# AC-LGAD readout using ALTIROC 0

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# I. Tests with Pulse Generator

Signal injected from fast Pulse generator:

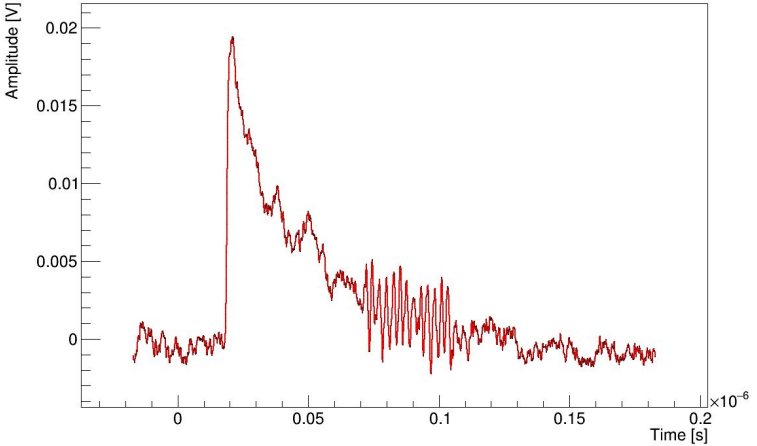
- $V_{low}$ = - 4.00 V (attenuated as needed)
- Width = 188 ns
- Delay = 0 ns
- Lead = 0.90 ns
- Trail = 0.90 ns
- Pulse period = 100 ms
- Frequency = 10 Hz
- Pulses per DAC point = 200 (signal)/1000 (noise)

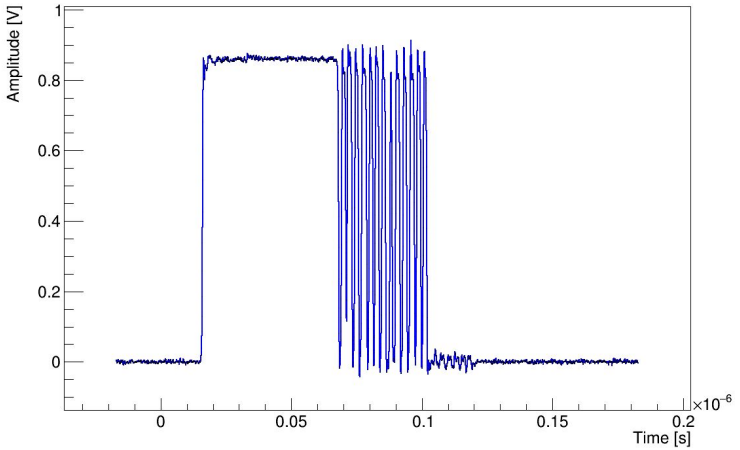
S-curves scan repeated with **multiple input charges** (5, 10, 20, 40, 80 fC) obtained by modulating input signal amplitude using an attenuator (50 - 800 mV)*

Oscilloscope threshold at -15.5 mV, negative edge

Signal fraction computed for each DAC point as:

***Signal fraction*** *= fraction of signals with amplitude > 500 mV*




**considering the ALTIROC0 input capacitance of 100 fF and Q = C * V*

# Noise Occupancy

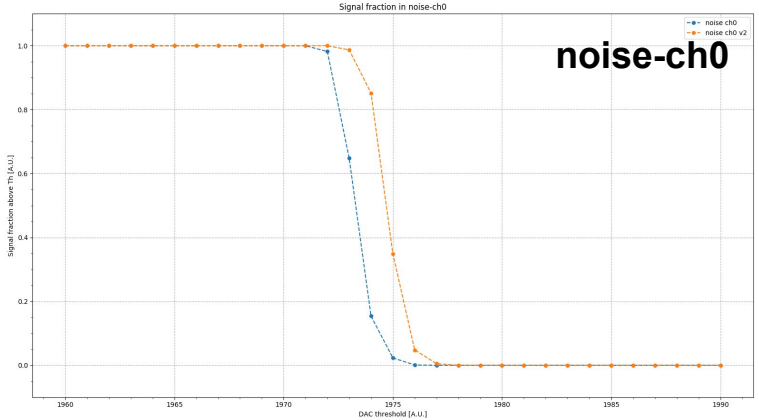
***1.*** Noise occupancy computed from all channels, with sensor biased at -170 V, as:

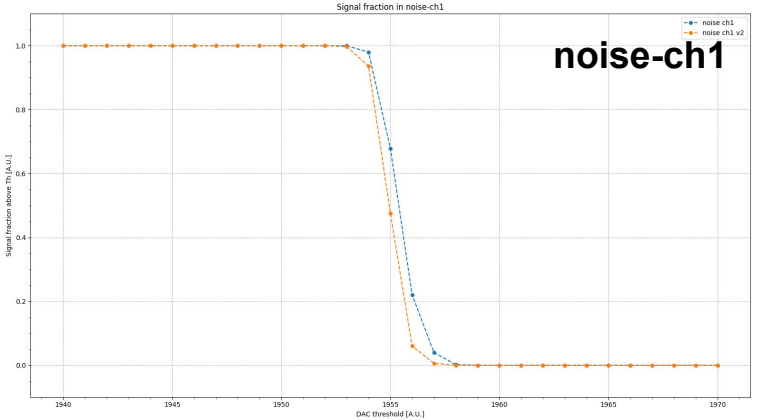
***Noise occupancy*** = *fraction of signals with amplitude > 500 mV*

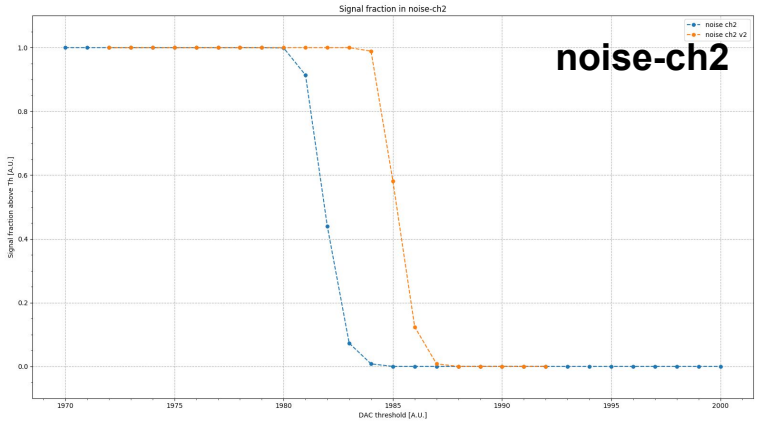
***2.*** Generator connected to oscilloscope to randomly trigger noise

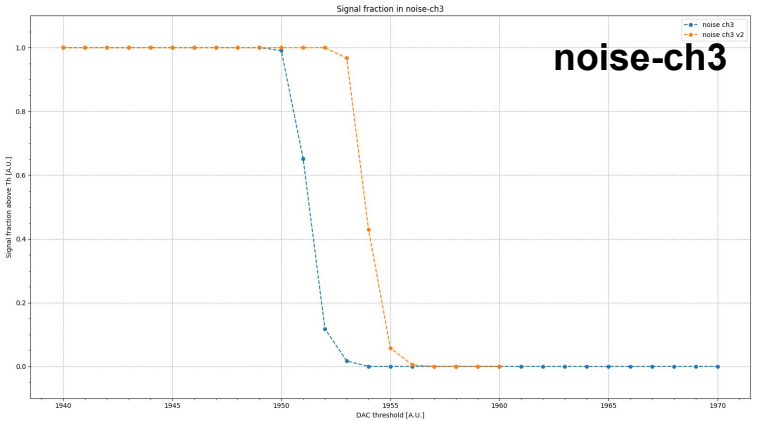
***3.*** 1000 waveforms acquired per DAC point

***4.*** Subsequent data acquisitions show **small time-dependent shift in VT50** for all channels (compare **blue** and **orange** curves)



# Noise Occupancy

## Fit values

Little shift in DAC values observed in subsequent datasets

To bypass this issue, selected point at **0.1% Noise Occupancy** instead of 1% for all tests

| Ch | $VT^{50}$ | $\sigma(VT^{50})$ | $\sigma^{ERF}$ | DAC(1%) | DAC(0.1%) |
|---|---|---|---|---|---|
| 0 | 1973.28 | 0.01 | 0.99 | 1975 | 1977 |
| | 1974.73 | 0.01 | 1.01 | 1977 **(+2)** | **1978** |
| 1 | 1955.38 | 0.01 | 1.12 | 1958 | **1959** |
| | 1954.96 | 0.01 | 0.92 | 1957 **(-1)** | 1958 |
| 2 | 1981.91 | 0.02 | 0.98 | 1984 | 1985 |
| | 1985.16 | 0.01 | 0.95 | 1987 **(+3)** | **1988** |
| 3 | 1951.25 | 0.01 | 0.88 | 1953 | 1954 |
| | 1953.91 | 0.01 | 0.78 | 1956 **(+3)** | **1957** |

**Red bold values** = DAC candidate values (NO=0.1%)

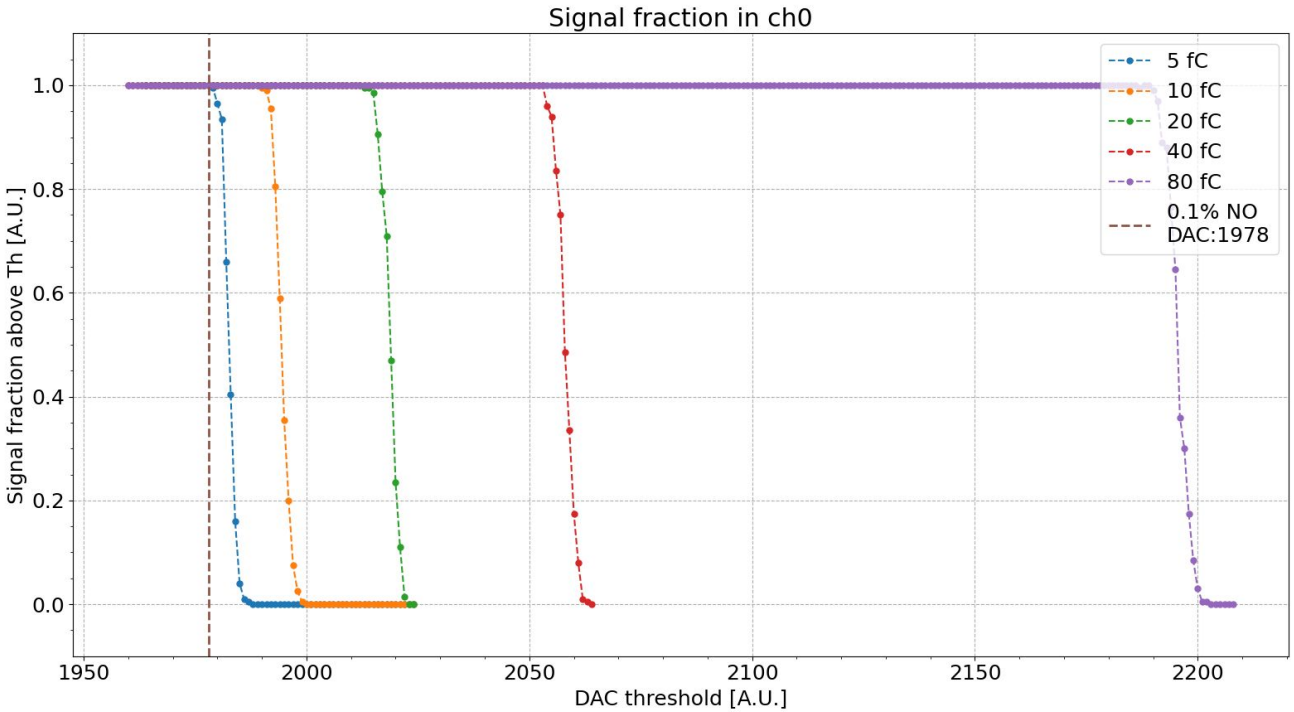
# S-curve

## Ch0

Distributions of signal fraction above threshold as a function of DAC threshold for injected charge of **5 fC**, **10 fC**, **20 fC**, **40 fC** and **80 fC**

Dotted brown line represents 0.1% noise occupancy

For most channels (0, 1, 3) 5 fC curve is above 0.1% noise occupancy level



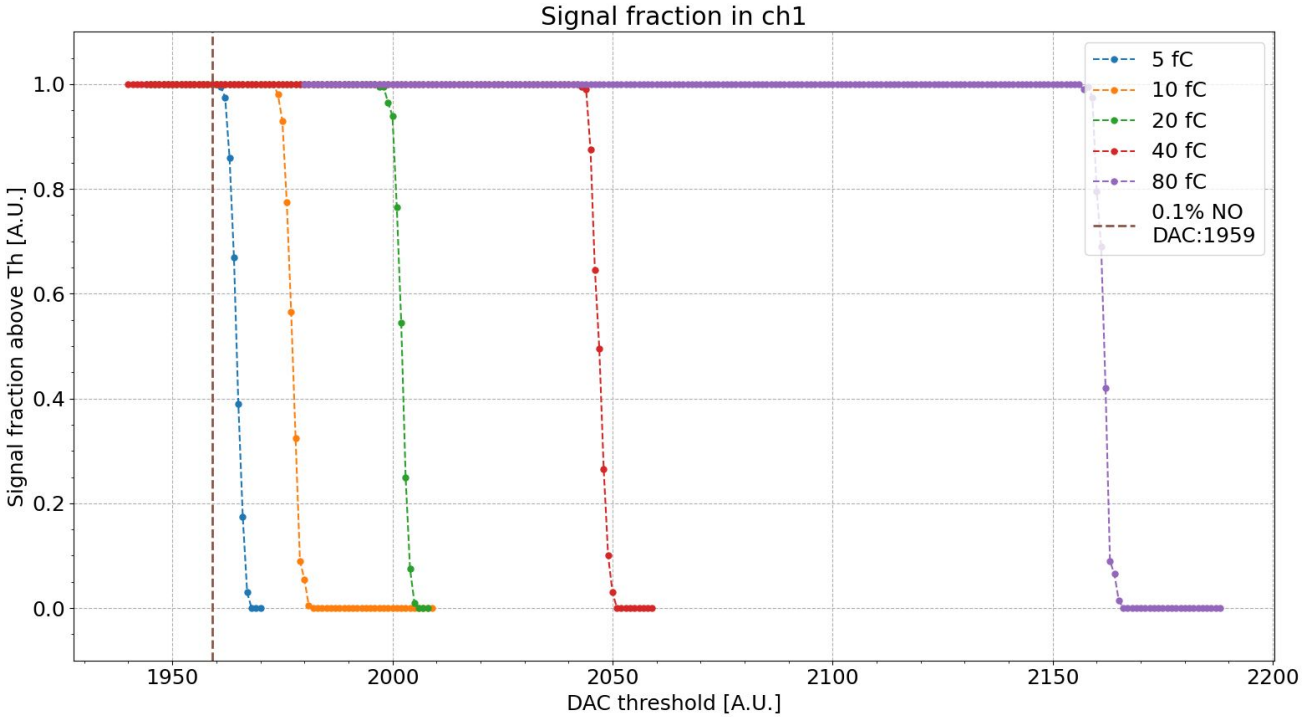
# S-curve

## Ch1

Distributions of signal fraction above threshold as a function of DAC threshold for injected charge of **5 fC**, **10 fC**, **20 fC**, **40 fC** and **80 fC**

Dotted brown line represents 0.1% noise occupancy

For most channels (0, 1, 3) 5 fC curve is above 0.1% noise occupancy level



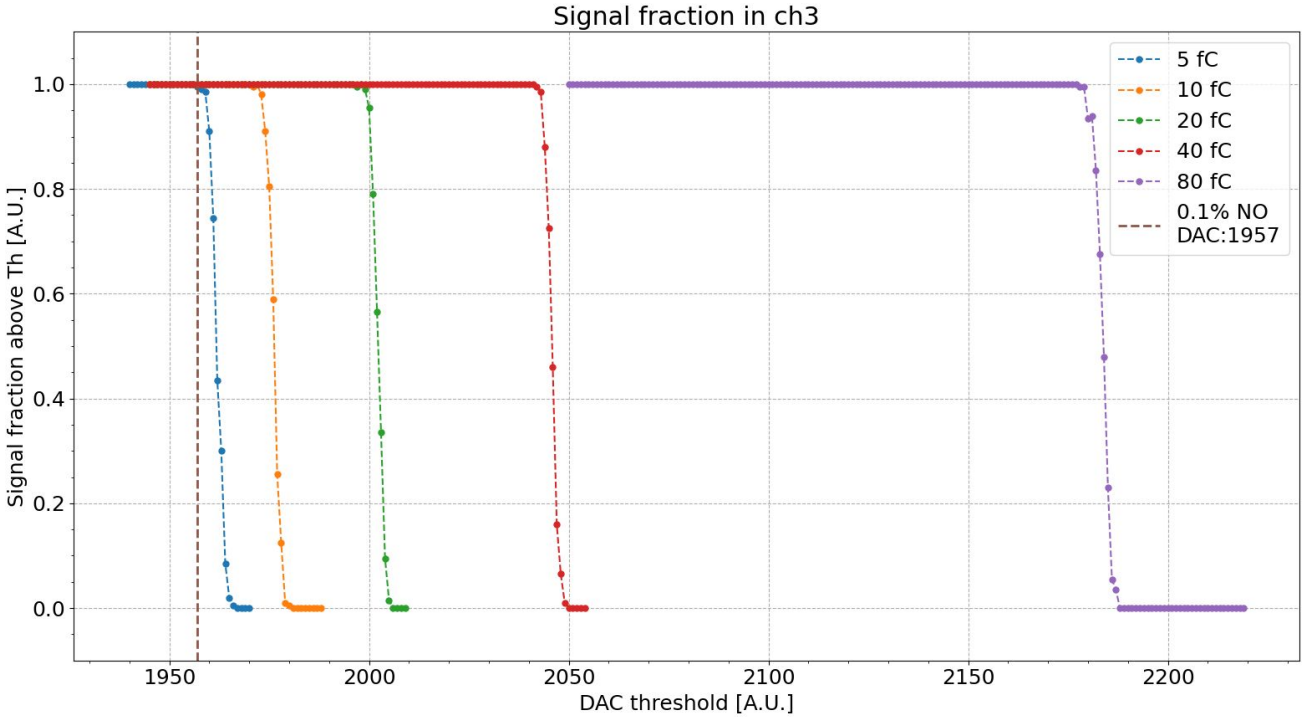
# S-curve

## Ch3

Distributions of signal fraction above threshold as a function of DAC threshold for injected charge of **5 fC**, **10 fC**, **20 fC**, **40 fC** and **80 fC**

Dotted brown line represents 0.1% noise occupancy

For most channels (0, 1, 3) 5 fC curve is above 0.1% noise occupancy level



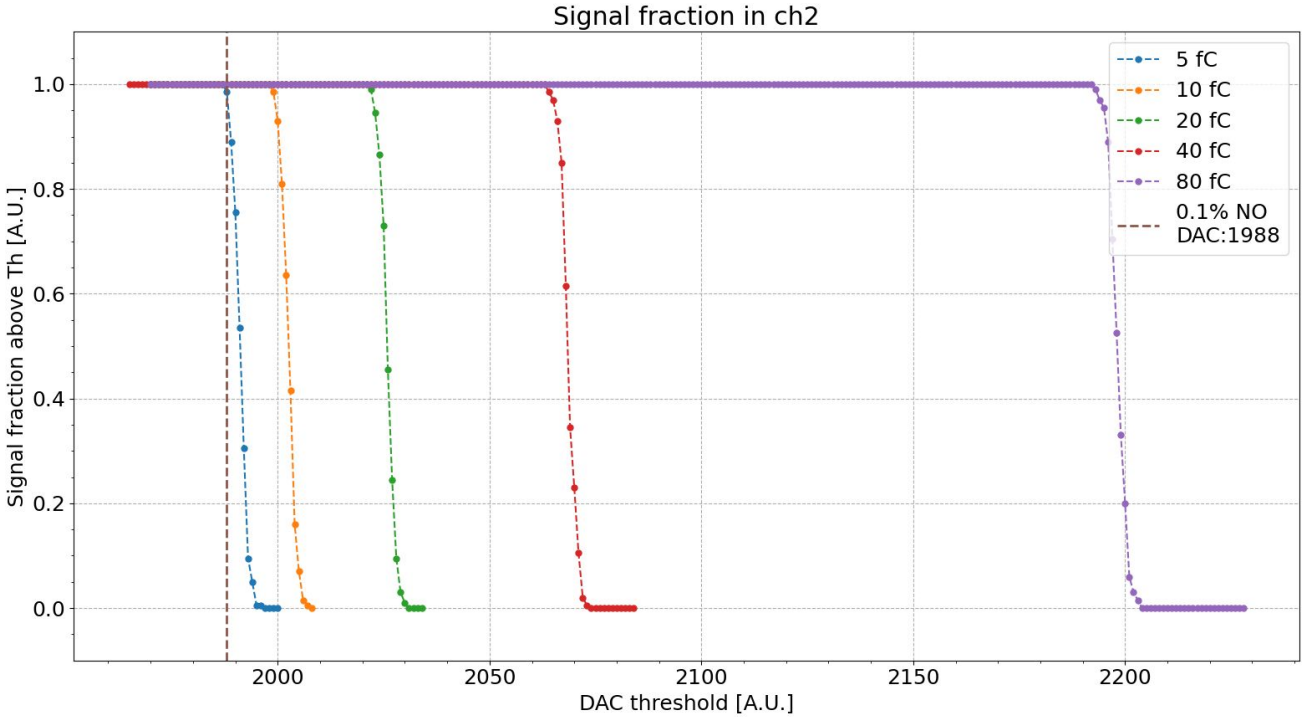
# S-curve

## Ch2

Distributions of signal fraction above threshold as a function of DAC threshold for injected charge of **5 fC**, **10 fC**, **20 fC**, **40 fC** and **80 fC**

Dotted brown line represents 0.1% noise occupancy

For most channels (0, 1, 3) 5 fC curve is above 0.1% noise occupancy level



# S-curve

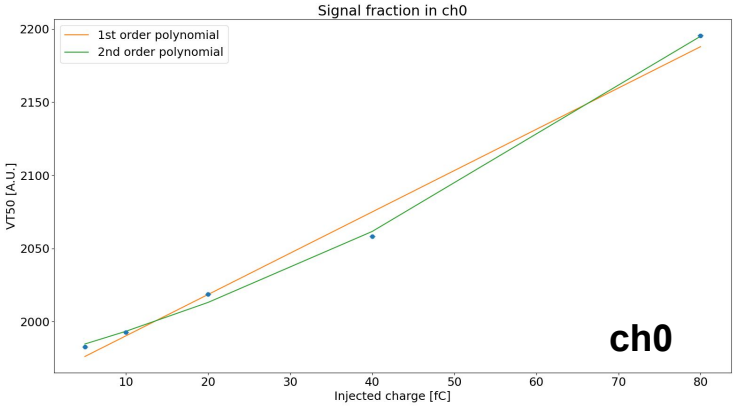
## VT50

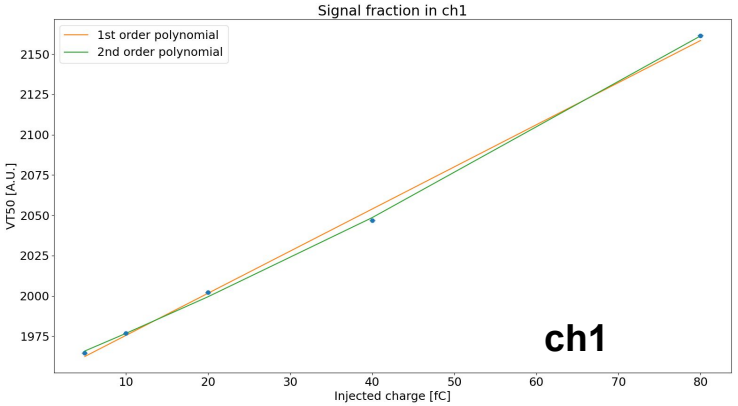
S-curves fitted with **Complementary Error function** (ERFC)

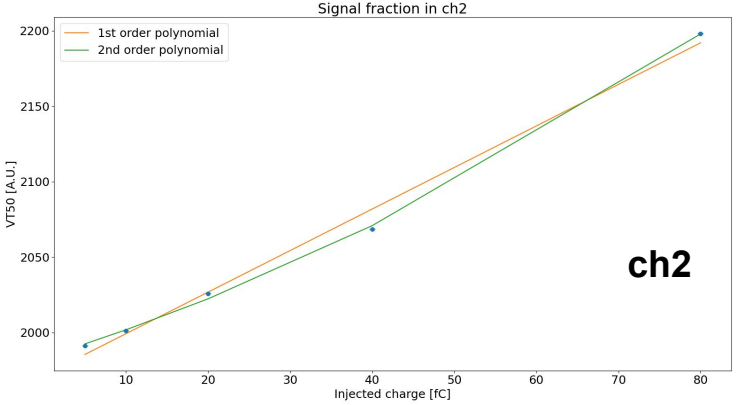
Value of VT50 plotted as a function of input charge (5 - 80 fC) for each channel

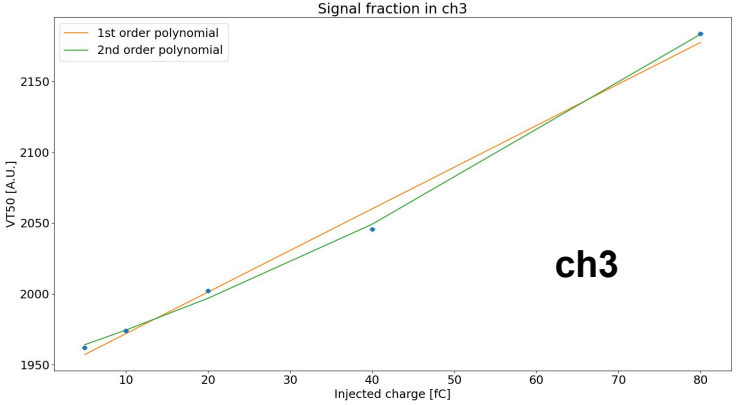
Uncertainty on VT50 position from fit used as error bar in the plot

Beheaviour **not linear** for any channel



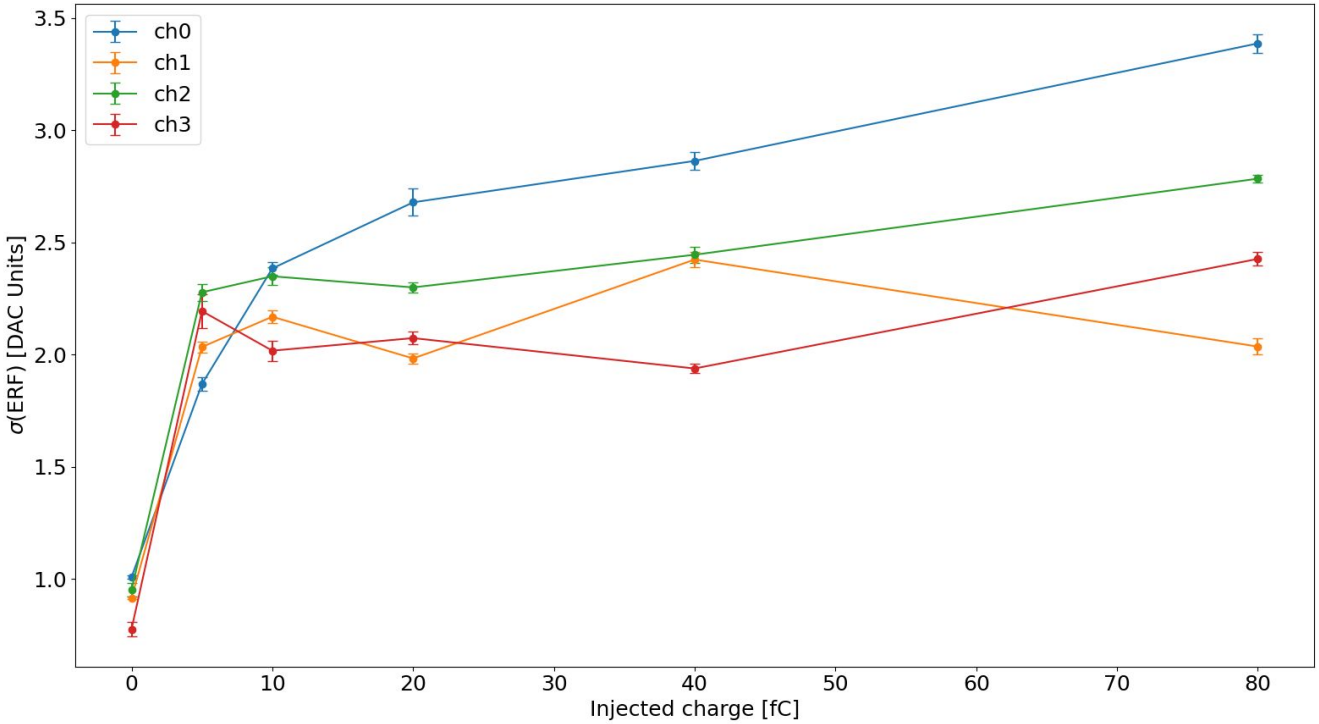
# S-curve

## sigma

**Sigma of the signal and noise s-curves** extrapolated from ERFC fit

- Value of ERFC sigma plotted as a function of input charge (5 - 80 fC) for each channel
- Values of noise ERFC used for the 0 fC point

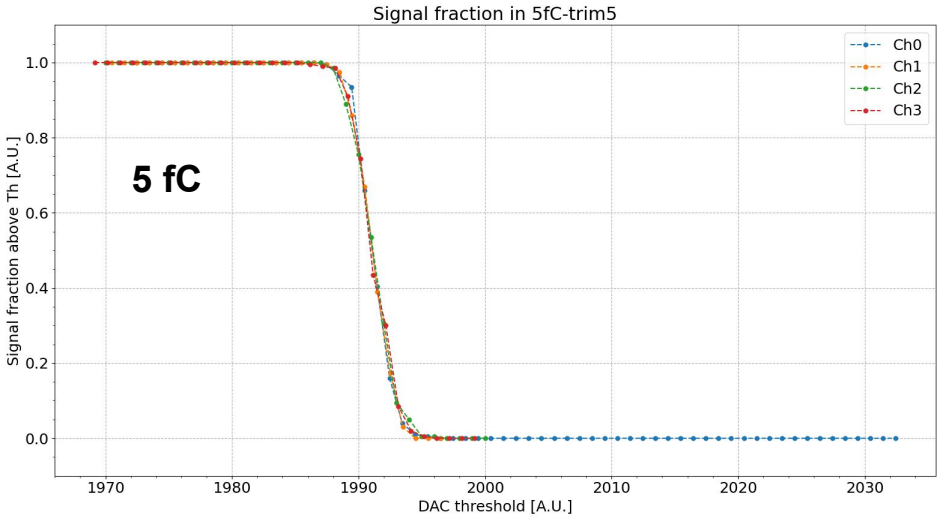
Uncertainty on sigma distribution value from fit used as error bar in the plot

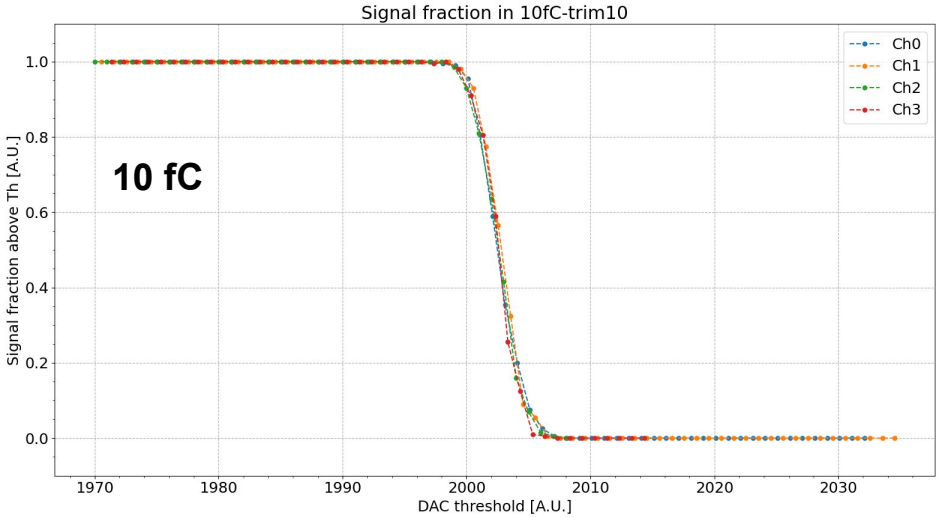


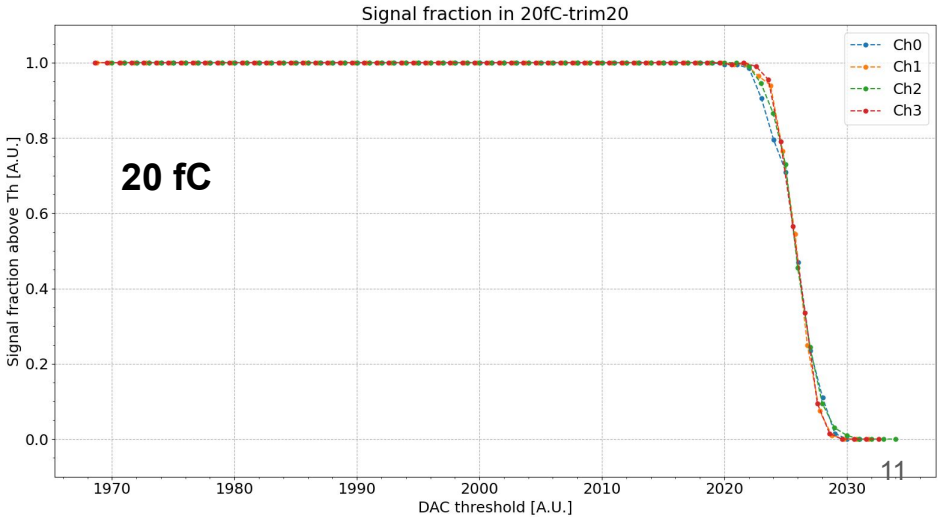
# Signal Trimming

We attempted a *"**handmade**"* **trimming** by shifting Ch0, Ch1 and Ch3 curves of the distance between the VT50 of Ch2 and the VT50 of the channel

$$\Delta DAC^{chN}(x\ fC) = VT50^{ch2}(x\ fC) - VT50^{chN}(x\ fC)$$



# Signal Trimming

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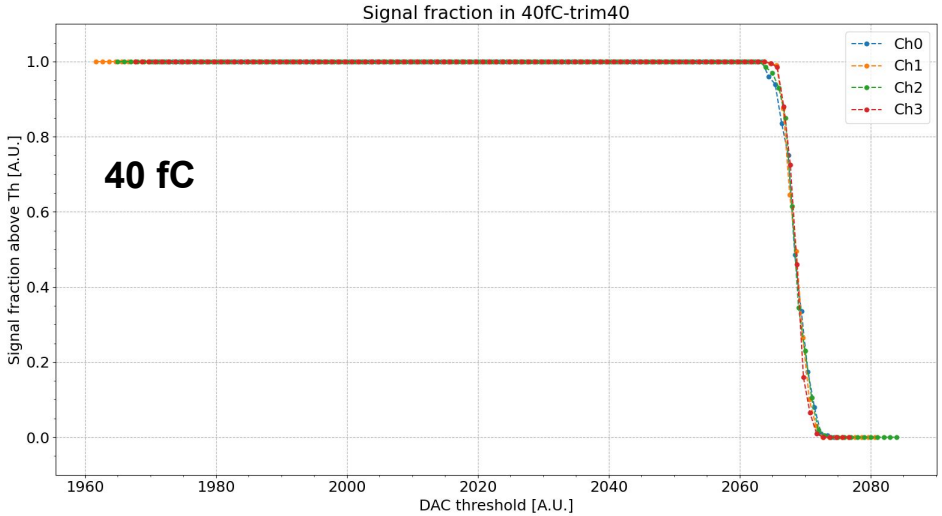
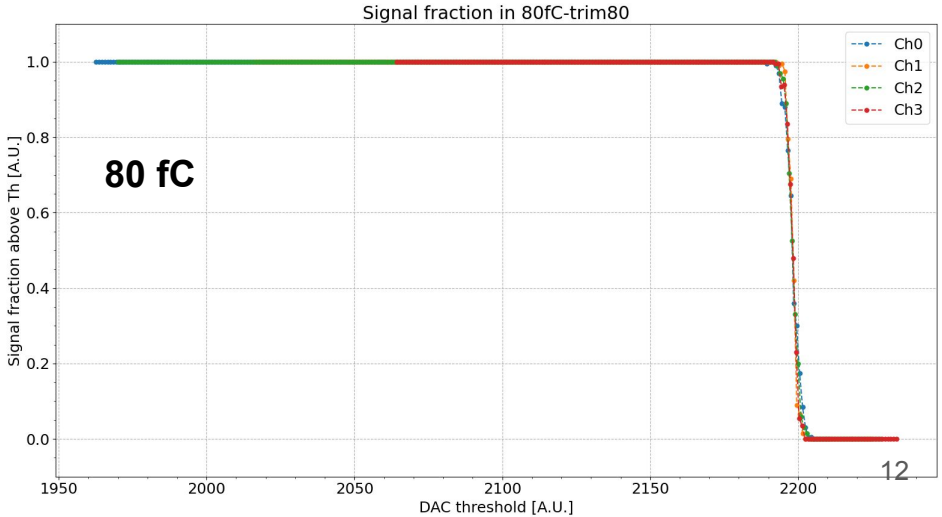
$$\Delta DAC^{chN}(x\ fC) = VT50^{ch2}(x\ fC) - VT50^{chN}(x\ fC)$$

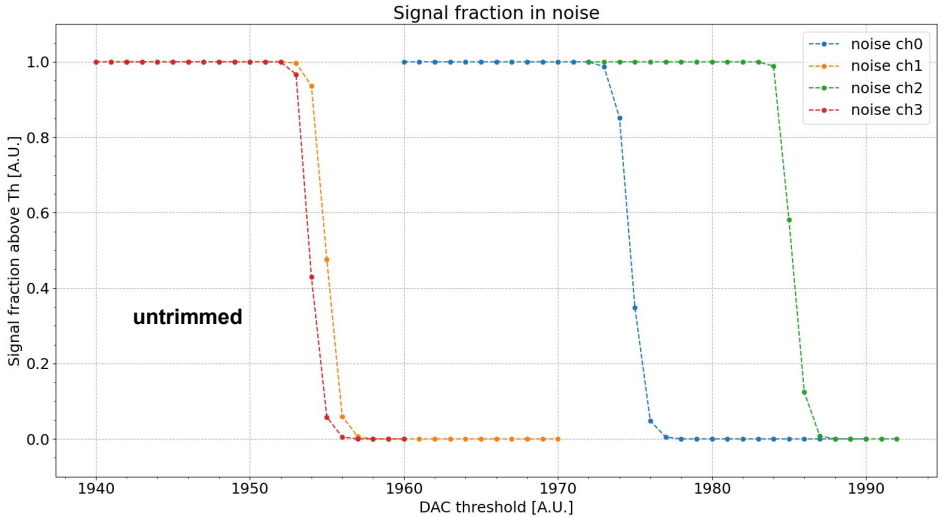
| Ch | ΔDAC 5 fC | ΔDAC 10 fC | ΔDAC 20 fC | ΔDAC 40 fC | ΔDAC 80 fC |
|---|---|---|---|---|---|
| 0 | 8.46 | 8.11 | 7.03 | 10.43 | 2.54 |
| 1 | 26.5 | 25.56 | 23.78 | 21.66 | 36.59 |
| 3 | 29.16 | 26.34 | 23.6 | 22.75 | 14.39 |

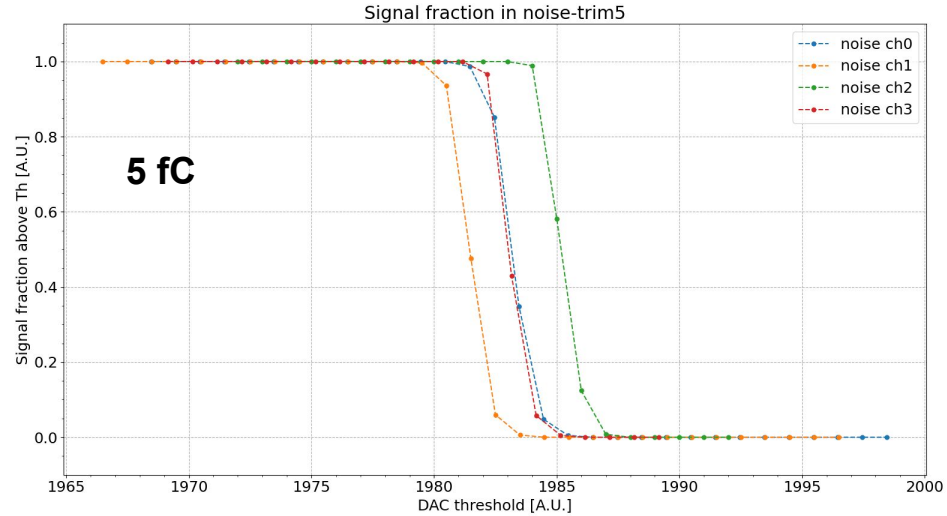


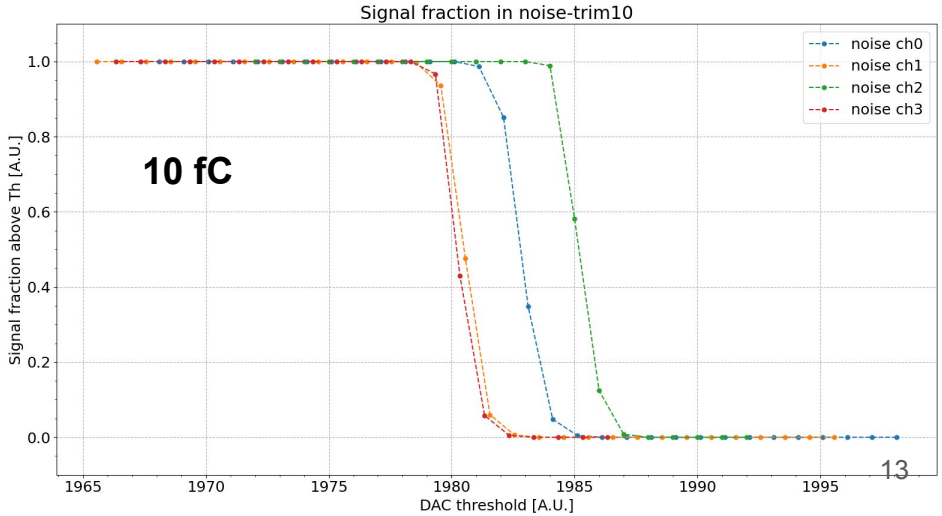



# Noise Trimming

*"**Handmade"** **trimming** done for noise dataset using trimming values extracted from the 5 and 10 fC datasets*

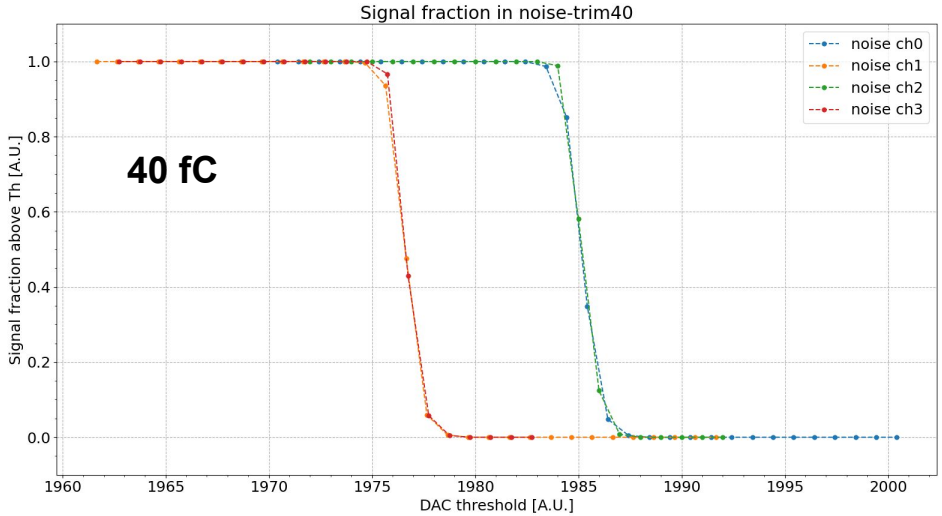


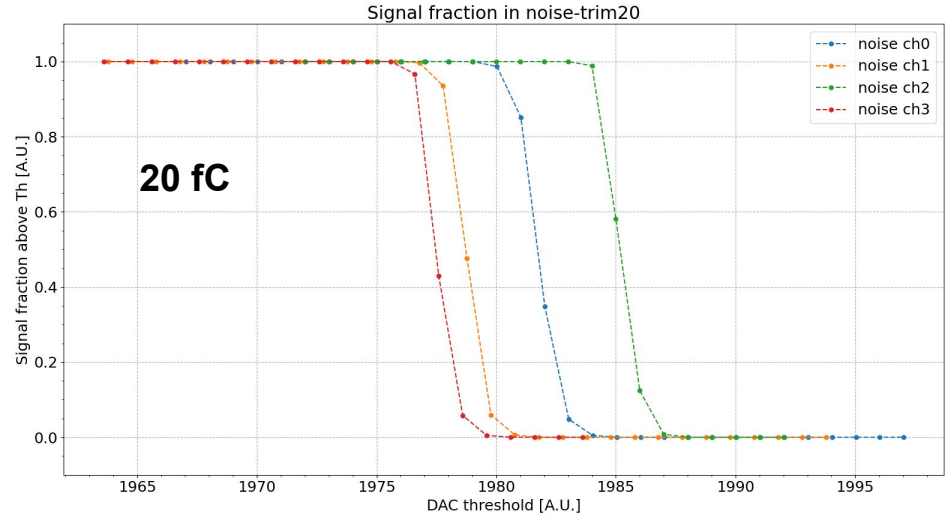



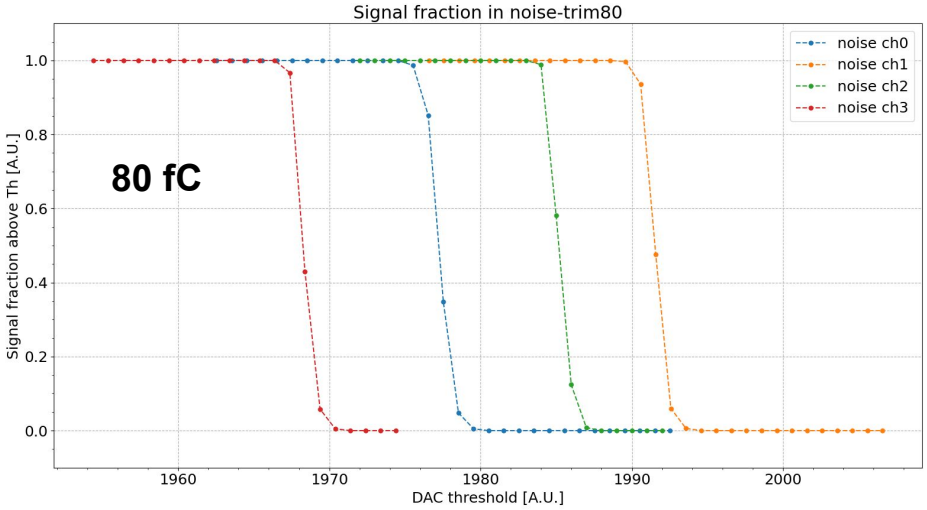



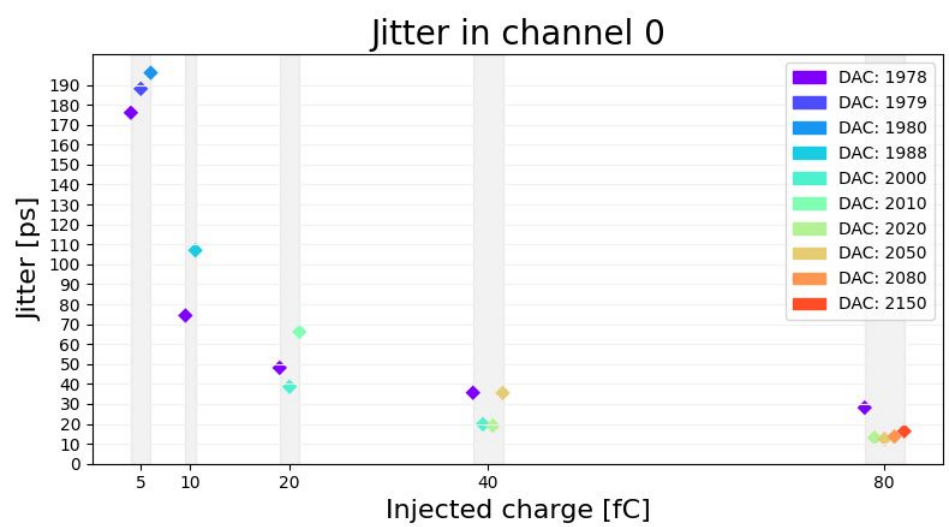
# Noise Trimming

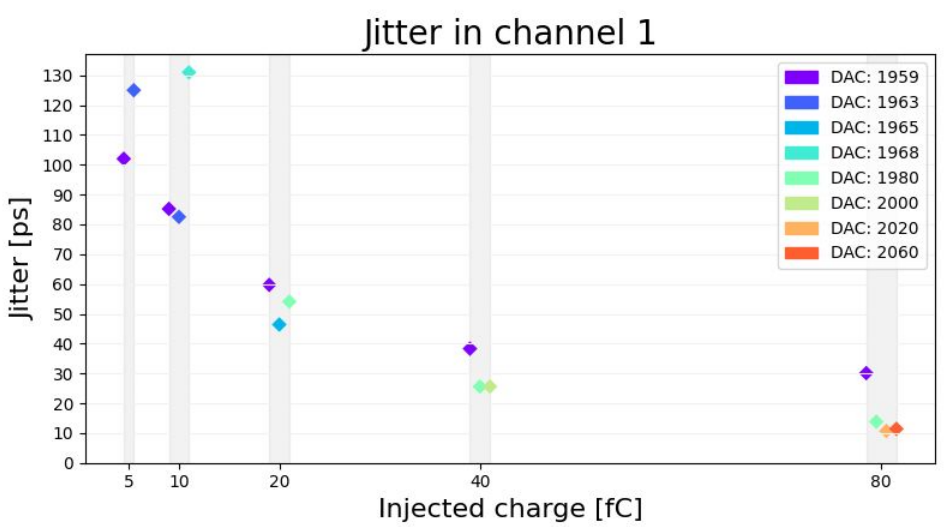
*"**Handmade"** **trimming** done for noise dataset using trimming values extracted from the 20, 40, and 80 fC datasets

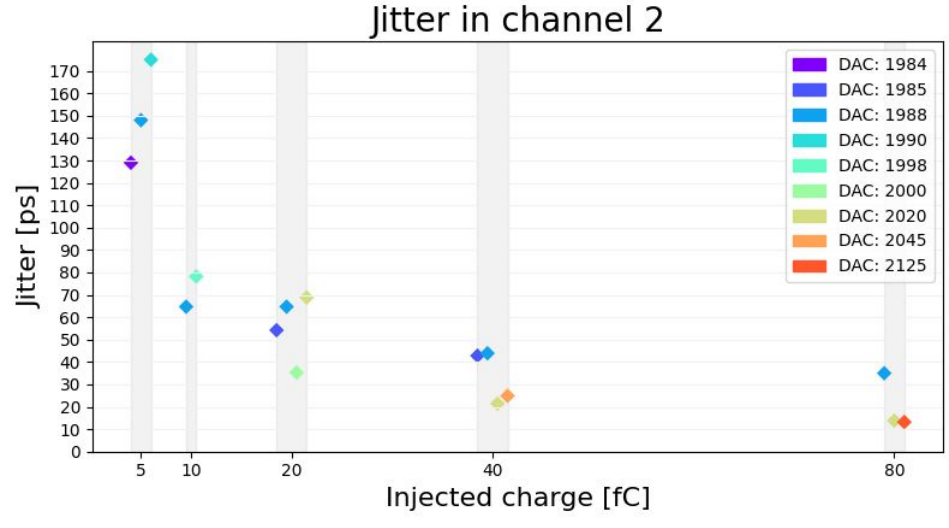


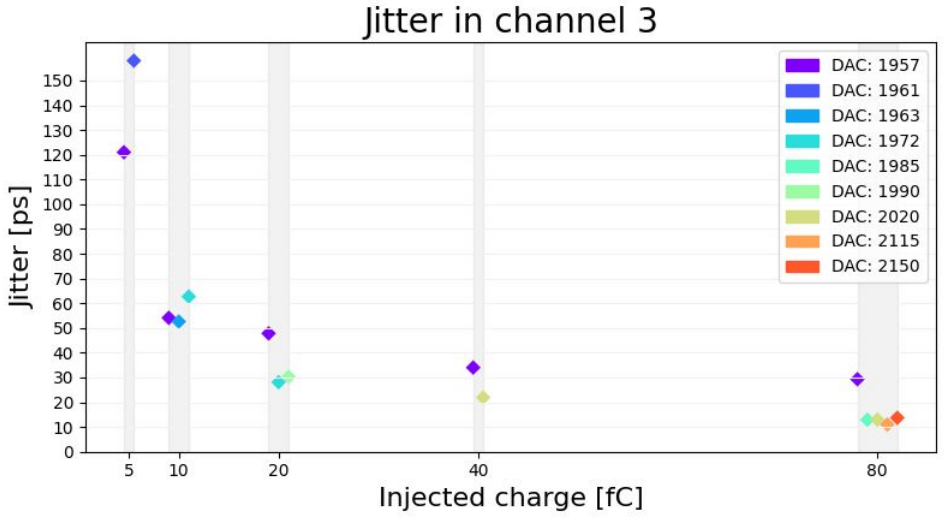



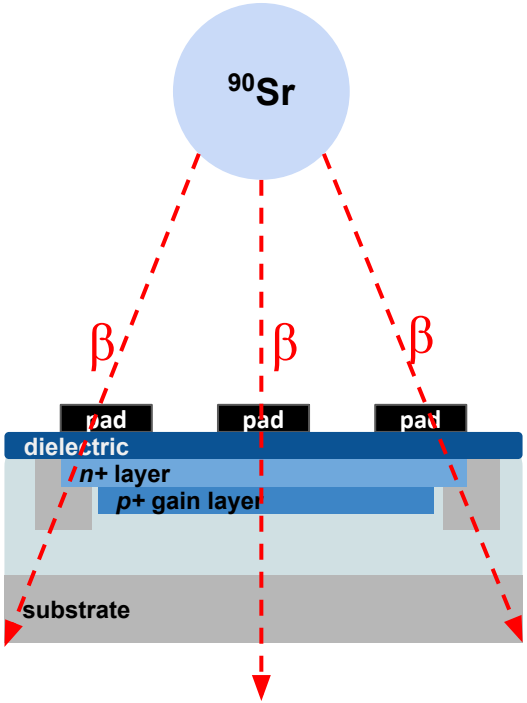

Jitter in channel 0
Jitter [ps]
Injected charge [fC]
DAC: 1978
DAC: 1979
DAC: 1980
DAC: 1988
DAC: 2000
DAC: 2010
DAC: 2020
DAC: 2050
DAC: 2080
DAC: 2150


Jitter in channel 1
Jitter [ps]
Injected charge [fC]
DAC: 1959
DAC: 1963
DAC: 1965
DAC: 1968
DAC: 1980
DAC: 2000
DAC: 2020
DAC: 2060


Jitter in channel 2
Jitter [ps]
Injected charge [fC]
DAC: 1984
DAC: 1985
DAC: 1988
DAC: 1990
DAC: 1998
DAC: 2000
DAC: 2020
DAC: 2045
DAC: 2125


Jitter in channel 3
Jitter [ps]
Injected charge [fC]
DAC: 1957
DAC: 1961
DAC: 1963
DAC: 1972
DAC: 1985
DAC: 1990
DAC: 2020
DAC: 2115
DAC: 2150

# II. Tests with $^{90}$Sr beta source




**1) Discriminator response tests:**

Checked each channel separately, analog and digital. Characterization of discriminator response as a function of the analog signal amplitude

Tested at 3 DAC levels, **Low DAC** (0.1% Noise occupancy, ), **High DAC** (best jitter) and **Mid Value** (average between Low and High)

**2) Signal sharing tests:**

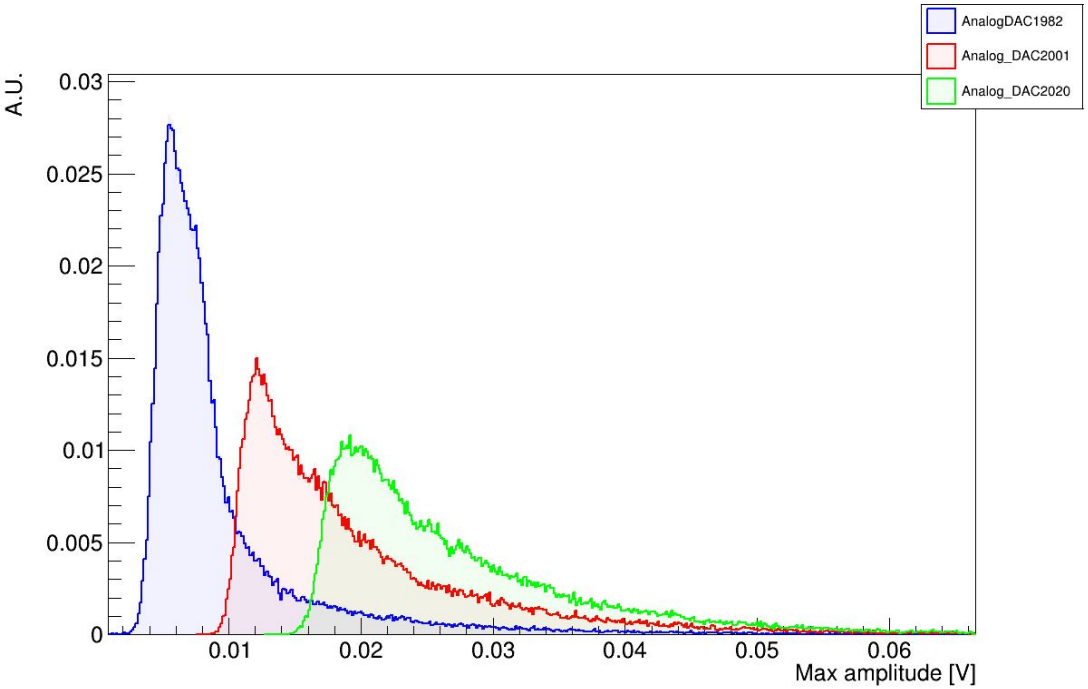
Checked response of all 4 digital channels at the same time to evaluate signal sharing between strips

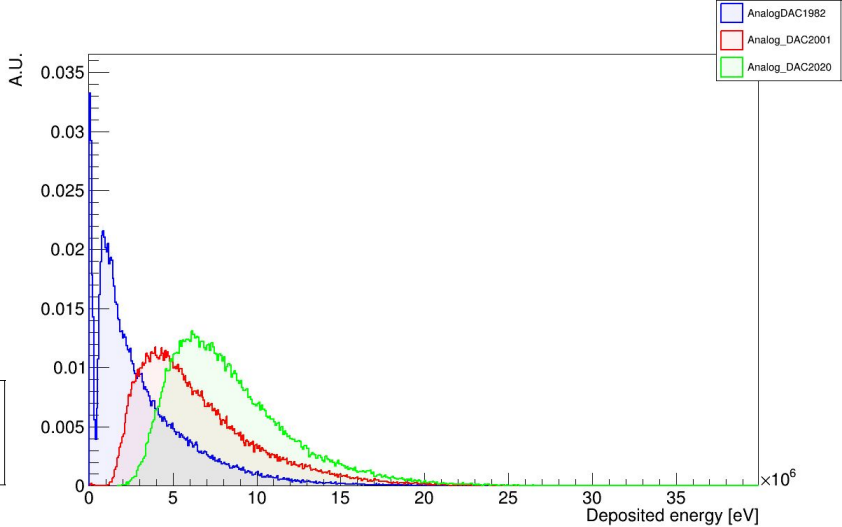
**Discriminator response test**

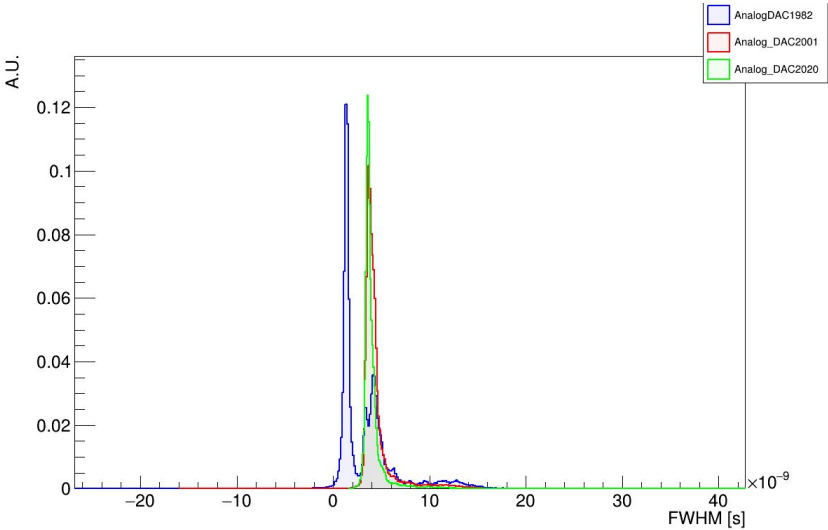
# Analog distributions - Ch0 ($^{90}$Sr)

Distributions of deposited energy and signal FWHM for Low DAC dataset show a **second peak at low values**, not present in Mid and High datasets, interpreted as originating from **above threshold noise**

Second peak higher in external strips (0 and 2)



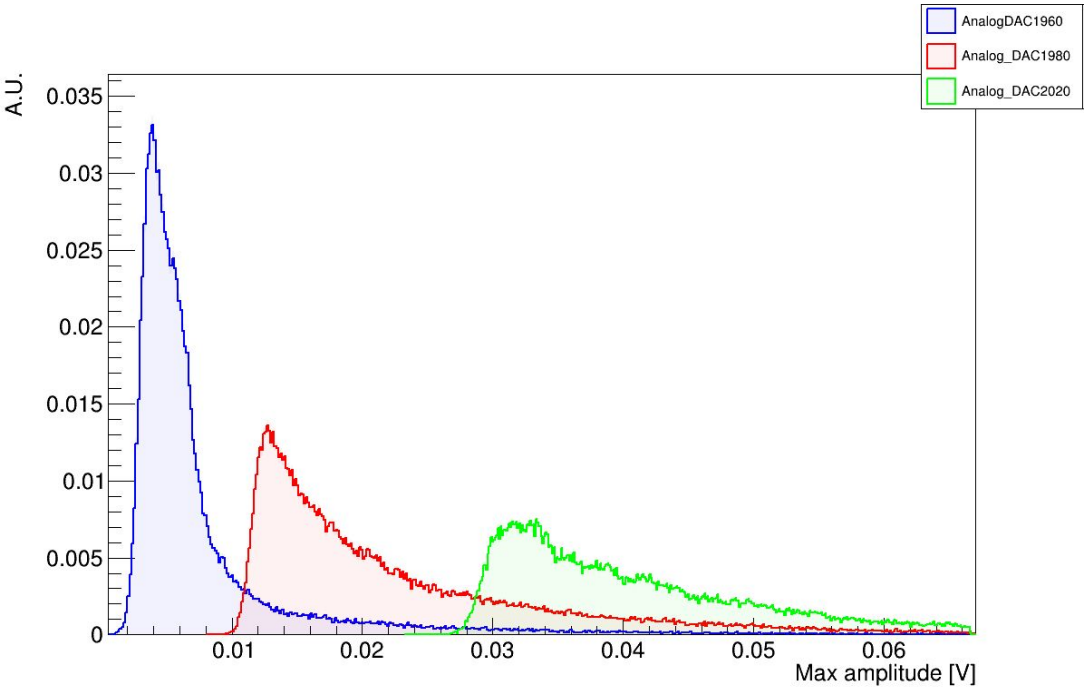



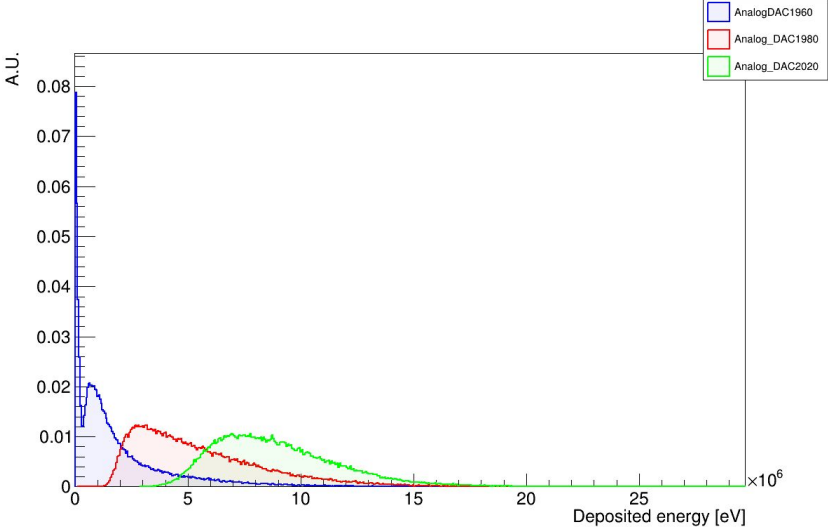
**Discriminator response test**

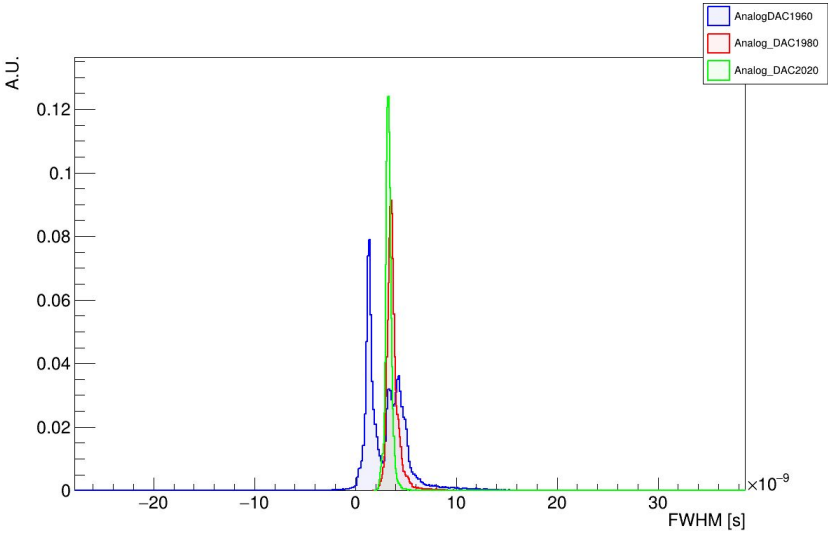
# Analog distributions - Ch1 ($^{90}$Sr)

Distributions of deposited energy and signal FWHM for Low DAC dataset show a **second peak at low values**, not present in Mid and High datasets, interpreted as originating from **above threshold noise**

Second peak higher in external strips (0 and 2)



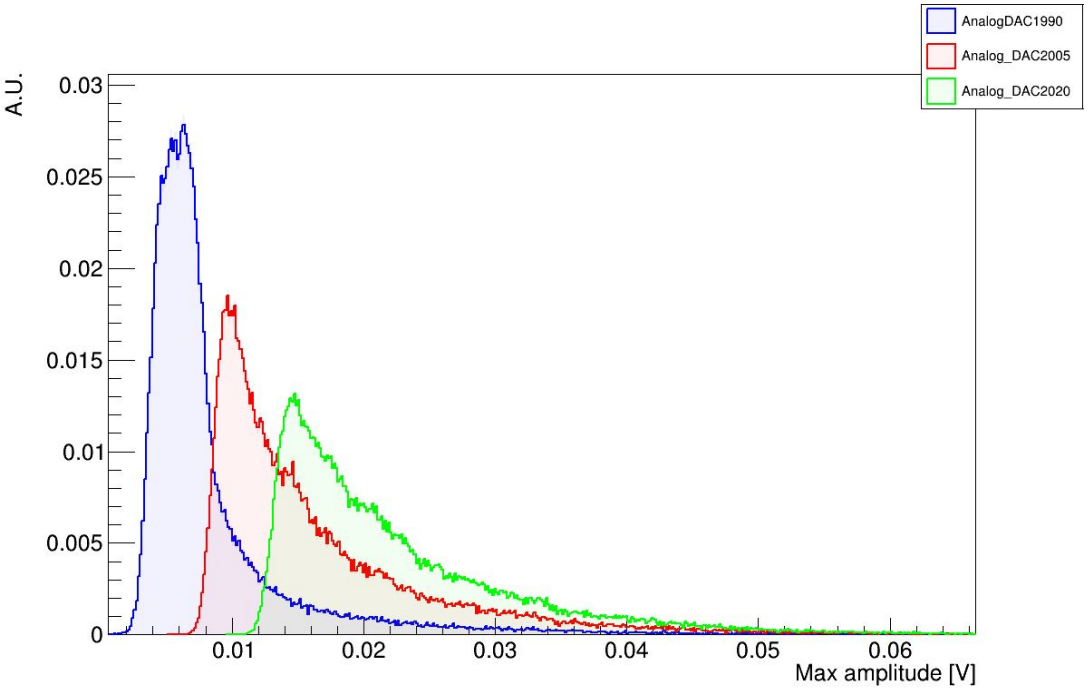



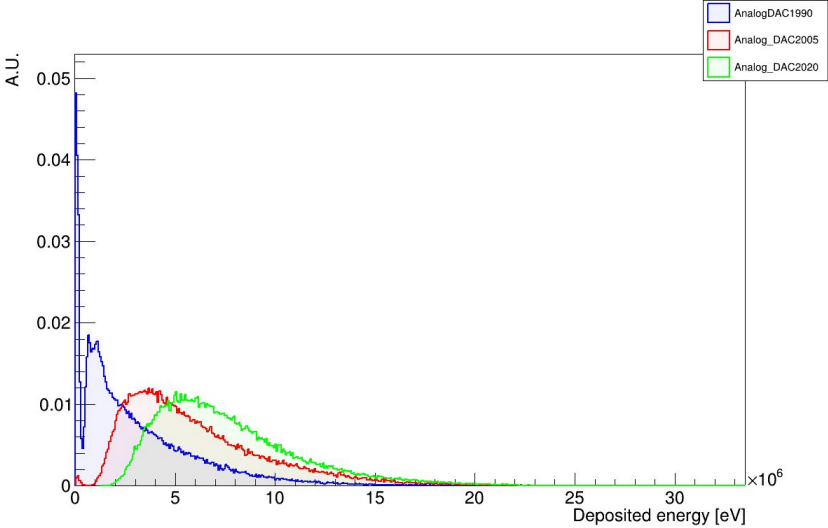
**Discriminator response test**

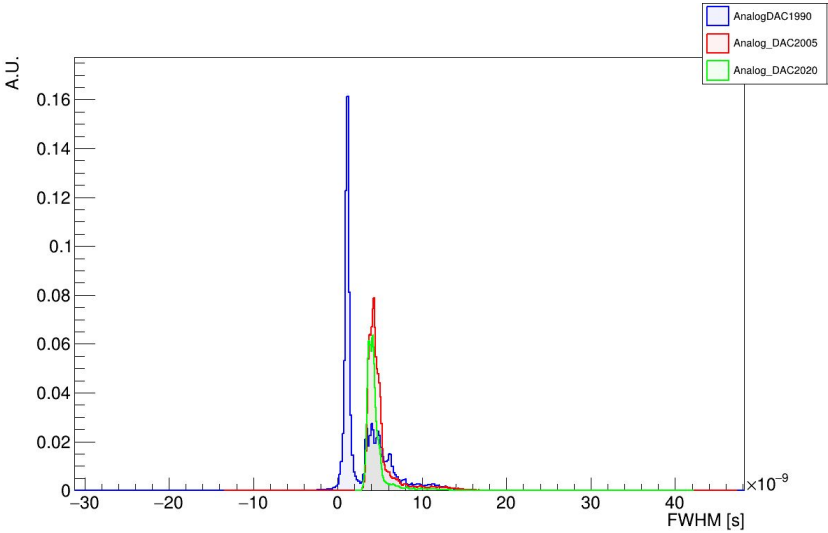
# Analog distributions - Ch2 ($^{90}$Sr)

Distributions of deposited energy and signal FWHM for Low DAC dataset show a **second peak at low values**, not present in Mid and High datasets, interpreted as originating from **above threshold noise**

Second peak higher in external strips (0 and 2)



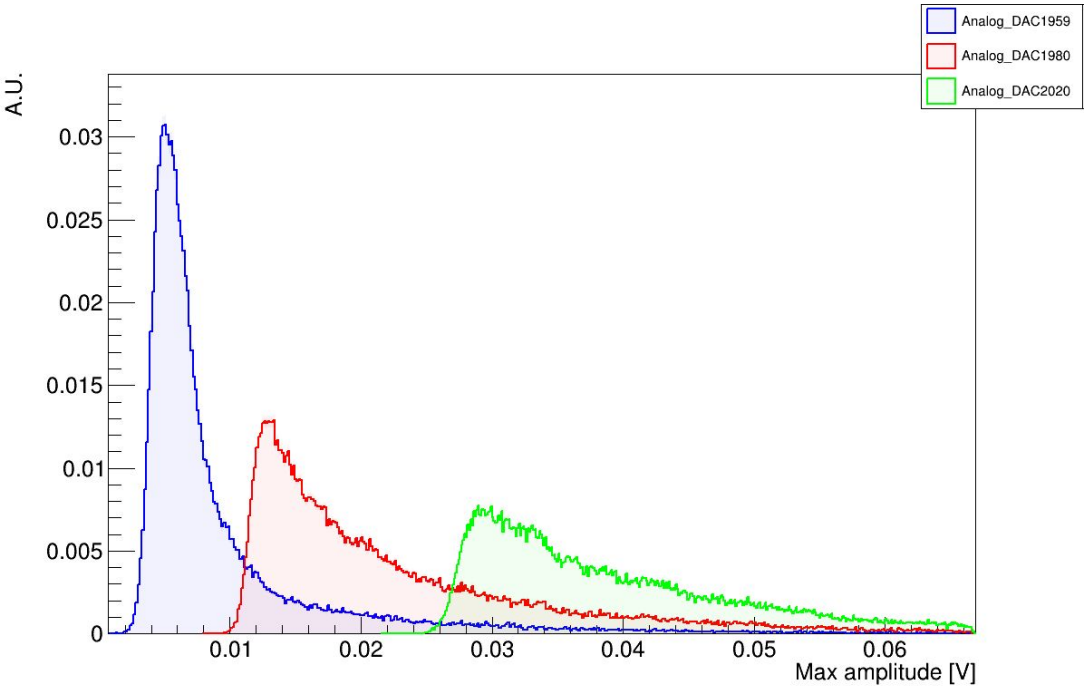



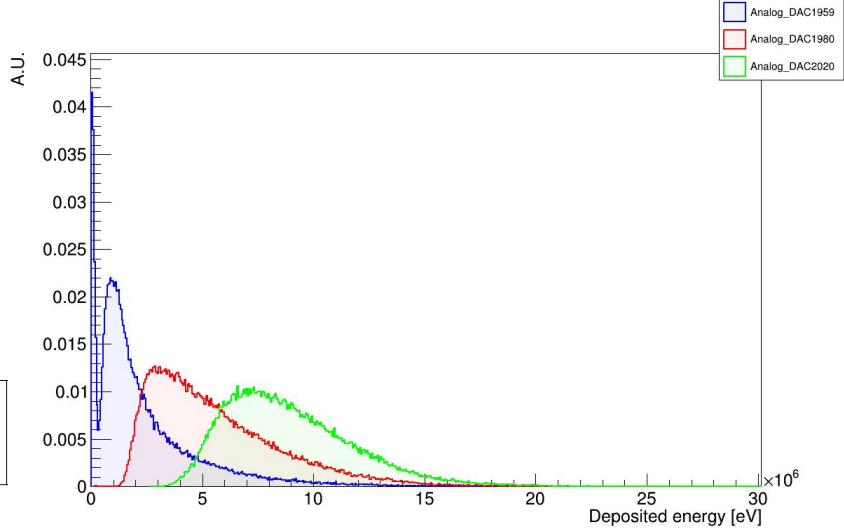
**Discriminator response test**

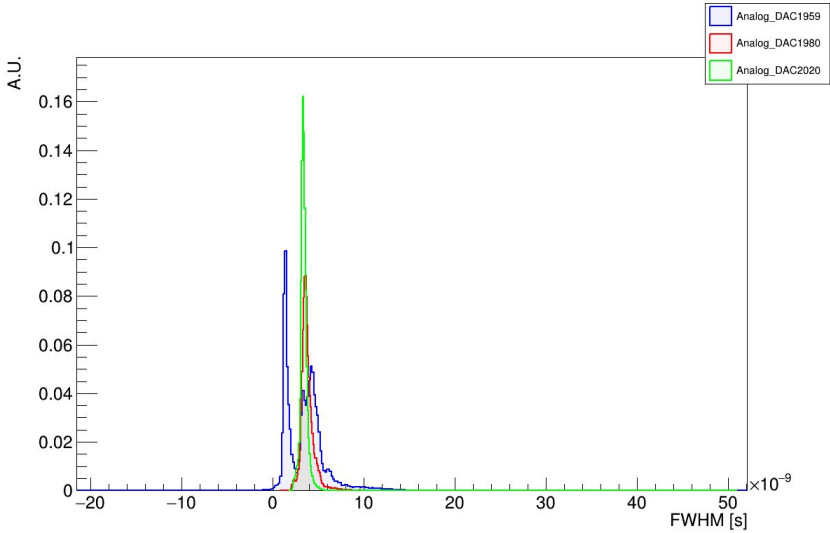
# Analog distributions - Ch3 ($^{90}$Sr)

Distributions of deposited energy and signal FWHM for Low DAC dataset show a **second peak at low values**, not present in Mid and High datasets, interpreted as originating from **above threshold noise**

Second peak higher in external strips (0 and 2)

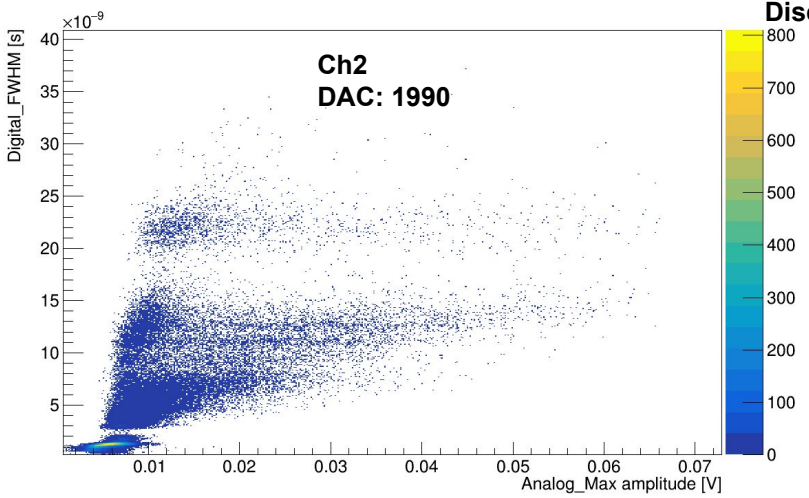


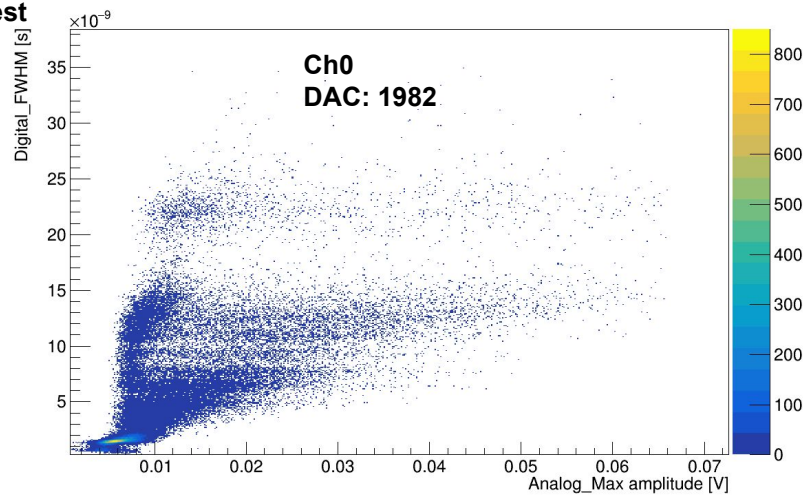



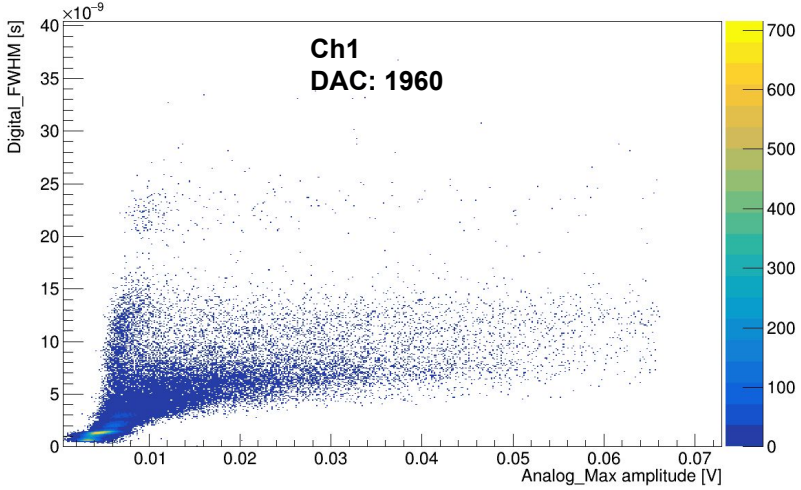



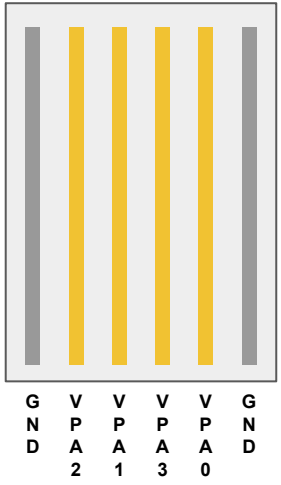
# Discriminator response test

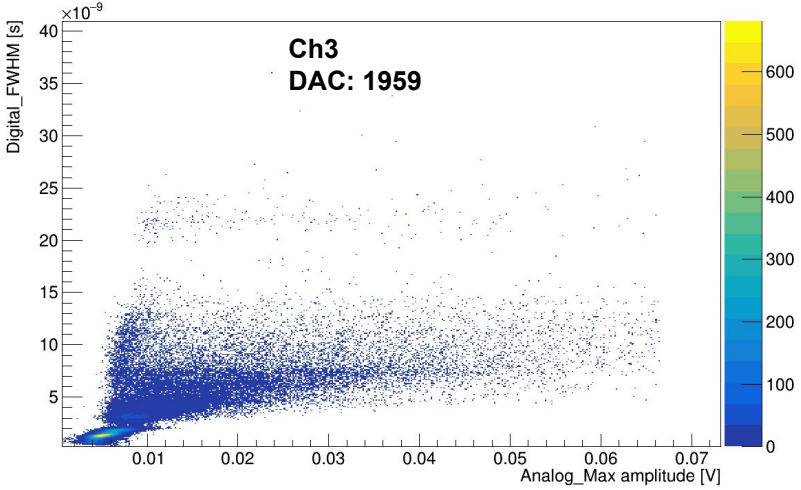
## Low DAC
## (0.1% NO)



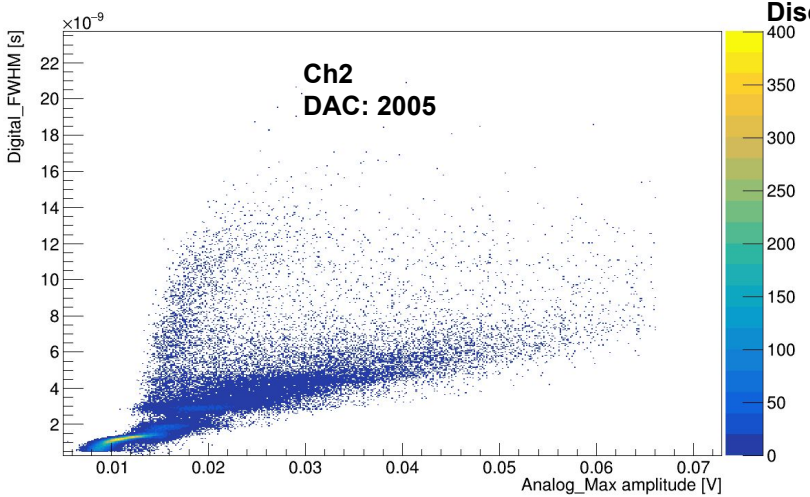



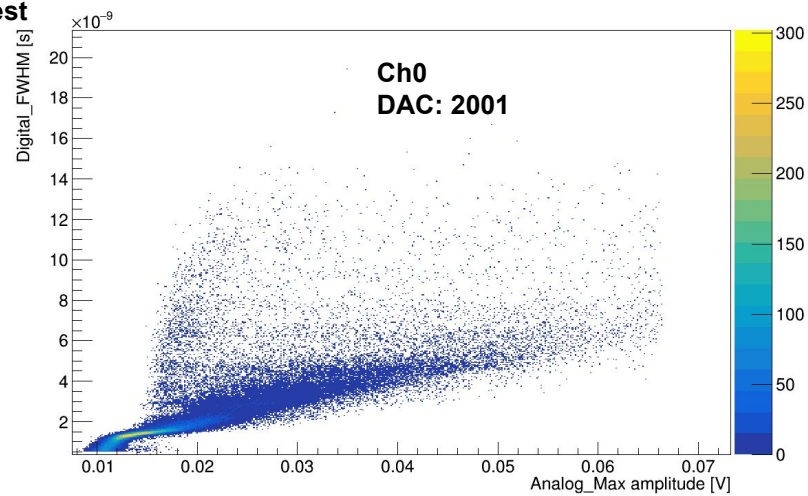



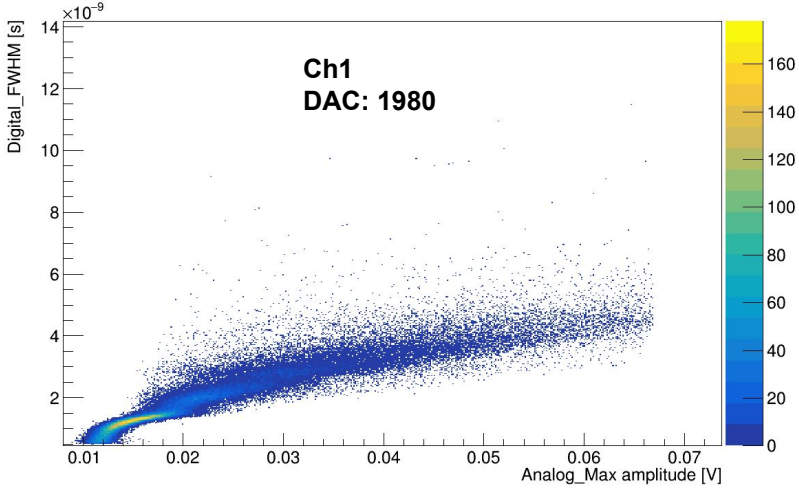



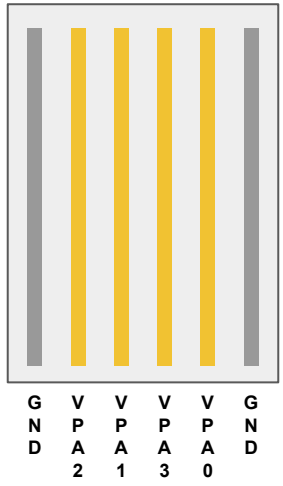
# Discriminator response test

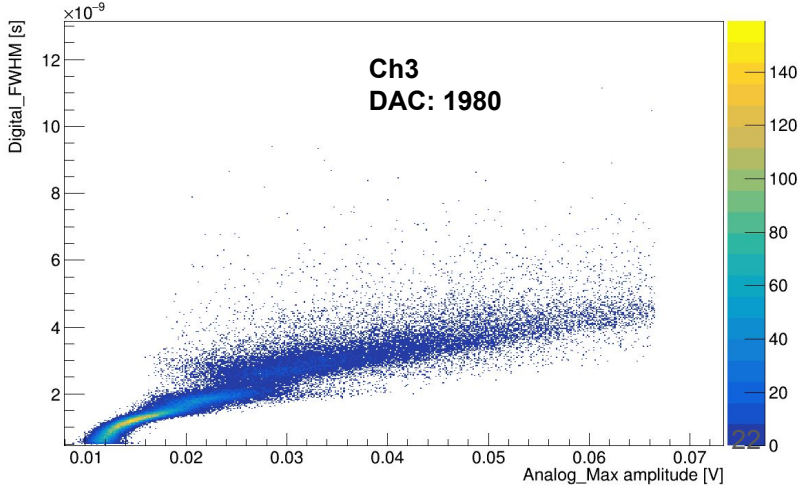
## Mid DAC



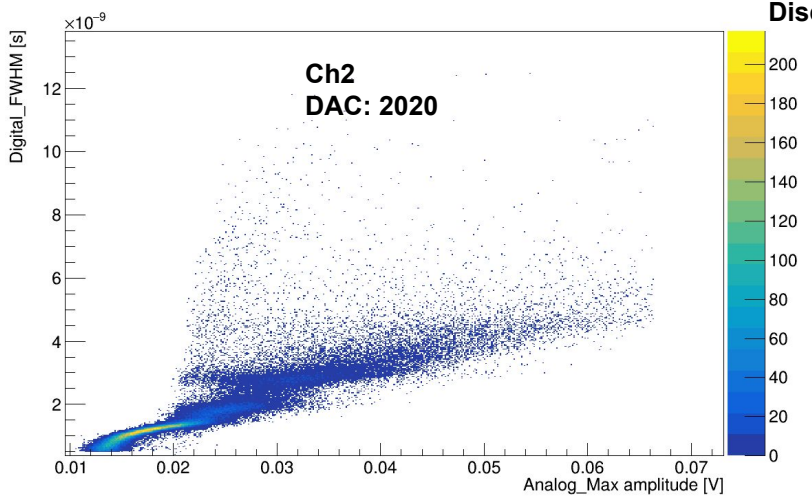



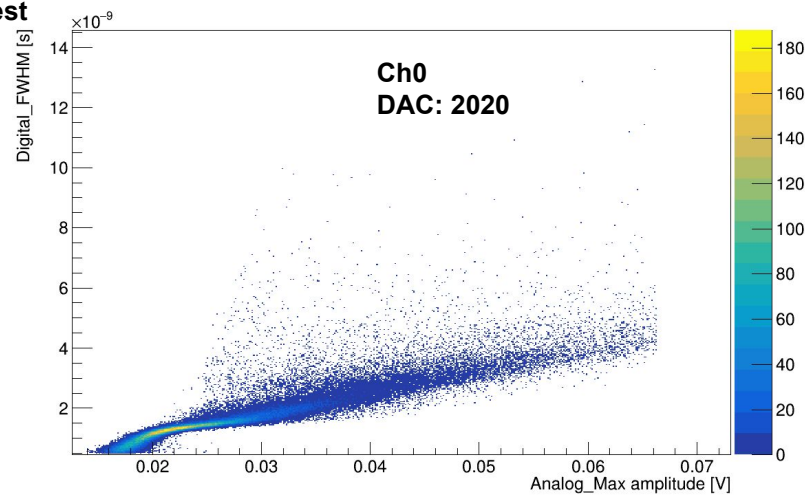



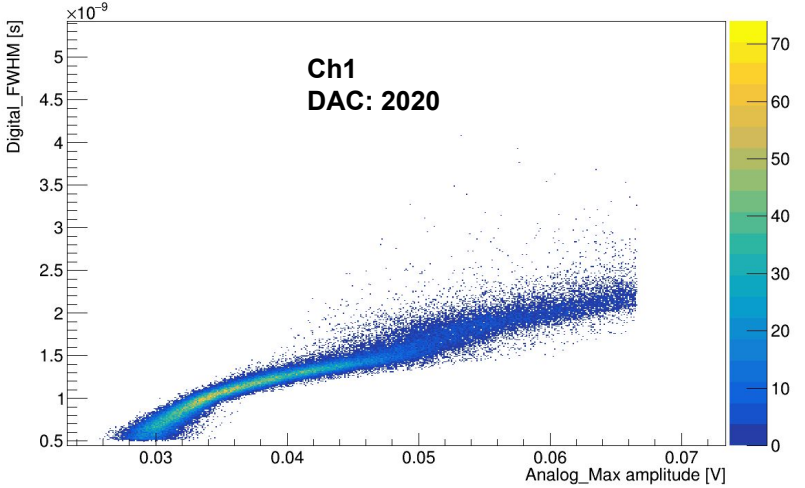



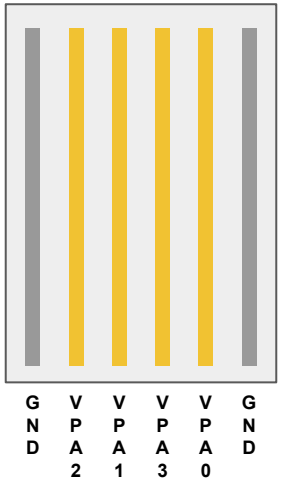
Discriminator response test

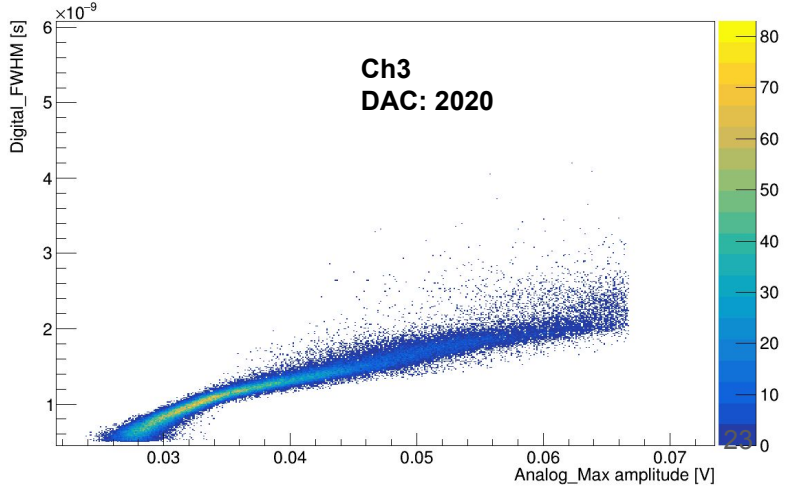
# High DAC
## (best jitter)



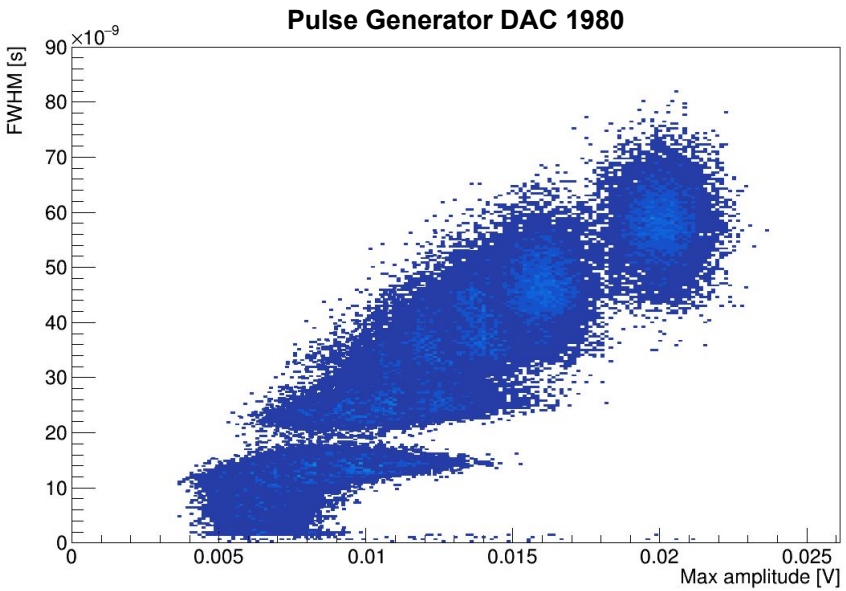



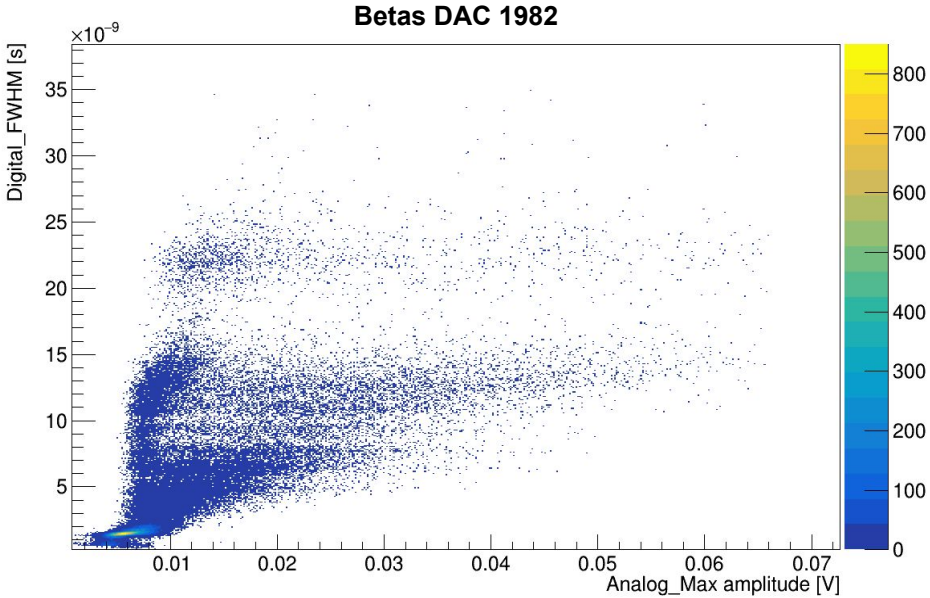



# Comparison to Pulse Generator




Superimposition of signals from different datasets at:

50, 56, 60, 69, 77, 86, 96, 107, 120, 130, 150, 170, 215 mV

of injected amplitude.

**No second population observed** with the Pulse Generator

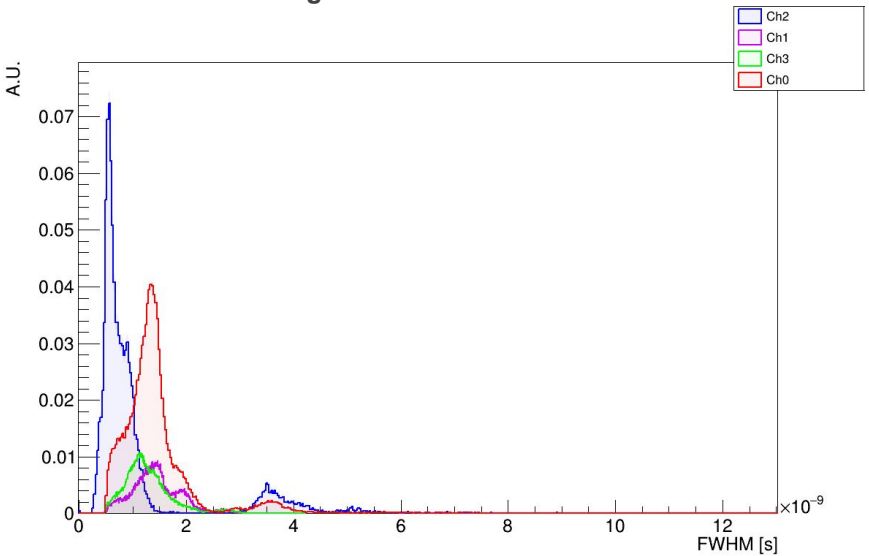
**Signal sharing tests**

# Multi-channel digital distributions

To evaluate signal sharing, all four digital channels readout in parallel

- trigger on Ch0
- **ALTIROC DAC: 2020**

Betas emitted isotropically, no way to discriminate signals from **direct interaction** with Ch0 to **signals shared** on Ch0

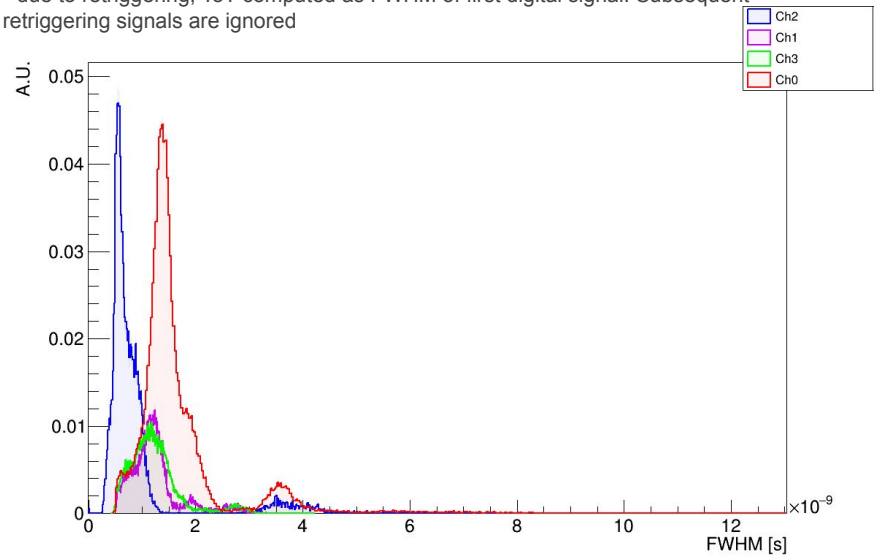



***no Veto:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}$Sr dataset*

We applied a **software hierarchical veto**, keeping only signals with:

$$ToT^0 > ToT^3 > ToT^1 > ToT^2$$

* due to retriggering, ToT computed as FWHM of first digital signal. Subsequent retriggering signals are ignored

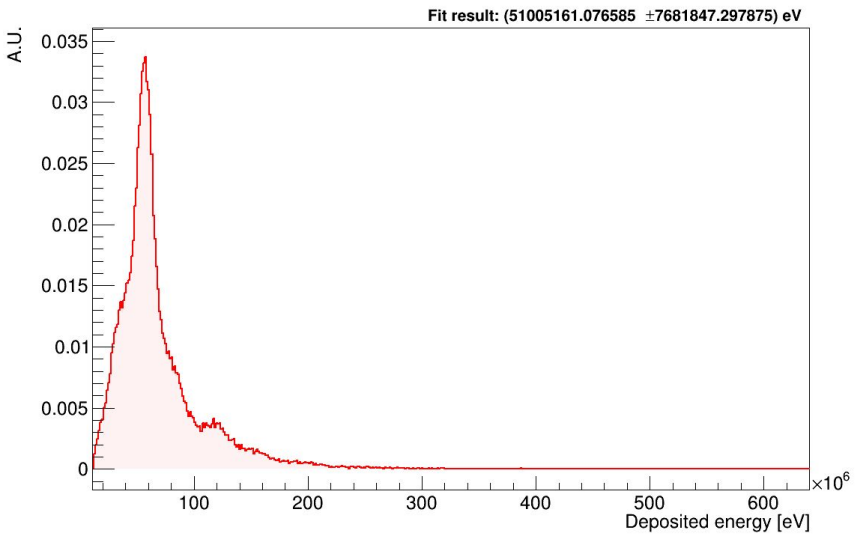



***Hierarchical Veto:*** *distribution of digital signal integrals for channel 0 when reading out 4 digital channels in parallel*

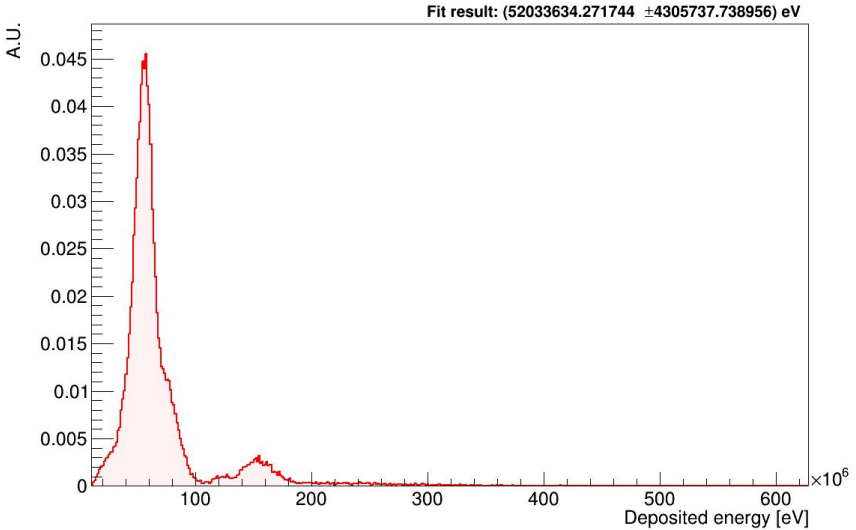
Signal sharing tests

# Multi-channel digital distributions

Distributions obtained when all digital channels are readout seems different than those obtained when a single channel is readout (and **higher noise** is observed)




***single channel:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}$Sr dataset*




***multichannel:*** *distribution of digital signal integrals obtained for channel 0 when reading out 4 digital channels in parallel (with Hierarchical Veto applied)*

# A few considerations

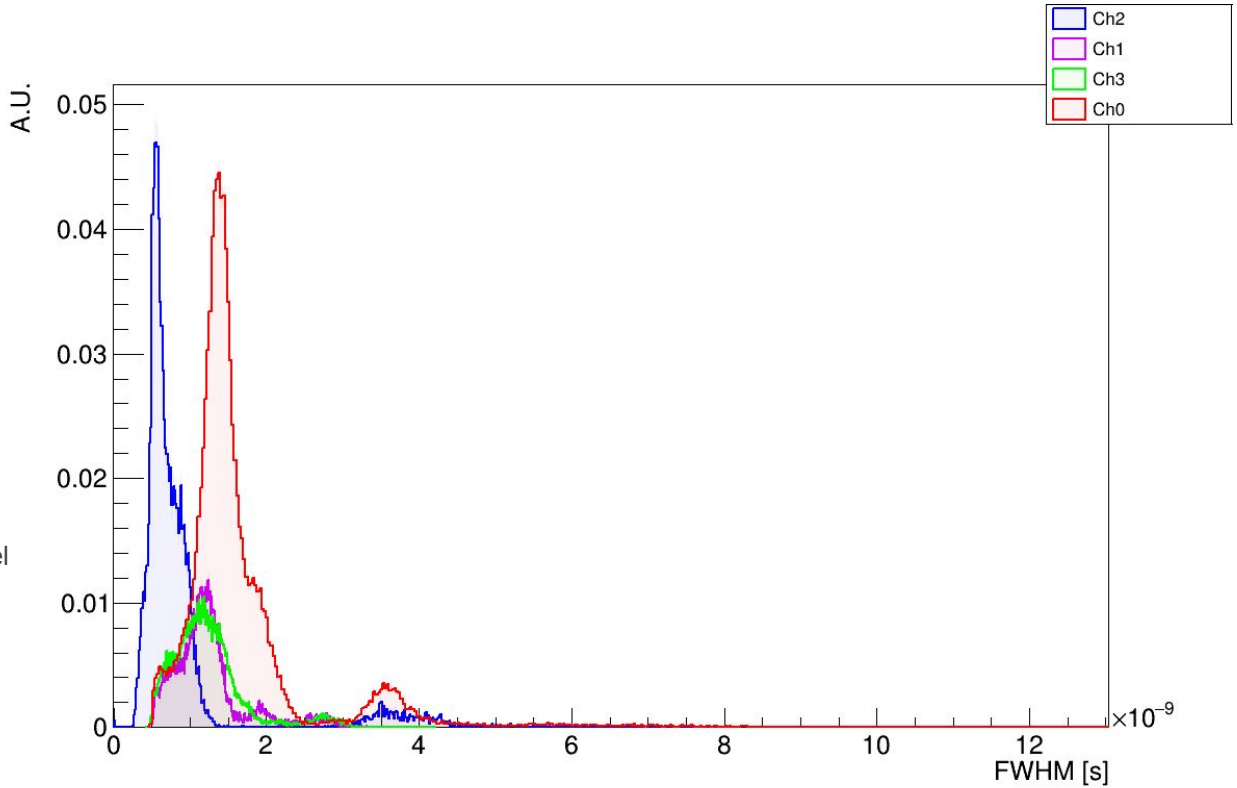
1) All channels show a **double peak structure** in the FWHM and Deposited charge distributions.

2) This could be either a **physical effect** (signal sharing, …), **electronics cross-talk**, or something else

3) This effect is **also seen in the single-channel** dataset

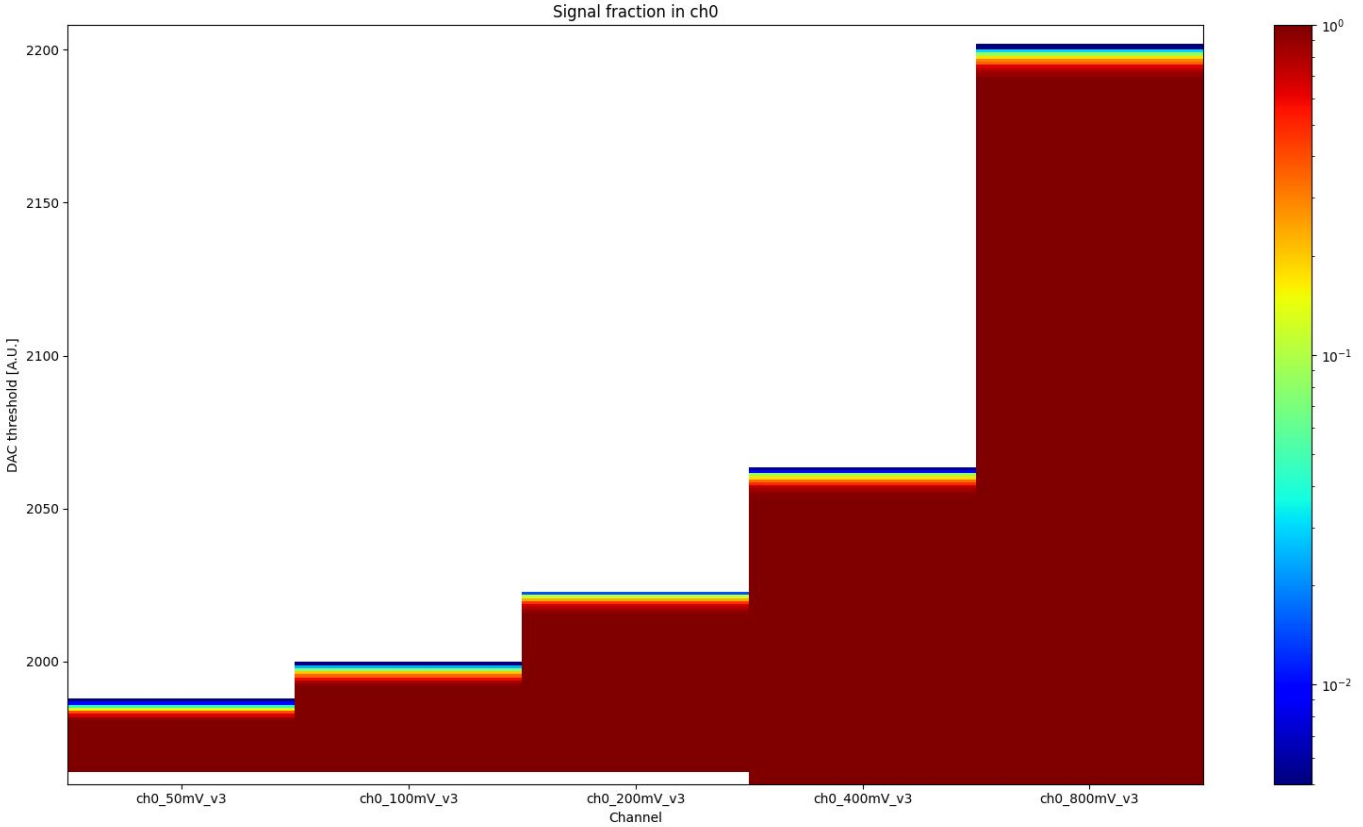
4) Since all channels share DAC threshold and trimming is not available, **hierarchical veto needs to be calibrated** to account for different channels response at the same DAC level

5) We plan to further investigate this double-peak structure by comparing analog vs digital signals

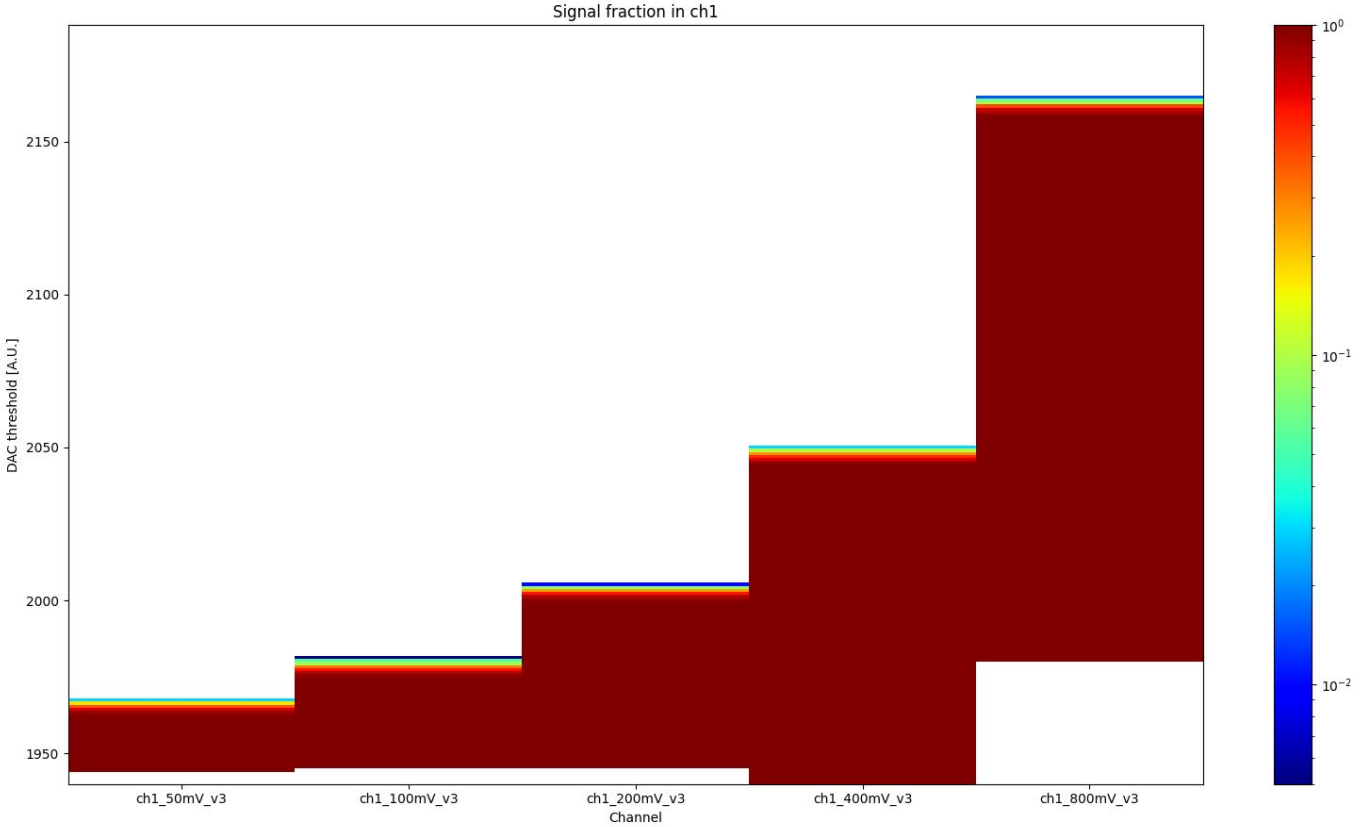


# BACKUP

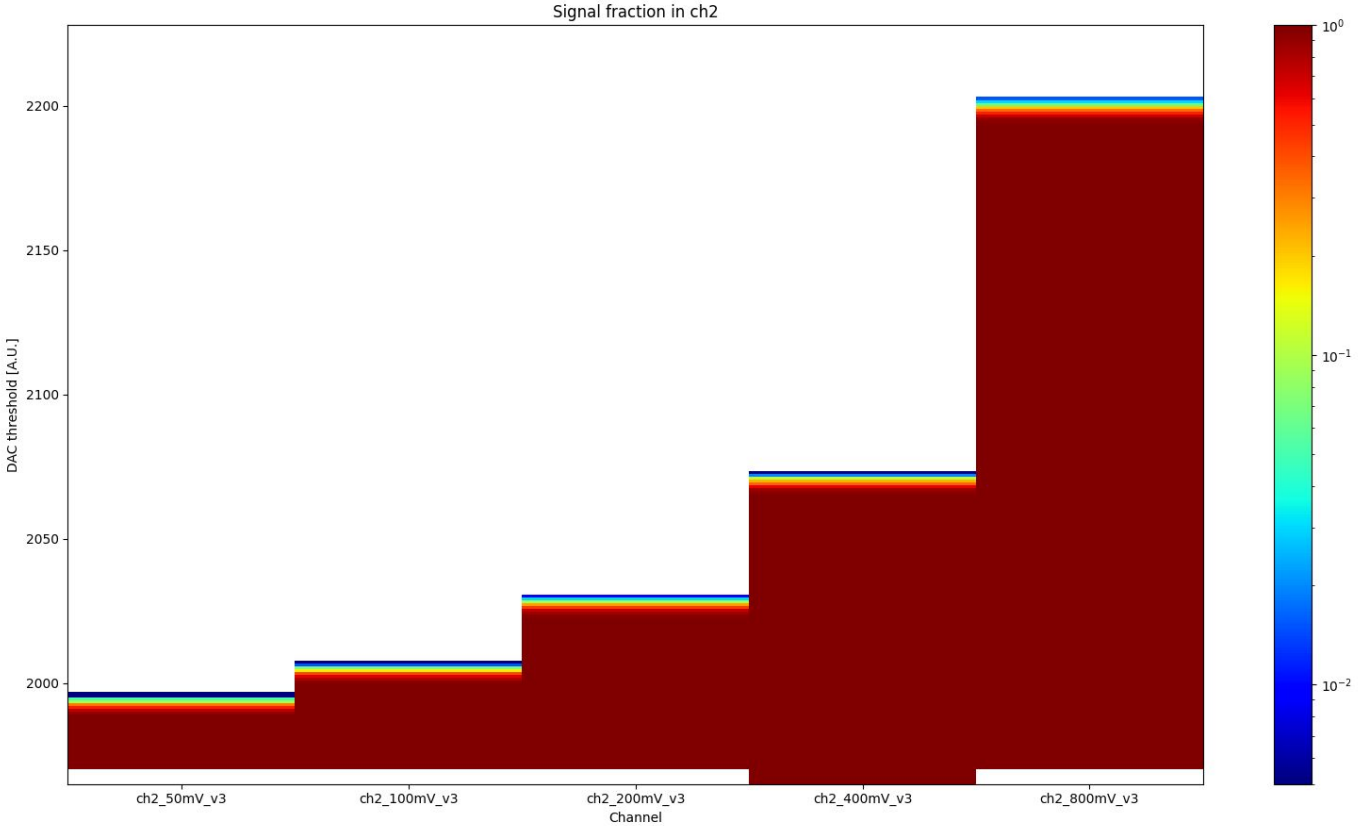
# Fraction overview - Ch0



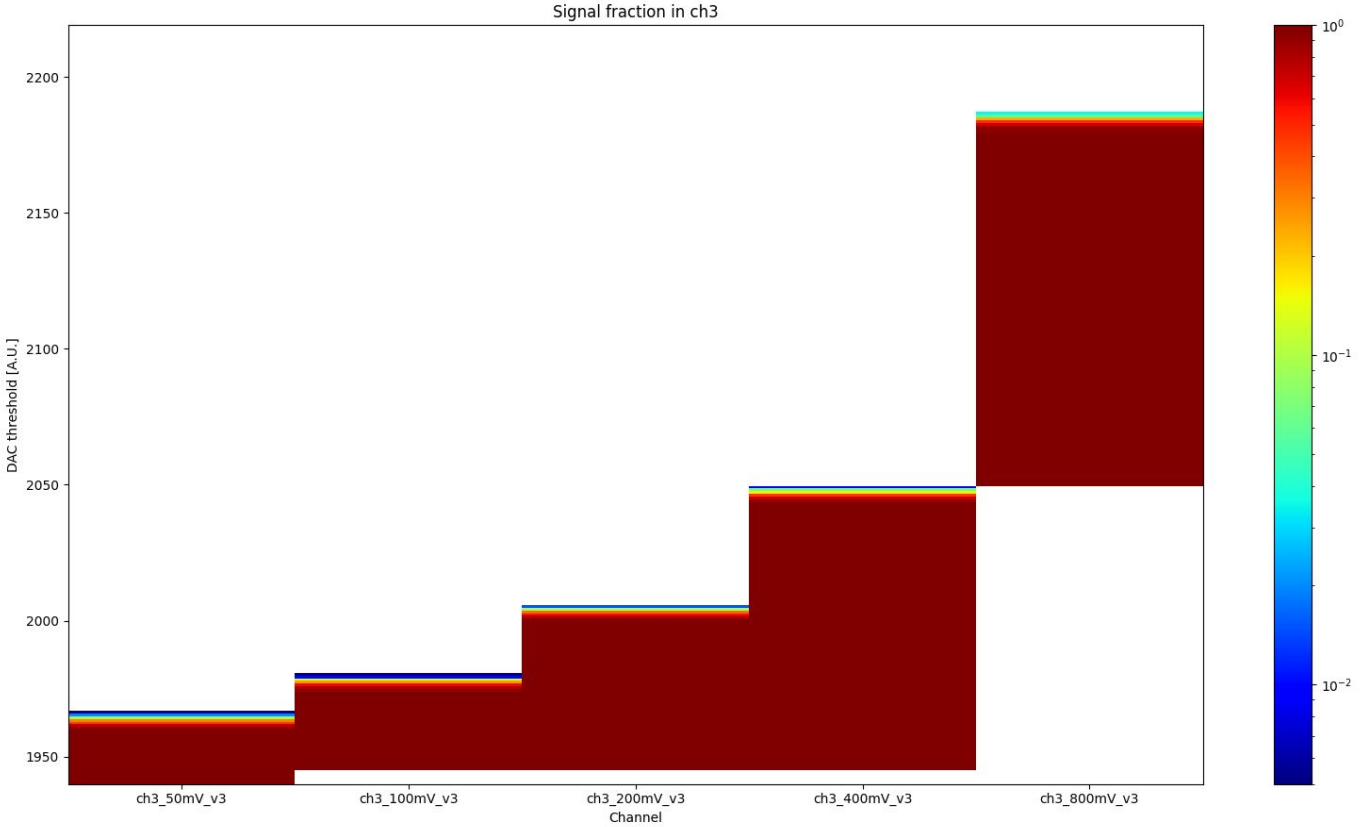
# Fraction overview - Ch1



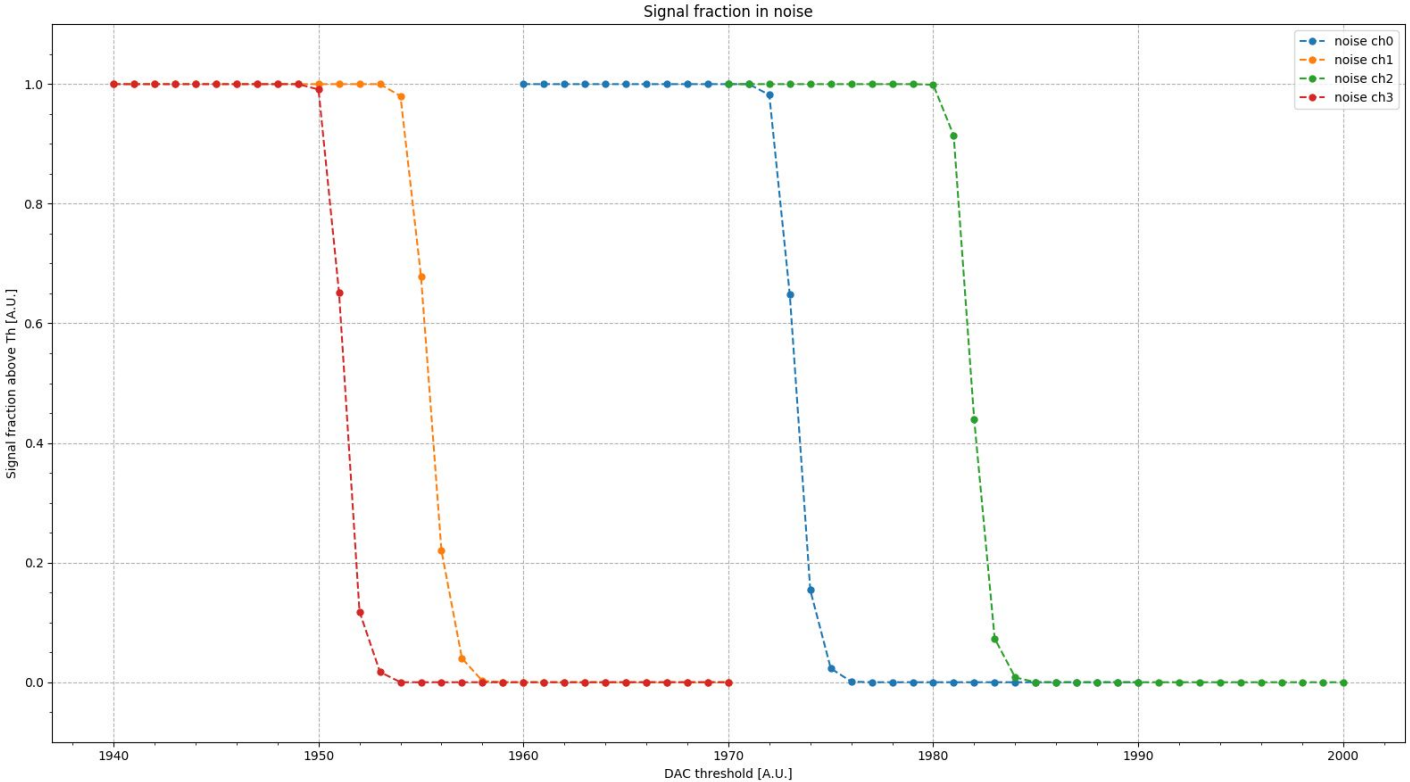
# Fraction overview - Ch2



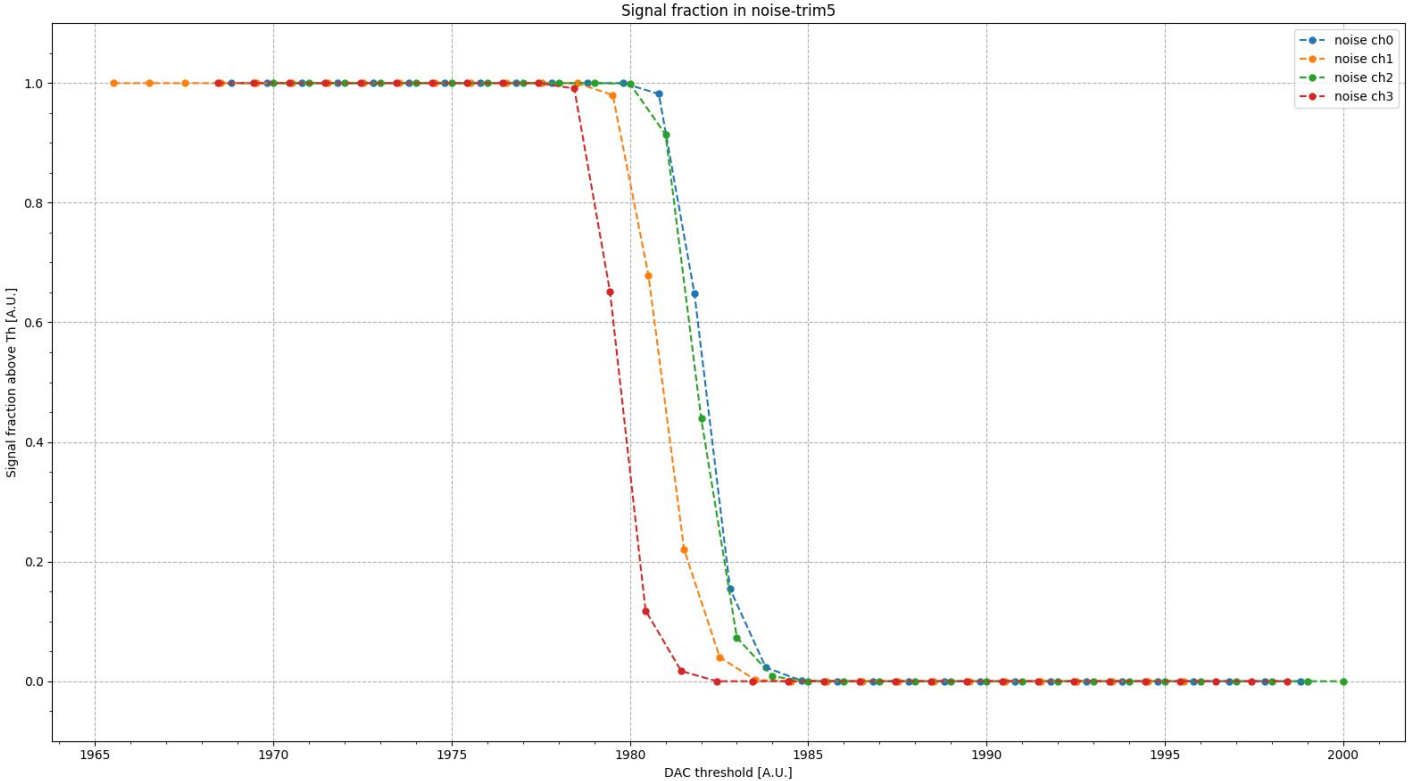
# Fraction overview - Ch3



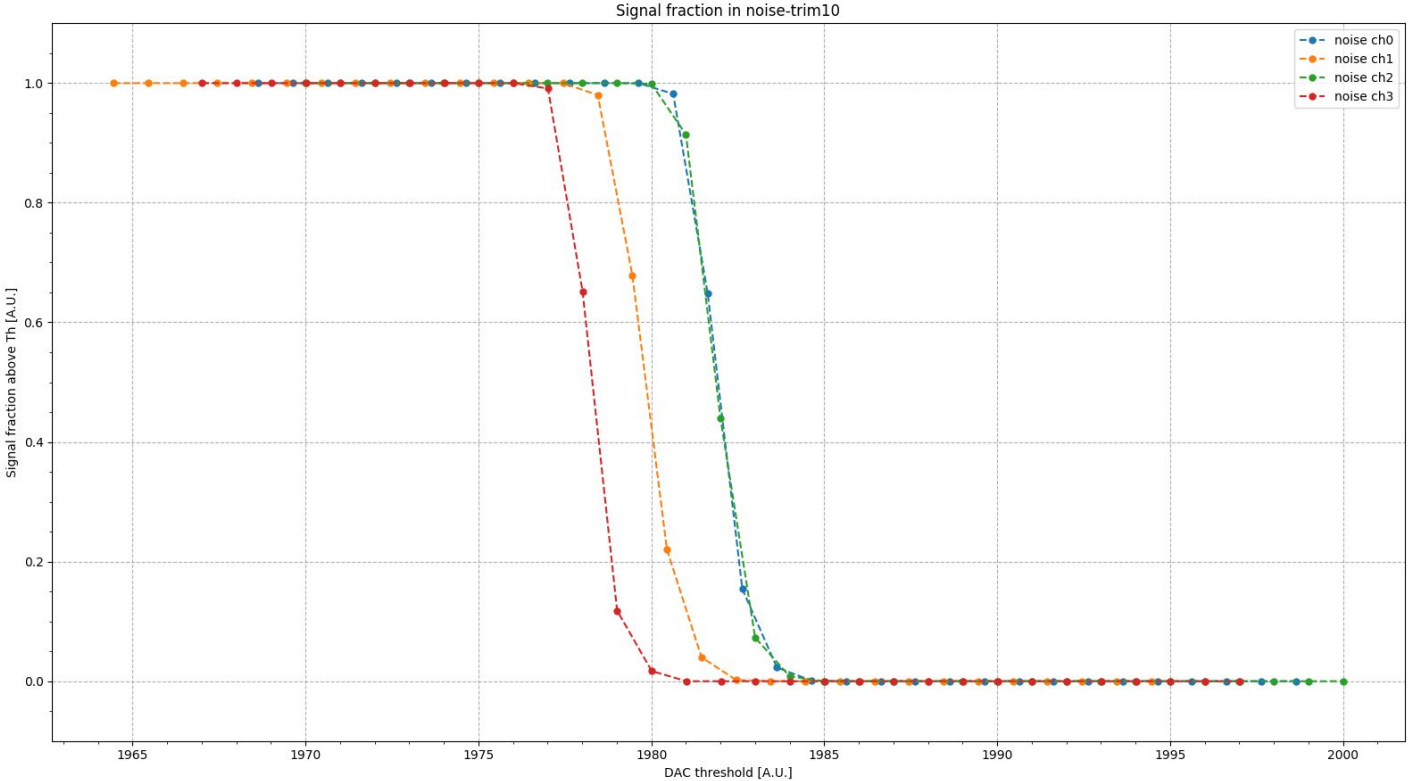
# Noise Trimming - untrimmed



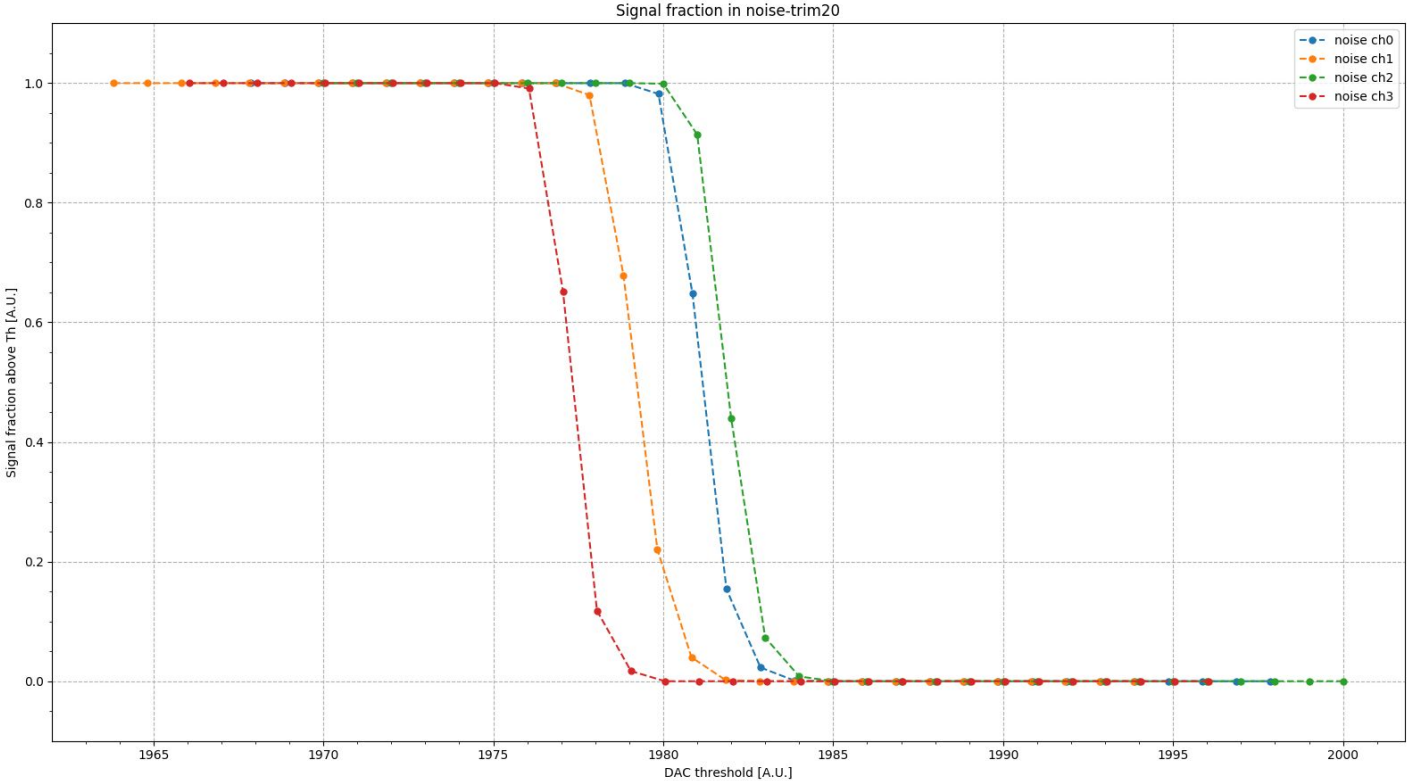
# Noise Trimming - 5 fC



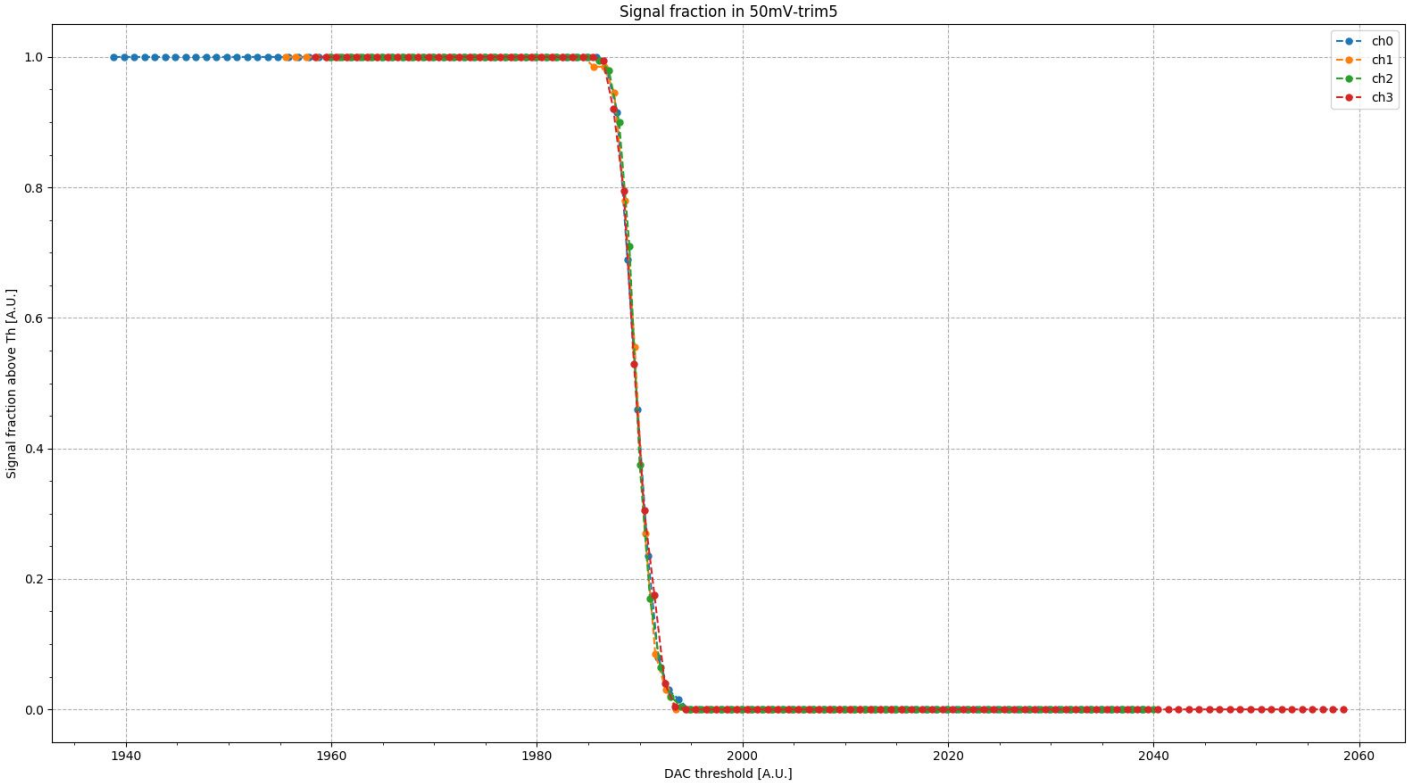
# Noise Trimming - 10 fC



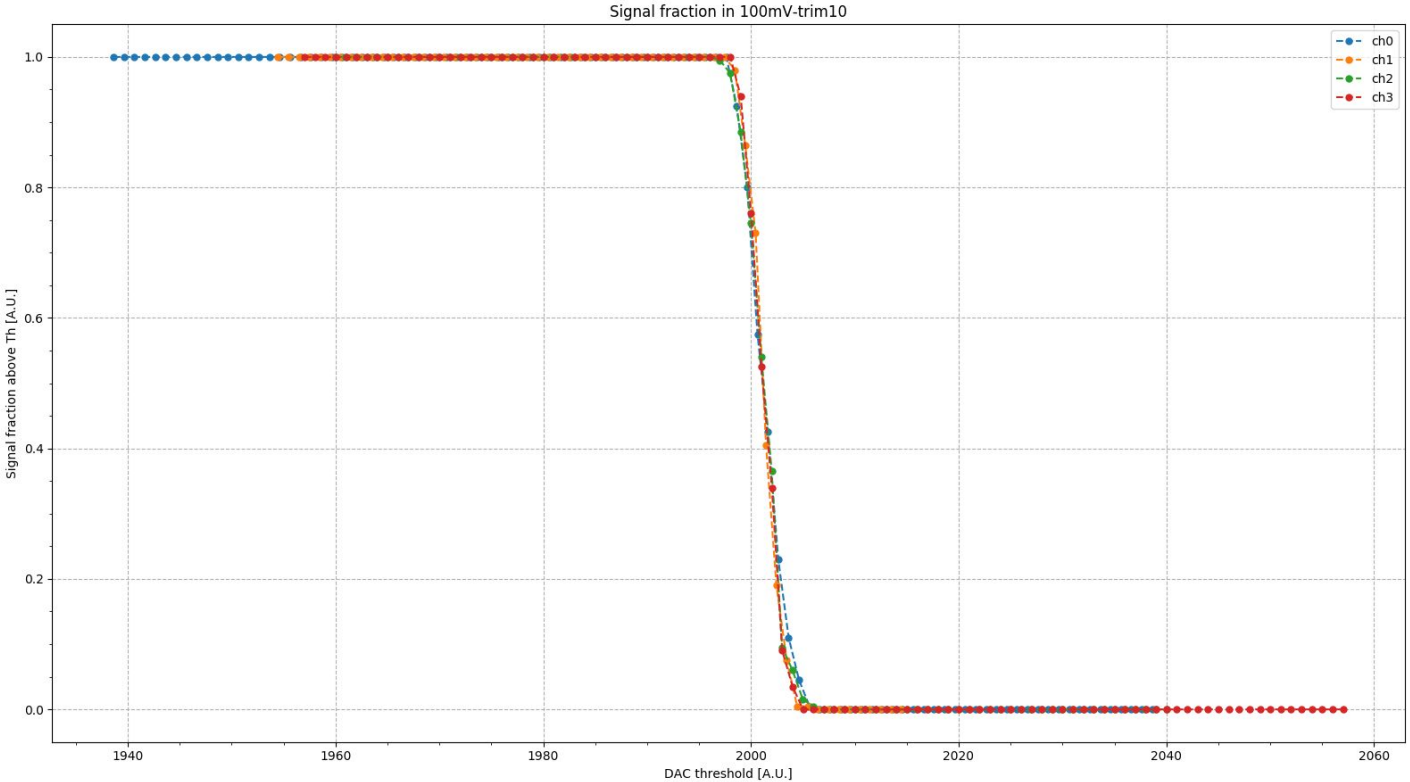
# Noise Trimming - 20 fC



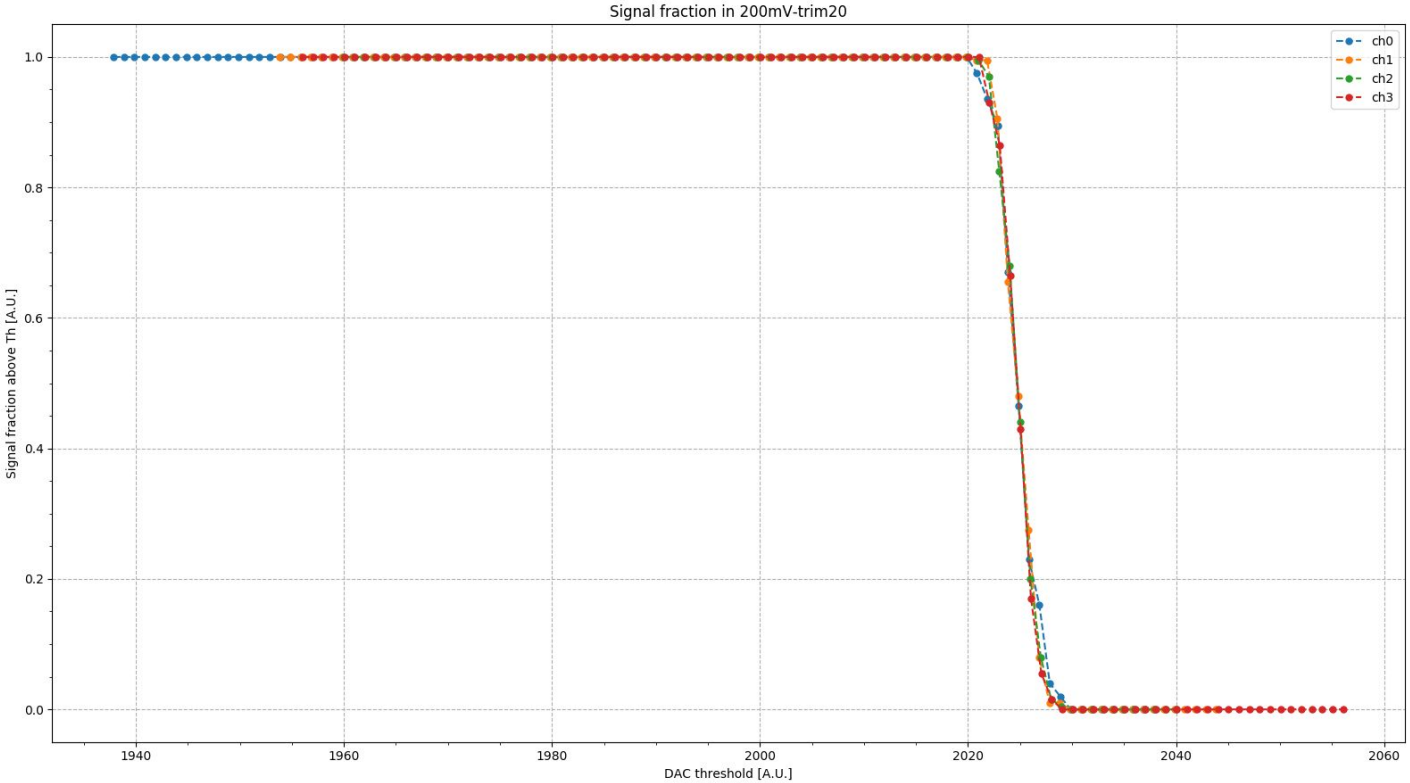
# Signal Trimming - 5 fC



# Signal Trimming - 10 fC



# Signal Trimming - 20 fC



# Measured jitters (Pulse Gen) - ch0

| Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|
| 0 | 5 | 1978 | 176 |
| | 5 | 1979 | 188 |
| | 5 | 1980 | 196 |
| | 10 | 1978 | 74.3 |
| | 10 | 1988 | 107 |
| | 20 | 1978 | 48.1 |
| | 20 | 2000 | 38.6 |
| | 20 | 2010 | 66.1 |

| Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|
| 0 | 40 | 1978 | 35.6 |
| | 40 | 2000 | 19.8 |
| | 40 | 2020 | 19.1 |
| | 40 | 2050 | 35.5 |
| | 80 | 1978 | 28.1 |
| | 80 | 2020 | 13 |
| | 80 | 2050 | 12.4 |
| | 80 | 2080 | 13.6 |
| | 80 | 2150 | 16.3 |

# Measured jitters (Pulse Gen) - ch1

| Ch | Charge [fC] | DAC | jitter [ps] | Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|---|---|---|---|
| 1 | 5 | 1959 | 102 | 1 | 40 | 1959 | 38.3 |
| | 5 | 1963 | 125 | | 40 | 1980 | 25.6 |
| | 10 | 1959 | 85.2 | | 40 | 2000 | 32.2 |
| | 10 | 1963 | 82.5 | | 80 | 1959 | 30.1 |
| | 10 | 1968 | 131 | | 80 | 1980 | 13.8 |
| | 20 | 1959 | 59.7 | | 80 | 2020 | 10.7 |
| | 20 | 1965 | 46.4 | | 80 | 2060 | 11.4 |
| | 20 | 1980 | 54.1 | | | | |

# Measured jitters (Pulse Gen) - ch2

| Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|
| 2 | 5 | 1984 | 129 |
| | 5 | 1988 | 148 |
| | 5 | 1990 | 175 |
| | 10 | 1988 | 64.7 |
| | 10 | 1998 | 78.2 |
| | 20 | 1985 | 54.2 |
| | 20 | 1988 | 55.7 |
| | 20 | 2000 | 35.3 |
| | 20 | 2020 | 68.8 |

| Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|
| 2 | 40 | 1985 | 42.8 |
| | 40 | 1988 | 43.9 |
| | 40 | 2020 | 21.4 |
| | 40 | 2045 | 24.9 |
| | 80 | 1988 | 35 |
| | 80 | 2020 | 13.8 |
| | 80 | 2125 | 13.2 |

# Measured jitters (Pulse Gen) - ch3

| Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|
| 3 | 5 | 1957 | 121 |
| | 5 | 1961 | 158 |
| | 10 | 1957 | 54.1 |
| | 10 | 1963 | 52.6 |
| | 10 | 1972 | 62.7 |
| | 20 | 1957 | 47.8 |
| | 20 | 1972 | 28.1 |
| | 20 | 1990 | 30.3 |

| Ch | Charge [fC] | DAC | jitter [ps] |
|---|---|---|---|
| 3 | 40 | 1957 | 34 |
| | 40 | 2020 | 21.9 |
| | 80 | 1957 | 29.3 |
| | 80 | 1985 | 12.9 |
| | 80 | 2020 | 13 |
| | 80 | 2115 | 11 |
| | 80 | 2150 | 13.7 |

Signal sharing tests

# Multi-channel digital distributions

To evaluate signal sharing, all four digital channels readout in parallel

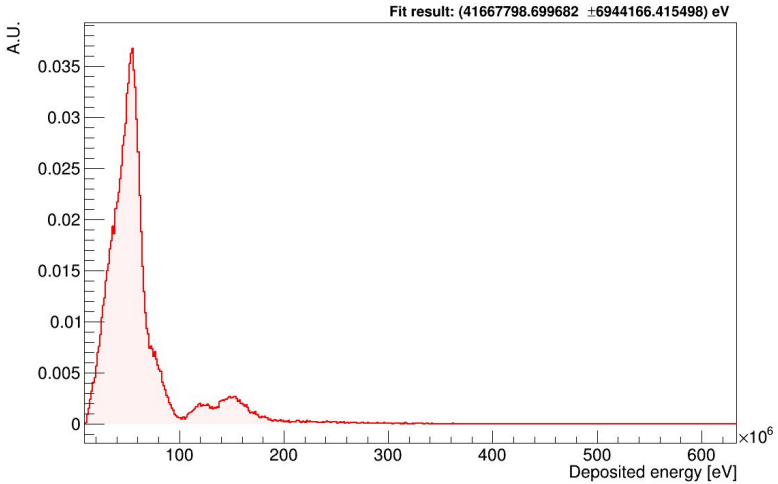
- trigger on Ch0
- **ALTIROC DAC: 2020**

Betas emitted isotropically, no way to discriminate signals from **direct interaction** with Ch0 to **signals shared** on Ch0

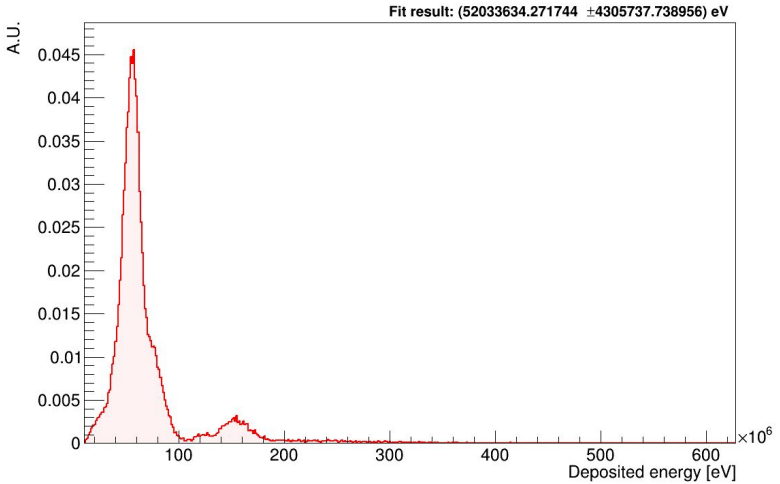
We applied a **software hierarchical veto**, keeping only signals with:

$$ToT^0 > ToT^3 > ToT^1 > ToT^2$$

* due to retriggering, ToT computed as FWHM of first digital signal. Subsequent retriggering signals are ignored




***no Veto:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}$Sr dataset*




***Hierarchical Veto:*** *distribution of digital signal integrals for channel 0 when reading out 4 digital channels in parallel*

Signal sharing tests

# Multi-channel digital distributions

To evaluate signal sharing, all four digital channels readout in parallel

- trigger on Ch0
- **ALTIROC DAC: 2020**

Betas emitted isotropically, no way to discriminate signals from **direct interaction** with Ch0 to **signals shared** on Ch0

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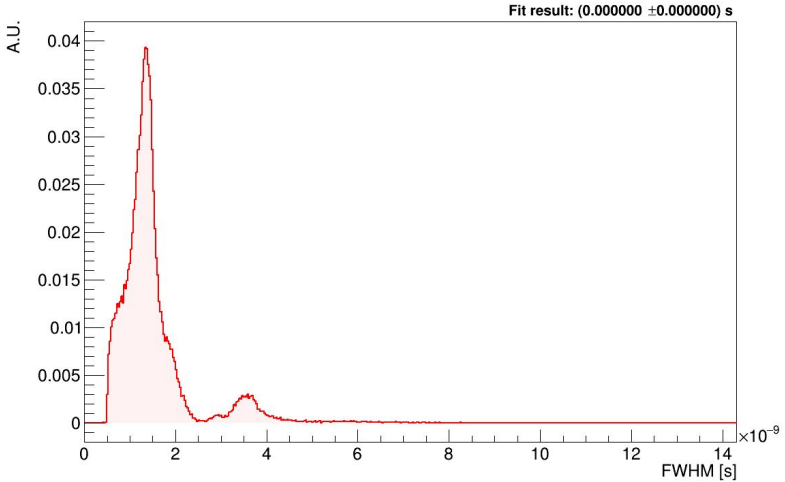
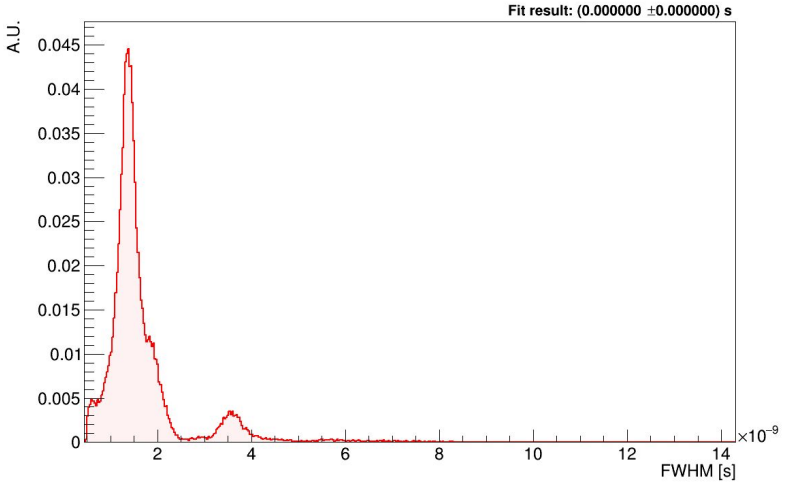



***no Veto:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}$Sr dataset*




***Hierarchical Veto:*** *distribution of digital signal integrals for channel 0 when reading out 4 digital channels in parallel*

Signal sharing tests

# Multi-channel digital distributions

To evaluate signal sharing, all four digital channels readout in parallel

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Betas emitted isotropically, no way to discriminate signals from **direct interaction** with Ch0 to **signals shared** on Ch0

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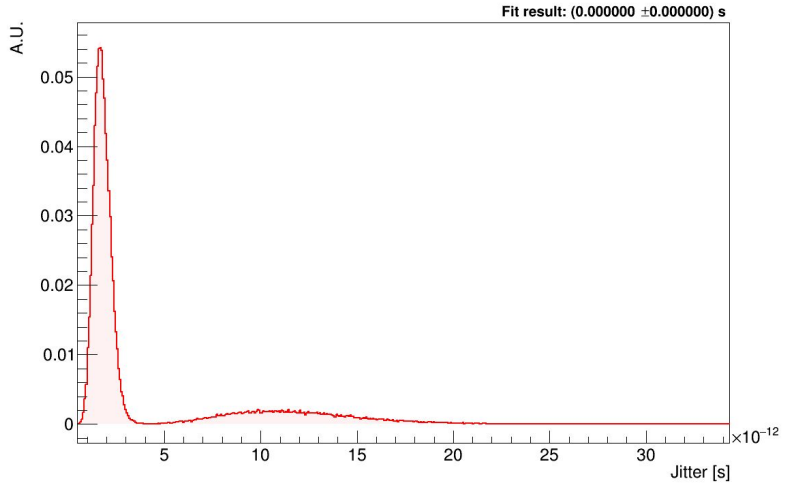
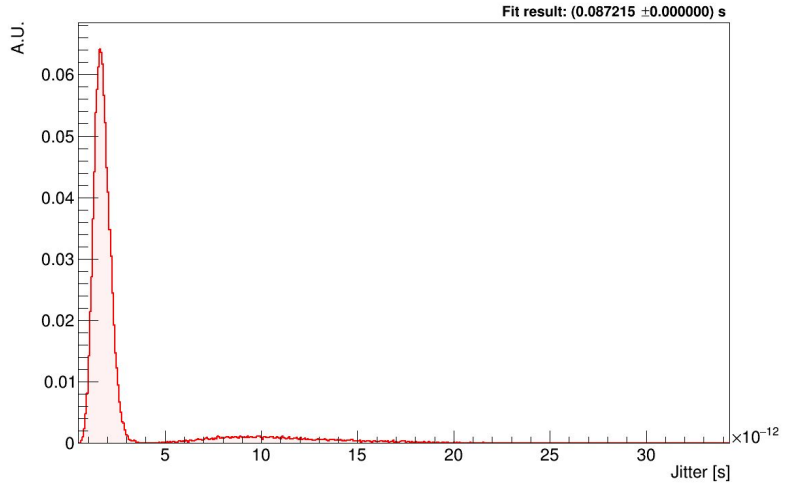



***no Veto:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}$Sr dataset*




***Hierarchical Veto:*** *distribution of digital signal integrals for channel 0 when reading out 4 digital channels in parallel*

Signal sharing tests

# Multi-channel digital distributions

To evaluate signal sharing, all four digital channels readout in parallel

- trigger on Ch0
- **ALTIROC DAC: 2020**

Betas emitted isotropically, no way to discriminate signals from **direct interaction** with Ch0 to **signals shared** on Ch0

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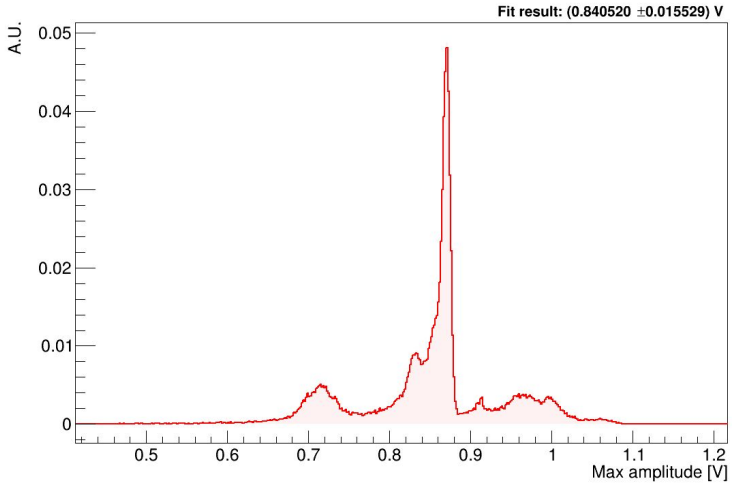
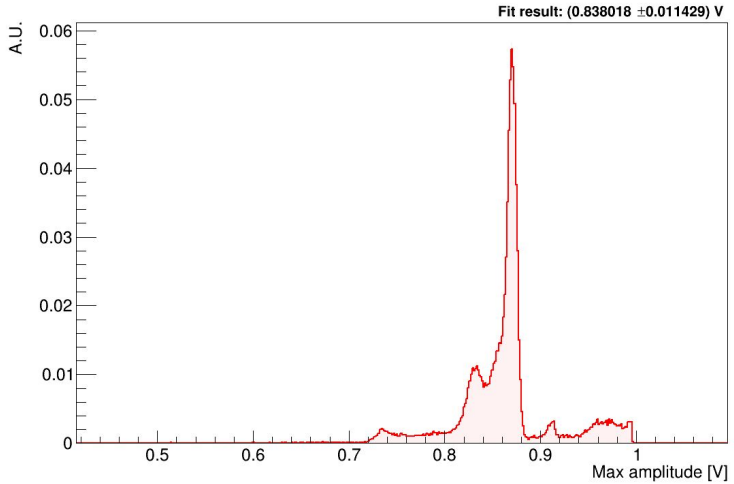
* due to retriggering, ToT computed as FWHM of first digital signal. Subsequent retriggering signals are ignored




***no Veto:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}Sr$ dataset*




***Hierarchical Veto:*** *distribution of digital signal integrals for channel 0 when reading out 4 digital channels in parallel*

Signal sharing tests

# Multi-channel digital distributions

To evaluate signal sharing, all four digital channels readout in parallel

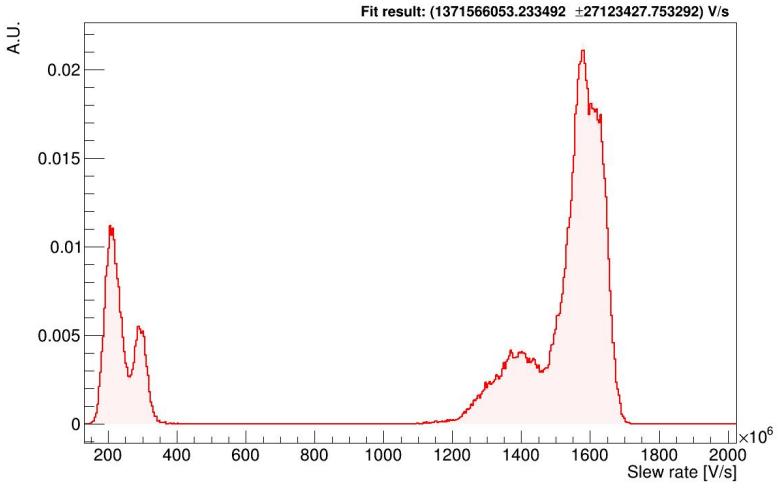
- trigger on Ch0
- **ALTIROC DAC: 2020**

Betas emitted isotropically, no way to discriminate signals from **direct interaction** with Ch0 to **signals shared** on Ch0

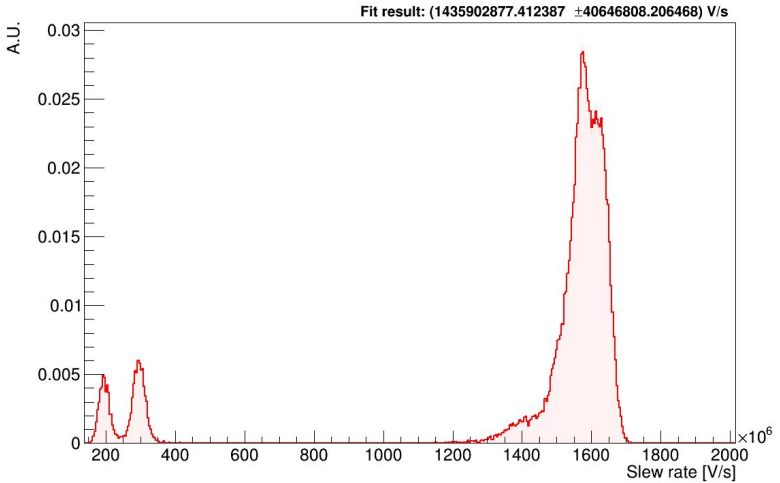
We applied a **software hierarchical veto**, keeping only signals with:

$$ToT^0 > ToT^3 > ToT^1 > ToT^2$$

* due to retriggering, ToT computed as FWHM of first digital signal. Subsequent retriggering signals are ignored




***no Veto:*** *distribution of digital signal integrals obtained from single channel 0 $^{90}$Sr dataset*




***Hierarchical Veto:*** *distribution of digital signal integrals for channel 0 when reading out 4 digital channels in parallel*