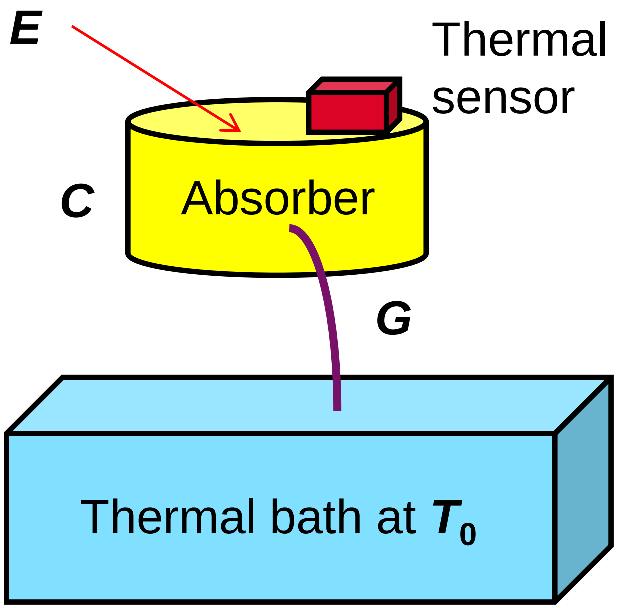
DE LA RECHERCHE À L'INDUSTRIE

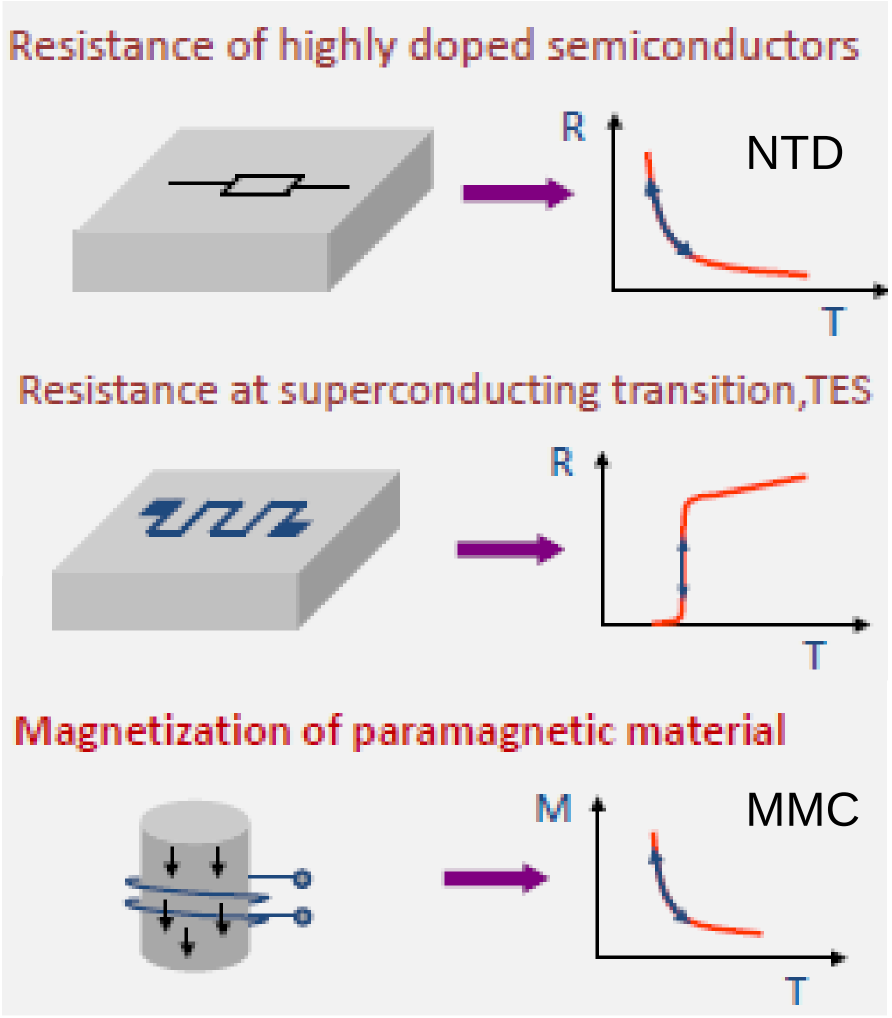
MMCD:
Metallic Magnetic Calorimeters Development

Xavier-François NAVICK and Yong-Hamb KIM

5th joint workshop FKPPL and TYL/FJPPL ,
SEOUL 05/19/16

What is a microcalorimeter?





T_0~20mK E = 10keV

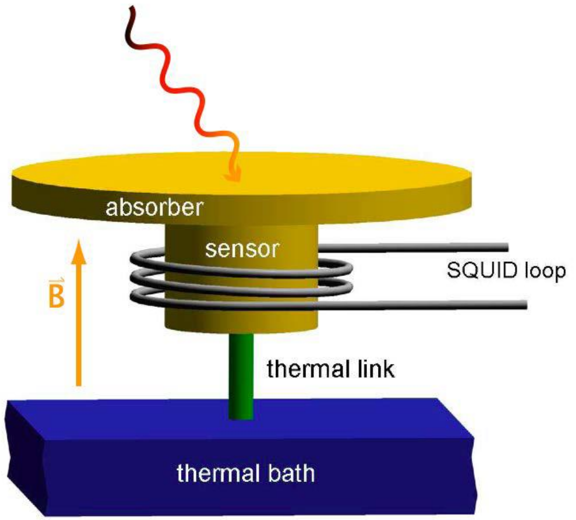
$$\Delta T \approx \frac{E}{C}$$

$\Rightarrow$ 1mK for C = 1pJ/K

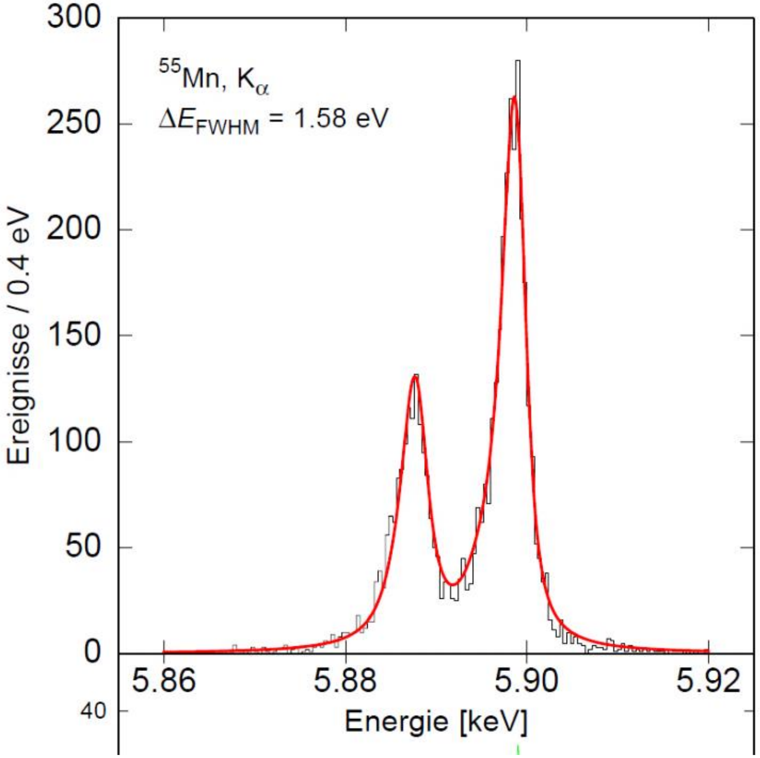
1µK for C = 1nJ/K

WHAT IS A MMC?

MMC (Metallic Magnetic Calorimeter)



Meas. by the MMC group Heidelberg Univ.



- Very sensitive detector highest energy resolution <2eV FWHM@ 6keV
- Good linearity
- Relatively fast signals (1μs risetime)
- No dissipation in the sensor, no galvanic contact

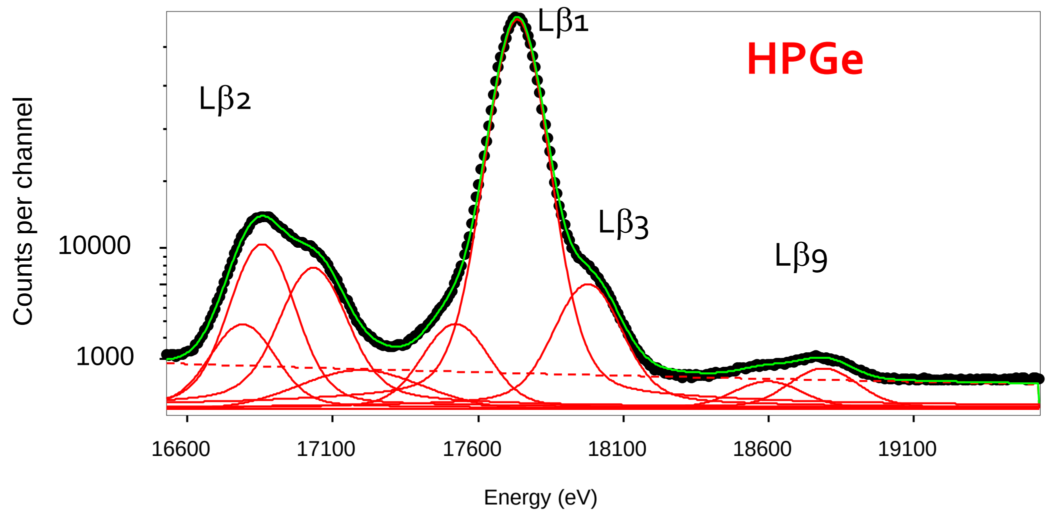
X-RAY SPECTROMETRY USING MMC

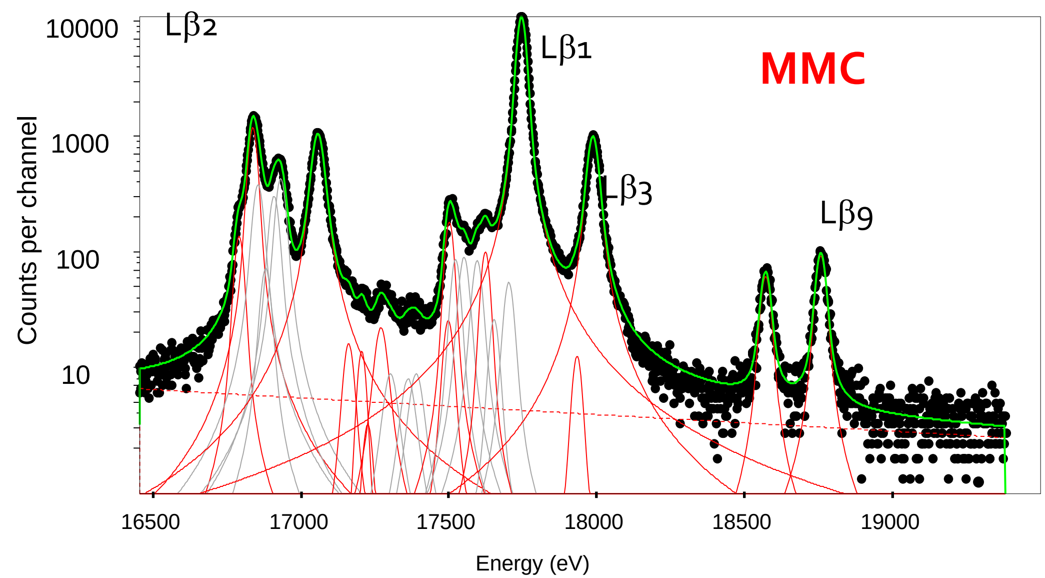
XL lines of ^{241}Am

30 eV FWHM at 60 keV with MMC

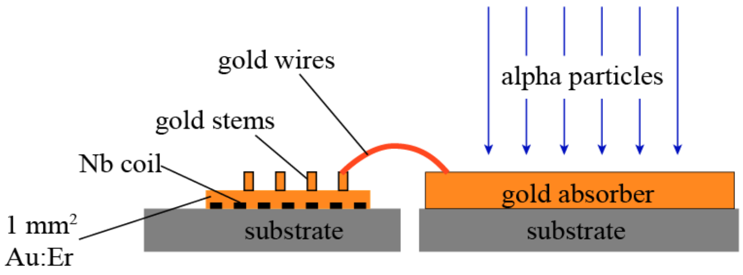
Evidence of satellite lines: shifted in energy from diagram lines due to multiple inner shell vacancies

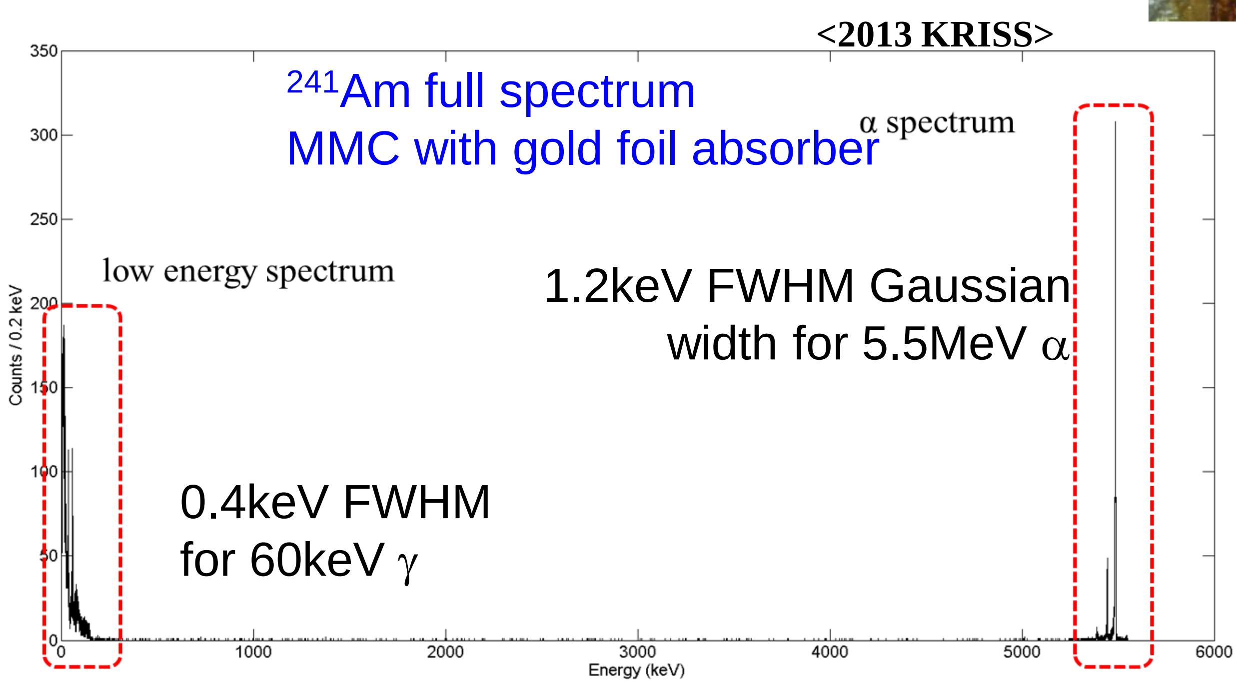
M. Rodrigues and M. Loidl, Applied Radiation and Isotopes 109 (2016) pp 570-575

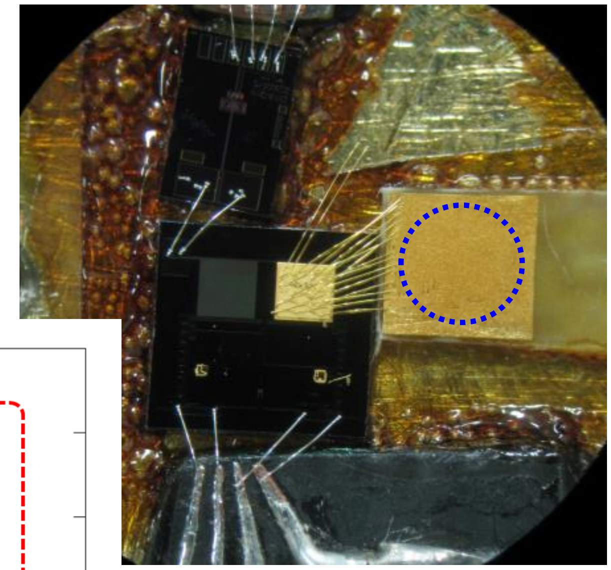




Alpha spectrometer using MMC

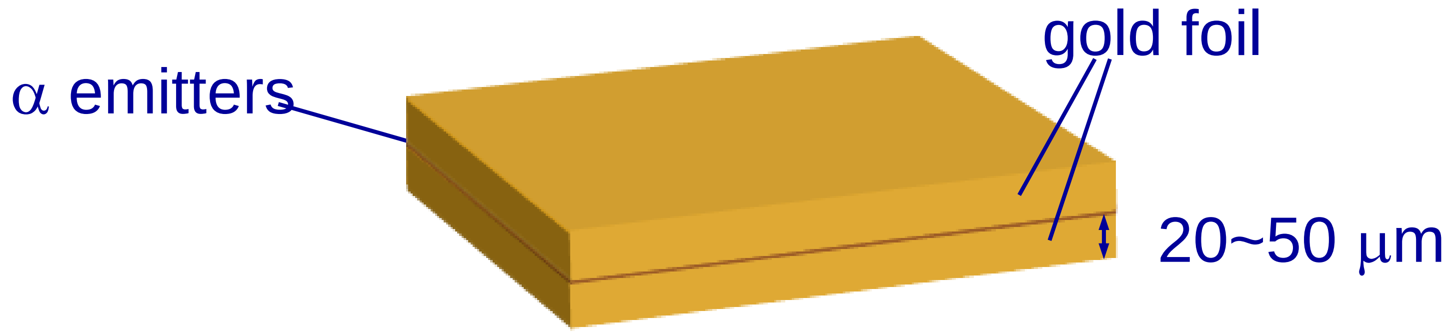






W.S. Yoon, et al., NIM A 784 143-146 (2015)

ALPHA DECAY IN 4π METAL ABSORBER



S.J. Lee, et al., J Phys. G 37 055103 (2010)

Alpha decay energy (Q)

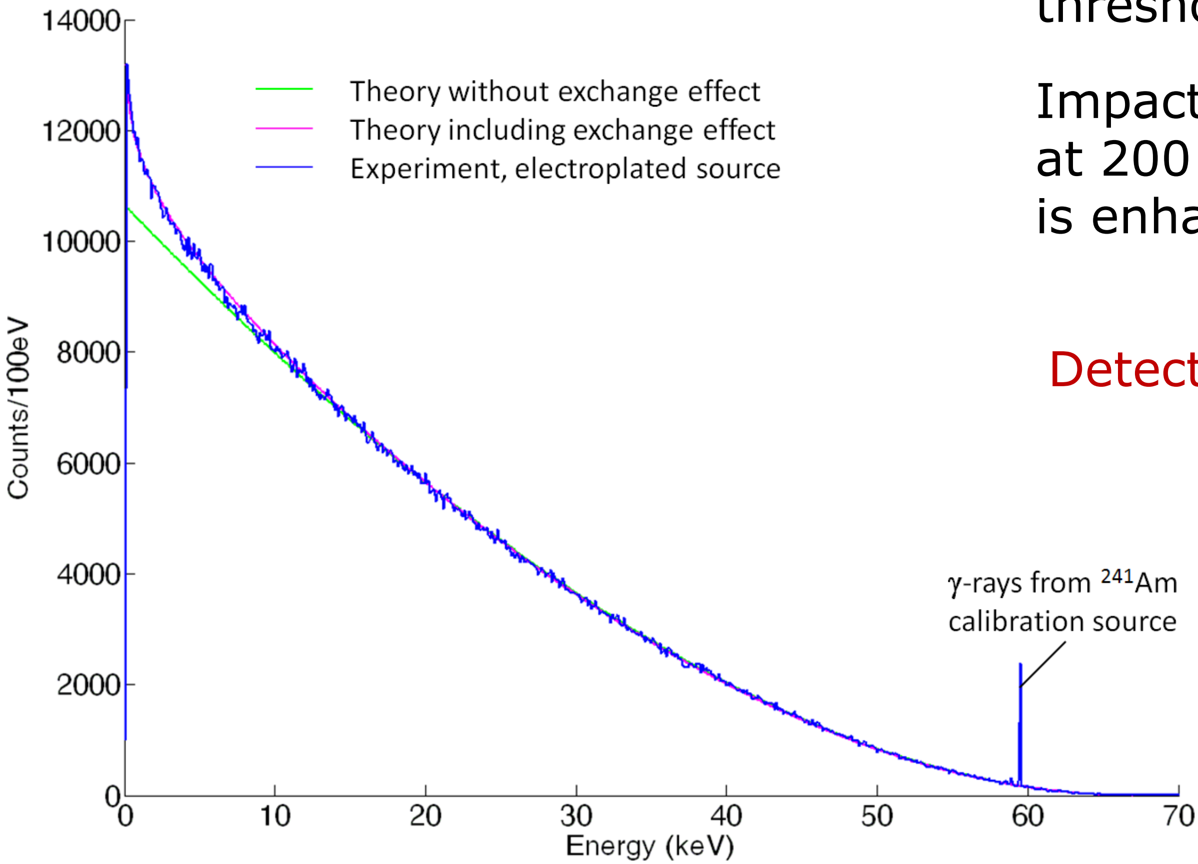
Alpha particle
Recoil nucleus
ce., γ, x, Auger electron

➔ Heat generation

1. Minimize the loss of energy in source and detector
2. No count loss

BETA SPECTROMETRY

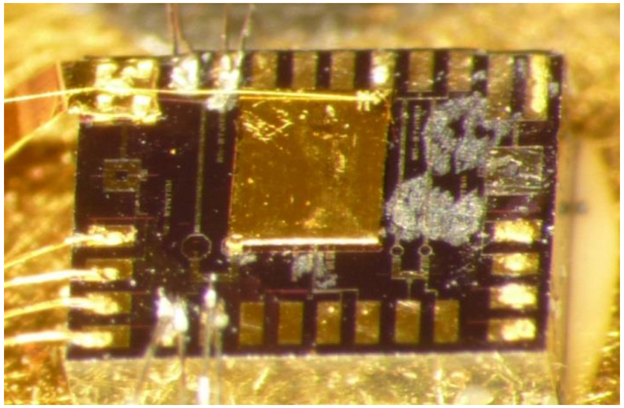
electroplated ^{63}Ni source in 4π geometry



Confirmation of atomic exchange effect down to very low energy: threshold ~ 200 eV

Impact of exchange effect:
at 200 eV the emission probability is enhanced by > 20 %

Detector placed on readout SQUID

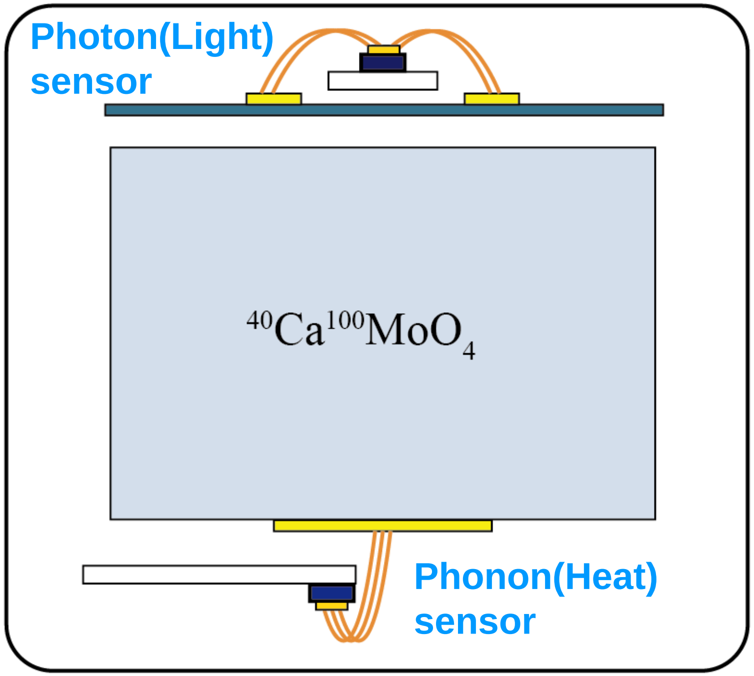


1 mm

M. Loidl et al., J Low Temp.Phys.176 (2014) pp1040-1045

AMoRE (Advanced Mo-based Rare process Experiment)

$^{40}Ca^{100}MoO_4$ + MMC : Source = Detector



$CaMoO_4$

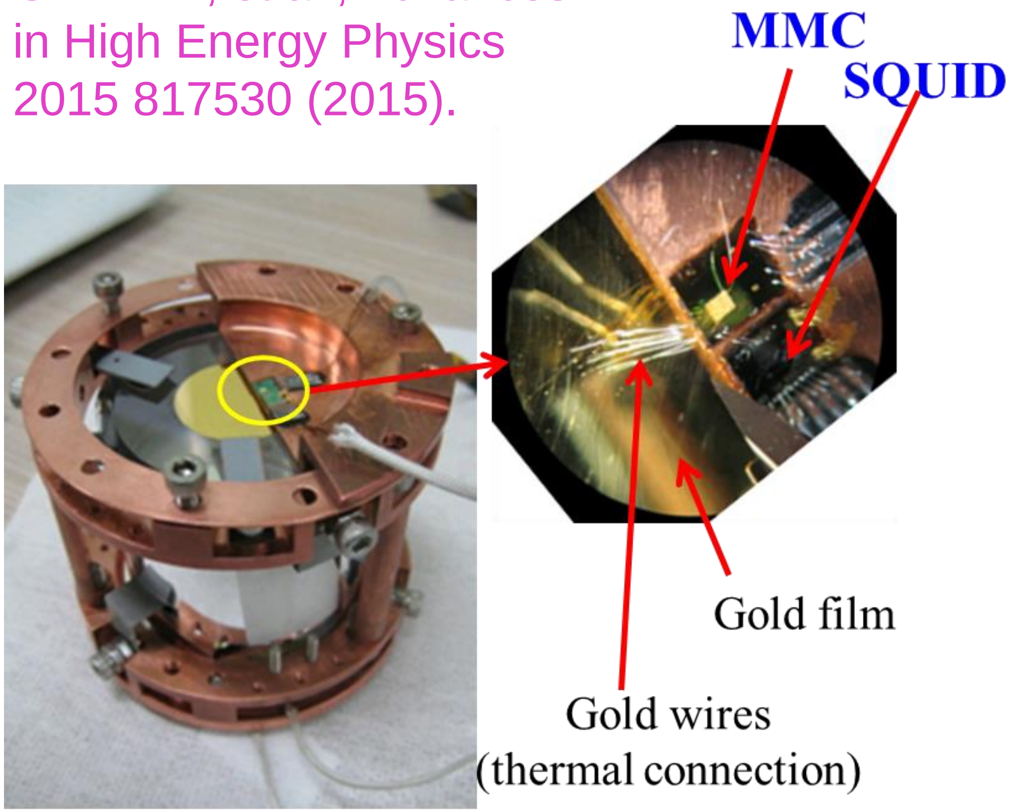
- Scintillating crystal
- High Debye temperature: T_D = 438 K, $C \sim (T/T_D)^3$
- ^{48}Ca, ^{100}Mo 0νββ candidates
- AMoRE uses $^{40}Ca^{100}MoO_4$ w. enriched ^{100}Mo and depleted ^{48}Ca

AMoRE TDR, arXiv:1512.05957 (2015)

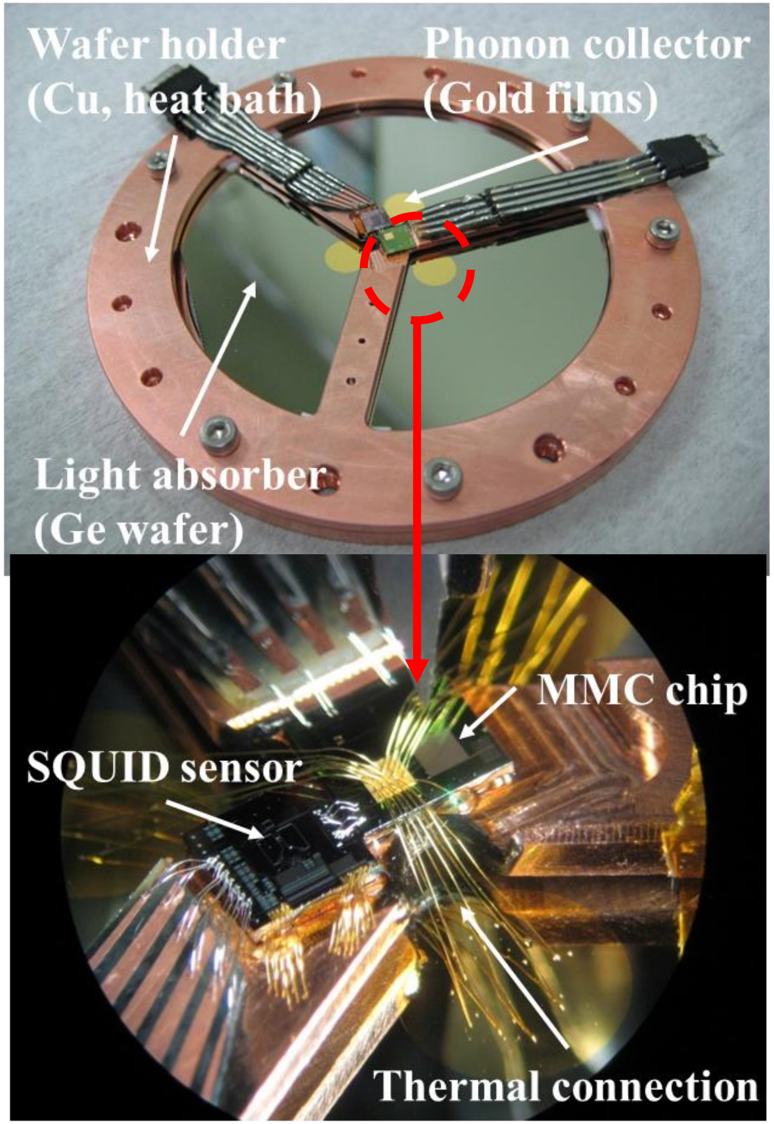
MMC-BASED HEAT AND LIGHT SENSORS FOR AMORE

Heat (phonon) sensor

G.B. Kim, et al., Advances in High Energy Physics 2015 817530 (2015).

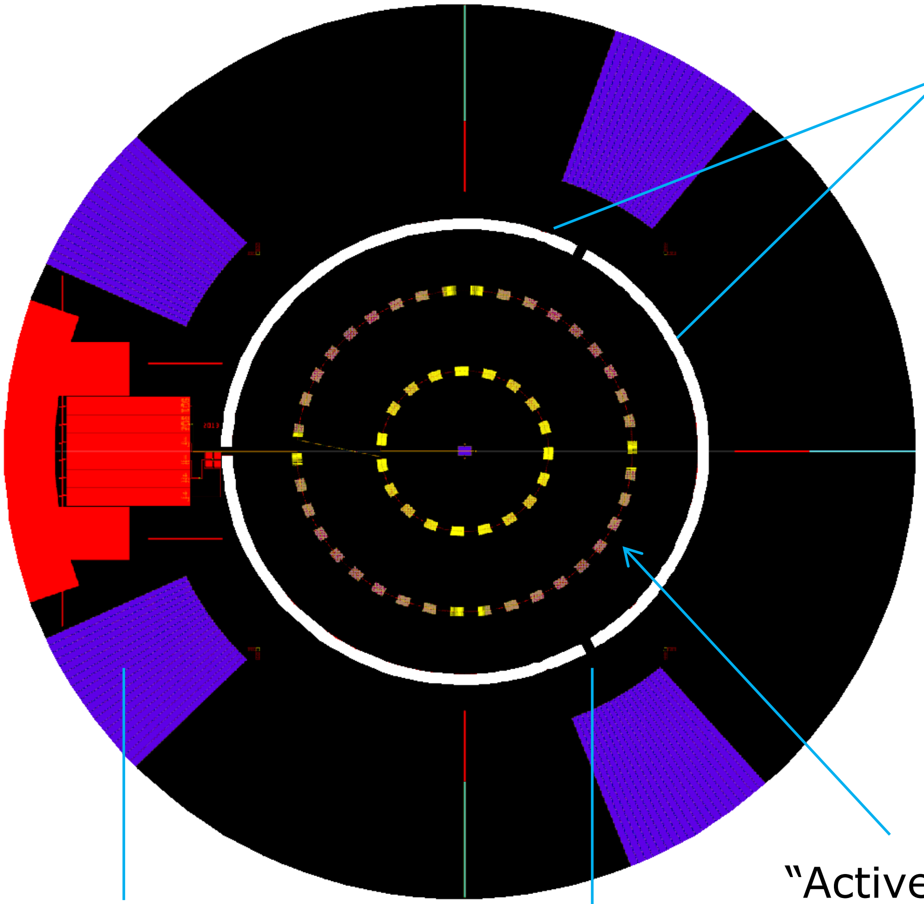


Light (photon) sensor



H.J. Lee, et al, NIMA 784 508-512 (2015)

PHOTON SENSOR WITH MMC

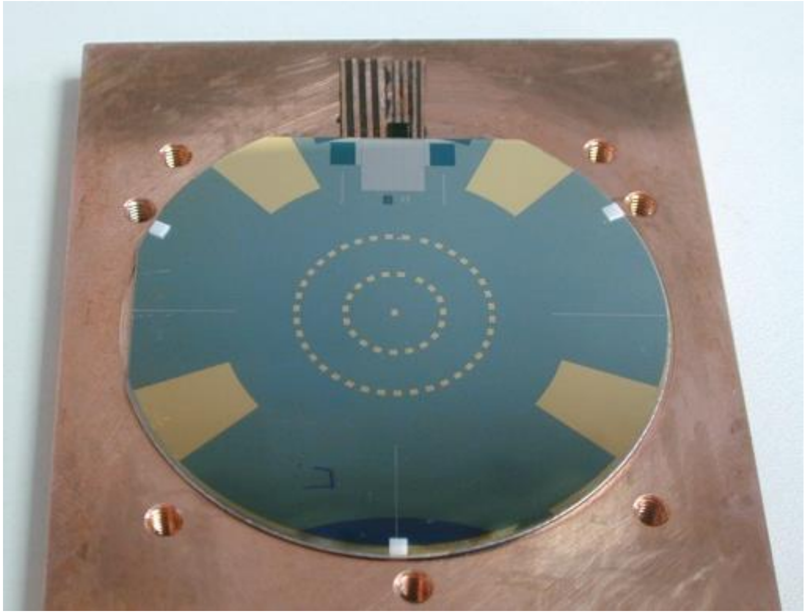


Trenches through the wafer

Thermalization pad

Ge bridge: Thermal link

"Active" part of the detector: $\phi = 25$ mm

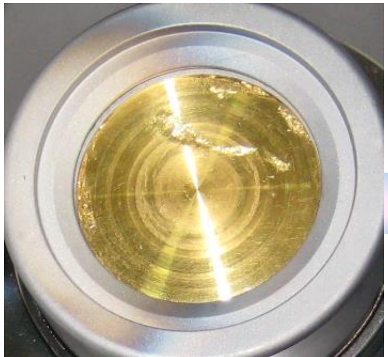


risetime: ~ 20 µs for X-rays
250 µs with ZMO scintillation

MMC designed and produced: Heidelberg Univ.

D.Gray et al., J. Low Temp. Phys. (2016), DOI: 10.1007/s10909-016-1535-7

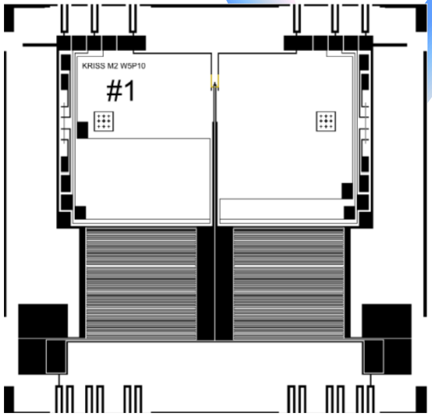
- 2 inches Au:Er target



- Au:Er sputtering system

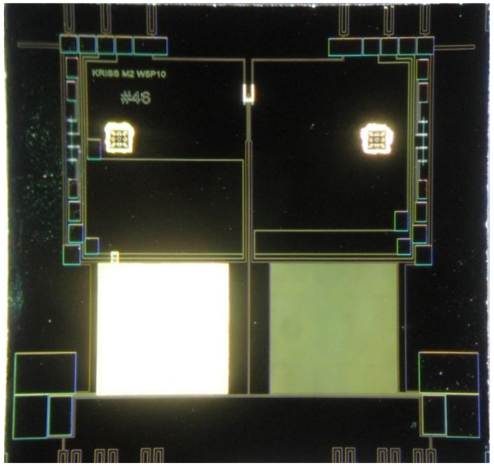
KRISS Clean room

- Meander pickup coil



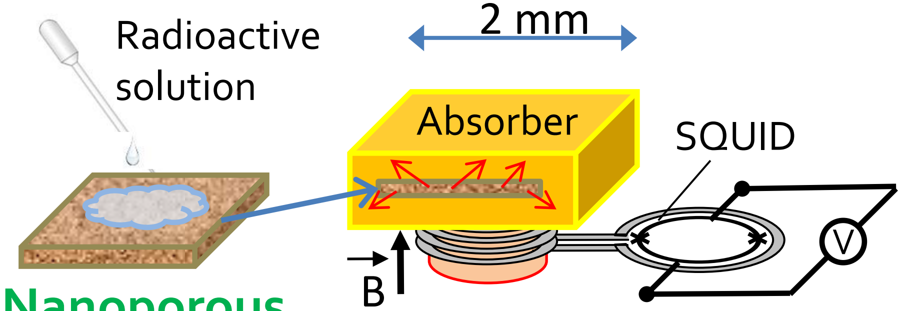
Chip design: Heidelberg Univ.

- Device fabricated at KRISS



W.S. Yoon, et al., J. Low Temp. Phys 176 644-649 (2014)

Simplified isotopic analysis of actinides

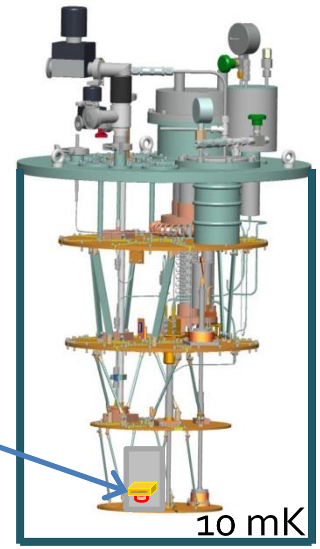


Nanoporous gold

High source quality

Metallic magnetic calorimeters

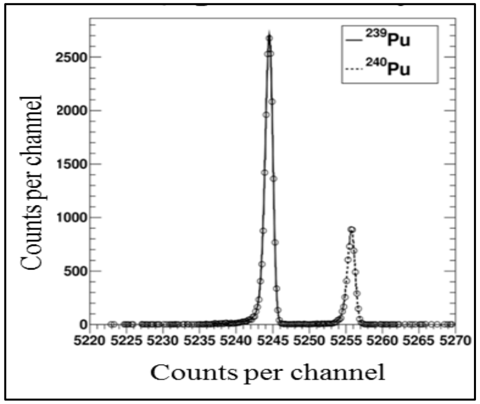
High energy resolution



Cryogen free dilution cryostat

Fast cooling to 10mK

Digitizing Online DSP



Acquisition system

High energy resolution spectrum

- → Simpler source preparation than α and mass spectrometry
- → Minimize the radiochemical process steps, strong reduce of the time
- → More precise than α spectrometry
- → Wide number of actinide possible

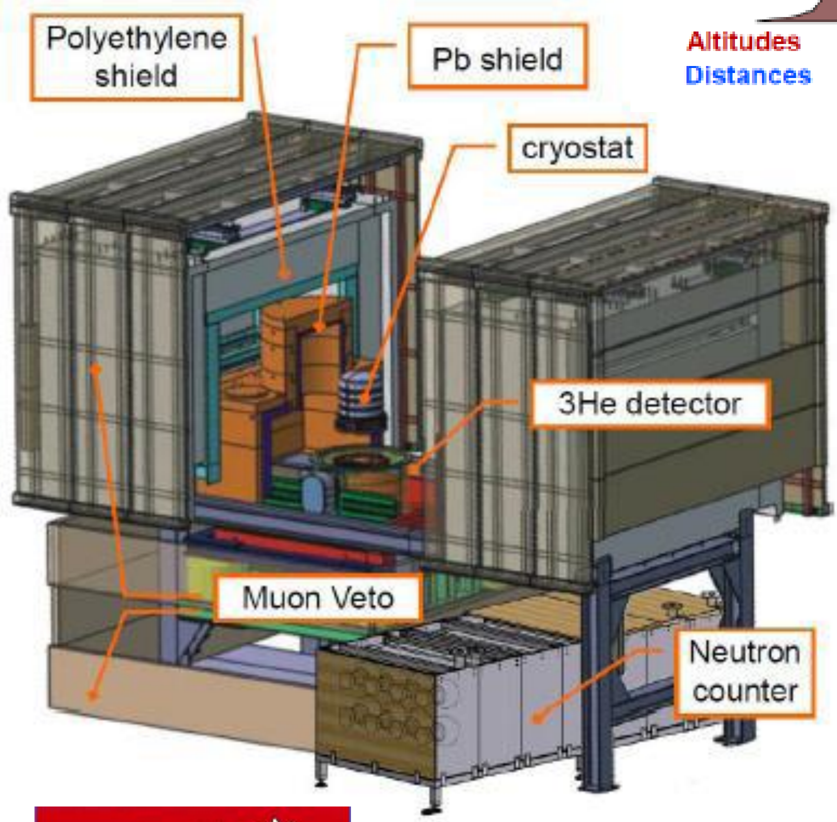
YangYang(Y2L) Underground Laboratory

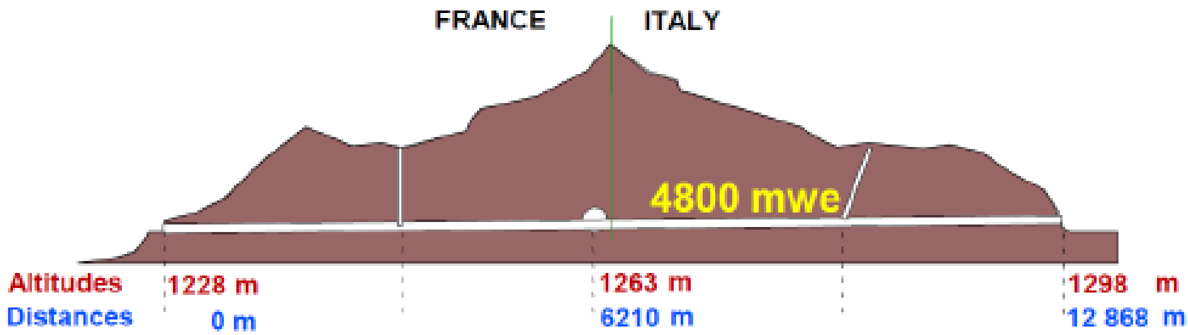
KIMS (Dark Matter Search)

AMoRE (Double Beta Decay Experiment)

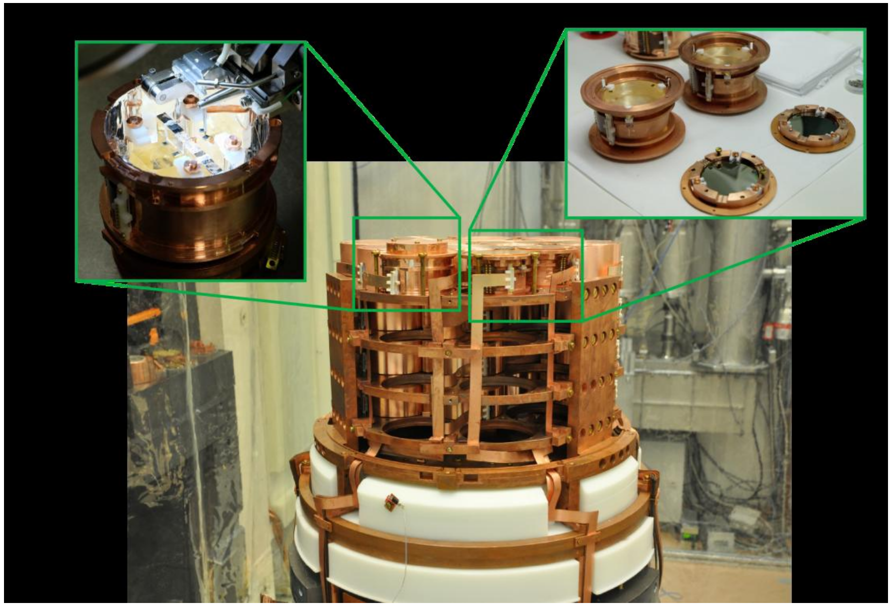
Minimum depth : 700 m / Access to the lab by car (~2km)

EDELWEISS cryostat and shielding





cosmic muon flux
4 μ/m2/day



Natural convergence

MMC is a recent technique.

The worldwide community of MMC users is very small (less than 50 people)

Both French-CEA and Korean-IBS-KRISS groups collaborate with Heidelberg University. It is natural to begin France-Korea own collaborative projects.

Both teams are contributing to

- WIMPS search (KIMS and EDELWEISS resp.)
- DBD projects (AMoRE and LUMINEU resp.)
- Spectrometry, Q measurement,

Natural convergence between our two groups to share expertise, experiences and means of production

MMCD Collaboration

- Phone meeting every two months

to discuss data analysis, simulations, feedback of instrumental work, and to exchange ideas for detector design and fabrication.

- Design new detectors / holders

to improve the detector performance for present and future projects.

R&D plan and prototype design for a non-proliferation application.

- Share our expertise

in low radioactivity techniques, electro magnetic compatibility, radiopurity measurement and radioactive source production.

- Exchange of visitors.

One Korean student will participate in a test of a detector in CEA.
One or two French researchers will come to Korea to participate in measurements, productions or discussions if required.

We thank you for your attention

Participants to MMCD

Yong-Hamb KIM from IBS, UST and KRISS

Xavier-François NAVICK from CEA/DSM/IRFU

Martin LOIDL and Matias Rodriguez from CEA/ DRT/LIST/LNHB

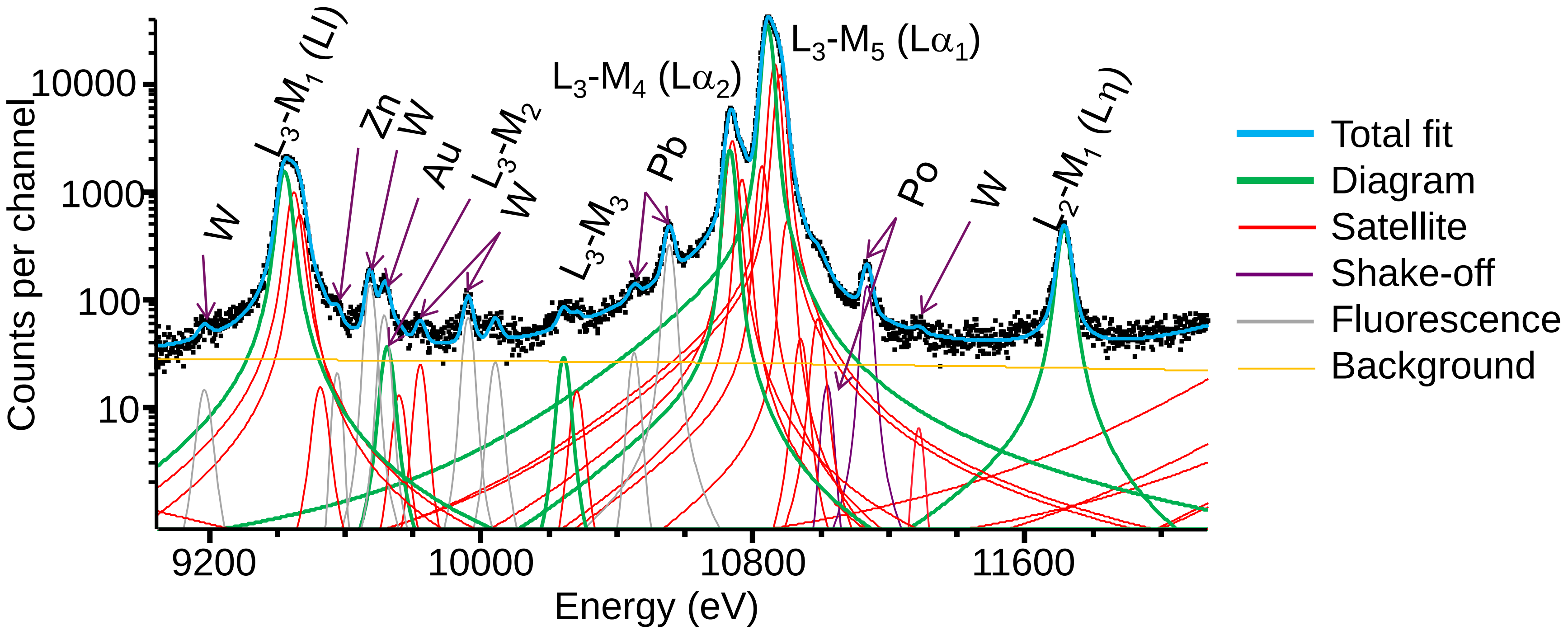
MinKyu LEE from KRISS

Hyejin LEE and HyonSuk JO from IBS

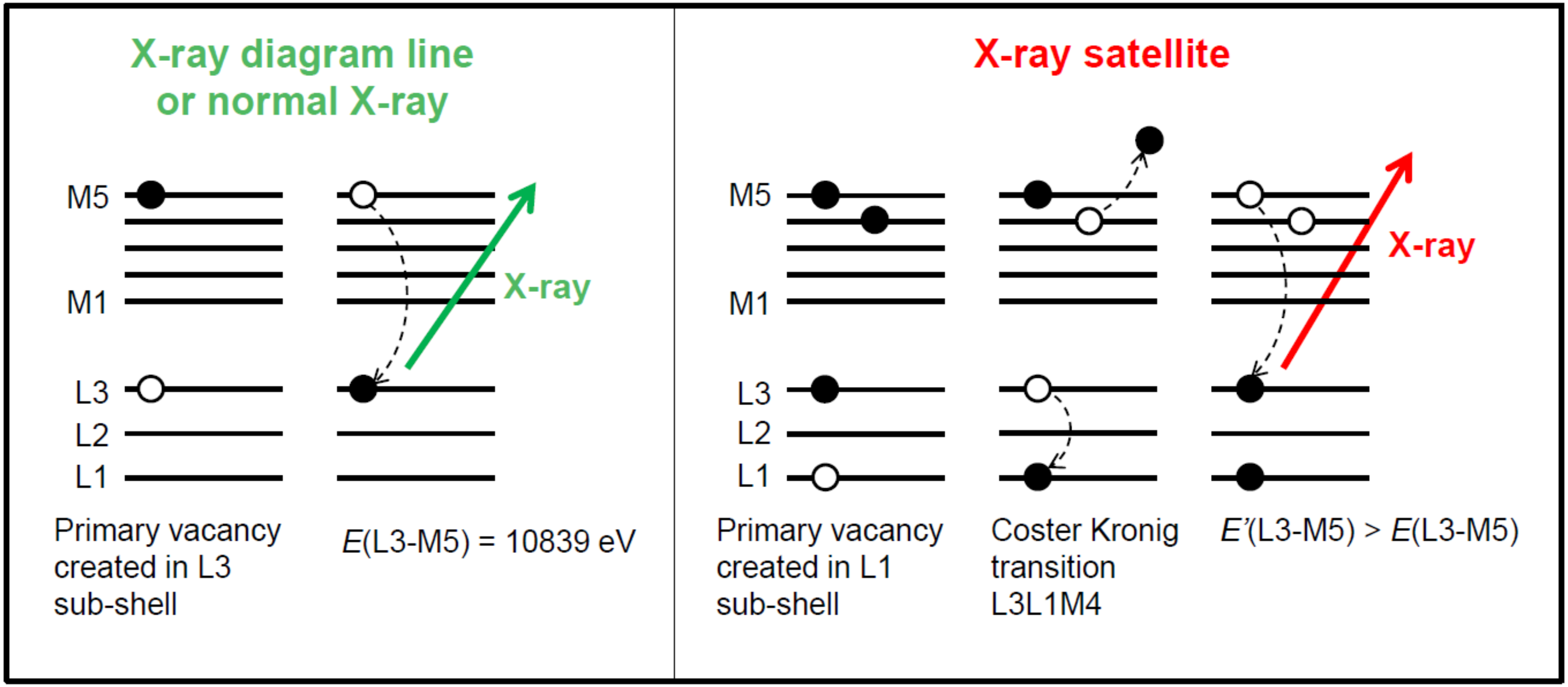
Back-up slides

Evidence of satellite lines: shifted in energy from diagram lines due to multiple inner shell vacancies

30eV FWHM at 60 keV



M. Rodrigues, M. Loidl, Applied Radiation and Isotopes 109 (2016) pp 570-575

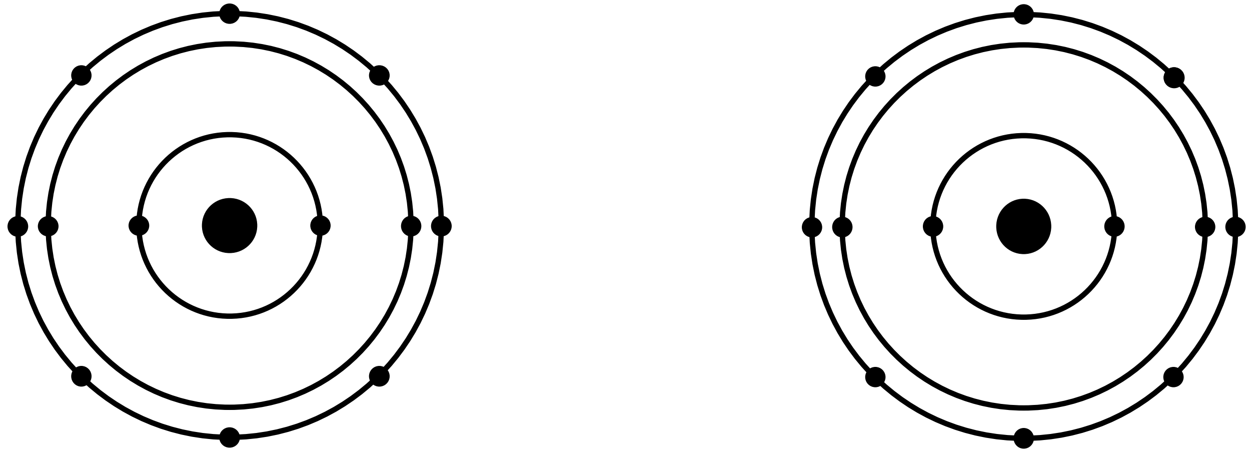

X-ray diagram line
or normal X-ray
M5
M1
L3
L2
L1
X-ray
Primary vacancy created in L3 sub-shell
E(L3-M5) = 10839 eV
X-ray satellite
M5
M1
L3
L2
L1
X-ray
Primary vacancy created in L1 sub-shell
Coster Kronig transition L3L1M4
E'(L3-M5) > E(L3-M5)

EXCHANGE EFFECT IN BETA DECAY

Creation of a beta electron into a bound orbital with simultaneous ejection of a bound electron from the same shell

Direct process

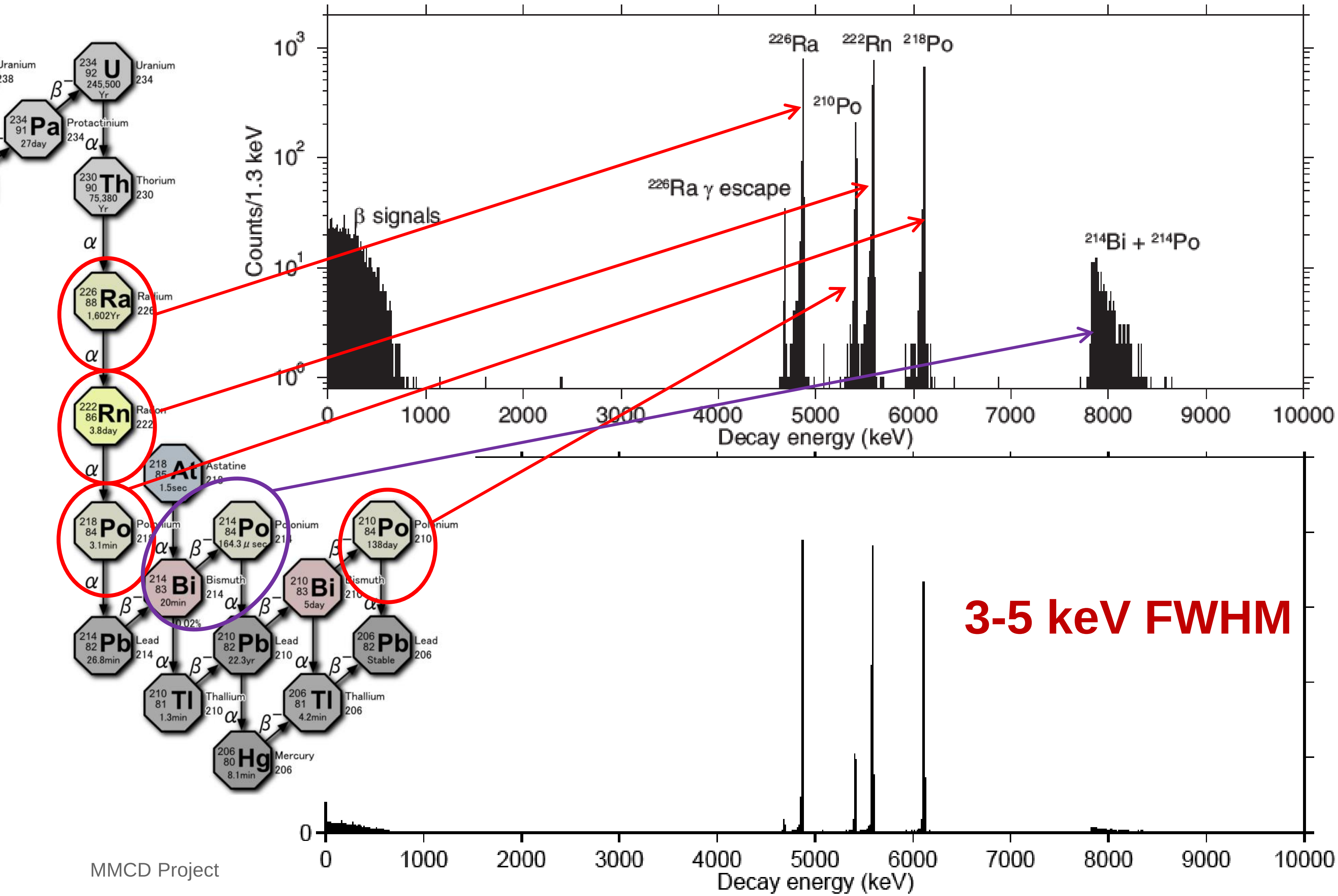
Exchange process



Energy-dependent enhancement of the beta emission probability

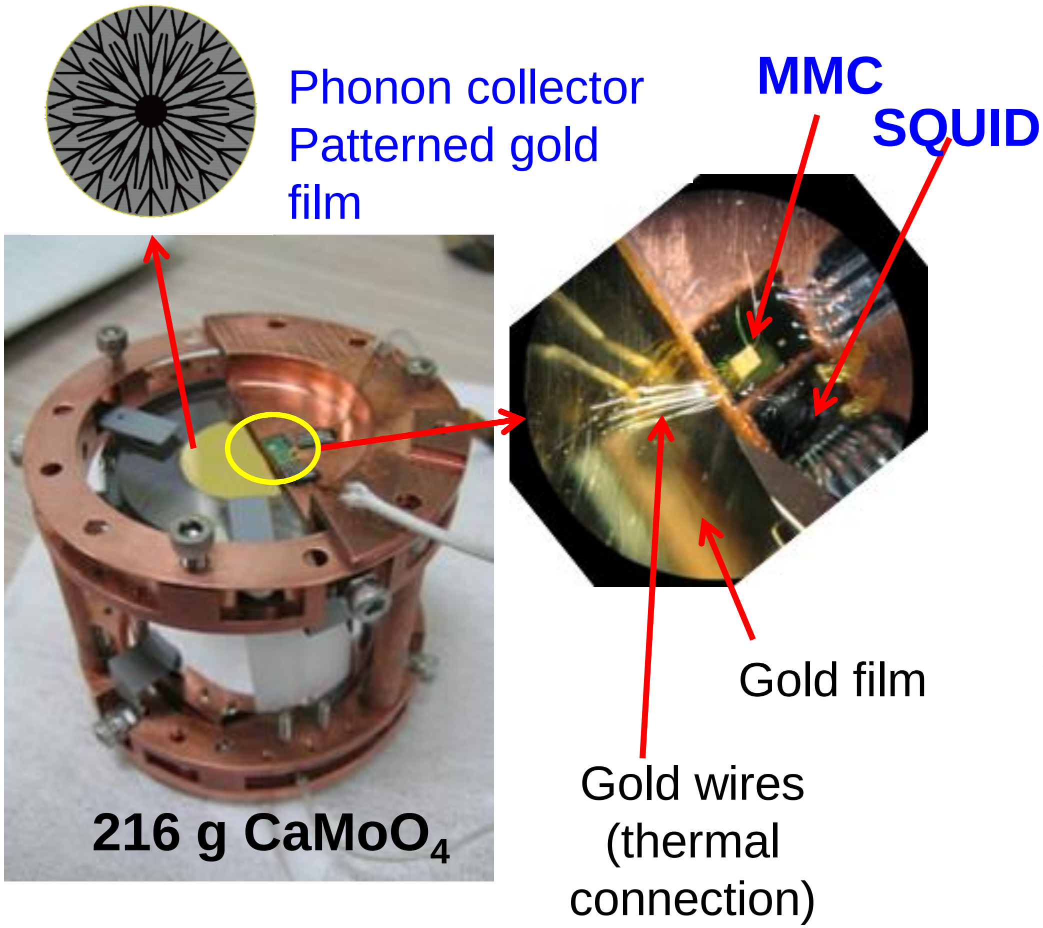
- very small in the higher energy part of the spectrum
- increases towards low energies

B- Full Q spectrum of ^{226}Ra

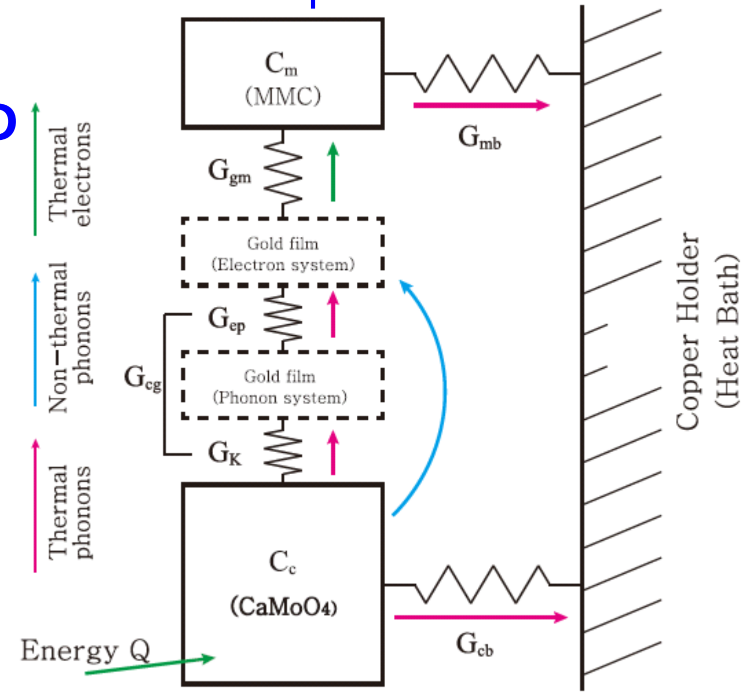


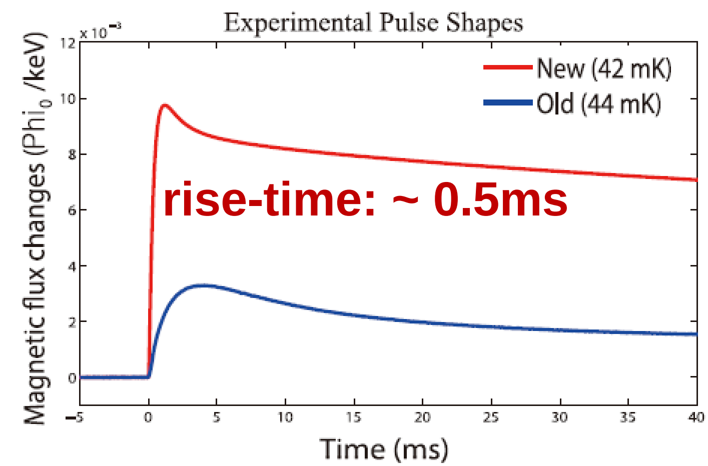
3-5 keV FWHM

B- HEAT(PHONON) SENSOR FOR AMORE



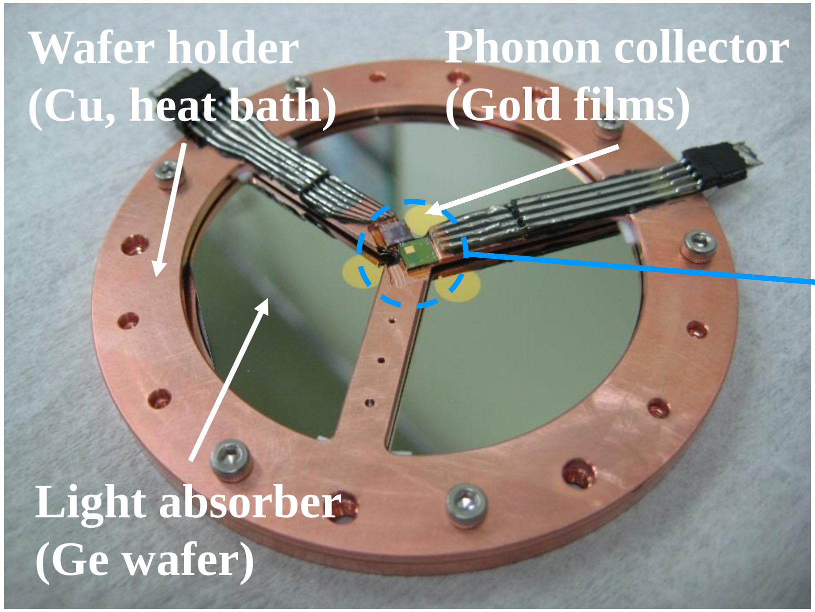
Heat flow optimization

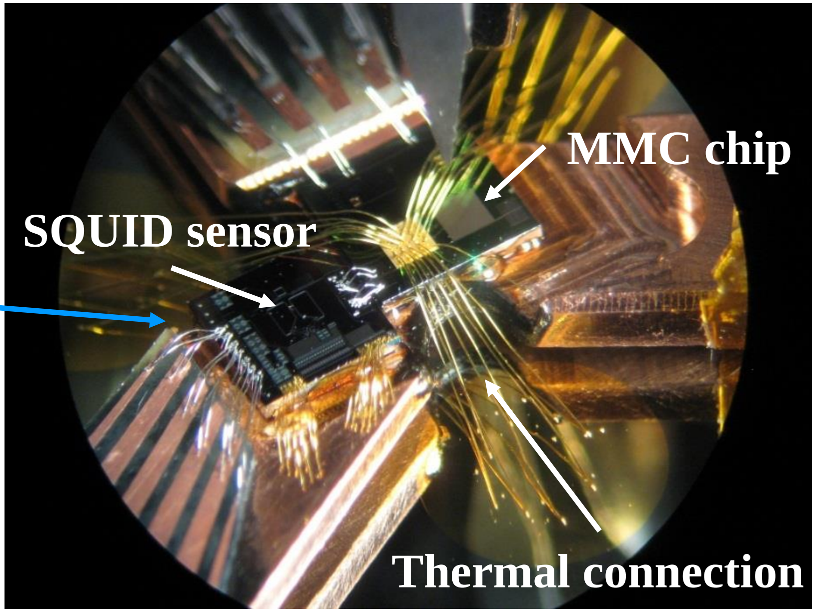


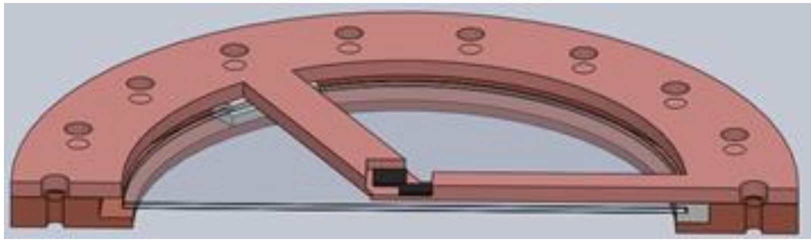


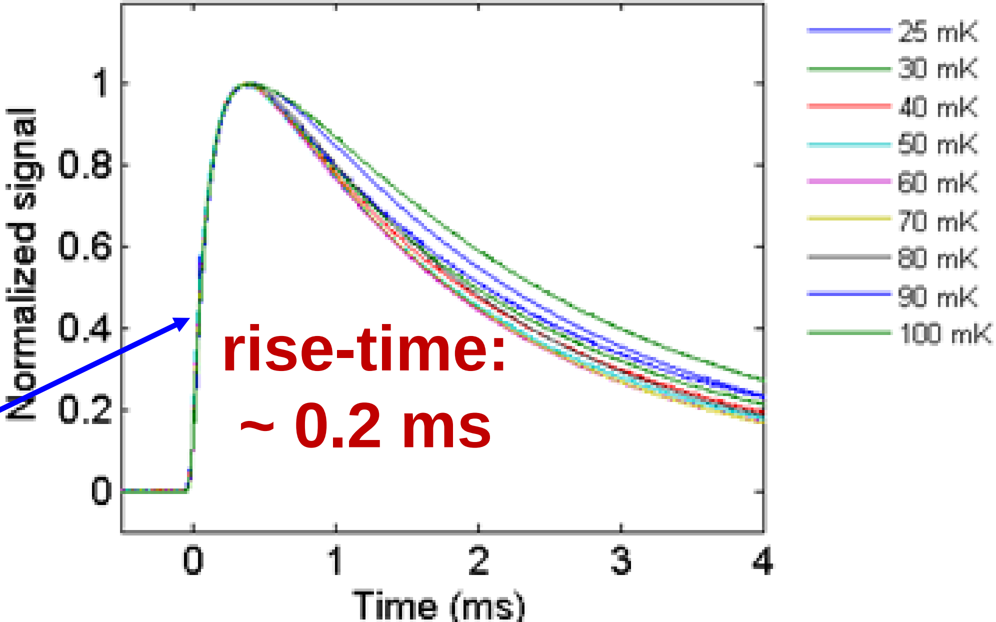
both thermal and athermal phonons are measured.

B- PHOTON SENSOR WITH MMC









Temperature independent rise-time !