Progress Towards the

Direct Detection of Sub-GeV Dark Matter Using a Superfluid Helium-4 Target

Andreas Biekert
UC Berkeley
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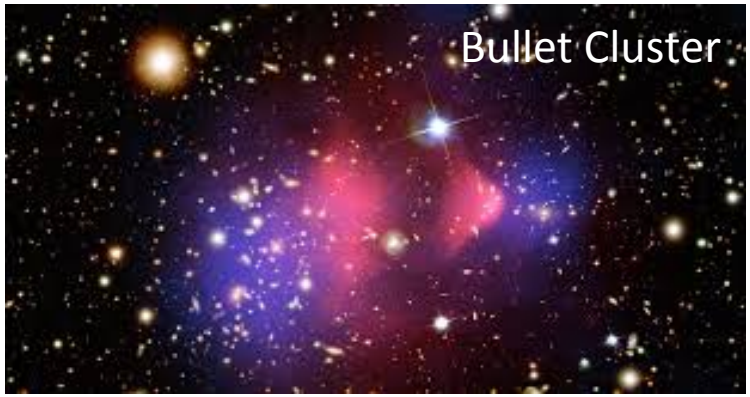
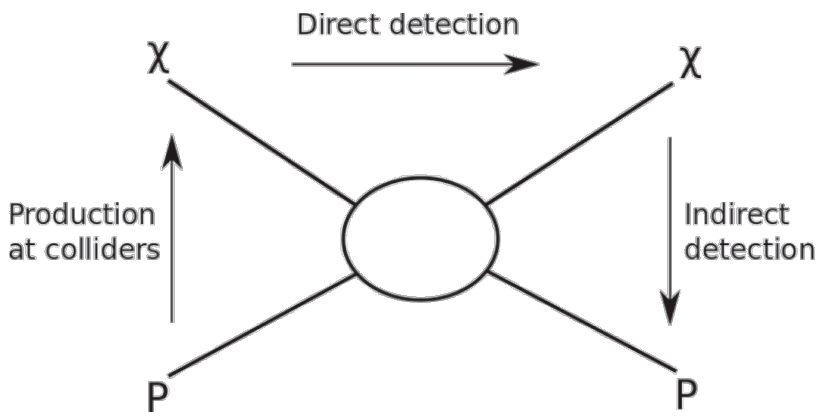
NorCal HEP-EX

With: Scott Hertel (UMass Amherst),
Daniel McKinsey, Junsong Lin, Vetri Velan,
Scott Kravitz

Dark Matter Direct Detection Approach

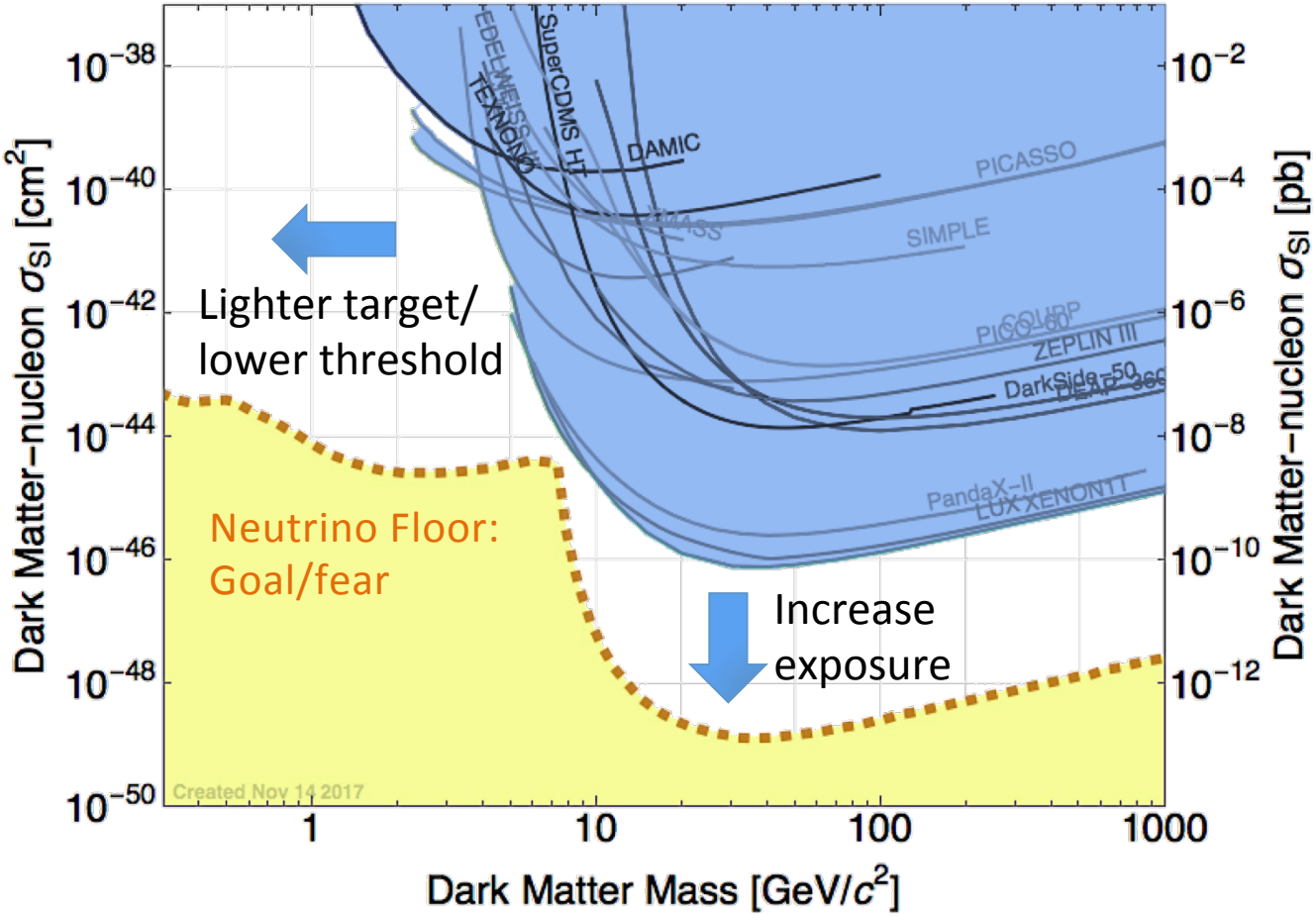




J. Phys. G43 (2016) no.1, 013001/arXiv: 1509.08767

- Many pieces of evidence for dark matter across many scales.
- One solution is weakly interacting massive particles (WIMPS).
- DM Particle scattering off target is **Direct Detection**.
- Detector design strategies include ways to distinguish electron recoils (ER) from nuclear recoils (NR).

Your Basic Dark Matter Plot



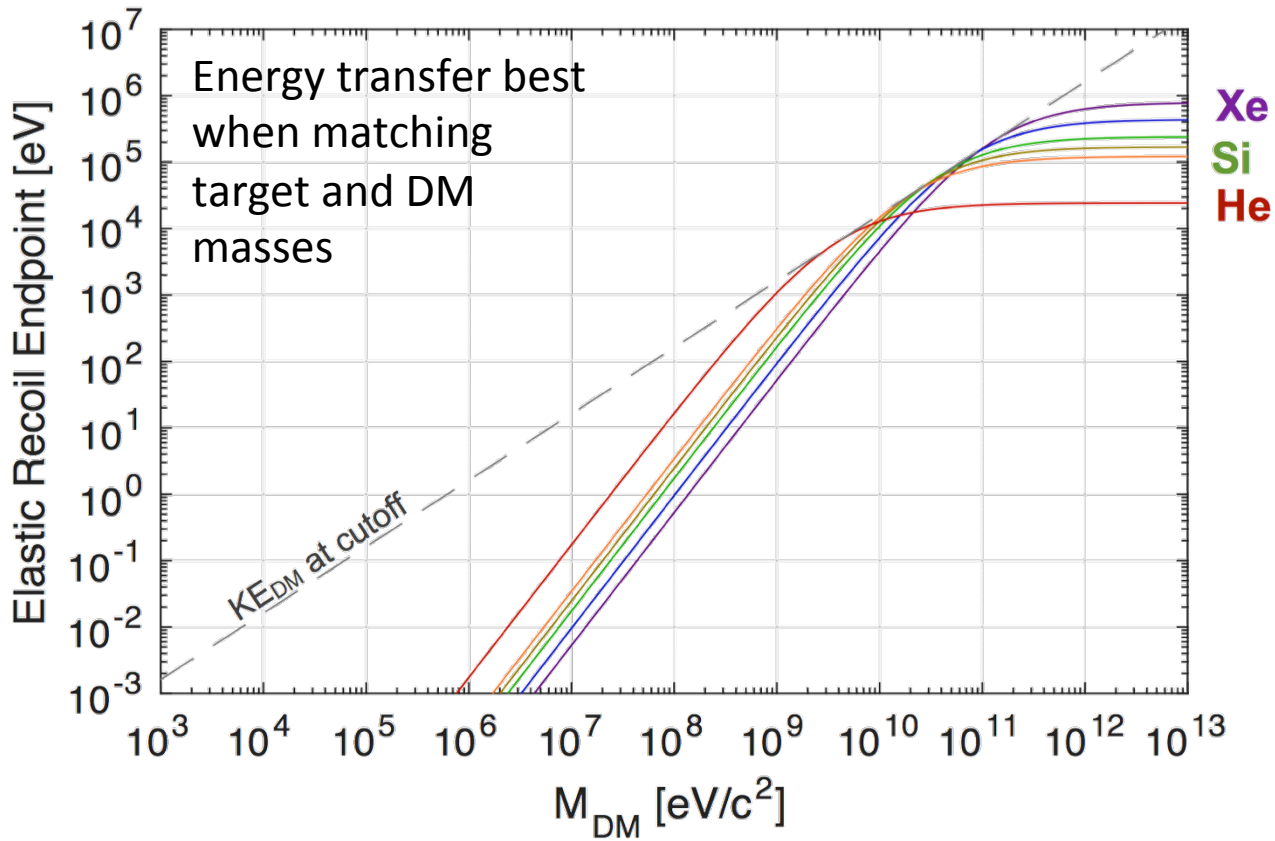
Light DM models more interesting (and common) as limits move down.

Helium Kinematics and Benefits

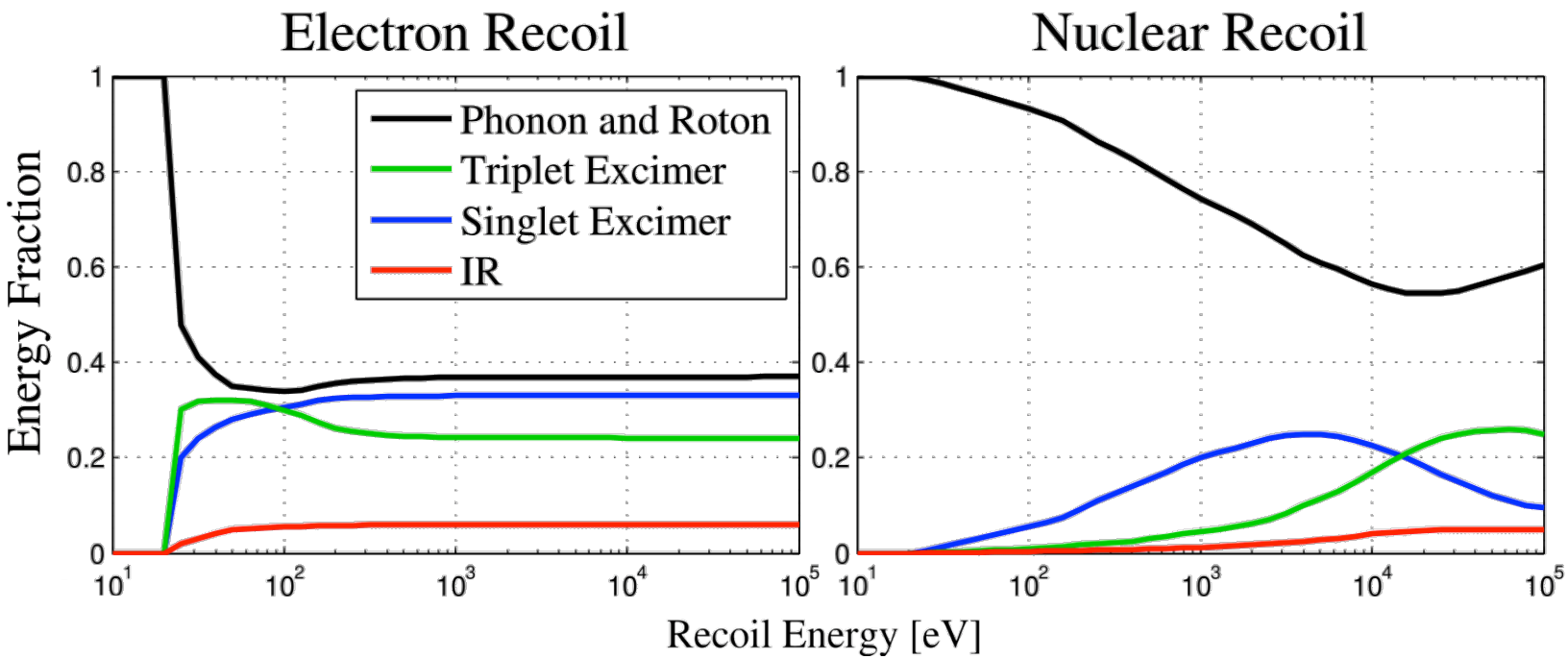
Helium is easy to:

- Buy
- Keep clean
- Scale up

Main benefit is that helium is very compatible with calorimetry (TESs)



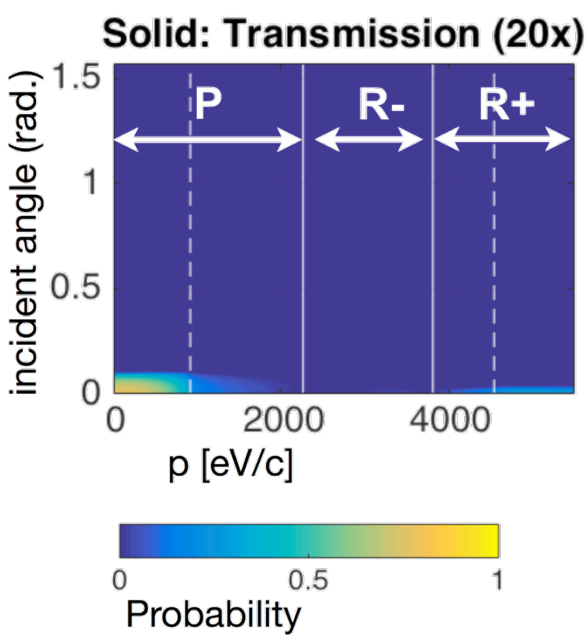
Superfluid Helium Excitations

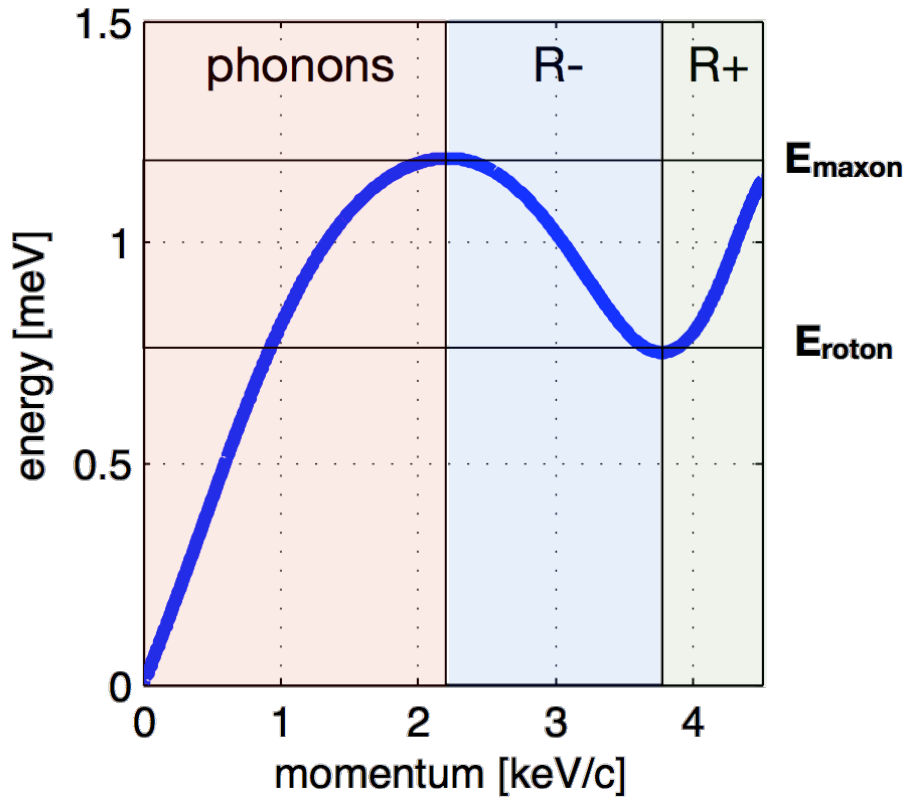


- Singlet molecules and IR detectable as scintillation.
- Triplet molecules detectable ballistically
- Phonons and rotons can be detected with bolometers, with some extra work.

Quasiparticles in Superfluid Helium

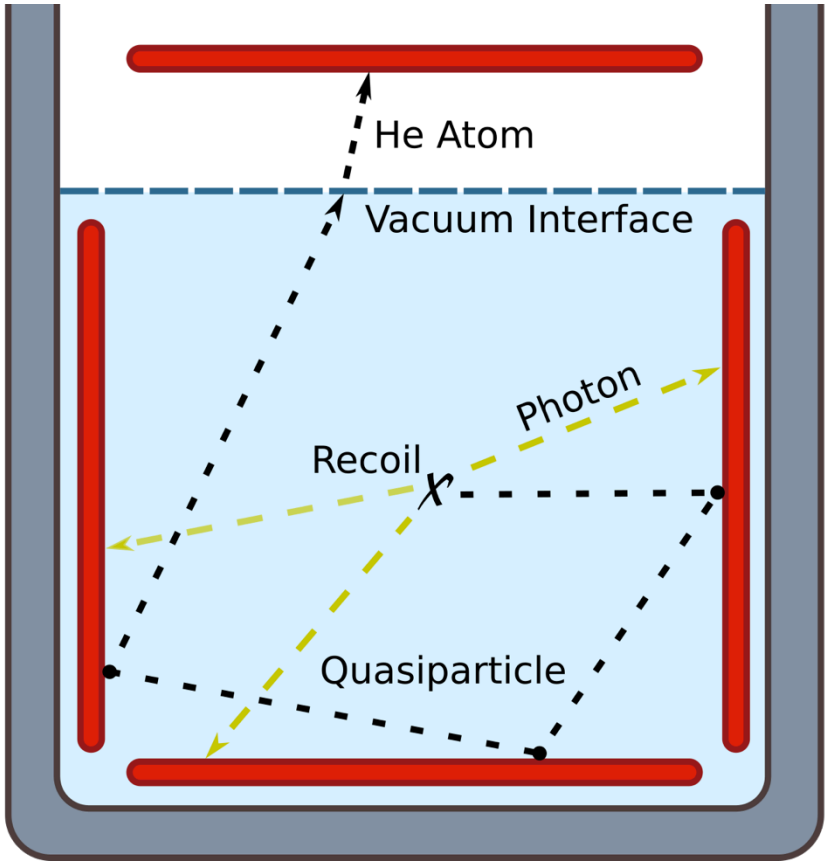
- meV scale vibrational modes in the superfluid.
- Superfluid is not a crystal lattice so dispersion is isotropic.
- Quasiparticles cross into solids very infrequently:



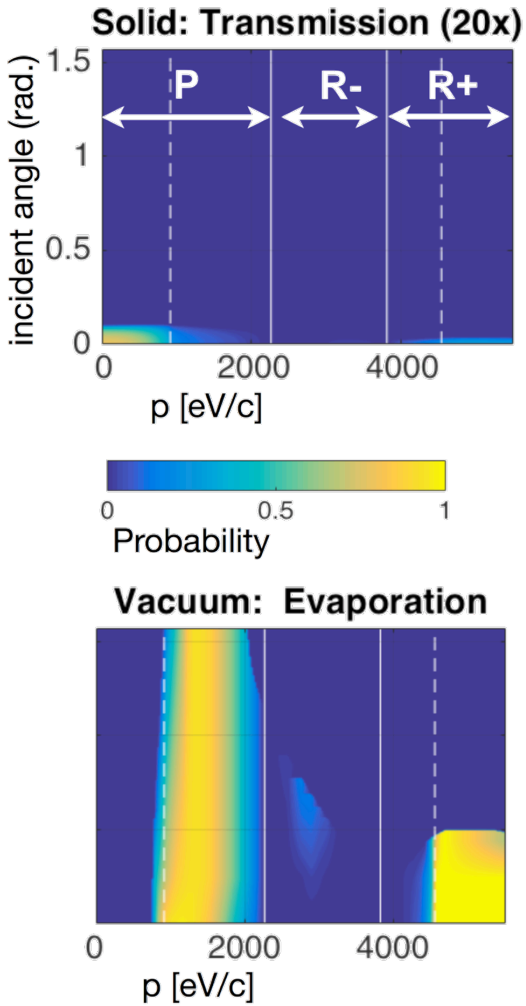


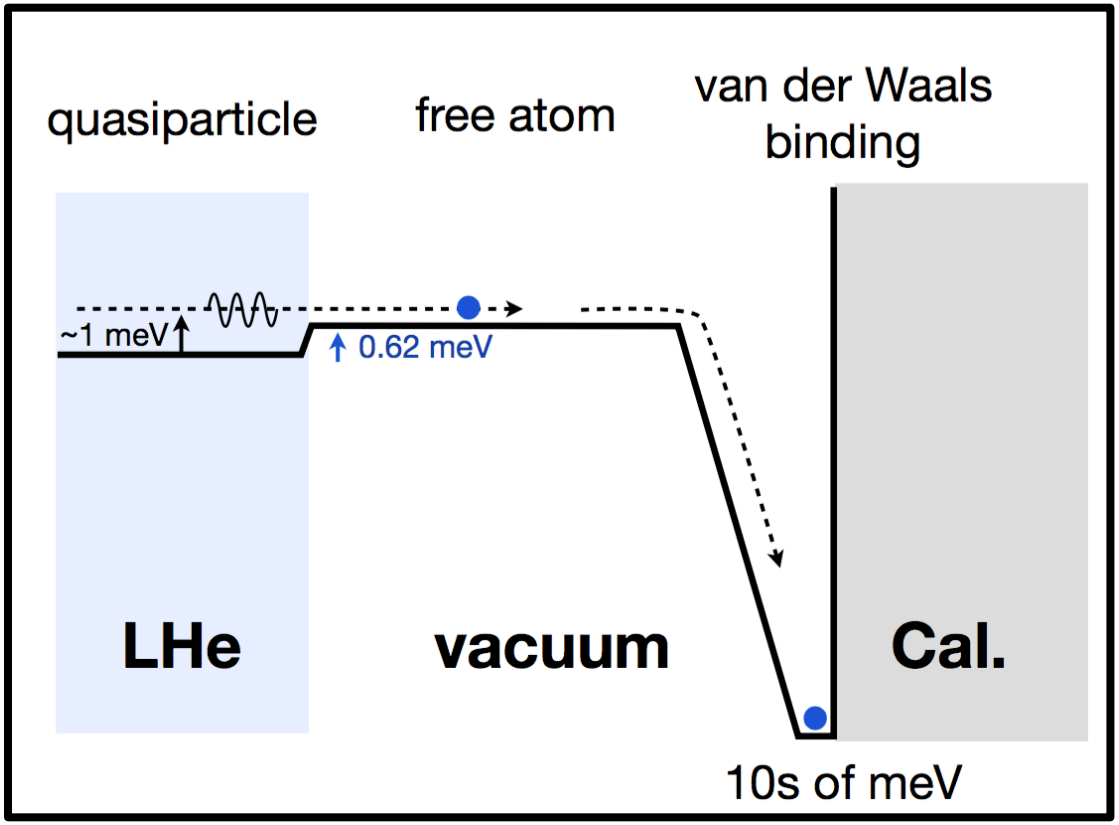
How the Detector Works

- Quasiparticles bounce around the detector walls.
  - Can eject helium atom from vacuum surface.
  - Helium atom read out through surface binding.
- Everything else read out directly.
  - Good coverage!



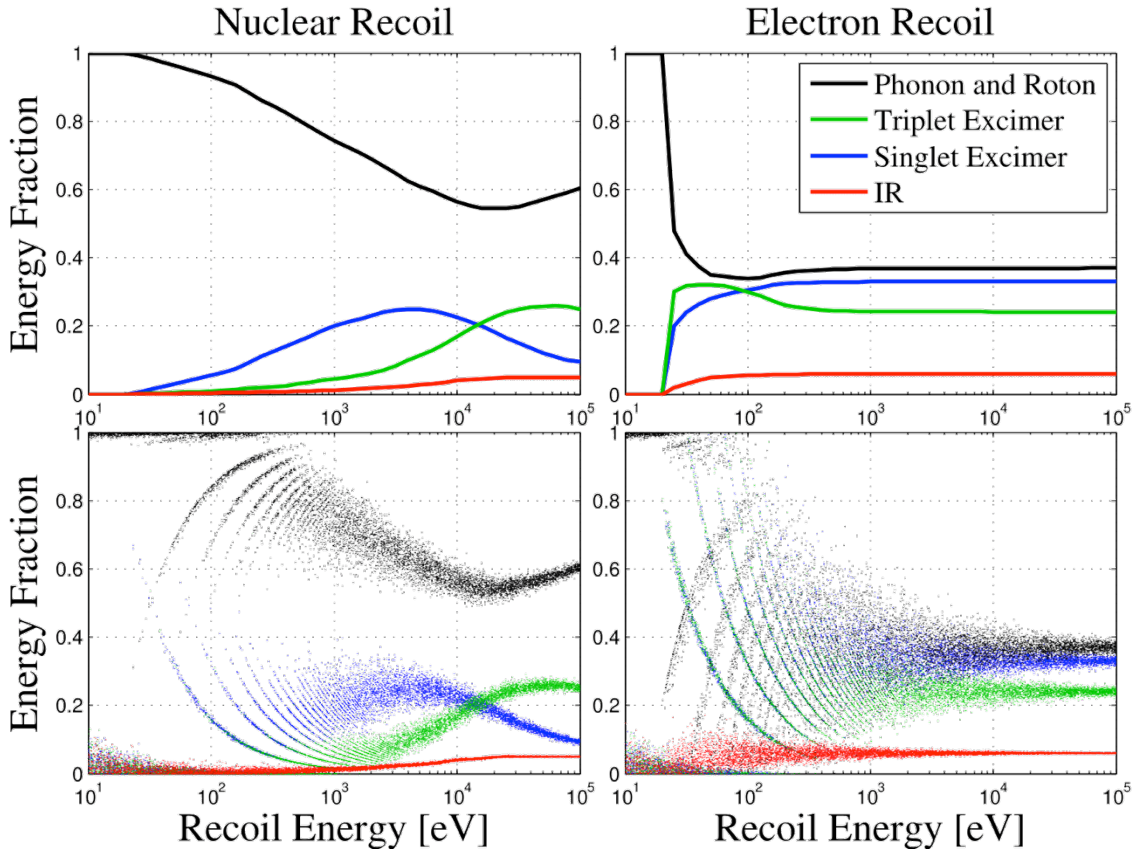
The Quantum Evaporation Process





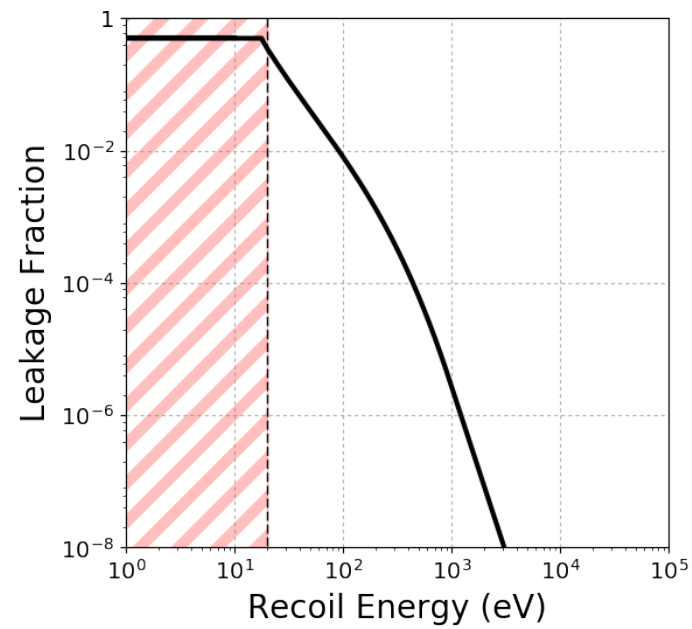
~10x signal energy enhancement!

Discriminating Between Recoil Types

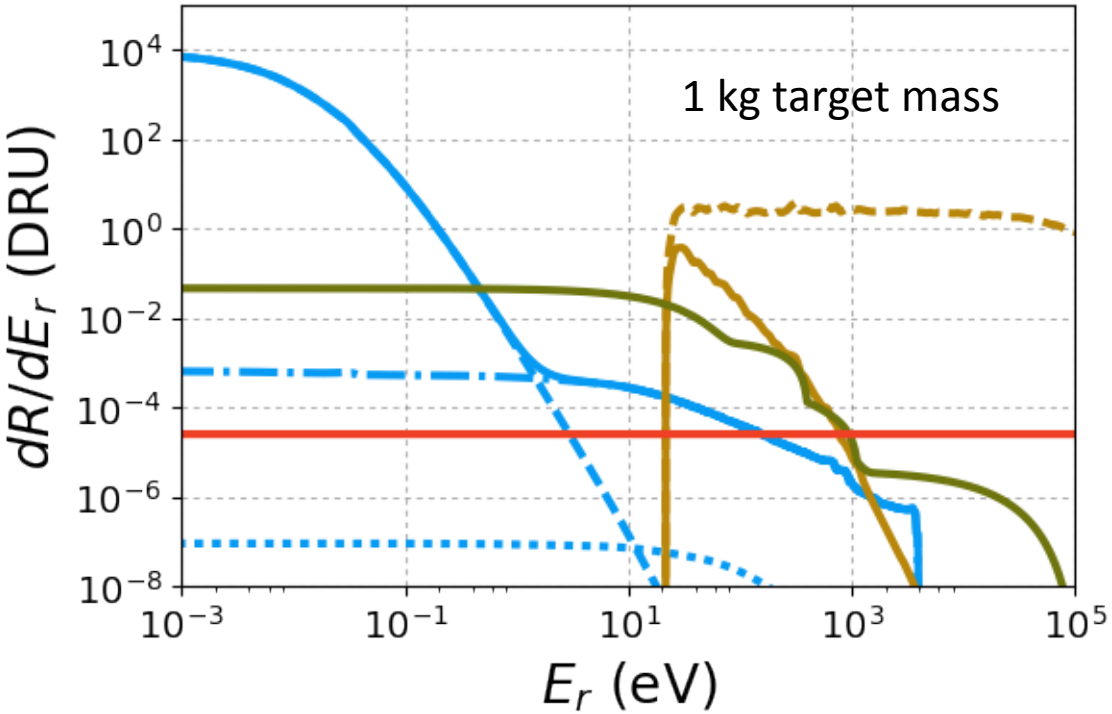


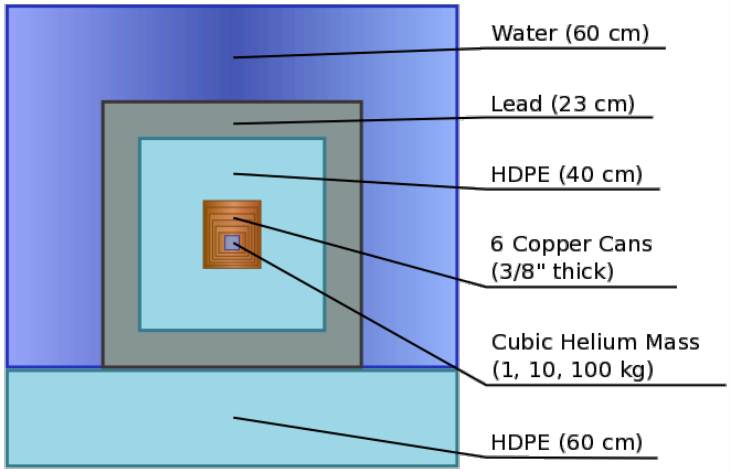
Lower panels include Poisson statistics assuming 0.95 detection efficiency for singlets & IR, 5/6 for triplets.

Leads to good discrimination power:



Background Estimates

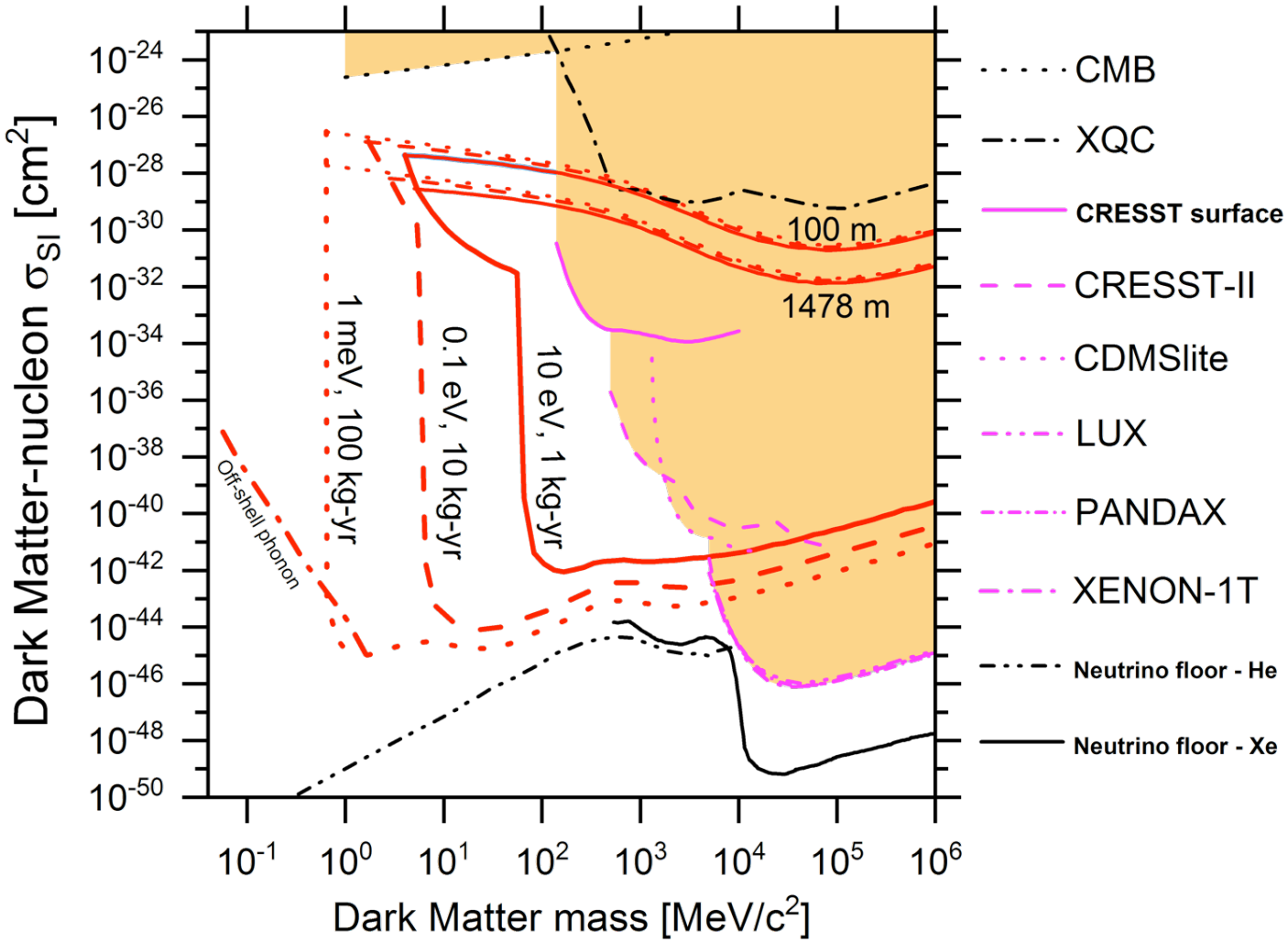




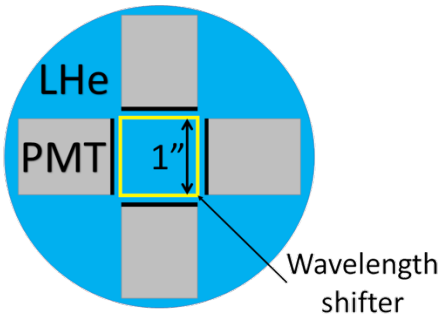
Shielding geometry and impurities from SuperCDMS SNOLAB: Phys. Rev. D 95, 082002 (2017)/arXiv: 1610.00006

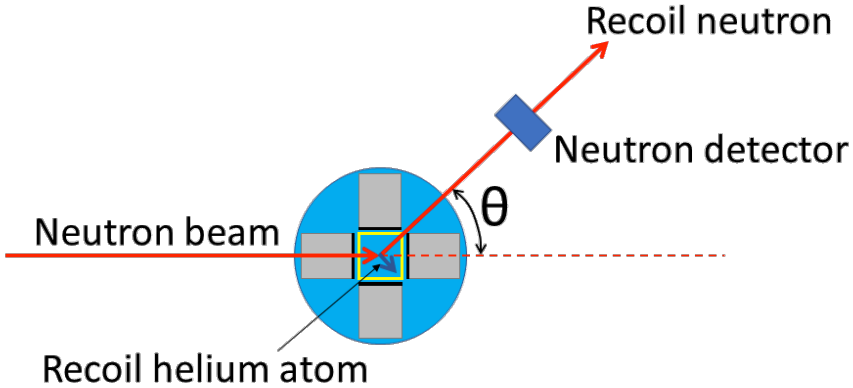
- Interesting features:
  - Compton scattering lower limit.
  - New gamma nuclear recoil backgrounds at low energies.

Our Projected Limits and Other Goodies

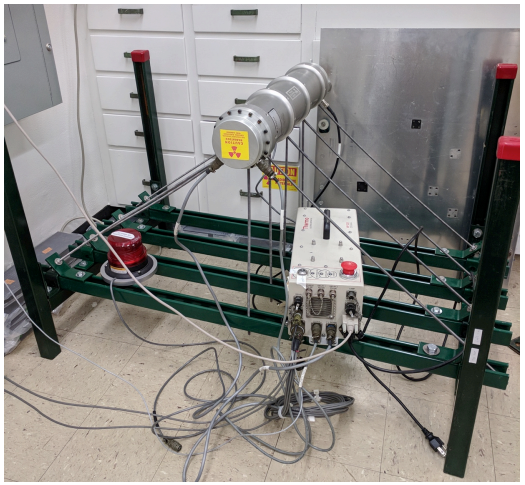


Neutron Scattering on Superfluid Helium





DD neutron generator up and running:



- Measure scintillation light yield from low energy nuclear recoils.
- Goal is 2 keV nuclear recoil energy.
- Cryostat gas handling in progress.

Neutron Scattering on ~~Superfluid~~ Gaseous Helium

arktis
RADIATION DETECTORS

- Run same experiment on commercial neutron detector.
  - High pressure helium-4 gas.
- Test scintillation response to low energy nuclear recoils.

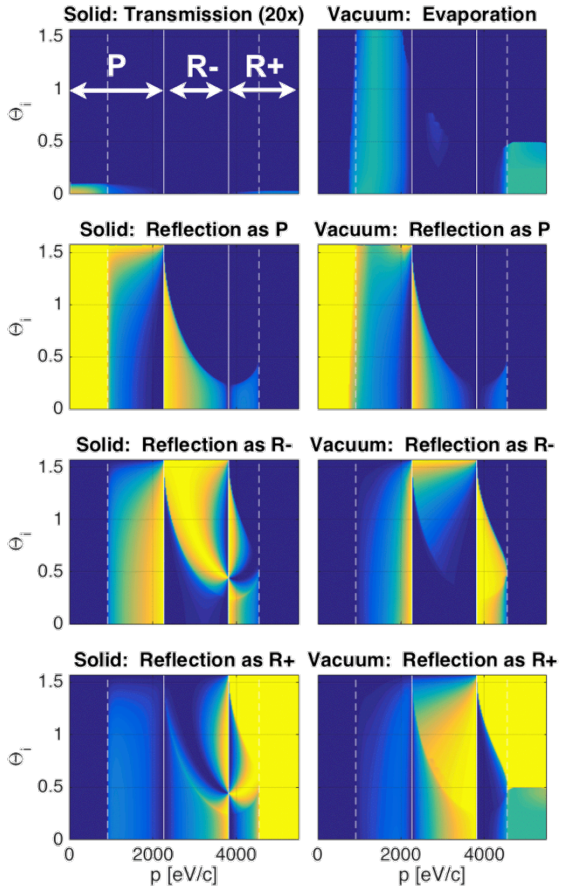
We’re also working on naming the DM search experiment!

Summary

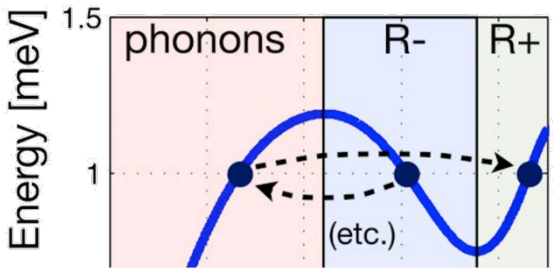
- Preliminary studies on limits for a dark matter search using superfluid helium are very promising.
- Current technology already makes large new areas of parameter space accessible.
- Future generations aided by current R&D in TES technology.
- Lots of experimental investigation into helium detector properties on UC Berkeley campus

Backup Slides

Quasiparticle Reflections



Schematically:

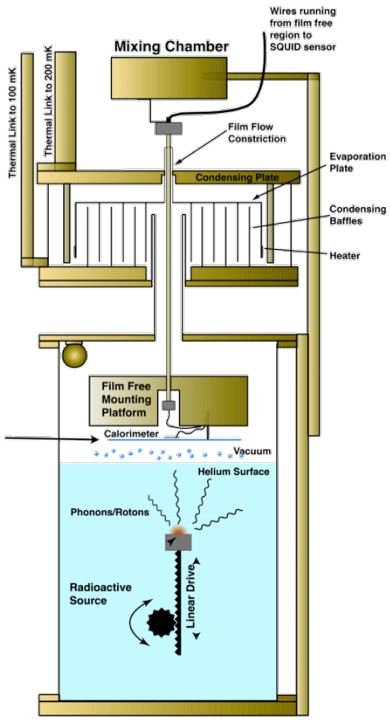


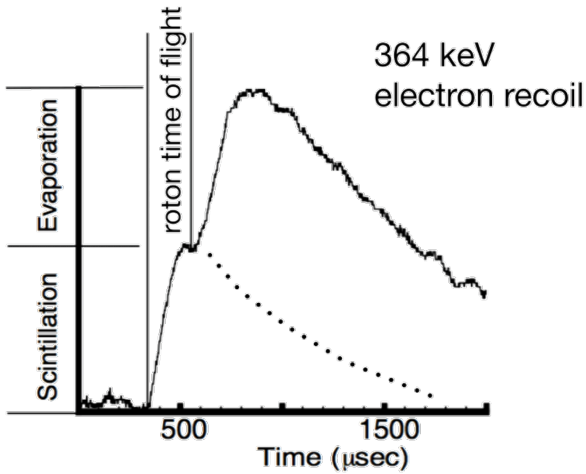
HERON Neutrino Detector

He film burner

wafer calorimeter
single TES channel

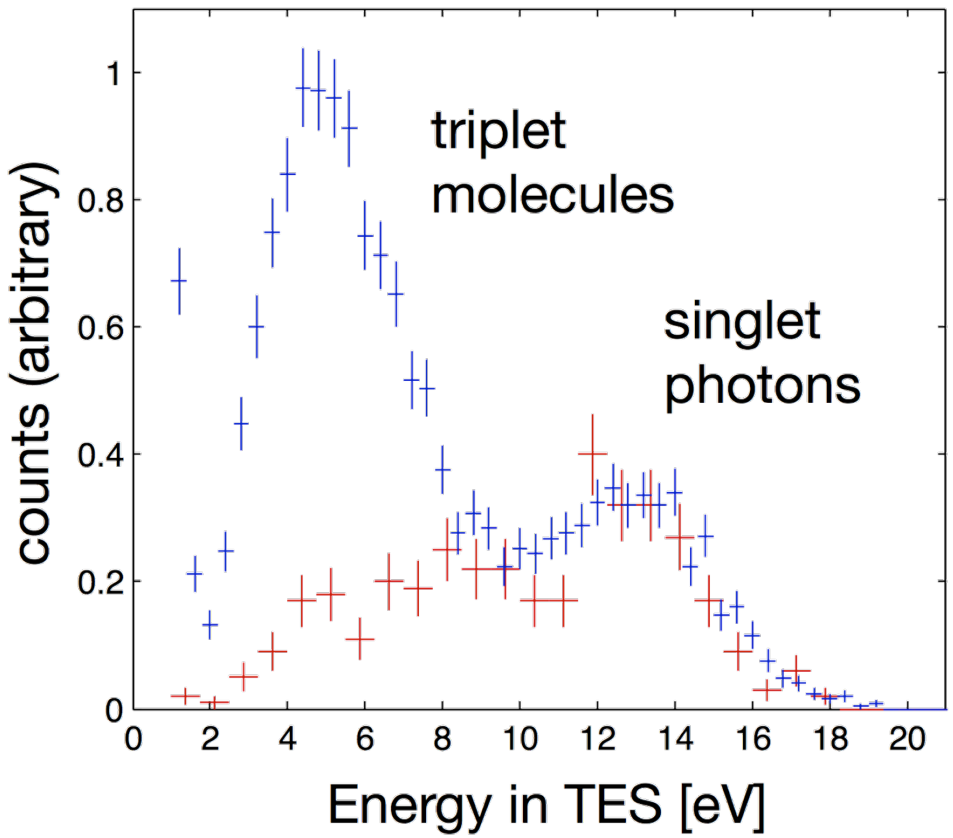
kg-scale
LHe mass





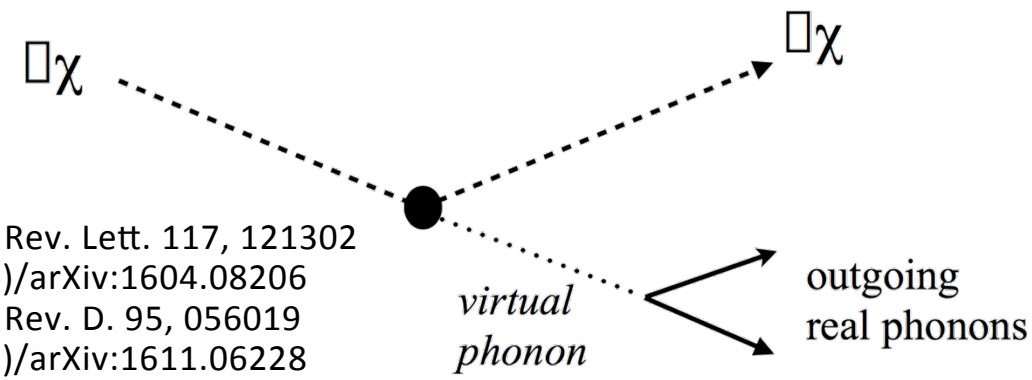
Phys. Rev. Lett. 58, 2498 (1987)
Phys. Rev. Lett. 68, 2429 (1992)
Rev. Sci. Instrum. 63, 230 (1992)
Phys. Rev. Lett. 74, 3169 (1995)

Triplet Excitation Detection



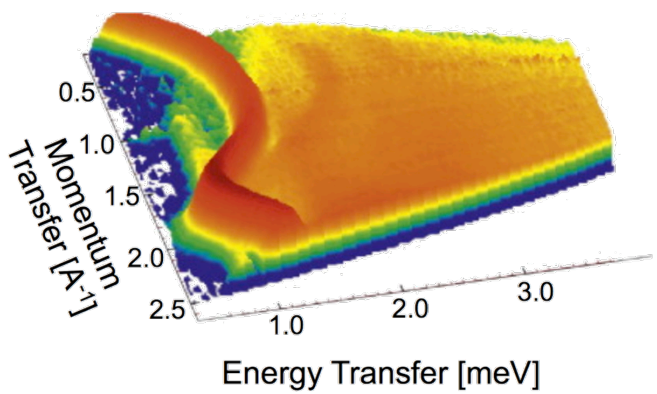
J. Low Temp. Phys. 186(3) 183-196 (2017)/arXiv:1605.00694

Higher Order Excitations



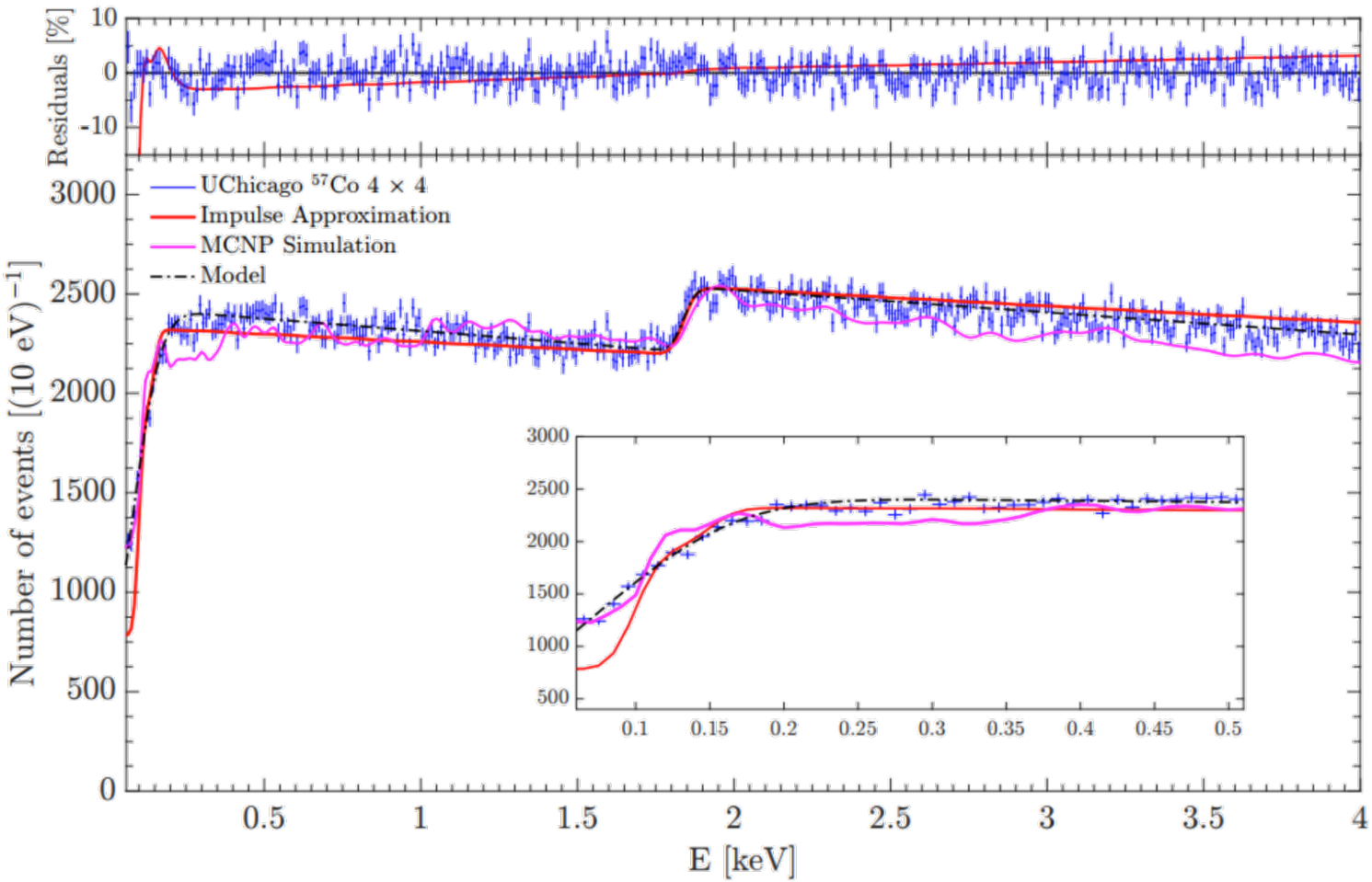
Phys. Rev. Lett. 117, 121302 (2016)/arXiv:1604.08206
Phys. Rev. D. 95, 056019 (2017)/arXiv:1611.06228

- Virtual phonons not limited to dispersion relation.
- Experimentally observed in neutron scattering (below).



Nucl. Instr. Meth. Phys. Res. A 611, 259-262 (2009)/arXiv:0811.4332

Low Energy Compton Scatters



Phys. Rev. D 96, 042002 (2017)/arXiv:1706.06053