Karlsruhe Institute of Technology

DELight

# Large-Area Cryogenic Microcalorimeters (LAMCALs) for the DELight experiment

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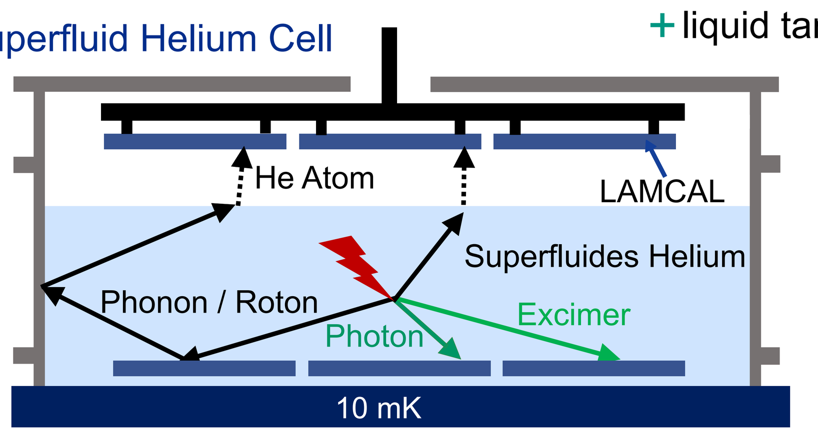
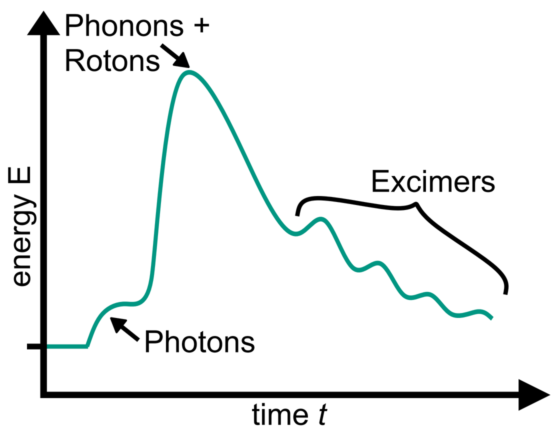
## DELight: Basics, Goals, and Challenges

Direct search Experiment for Light Dark Matter with Superfluid Helium (DELight):

- Detection of DM down to masses below 100 MeV with a nuclear recoil energy threshold of 20 eV
- Superfluid helium-4 as target material:
  + sensitive to low DM masses
  + radiopure and compact low-background target
  + three signal channels
  + liquid target (easily scalable)

Superfluid Helium Cell



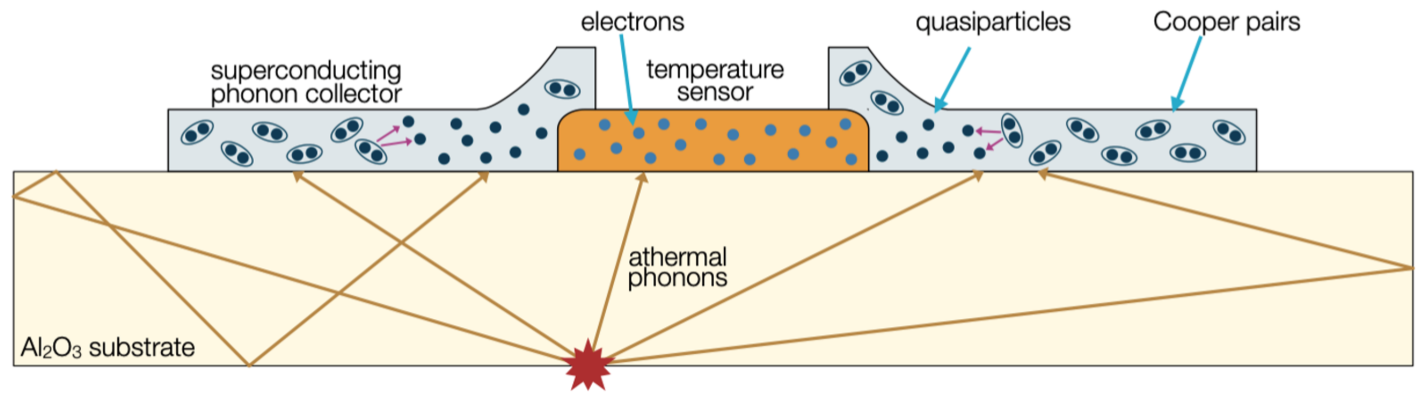

Detector specifications for Phase I:

- Near-complete area coverage→ large-area absorber
- Excellent energy $\Delta E_{FWHM}$ ~ O(1-2 eV) and time resolution $\Delta t$ ~ O(1-10 μs) (10 % – 90 % signal rise time)

➡ Large Area Microcalorimeters (LAMCALs)

## Detector concept

Magnetic microcalorimeter (MMC) based athermal phonon detector:




Creation of athermal phonons ➡ Ballistic propagation ➡ Cooper pair breaking; quasiparticles (QPs) creation ➡ QP diffusion ➡ De-excitation in sensor through el.-el. interactions → local temperature increase

Advantages:

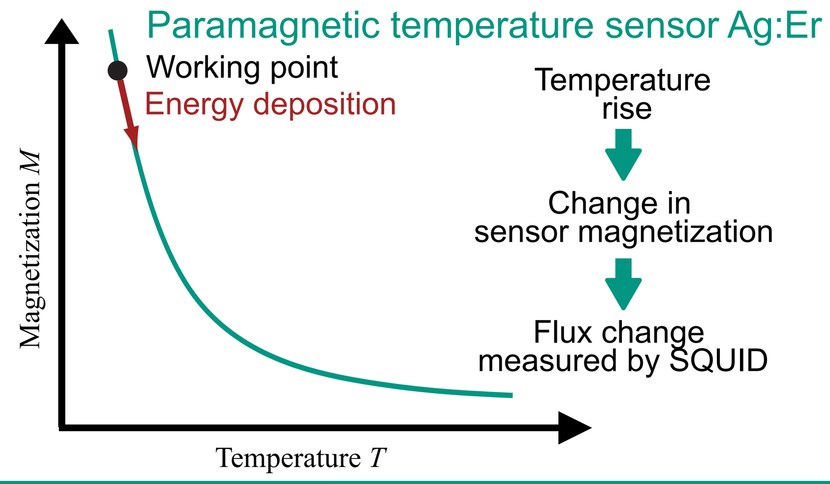
- Fast signal rise time
- Realisation of large-area absorbers

$C_{tot} = C_{sens} + C_{coll} + \cancel{C_{abs}}$

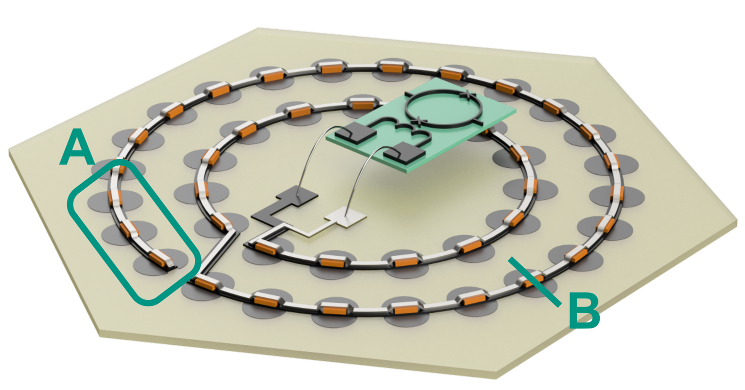
Challenges:

- Minimization of phonon collection time
- **QP losses** due to recombination

Paramagnetic temperature sensor Ag:Er




## LAMCAL Development




Integrated detector design:
(Absorber + phonon collector + sensor on a single device)

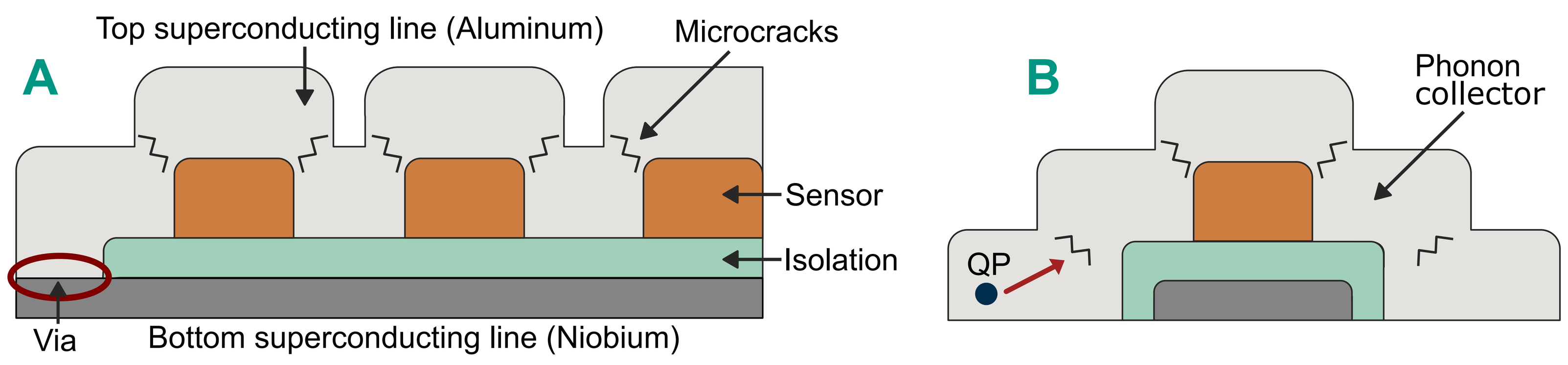
Phonon collectors equally distributed among the wafer

- Minimizing phonon collection time
- Take into account the finite lifetime of the quasiparticles in the phonon collector

Detector pieces connected via "sandwich" stripline

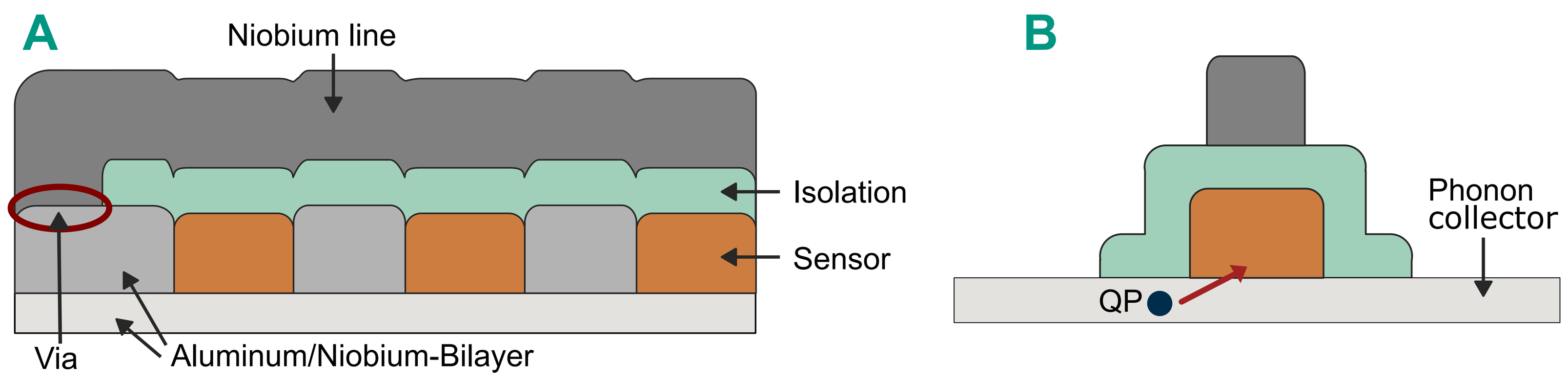
- Minimizing parasitic inductance

Intuitive ("standard") approach:




- Bends in the upper stripline may induce microcracks → reduces critical current
- Critical current reduction caused by the Nb/Al-via
- Microcracks affect quasiparticle diffusion toward the sensor

New design idea:

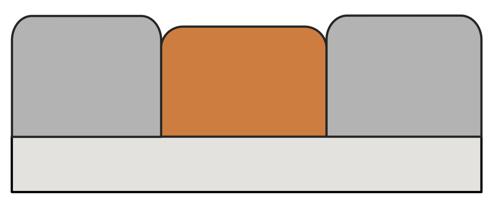



- Planarization of the top stripline → reducing microcracks
- In situ Aluminum/Niobium-Bilayer sputtering → no Al/Nb-via; less critical Nb/Nb-via
- Planar contact between sensor and phonon collector

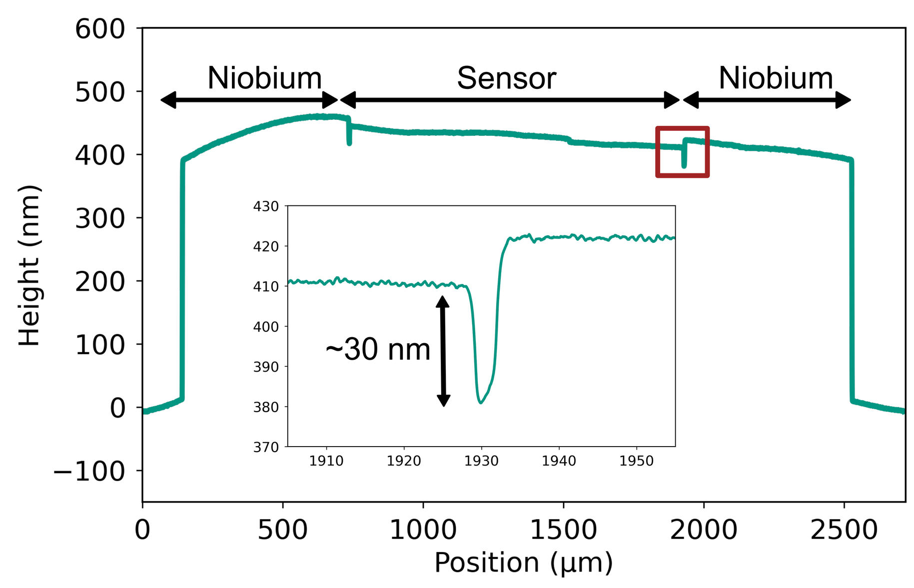
Evidence of successful planarization:

- Measurement of the height profile

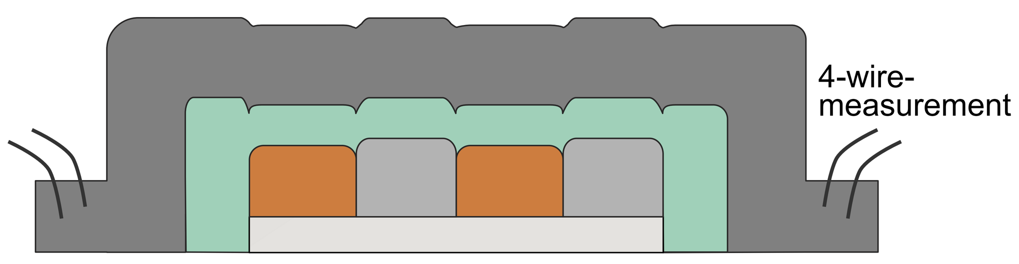
Structure:



➡ Small gap filled by following layers



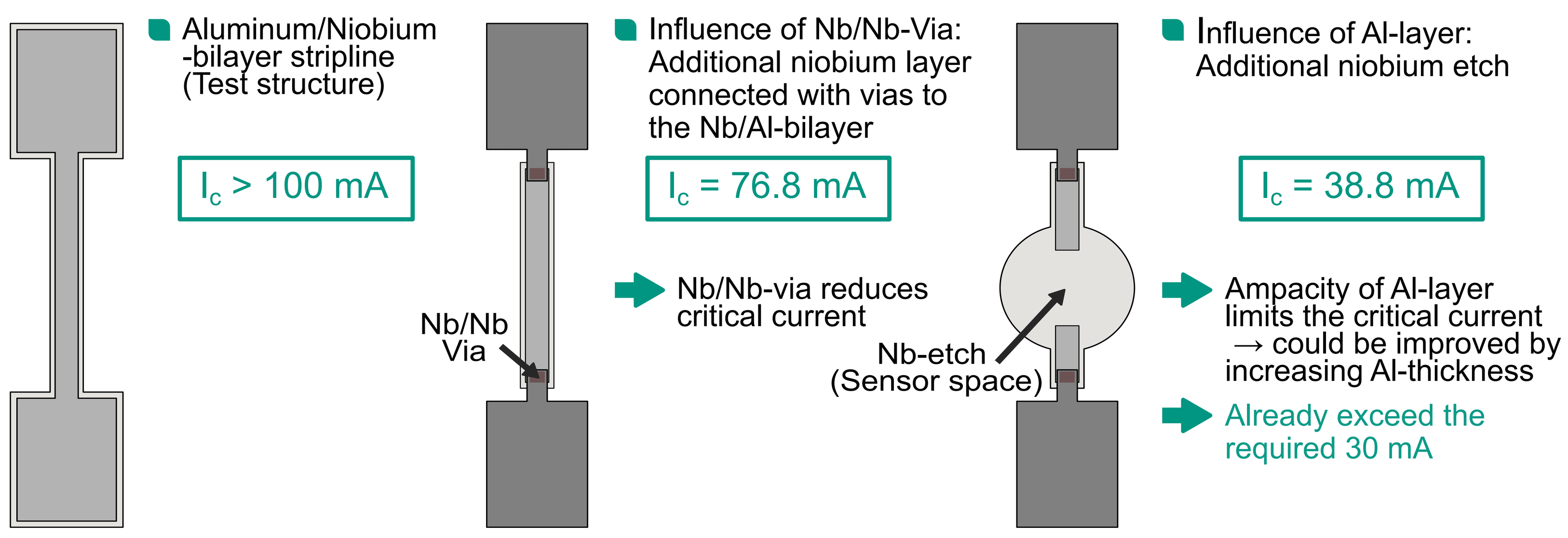

- Comparison room temperature resistance of planarized structure with different numbers of sensors with niobium stripline of same length




| | Width $w = 10$ nm | Width $w = 14$ nm |
|---|---|---|
| 4 Sensors | 418 Ω | 287 Ω |
| 6 Sensors | – | 282 Ω |
| 8 Sensors | 419 Ω | 289 Ω |
| Test structure | 416 Ω | 283 Ω |

➡ No significant resistance difference between planarized and test structures

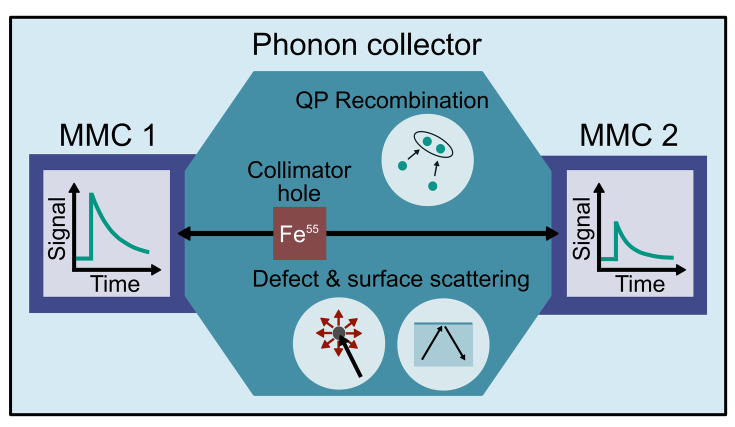
Investigation of the critical current: The critical current of the stripline must exceed 30mA




## Quasiparticle lifetime experiment

Experiment motivated by CRESST

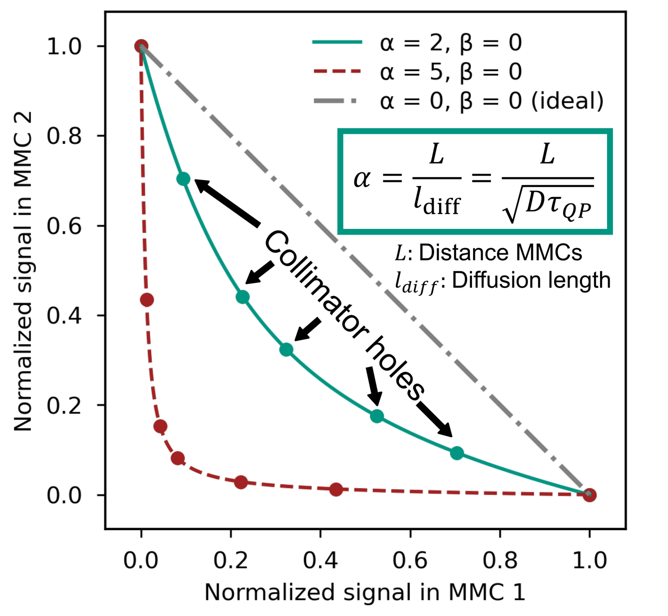
- Determination of diffusion length and quasiparticle lifetime
- Dependent on the choice of material and the quality of material
- Phonon collector geometry optimization



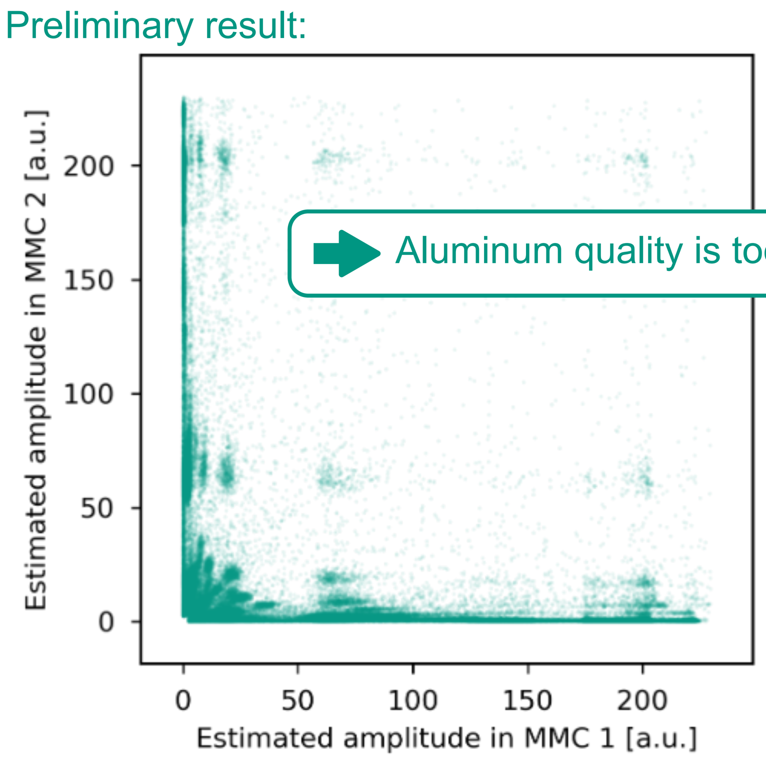

1D Diffusion equation

$$\frac{\delta n}{\delta t} = D\frac{\delta^2 n}{\delta x^2} - \frac{n}{\tau_{QP}}$$

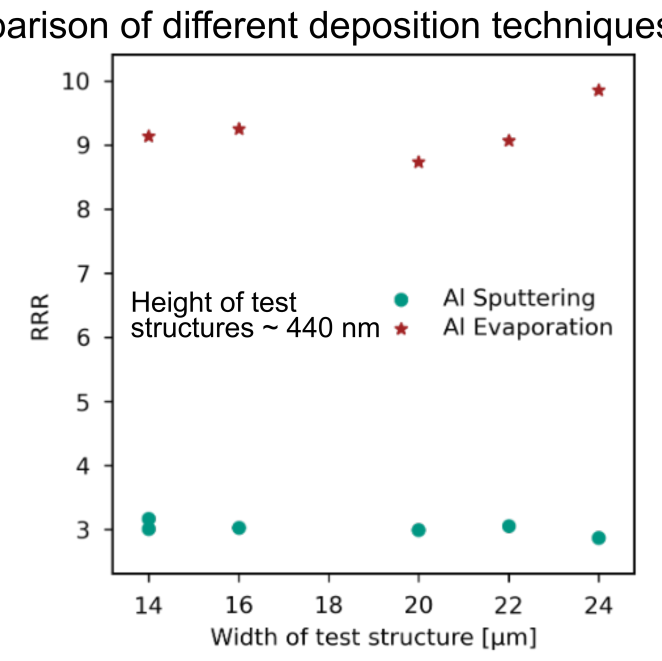
$n$: QP density
$D$: Diffusion constant
$\tau_{QP}$: QP lifetime




Preliminary result:




Comparison of different deposition techniques:




- ~3x better RRR value for evaporated aluminum
- Further improvements are expected through the new UHV e-beam evaporation system.