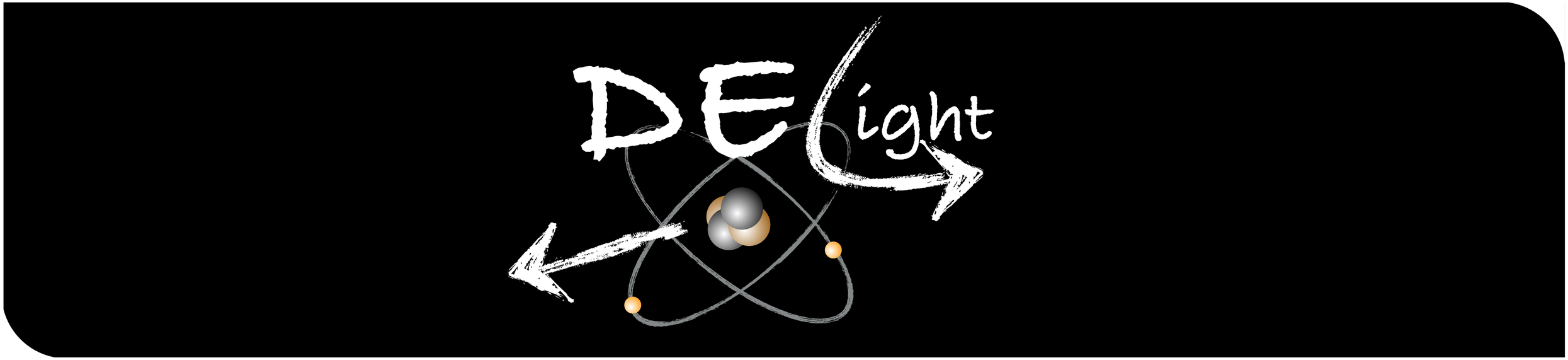
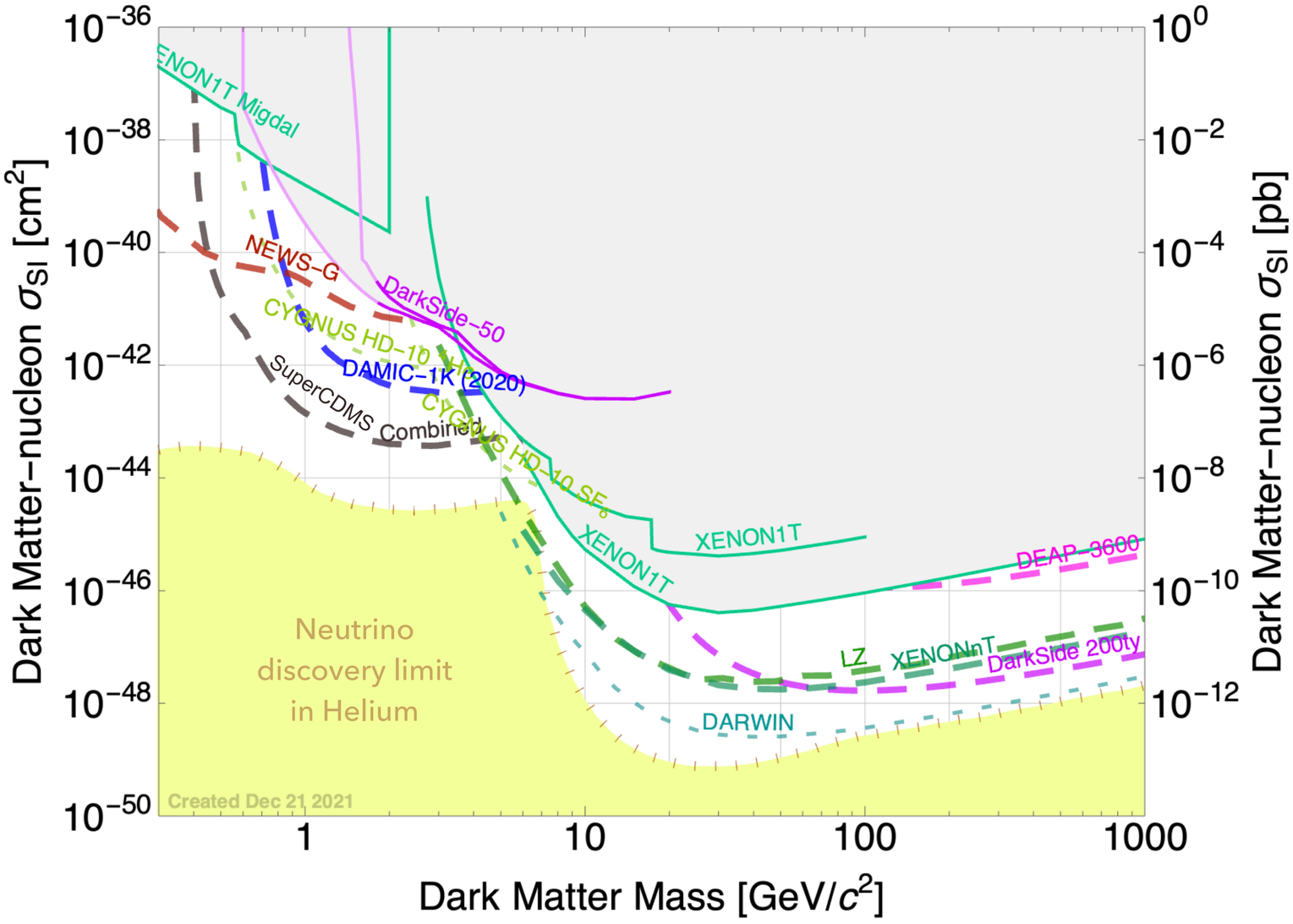
DELight: a Direct search Experiment for Light dark matter with superfluid helium

IDM 2022, Vienna, 18.05.2022

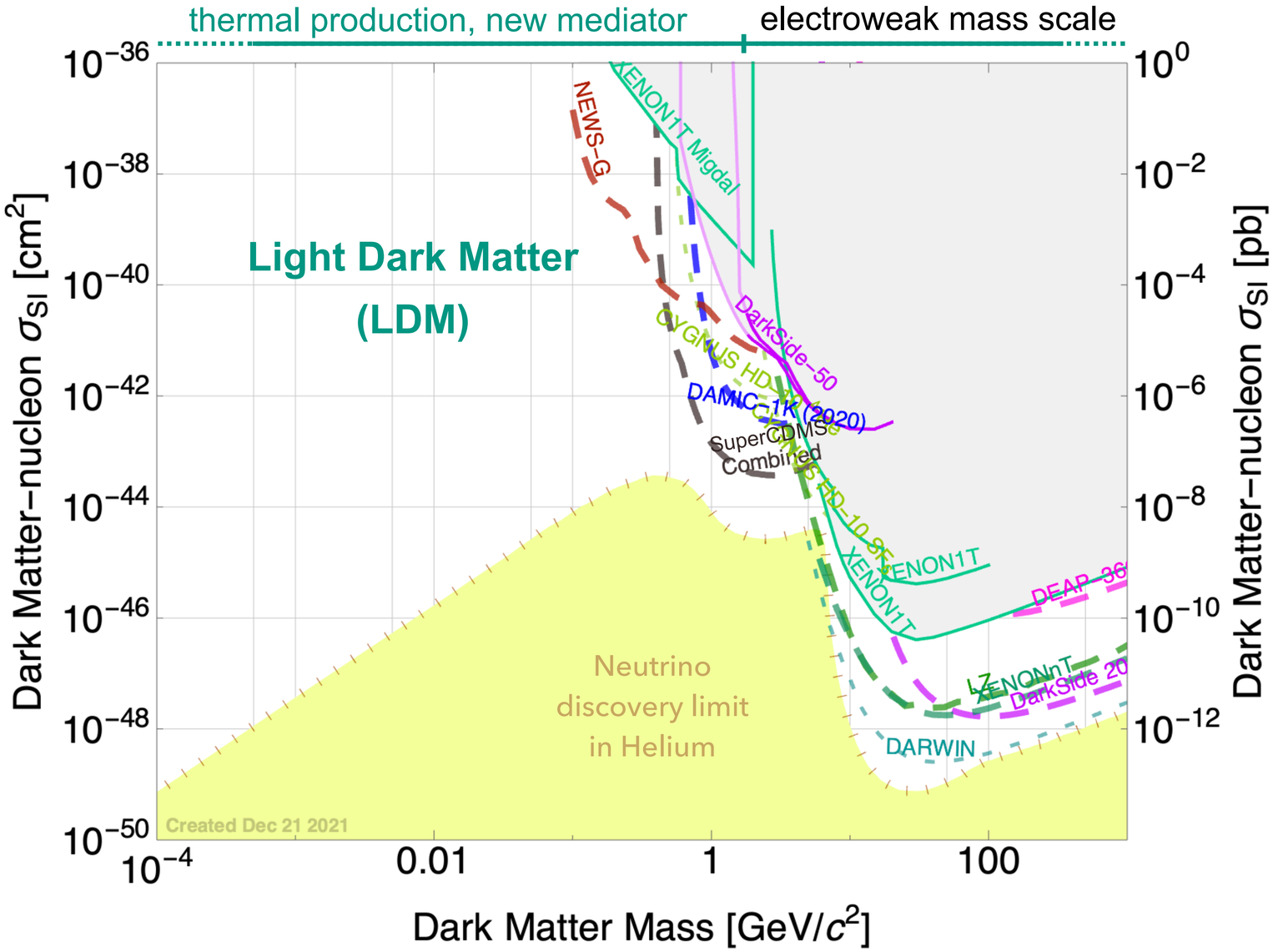
Belina von Krosigk, K. Eitel, C. Enss, T. Ferber, L. Gastaldo, F. Kahlhoefer, S. Kempf, M. Klute, S. Lindemann, M. Schumann, K. Valerius



Current direct WIMP search landscape

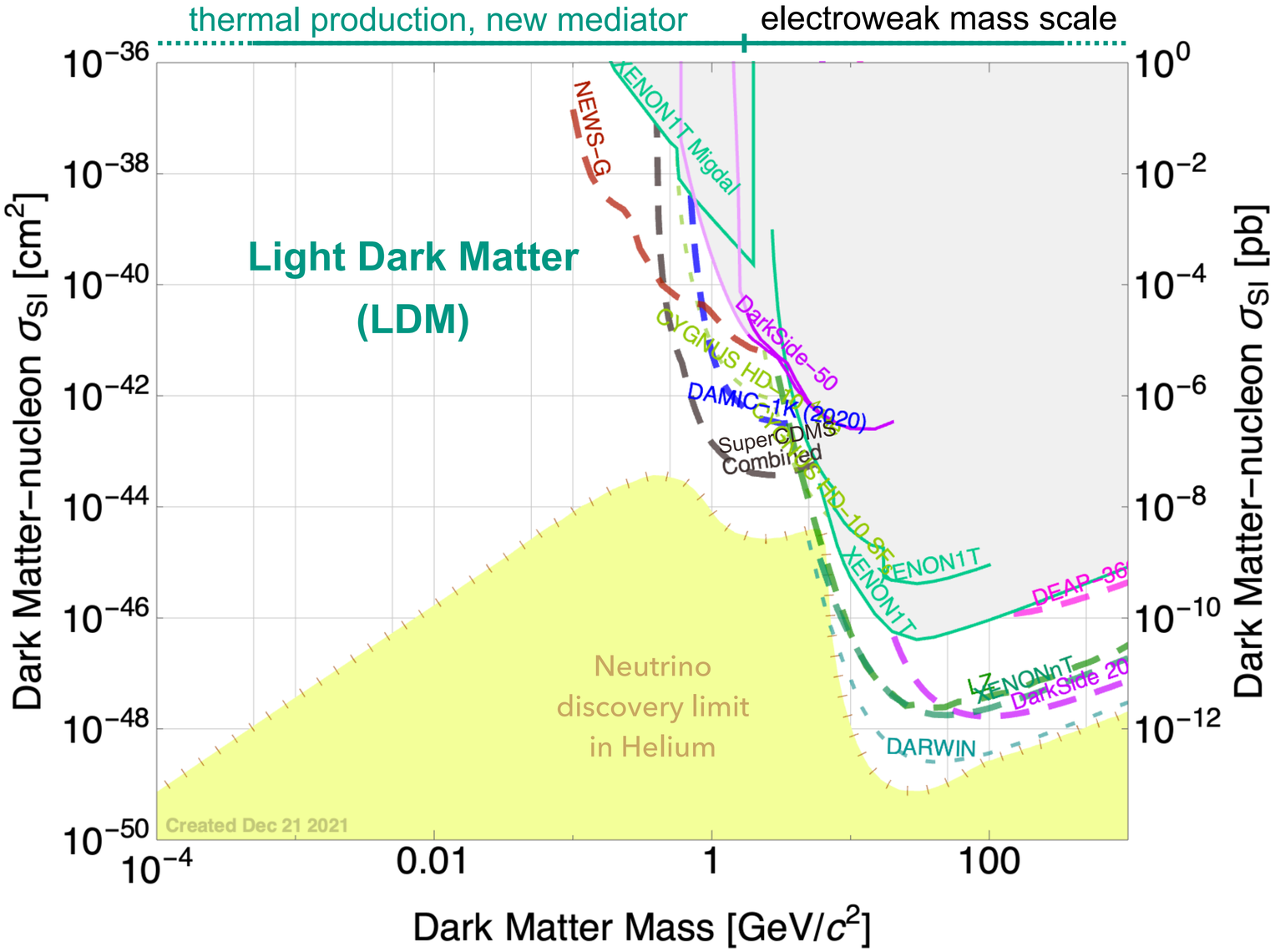


Light Dark Matter

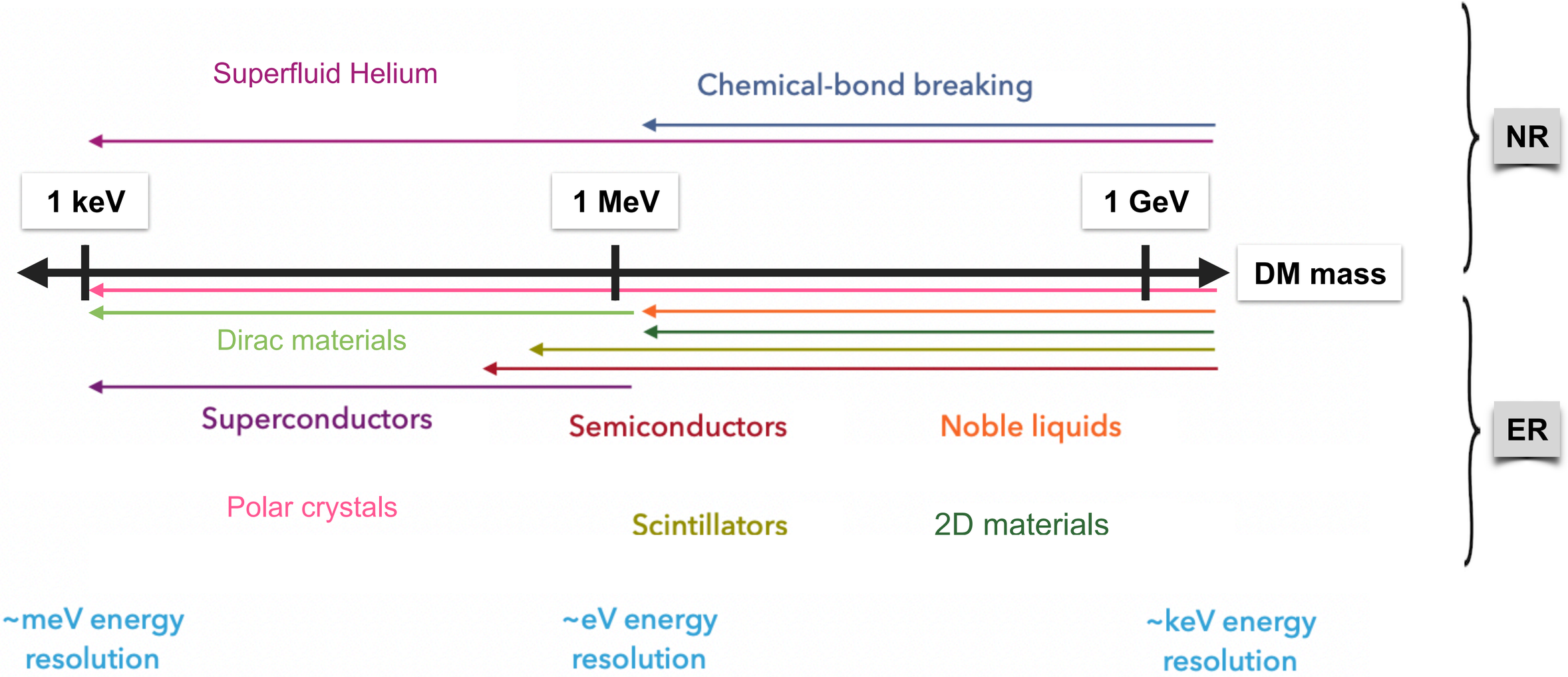


Probing Light Dark Matter

- Two approaches:
  - Alternate interaction channels in existing and upcoming experiments optimized for WIMP-nucleon scattering.
  - Alternate target materials in new experiments.

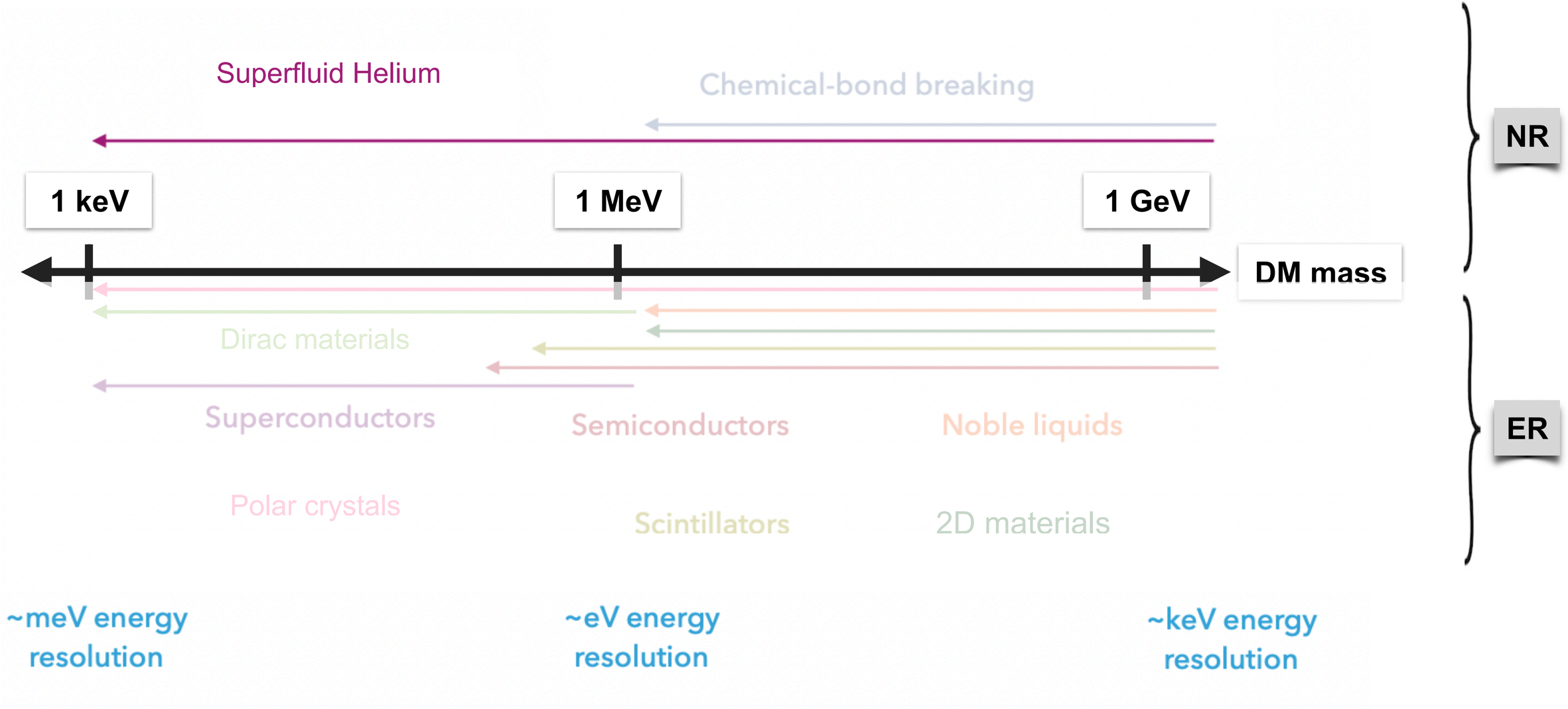


New avenues for Light DM direct detection



Dark Sectors 2016 Workshop: Community Report
arXiv:1608.08632 [hep-ph], (2016)

New avenues for Light DM direct detection



Dark Sectors 2016 Workshop: Community Report
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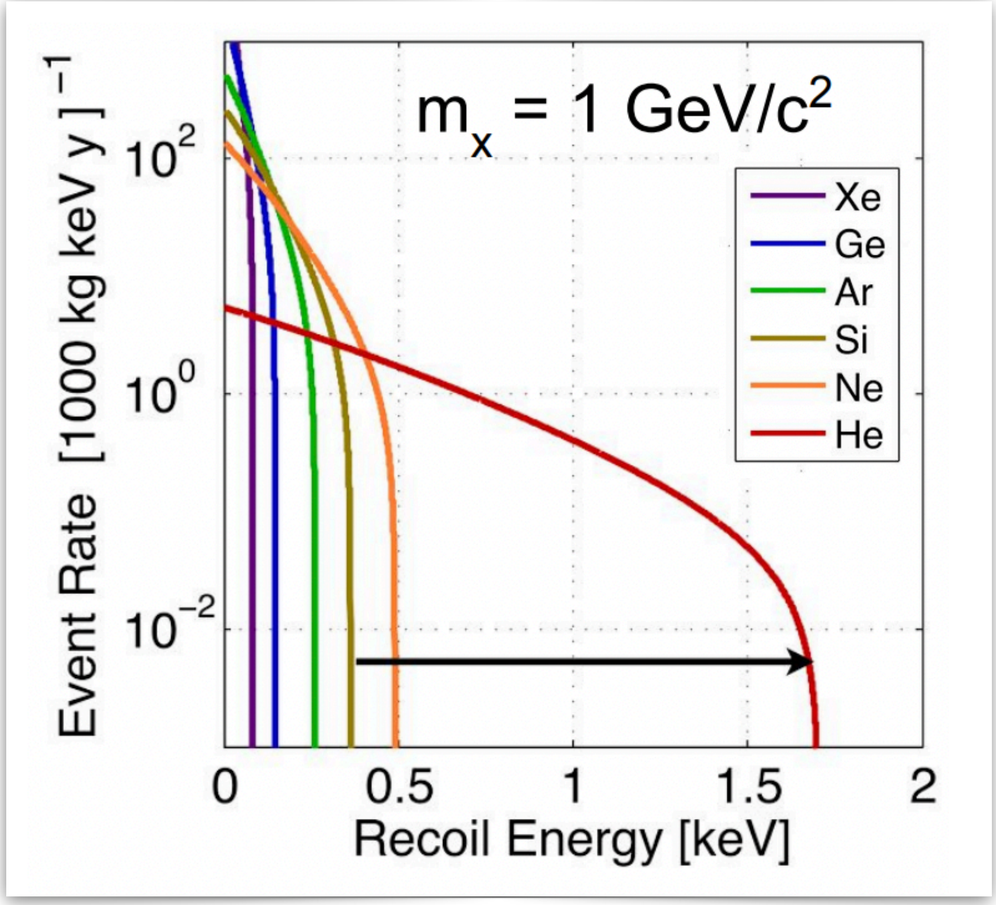
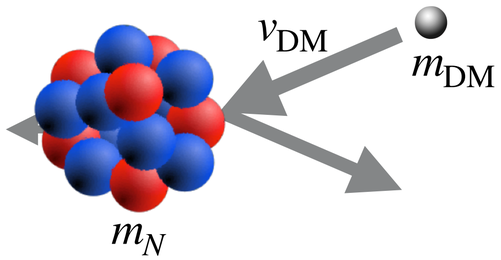
Why superfluid helium?

- Very light
- Cheap
- Ultra-pure (no internal background)
- Multiple signals (phonon & rotons, photons, excimers)
  - NR / ER discrimination
- Fiducialization possible
- Scalable
- Overall concept demonstrated





$$\Delta E = \frac{1}{2}\frac{\Delta p^2}{m_N} \lesssim \frac{2\, m_{DM}^2 v_{DM}^2}{m_N}$$

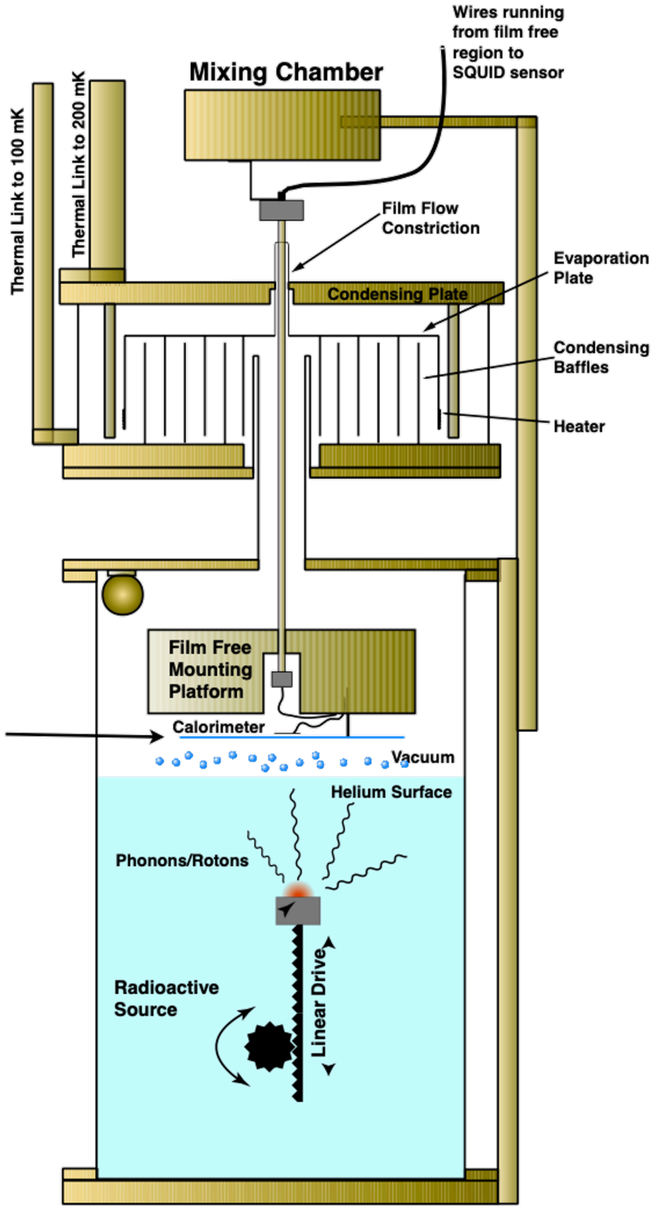
S. Bandler et al. PRL 78, 2429 (1992)
C. Enss et al. Physica B 194-196, 515 (1994)
S. Bandler et al. PRL 74, 3169 (1995)
D.N. McKinsey et al. PRA 59, 200 (1999)
W. Guo et al. PRL 102, 235301 (2009)
F.W. Carter et al. JLTP 186, 183 (2017)

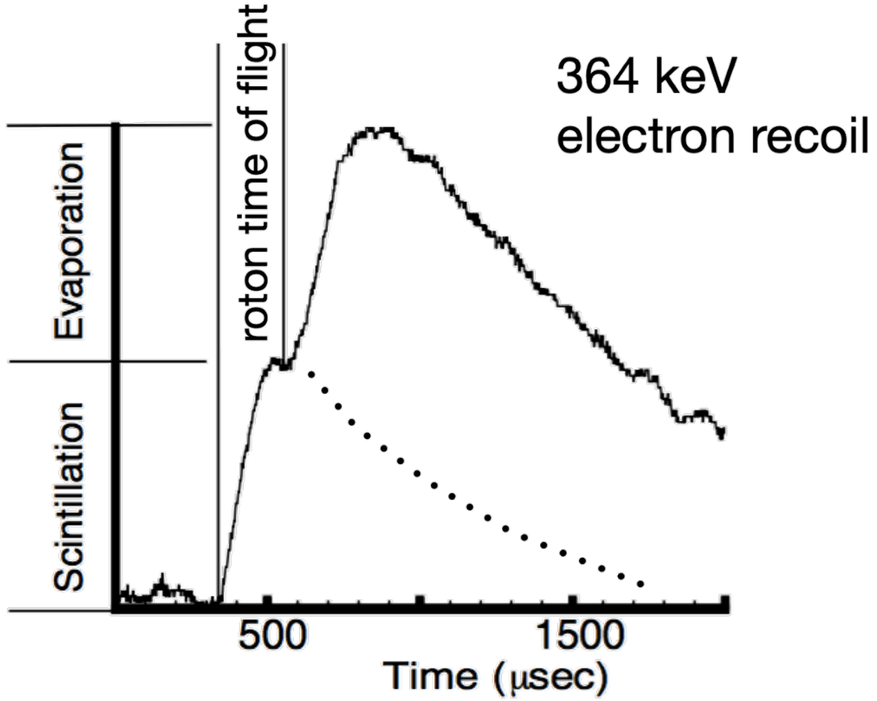
HERON: HElium-ROton detection of Neutrinos

He film burner

wafer calorimeter

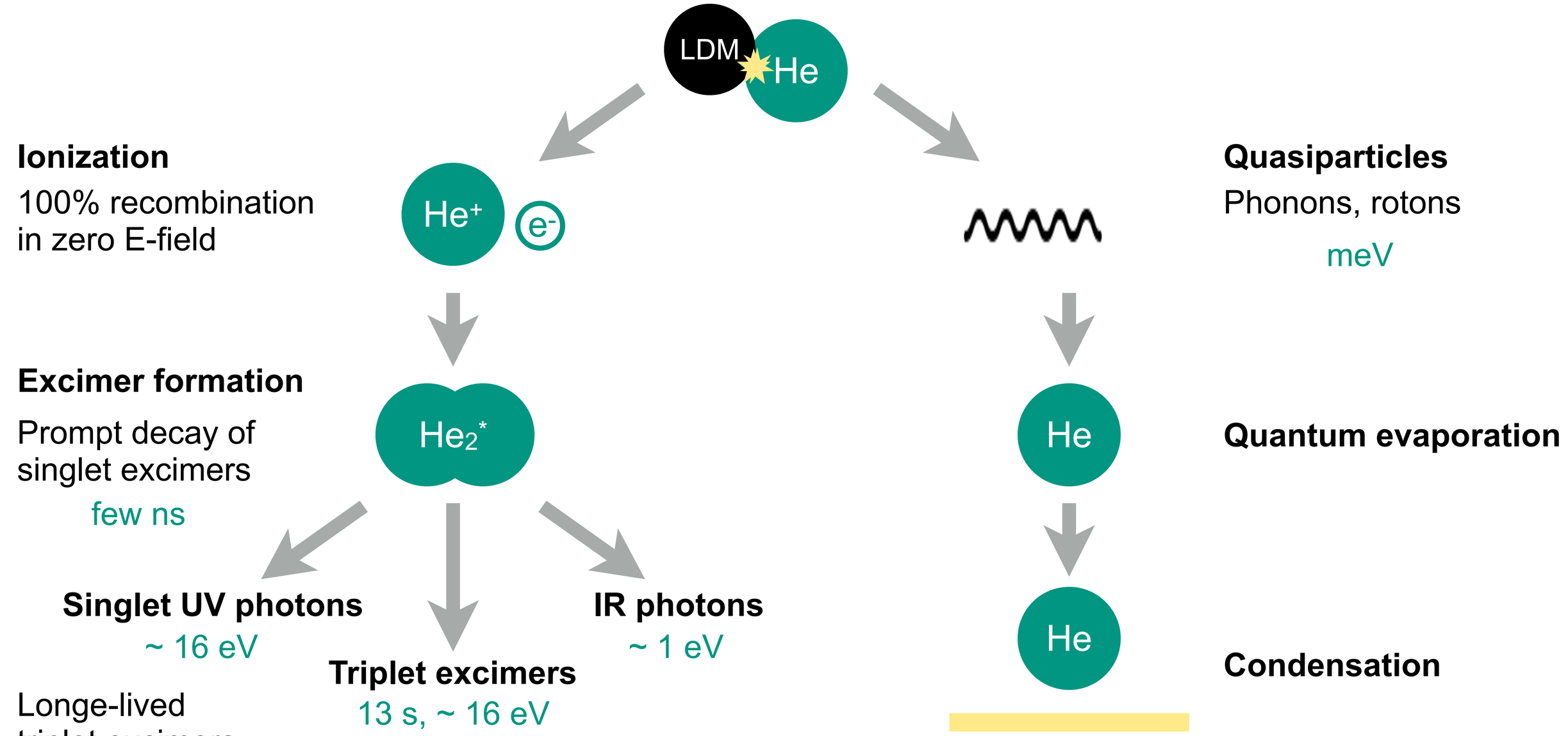
kg-scale
LHe mass



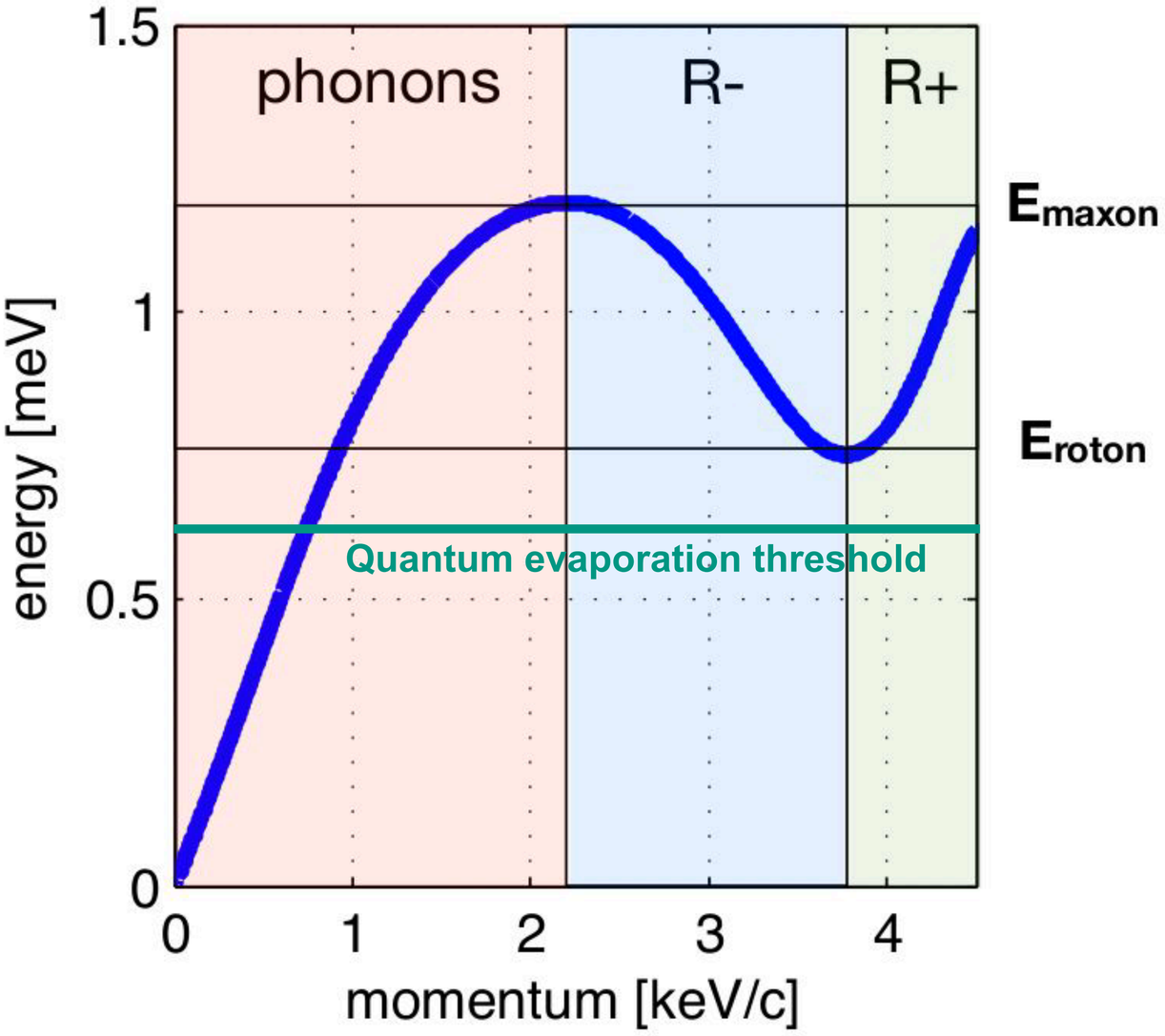


C. Enss et al., Physica B 194-196, 515 (1994)
S. Bandler et al., PRL 74, 3169 (1995)
J. S. Adams et al. Phys. Let. B 341, 431-434 (1995)

Multiple signals in superfluid ^{4}He

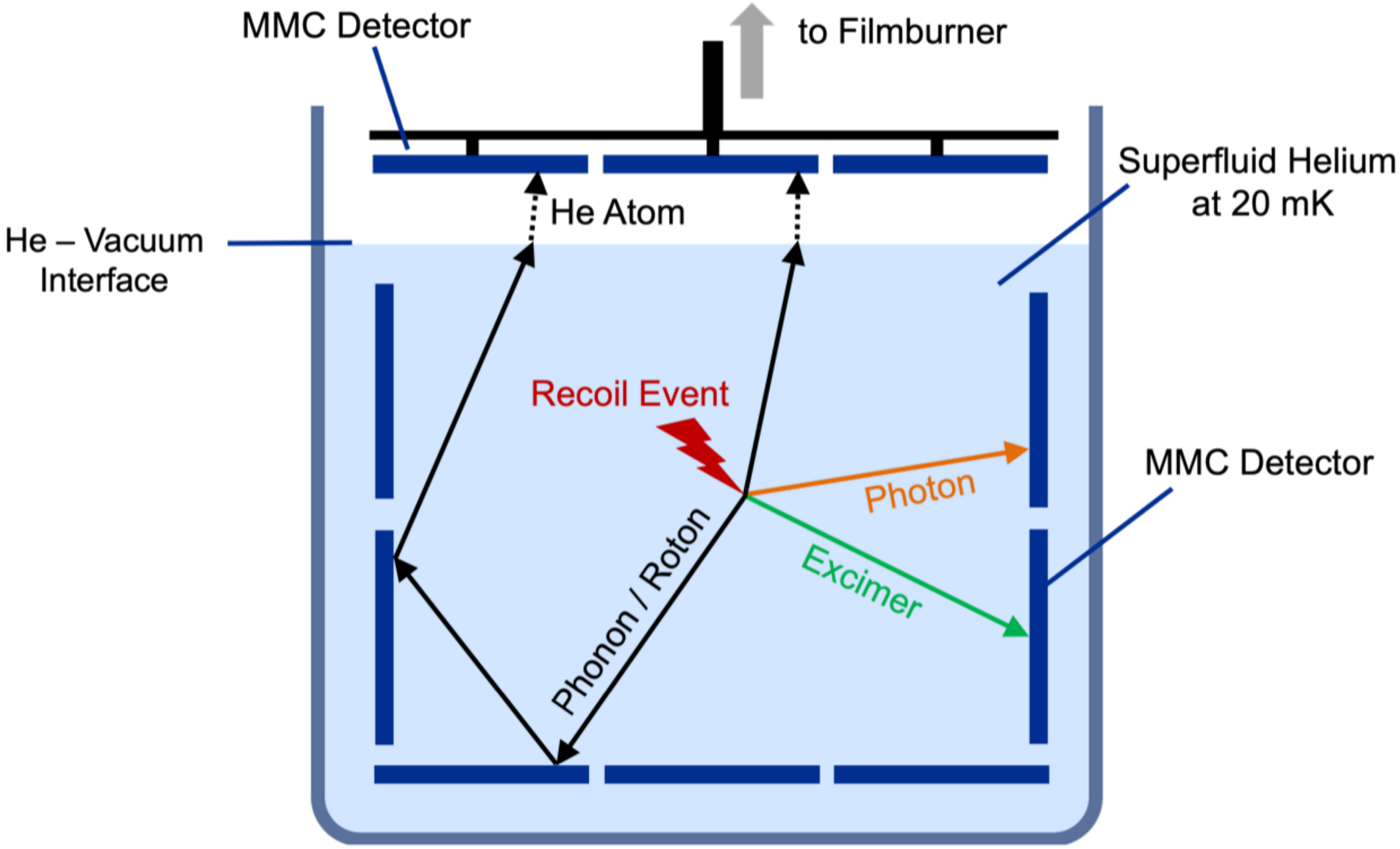


Quasiparticles in ^{4}He: phonons and rotons



- Collective long-lived excitations in superfluid He
- Classified based on momentum
  - Phonons, R- rotons, R+ rotons
  - Roton ≈ high-momentum phonon

The DELight concept

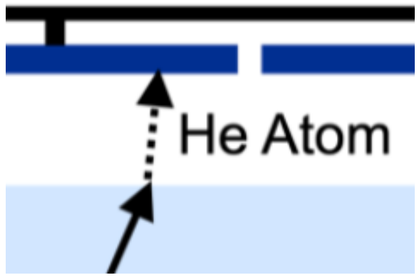


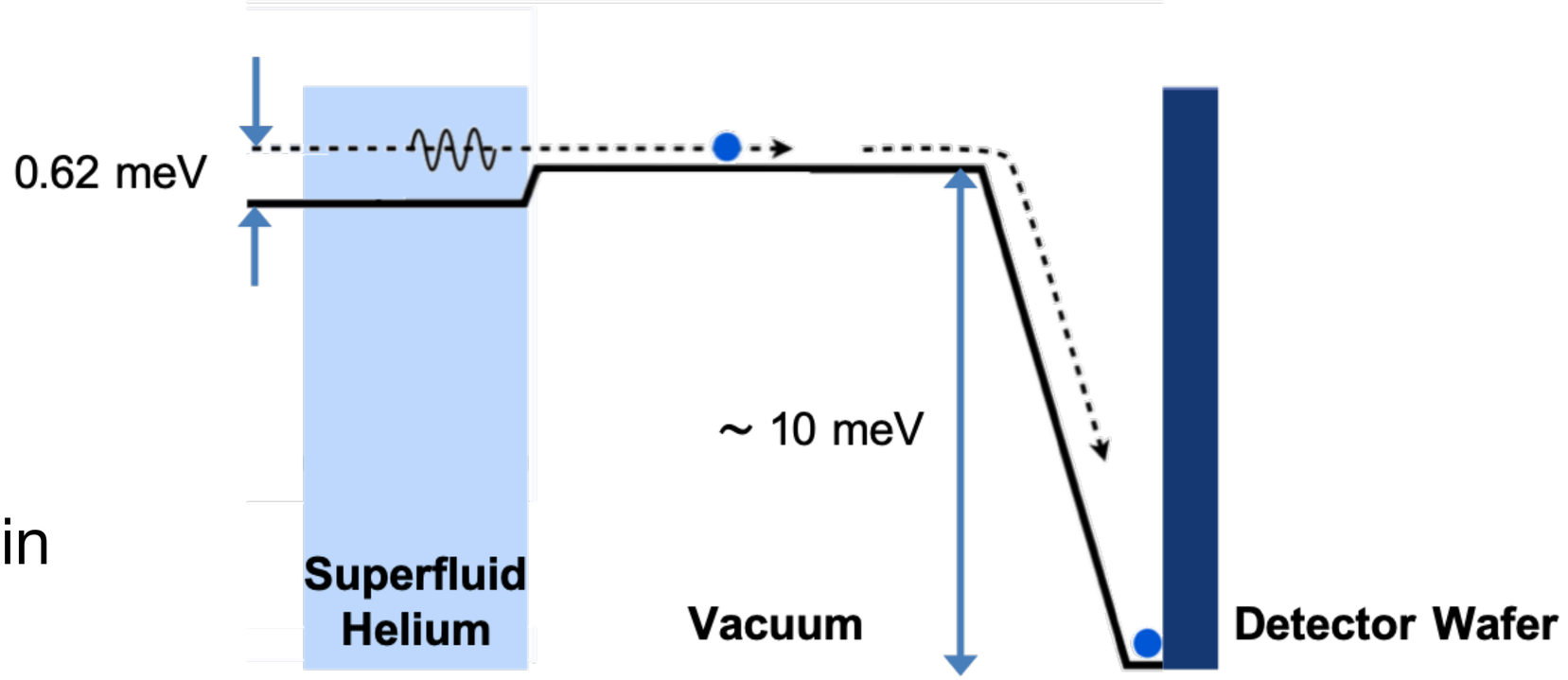
The DELight concept

Phonon / Roton → Free He atom → He atom on solid

Quantum evaporation

Condensation

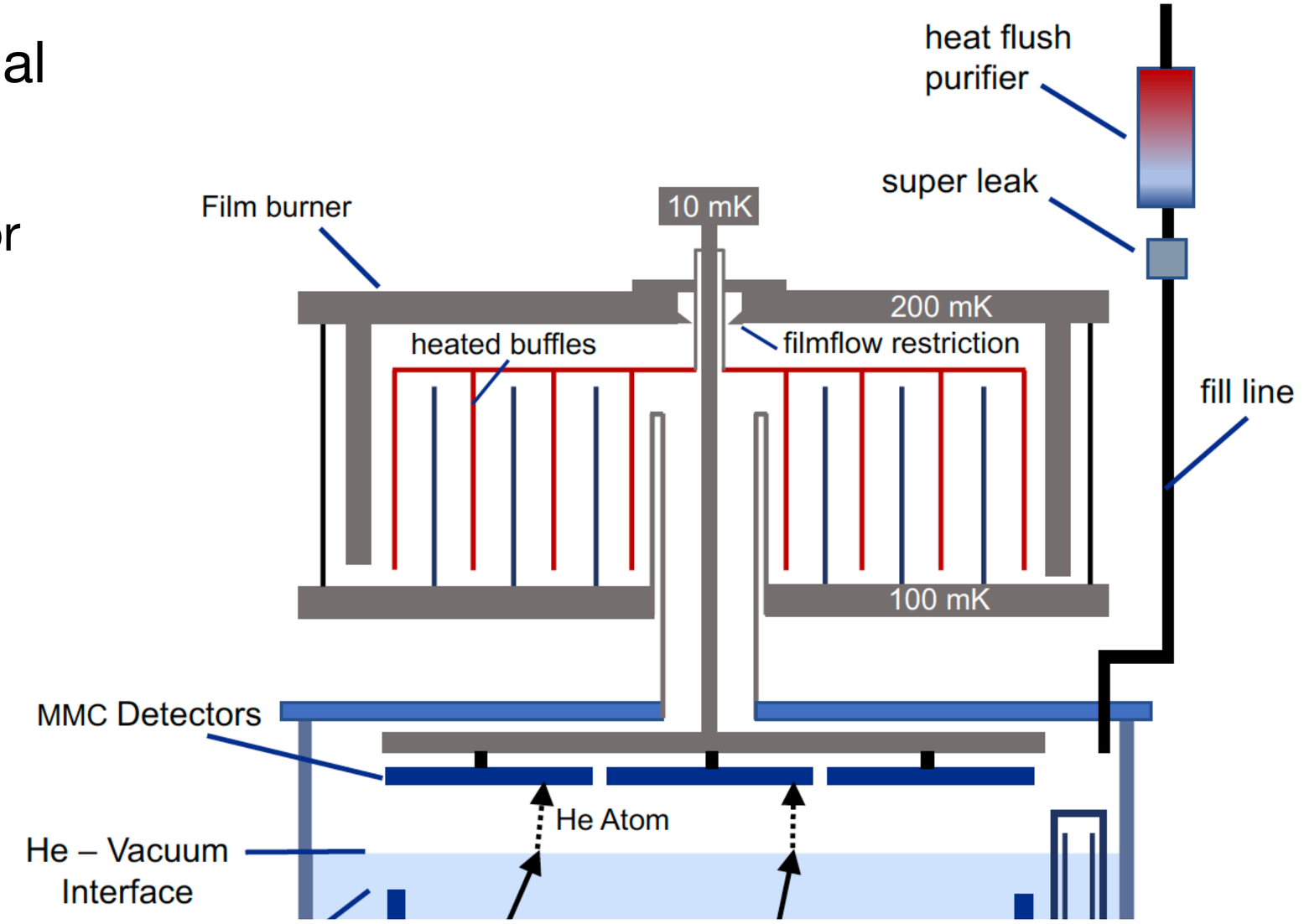




- Noise-free signal gain by a factor 10 to 40

The DELight concept

- Film burner to keep external MMC wafers He free
  - Maintain amplification factor



The DELight concept

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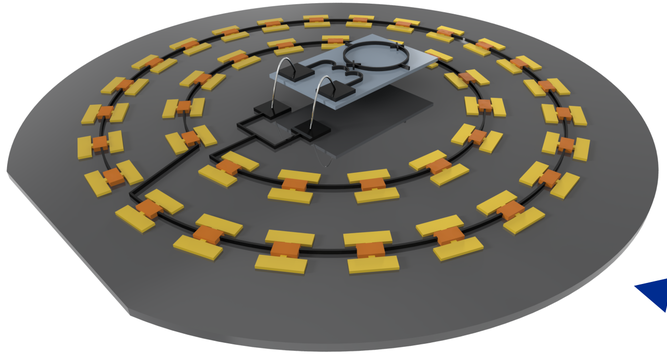
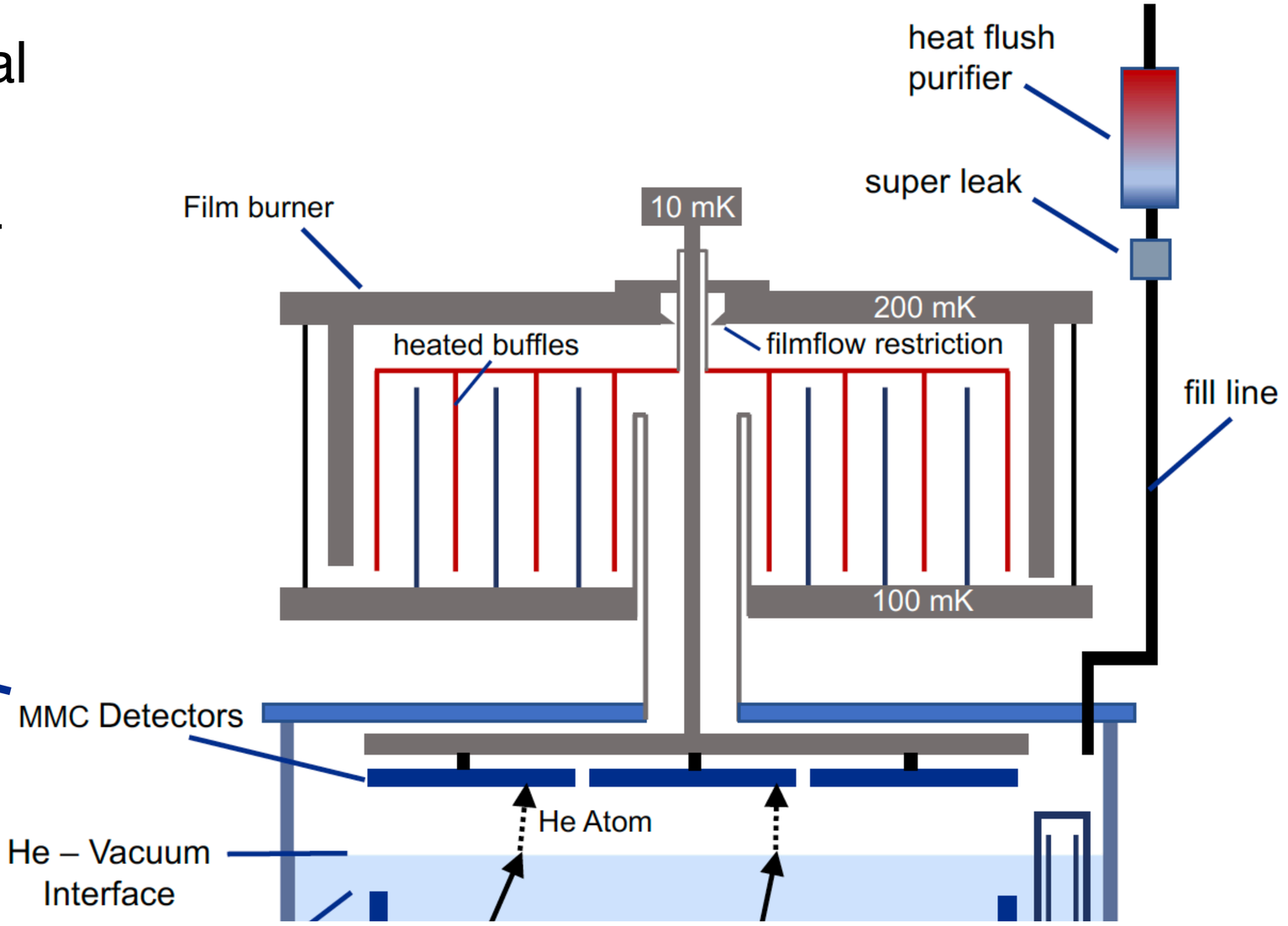
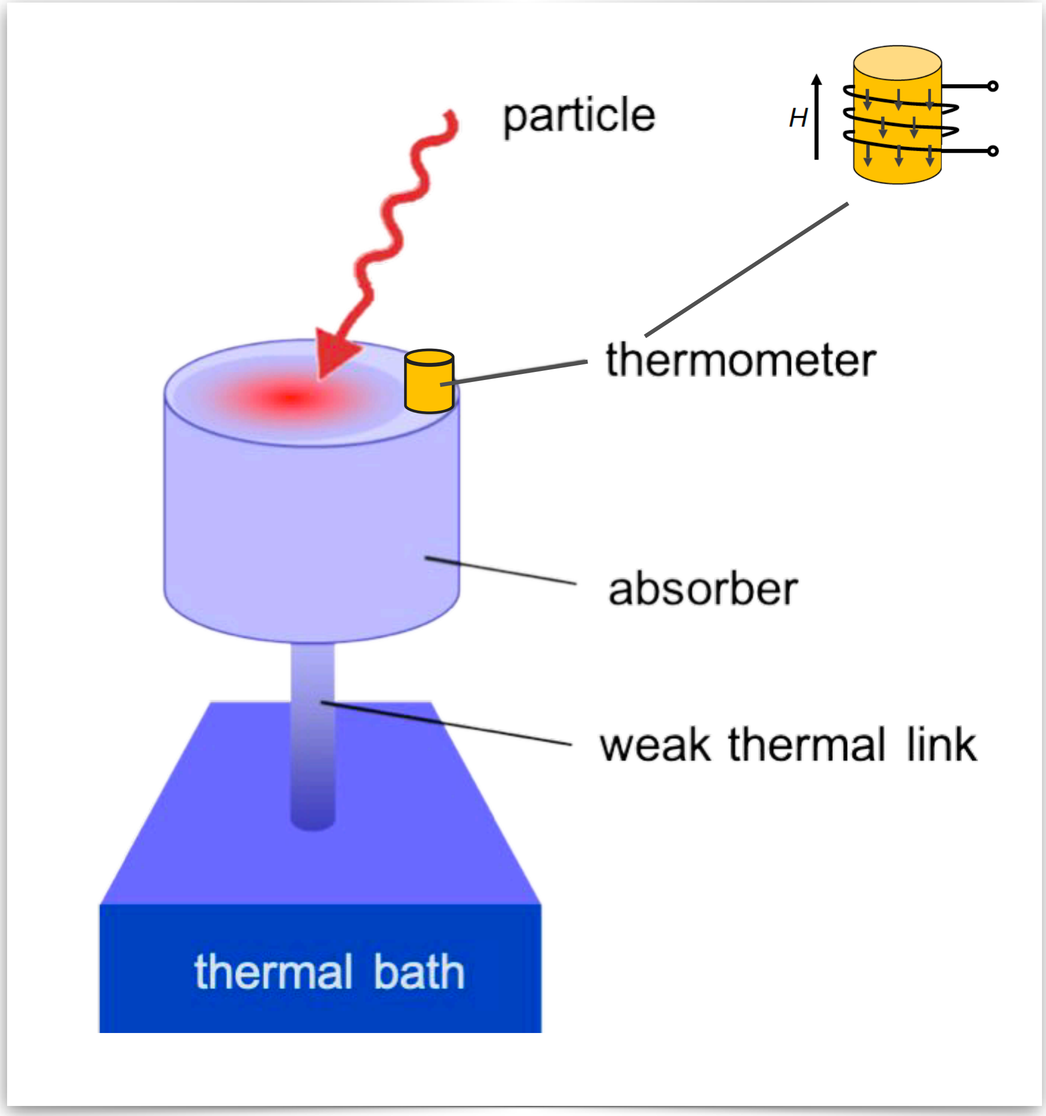
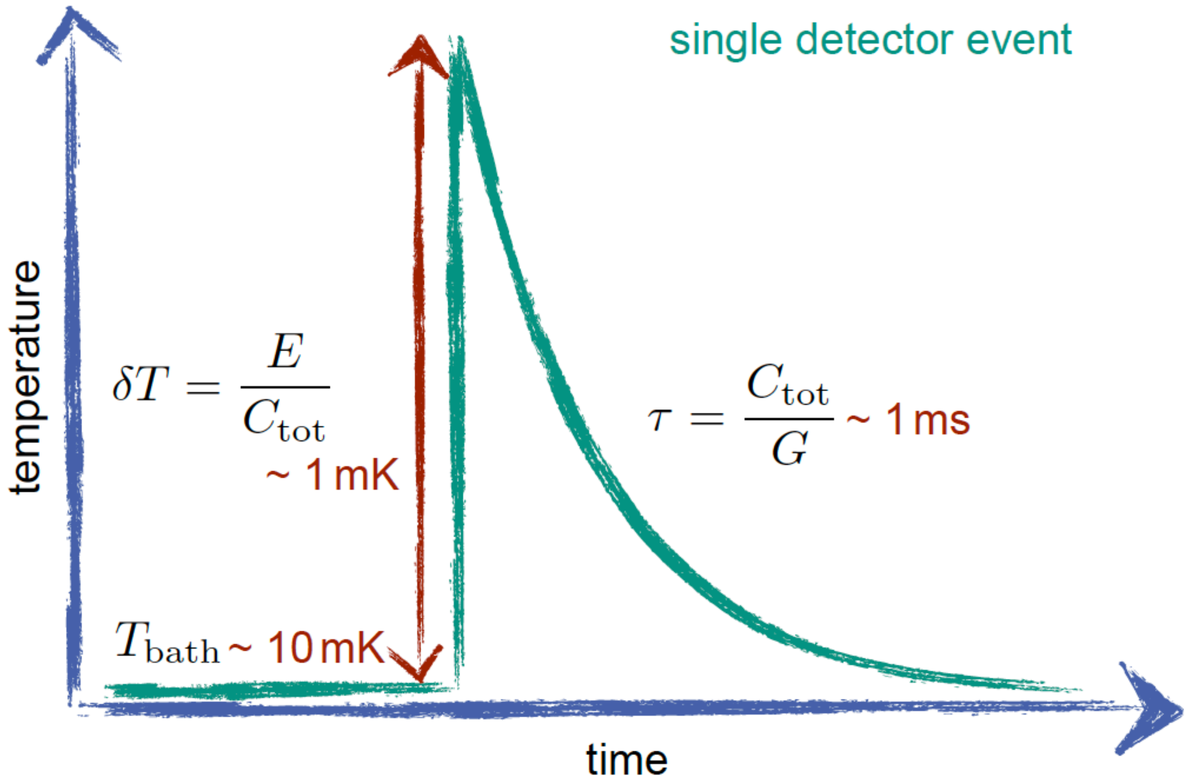


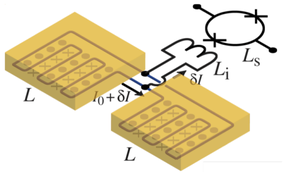
- 3-inch Si wafers of 300 µm thickness



MMC: metallic magnetic calorimeter





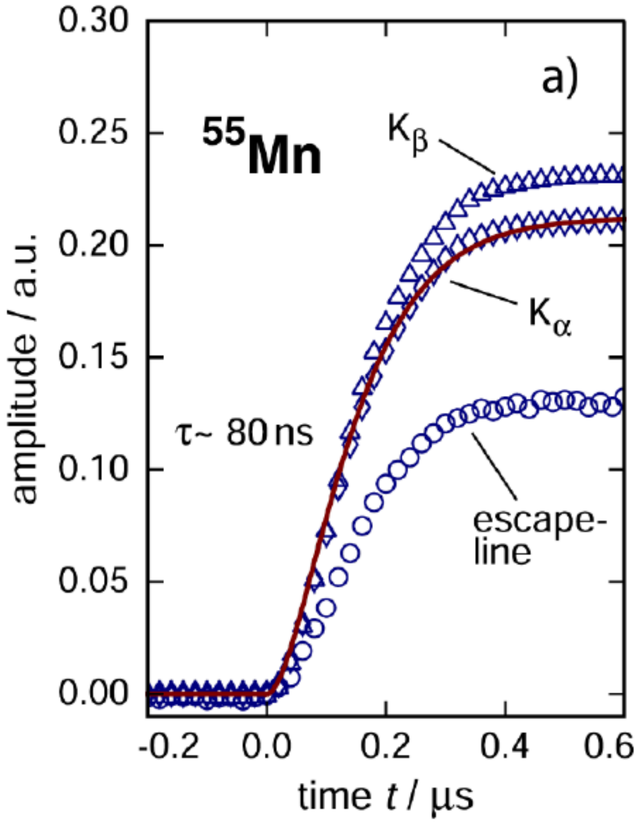


Key features of MMCs

250µm × 250µm gold, 5µm thick

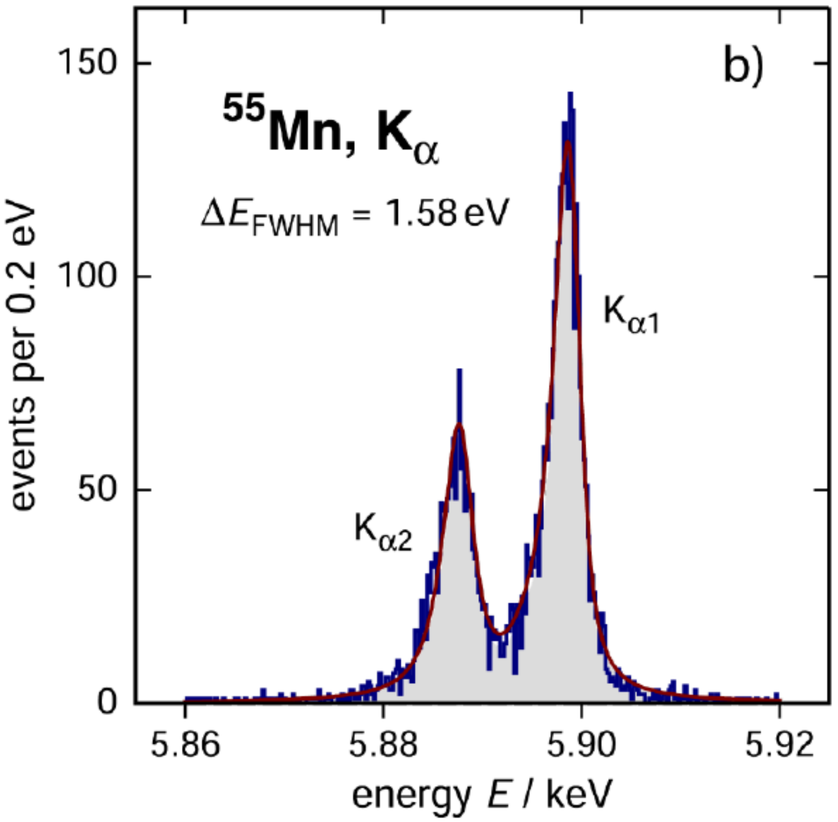
fast signal rise time

$\tau_{rise} < 100$ ns



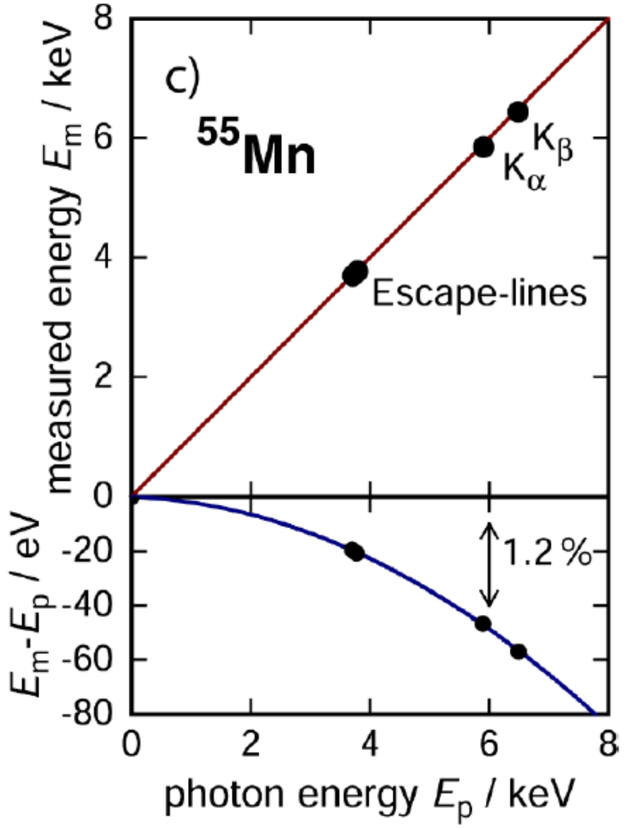
excellent energy resolution

$\Delta E_{FWHM} = 1.6$ eV @ 6 keV



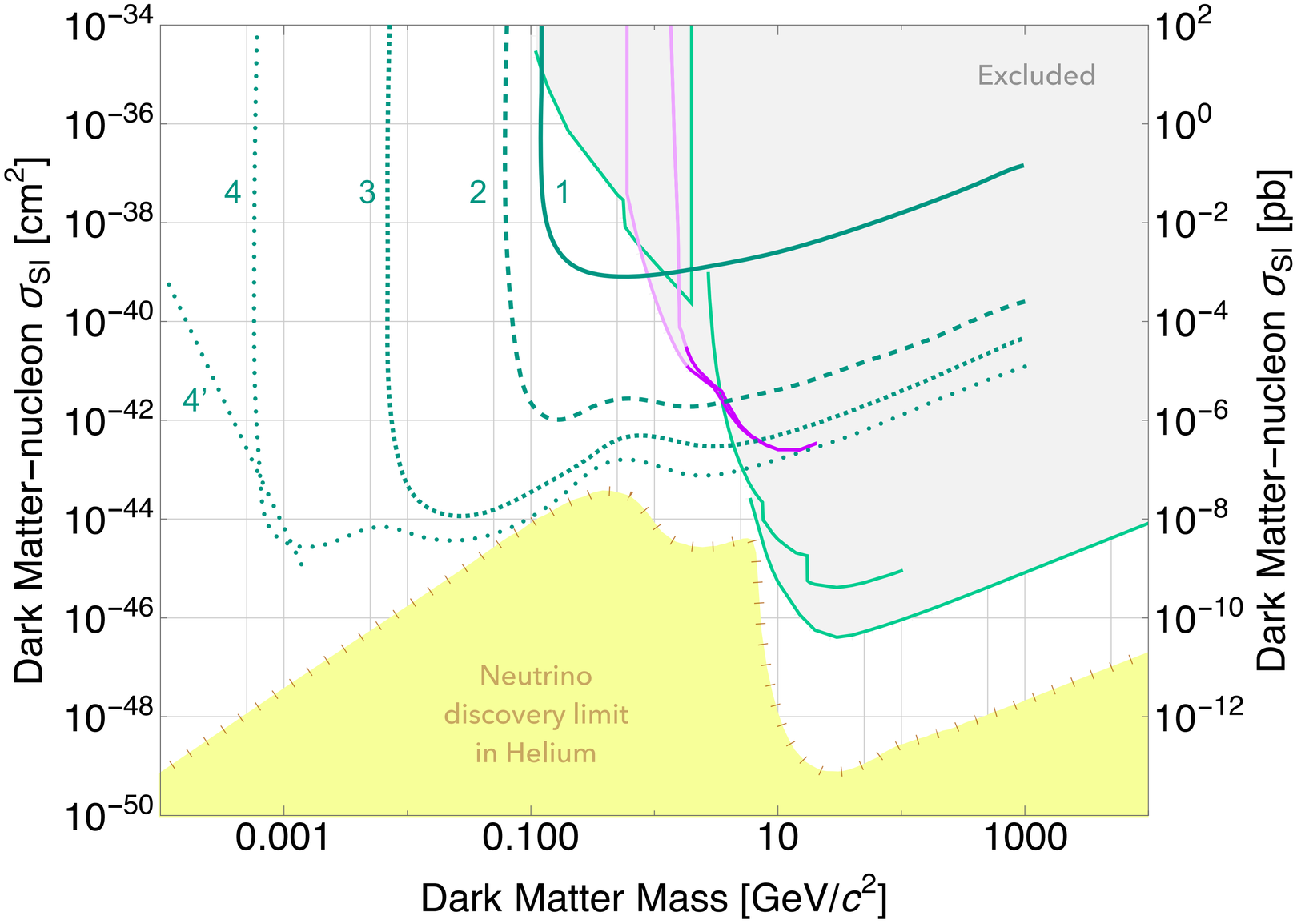
linear detector response

NL = 1.2% @ 6 keV



S. Kempf, A. Fleischmann, L. Gastaldo, C. Enss, J. Low Temp. Phys. 193, 365 (2018)

Towards Light Dark Matter with superfluid ^{4}He



HeRALD

S. A. Hertel et al.
Phys. Rev. D 100, 092007 (2019)

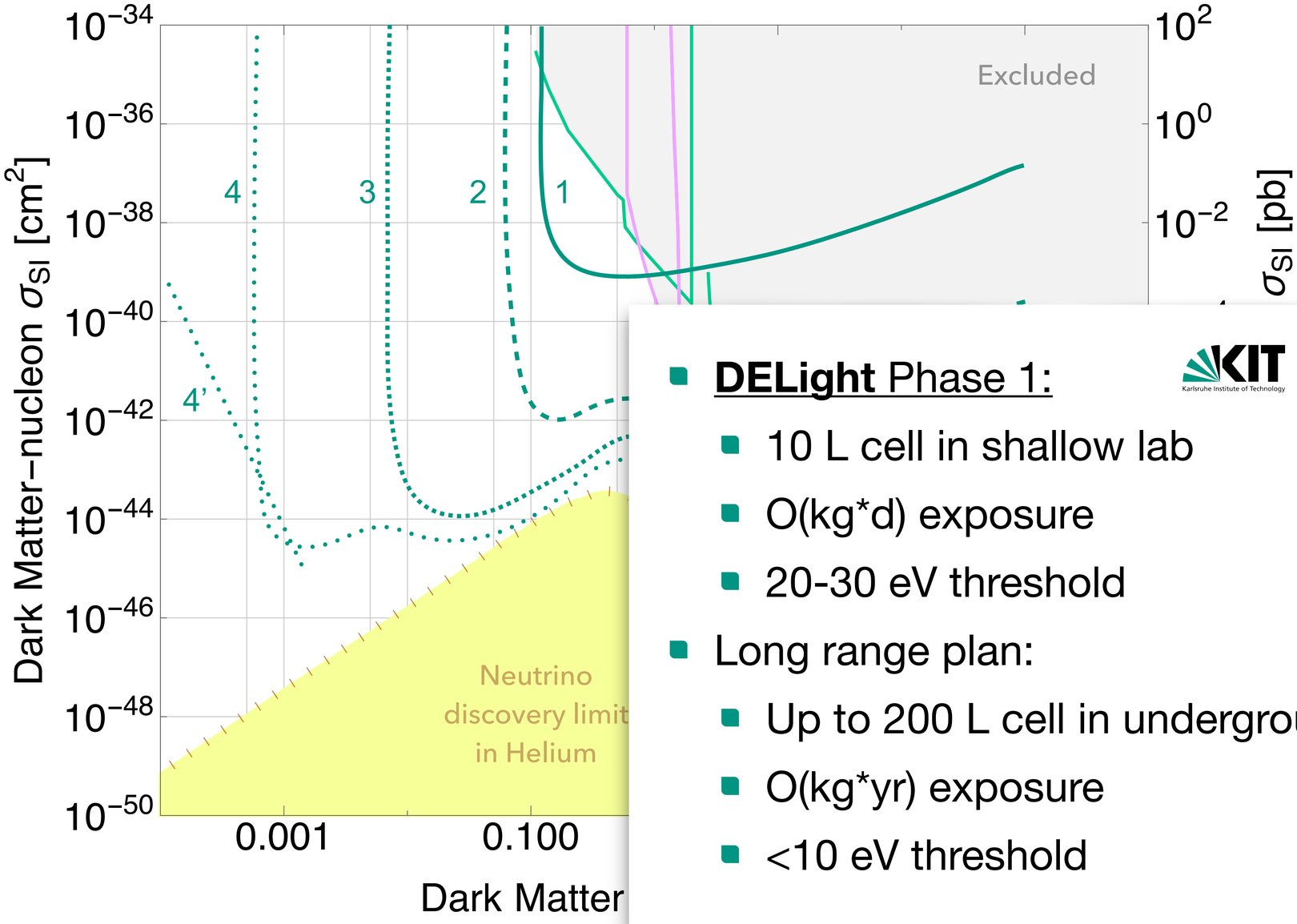
- He projections:
  - 1: 1 kg-d, 40 eV
  - 2: 1 kg-yr, 10 eV
  - 3: 10 kg-yr, 0.1 eV
  - 4: 100 kg-ry, 1 meV

See IDM2022 talk:

D. McKinsey, Tue. 9:30h

The TESSERACT Project for Sub-GeV Dark Matter Direct Detection

Towards Light Dark Matter with superfluid ^{4}He



- **DELight** Phase 1:
  - 10 L cell in shallow lab
  - O(kg*d) exposure
  - 20-30 eV threshold
- Long range plan:
  - Up to 200 L cell in underground lab
  - O(kg*yr) exposure
  - <10 eV threshold

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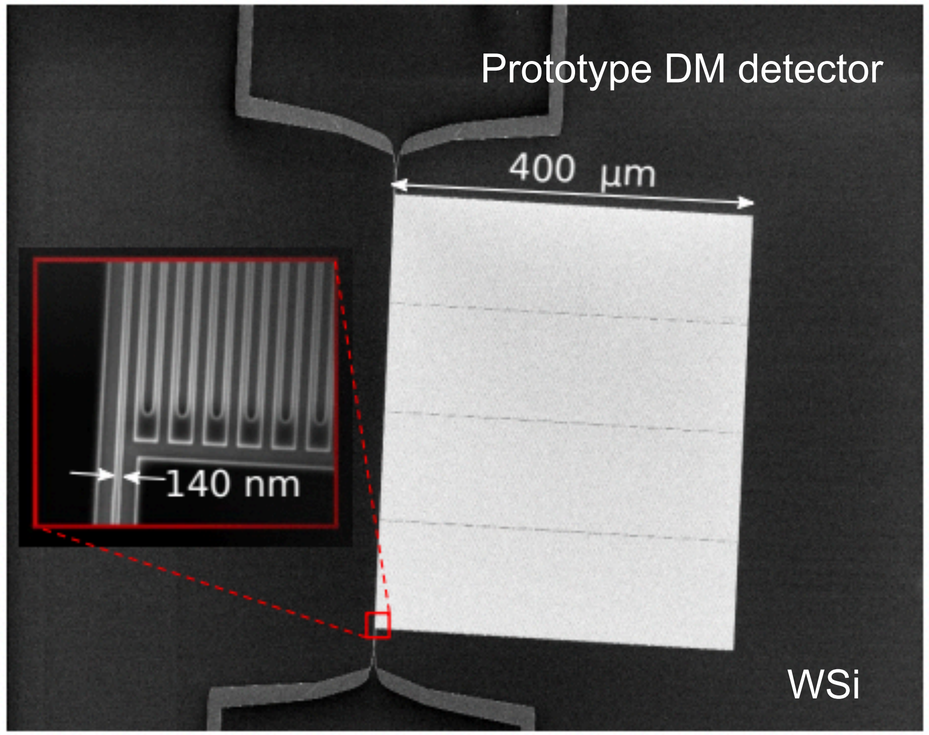
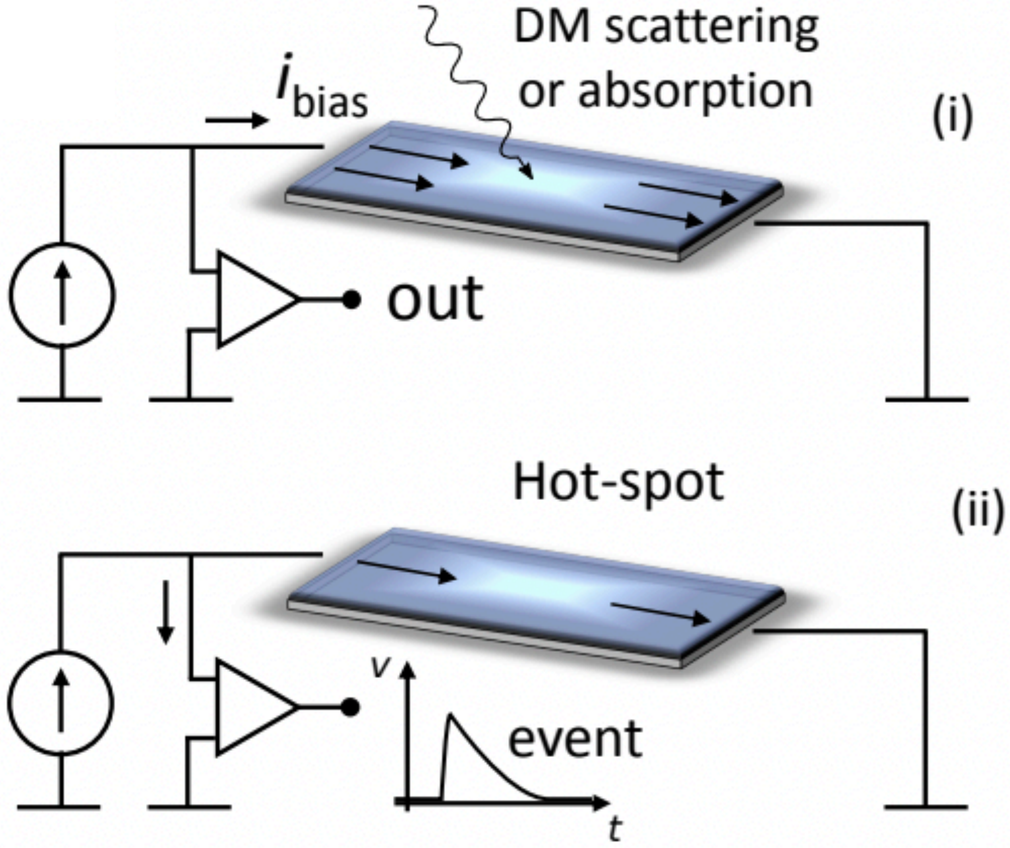
ADDITIONAL MATERIAL

Superconducting Nanowire Single Photon Detector (SNSPD)

Y. Hochberg, I. Charaev, S.-W. Nam, V. Verma, M Colangelo, K.K. Berggren
Phys. Rev. Lett. 123, 151802, (2019)





- Superconducting gap of O(meV)

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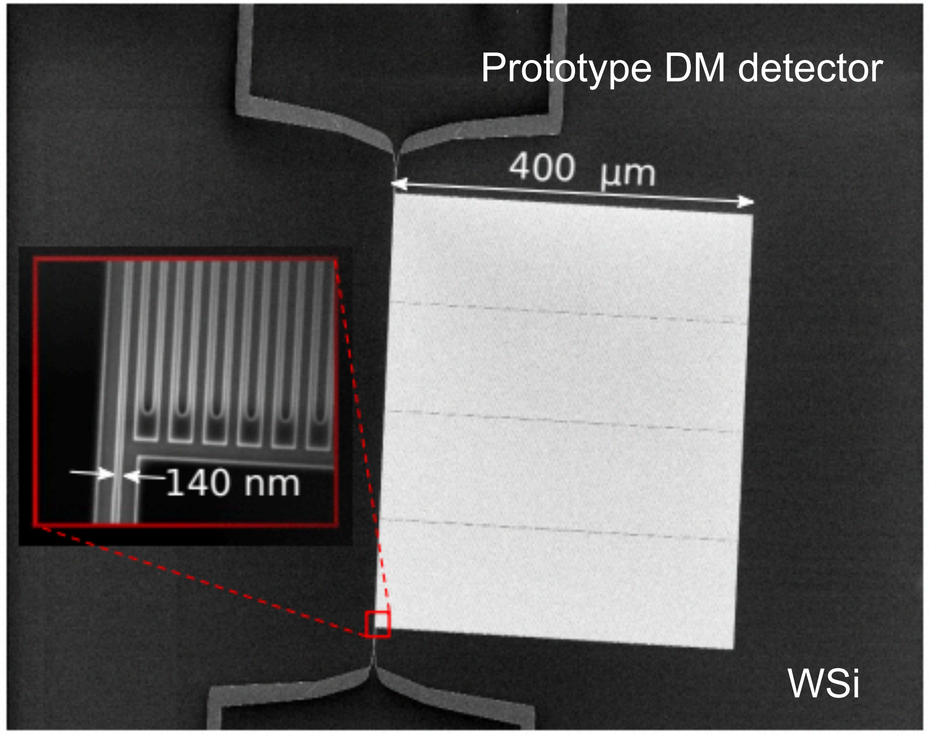
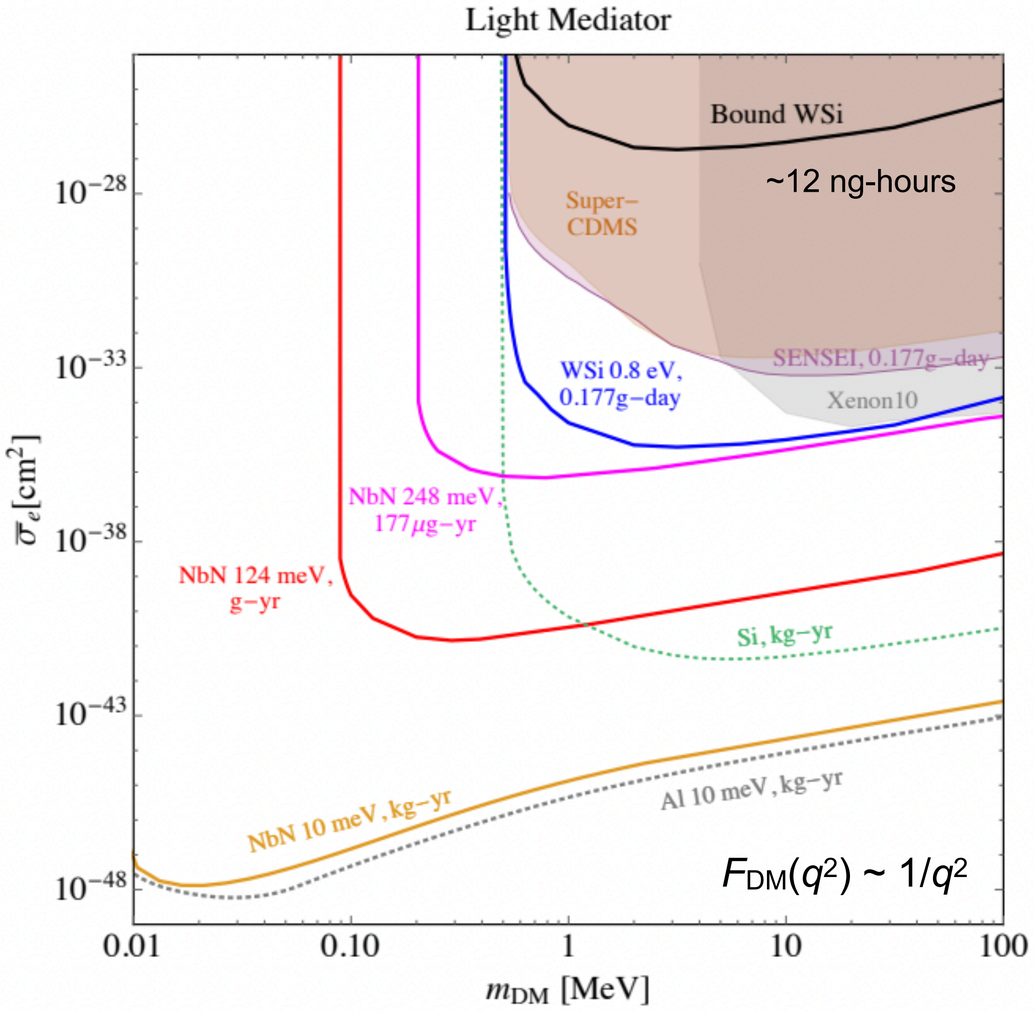
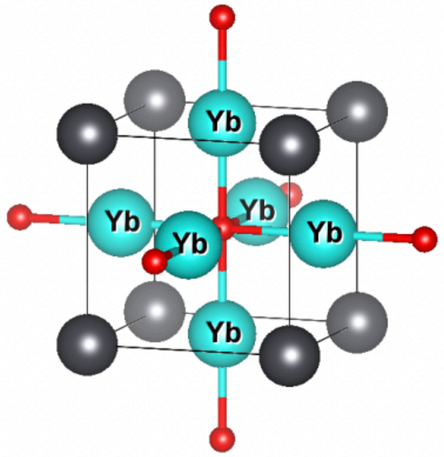
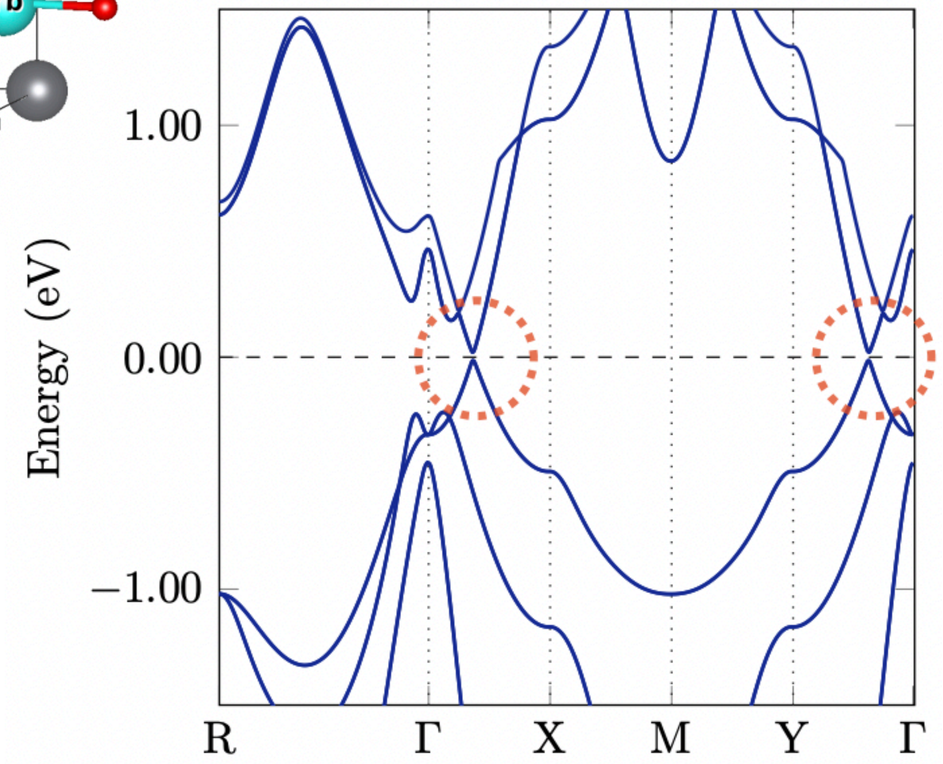




- Superconducting gap of O(meV)

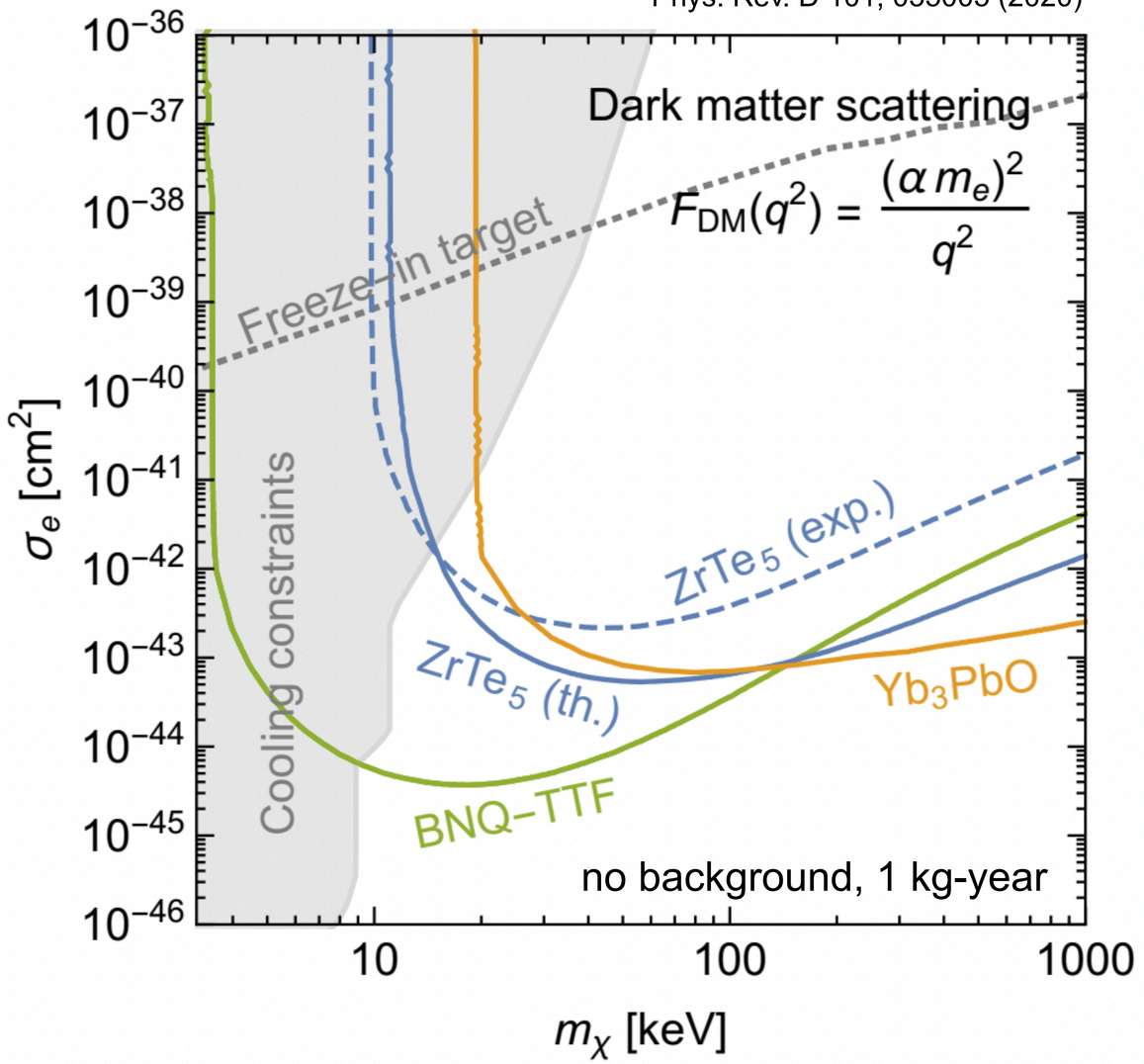
Dirac Materials: Example Yb_3PbO



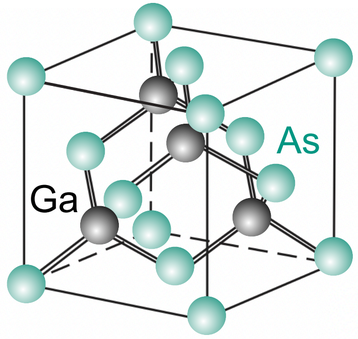


- Band gap: ~17 - 19 meV

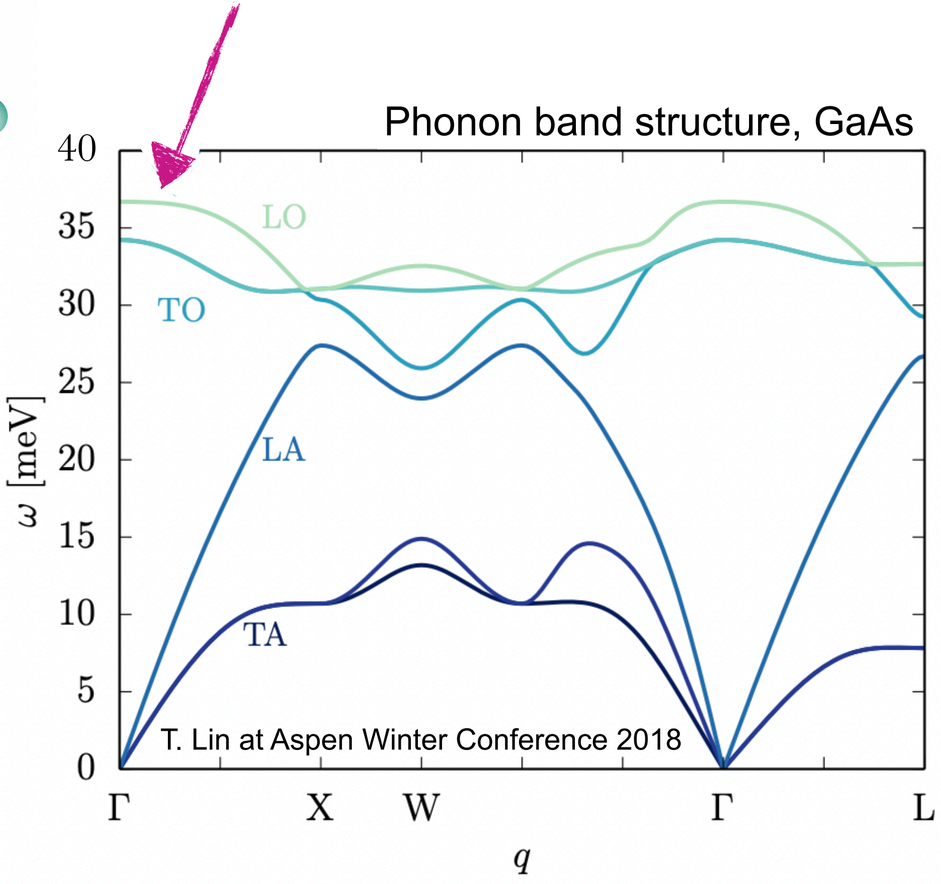
R. M. Geilhufe, F. Kahlhoefer, M. W. Winkler
Phys. Rev. D 101, 055005 (2020)



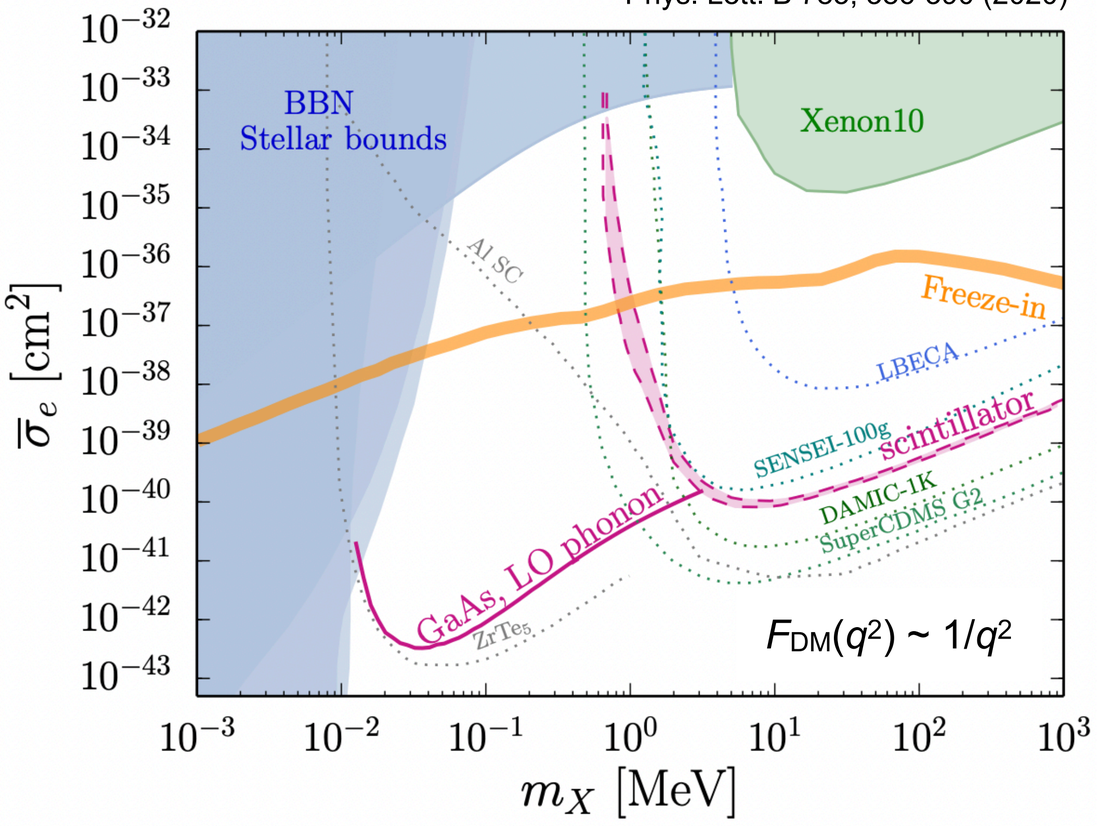
Polar Crystals: Example GaAs



- Gapped optical phonons



S. Knapen, T. Lin, M. Pyle, K. M. Zurek, Phys. Lett. B 785, 386-390 (2020)



Upcoming experiment: SPICE (TESSERACT Collaboration)