# The Electron Capture in $^{163}$Ho (ECHo) experiment

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*on behalf of the ECHo Collaboration*

Kirchhoff Institute for Physics
Heidelberg University

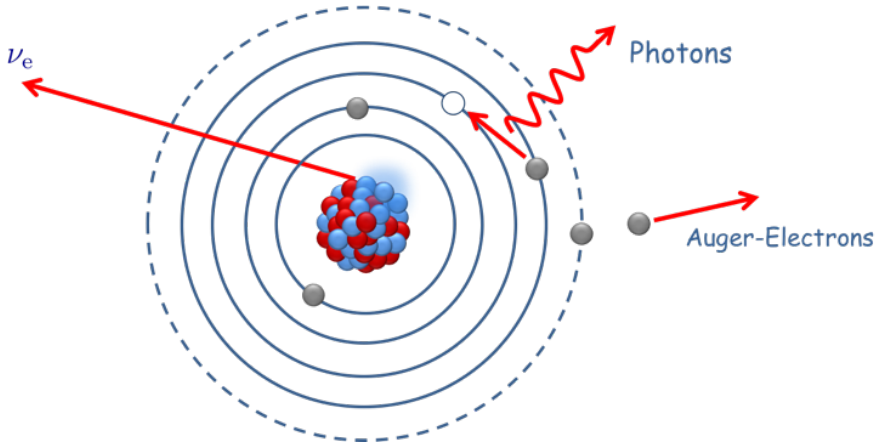
**LTD-18, Milano**
23 July 2019

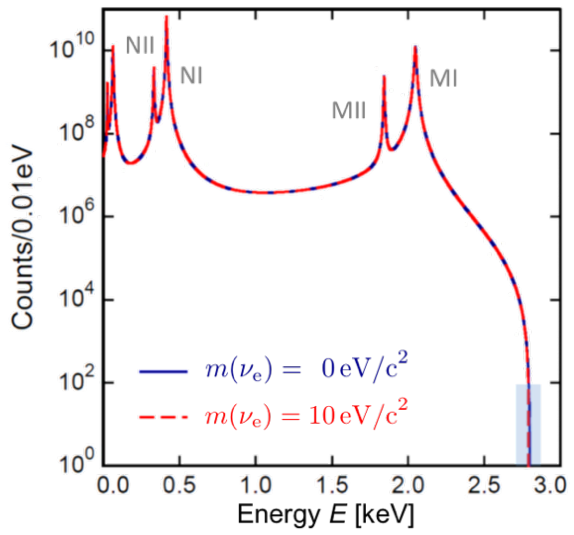
# Direct Neutrino Mass Determination

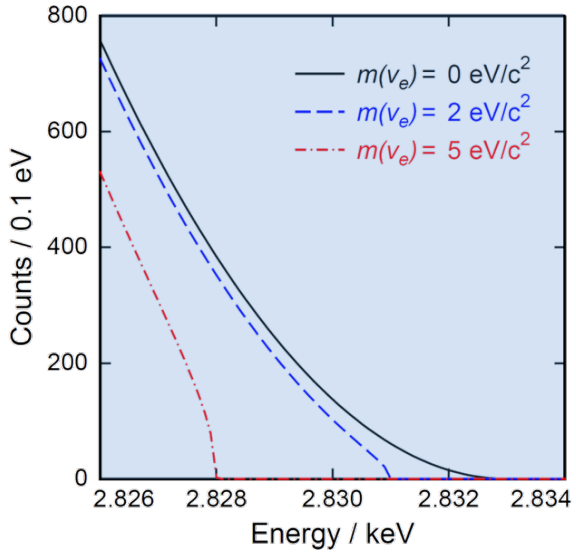
## Electron capture in Holmium-163

$$^{163}_{67}\mathrm{Ho} \rightarrow {}^{163}_{66}\mathrm{Dy}^{*} + \nu_e$$

$$^{163}_{66}\mathrm{Dy}^{*} \rightarrow {}^{163}_{66}\mathrm{Dy} + E_C$$




- $\tau_{1/2} \cong 4570$ years ($2 \cdot 10^{11}$ atoms for 1 Bq)
- $Q_{EC} = (2.833 \pm 0.030_{stat} \pm 0.015_{syst})$ keV

S. Eliseev et al., *Phys. Rev. Lett.*, 115, 062501 (2015)

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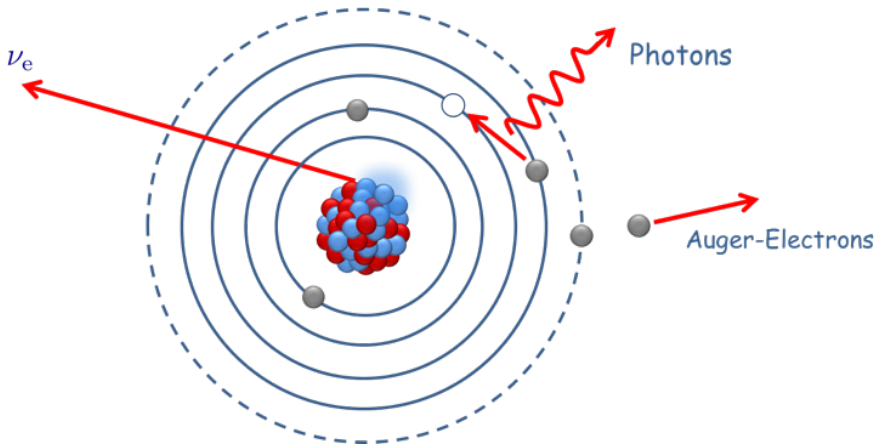


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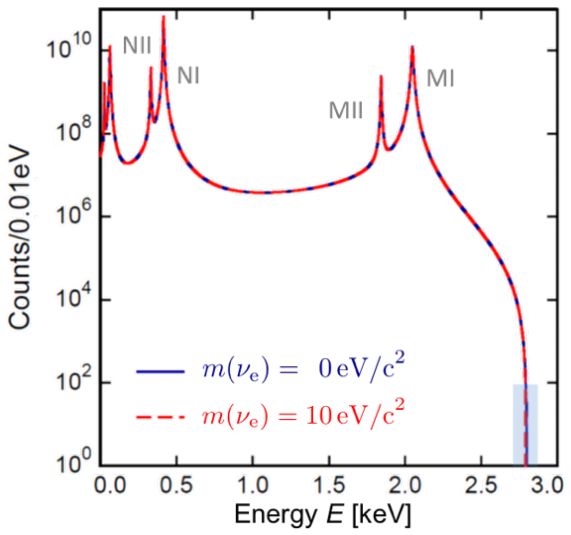
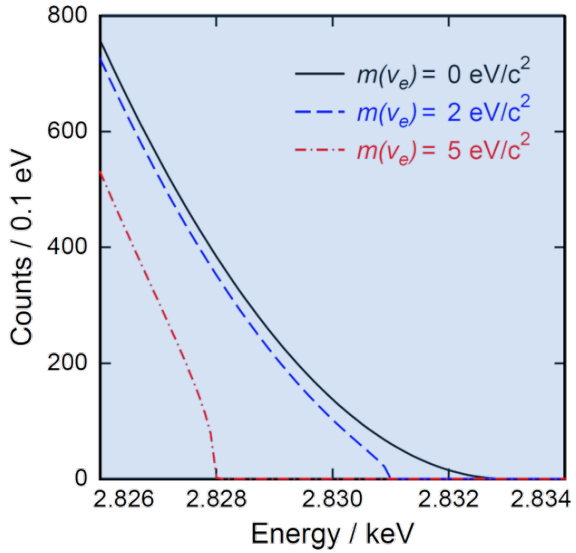
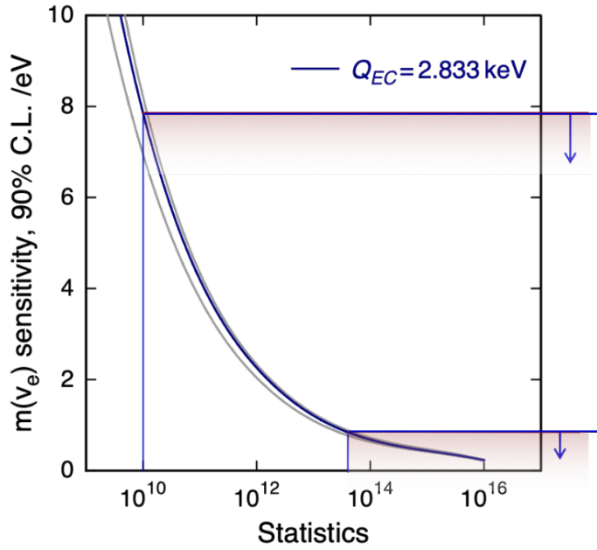



**ECHo-1k** → $10^{10}$ events

→ sub 10 eV sensitivity

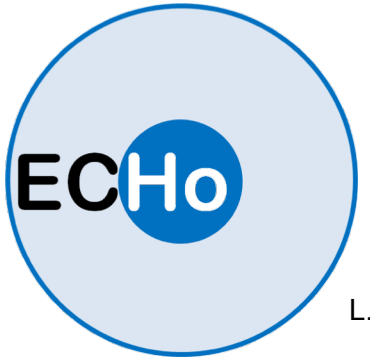
**ECHo-100k** → 3 x $10^{13}$ events

→ sub 2 eV sensitivity

# The ECHo Experiment

**Goal:**

- Precise high statistics calorimetric measurement of the EC de-excitation energy
- Sub-eV sensitivity on the effective electron neutrino mass




L. Gastaldo et al., EPJ ST 226, 8 (2017)

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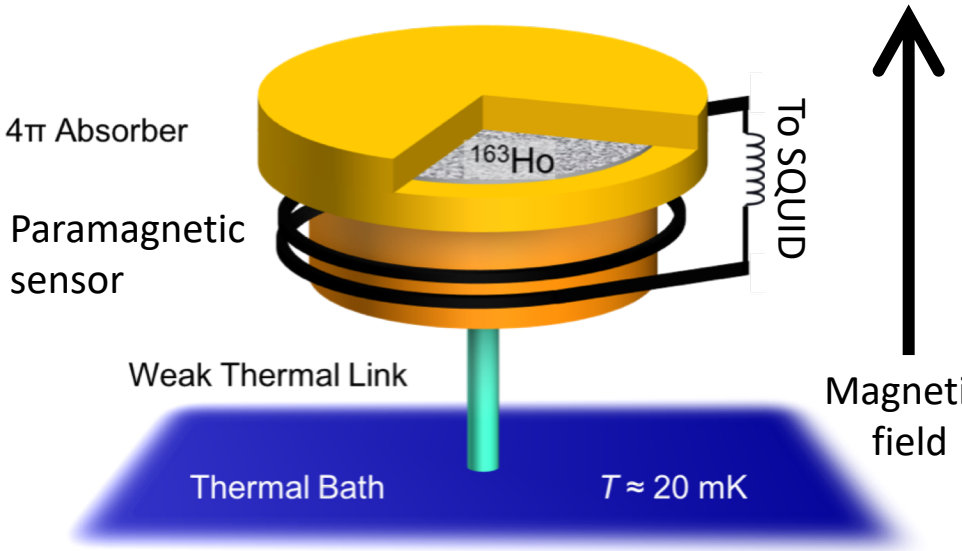
ECHo

L. Gastaldo et al., EPJ ST 226, 8 (2017)

⇨ Metallic Magnetic Calorimeters (MMCs)




$$\delta E$$

$$\delta T = \frac{\delta E}{C}$$

$$\delta M = \frac{\partial M}{\partial T}\frac{\delta E}{C}$$

$$\delta\Phi \sim \delta M \sim \delta T \sim \delta E$$

# The ECHo Experiment

**Goal:**

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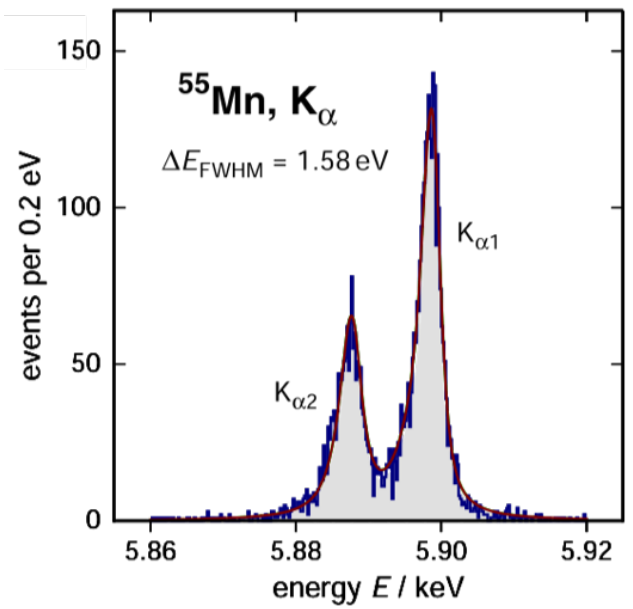
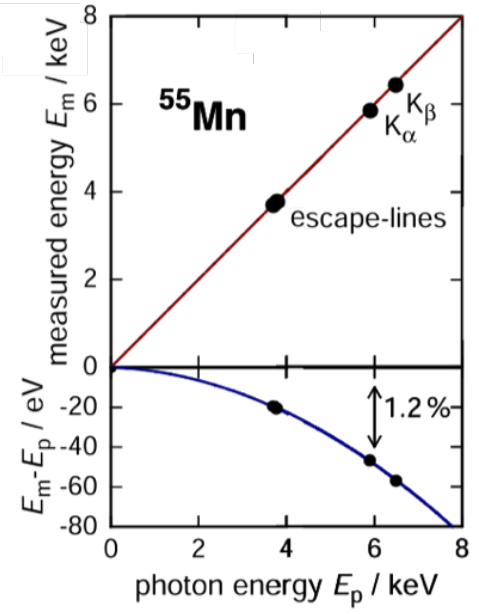
- Sub-eV sensitivity on the effective electron neutrino mass

⇨ Metallic Magnetic Calorimeters (MMCs):

- High energy resolution, linearity




$\Delta E_{FWHM}$ = 1.6 eV @6keV




Non-linearity < 1 % @6keV

# The ECHo Experiment

**Goal:**

- Precise high statistics calorimetric measurement of the EC de-excitation energy
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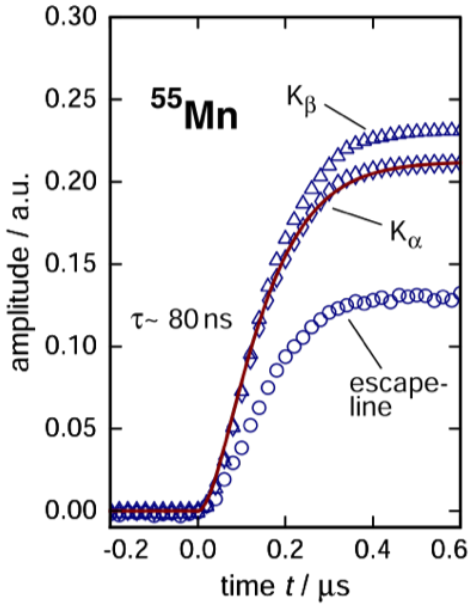
⇨ **Metallic Magnetic Calorimeters (MMCs):**

- High energy resolution, linearity
- Large activity per pixel → fast risetime to minimise unresolved pile-up




**Risetime: ~ 90 ns**

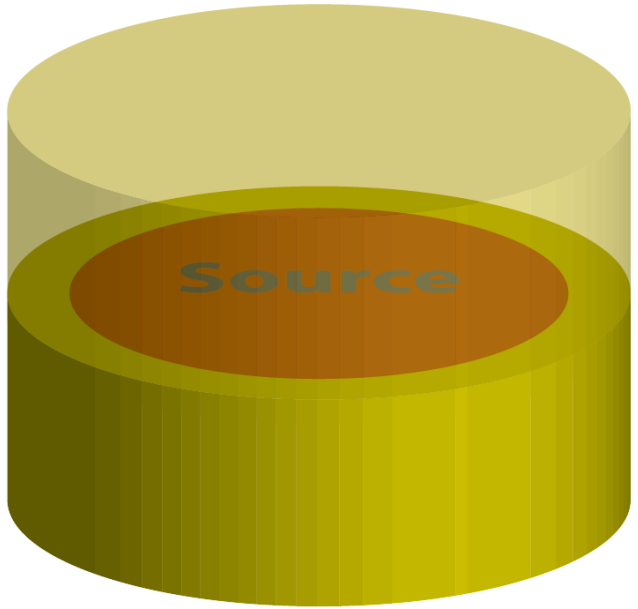
# The ECHo Experiment

**Goal:**

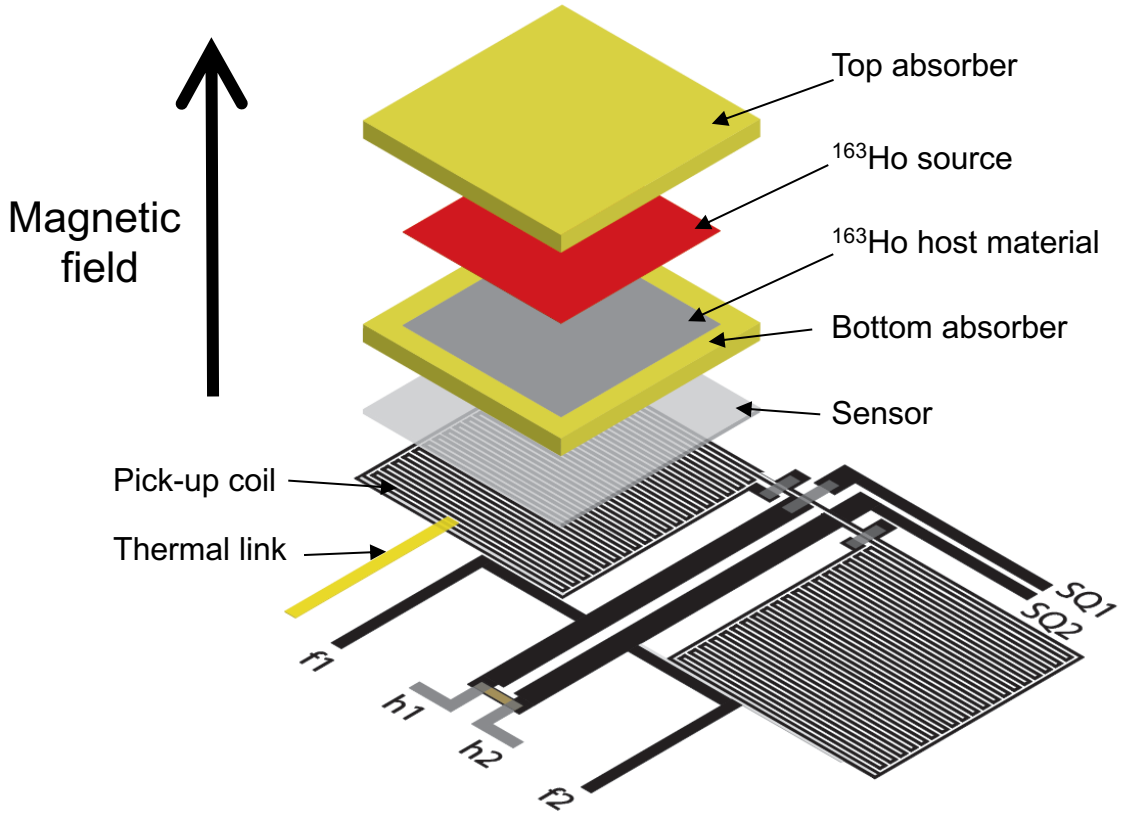
- Precise high statistics calorimetric measurement of the EC de-excitation energy
- Sub-eV sensitivity on the effective electron neutrino mass

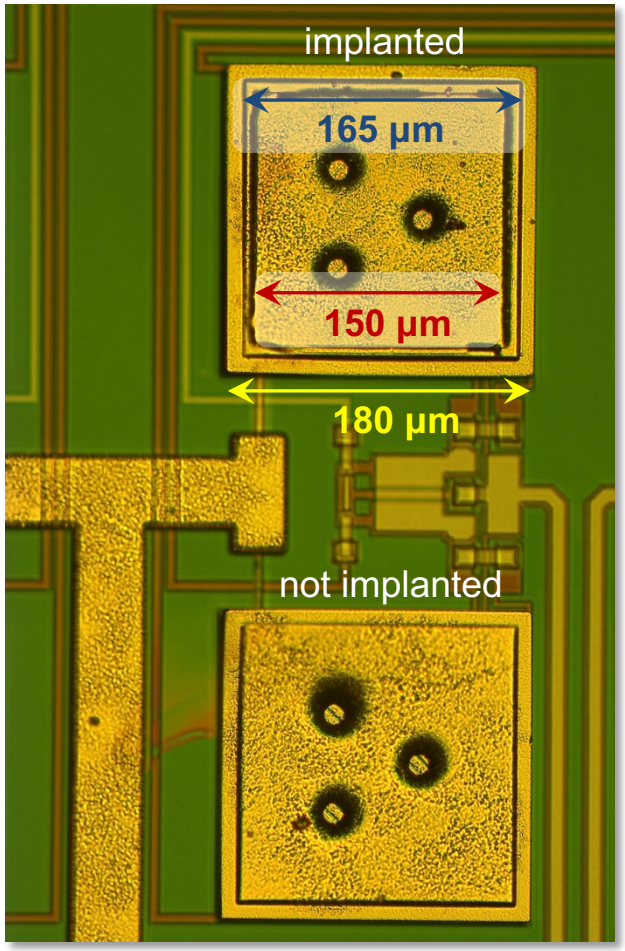
⇨ **Metallic Magnetic Calorimeters (MMCs):**

- High energy resolution, linearity
- Large activity per pixel → fast risetime to minimise unresolved pile-up
- Source embedded in the detector



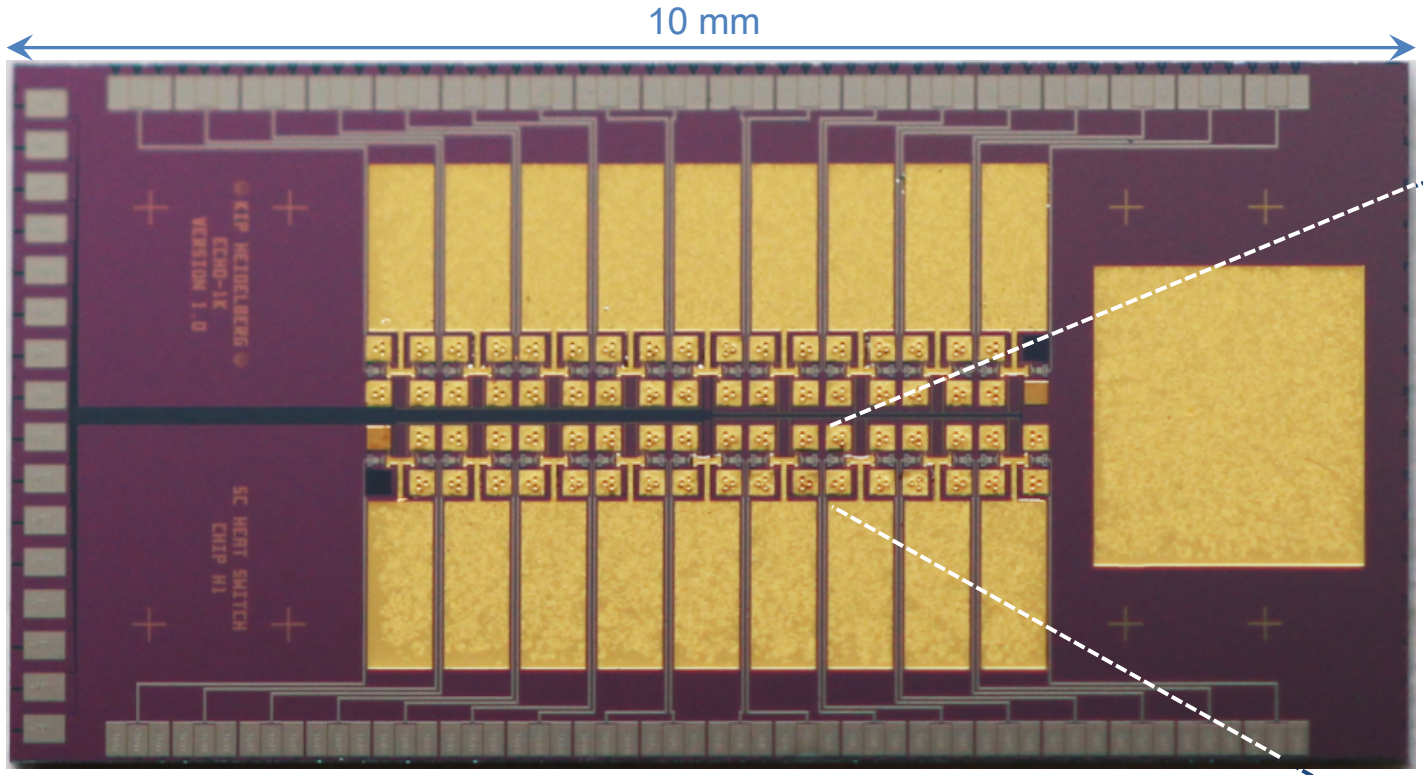
# Metallic Magnetic Calorimeters

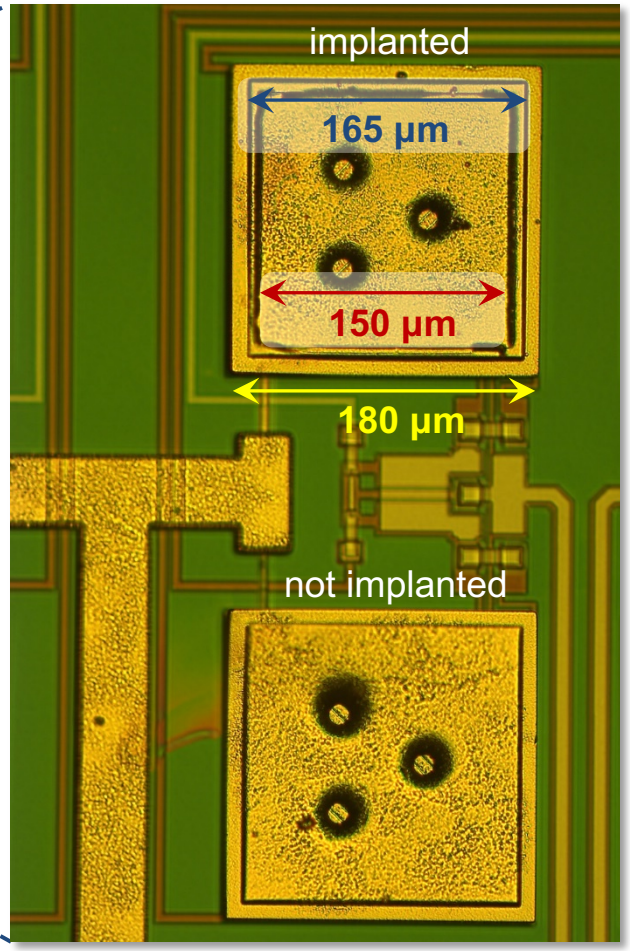



*Microscope image of implanted MMC channel*

# ECHo-1k Detector



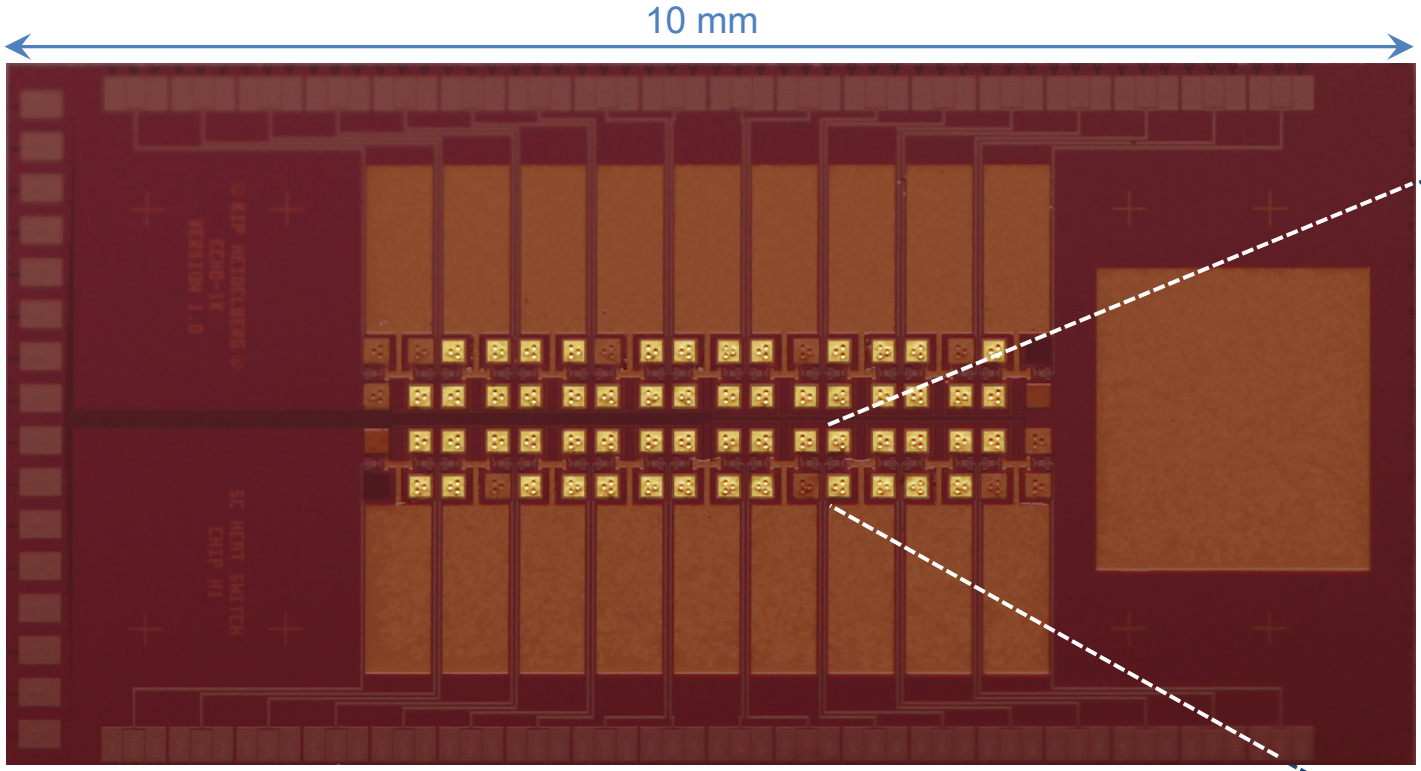



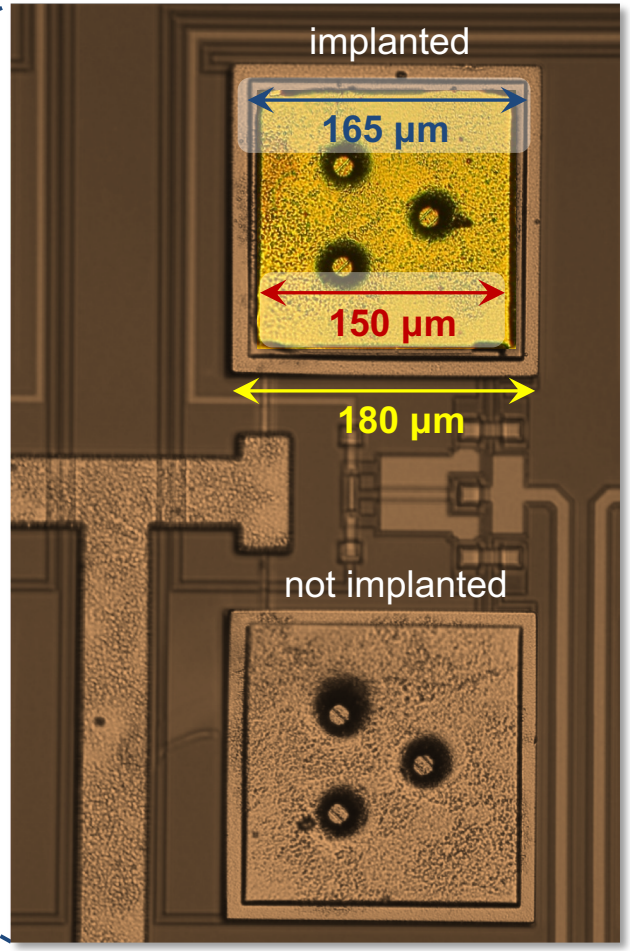

*Microscope image of implanted MMC channel*

**32 gradiometric channels → 64 MMC pixels**

+ 4 channels for temperature monitoring and diagnostics

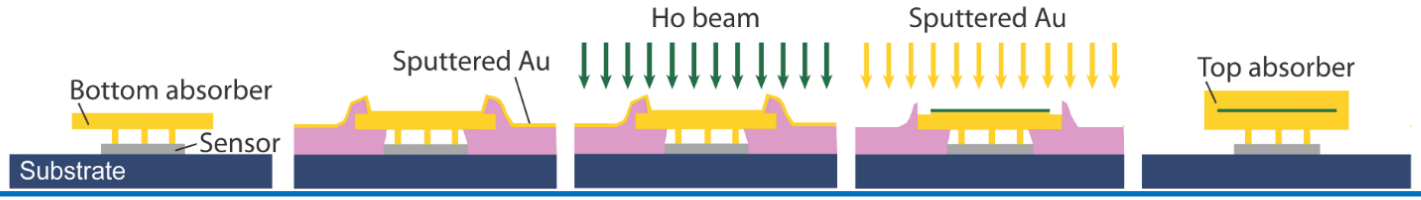
# $^{163}$Ho Production & Implantation



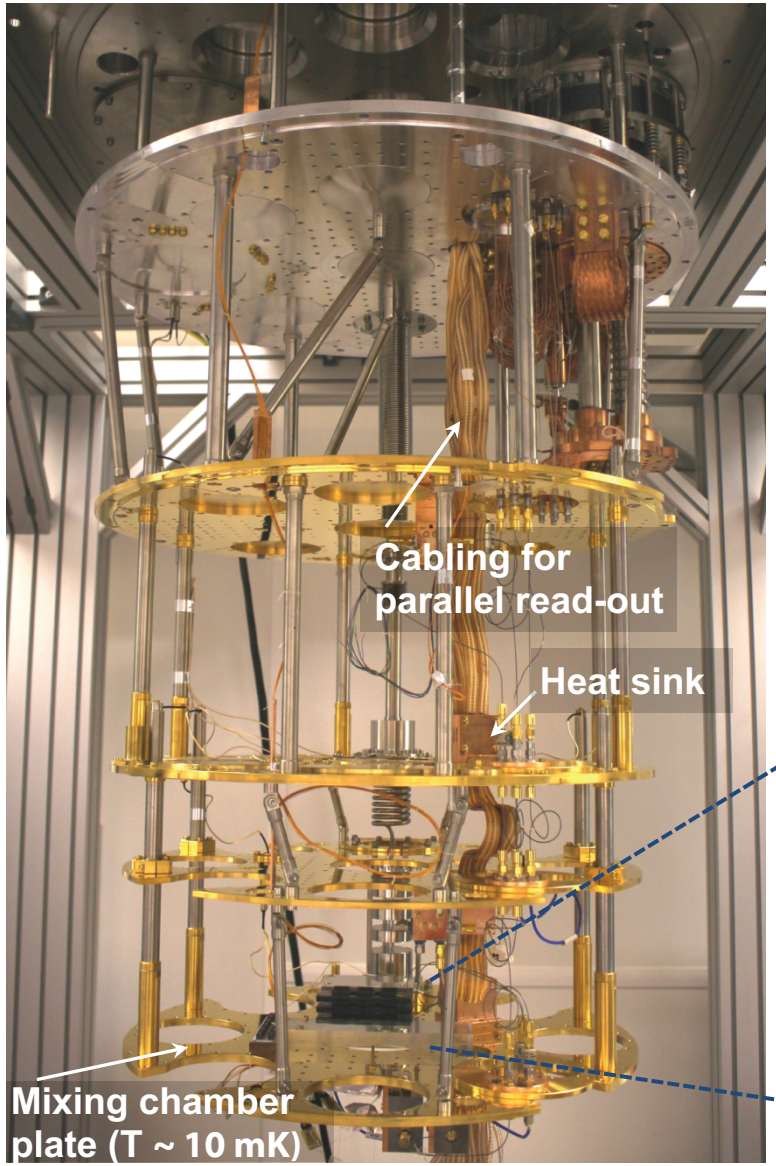

*Microscope image of implanted MMC channel*

- ✓ **$^{163}$Ho production**: neutron irradiation (n,γ)-reaction on $^{162}$Er
- ✓ **Chemical separation**: → ~ $10^{18}$ atoms already available
- ✓ **Mass separation and detector implantation** @ RISIKO (Uni Mainz)



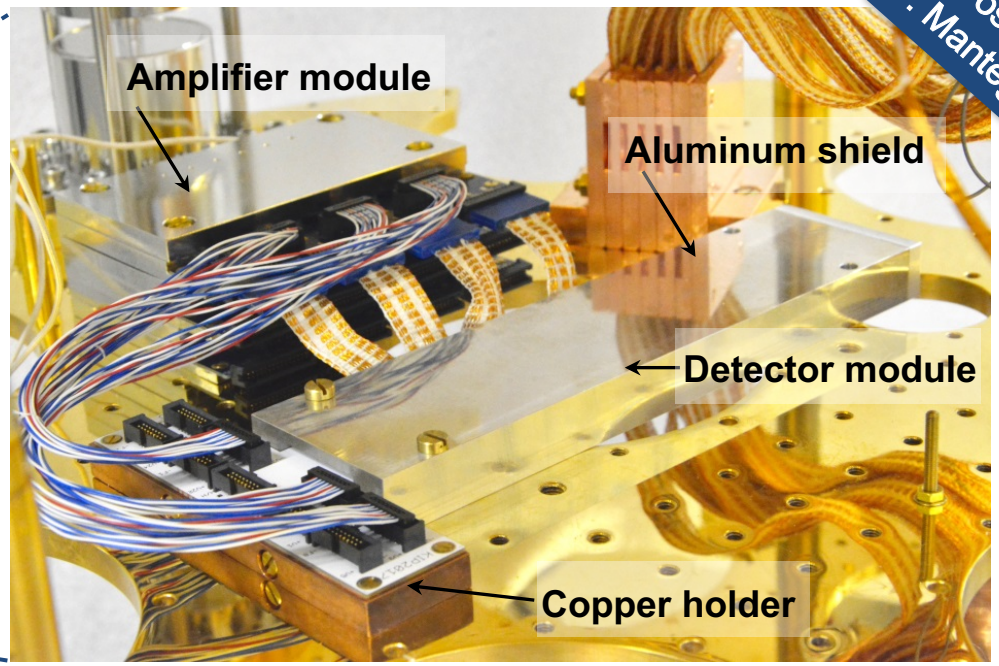

H. Dorrer et al., Radiochim. Acta **106**, 535 (2018)

# ECHo-1k Cryogenic Set-up

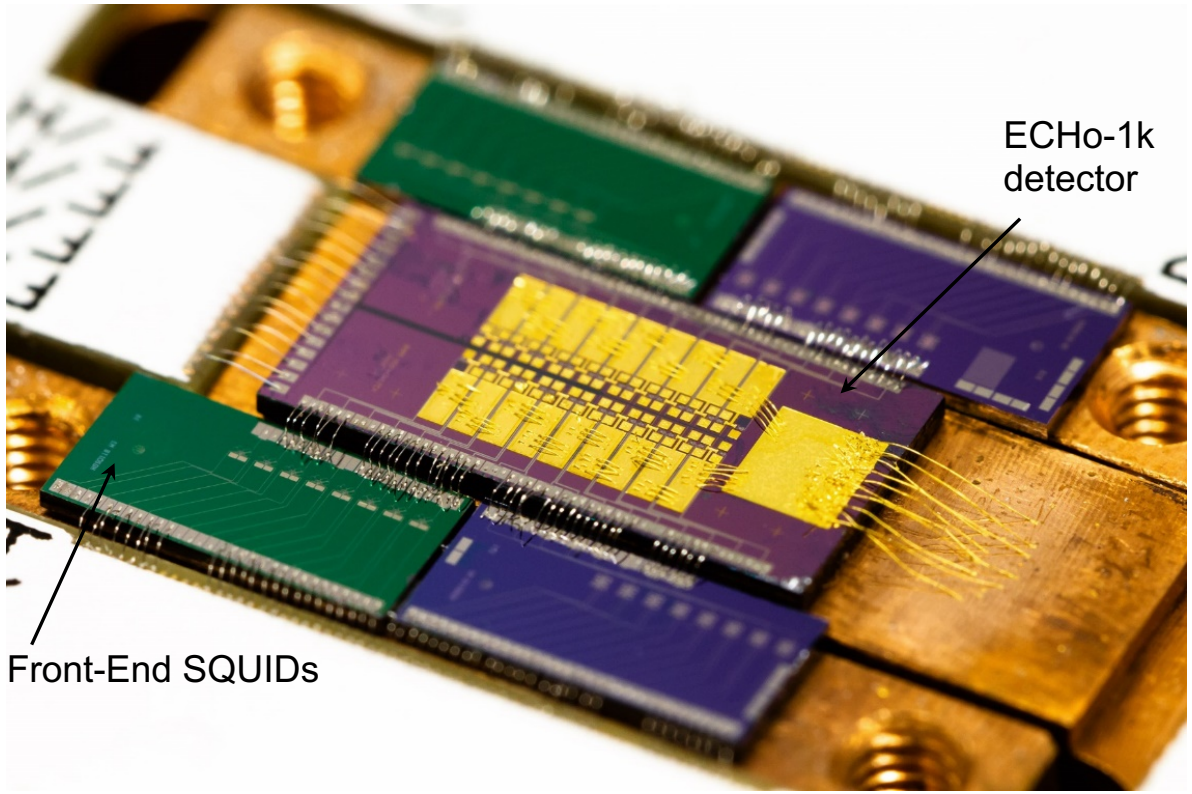



## ECHo-1k detector module

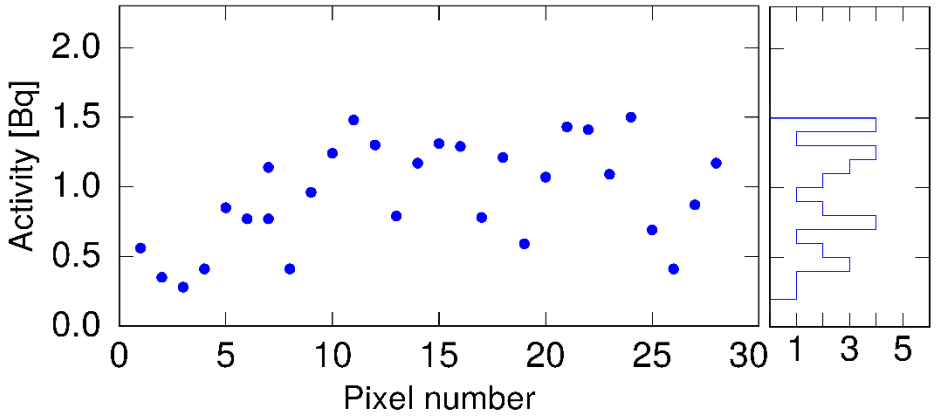
- Copper holder to ensure detector thermalisation
- T-shaped copper holder with optimised aluminum shield against external magnetic fields



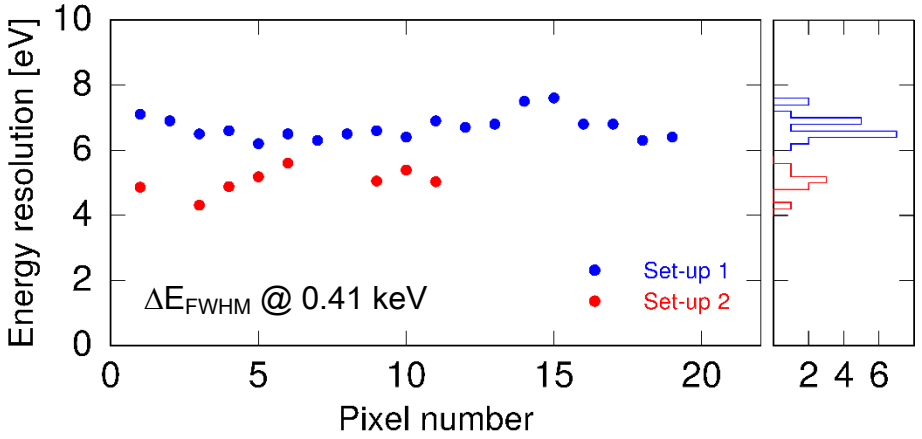
# ECHo-1k Detector Characterisation




Average activity = 0.94 Bq



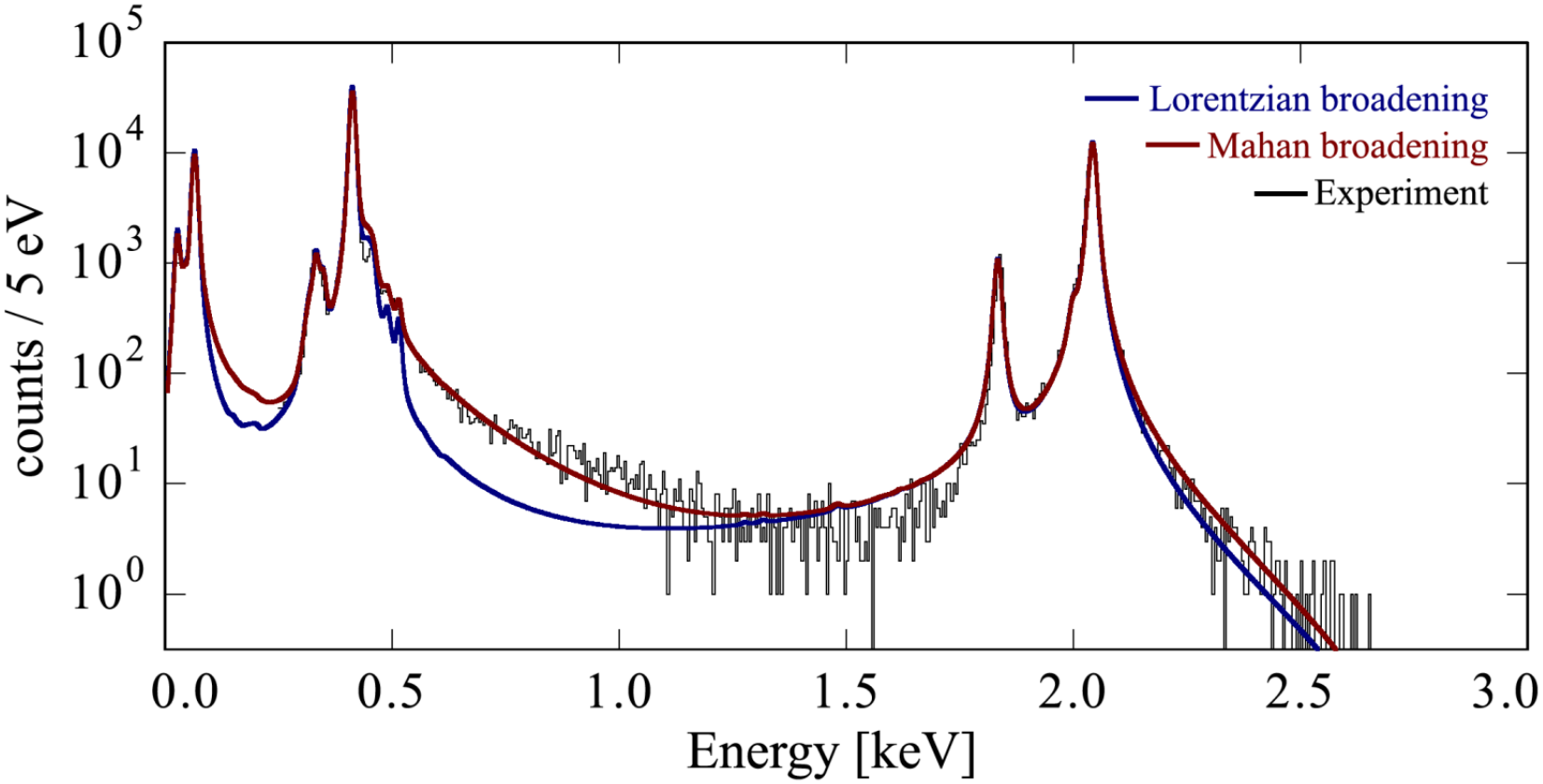

Energy resolution lies between 4.2 eV and 7.7 eV



# EC Spectrum - Example

Measurement performed at the Modane Underground Laboratory

4 MMC pixels (A ≈ 0.2 Bq), 4 days → **275000 counts**




- ✓ Energy resolution:
  $\Delta E_{FWHM}$ = 9.2 eV
- ✓ Background level:
  B < 1.6 × $10^{-4}$ events/eV/pixel/day
- ✓ Q-value:
  $Q_{EC}$ = (2838 ± 14) eV
- ✓ New limit on neutrino mass
  $m(\nu_e)$ < 155 eV (95% C.L.)
  (likelihood ratio test)

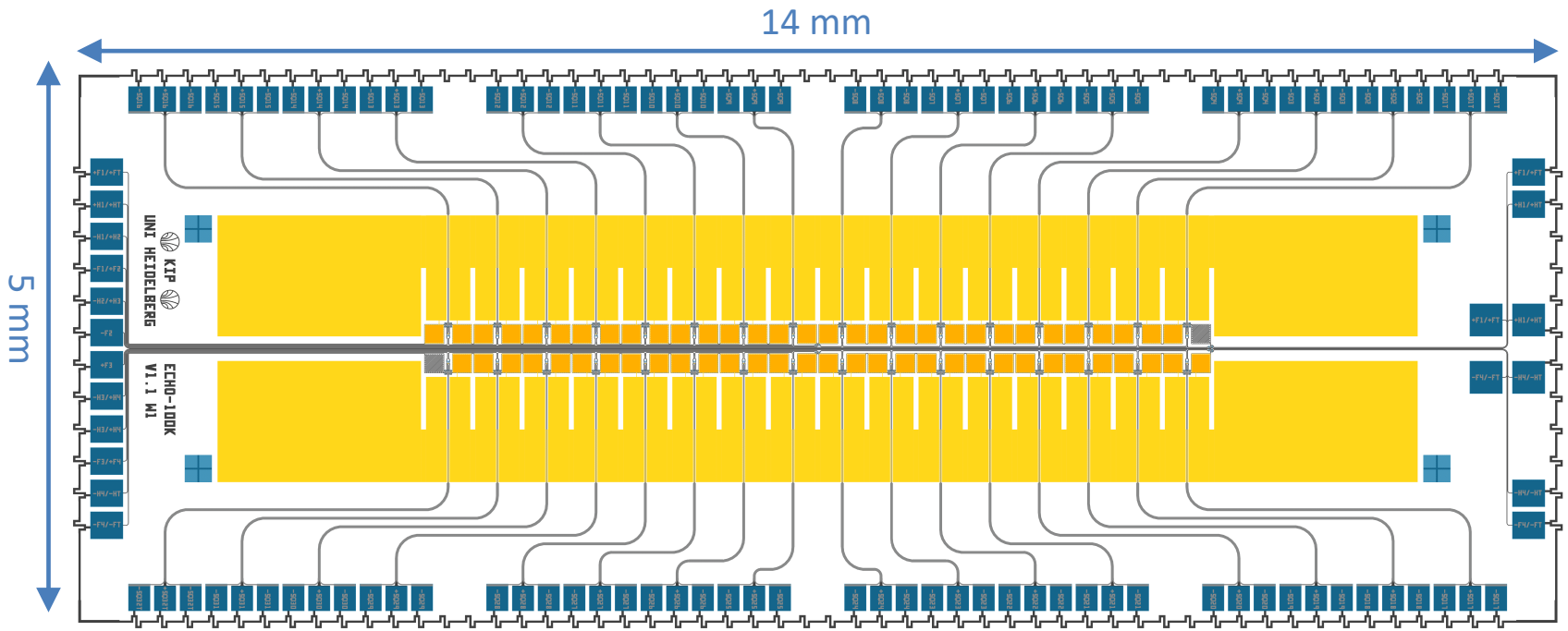
M. Brass et al, Phys. Rev. C 97, 054620 (2018)

C. Velte et al., to be submitted

# New Design Towards ECHo-100k

**ECHo-1k**
2 Bq / pixel
57 MMCs

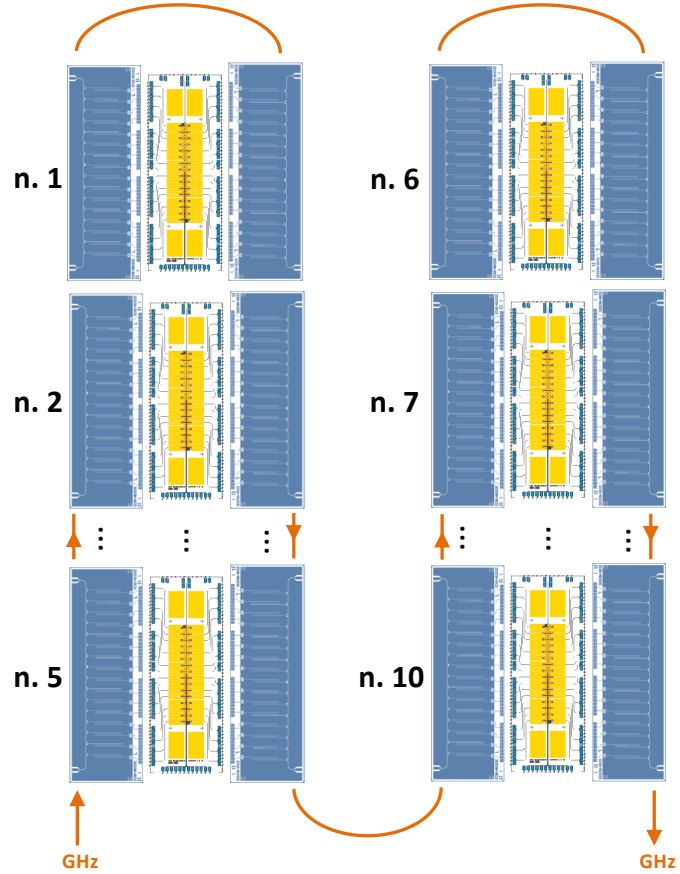
**ECHo-100k**
10 Bq / pixel
12000 MMCs




## ECHo-100k design

Talk by M. Wegner

- Allows for **multiplexed** and **multichip read-out**



# New Design Towards ECHo-100k

**ECHo-1k**
2 Bq / pixel
57 MMCs

**ECHo-100k**
10 Bq / pixel
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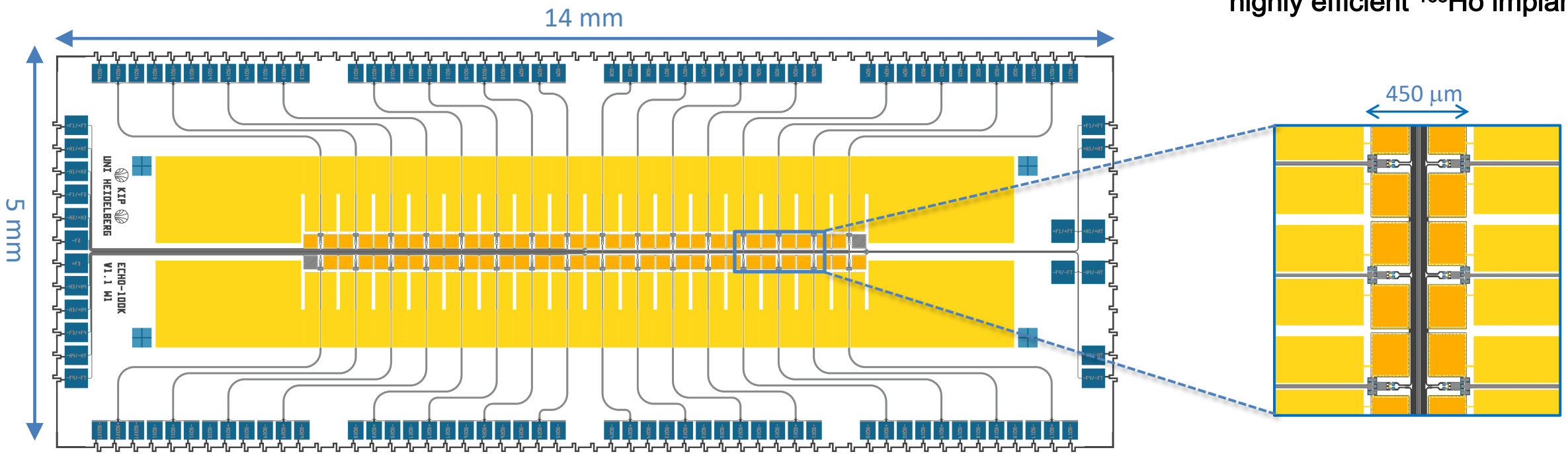
## ECHo-100k design

- Allows for **multiplexed** and **multichip read-out**
- Optimised absorber geometry for **highly efficient $^{163}$Ho implantation**




Poster by
F. Mantegazzini

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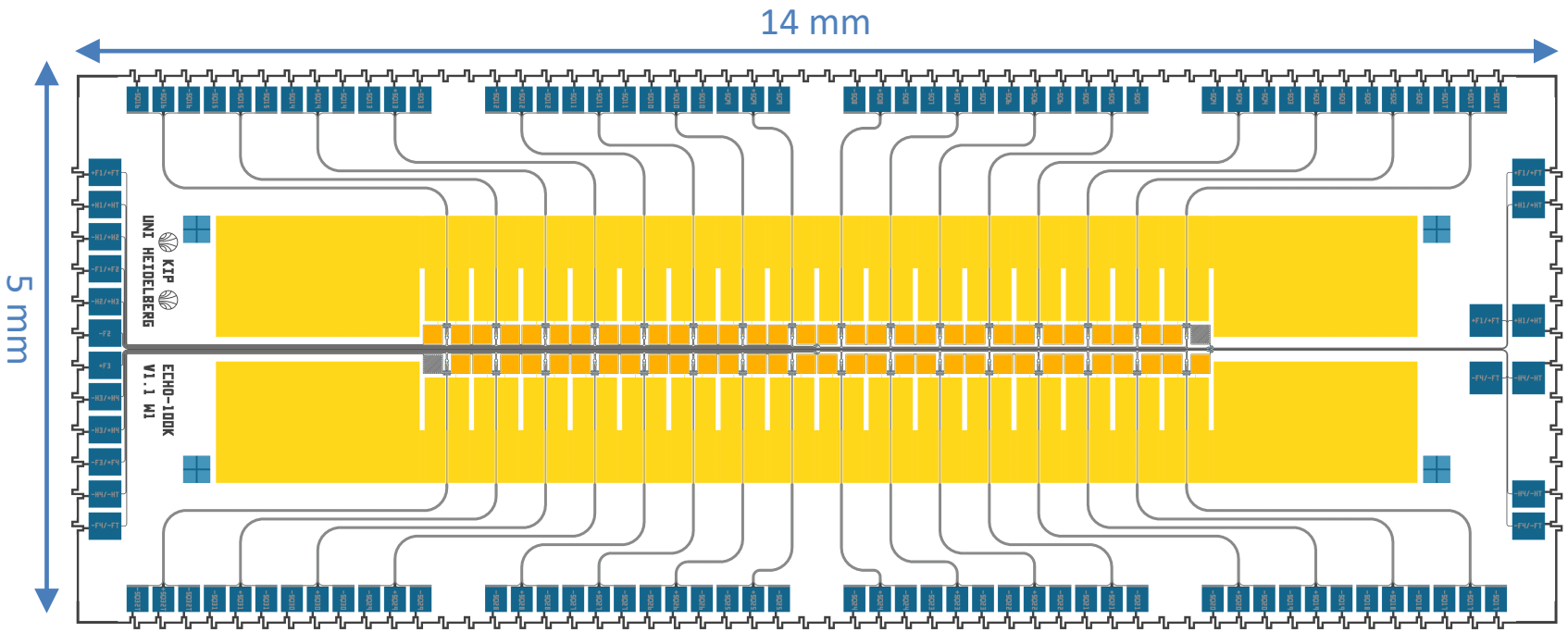
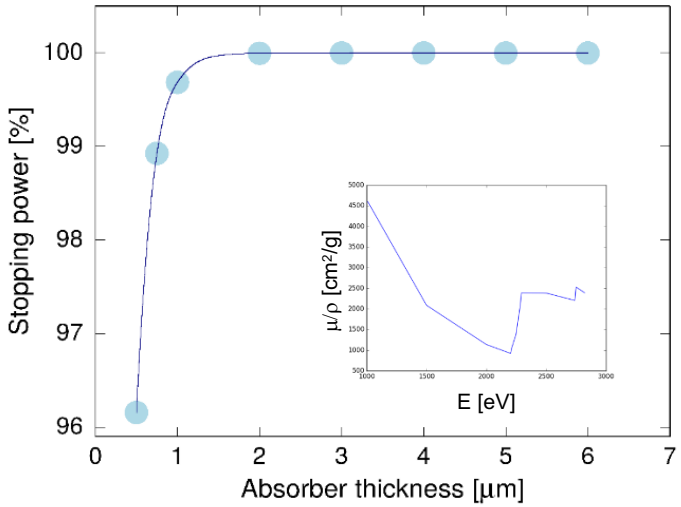


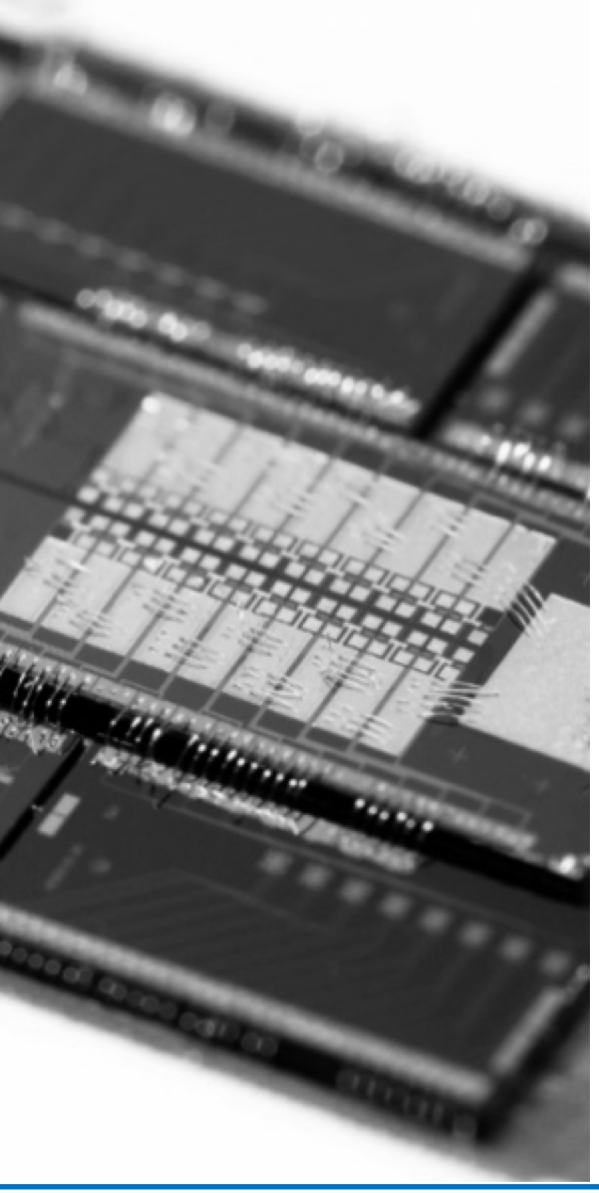

Poster by A. Reifenberger

## ECHo-100k design

- Allows for **multiplexed** and **multichip read-out**
- Optimised absorber geometry for **highly efficient $^{163}$Ho implantation**
- **Reduced absorber volume and optimised activity** to minimise heat capacity



# Summary & Outlook



## ECHo-1k phase

- ✓ **$^{163}$Ho source** production, chemical separation and implantation
- ✓ **Cryogenic set-up** for parallel read-out
  - Detector characterisation & background investigations
  - High-statistics data acquisition
- ✓ **Data reduction and data analysis**
- ✓ Data taking still on-going...

**ECHo-1k**
**2 Bq / pixel**
**57 MMCs**

## ECHo-100k phase

- ✓ **Dedicated design** to fulfil new requirements in terms of
  - Read-out (parallel & multiplexed)
  - Source implantation
  - Detector performances
- ✓ Fabrication is on-going…

**ECHo-100k**
**10 Bq / pixel**
**12000 MMCs**

# More Details…

# Background

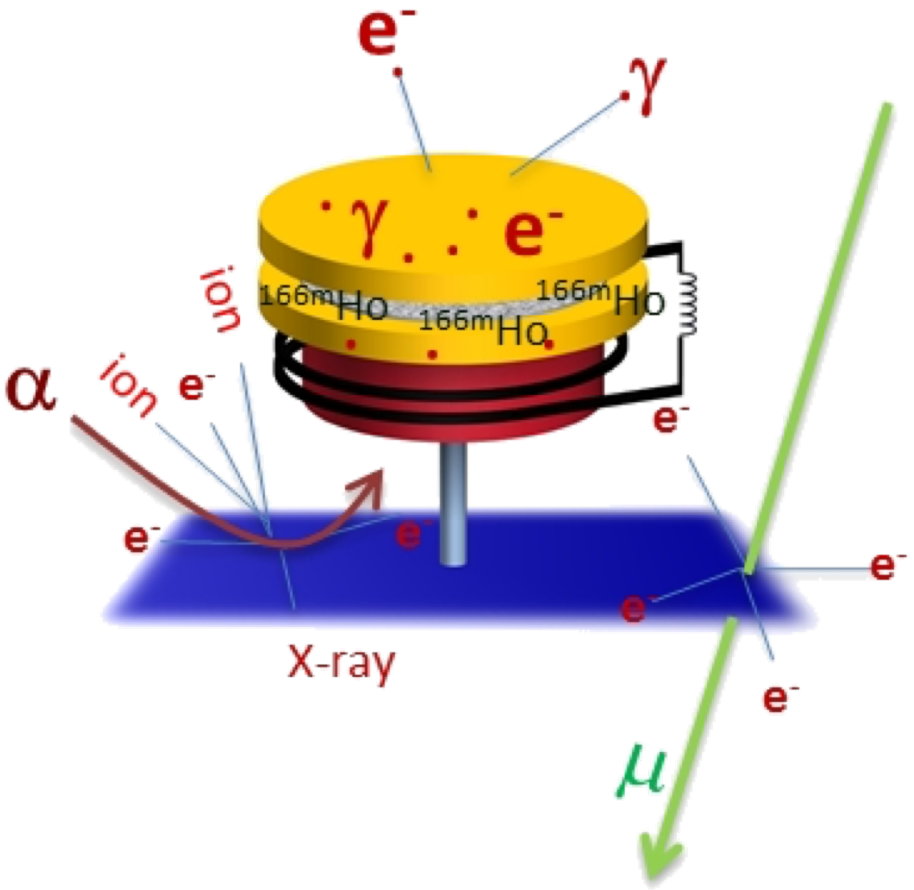
Background sources:

- Radioactivity in the detector
- Environmental radioactivity

→ Material screening

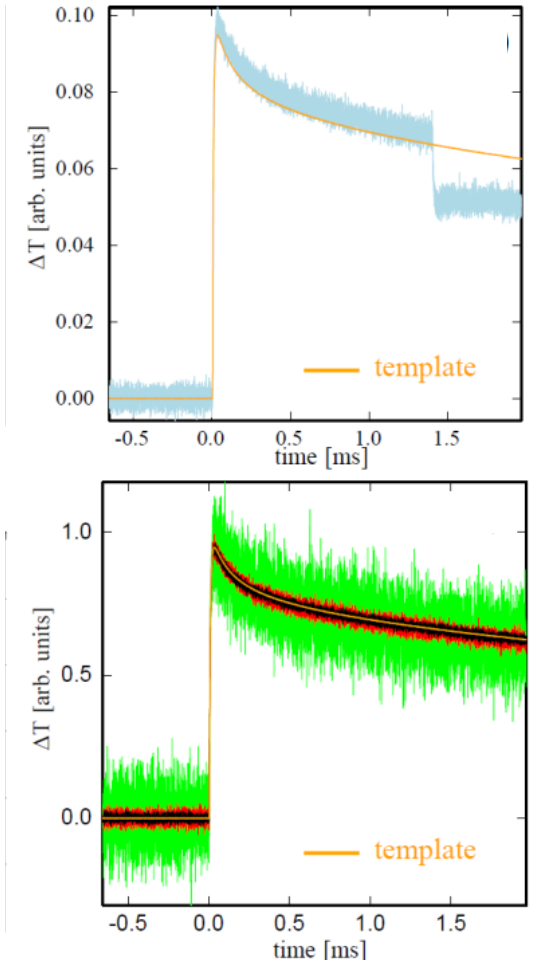
- Cosmic rays

→induced secondary radiation → Muon veto / Pulse shape analysis

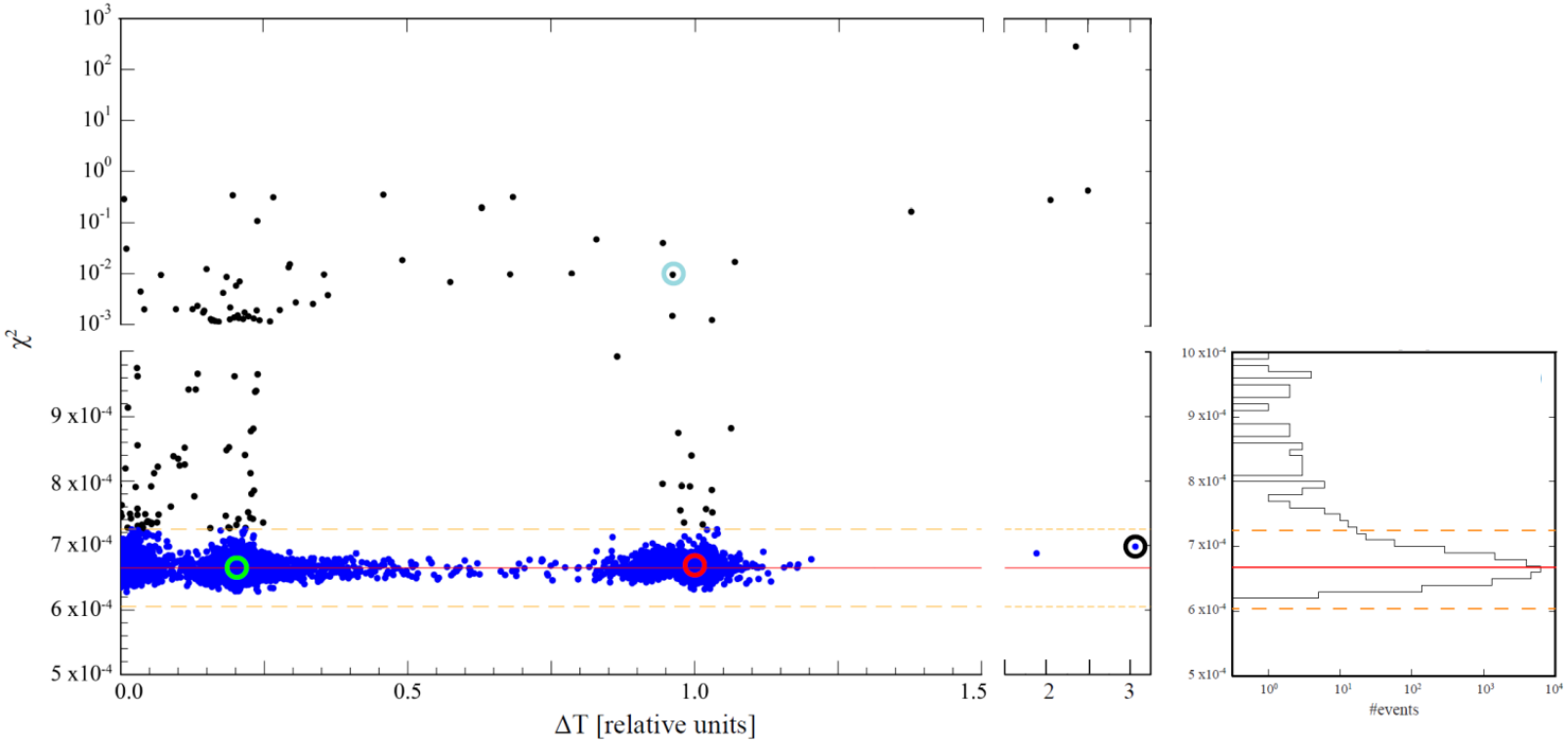


# From Signals to Spectrum

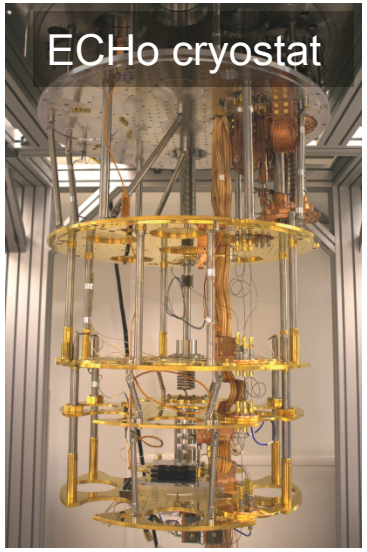
Fit with template pulse

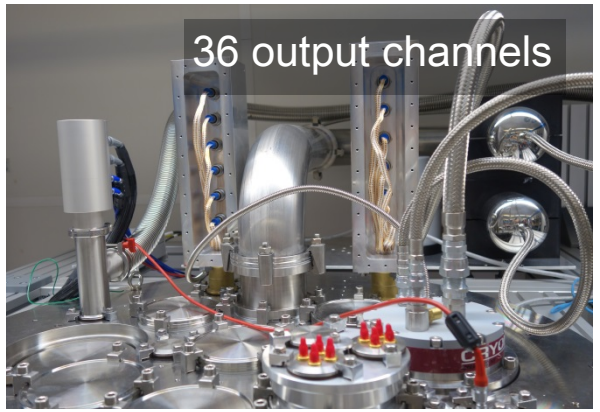


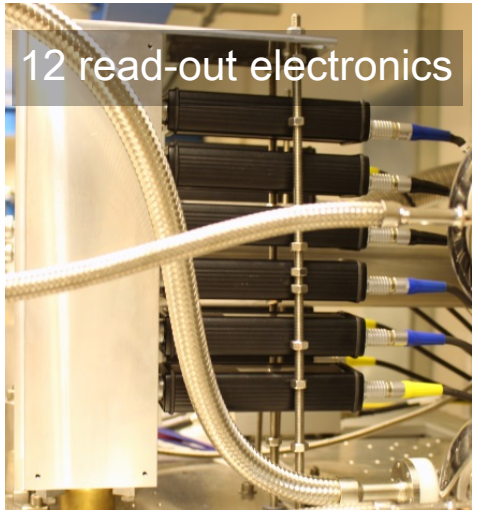

$X^2$ cut

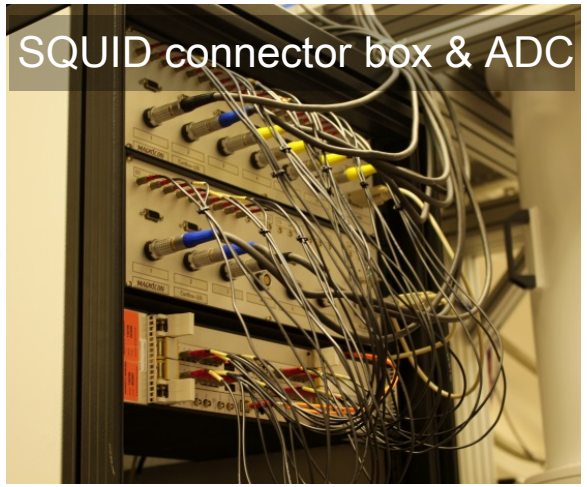


# ECHo-1k Read-out & DAQ



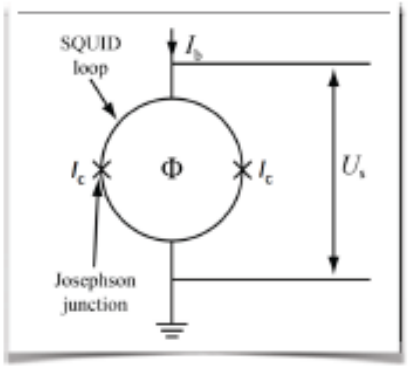




# Parallel Read-out

**dc-SQUID**:
flux to voltage converter




**Periodic response**
→ small linear range response

**Negative flux feedback**:
compensation of initial flux change