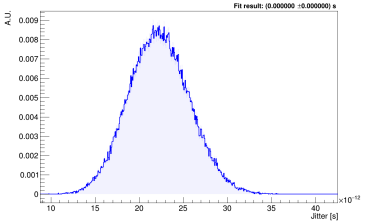
Channel 2



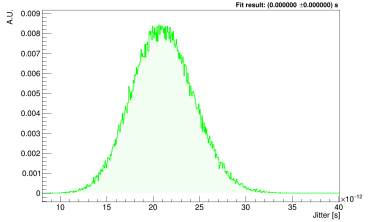
- Jitter of signals acquired from **analog output** of the ALTIROC shaper for all 4 channels
- Jitter distributions consistent for all 4 channels

$$jitter = \sigma_{noise} \left(\frac{dV}{dt} \right)^{-1}$$

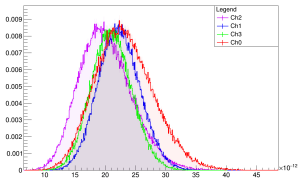
Channel 1



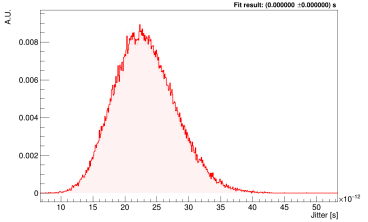
Channel 3



Superimposed distributions



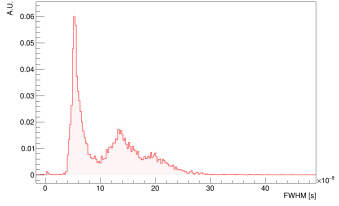
Channel 0



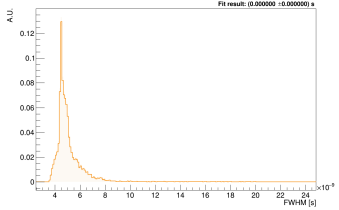
Signals from β particles (^{90}Sr)

Analog FWHM distributions - β particles

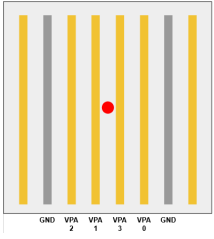
Channel 2



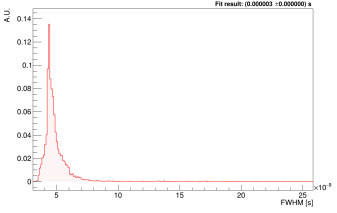
Channel 3



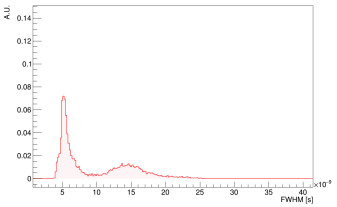
- Lateral channels (ch 0, ch 2) show **complex distribution** with multiple peaks
- Central channels (ch1, ch3) show a **single peak** at FWHM $\sim$ 5 ns
- β spatial distribution should be isotropic, so second population may be caused by proximity to grounded strips (in **grey**)



Channel 1

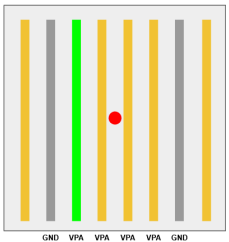


Channel 0

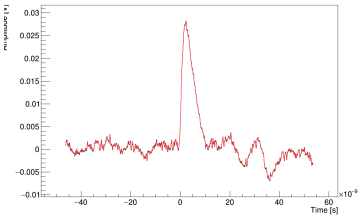


Waveforms from Channel 2 - β particles

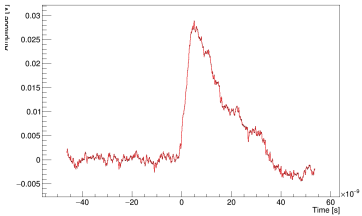
- **Investigation of the shape of analog and digital signals**
- In lateral Ch. 2 (in **green**) are present **two different populations** with different features
- Type 2 signals are wider and often cause the **discriminator to trigger multiple times**



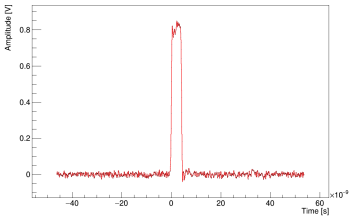
Type 1 analog



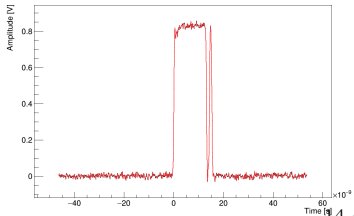
Type 2 analog



Type 1 digital

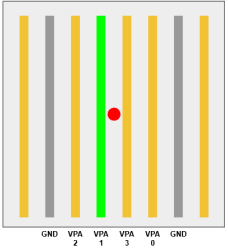


Type 2 digital

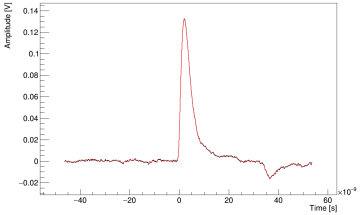


Waveforms from Channel 1 - β particles

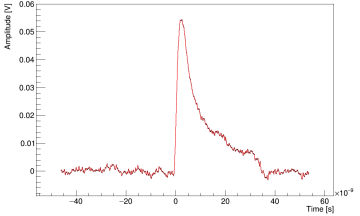
- In central Ch. 1 (in **green**) the two populations seems to be more similar with respect to those in Ch.0
- Type 2 signals are still wider but not as much as in lateral strips



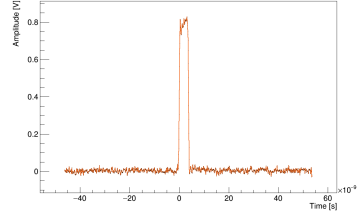
Type 1 analog



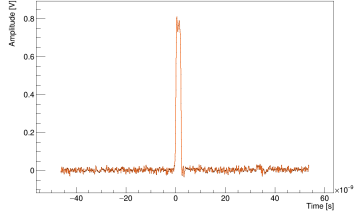
Type 2 analog



Type 1 digital

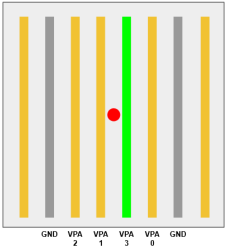


Type 2 digital

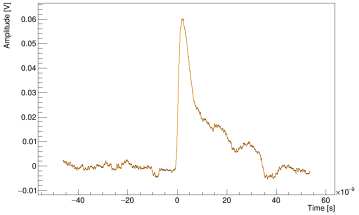


Waveforms from Channel 3 - β particles

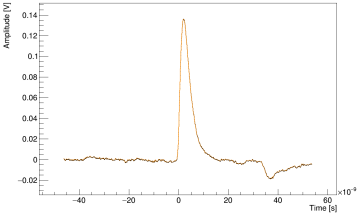
- In central Ch. 3 (in **green**) the two populations seems to be similar to those in the central Ch. 1
- The two **central channels behave similarly**, bolstering our hypothesis



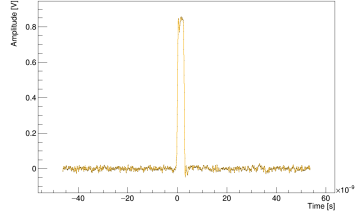
Type 1 analog



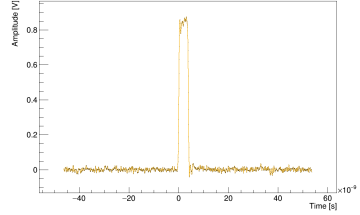
Type 2 analog



Type 1 digital

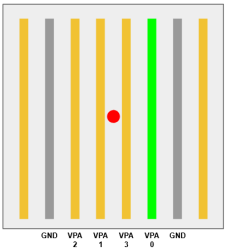


Type 2 digital

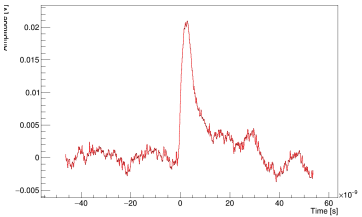


Waveforms from Channel 0 - β particles

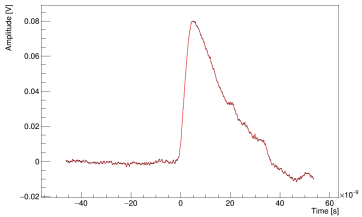
- Finally, lateral Ch. 3 (in **green**) shows types of population that are very similar to those observed in Ch. 0
- **Consistency in populations behaviour**. Further investigations are needed to understand if this effect is originated by signal sharing



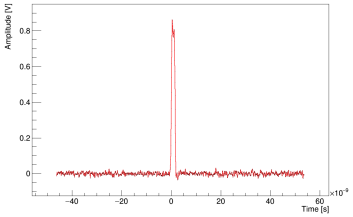
Type 1 analog



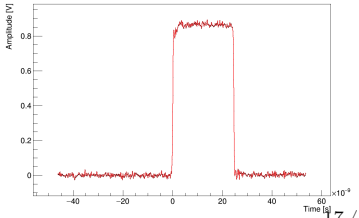
Type 2 analog



Type 1 digital

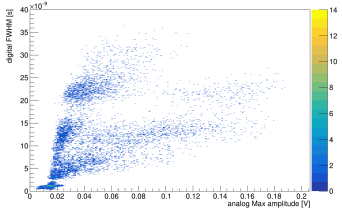


Type 2 digital

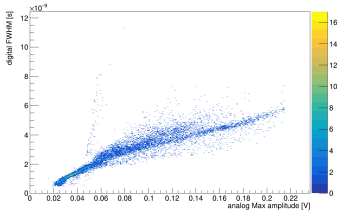


Analog amplitude vs Digital FWHM - β particles

Channel 2

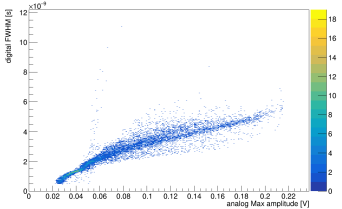


Channel 3

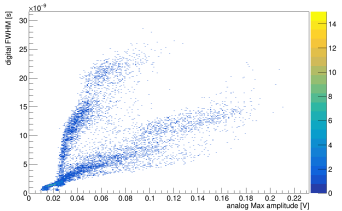


- Discriminator response analyzed by **correlating FWHM of the digital output to the ToT of the analog signal**
- Amplitude of the analog signal used as a proxy to the ToT
- **Linearity** can be observed **in central channels 1/3**
- Clear presence of second population observed in lateral channels 0/2

Channel 1



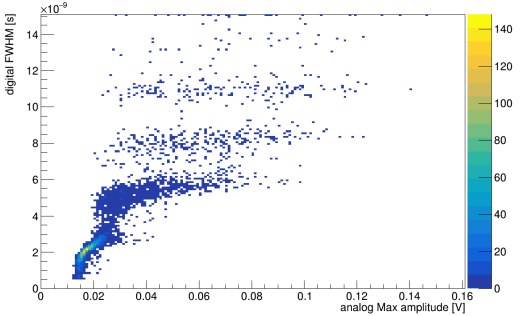
Channel 0



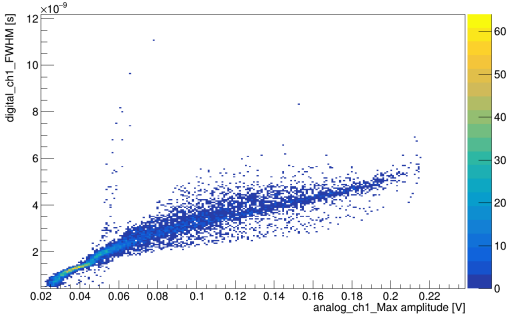
Analog amplitude vs Digital FWHM - β particles

Comparison with previous ALTIROC version

*Old **AC-LGAD + ALTIROC 0** setup*



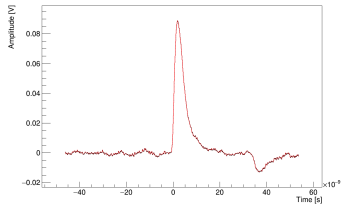
*New **AC-LGAD + ALTIROC 0V2B** setup*

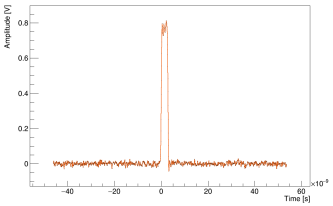


Same test performed using an **older ALTIROC setup** (different strip AC-LGAD wirebonded to ALTIROC 0, Testing PCB model 1702) **showed different "step" non-linear structure**

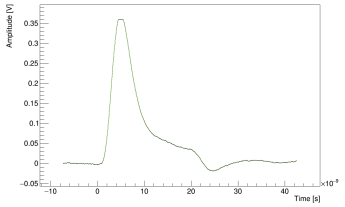
Beta/IR laser comparison

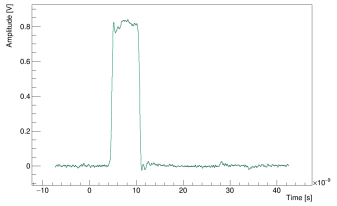
Betas (^{90}Sr)





IR laser (TCT)





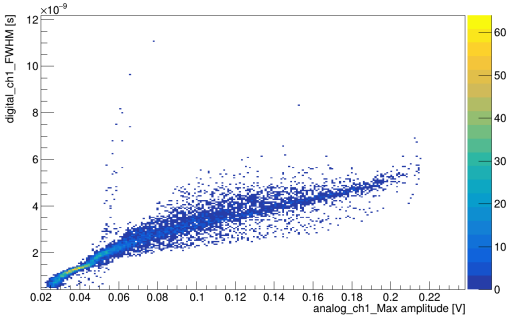
Comparison between Beta and Laser signals

- Similar shape
- Similar FWHM (TCT signals are $\sim$15/20% longer)
- Amplitude distribution of β signals is a Landau; Laser signals is a peak

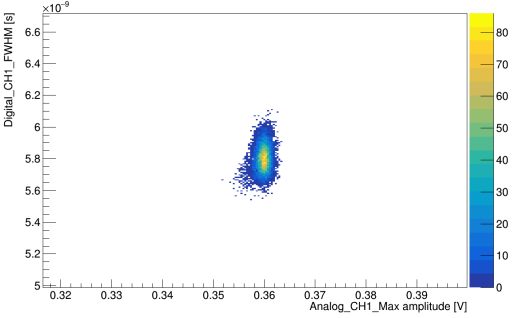
Beta/IR laser comparison

Discriminator response characterization comparison for ^{90}Sr β (left) and IR Laser (right)

^{90}Sr Betas



TCT IR Laser



- Using **Analog signal amplitude** as proxy for ToT
- Good linearity between Digital FWHM and Analog amplitude in the Landau peak of the β distribution
- Digital FWHM is a good alternative to Analog amplitude

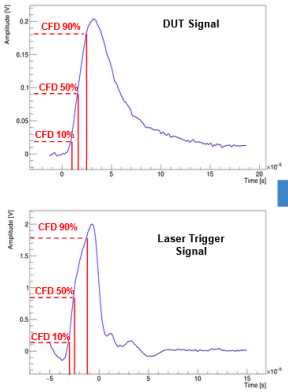
4D performances

4D performances

Time resolution

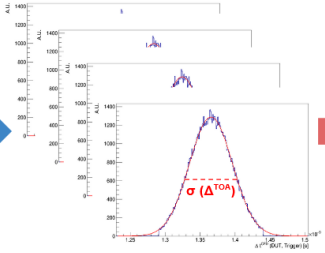
Time resolution measured using IR laser from ToA of ALTIROC signals and Laser Trigger at different values of **Constant Fraction Discrimination (CFD)** to minimize time-walk effects

1. Waveforms from DUT and Trigger and measure TOA at different CFD levels



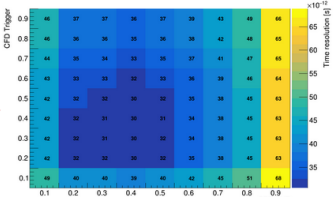
A

2. Compute TOA difference and extrapolate width of gaussian distributions



B

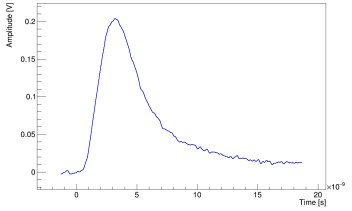
3. Repeat measurement of width for different CFD of Trigger and DUT



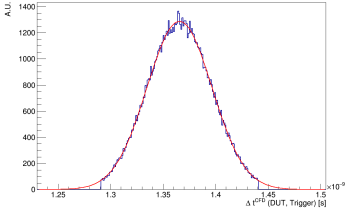
4D performances

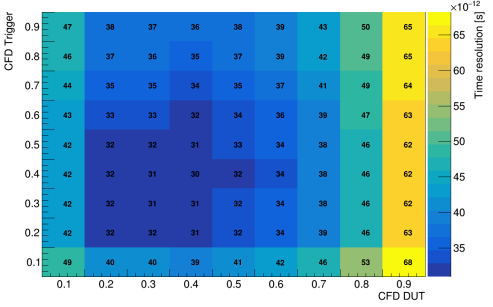
Time resolution

Analog waveform



Time arrival difference





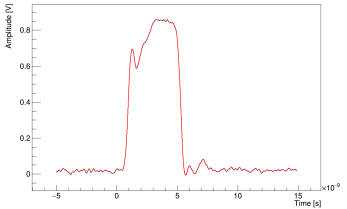
- Gaussian fit of Δt^{CFD}(Laser Trigger, Analog Channel)
- Computed for CFD levels between 10 and 90%

$$\sigma(\Delta t^{CFD}) = f\left(\sigma_t^{ACLGAD}, \sigma_t^{TCT}, \sigma_{jitter}^{ALTIROC}\right)$$

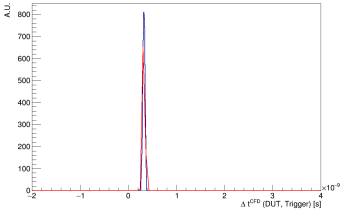
4D performances

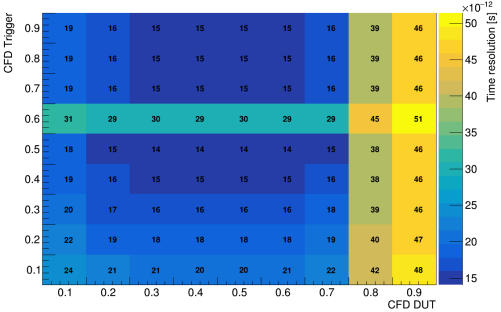
Time resolution

Digital waveform



Time arrival difference





- Gaussian fit of Δt^{CFD}(Laser Trigger, Digital Channel)
- Computed for CFD levels between 10 and 90%
- **Jitter** down to **$\sim$14 ps**, compatible with previous results

Expected ALTIROC jitter

ALTIROC output voltage V_{out} given by the preamp **transistor trans-inductance** g_m the preamp **load impedance** Z_L and by the input voltage on the preamp:

$$V_{out} = g_m Z_L V_{in}$$

V_{in} given by the integral of the total current Q_{in} on the PA divided by the device capacitance:

$$V_{in} = \frac{Q_{in}}{C_d} \rightarrow Q_{in} = V_{in} C_d$$

Jitter can be extrapolated from the board characteristics g_m and Z_L, the signal output V_{out}, the noise spectral density e_n, and the detector capacitance C_d.
Electronic jitter of the ALTIROC is computed as:

$$\sigma_{jitter}^{ALTIROC} = \frac{e_n C_d \sqrt{t_d}}{Q_{in}} = \frac{e_n C_d \sqrt{t_d}}{V_{in} C_d} = \frac{e_n \sqrt{t_d}}{V_{in}} = \frac{e_n g_m Z_L \sqrt{t_d}}{V_{out}}$$

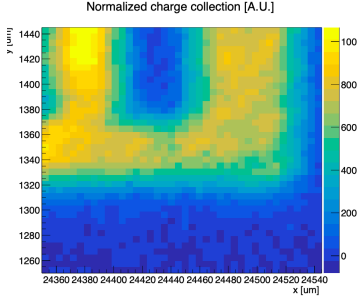
Question: what is the expected ALTIROC jitter contribution for our signals? **To be defined**

4D performances

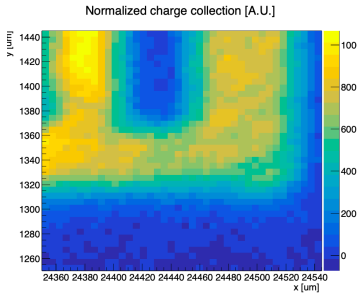
Spatial resolution - Setup oscillations

- Measurement of spatial resolution or precise positions using this setup are not straightforward due to consistent oscillations of the setup
- Consecutive pixel maps using TCT show **oscillations in both x and y axes of $\sim$20μm**

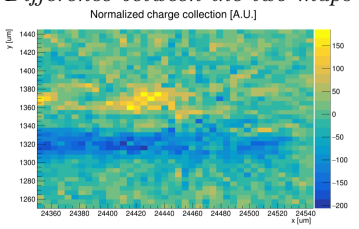
First pixel map



Second pixel map

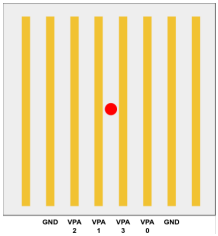


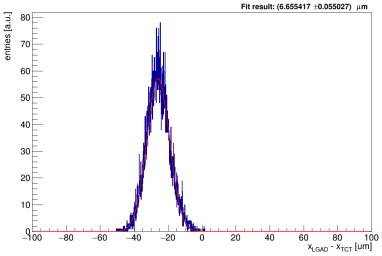
Difference between the two maps



4D performances

Spatial resolution





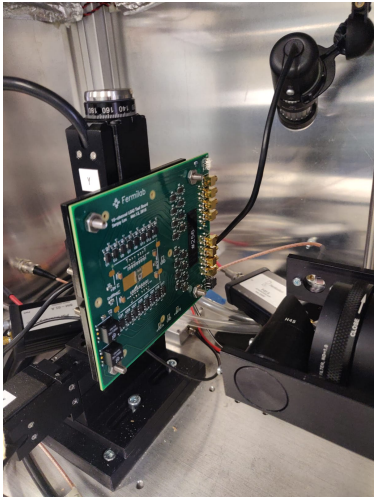
- **Oscillations** $\sim$20 μm in the setup (due to board size) make impossible a precise estimate of the spatial resolution
- We can try to estimate spatial dispersion of the dataset using FWHM from digital signals via χ^2 minimization

$$\chi^2 = \sum_{i=strips} \left(\frac{m^i * x + q^i - f^i}{\sigma^i} \right)^2$$

x: laser position
f^i: FWHM fraction observed by i^{th} strip

- Spatial dispersion of $\sim$10 μm observed in data

Current activities



- Mounted "twin" AC-LGAD strip sensor (same geometry, wafer, etc.) on **FNAL multi-channel board** to repeat TCT and ^{90}Sr betas characterizations
- Comparing time resolution and distributions of amplitudes, FWHM, deposed charge, slew-rate, jitter, etc. obtained for sensors mounted on ALTIROC and FNAL board
- Using AC-LGAD mounted on FNAL board to **measure AC-LGAD spatial resolution**

Scheduled tests - ALTIROC board

ALTIROC Board:

IR Laser

- ✓ **DAC scans** (Analog vs Digital): response characterization at different DAC th
- ✓ **Time resolution** with Analog Channels (Analog vs Laser Trigger)
- ✓ **Time resolution** with Digital Channels (Digital vs Laser Trigger, 4 channels in parallel)
- ✓ **Charge sharing** with Analog Channels
- ✓ **Charge sharing** with Digital Channels

Beta

- **DAC scans** (Analog vs Digital)
- **Charge sharing** with digital channels (4 channels in parallel)
- **Jitter** measurement

Pulse generator

- **Jitter** measurement
- **Analog noise** measurement
- **Digital noise** measurement
- Characterization of **ToA vs TOT**

Scheduled tests - FNAL board

FNAL Board:
TCT

- **Space resolution** with Analog channel
- **Time resolution** with Analog channels
- **Charge sharing** with Analog Channels

Beta

✓ **Charge sharing** (4 channels in parallel)

Any idea? We are open to suggestions

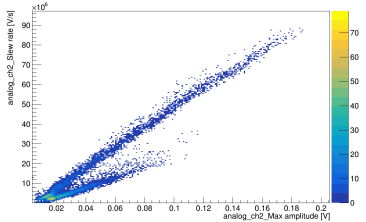
Recap & conclusions

- **ALTIROC 0V2B** proved to be a **suitable readout for AC-coupled signals** generated in a BNL AC-LGADs
- Characteristics of the readout signals are compatible with expectations for AC-LGAD signals and previous ALTIROC results
- Signals generated in interactions with β from a ^{90}Sr source show a **secondary population of wider signals**. This effect was not seen using the IR laser and is potentially a result of signal sharing
- **Time resolution of the ALTIROC + AC-LGAD was estimated** using an IR-Laser at around 30 ps. A precise estimate of the ALTIROC Jitter is needed to extrapolate AC-LGAD time resolution
- **Characterization of the space resolution** of the system is difficult due to mechanical constraints. Preliminary results based on the spatial dispersion of signals obtained using the IR laser are presented
- Characterization of the sensor as well as its time and space resolution will be compared to those obtained using a Fermilab-designed trans-impedance test board

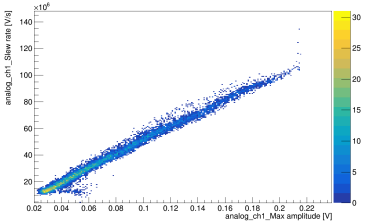
Backup

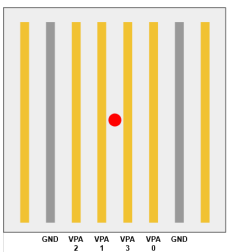
Analog amplitude vs Analog slew rate - β particles

Channel 2

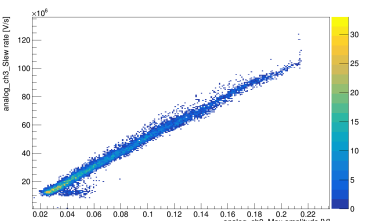


Channel 1





Channel 3



Channel 0