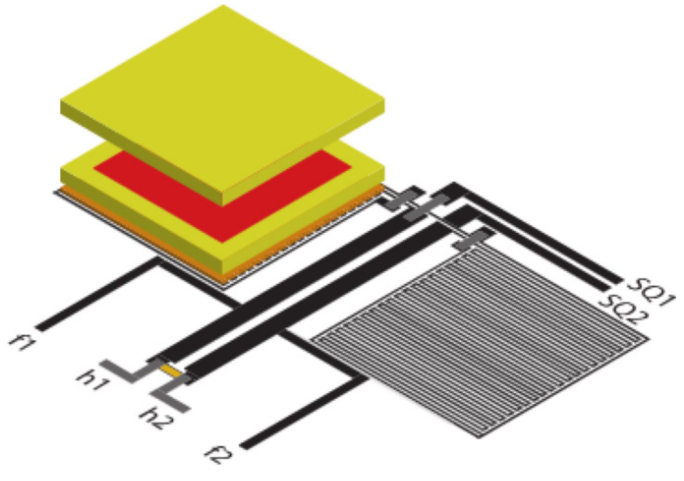
Electron Capture in ^{163}Ho experiment

Loredana Gastaldo
for the ECHo Collaboration

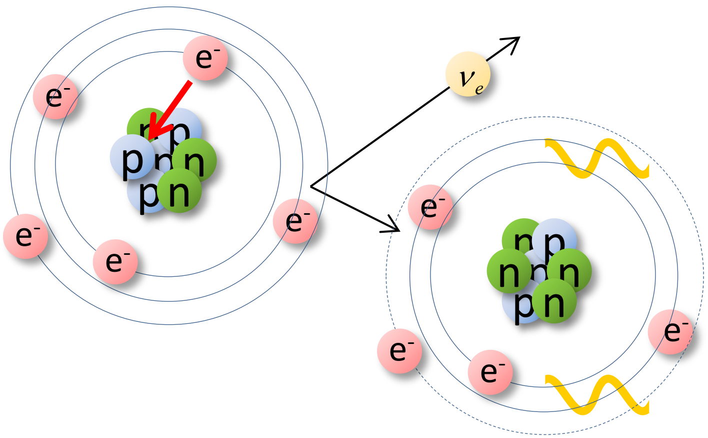
Kirchhoff Institute for Physics, Heidelberg University



Contents

- ^{163}Ho and neutrino mass
- The ECHo neutrino mass experiment
- Conclusions

^{163}Ho and neutrino mass



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

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

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

  Experimental range 2.3 keV – 2.8 keV

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

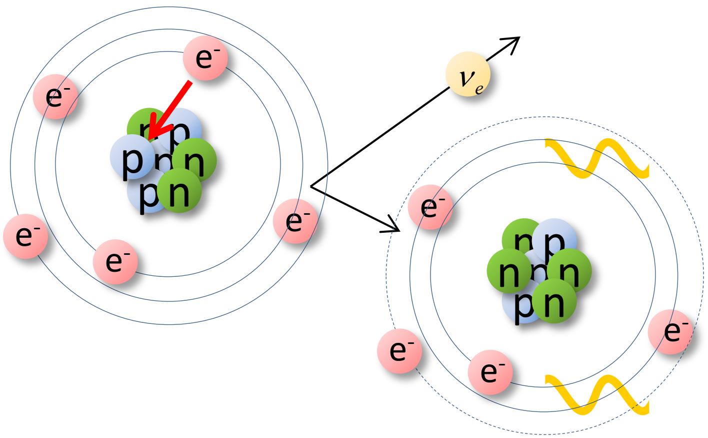
Atomic de-excitation:

- X-ray emission
- Auger electrons
- Coster-Kronig transitions

} Calorimetric measurement

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

^{163}Ho and neutrino mass



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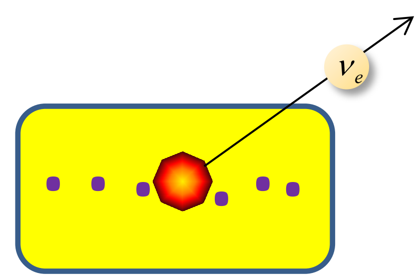
Source inside



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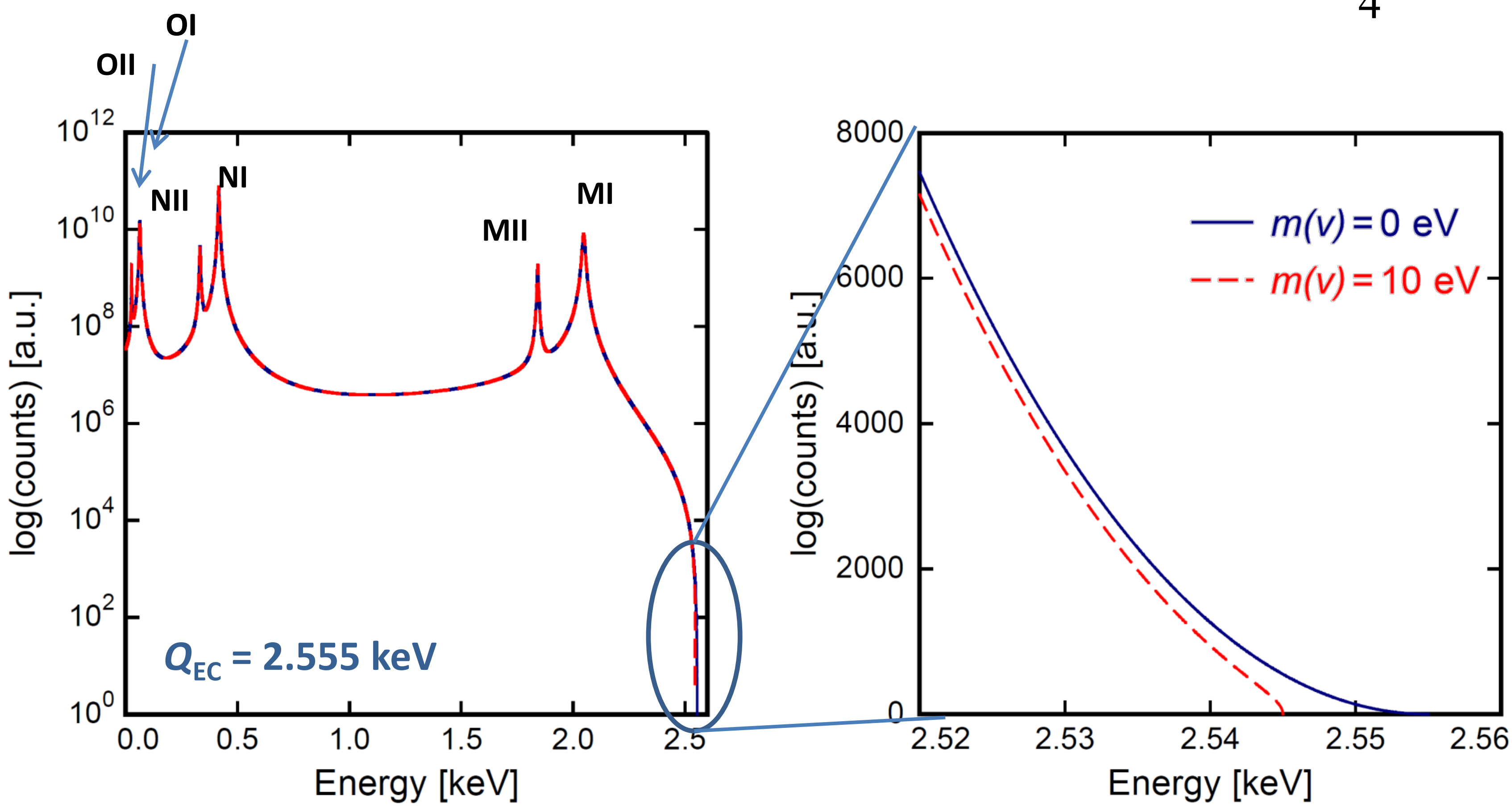
^{163}Ho and neutrino mass

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



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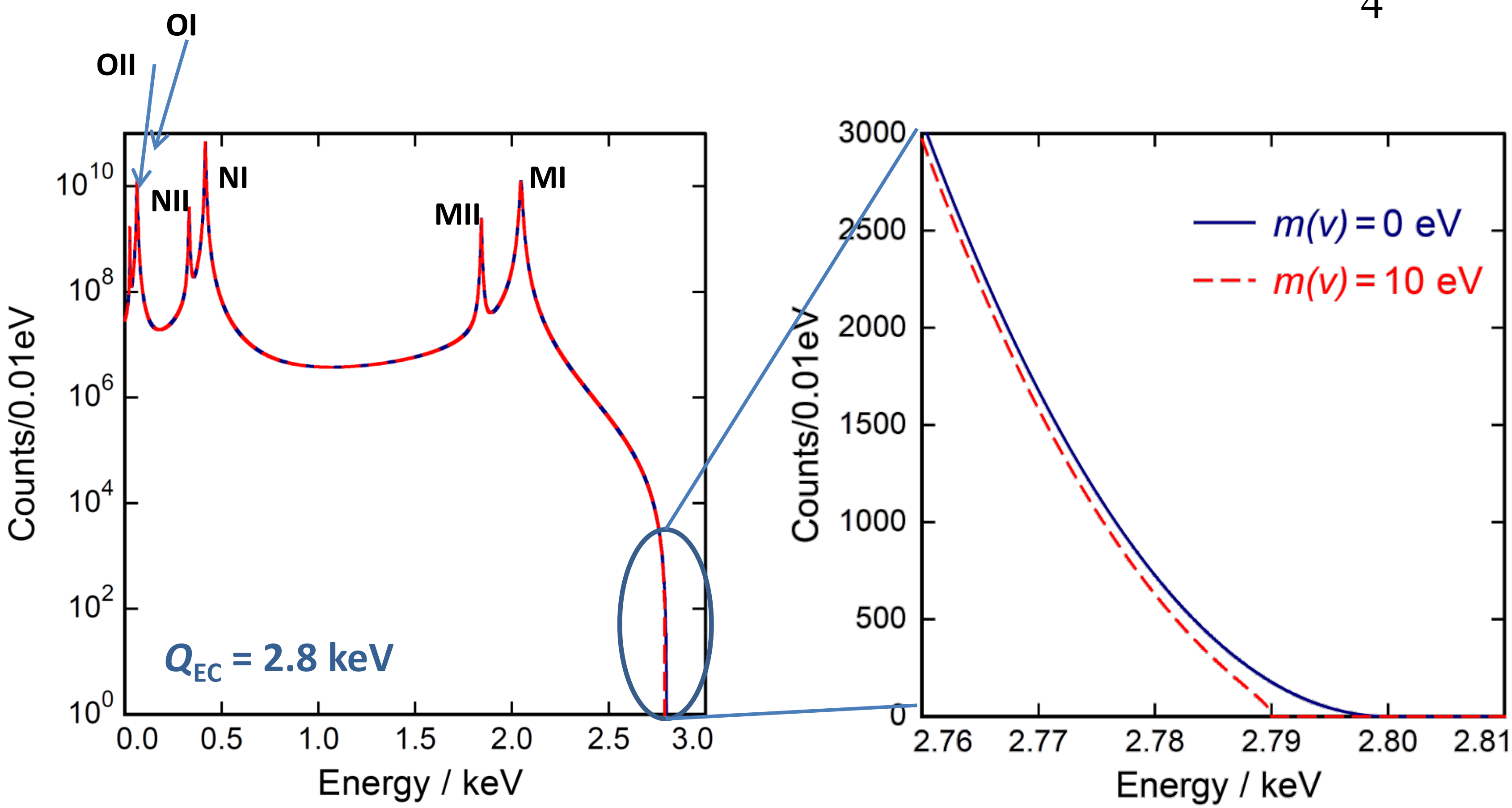
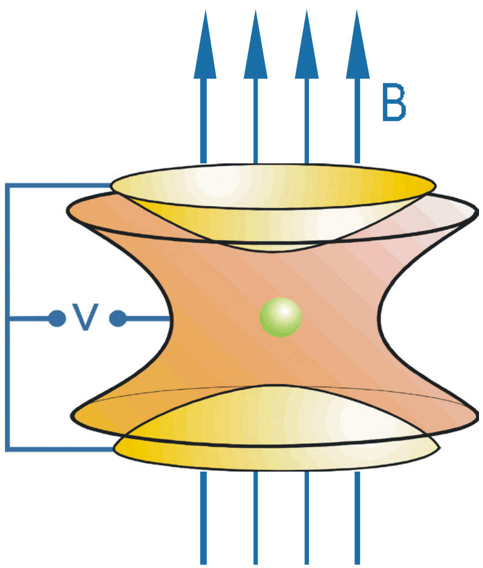
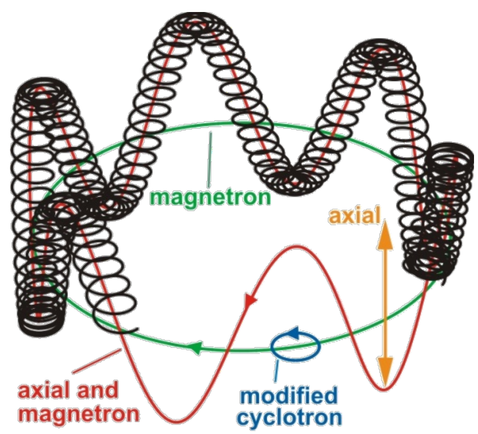


Q_{EC} determination of ^{163}Ho

Penning Trap mass spectrometry

- Precise measurement of the ^{163}Ho and ^{163}Dy atomic mass





$$\nu_c^2 = \nu_+^2 + \nu_-^2 + \nu_z^2$$

Talk by Klaus Blaum yesterday

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

JG|U

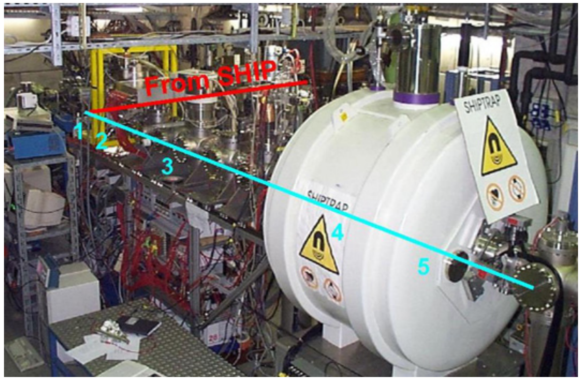
Q_{EC} determination of ^{163}Ho

Penning Trap mass spectrometry

- First experiments at TRIGA-TRAP (Uni-Mainz) in 2014 *
  - Development of efficient Ho ion source using laser ablation
  - Uncertainties on ^{163}Dy and ^{163}Ho mass reduced by a factor of 2
  - Know-how to be applied in SHIPTRAP

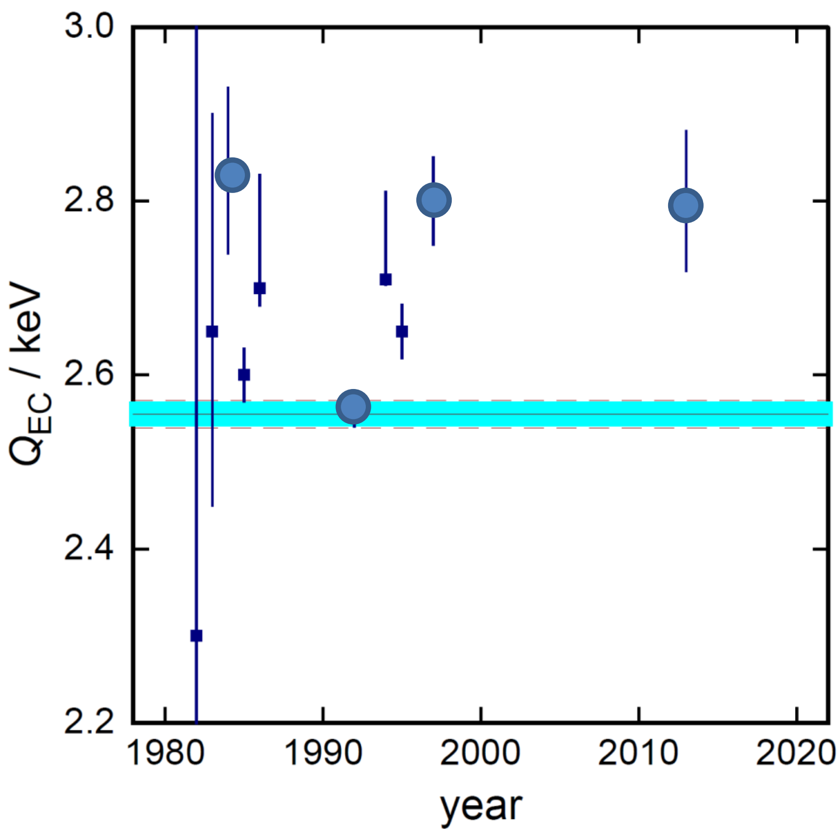
*Preparatory studies for a high-precision Penning trap measurement of the ^{163}Ho electron capture Q-value
F. Schneider et al., submitted to EPJ

- Presently: SHIPTRAP (GSI) **
  - Q_{EC} determination with smaller uncertainties
  - Define scale of the experiment



** 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., submitted to PRL

Q_{EC} determination of ^{163}Ho



- Calorimetric measurements
- Other methods

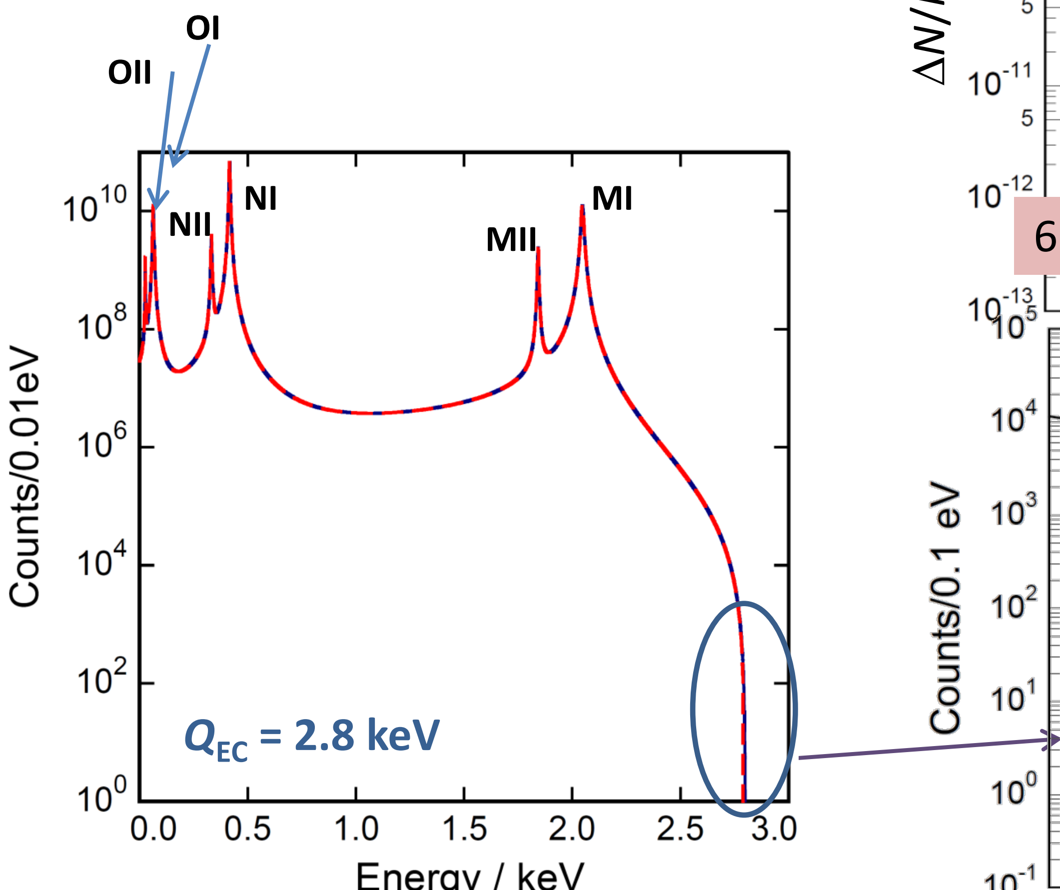
To reduce uncertainties in the analysis:
Q_{EC} determination within **1 eV**
→ PENTATRAP (MPIK HD)

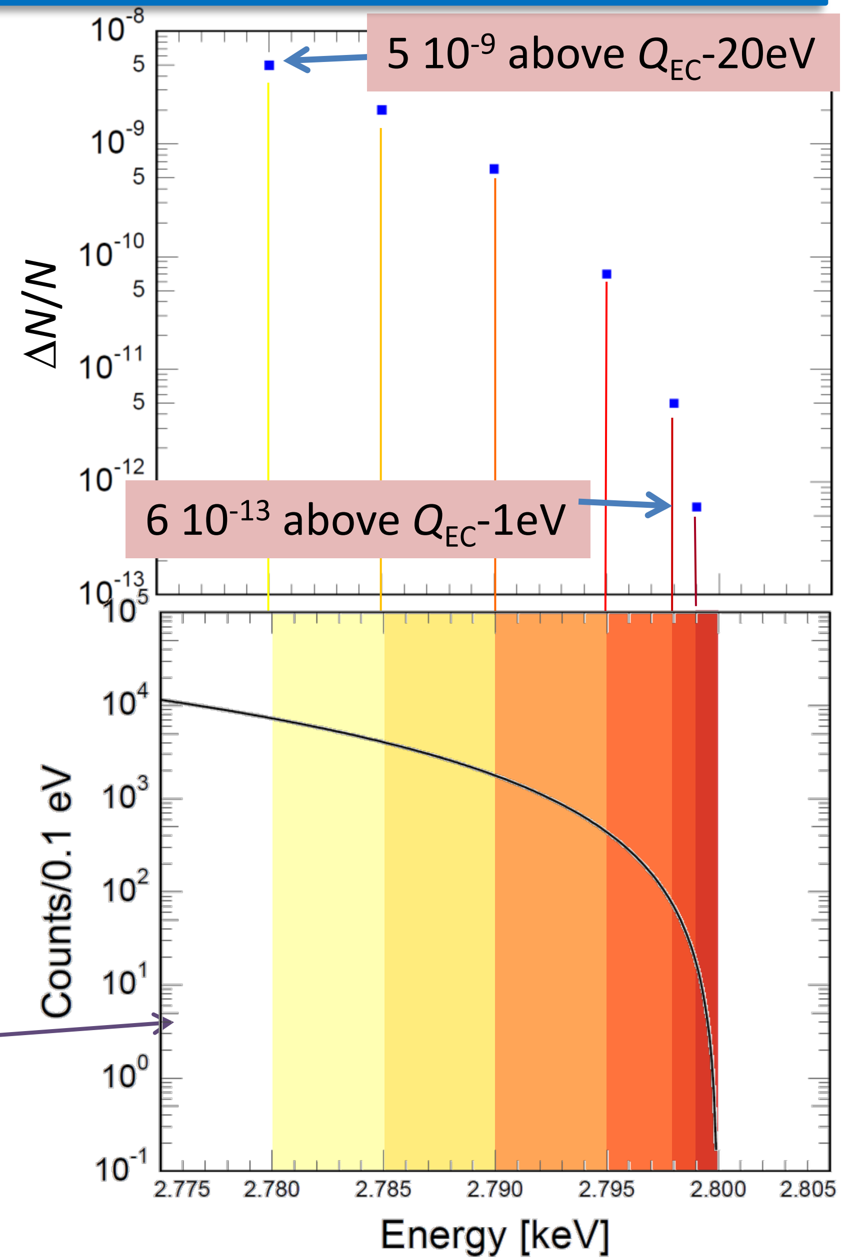
Talk by Klaus Blaum yesterday

^{163}Ho and neutrino mass: sub-eV sensitivity

Statistics in the end point region

- $N_{ev} > 10^{14}$ → $A \approx 1$ MBq





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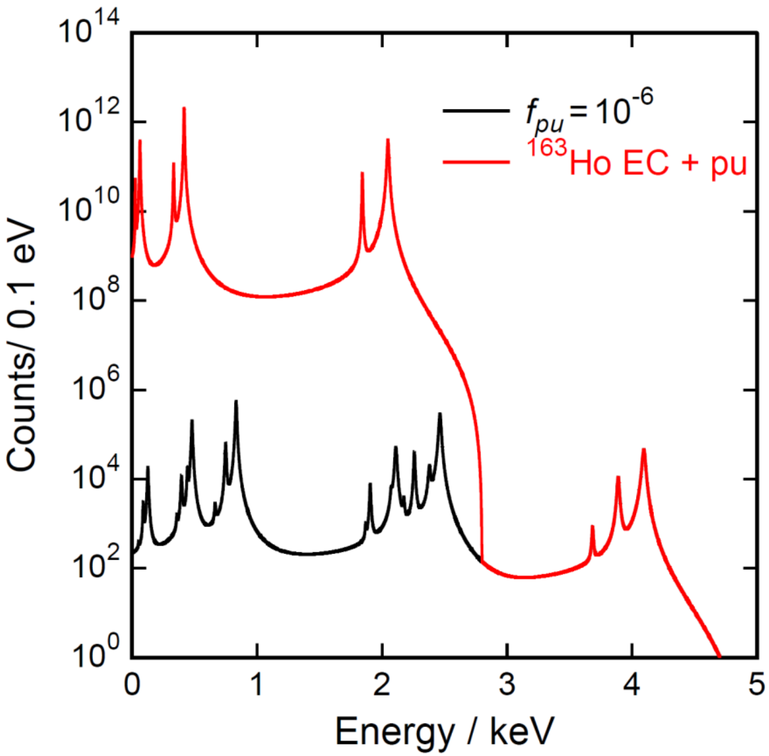
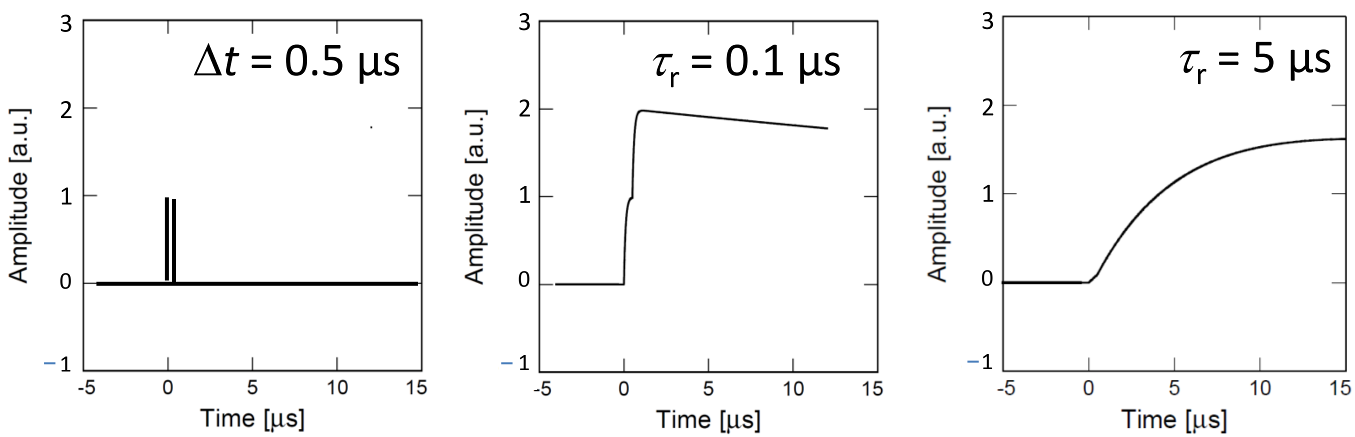
Unresolved pile-up ($f_{pu} \sim a \cdot \tau_r$)

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





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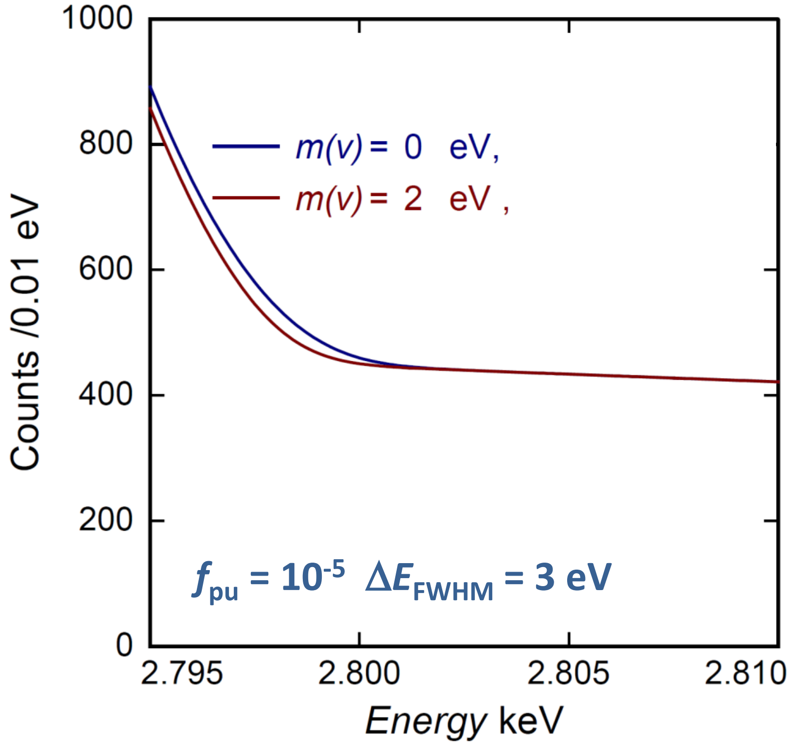
Precision characterization of the endpoint region

- $\Delta E_{FWHM} < 2$ eV



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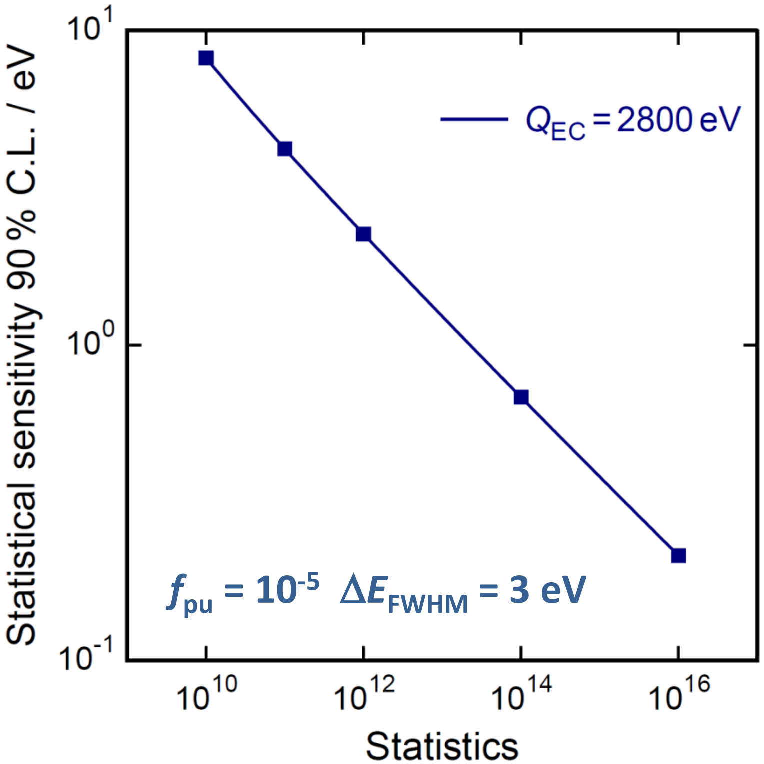
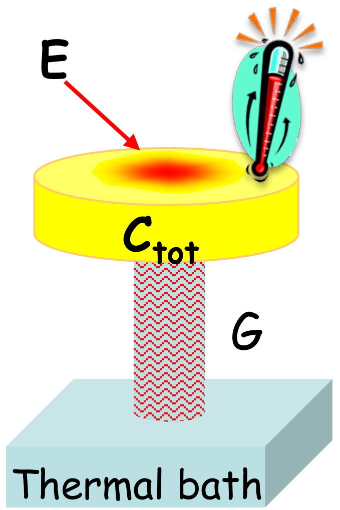


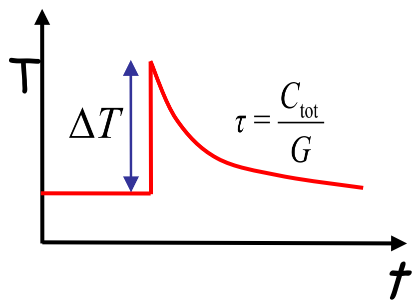
Low temperature

Metallic Magnetic Calorimeter

Low temperature micro-calorimeters



$$\Delta T \cong \frac{E}{C_{tot}}$$



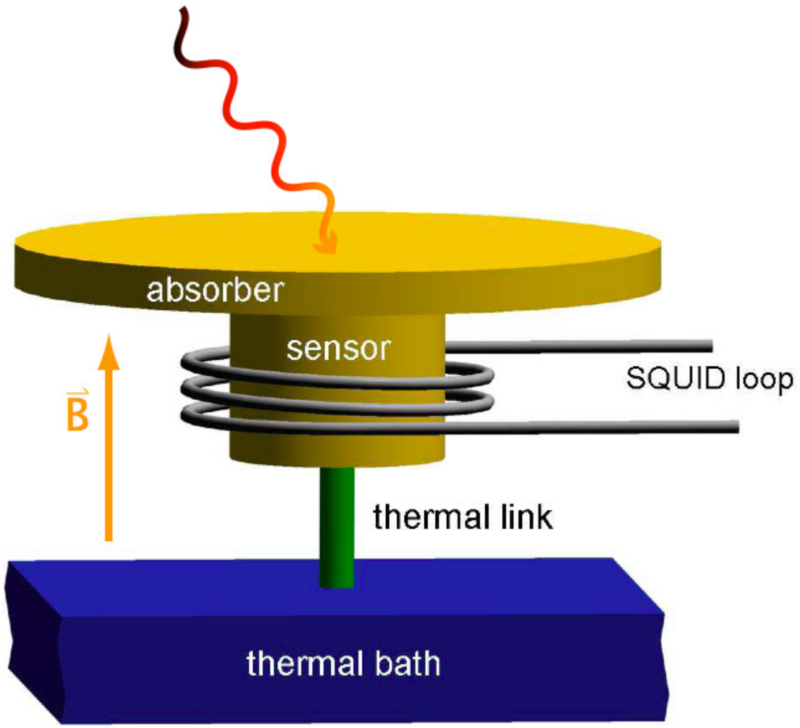
***E* = 10 keV**
***C*$_{tot}$ = 1 pJ/K**
→ ~ 1 mK

- Very small volume
- Working temperature below 100 mK
  small specific heat
  small thermal noise
- **Very sensitive temperature sensor**

Metallic magnetic calorimeters (MMCs)

A. Fleischmann et al.,
AIP Conf. Proc. **1185**, 571, (2009)

- Paramagnetic Au:Er sensor

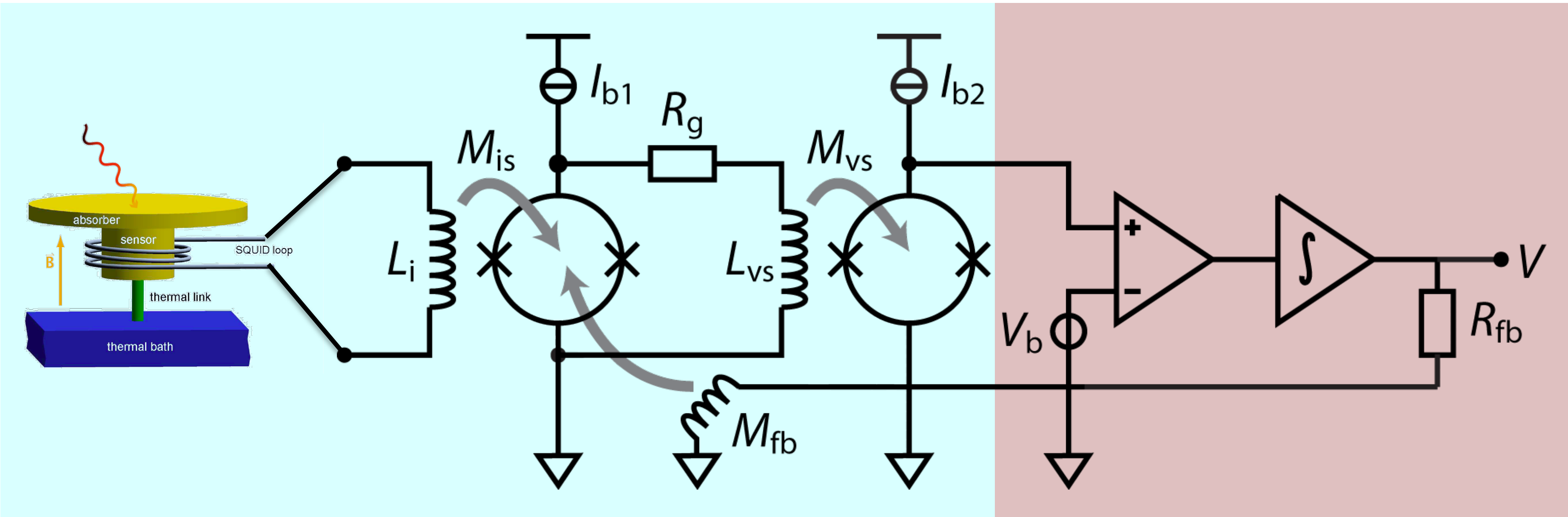


$$\Delta\Phi_S \propto \frac{\partial M}{\partial T}\Delta T \quad \rightarrow \quad \Delta\Phi_S \propto \frac{\partial M}{\partial T}\frac{E}{C_{sens}+C_{abs}}$$

MMCs: Readout

T ~ 30 mK

T ~ 300 mK

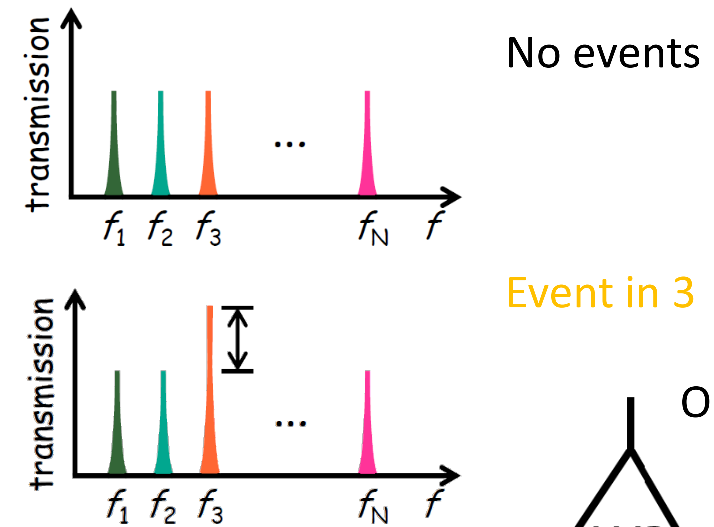


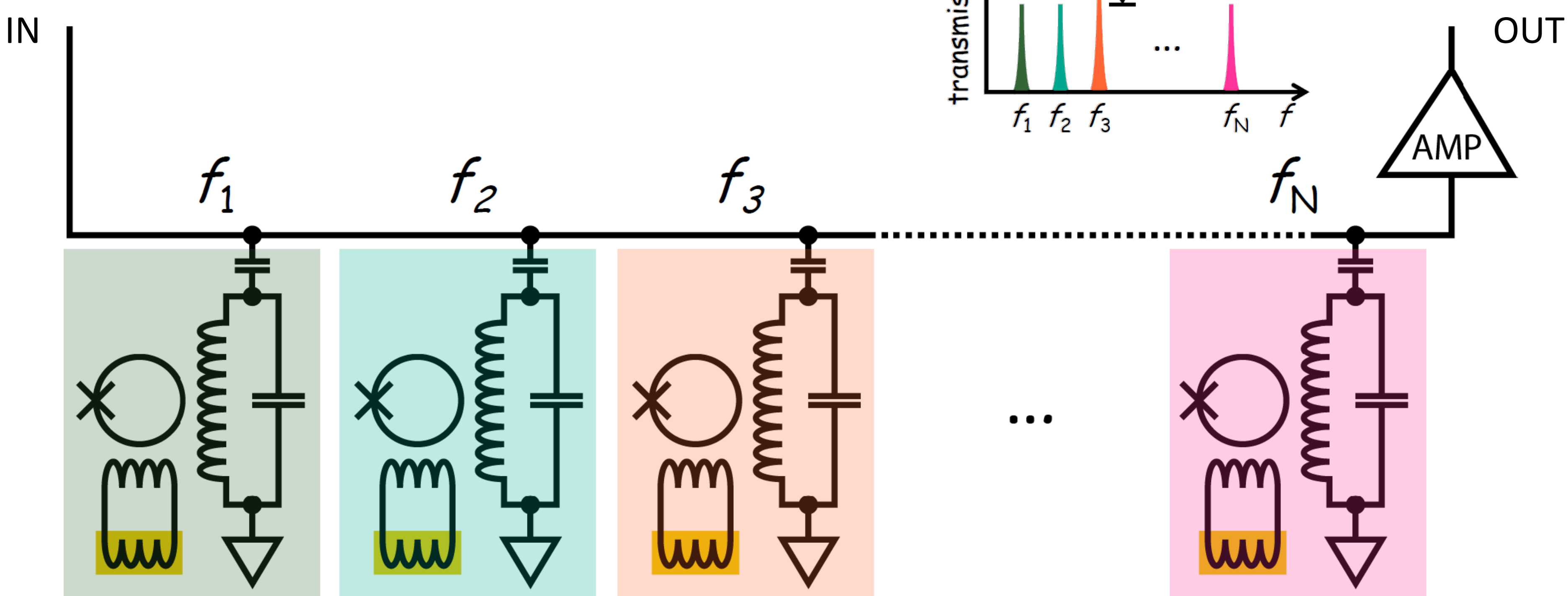
Two-stage SQUID setup with flux locked loop allows for:

- low noise
- large bandwidth / slewrate
- small power dissipation on detector SQUID chip (voltage bias)

MMCs: Microwave SQUID multiplexing

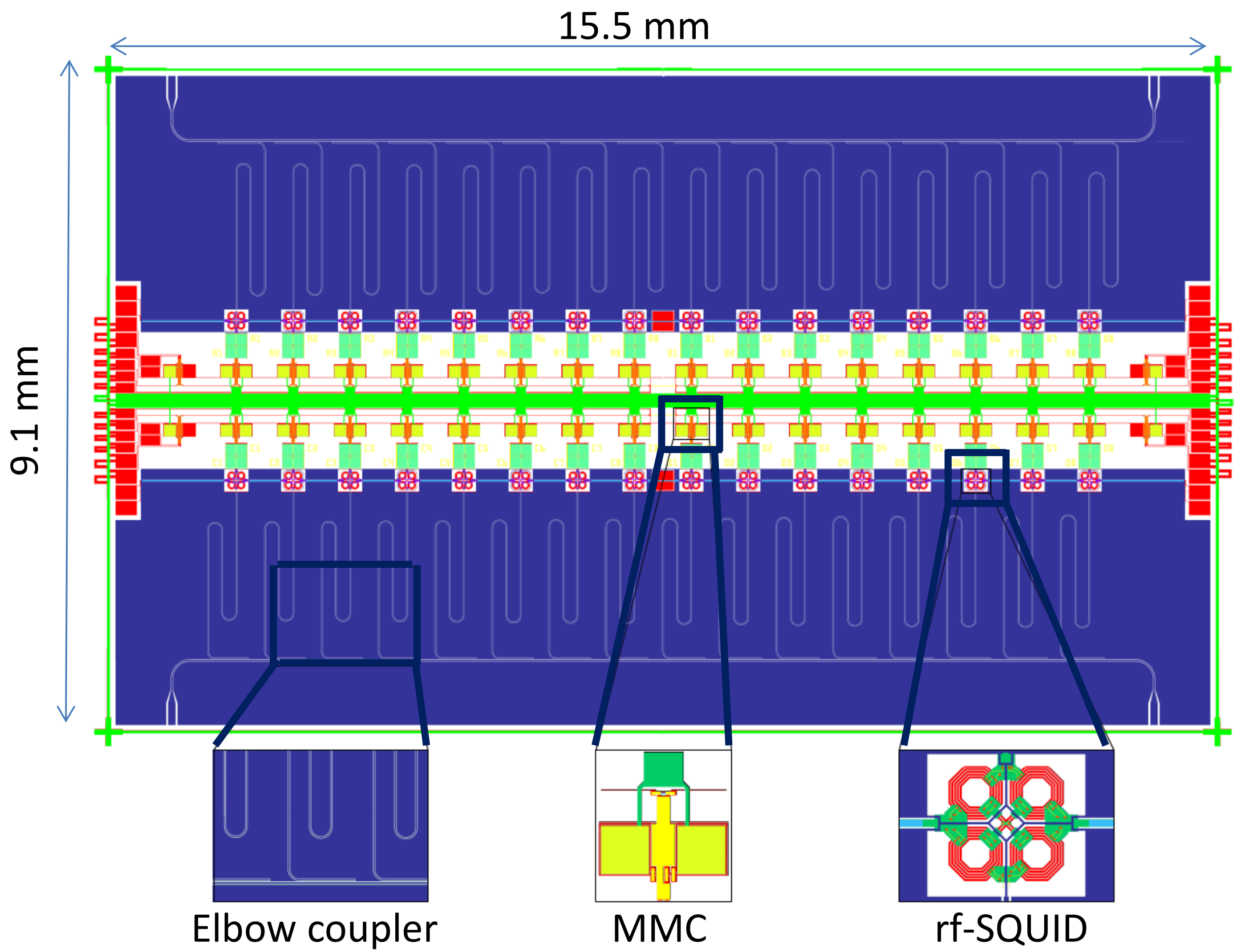
- Single HEMT amplifier and 2 coaxes to read out **100 - 1000** detectors





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

MMCs: Microwave SQUID multiplexing



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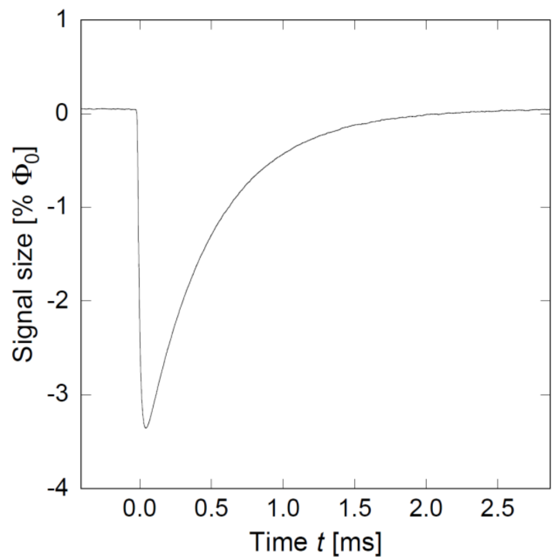
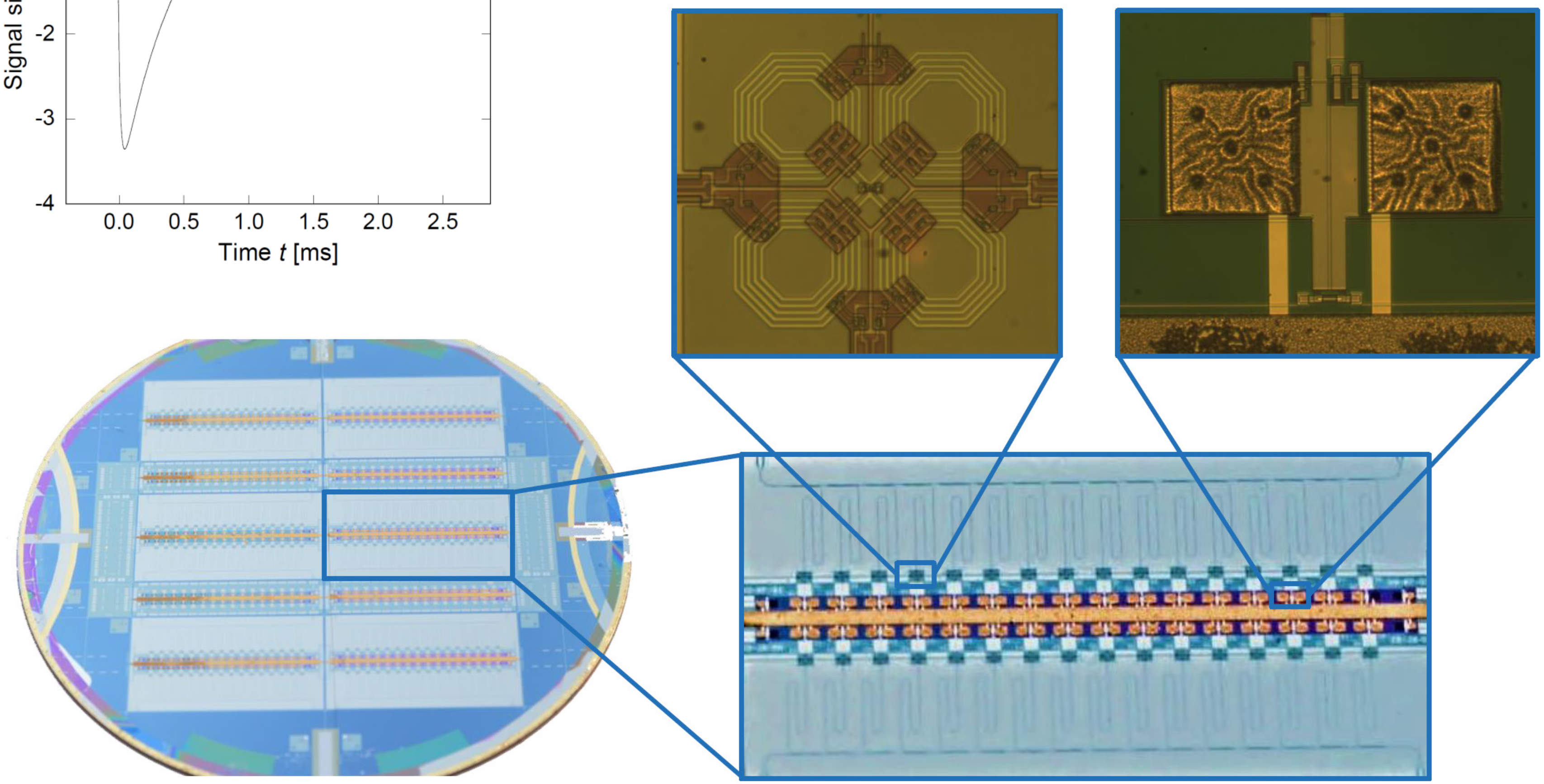
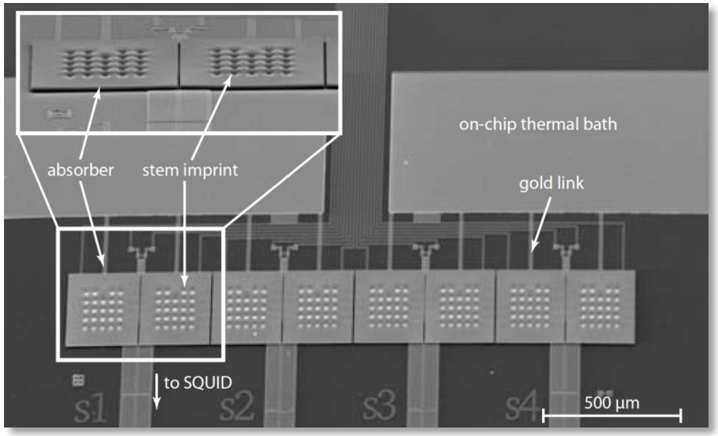


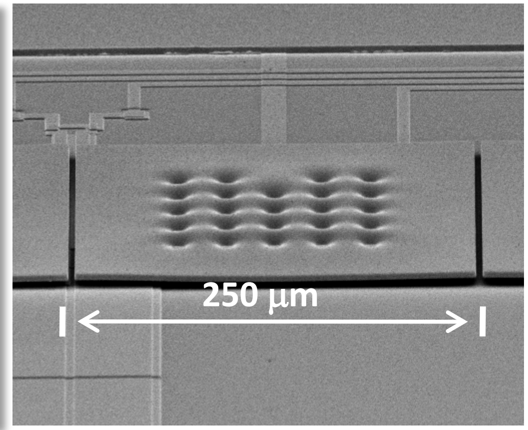
Successful production and test of the first prototype



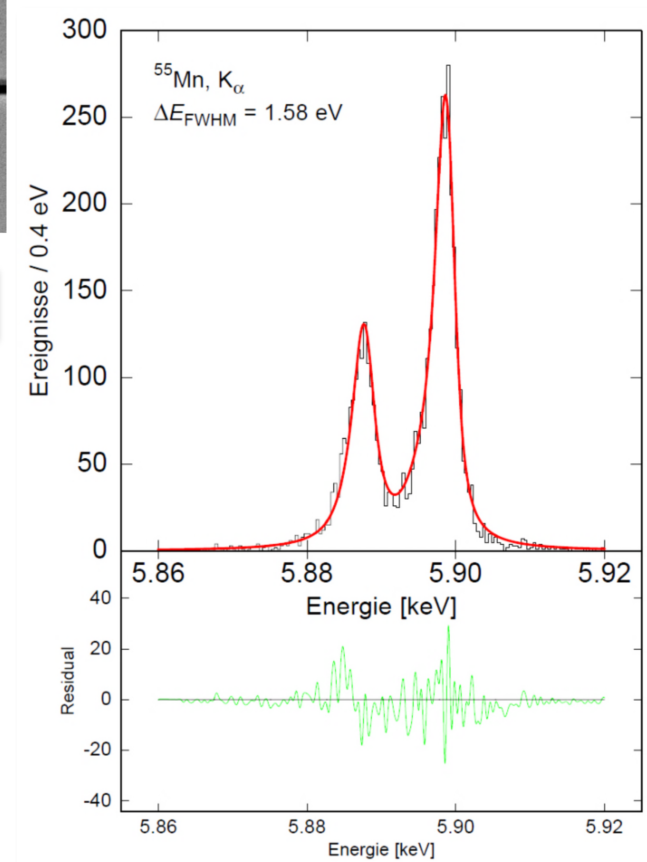
M. Wegner et al., in preparation

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

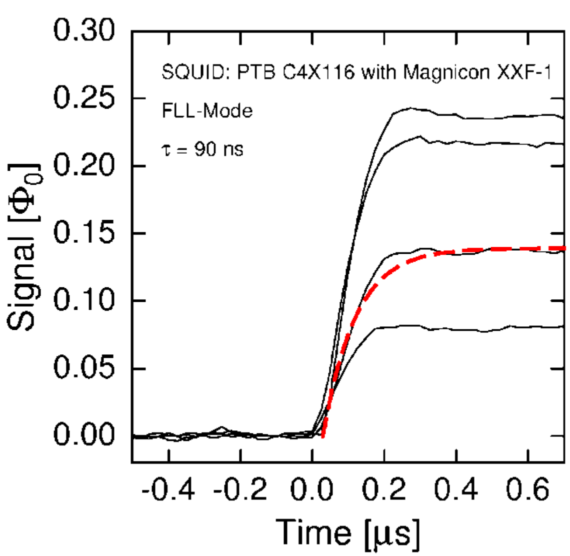




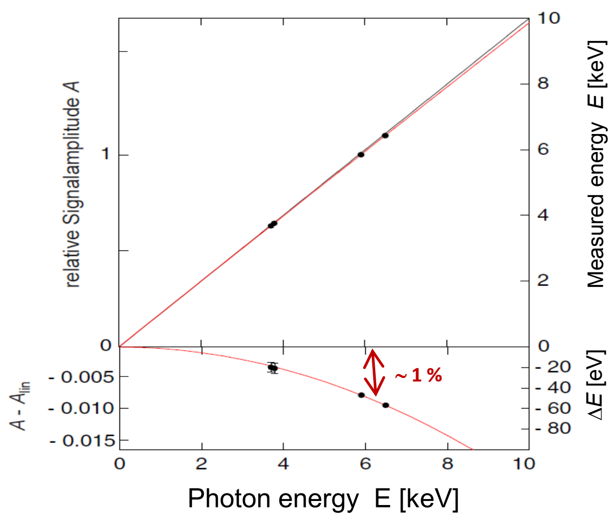
ΔE_{FWHM} = 1.6 eV @ 6 keV



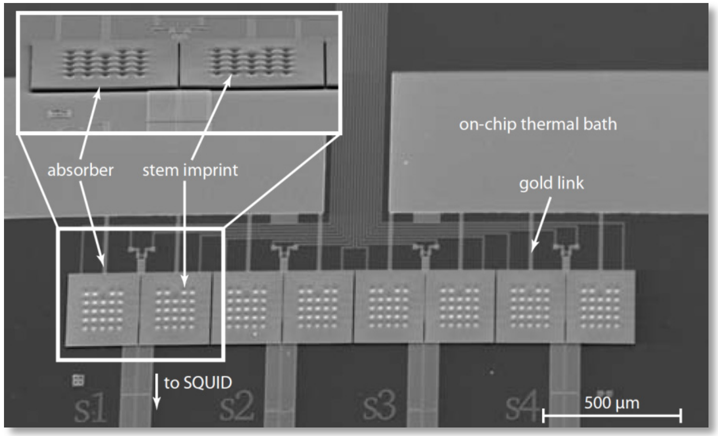
Rise Time: 90 ns

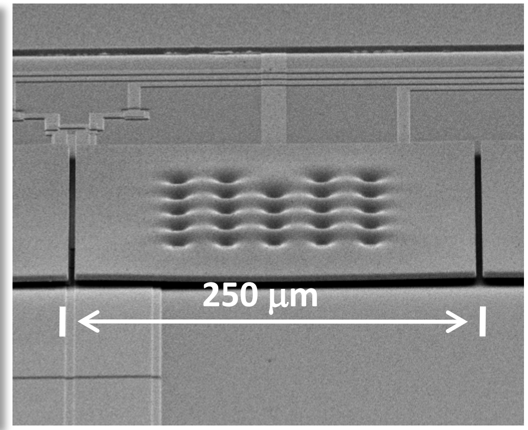


Non-Linearity < 1% @6keV



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





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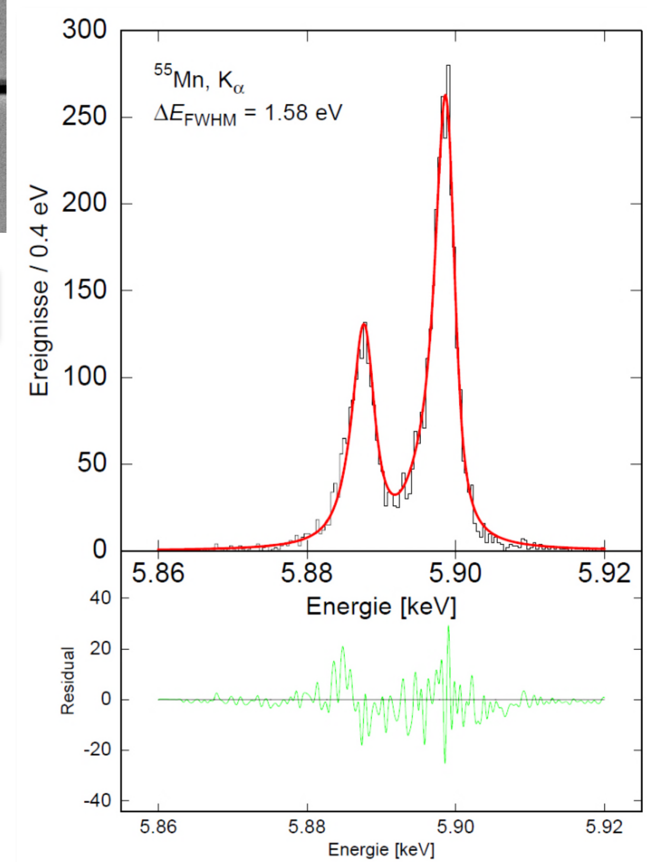

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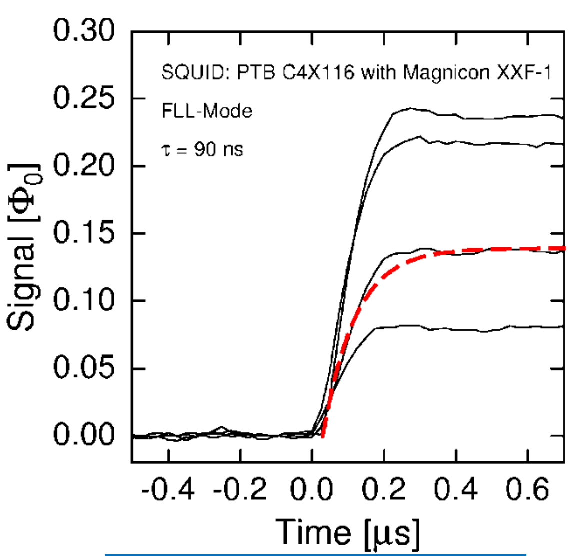

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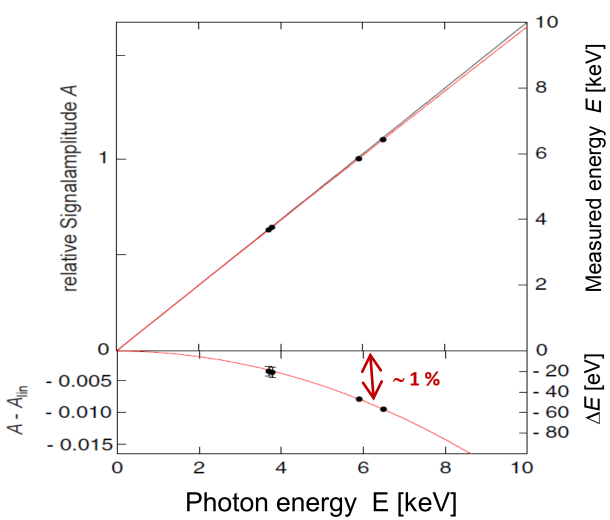

Reduction un-resolved pile-up

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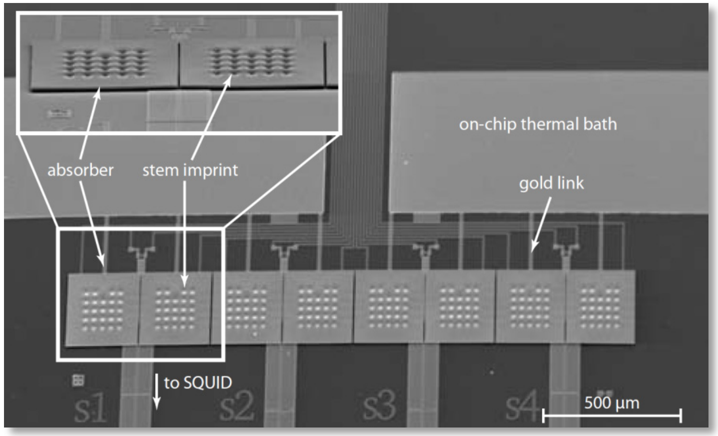

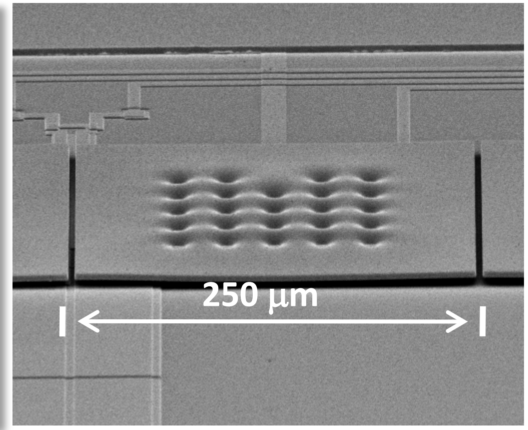

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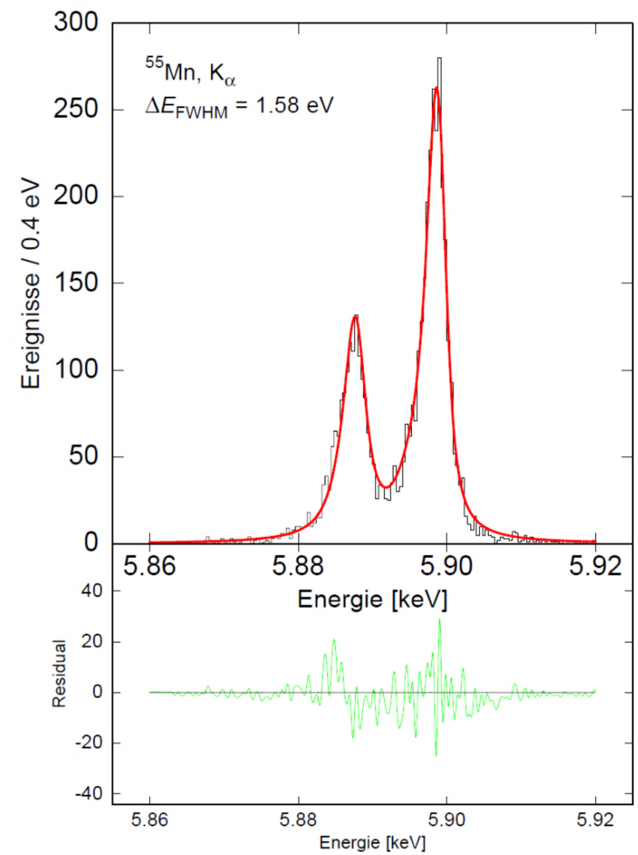

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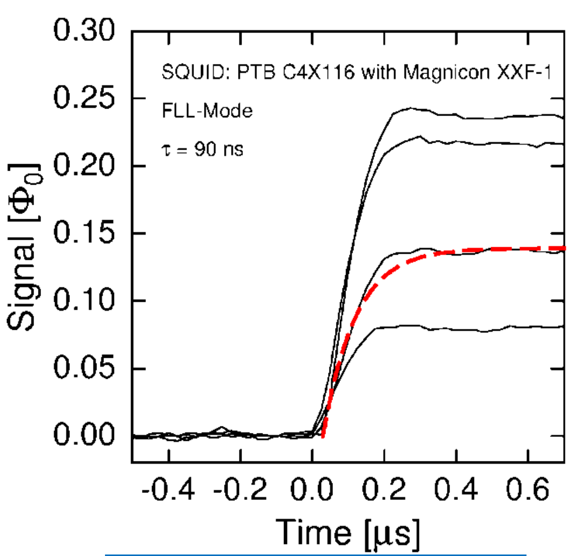

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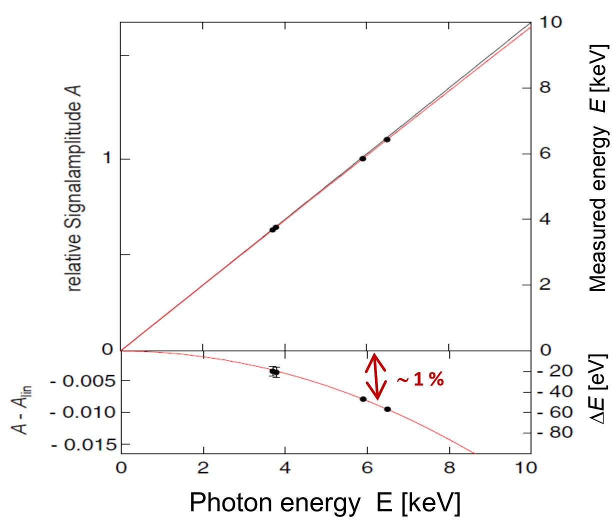

Definition of the energy scale

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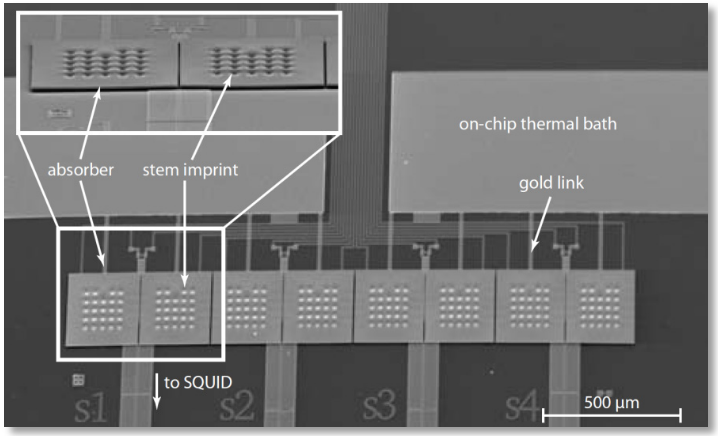

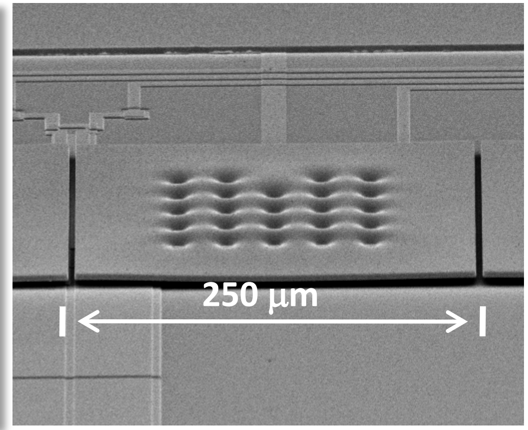

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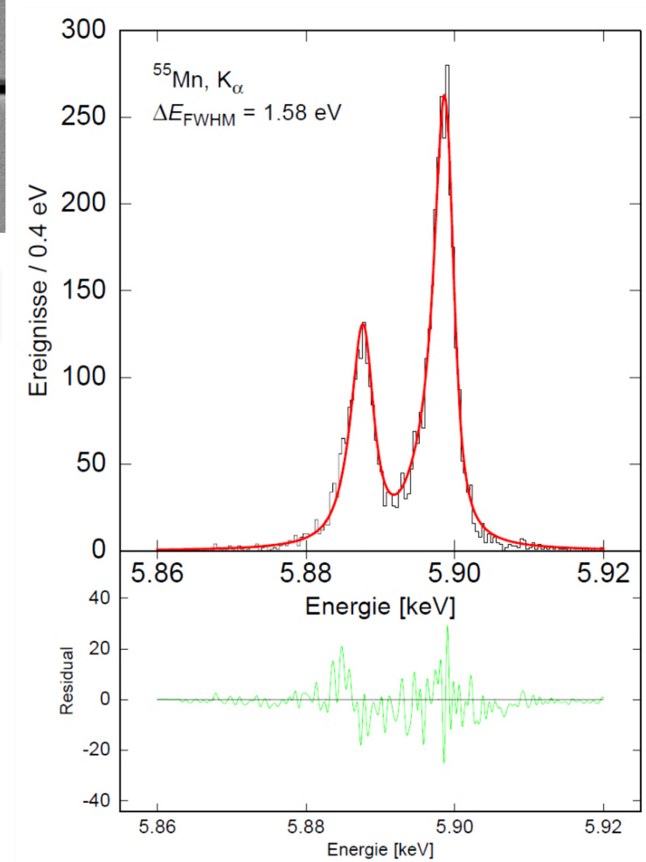

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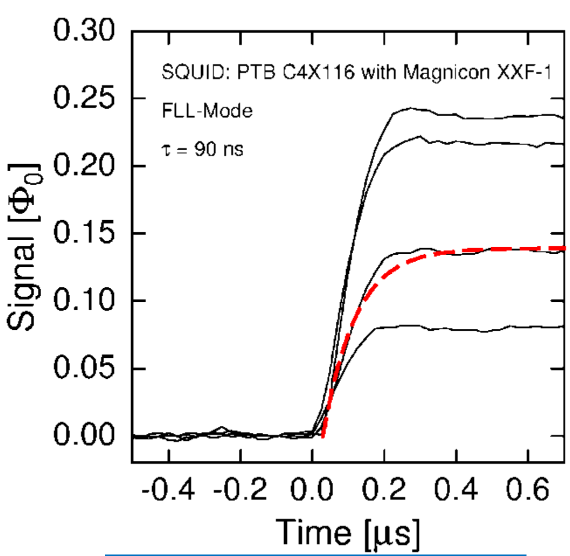
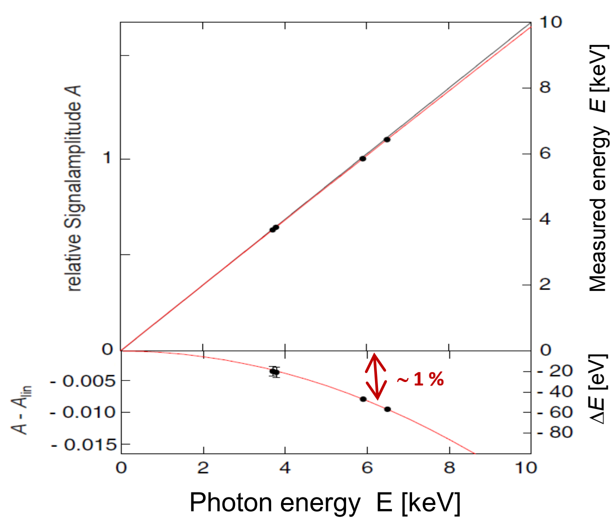




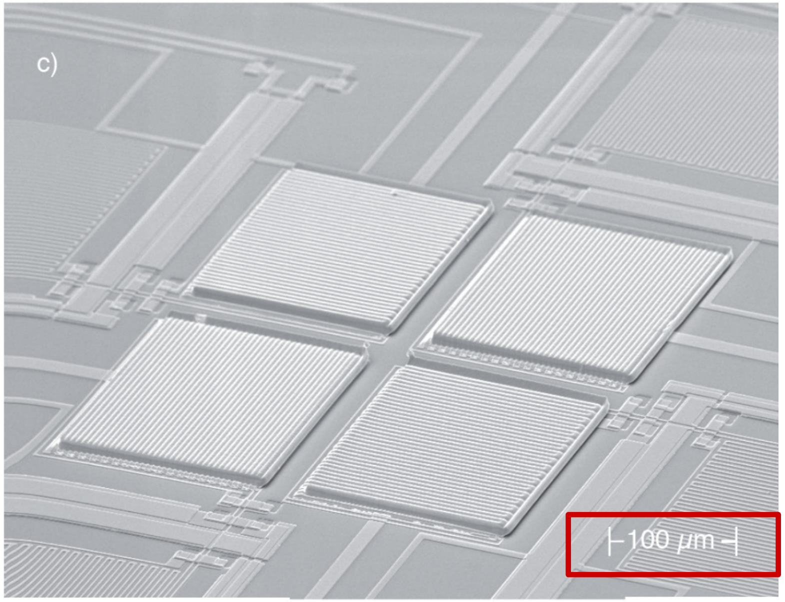
Reduction un-resolved pile-up

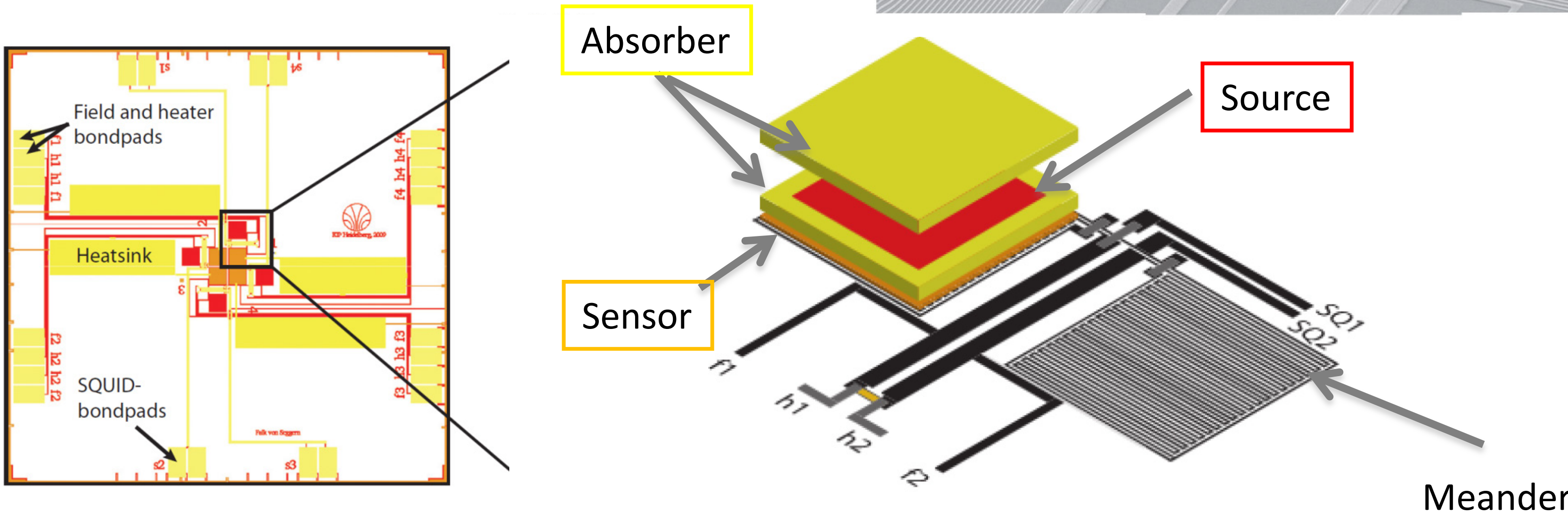
Definition of the energy scale

Reduced smearing in the end point region

First detector prototype for ^{163}Ho

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



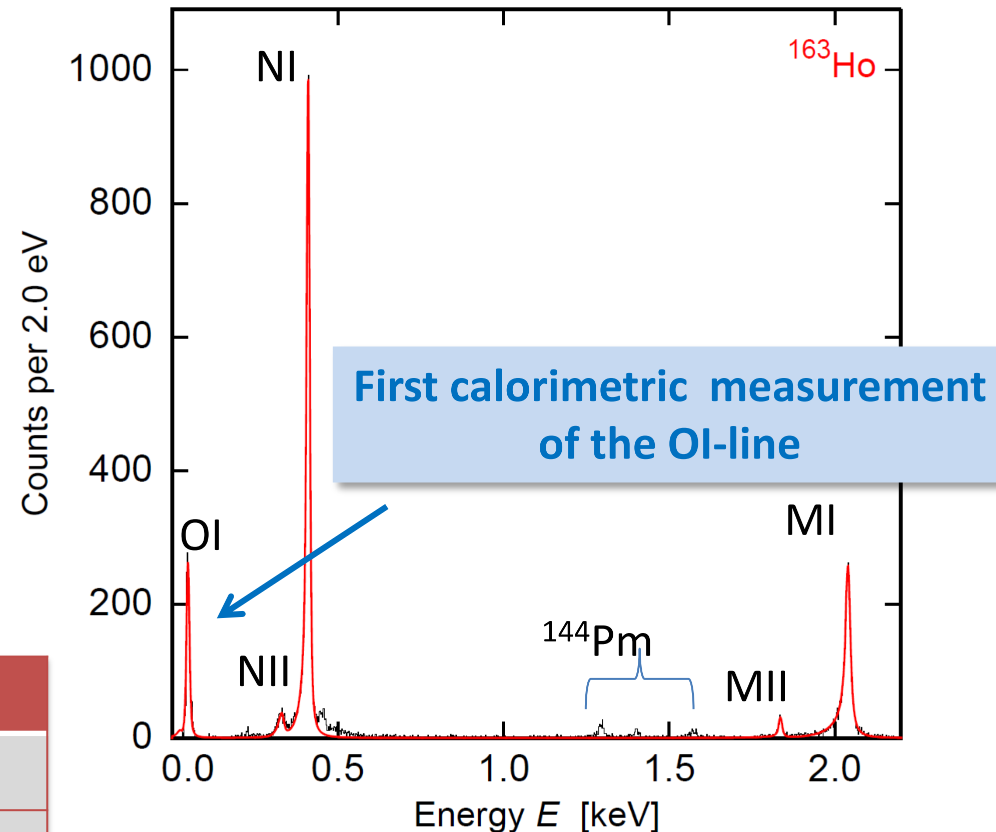


L. Gastaldo et al.,
Nucl. Inst. Meth. A, 711 (2013) 150

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)
  ΔE_{FWHM} = 2.4 eV @ 0 keV (2014)
- Non-Linearity < 1% @ 6keV
- Synchronized measurement of 2 pixels
- Presently most precise ^{163}Ho spectrum



	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

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

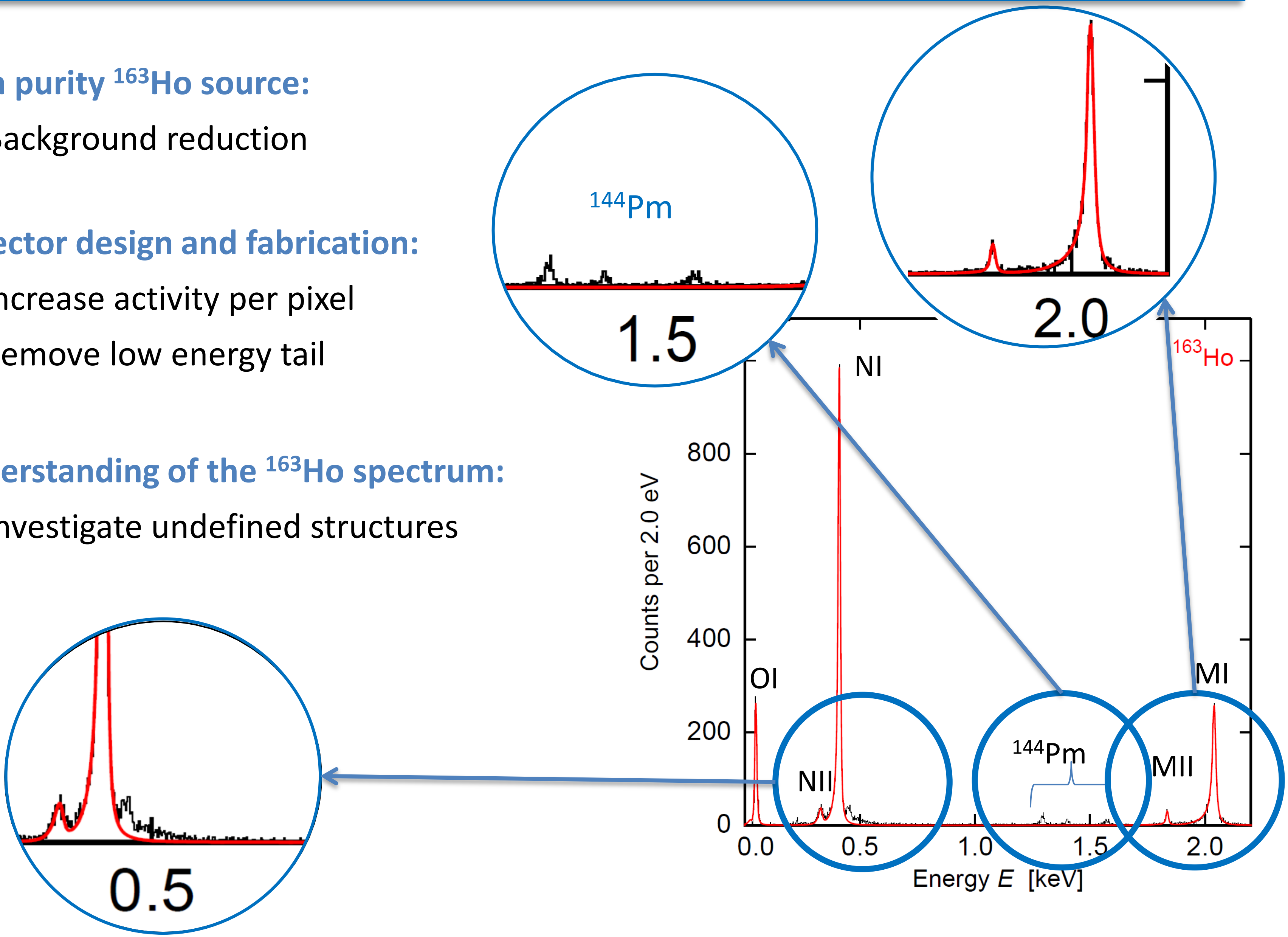
- Background reduction

Detector design and fabrication:

- Increase activity per pixel
- Remove low energy tail

Understanding of the ^{163}Ho spectrum:

- Investigate undefined structures



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

June 2012 : one irradiation at BER II Research Rector Berlin :

-Irradiate 5 mg Er for 11 days $\Rightarrow$ 1.5•10^{16} atoms ^{163}Ho

Summer 2013: two irradiations at ILL Grenoble

- Prior to irradiation:
  all elements lighter than Er separated (including holmium)

- After irradiation:
  all elements heavier than Ho are separated
  →pure holmium fraction

- 30 mg for 55 days $\Rightarrow$ 1.6•10^{18} atoms ^{163}Ho
- 7 mg for 7 days $\Rightarrow$ 1.4•10^{16} atoms ^{163}Ho

Thermal neutron flux (Φ): 1.3x10^{15} $cm^{-2}s^{-1}$

NEUTRONS FOR SCIENCE

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High purity ^{163}Ho source: Chemical separation

γ spectrum of the 30 mg sample after chemical separation:

$\Rightarrow$ **only ^{166m}Ho visible**

Excellent chemical separation!

High purity needed for MMC measurements:

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

H. Dorrer, A. Türler et al., to be submitted

High purity ^{163}Ho source: Mass separation

RISIKO off-line mass separator

- Optimized resonant laser ionization for Ho
- Focalization of the beam for implantation onto sub-mm detector absorber

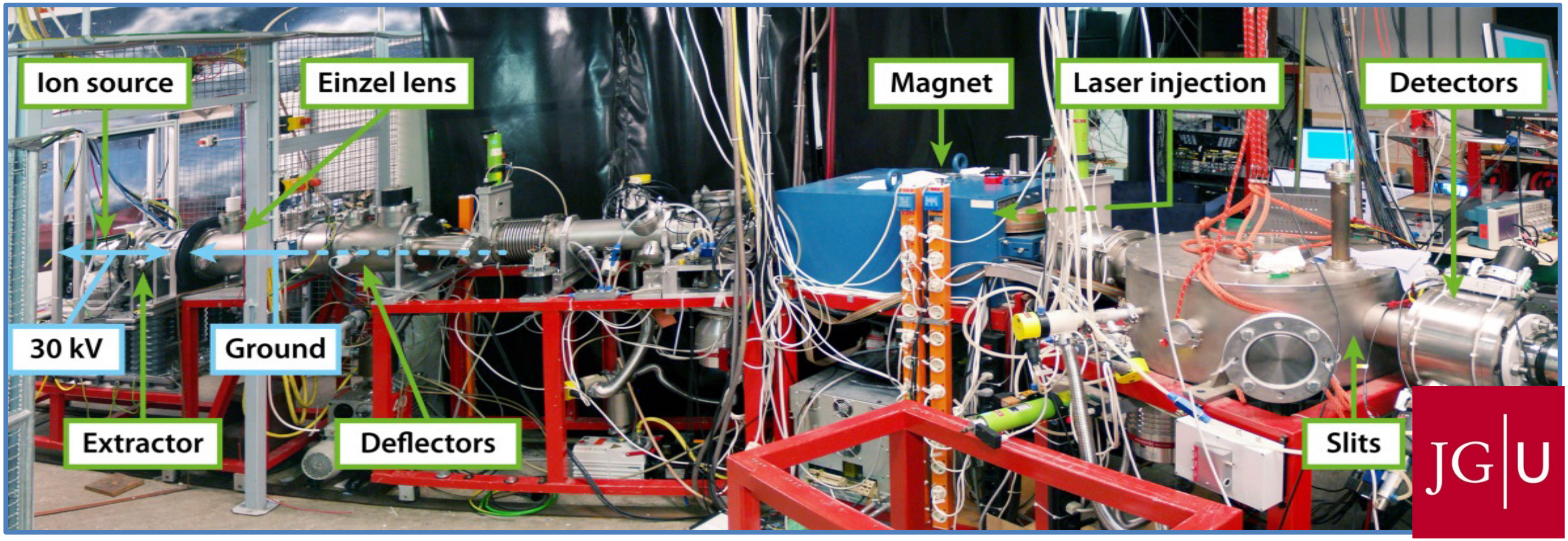
Magnetic sector-field Mass Spect.

30 kV two stage acceleration

60° double focussing separator magnet

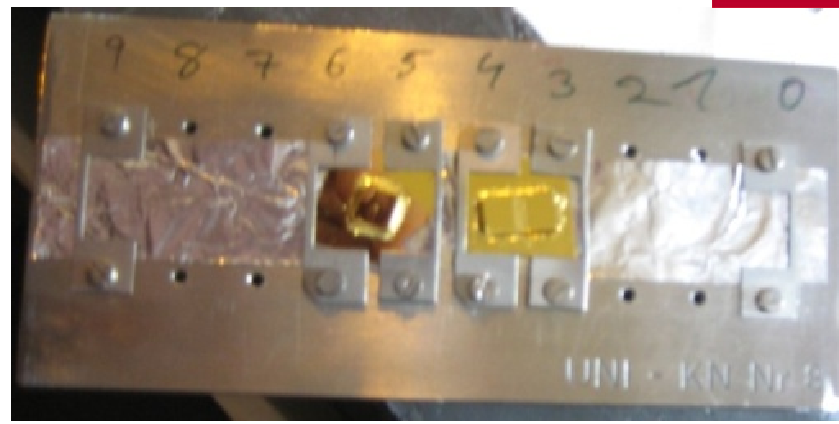
Mass resolution: $\frac{m}{\Delta m} = 500 - 1000$

Suppression of neighboring masses > 10^3



High purity ^{163}Ho source: Mass separation

Chemically purified ^{163}Ho source as offline target at ISOLDE/CERN



- Separation performed in December 2014
- 2 new chips to test!

  … each with 16 pixel detector arrays

- First low level gamma measurement in Tübingen

  No evidence of ^{166m}Ho

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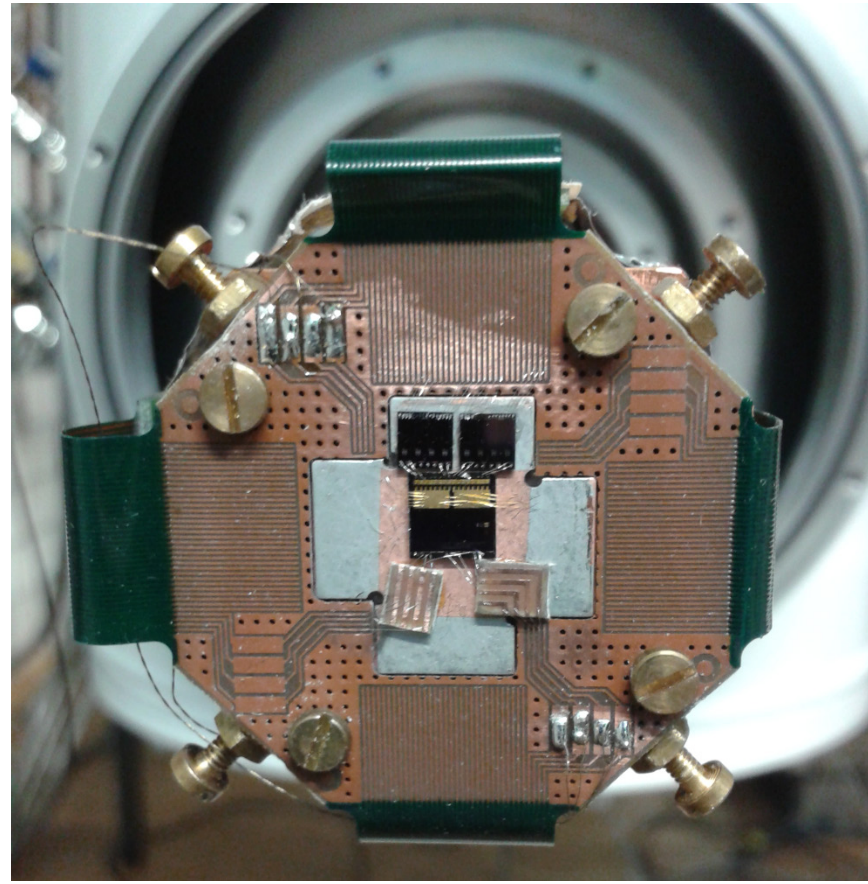
New detector ready for first tests....

At 18 mK since last Wednesday.....

Mounted on a cold arm of a dry cryostat



- Activity per pixel $A \sim 0.2$ Bq
- Baseline resolution $\Delta E_{\mathrm{FWHM}} = 5$ eV
- No evidence of radioactive contamination in the source

DON'T MISS
NEXT ECHo TALKS
!

Where to improve

High purity ^{163}Ho source:

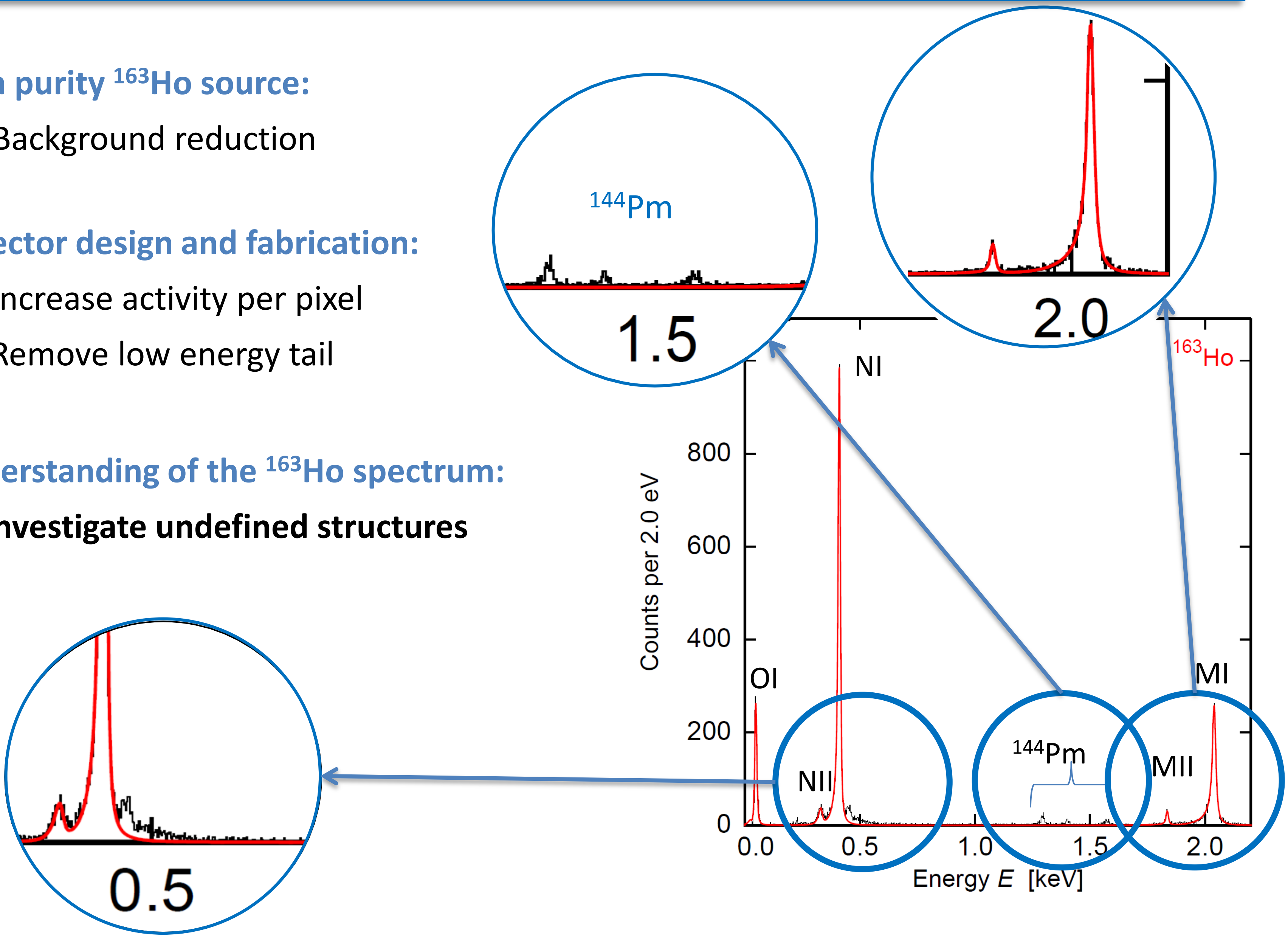
- ✓ Background reduction

Detector design and fabrication:

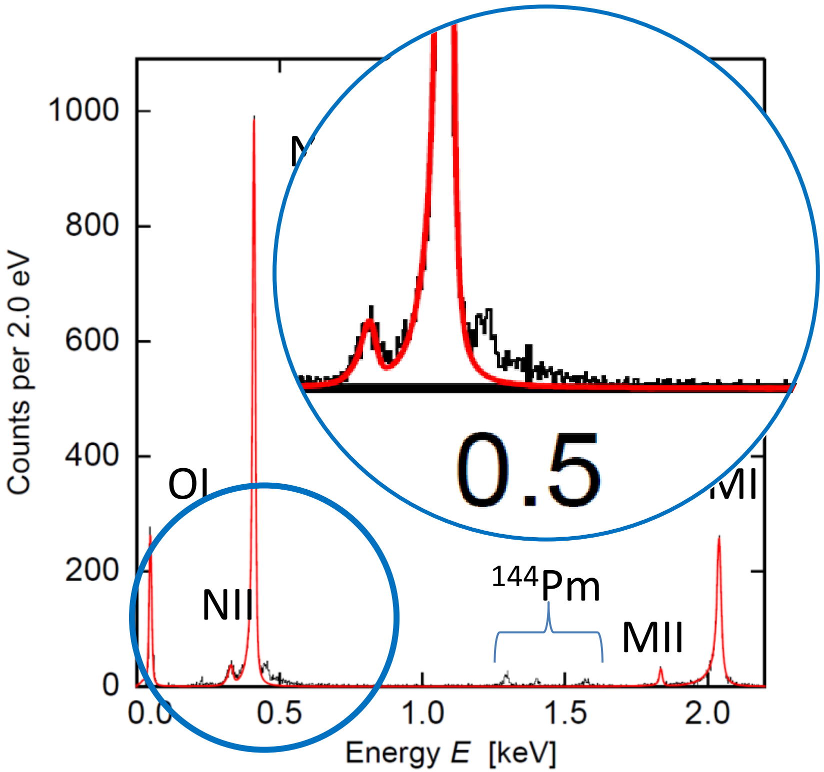
- ✓ Increase activity per pixel
- ✓ Remove low energy tail

Understanding of the ^{163}Ho spectrum:

- **Investigate undefined structures**



Characterisation of spectral shape



A. Faessler et al.
J. Phys. G **42** (2015) 015108

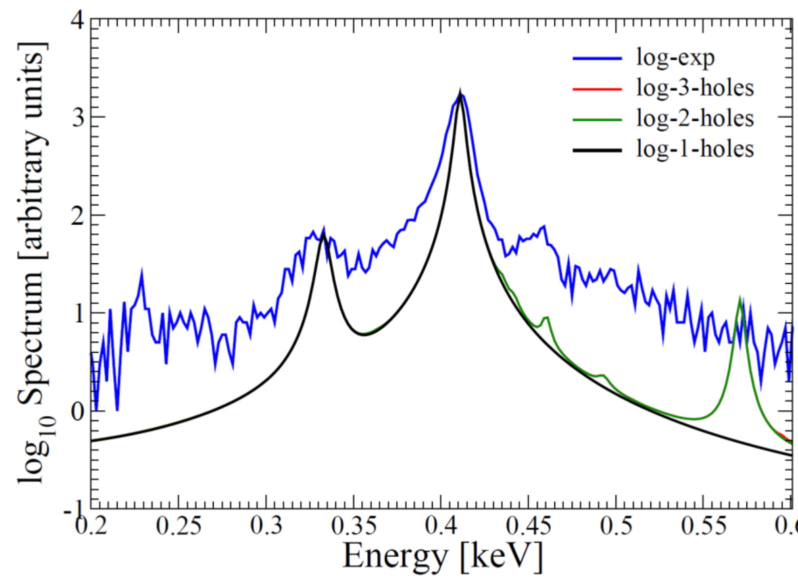
R. G. H. Robertson
Phys. Rev. C **91**, 035504 (2015)

A. Faessler et al.
Phys. Rev. C **91**, 045505 (2015)

A. Faessler et al.
Phys. Rev. C **91**, 064302 (2015)

Estimate the effect of

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



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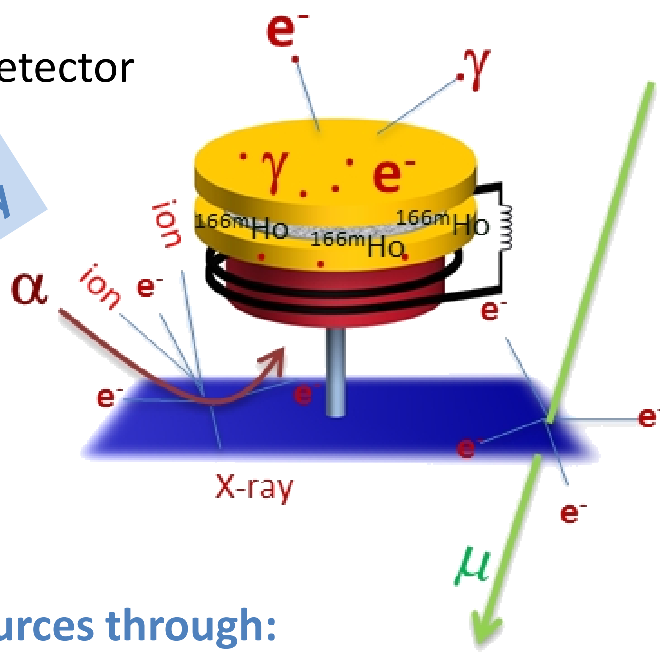
Background

Background sources:

- Environmental radioactivity → Material screening
- Cosmic rays
- Induced secondary radiation by cosmic rays → Underground labs / μ-Veto → Underground measurements in **Modane**
- Radioactivity in the detector

Background level
5×10^{-5} counts/eV/det/day



Study of background sources through:

- Monte Carlo simulations
- Dedicated experiments

Screening facilities
- **Uni-Tübingen**
- **Felsenkeller**

ECHo overview

- Prove scalability with medium large experiment **ECHo-1K**
  - A ~ 1000 Bq High purity ^{163}Ho source (produced at reactor)
  - $\Delta E_{\mathrm{FWHM}} < 5$ eV
  - $\tau_r < 1$ µs
  - multiplexed arrays → microwave SQUID multiplexing
  - 1 year measuring time → 10^{10} counts = Neutrino mass sensitivity $m_\nu < 10$ eV

Just approved

Research Unit FOR 2202/1

„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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ECHo