



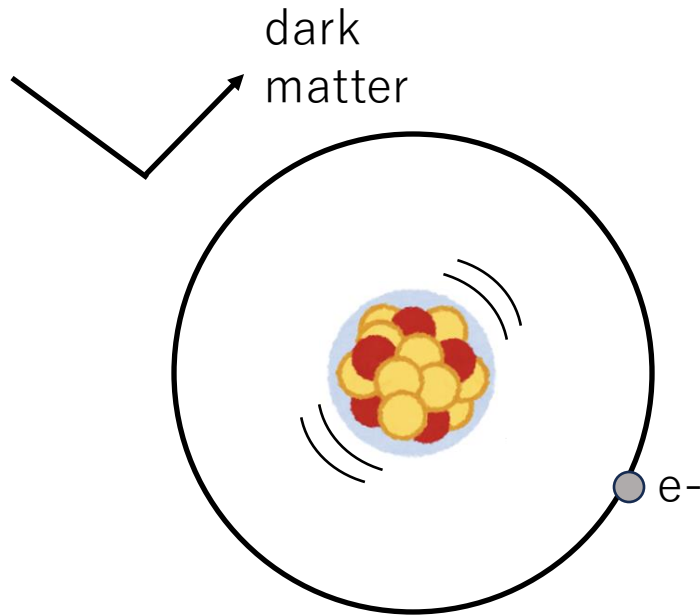
軽い暗黒物質直接探索に向けた 新規超伝導検出器の開発

K. Hattori¹, M. Garcia-Sciveres^{1,2}, R. Hayakawa¹,
A. Suzuki^{1,2}, Y. Zhou¹,

¹KEK, QUP ²LBNL



MeV dark matter direct detection

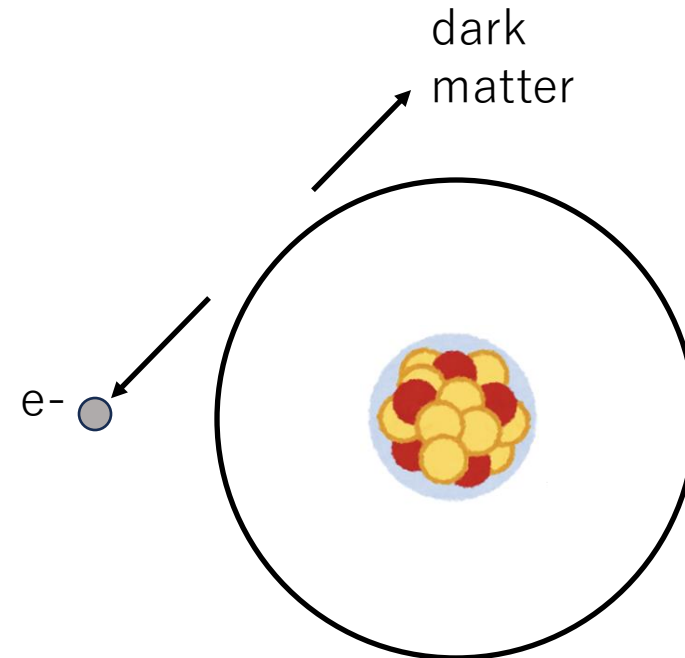


DM-nuclear scattering

$$E_R \sim 50 \text{ keV} \left(\frac{m_\chi}{100 \text{ GeV}} \right)^2 \left(\frac{100 \text{ GeV}}{m_N} \right)$$

$$E_R \sim 10^{-5} \text{ eV}$$

$$\begin{aligned} m_\chi &= 1 \text{ MeV} \\ m_N &= 25 \text{ GeV} \end{aligned}$$



DM-electron scattering

$$E_R \sim 0.5 \text{ eV} \left(\frac{m_\chi}{1 \text{ MeV}} \right)$$

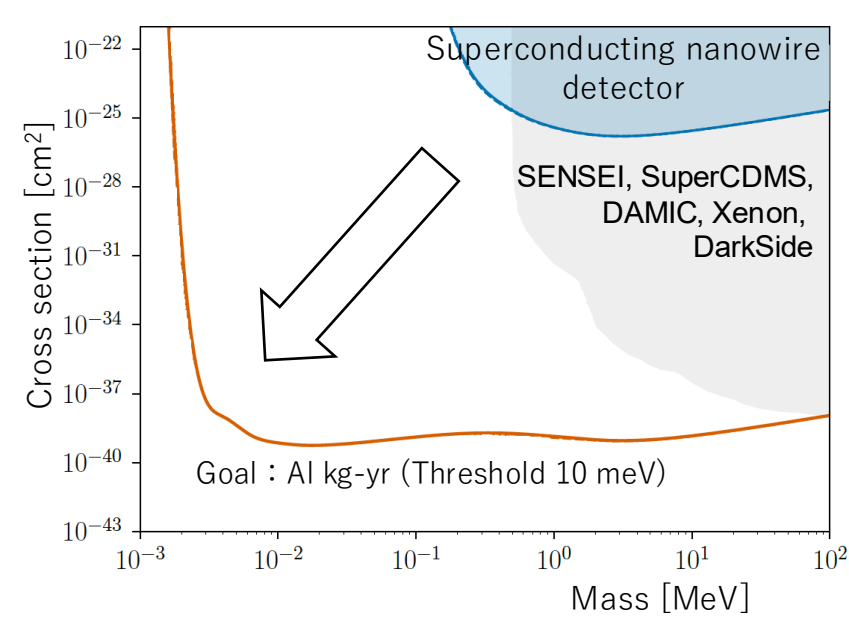
$$E_R \sim 0.5 \text{ eV}$$

Superconducting detectors
sensitive to sub-eV signals



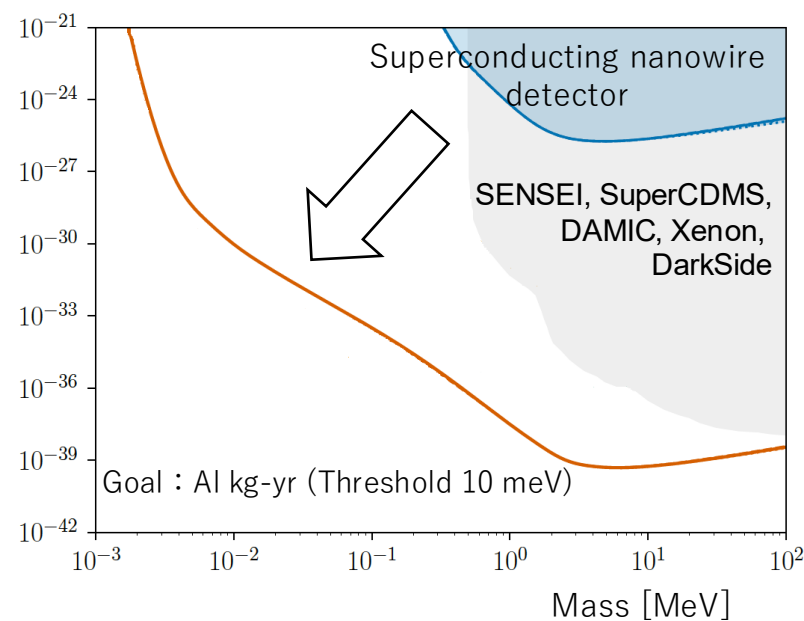
MeV dark matter search

DM-electron scattering : light mediator

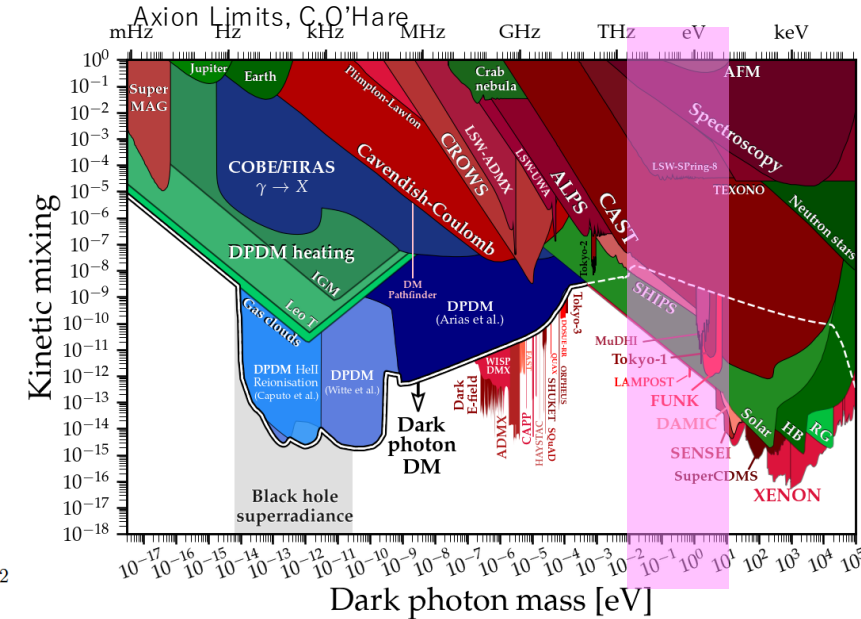


Y. Hochberg et al., arXiv:2110.01586

Heavy mediator



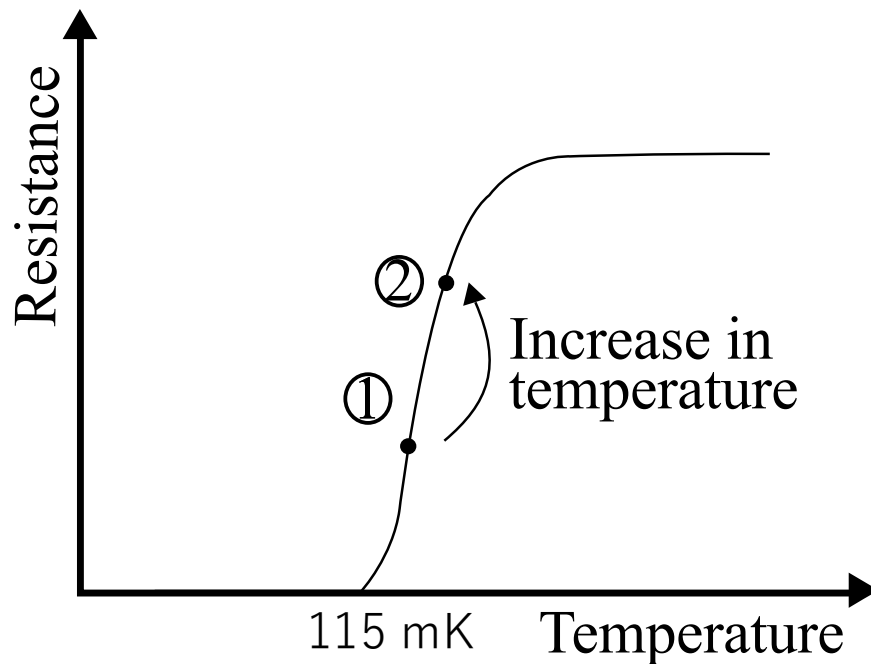
Absorption : dark photon



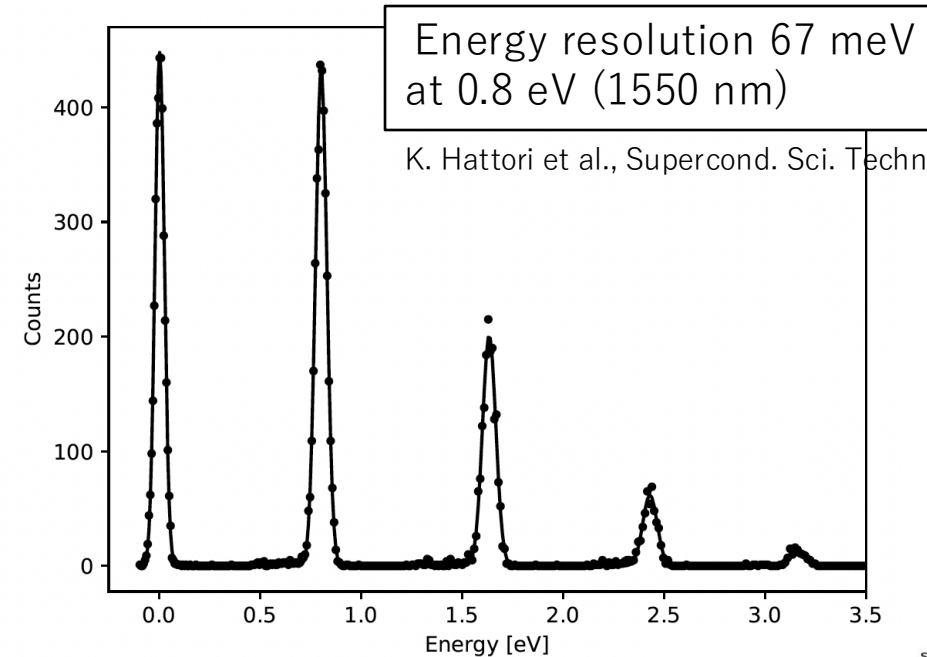
Explore 0.01 – 10 eV

Explore MeV region with detectors sensitive to sub-eV signals.

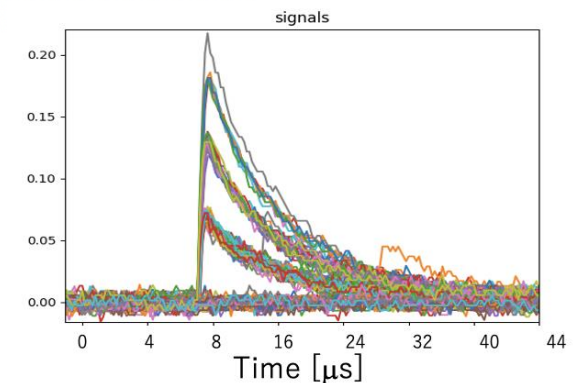
超伝導転移端センサ: Transition-edge sensor



1. Bias the detector in transition
2. Energy is deposited in a detector and is converted to heat.
3. Increase in temperature results in increase in resistance



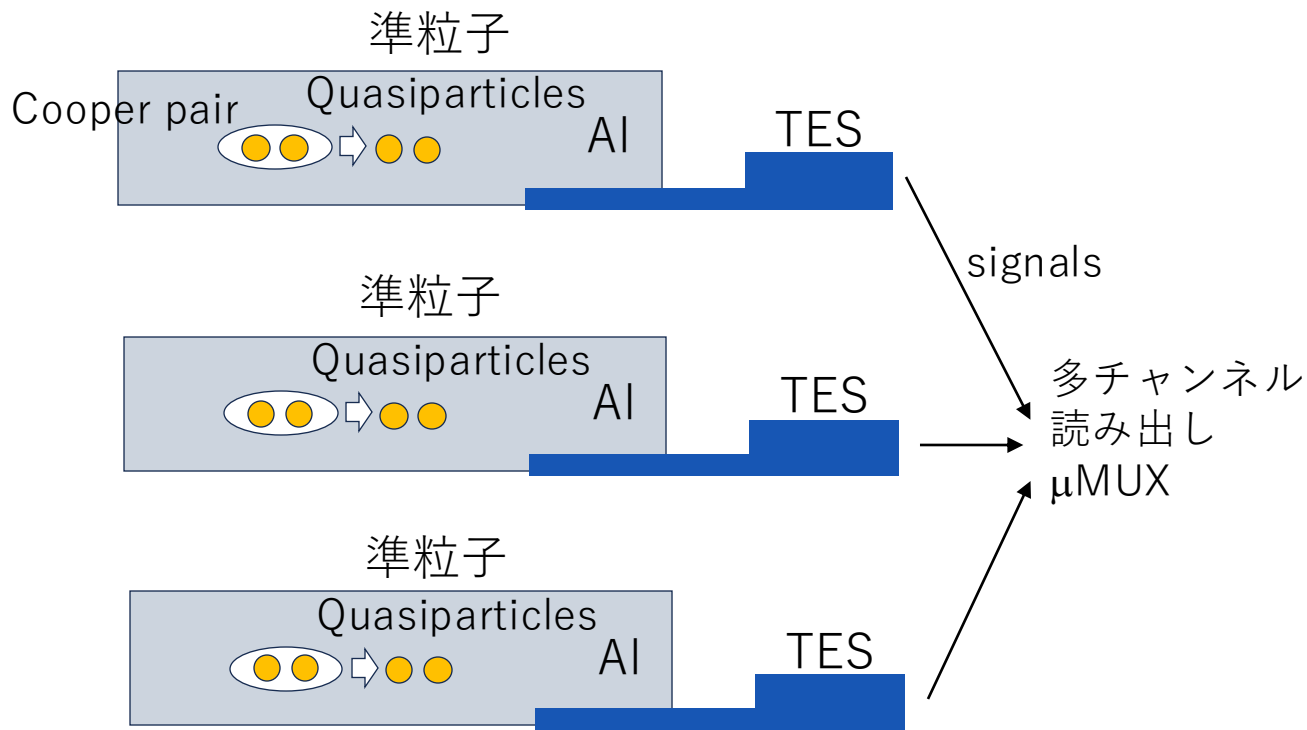
K. Hattori et al., Supercond. Sci. Technol. 35 (2022) 095002.



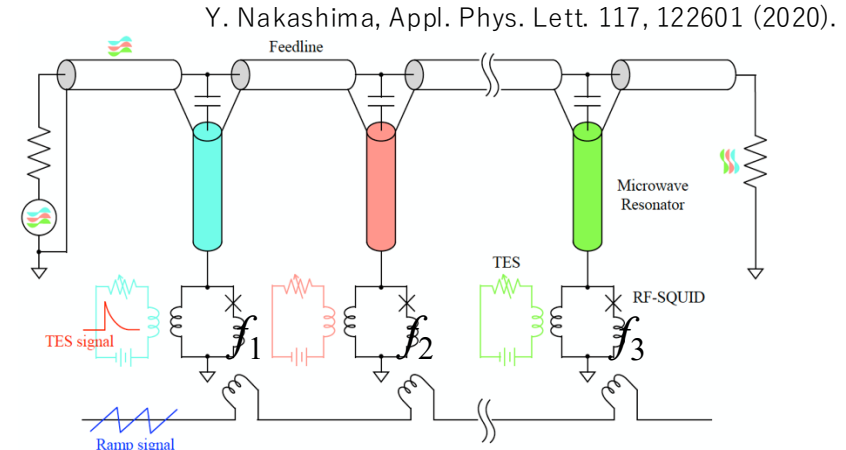


TES coupled with aluminum target

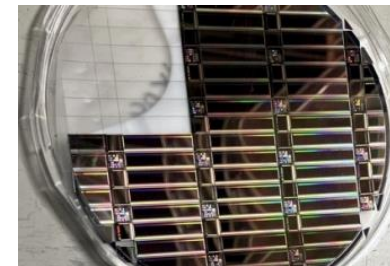
Low energy threshold is crucial to search sub-MeV dark matter.



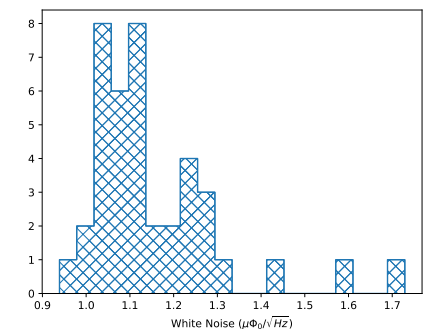
quasiparticle-trap-assisted TES (QET)
K. Irwin et al., Rev. Sci. Instrum. 66, 5322 (1995).



Flux-ramp modulation to linearize SQUID readout



産総研で作製



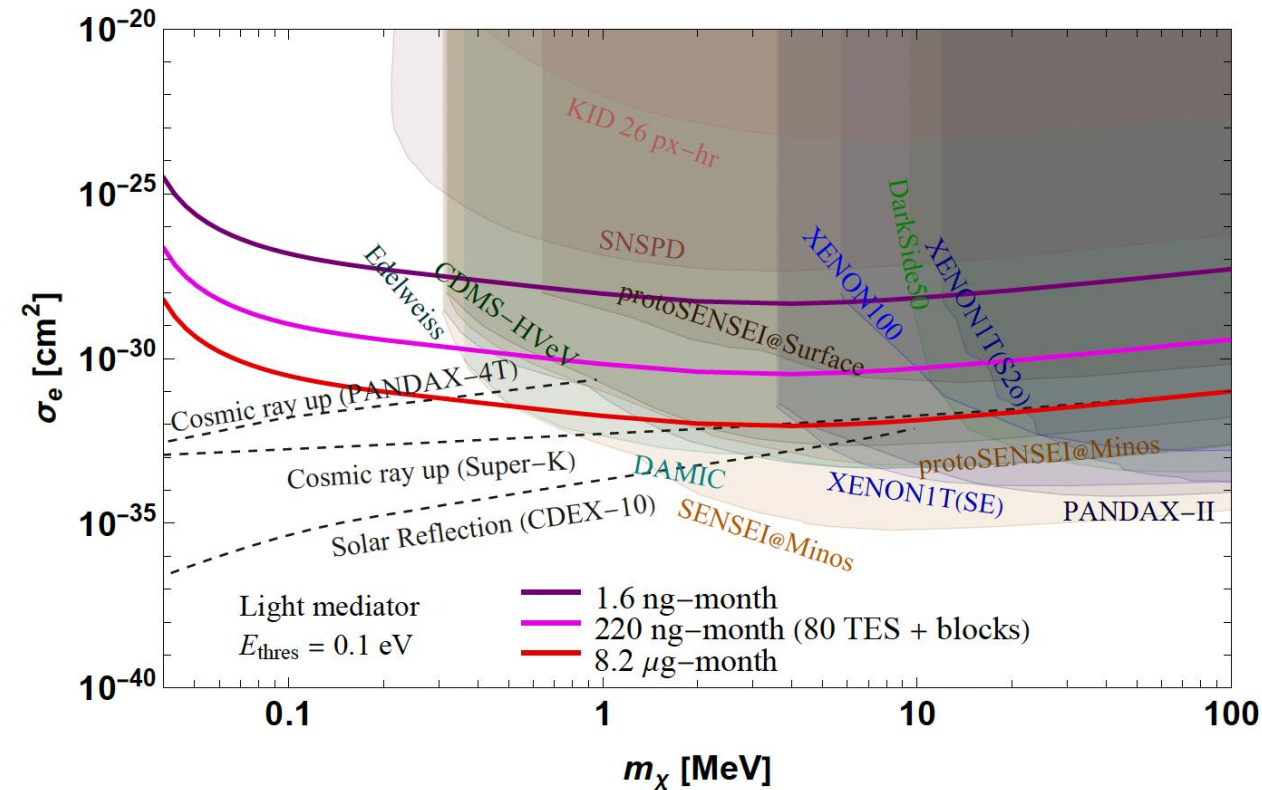
先行研究と遜色ない
ノイズレベル



Estimated Sensitivity

With low energy threshold, search with small mass can be competitive.

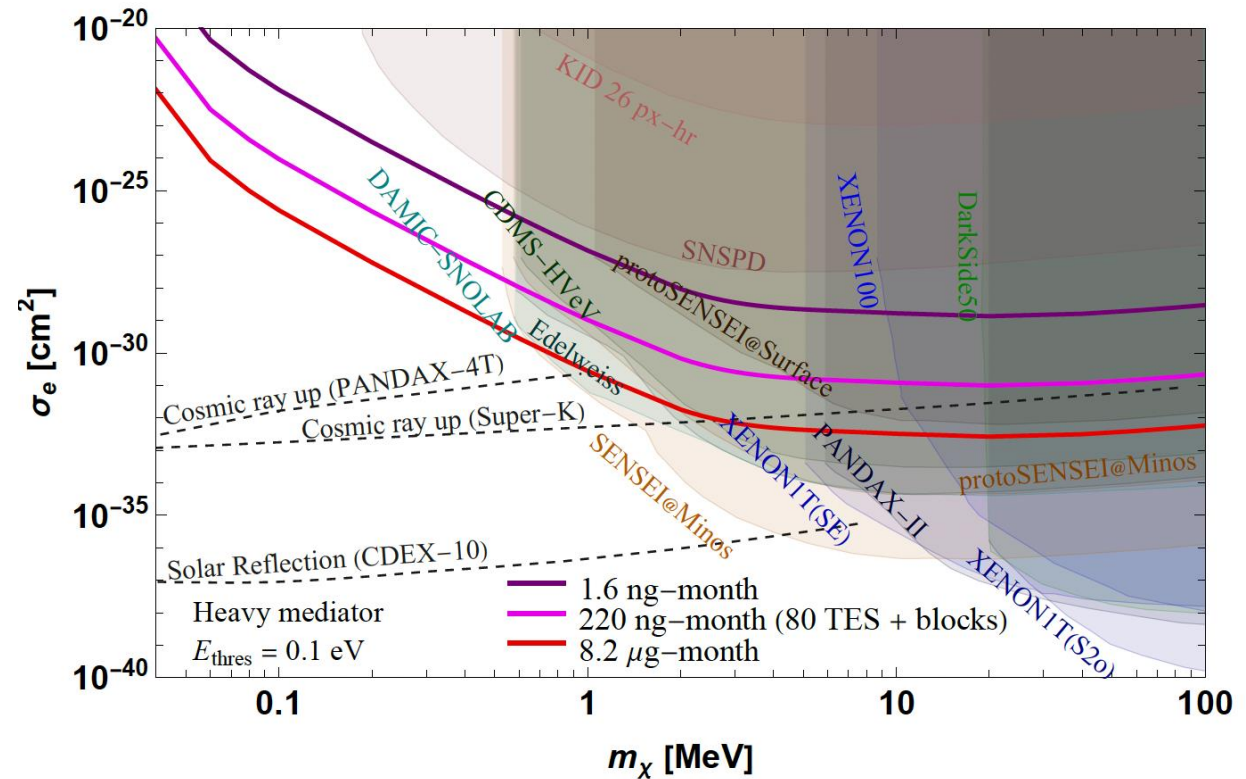
Light mediator



Zero background and 100% collection efficiency of quasiparticles are assumed.

Heavy mediator

M. Cheng et al., arxiv:2506.10070v1

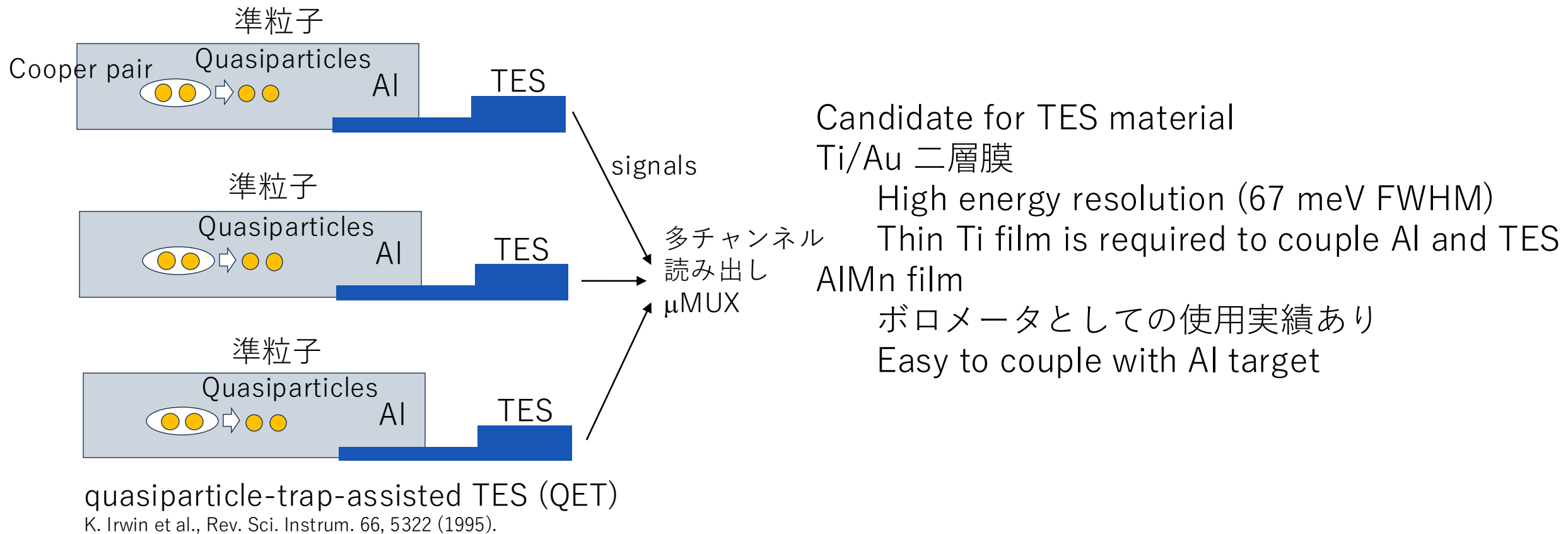


1.6 ng-month : 40 TESアレイ, AIターゲットなしでもsub-MeV領域を探索可能



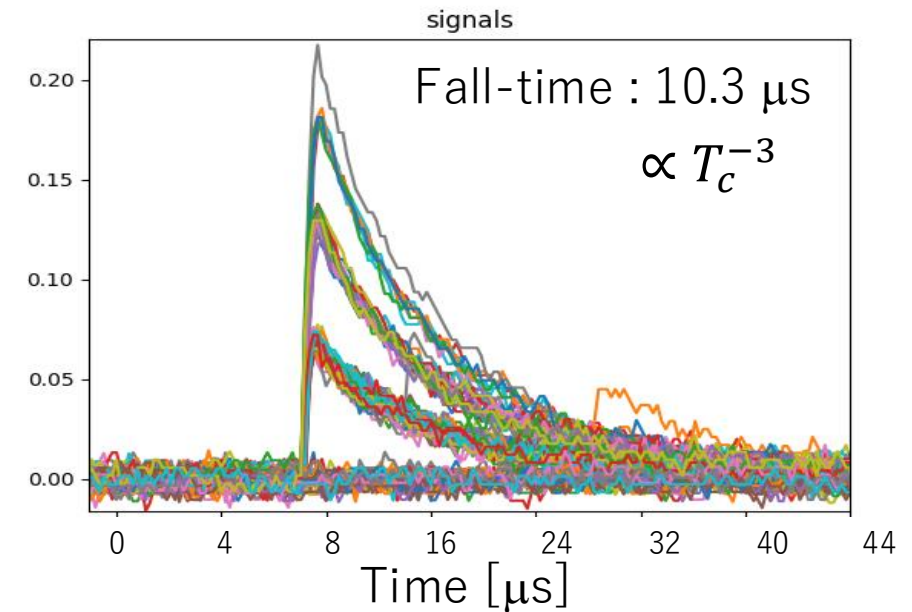
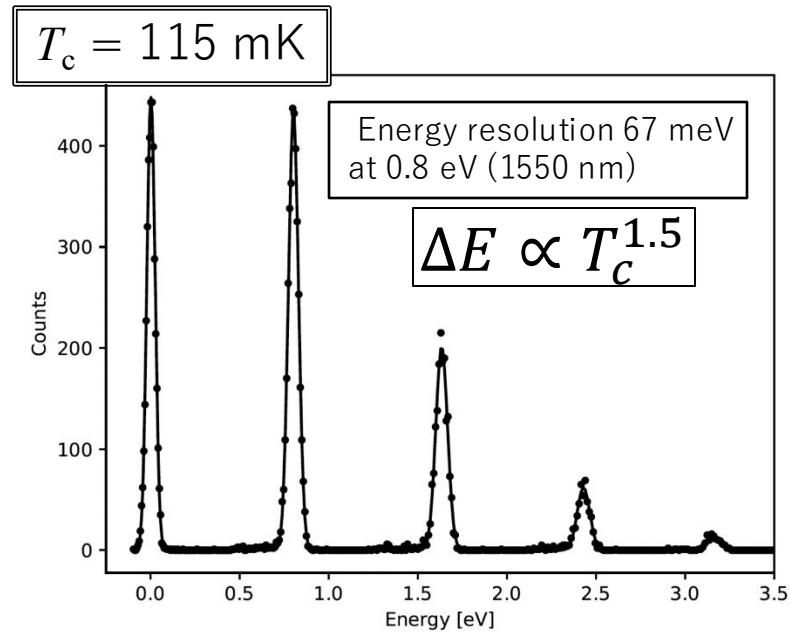
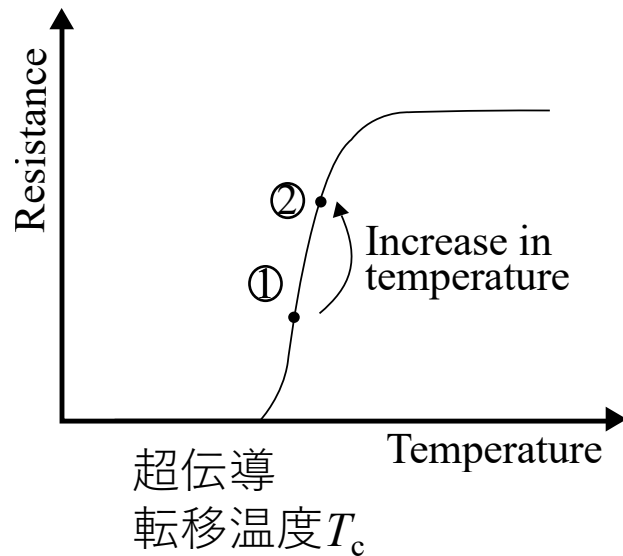
TES coupled with aluminum target

Low energy threshold is crucial to search sub-MeV dark matter.





10 meVのエネルギー分解能を目指して



エネルギー分解能を向上させたい
 $T_c = 50$ mKで20 meV(FWHM)
 $T_c = 20$ mKで5 meV(FWHM)
低い超伝導転移温度を実現する方法を検討



TESを構成する超伝導薄膜

これまで使用してきた超伝導薄膜



常伝導金属(Au, 20 nm)

超伝導体(Ti, $T_c = 390$ mK, 10 nm)

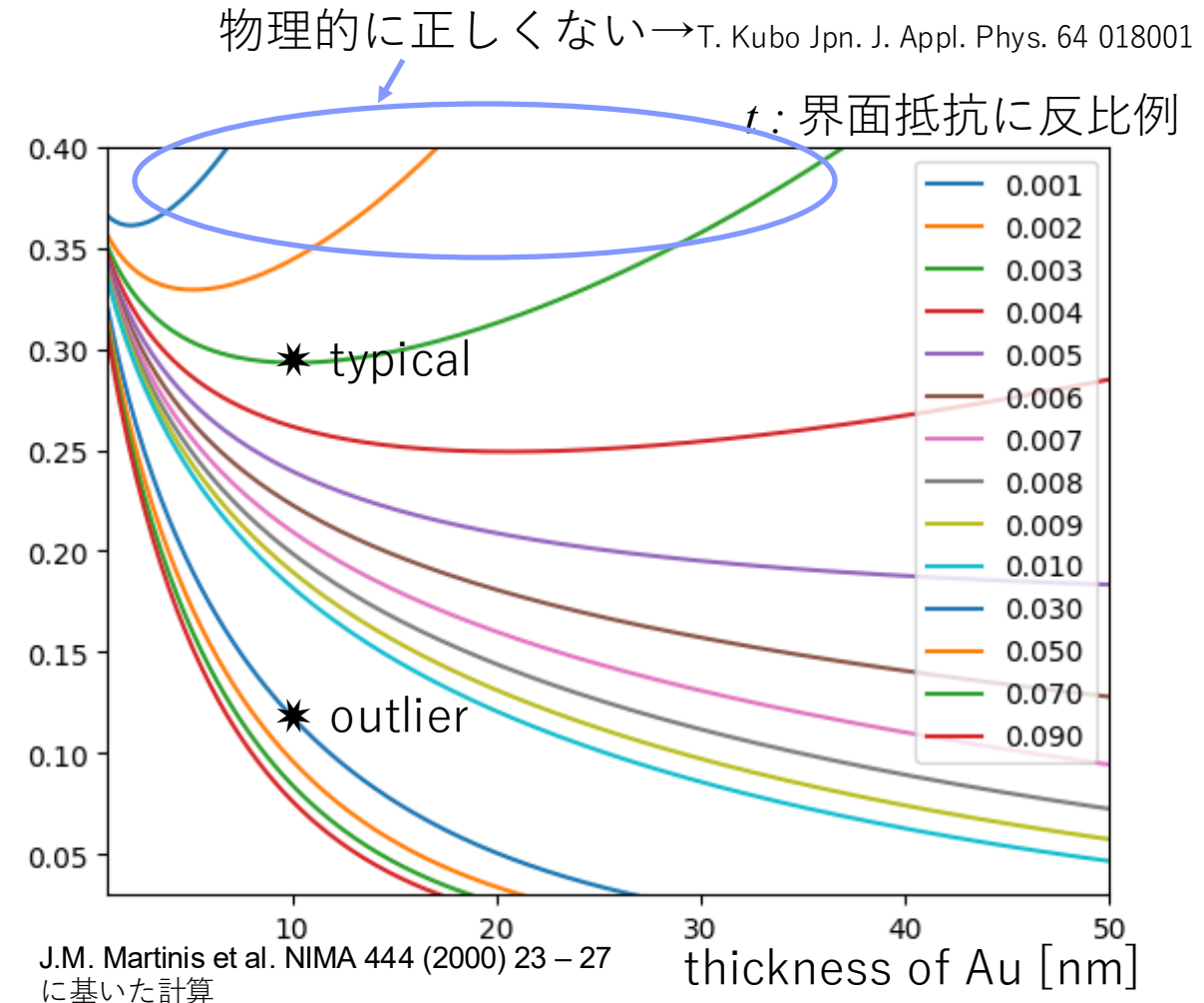
近接効果

膜厚と界面の抵抗で超伝導転移温度が決定される
界面のコントロールは非常に困難

100 mK以下の超伝導転移温度を実現するためには
膜厚を1 nmかそれ以下のオーダーで精密にコントロール
→技術的に不可能

Auとアルミは直接くっつかないので薄いTi膜が必要
→準粒子の収集効率が低下

新規物質の開拓

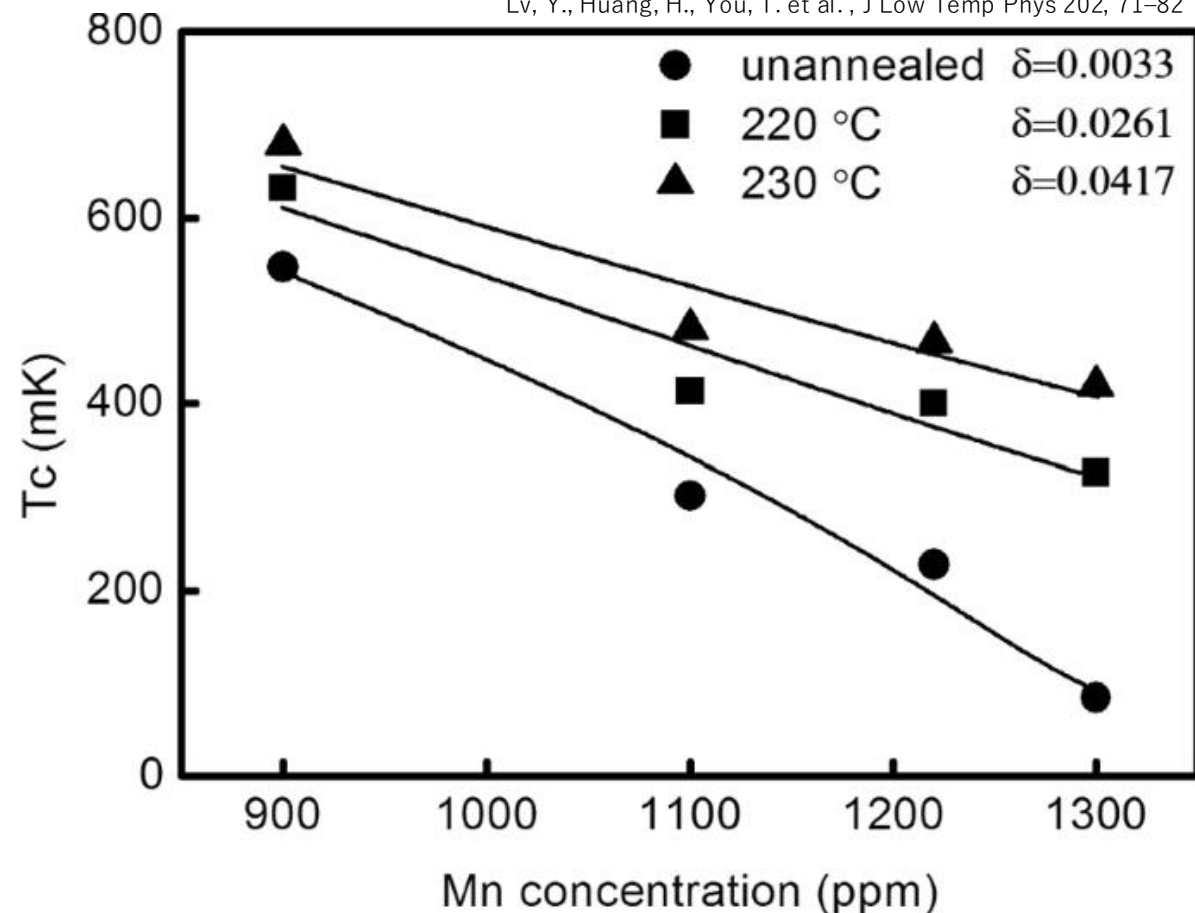




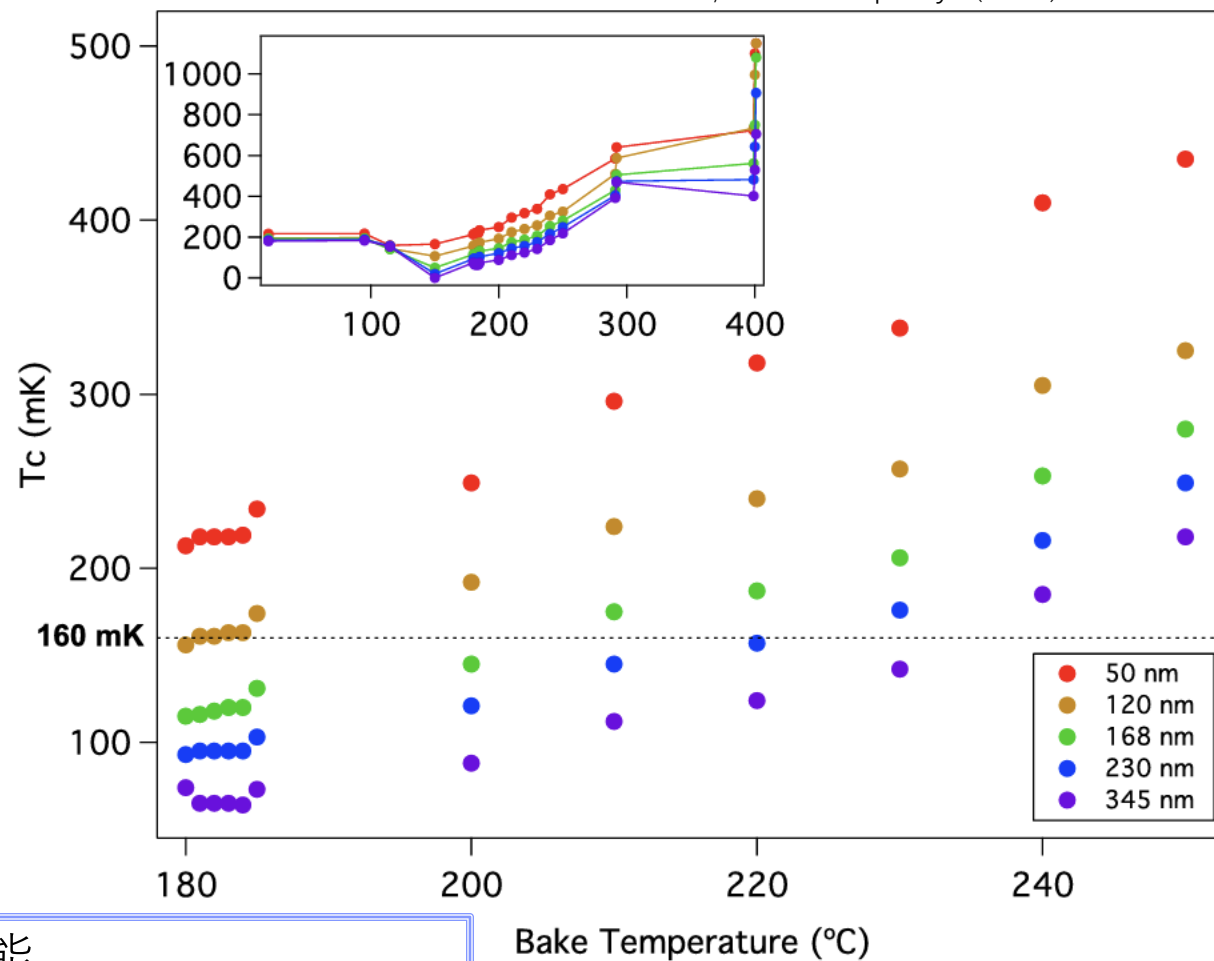
AlMn

Mn濃度と加熱時間で超伝導転移温度を調節可能
CMB観測のためのTESボロメータに使用実績あり

Lv, Y., Huang, H., You, T. et al., J Low Temp Phys 202, 71–82



D. Li et al., J Low Temp Phys (2016) 184:66–73

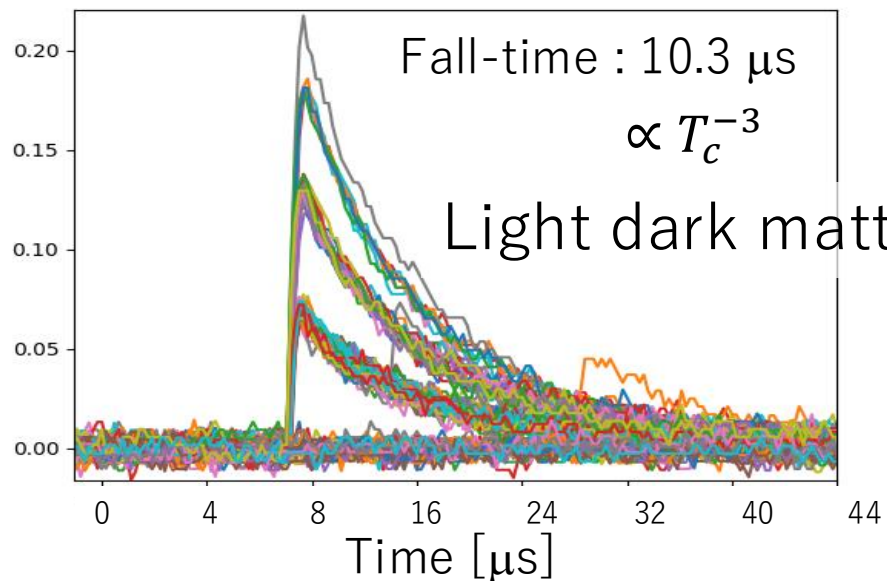
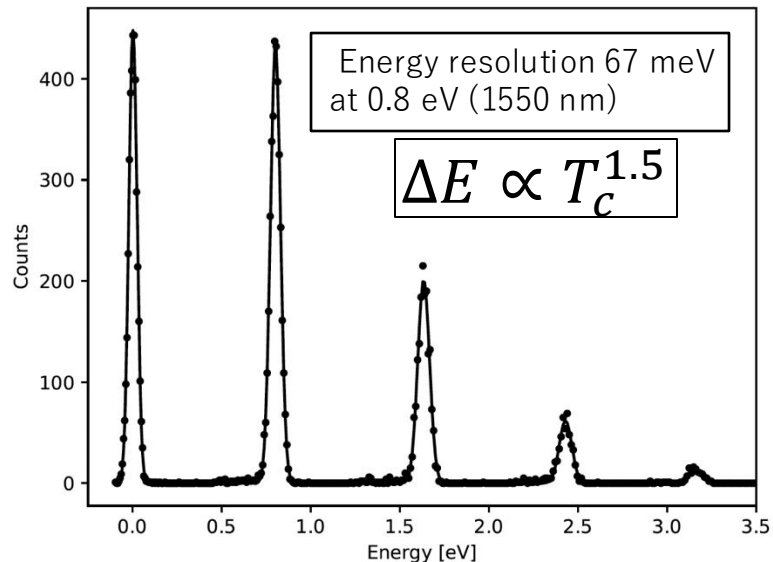


AlMn TESとアルミターゲットは高効率で結合可能
超伝導転移温度をフレキシブルに調節することで応用範囲が広がる

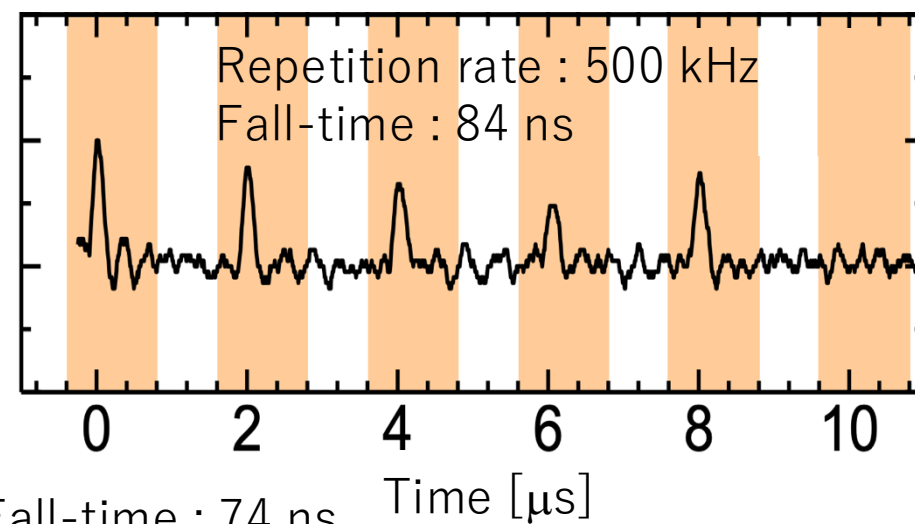
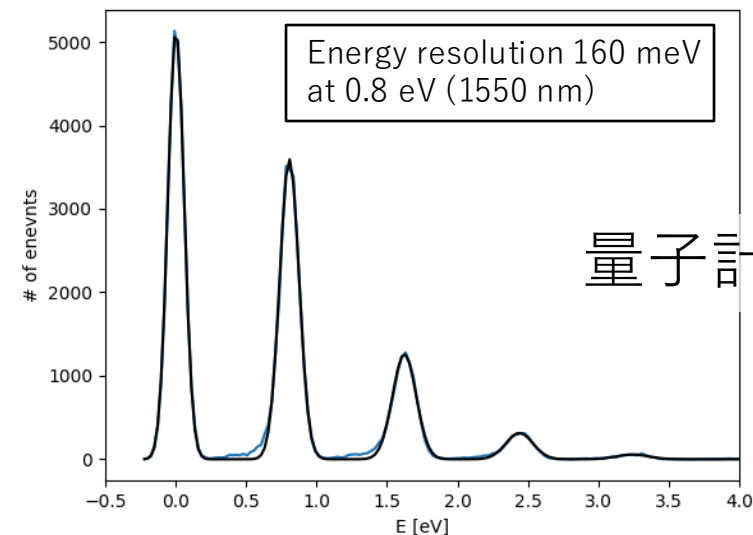


超伝導転移温度とアプリケーション

Slow TES ($T_c = 115$ mK)



Fast TES ($T_c = 300$ mK)

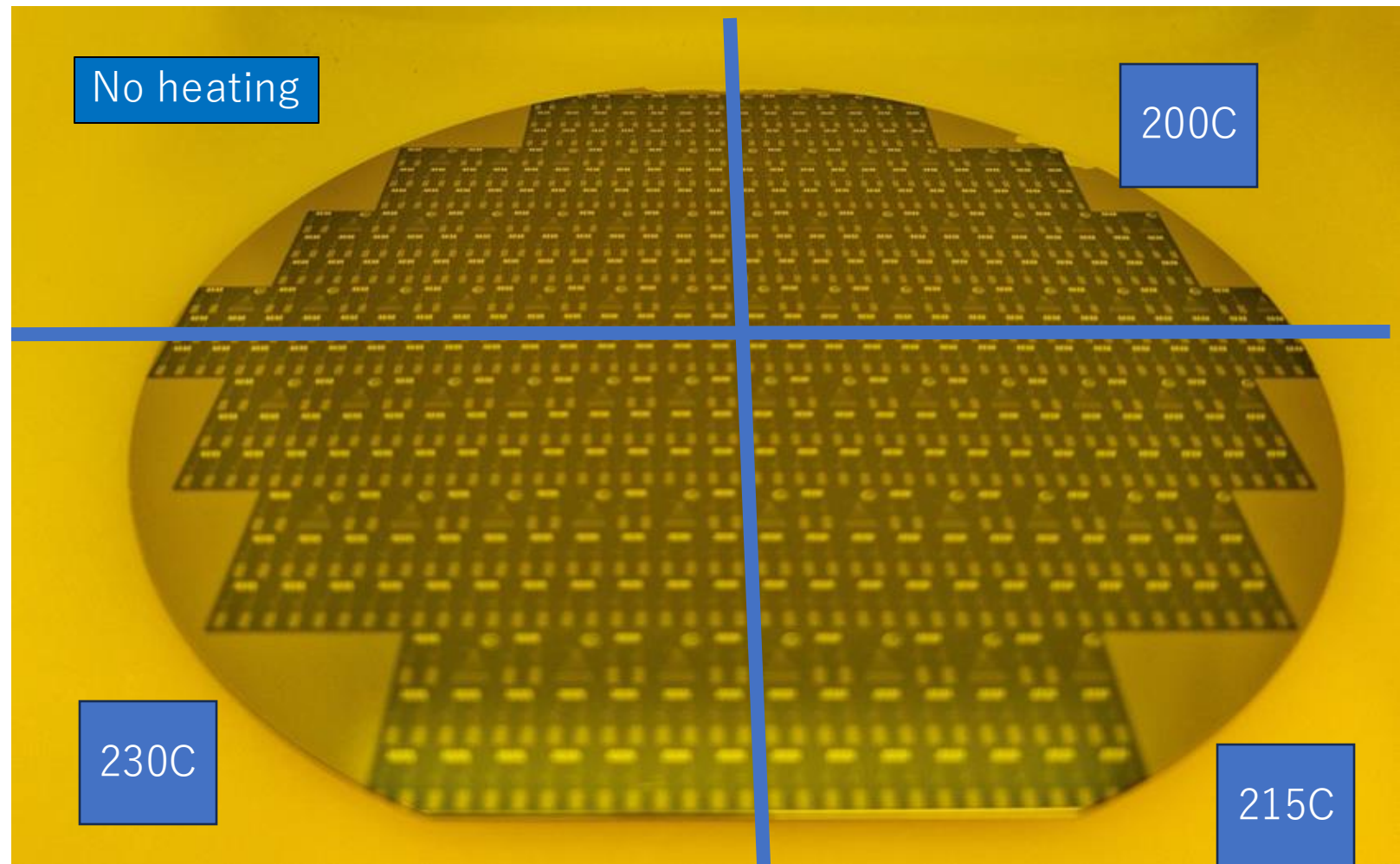




AlMn TESs

M. Garcia-Sciveres, K. Hattori, A. Suzuki, Y. Zhou
Fabricated by Seeqc (US).

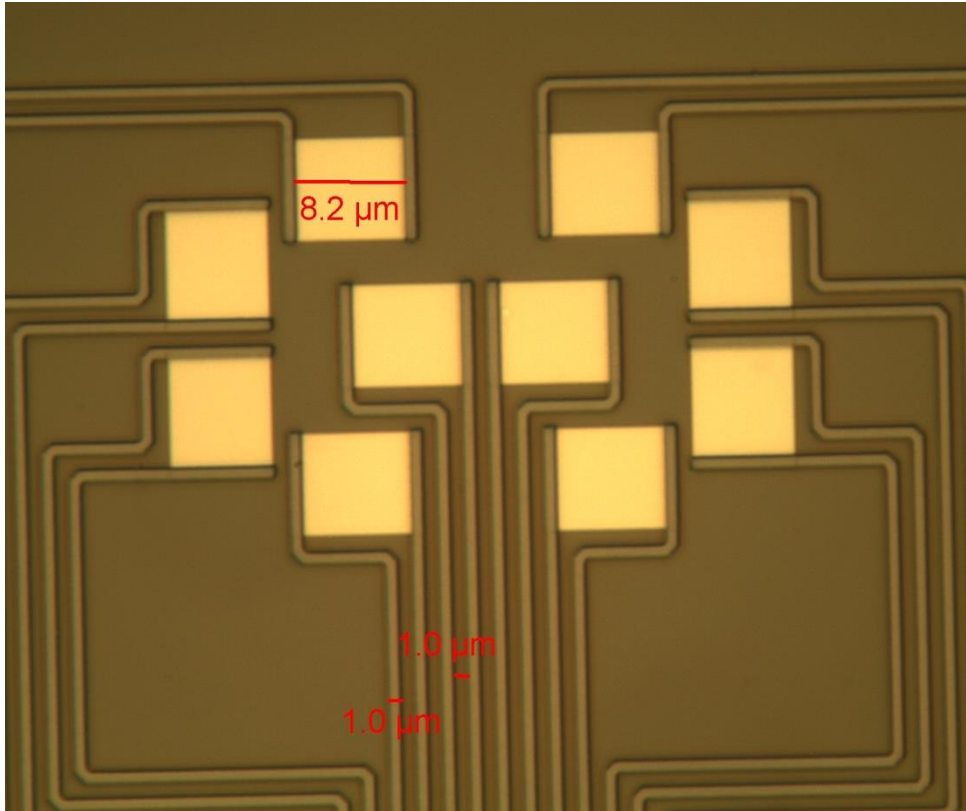
6 inch wafer.
 T_c can be controlled
by heating temperature.



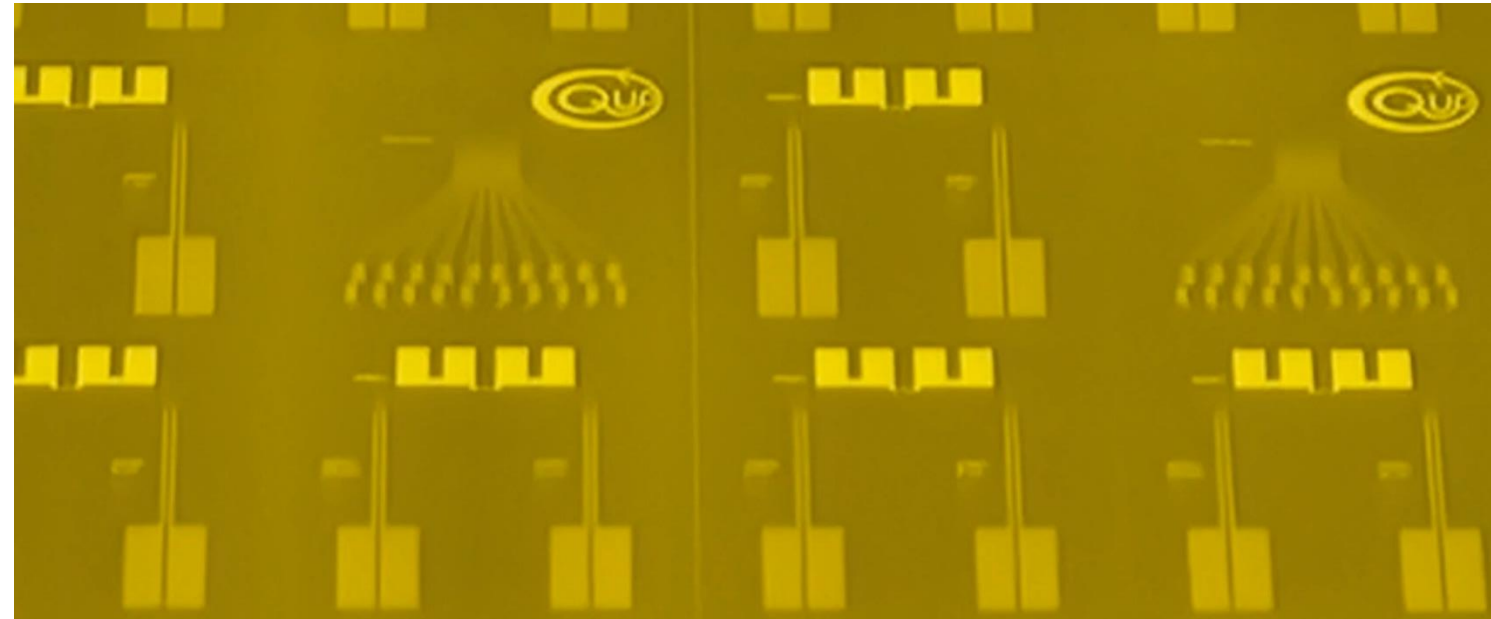


AlMn TESs

TES array



Design : T. Hayashi (立教大)



CMB TESボロメータと我々のTESの違い
sub-eVに感度を持たせるため、TESの面積 $\sim 10^{-2}$
TESが小さいほど製作の難易度が上がる

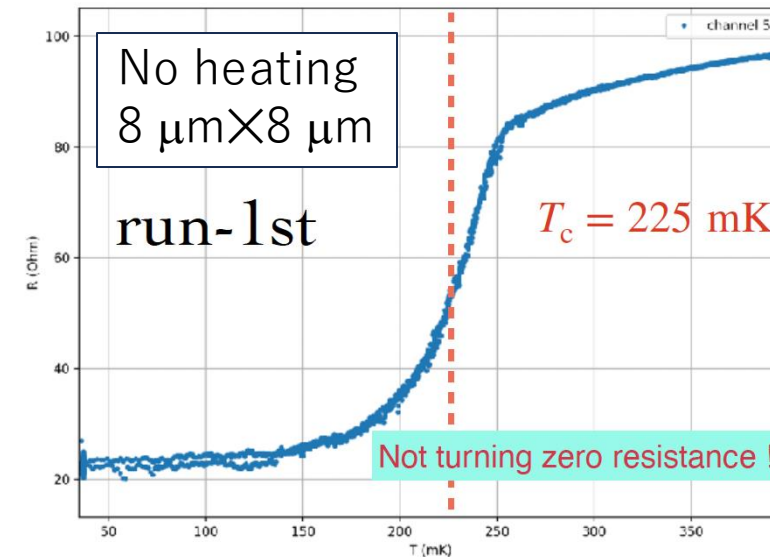
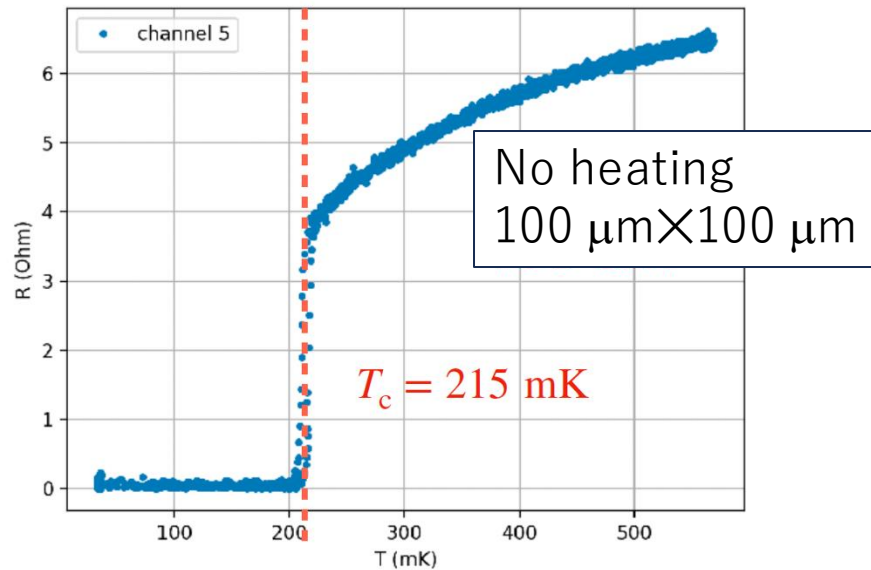
Backup plan

Ti/Au TES array (40 channels) fabricated by JAXA – next fiscal year



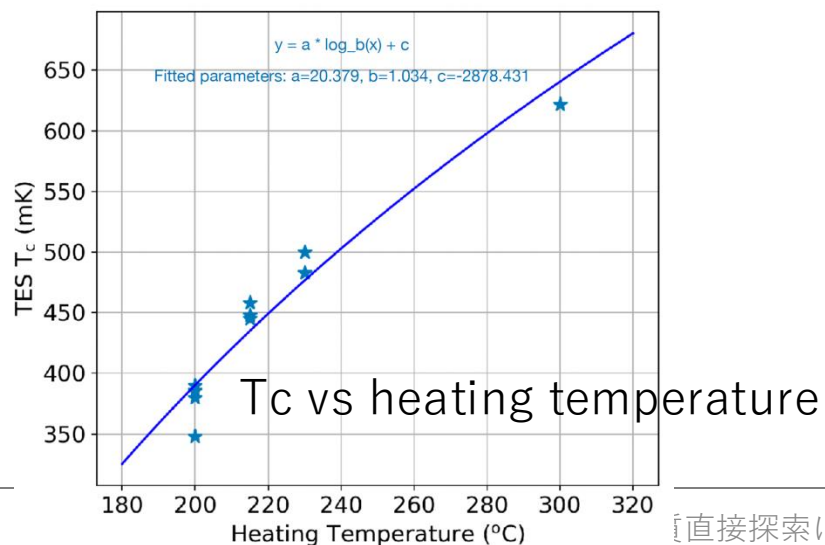
AlMn TESs

初めてなので、測定しやすい $T_c \sim 200$ mK で試作した



Large residual resistance and normal resistance were observed in small TESs.

- ✓ AlMn TESs have previously been fabricated for CMB.
- ✓ First attempt to fabricate small and thin TESs suitable for sub-eV photon detection.
- ✓ Multiple fabrication iterations are necessary for optimization.





Summary

- ✓ MeV dark matter direct detection
 - TESs sensitive to sub-eV signals coupled with aluminum targets
 - 準粒子の収集効率を向上させるための新たなアイデア
 - 新しい超伝導体(AIMn)を用いたTESの設計・試作
- ✓ AIMn TESの第一回試作
 - 測定しやすい $T_c \sim 200$ mKで試作
 - sub-eVに感度のある小さいTES(8 μ m角)では、残留抵抗が見られた
 - TES薄膜と電極の界面の問題と考えられる
- ✓ 今後
 - AIMn TESの再試作
 - T_c のチューニング
 - 神岡地下実験施設に希釈冷凍機を移設
 - 東北大・QUP他とのコラボレーション
 - HeRALD実験を行った後、我々の検出器を設置
- ✓ 長期的目標
 - 結晶とTES を光ファイバーで結合することで、
 - 単一光子レベルのシンチレーション光を捉える