KID-Based Phonon-Mediated Detectors for Dark Matter and CEνNS

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Magnificent CEνNS

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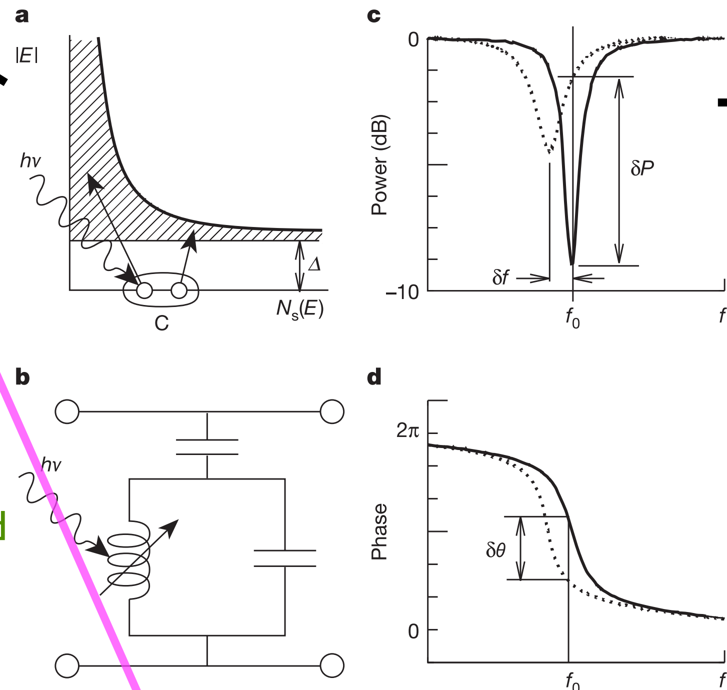
w/NEXUS-FNAL group and LBNL QIS program

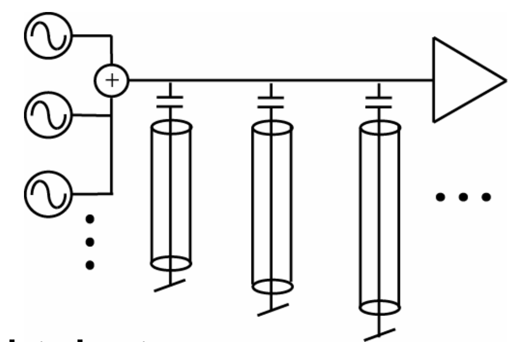
Why sense phonons with kinetic inductance detectors (KIDs)?

Energy resolution:
sub-eV → meV
thresholds w/o HV

- Direct sensitivity to pair-breaking phonons
  - Large resonators obviate qp trapping
- Gapped density of states
  - Thermal qp population exponentially suppressed
- Fundamentally non-dissipative
- Noise is limited by
  - qp population fluctuations
  - amplifier noise

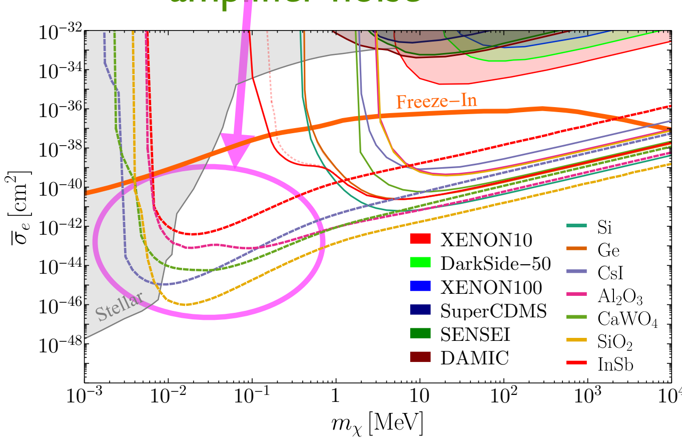


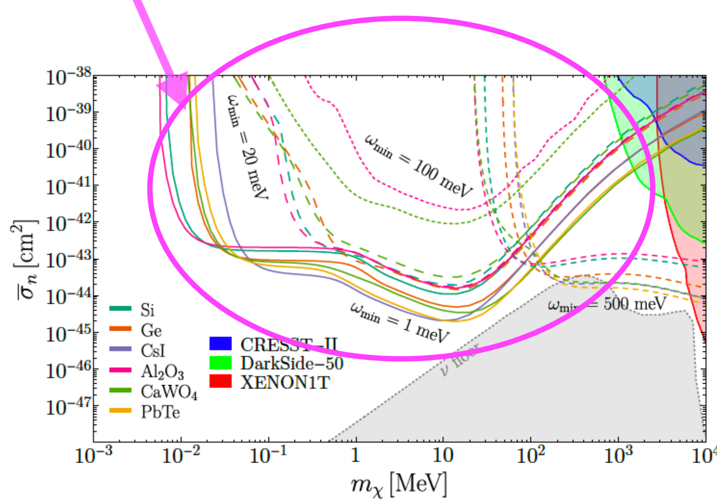
Day

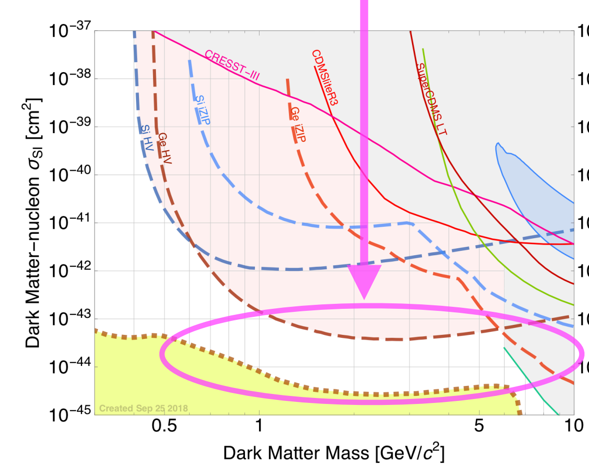


Multiplexing:
Highly position-resolved phonon detection
→ NR/ER discrimination, position fiducialization

- KIDs are Q>10^5 resonators
- → Readout many with one cryo line/amplifier; most electronics at 300K







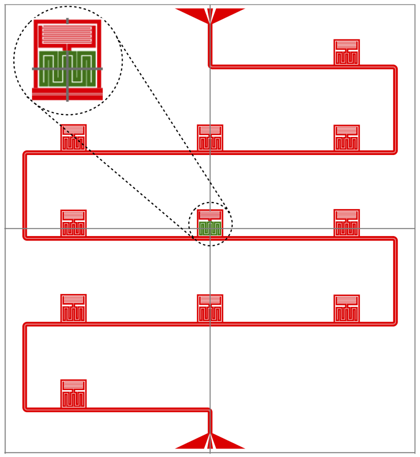
\+ dark photons, ALPs, etc.

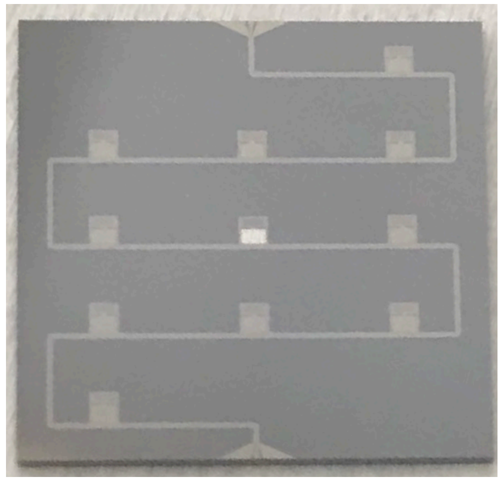
Griffin et al. https://doi.org/10.1103/PhysRevD.101.055004

Two Architectures

Low-threshold:

1 KID on a gm substrate for NEXUS/LBNL



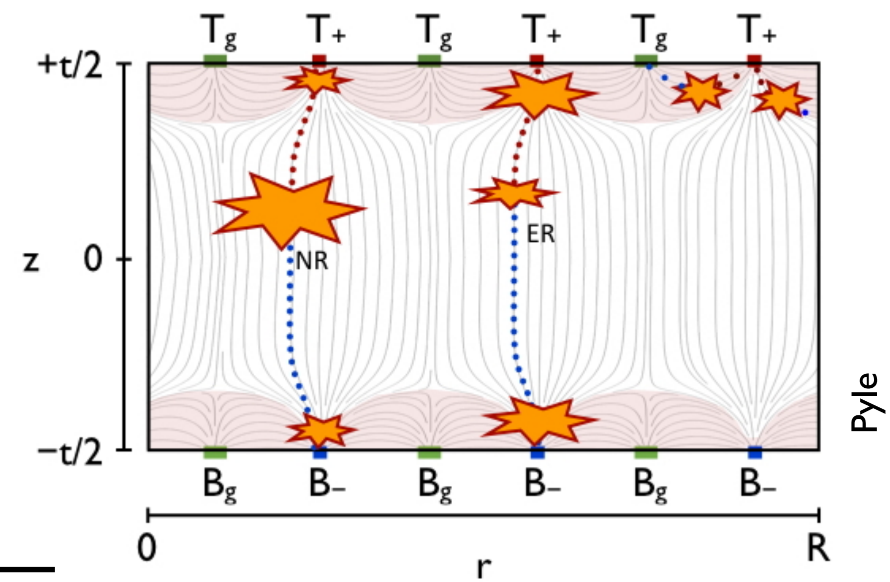


22 mm
x 1 mm

"piZIP": Fine-grained phonon sensor enables:

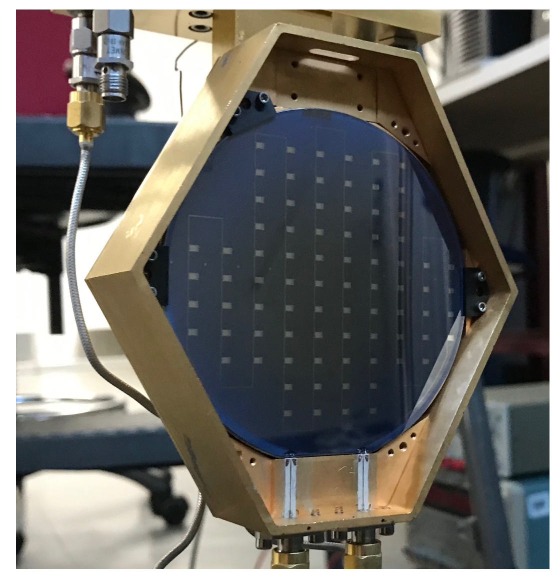
Phonon-based fiducialization in z and r

NR/ER discr. via NTL phonon position



stage	σ_{pt} low-threshold	σ_{pt} piZIP
current (estimated)	10 eV	240 eV
single-KID optimized	1-7 eV	—
increase τ_{qp} to 1 ms	0.3-2 eV	80 eV
quantum-limited amplifier	45-360 meV	25 eV
AlMn (T_c in K)	5-70 meV (0.1K)	5 eV (0.2K)
squeezed vacuum/ amplification	0.5-7 meV	—

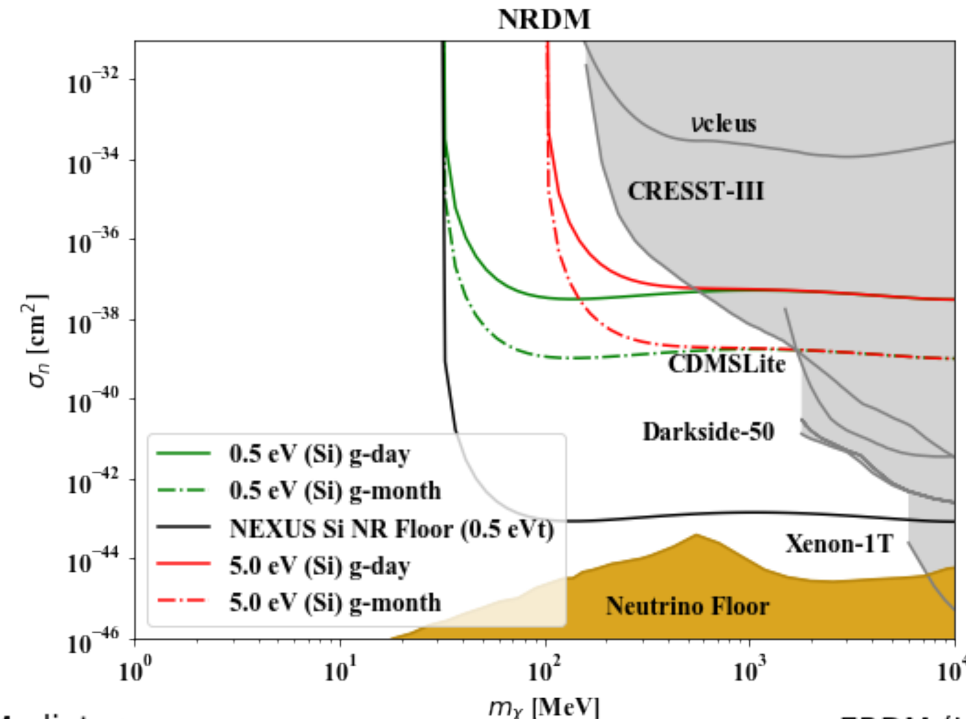
NR/ER discr. down to O(100) MeV!



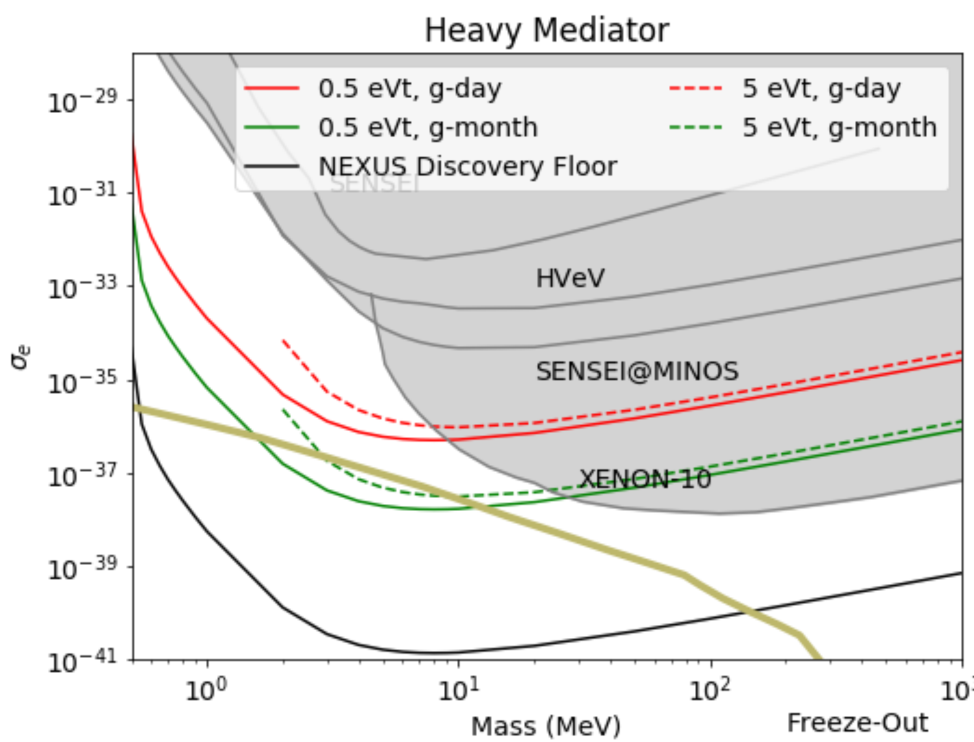
75 mm
x 1 mm

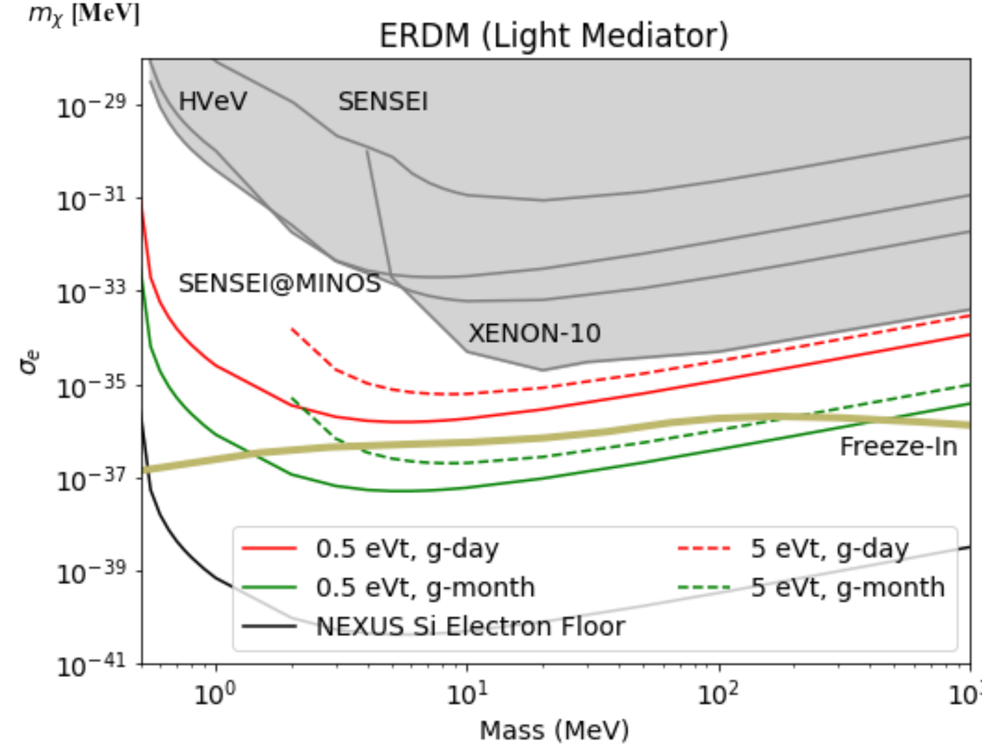
Both architectures funded for development.: LBNL QIS + FNAL LDRD for low-threshold, DOE HEP DetRnD for piZIP, grad+postdoc fellowships

Demonstration Runs Planned at NEXUS



Thresholds (not σ_{pt}) are shown





Limit plots from N. Kurinsky

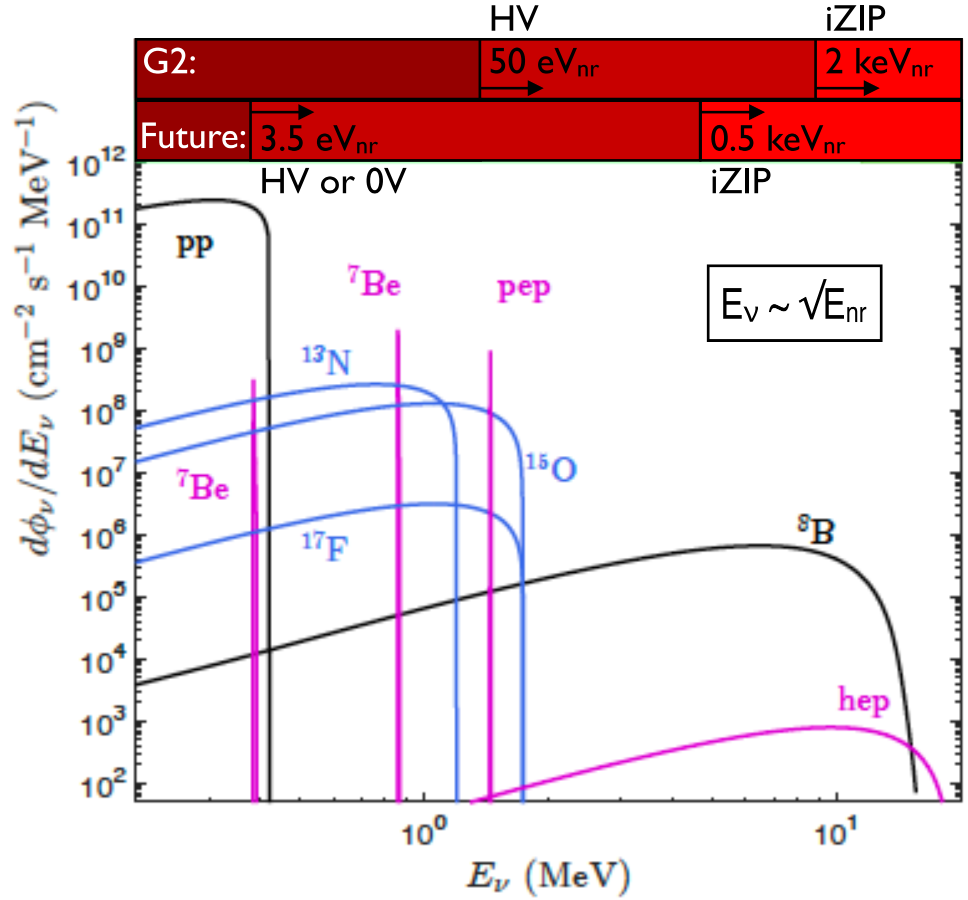
CEvNS Energy Scales (Redux)

Reference point: SuperCDMS SNOLAB G2
(https://doi.org/10.1103/PhysRevD.95.082002)

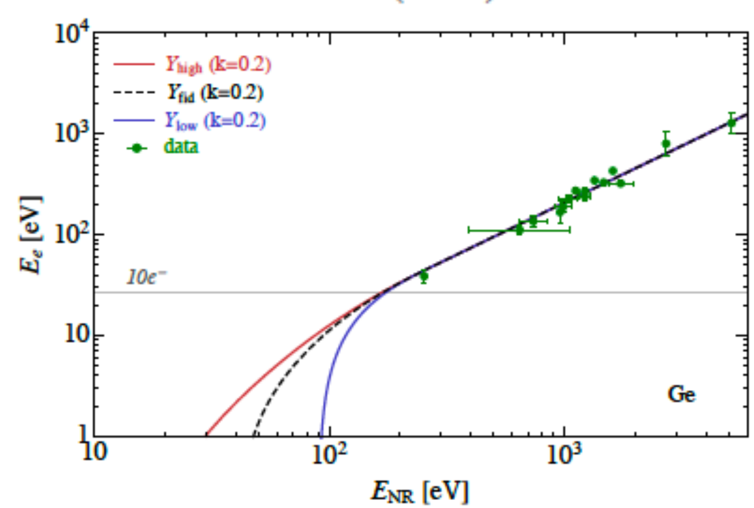
- 2 keV_{nr} threshold for NRs w/discrimination based on ionization yield (iZIP)
  - few ^{8}B, hep neutrinos above discr. threshold
    - ~50 total at 350 eV_{nr} threshold, but no discr.
- 50 eV_{nr} threshold for NRs w/o discr. (HV)
  - pep, ^{15}O neutrinos detectable above threshold, but << backgrounds (cosmo, radon, Compton)

KID-Based Future Options

- Key point: Frenkel defect energy ~ 20 eV_{nr}
  - No ionization production below this energy
- Three energy regimes:
  - Down to 10s of eV_{nr}: phonon-based iZIP (piZIP):
    - Drift-phonon-position-based NR discrimination
  - E_{gap} (~1 eV) to 10s of eV_{nr}: 10 cm^3 piZIP
    - NR discrimination to lower energies via improved energy resolution
  - < E_{gap}: small-format (1 cm^3) 0V detectors provide access to < eV_{nr} recoils, no ERs possible
- Environmental, coherent photon-nucleus scattering bgnds likely to become dominant problems



Cerdeno et al, https://doi.org/10.1007/JHEP05(2016)118



Essig et al, https://doi.org/10.1103/PhysRevD.97.095029