Feasibility of sub-GeV mass dark matter search using STJ detector for COBAND experiment

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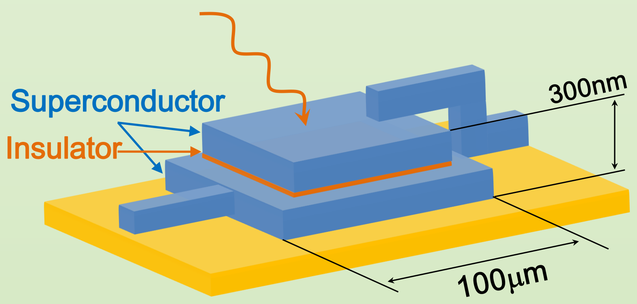
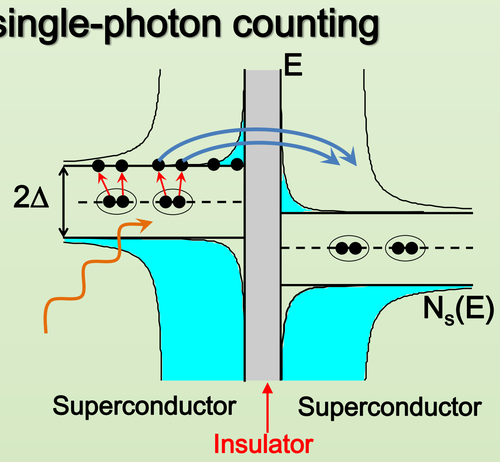
on behalf of COBAND Collaboration

Superconducting Tunnel Junction (STJ)

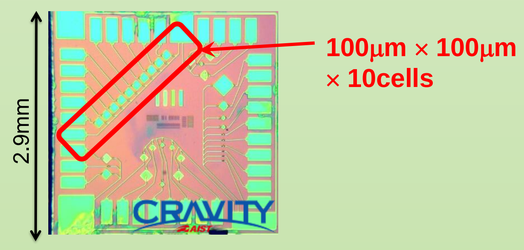
- In superconductors, density of states has energy gap Δ
- Superconductor /Insulator/Superconductor Josephson junction device
- A constant bias voltage (|V|<2Δ/e) is applied across the junction.
- A energy absorbed in the superconductor breaks Cooper pairs and creates tunneling current of quasi-particles proportional to the deposited energy.
  - $N_{qp} = E/1.7\Delta$
  - Energy resolution : $\frac{\delta N_{qp}}{N_{qp}} = \sqrt{\frac{F}{N_{q.p.}}} = \sqrt{\frac{1.7\Delta \cdot F}{E}}$
- Faster response (~μs) ➔ Suitable for single-photon counting



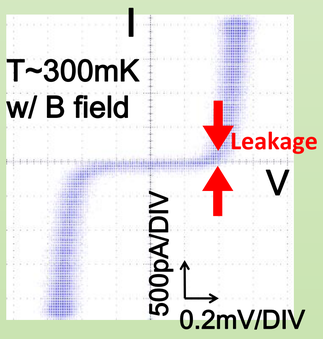


	Si	Nb	Al	Hf
Tc[K]		9.23	1.20	0.165
Δ[meV]	1100	1.550	0.172	0.020

Δ: Superconducting gap energy



Nb/Al-STJ fabricated in CRAVITY* at AIST



50μm sq. Nb/Al-STJ I-V curve
Leakage at V=0.4mV is 200pA

*M. Ukibe et al., Jpn. J. Appl. Phys. 51, 010115 (2012)
M. Ohkubo et al., IEEE Trans. Appl. Super, 24, 2400208 (2014)

Dark matter velocity distribution

Velocity dist. around Earth wrt Milky Way Galaxy

- Maxwell-Boltzmann distribution: $v_{\mathrm{mp}} = v_{\odot} = 220$ km/s

$$f(v) = \frac{4}{v_{\mathrm{mp}}^3\sqrt{\pi}} v^2 \exp\left(-\frac{v^2}{v_{\mathrm{mp}}^2}\right)$$

- Escape velocity from the Milky way galaxy: 544km/s

Velocity dist. around Earth wrt Earth

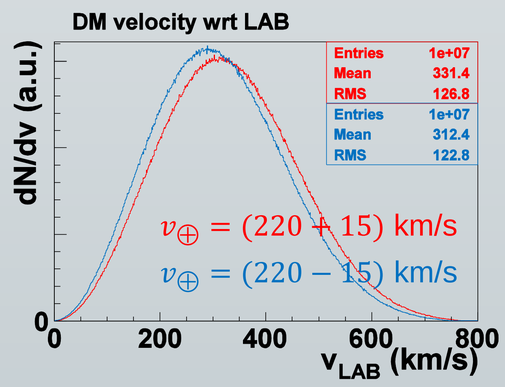
- Earth velocity wrt Milky Way Galaxy

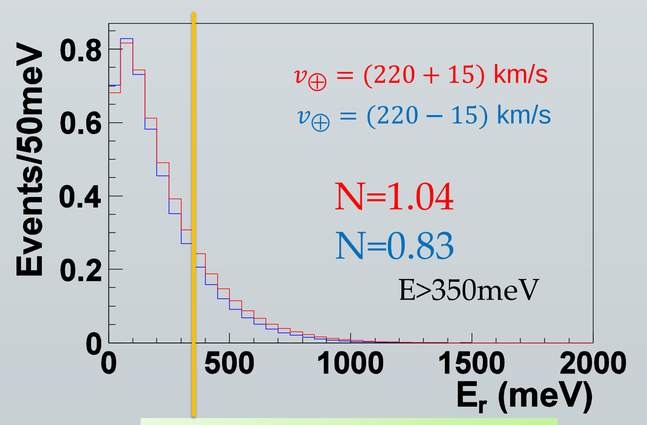
$$v_{\oplus} \cong v_{\odot} + 15\cos\left(2\pi\frac{t-152.5}{365.25}\right)\ \mathrm{km}/s$$

- $v_{\mathrm{DM}} \oplus v_{\oplus}$

Expected recoil energy dist. including STJ σ_E and Leakage

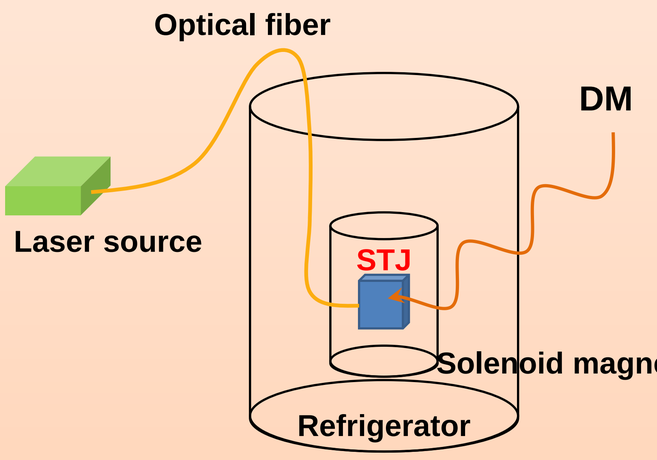
- $M_{\mathrm{DM}} = 0.1\ \mathrm{GeV}/c^2,\ \sigma_{\mathrm{Nb}} = 1\ \mathrm{mb} = 10^{-27}\ \mathrm{cm}^2$
- Target: ^{93}Nb (92.9u) 100μm × 100μm × 1μm × 10
- Measurement time: 10000sec
- STJ leakage: 10nA ➔ contribution 50meV to σ_E
- STJ energy resolution: $\sigma_E = \sqrt{(1.7\Delta)FE} \oplus 50\mathrm{meV} \sim 50\mathrm{meV}$





Use E=350meV threshold

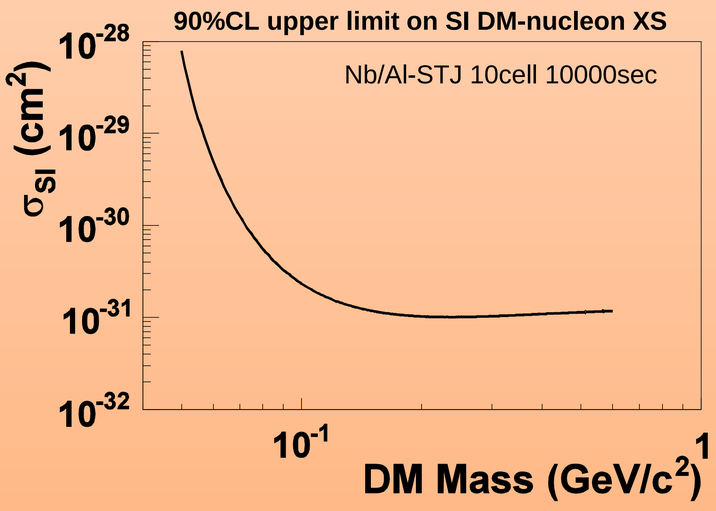
Experimental Setup and Expected Sensitivity



- **Nb/Al-STJ**
  100μm × 100μm × 1μm × 10cells
- **^{3}He sorption refrigerator**
- **SC Solenoid (B=100gauss)**
- **Optical fiber & Laser source**
  λ=10μm (hν=124meV) for calibration

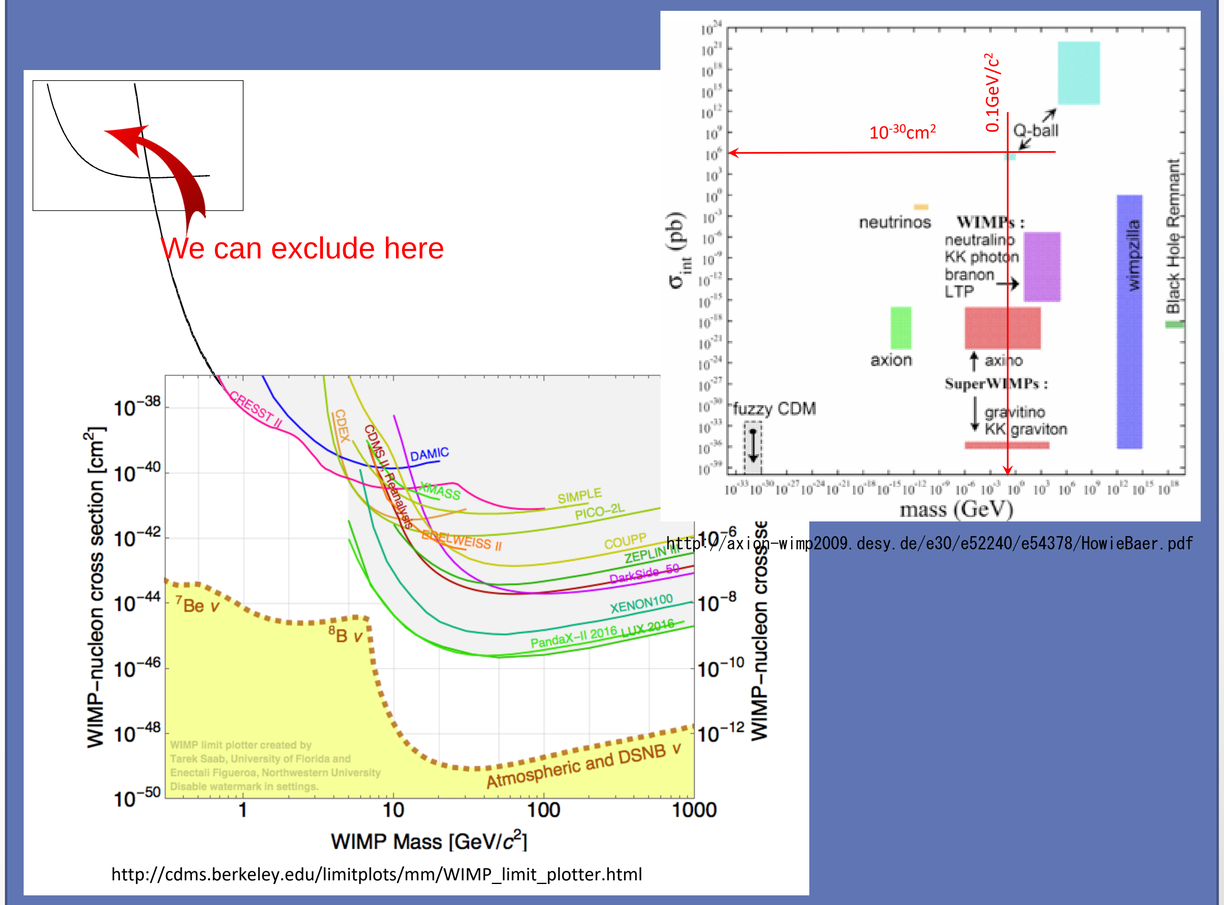
Background consideration

- Cosmic muon & Environmental radioactive source: Negligible and easy to veto
  - Maximum active area: **100μm × 100μm × 10cells** ➔ 0.167 muons /10000sec
  - MIP energy E>1.03keV
  - Energy deposited on Si wafer will make multiple hits on 10cells simultaneously
- Dark count from fluctuation in STJ leakage
  - 10nA leakage contribution to energy resolution: 50meV
  - 7σ away from 350meV threshold
    ➔0.1 events /10000sec



Summary

- Very easy to perform once the STJ development for COBAND is completed.
  - Requirement for STJ is looser than one for COBAND
  - Need no extra component except for STJ. No need underground exp.
- Explore lower mass region in direct DM search
  - Since active volume of STJ is small, we quest for lower energy threshold rather than smaller cross-section



COBAND collaboration (As of Nov. 2017)

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