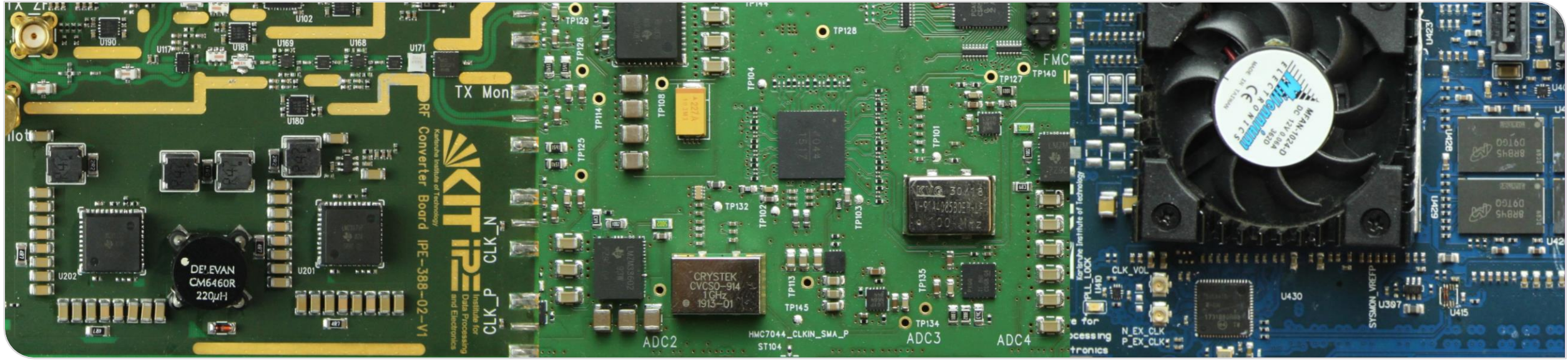
Karlsruher Institut für Technologie

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

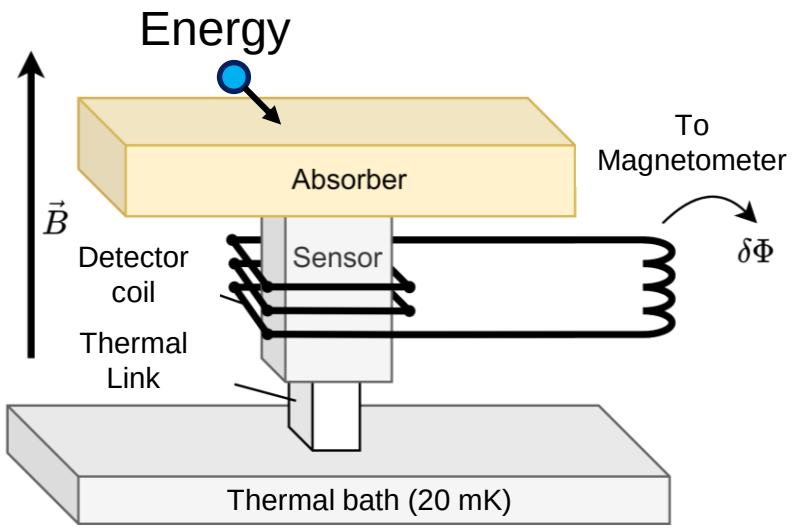
Readout Electronics for Magnetic Microcalorimeters with Frequency Multiplexing

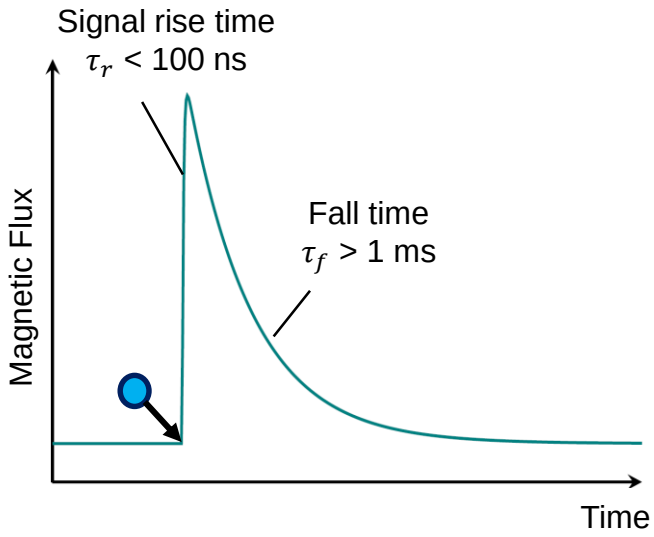
Dr.-Ing. Nick Karcher – Institute for Data Processing and Electronics (IPE)

3.5.2023



Magnetic Microcalorimeter (MMC)



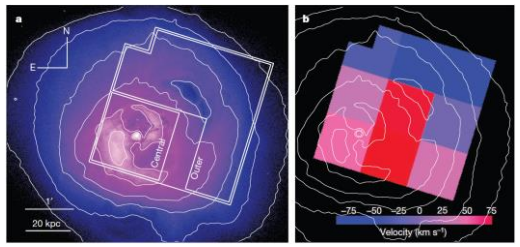


High energy resolution:

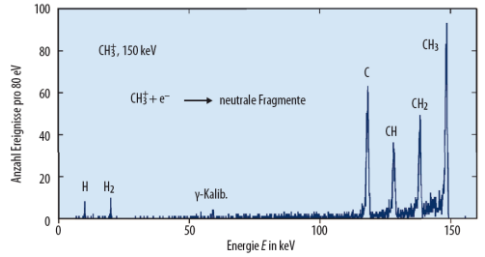
ΔE_{FWHM} = 1.6 eV at 6 keV

Large energy bandwidth:

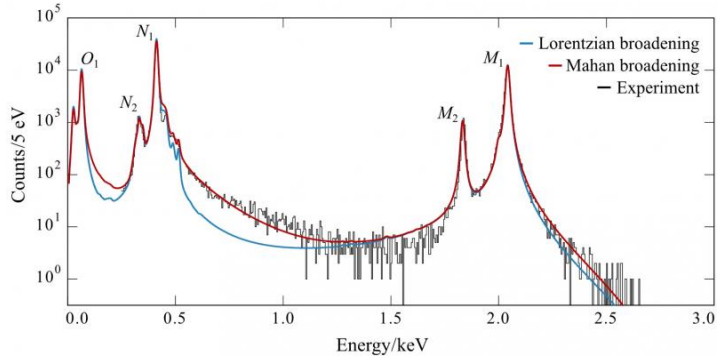
10 eV to 100 keV



Astronomy[1]



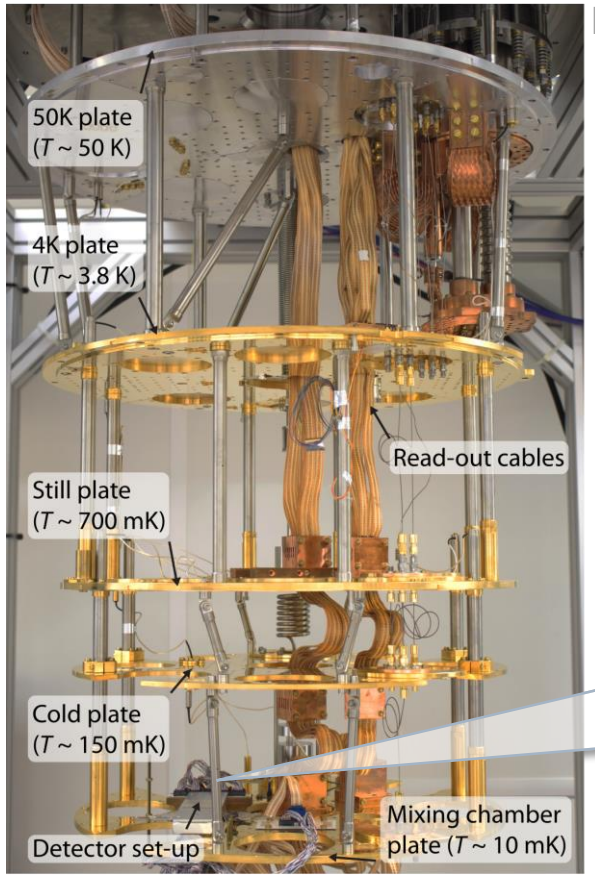
Mass spectrometry[2]



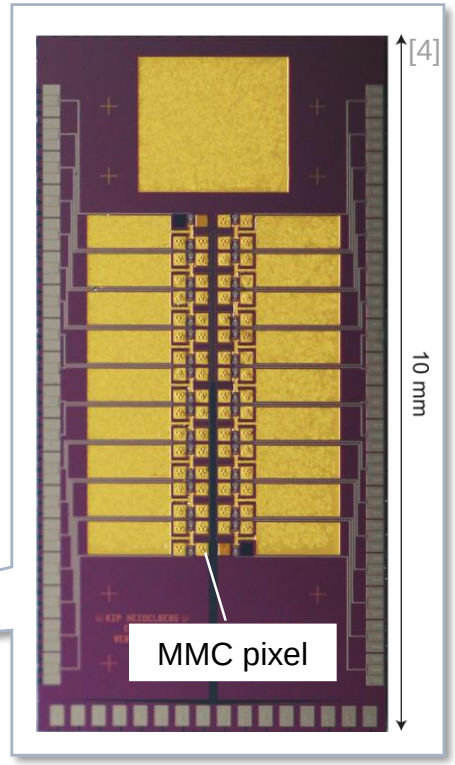
Neutrino physics[3]

[1] The Hitomi collaboration, Nature 2016 [2] A. Fleischmann et al., Physik Journal 2016 [3] L. Gastaldo et al., EPJC 2019

Cryostat Setup Conventional Readout

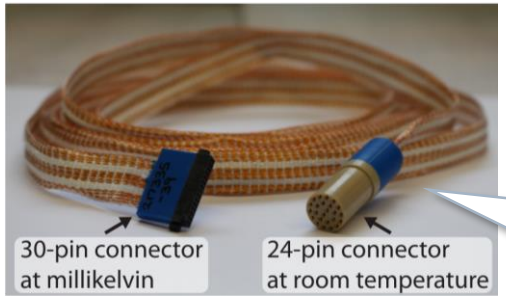


[4]



[4]

- Single channel readout
  - Approx. 8 readout cables per channel
  - With large sensor arrays:
    high complexity & heat input
  - Poorly scalable
- **Multiplexing method required**



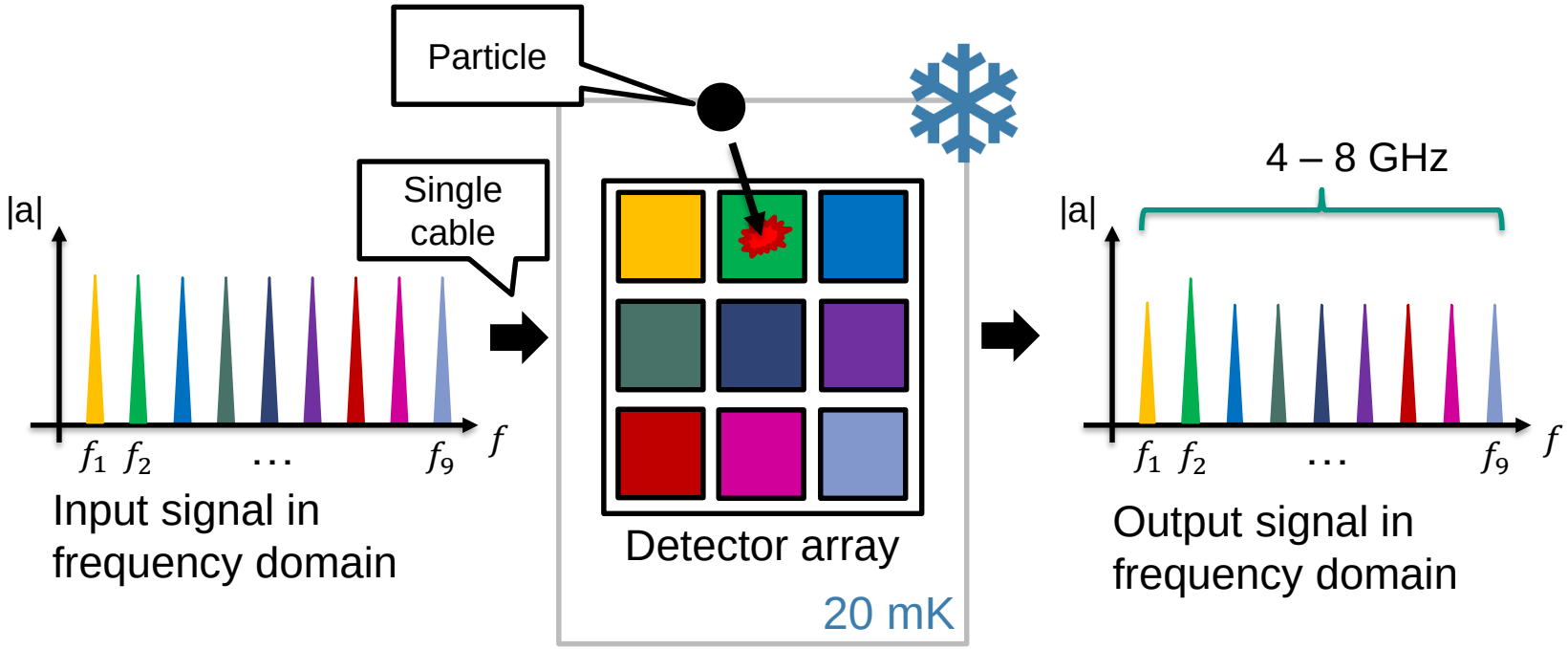
[4]

24 pins for three readout channels

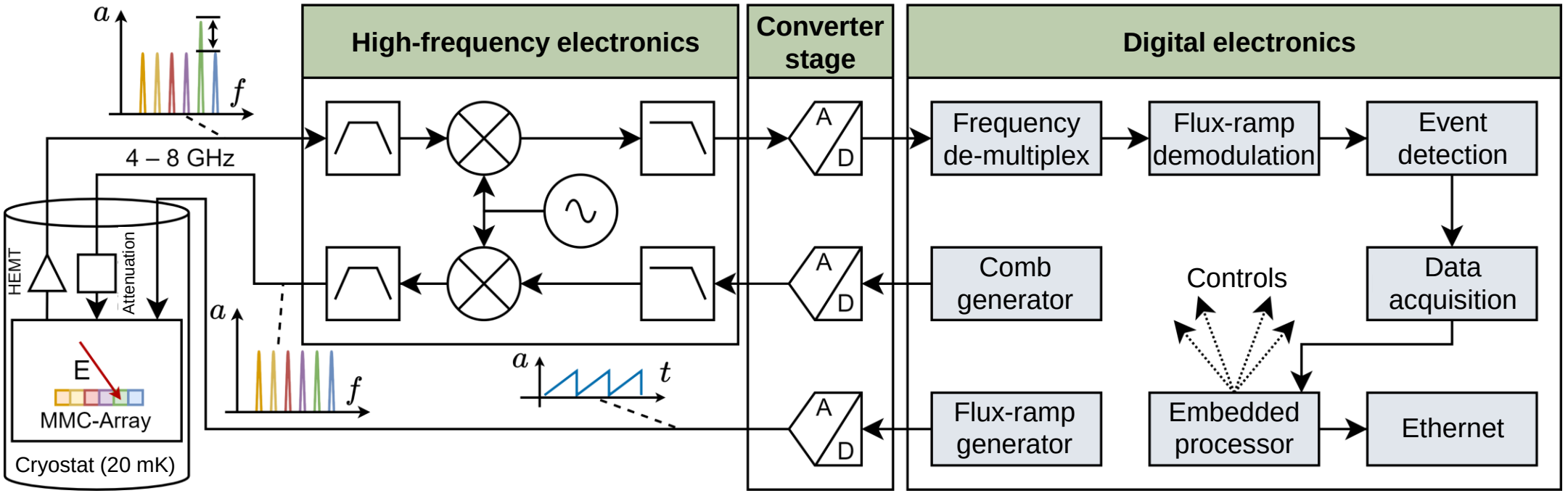
[4] F. Mantegazzini et al., JINST 2021

Frequency Multiplexing

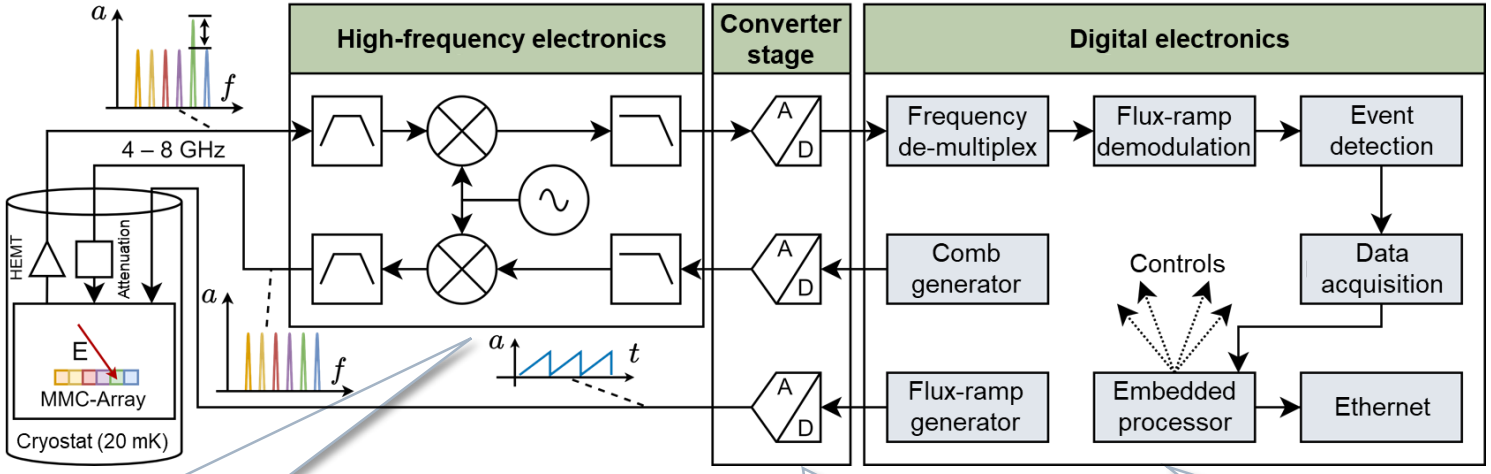
with the „microwave SQUID multiplexer“



Readout with Software-defined Radio System

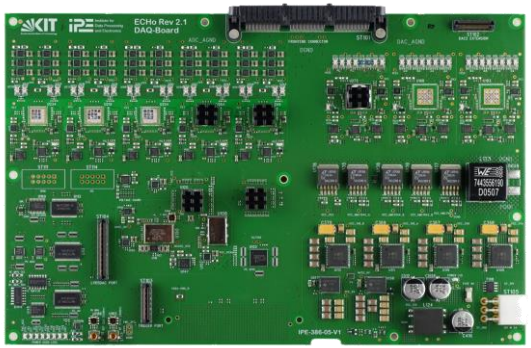


SDR Prototype System



My PhD

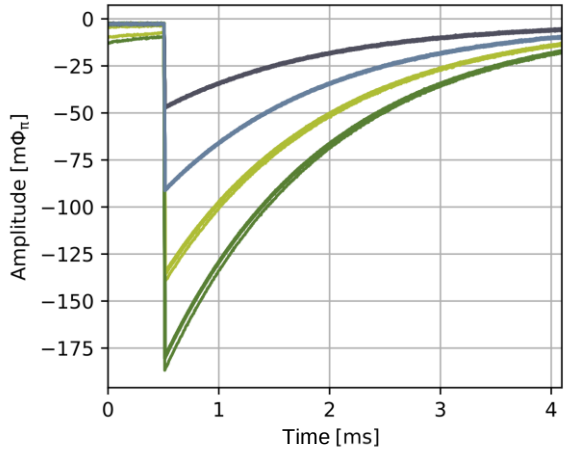
Two-stage high-frequency electronics:
800 MHz bandwidth, 4-12 GHz



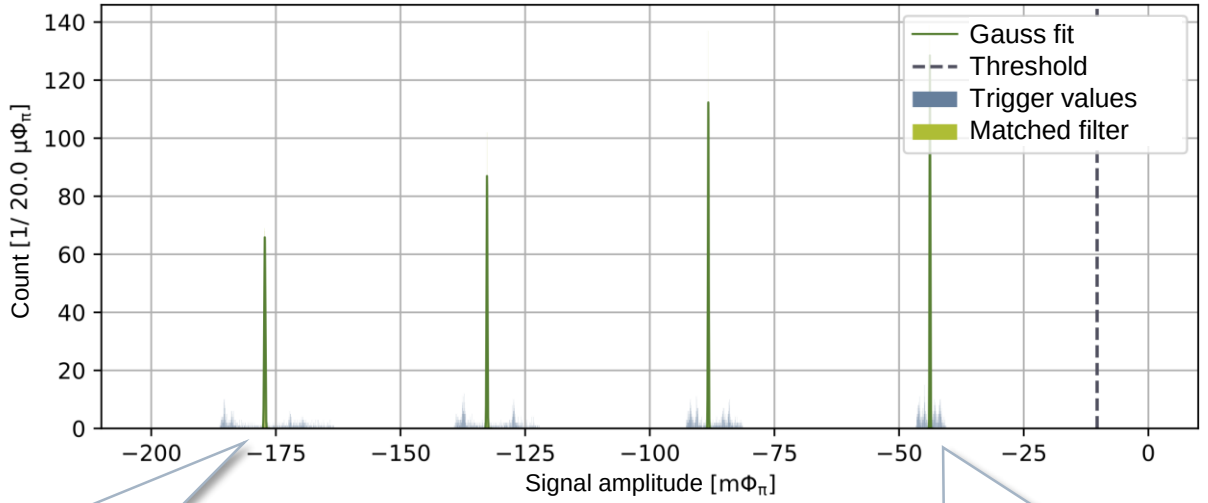
Converter electronics:
4 GHz maximum total bandwidth

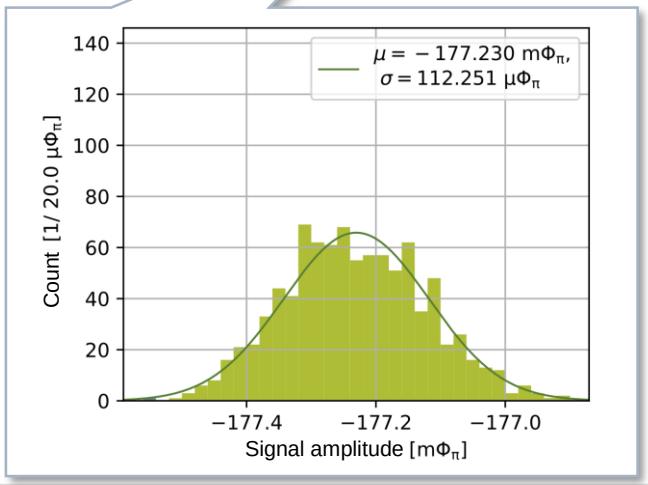
Digital electronics:
Evaluation board for custom firmware

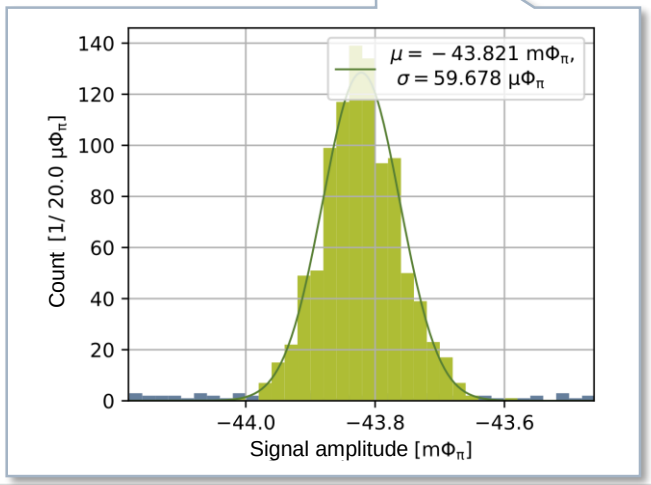
Measurement with Detector Emulation



Amplitude spectrum for Benchmark

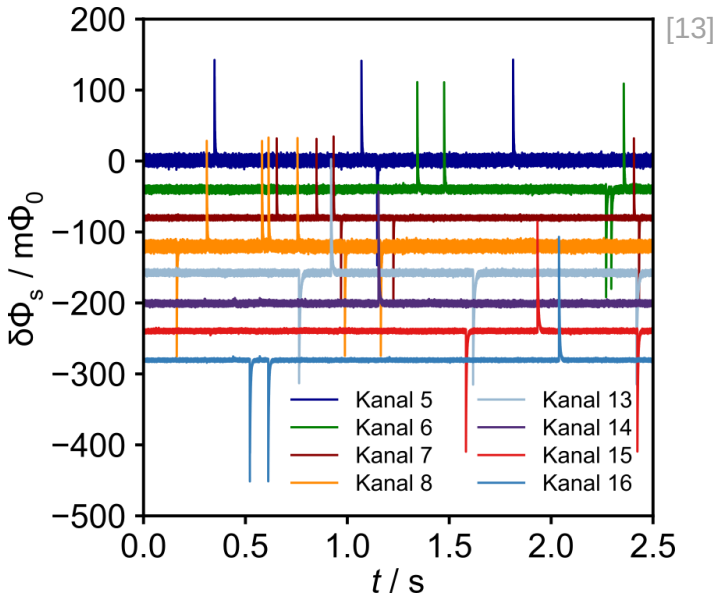






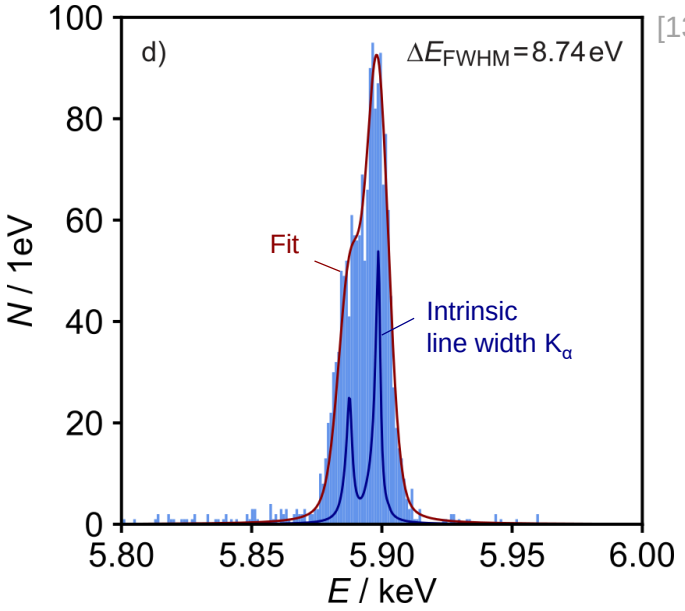
- Setup with Laboratory equipment
- Measure with arbitrary number of channels and settings
- 16 channel measurement: 6.2 eV at 3.4 keV
- 80 channel measurement: 10.7 eV at 3.3 keV

Results Low Temperature Measurements



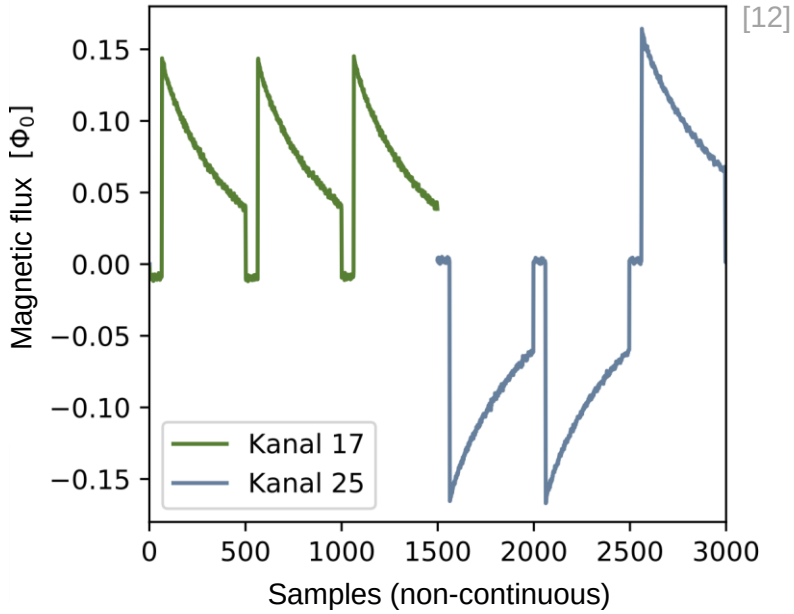
[13]

- First simultaneous measurement of 16 MMC pixels
- Real-time channelization & flux ramp demodulation



[13]

- Long-term measurements for iron-55 spectrography
- < 8.8 eV achieved at 5.9 keV with 8 channel readout



[12]

- First demonstration of real-time event detection in microwave SQUID multiplexer.

[13] D. Richter, Dissertation 2021 [12] N. Karcher et al., JLTP 2022

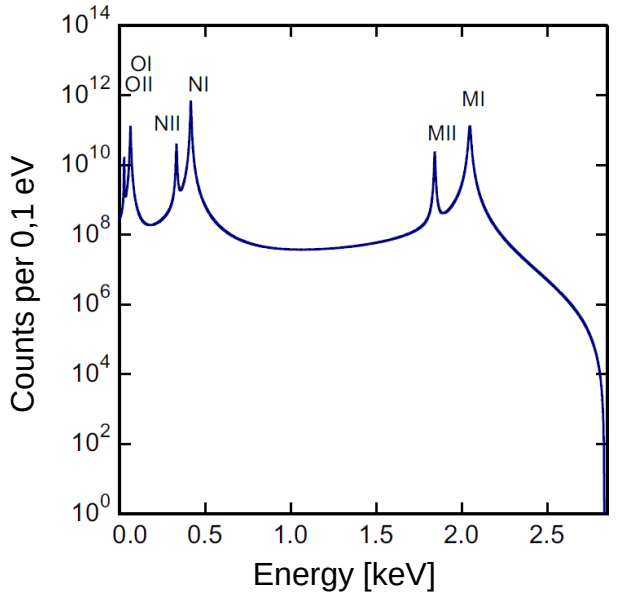
ECHo Experiment

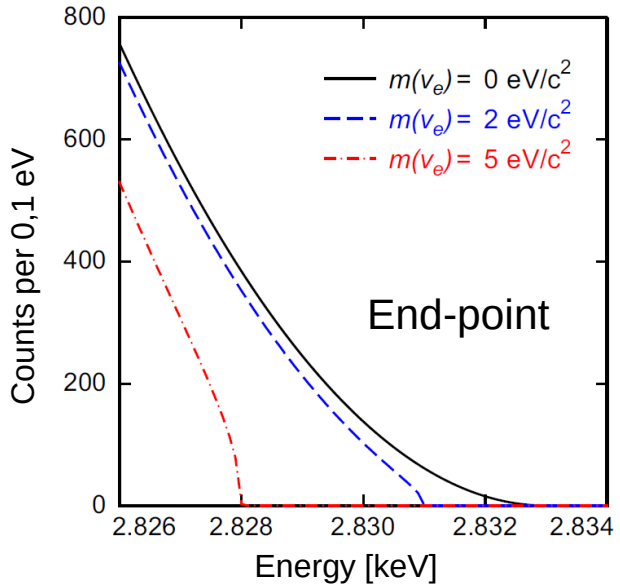
Electron **C**apture ^{163}**Ho**lmium

- Mass investigation of the Electron-Neutrino
- 12000 sensor pixel measure in parallel
- 100 kBq total decay rate

- Readout electronics for multiplexer
  - 400 channels with 2 sensor pixels each
  - 4-8 GHz readout interval
- 15 Electronics
- 2.4 Tbit/s total raw data rate

$$^{163}\mathrm{Ho} \rightarrow {}^{163}\mathrm{Dy} + E_c + \nu_e$$





[5]

[5] L. Gastaldo et al., EPJST 2017

Conclusion and Outlook

- First readout system for Magnetic Microcalorimeters with frequency multiplexing
- Actively used for measurements
- 160 MMC pixels for current prototype, 800 Pixels for final system
- Generic approach for various low temperature detectors and superconducting Qubits
- Final system for ECHo readout is build up @ KIT

Picture: Timo Muscheid and Robert Gartmann