LTD-18 [210]

Metallic Magnetic Calorimeters for High-Accuracy Nuclear Decay Data

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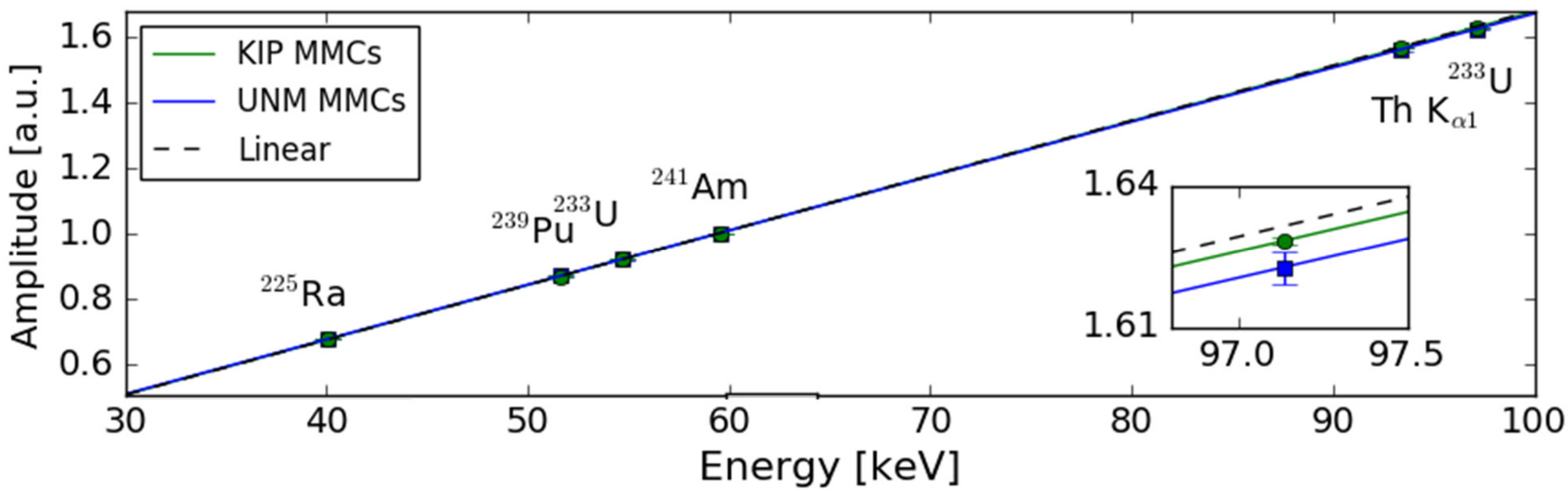
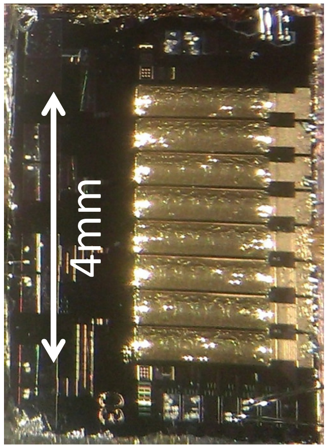
MMC Calibration



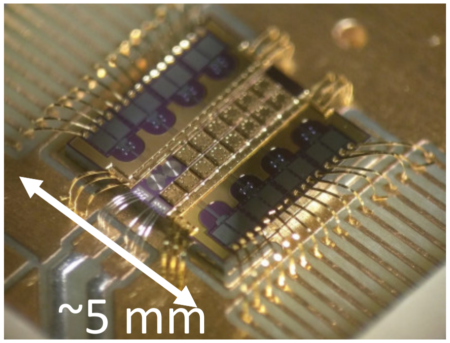
- MMCs have very little "personality"
- magnetization-based thermometer
  - equilibrium thermodynamic property
  - less sensitive to process conditions
- absorber and heat flow path are normal-metal
- linear with a small quadratic term
  - quadratic correction ~100 eV at 100 keV

KIP



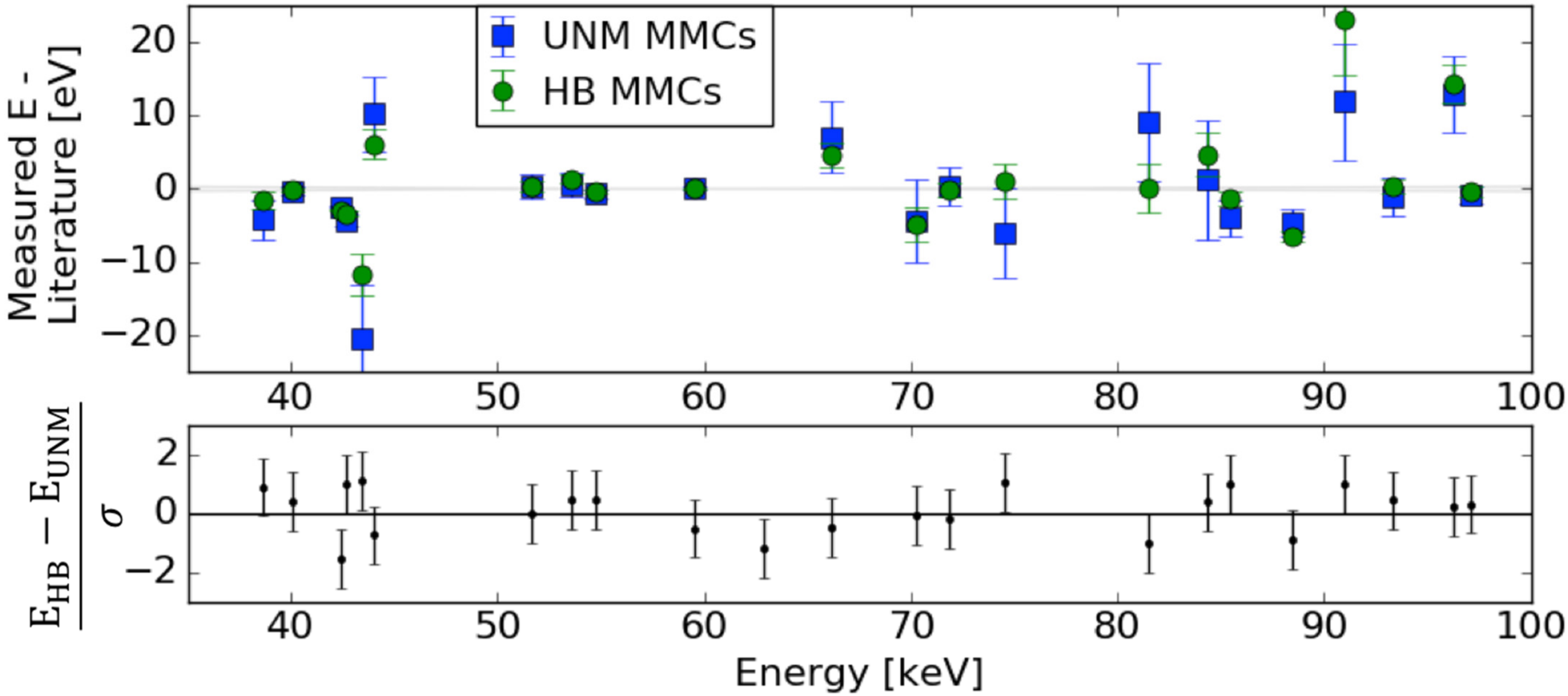
8 Ag:Er pixels, "split" design

UNM



14 Ag:Er pixels, "integrated" design

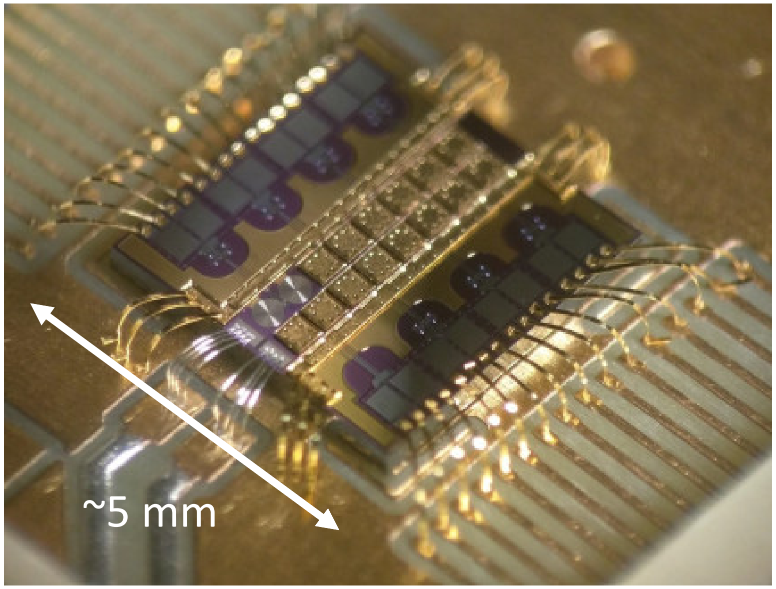
MMCs versus literature

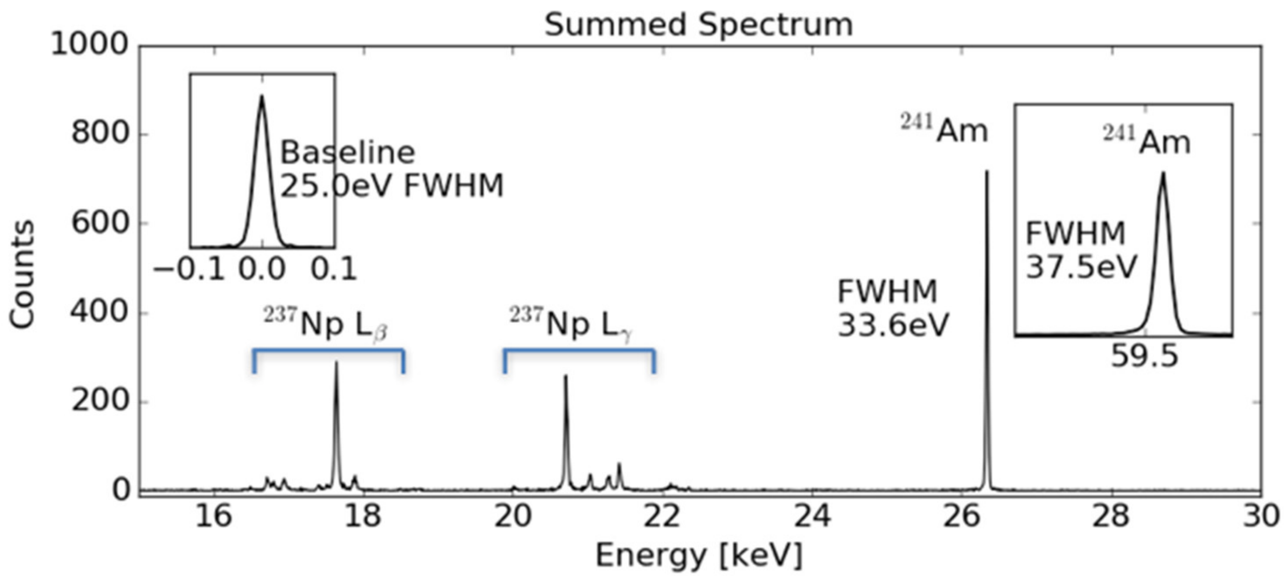


- What's different between the two devices? everything.
  – device geometries, fabs, temperatures, source-detector geometries, SQUIDs, and readout electronics

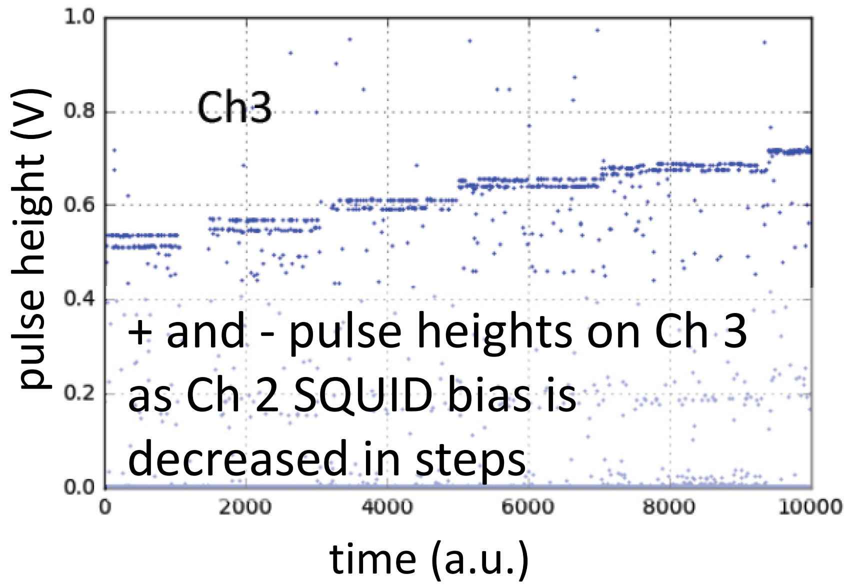
previous exploratory MMC

- "integrated" MMC
  - SQUIDs and Sensors on same chip
  - always the best performance, if you can keep the paramagnet cool
- paramagnet: Ag:Er
- 7 SQUIDs for 14 pixels
- 1 SQUID for on-chip thermometer





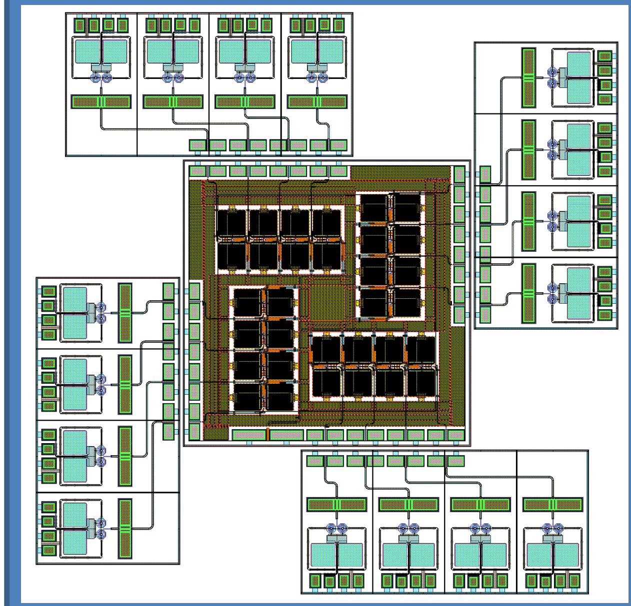
New MMC designs



heating of paramagnet by SQUID bias power in "integrated" devices

- also:
- new "integrated" designs
  - 10 keV <5eV @ 30 mK
  - direct-coupled

"split" designs, up to 30 pixels

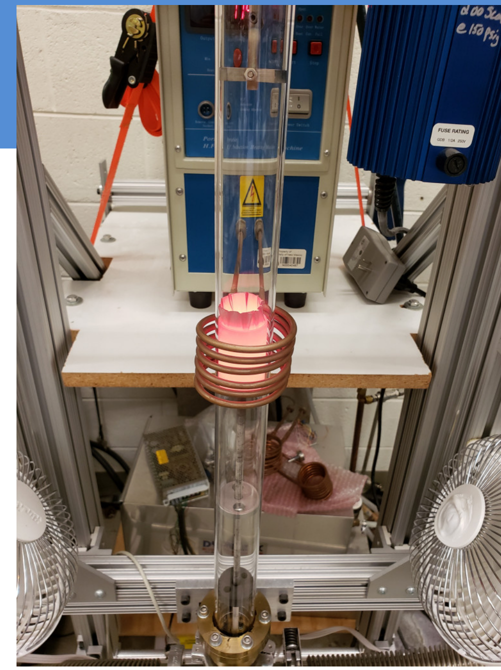


LBond:
2→1 nH,
↓ ~1 eV

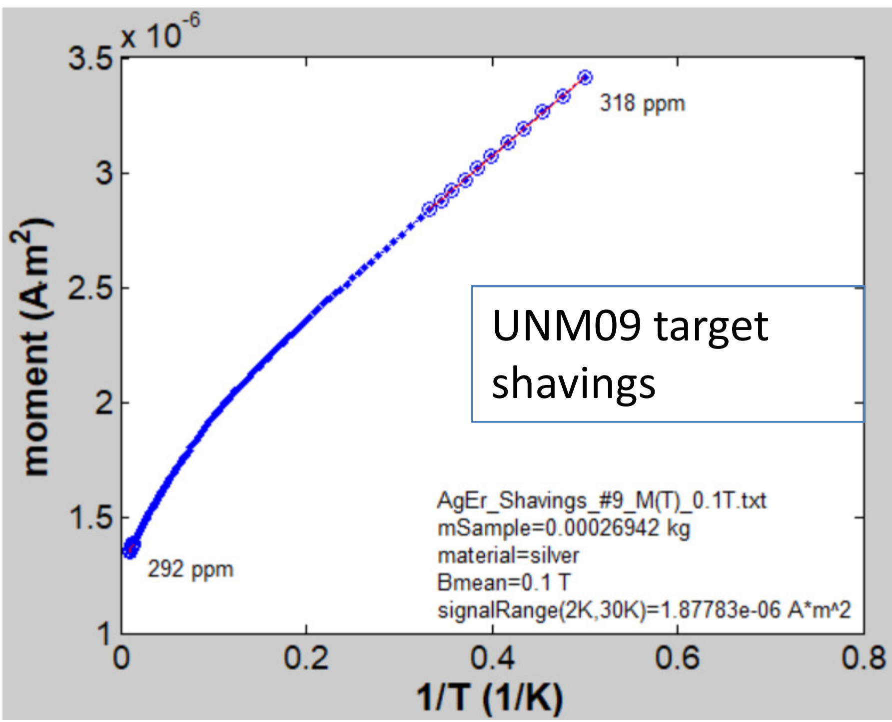
SQUID noise:
2→1 $\mu\Phi_0$/rt Hz,
↓ ~6 eV

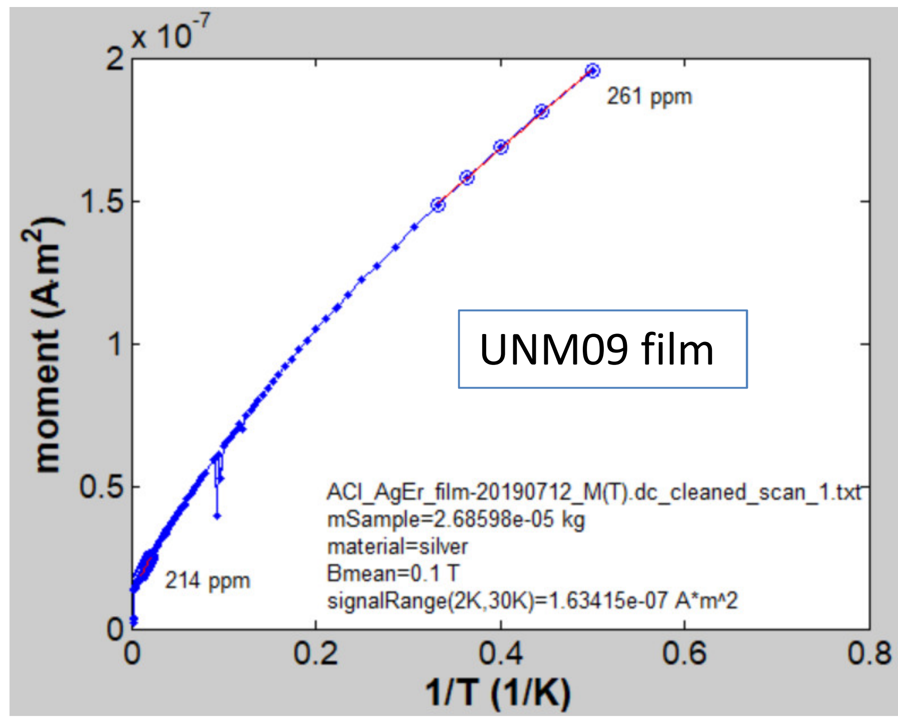
est. eV	Ag + natural Er ^{167}Er=23%		Ag + enriched Er ^{167}Er=2%	
	no cap	with cap	no cap	with cap
mean	27.8	20.7	25.5	19.3
sigma	4.0	1.2	3.5	1.0
best	23	19	21	18
worst	35	23	32	21

New devices still in fab



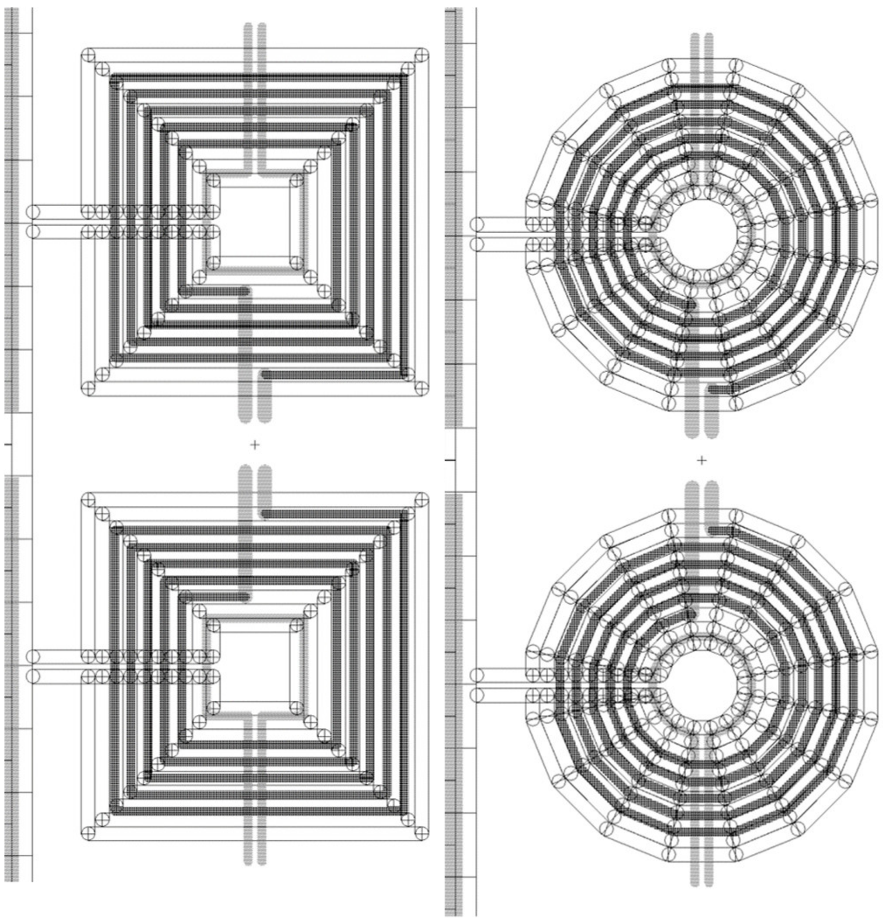
- wafer-scale fab of new MMCs completed in February
- problem with paramagnet depo system
  - solved problem last week

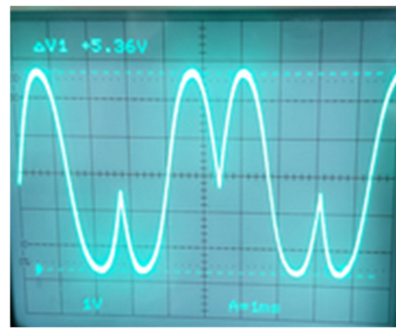




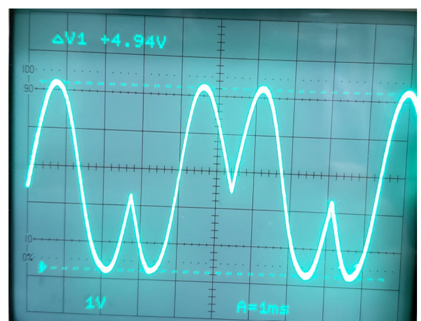
SQUID Design and Test

- new family of SQUIDs matched to “split” sensor designs
  - series flux transformers
  - with and without isolated feedback coil (Magnicon)





FLL via washer
est. 25.6, meas. 26.4 μA/Φ_0
3.8 μΦ_0/rt Hz @ 4K



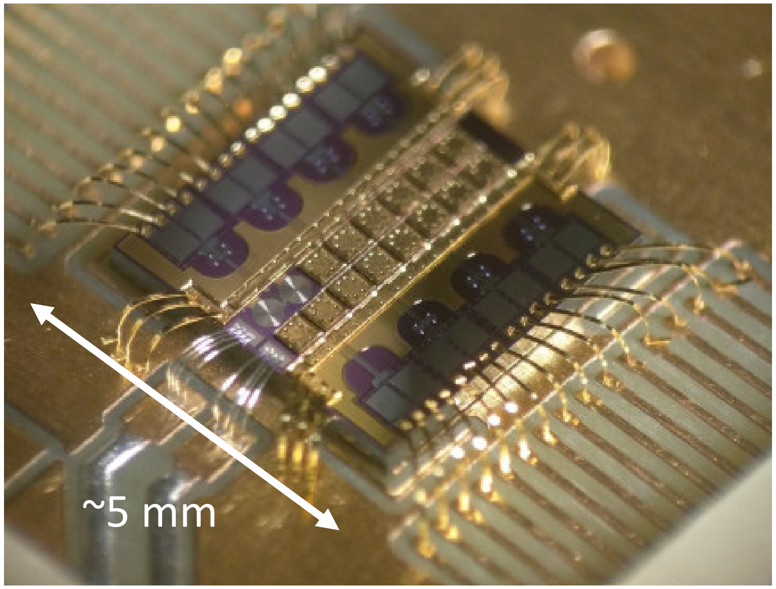
FLL via isolated coil
est. 70.4, meas. 66.6 μA/Φ_0
3.5 μΦ_0/rt Hz @ 4K

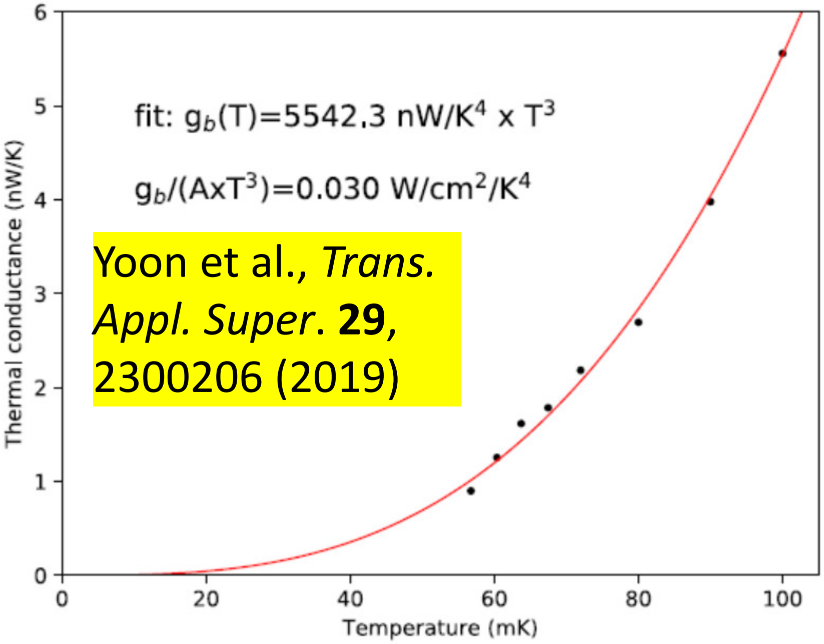
L_{input} (nH)	k_{input}
4.3	0.64
5.8	0.66
7.5	0.65
9.5	0.66
11.7	0.67
14.3	0.68

- 36 new designs
- meas. Ic ~8uA

Can we keep an "integrated" MMC chip cool?

- semi-quantitative model
  - metallic conduction
    - Wiedemann-Franz
  - phonon conduction
    - thermal boundary resistance
      - $Q = \sigma A\left(T_{\mathrm{hot}}^4 - T_{\mathrm{cold}}^4\right)$
    - recent NASA data σ ~75 $W/m^2/K^5$
- on-chip thermometer
  - one SQUID of the 8 is configured as a paramagnetic thermometer
    - simple uncapped meander
    - paramagnet only on one side

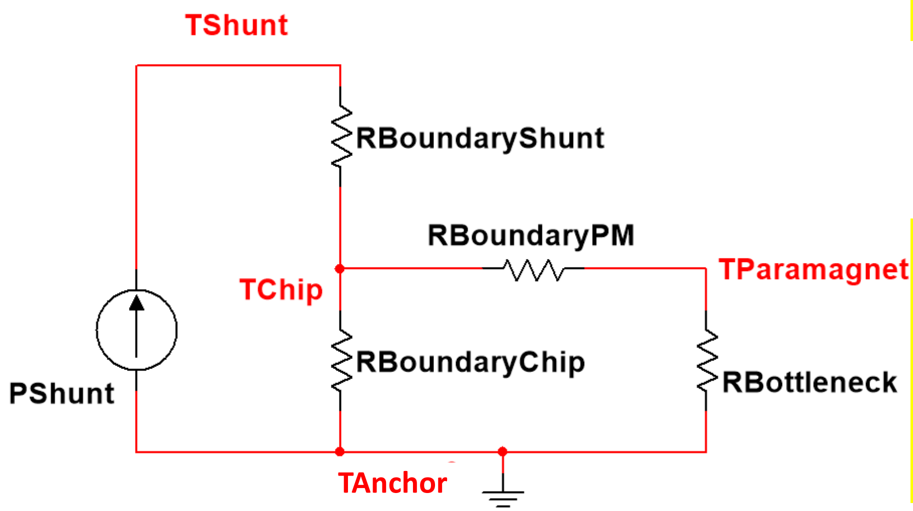




Yoon et al., *Trans. Appl. Super*. **29**, 2300206 (2019)

Can we keep integrated MMC cool?

- Thermal network

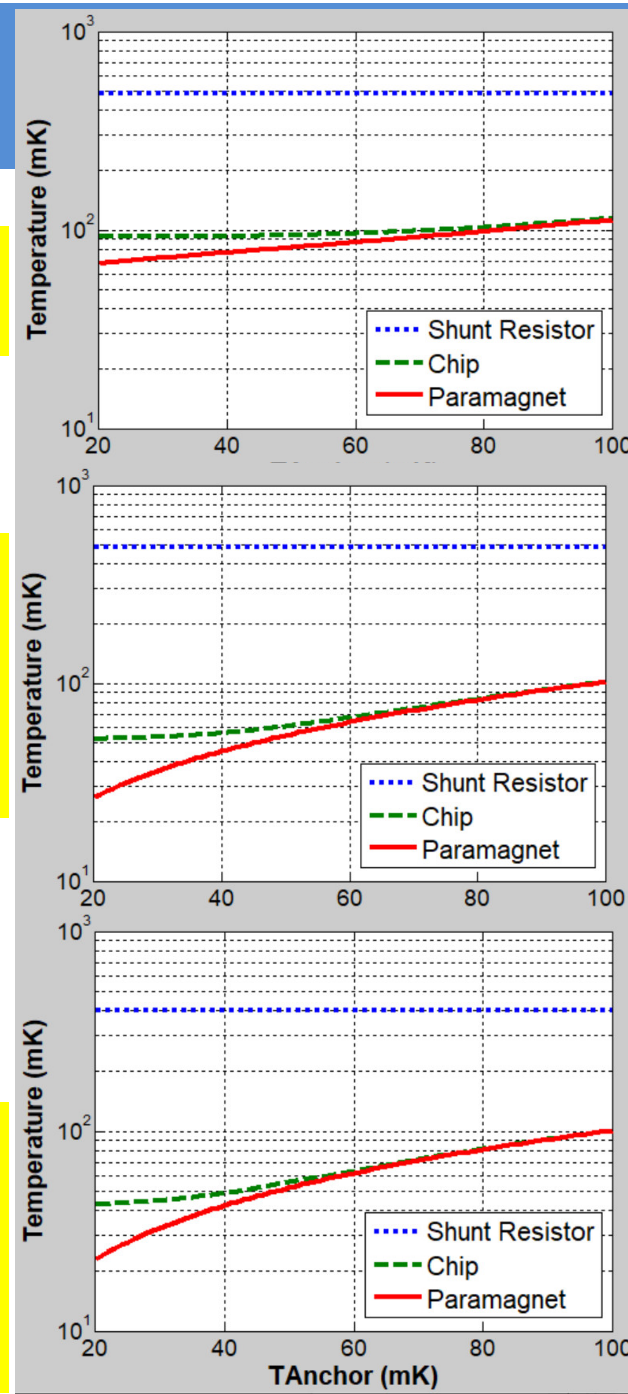


- our worst case
  - 8 SQUIDs on 5mm x 5mm chip
- approach works best if $R_{\mathrm{Bottleneck}}$ is small (G large)
  - large C or low τ

nominal case, T_{PM}~68mK

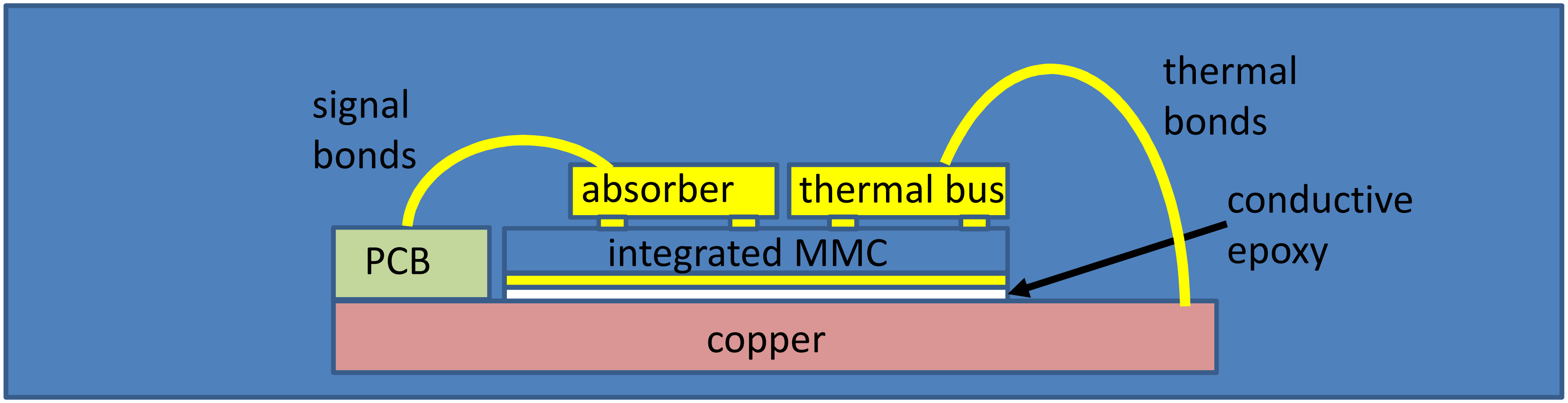
using ½ of back-side as metallic contact area, T_{PM}~27mK

use ½ of back-side and reduced I_c=8uA, T_{PM}~23mK



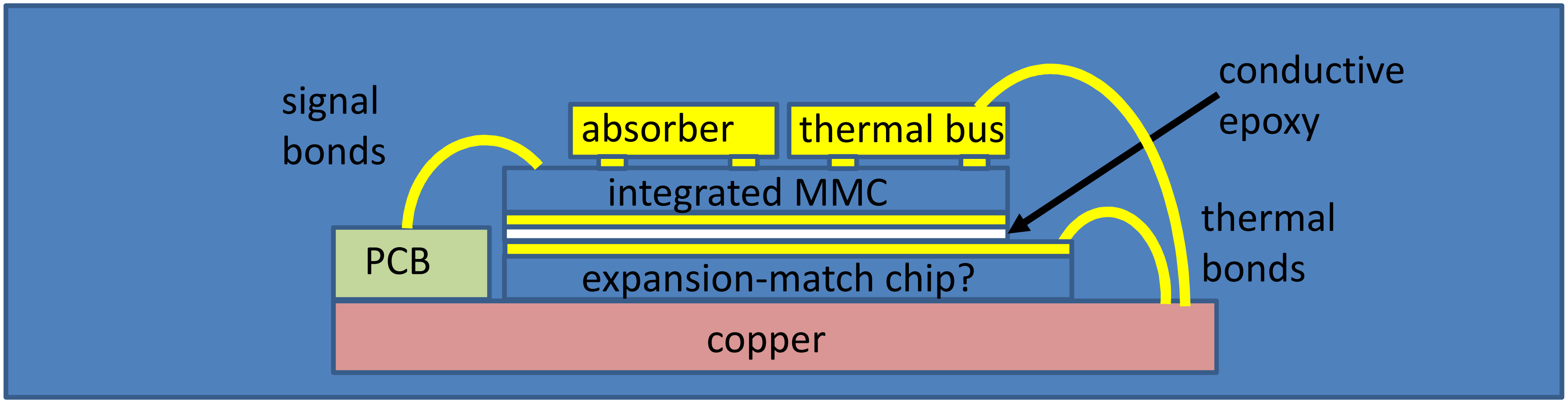
Can we keep an "integrated" MMC chip cool?

- Establishing metallic thermal contact between chip and cryostat?
  - try: electrically-conductive epoxy



Can we keep an "integrated" MMC chip cool?

- Establishing metallic thermal contact between chip and cryostat?
  - try: electrically-conductive epoxy
    - avoid die breakage



Summary

- MMCs (still) look great for high-accuracy gamma spectroscopy and nuclear data improvement
  - see also Geon-Bo Kim's poster "A New Measurement of the 60 keV Transition in Am-241 Decays using MMC" 269-276
- new devices still in fab, but hopefully REAL SOON NOW
  - wafer-scale processing completed
  - sensor-matched SQUIDs look good
- modeling development
- we may be able to keep integrated MMCs cool with minimal process development