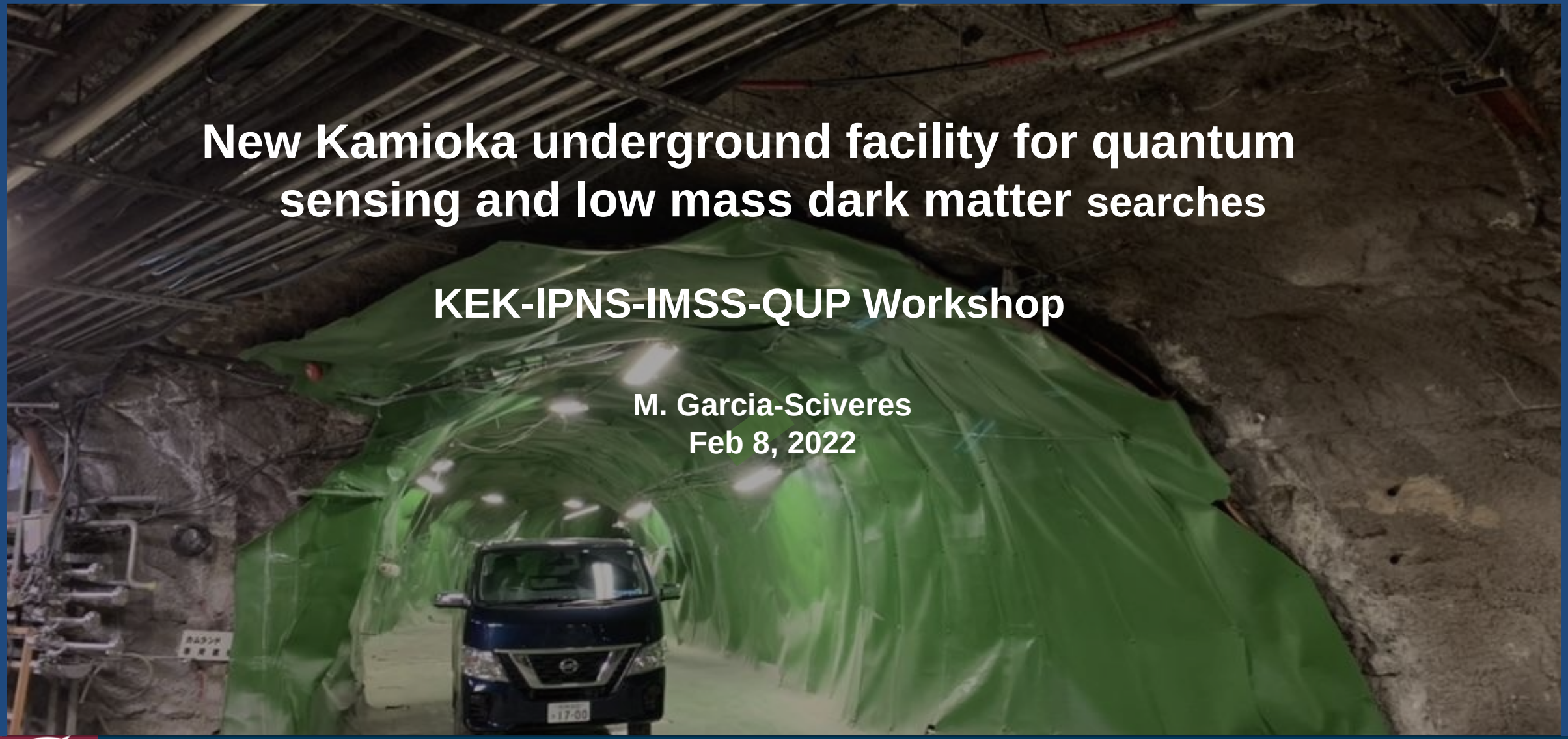


New Kamioka underground facility for quantum sensing and low mass dark matter searches

KEK-IPNS-IMSS-QUP Workshop

M. Garcia-Sciveres
Feb 8, 2022

BERKELEY LAB

Introduction

- We recently started an effort to set up a new underground lab in an available cavern at Kamioka, to enable low mass dark matter searches
- We plan to develop a project Q proposal based on this new facility
- We just submitted a US-Japan proposal (under review) to seed the collaboration
- Much of this talk is based on the US-Japan proposal
  - But the main contributors to the construction and equipment will be:
    - the Tohoku U, Research Center for Neutrino Science
    - QUP (via startup funds and personnel for co-Pi's Garcia-Sciveres and Hasegawa

US - Japan Proposal

Quantum sensing consortium for a new underground cryogenic facility at Kamioka

K. Ishidoshiro (Tohoku, JP PI) and M. Garcia-Sciveres (LBNL, US PI, QUP)

JP collaboration:
M. Hasegawa (KEK, **QUP**), O. Tajima (Kyoto), K. Kiuchi (U-Tokyo),
J. Suzuki (Kyoto), K. Ichimura (Tohoku), S. Yoshida (Osaka)

US collaboration:
A. Kusaka (LBNL), A. Suzuki (LBNL)

RCNS

+

Motivation

1 meV | 1 eV | 1 keV | 1 MeV | 1 GeV | 100 GeV → DM mass

← Axions

Hidden DM Models

Traditional WIMP

See talk by S. Knappen tomorrow

?

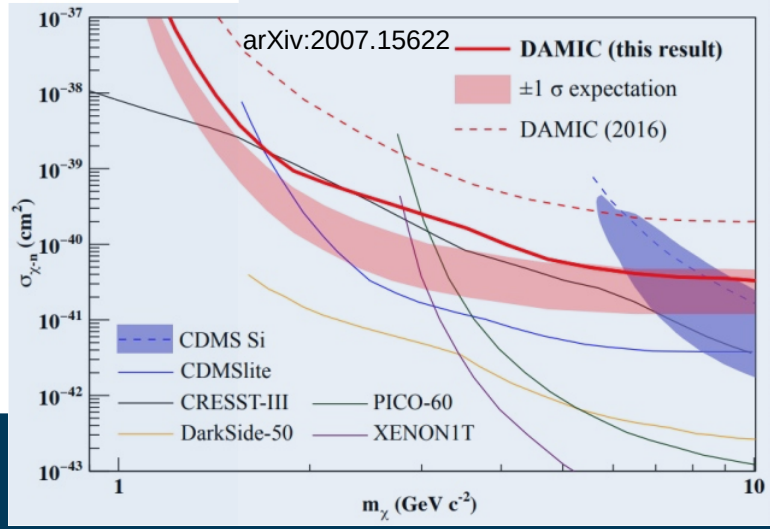
Whole electron recoil

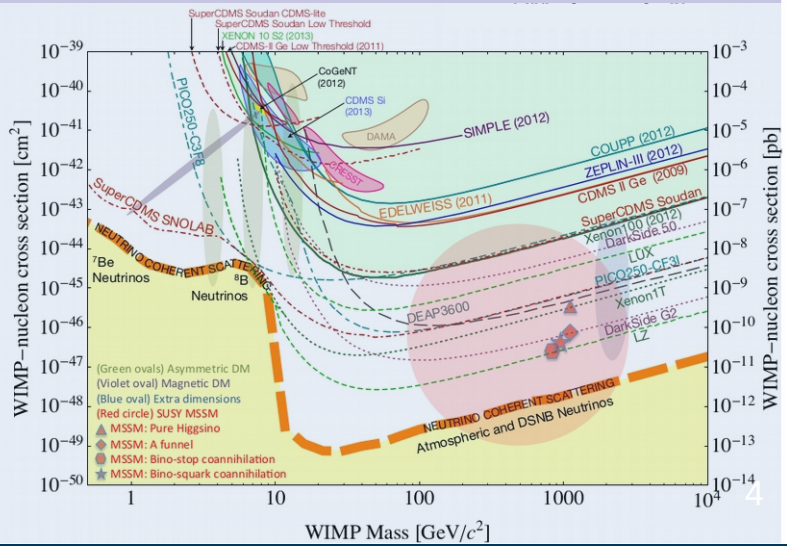
Whole nucleus recoil

← classical waves

>eV energy deposit

~keV energy deposit





Motivation

Axions ←

Hidden DM Models

Traditional WIMP

See talk by S. Knappen tomorrow

Coherent excitation (no ionization)

Whole electron recoil

Whole nucleus recoil

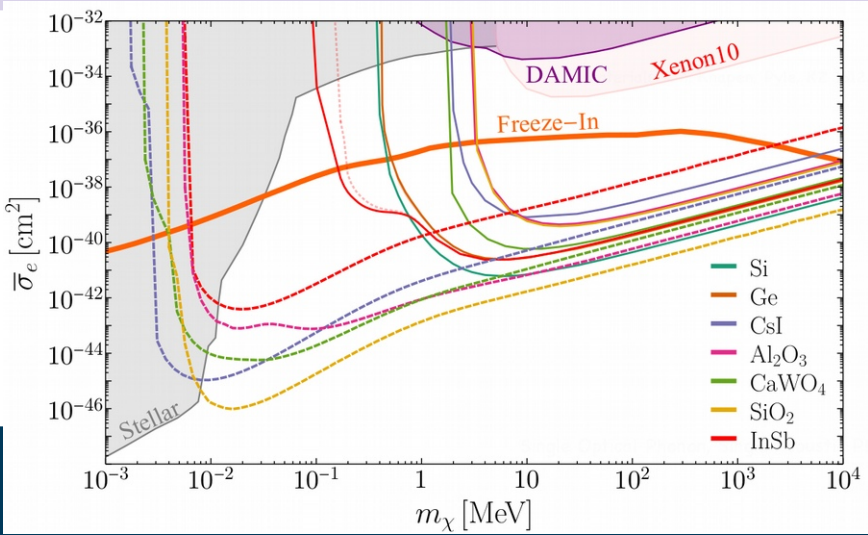
classical waves ←

>ueV energy deposit (phonons / rotons)

>eV energy deposit

~keV energy deposit

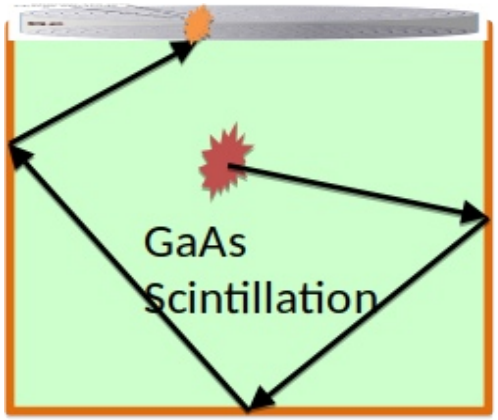
How to measure down to a single phonon with zero dark counts?



eg: calculated optical phonon DM signals in polar materials arXiv:1910.10716

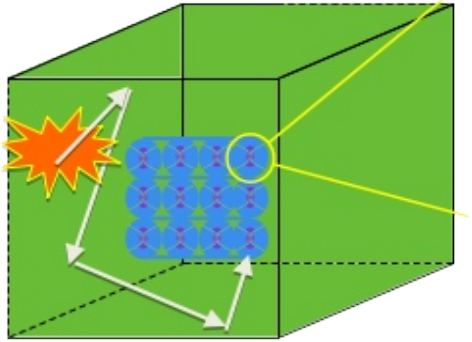
note many target options

SPICE-HeRALD experiment –
improving TES athermal phonon detectors and using same sensors on multiple targets



1607.01009 1802.09171

sapphire optical phonons



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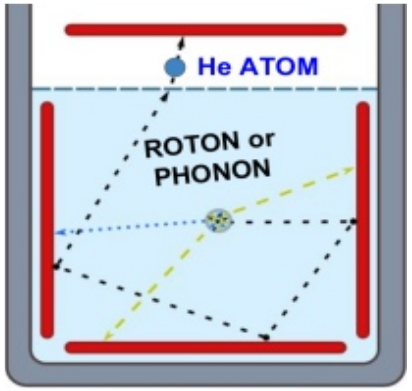

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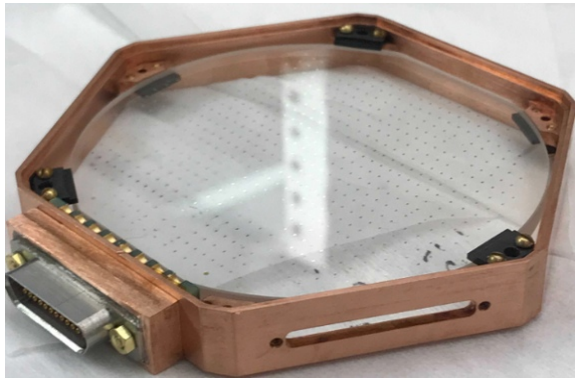
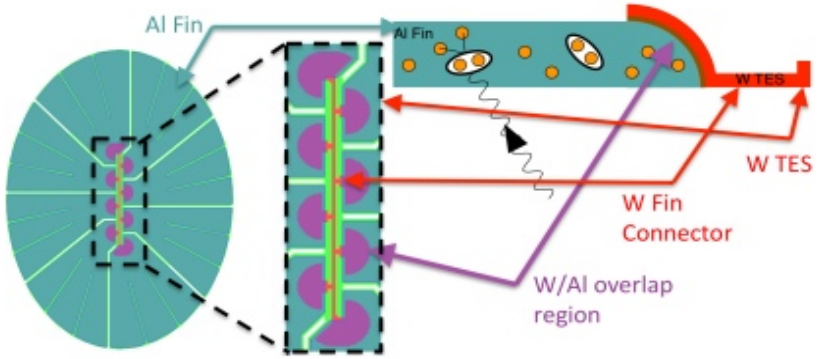
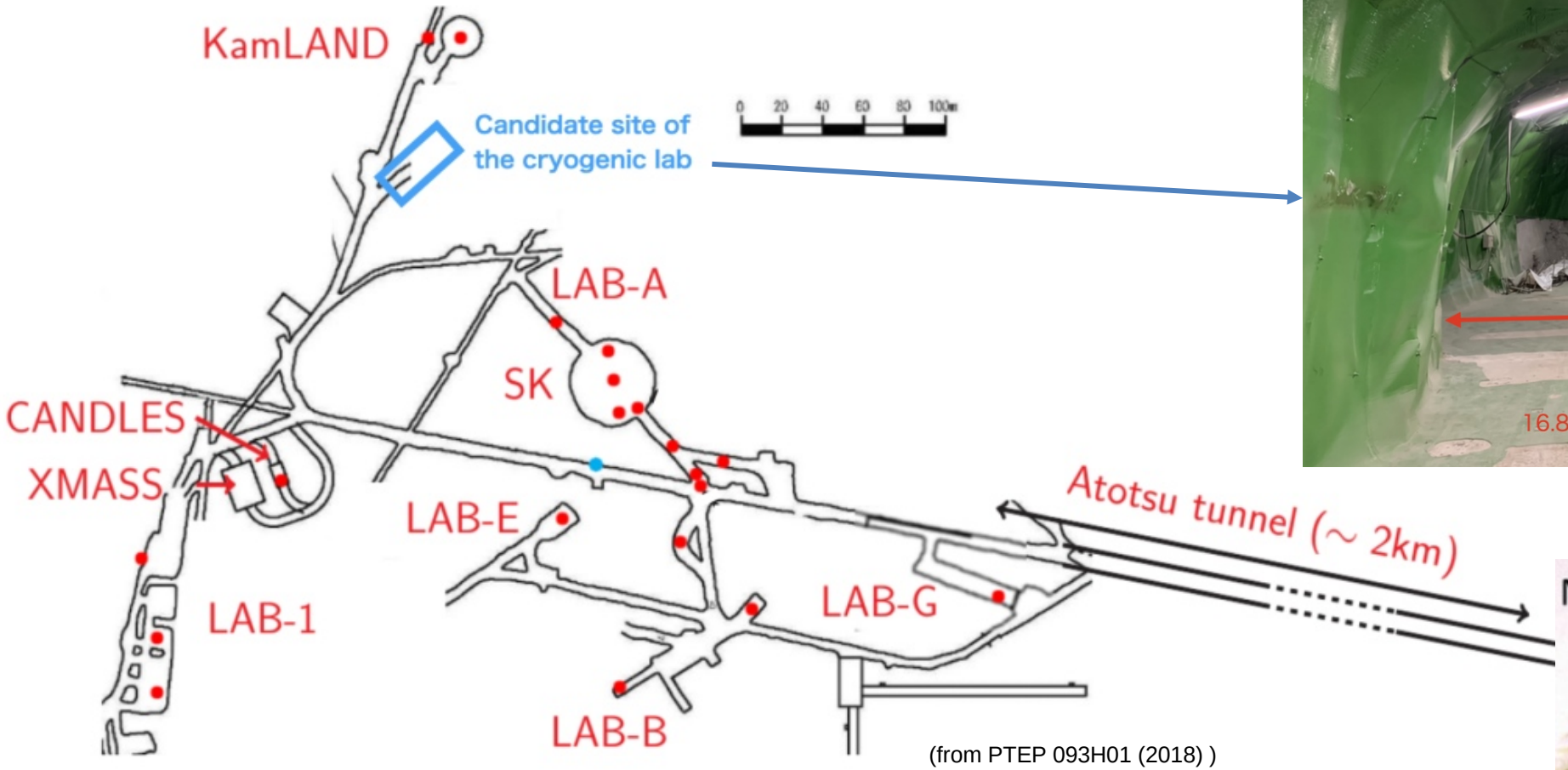
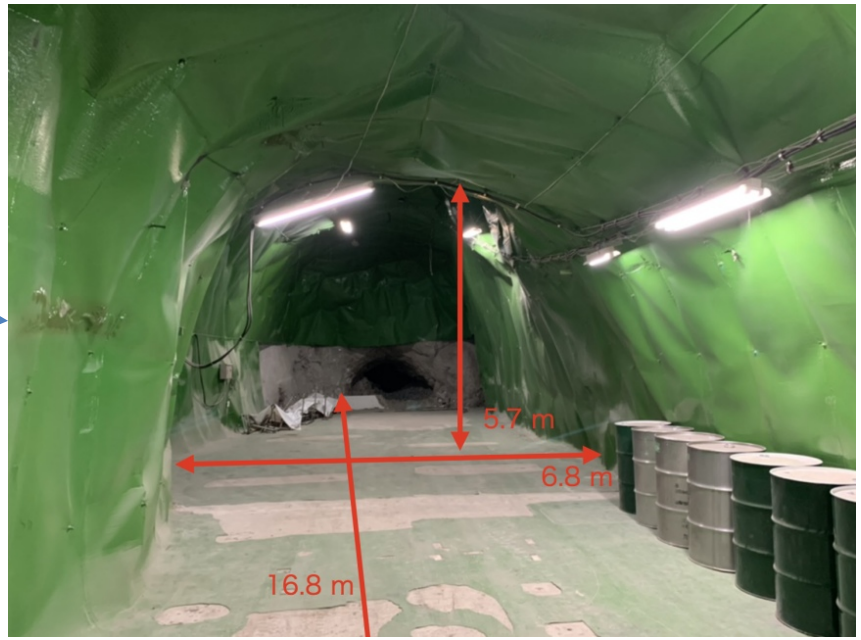




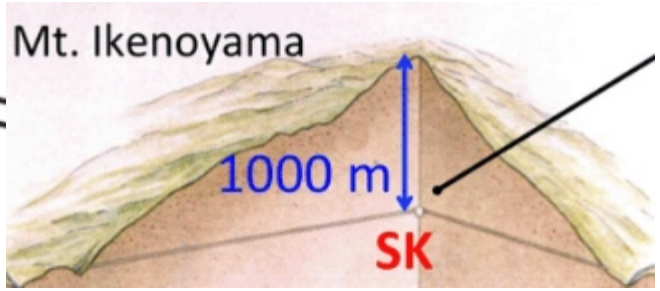
But does not yet have an underground lab home. First "peeks" at lower mass phase space can happen with gram-days on the surface. But proper exploration of low mass phase space requires Kg-year exposures…

Ideal space and underground lab expertise ready to go at Kamioka

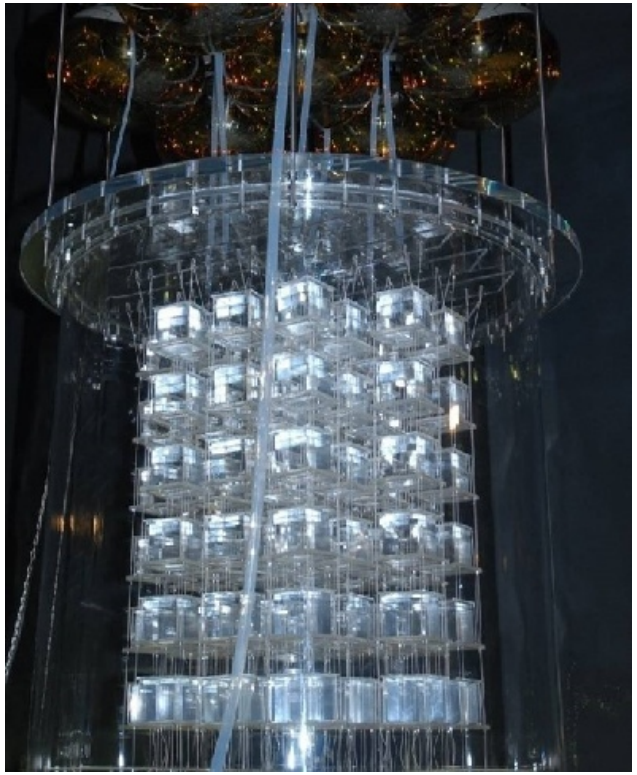




(from PTEP 093H01 (2018))



Additional targets of interest besides those being explored by SPICE-HeRALD



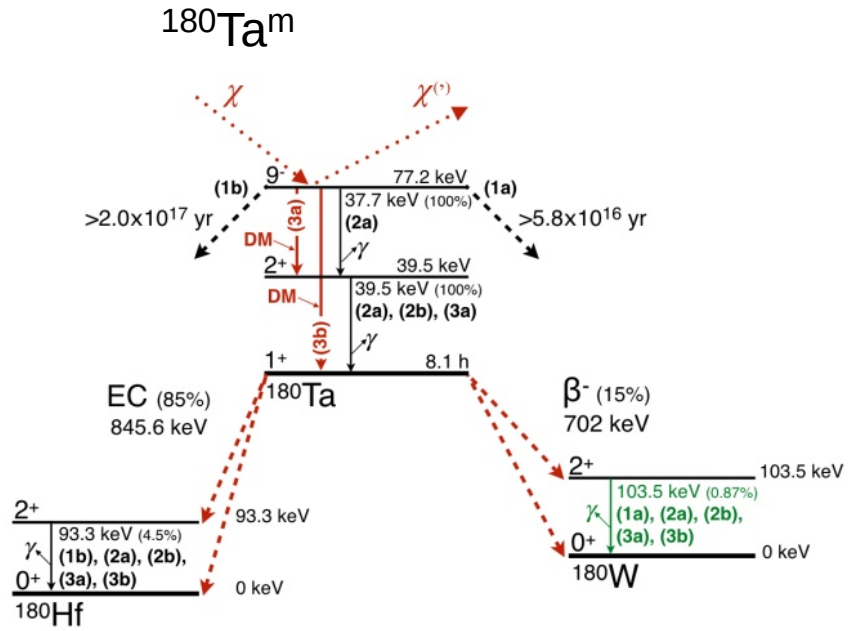
CaF_2 Scintillator in the Candles experiment to search for 0νββ (highest Q ββ isotope)

^{19}F is sensitive to DM spin-dependent interactions and it's natural abundance is almost 100%

Availability, local expertise, and sensitivity potential make it a good candidate for a DM search with low threshold sensors and different optimization

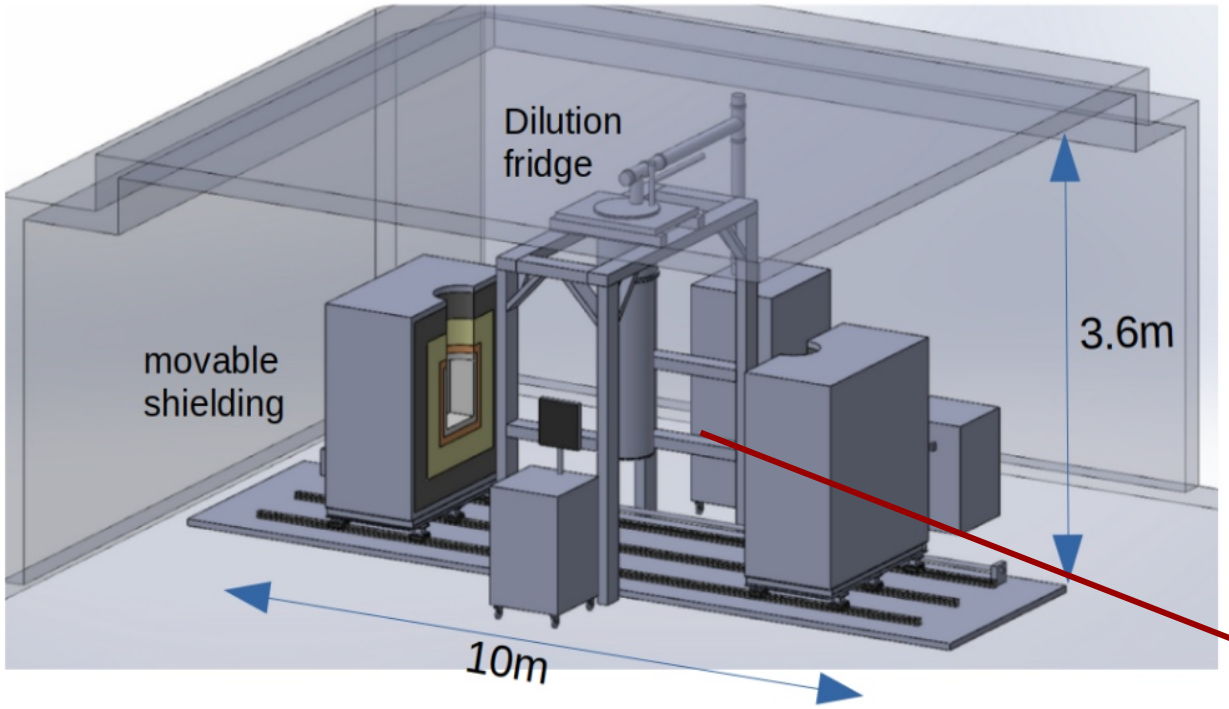
Directional sensitivity targets
Eg $ZnWO_4$ for photons
DOI: 10.1109/TNS.2020.2985027

or $CaWO_4$ for phonons
DOI: 10.1103/PhysRevD.105.015010

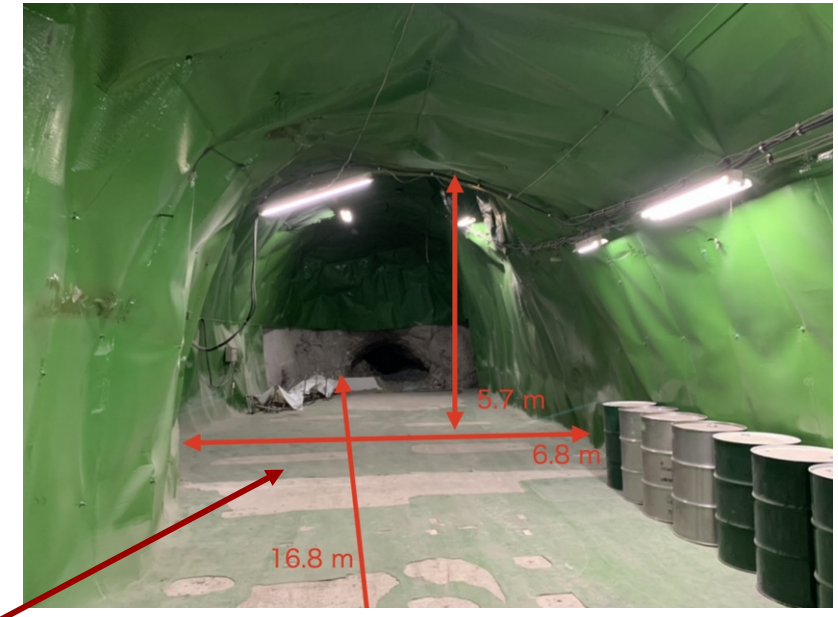


DOI:https://doi.org/10.1103/PhysRevLett.124.181802

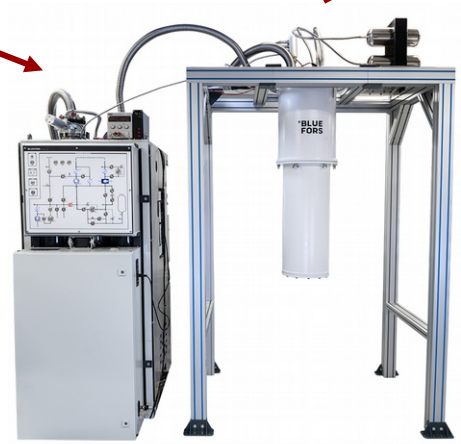
From empty cavern to experimental hall



Dilution fridge + shielding preliminary design from SPICE-HeRALD
Engineering to finalize to be done by LBNL



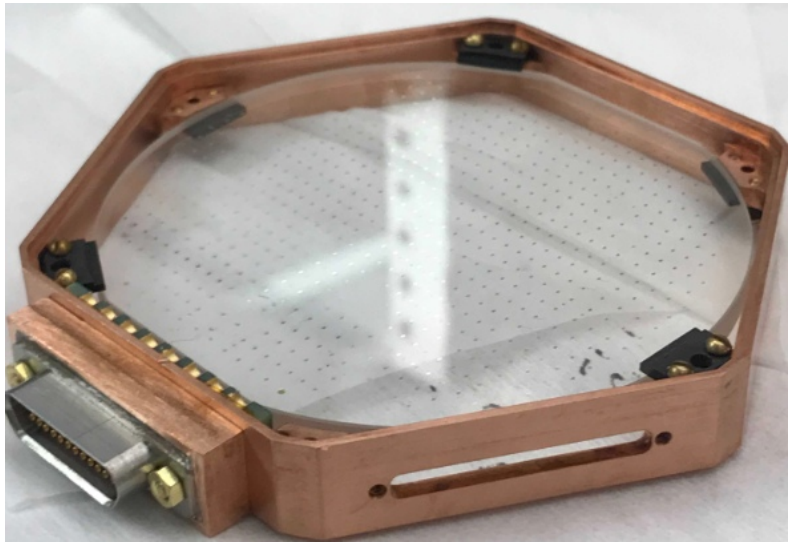
Cavern preparation by Tokoku RCNS
(already started)



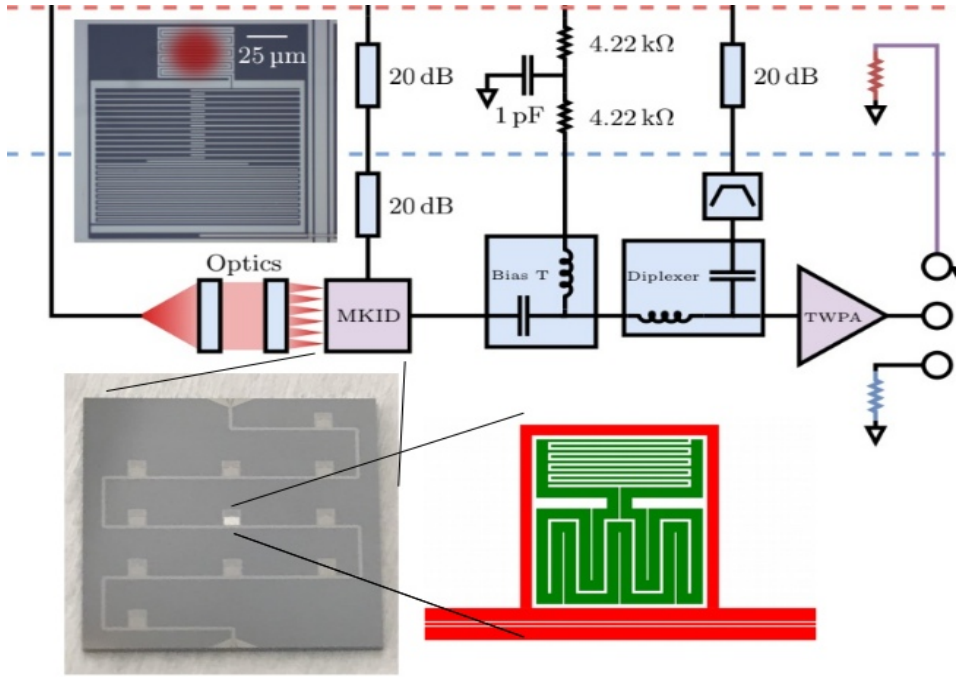
Dilution fridge being ordered by
QUP (startup for co-PIs)

Additional sensors of interest besides TES APDs

Golden reference TES athermal phonon detector

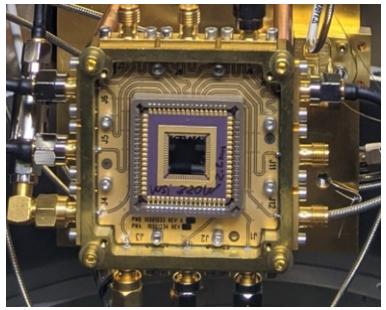


we're close to achieving 1eV energy threshold in a large area (3" dia.) This is the current world's best microcalorimeter



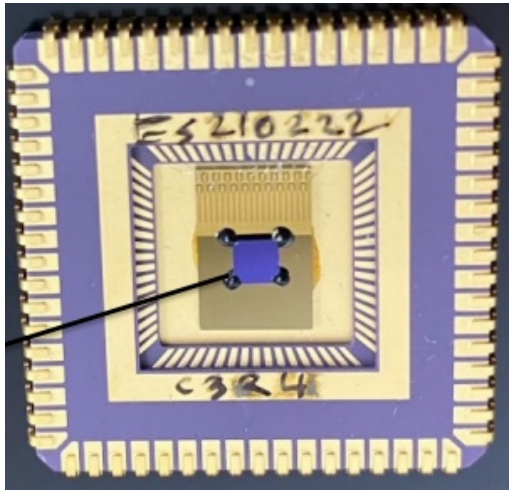
MKIDs

Limited by readout-dominated noise. Need to reduce and apply squeezing



SNSPDs

Have to increase area while keeping threshold low. Want to reach 20meV threshold



1sq.mm. SNSPD with GaAs crystal on top

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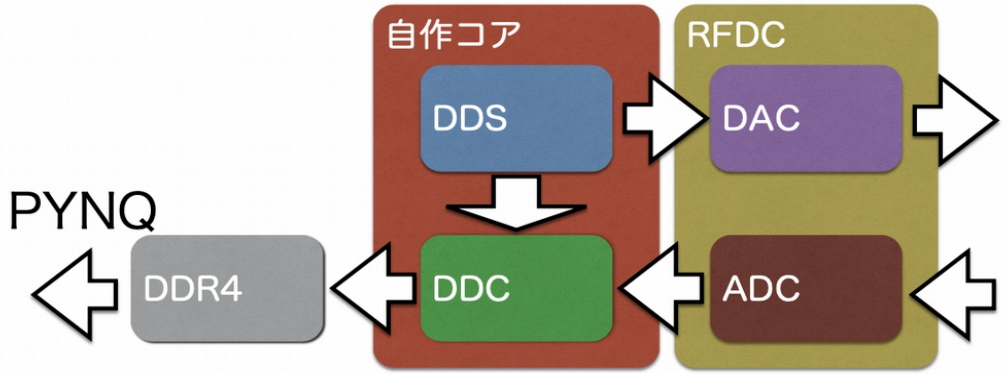
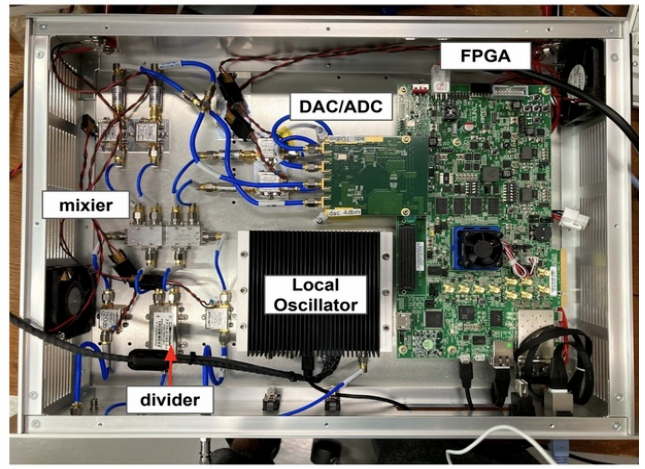
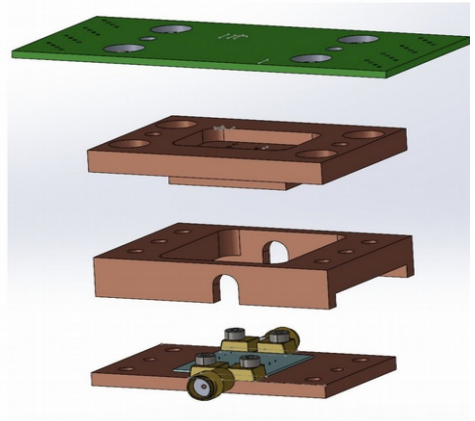
Still others with longer term potential in backup

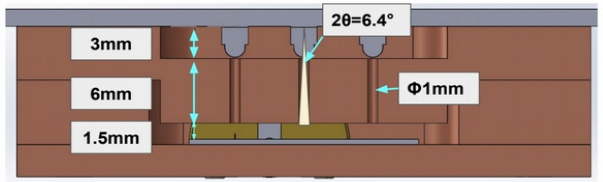
MKID R&D Example

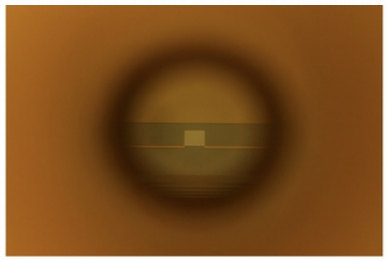


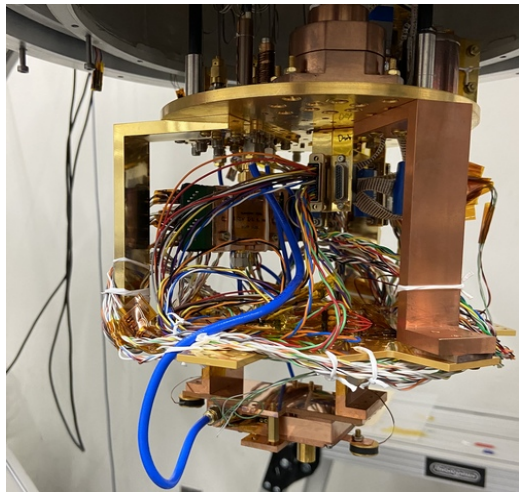


Readout system with RFSoC (FPGA+CPU+ADC+DAC) (Kyoto 、 Tohoku)





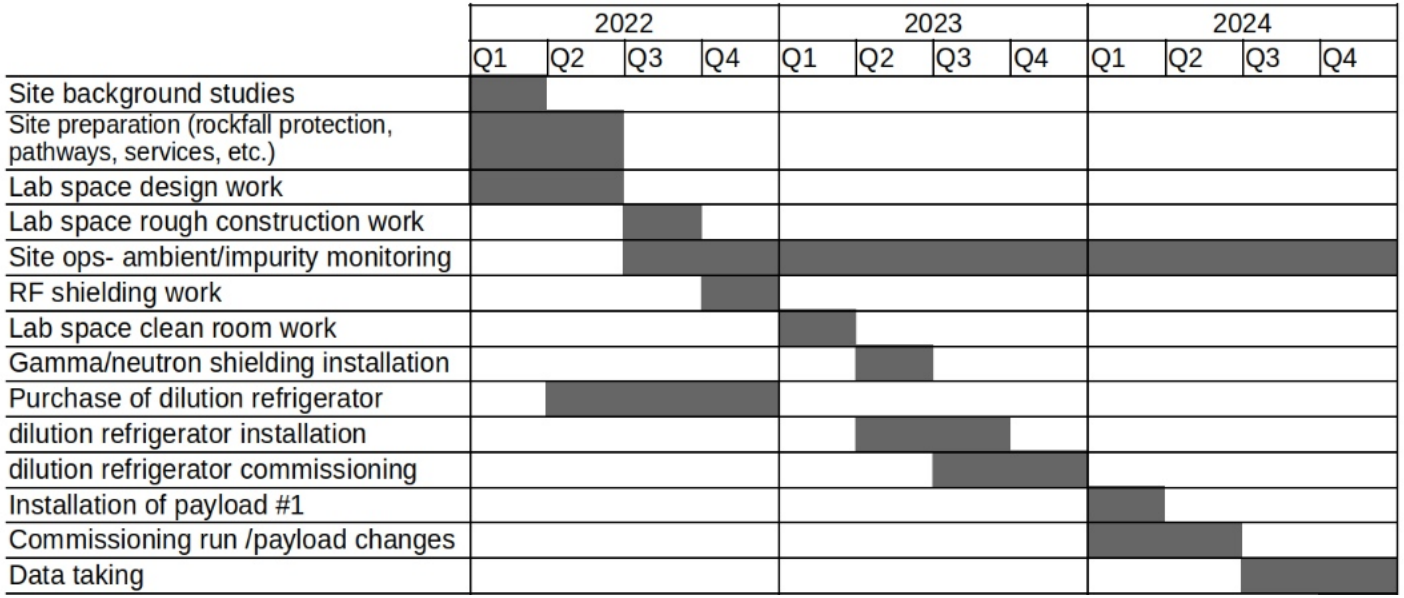




Infrared test system for quantum sensor (Tokyo)

Underground lab future

Timeline proposed in US-Japan



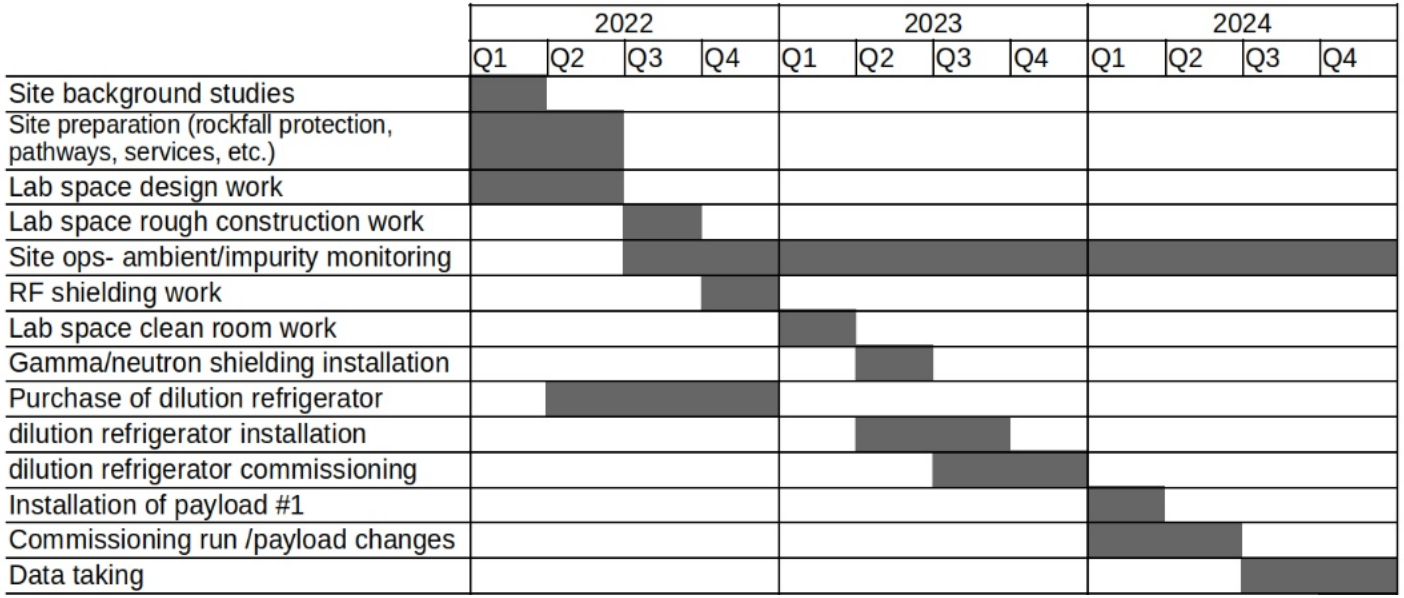
first DM results ASAP!

Large science program to follow

- Multiple DM targets options
- Evolving and improving quantum sensor technology options
- QIS experiments
- Expansion of facility

Underground lab future

Timeline proposed in US-Japan



first DM results ASAP!

Project Q

Large science program to follow

- Multiple DM targets
- Evolving and improving quantum sensor technologies
- QIS experiments
- Expansion of facility

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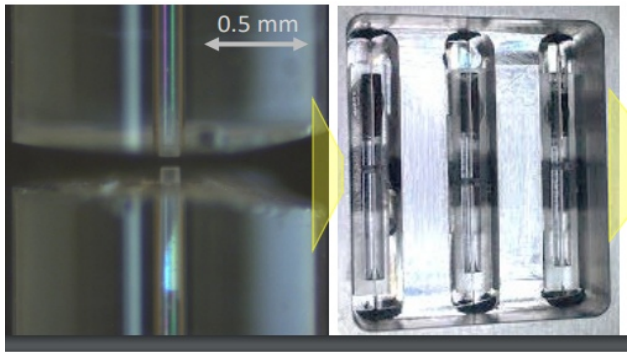
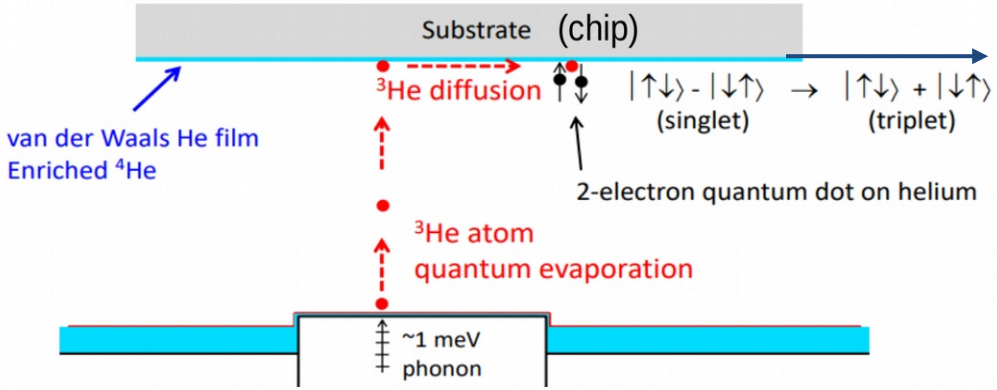
BACKUP

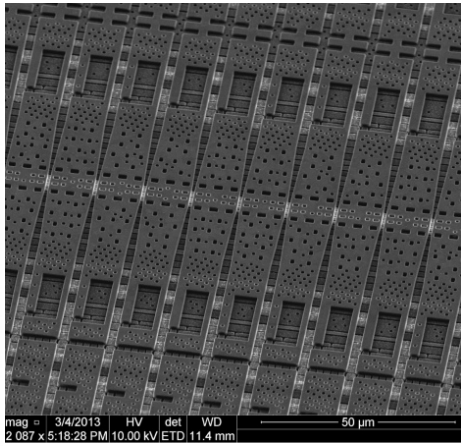
Additional quantum sensors under investigation

Opto-Mechanical cavities

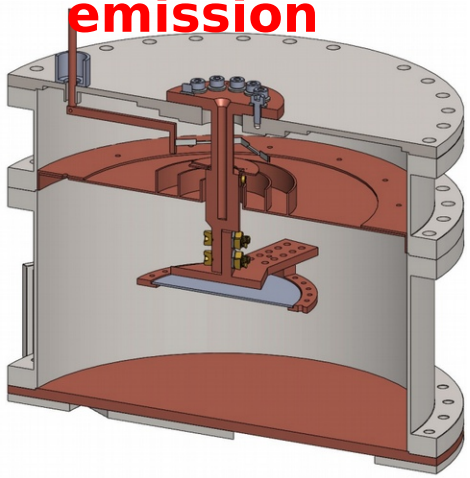


Electron surface states in LHe





He Quantum Evaporation emission



film-stopping setup to suspend dry sensor above LHe bath is up and running.

He surface