The Phonon Background from Gamma-Rays in Sub-GeV Dark Matter Detectors

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Yang Institute for Theoretical Physics

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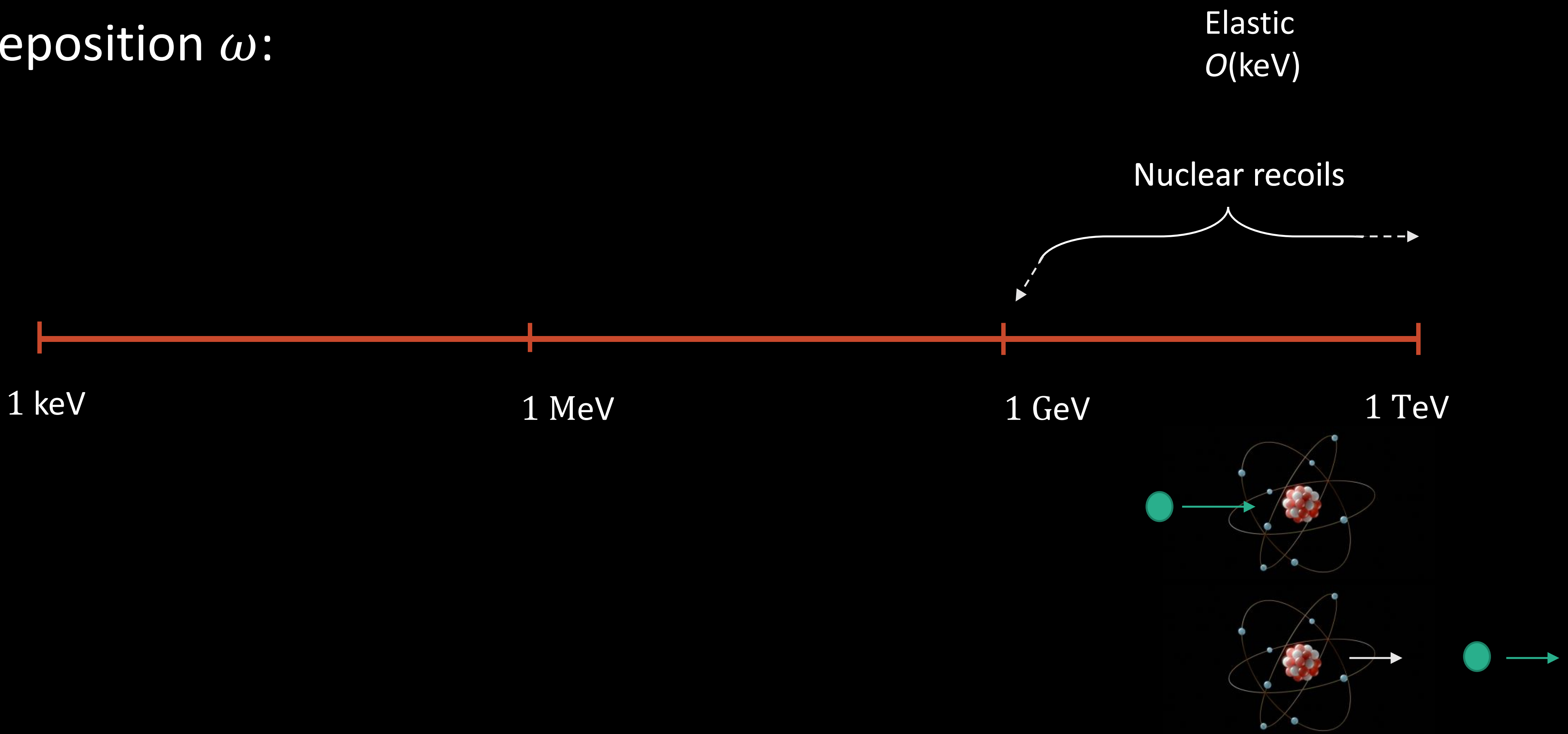
Based on: arXiv2112.09702

Collaborators: Rouven Essig, Yonit Hochberg, Yutaro Shoji, Mukul Sholapurkar

Sub-GeV Dark Matter Direct Detection

Energy Deposition ω:

Signals:



Sub-GeV Dark Matter Direct Detection

Energy Deposition ω:

Inelastic
O(eV)

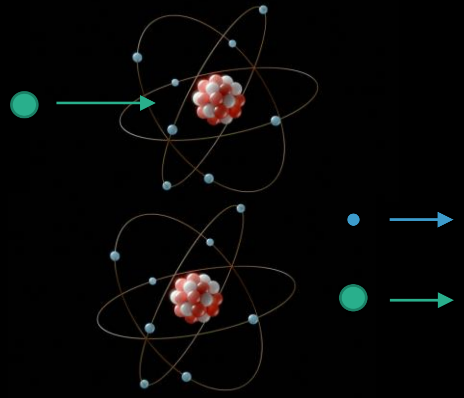
Elastic
O(keV)

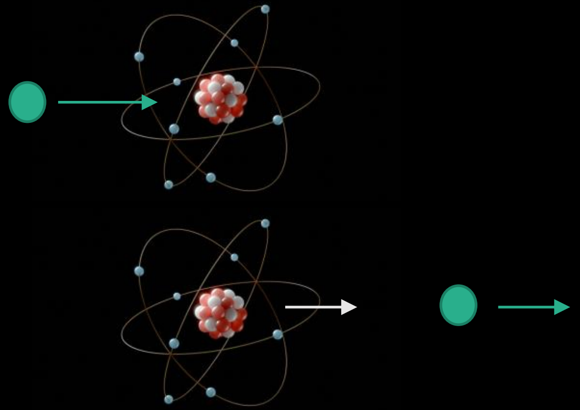
Signals:

Ionization

Nuclear recoils

1 keV — 1 MeV — 1 GeV — 1 TeV





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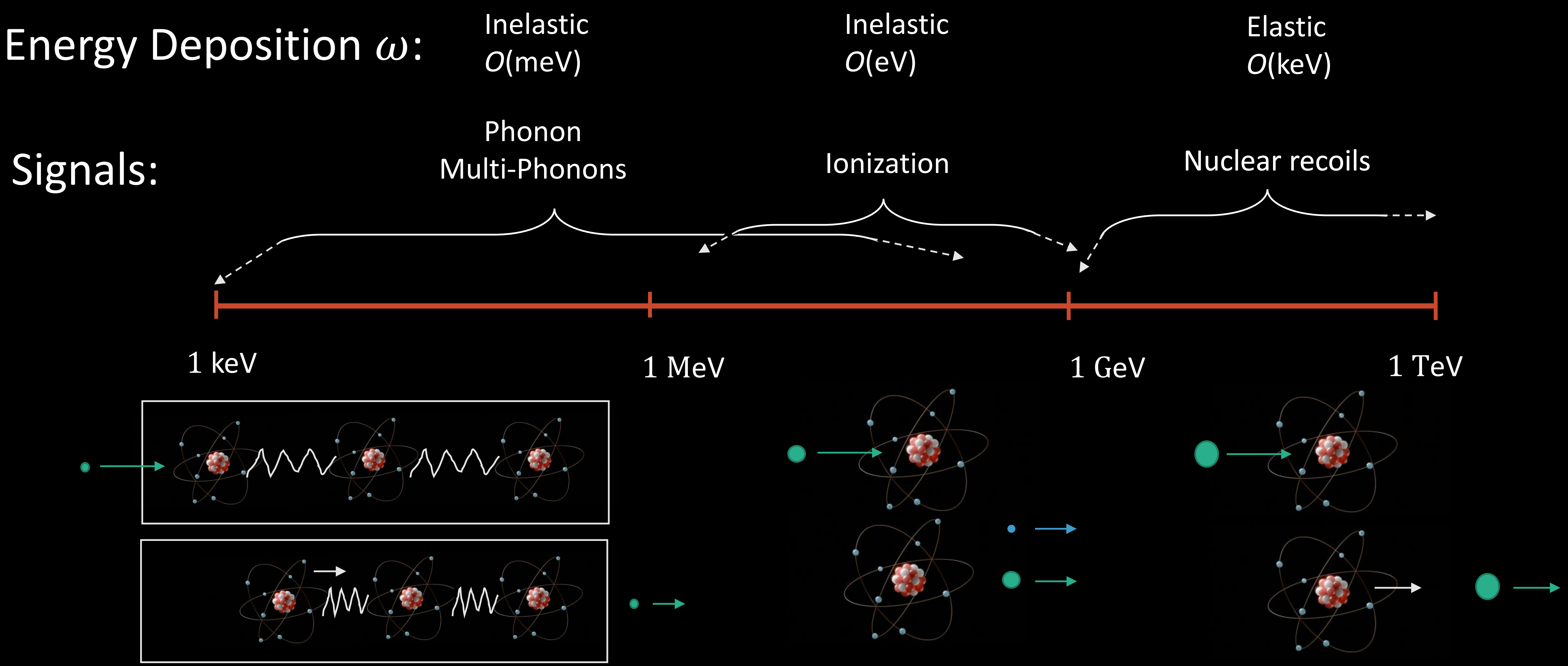
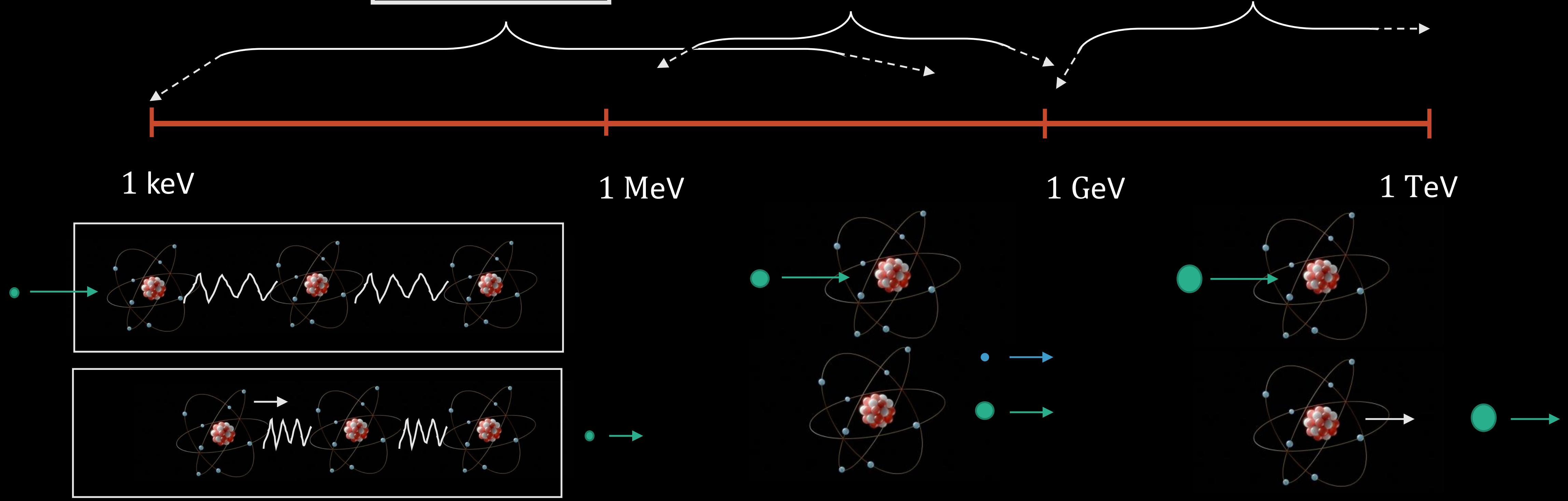
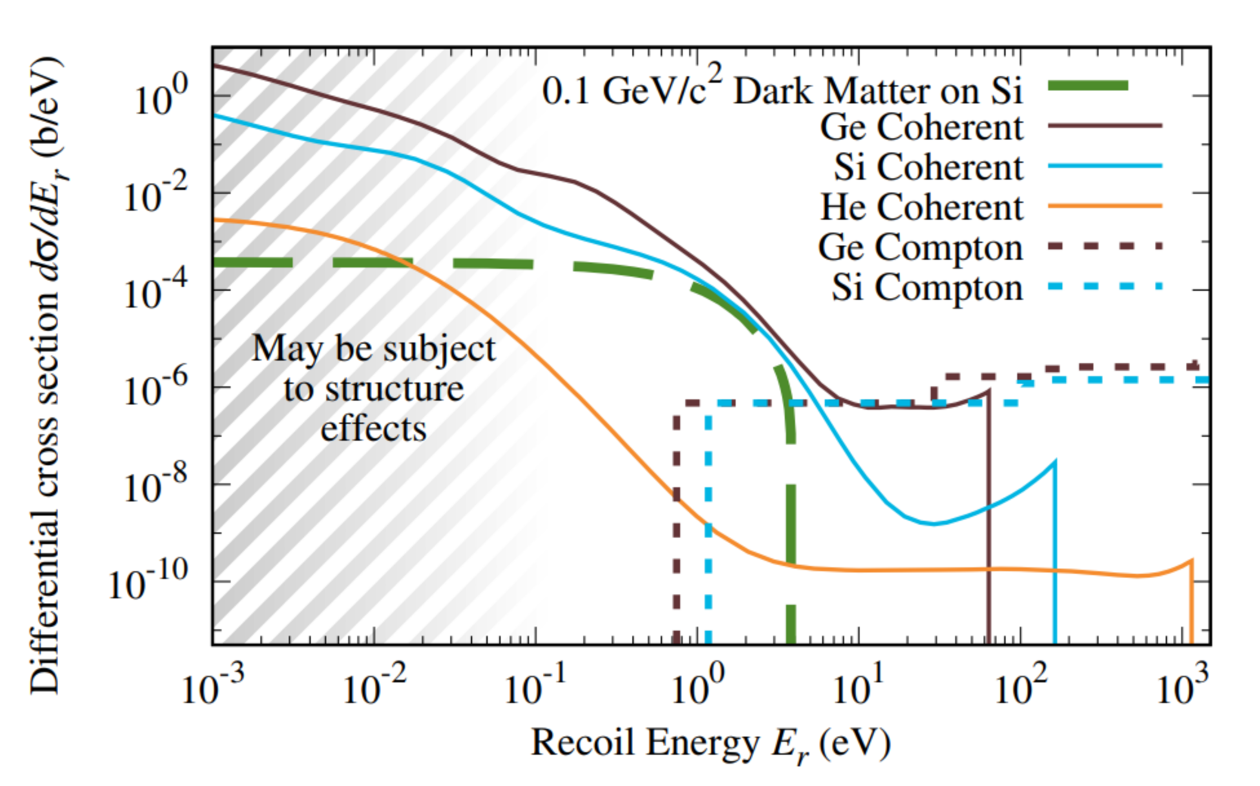


Sub-GeV Dark Matter Direct Detection

	Inelastic $\mathcal{O}$(meV)	Inelastic $\mathcal{O}$(eV)	Elastic $\mathcal{O}$(keV)
Energy Deposition ω:	Inelastic $\mathcal{O}$(meV)	Inelastic $\mathcal{O}$(eV)	Elastic $\mathcal{O}$(keV)
Signals:	Phonon Multi-Phonons	Ionization	Nuclear recoils



The Gamma-Ray Background in DM Direct Detection



Alan Robinson, Phs.Rev. D 95,021301(R), 2017

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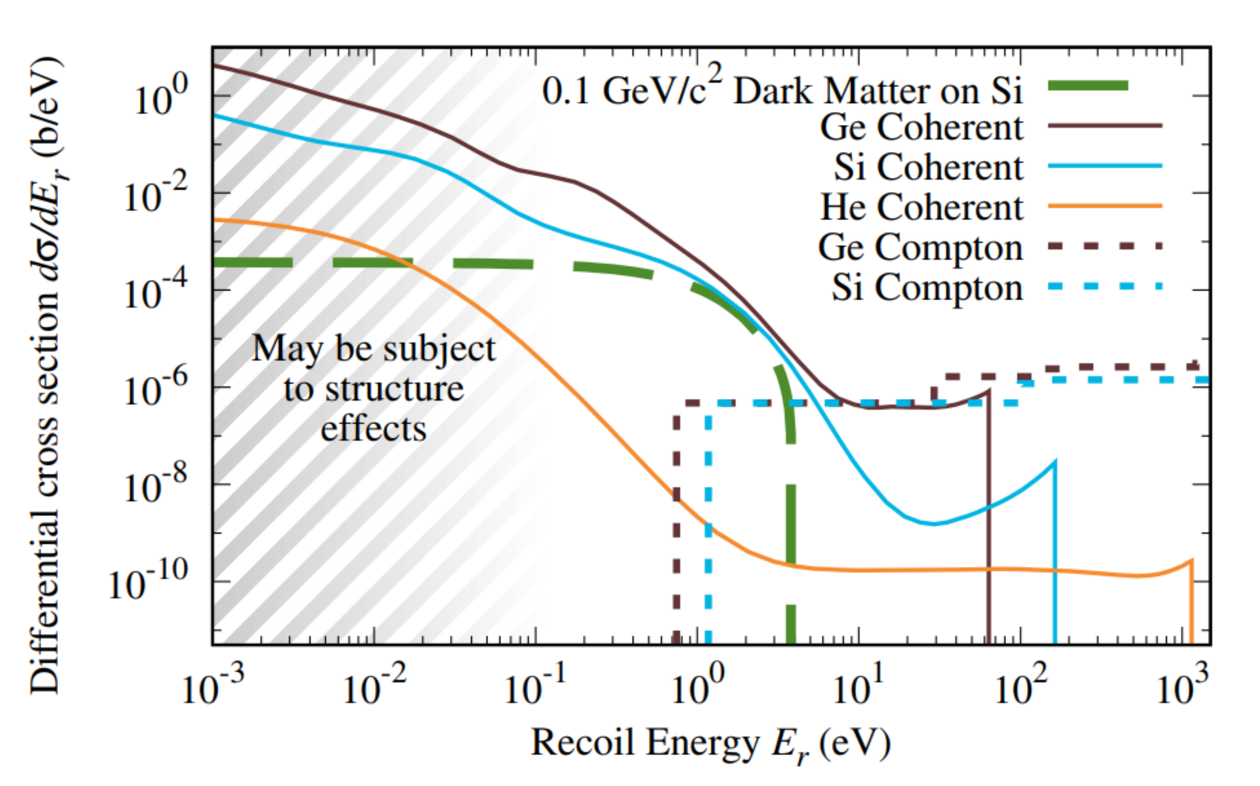

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low-energy Compton scatter recoils of

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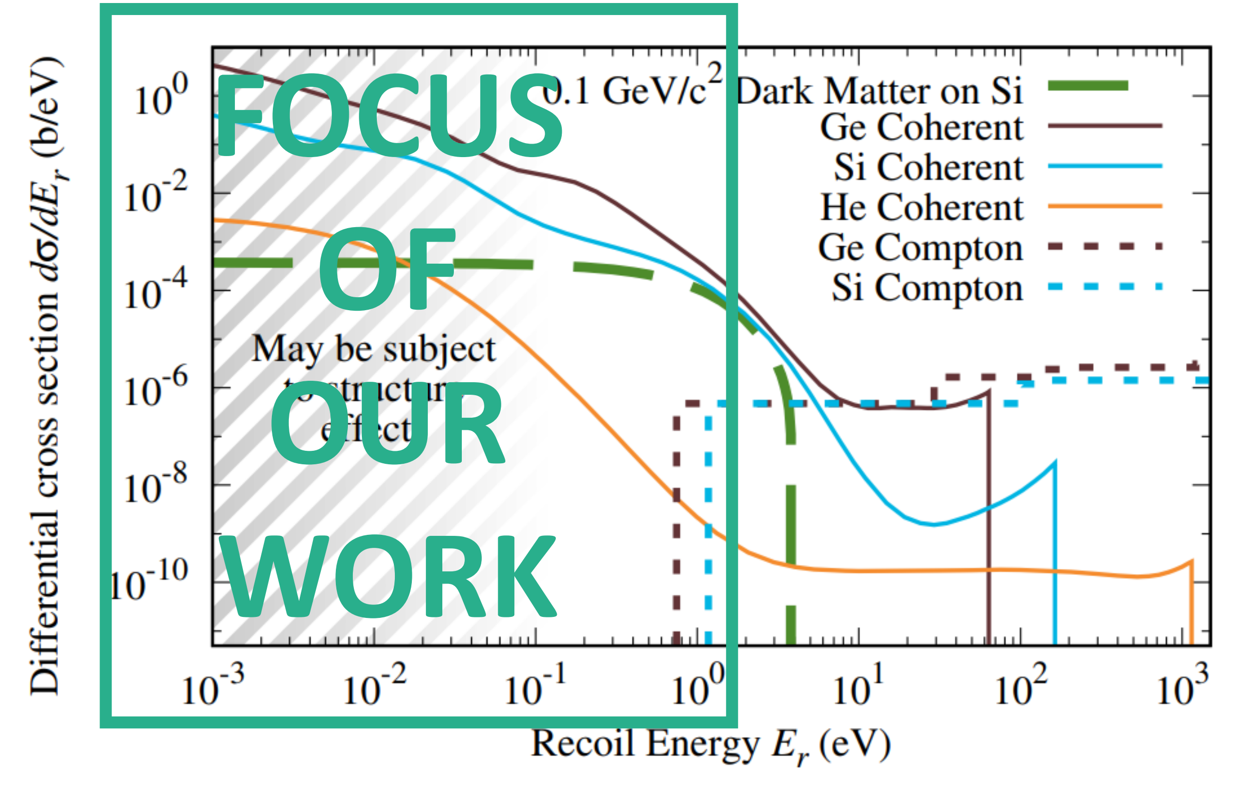

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The Gamma-Ray Flux in DM Direct Detection

Assumed Gamma-rays based on EDELWEISS shielding capabilities

AIP Conference Proceedings 1672, 100002 (2015);

EDELWEISS Collaboration10.1103/PhysRevD.98.082004

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Table credit Mukul Sholapurkar

~ 0.04 events/kg/day/keV
of flat Compton background

Gamma-Ray Phonon Scattering

The process factors into Photon-Ion scattering $\times$ material specific response

$$\frac{d\sigma}{d\Omega d\omega} = \frac{d\sigma}{d\Omega}(\boldsymbol{q}, E_\gamma) \times S(\boldsymbol{q}, \omega)$$

Phonons are produced by forward scattering since $E_\gamma \gg \omega$

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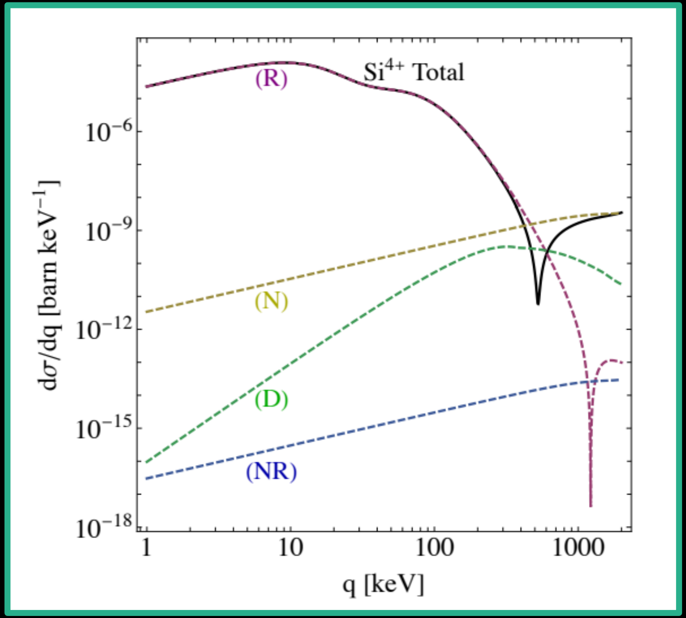
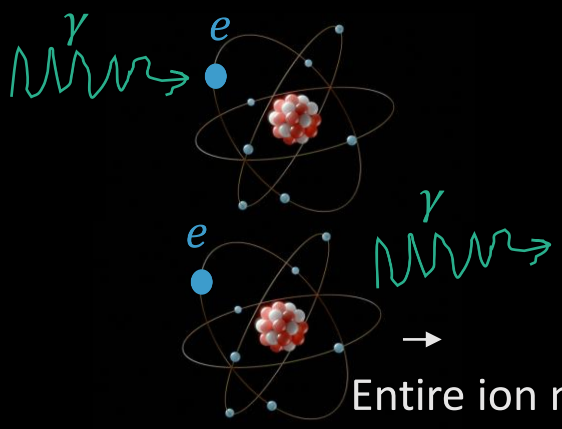


Figure credit Yutaro Shoji

Photon-electron Rayleigh scattering



arXiv 2112.09702

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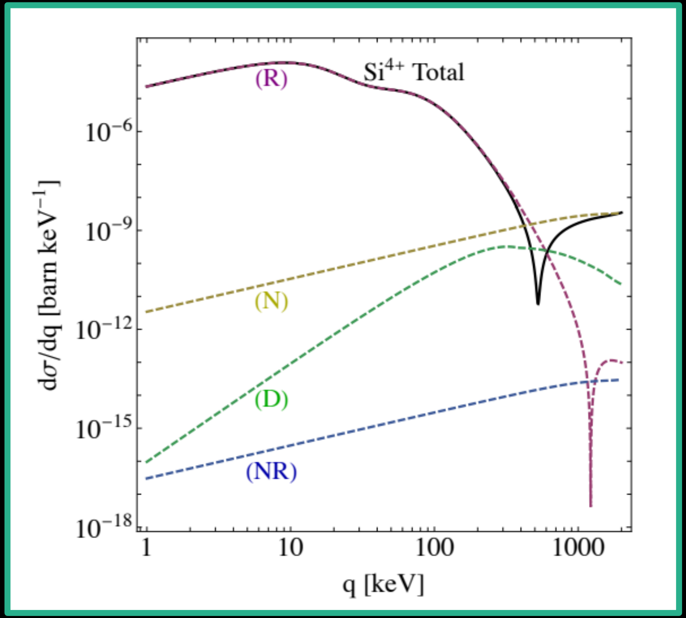

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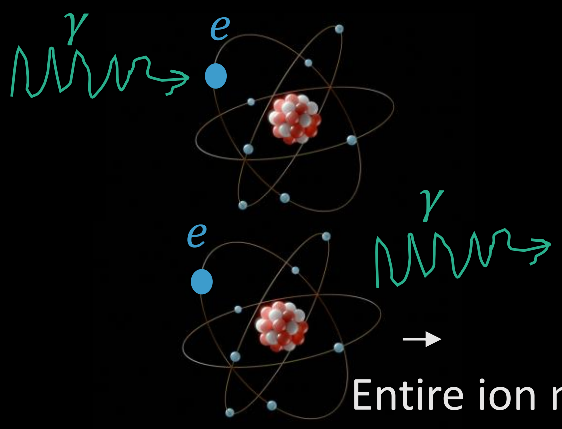

$$\frac{d\sigma}{d\Omega}(\boldsymbol{q}, E_\gamma) = \frac{q^2}{{E_\gamma}^2}\frac{\alpha^2\pi}{m_e^2} \times \left(1 + \left(1 - \frac{q^2}{2{E_\gamma}^2}\right)^2\right)|g(q)|^2$$

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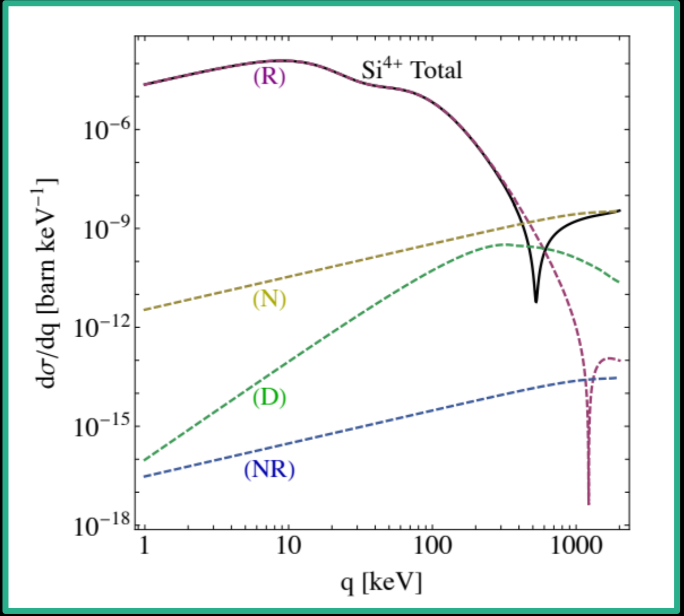

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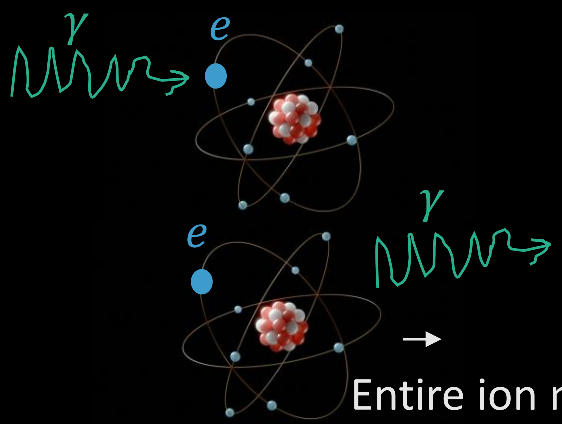

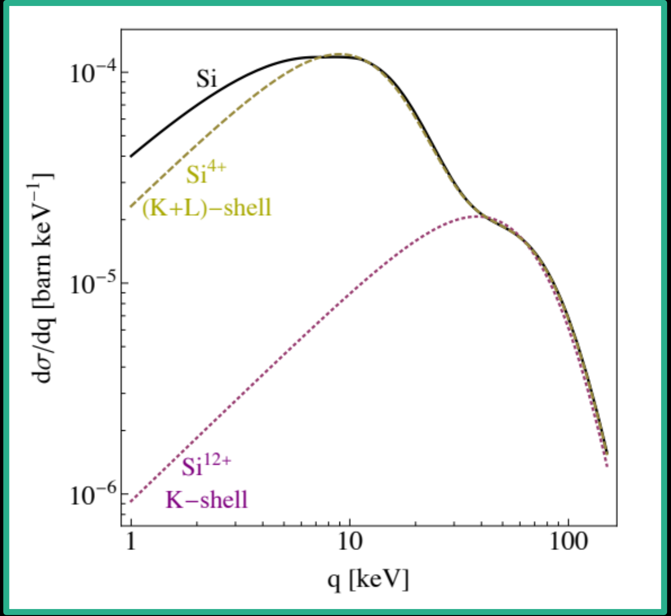

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Gamma-Ray Phonon Scattering

material specific response: $$S(\boldsymbol{q},\omega) = \sum \langle f|e^{iqR}|i\rangle^2 \, \delta(E_i - E_f - \omega)$$

Same operator appears in
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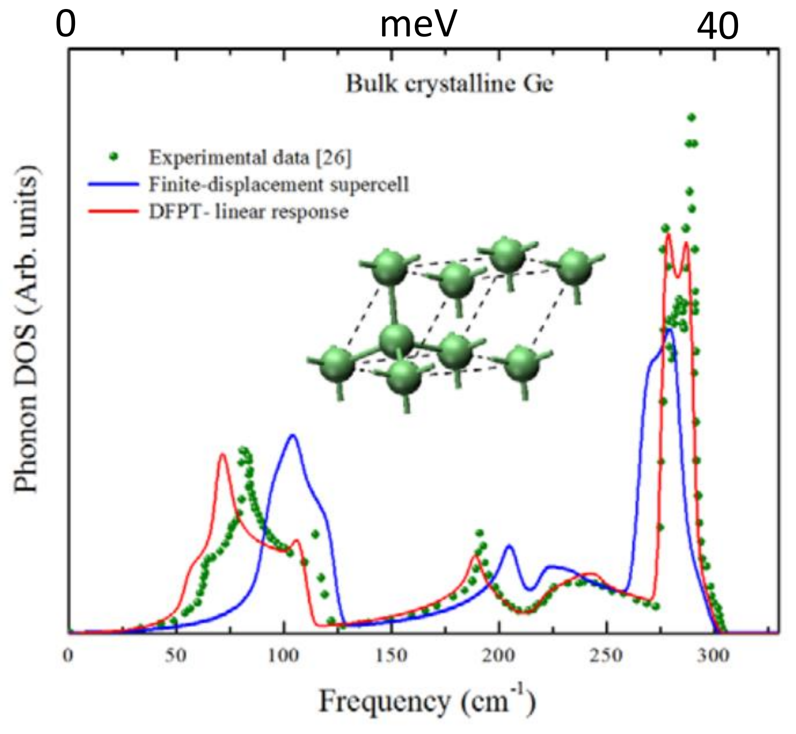

2013 Apr 22;18(4):4776-85. doi: 10.3390/molecules18044776. PMID: 23609626; PMCID: PMC6269924

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Neutron scattering measures Phonon Density of States

Gamma-Ray Phonon Scattering

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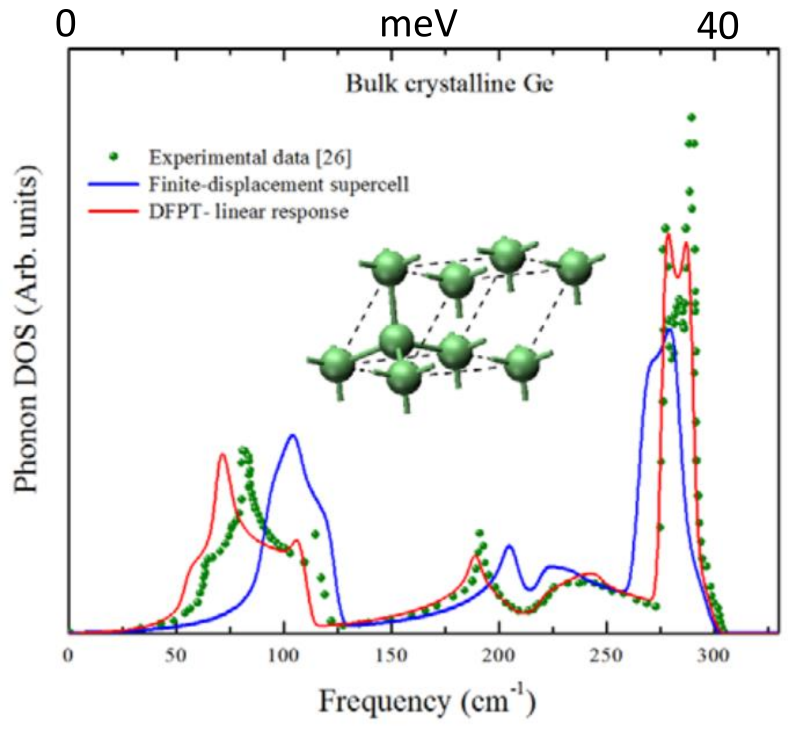

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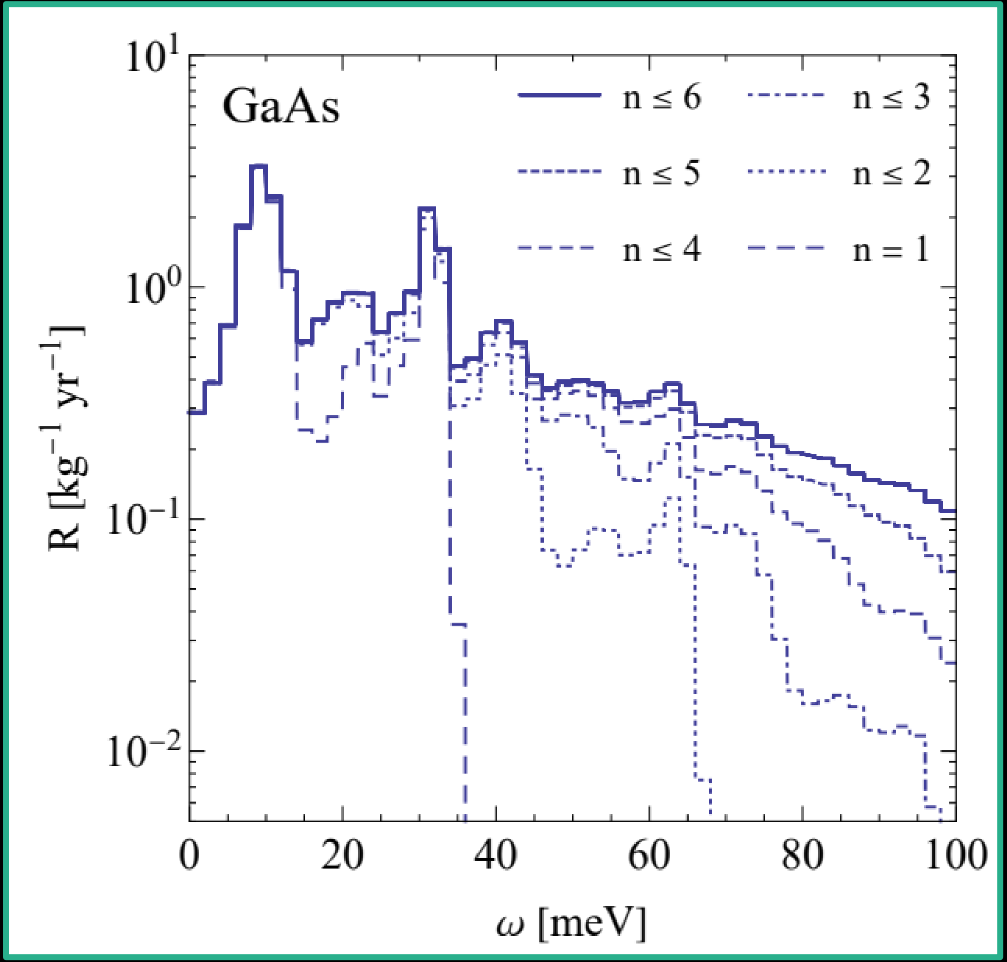
$$S^1(\boldsymbol{q},\omega) \sim e^{-\frac{q^2}{M\,\bar{\omega}_{ph}}} \frac{q^2}{2M} \frac{F(\omega)}{\omega}$$

Neutron scattering measures Phonon Density of States

$$S^n(\boldsymbol{q},\omega) \propto S^1 S^{n-1}$$

Phonon Background Rates from Gamma-Rays



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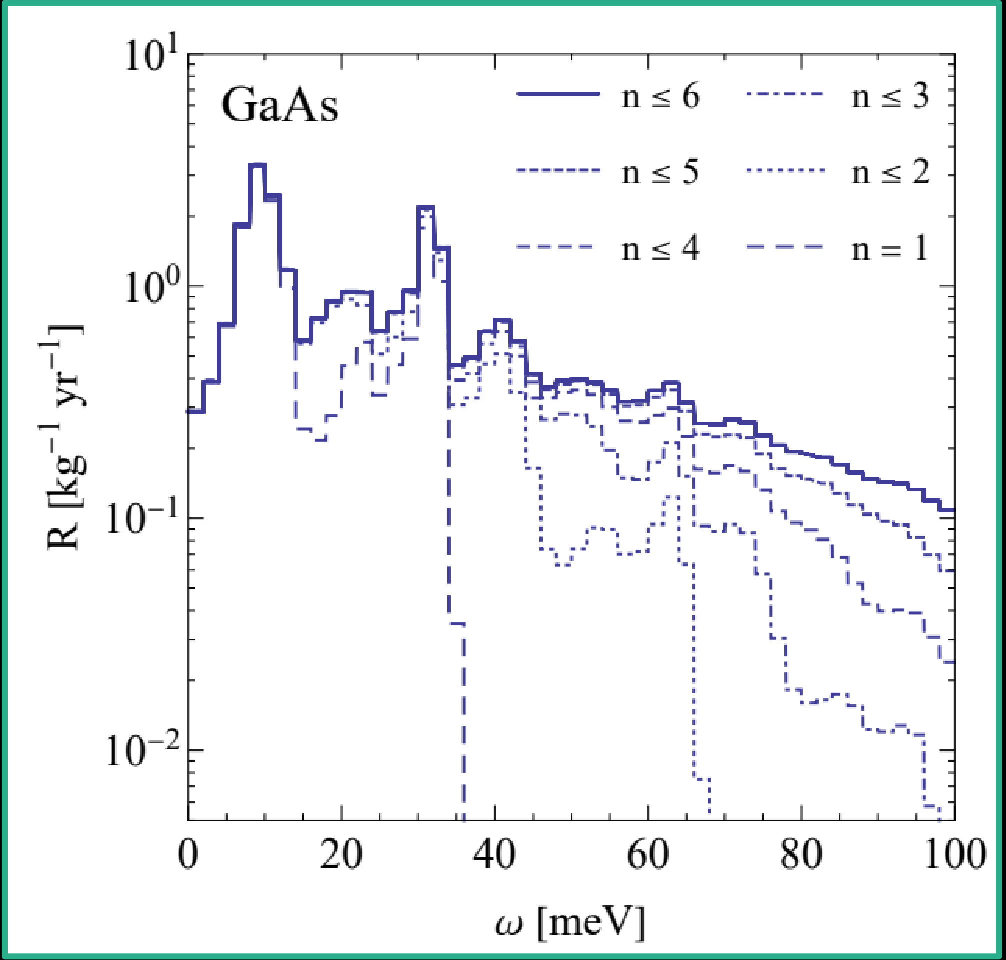

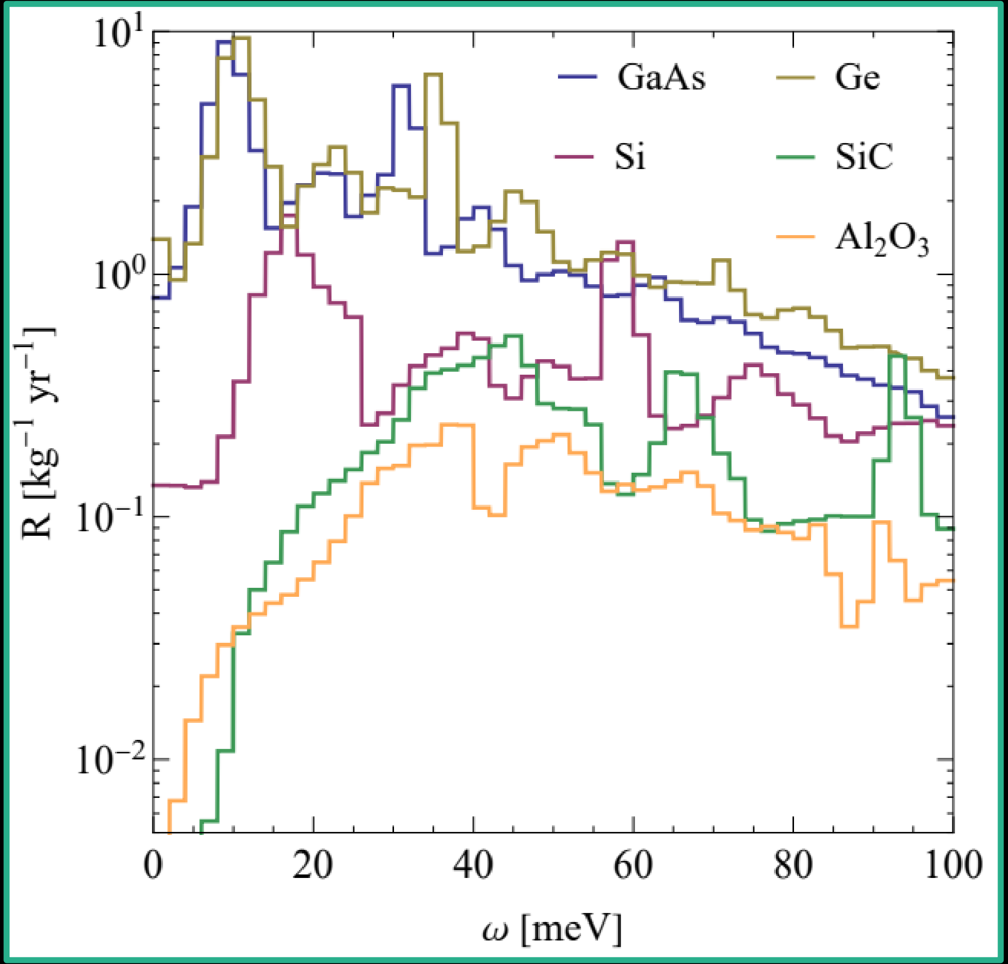

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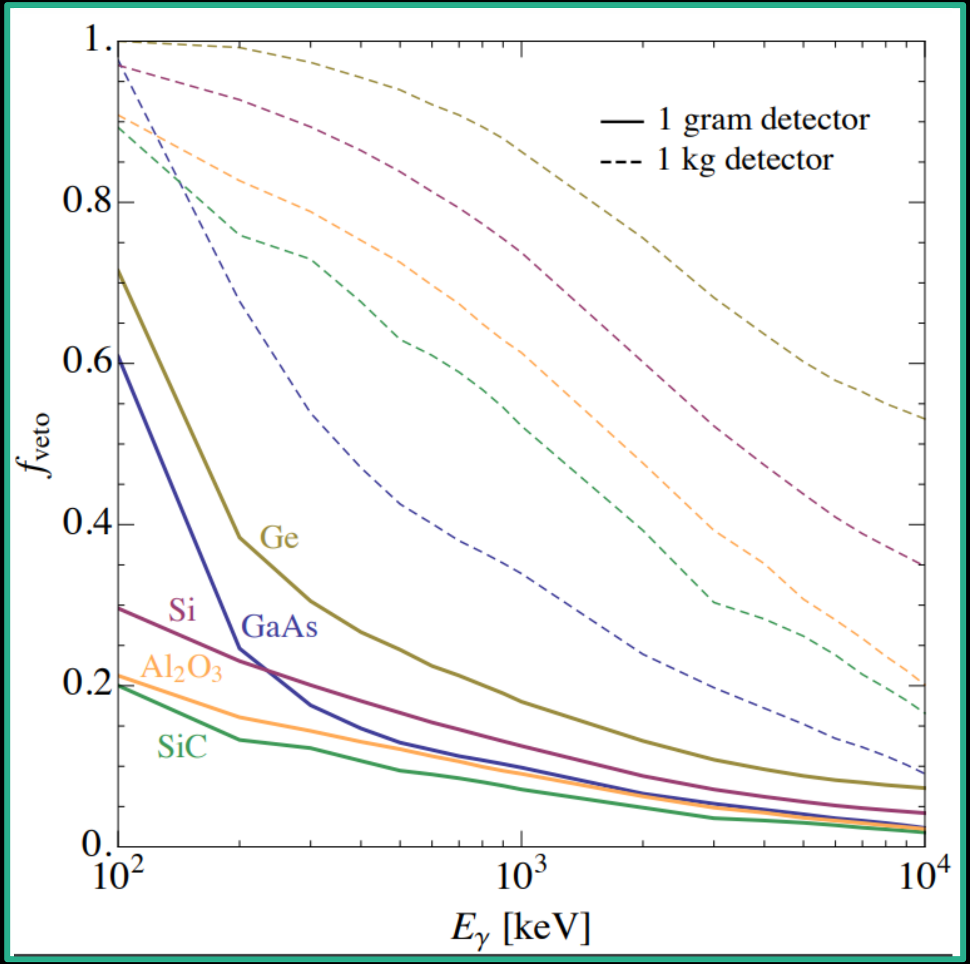
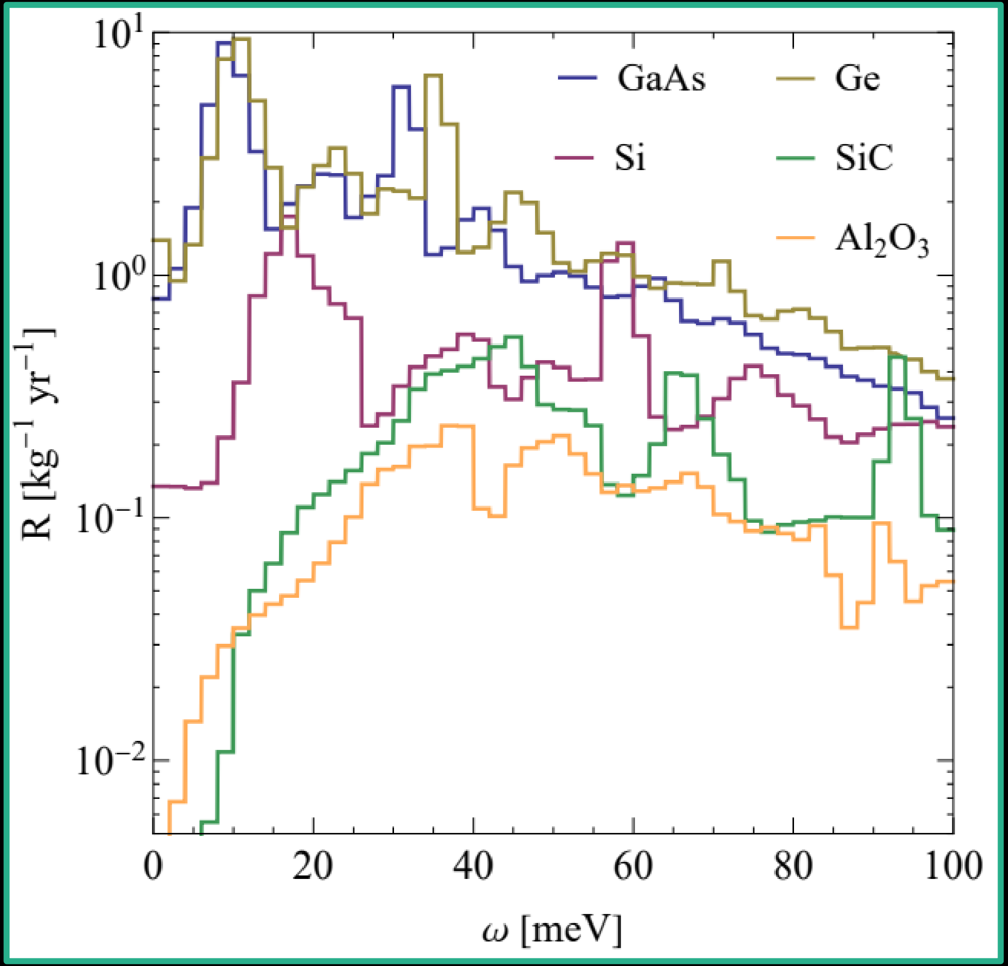


Figure credit to Mukul Sholapurkar



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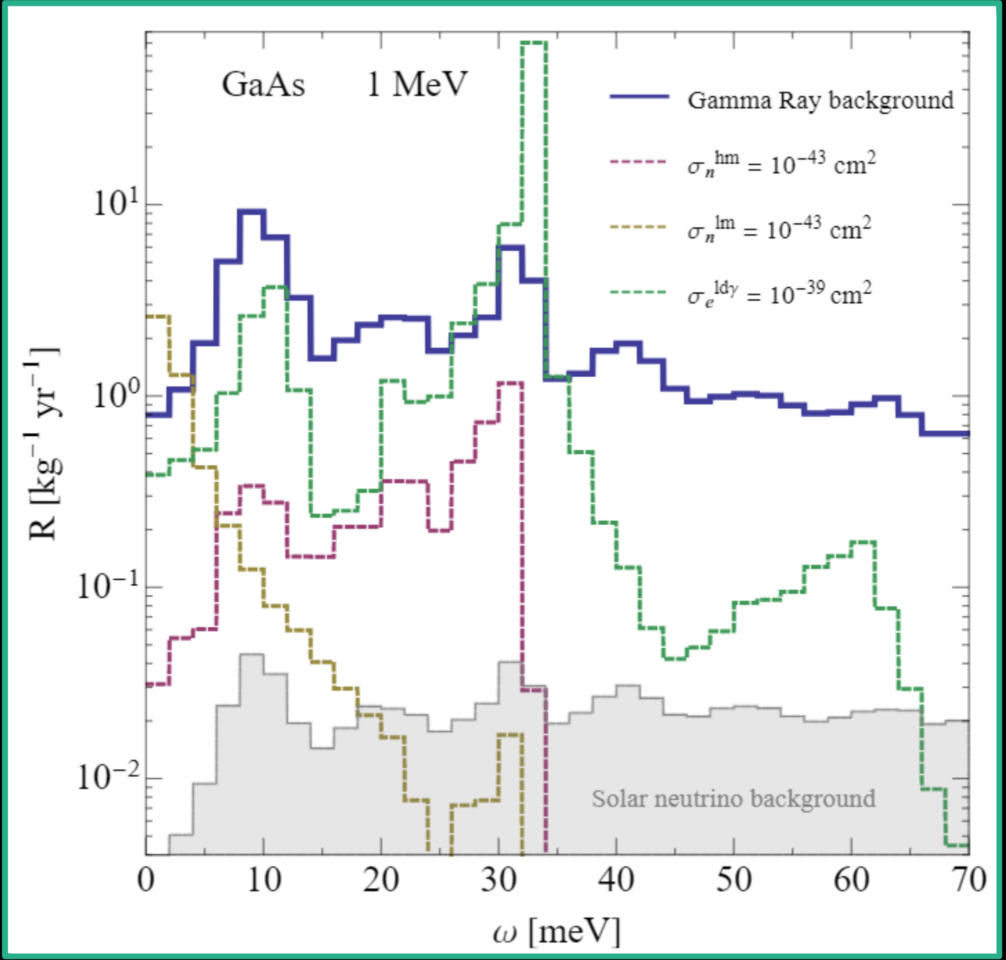
Comparison to Signal Rates



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lm: light scalar mediator (Trickle et al., 2021)

ldγ: ultralight dark photon mediator (Knapen et al. 2021)

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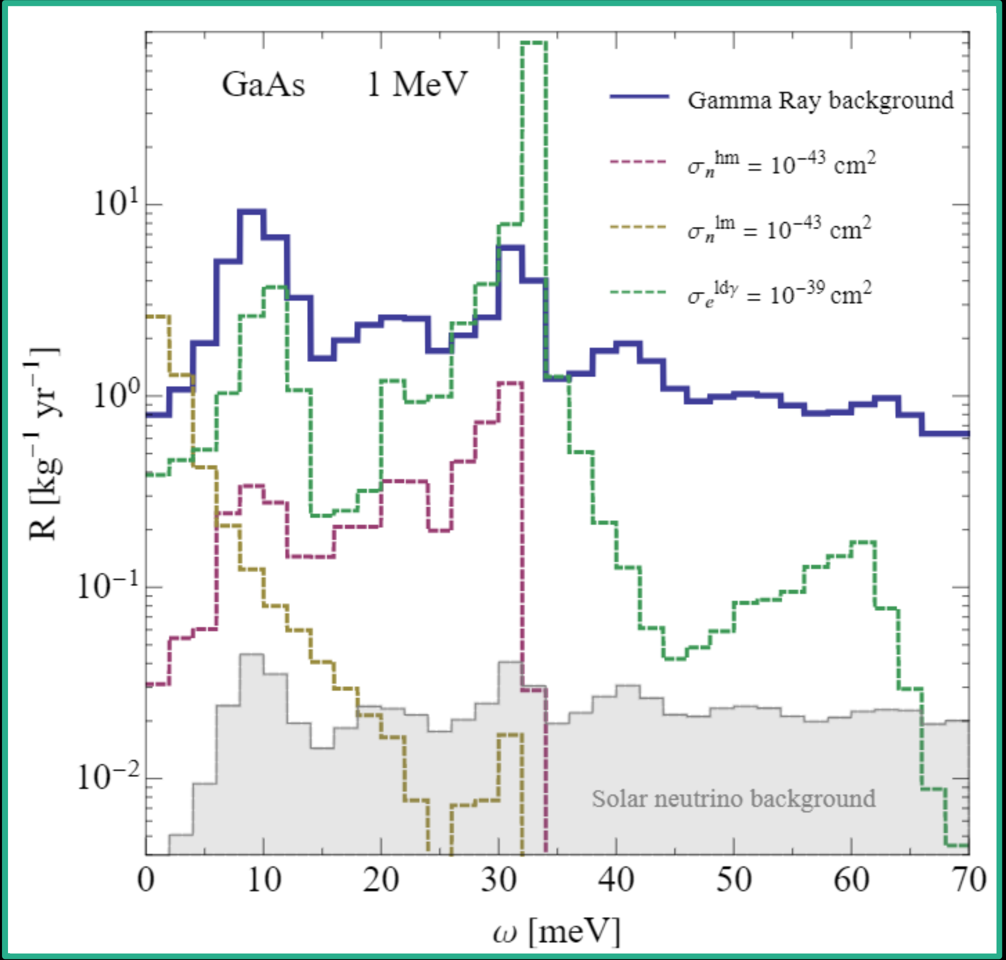

hm: heavy scalar mediator (Trickle et al., 2021)
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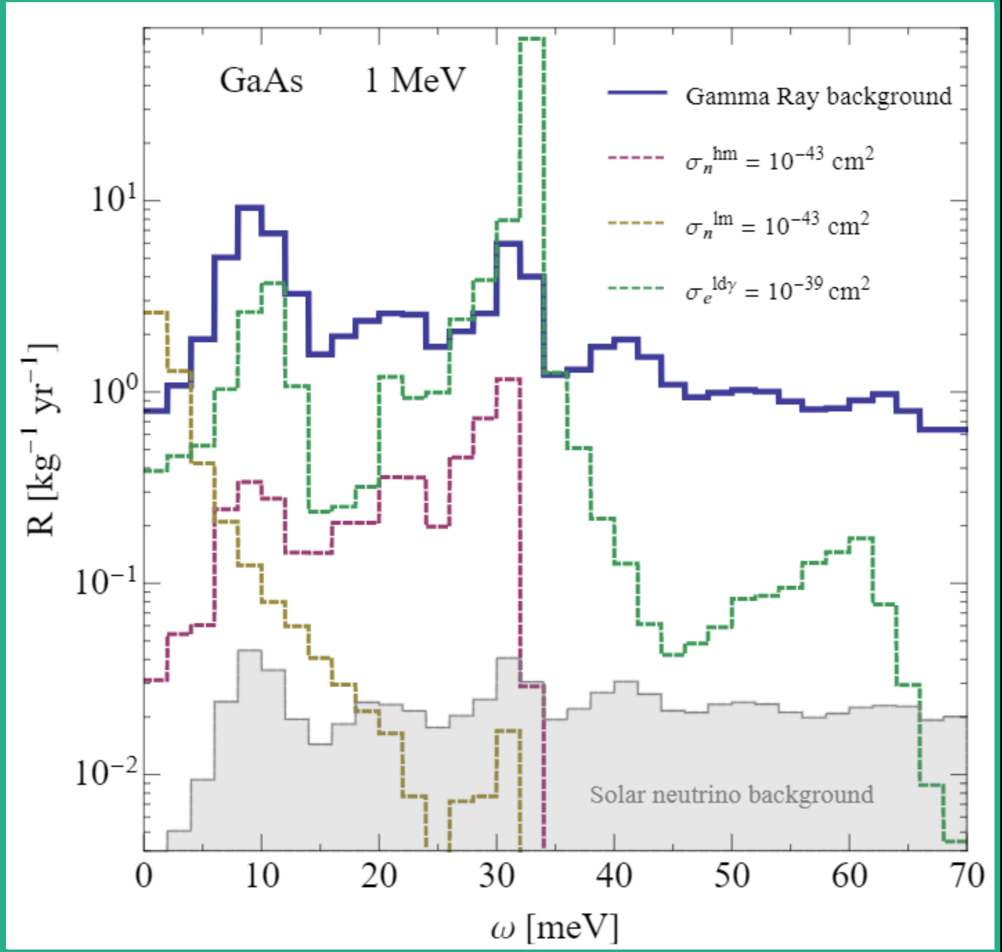
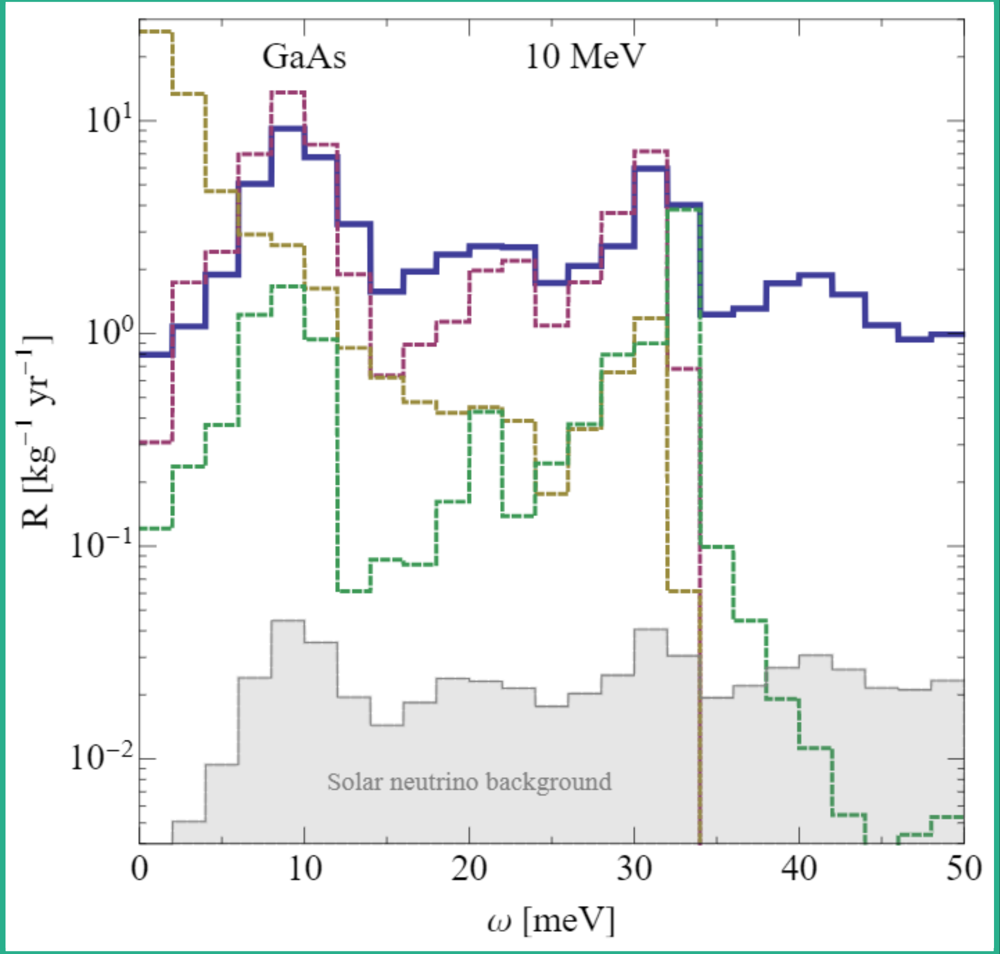
hm and lm have the same $S(\boldsymbol{q}, \omega)$ as the background

ldγ model can polarize materials (different $S(\boldsymbol{q}, \omega)$)

lm gets enhancement at small ω due to $\frac{d\sigma}{dq} \propto \frac{q_0^4}{q^4}$

Comparison to Signal Rates





Conclusions

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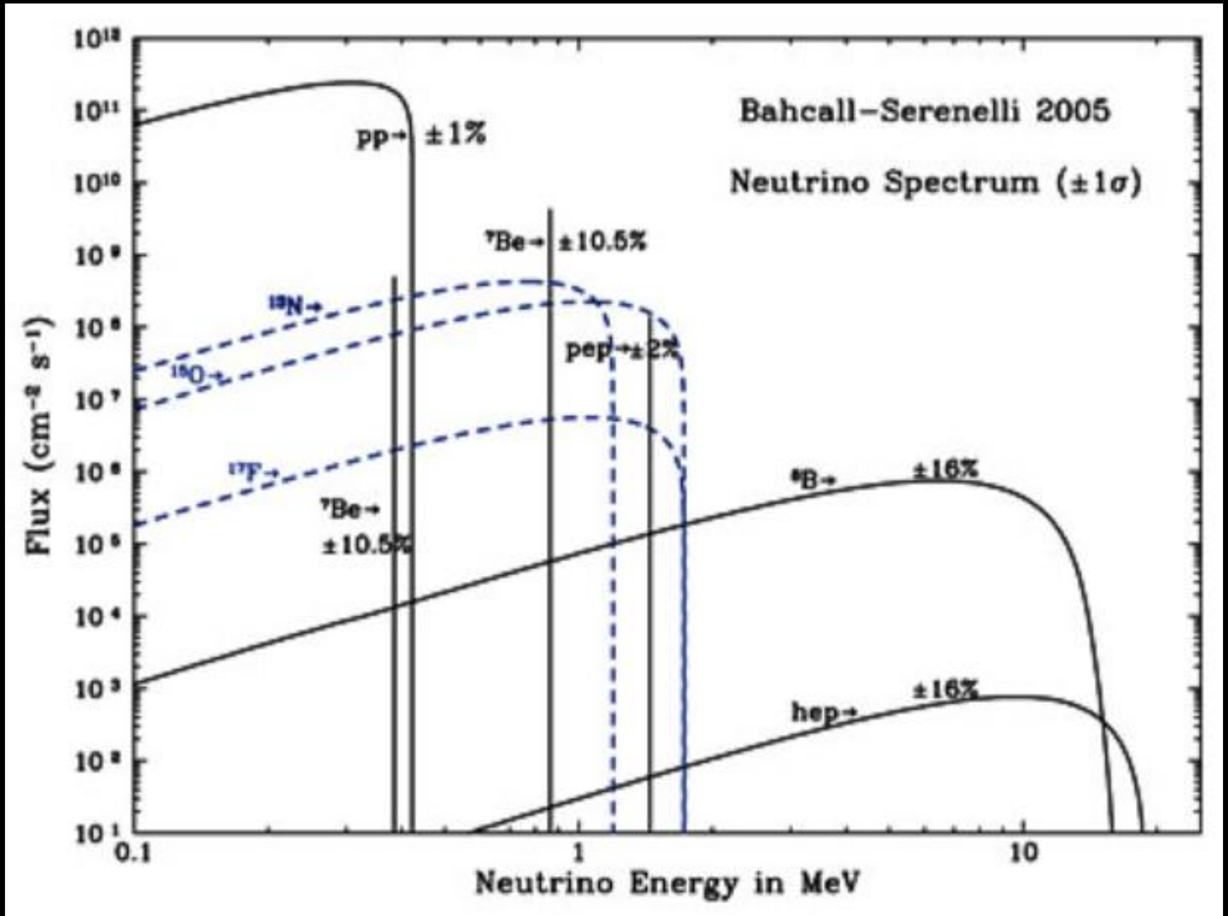
- Detector veto can only reduce background by O(1) fraction
- Gamma-ray background dominant over neutrino background
- Active veto needed to achieve sufficient background suppression
- Calculations available publicly on Github: https://github.com/KBerghaus/phonon_background

Thank you!

Backup

Solar Neutrino Flux



Bahcall, Serenelli, and Basu, *ApJ*, 621, L85 (2005)

$$\frac{d\sigma_{N\nu}}{d\Omega}(\boldsymbol{q}, E_\gamma) = \frac{G_F^2}{4\pi}\, q\, Q_W^2 \left(1 - \frac{q^2}{4{E_\gamma}^2}\right) |F(q)|^2$$

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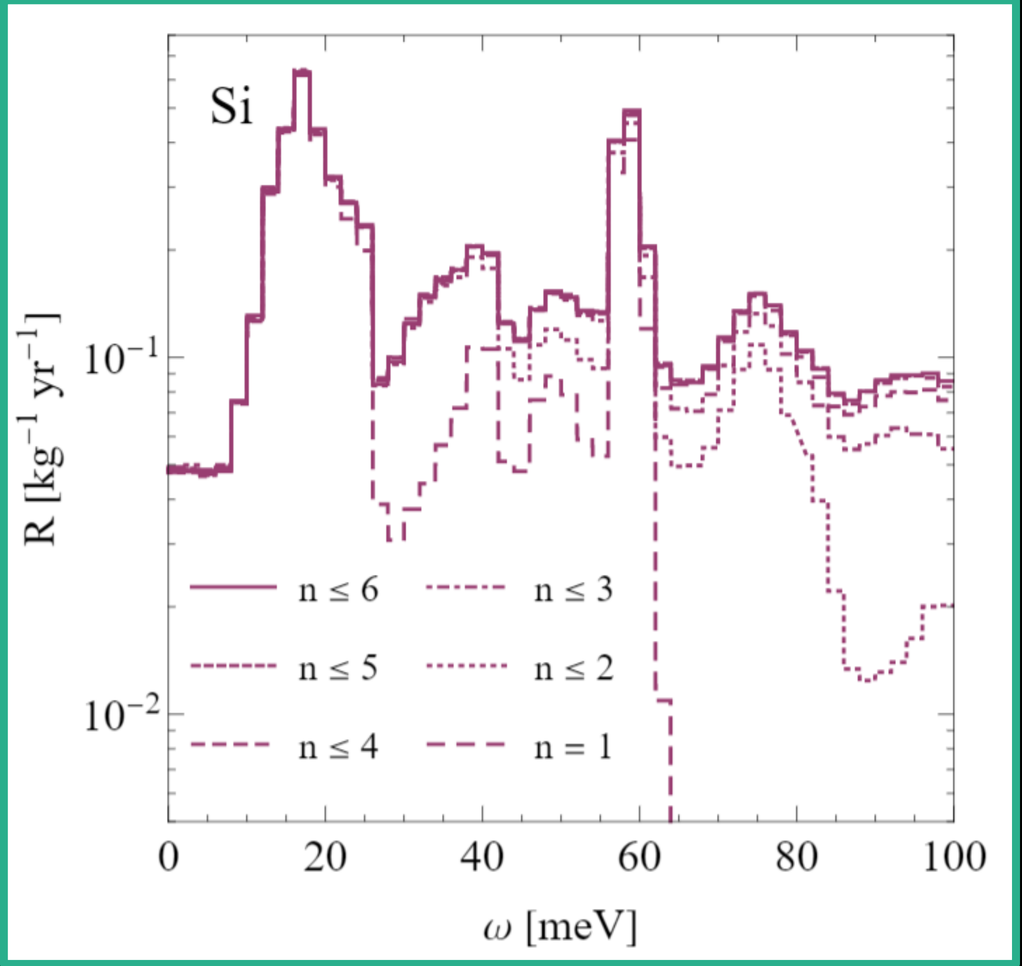
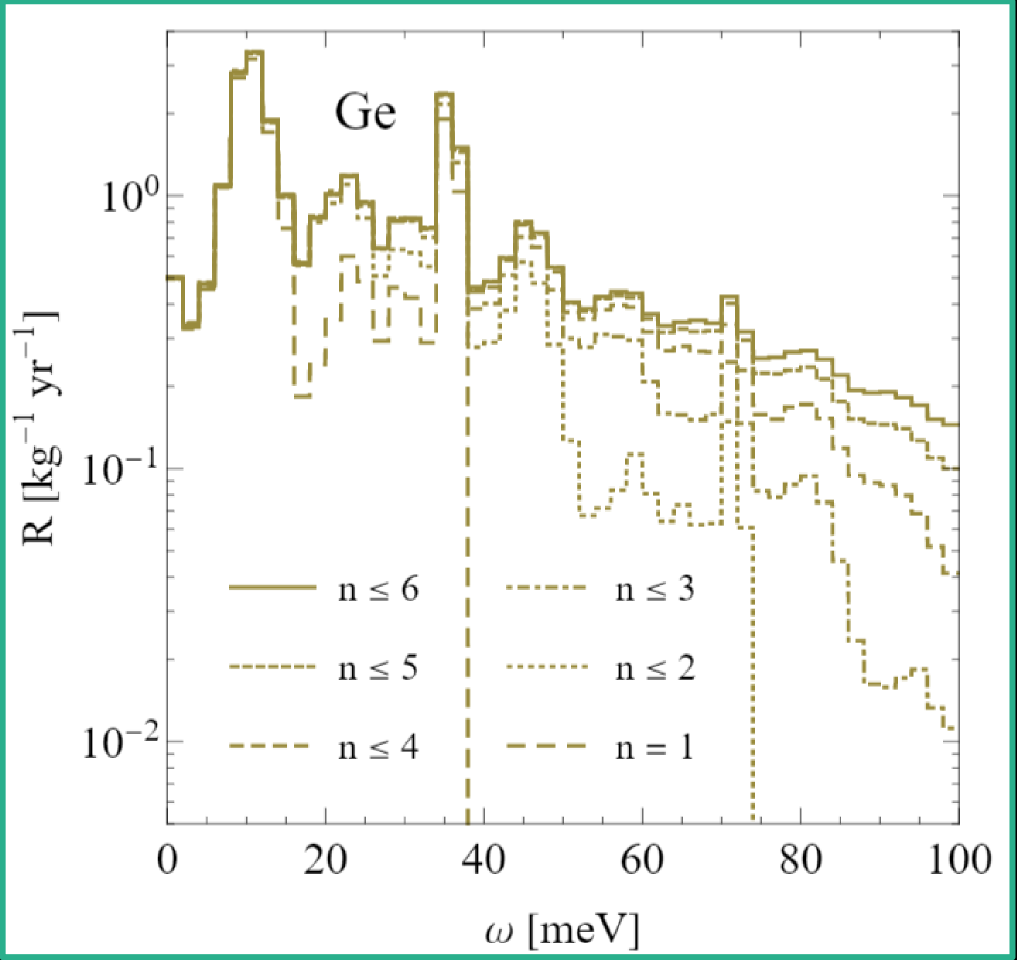


Si
R [kg^{-1} yr^{-1}]
10^{-1}
10^{-2}
n ≤ 6
n ≤ 5
n ≤ 4
n ≤ 3
n ≤ 2
n = 1
0
20
40
60
80
100
ω [meV]



Ge
R [kg^{-1} yr^{-1}]
10^{0}
10^{-1}
10^{-2}
n ≤ 6
n ≤ 5
n ≤ 4
n ≤ 3
n ≤ 2
n = 1
0
20
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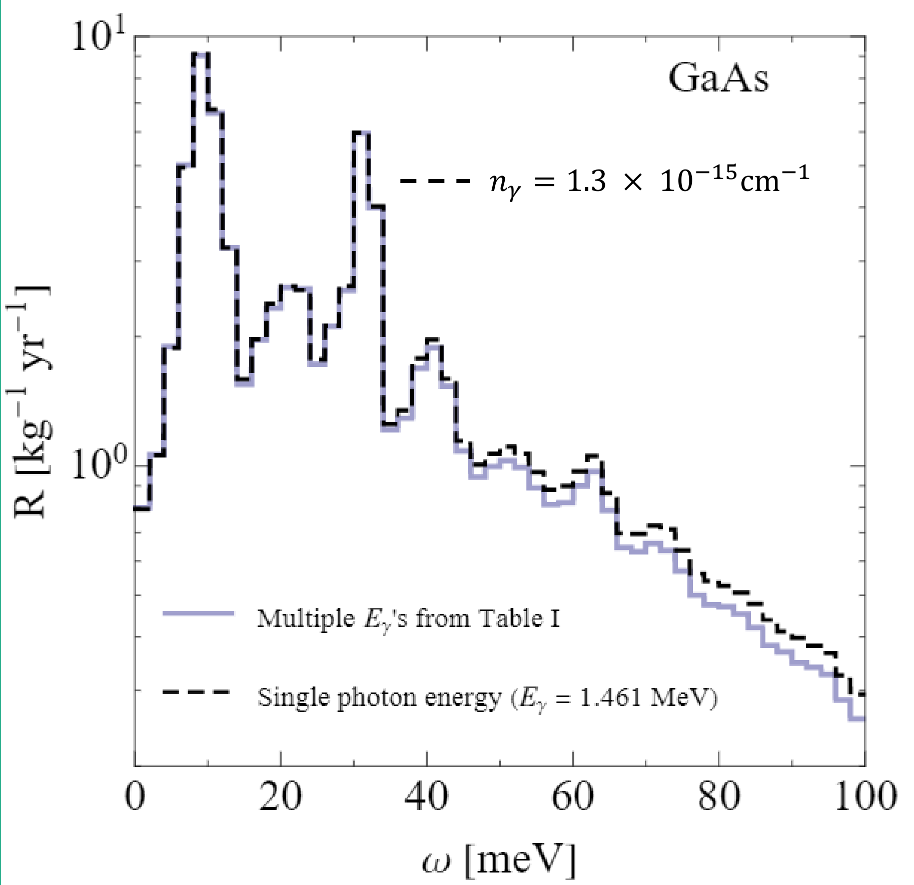
100
ω [meV]

Backup



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