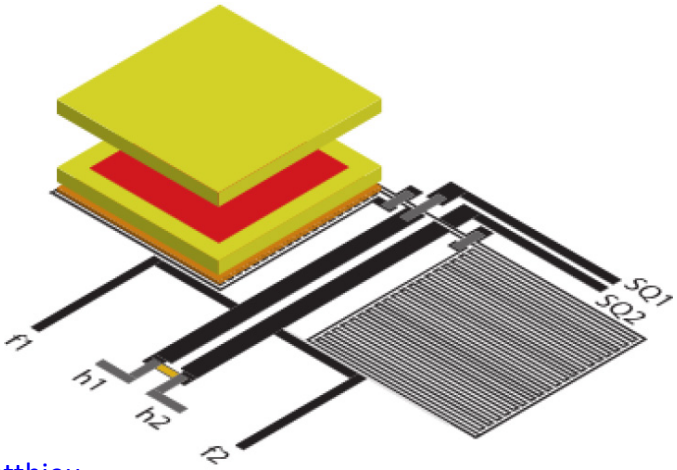
Recent results from the neutrino mass experiment ECHo using the new detectors with ^{163}Ho implanted at ISOLDE



Gastaldo Loredana, Enss Christian, Fleischmann Andreas, Hassel Clemens, Hengstler Daniel, Hähnle Sebastian, Kempf Sebastian, Krantz Matthäus, Wegner Mathias

Dorrer Holger, Düllmann Christoph, Eberhardt Klaus, Kieck Tom, Schneider Fabian, Wendt Klaus

Köster Ulli

Türler Andreas

Marsh Bruce, Day Goodacre Tom, Johnston Karl, Rothe Sebastian, Stora Thierry, Veinhard Matthieu

Riccio Charlotte, Jean-Luis Margueron, Thierry Zampieri, Michael Zampaolo, Fabrice Piquemal

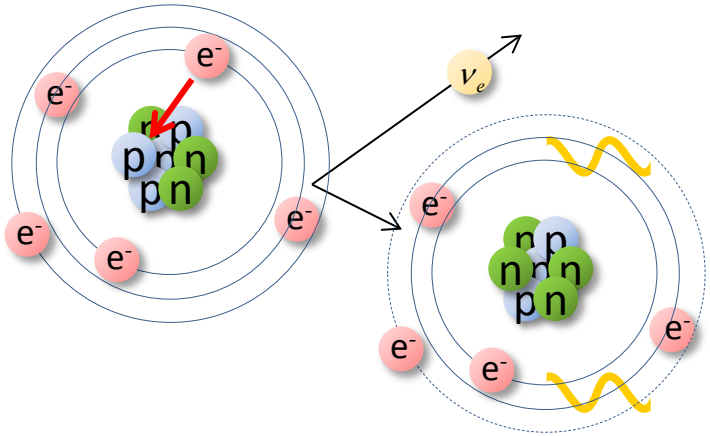
^{163}Ho and neutrino mass

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

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

- $\tau_{1/2} \cong 4570$ years (2*10^{11} atoms for 1 Bq)
- $Q_{EC} = (2.555 \pm 0.016)$ keV

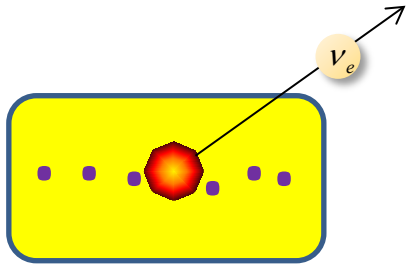
M. Wang, G. Audi et al., *Chinese Phys. C* **36**, 1603, (2012)



A non- zero neutrino mass affects the de-excitation energy spectrum

Atomic de-excitation:
- X-ray emission
- Auger electrons
- Coster-Kronig transitions

} Calorimetric measurement



^{163}Ho Q_{EC}-value

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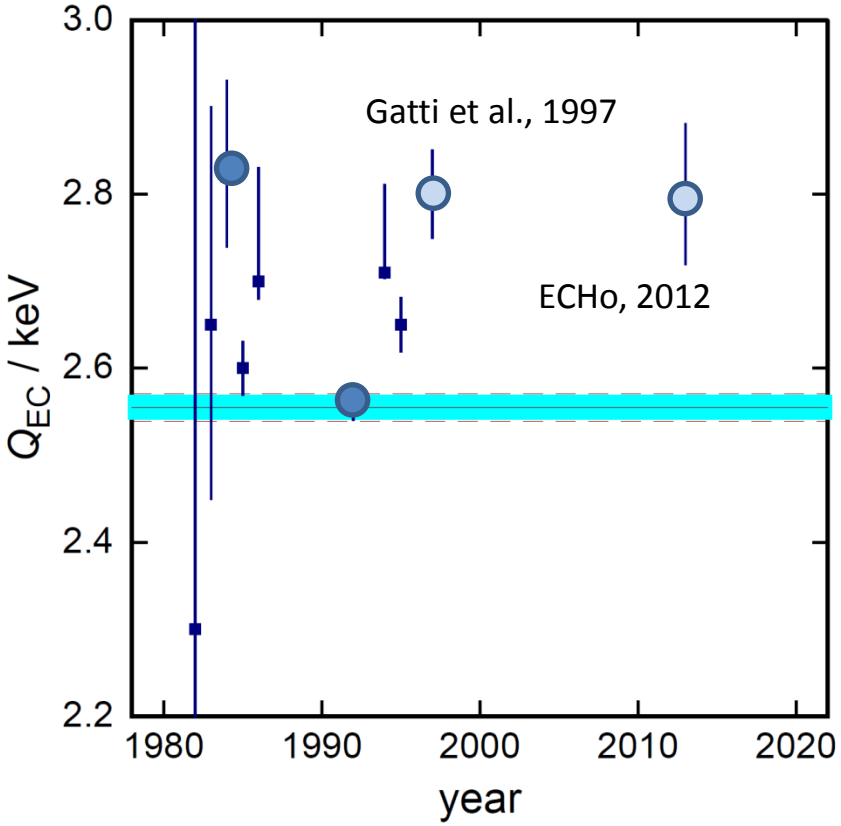

Calorimetric measurements

Measurements of x-rays

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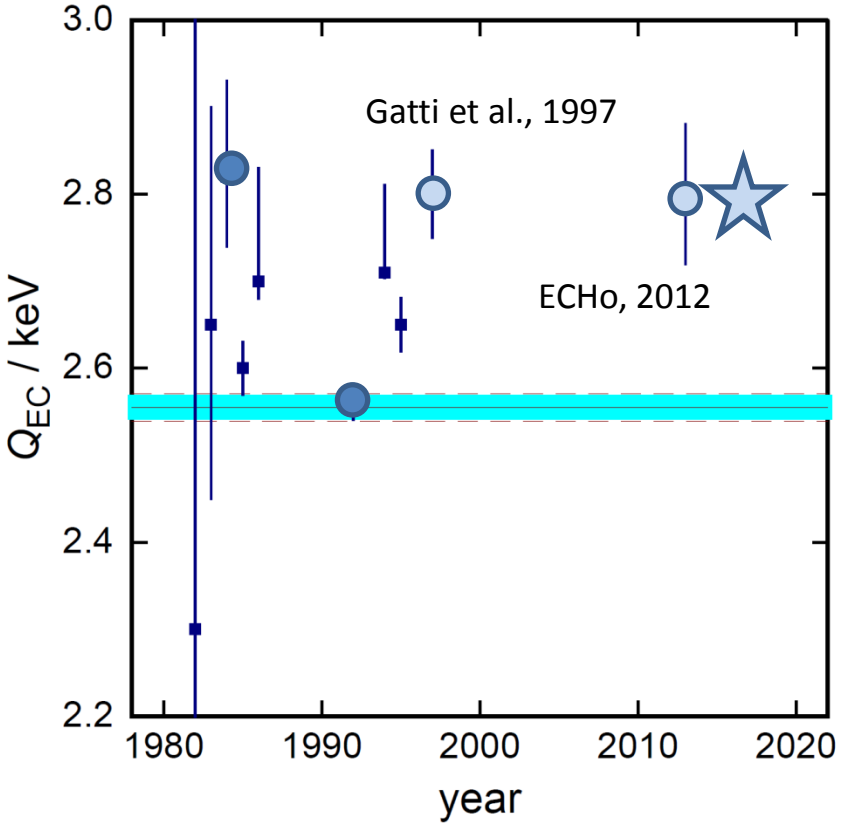

Calorimetric measurements

Measurements of x-rays

Penning Trap Mass Spectroscopy

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

Direct measurement of the mass difference of ^{163}Ho and ^{163}Dy as prerequisite to a determination of the electron neutrino mass
S. Eliseev et al., *Phys. Rev. Lett.*, 115, 062501 (2015)

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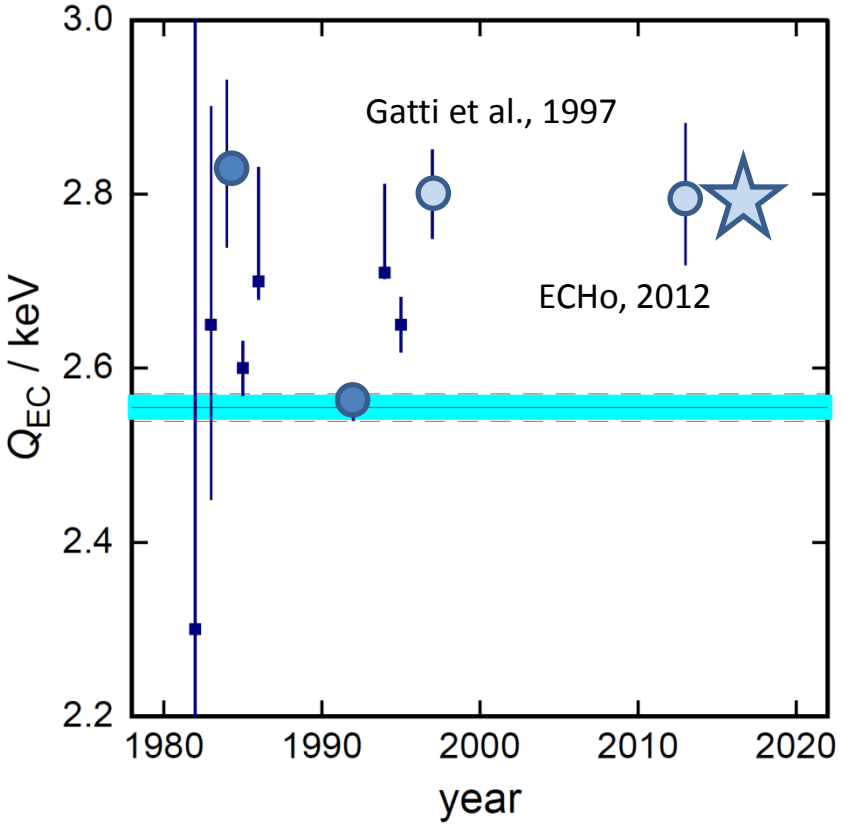
M. Wang, G. Audi et al., *Chinese Phys. C* **36**, 1603, (2012)



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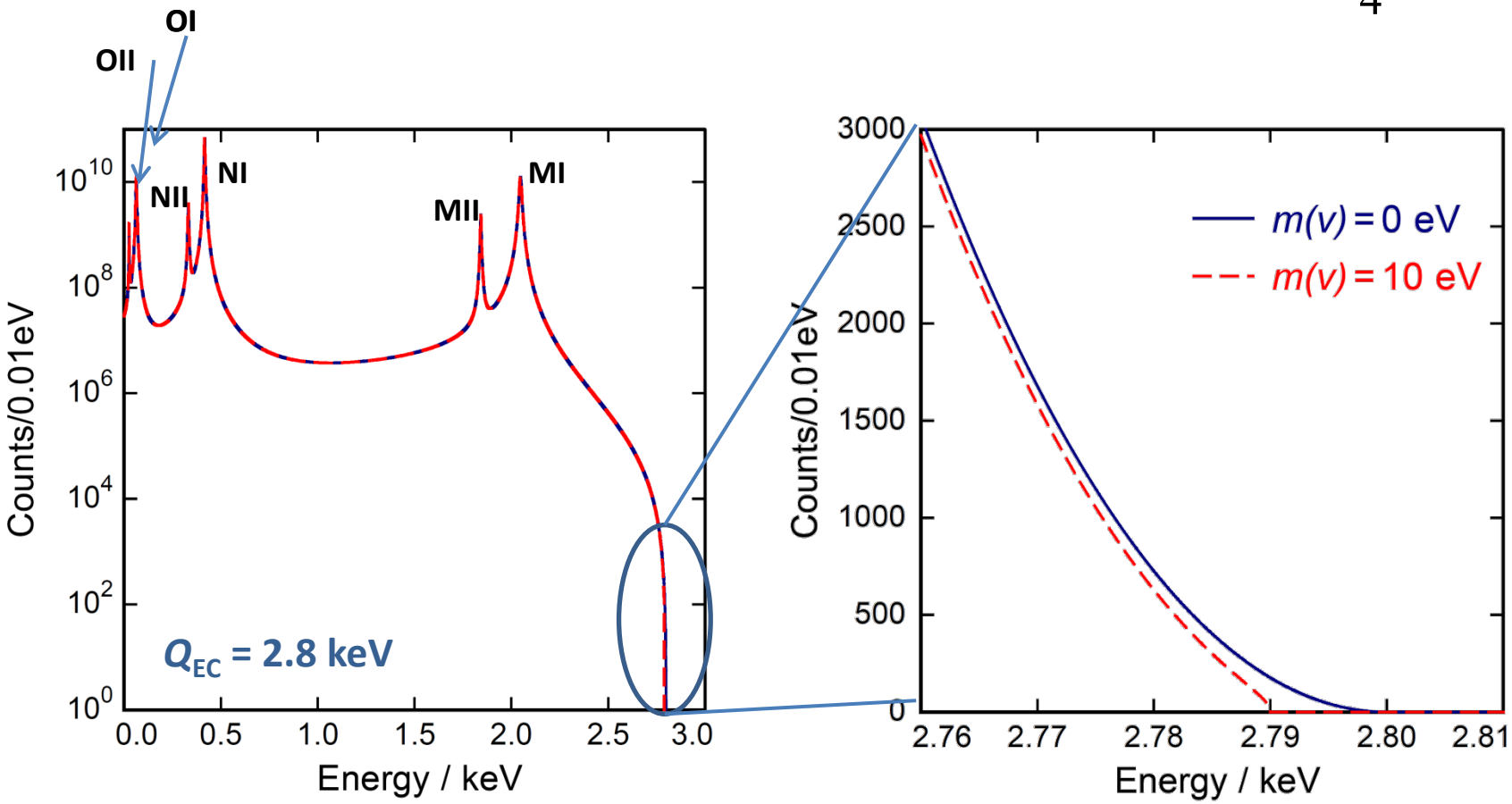
S. Eliseev et al., *Phys. Rev. Lett.*, 115, 062501 (2015)

To reduce uncertainties in the analysis:
Q_{EC} determination within **1 eV**
→ **PENTATRAP (MPIK HD)**

^{163}Ho Q_{EC}-value

$$\frac{dW}{dE_C} = A(Q_{EC} - E_C)^2 \sqrt{1 - \frac{m_\nu^{\,2}}{(Q_{EC} - E_C)^2}} \sum_H B_H \varphi_H^{\,2}(0) \frac{\frac{\Gamma_H}{2\pi}}{(E_C - E_H)^2 + \frac{\Gamma_H^{\,2}}{4}}$$



Requirements for sub-eV sensitivity in ECHo

Statistics in the end point region

- $N_{ev} > 10^{14}$ → A ≈ 1 MBq

Unresolved pile-up ($f_{pu} \sim a \cdot \tau_r$)

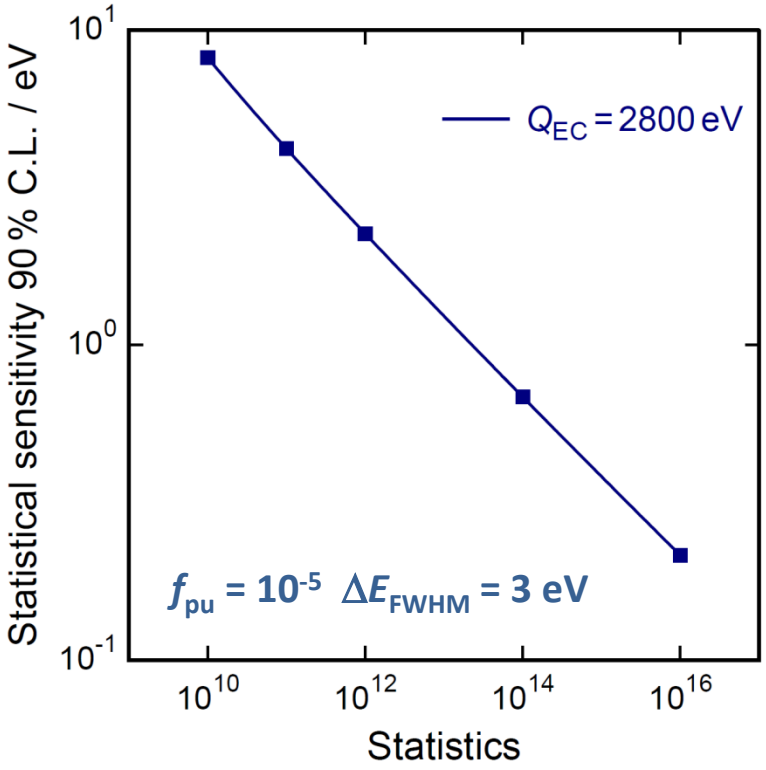
- $f_{pu} < 10^{-5}$
- $\tau_r < 1$ µs → a ~ 10 Bq
- 10^5 pixels

Precision characterization of the endpoint region

- $\Delta E_{FWHM} < 3$ eV

Background level

- $5*10^{-5}$ events/eV/det/day



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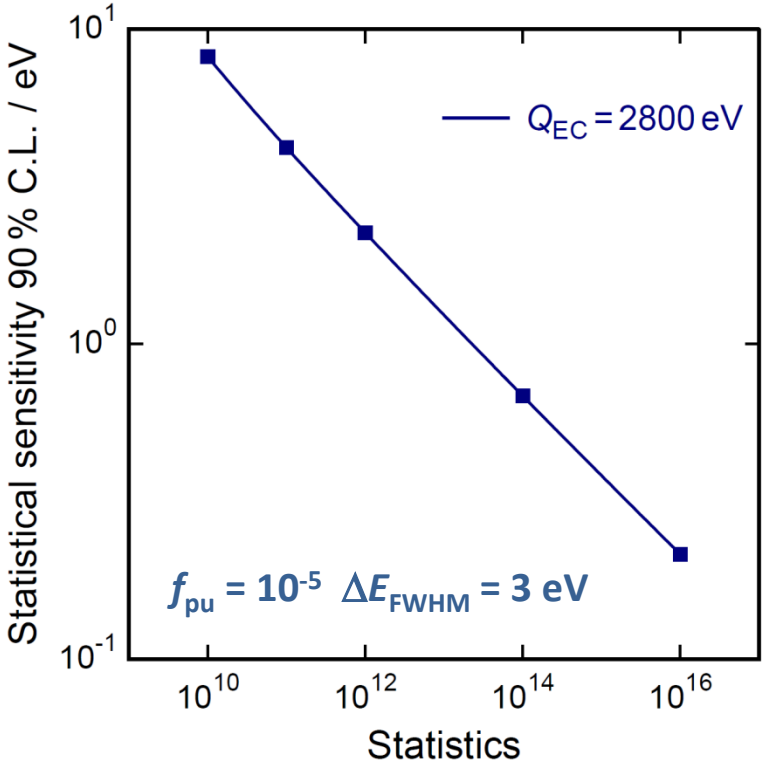
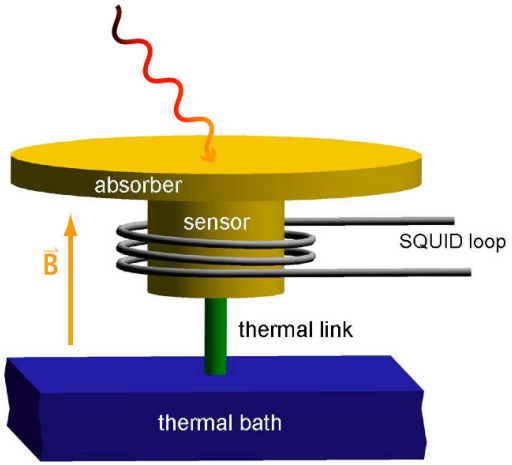
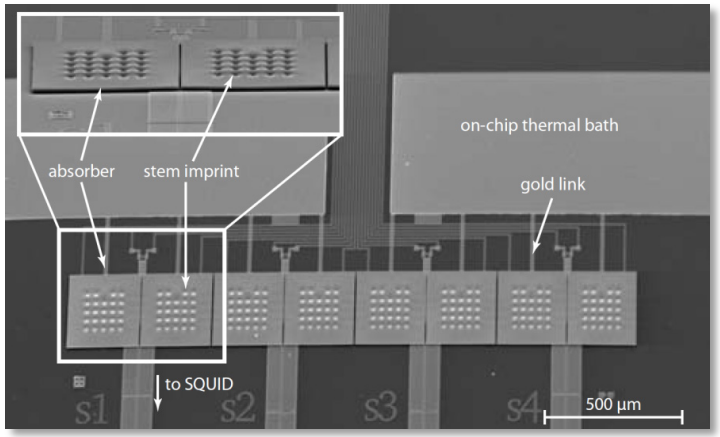
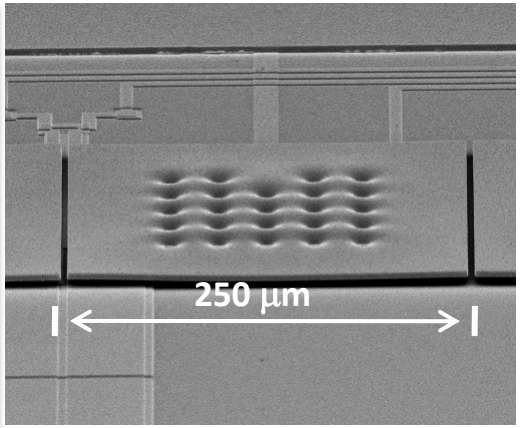




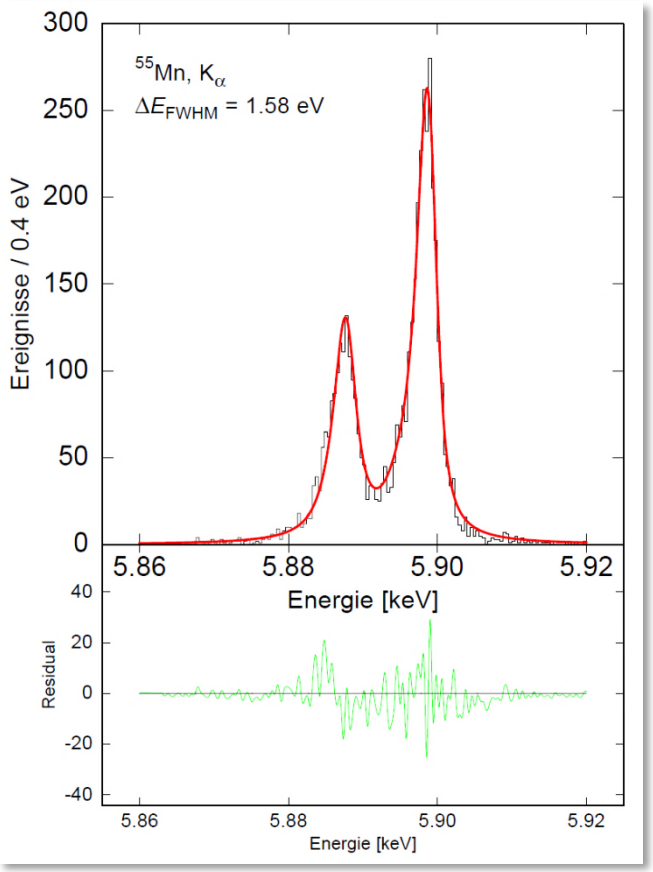
Low temperature
Metallic Magnetic Calorimeter

MMCs: 1d-array for soft x-rays (T=20 mK)

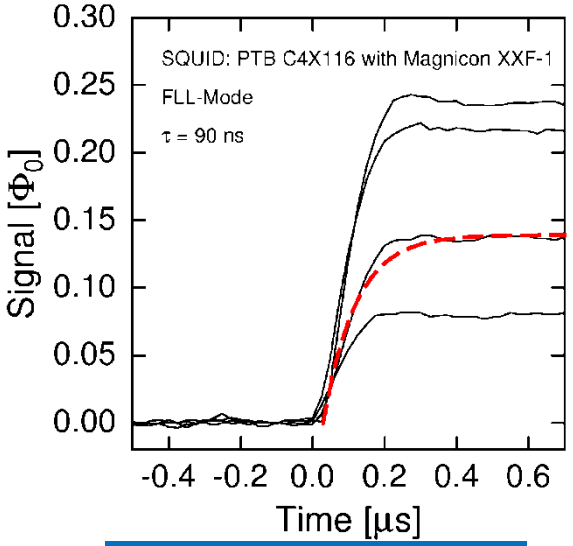




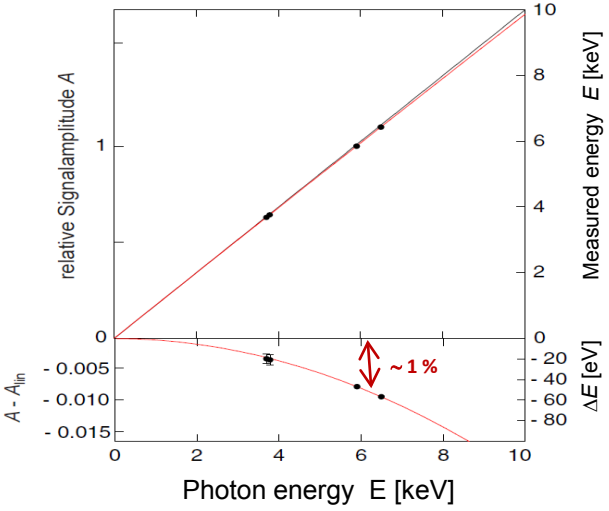
ΔE_{FWHM} = 1.6 eV @ 6 keV



Rise Time: 90 ns



Non-Linearity < 1% @6keV

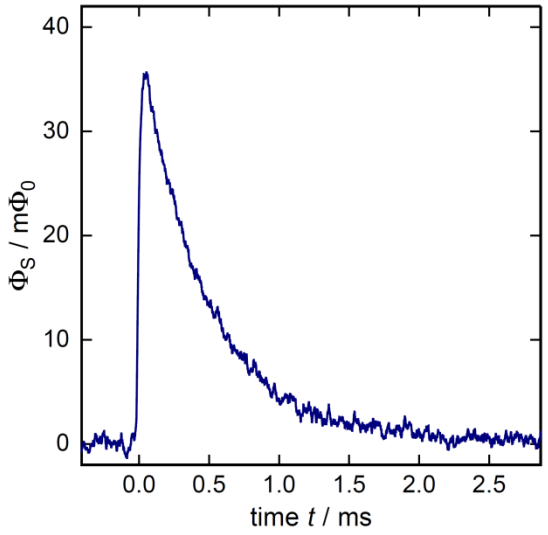


Reduction
un-resolved pile-up

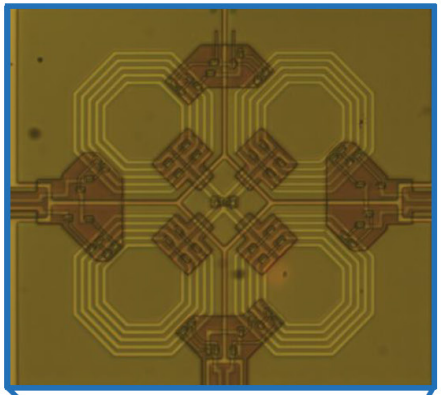
Definition
of the energy scale

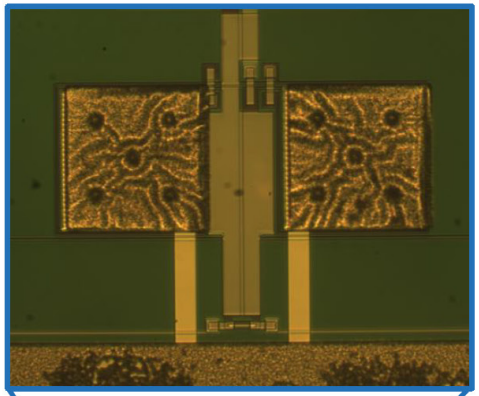
Reduced smearing
in the end point region

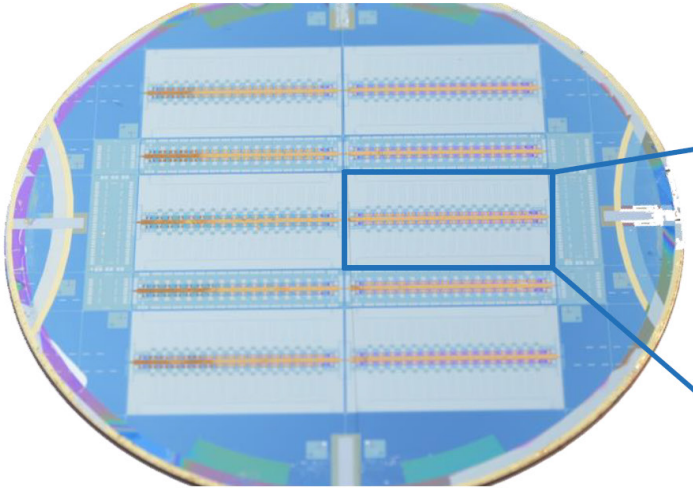
MMCs: Microwave SQUID multiplexing

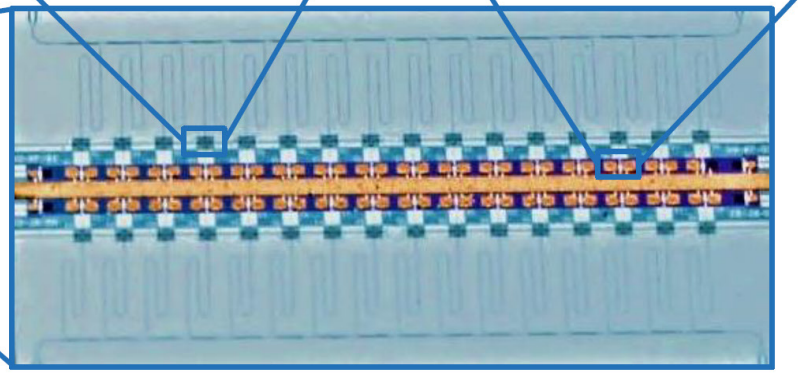


Successful production and test of the first prototype





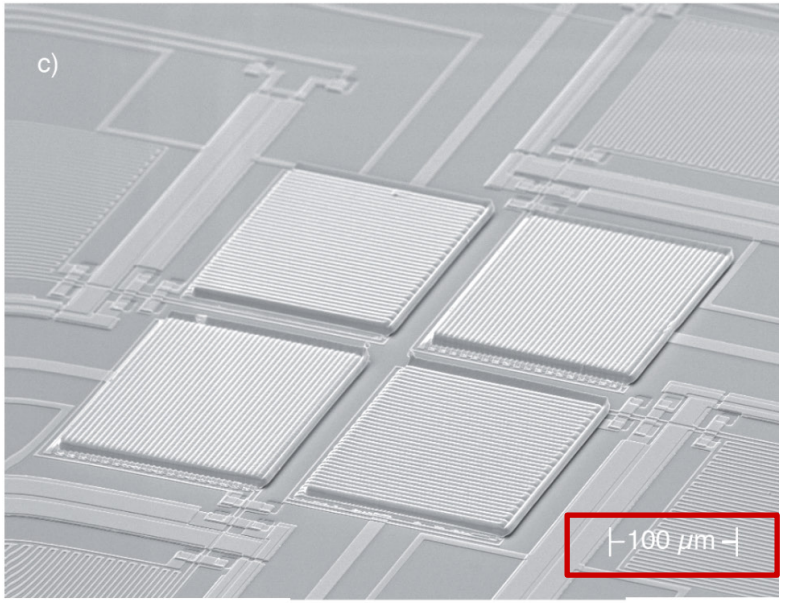


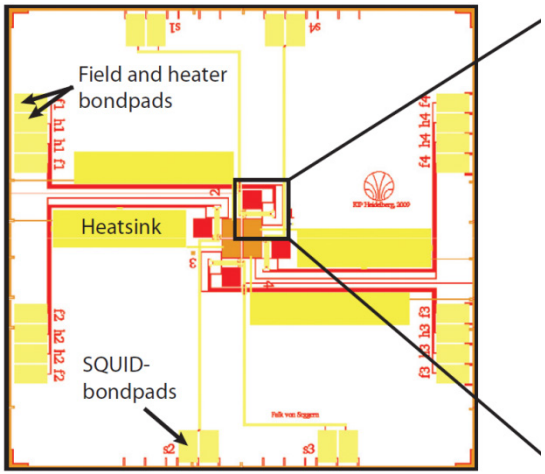


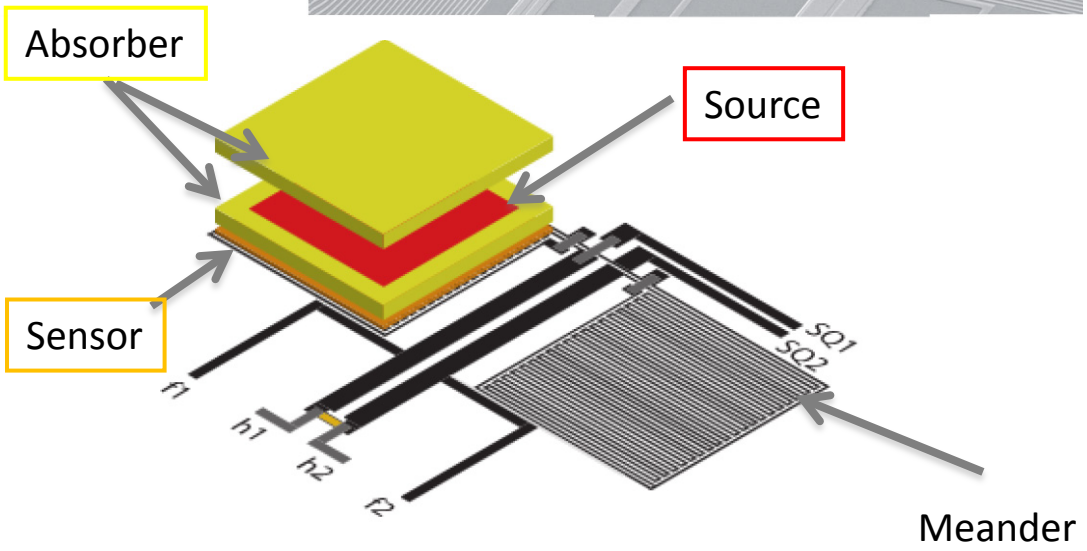
Microwave SQUID Multiplexer for the Readout of Metallic Magnetic Calorimeters
S.Kempf et al., *J. Low. Temp. Phys.* **175** (2014) 850-860

First detector prototype for ^{163}Ho

- Absorber for calorimetric measurement
  → ion implantation @ ISOLDE-CERN in 2009
  on-line process
- About 0.01 Bq per pixel
- Operated over more than 4 years





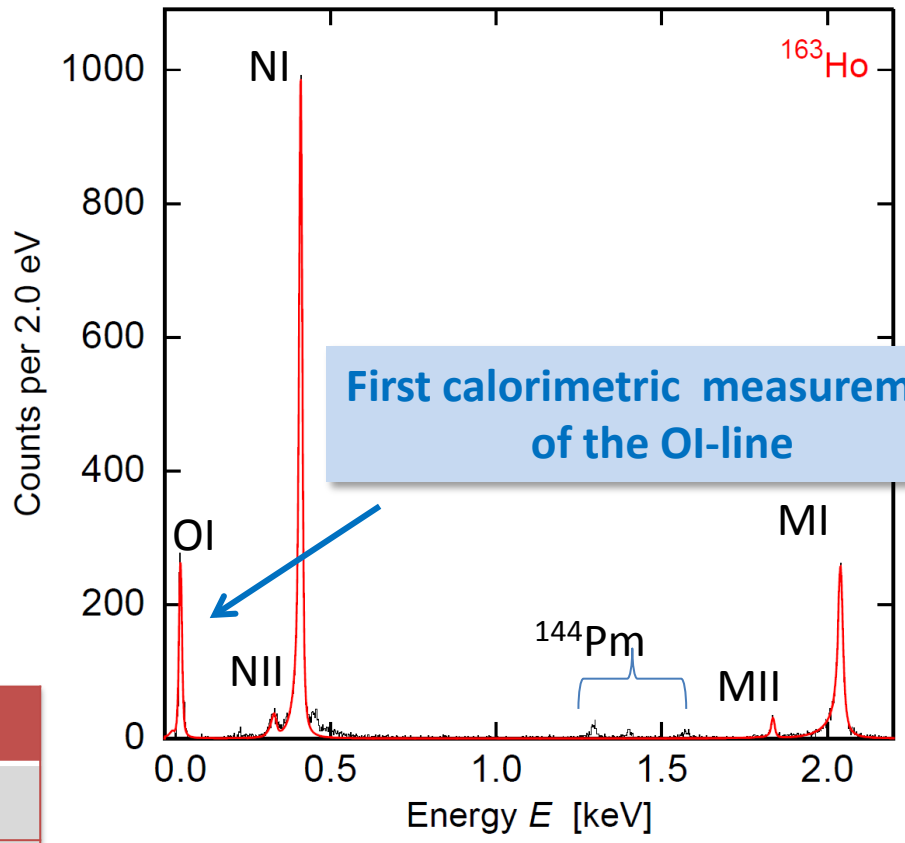


L. Gastaldo et al.,
Nucl. Inst. Meth. A, 711 (2013) 150

P. C.-O. Ranitzsch et al.,
http://arxiv.org/abs/1409.0071v1

Calorimetric spectrum

- Rise Time ~ 130 ns
- ΔE_{FWHM} = 7.6 eV @ 6 keV (2013)
- Non-Linearity < 1% @ 6keV
- Synchronized measurement of 2 pixels



First calorimetric measurement of the OI-line

	E_H bind.	E_H exp.	Γ_H lit.	Γ_H exp
MI	2.047	2.040	13.2	13.7
MII	1.845	1.836	6.0	7.2
NI	0.420	0.411	5.4	5.3
NII	0.340	0.333	5.3	8.0
OI	0.050	0.048	5.0	4.3

$$Q_{EC} = (2.843 \pm 0.009^{stat} - 0.06^{syst})\ \text{keV}$$

P. C.-O. Ranitzsch et al ., http://arxiv.org/abs/1409.0071v1)
L. Gastaldo et al., Nucl. Inst. Meth. A, 711, 150-159 (2013)

Where to improve

High purity ^{163}Ho source:

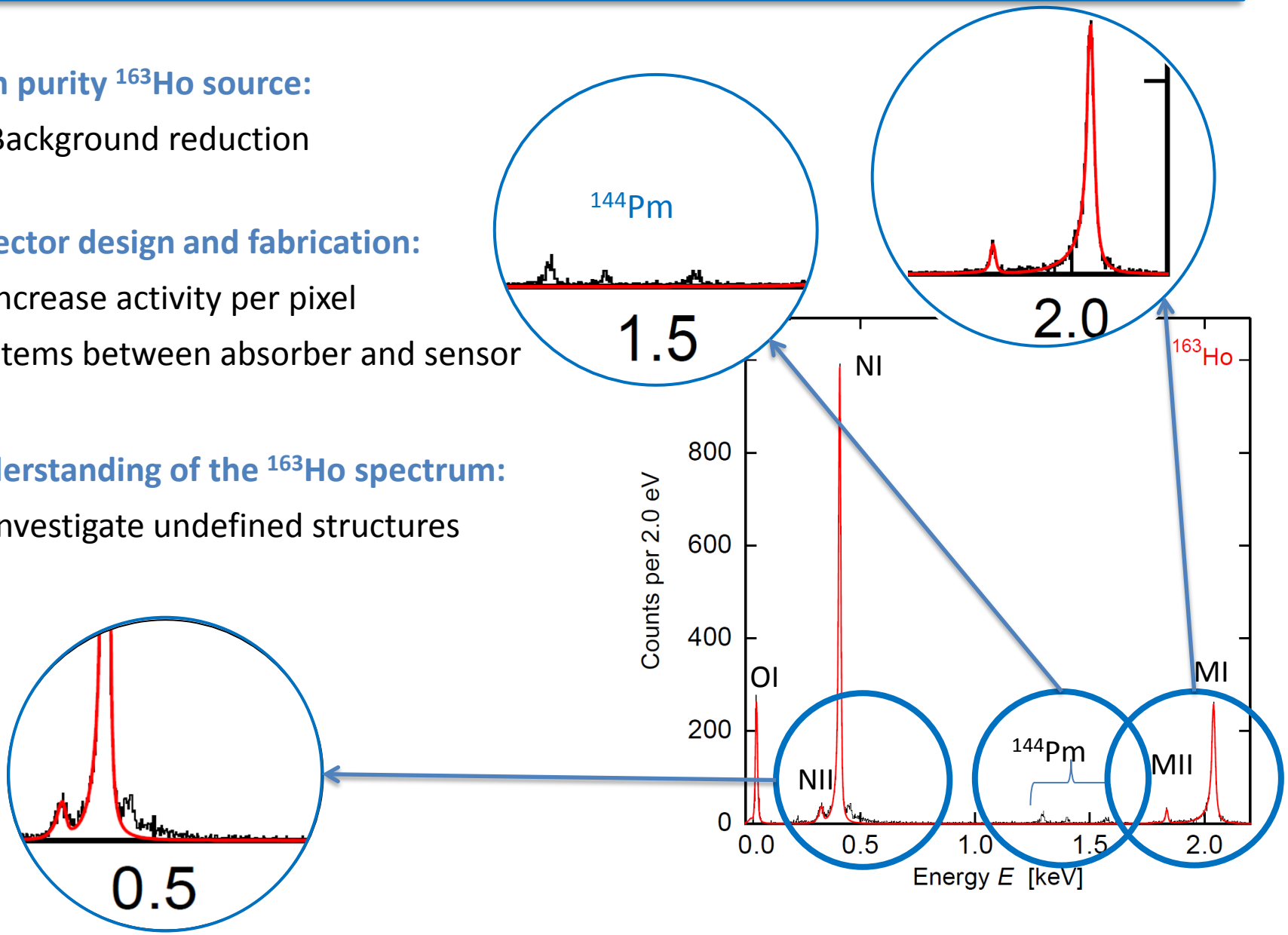
- Background reduction

Detector design and fabrication:

- Increase activity per pixel
- Stems between absorber and sensor

Understanding of the ^{163}Ho spectrum:

- Investigate undefined structures

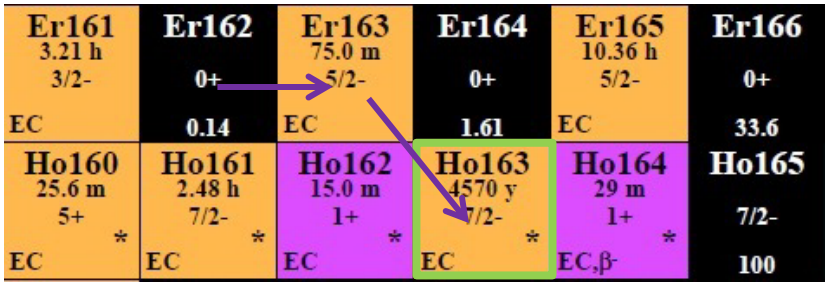


High purity ^{163}Ho source: (n,γ)-reaction on ^{162}Er

Requirement : >10^6 Bq → >10^{17} atoms

^{163}Ho sample produced at **ILL, Grenoble**

- (n,γ)-reaction on ^{162}Er
  - High cross-section
  - Radioactive contaminants



- Excellent chemical separation

  Only ^{166m}Ho

- Available ^{163}Ho source:

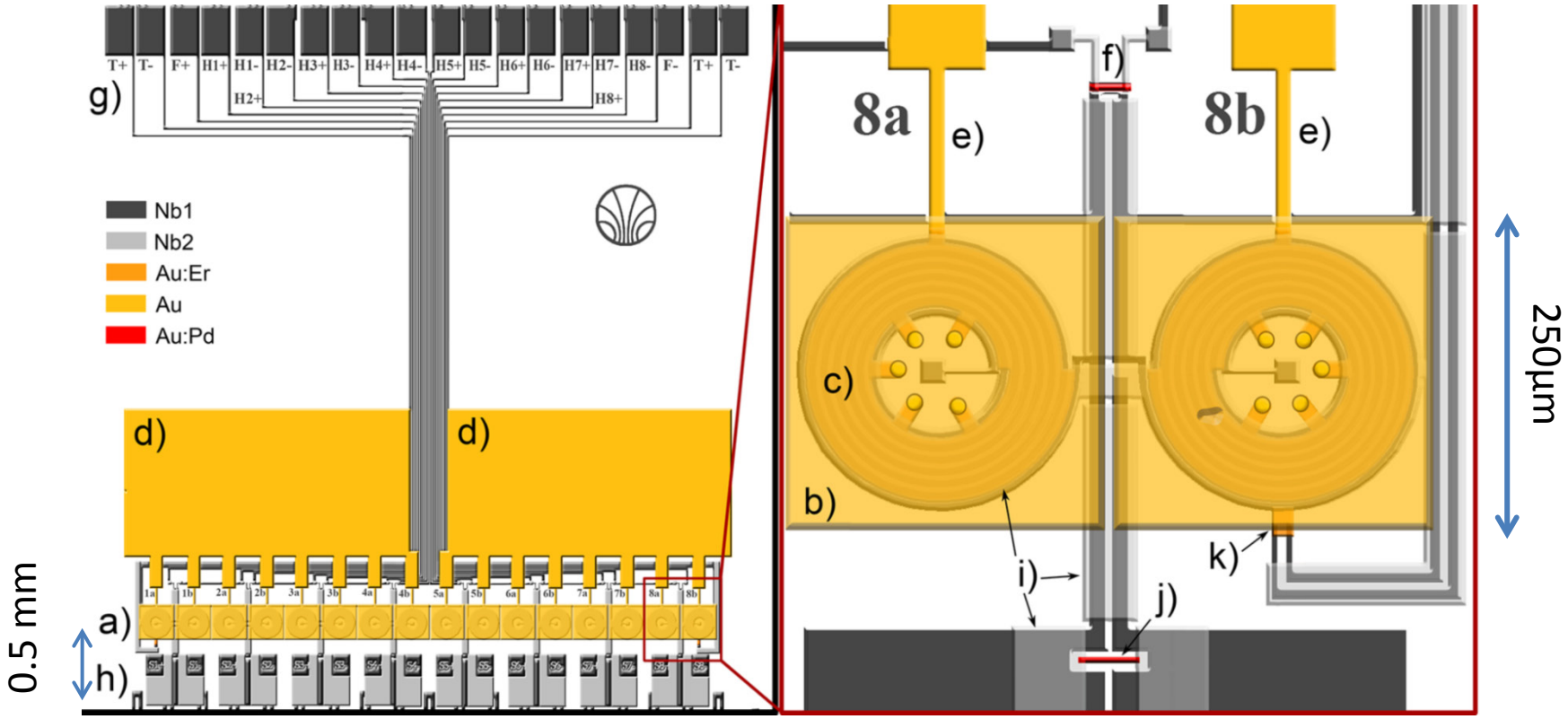
  ~ 10^{18} atoms

ECHo requirements:
^{166m}Ho/ ^{163}Ho < 10^{-9}

Offline mass separation:
RISIKO, Mainz University
ISOLDE-CERN

Detector chip for second ^{163}Ho implantation

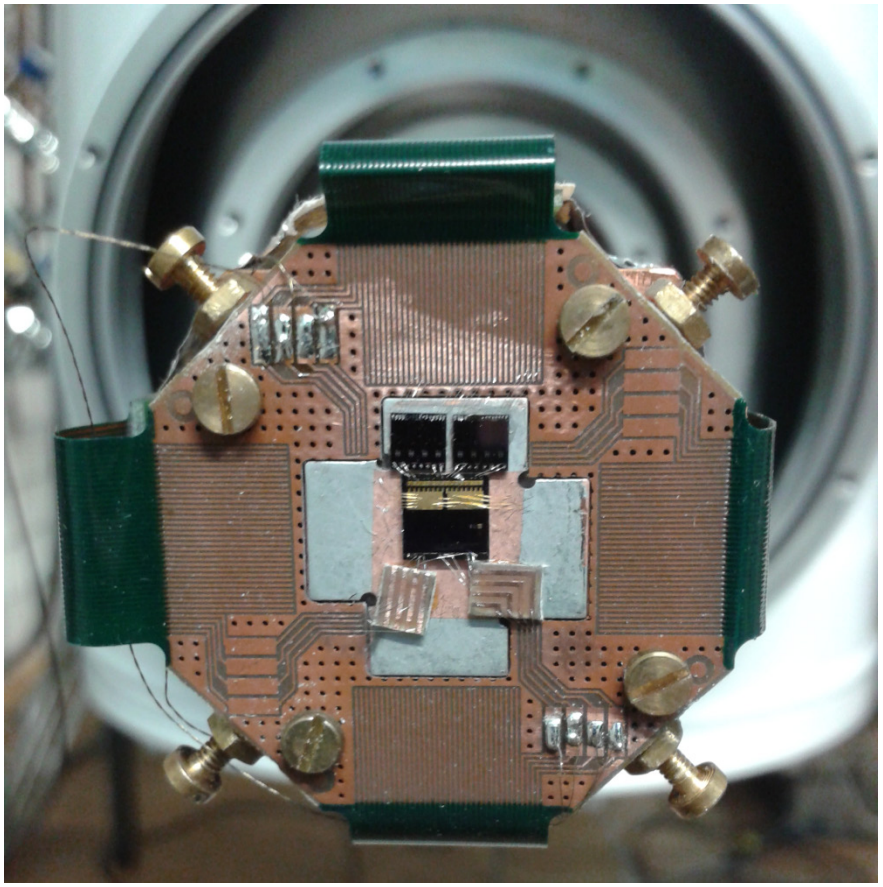
- maXs-20: - sandwich sensor design
  - absorber connected to sensor through stems
  - 16 pixels



- Chemically purified ^{163}Ho source
- Offline implantation @ISOLDE-CERN using GPS and RILIS (December 2014)

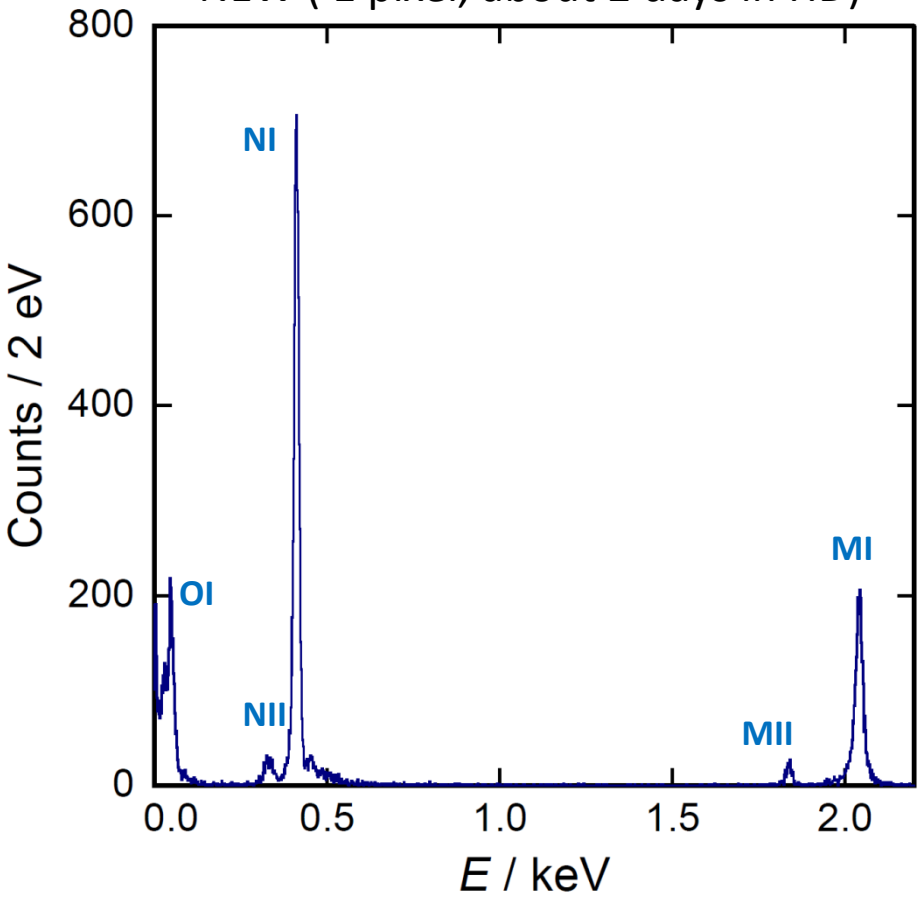
New detectors ready for …

Mounted on a cold arm of a dry cryostat

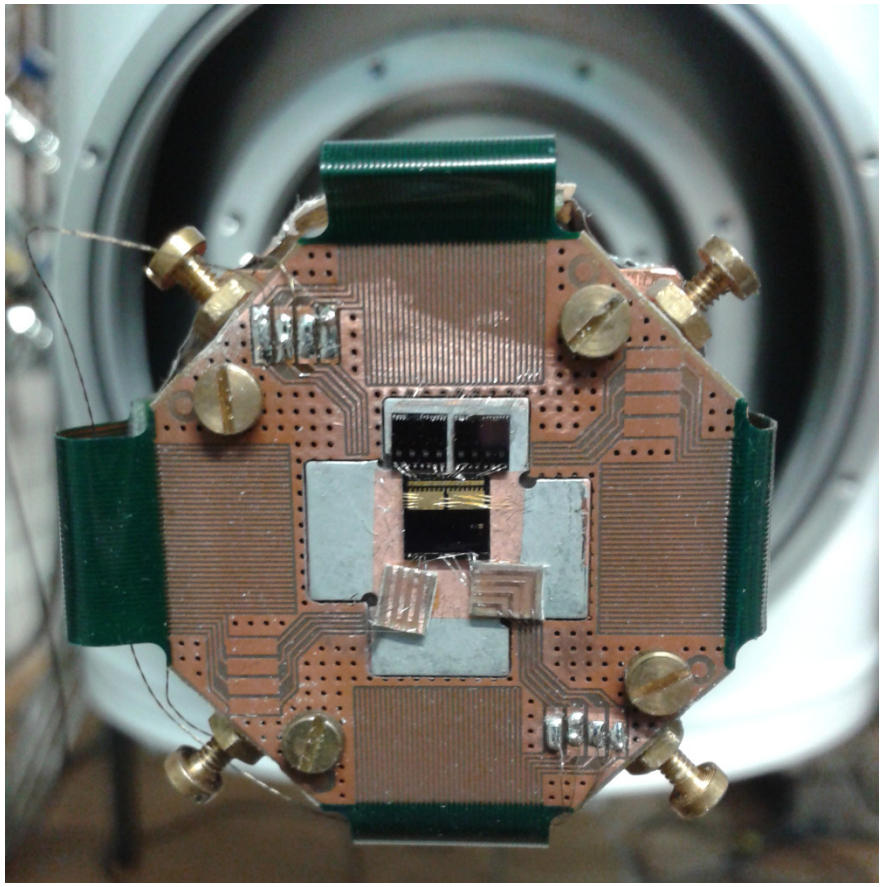


… first results

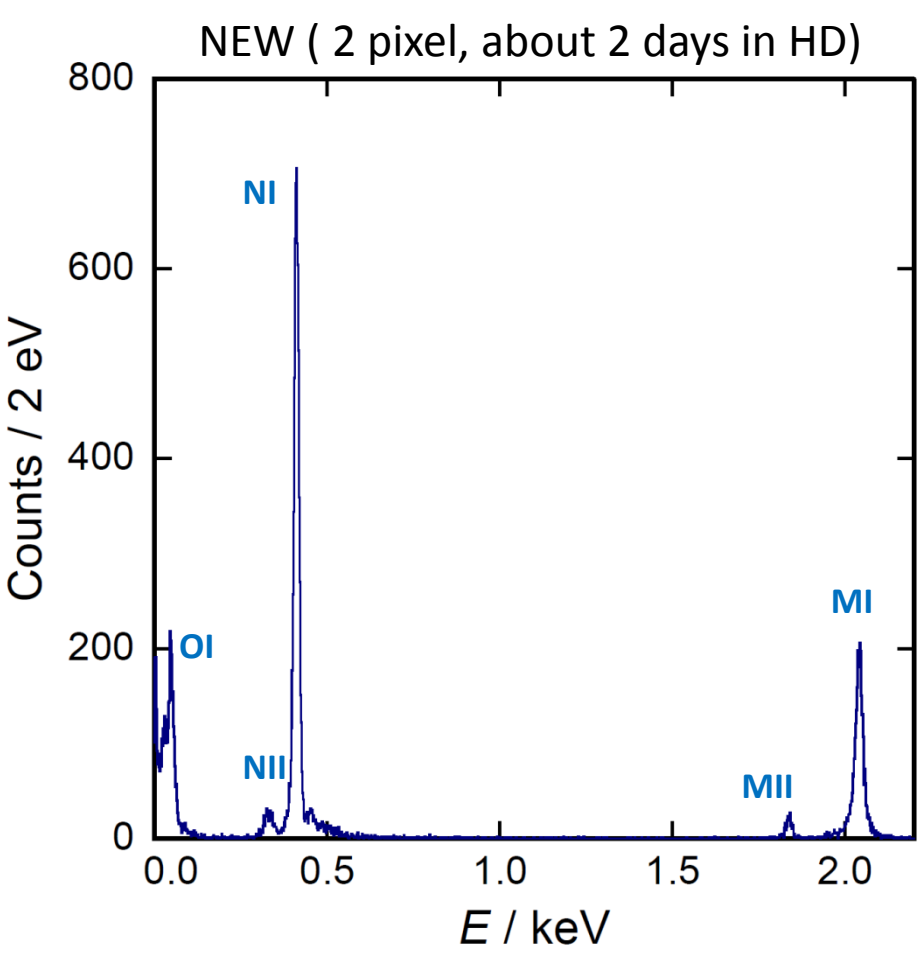
NEW (1 pixel, about 2 days in HD)

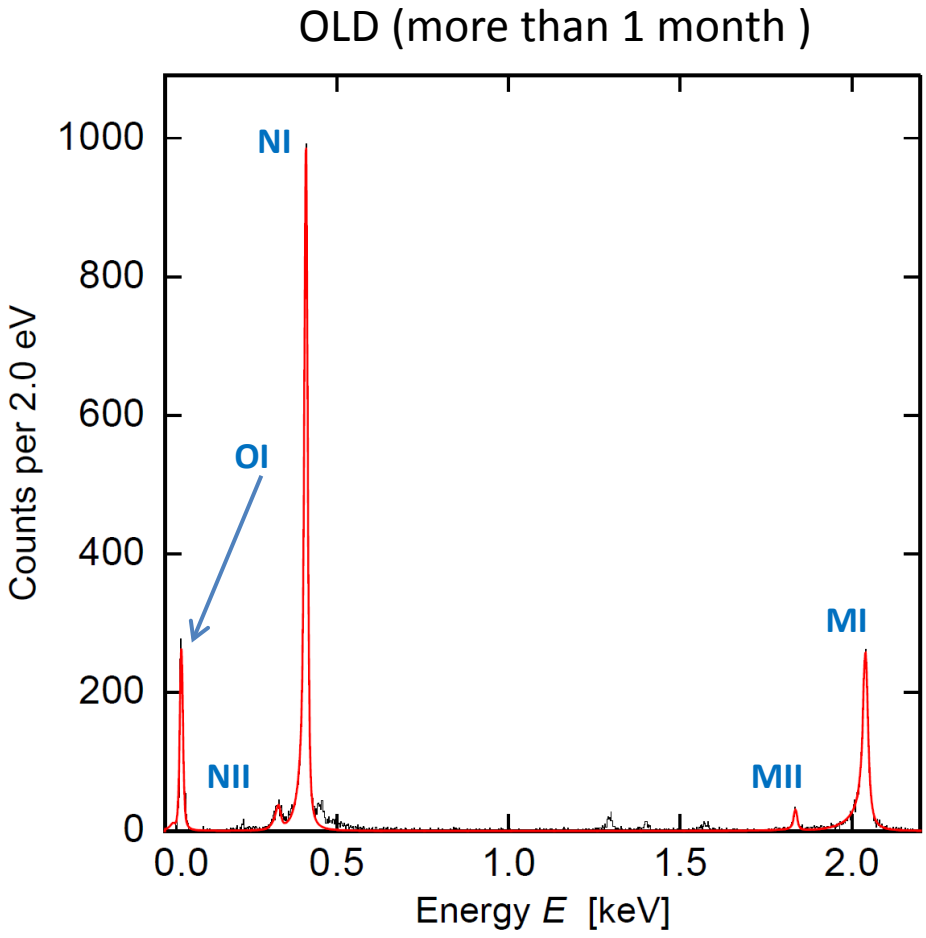


Mounted on a cold arm of a dry cryostat



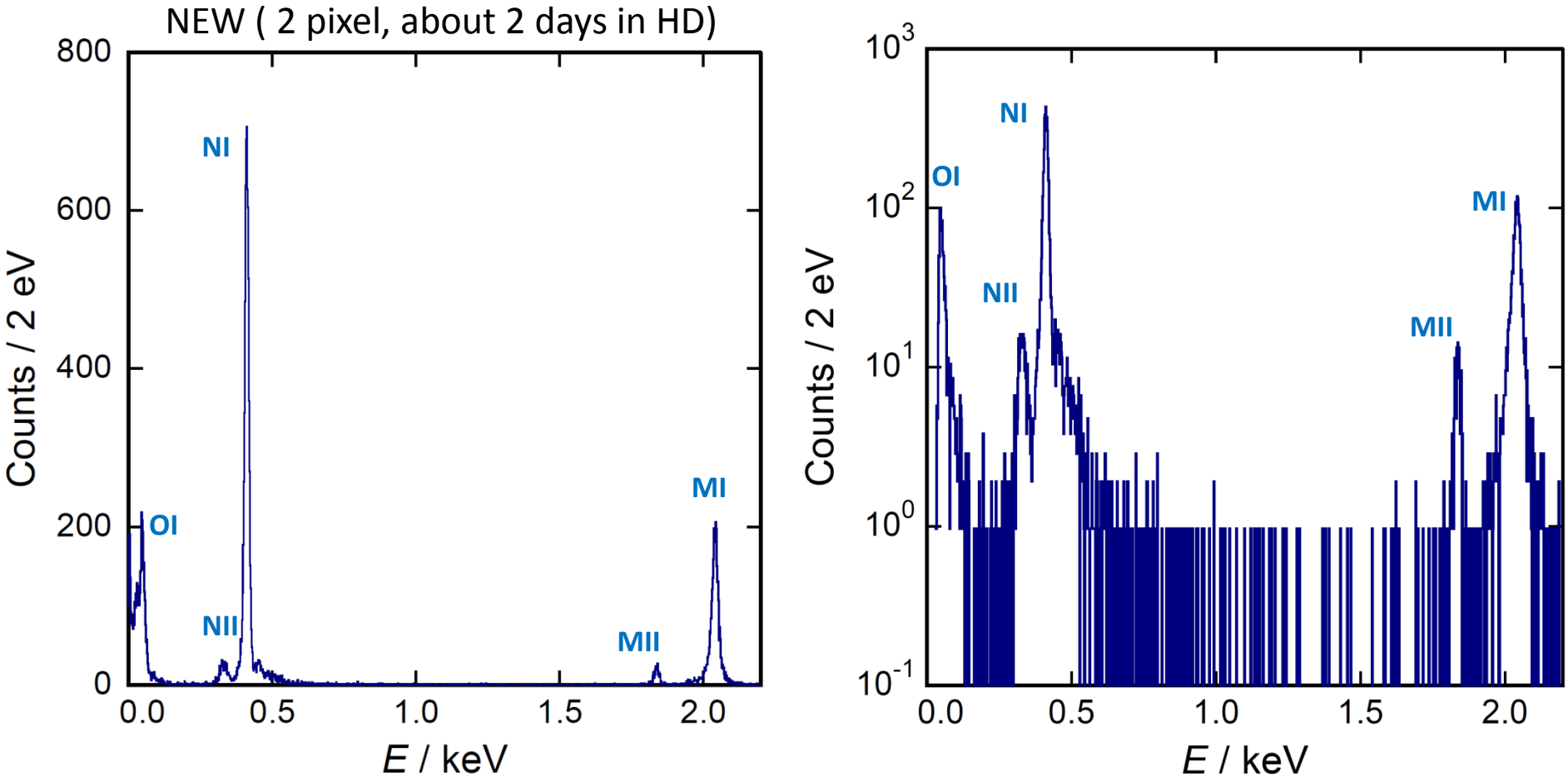
… first results





- Activity per pixel A ~ 0.1 Bq
- Baseline resolution ΔE_{FWHM} ~ 5 eV
- No strong evidence of radioactive contamination in the source

… first results



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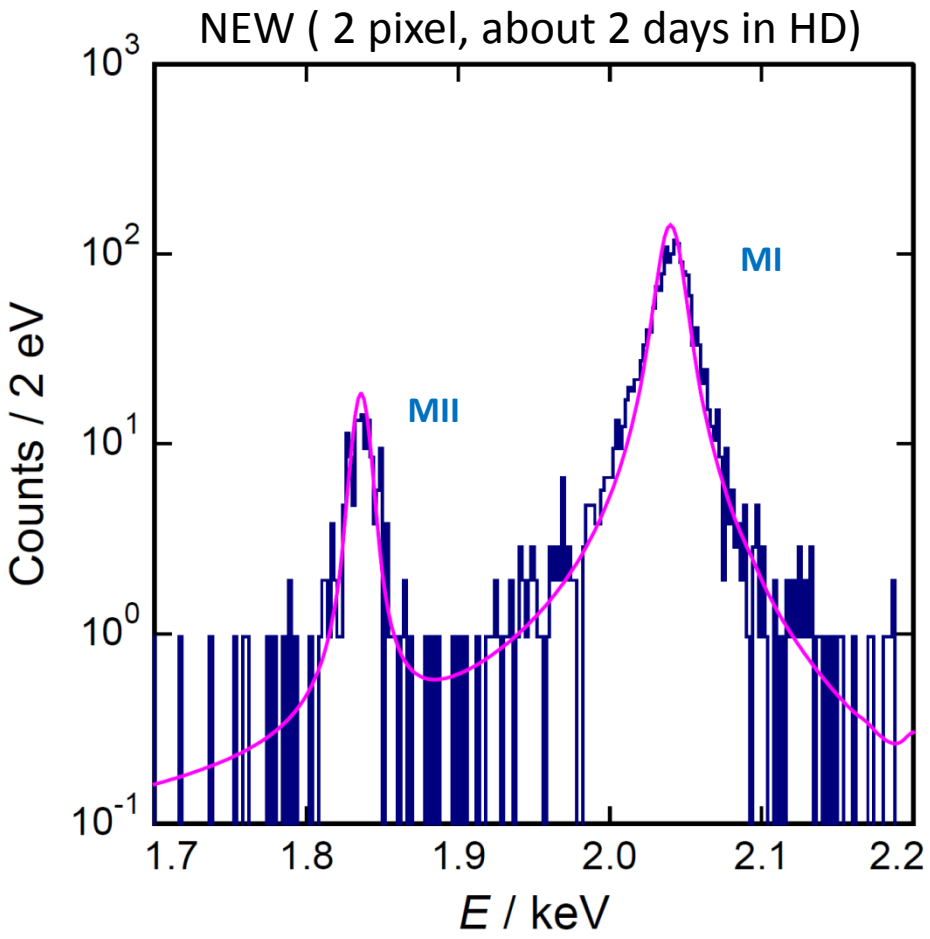
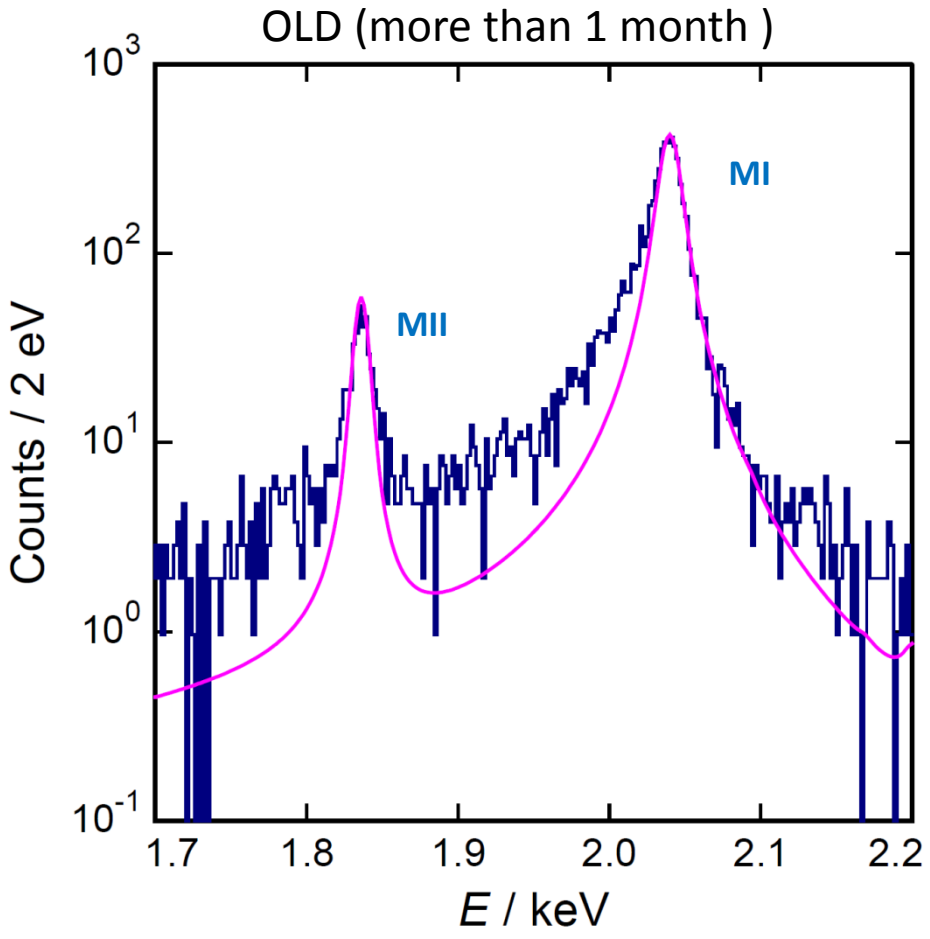
C. Hassel et al., submitted to JLTP (2015)

… first results

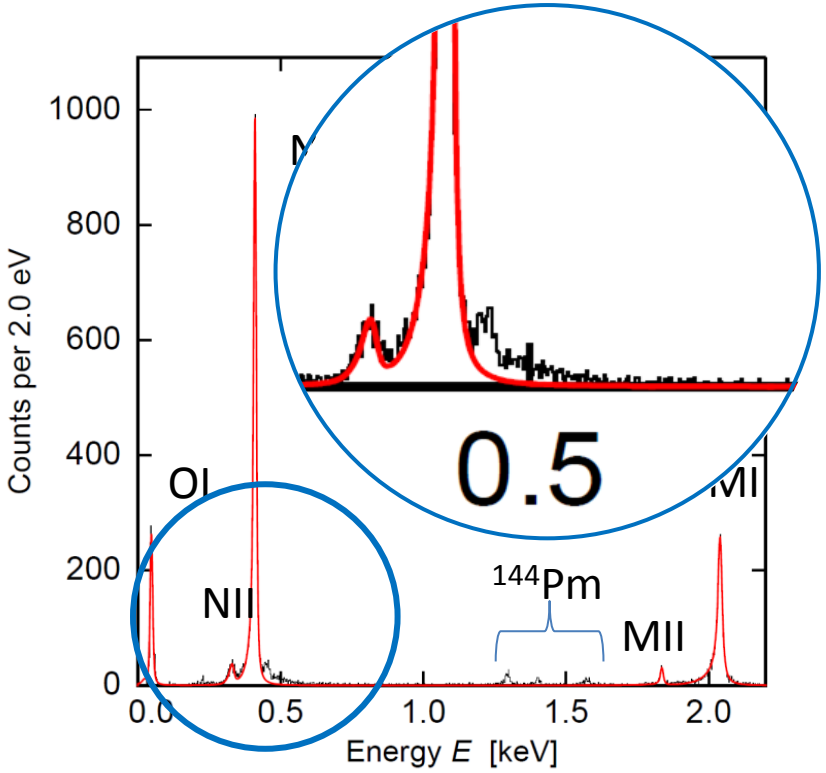




- Activity per pixel A ~ 0.1 Bq
- Baseline resolution ΔE_{FWHM} ~ 5 eV
- No strong evidence of radioactive contamination in the source
- Symmetric detector response

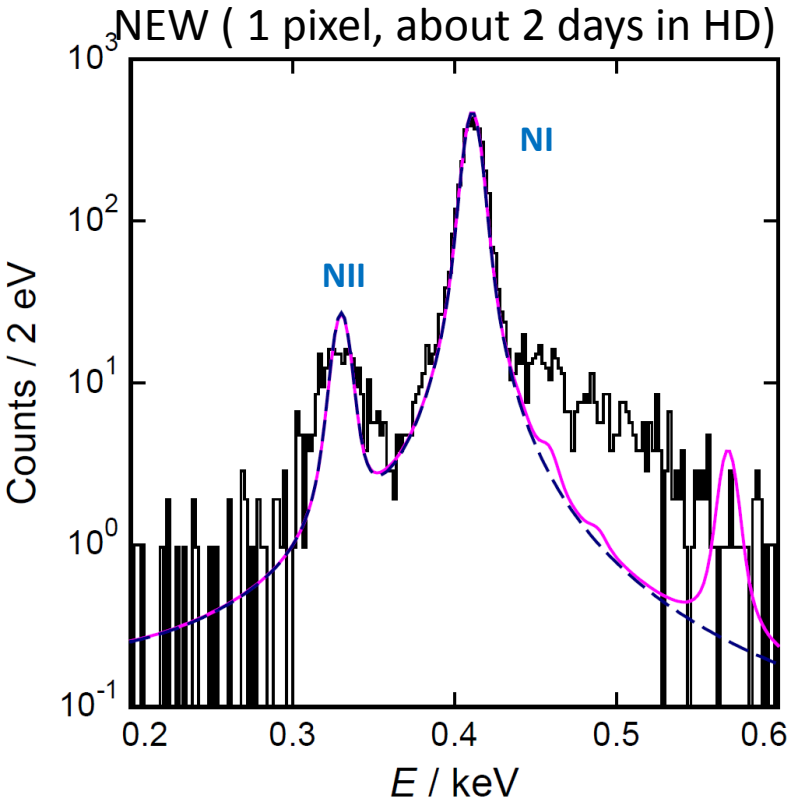
C. Hassel et al., submitted to JLTP (2015)

Characterisation of spectral shape



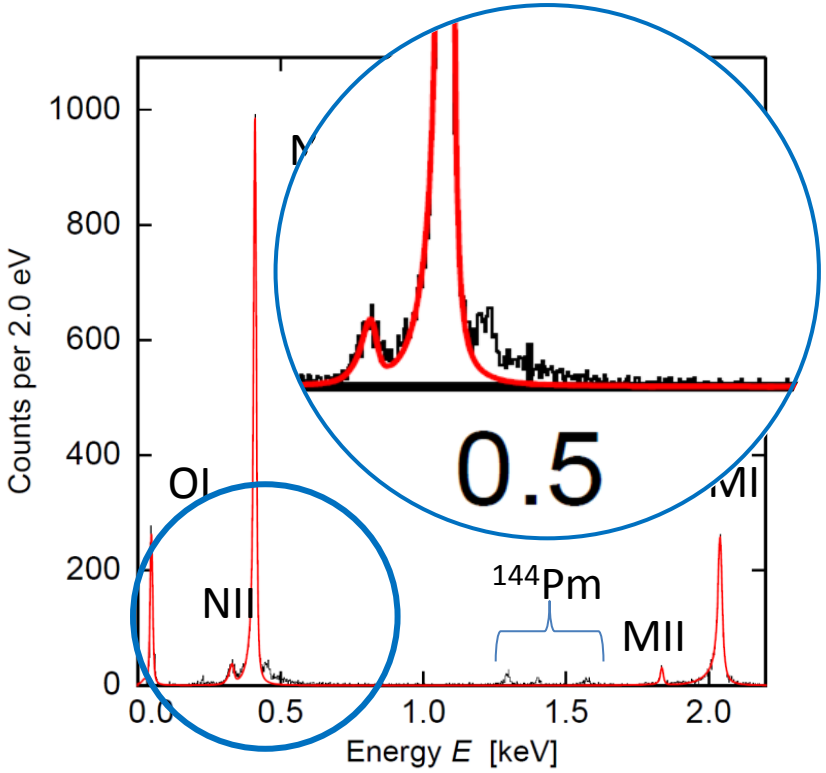
Estimate the effect of

- Higher order excitation in ^{163}Dy
- ^{163}Ho ion embedded in Au



- A. Faessler et al.
  J. Phys. G **42** (2015) 015108
- R. G. H. Robertson
  Phys. Rev. C **91**, 035504 (2015)
- A. Faessler et al.
  Phys. Rev. C **91**, 045505 (2015)
- A. Faessler et al.
  Phys. Rev. C **91**, 064302 (2015)
- A. De Rujula et al.
  http://arxiv.org/pdf/1510.05462.pdf

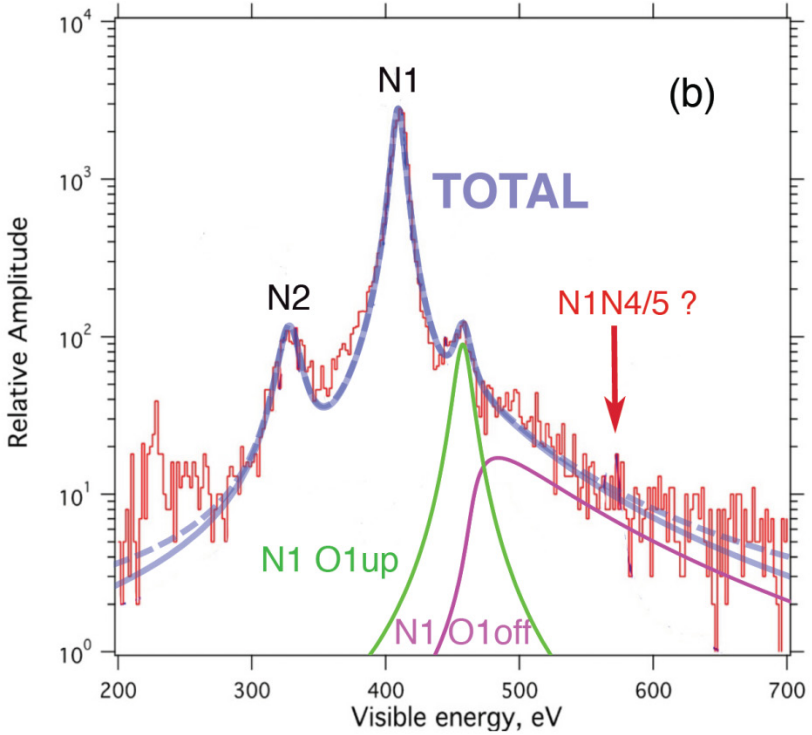
Characterisation of spectral shape



Estimate the effect of

- Higher order excitation in ^{163}Dy
- ^{163}Ho ion embedded in Au

OLD (more than 1 month)



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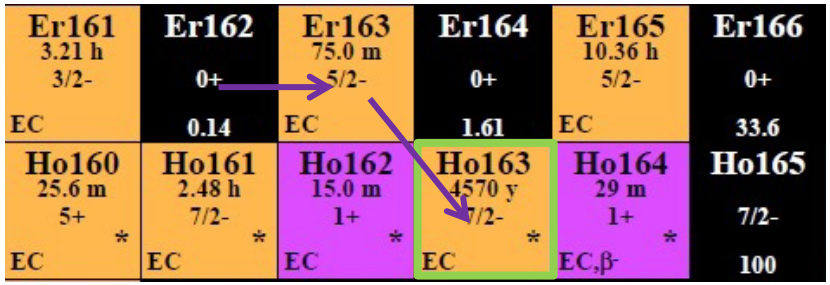
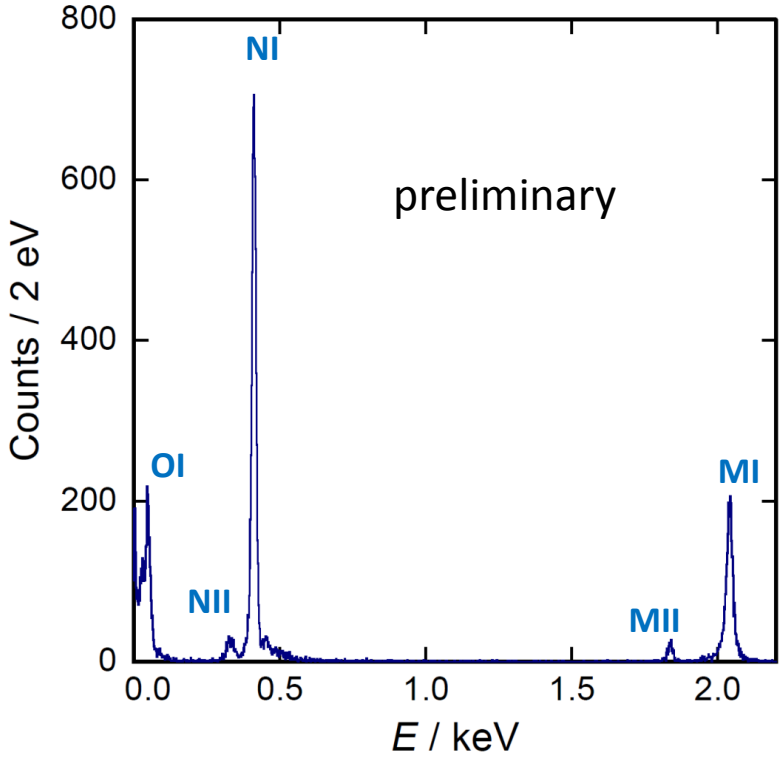
- A. Faessler et al.
  Phys. Rev. C **91**, 064302 (2015)
- A. De Rujula et al.
  http://arxiv.org/pdf/1510.05462.pdf

Conclusions and outlook

- High purity ^{163}Ho source has been produced
- ^{163}Ho ions have been successfully implanted in offline process @ISOLDE-CERN
- 32 new implanted detectors already show
  - Larger activity ~10^{-1} Bq
  - Low background ~10^{-4} events/eV/det/day
  - Good energy resolution
- new interesting results are coming!





Conclusions and outlook

- Prove scalability with medium large experiment **ECHo-1K**

  - A ~ 1000 Bq — High purity ^{163}Ho source (produced at ILL)
  - $\Delta E_{FWHM} < 5$ eV
  - $\tau_r < 1$ µs
  - multiplexed arrays → microwave SQUID multiplexing

  - 1 year measuring time → 10^{10} counts = Neutrino mass sensitivity $m_\nu < 10$ eV

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„Neutrino Mass Determination by Electron Capture in Holmium-163 – ECHo“

DFG Deutsche Forschungsgemeinschaft

- **ECHo-1M** towards sub-eV sensitivity

Thank you!

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