

NI

# Update on the ECHo experiment

MI

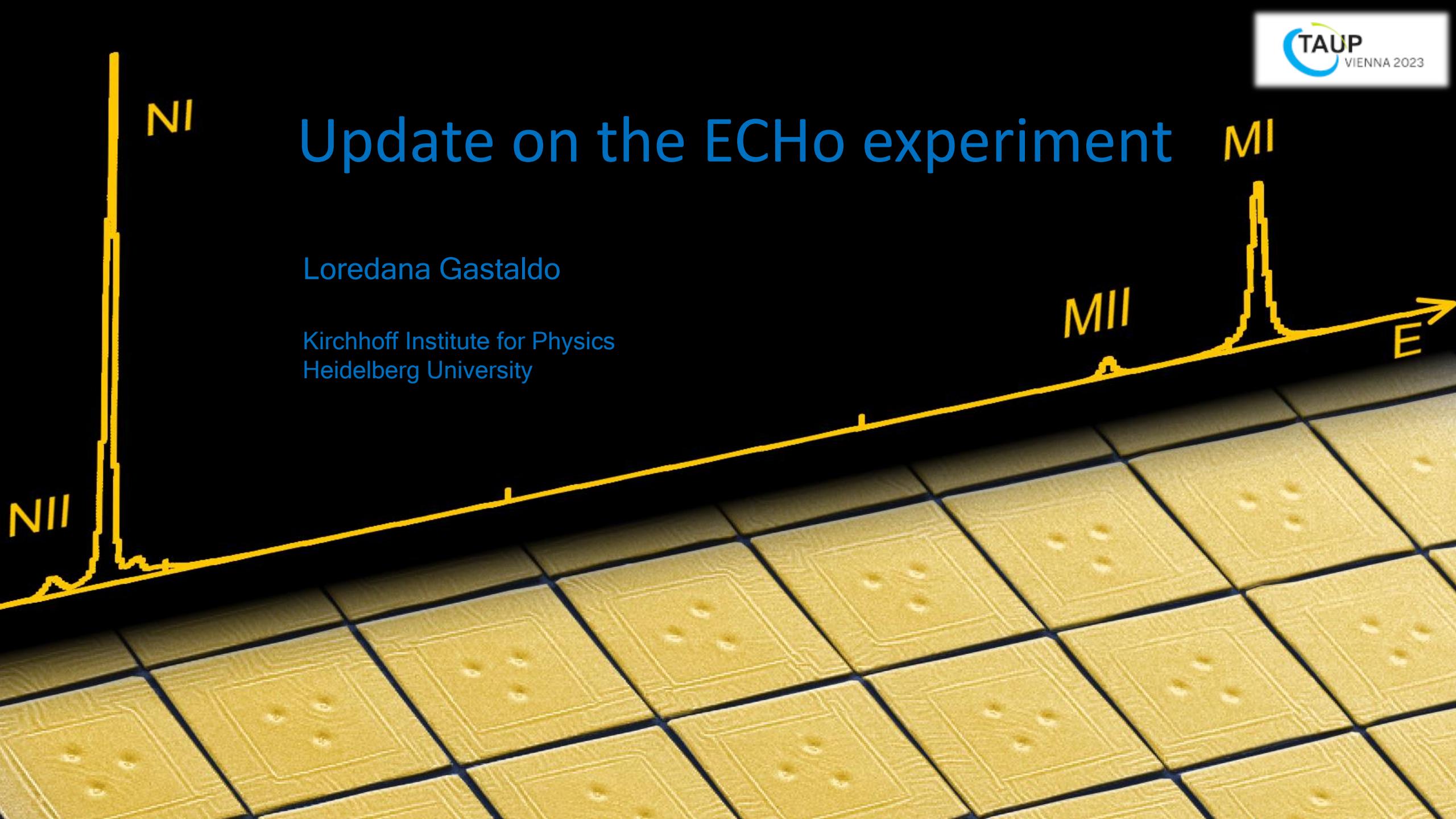
Loredana Gastaldo

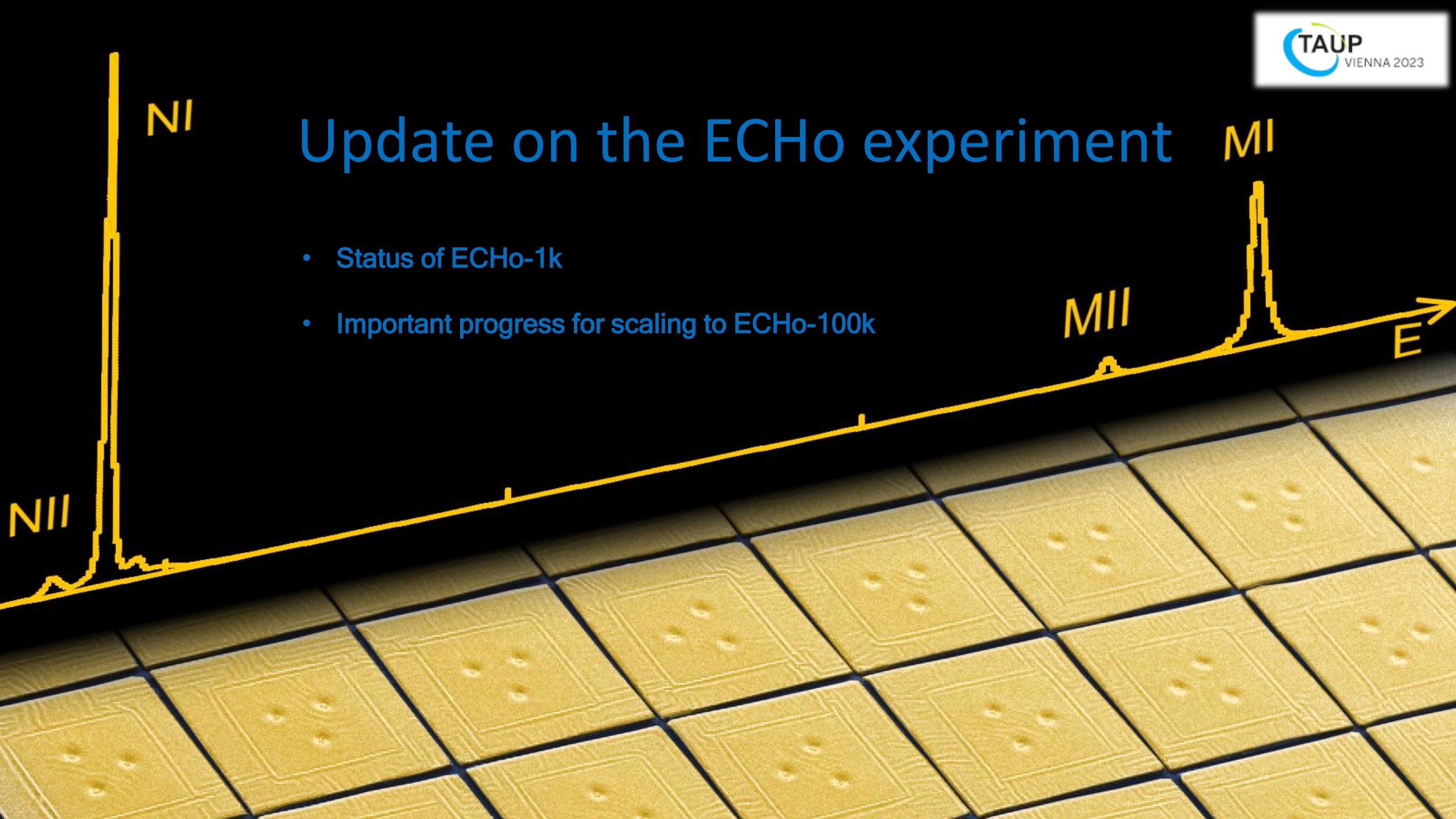
Kirchhoff Institute for Physics  
Heidelberg University

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# Update on the ECHo experiment

- Status of ECHo-1k
- Important progress for scaling to ECHo-100k

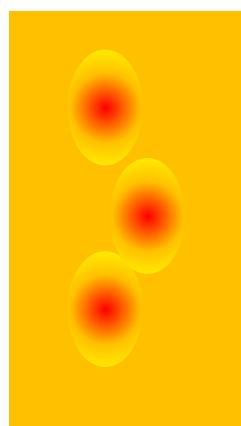
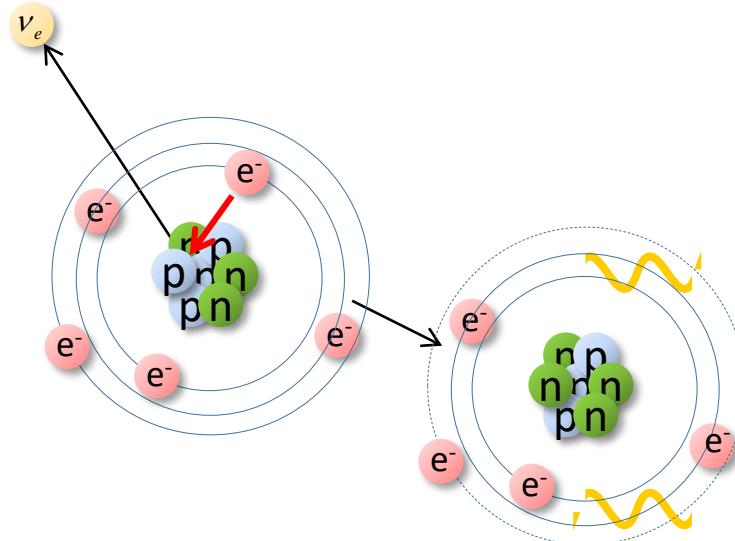
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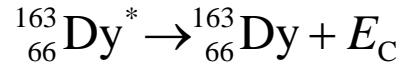
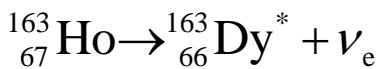
# Electron Capture in $^{163}\text{Ho}$ – Spectrum



Source = Detector

## Calorimetric measurement

A. De Rujula and M. Lusignoli, *Phys. Lett.* **118B** (1982)



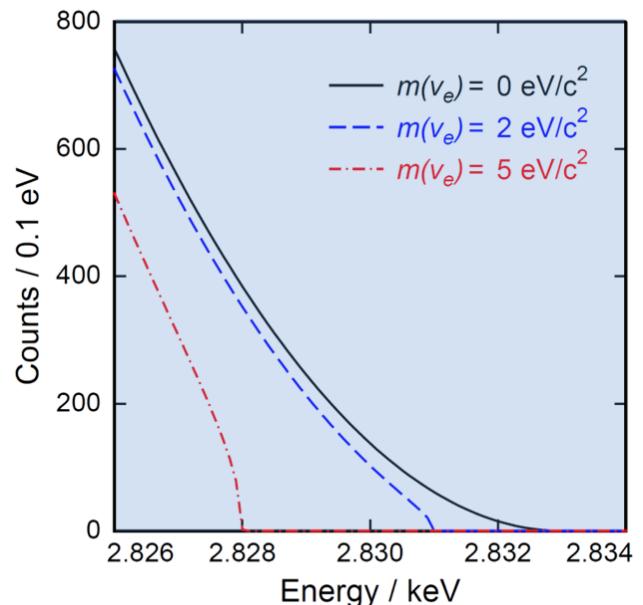
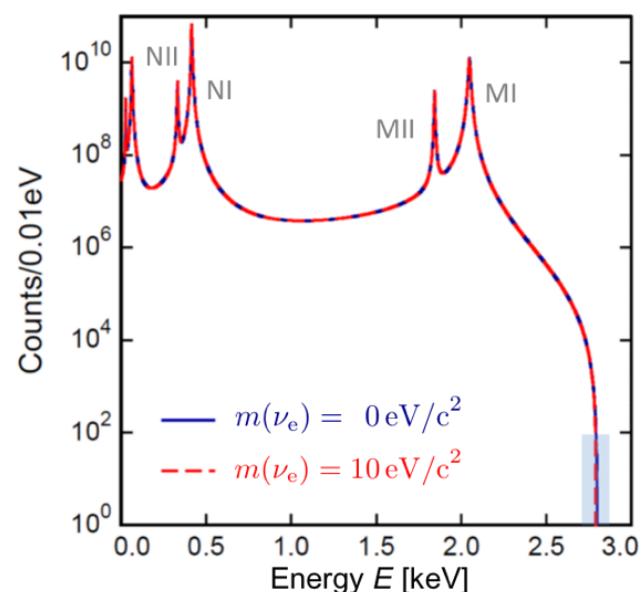
- $\tau_{1/2} \approx 4570 \text{ years}$  ( $2 \times 10^{11}$  atoms for 1 Bq)
- $Q_{EC} = (2.833 \pm 0.030^{\text{stat}} \pm 0.015^{\text{syst}}) \text{ keV}$   
S. Eliseev et al., *Phys. Rev. Lett.* **115** (2015) 062501



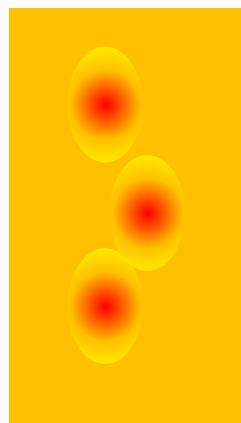
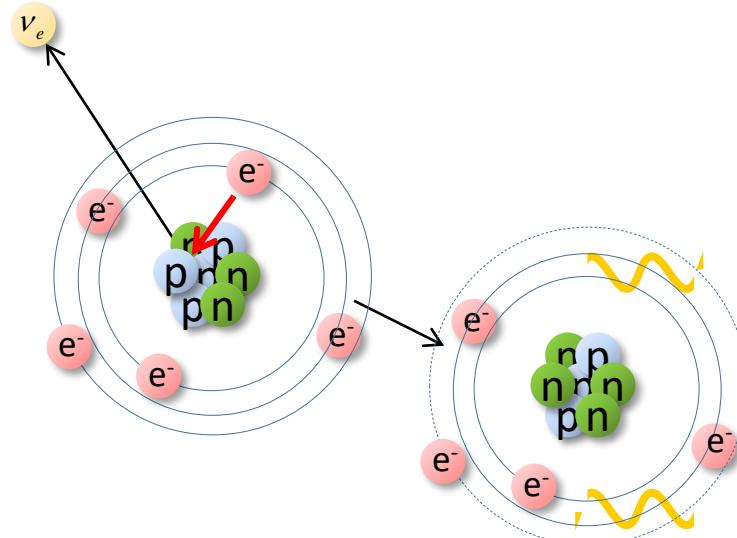
The ECHO Collaboration  
*EPJ-ST* **226** 8 (2017) 1623



B. Alpert et al, *Eur. Phys. J. C* **75** (2015) 112



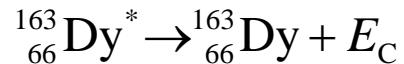
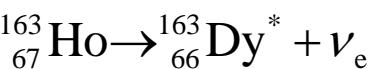
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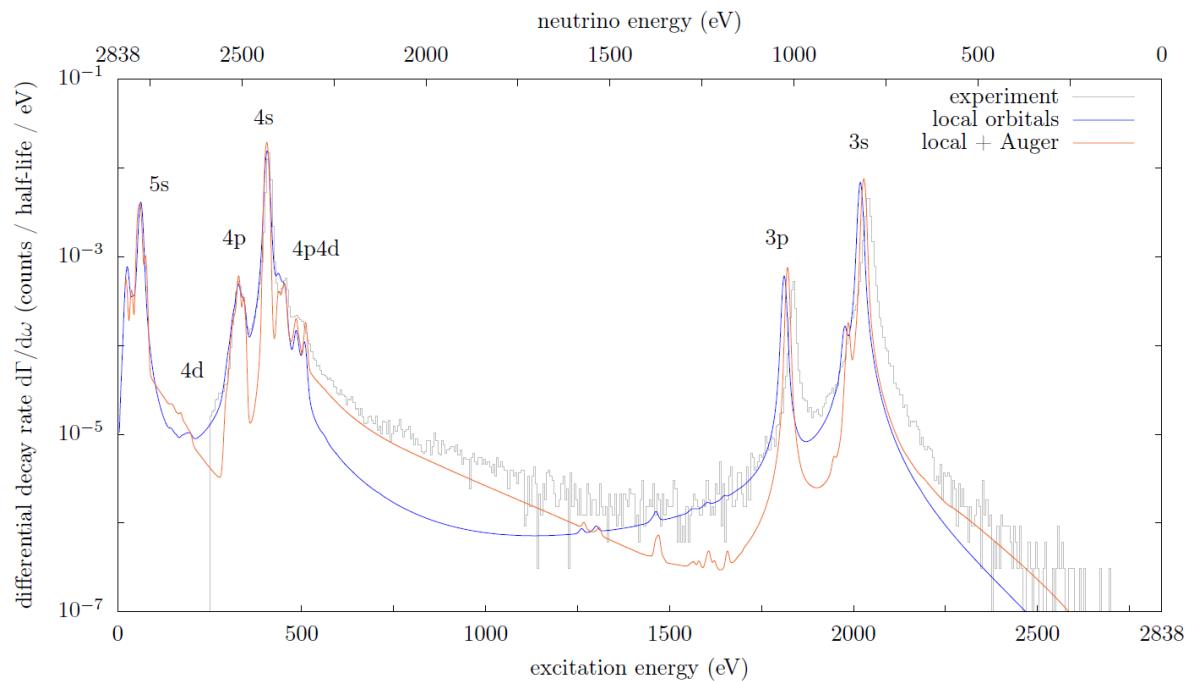
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M. Braß and M. W. Haverkort, *New J. Phys.* **22** (2020) 093018

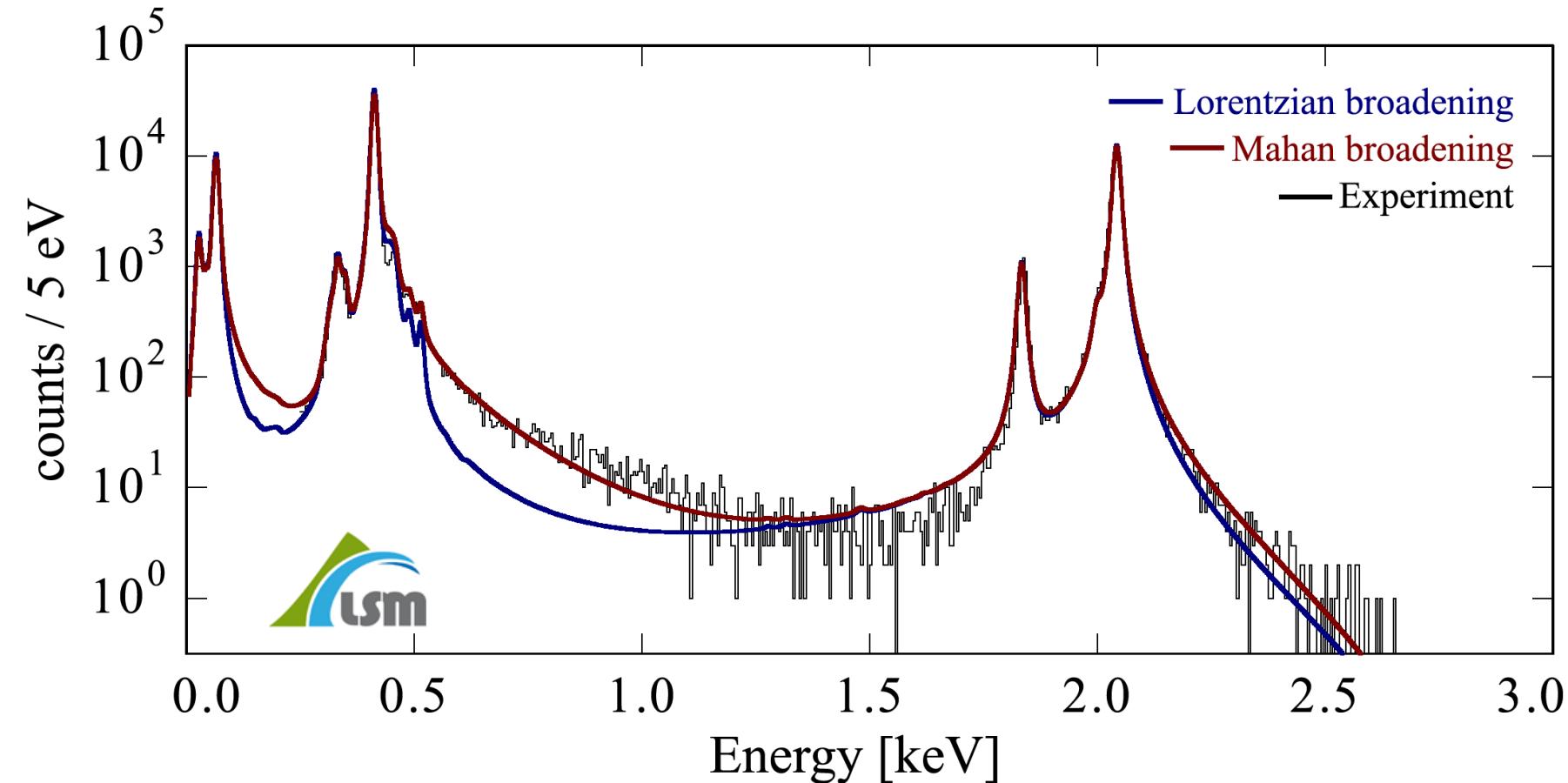
ECHO

The ECHO Collaboration  
EPJ-ST 226 8 (2017) 1623

HOLMES

B. Alpert et al, Eur. Phys. J. C 75 (2015) 112

# Proof of ECHO concept



C. Velte et al., EPJC **79** (2019) 1026

Energy resolution

$$\Delta E_{FWHM} = 9.2 \text{ eV}$$

Background level

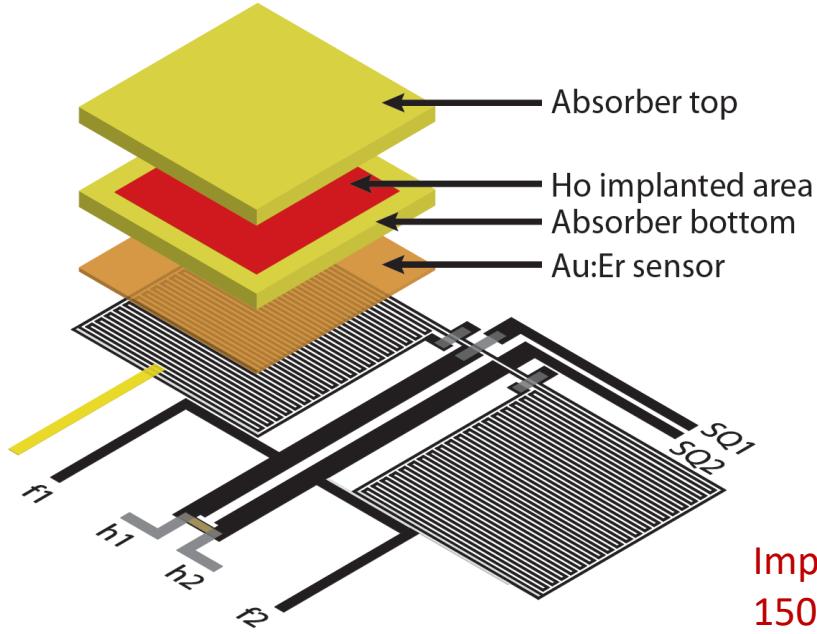
$$b < 1.6 \times 10^{-4} \text{ events/eV/pixel/day}$$

- 4 day measurement with 4 pixels loaded with  $\sim 0.2 \text{ Bq}^{163}\text{Ho}$
- measurement performed underground
- test for data reduction and spectral shape analysis

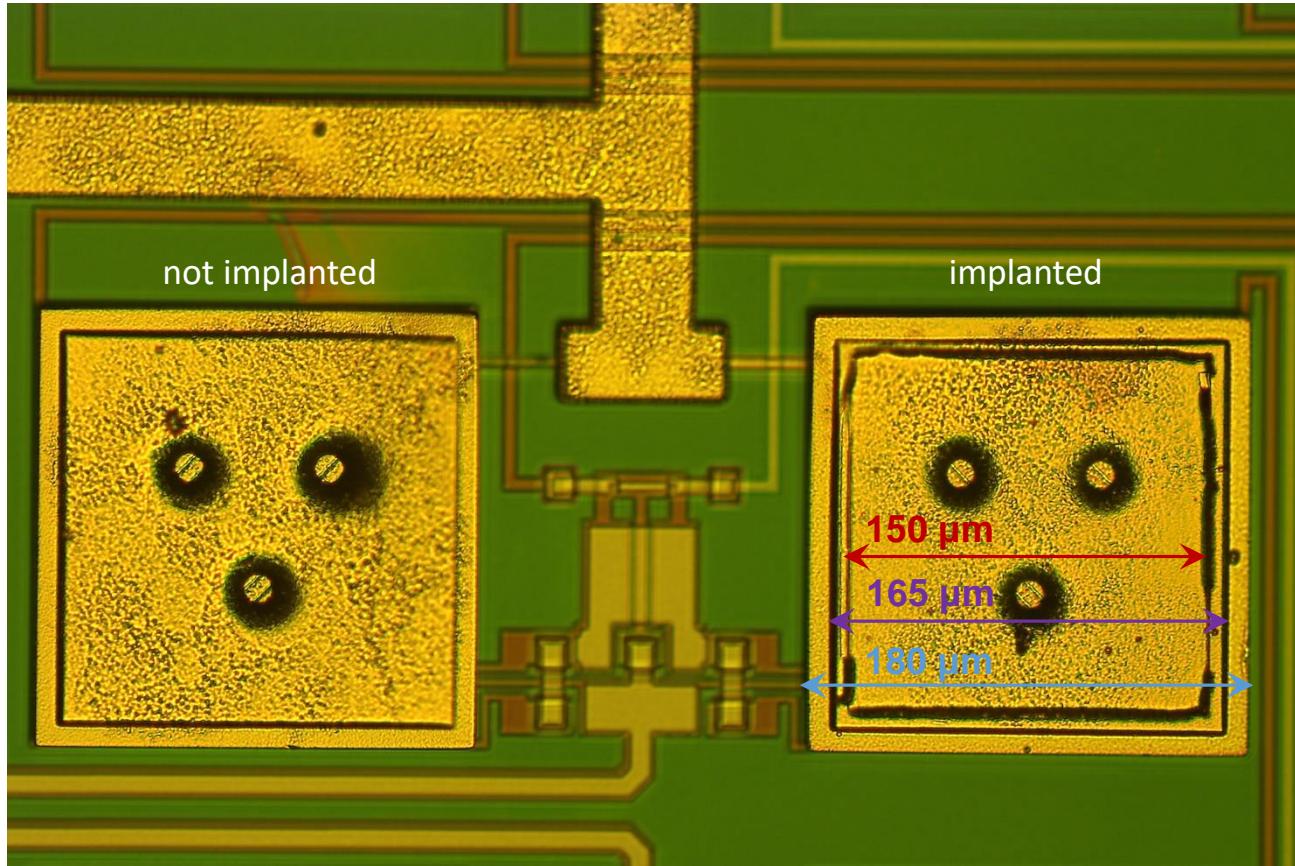
- $Q_{EC} = (2838 \pm 14) \text{ eV}$
- $m(v_e) < 150 \text{ eV} \text{ (95\% C.L.)}$

# Calorimetric measurement – $4\pi$ geometry

ECHO uses large arrays of low T metallic magnetic calorimeters with enclosed  $^{163}\text{Ho}$



Implantation square:  
150  $\mu\text{m} \times$  150  $\mu\text{m}$   
Second absorber:  
165  $\mu\text{m} \times$  165  $\mu\text{m}$   
First absorber:  
180  $\mu\text{m} \times$  180  $\mu\text{m}$



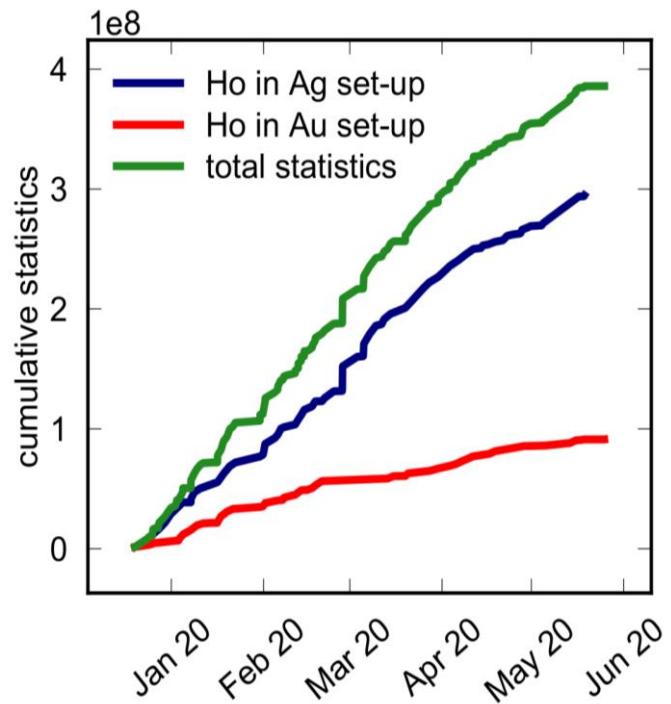
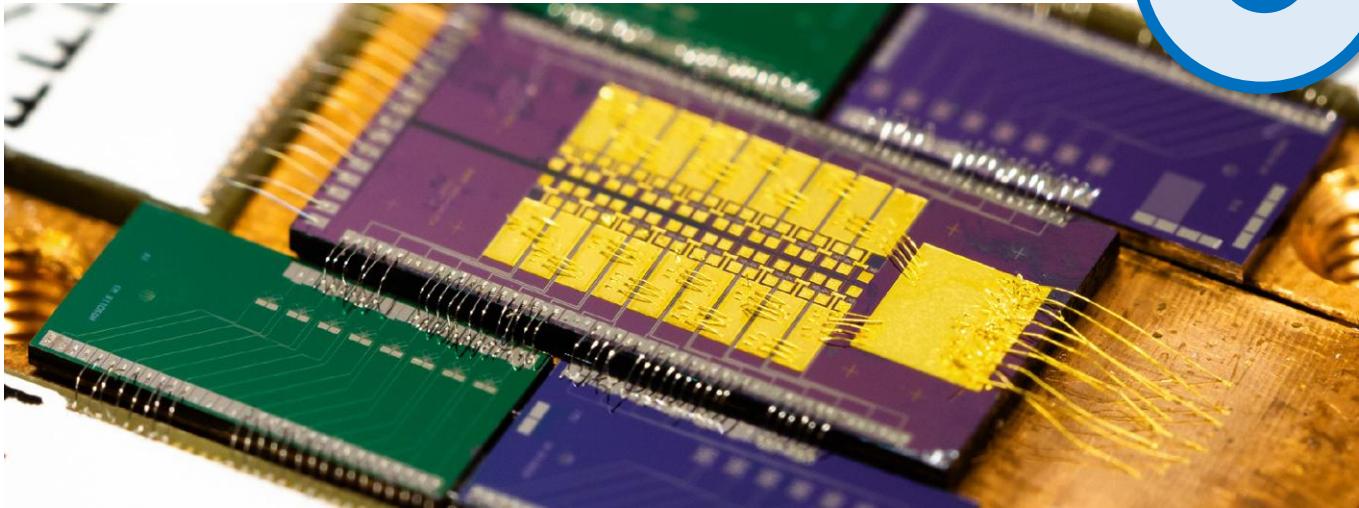
# ECHO-1k high statistics spectrum

ECHO-1k chip-Au

23 pixel with implanted  $^{163}\text{Ho}$   
3 background pixels  
average activity = 0.94 Bq  
**total activity of 28.1 Bq**

ECHO-1k chip-Ag

34 pixel with implanted  $^{163}\text{Ho}$   
6 background pixels  
average activity = 0.71 Bq  
**total activity of 25.9 Bq**



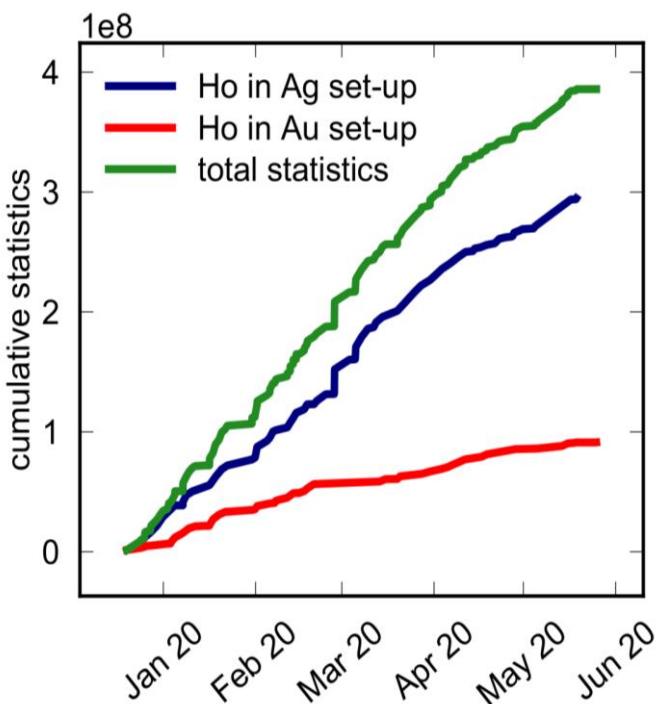
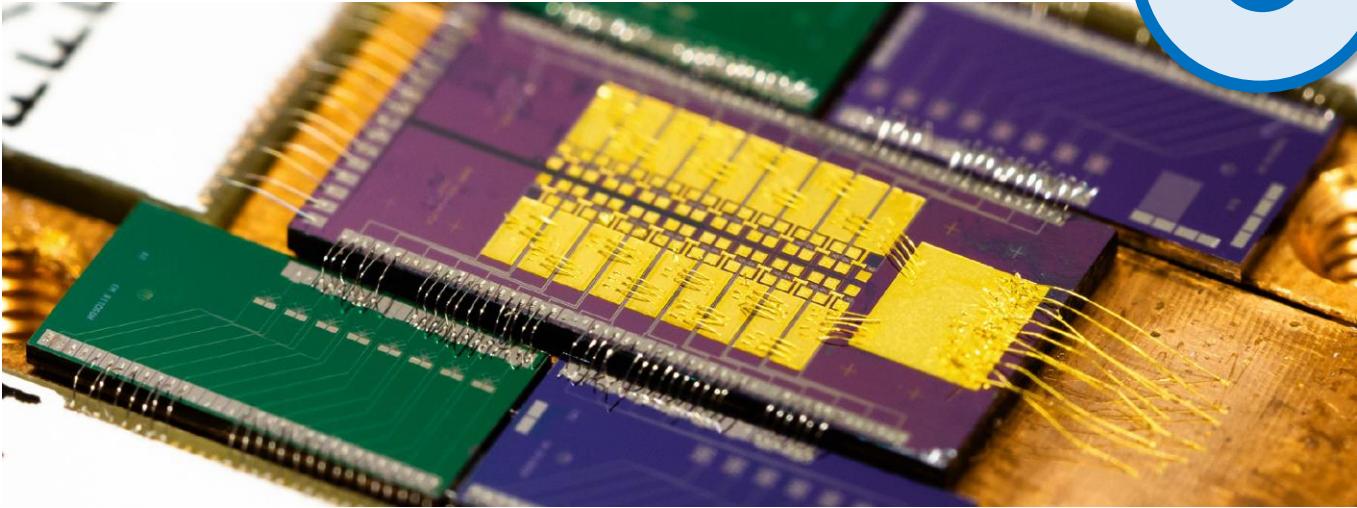
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 average activity = 0.71 Bq  
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## Data Reduction

### First Level: Time Information Filter

#### Holdoff Filter

Discard traces with  $\Delta T_{\text{Ch}} < T_{\text{Holdoff}}$

#### Coincidence Filter

Discard traces with  $\Delta T < T_{\text{Coincidence}}$

#### Burst Filter

Discard time intervals with abnormally high rate

#### GSM Filter

Discard traces with  $\Delta T$  associated to GSM pulse frequencies

### Second Level:

#### Template Fit

- Create mean pulse from traces by cross-fitting traces in batches
- Fit traces to template to recover amplitude and  $\chi^2_{\text{red}}$

#### Pulse Shape Filter

Discard traces with high deviation from template

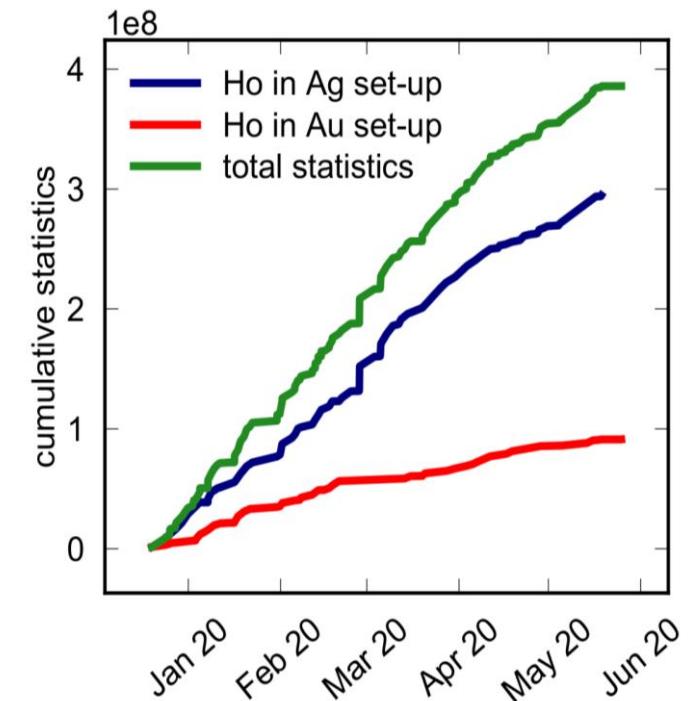
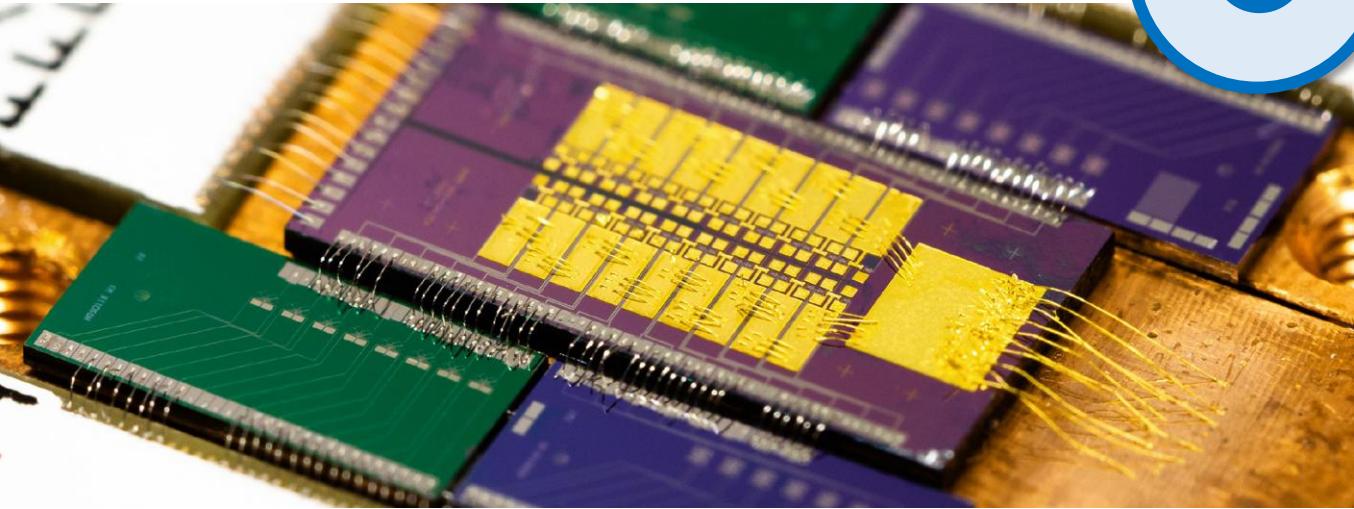
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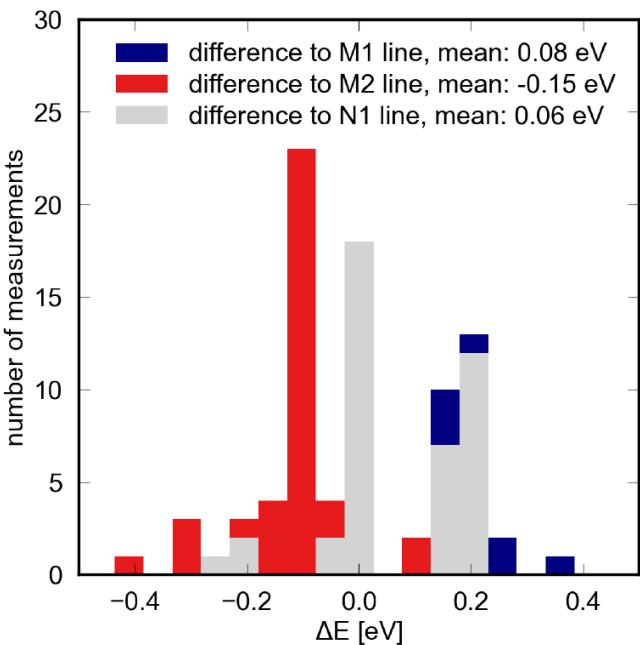
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ECHO-1k chip-Ag

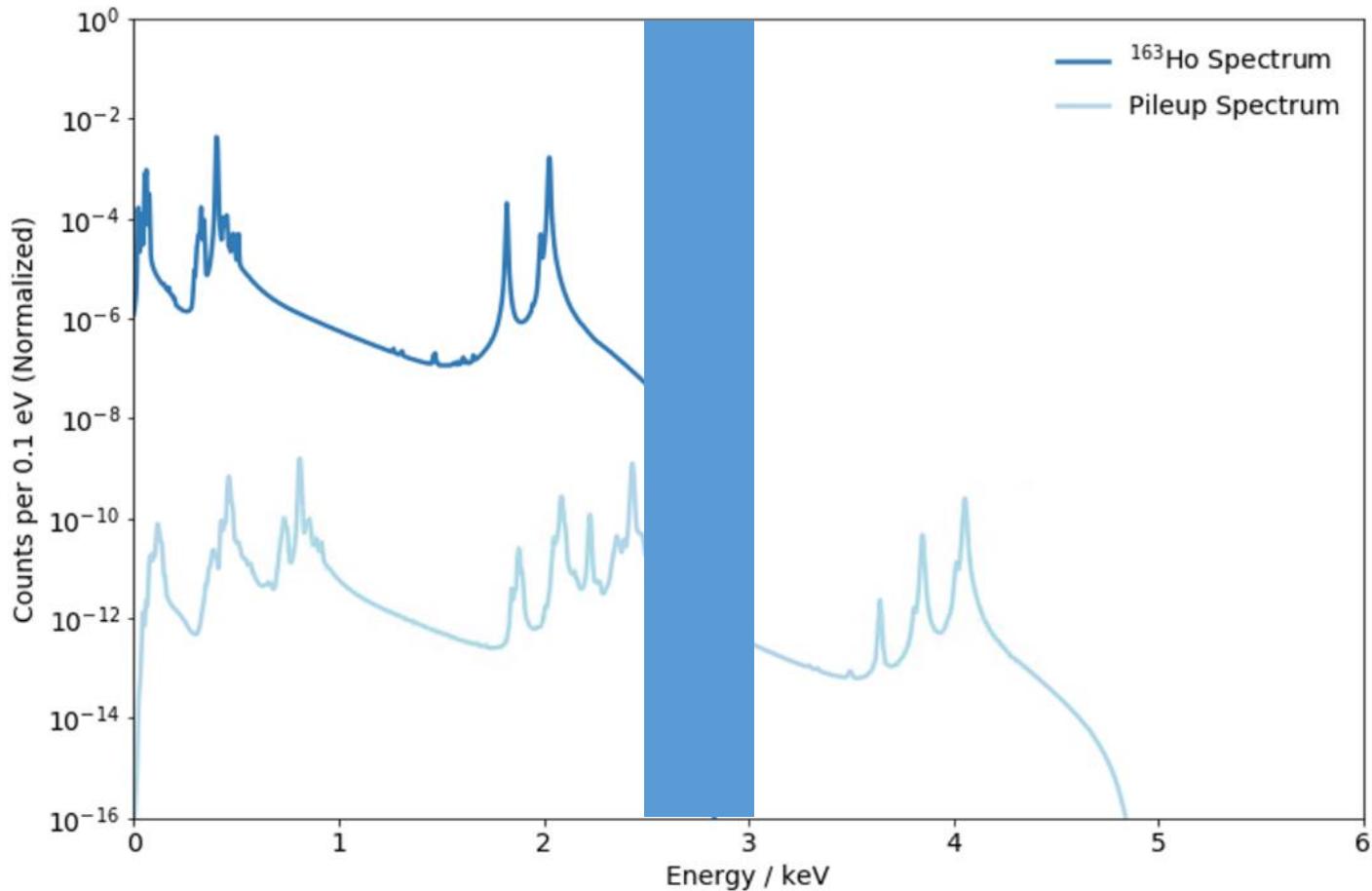
34 pixel with implanted  $^{163}\text{Ho}$   
 6 background pixels  
 average activity = 0.71 Bq  
**total activity of 25.9 Bq**



Quality checks on data reduction  
cuts and spectra features



# Analysis of the $^{163}\text{Ho}$ electron capture spectrum



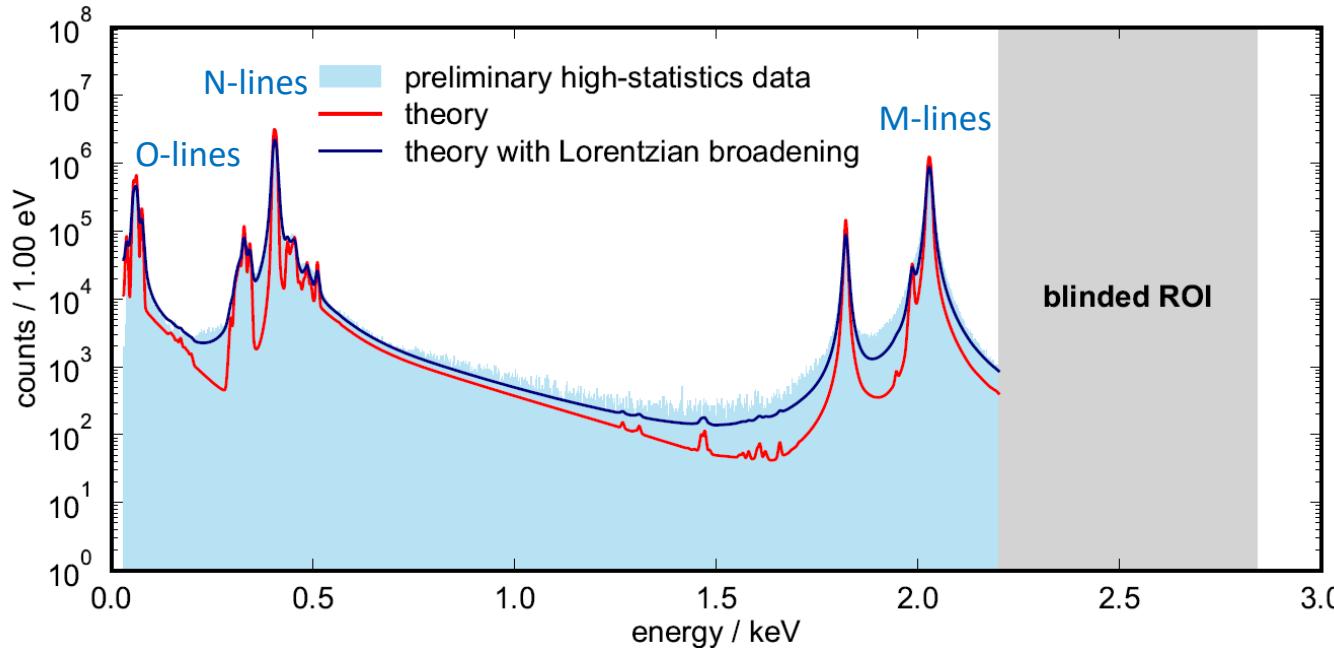
$E \leq 2.5$  keV

determination spectrum parameters  
(intensity, peak energies, widths,  $Q$ -value)

$E \geq 3$  keV

determination unresolved pile-up spectrum  
and natural background

# $E < 2.5 \text{ keV}$



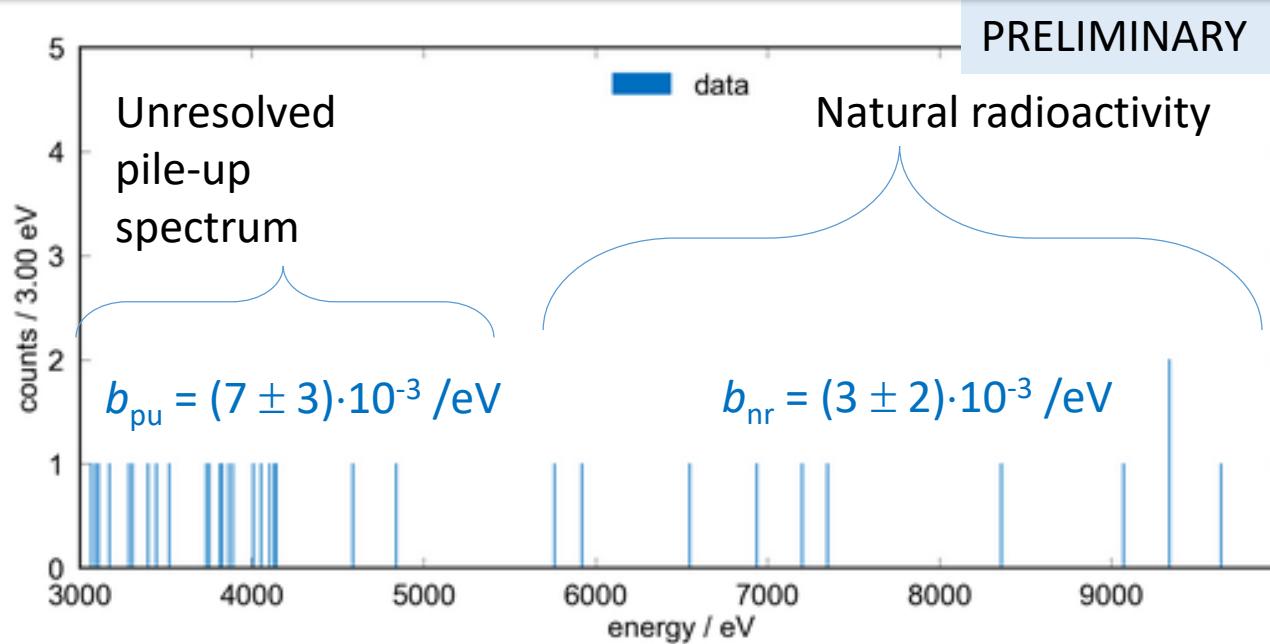
Fraction of data corresponding to  $6 \times 10^7$  events acquired with detectors having  $^{163}\text{Ho}$  in Ag

- Only data passing quality checks
- Energy scale defined in a new calibration measurement

New theory describes well the complex structure of line multiplets but tails are still not perfect

- more work is on extending the theoretical description and EC spectra measurements

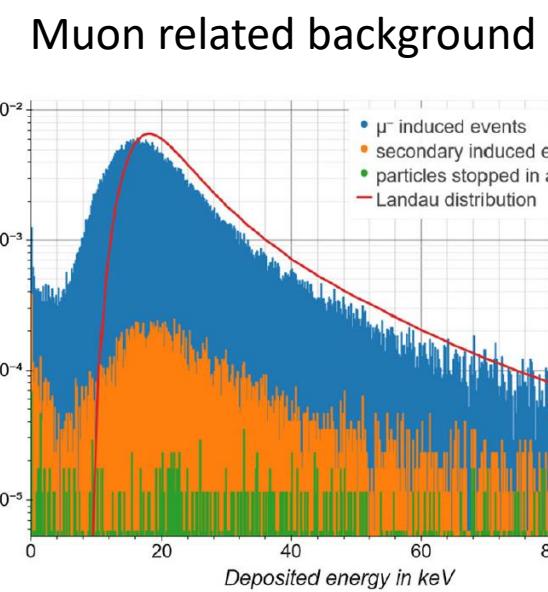
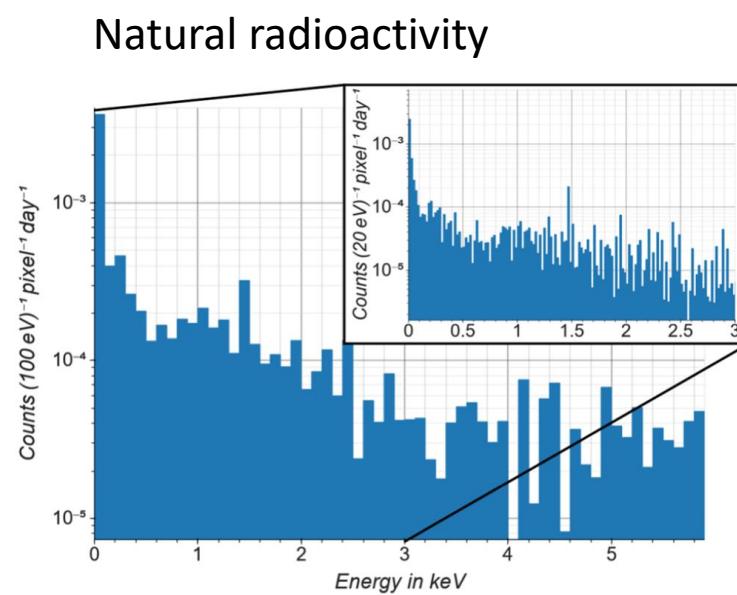
# $E > 3 \text{ keV}$



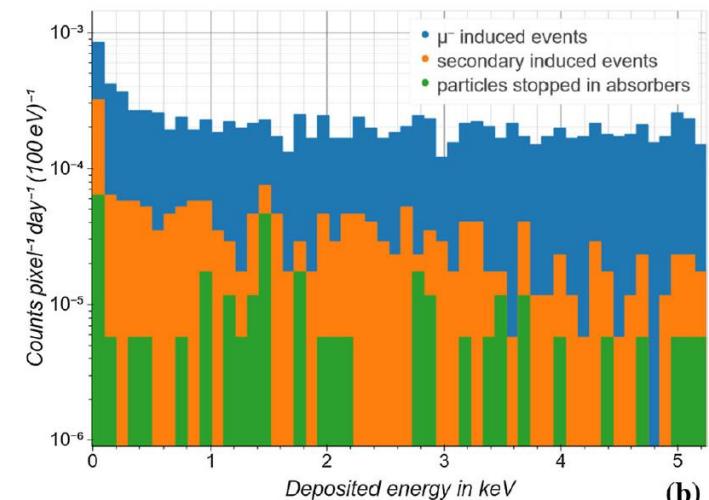
Two major contributions

- unresolved pile-up for  $E < 5.7 \text{ keV}$
- natural radioactivity + muon related events for  $E > 5.7 \text{ keV}$

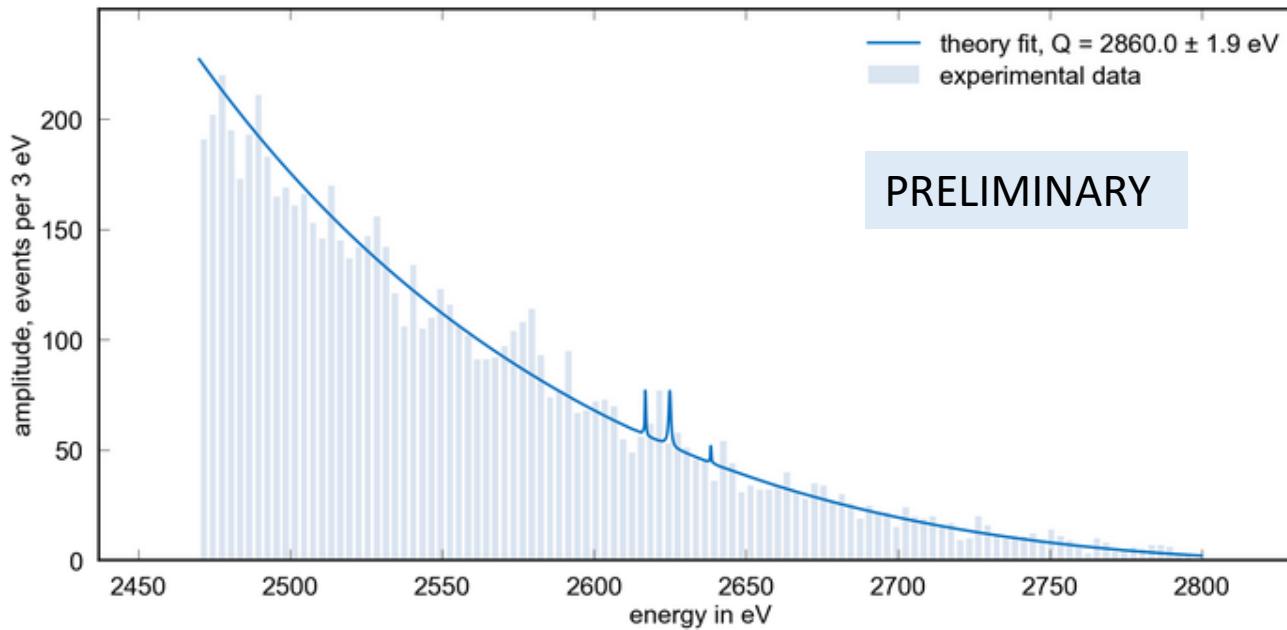
Comparison with simulation on-going



- A. Goeggelmann et al., *Eur.Phys.J.C* **81** (2021) 363  
A. Goeggelmann et al., *Eur.Phys.J.C* **82** (2022) 139



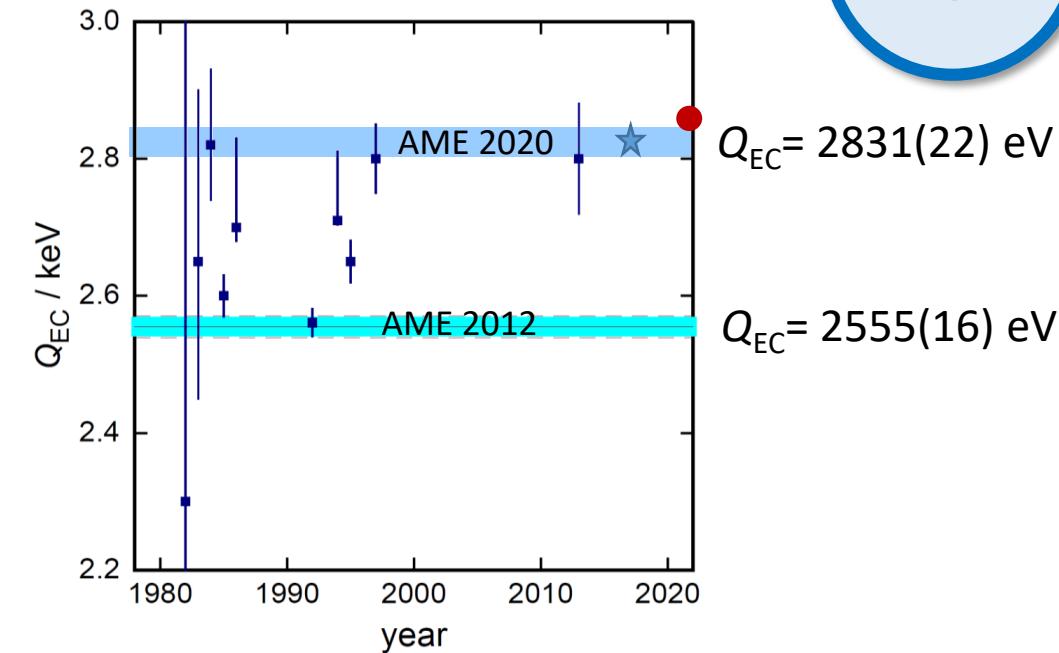
# $2.5 \text{ keV} < E < 2.8 \text{ keV}$



Determination of  $Q_{\text{EC}}$  by fitting the spectrum using:

- Brass & Haverkort theory
- Flat background

$$Q_{\text{EC}} = (2860 \pm 2_{\text{stat}} \pm 5_{\text{syst}}) \text{ eV}$$



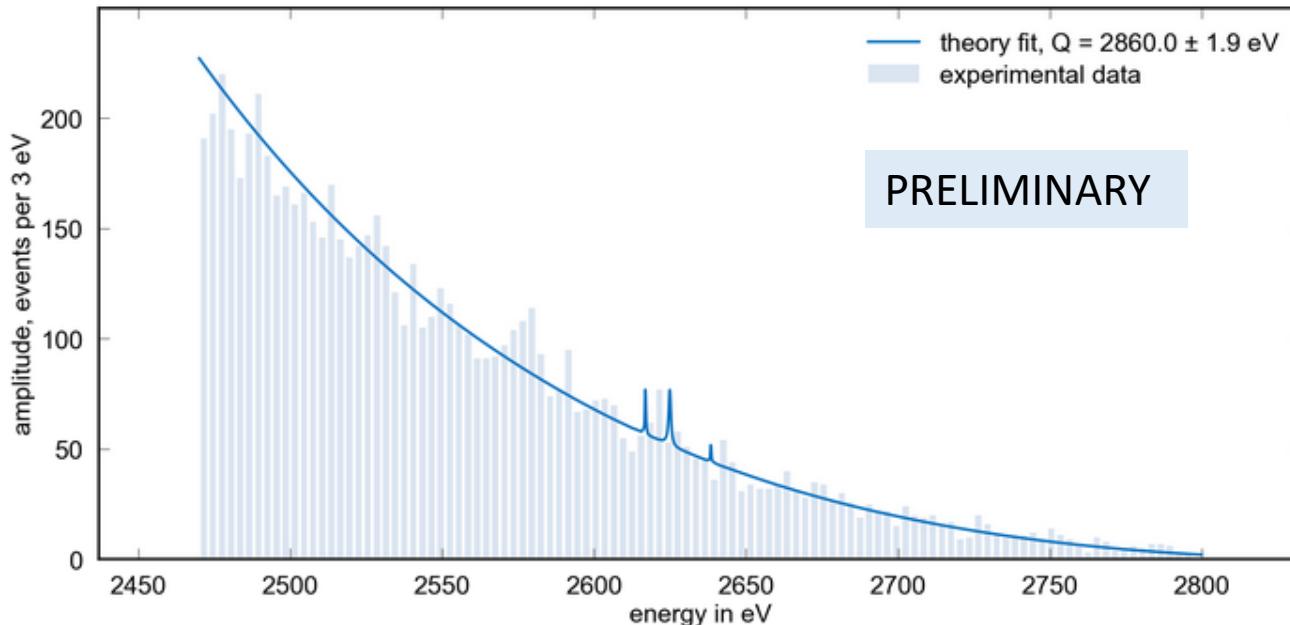
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S. Eliseev et al., *Phys. Rev. Lett.* **115** (2015) 062501

Waiting for new PENTATRAP\* results

(\*) J. Repp et al., *Appl. Phys. B* **107** (2012) 983  
C. Roux et al., *Appl. Phys. B* **107** (2012) 997

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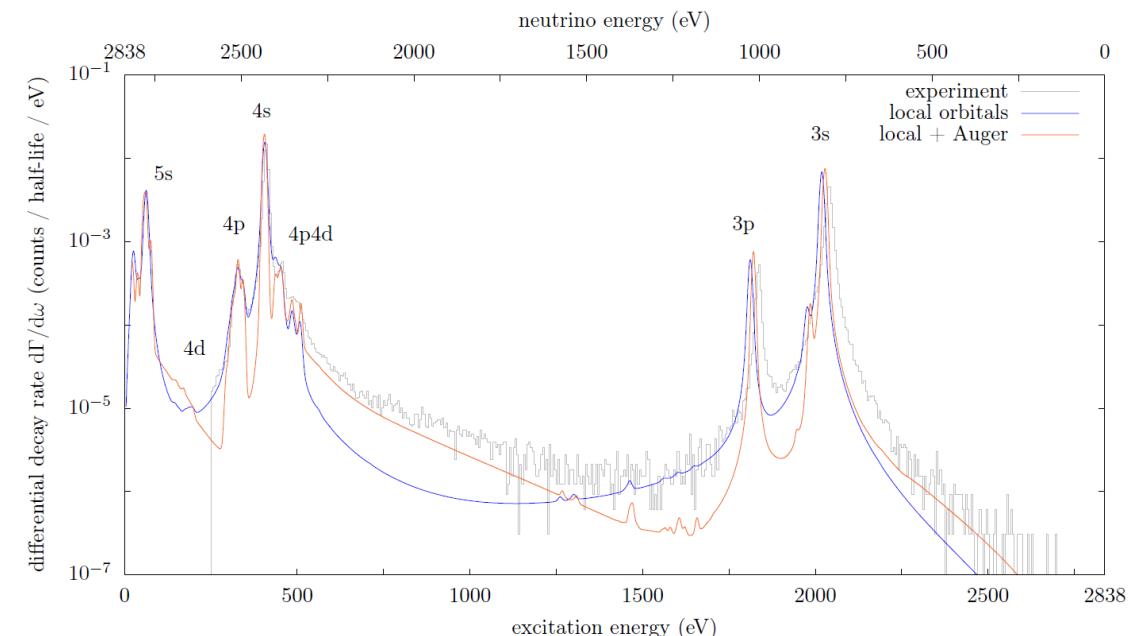


On going:

Quantification of **systematic uncertainties** for precise endpoint region analysis

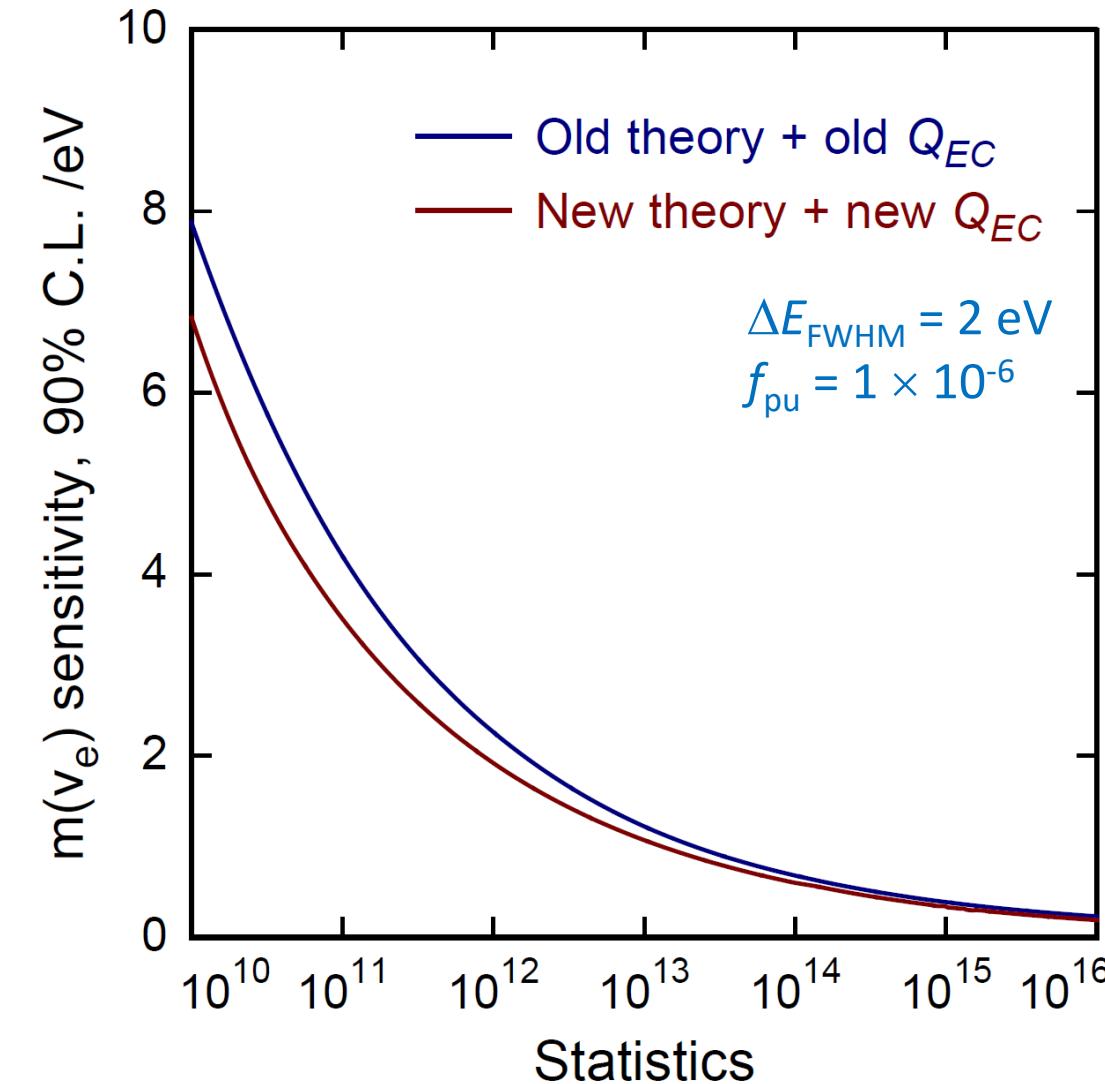
- Detector response
- Theoretical model

Through **experiments** and **simulations**

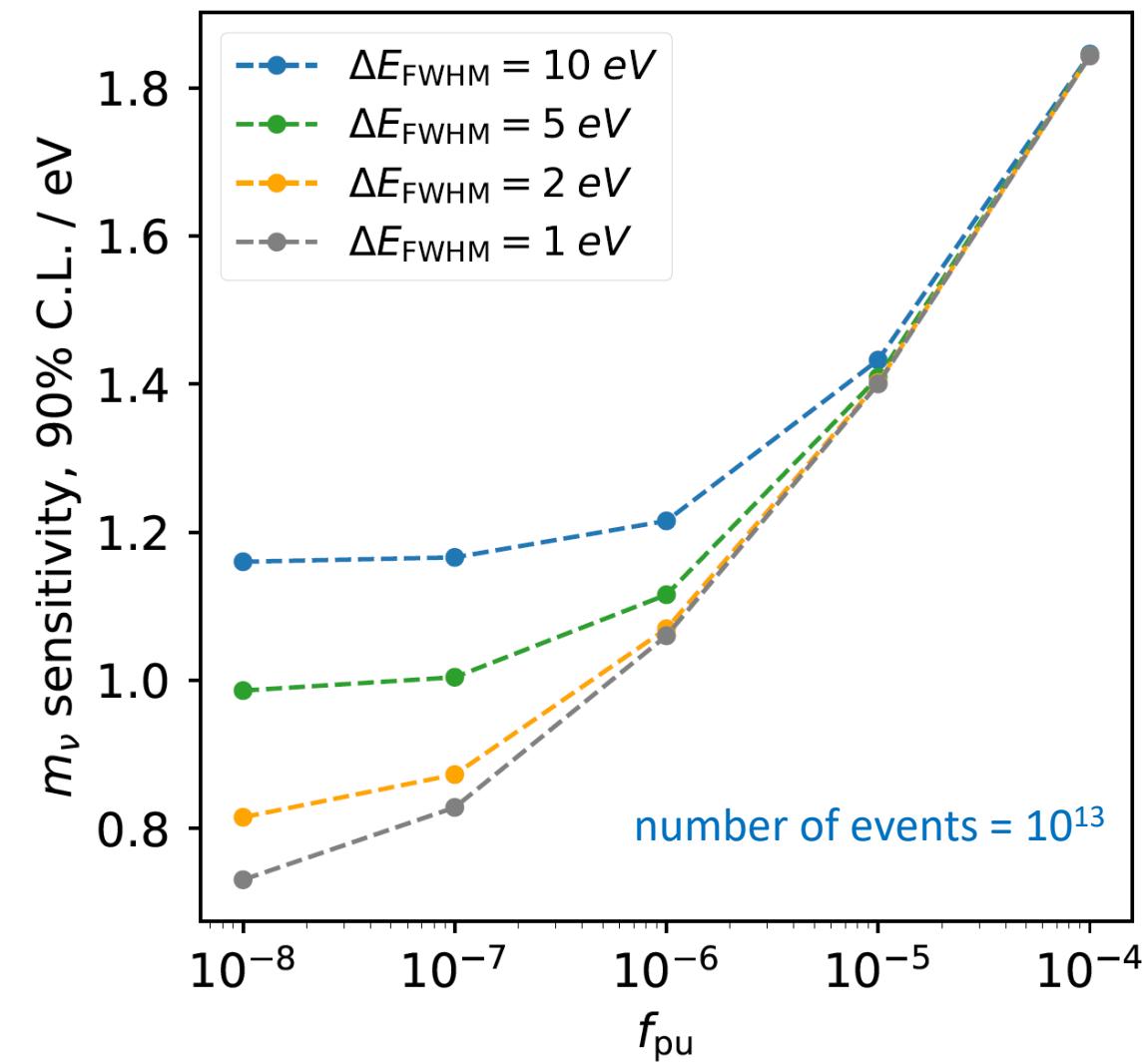


# Updated sensitivity

Brass & Haverkort theoretical model + new  $Q_{EC}$ -value



Sensitivity for the coming phase of ECHO



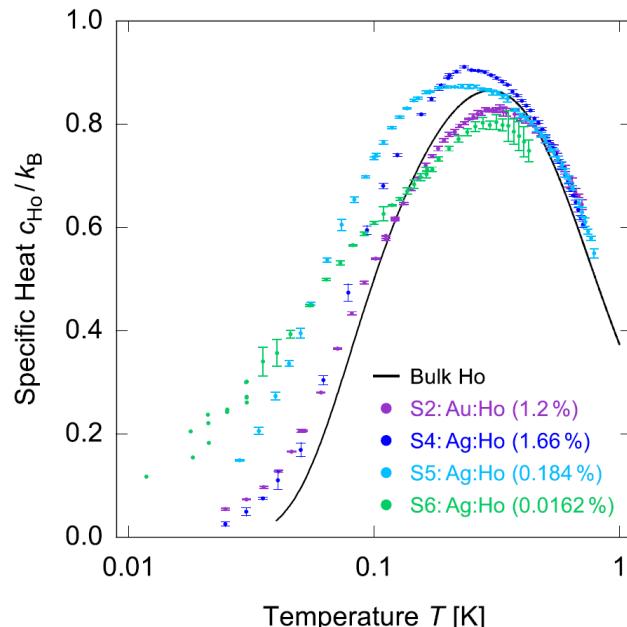
# ECHO-100k – MMC array

## Maximum activity per pixel

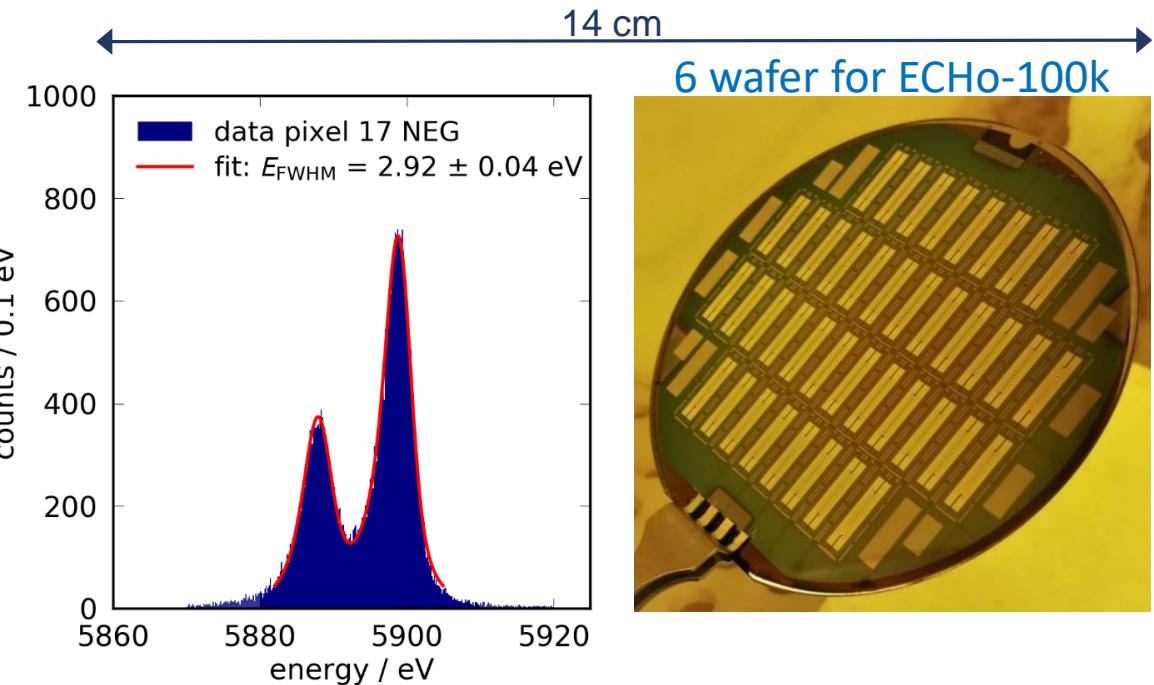
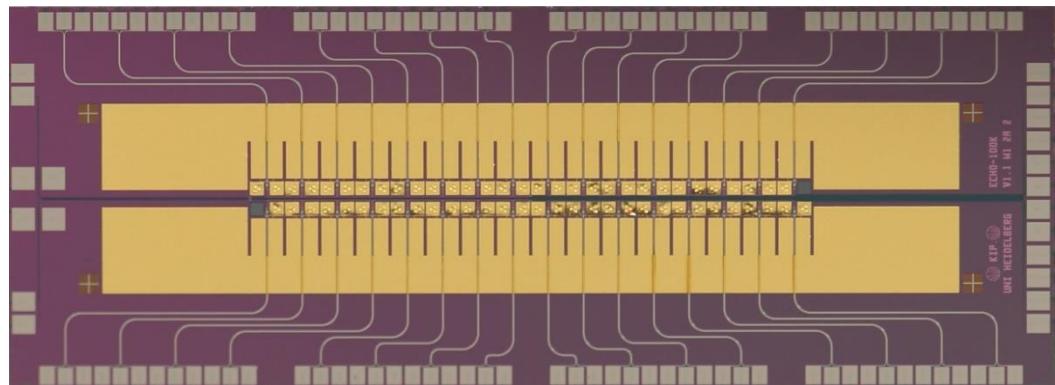
Maximum  $^{163}\text{Ho}$  activity in microcalorimeters is affected by:

- specific heat per  $^{163}\text{Ho}$  atom (2\* $10^{11}$  atoms for 1 Bq) compromise detector performance
- allowed unresolved pile-up unavoidable background in the endpoint region

## 10 Bq per pixel for ECHO-100k



## New ECHO-100k chip design



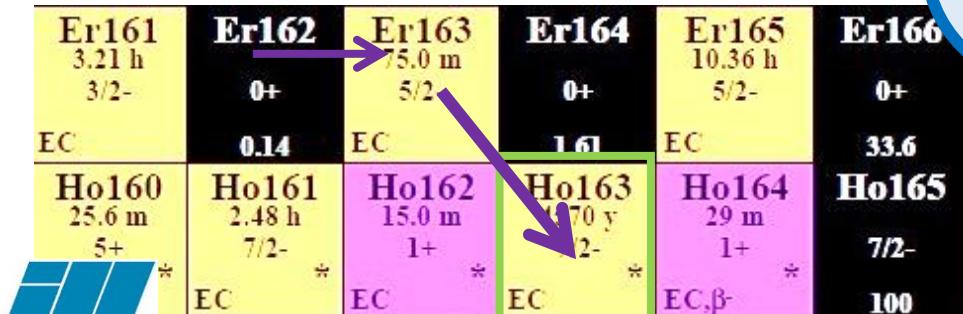
# $^{163}\text{Ho}$ Source Production + Implantation

$^{163}\text{Ho}$  production via neutron irradiation  $\rightarrow$   $(n,\gamma)$ -reaction on  $^{162}\text{Er}$

Excellent chemical separation  $\rightarrow$  95% efficiency

$^{163}\text{Ho}$  available for coming experiments

**ECHO**  $\sim 6 \times 10^{18}$  atoms (30 MBq)

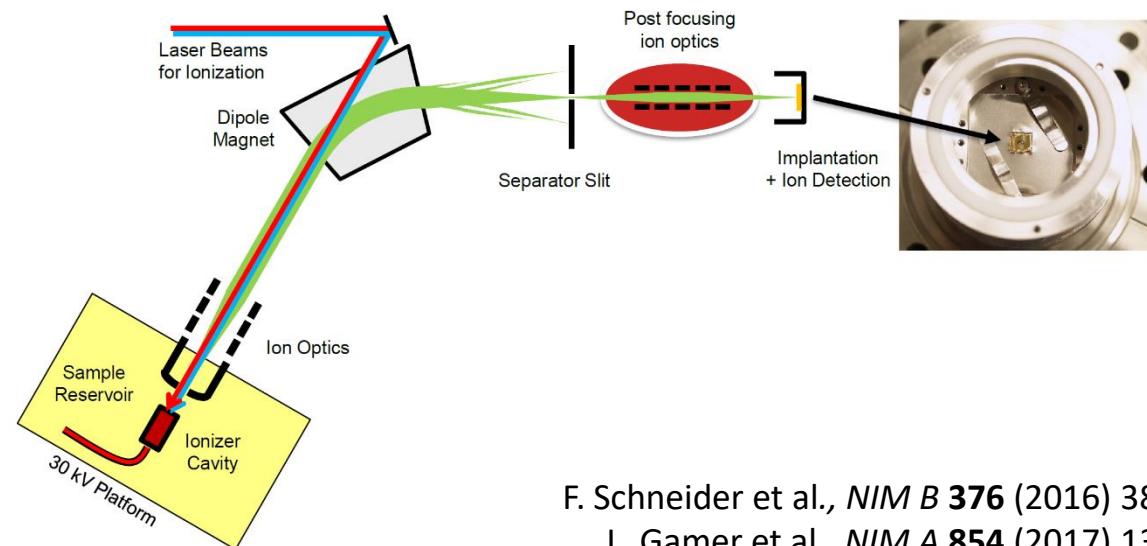


NEUTRONS  
FOR SCIENCE

H. Dorrer et al, Radiochim. Acta 106(7) (2018) 535–48

**Ion implantation** @ RISIKO, Institute of Physics, Mainz University

- Resonant laser ion source  $\rightarrow (69 \pm 5^{\text{stat}} \pm 4^{\text{syst}})\%$  efficiency
- Reduction of  $^{166m}\text{Ho}$  in MMC  $\rightarrow ^{166m}\text{Ho}/^{163}\text{Ho} < 4(2)10^{-9}$
- Optimization of beam focalization



- F. Schneider et al., NIM B 376 (2016) 388  
 L. Gamer et al., NIM A 854 (2017) 139  
 T. Kieck et al., Rev. Sci. Inst. 90 (2019) 053304  
 T. Kieck et al., NIM A 945 (2019) 162602

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Er161 3.21 h 3/2-	Er162 0+ EC 0.14	Er163 75.0 m 5/2- EC	Er164 0+ EC 1.6	Er165 10.36 h 5/2- EC	Er166 0+ 33.6 Ho165 7/2- 100
Ho160 25.6 m 5+ *	Ho161 2.48 h 7/2- EC	Ho162 15.0 m 1+ EC	Ho163 70 y 2- EC	Ho164 29 m 1+ EC, $\beta^-$	

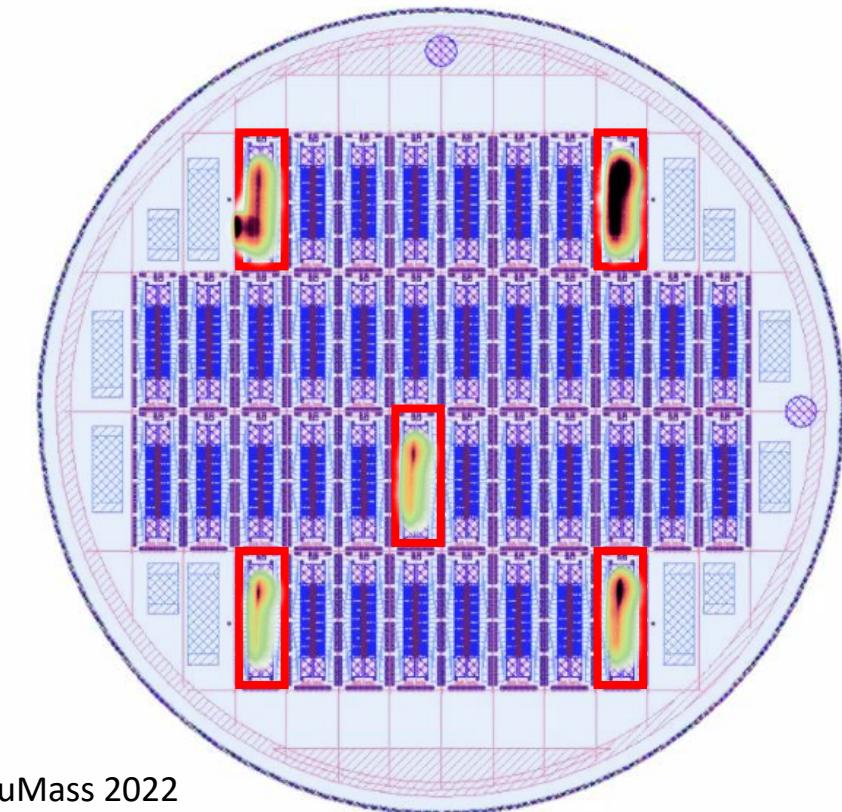


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- Optimization of beam focalization
- Implantation on wafer scale demonstrated

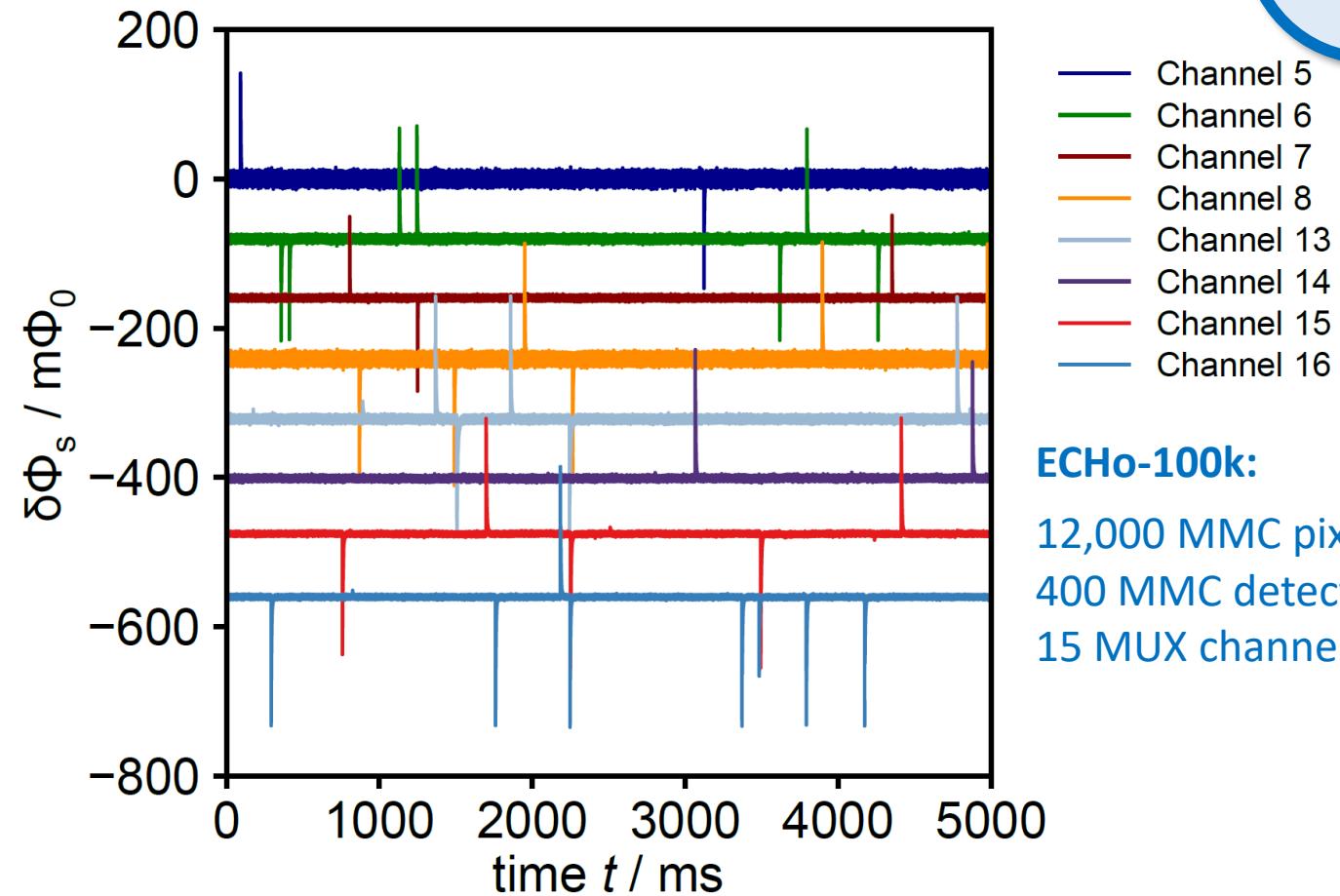
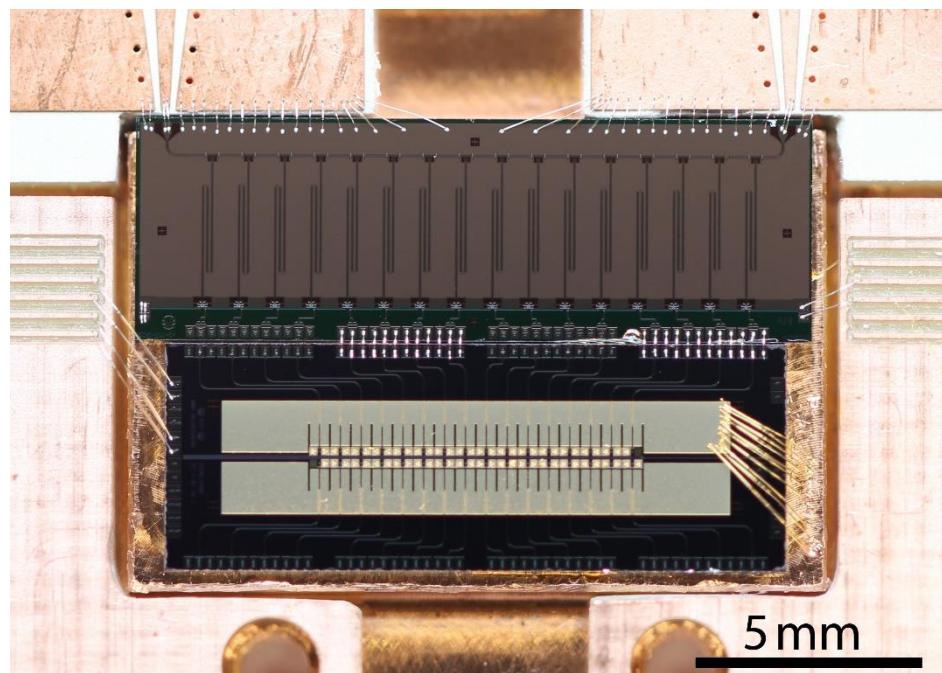


# ECHO-100k – Multiplexing

## Microwave SQUID multiplexing

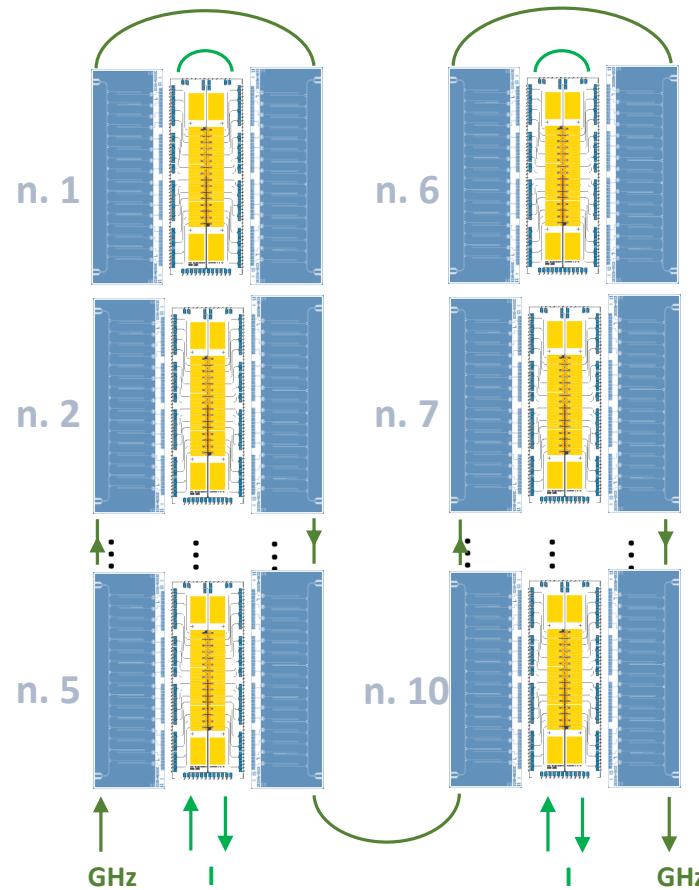
Single HEMT amplifier and 2 coaxes  
to read out **100 - 1000** detectors

- Successful characterization of first prototypes with external  $^{55}\text{Fe}$   
→ **Very promising results:**  
8 channels (16 pixels)



**ECHO-100k:**  
12,000 MMC pixels =  
400 MMC detectors ×  
15 MUX channels

# ECHo-100k for eV-scale sensitivity



Deutsche  
Forschungsgemeinschaft

**ECHo-100k baseline: large arrays of metallic magnetic calorimeters**

Number of detectors: 12000

Activity per pixel: 10 Bq ( $2 \times 10^{12} {}^{163}\text{Ho}$  atoms)

**Present status:**

High Purity  ${}^{163}\text{Ho}$  source:

- available about 30 MBq

Ion implantation system:

- demonstrated and continuously optimized

Metallic magnetic calorimeters

- reliable fabrication of large MMC array
- successful characterization of arrays with  ${}^{163}\text{Ho}$

Multiplexing and data acquisition:

- demonstrated for 8 channels
- development of the SDR electronics
- still to show scaling of the system

Data reduction

- optimized energy independent algorithm to identify spurious traces

# Conclusions

- ✓ The results obtained with  $^{163}\text{Ho}$  loaded MMCs paved the way to large scale neutrino mass experiments based on  $^{163}\text{Ho}$
- ✓ The ECHo collaboration has already contributed to a more precise description of the  $^{163}\text{Ho}$  spectrum
- ✓ A first improvement on the effective electron neutrino mass limit has been obtained in a proof of concept measurement
- ✓ More than  $10^8$   $^{163}\text{Ho}$  events have been acquired within the ECHo-1k phase →  
A new limit at the level of 20 eV on the effective electron neutrino mass is on the way
- ✓ Important steps towards ECHo-100k have been demonstrated  
new ECHo-100k array + implantation of wafer scale + multiplexed readout

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UNIVERSITÄT  
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ZUKUNFT  
SEIT 1386



JOHANNES GUTENBERG  
UNIVERSITÄT MAINZ

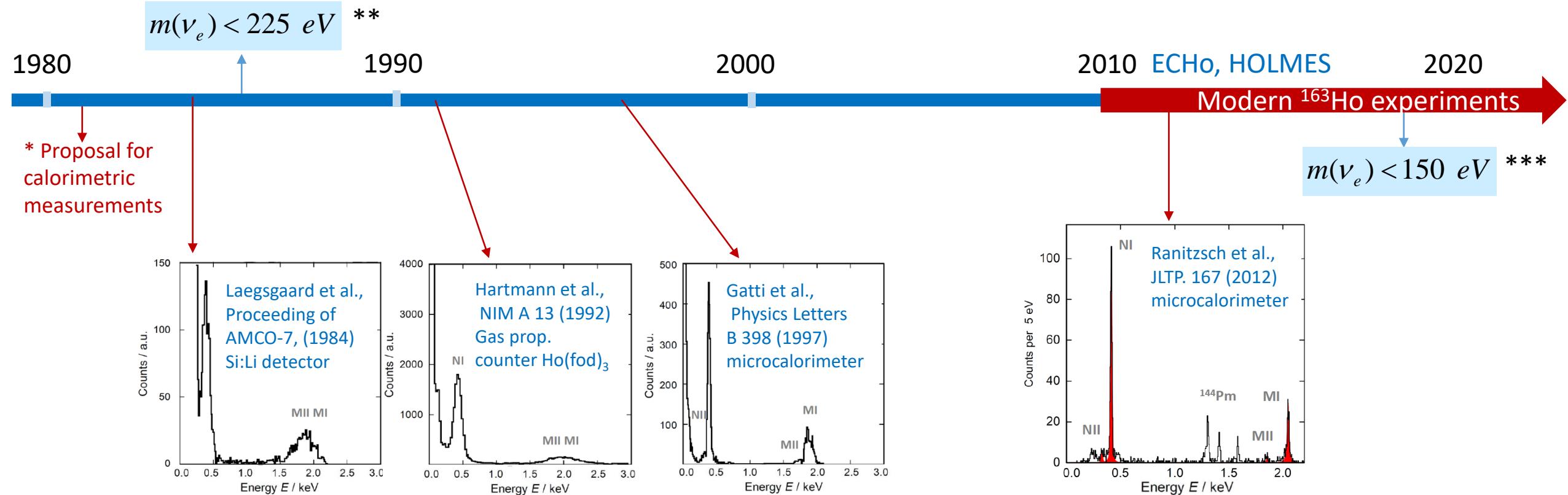


MAX-PLANCK-INSTITUT  
FÜR KERNPHYSIK



*Thank you!*

# Electron Capture in $^{163}\text{Ho}$ - Timeline



\* A. De Rujula and M. Lusignoli, *Phys. Lett.* **118B** (1982)

\*\* P. T. Springer, C. L. Bennett, and P. A. Baisden *Phys. Rev. A* **35** (1987) 679

\*\*\* C. Velte et al., (The ECHo Collaboration) *Eur. Phys. J. C* **79** (2019) 1026

# ECHO-1k read-out

10

