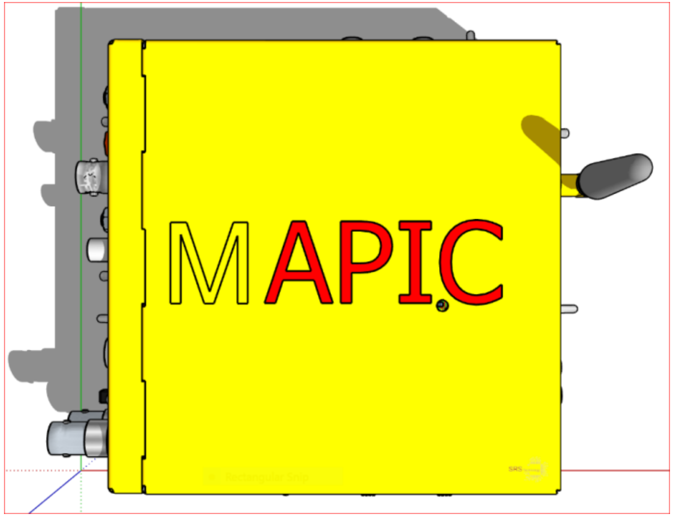
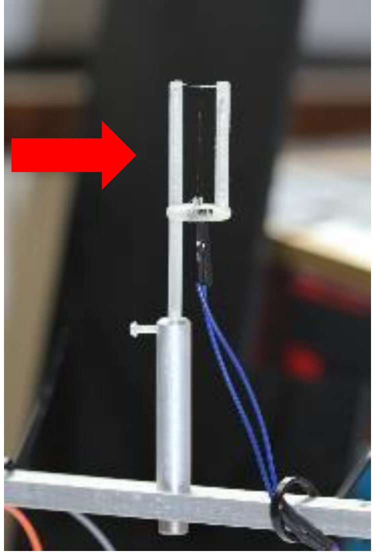
MAPIC
Multichannel Analysis and wireless DAQ for the APIC



Ryan Griffiths, summer student project, CERN GDD lab, July –Aug 2019
supervisors Hans Muller, Dorothea Pfeiffer, Eraldo Oliveri.

My Background

- Summer student in the CERN GDD lab.
- Going into 4th year of physics degree at Durham University, UK.
- Background in microcontrollers, instrumentation and optics.
- Working on software and data analysis for the MAPIC project.



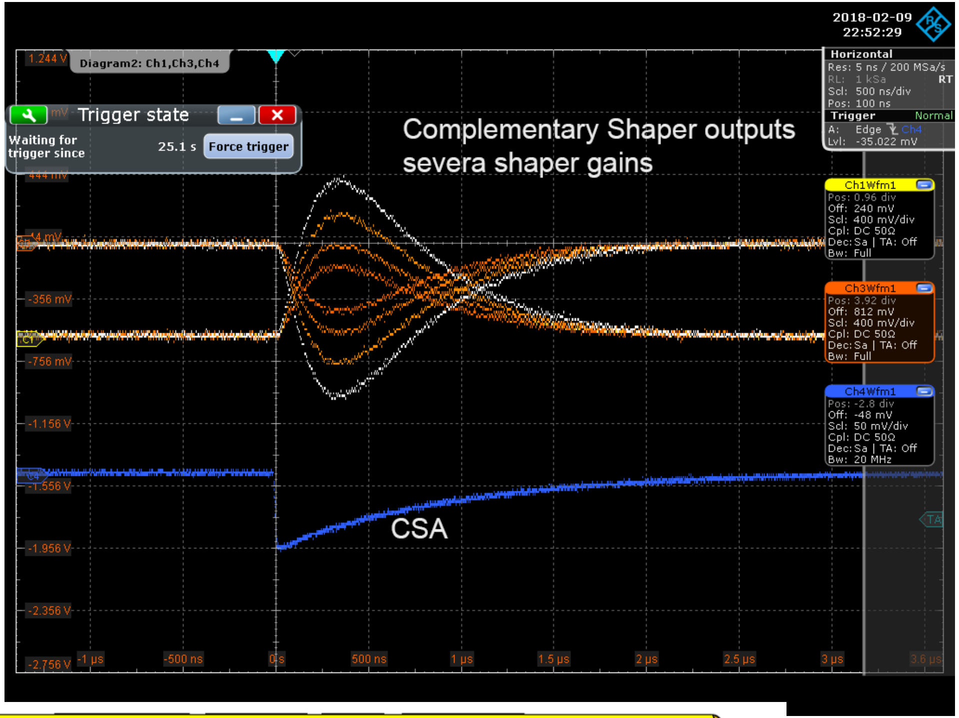
Meadowlark: ://www.meadowlark.com/linear-series-spatial-light-modulator-p-121?mid=18

Motivation

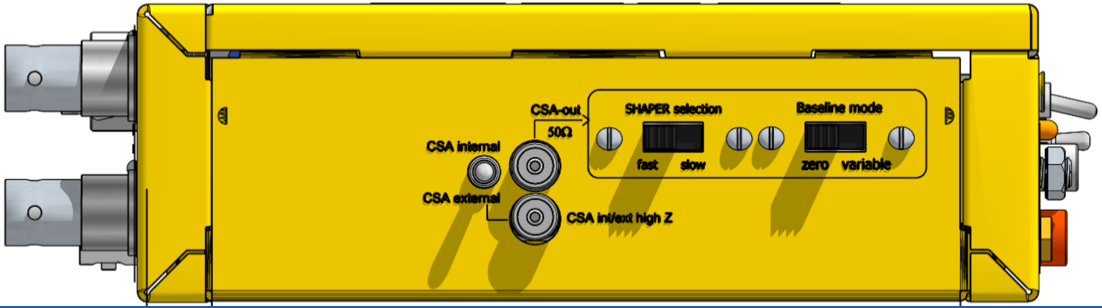
- We want to add a multi channel analyser (MCA) function to the APIC.
- I.E we want to measure the voltage of output pulses from the APIC and produce a histogram.
- We want to do this more cheaply than commercial MCA ($4000)
- We want to implement wireless DAQ and control.

APIC

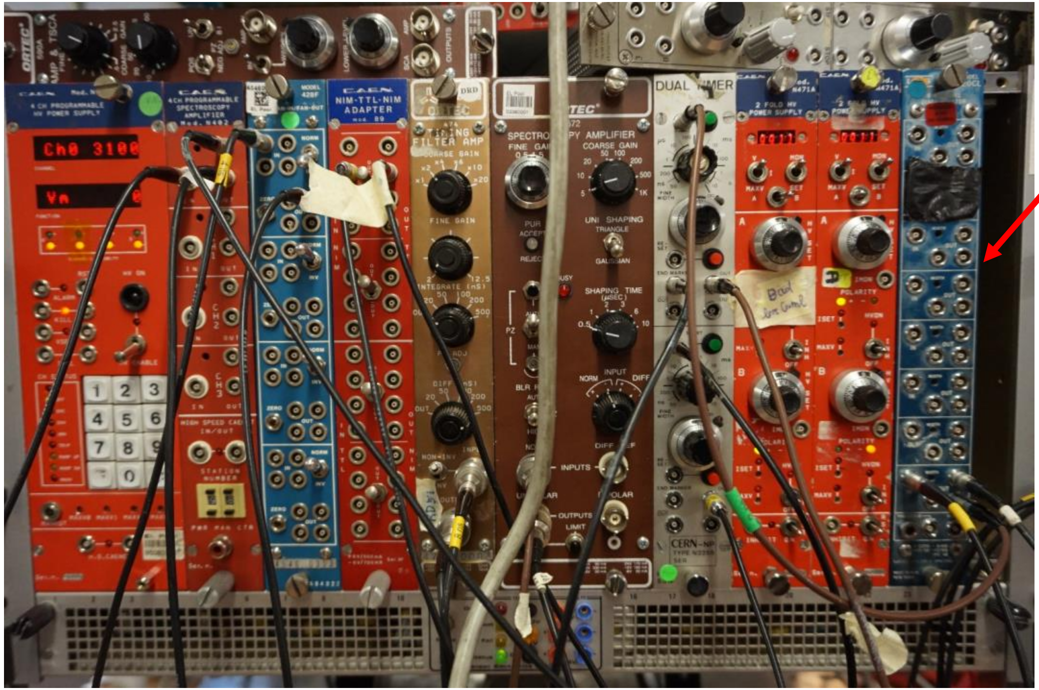
- The APIC box contains a preamplifier and shaper.
- Amplifies and shapes weak input pulse into a semi-gaussian.



Detector IN

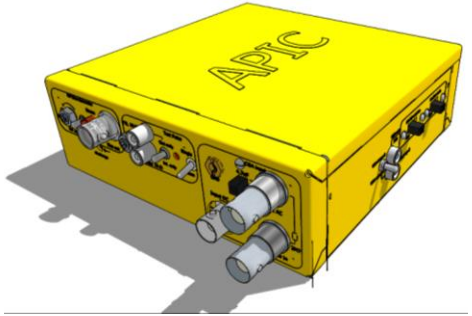


Analogue OUT

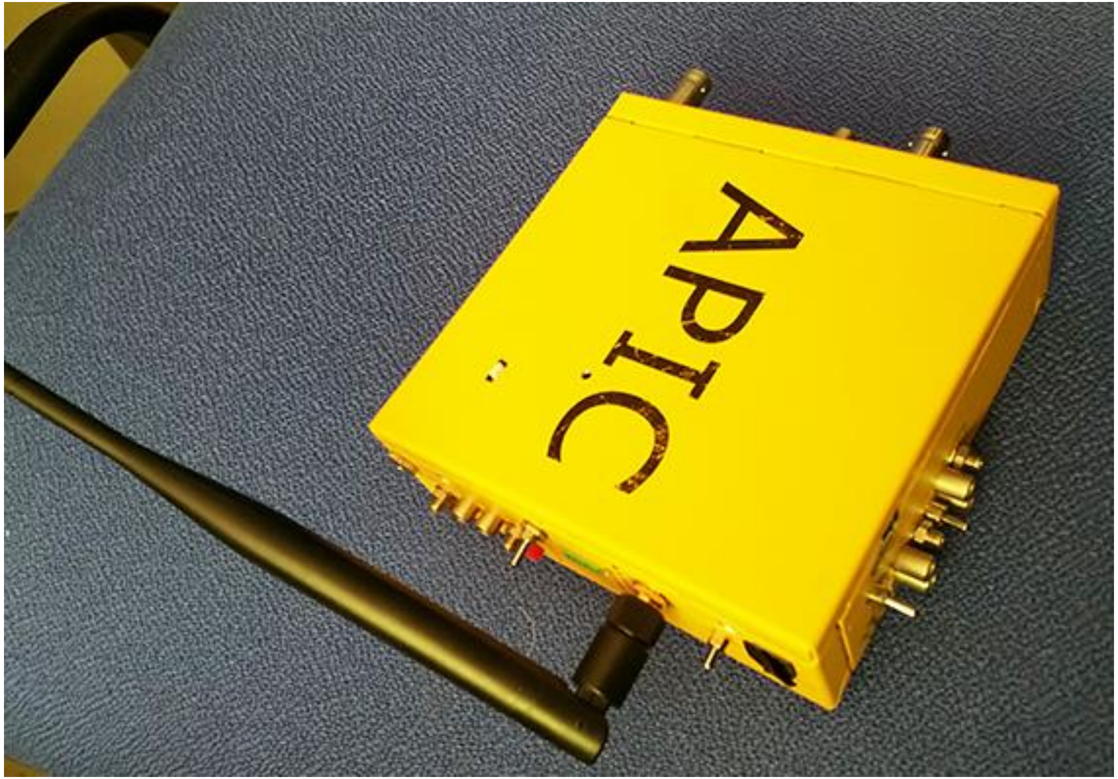


APIC V4.x contains the essential subset of a bunch of NIM modules

plus an external an CSA pre-amplifer
+
plus autonomous power from a Lithium Battery
+
plus a charge controller for small solar panels



NEW addition 2019: Wifi - MCA

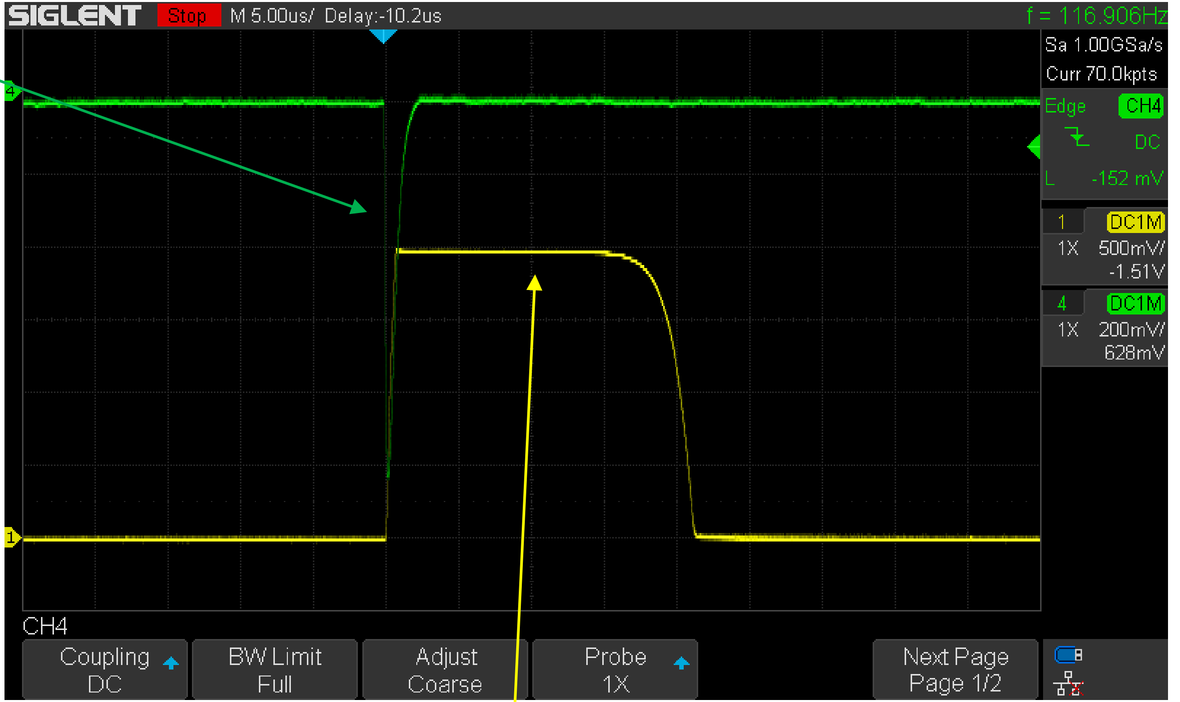

APIC

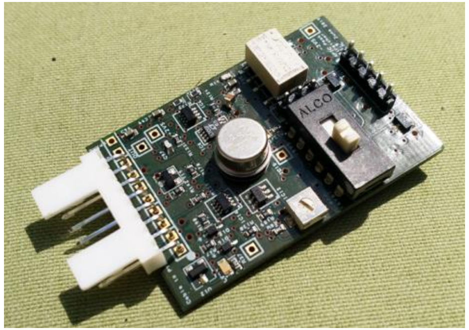
APIC shaper signal
(input to pulse stretcher)

APIC Plugin:

Peak stretcher board,

Stretch peaks from the APIC so that they can be sampled with slow ADC (~1MSps) + averaged.

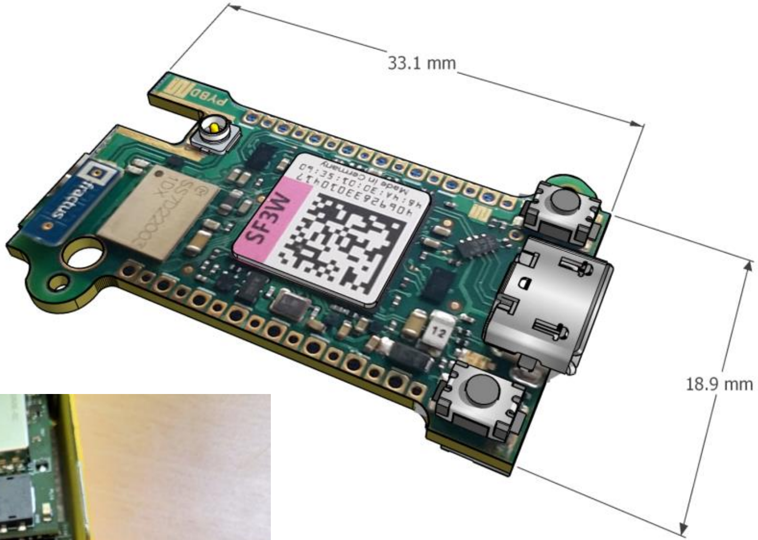


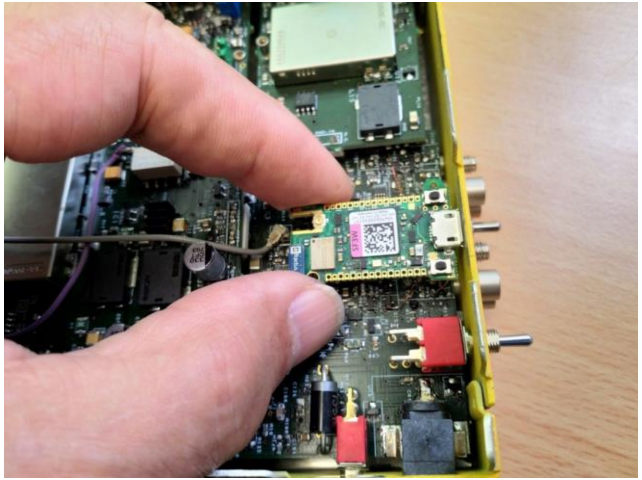


Pulse stretcher flat top output 15 us
(to SAR ADC input)

Python card. “Pyboard D”

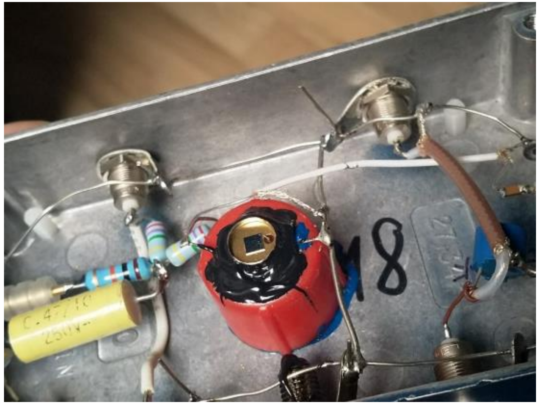
- **WiFi 100 Mbps** and USB Phy.
- Coax Antenna plug
- Three **12 bit** SAR ADCs, at **2 MSps.**

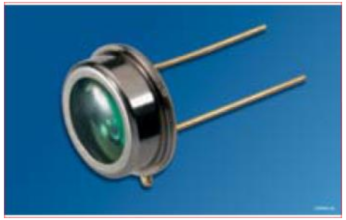




Test Sources for DAQ

(1) Photodiode





Photodiode ! with quartz window, it is sensitive to alpha particles. Functions as a pin diode.

(2) Internal APIC Test Pulses

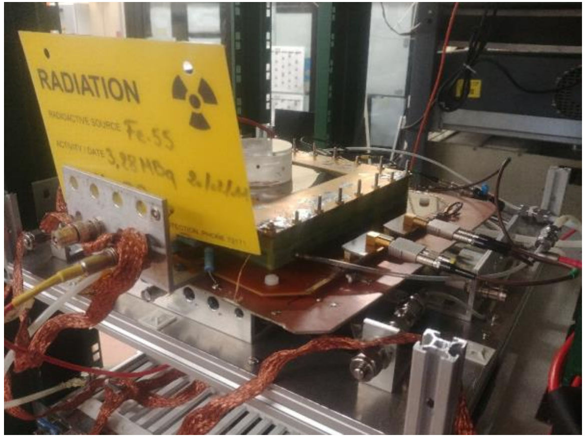
Regular pulses, all with charge of 1 million electrons.

Can change gain + frequency.

Transmit via Wi-Fi and plot histogram on laptop.

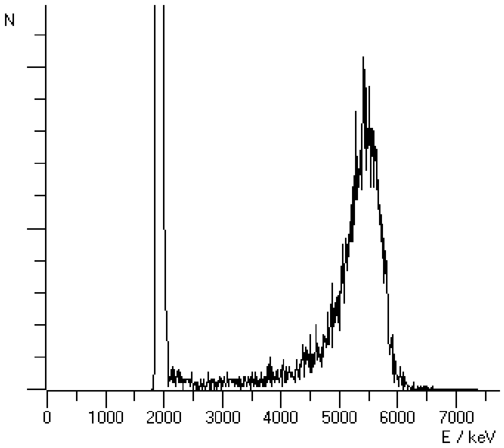
(3) GEM Detector

Pickup charge from bottom plate.
Adjust APIC gain + calibrate stretcher.



(1) ^{241}Am α Measured with pin diode

α Bragg peak with MAPIC



ld-didactic: https://www.ld-didactic.de/software/524221en/Content/Appendix/Am241.htm

AM-241 Spectrum

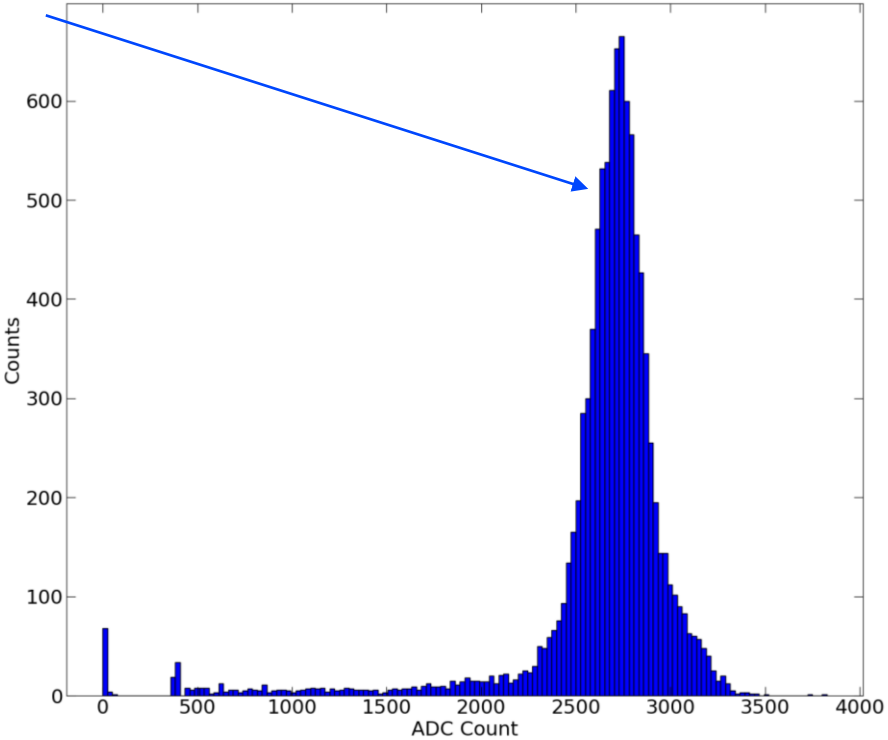


Figure 1: ADC count vs number of counts for 10k samples of ^{241}Am with pin diode.

(2) APIC Internal Test Pulses

Select either positive or negative input polarity.

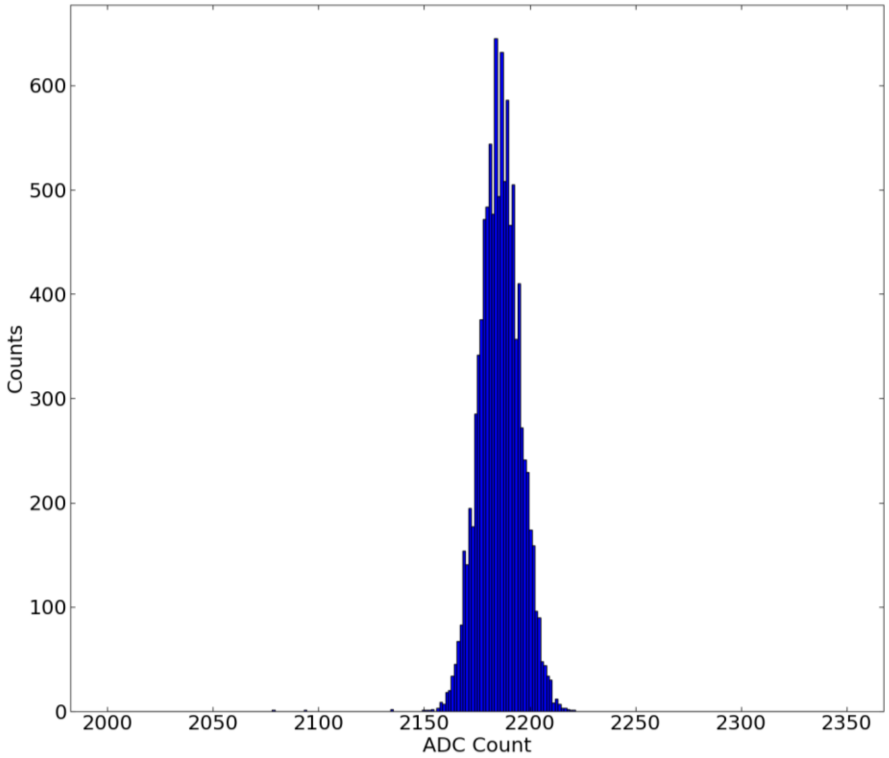
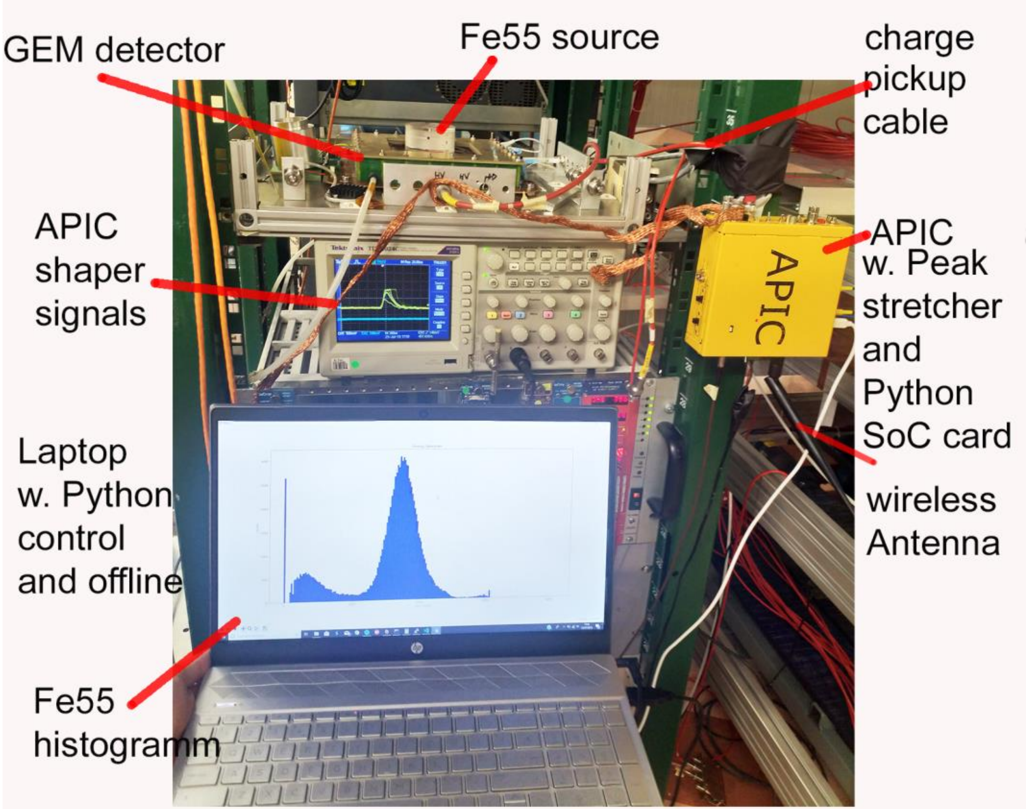


Figure 2: ADC count vs number of counts for 10k samples the internal test pulses.

^{55}Fe GEM Setup

- Want to measure energy spectrum of ^{55}Fe radioactive isotope.
- We should see two peaks, main peak (5.9keV) and escape peak (2.9keV) in 2:1 ratio of energies.
- Calibrate ADU to energies.



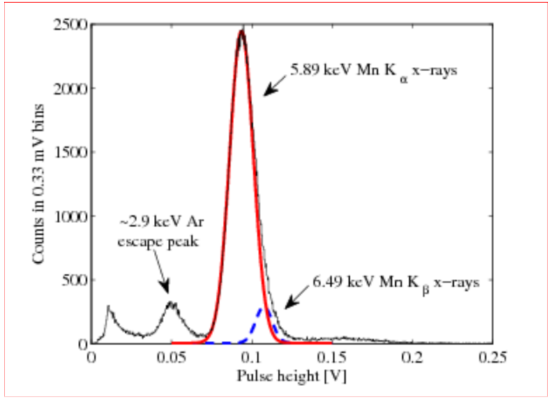
Max sample rate 2kHz

(3) ^{55}Fe Spectrum

100,000 samples at a rate of 2kHz. Large number of samples cut into overflow.

What would we expect:

Ahmed, Z. et al. JINST 9 (2014) no.01, P01009 arXiv:1307.6154



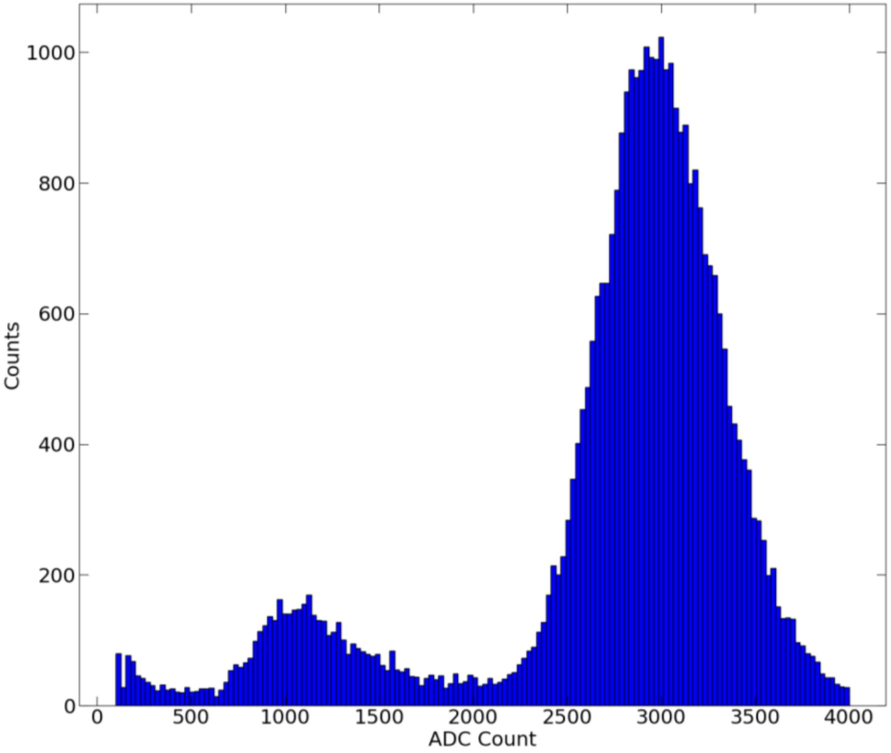
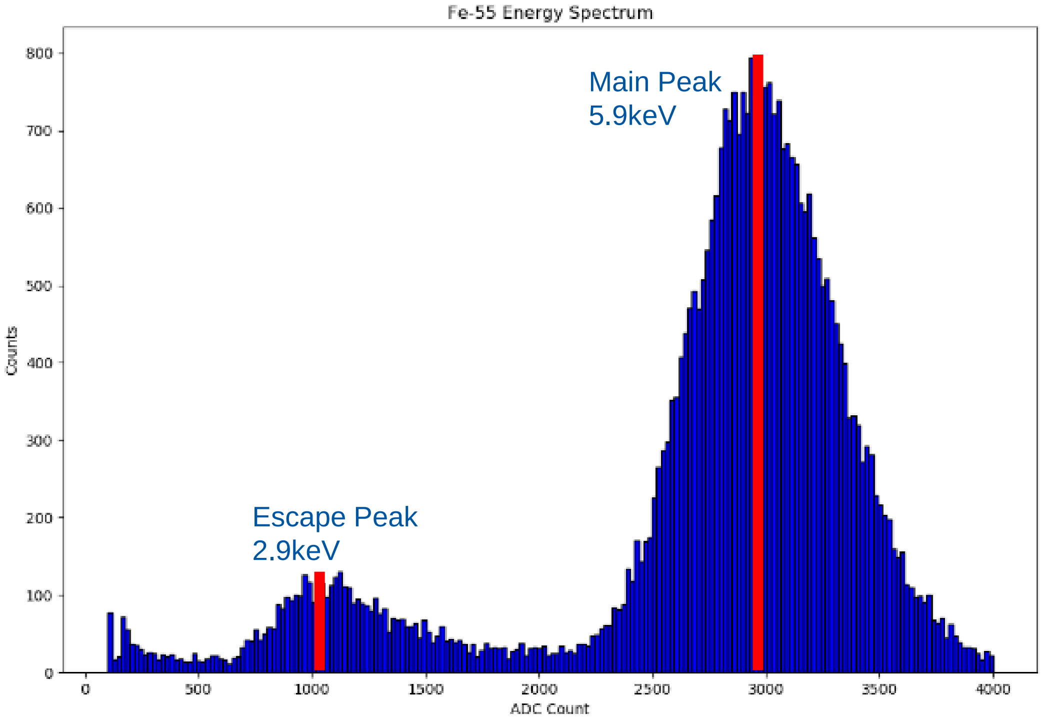


Figure 3: ADC count vs number of counts for ^{55}Fe measured with GEM detector.

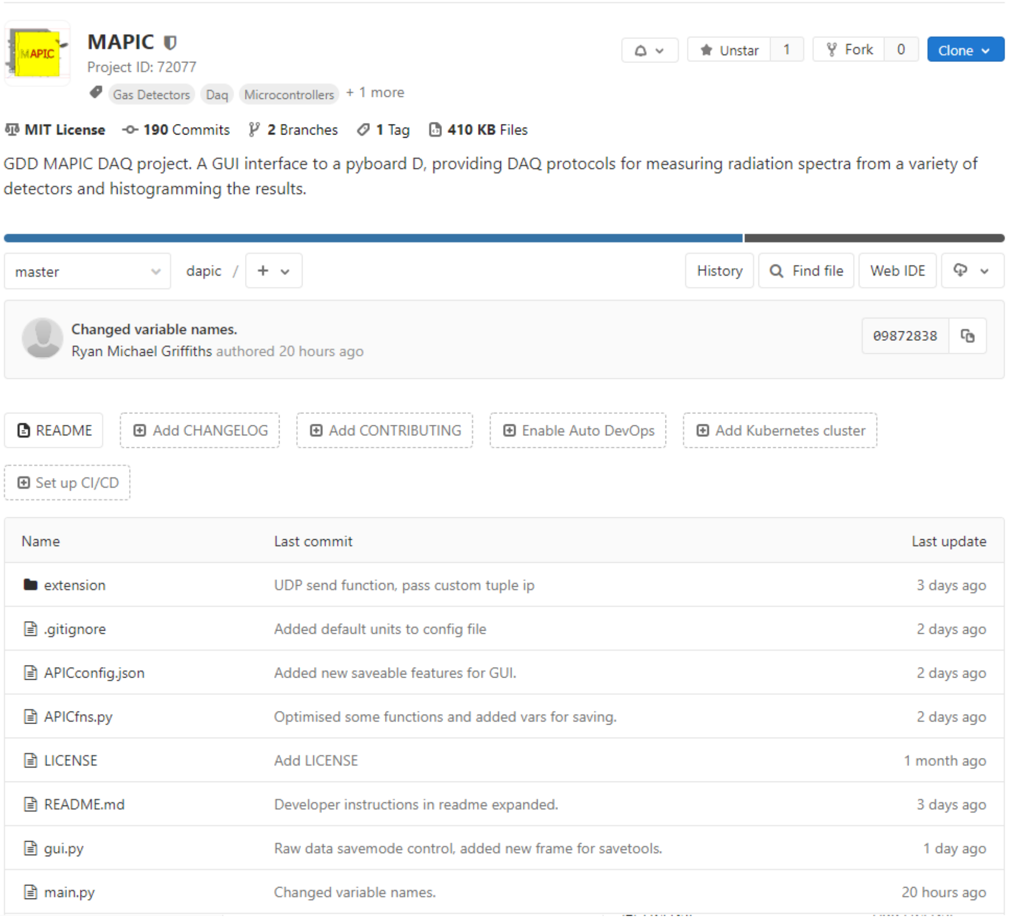
Calibration



Peak ratio not 2:1

3000:1100

As mentioned before – we need a linearity calibration to find offset.



GITLAB REPO FEATURES

- Readme instructions.
- GUI control of APIC.
- Saving experimental setup.
- **Wireless control of the APIC & readout.**
- Histogram data processing on PC side.

Software Tools

On The Pyboard

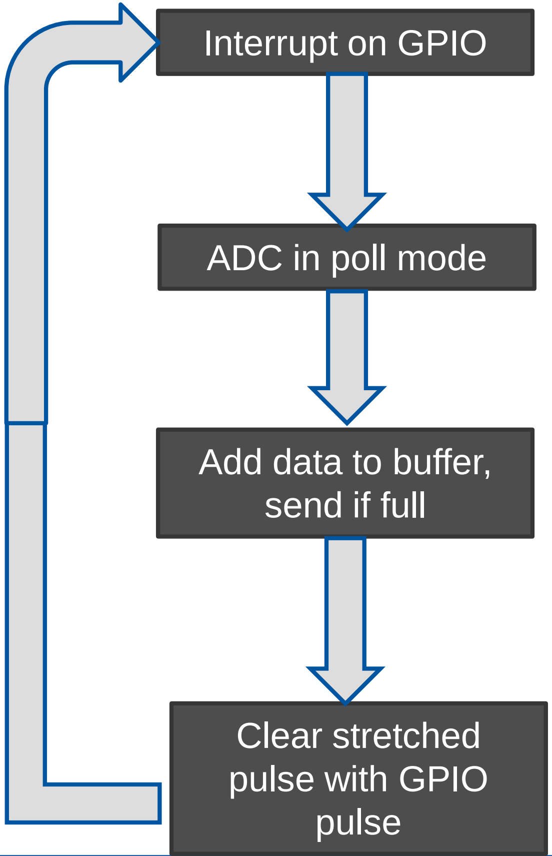
- Micropython language.
- lwIP network sockets – Wi-Fi data streaming.
- STM32 HAL Drivers – extend Micropython.

On The PC

- Python Tkinter GUI control.
- Python Matplotlib + NumPy for data processing.
- Python network sockets.

ADC Datalogging in MP

- Requires **3 pins** and takes approximately **75us** for 4us of ADC data!
- Sampling queue can overflow – runtime error.
- Limits performance to **1-2kHz** sampling rate.



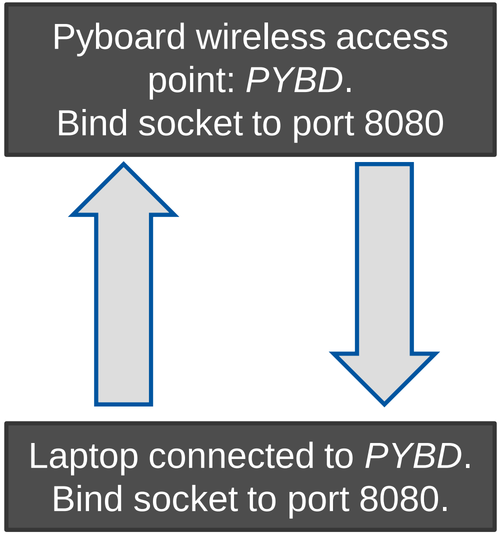
Sampling in action

C Optimisation – HAL Analog Watchdog

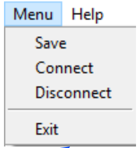
- Watchdog constantly monitors ADC values.
- When outside of a threshold, generate an interrupt, peak occurred. Sample peak.
- Could improve 75us peak to around **10us**! Possible to reach **100kHz** rate.
- Also only uses ADC pin, simpler hardware needs.

Wireless Readout

- Performance up to 80Mb/s, fast data readout over Wi-Fi.
- Much faster than 8Mbps USB.
- Range of a couple of meters with only antenna, can be increased with a repeater.



TKinter GUI

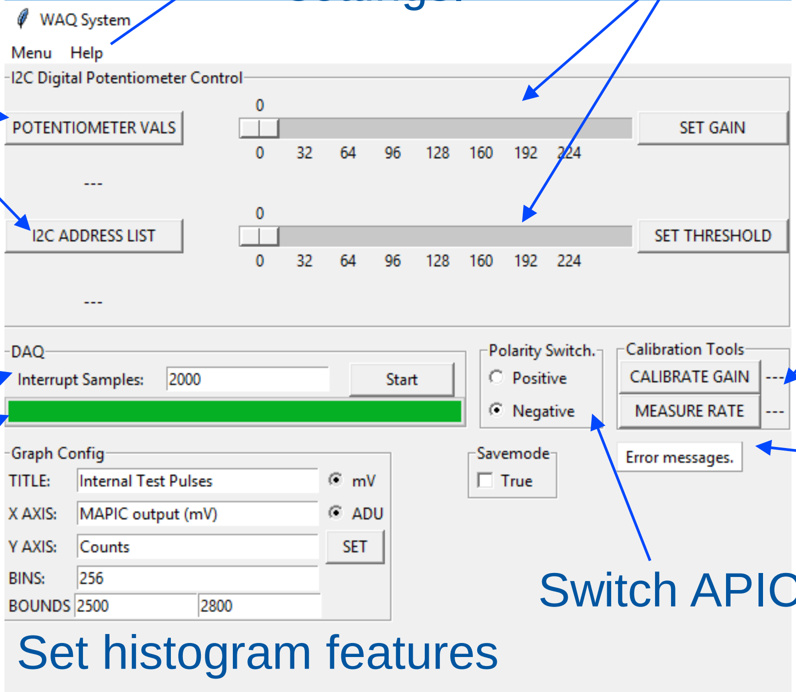


Menu for connecting + saving default settings.

Use sliders to set value of the digital potentiometers.

Read digital potentiometer values/addresses on the pulse stretcher via I^2C

Measure rate of pulses + get calibration equation.

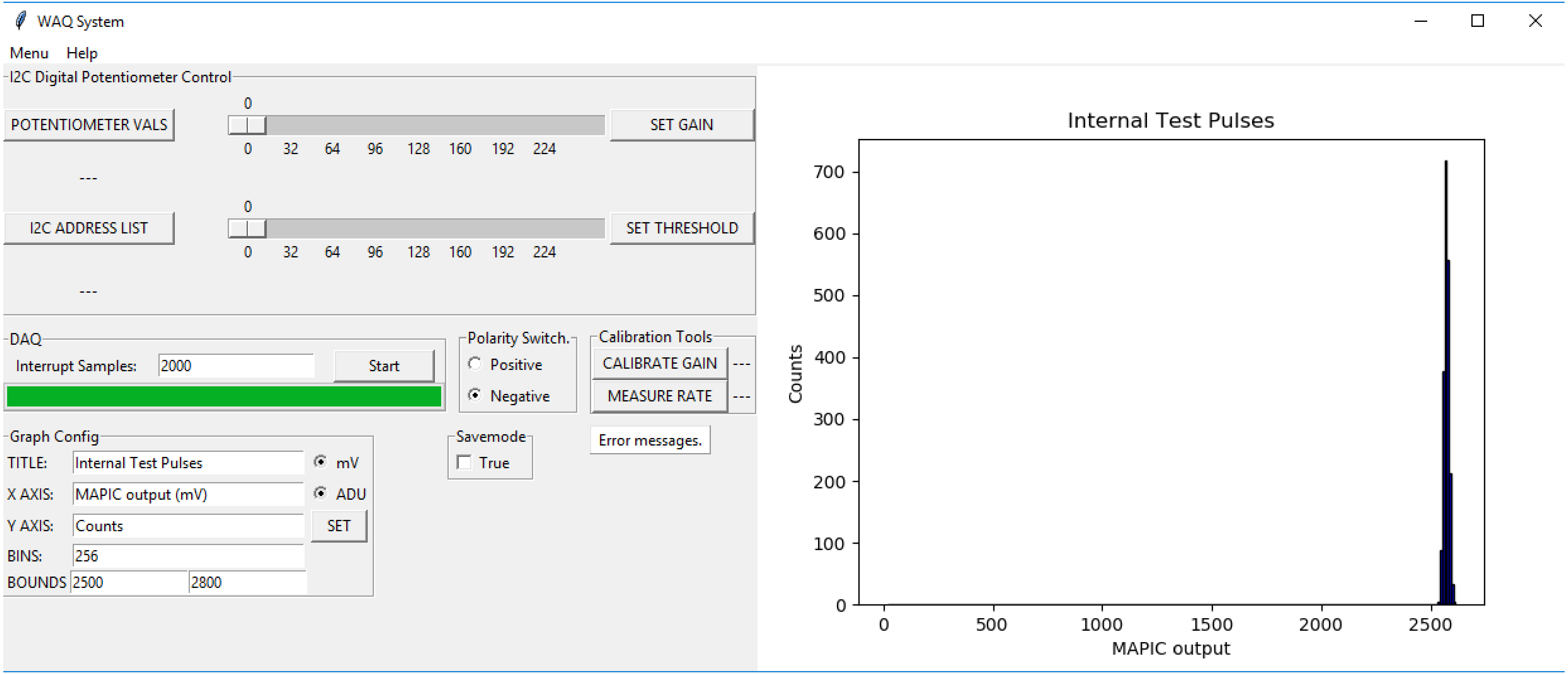


Up to 64-bit number of samples from ADC + progress bar

Error messages displayed here

Switch APIC polarity

Set histogram features


WAQ System
Menu
Help
I2C Digital Potentiometer Control
POTENTIOMETER VALS
0
0 32 64 96 128 160 192 224
SET GAIN

I2C ADDRESS LIST
0
0 32 64 96 128 160 192 224
SET THRESHOLD

DAQ
Interrupt Samples:
2000
Start
Polarity Switch.
Positive
Negative
Calibration Tools
CALIBRATE GAIN

MEASURE RATE

Graph Config
TITLE:
Internal Test Pulses
mV
X AXIS:
MAPIC output (mV)
ADU
Y AXIS:
Counts
SET
BINS:
256
BOUNDS
2500
2800
Savemode
True
Error messages.
Internal Test Pulses
Counts
0
100
200
300
400
500
600
700
0
500
1000
1500
2000
2500
MAPIC output

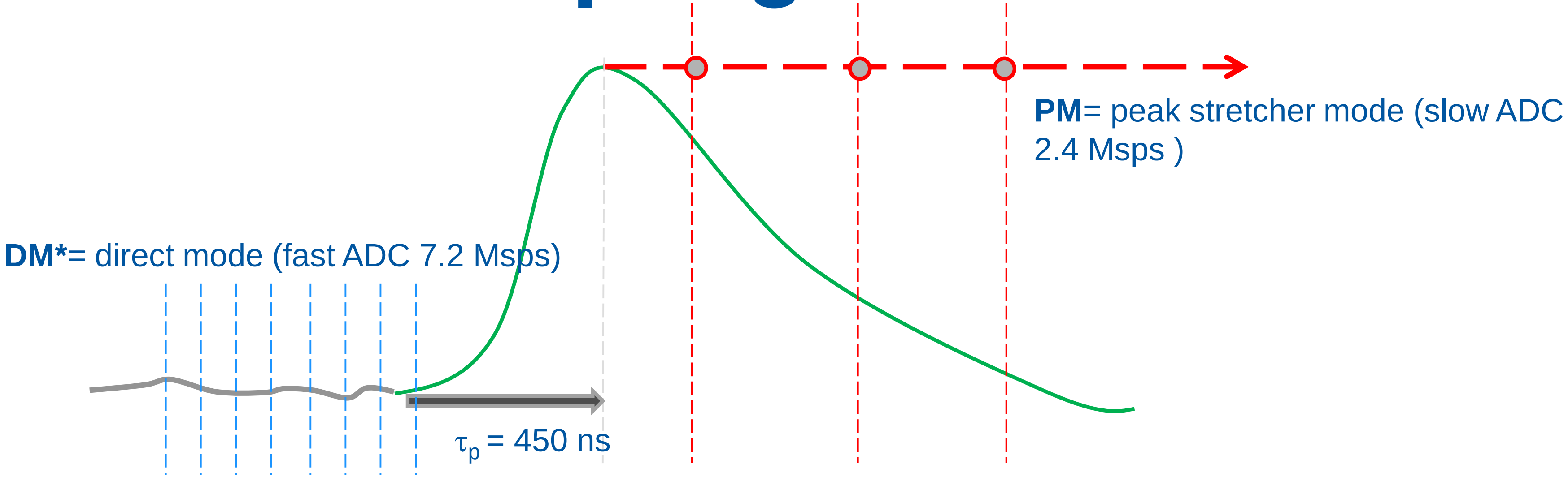
Main Tasks and ToDo list

- Complete analog watchdog code.

- Calibrate the stretcher gain/offset to achieve correct ^{55}Fe spectrum.

- Configure the three ADCs in triple interleaved mode to increase sampling time to 200ns?

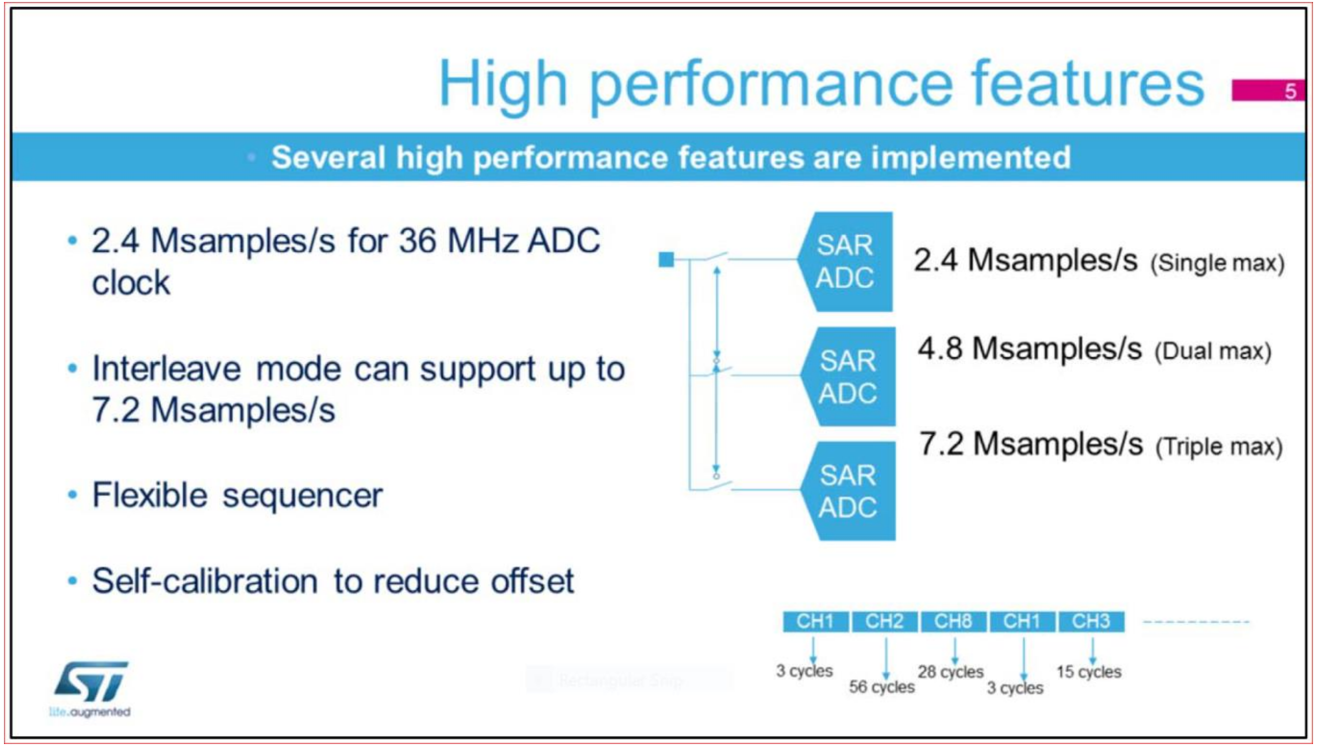
MAPIC sampling modes



Noise and baseline measurements

Charge and timing measurements

DM mode currently “in the works”


High performance features
5
Several high performance features are implemented
• 2.4 Msamples/s for 36 MHz ADC clock
• Interleave mode can support up to 7.2 Msamples/s
• Flexible sequencer
• Self-calibration to reduce offset
SAR ADC
SAR ADC
SAR ADC
2.4 Msamples/s (Single max)
4.8 Msamples/s (Dual max)
7.2 Msamples/s (Triple max)
CH1
CH2
CH8
CH1
CH3
3 cycles
56 cycles
28 cycles
3 cycles
15 cycles
life.augmented

Conclusion

- Successfully implemented readout and APIC control over Wi-Fi.
- Functional Tkinter GUI with useful features.
- Close to implementing high performance C code to increase sample rate limit from 2kHz to ~100kHz.

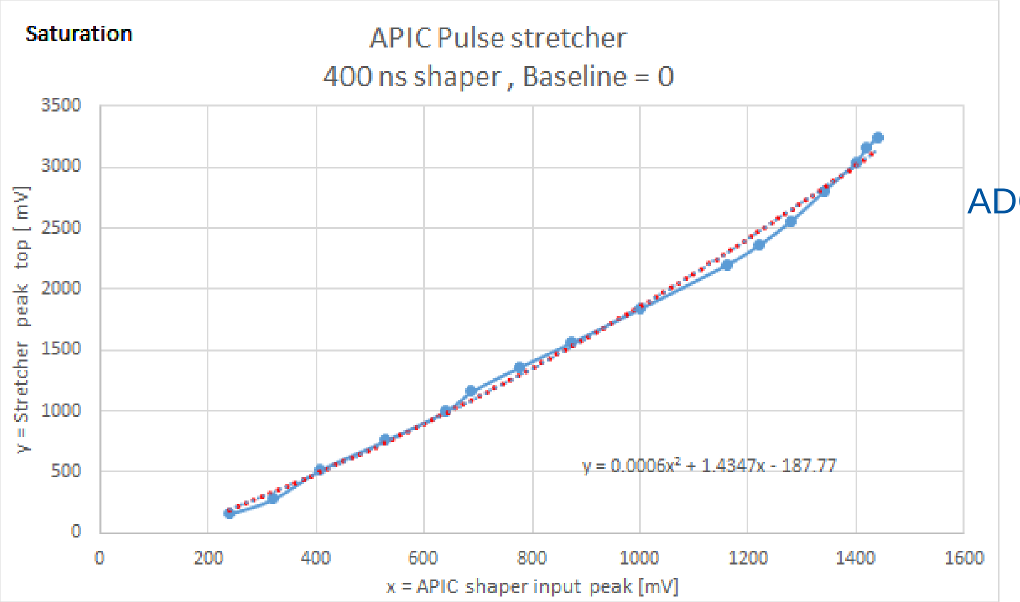
Acknowledgements

I would like to thank my supervisors:

Hans Muller, Dorothea Pfeiffer and Eraldo Oliveri.

Extra Information

Transfer characteristics peak stretcher card V1.1



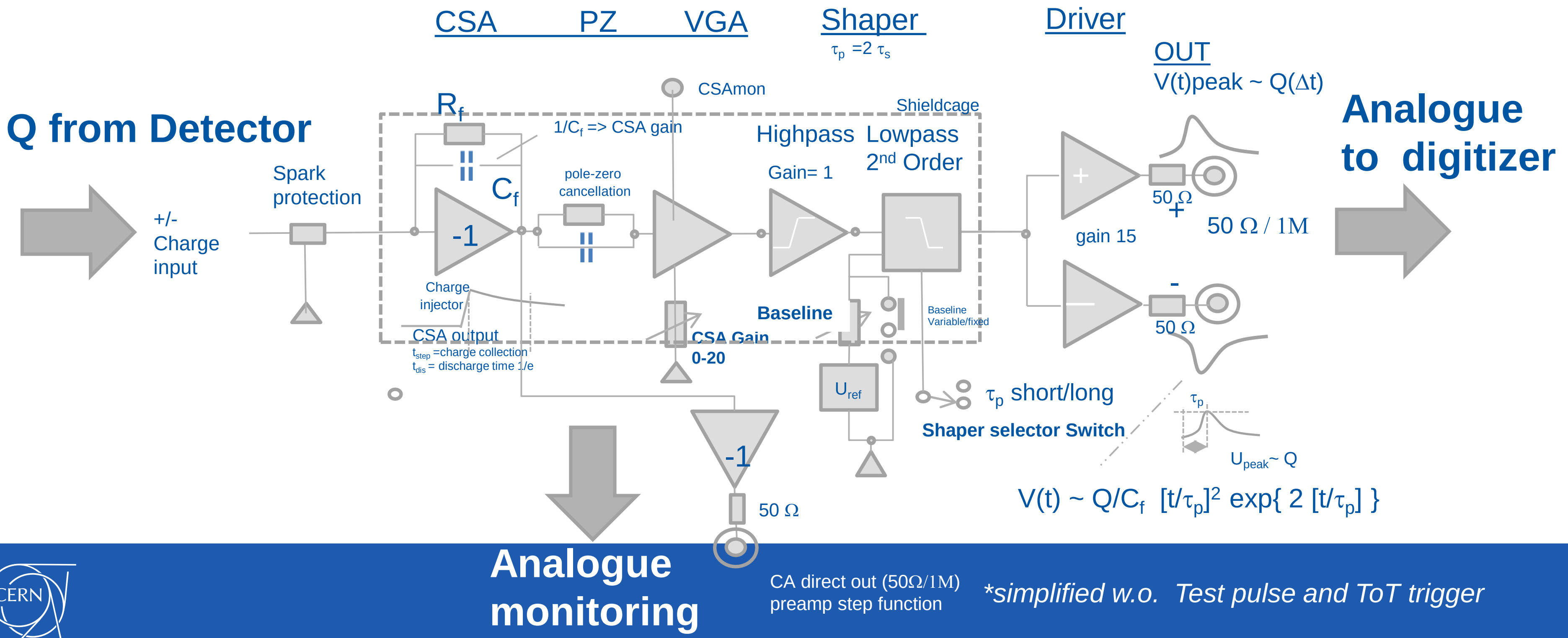
ADC dyn. range up 3.3V

quasi linear
Y = 1.43 X – 187.8

For final peak stretcher implementation:
- refine linearity
- reduce 187.77 mV input pulse offset
- measure transfers function for all gain

Auto-Cal function in final SW version
Pre-measurement of transfer curve

APIC preamplifier-shaper chain*



*simplified w.o. Test pulse and ToT trigger

APIC feature summary

1x built-in CSA preamplifier with spark protection
- default trimmer set to 1mV/fC, 1us decay
- triple-spark-filter << 1nA leak

3x AC/DC input coupling modes
- direct DC, AC up 4 kV via slide switch: 360pF /4.7nF

1x detector Bias plug to detector
- LRC filtered via SHV connector to AC input

1x direct CSA output
- direct CSA output up +/- 1.1V 1MΩ, +/- 2.2V **50 Ω**
- output polarity = input charge
- internal Pole-Z trimmer (pre-adjusted)

1x input for an external CSA preamplifier (SIPA)
- internal CSA disabled, adjust internal Pole-Z trimmer
- Signal input 50 Ohm Lemo-00, power cable Jack

1x testpulse generator 50 Ω LVTTL / NIM , 1M TLL
- permanent or single toggle with LED
- variable rate 1Hz..1 kHz via 15-turn potentiometer

1x test charge injector testpulse
- 200ps neg / 700ps pos. int. test pulse 1.4V via 0.125pF

2x shapers
-slide switches: 2 shapers, baseline zero/variable
-Gamma-2 shape, default: $t_{p,fast}$= 30ns, $t_{p,slow}$ =350ns

1x variable gain amplifier
- CSA -> shaper gain 0 – 20 via 15-turn potentiometer
- Gain Monitor Voltage plug (2mm Banana)

2x shaper outputs
- complementary up +/- 1V 50 Ω , +/- 2V 1MΩ
- 150 mV variable baseline +/-

1x dual polarity discriminator -> trigger generator
- Trigger via 15- turn discriminator over +/-CSA polarity
- TOT and TBT threshold over CSA signal slope

4 x Trigger LEDs: charge polarity and discriminator lock
- red/blue : +/- input signal polarity level in range
- orange/green: +/- TOT or TBT trigger locked

1x complementary 50 Ω NIM trigger output
- TOT time-over-threshold (prompt, short) NIM signal
- TBT time below threshold (prompt, short) NIM signal

1x 50 Ω NIM trigger pulse stretcher output*
- 50ns-500ns out via 15- turn trimmer

1 x classic audible beep
- audible beep from stretched NIM triggers

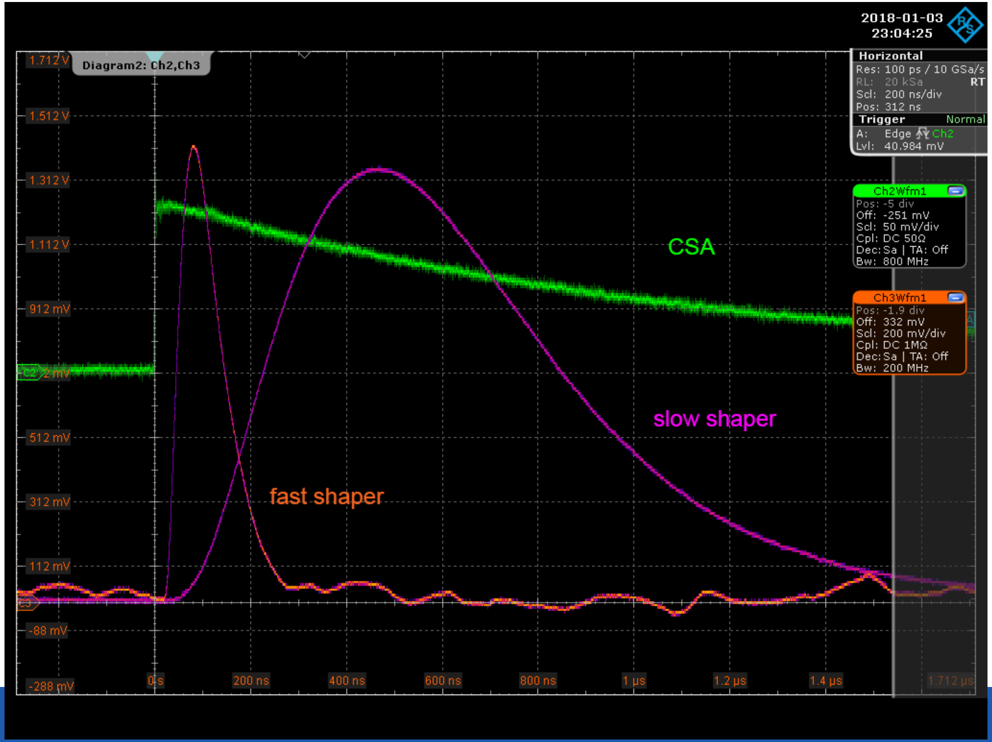
1 x 50 Ω -input for 3 selectable output functions (NIM 50 Ω)
- Input pulse stretching only*
- input gated with TOT trigger, stretched
- input gated with TBT trigger, stretched

1x optional HV bias generator (for Si Diodes)
- 10V-100V low noise , temp. stable via 15 turn pot.

- stretch prompt TOT/TBT triggers by connecting an external coax cable to input

CERN

Relative shaper CSA amplitudes



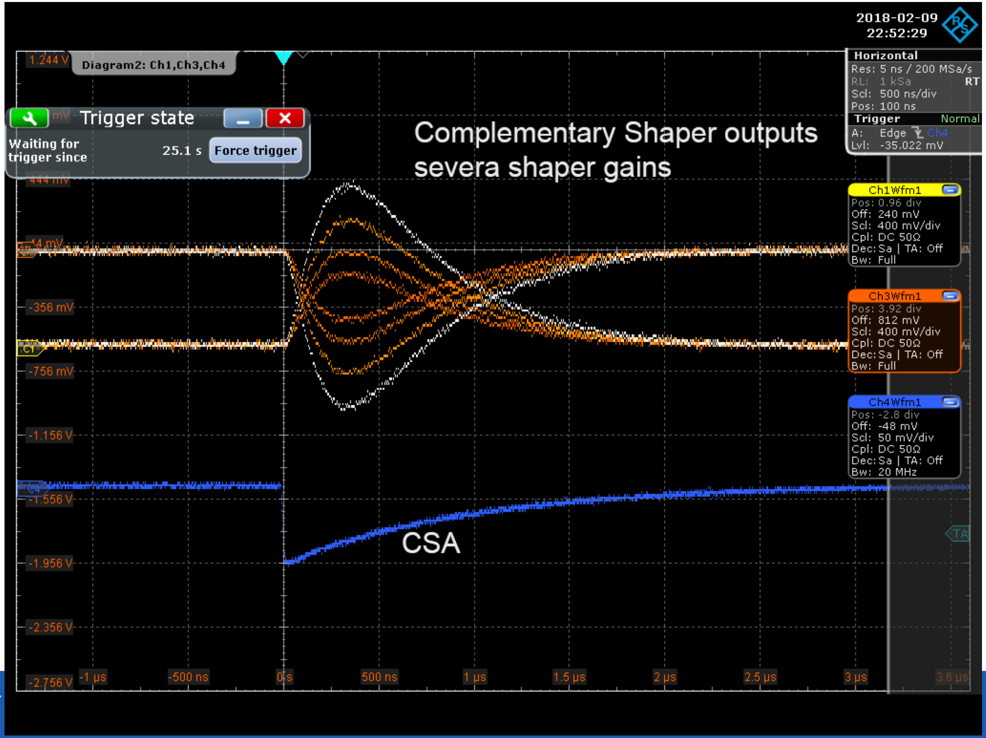
The slide-switch selections (fast/slow) result in fast or slow peaking times (default 25 ns/400ns) of approximately equal amplitudes*.

The fast shaper selection applies to high-rate, low capacitance detectors with average rates up to 1 MHz.

The slow shaper selection applies to low noise measurements of detectors up to C_{det} ~ 1 nF

* Can be tuned on request to +/-2% equality

Complementary shaper outputs



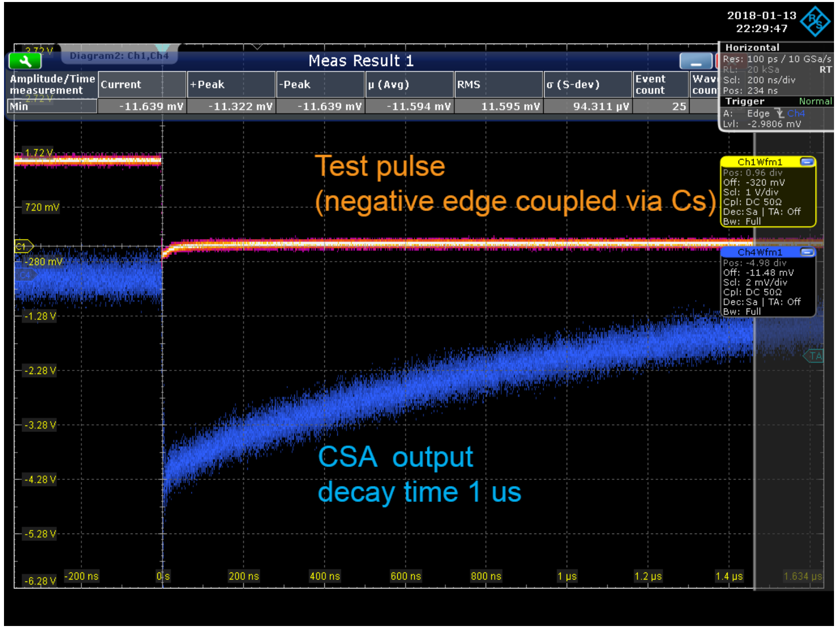
The 2 shaper outputs are complementary with a common gain control.

The non-inverted output has the same polarity as the input charge.

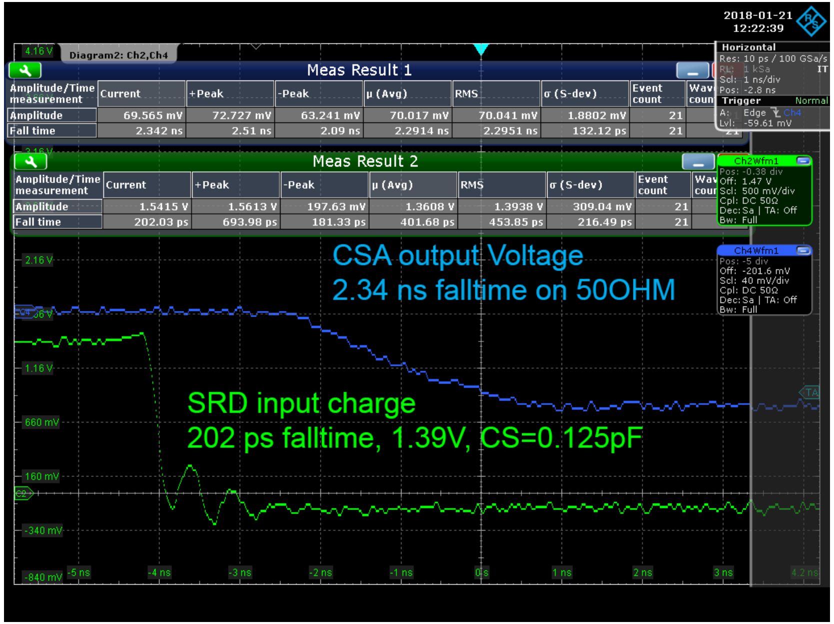
Also the CSA output has the same polarity as the input charge.

APIC test pulse

CSA preamplifier response to test charge

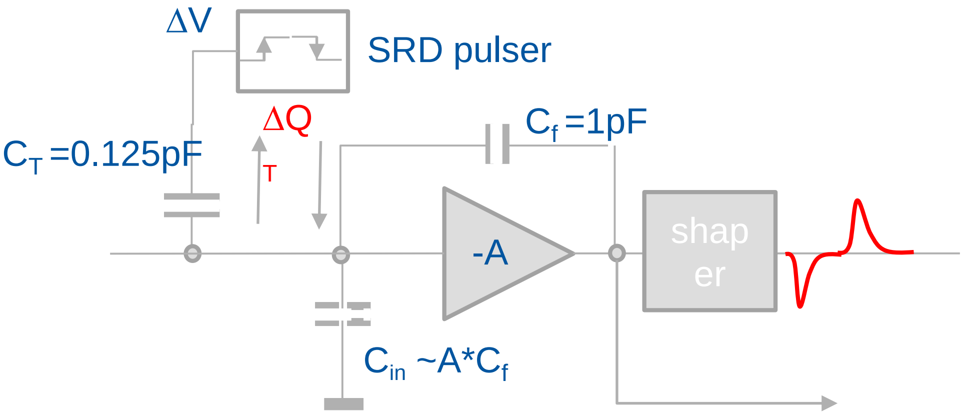


Picosec test charge



APIC test pulser charge calculation

ΔV amplitude = 1.39 V



$$\Delta Q^*_T = \frac{C_T}{1+\frac{C_T}{C_{in}}}\Delta V \sim C_T\left[1-\frac{C_T}{C_{in}}\right]\Delta V$$

$$\frac{C_T}{C_{in}} << 1$$

$C_T = 0.125$ pF

$C_{in} = 5600$ pF

CSA

$\Delta Q_T \sim C_T * \Delta V$ = **173 fC***

* ~ 1.081 Million electrons