Initial Dark Matter Results from the SuperCDMS Single-Charge Sensitive Detectors

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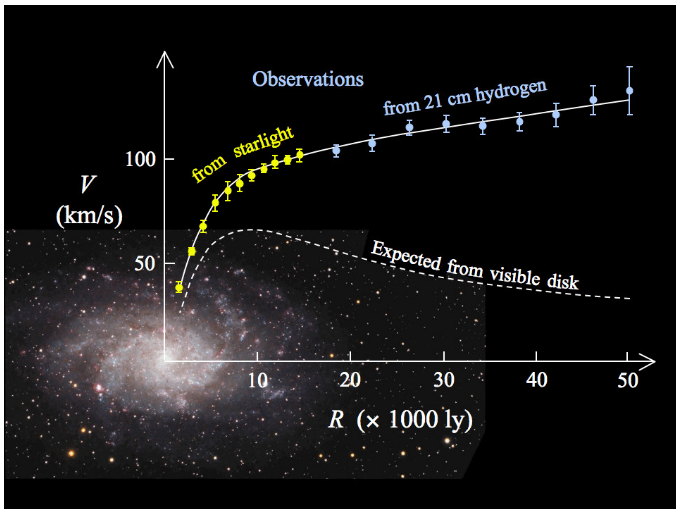
TRIUMF
U. British Columbia
U. California, Berkeley
U. Colorado Denver
U. Evansville
U. Florida
U. Montréal
U. Minnesota
U. South Dakota
U. Toronto

* Associate members

Missing Matter

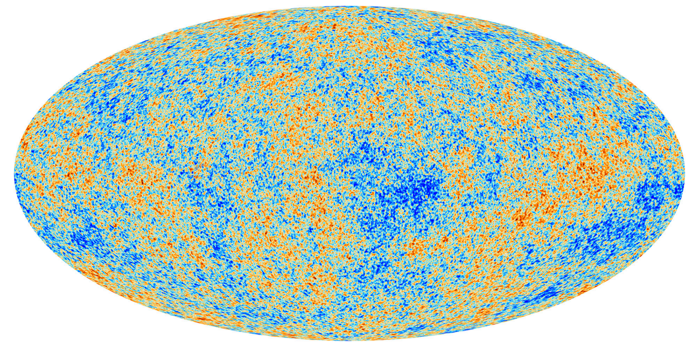
M33 Galactic Rotation Curve

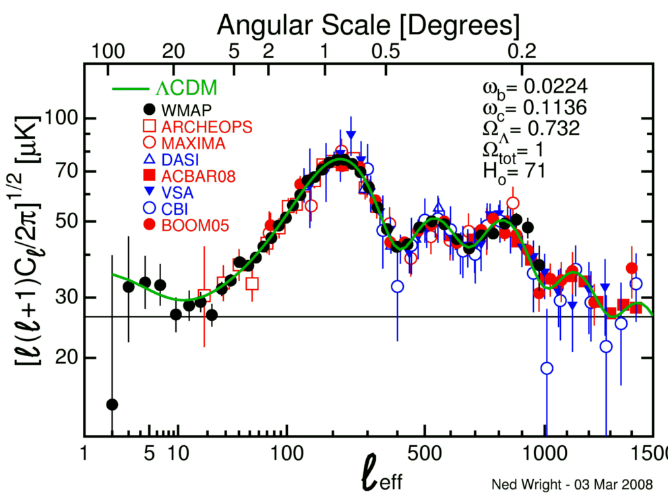


$$a_c = \frac{v^2}{r} \qquad a_g = \frac{GM}{r^2}$$

$$v = \sqrt{\frac{GM}{r}} = r\sqrt{G\rho(r)}$$

CMB Anisotropy



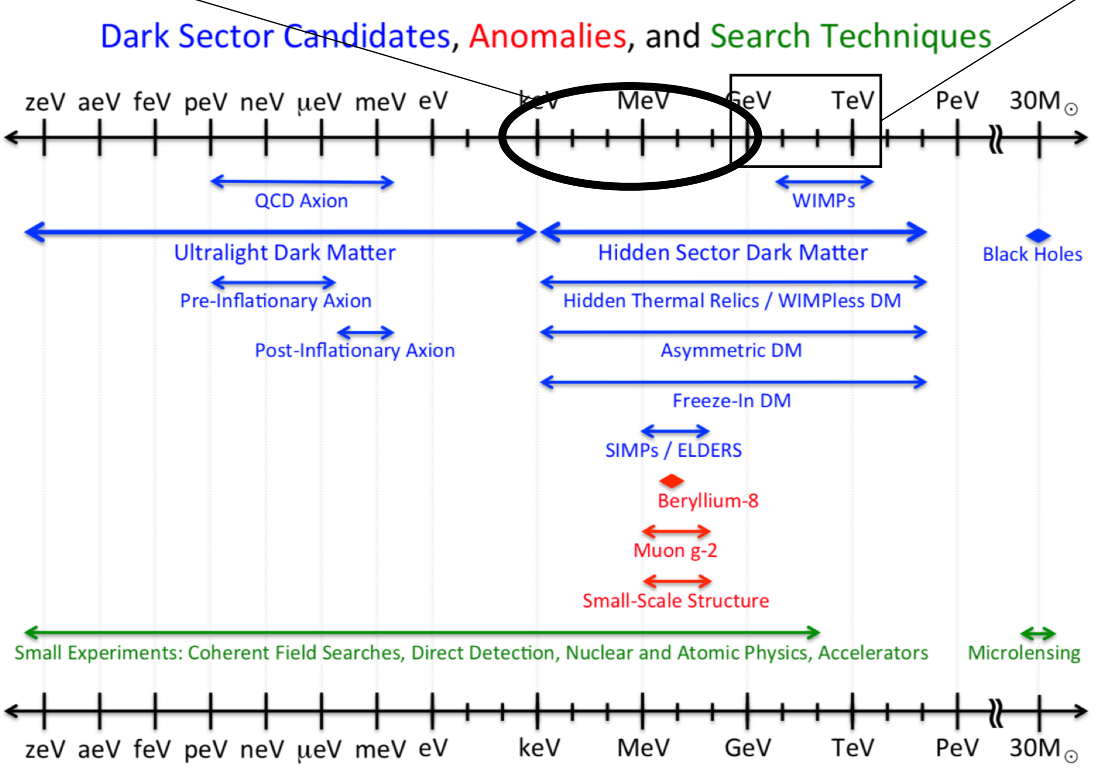


Insufficient mass in the universe!

Dark Matter Candidates

High resolution detectors: SuperCDMS

Noble liquids



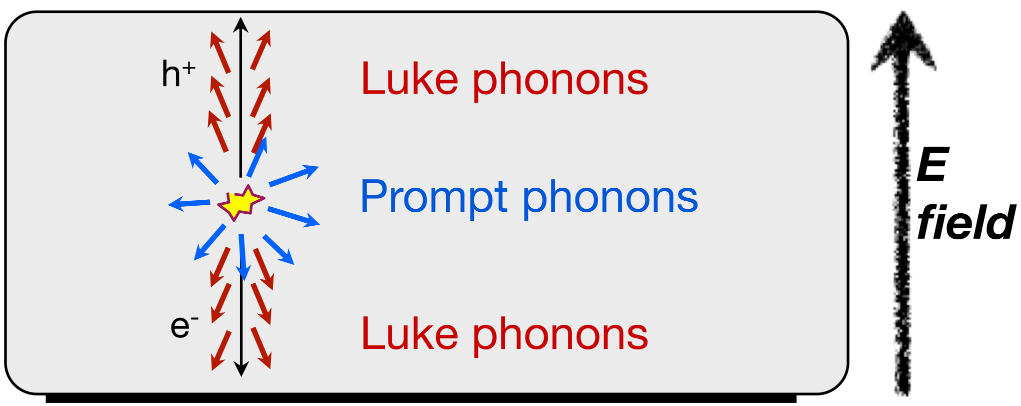
US Cosmic Visions: New Ideas in Dark Matter: 1707.04591

SuperCDMS is focused on keV to GeV mass range

SuperCDMS Detector Technology: HV

(CDMSlite)

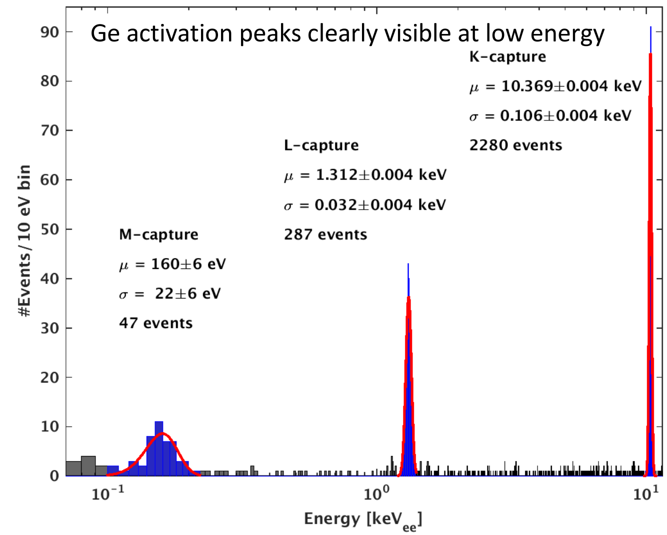
Neganov-Trofimov-Luke Effect

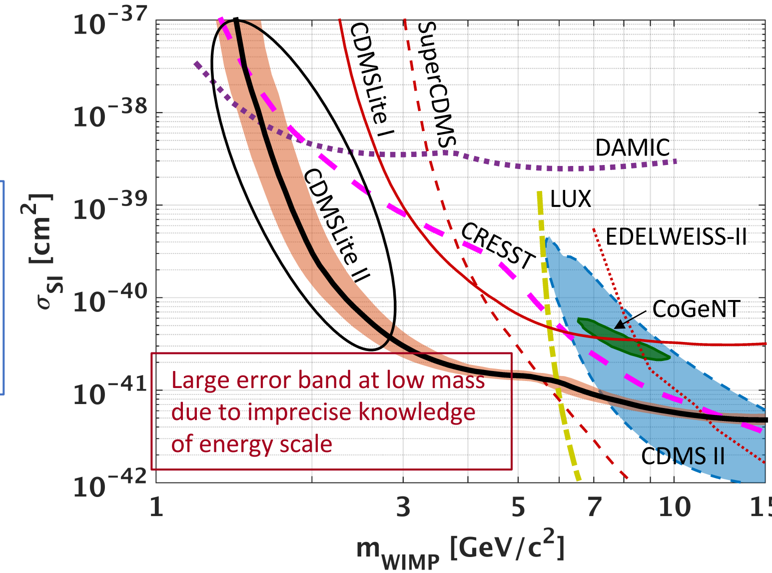


Phonon energy = E_{recoil} + E_{Luke}

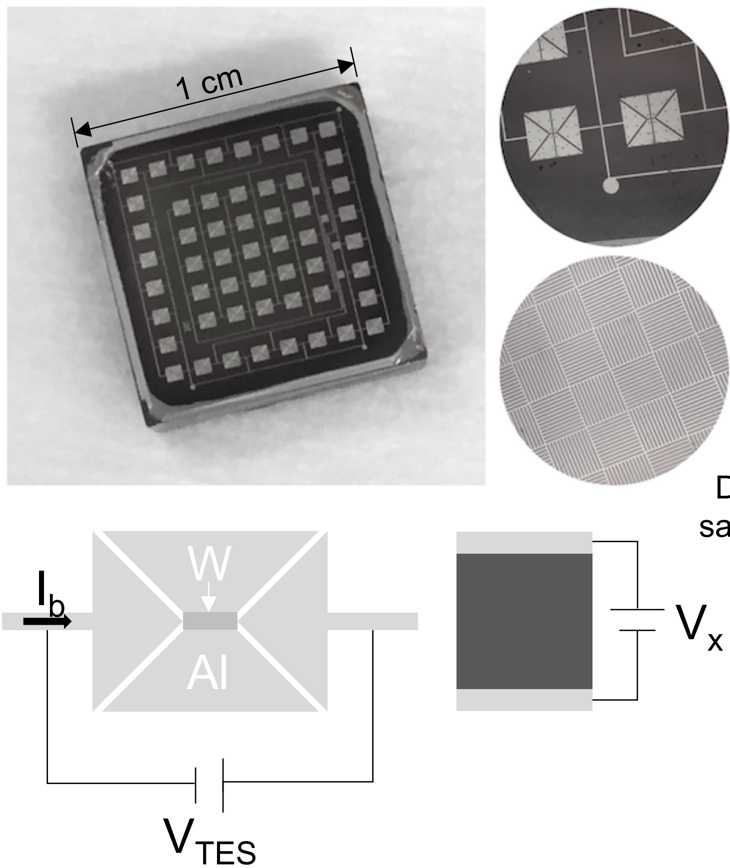
Must understand the nuclear recoil energy calibration, especially at low energies

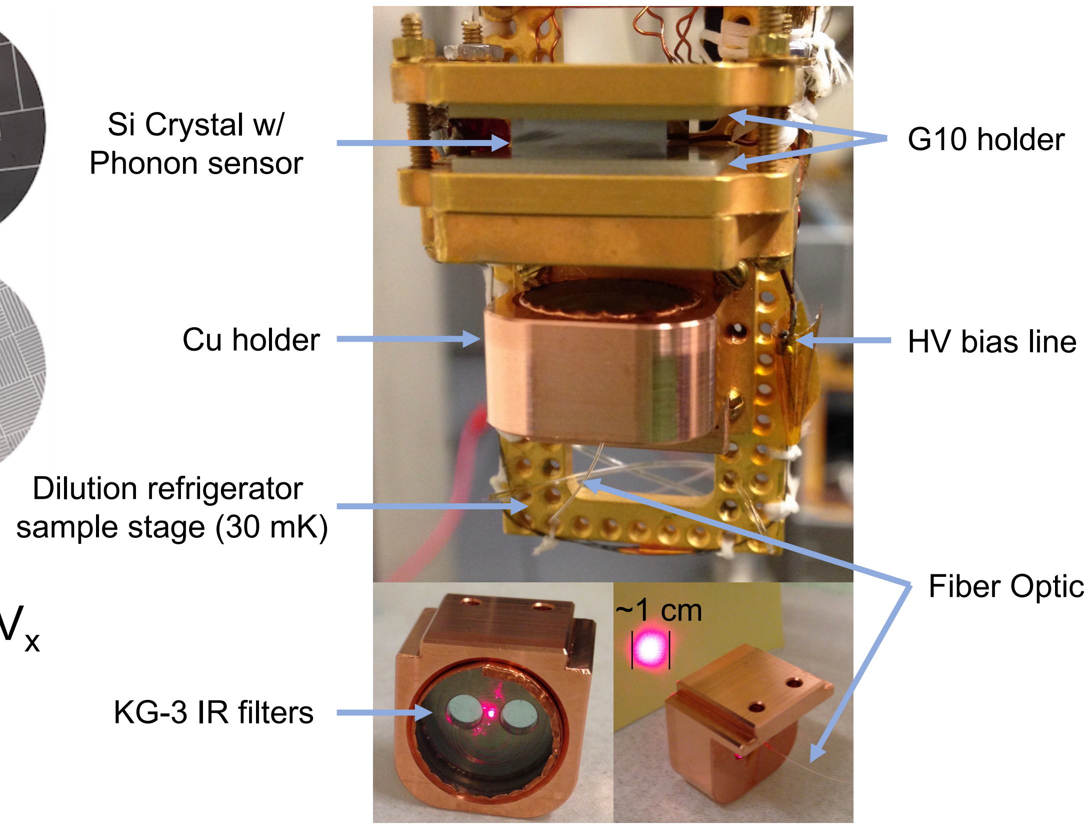
Soudan CDMSlite Run 2 result (arXiv 1509.02448)





SuperCDMS High Voltage Detector



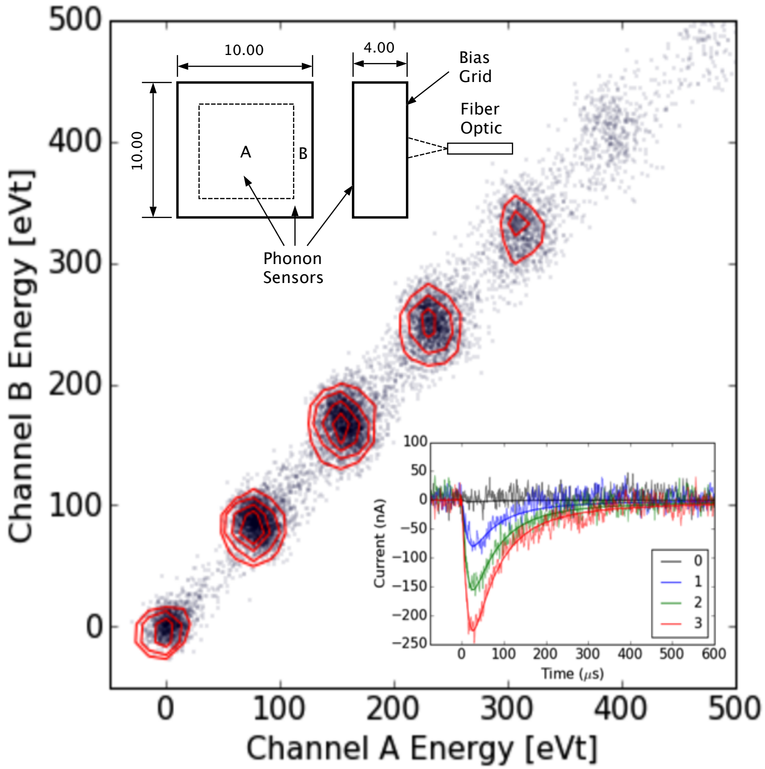


Amplification of $e^{-}h^{+}$ signals

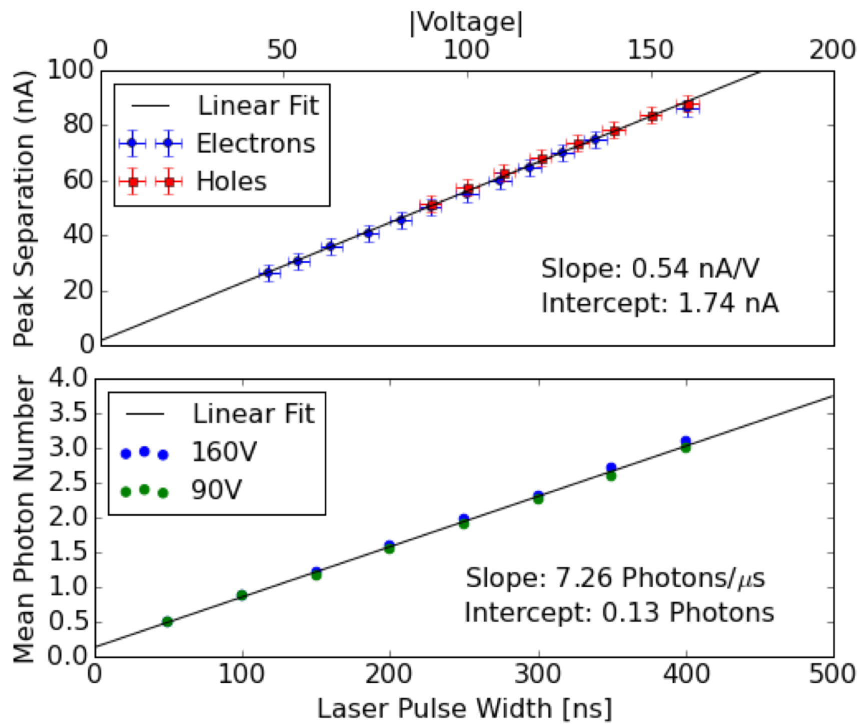
TES Phonon Sensor Laser Response

APL (arXiv 1710.09335)

Integer e^-h^+ Pairs @ 160V Bias



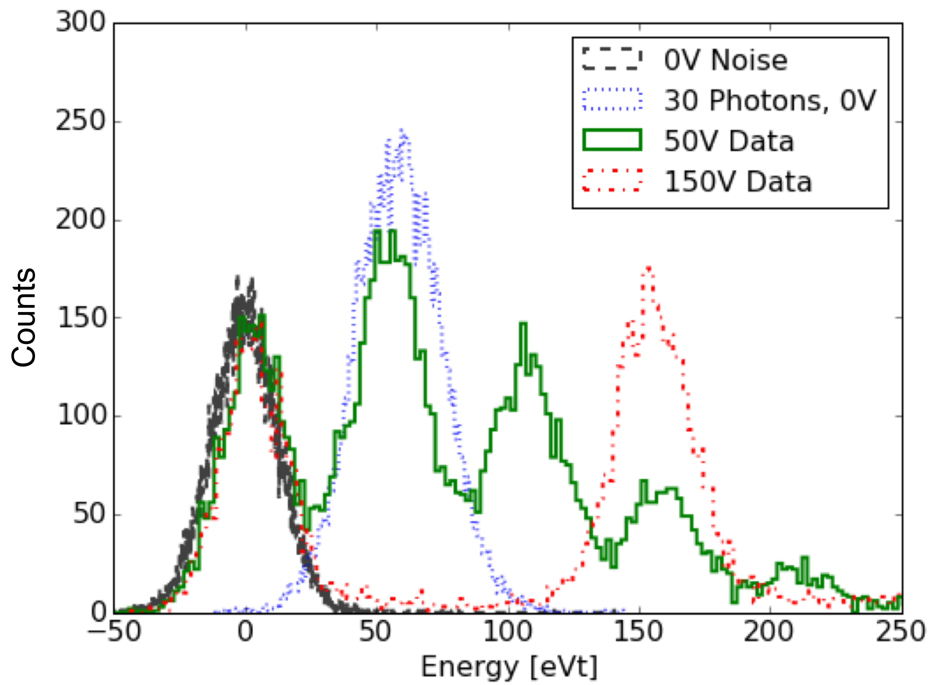
Gain Linearity



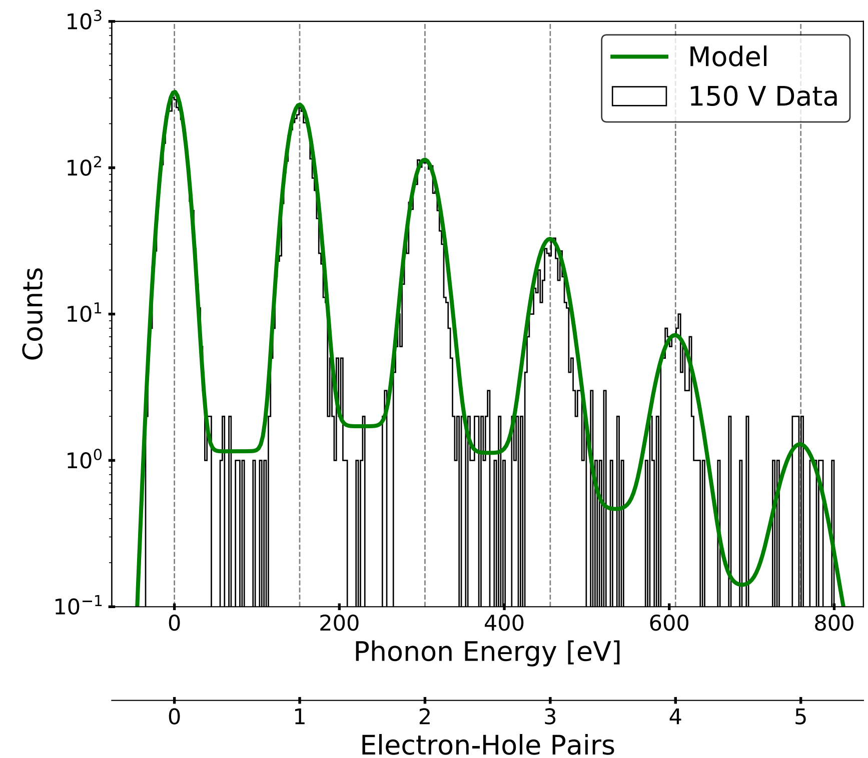
First observation of e^-h^+ pairs in Si crystal with a phonon sensor

TES Calibration and Modeling

QET Calibration



Impact Ionization and Trapping



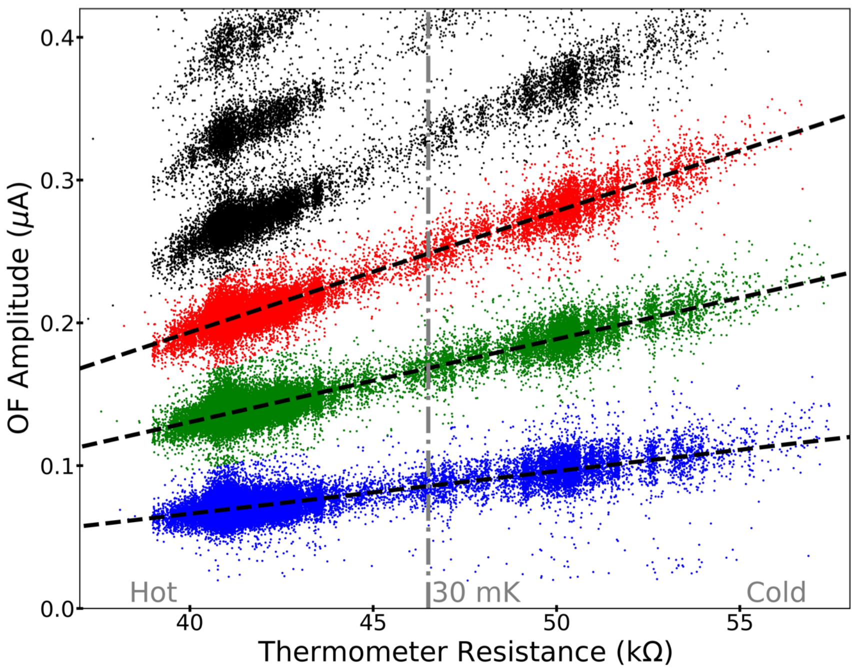
Laser may be used to calibrate detectors without an NTL gain by comparing to the calibration with a NTL gain.

A model with trapping at 1% and impact ionization at 2% (green curve) is consistent with events between peaks.

Calibration laser shows minute trapping and impact ionization effects

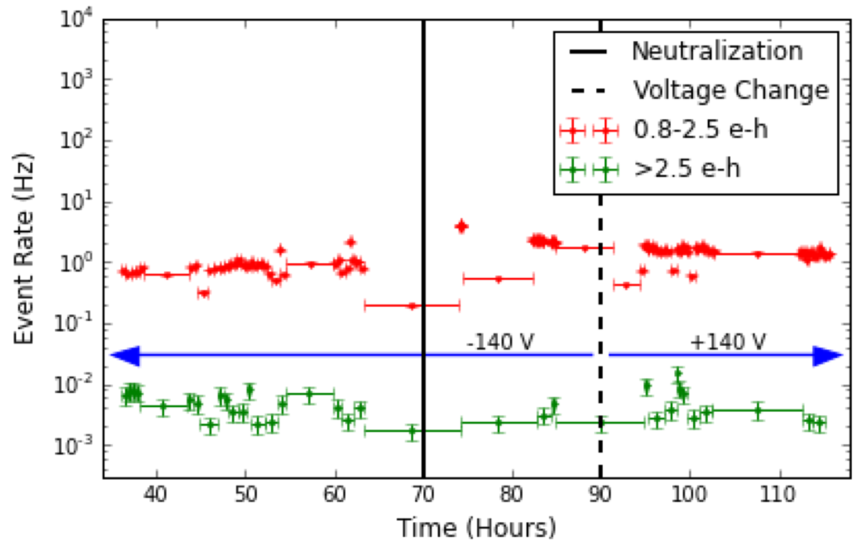
System Stability During Acquisition

Temperature Calibration



Reconstructed amplitude scales linearly with resistance from a RuOx thermometer used to measure the DR temperature.

DM Search Data

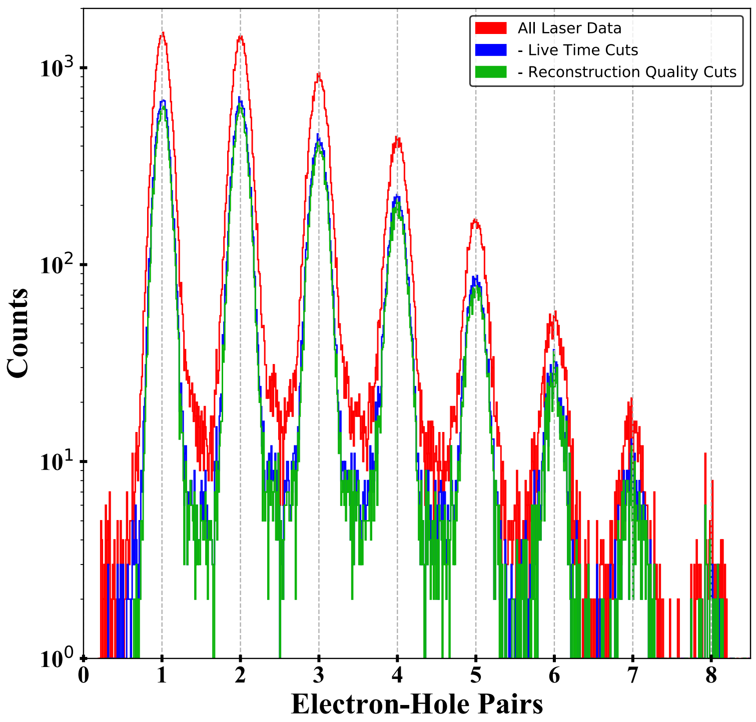


Detector neutralization performed at 70 hours due to increased levels of surface leakage. An increase in the bulk leakage rate was observed afterwards.

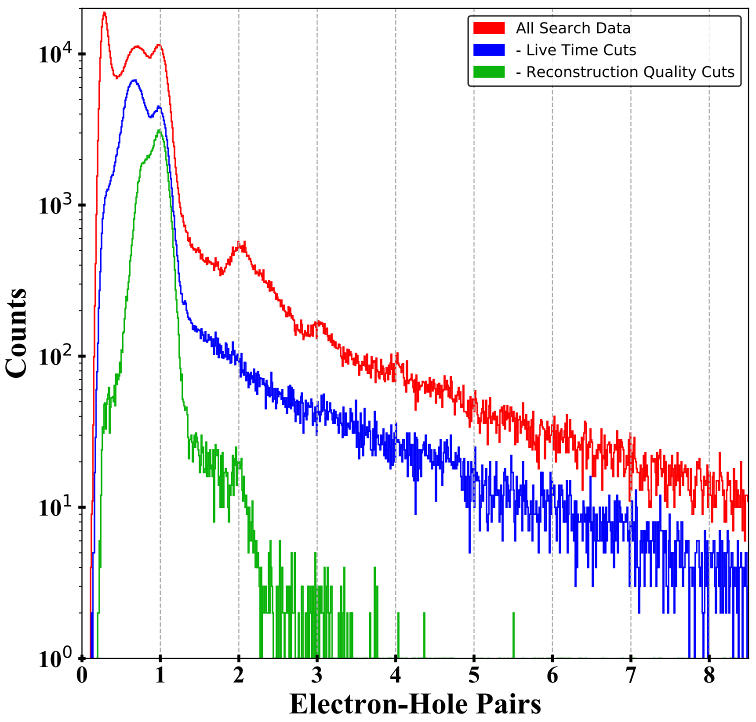
Temperature varied and bulk leakage rate was constant

Data Selection

Calibration Laser Data



DM Search Data

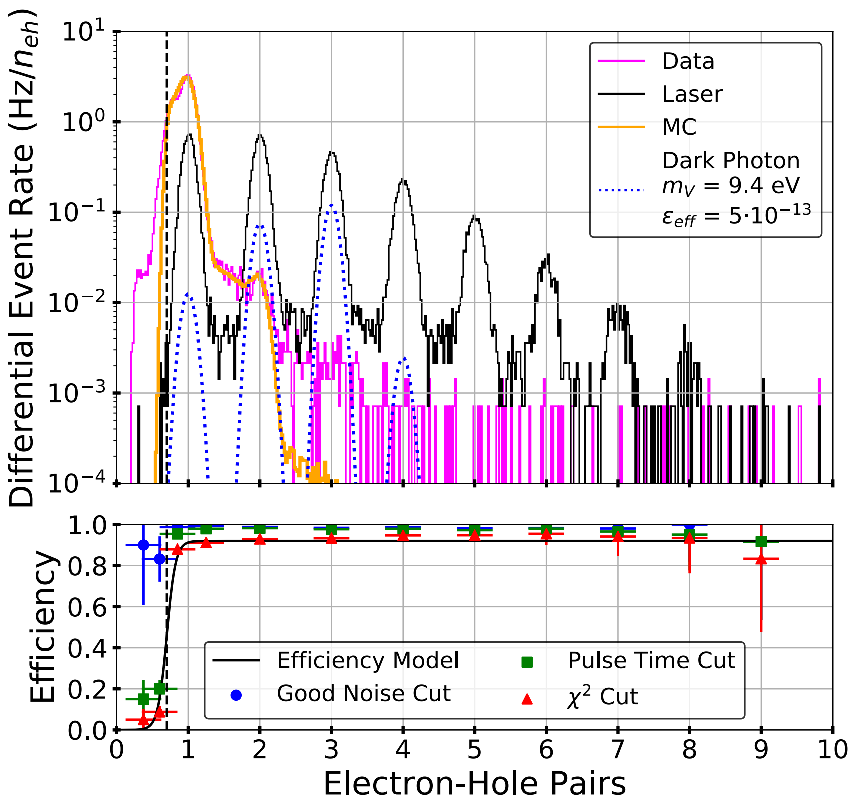


Periods of high low-frequency background, high surface leakage, and poor system stability were removed as part of the live time cuts. Events with excessive noise in the pre-trigger, start times far from the trigger window or bad time domain chi-square were rejected as part of the reconstruction quality cuts.

Science exposure of 0.49 gram-days

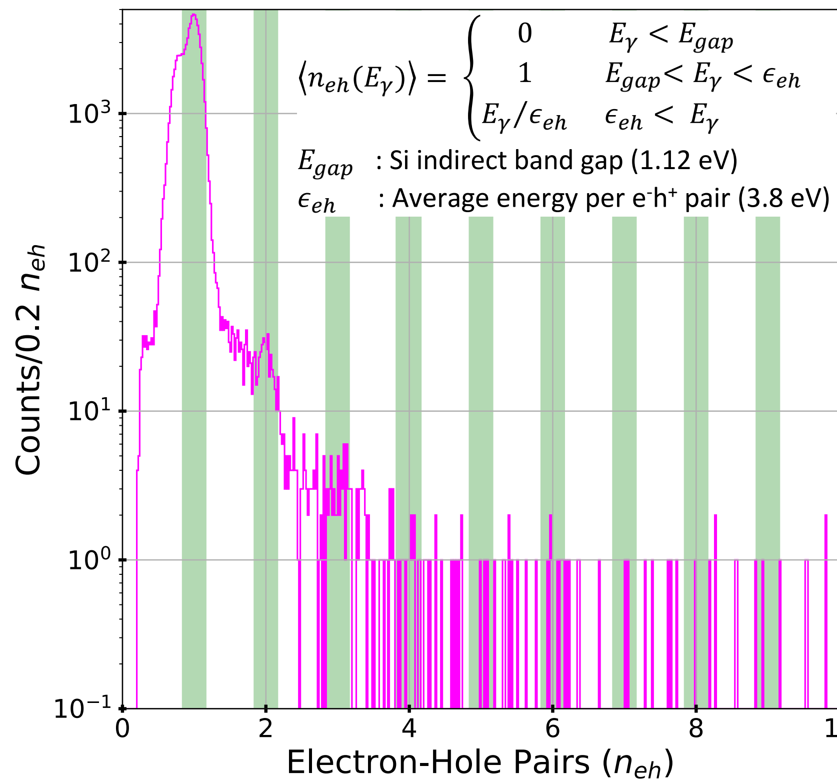
DM Search Data

Models and Cut Efficiency



Laser spectrum is used to calculate the reconstruction quality cut efficiency

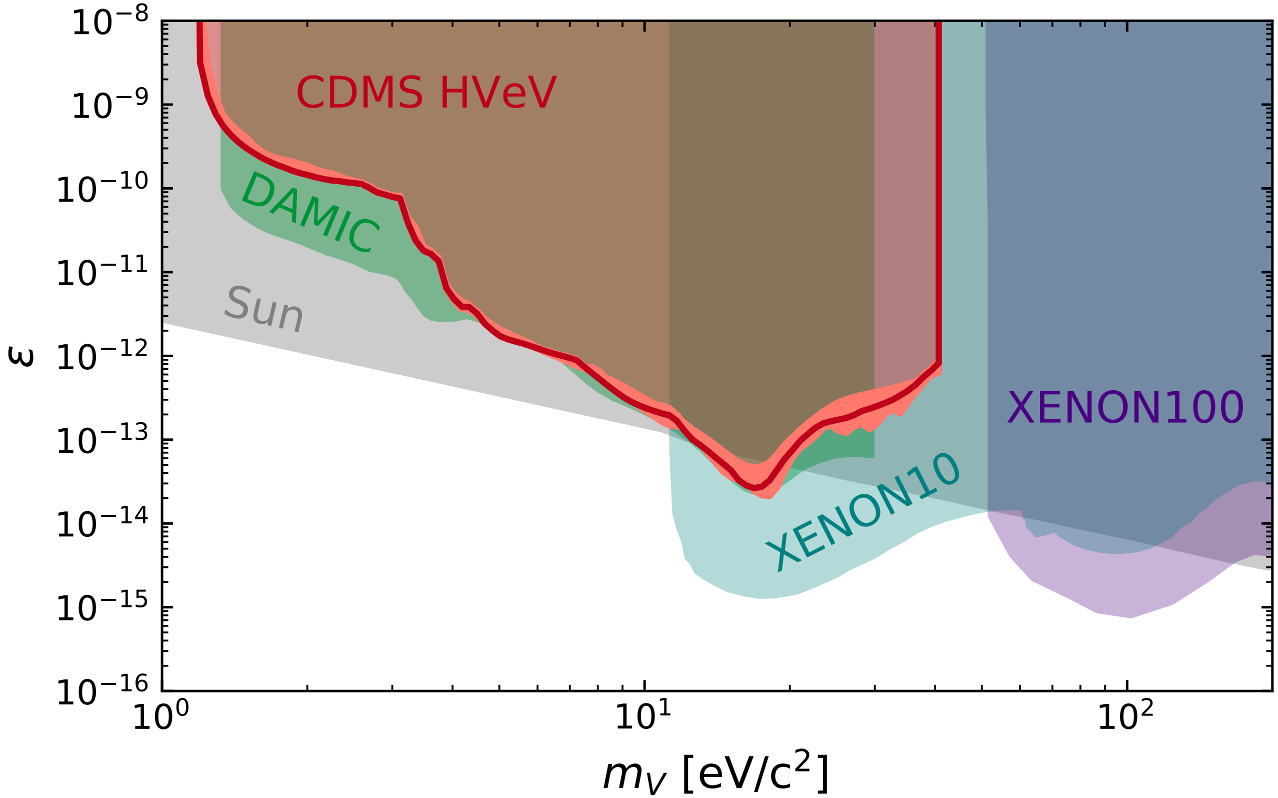
Optimal Interval



Optimal interval method is applied to sections of data within 2σ of quantized laser peaks.

Limit search region to expected DM signal regions

Dark Photon Dark Matter Search

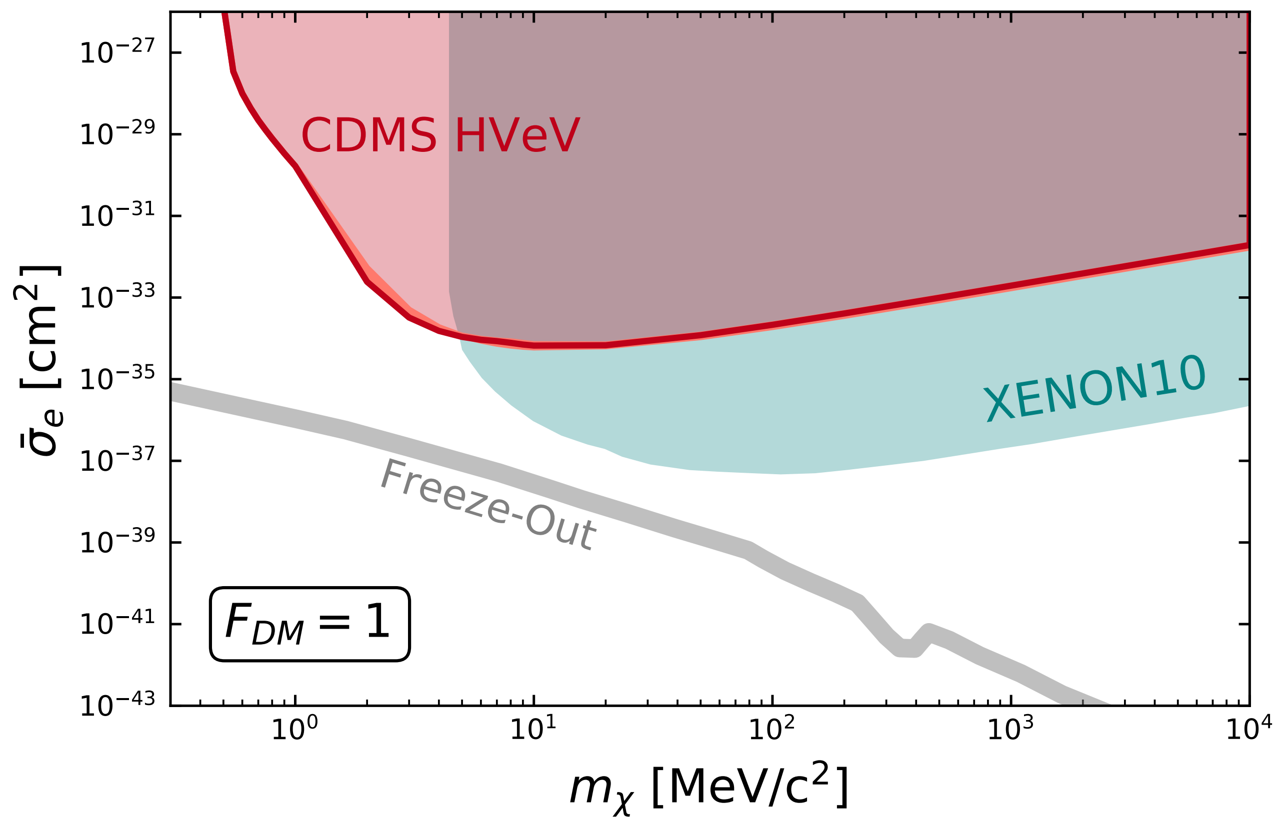


$$R = V_{Det}\frac{\rho_{DM}}{m_V}\varepsilon_{eff}^2(m_V,\sigma)\sigma_1(m_V)$$

2016 Essig 10.1007/JHEP05(2016)046

Dark photon limit is consistent with other measurements

Electron Recoil Dark Matter Search

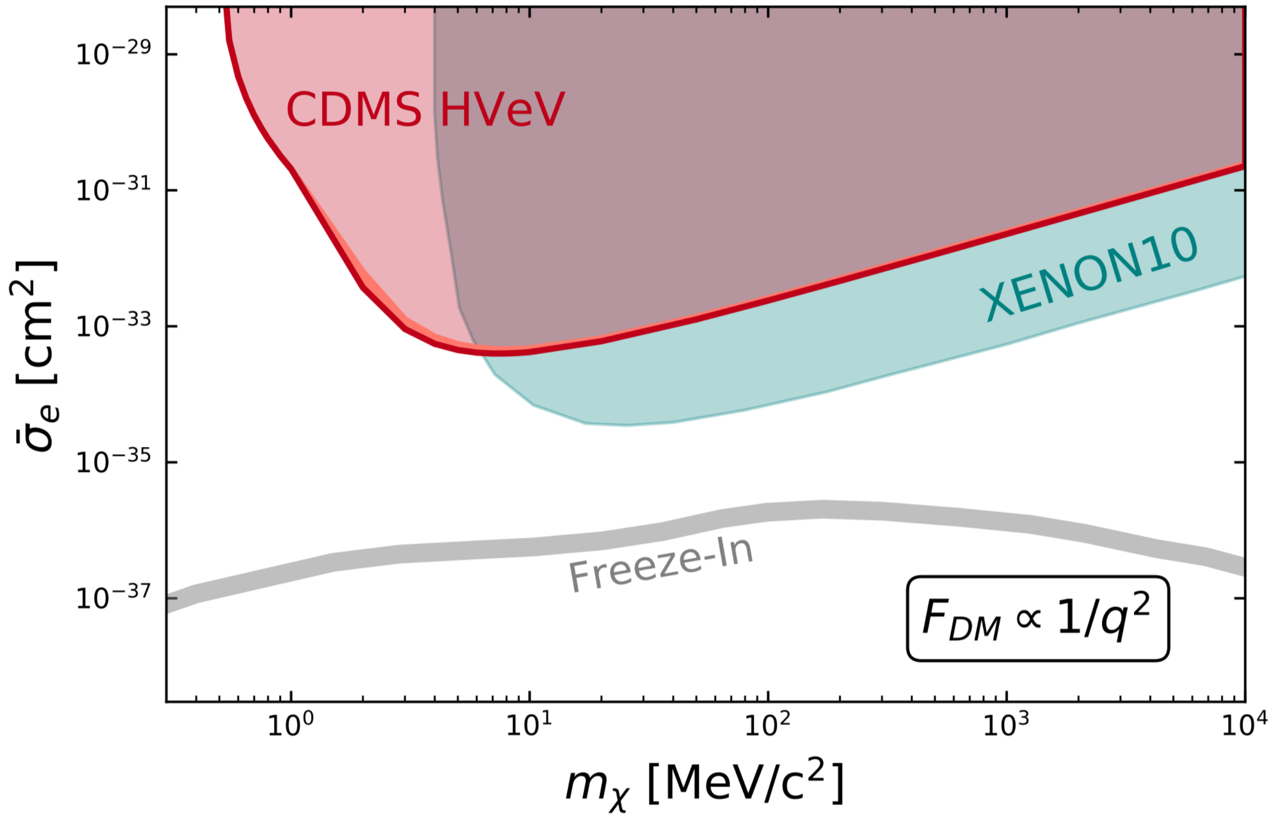


$$\frac{dR}{d(\ln(E_R))} = V_{Det}\frac{\rho_{DM}}{m_X}\frac{\rho_{Si}}{2m_{Si}}\bar{\sigma}_e\alpha\frac{m_e^2}{\mu_X^2}I_{Crystal}$$

2017 Hochberg 10.1103/PhysRevD.95.023013

Improved heavy mediator ERDM limits to 0.5 MeV

Electron Recoil Dark Matter Search



$$\frac{dR}{d(\ln(E_R))} = V_{Det}\frac{\rho_{DM}}{m_X}\frac{\rho_{Si}}{2m_{Si}}\bar{\sigma}_e\alpha\frac{m_e^2}{\mu_X^2}I_{Crystal}$$

2017 Hochberg 10.1103/PhysRevD.95.023013

Improved light mediator ERDM limits to 0.5 MeV

Conclusion

- Single e^-h^+ pair resolution with NTL gain
- Achieved comparable sensitivity to that reported by DAMIC for Dark Photons
- Improved constraints on inelastic ERDM for both heavy and light mediators down to 0.5 MeV

Backup Slides

Dark Matter Models

$$\langle n_{eh}(E_\gamma)\rangle = \begin{cases} 0 & E_\gamma < E_{gap} \\ 1 & E_{gap} < E_\gamma < \epsilon_{eh} \\ E_\gamma/\epsilon_{eh} & \epsilon_{eh} < E_\gamma \end{cases}$$

E_{gap} : Si indirect band gap (1.12 eV)

ϵ_{eh} : Average energy per e^-h^+ pair (3.8 eV)

Dark Photons

$$R = V_{Det}\frac{\rho_{DM}}{m_V}\varepsilon_{eff}^2(m_V,\sigma)\sigma_1(m_V)$$

$\rho_{DM}/\, m_V$: DM number density

ε_{eff} : Effective kinetic mixing angle

σ : Complex conductivity

Inelastic Electron Recoil Dark Matter Interaction

$$\frac{dR}{d(\ln(E_R))} = V_{Det}\frac{\rho_{DM}}{m_X}\frac{\rho_{Si}}{2m_{Si}}\bar{\sigma}_e\alpha\frac{m_e^2}{\mu_X^2}I_{Crystal}$$

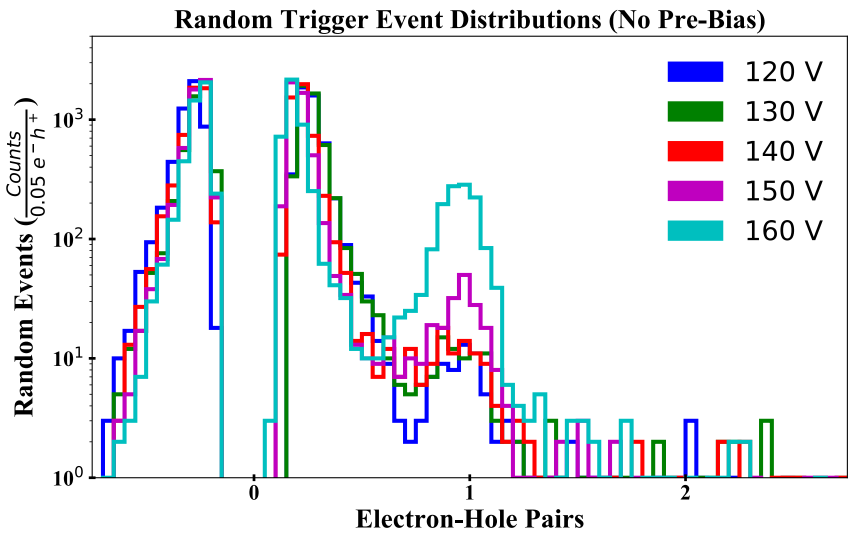
$\bar{\sigma}_e\alpha$: Effective DM-SM coupling

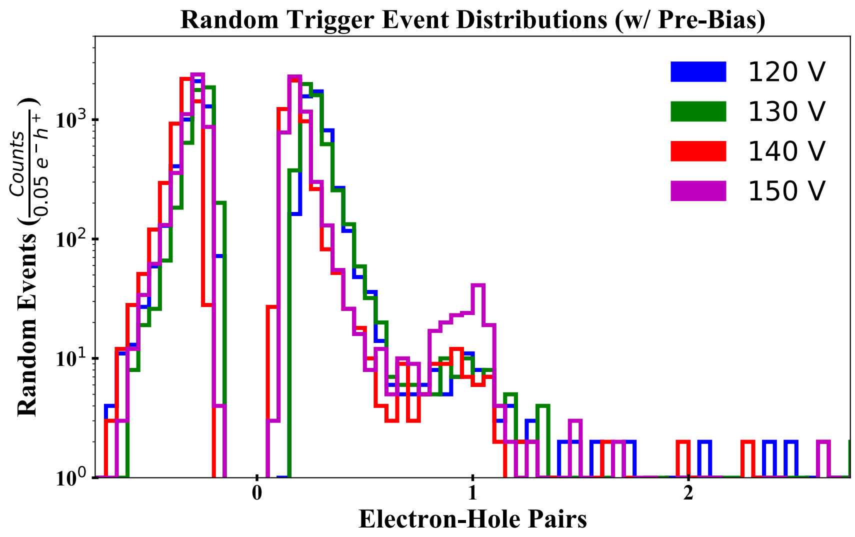
μ_X : Reduced mass

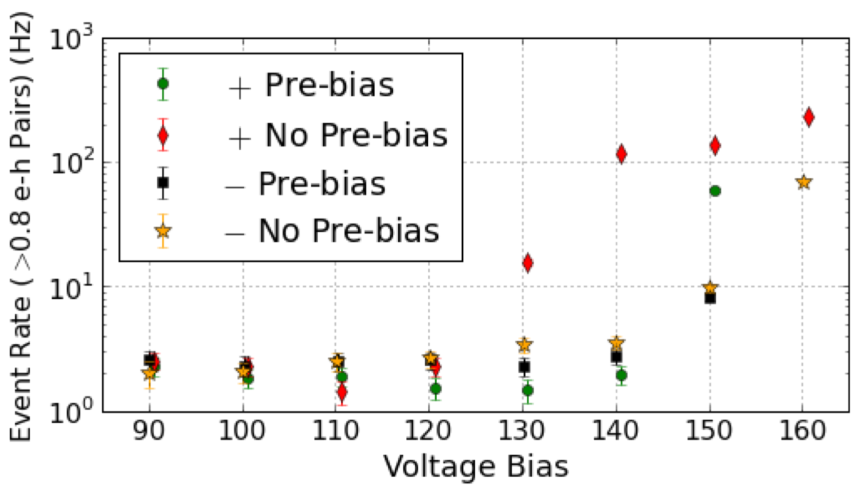
$I_{Crystal}$: Scattering integral

V_{Det} : Detector volume

Limitations on NTL Gain



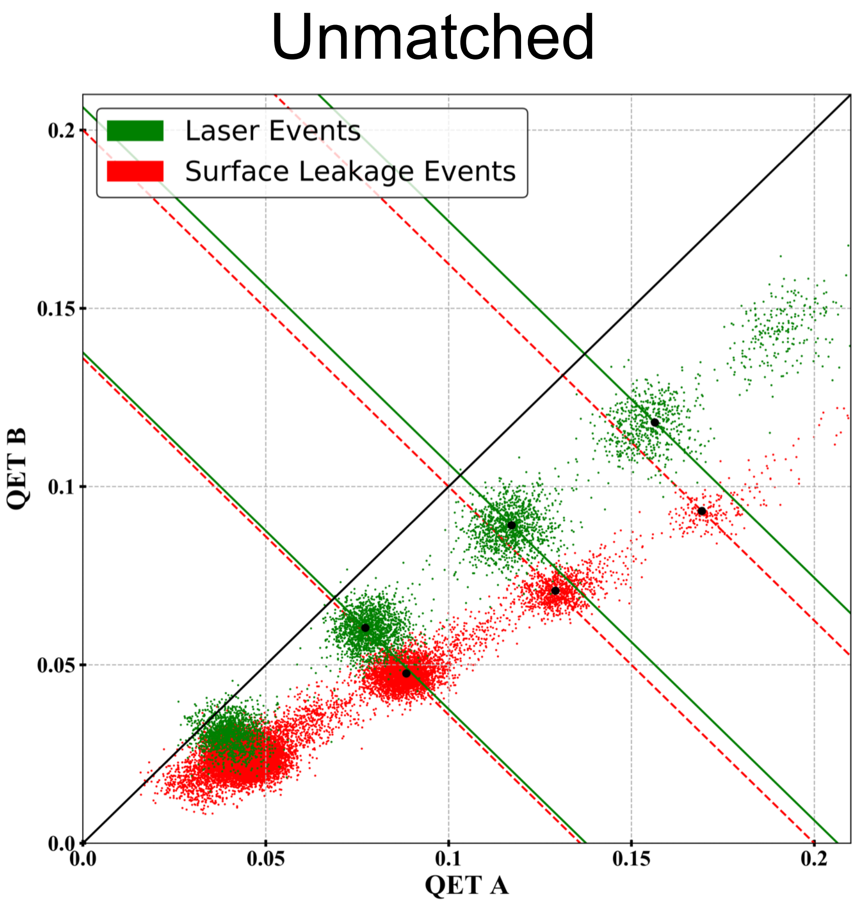


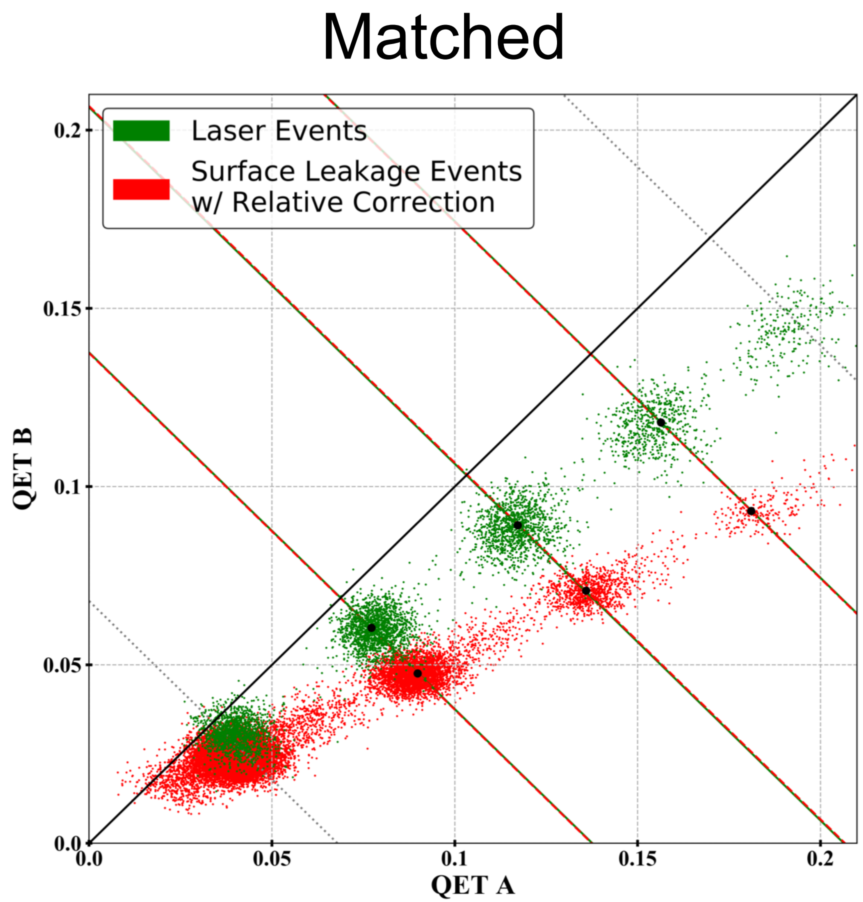


- Bi-modal distribution caused by time shifting optimal filter
- Bulk leakage events have a flat distribution between 0-1 e^-h^+ pairs
- Surface leakage events have quantized energy
- Full break down at 180 V

Avoid surface leakage by using ±140 V

Relative Detector Calibration

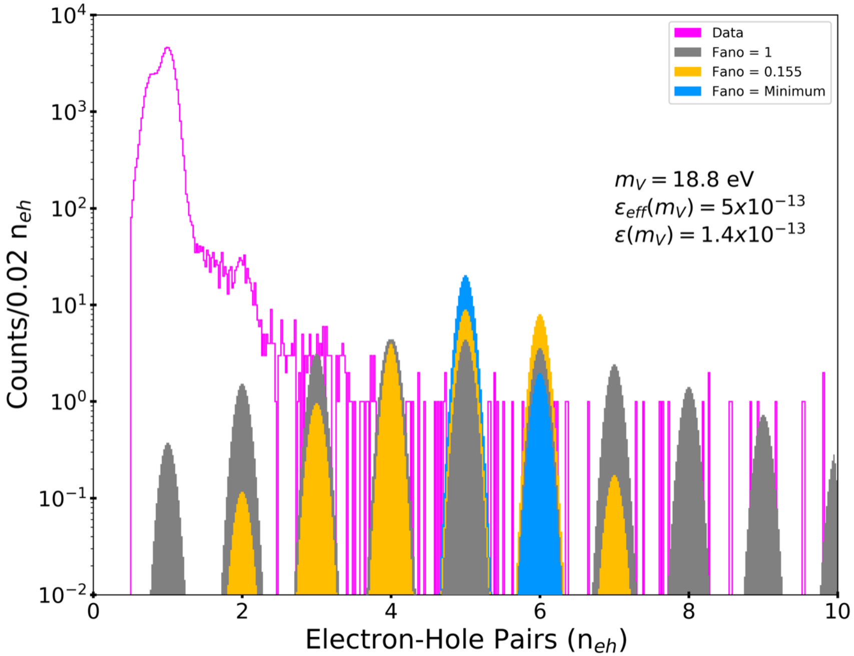




QET A appears to have losses requiring a 13% correction to get surface events to land on lines of equal energy with the laser

Model Assumptions

Fano Factor

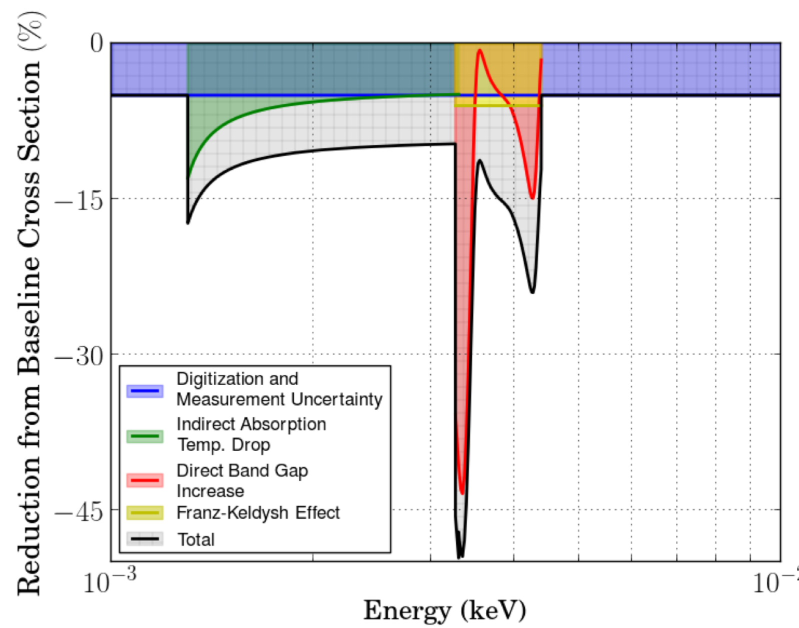


Example of an excluded dark photon signal

$$R = V_{Det}\frac{\rho_{DM}}{m_V}\varepsilon_{eff}^2(m_V,\sigma)\sigma_1(m_V)$$

2016 Essig 10.1007/JHEP05(2016)046

Photoelectric Cross Section



Reductions in photoelectric cross section to account for experimental parameters