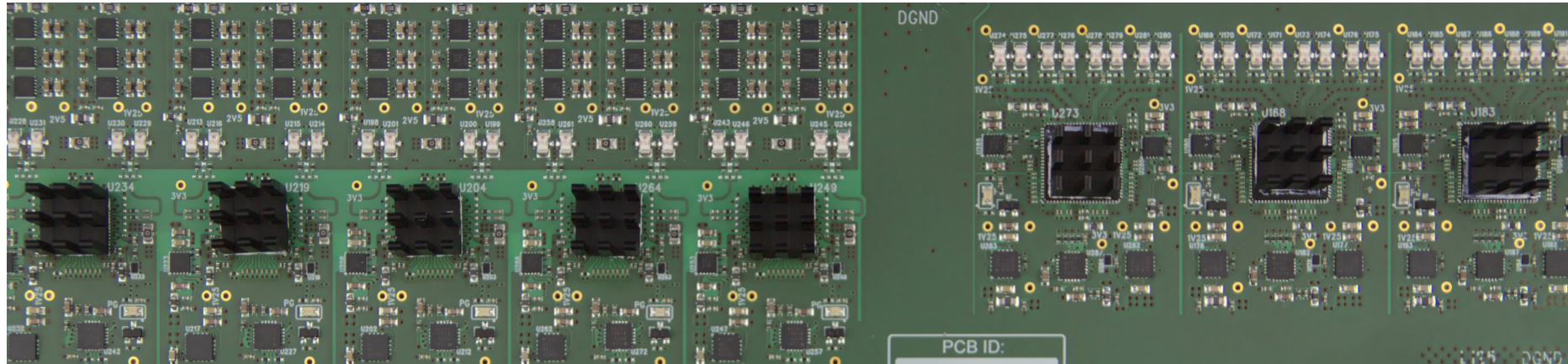# The ECHo superconducting detectors and DAQ-electronics

From proof-of-concept to full scale system
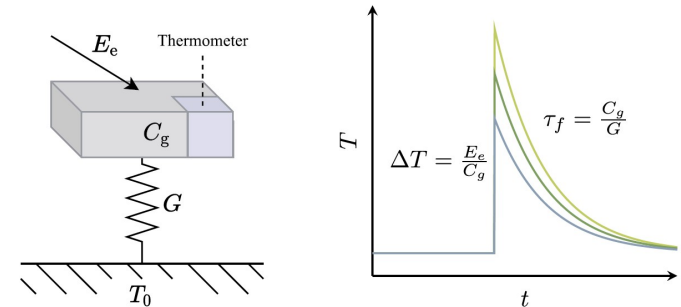
The ECHo Experiment

- Electron Capture ^{163}Holmium

- Determination of electron neutrino mass with <u>magnetic microcalorimeters</u>

- Analysis of Ho^{163} isotope decay, calculation of the spectrum

- Measurement of 10^{14} decays with 10.000 sensors (ECHo-100k)

- Goal: Sensitivity < 1eV
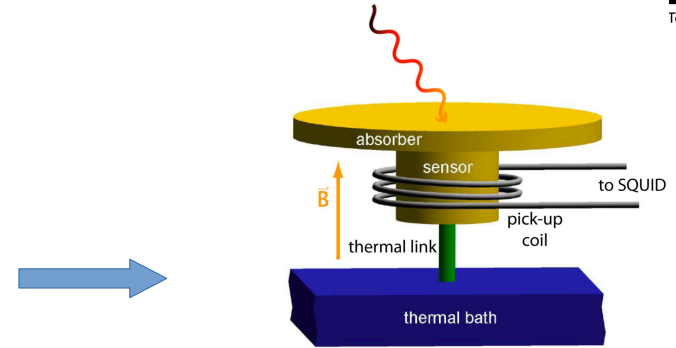
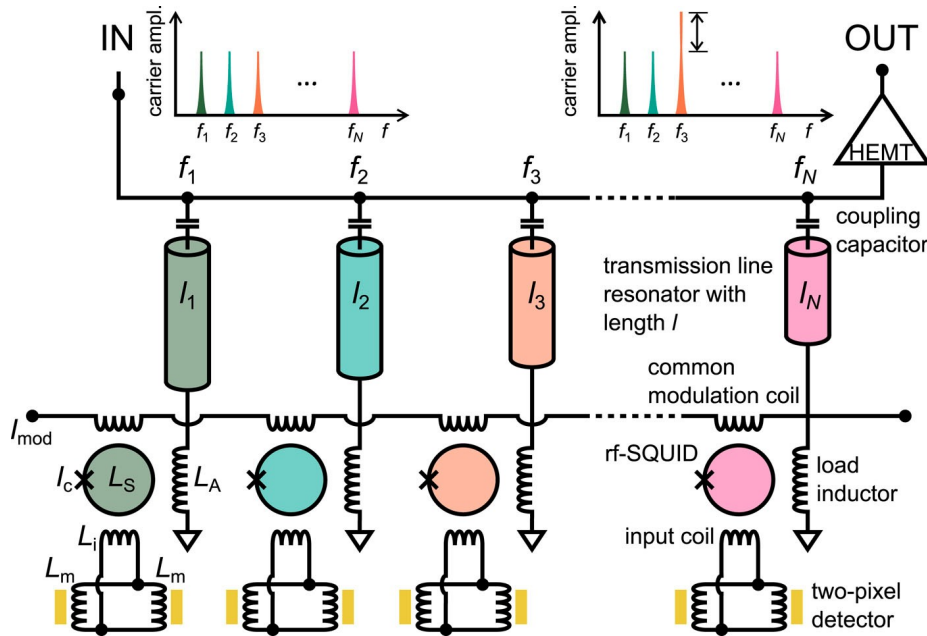[doi: 10.1109/TASC.2009.2012724]

[doi: 10.5445/IR/1000148040]

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SQUID Multiplexer

[doi: 10.1109/TNS.2019.2914665.]

- Individual resonance frequency for each channel
- Two pixels per channel
- SQUIDs are stimulated by ramp signal
  - Sinusoidal SQUID signal
  - Amplitude modulation of the readout tones

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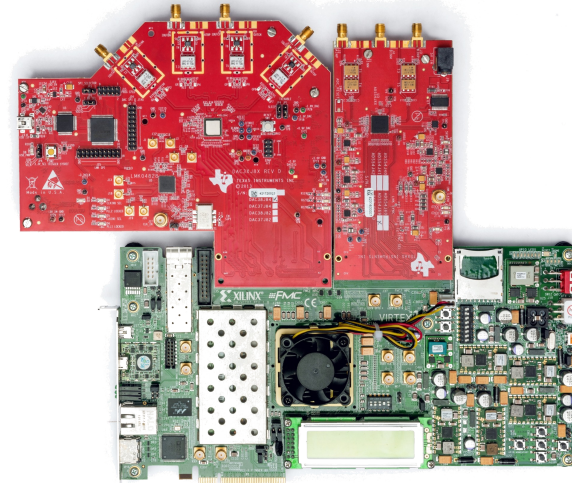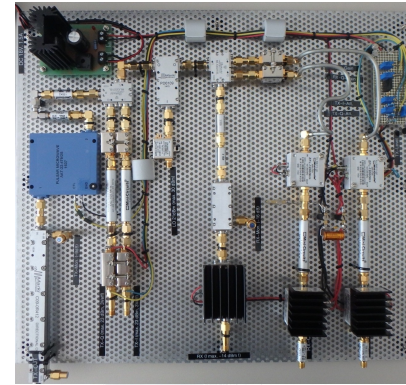Institute for Data Processing and Electronics (IPE)

Readout concept

ECHo conditions:

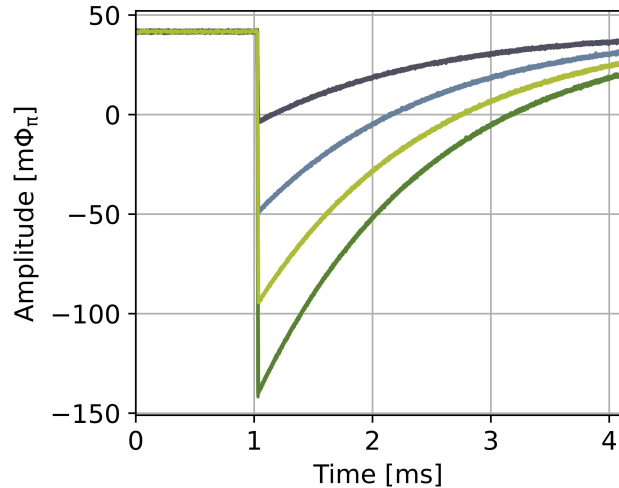| Parameter	Value
Sensors	10.000
Bandwidth	4 – 8 GHz
Channel Spacing	10 MHz
Channels	400
Platforms	15
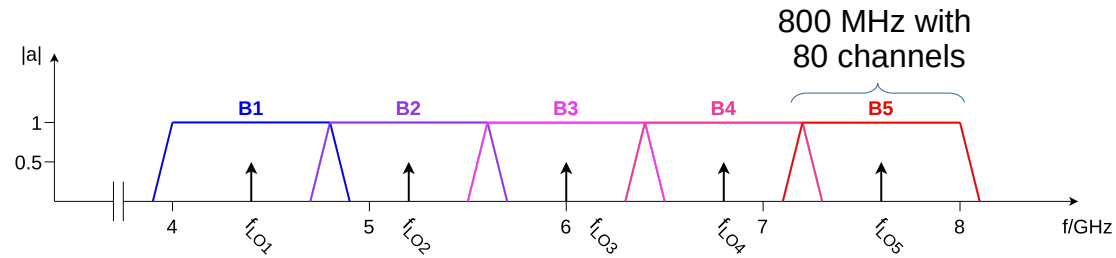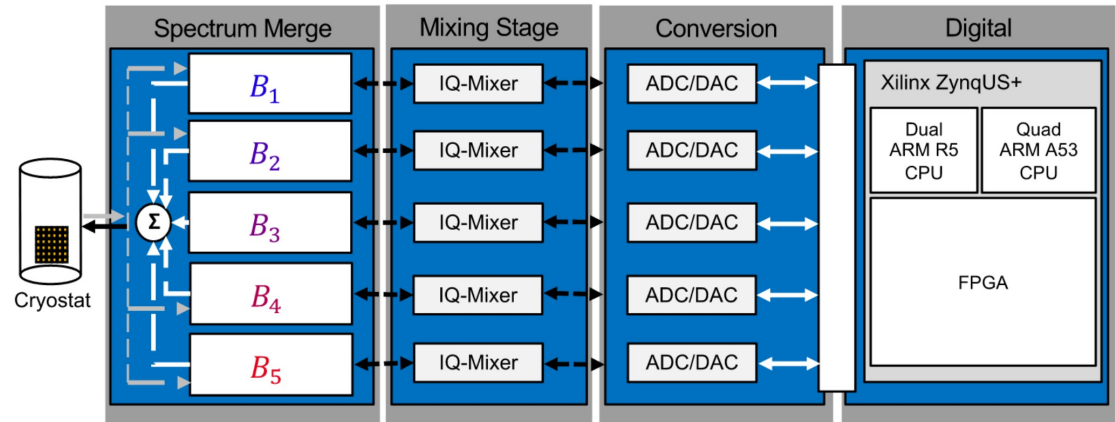
Prototype

- One of five sub-bands available

- Enabled system characterization & parameter optimization

- Full software stack and processing chain implemented on MPSoC

- Room-temperature and cryogenic measurements performed

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Preliminary Measurement Results

Measurements with demonstrator setup

Calculated spectrum

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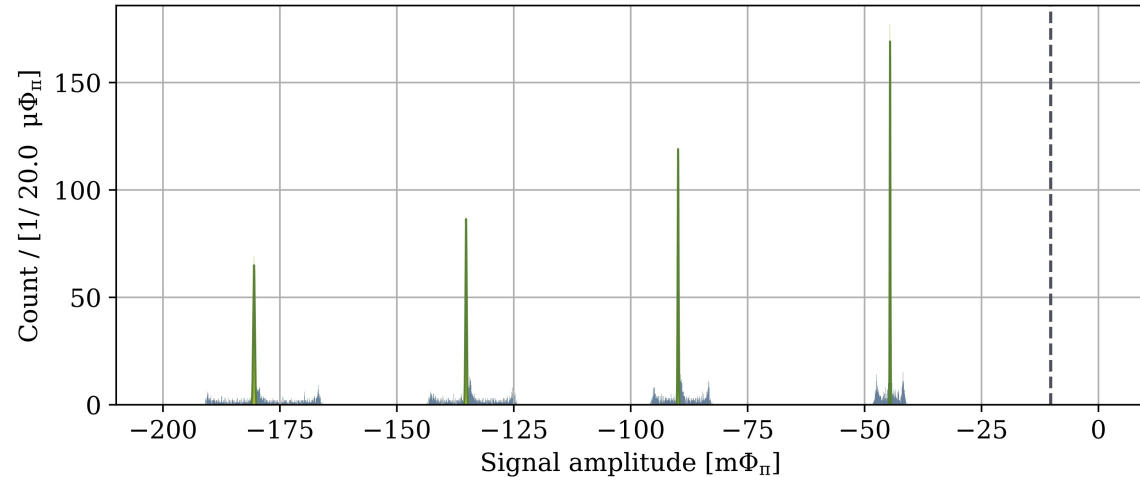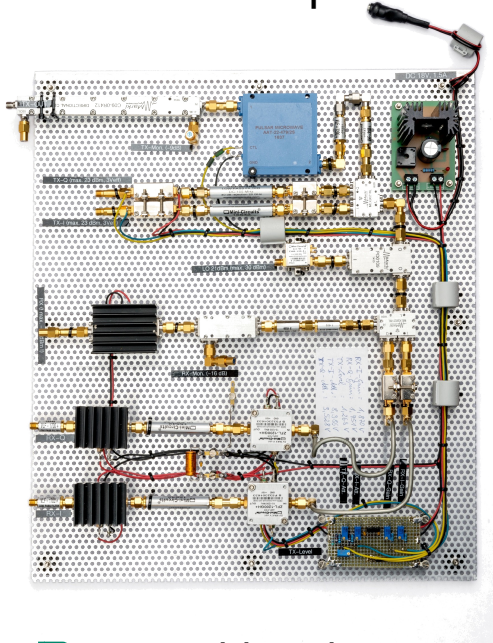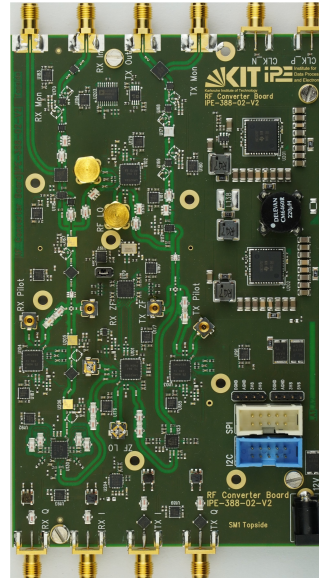
Hardware – RF-Frontend

Discrete setup

🟩 One subband

Prototype board

🟩 One subband

Full-Scale ECHo board

🟩 Five subbands

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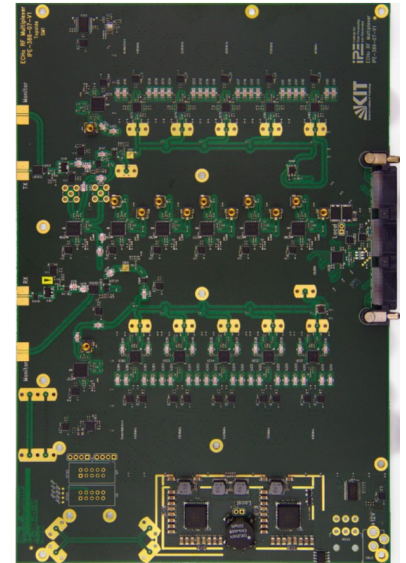
Hardware – Converter Board

Texas Instruments
Evaluation Boards

ECHo DAQ
Rev 2.1
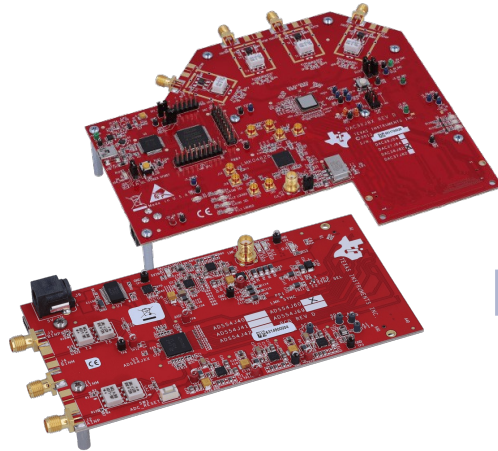
ECHo DAQ
Rev 2.2

- 4 DAC (500 MSPS)
- 2 ADC (500 MSPS)
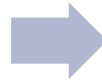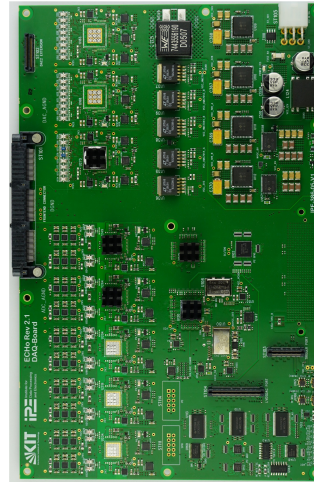
- 4 DAC (1 GSPS)
- 4 ADC (1 GSPS)
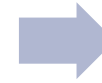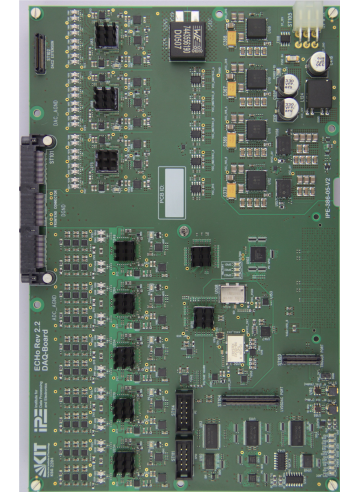
- 12 DAC (1 GSPS)
- 10 ADC (1 GSPS)

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Hardware – FPGA Board

Xilinx ZCU102 Evaluation Board
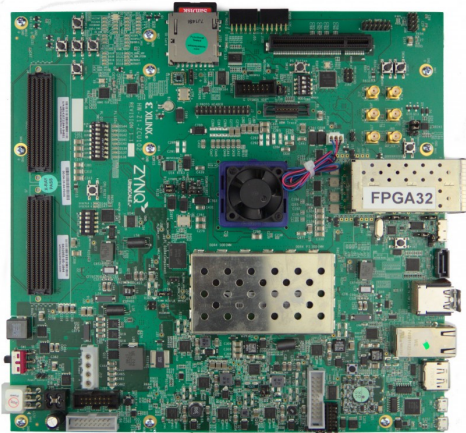
DTS-100G (DESY & KIT)

- ZUS+ ZU9EG MPSoC
- FMC Connector
  (10 Highspeed Links)
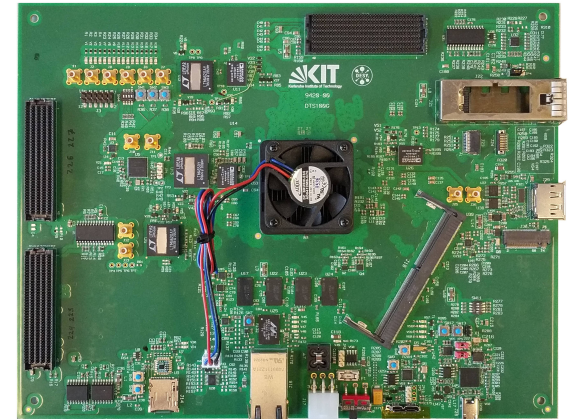
- ZUS+ ZU11EG MPSoC
- FMC+ Connector
  (24 Highspeed Links)

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Firmware
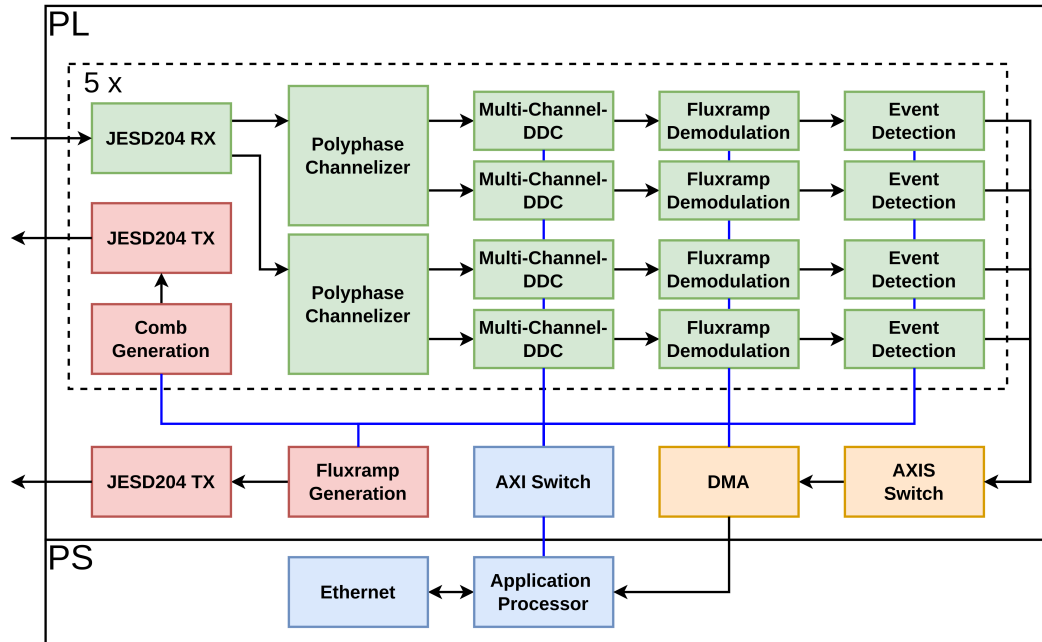
Processing chain components:

Polyphase Channelizer	Separation of channels into TDM-Scheme
DDC	Down-Conversion of tones to DC
Fluxramp Demodulation	Recovery of raw sensor signal
Event Detection	Extraction of important data
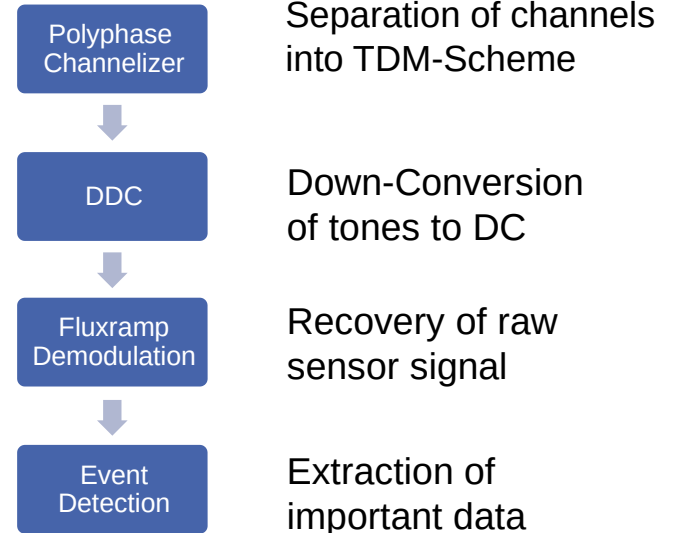
■ Reduction of data rate from 17.5 GB/s to ~10 MB/s

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Software

- Preparation for measurements with focus on usability:

  - Development of an automated calibration routine for configuring the electronics

  - Development of a GUI-based I/Q imbalance correction feature for the mixers on transmitter side

  - Log status registers in JSON file

Calibration routine:

Generate tones	→	Map tones to channels	→	Configure NCOs	→	Acquire raw channel data	→	Calculate frequency (FFT)	→	Configure fluxramp demodulation

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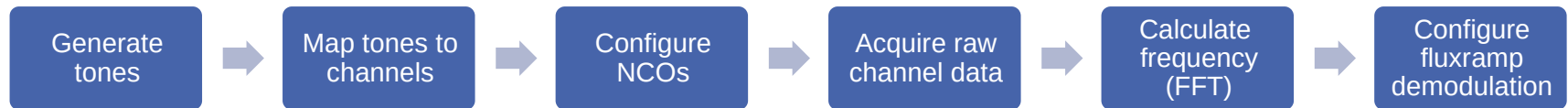
Outlook

- Characterization of complete electronic system is ongoing

- Usage of ZU19EG MPSoC to fit 5 readout chains into the programmable logic

- Cryostat for in-house measurements will arrive by the end of this year

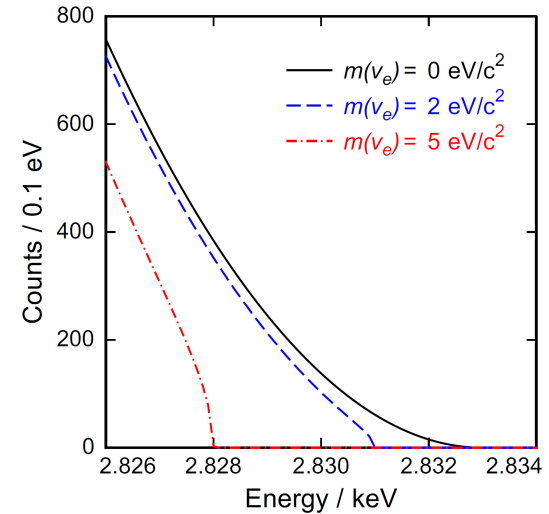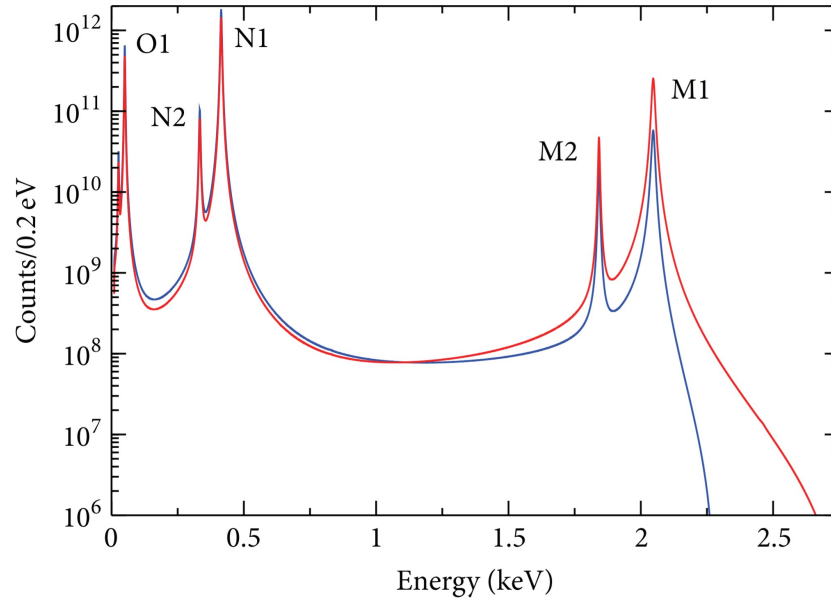- Assembly of 15 identical platforms

https://bluefors.com/products/ld-dilution-refrigerator/

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Thank you for your attention!

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Backup

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Energy spectrum

$$Q_{EC} = (2.833 \pm 0.030^{stat} \pm 0.015^{syst})\ keV$$

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SQUID Multiplexer

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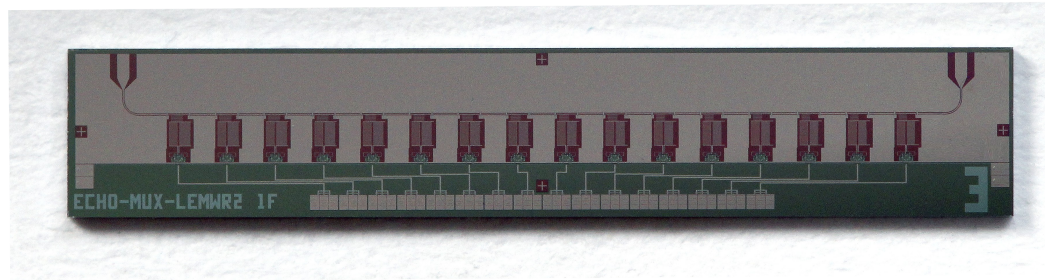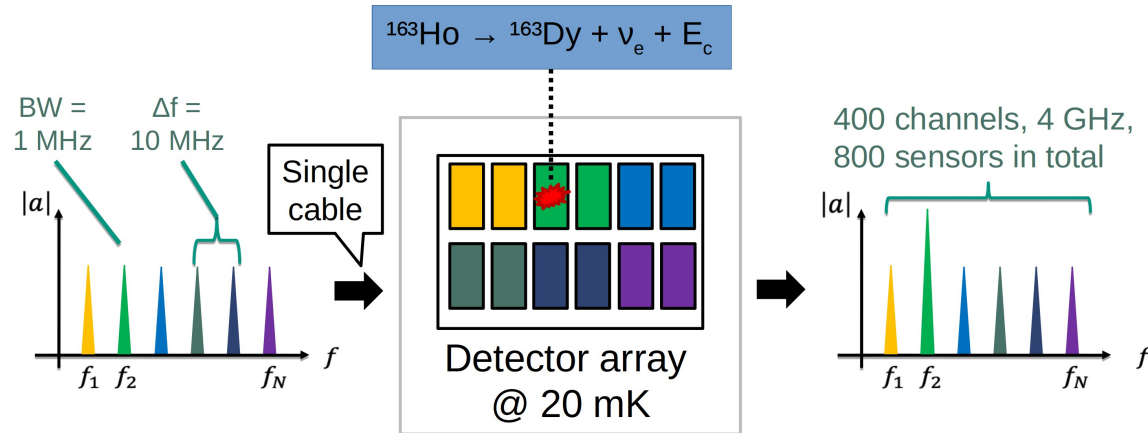
Signal Processing Chain

1   Input signal

2   Channelized signal
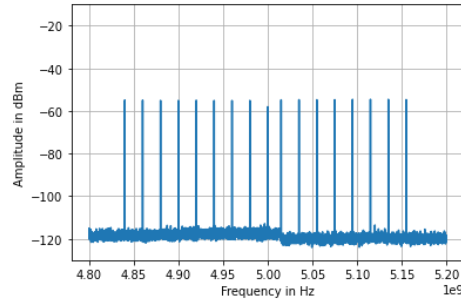
3   Fluxramp demodulated signal

Extracted events

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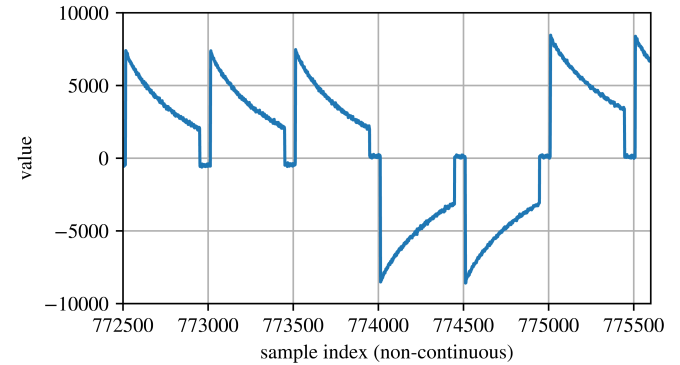
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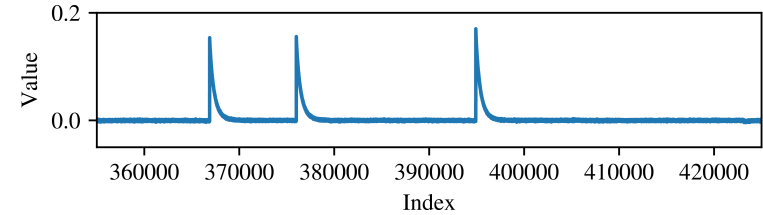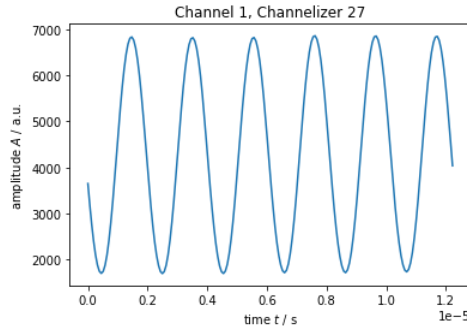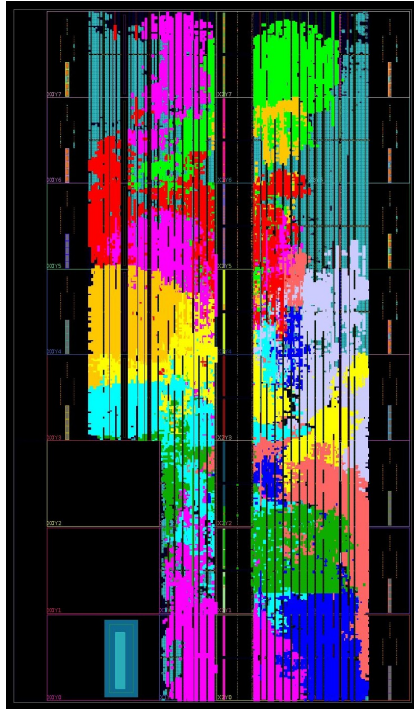
Firmware implementation

- DTS-100G is equipped with a ZU11EG (ZUS+)
- Optimizations of firmware ongoing

	Utilized	ZU11EG		ZU17EG		ZU19EG	
	total	total	%	total	%	total	%
LUT	290806	299000	97	423000	69	523000	56
FF	466722	597000	78	847000	55	1045000	45
BRAM [Mb]	22.45	21.1	106	28	80	34.6	65
URAM [Mb]	14.625	22.5	65	28.7	51	36	41
DSP	1313	2928	45	1590	83	1968	67

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Room-temperature demonstrator setup

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