Characterization of AC-LGAD sensors using the ALTIROC readout ASIC

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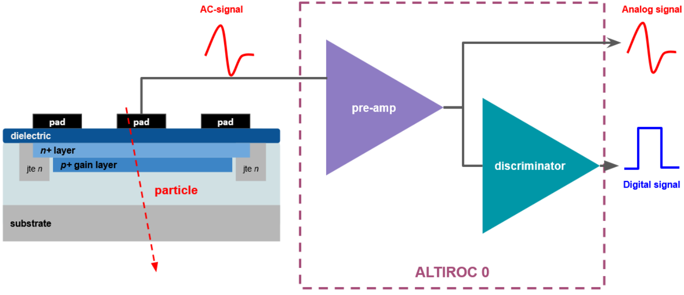
18 November 2021

The 39th **RD50 workshop**
Valencia

Readout with ALTIROC ASIC

The ALTIROC ASIC

ATLAS LGAD Timing ROC



- **ALTIROC designed for LGAD unipolar signals** for ATLAS High-Granularity Timing Detector (HGTD).
- Compatibility to AC-LGAD bipolar signals not ensured!
- **ALTIROC0 ASIC:** first prototype of ALTIROC chip (CMOS 130 nm); includes *Pre-amplifier* (Analog VPA signals) + *Discriminator* (Digital signals) for **ToT measurement**

[1]

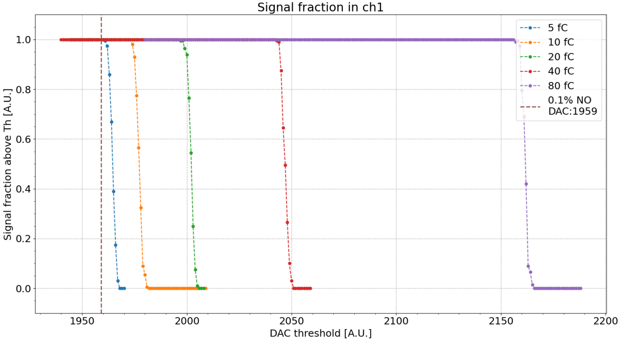
[1] For additional informations on ALTIROC, see: https://cds.cern.ch/record/2719855

ALTIROC ASIC characterization with pulse-generator

ASIC response to fast signals

- Fast signal injected from pulse generator
- **S-curve of digital signal fraction** computed for multiple DAC points in wide range
- Acquired pulses per DAC point = 200

$$\textbf{Signal\%} = \frac{signals\ above > 500\ mV}{total\ signals}$$

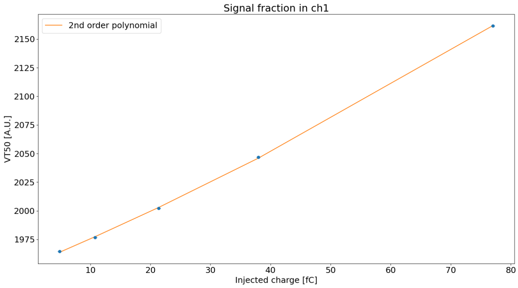


S-curves scan repeated with **multiple input charges** (**5 fC**, **10 fC**, **20 fC**, **40 fC** and **80 fC**) obtained by modulating input signal amplitude (50 - 800 mV)[1]

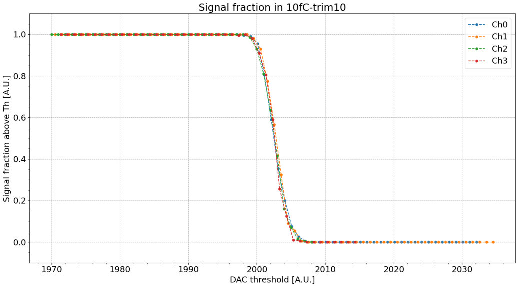
[1]ALTIROC0 input capacitance: 100 fF and Q = C * V

S-curve characterization

S-curves fitted with Complementary Error function (ERFC)



Value of **50% occupancy point (VT50)** plotted as a function of input charge



“Handmade” **trimming** by shifting Ch0, Ch1 and Ch3 curves of the distance between the VT50 of Ch2 and the VT50 of the channel, leading to similar response across channels

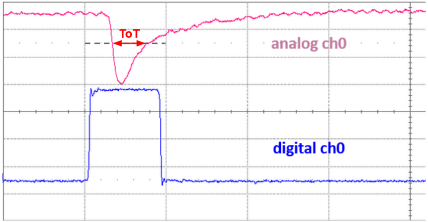
AC-LGAD sensor read-out using ALTIROC

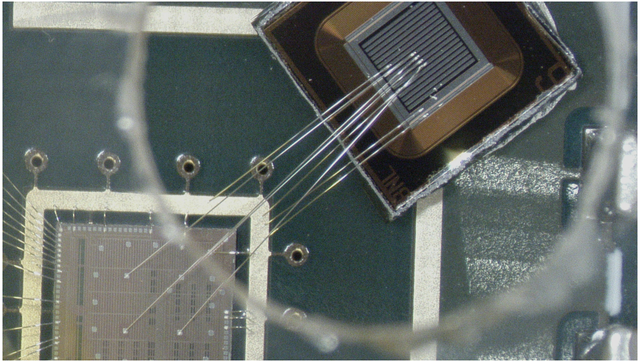
Readout with Altiroc ASIC

Device Under Test

16 strip BNL AC-LGAD

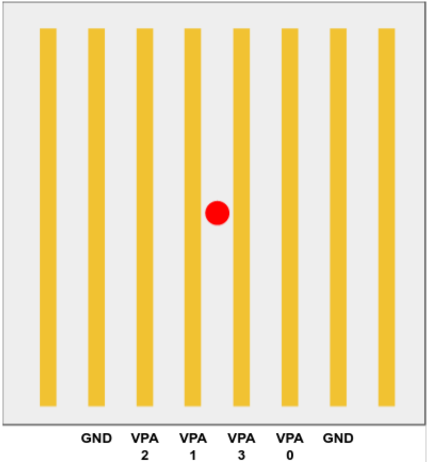
- Area: 2×2 mm^2
- 16 strips, pitch 100 μm, gap 44 μm
- V_{bias} = -170 V
- 4 strips bonded to 4 input channels of ALTIROC 0 ASIC





Readout with Altiroc ASIC

Wirebonding scheme



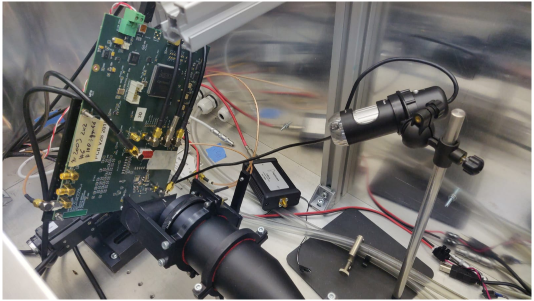
2

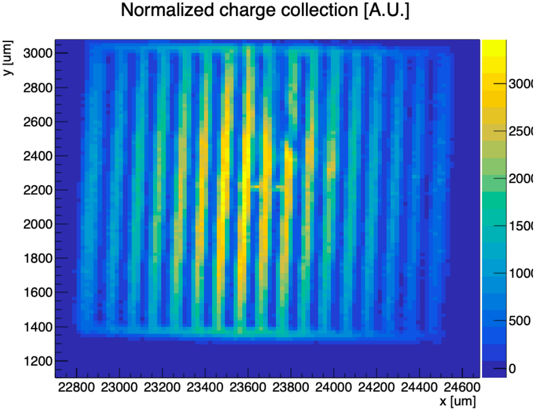
[2]Only central strips are shown

- **Central neighbouring strips** wire bonded to the four input channels on the ALTIROC ASIC
- Strips chosen to be **far from the device guard-ring** to minimize border effects
- Lateral strips on their left and right are wire-bonded to the same ground as the ASIC
- Focus is on **inter-strip signal sharing**

AC-LGAD characterization using IR laser

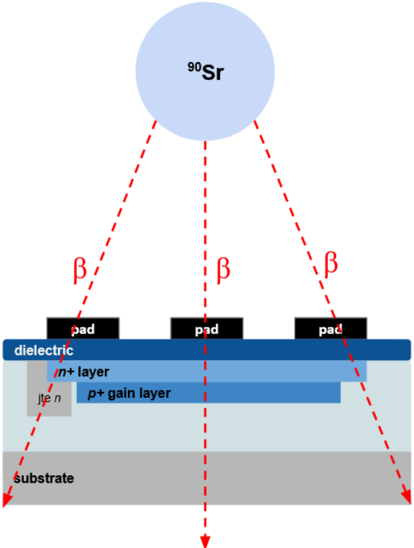
ALTIROC setup adapted to TCT station; characterization performed with IR laser with 10 kHz frequency





Colour indicates **integral charge of the signal peak** from the ALTIROC analog output

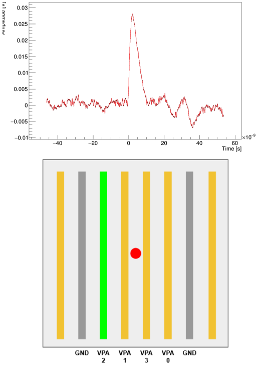
AC-LGAD characterization using β



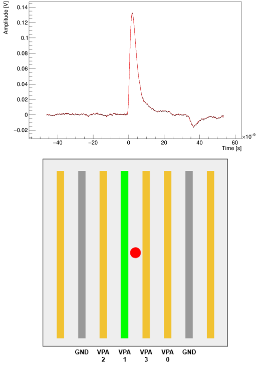
- β particles are close to MIPS
- **Isotropic distribution** of particles over solid angle
- **Landau interaction with matter** allows response study over continuous energy spectrum
- Betas penetrate through metallisation; sensor performance over its whole area can be studied
- Tested at 3 DAC levels, **Low DAC** (0.1% Noise occupancy), **High DAC** (best jitter) and **Mid Value** (average between Low and High)

β Waveforms

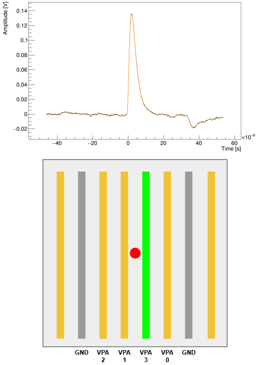
Channel 2
DAC 2020



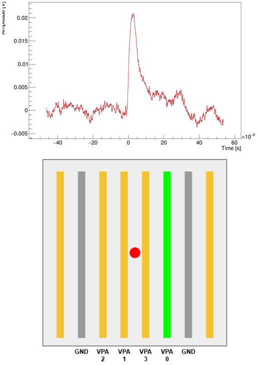
Channel 1
DAC 2020



Channel 3
DAC 2020



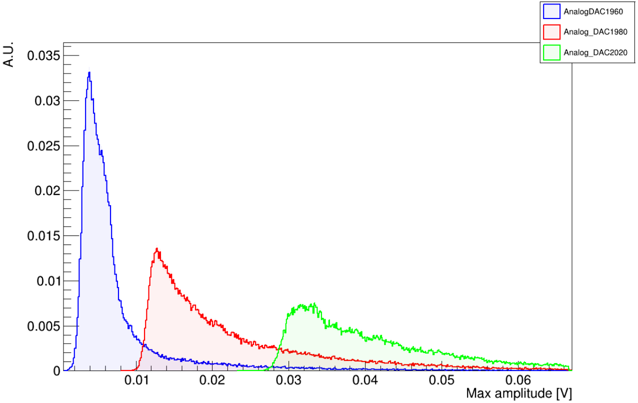
Channel 0
DAC 2020

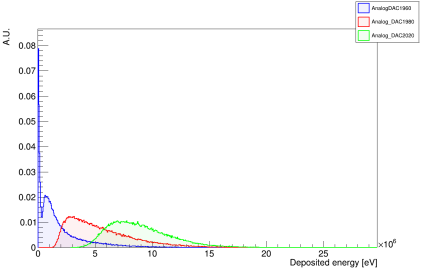


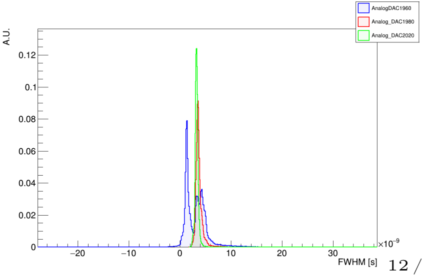
Study of relative signal amplitude on different neighbouring strips can be exploited in reconstruction with **center-of-mass algorithms**

Analog readout - Channel 1

Distributions of deposited energy and FWHM for Low DAC dataset show a **second peak at low values** interpreted as originating from **noise above threshold**

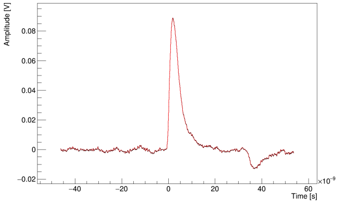


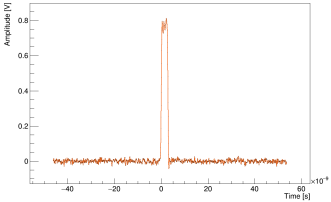




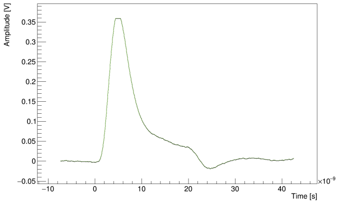
Beta/IR laser comparison

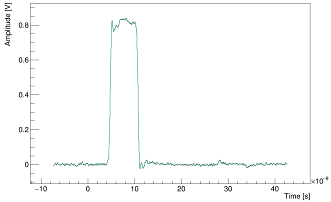
Betas (^{90}Sr)





IR laser (TCT)





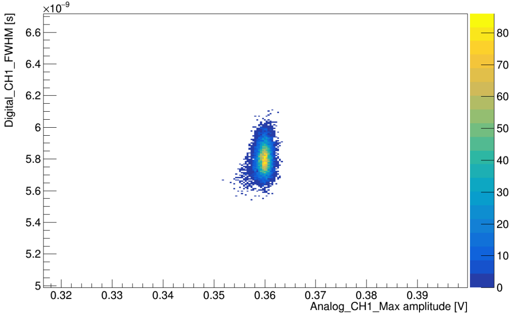
Comparison between Beta and Laser signals

- Similar shape
- Equivalent charge injected by IR laser equivalent to several (~ 40) MIPS; signal amplitude is far higher
- Amplitude distribution of β signals follows Landau distribution; Signal generated by IR Laser has point-like energy release

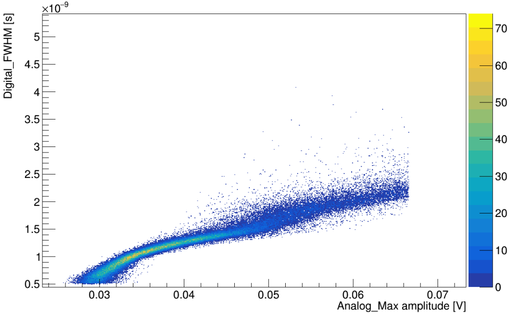
Beta/IR laser comparison

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

TCT IR Laser



^{90}Sr Betas

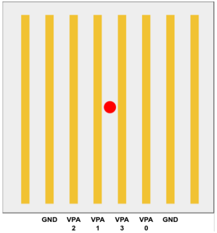


Approx. **linear correlation** between Digital FWHM(signal ToT) and Analog amplitude

ToT can be used as proxy for Amplitude when combining signals from neighboring electrodes in position and time measurements

4D performances

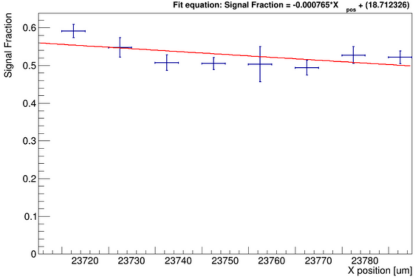
Spatial resolution



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

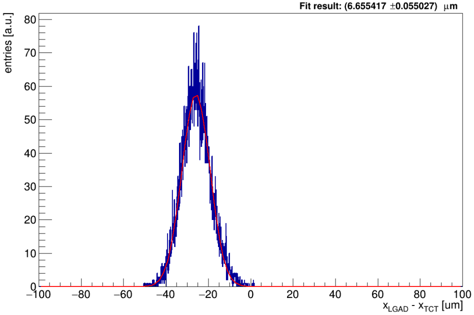
- x: laser position
- m^i, q^i: calibration params
- f^i: amplitude fraction observed by i^{th} strip

calibration - strip Ch1



- Use data points and TCT position information (x_{TCT}) to find **linear calibration parameters** (m^i, q^i) for each strip
- Spatial resolution computed via χ^2 **minimization of signal fractions** observed by multiple strips

Spatial resolution

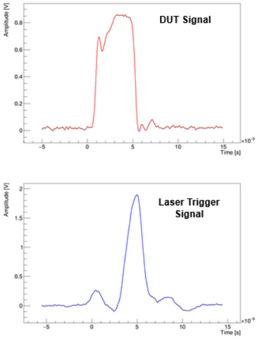


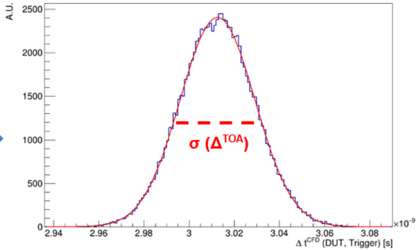
Space resolution reconstructed from **difference between laser focusing position** (from TCT) **and position obtained from χ^2 minimization** (statistically independent data set)

- **Oscillations** $\sim$20 μm in the setup (due to board size) make impossible a precise estimate of the spatial resolution[a]
- Spatial dispersion of $\sim$6-10 μm observed in dataset, measure of the intrinsic bias of the reconstruction method

[a]More details in the backup

Time resolution





- Time resolution obtained by temporal spread of ToA of digital signals compared to external trigger
- Signals generated by IR laser pulses
- Time resolution is the **width of the distribution**
- No Landau fluctuations for IR laser; equivalent to measurement of **signal jitter**

$$Width = \sqrt{(\sigma_t^{DUT})^2 + (\sigma_t^{trig})^2}$$

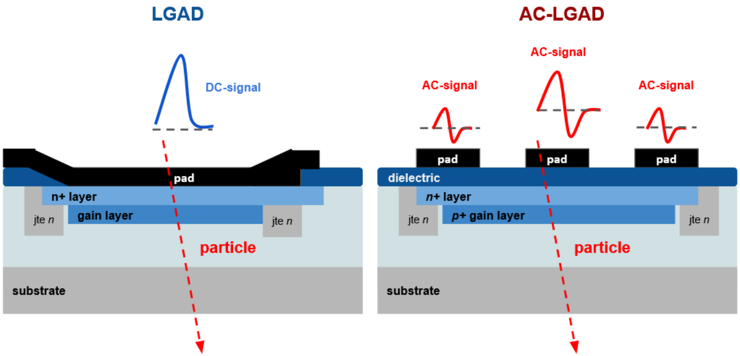
$\sigma_t^{DUT} \simeq$ 14 ps (**21 fC input charge**, DAC 2020)

Recap & conclusions

- **First characterization of bipolar AC-LGAD signals readout by an ASIC**
- **ALTIROC 0** proved to be a **suitable readout for bipolar 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
- **Time resolution (jitter) of the ALTIROC + AC-LGAD was estimated** using an IR-Laser at around 14 ps using digital signals generated by ALTIROC0 discriminator. 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. $<$10 μm resolution can be achieved, limited by experimental set up

Backup

AC-LGAD AS 4D DETECTORS



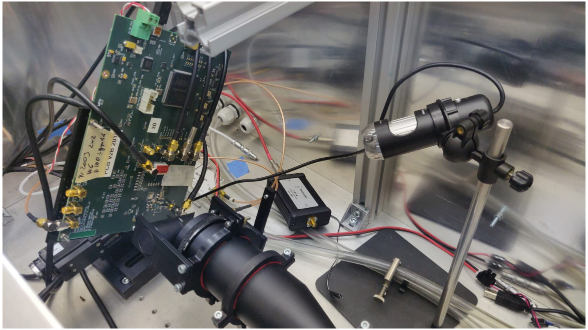
The AC-LGAD paradigm:

- Bipolar signal **AC-coupled** through dielectric to metal pads
- Both **100% Fill Factor and fast timing** ($\sim$30 ps)
- **Signal shared** on neighbouring pads helps in achieving spatial resolution $\mathcal{O}(10\ \mu\text{m})$

Our goal: smaller pixels, but same σ_t as LGADs!

Readout with Altiroc ASIC

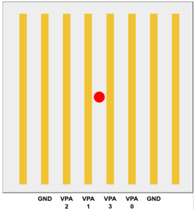
Altiroc Setup



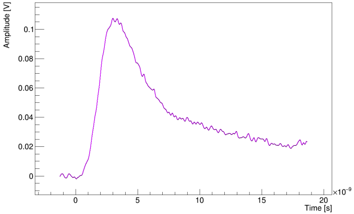
- ASIC ALTIROC 0V2 bonded to ALTIROC Testing PCB (2018, **ver. 1807**)
- **IR scans**: conducted using **Particulars Scanning-TCT** apparatus mounting IR laser (1064 nm)
- ALTIROC PCB mounted on a 3-axis computer-controlled mechanical stage with position resolution of less than 1 μm
- **Beta tests:** ^{90}Sr source used for beta tests

Waveforms TCT - IR Laser

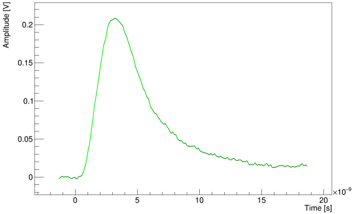
- Signals from IR laser interacting at the center of the sensor (between strip 1 and 3, as shown by **red dot**)
- **Analog output** of the ALTIROC
- Signals from channel 3 and 1 (closest to laser focus) have higher amplitude



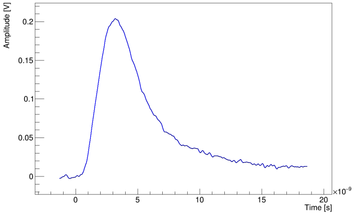
Channel 2



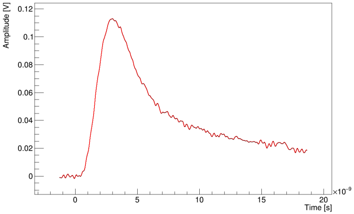
Channel 3



Channel 1

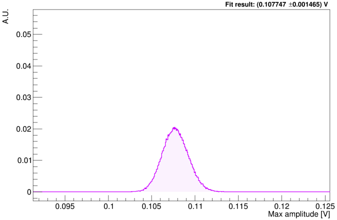


Channel 0

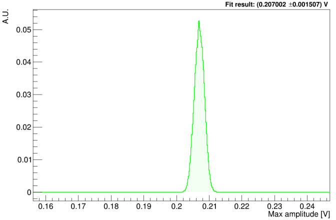


Maximum distributions - IR Laser

Channel 2

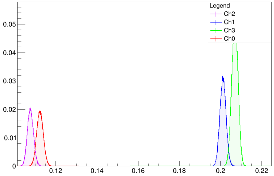


Channel 3

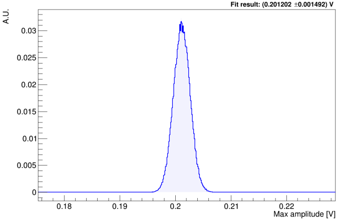


- Amplitude of signals acquired from **analog output** of the ALTIROC shaper for all 4 channels
- Amplitudes of channels 1 and 3 slightly different due to difficulty to focus laser on precise center between two strips caused by setup oscillations (details later)

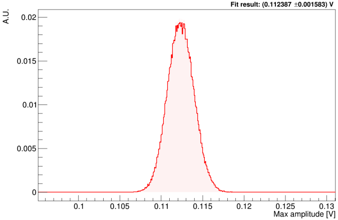
Superimposed distributions



Channel 1

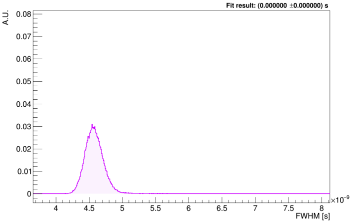


Channel 0

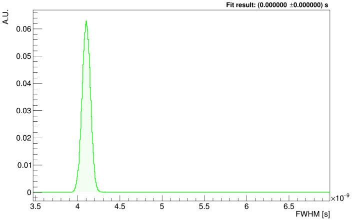


FWHM distributions - IR Laser

Channel 2

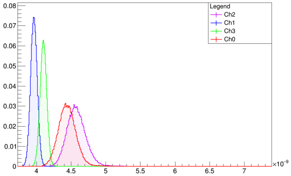


Channel 3

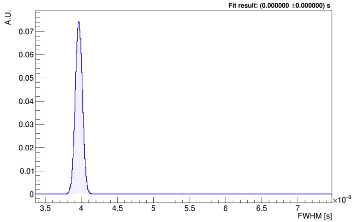


- FWHM of signals acquired from **analog output** of the ALTIROC shaper for all 4 channels
- Fast (∼5 ns) signal **compatible with published results for (DC-)LGAD sensors** read-out via ALTIROC0

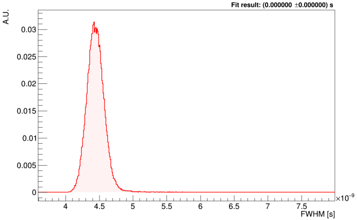
Superimposed distributions



Channel 1

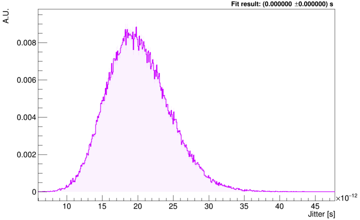


Channel 0

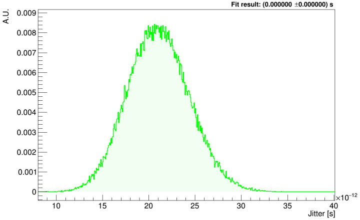


Jitter distributions - IR Laser

Channel 2



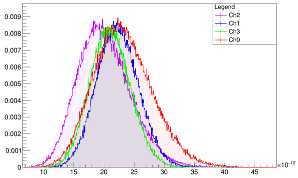
Channel 3



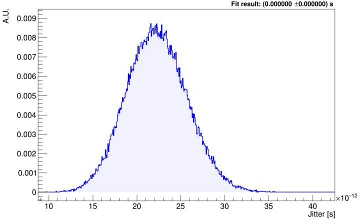
- Jitter of signals acquired from **analog output** of the ALTIROC shaper for all 4 channels
- Jitter distributions consistent for all 4 channels

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

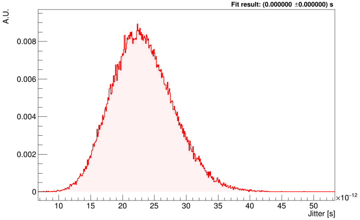
Superimposed distributions



Channel 1



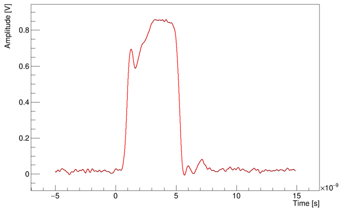
Channel 0



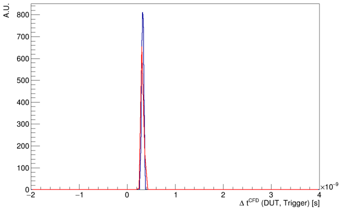
4D performances

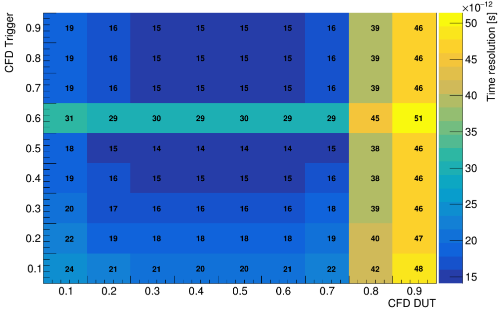
Time resolution

Digital waveform



Time arrival difference





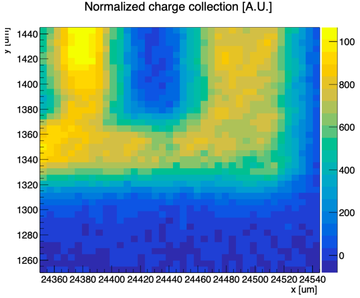
- Gaussian fit of Δt^{CFD}(Laser Trigger, Digital Channel)
- Computed for CFD levels between 10 and 90%
- **Jitter** down to **∼14 ps**, compatible with previous results

4D performances

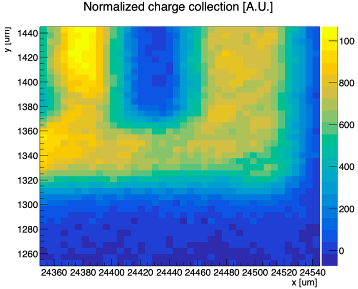
Spatial resolution - Setup oscillations

- 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 ~20μm**

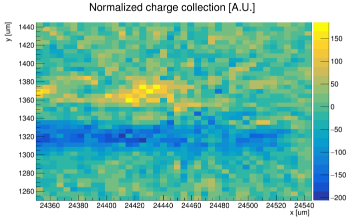
First pixel map



Second pixel map



Difference between the two maps



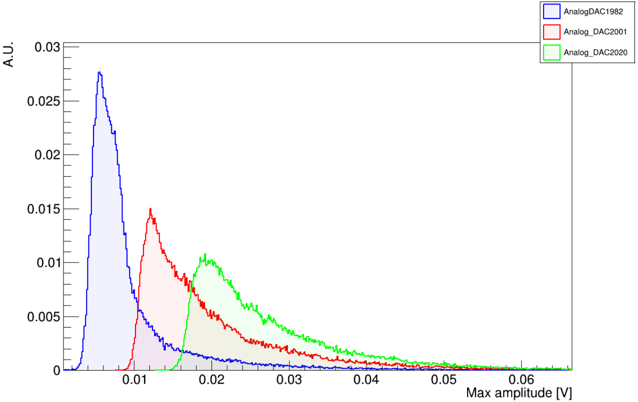
ALTIROC Specifications

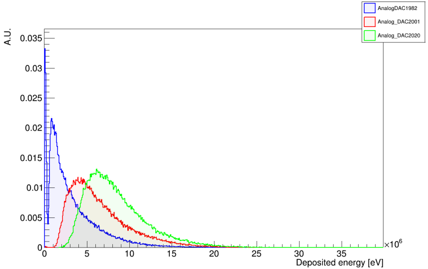
TID tolerance	Inner region: 4.7 MGy Outer region: 2.0 MGy
Pad size	$1.3 \times 1.3\,\mathrm{mm}^2$
Voltage	1.2 V
Power dissipation per area (per ASIC)	$300\,\mathrm{mW\,cm^{-2}}$ (1.2 W)
e-link driver bandwidth	$320\,\mathrm{Mbit\,s^{-1}}$, $640\,\mathrm{Mbit\,s^{-1}}$, or $1.28\,\mathrm{Gbit\,s^{-1}}$
Temperature range	−40 °C to 40 °C
SEU probability	$< 5\%$/hour

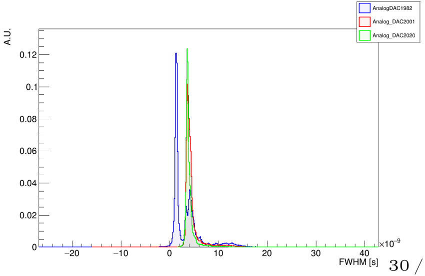
Maximum leakage current	5 µA
Single pad noise (ENC)	$< 1500\ e^- = 0.25$ fC
Cross-talk	$< 5\%$
Minimum threshold	1 fC
Threshold dispersion after tuning	10%
Maximum jitter	25 ps at 10 fC
TDC contribution	< 10 ps
Time walk contribution	< 10 ps
Dynamic range	2.5 fC–100 fC
TDC conversion time	< 25 ns
Trigger rate	1 MHz L0 or 0.8 MHz L1
Trigger latency	10 µs L0 or 35 µs L1
Clock phase adjustment	100 ps

Analog distribution - External Channel 0

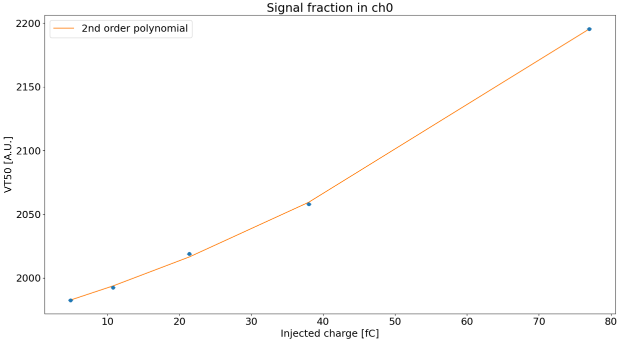
Second peak more prevalent in external strips (0 and 2)

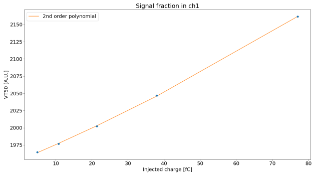


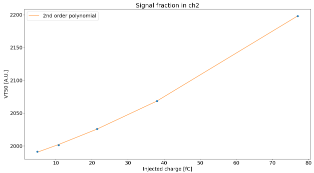


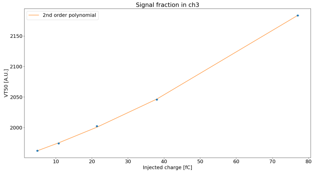


S-curves









Value of VT50 of Complementary Error function (ERFC) plotted as a function of input charge (5 - 80 fC) for each channel

Uncertainty on VT50 position from fit used as error bar in the plot