

Dark Matter

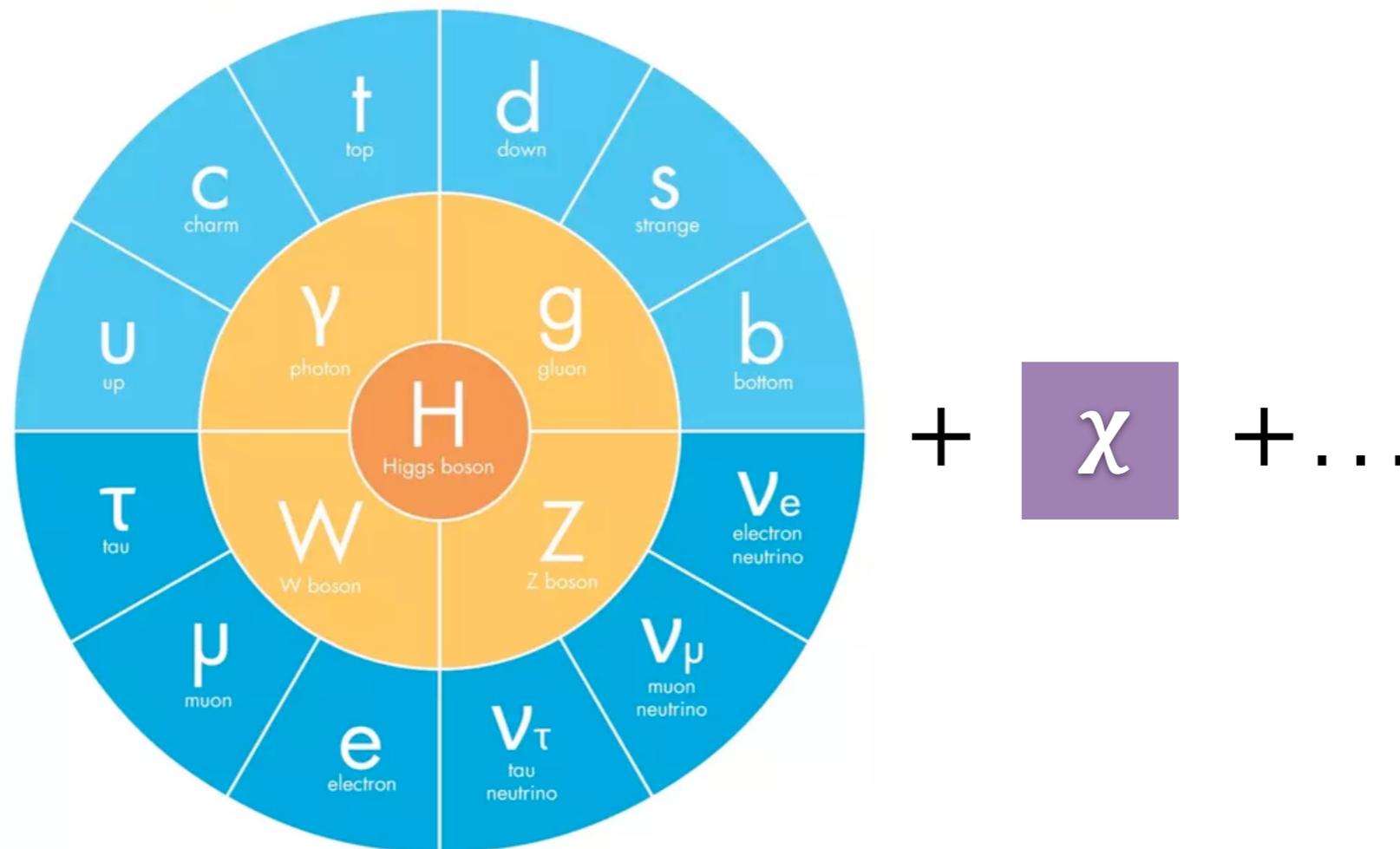
CPAD 2018, Providence

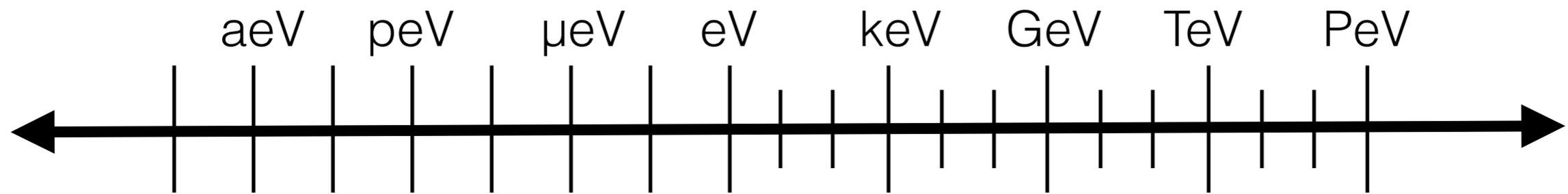
Scott Hertel, U. Massachusetts, Amherst

One of the most important scientific questions of our times

What is it?

Is it a first hint of something bigger?





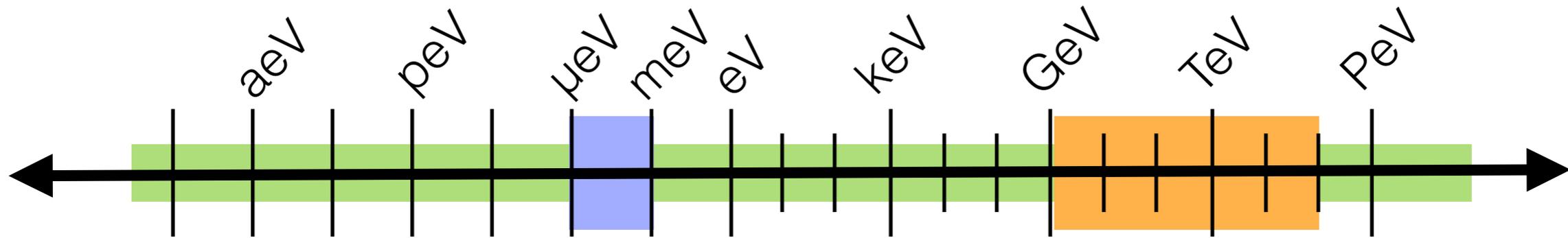
**bad news:
there is plenty
of work to do.**

we are faced with
a wide open
model space



**good news:
there is plenty
of work to do.**

we get to figure out
how to do lots of things
we've never done before



Outline

WIMP searches

G2 program (SuperCDMS & LZ)
Envisioning post-G2

Axion searches

G2 program (ADMX)
Envisioning post-G2

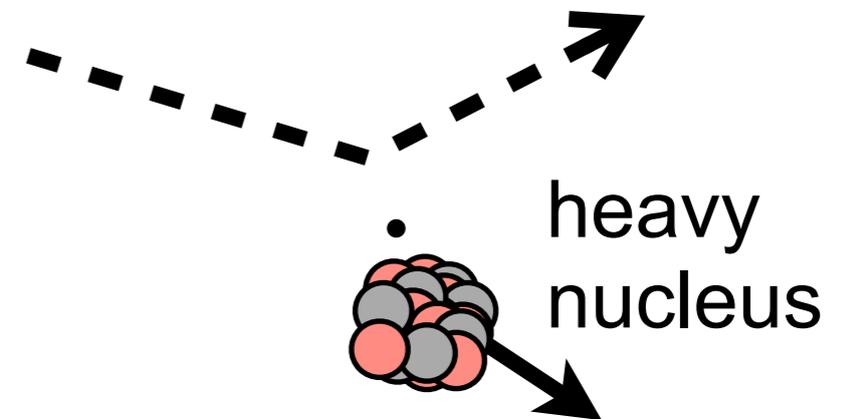
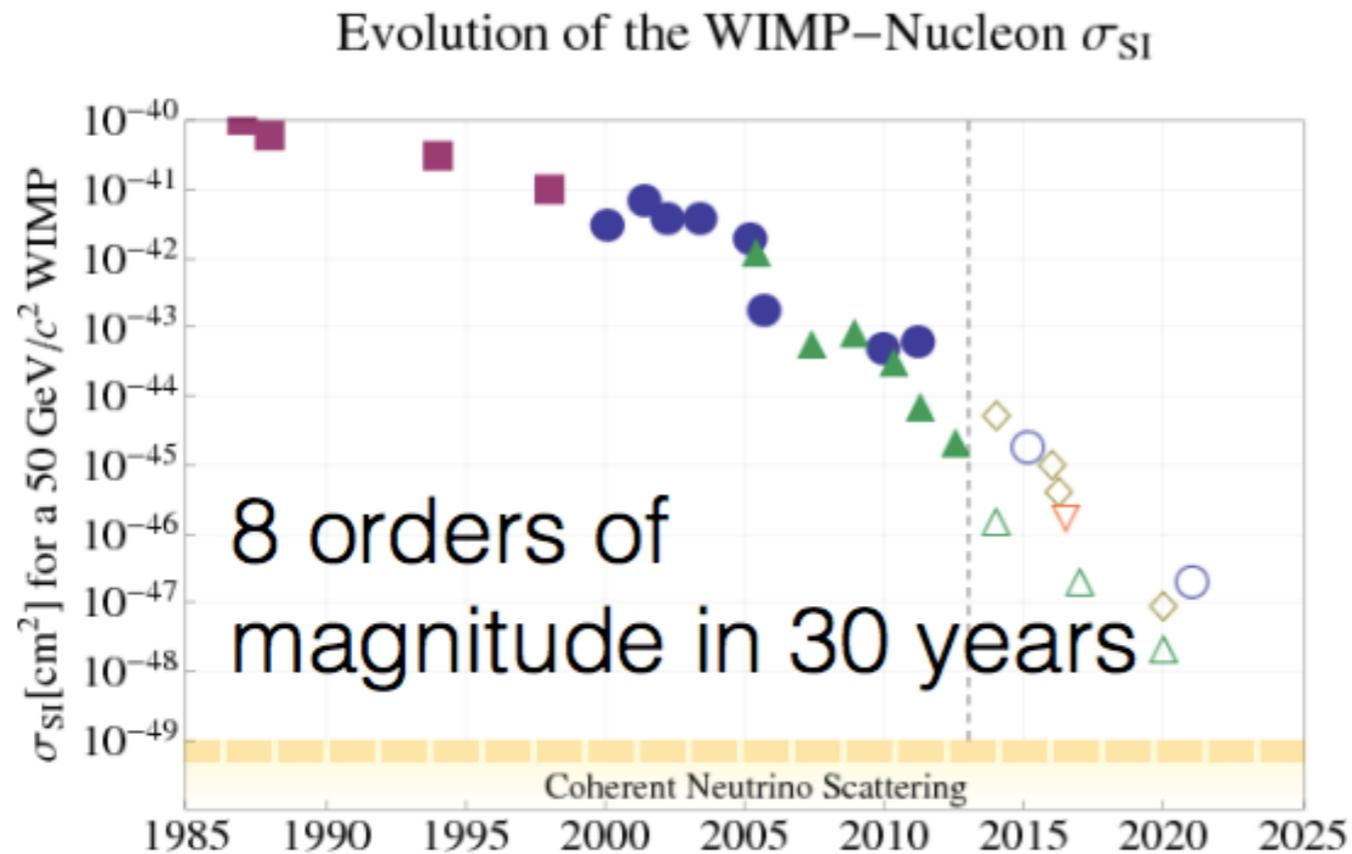
Broadening the search

Basic Research Needs (BRN) Study
Mention of a few efforts

WIMPs: G2 Program

WIMPs remain a compelling model.

G2 is the next step in an impressive technological development.

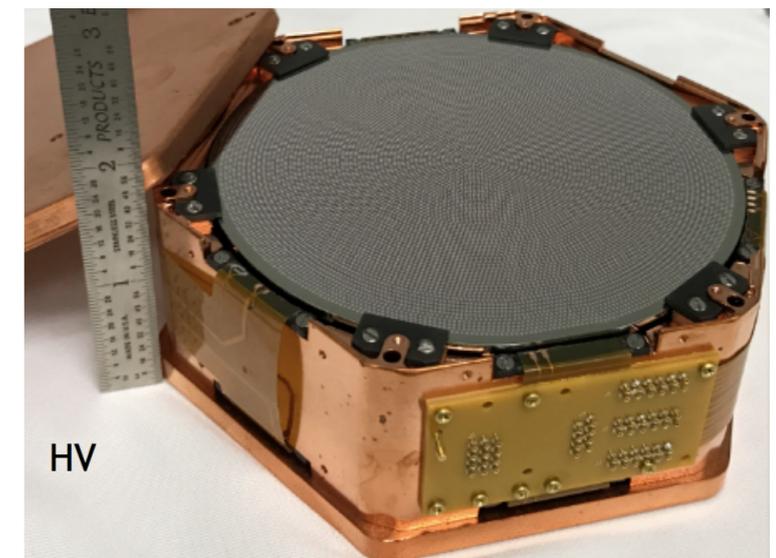
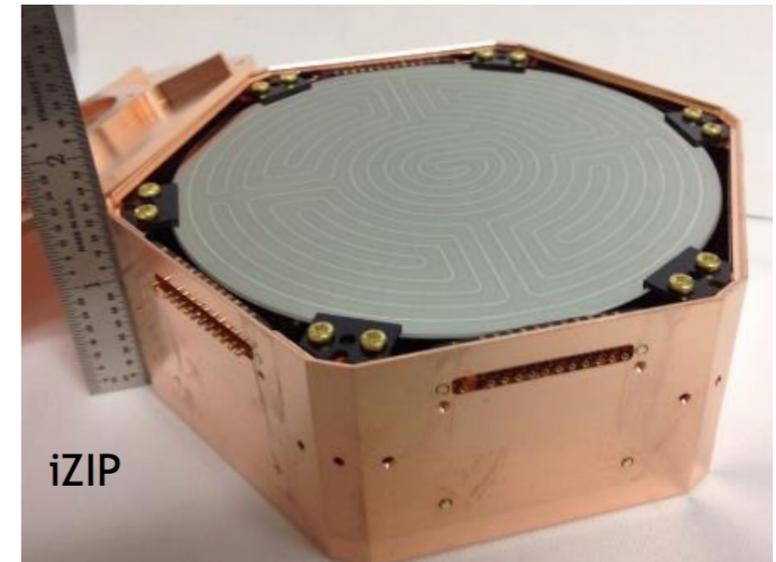
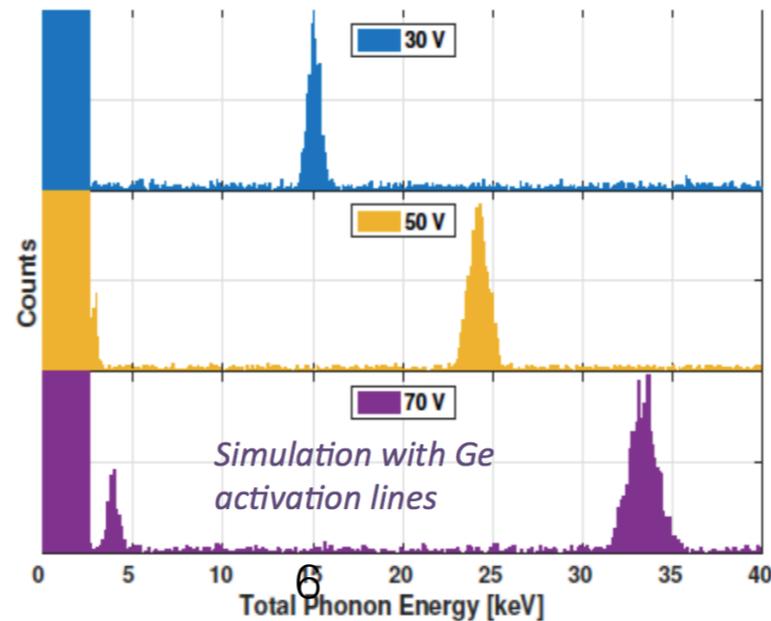
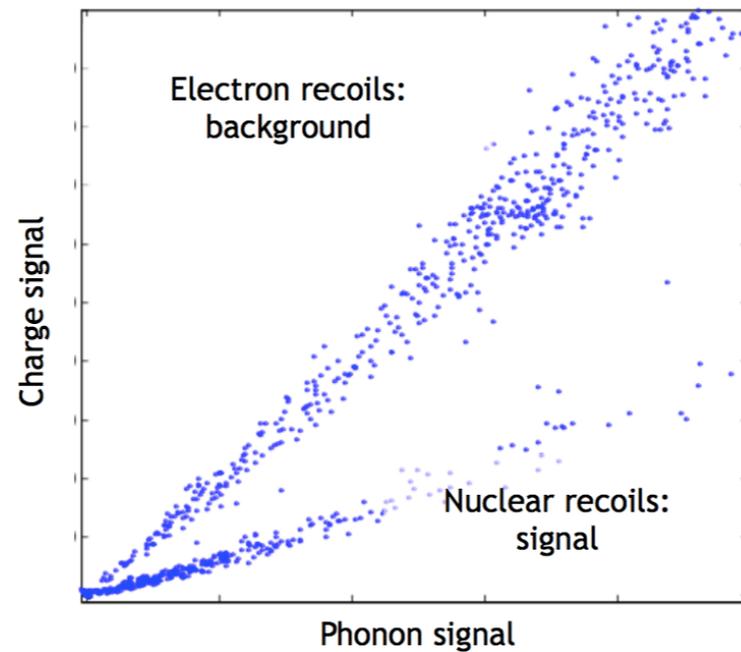


WIMPs: G2 Program

SuperCDMS

iZIP type:
emphasizes
discrimination

HV type:
emphasizes
threshold

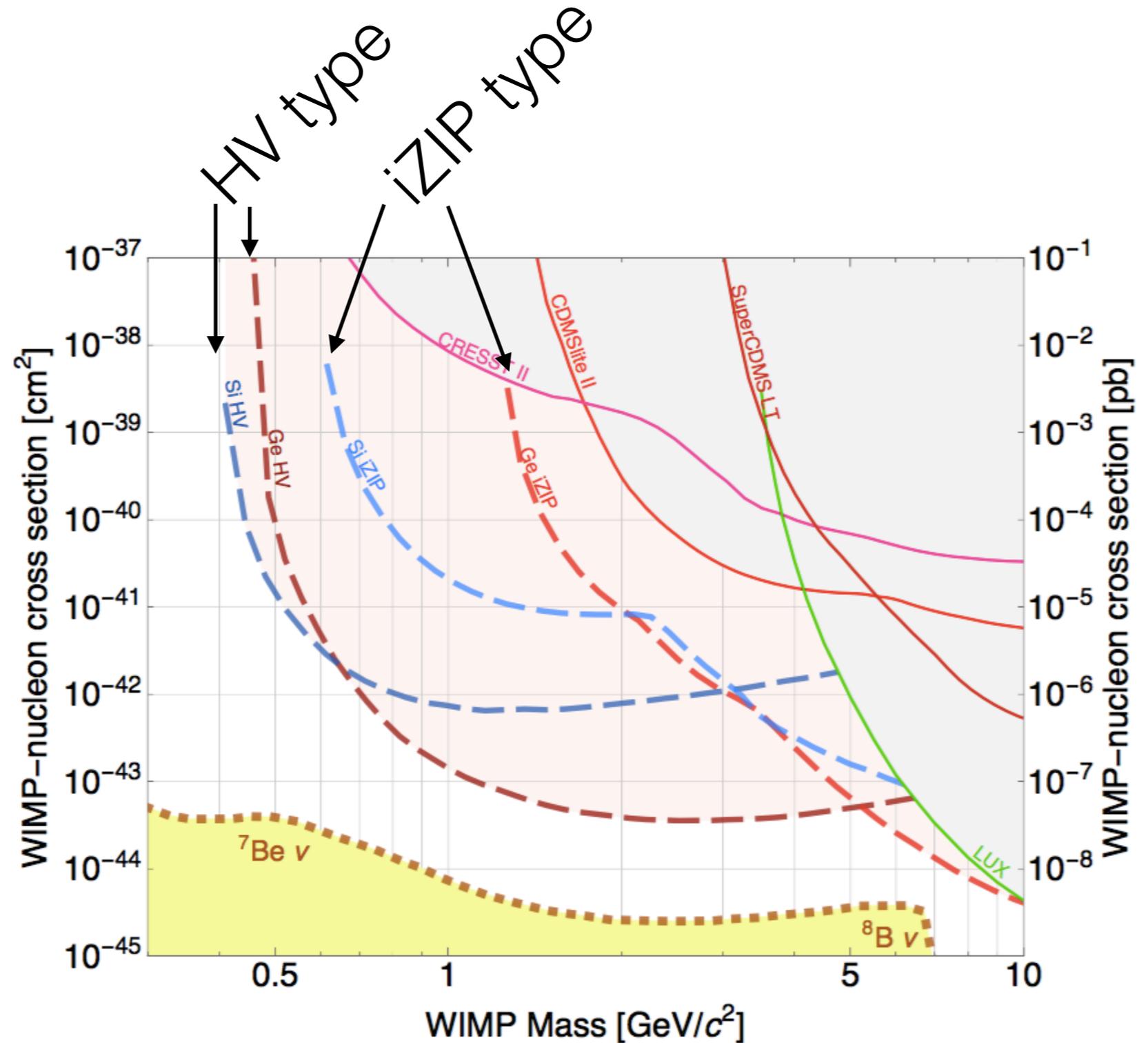


WIMPs: G2 Program

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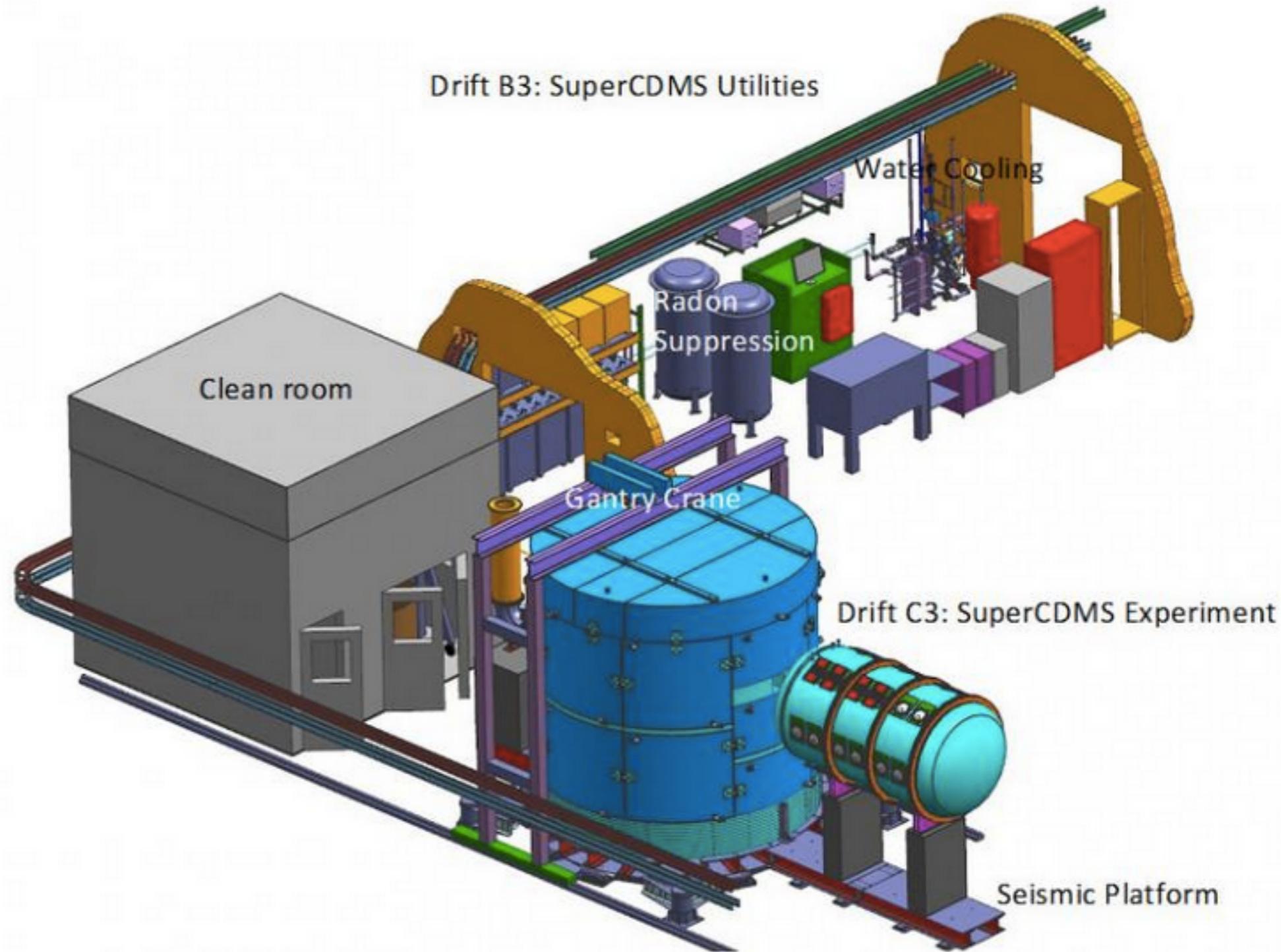
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WIMPs: G2 Program

SuperCDMS

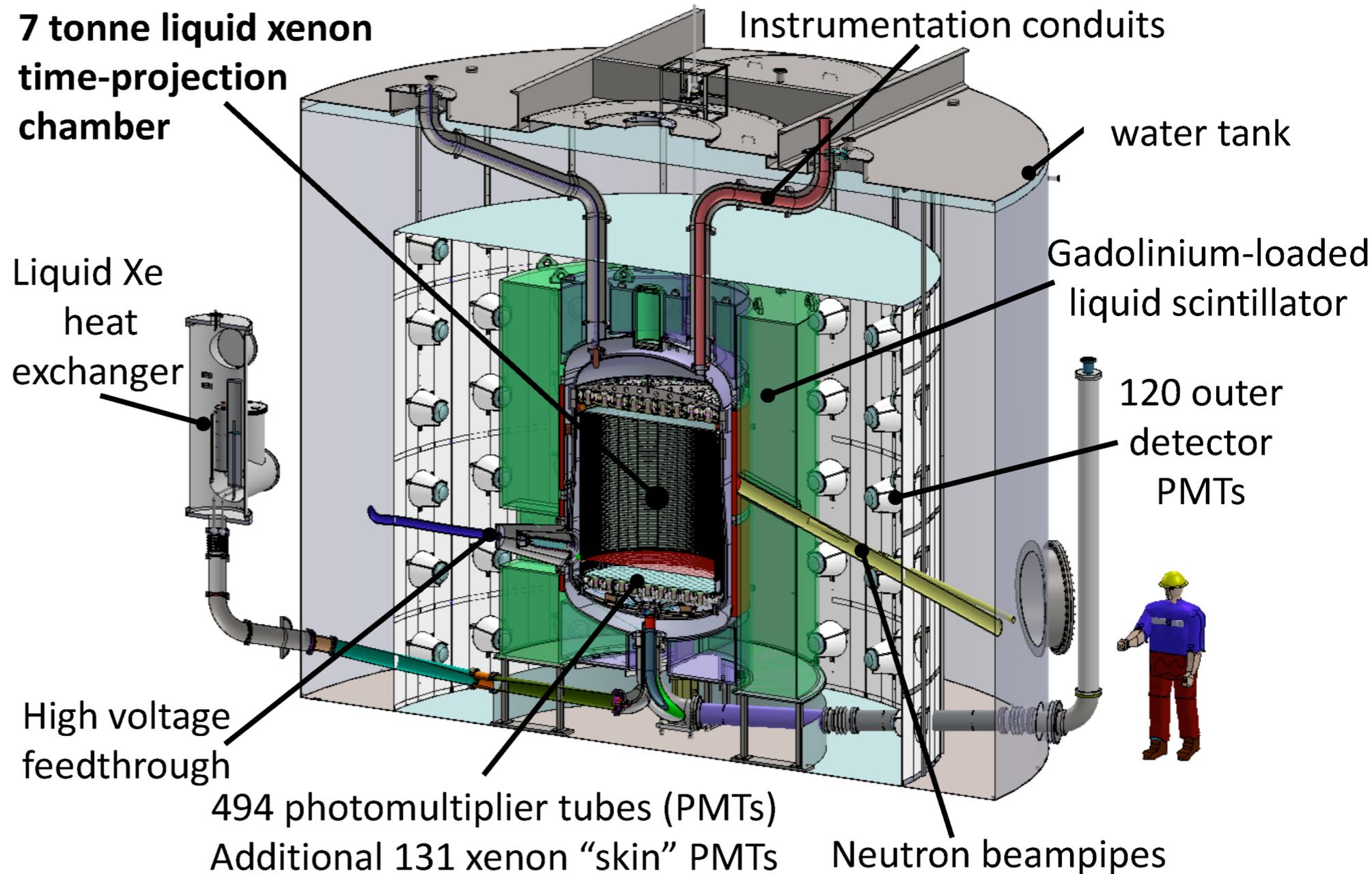
Significant
cryogenic
infrastructure
(SNOLAB)



WIMPs: G2 Program

LZ

emphasis:
exposure
(+low
background)



WIMPs: G2 Program

LZ

assembly on track

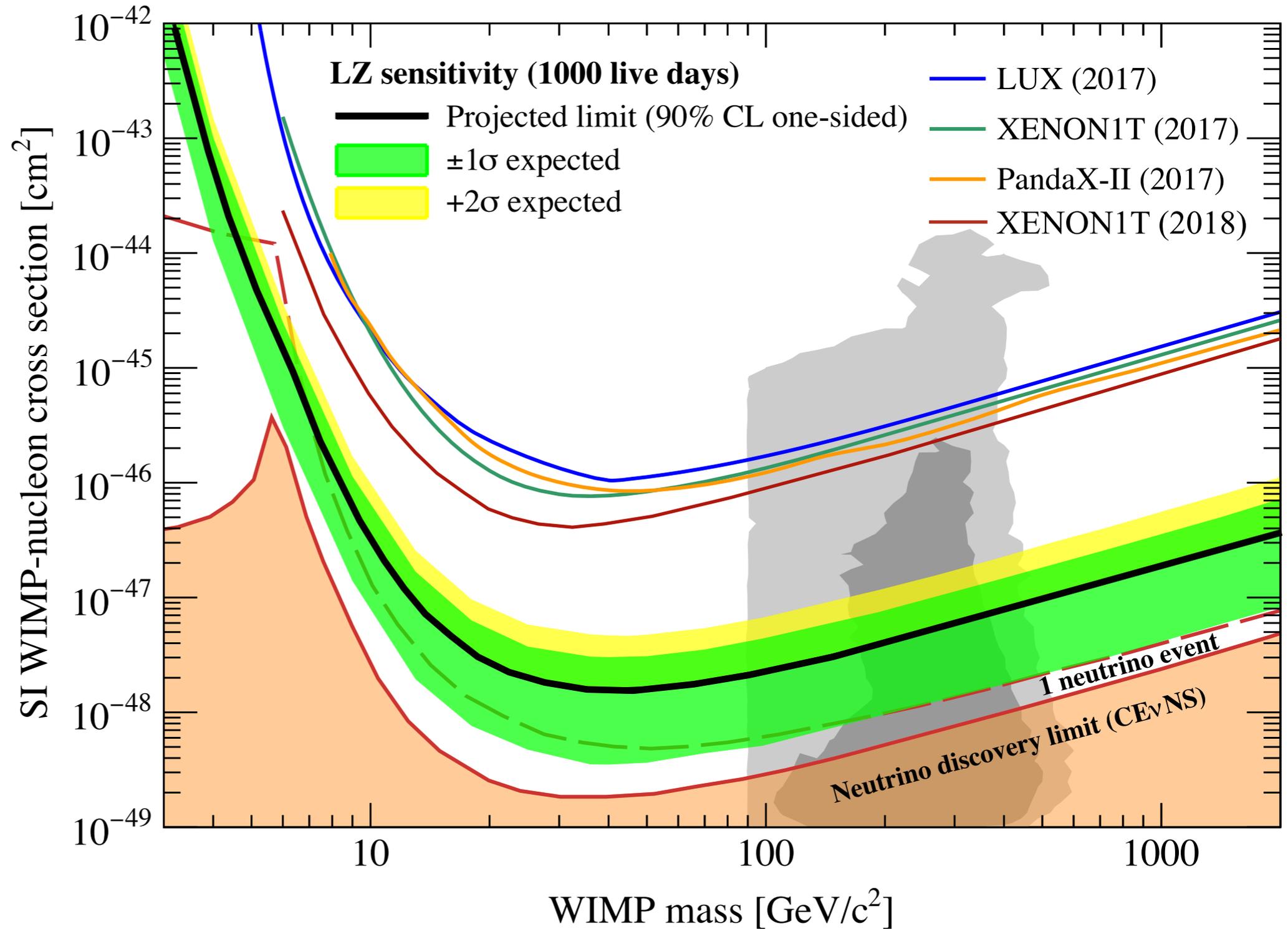


WIMPs: G2 Program

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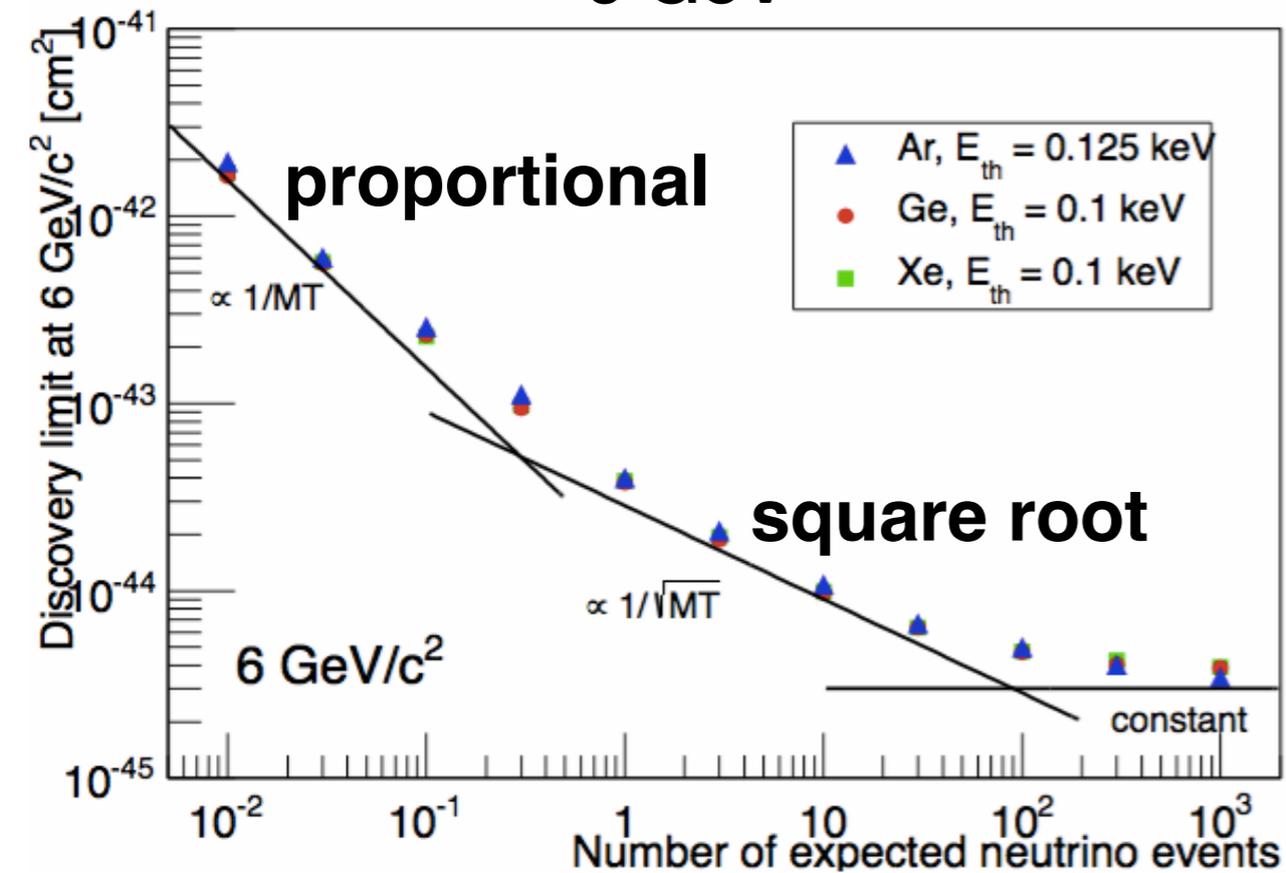


WIMPs: post-G2

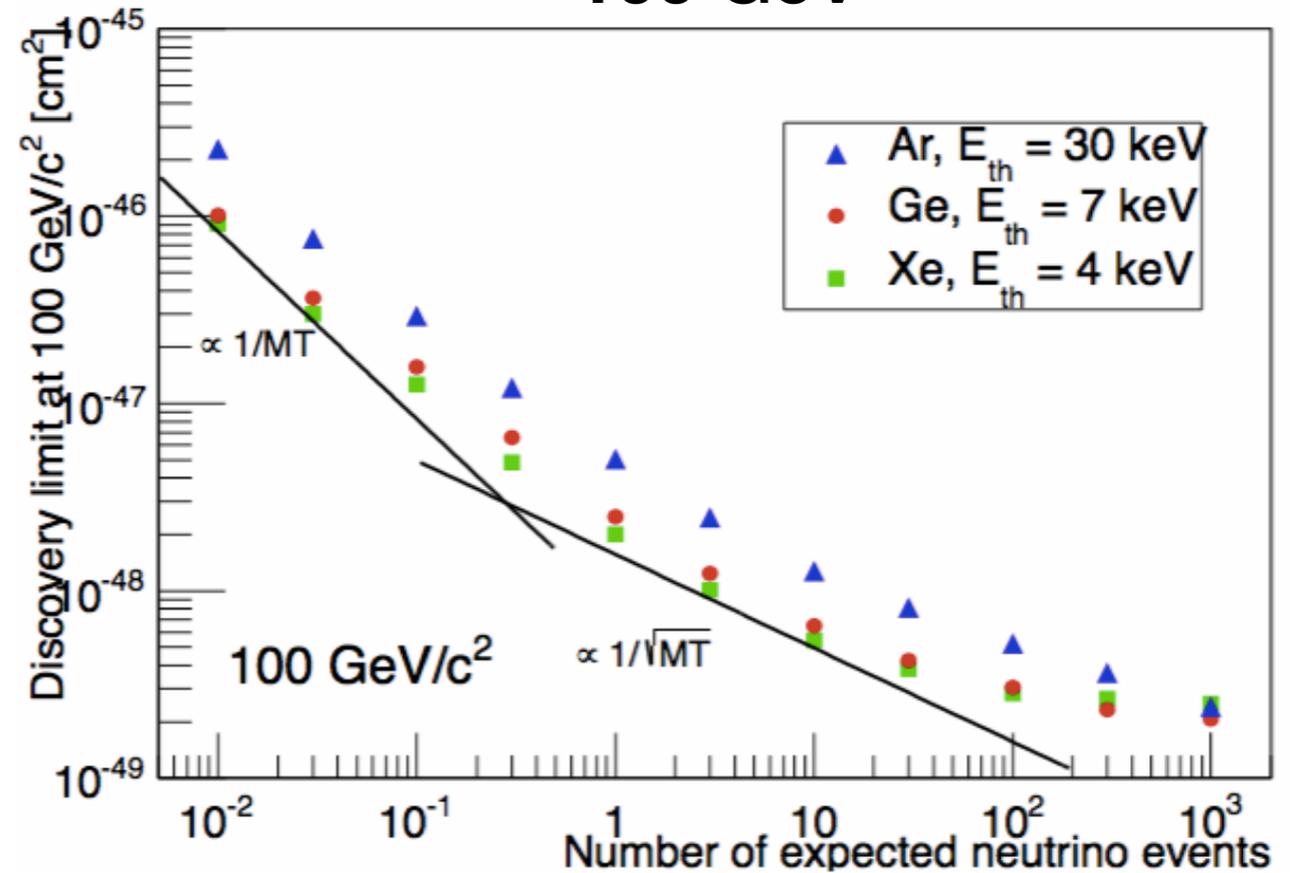
Room for one final generation

(while WIMPs remain motivated, neutrinos loom)

6 GeV



100 GeV



WIMPs: post-G2

Competition between LAr and LXe technologies

LAr community newly consolidated (DarkSide-20k)
SiPMs steadily improving
Large investment in Ar39 distillation infrastructure

Now is the time to think about G3 WIMP directions

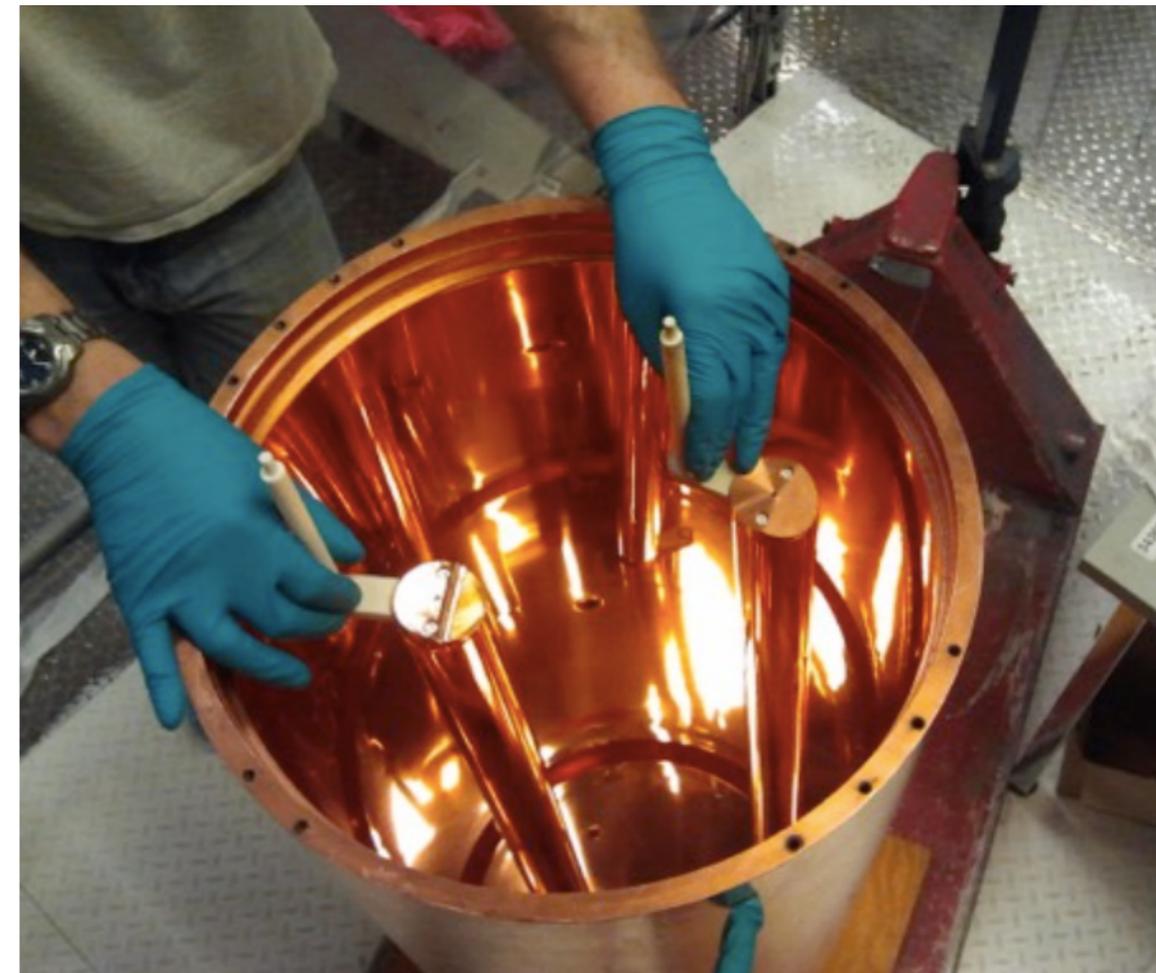
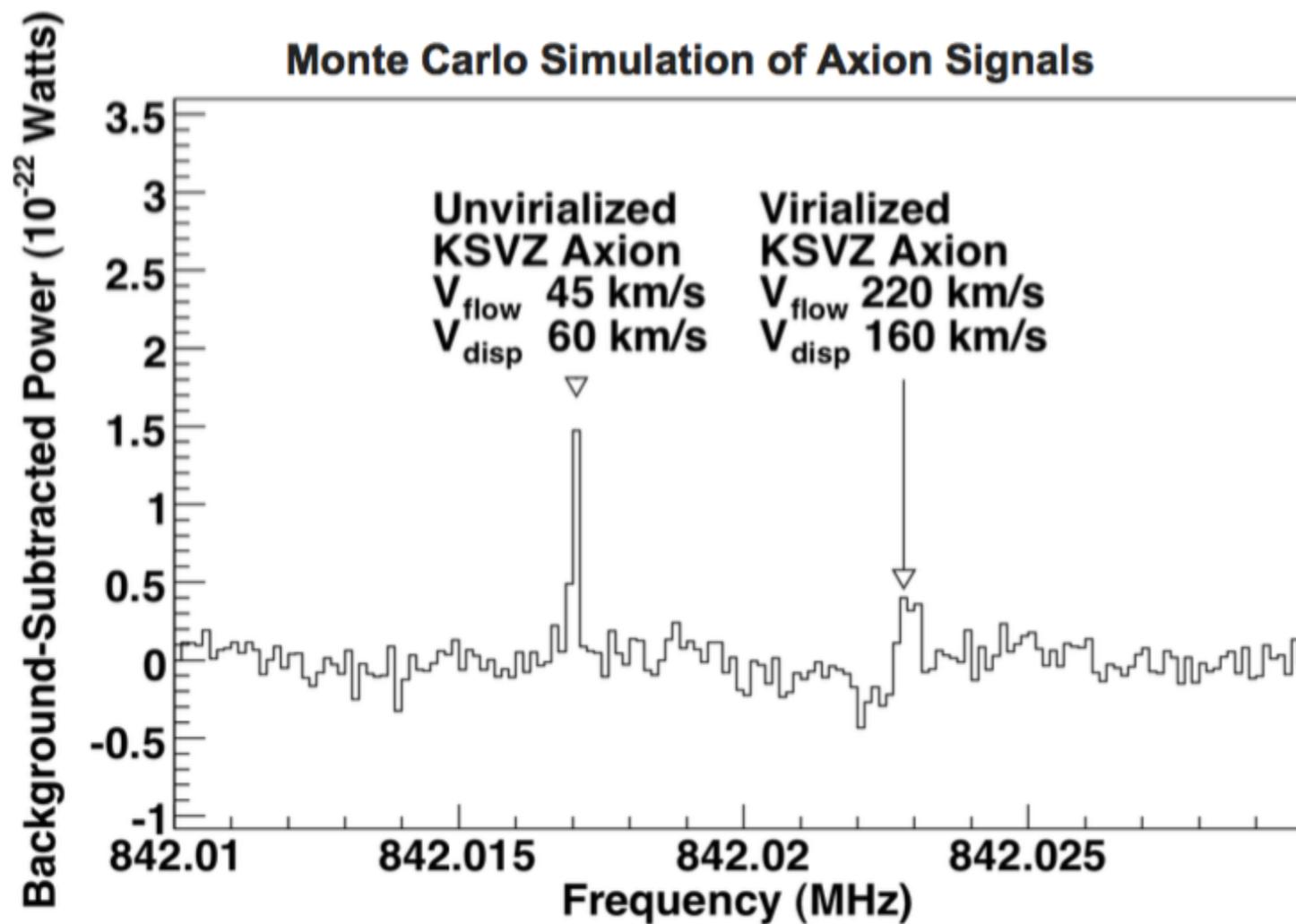
LAr vs LXe, Europe vs. US, ... decisions ahead
LXe G3 workshop: Feb 1,2

Axions: G2 Program

ADMX

Microwave resonant cavity/cavities

Scans frequencies, looks for excess power over noise

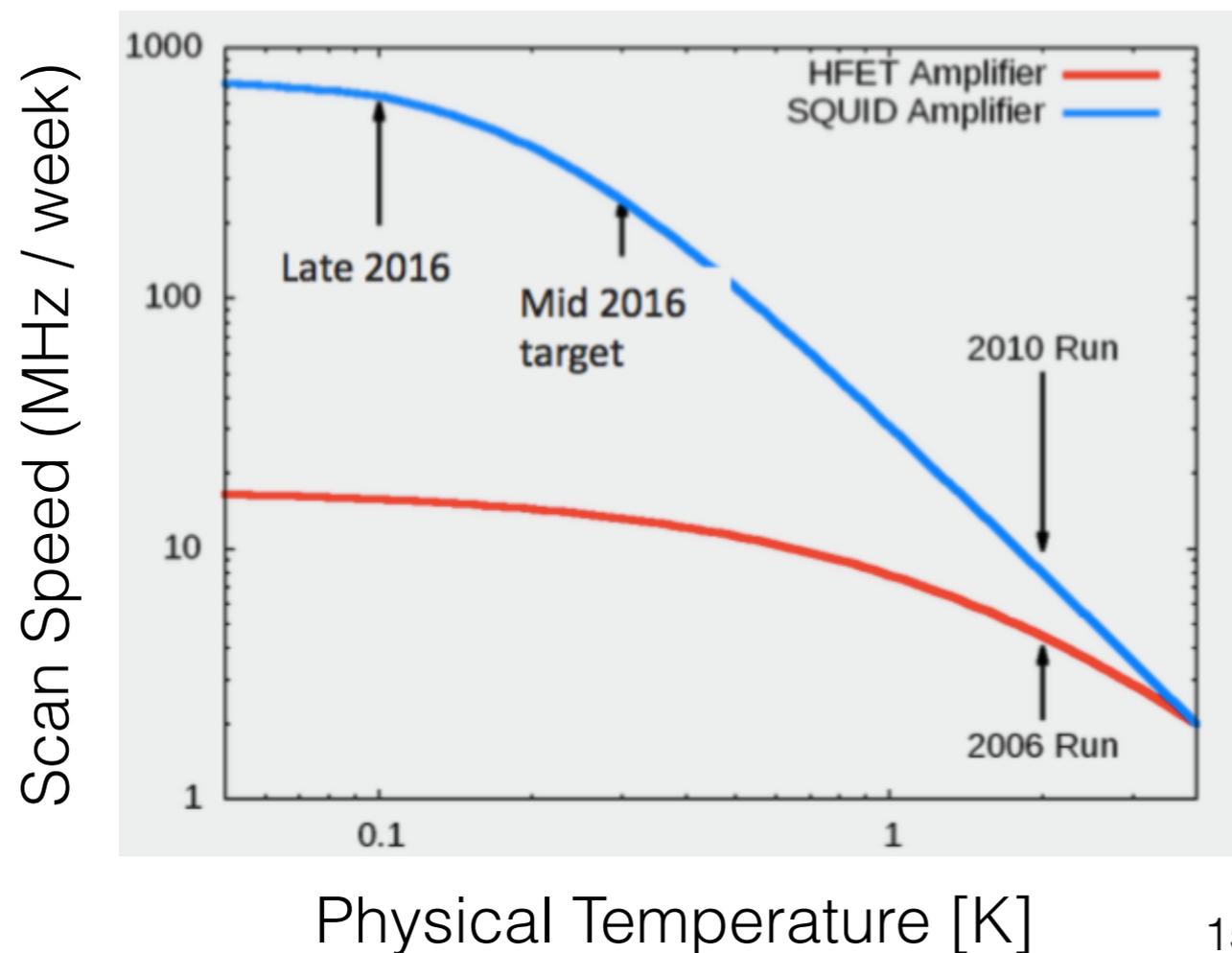


Axions: G2 Program

ADMX

Key metric: scan speed

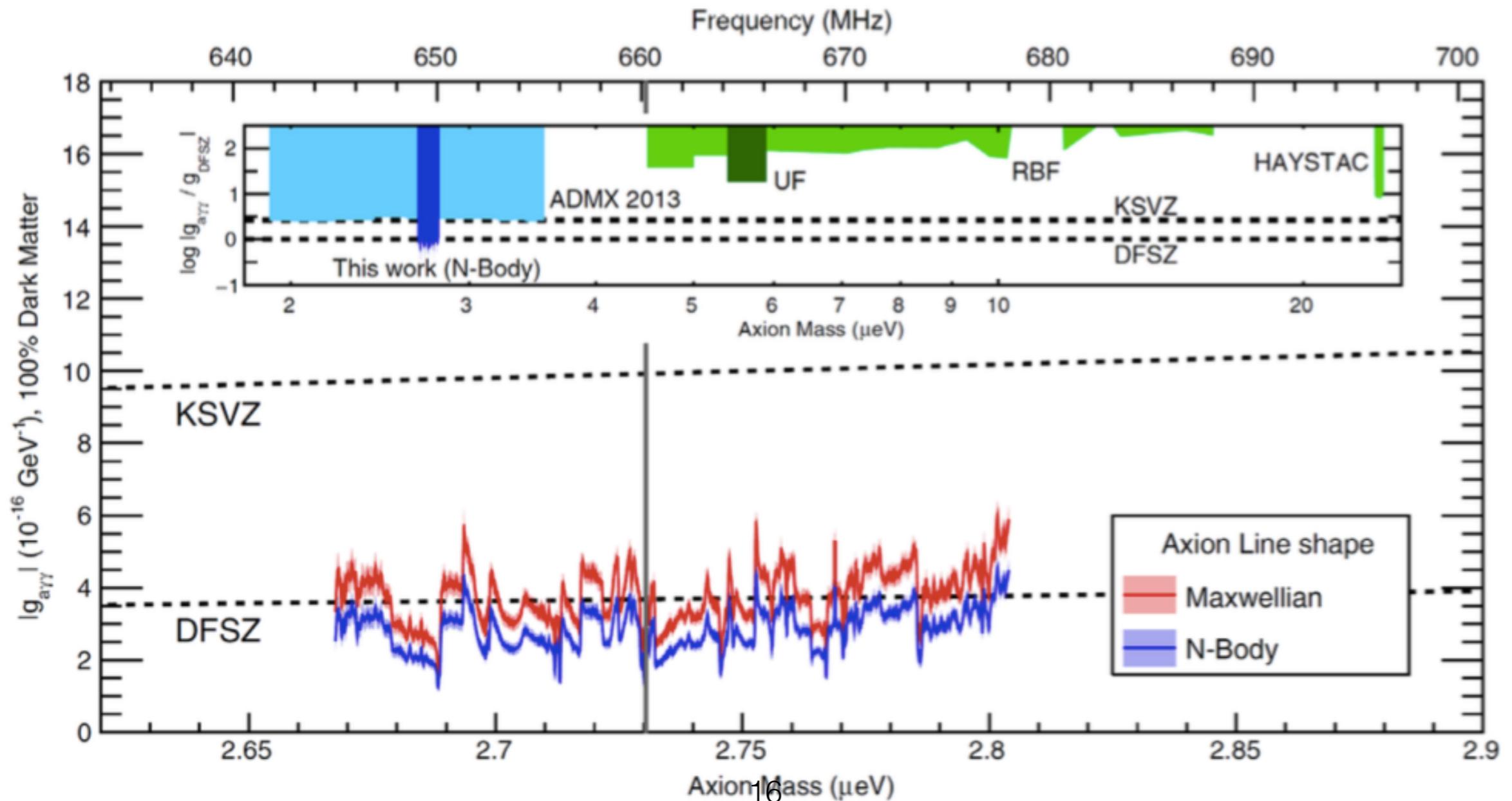
Key technology: quantum-limited amplifiers
(SQUIDs, JPAs,...)



Axions: G2 Program

ADMX

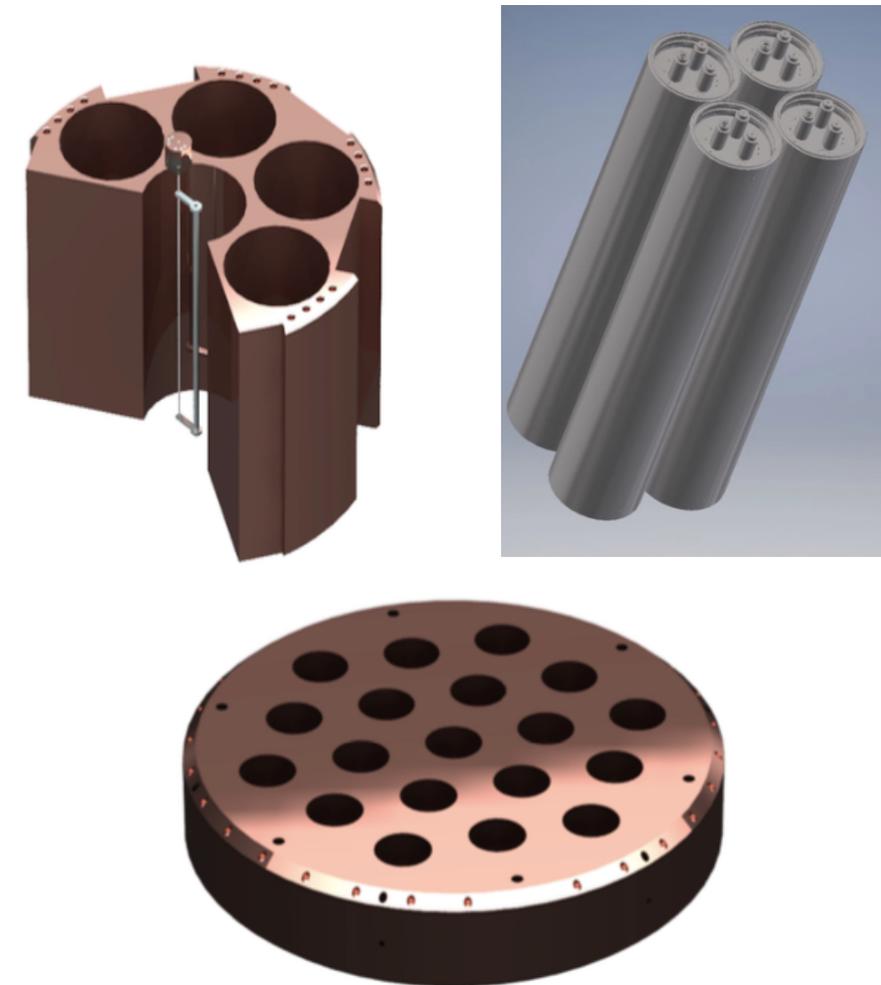
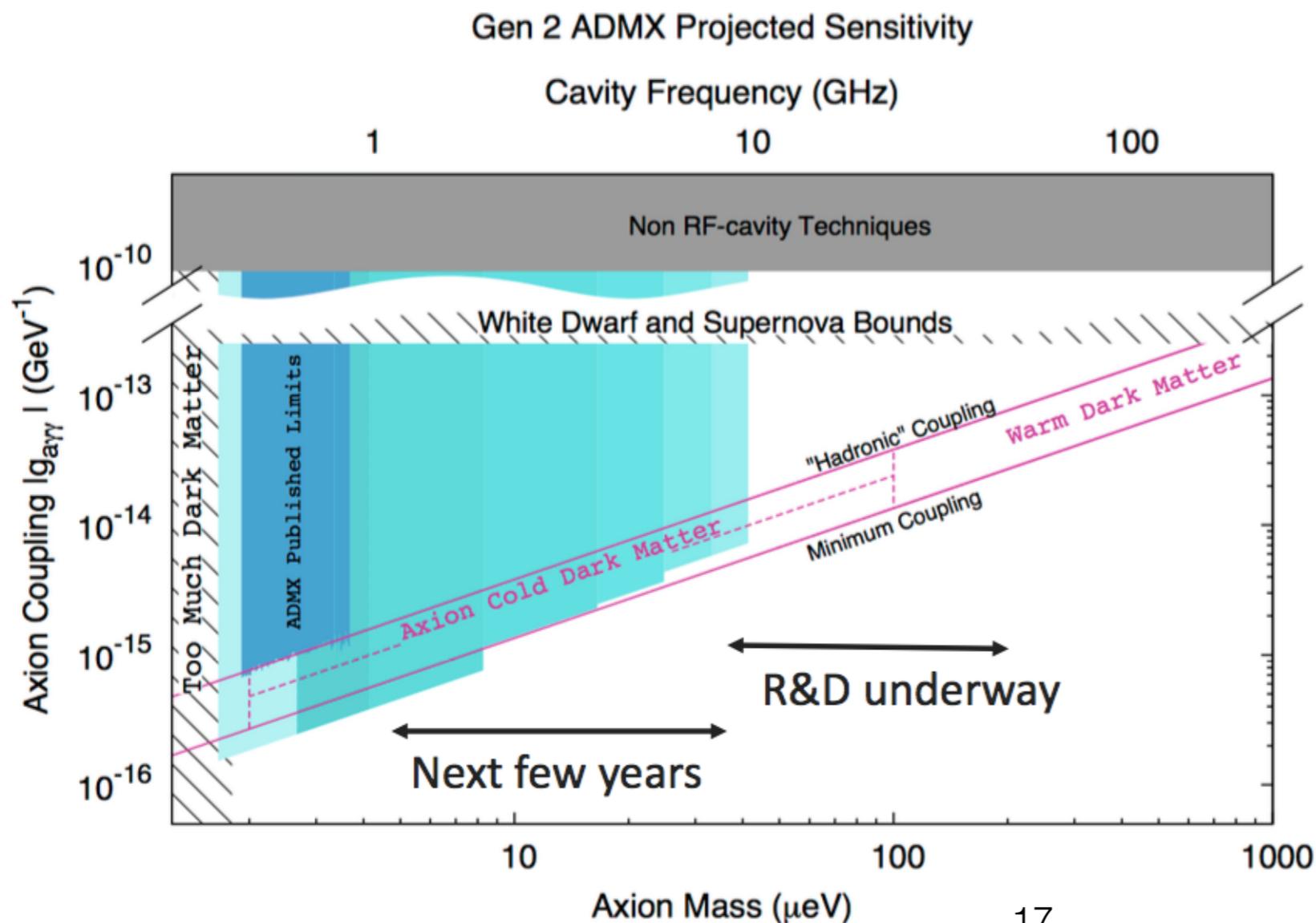
Recent milestone: first testing of DFSZ (pessimistic) models



Axions: G2 Program

ADMX

G2 plan starts at low mass/frequency and progresses up

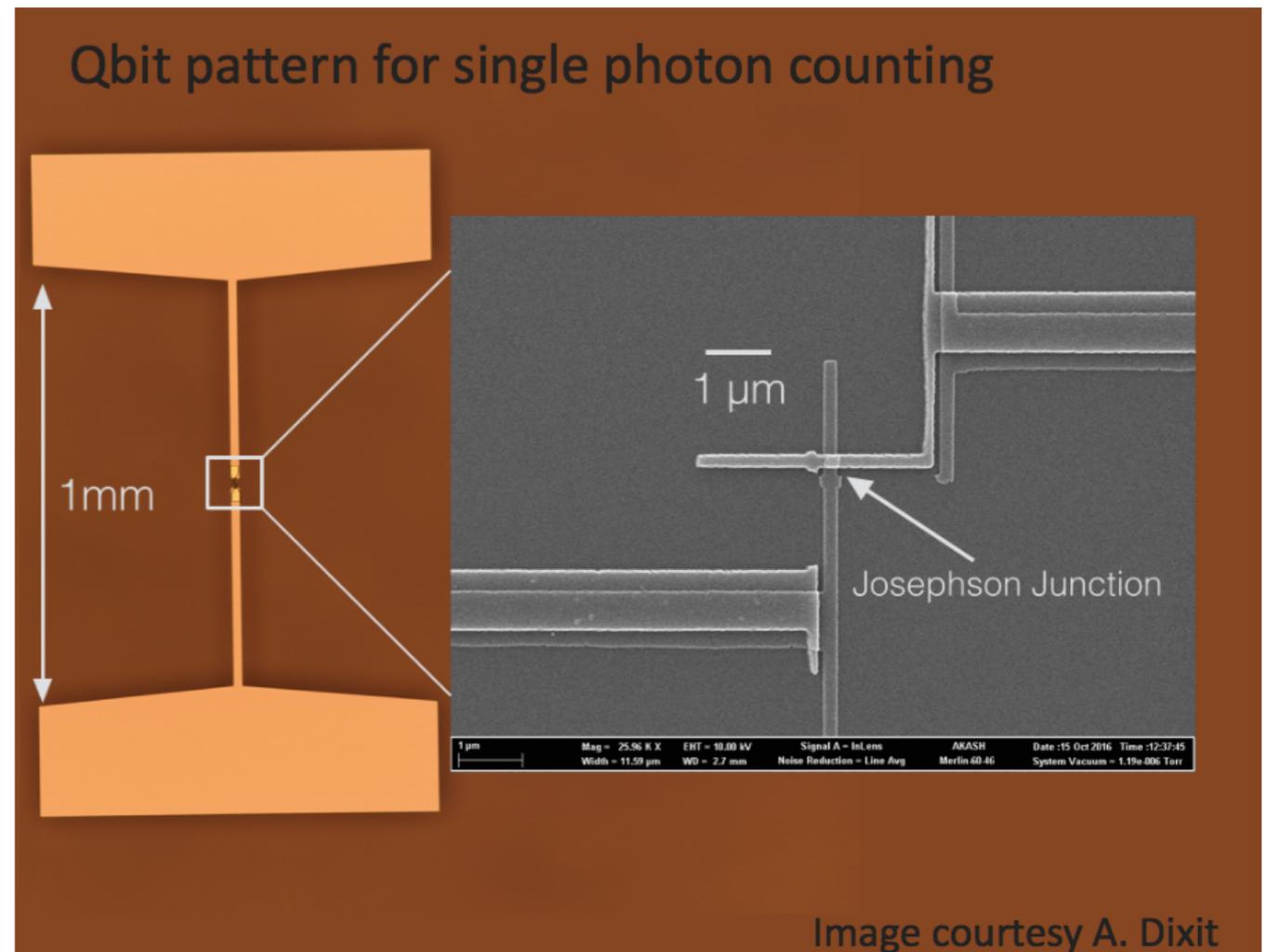


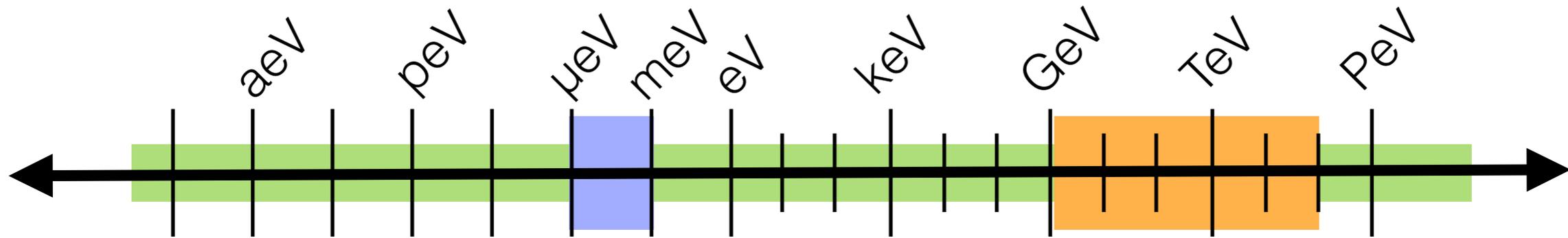
Axions: post-G2

SQUIDs etc. operate at the standard quantum limit.

Can do better: 1) squeezed state mode
2) single photon counting (via qubit).

Likely a smooth transition from G2 onwards.





Outline Reminder

WIMP searches

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Broadening the search

Basic Research Needs (BRN) Study
Mention of a few efforts

Broadening the search

Motivation

Lots of model space other than the WIMP & Axion regions is both interesting and accessible (or could be accessible in the near term).

If it's easy, we'd be fools not to look.

P5 report, 2014

“There are many well-motivated ideas for what the dark matter should be ... It is therefore imperative to search for dark matter along every feasible avenue.”

“The HEP program should contain a portfolio of small projects to enable an uninterrupted flow of high-priority science results.”

Broadening the search

US Cosmic Visions, 2017

workshop, focusing “... on the science case for additional new small-scale projects in dark-matter science that complement the G2 program ... “

100+ page whitepaper: [arXiv:1707.04591](https://arxiv.org/abs/1707.04591)

Basic Research Needs Study for Dark-Matter Small Projects, 2018

charge:

- Identify science opportunities for new directions and areas of parameter space that will provide high impact science return and advancement for DM particle detection.
- Determine the high impact science opportunities which could be pursued by small projects (approximately \$5M to \$15M in Total Project Cost) that could be ready to start within the next few years, and in which DOE’s laboratory infrastructure and/or technology capabilities are required to be realized.
- Suggest opportunities that could be pursued by future small projects, which also require DOE capabilities, but need further technology development before project initiation.

preliminary report to HEPAP: <https://science.energy.gov/hep/hepap/meetings/201811/>

Broadening the search

Mention of a few efforts

The archetype “small project”: CRESST/v-cleus

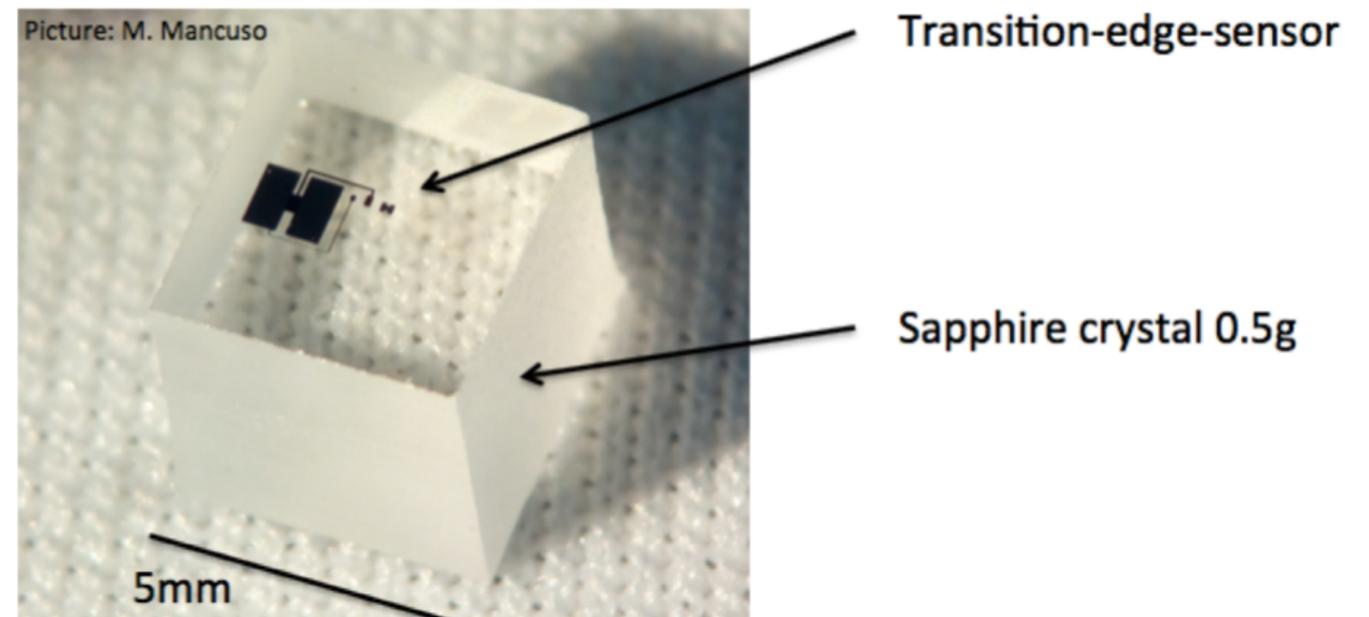
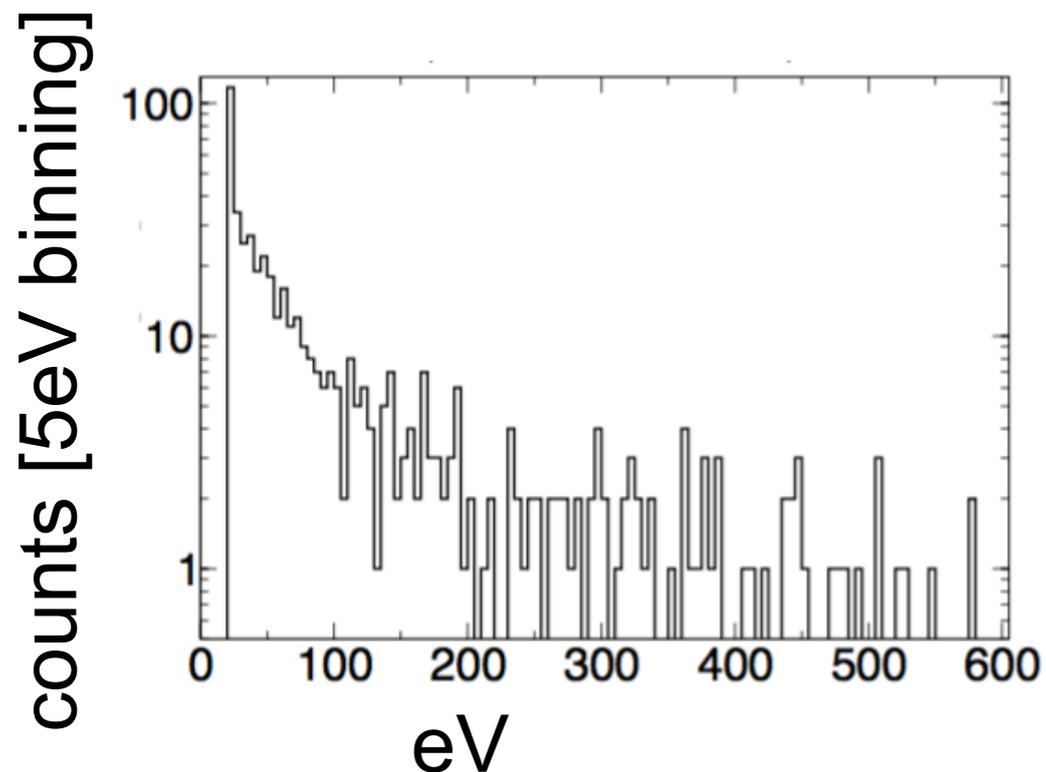
5x5x5mm (0.49g)

20 eV threshold (on oxygen \rightarrow 140 MeV mass threshold)

2.27h exposure

above ground, no shielding, with $\sim 0.2\text{Bq}$ Fe55 source

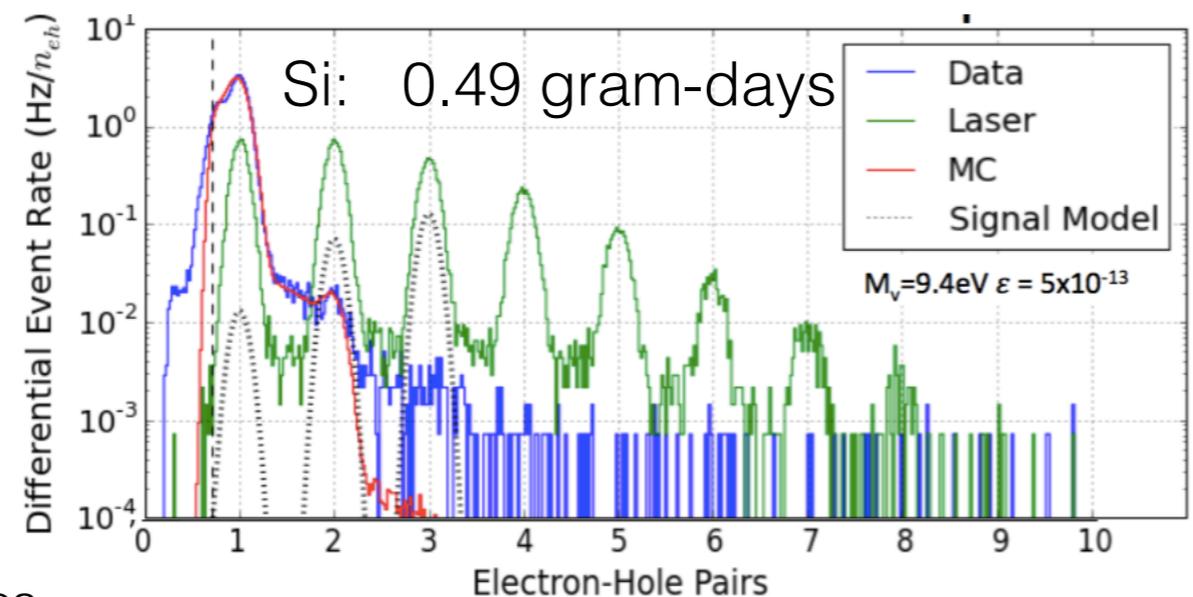
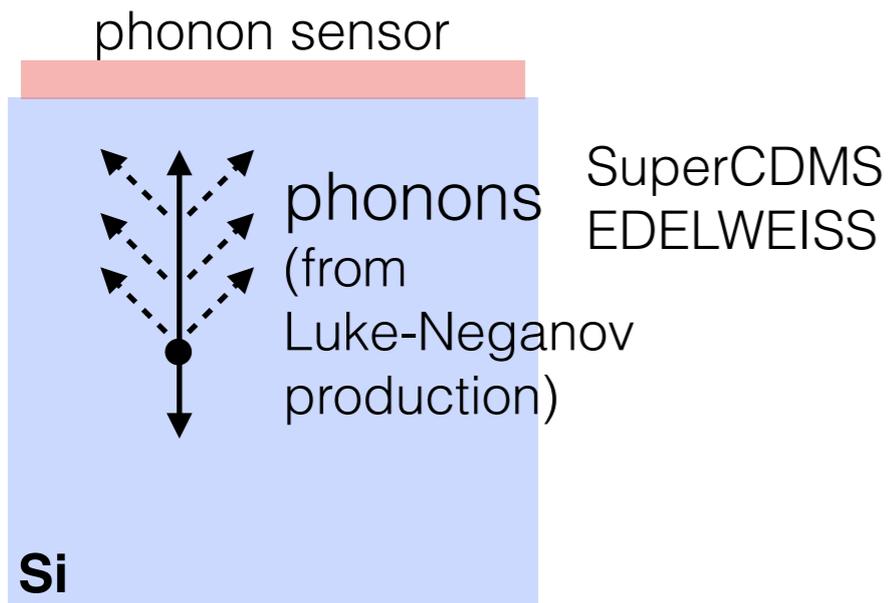
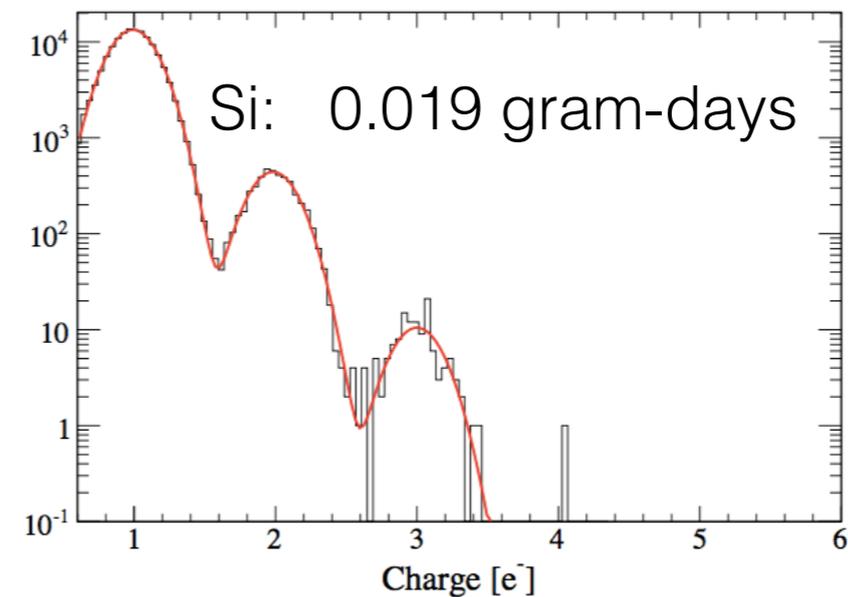
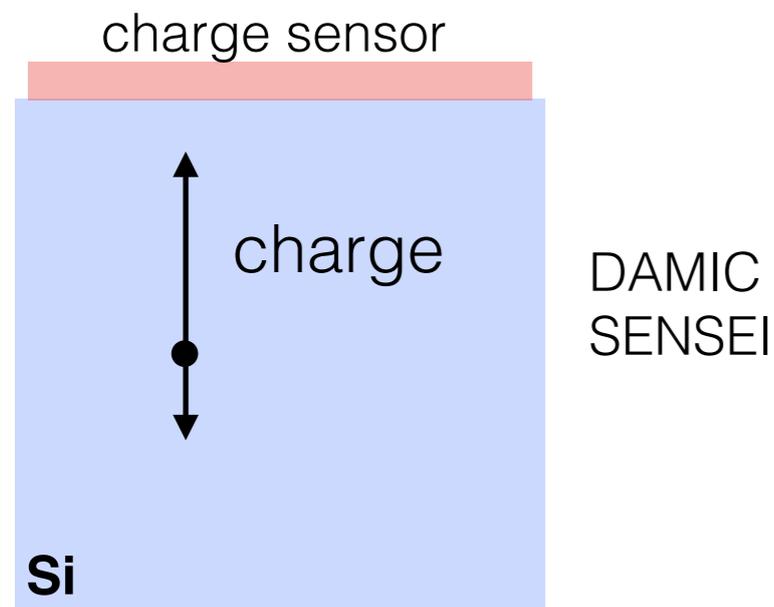
World-leading nuclear recoil sensitivity at low masses!



Broadening the search

Mention of a few efforts

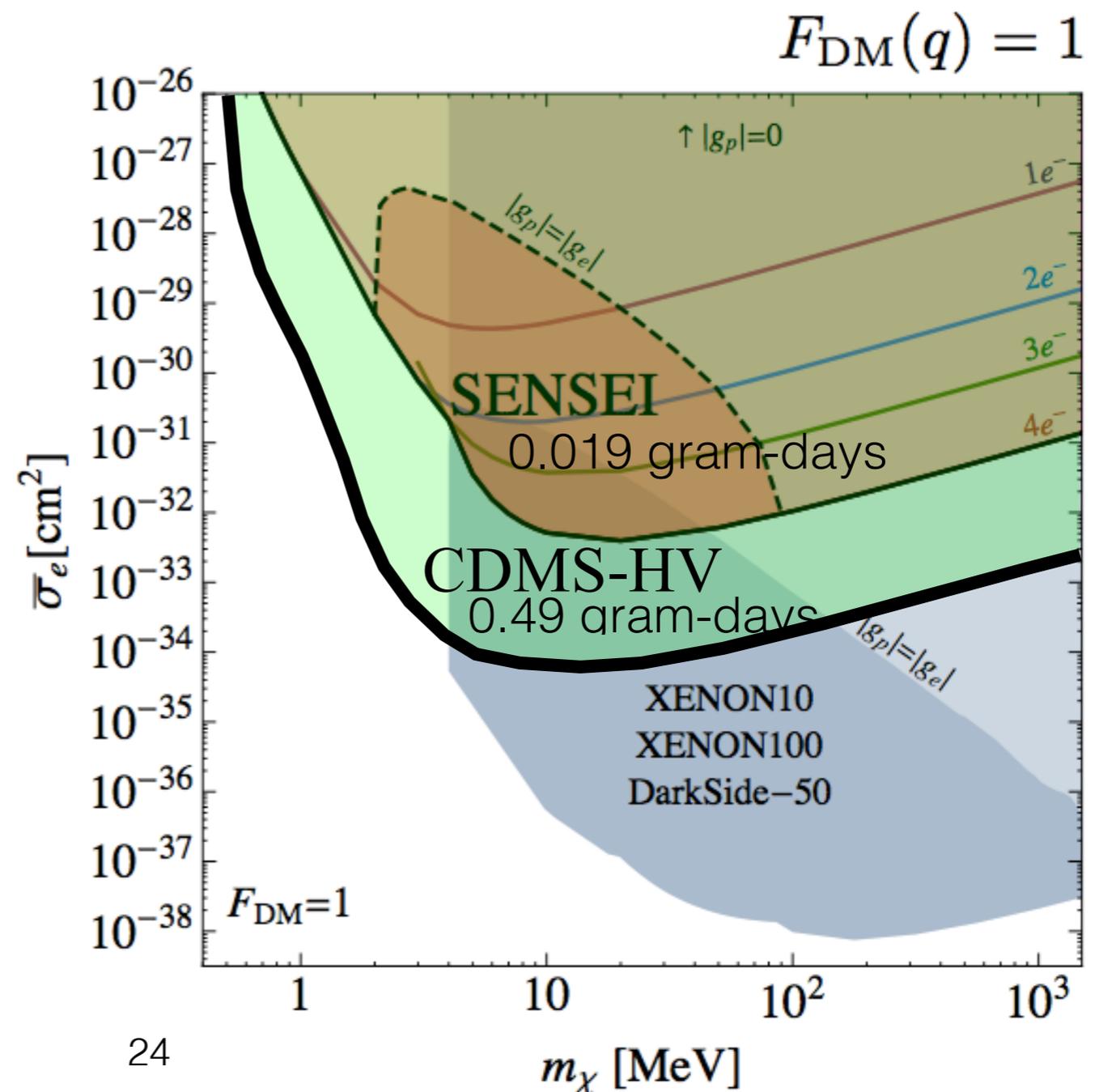
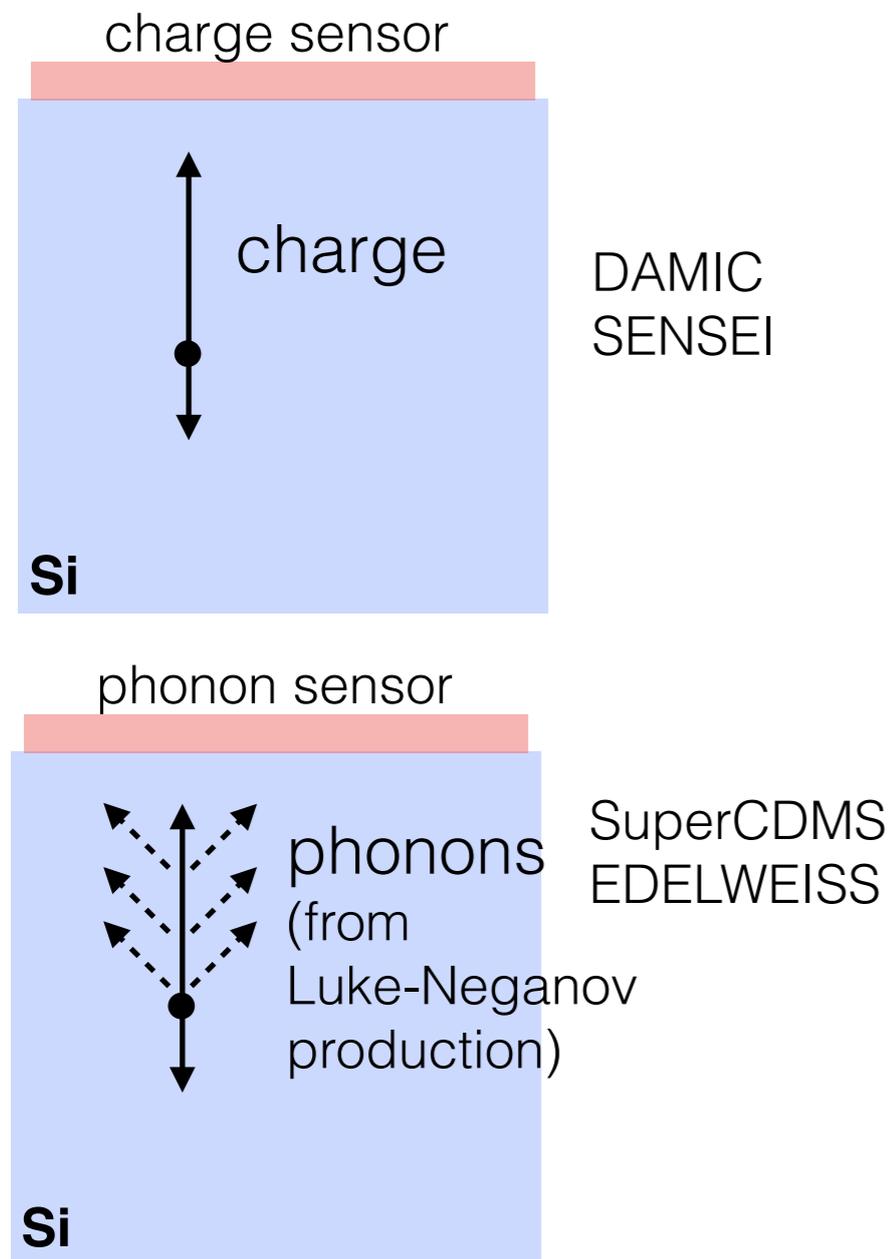
Sensing single semiconductor e-h pairs: now a solved problem.
Two complementary approaches both reach ~ 1 MeV mass.



Broadening the search

Mention of a few efforts

Sensing single semiconductor e-h pairs: now a solved problem.
Two complementary approaches both reach ~ 1 MeV mass.

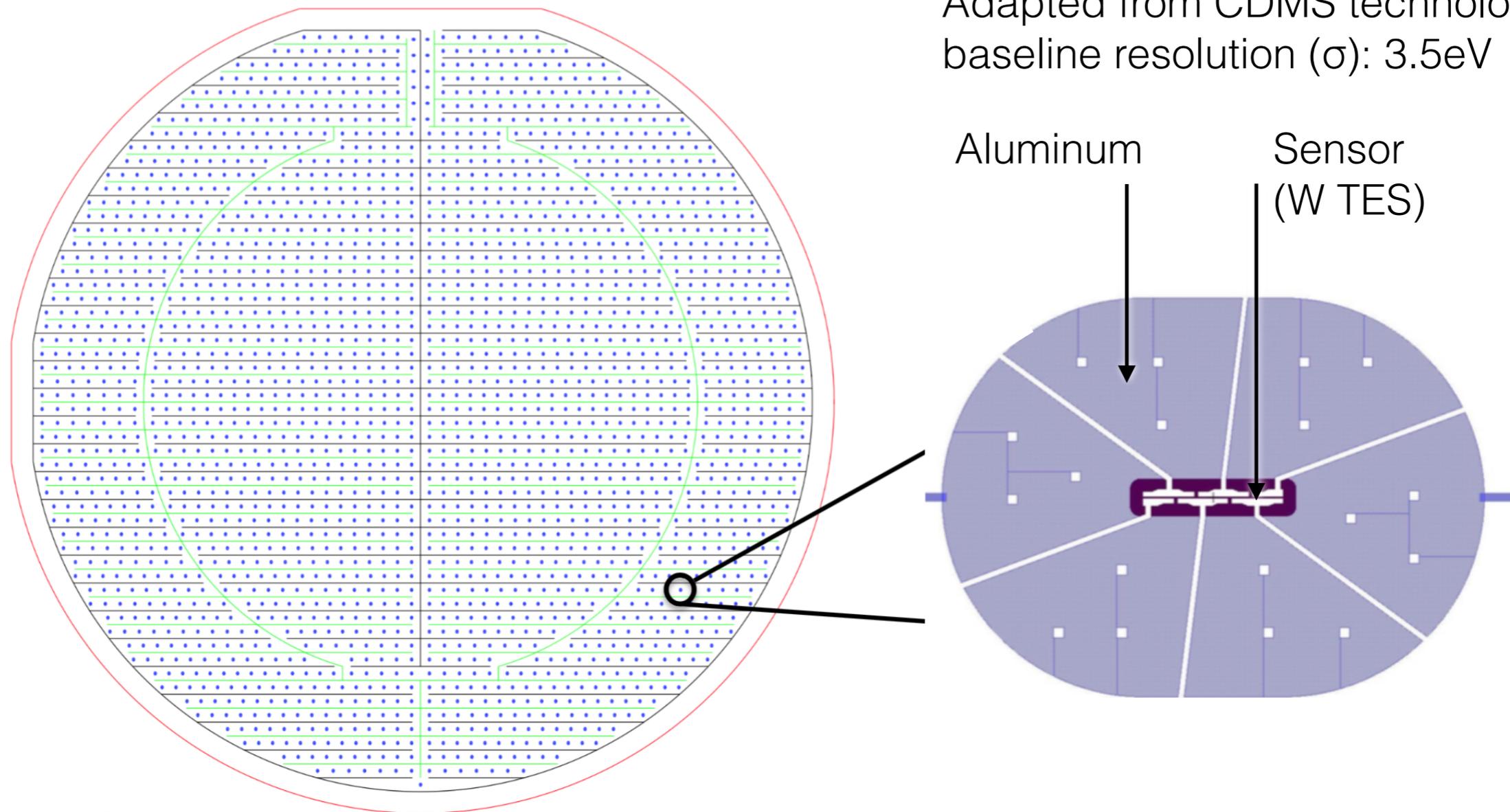


Broadening the search

Mention of a few efforts

Large-area Low-temperature calorimetry for diverse signal quanta

3" diameter Si wafer (46 cm²)
Adapted from CDMS technology
baseline resolution (σ): 3.5eV



Broadening the search

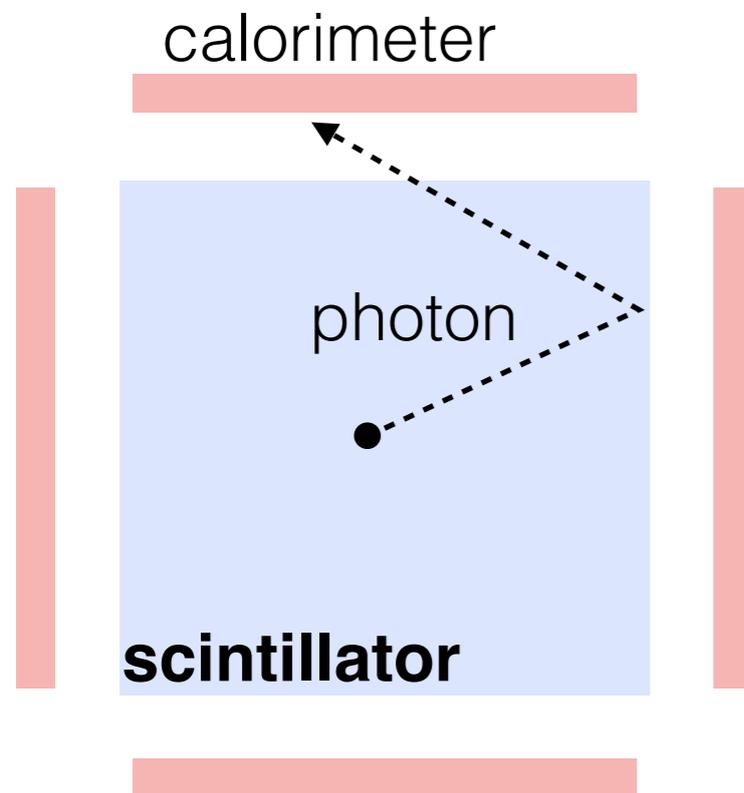
Mention of a few efforts

Large-area Low-temperature calorimetry for diverse signal quanta

Detect scintillation photons

- near-perfect efficiency
- near-zero dark count

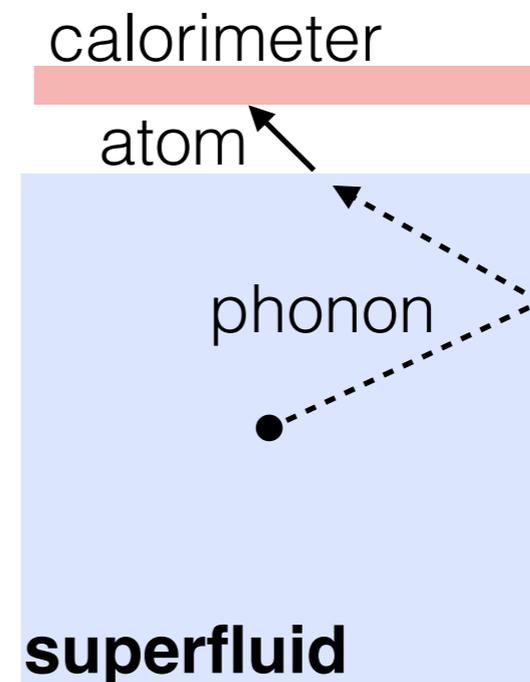
arXiv:1607.01009, 1802.09171



Detect quantum evaporation

- phonon liberates atom
- gain via adhesion energy

arXiv:1810.06283



Broadening the search

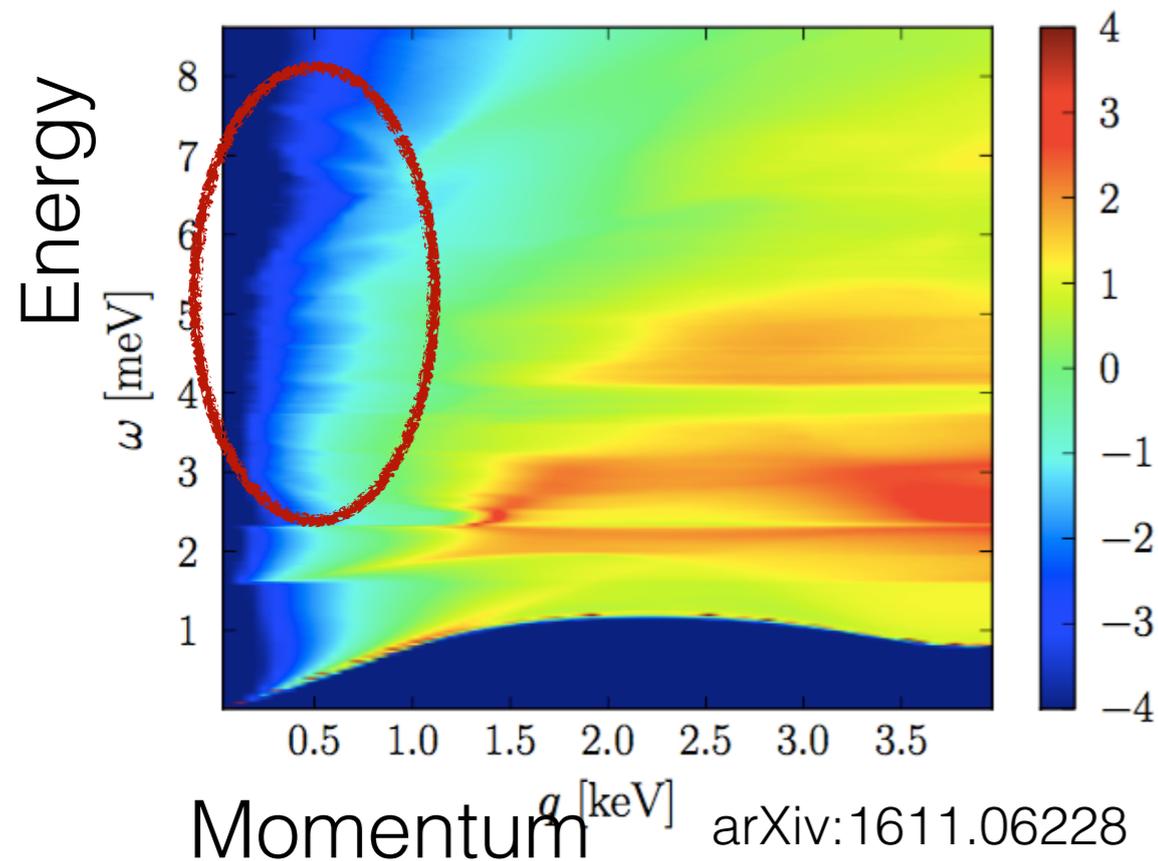
Mention of a few efforts

Materials sensitive to keV-mass dark matter recoils

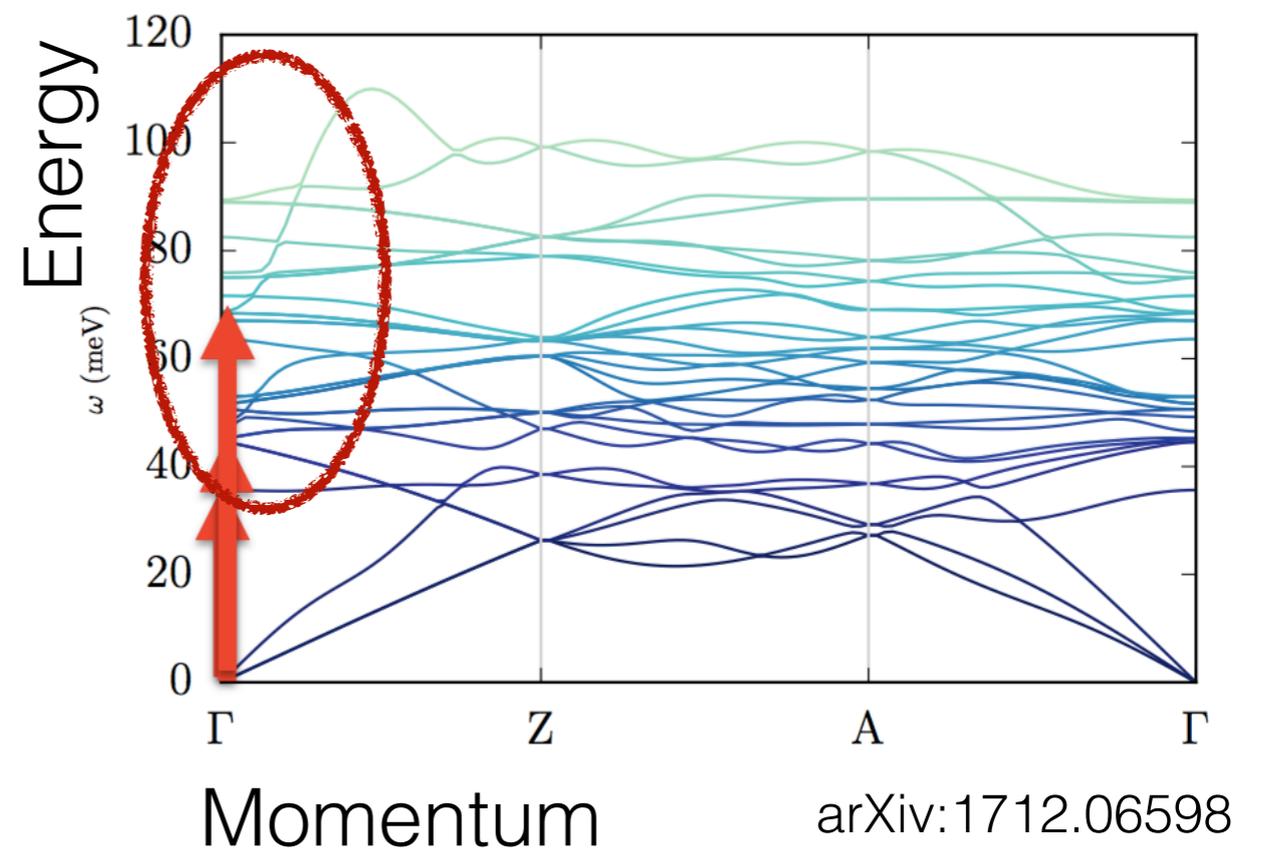
Below MeV mass scale, nuclear recoil technology fails
(severe mis-match between DM and nuclear masses)

Sensitivity possible via low-momentum material excitations.

${}^4\text{He}$



Al_2O_3



Broadening the search

Mention of a few efforts

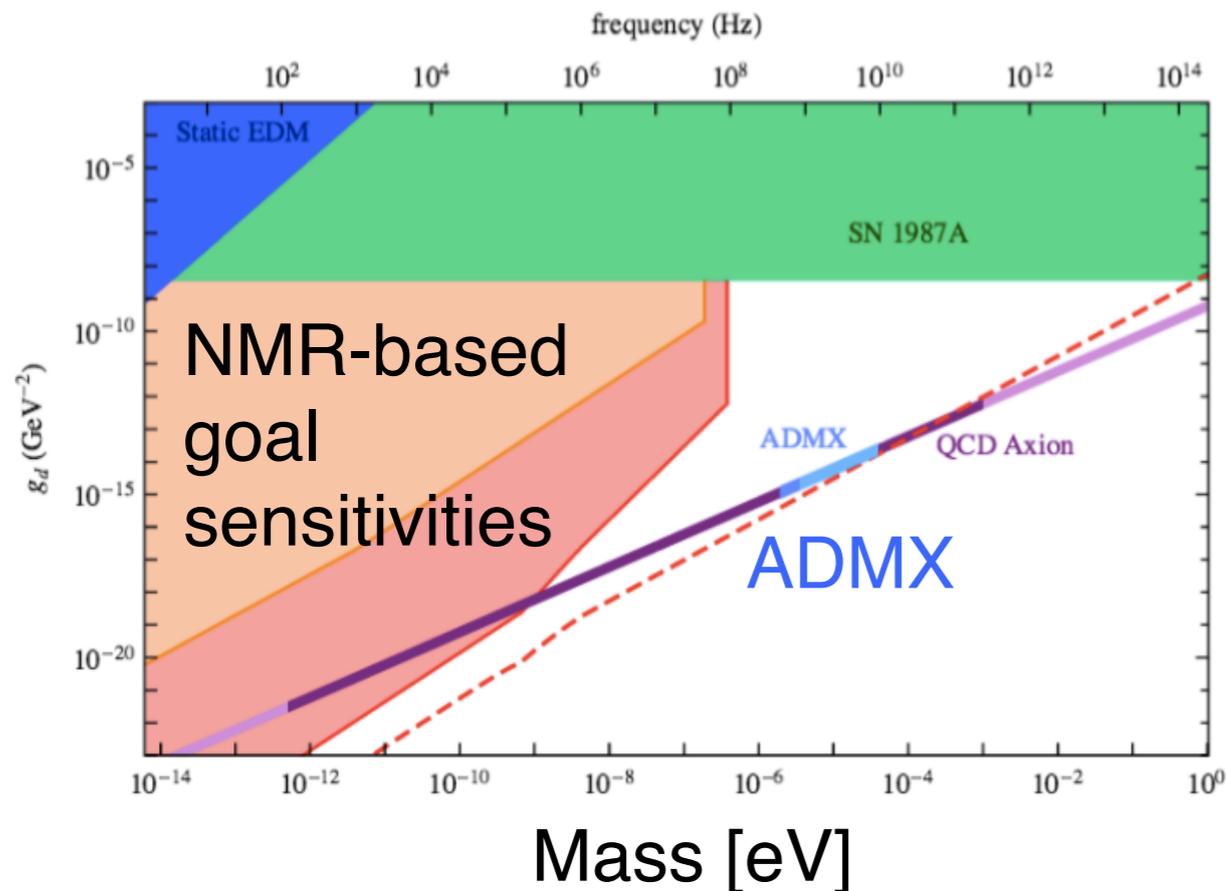
NMR-based detectors for super-light dark matter

Below μeV scale, resonant cavities become impractical.

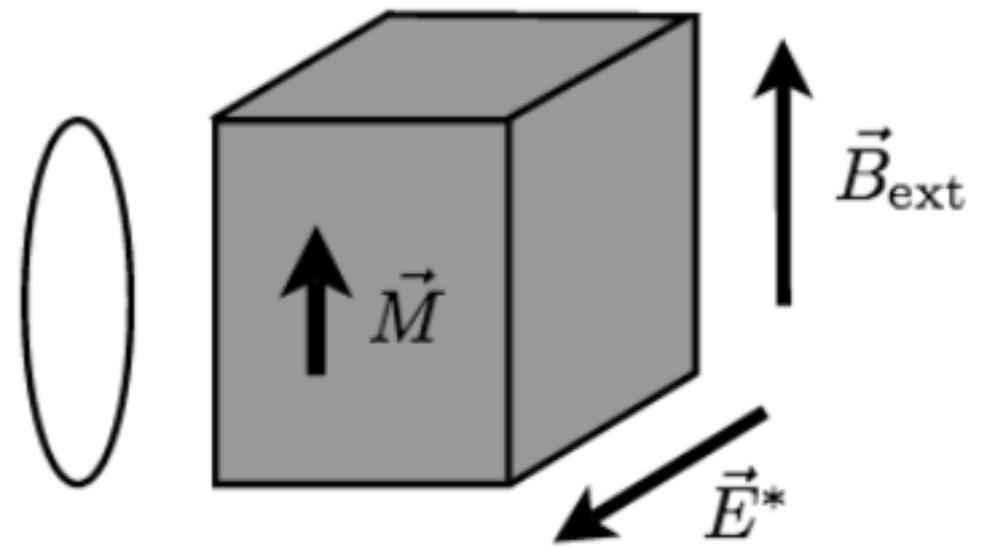
New strategy:

Axions induce an oscillating electric dipole moment

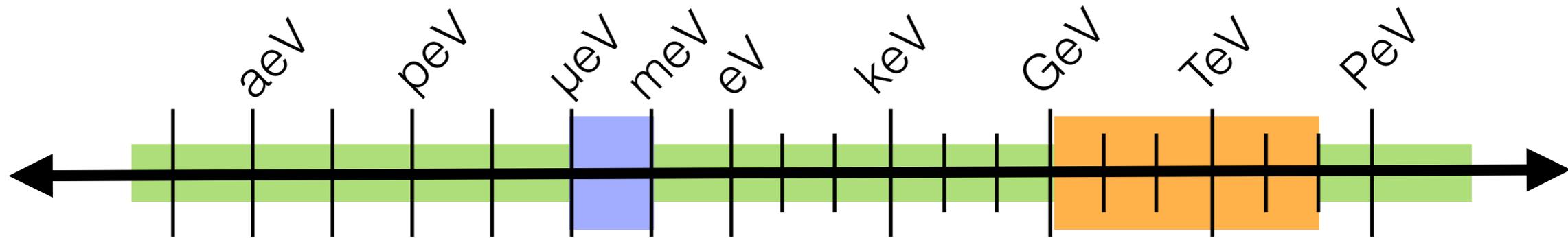
Detectable if resonant with material's Larmor frequency



SQUID pickup loop



arXiv:1707.05312



Summary

WIMP searches

G2: SuperCDMS & LZ progressing towards start

Beyond: room for one more round, starting to get organized

Axion searches

G2: ADMX progressing from μeV mass up

Beyond: transitioning to quantum information tools

Broadening the search

Increasing DOE interest

A wealth of creative ideas and R&D at all mass scales