# *Light DM searches (with xenon detectors)*

Christopher McCabe
arXiv:1702.04730

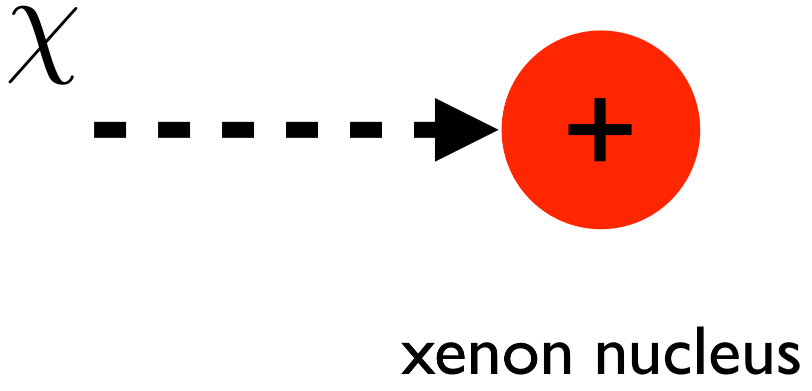
LDMA17
La Biodola - Isola d'Elba
26 May 2017

# Outline

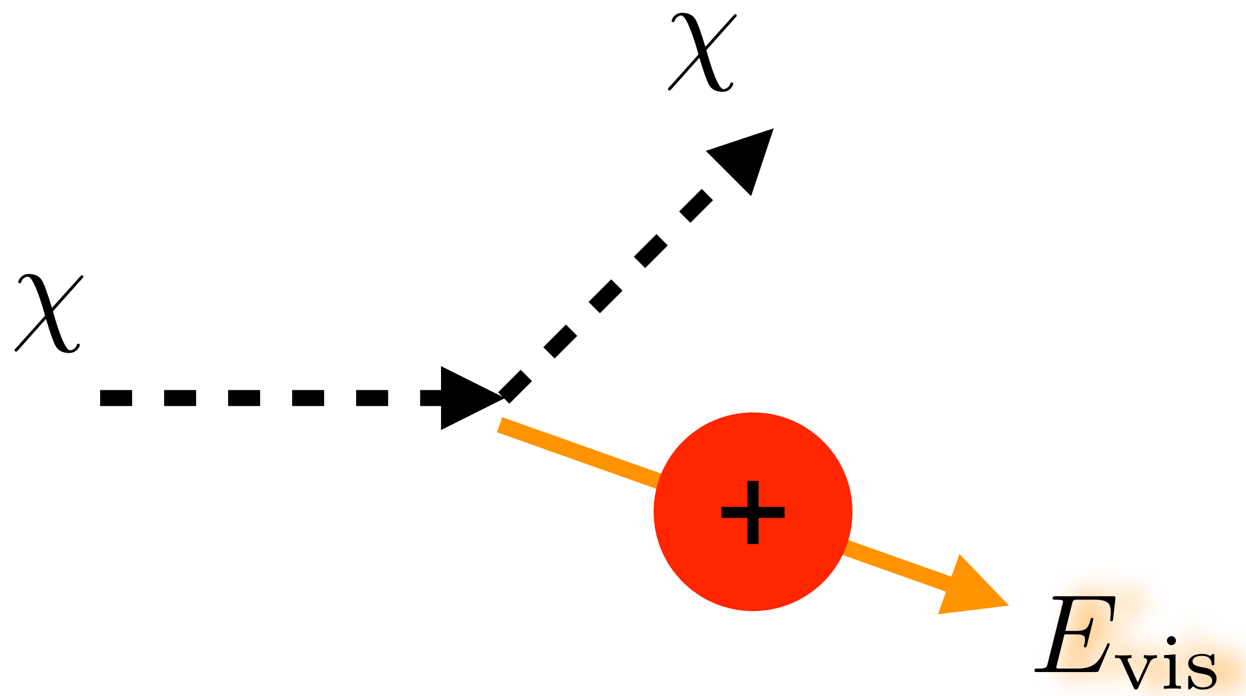
A theorists perspective on…

- Limitations of standard searches
- Light DM searches:
    - Scattering with electrons
    - Absorption by electrons
    - Polarised atom emission

# The standard search



# The standard search




measure recoil energy
of the xenon nucleus

$$E_{\rm vis}^{\rm max} \approx 0.1 \text{ keV} \times (m_{\rm DM}/1 \text{ GeV})^2$$

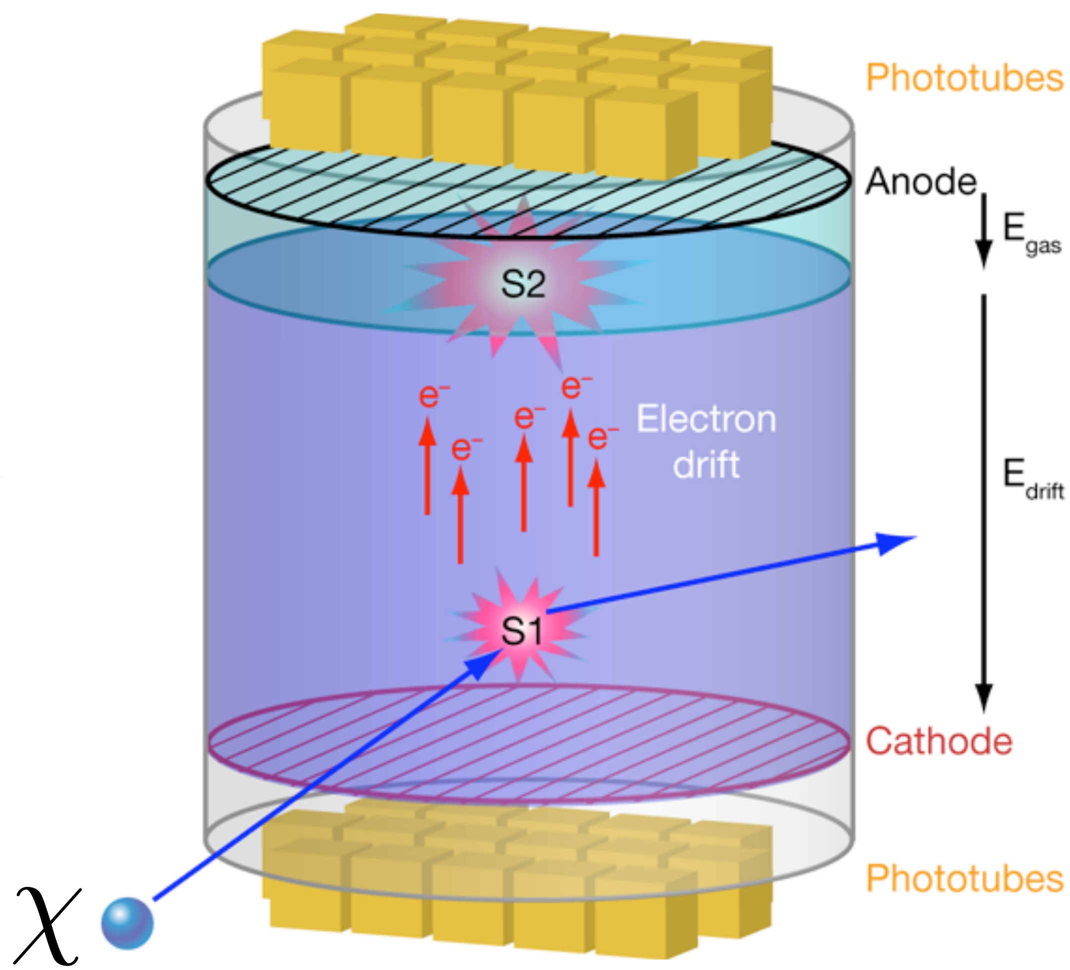
# The standard search: S1+S2

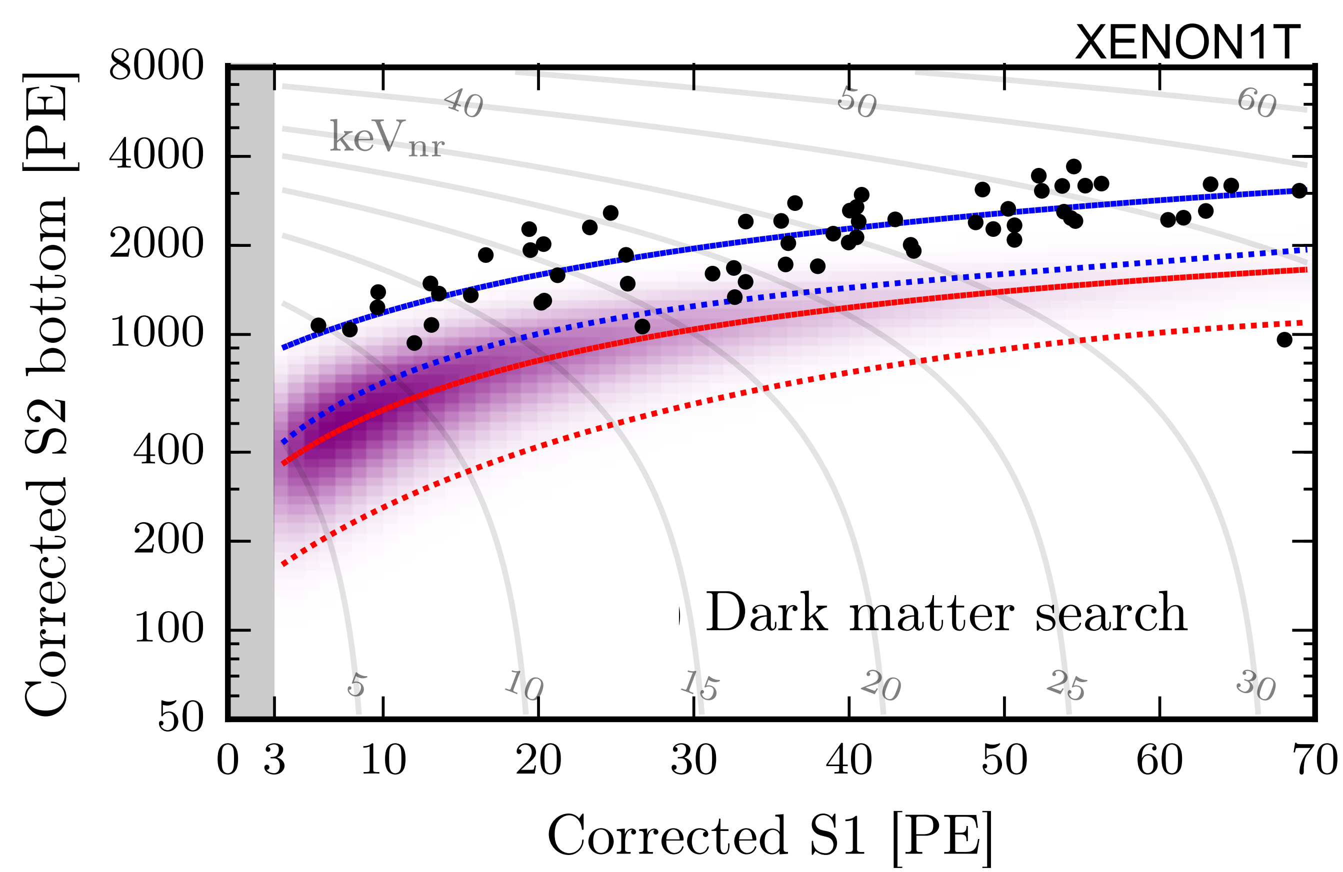
- The measurable signals are termed S1 and S2

S1: *proportional to # VUV photons*

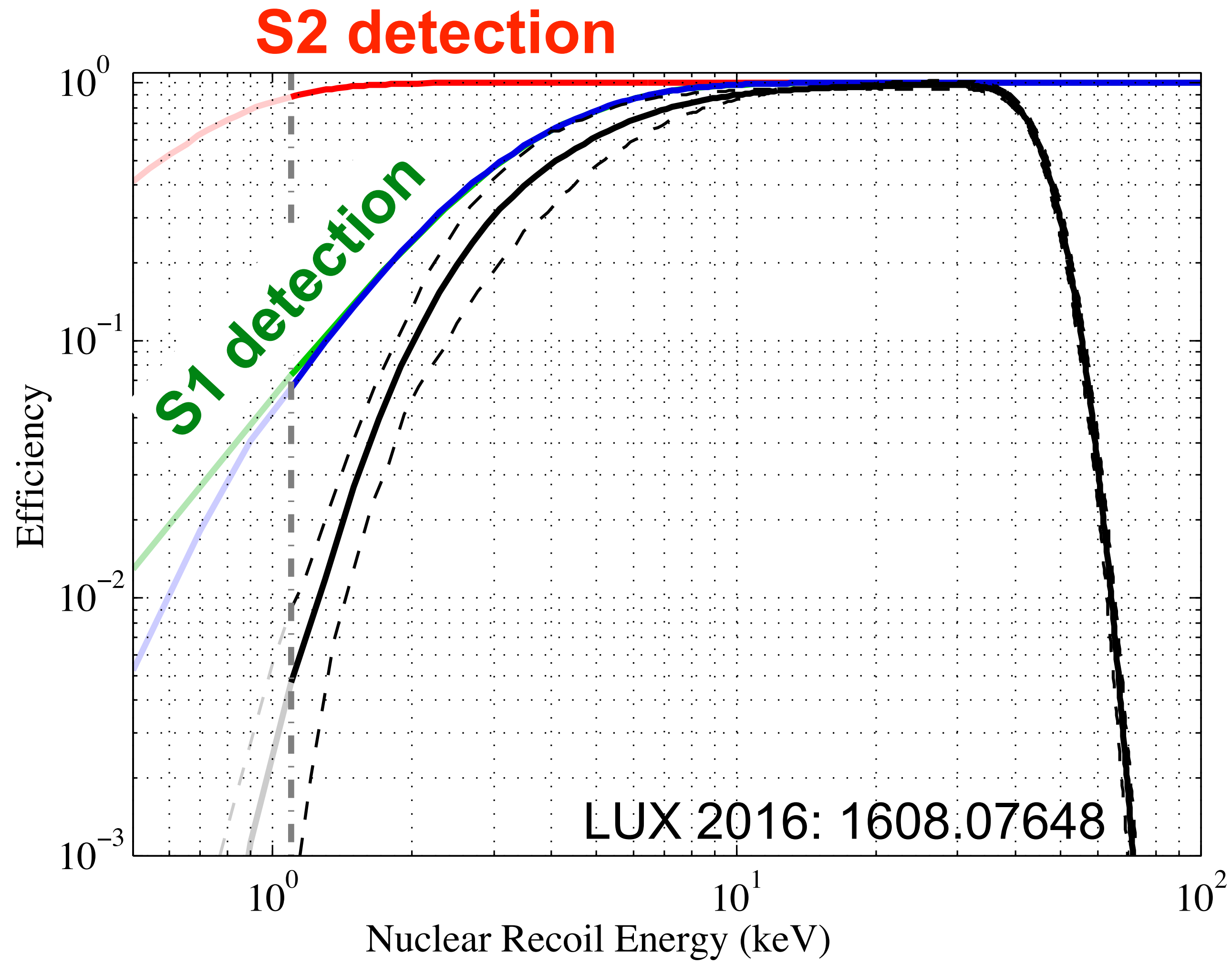
S2: *proportional to # electrons*

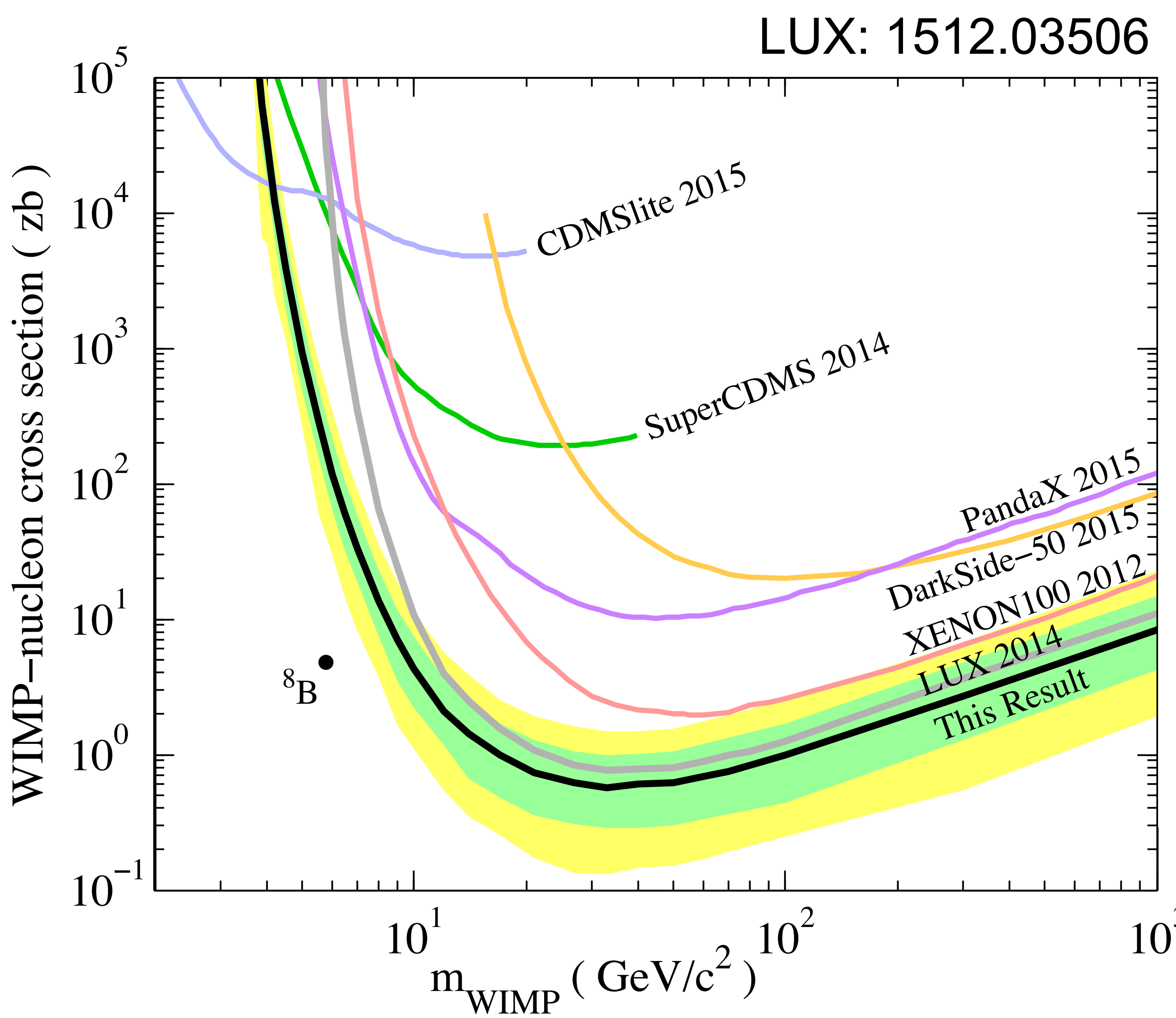
S1+S2: *3D position reconstruction + background identification*



# Standard S1+S2: limited by S1 efficiency



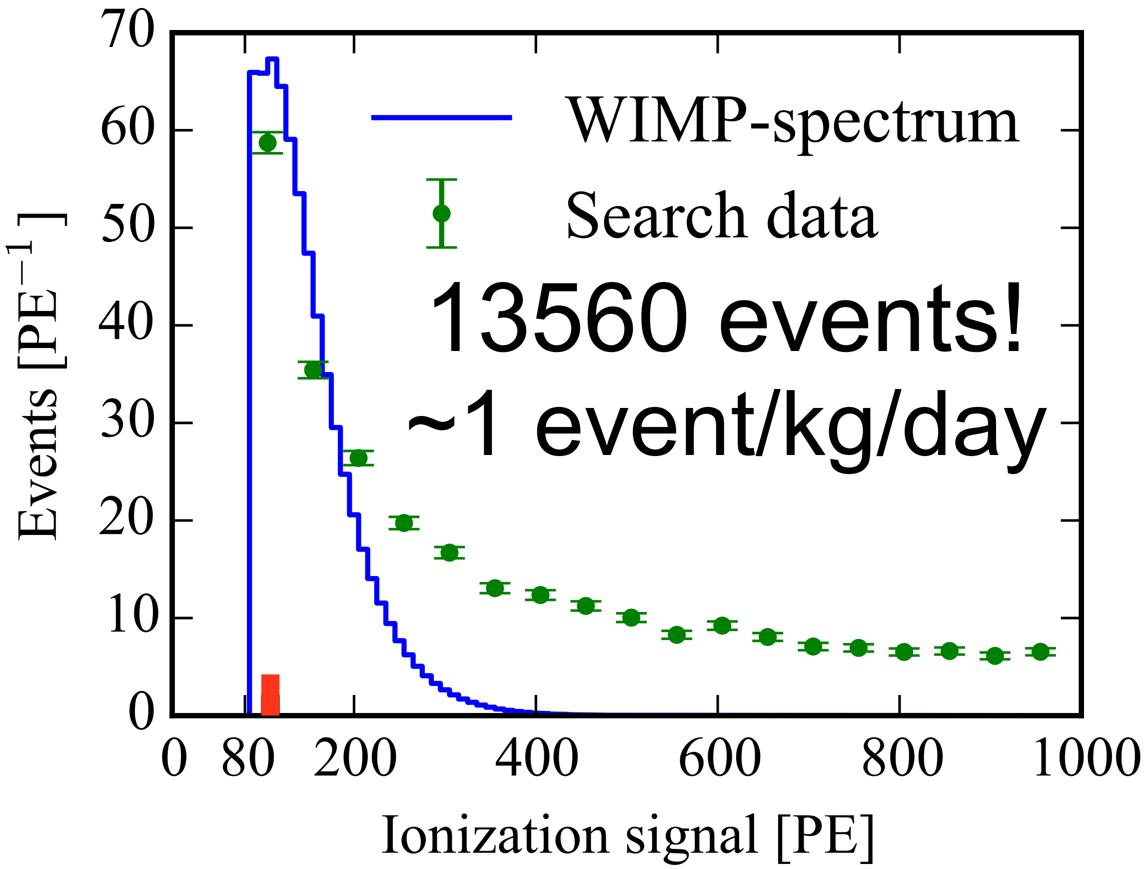



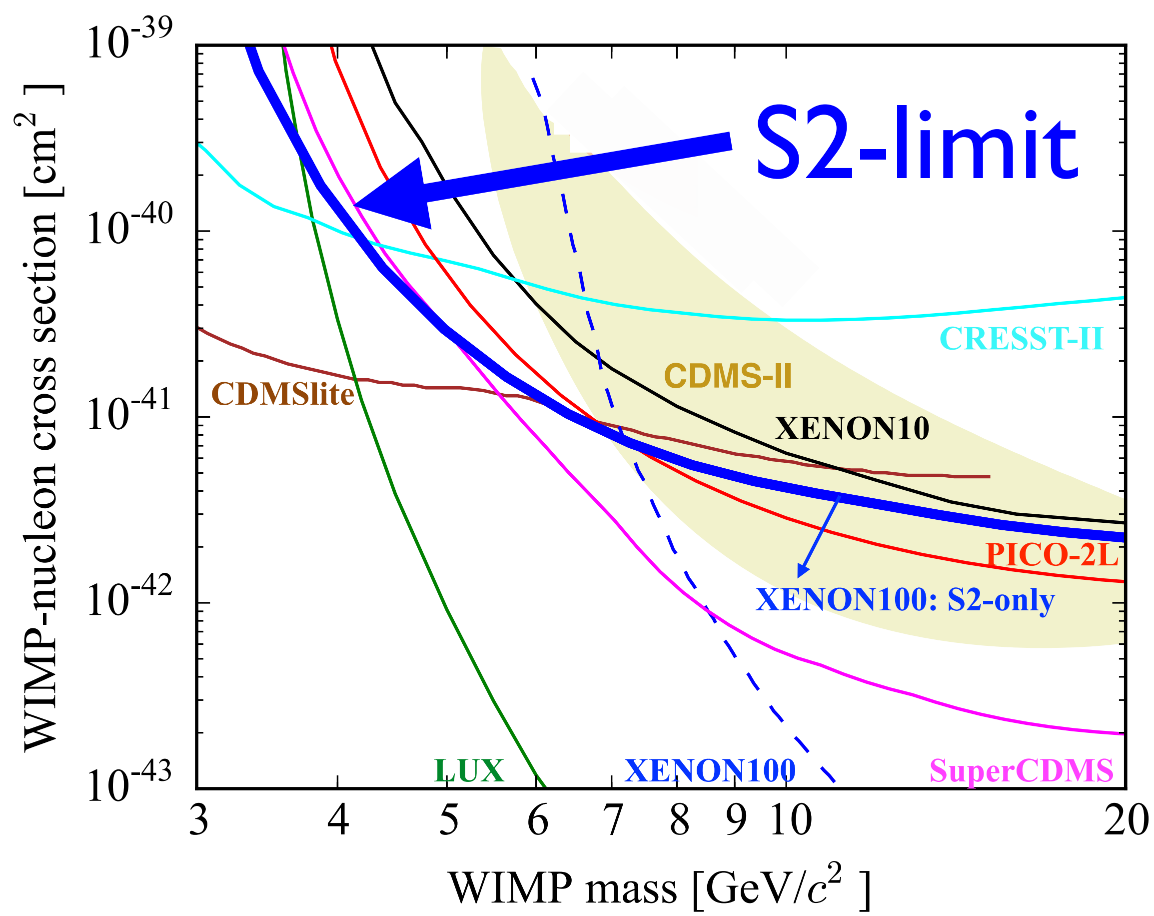

$$\boxed{m_{\mathrm{DM}} \gtrsim 4\ \mathrm{GeV}}$$

# S2-only (from XENON100)

XE100: 1605.06262

- Advantage: lower threshold (in principle)
- Disadvantage: background ~$10^4$ higher

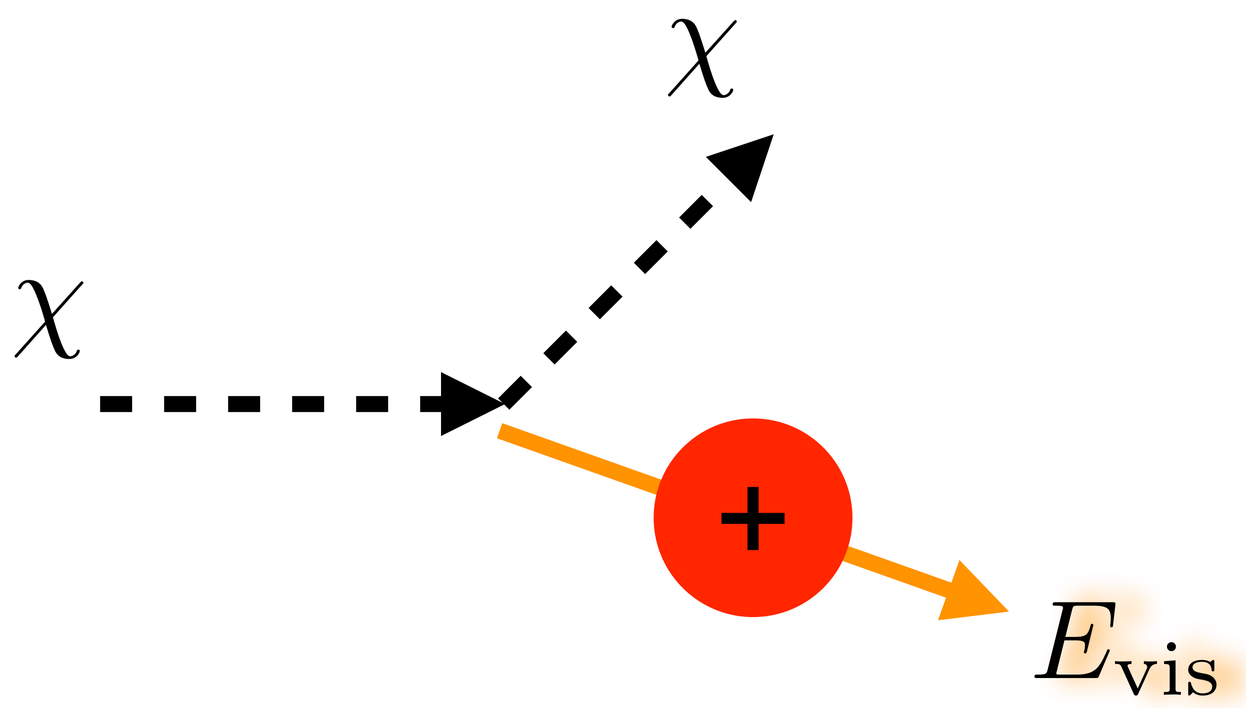



$$\boxed{m_{\mathrm{DM}} \gtrsim 3\ \mathrm{GeV}}$$

(conservative value)

# The standard search(es): summary

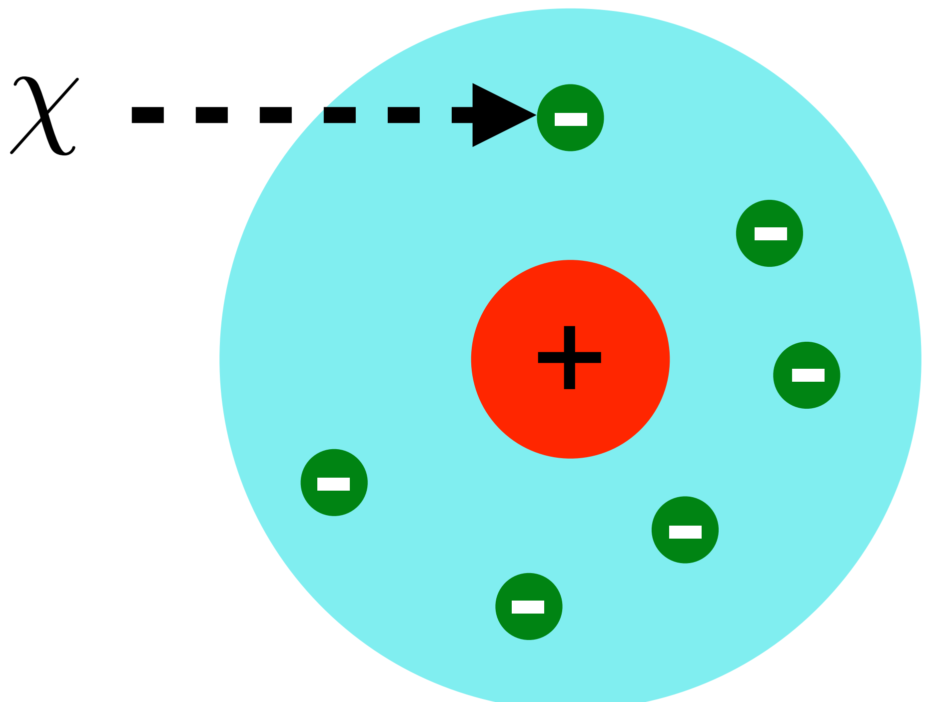



measure nucleus energy

$$\boxed{m_{\text{DM}} \gtrsim 3 \text{ GeV}}$$

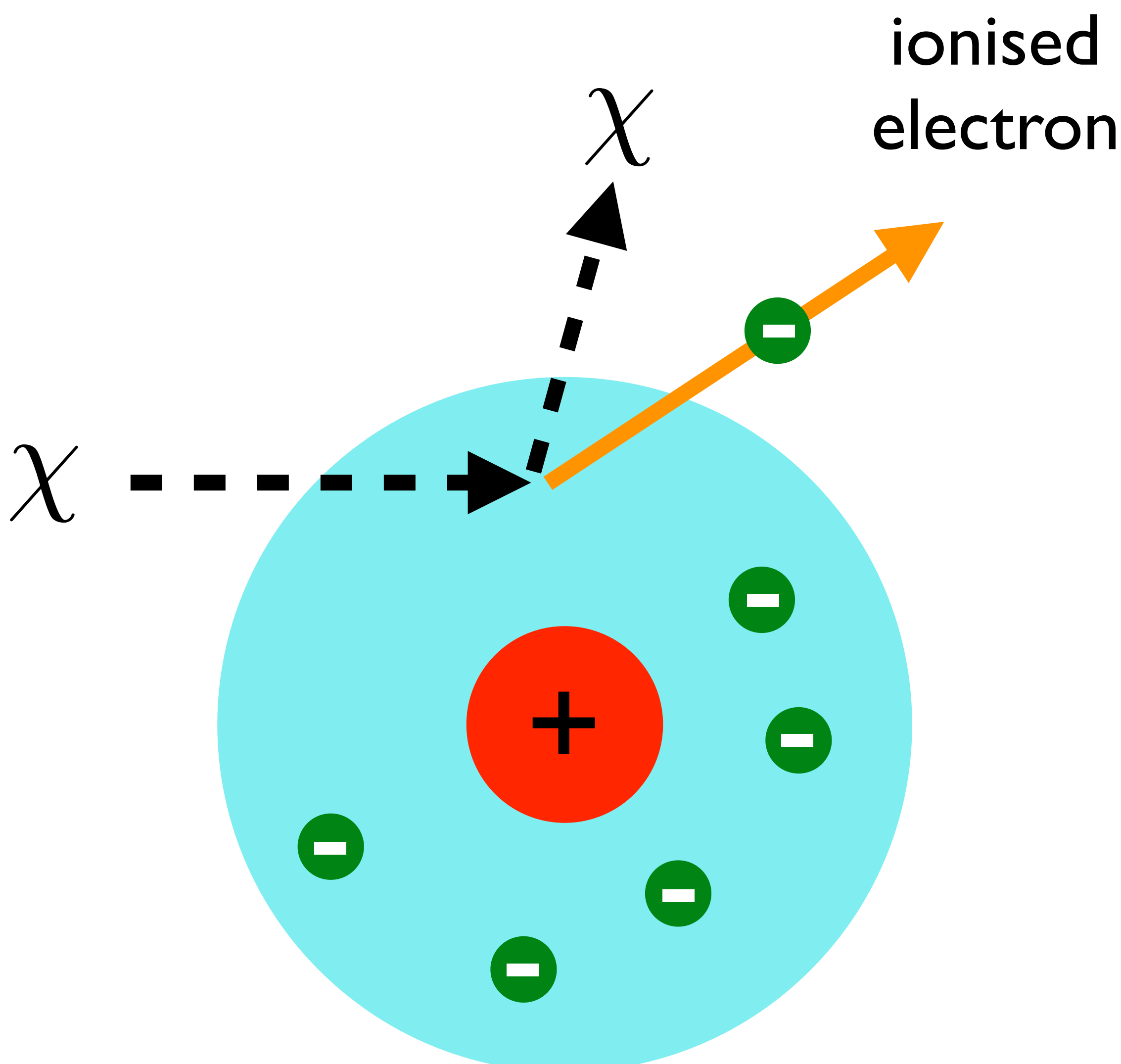
# Light DM 1: electron scattering

Kopp, Niro, Schwetz, Zupan, 0907.3159
Essig, Mardon, Volansky, 1108.5383, PRD
Essig, Manalaysay, Mardon, Sorensen, Volansky, 1206.2644, PRL
…




xenon atom
(ground state)

# Light DM 1: electron scattering

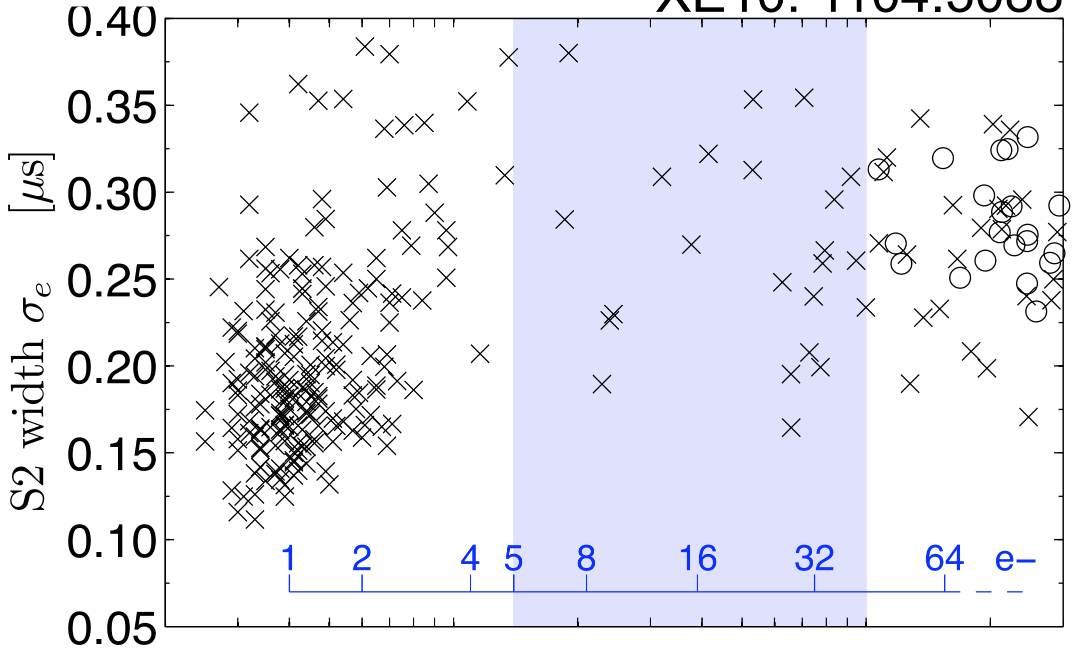



- $\frac{1}{2} m_{\rm DM} v_{\rm DM}^2 \gtrsim E_{\rm binding} (\sim 12 \text{ eV})$
- ZEPLIN, XE10 & XE100 all demonstrated single electron extraction (S2 only)

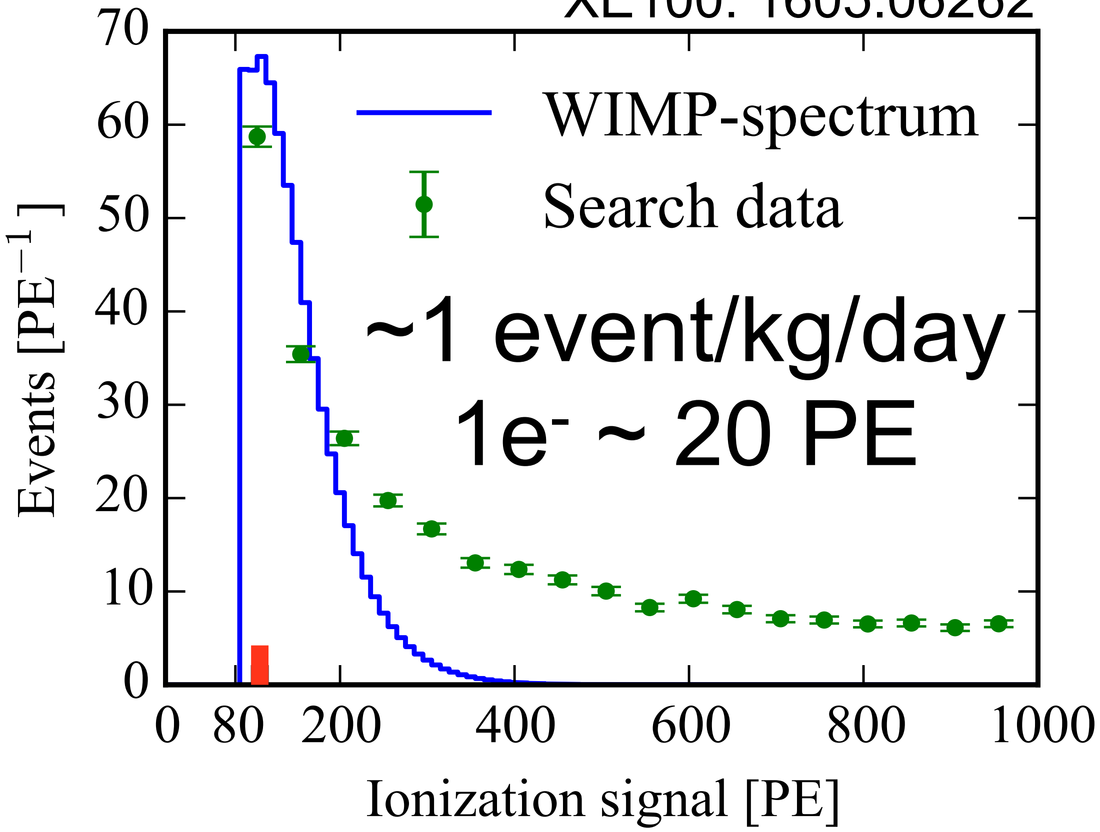
$$\boxed{m_{\rm DM} \gtrsim 4 \text{ MeV}}$$

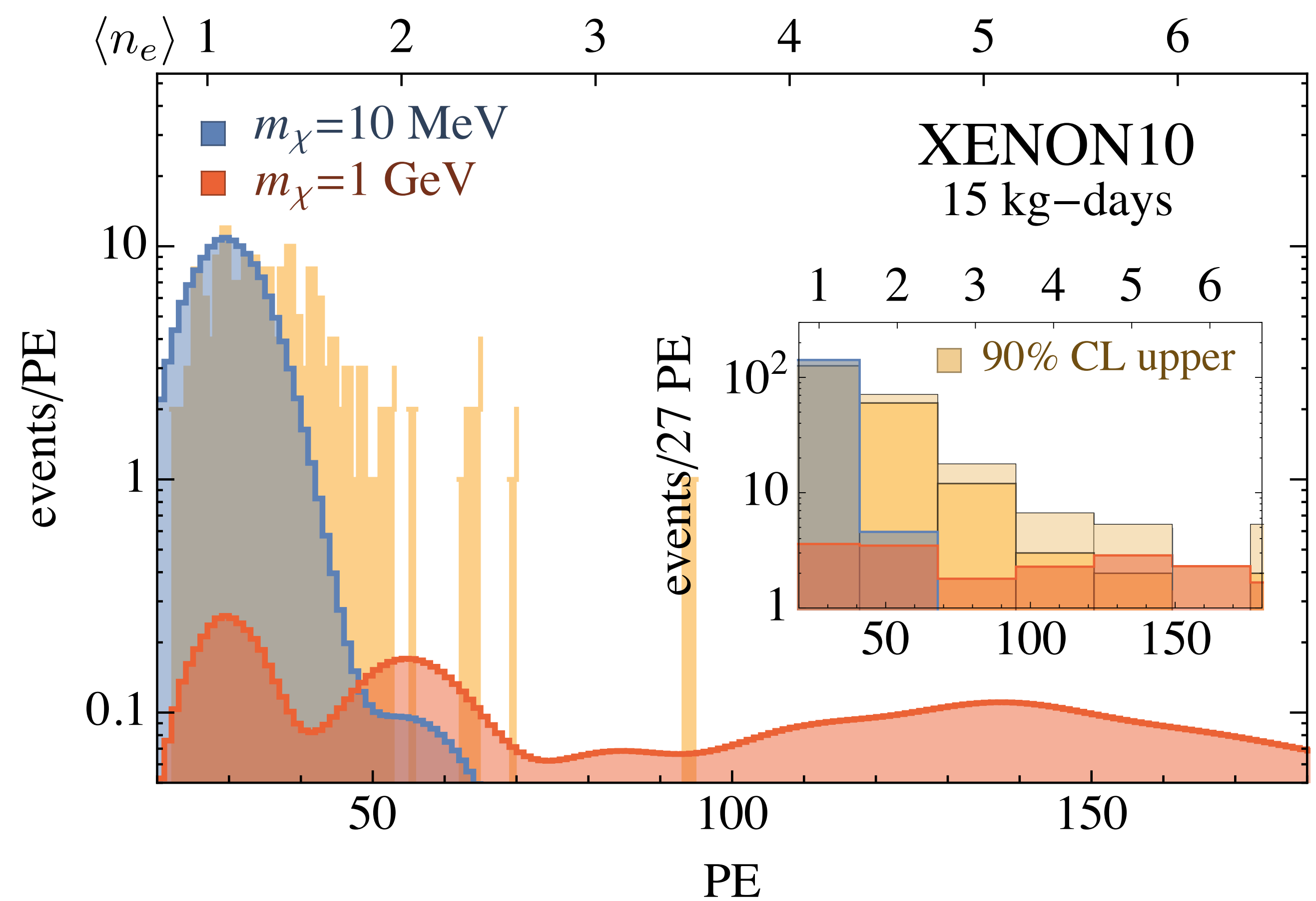
# Electron scattering: limits from S2-only

XE10: 1104.3088



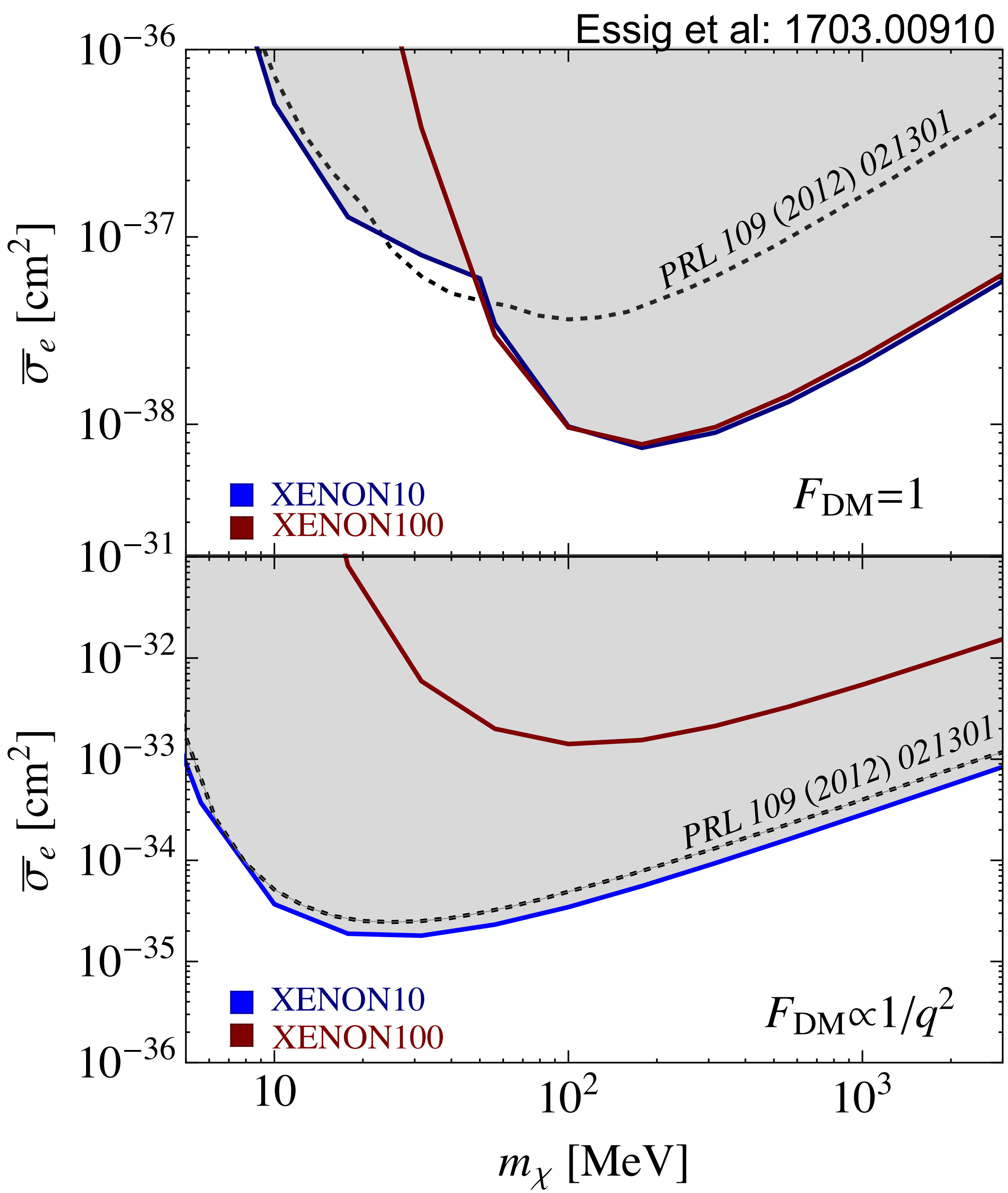

XE100: 1605.06262



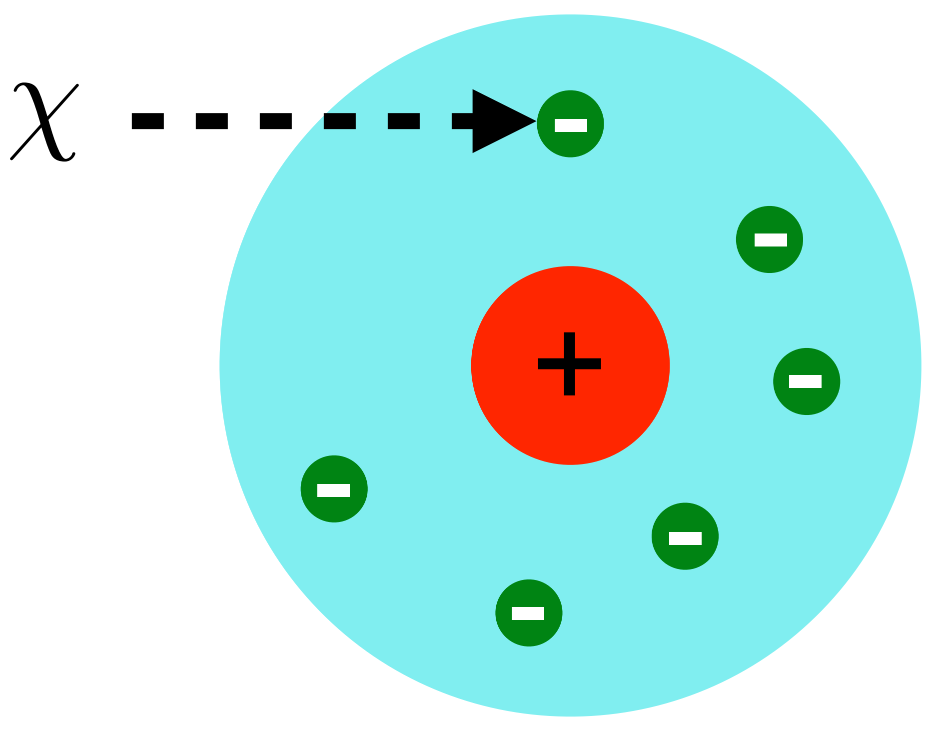




Essig et al: 1703.00910

# Electron scattering: limits from S2-only

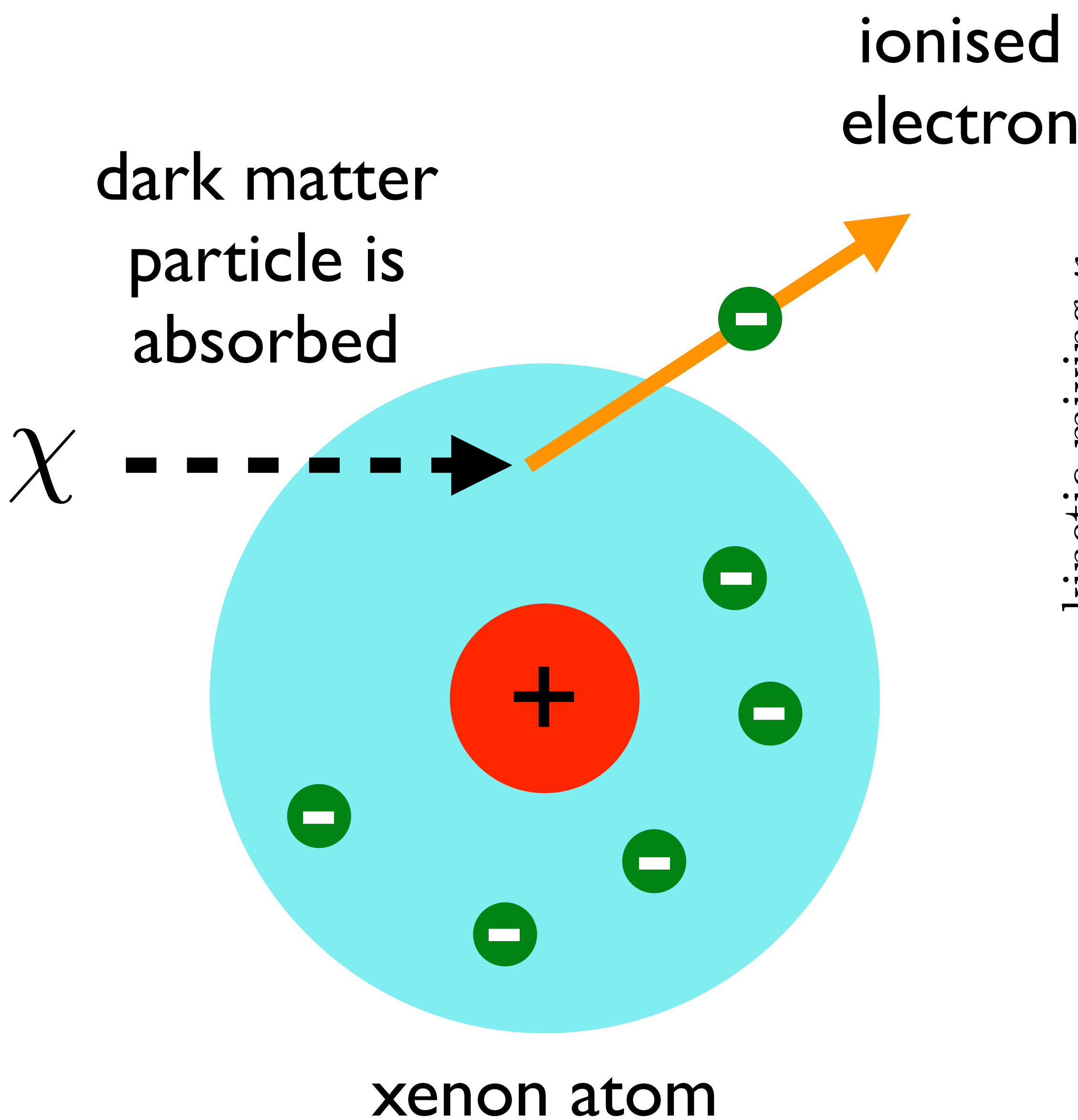


# Light DM 2: absorption

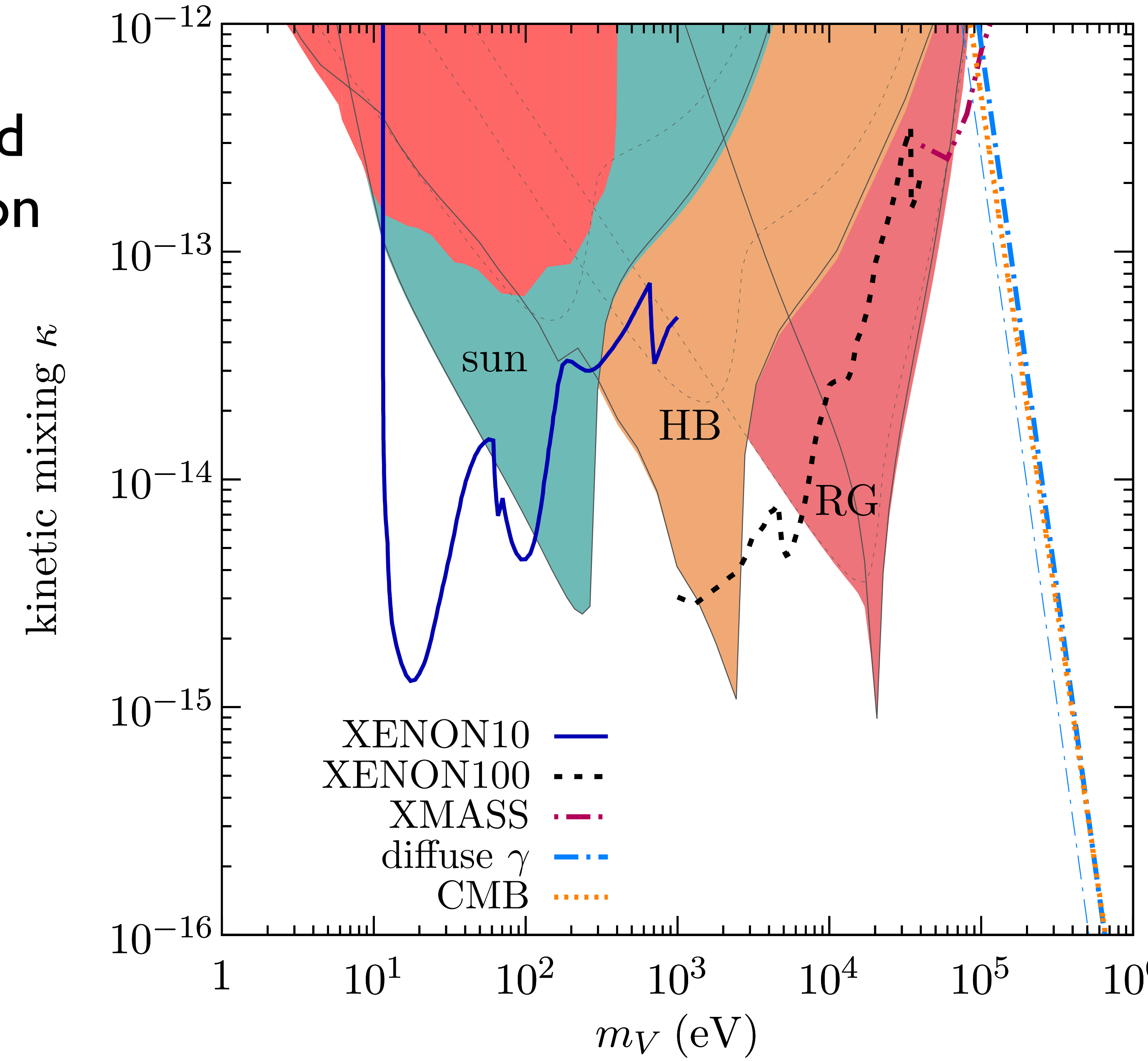



xenon atom
(ground state)

# Light DM 2: absorption



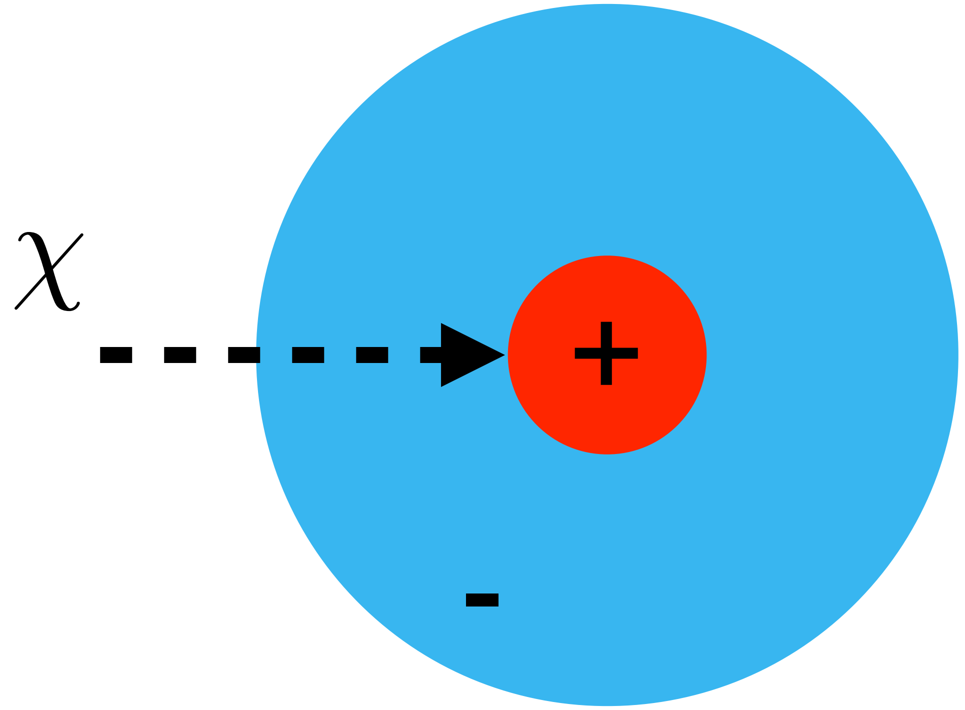

An et al: 1412.8378




$$m_{\rm DM} \gtrsim E_{\rm binding} (\sim 12 \text{ eV})$$

# Light DM 3: polarised atom emission

Kouvaris & Pradler
1607.01789, PRL




xenon atom
(ground state)

# Light DM 3: polarised atom emission

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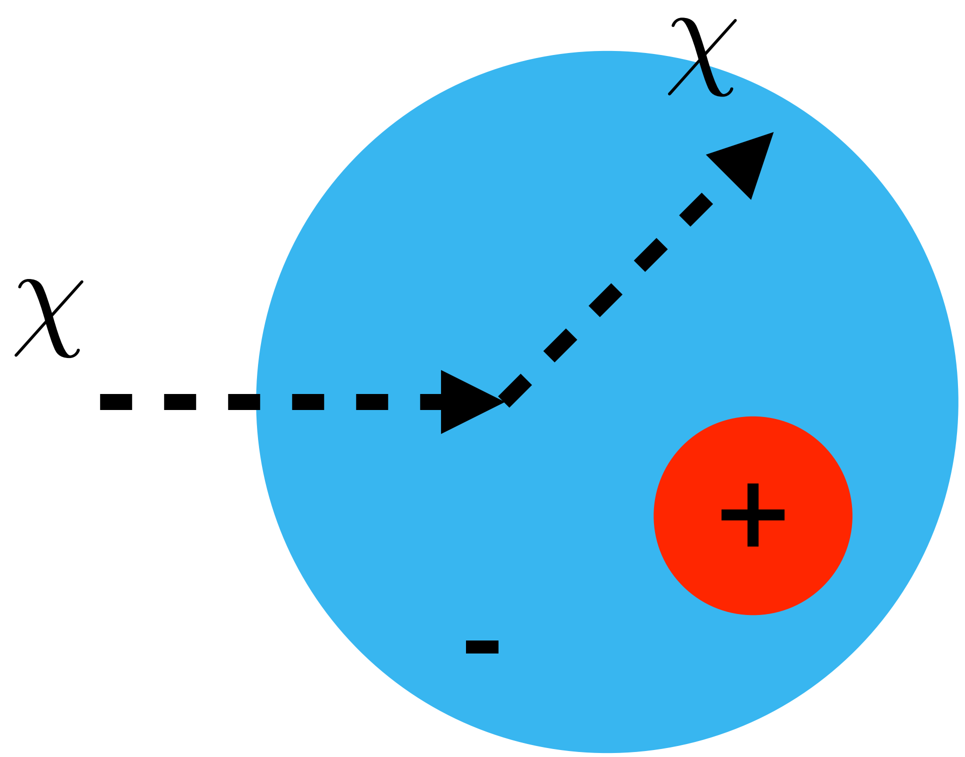
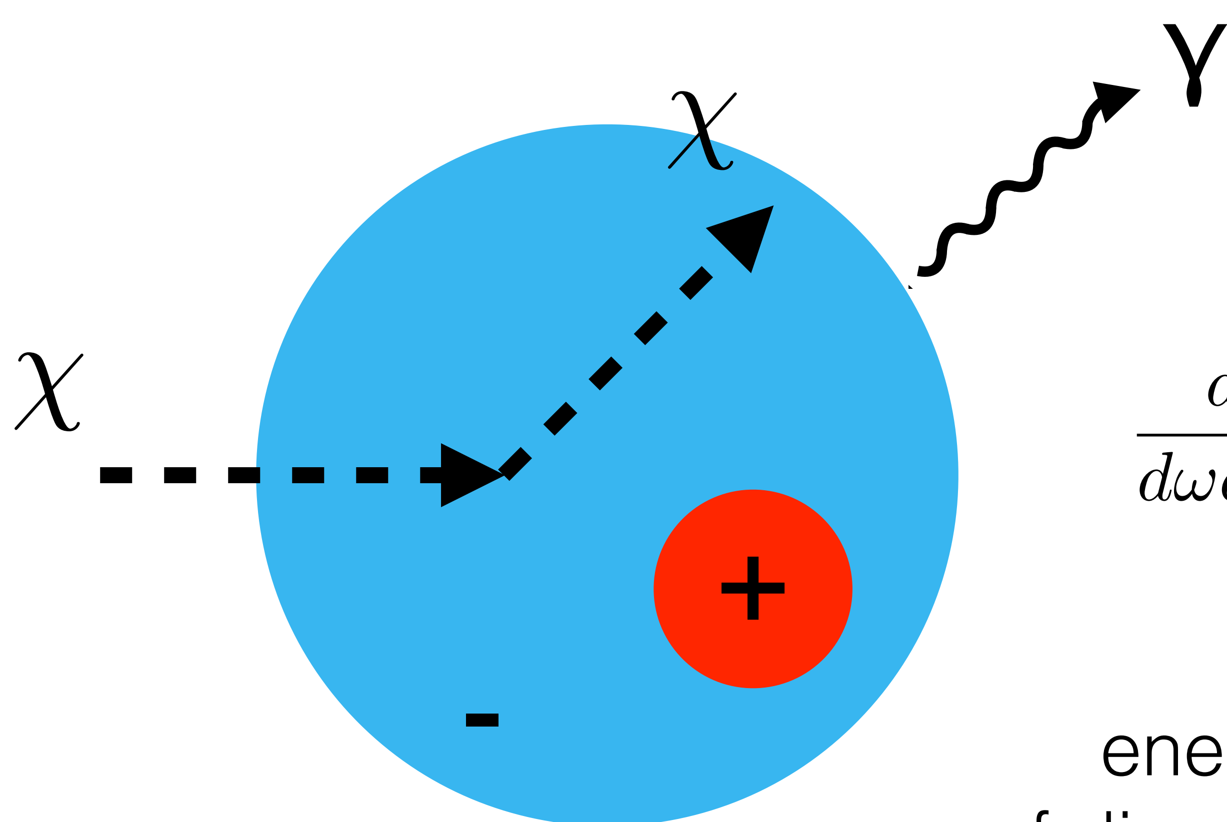



xenon atom
(polarised)

# Light DM 3: polarised atom emission

Kouvaris & Pradler
1607.01789, PRL



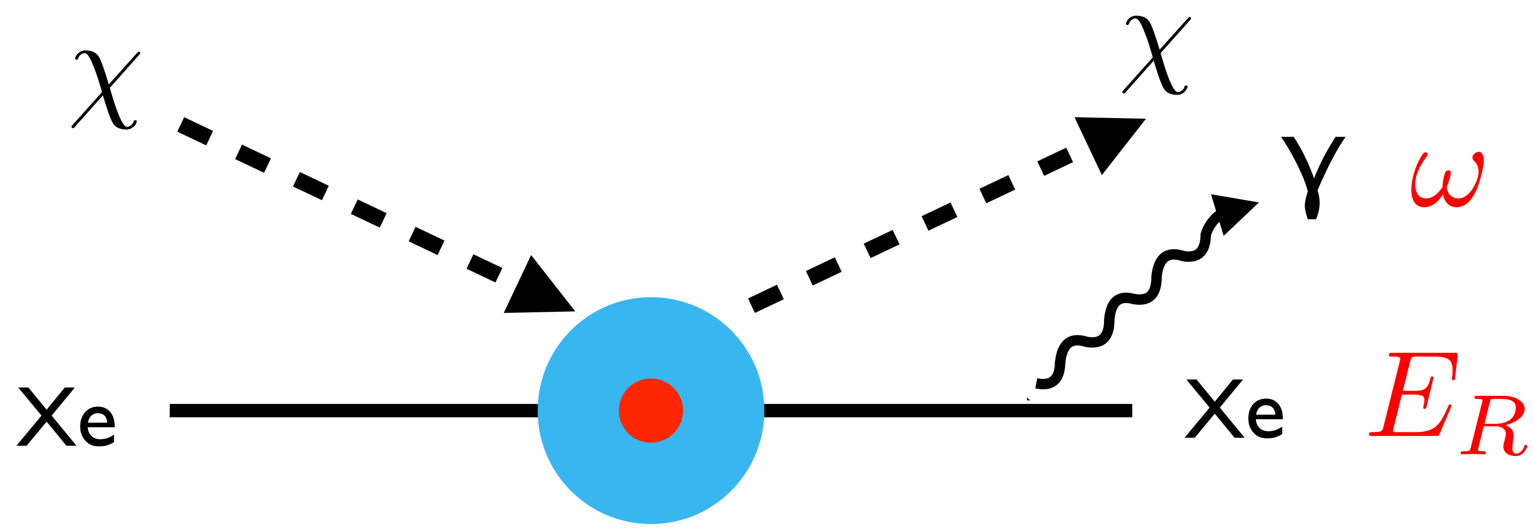

Polarised atom emits a photon

$$\frac{d\sigma}{d\omega dE_R} \propto \omega^3 \times |\alpha(\omega)|^2 \times \frac{E_R}{m_N} \times \frac{d\sigma}{dE_R}$$

energy scaling of dipole emission

polarizability of the atom

# Polarised atom emission: a detectable signal



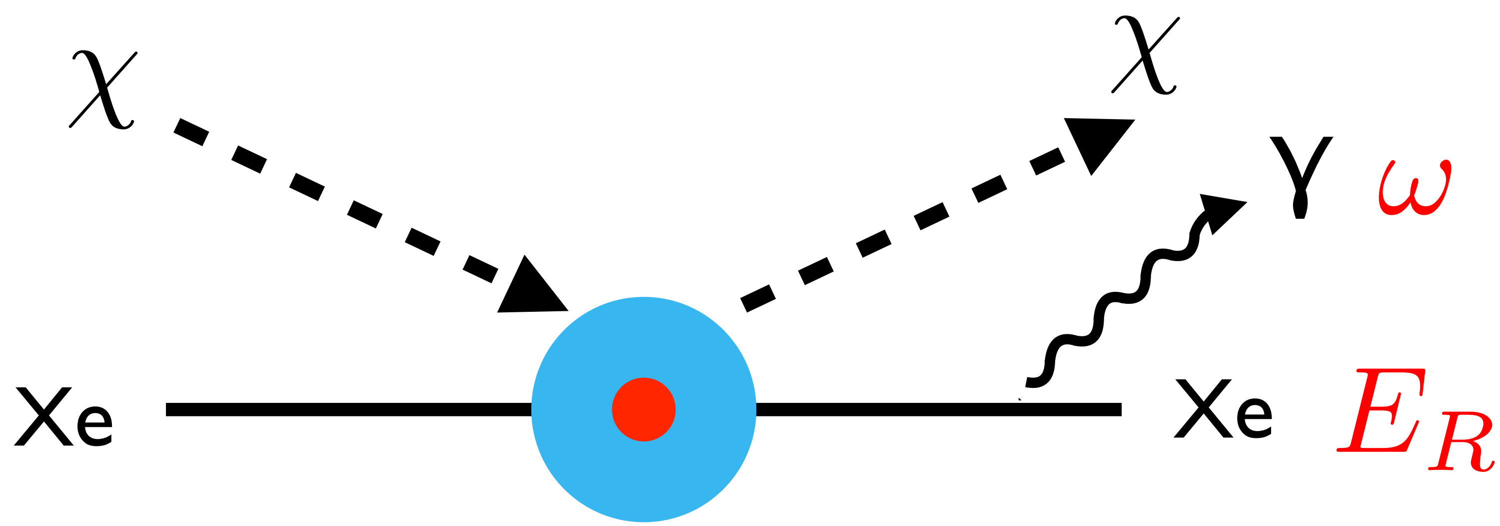

Photon energy is detectable:

$$\omega^{\rm max} \approx 3 \text{ keV} \cdot (m_{\rm DM}/1 \text{ GeV})$$

Nuclear recoil below threshold:

$$E_{\rm R}^{\rm max} \approx 0.1 \text{ keV} \cdot (m_{\rm DM}/1 \text{ GeV})^2$$

# Polarised atom emission: the catch

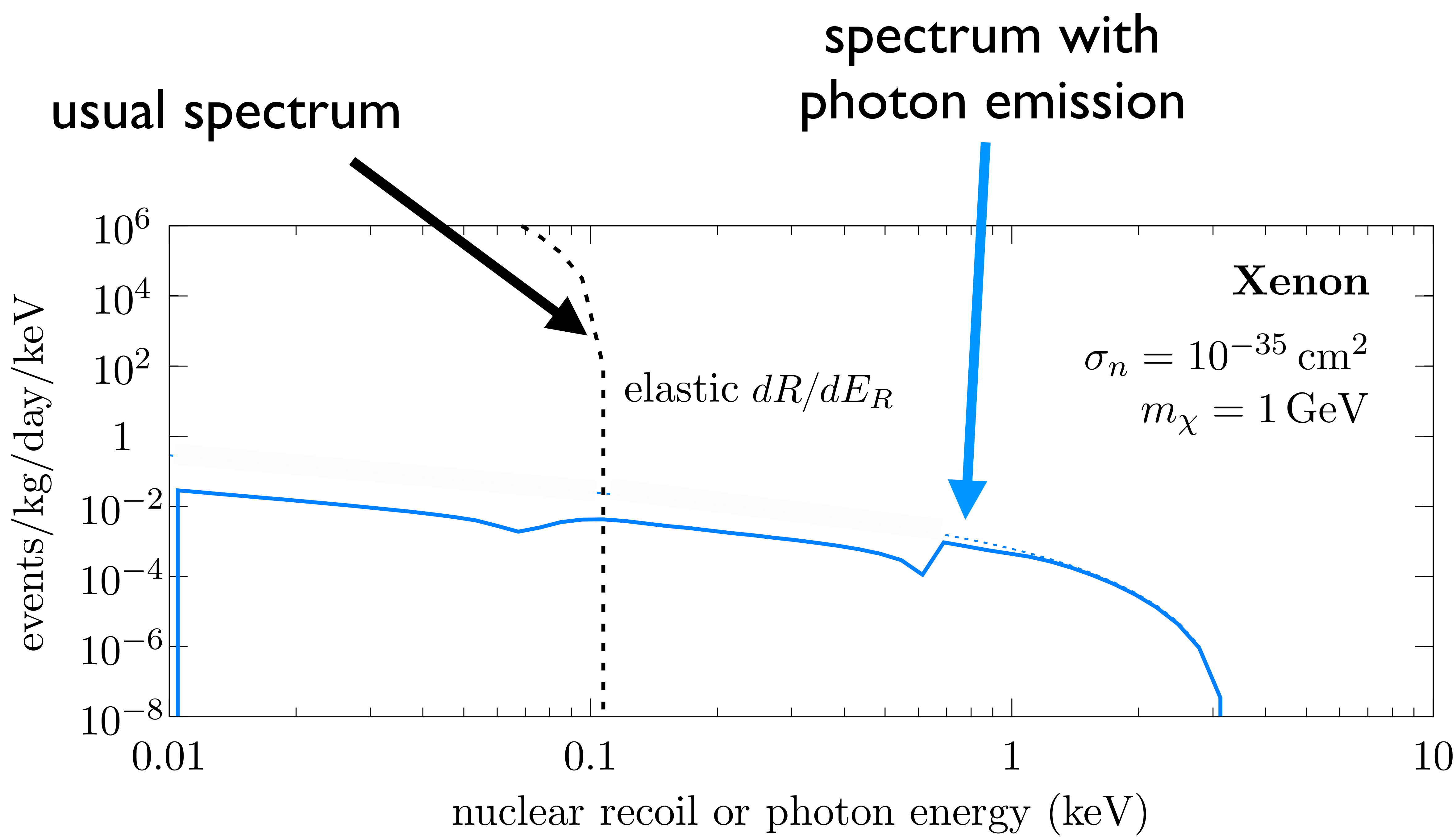



$$\frac{d\sigma}{dE_R d\omega} = \frac{4Z^2\alpha}{3\pi}\frac{1}{\omega}\frac{E_R}{m_N} \times \frac{d\sigma}{dE_R}\Theta(\omega - \omega_{\max})$$

**Price to pay**

$$\simeq \frac{7 \times 10^{-8}}{\omega}\left(\frac{E_R}{1\,\mathrm{keV}}\right) \times \frac{d\sigma}{dE_R} \quad \text{(Xenon)}$$

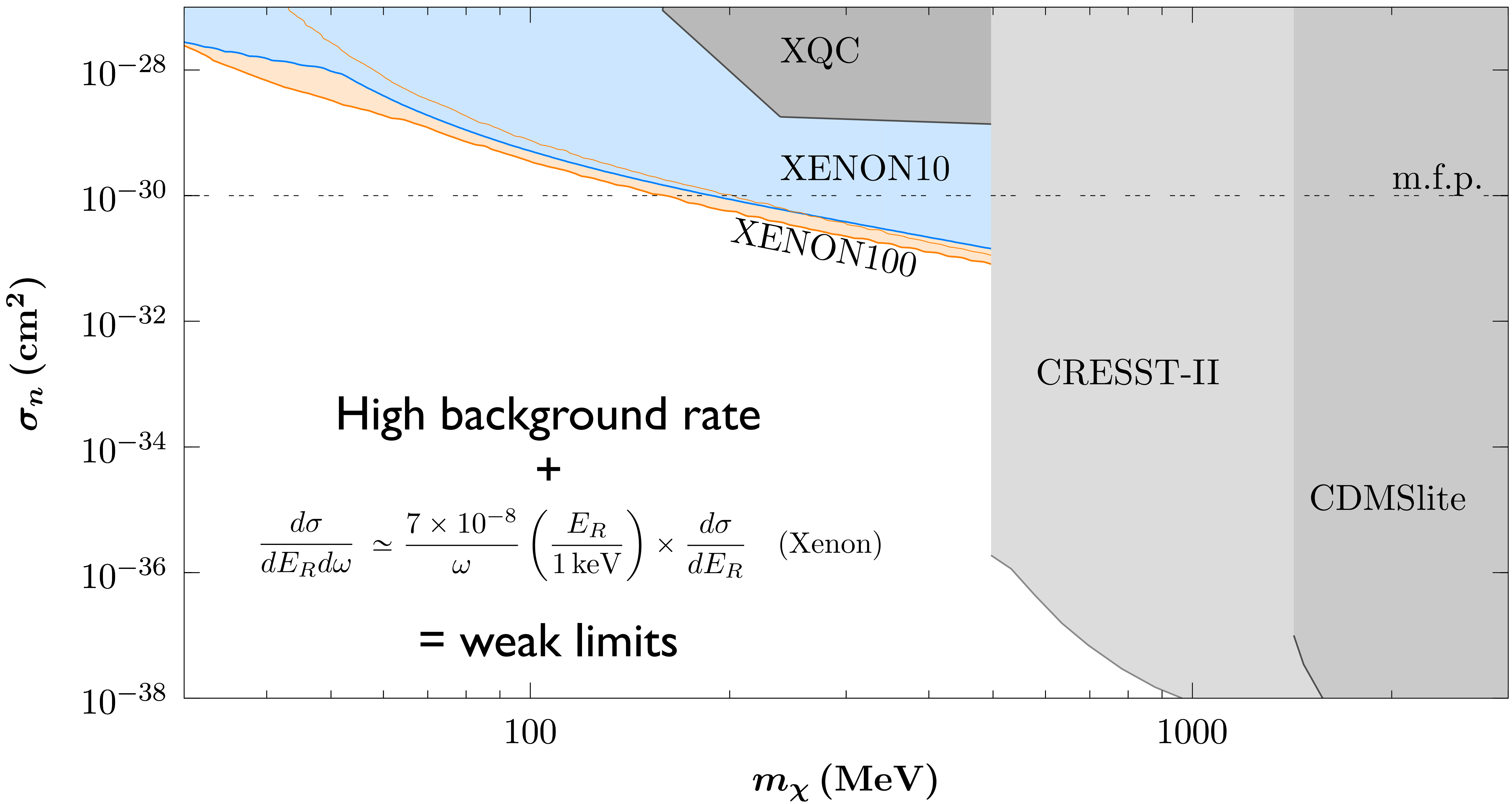
# Polarised atom emission: energy spectrum



# Polarised atom emission: S2-only

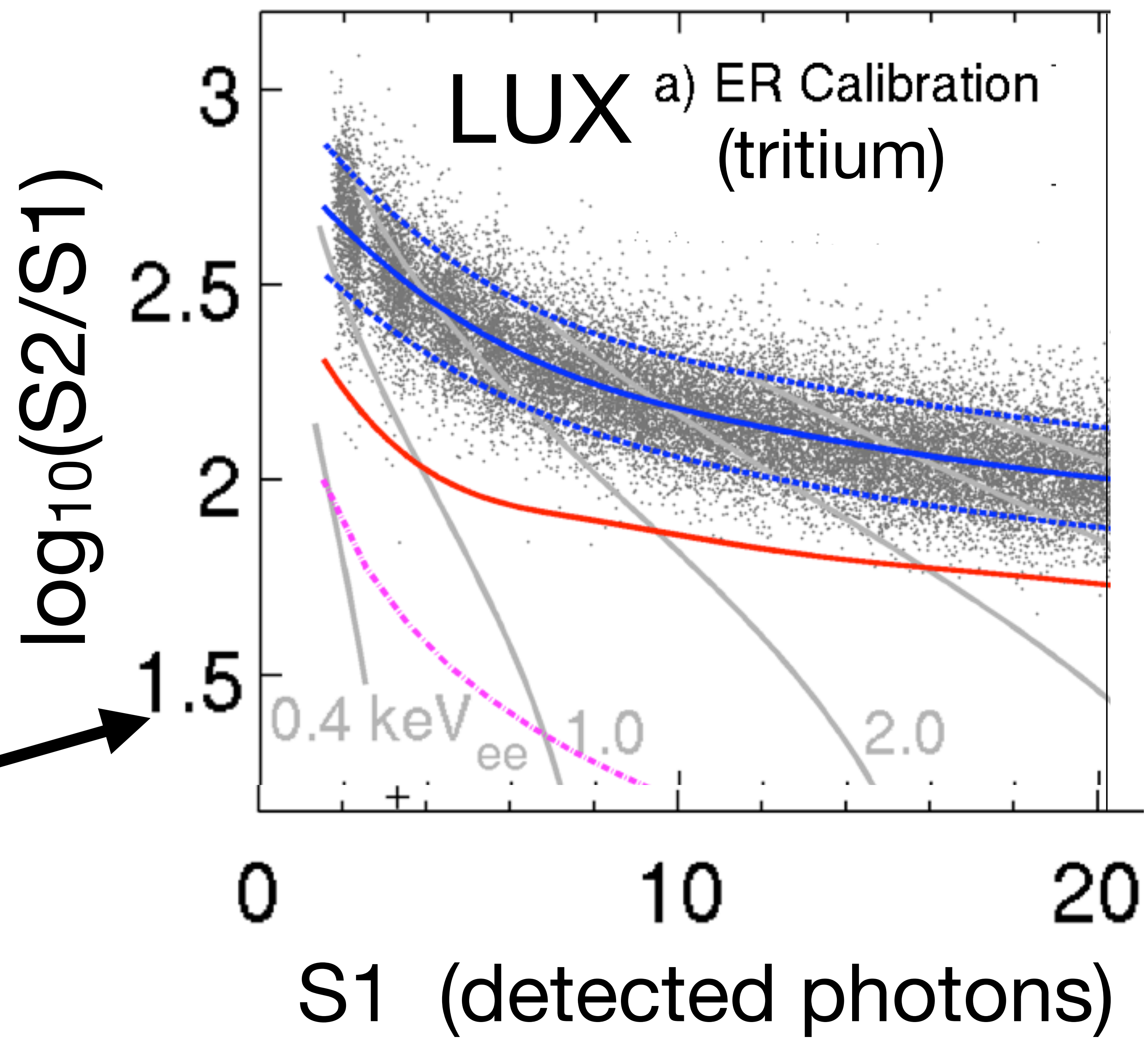
Kouvaris & Pradler
1607.01789, PRL

Weak constraints with S2-only analyses



# Polarised atom emission: S1+S2

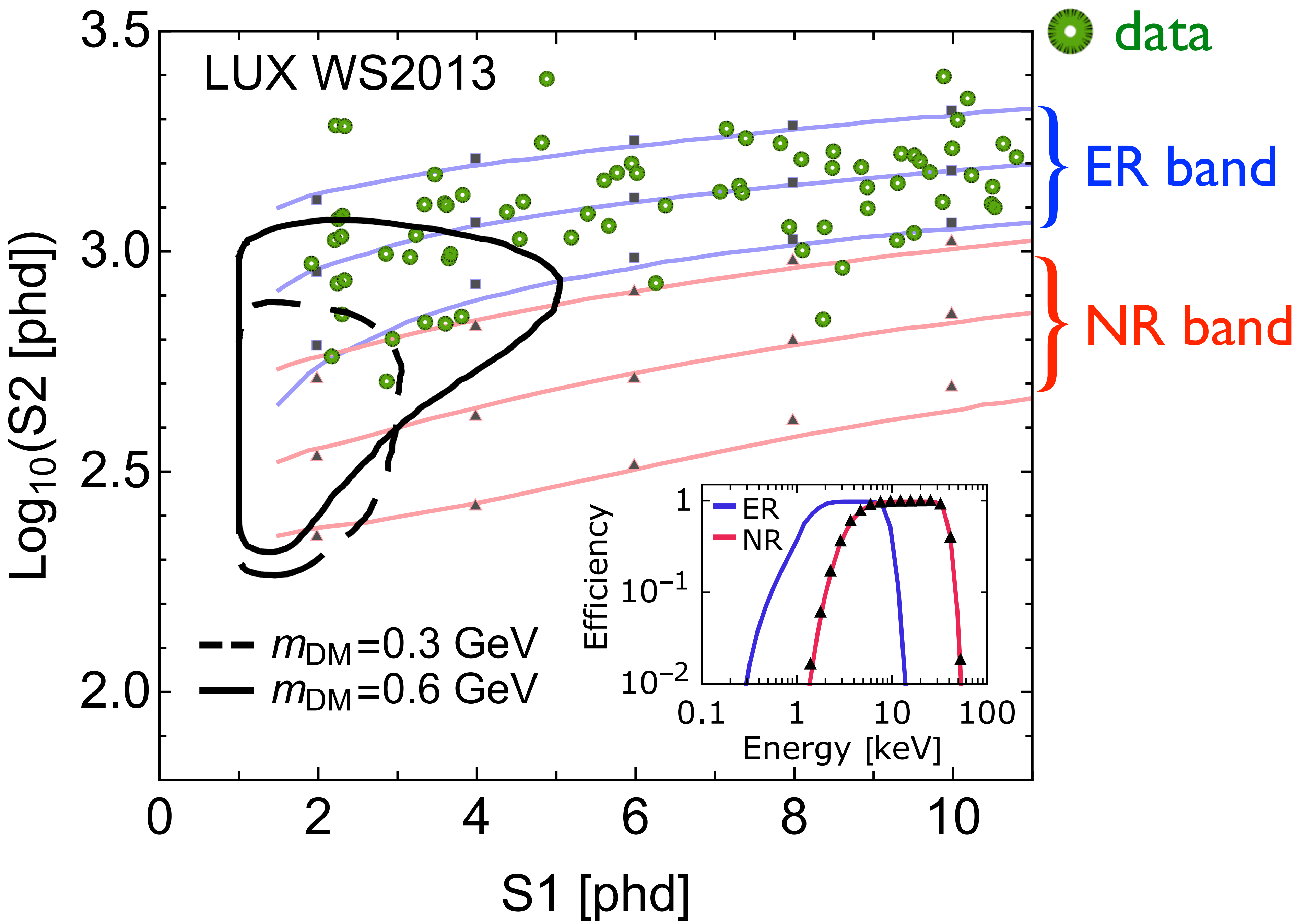
$$\omega^{\max} \approx 3\ \mathrm{keV} \cdot (m_{\mathrm{DM}}/1\ \mathrm{GeV})$$




- keV photons will be detected
- Lie below the ER band (in blue)

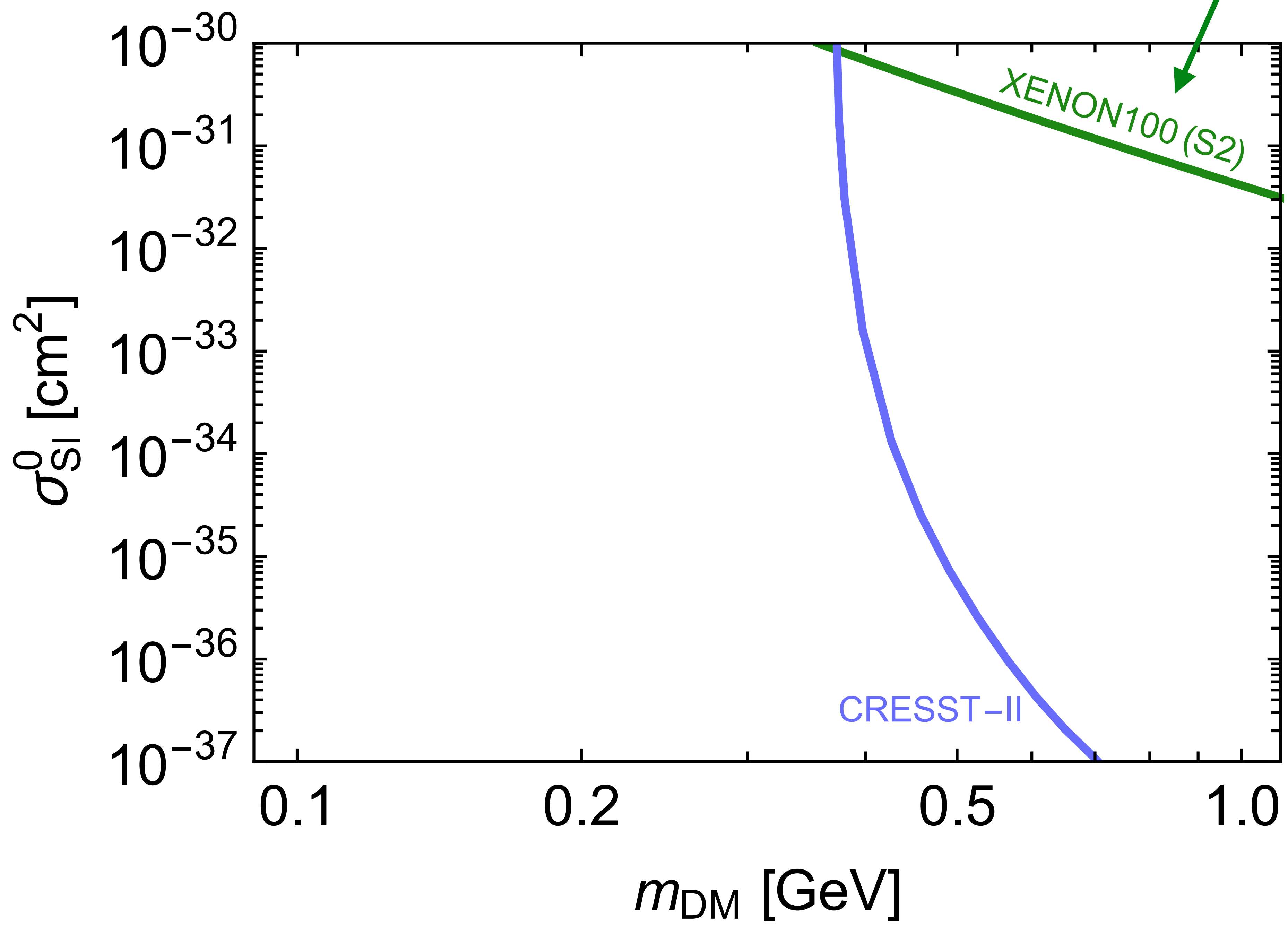
# Signal vs. LUX data

CM 1702.04730

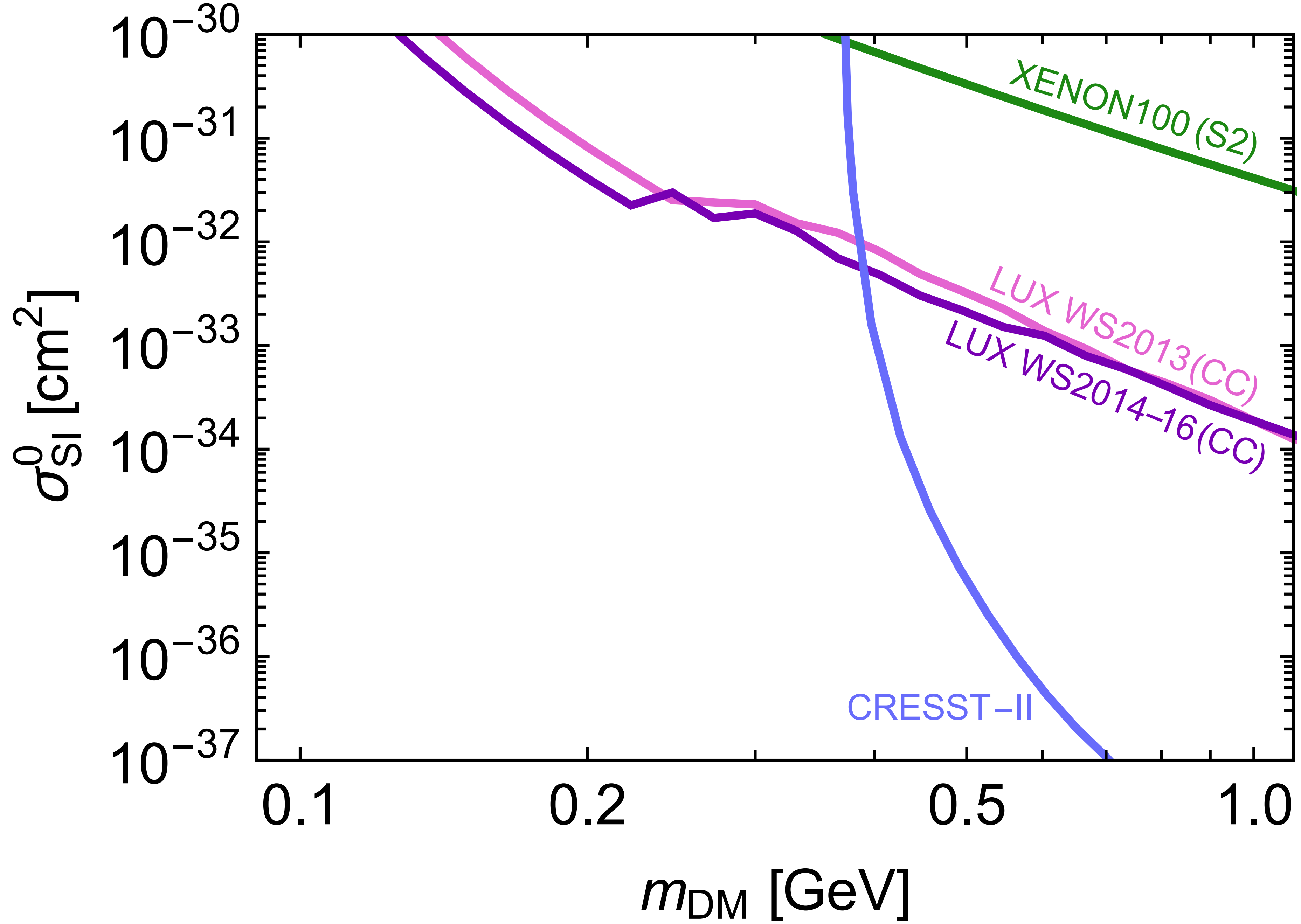


# Polarised atom emission: limits

Kouvaris & Pradler: S2-only limit



# Polarised atom emission: LUX



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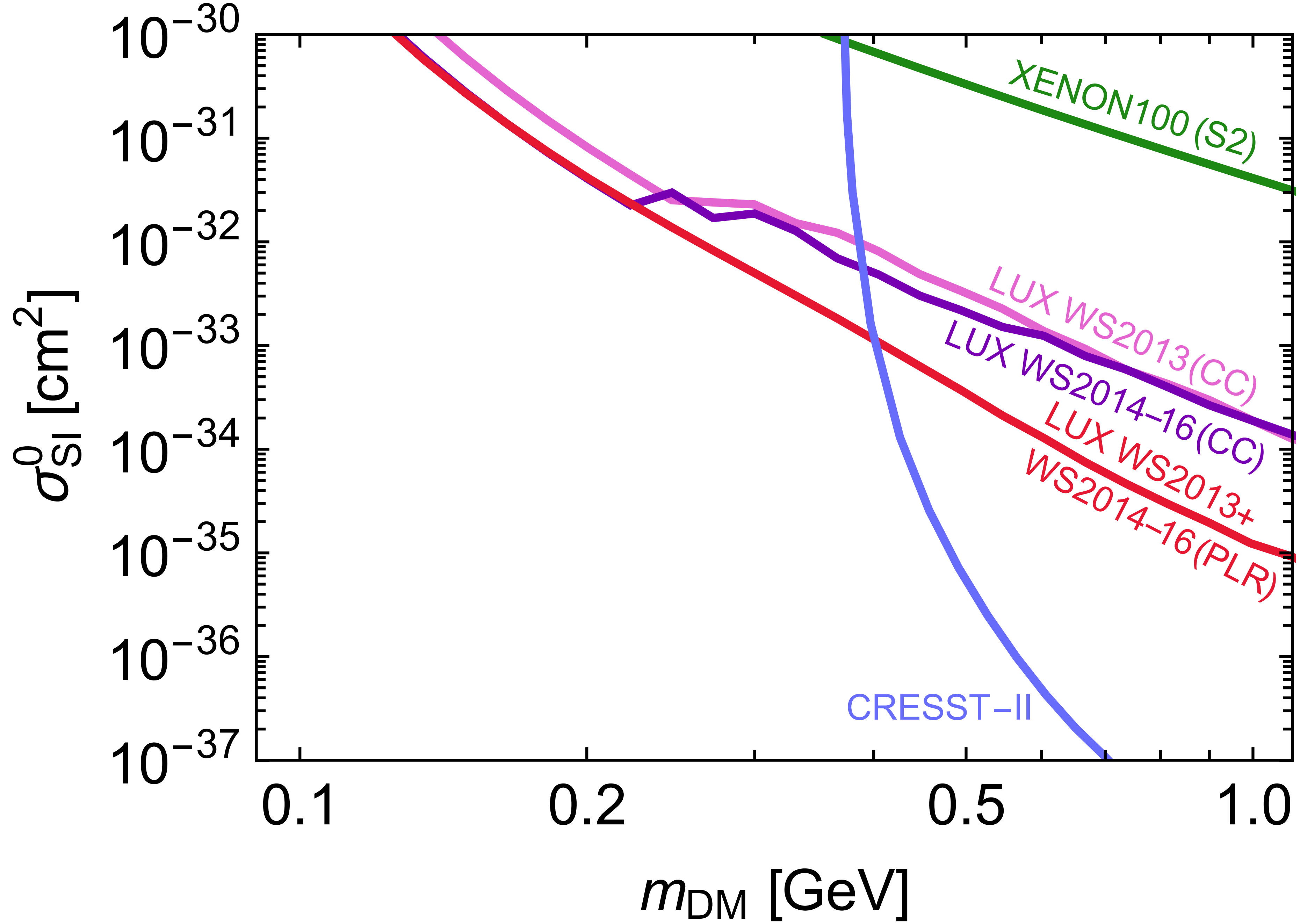
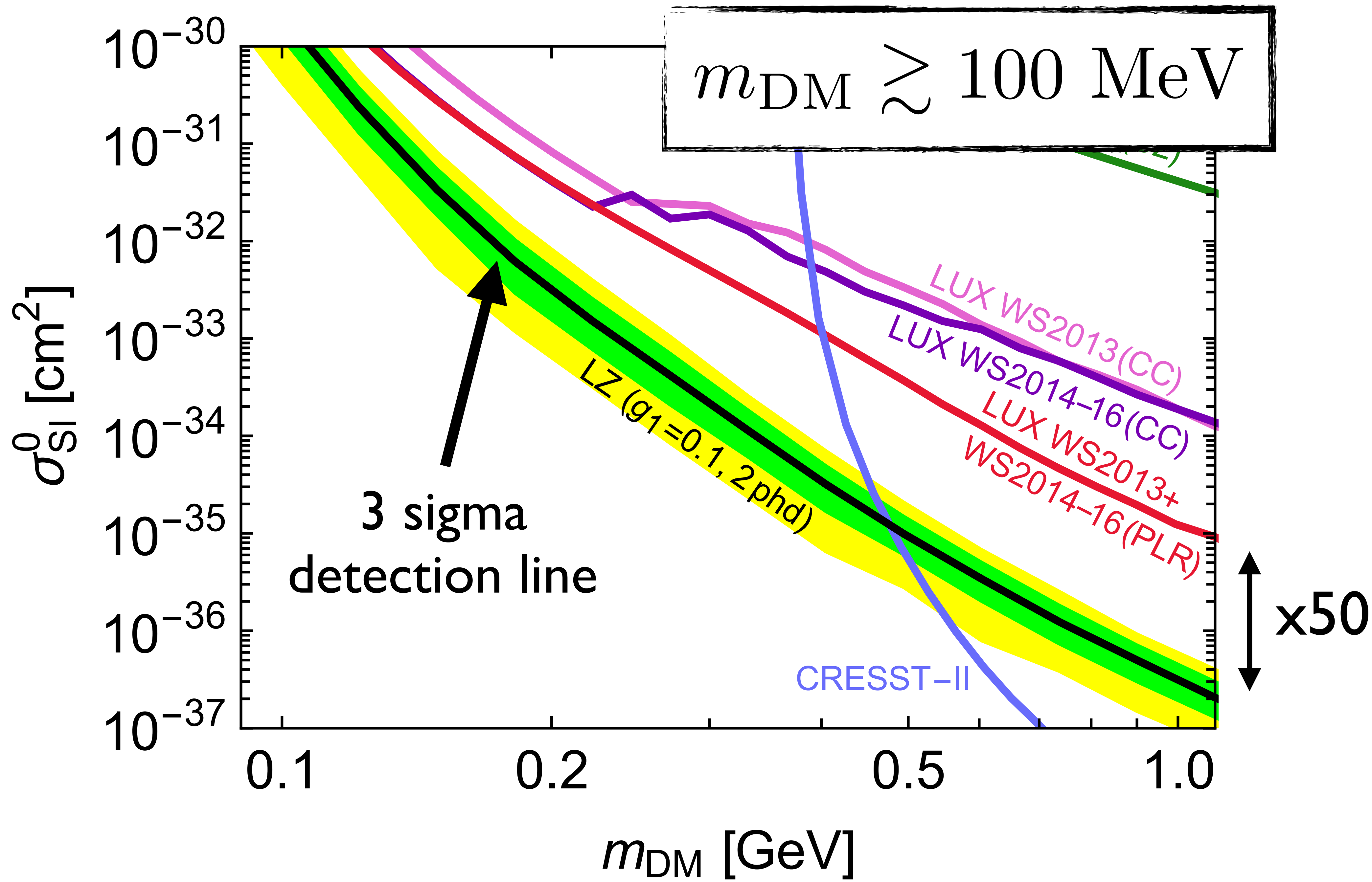
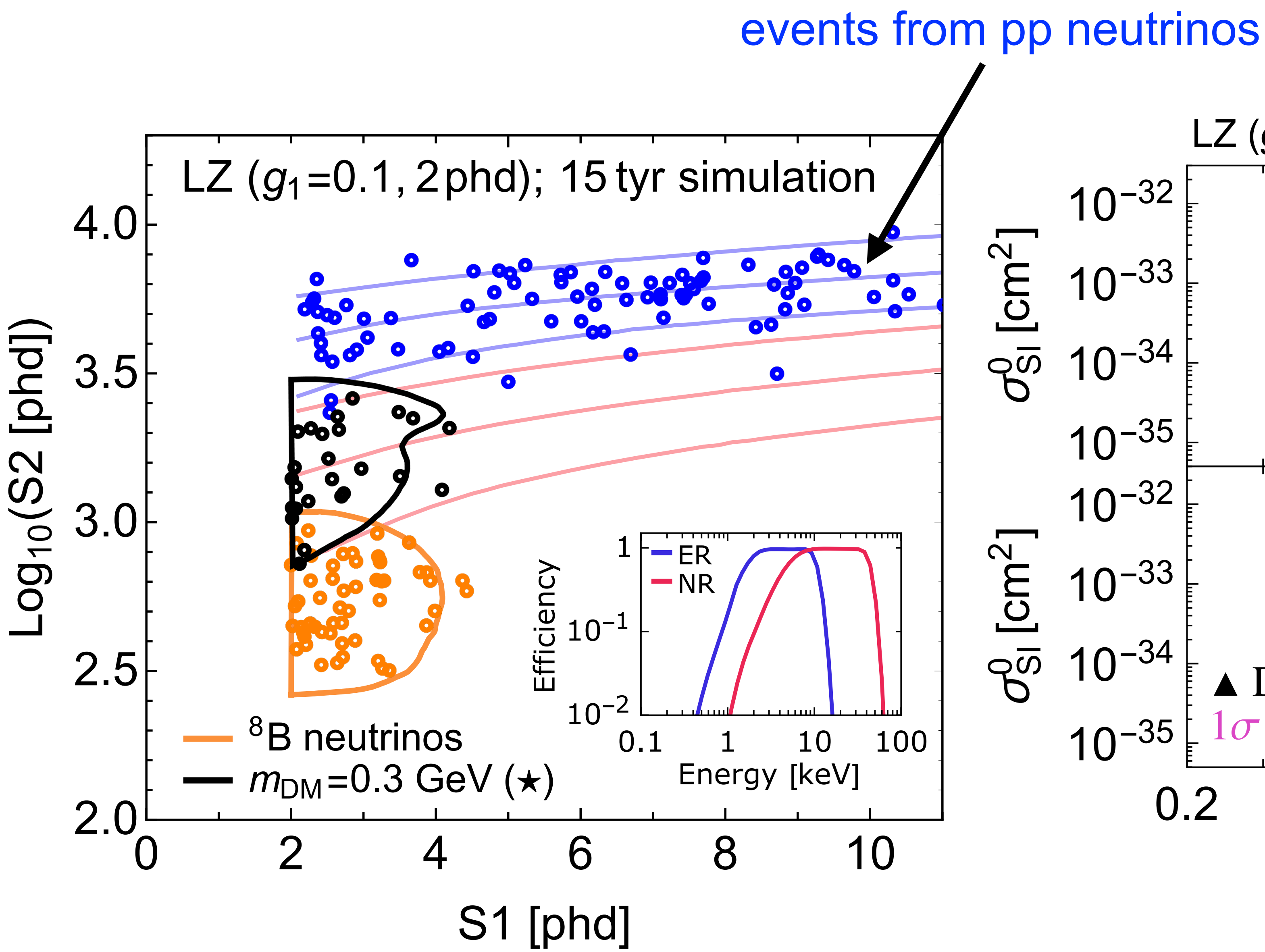


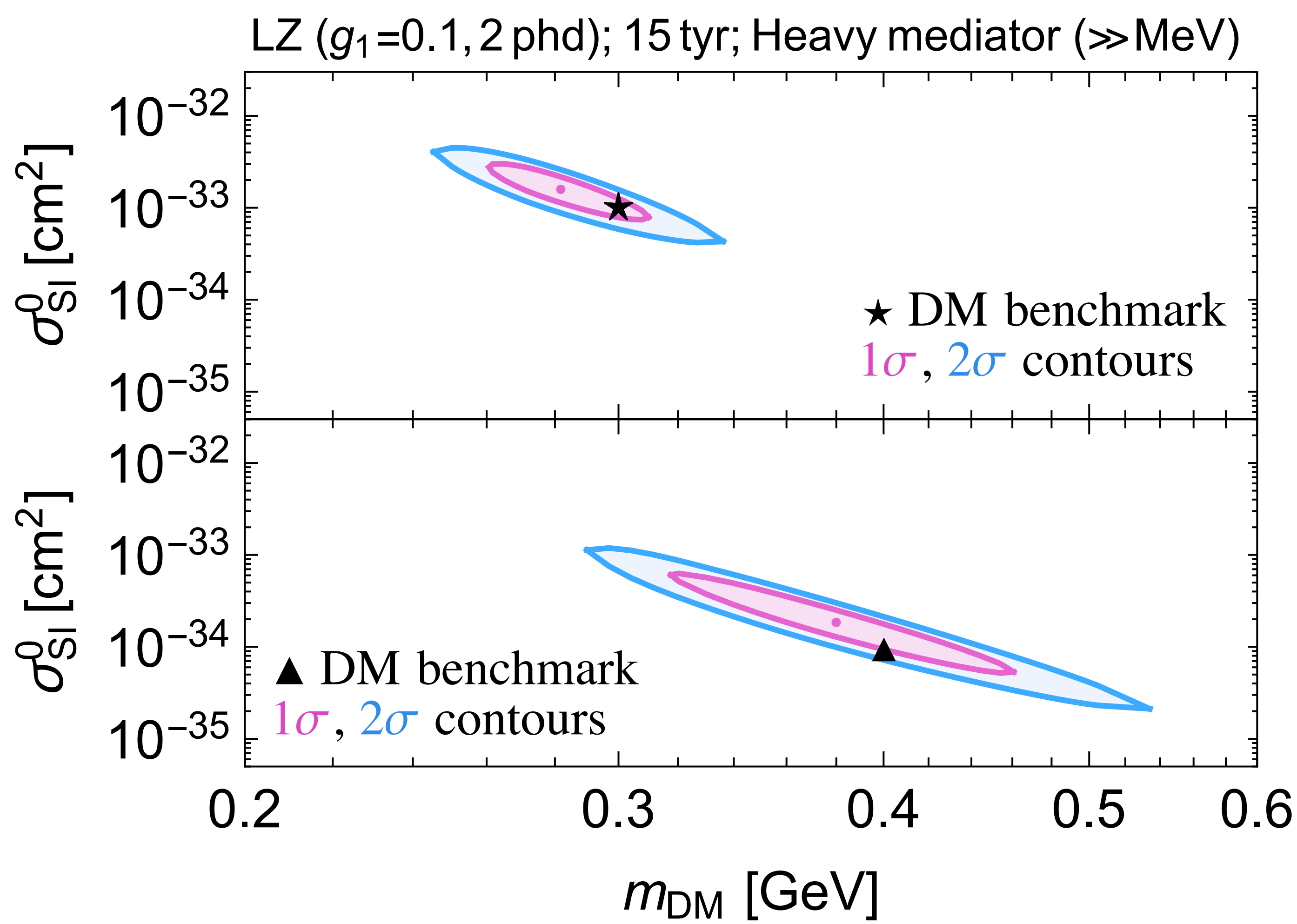

Includes background model

# Polarised atom emission: LZ



# Polarised atom emission: LZ




*The parameters of sub-GeV DM could be reconstructed with LZ!*

# Light DM: The Future…

## …many ideas to significantly improve current sensitivity

**Light Dark Matter in Superfluid Helium: Detection with Multi-excitation Production**

Simon Knapen,[1,2] Tongyan Lin,[1,2] and Kathryn M. Zurek[1,2]

**Absorption of light dark matter in semiconductors**

Yonit Hochberg,[*] Tongyan Lin,[†] and Kathryn M. Zurek[‡]

**Directional Detection of Dark Matter with 2D Targets**

Yonit Hochberg[1,2,*] Yonatan Kahn[3,†] Mariangela Lisanti[3,‡] Christopher G. Tully[3,§] and Kathryn M. Zurek[1,2¶]

**Searching for Dark Absorption with Direct Detection Experiments**

Itay M. Bloch,[1,*] Rouven Essig,[2,†] Kohsaku Tobioka,[1,3,‡] Tomer Volansky,[1,§] and Tien-Tien Yu[2,¶]

**Magnetic Bubble Chambers and Sub-GeV Dark Matter Direct Detection**

Philip C. Bunting,[1,*] Giorgio Gratta,[2,†] Tom Melia,[3,4,5,‡] and Surjeet Rajendran[3,§]

**Dark Matter Direct Detection with Accelerometers**

Peter W. Graham,[1] David E. Kaplan,[1,2,3,4] Jeremy Mardon,[1] Surjeet Rajendran,[3] and William A. Terrano[5,6]

**Direct Detection of Light Dark Matter and Solar Neutrinos via Color Center Production in Crystals**

Ranny Budnik Ori Chesnovsky Oren Slone and Tomer Volansky

**Detecting Ultralight Bosonic Dark Matter via Absorption in Superconductors**

Yonit Hochberg,[1] Tongyan Lin,[1] and Kathryn M. Zurek[1]

**Direct Detection of sub-GeV Dark Matter with Semiconductor Targets**

**Rouven Essig,[a] Marivi Fernández-Serra,[b,c] Jeremy Mardon,[d] Adrián Soto,[b,c] Tomer Volansky,[e] Tien-Tien Yu[a]**

Detection of sub-GeV Dark Matter and Solar Neutrinos via Chemical-Bond Breaking

**Rouven Essig,[a] Jeremy Mardon,[b] Oren Slone,[c] Tomer Volansky[c]**

# Summary

- Existing Xenon detectors can probe a wide range of masses:
  - Standard searches $\boxed{m_{\mathrm{DM}} \gtrsim 3\ \mathrm{GeV}}$
  - Scattering with electrons $\boxed{m_{\mathrm{DM}} \gtrsim 4\ \mathrm{MeV}}$
  - Absorption by electrons $\boxed{m_{\mathrm{DM}} \gtrsim 10\ \mathrm{eV}}$
  - Polarised atom emission $\boxed{m_{\mathrm{DM}} \gtrsim 100\ \mathrm{MeV}}$

- Upcoming optimised searches can go much further

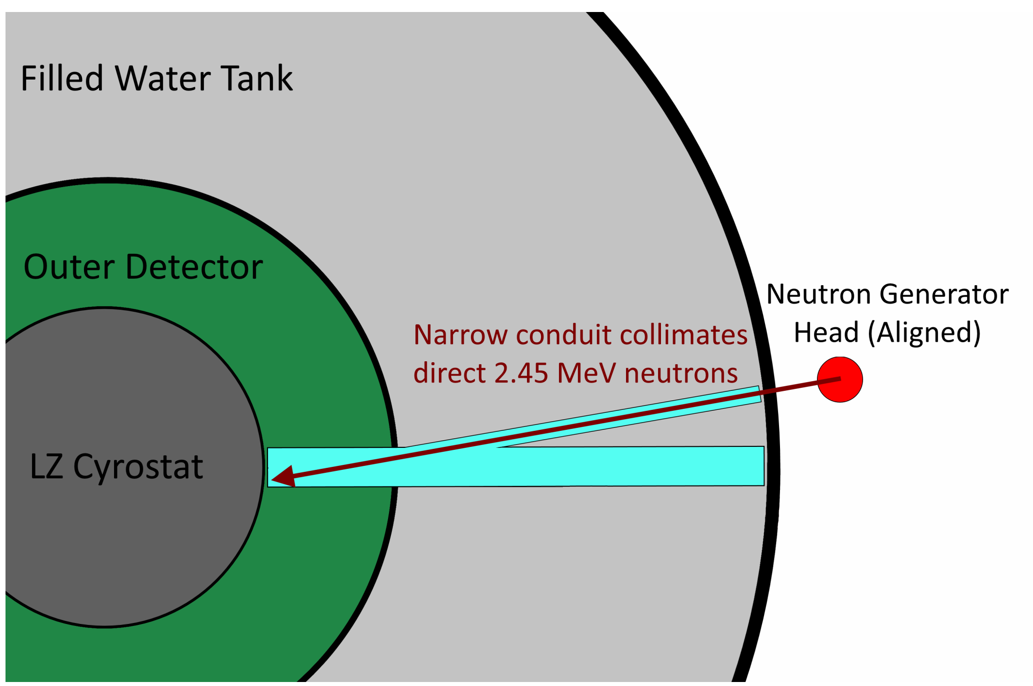
*Extra slides*

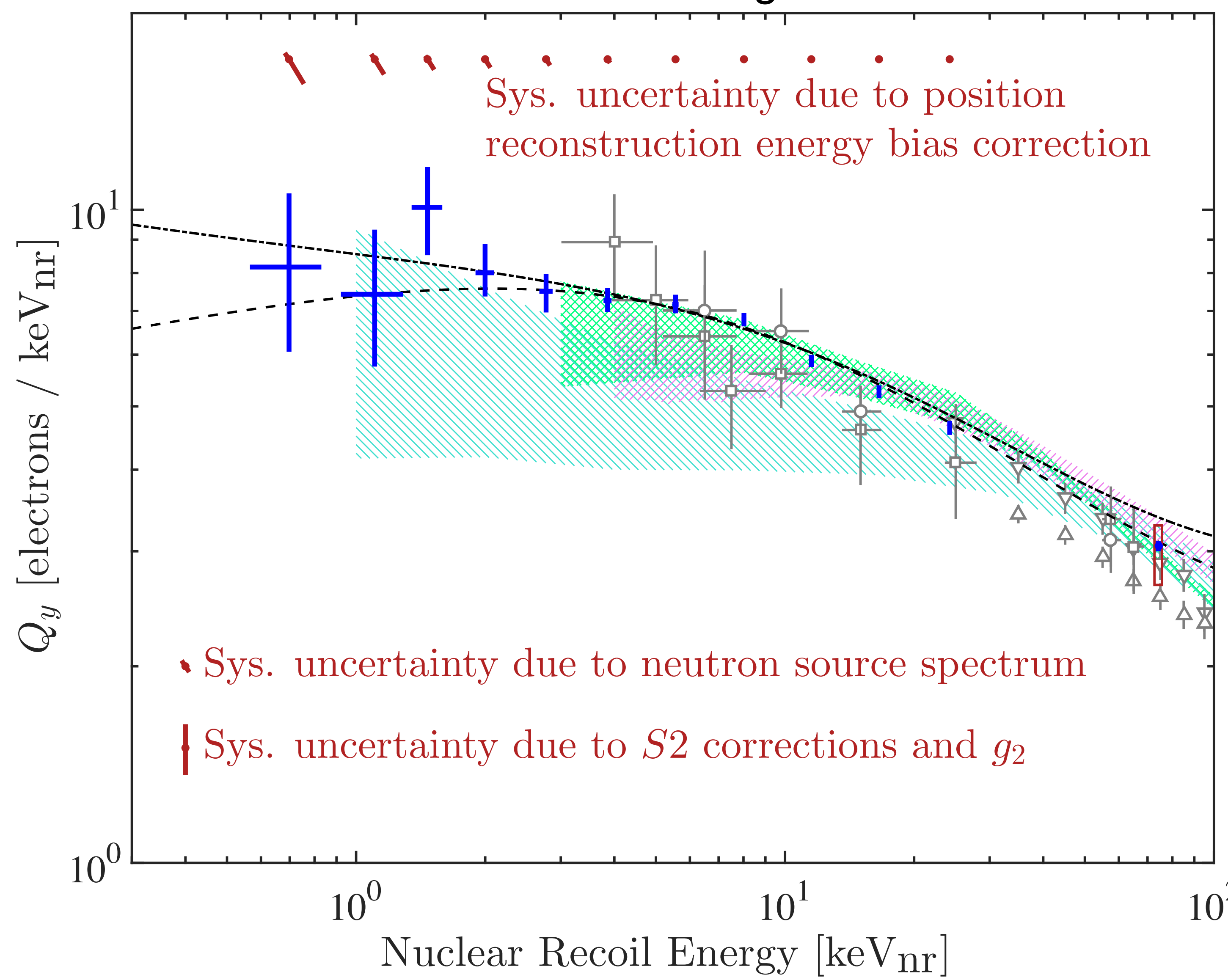
# Recent progress: Better calibration

LUX leads the way in sensitivity… and in calibrating their detector

Nuclear recoil calibration to 0.7 keV

D-D generator: arXiv:1608.05381

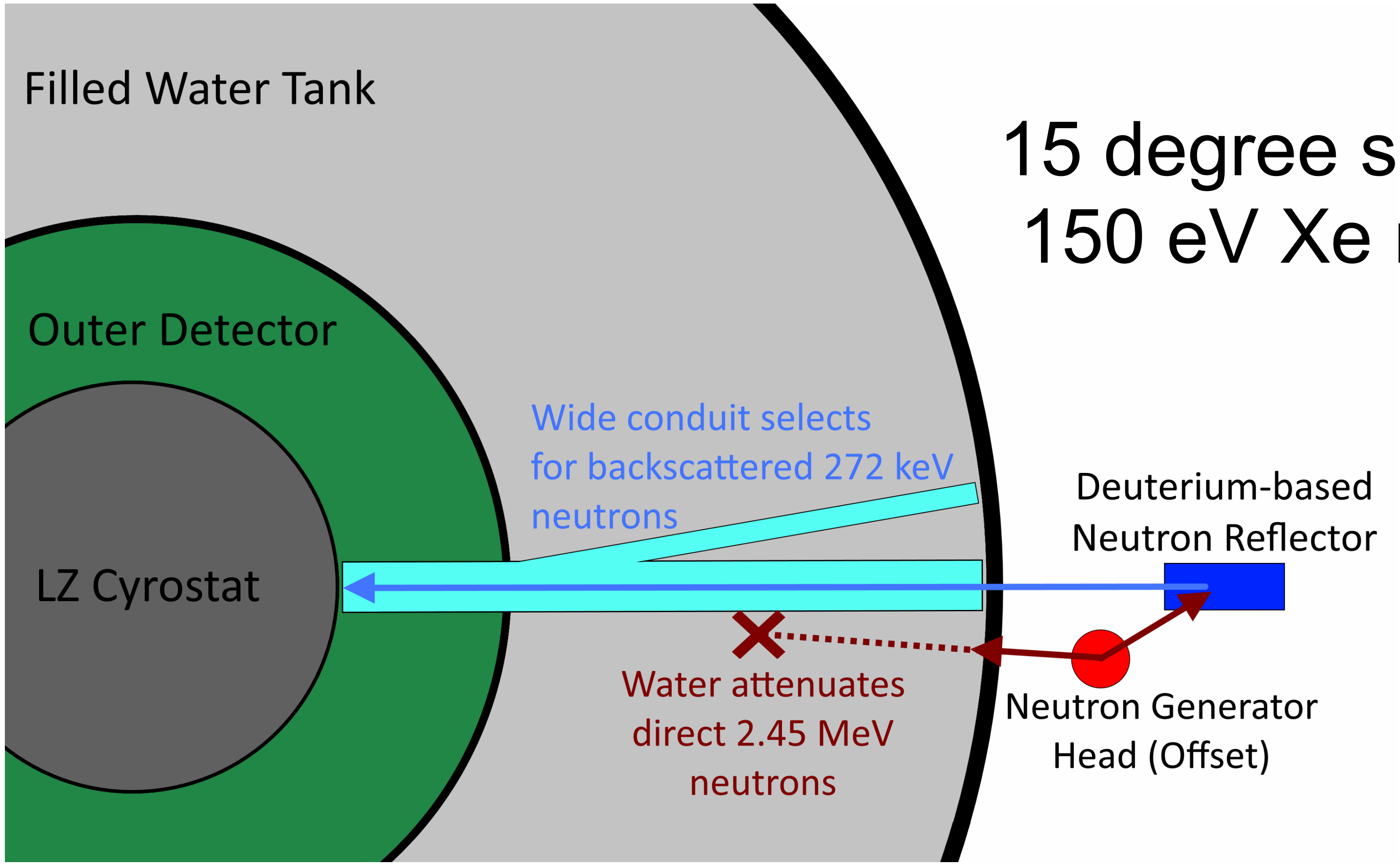


# Recent progress: Better calibration

LUX leads the way in sensitivity… and in calibrating their detector

Nuclear recoil calibration to 0.7 keV… and plans to go lower (150 eV?)




15 degree scatter:
150 eV Xe recoil possible

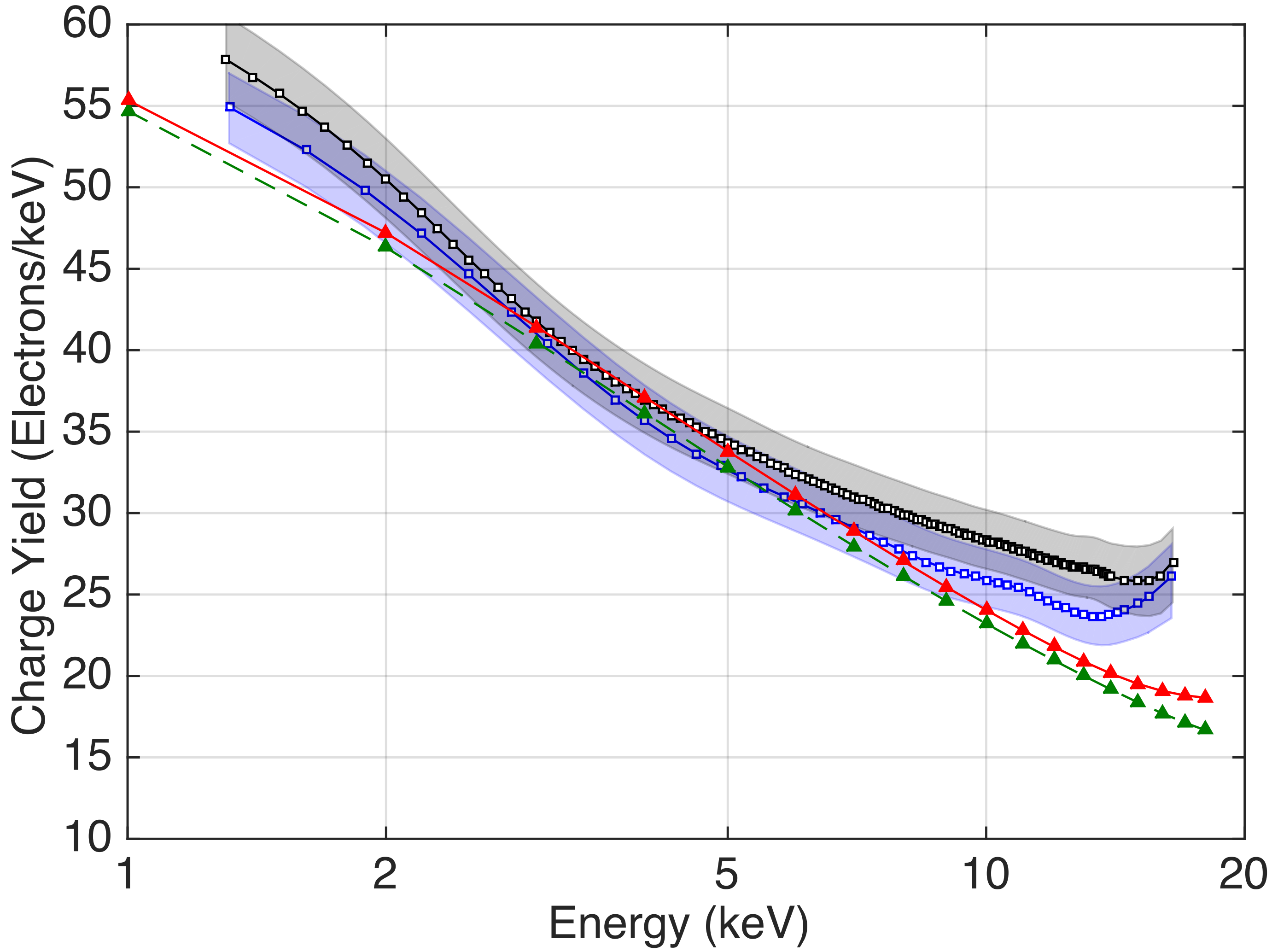
LZ TDR
arXiv:1703.09144

# Recent progress: Better calibration

LUX leads the way in sensitivity… and in calibrating their detector

Electronic recoil calibration to 1.3 keV (tritium)

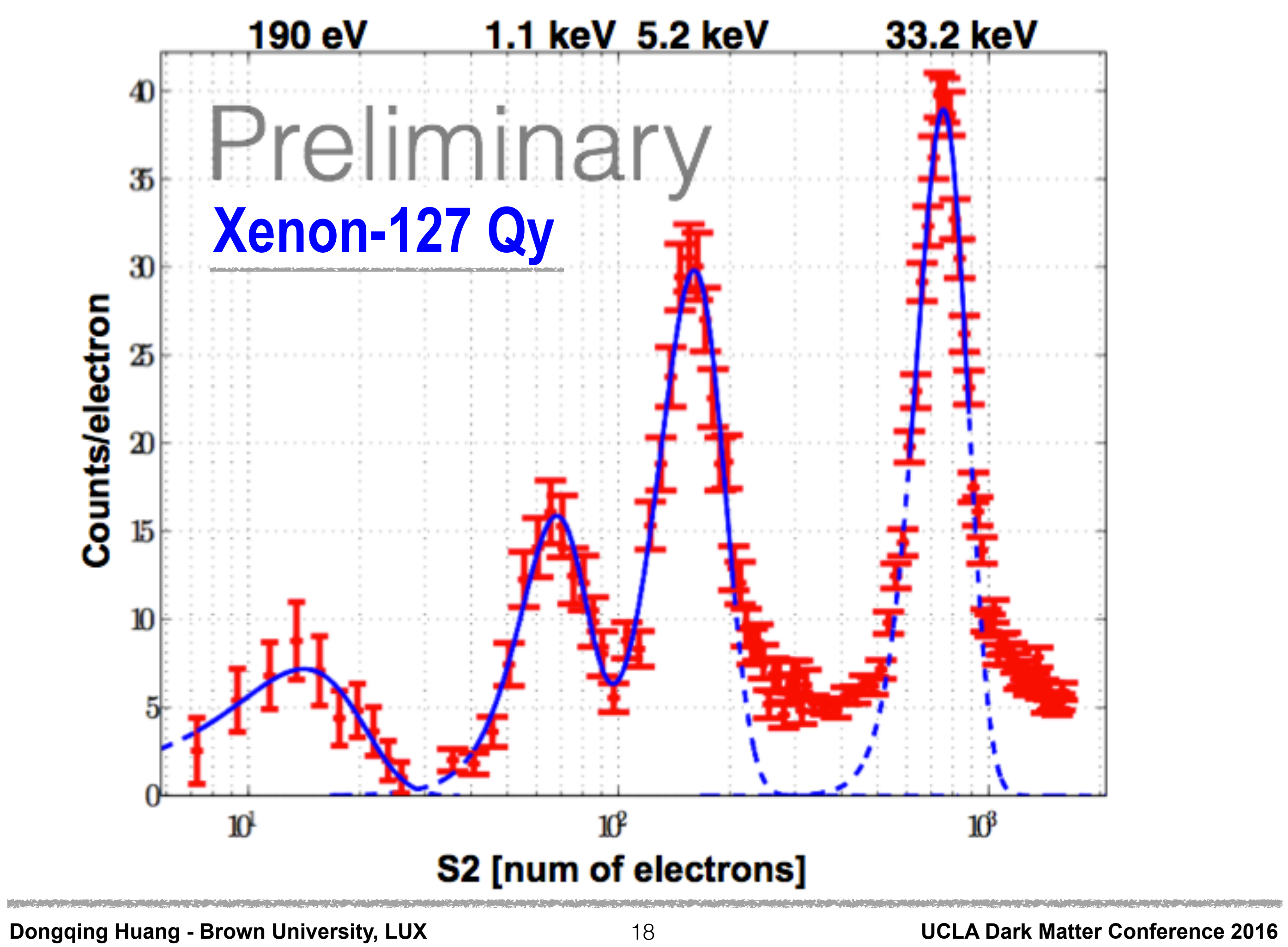
tritium, arXiv:1512.03133



# Recent progress: Better calibration

LUX leads the way in sensitivity… and in calibrating their detector

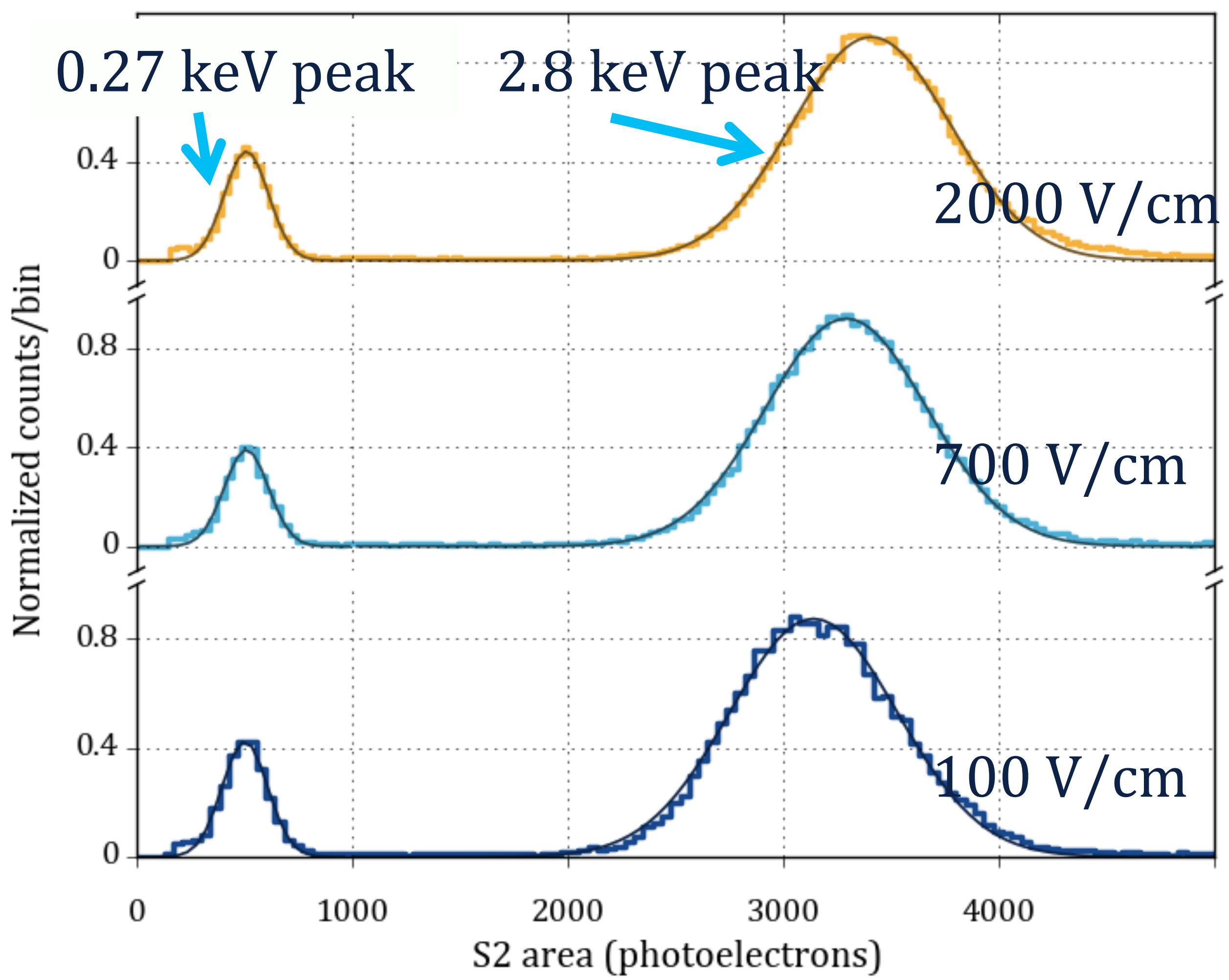
Electronic recoil calibration to 1.3 keV (tritium)
0.19 keV (127-Xe)



# Recent progress: Better calibration

LUX leads the way in sensitivity… and in calibrating their detector

Electronic recoil calibration to 1.3 keV (tritium)
0.19 keV (127-Xe)
0.27 keV (37-Ar)




PIXeY data
(E. Boulton)

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LUX leads the way in sensitivity… and in calibrating their detector

Electronic recoil calibration to 1.3 keV (tritium)
0.19 keV (127-Xe)
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