Dark Absorption in SuperCDMS Soudan

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Outline

- Introduction
  - Dark matter and dark absorption
  - The SuperCDMS Experiment
  - The detectors: iZIPs and CDMSlite
- iZIP Analysis
  - Adaptation of event selection criteria
  - Signal efficiency for electron recoils
  - Resolution model
- Limit Setting
  - Counting method
  - Combining datasets

Dark Matter (DM)

Strong evidence for exotic matter that:

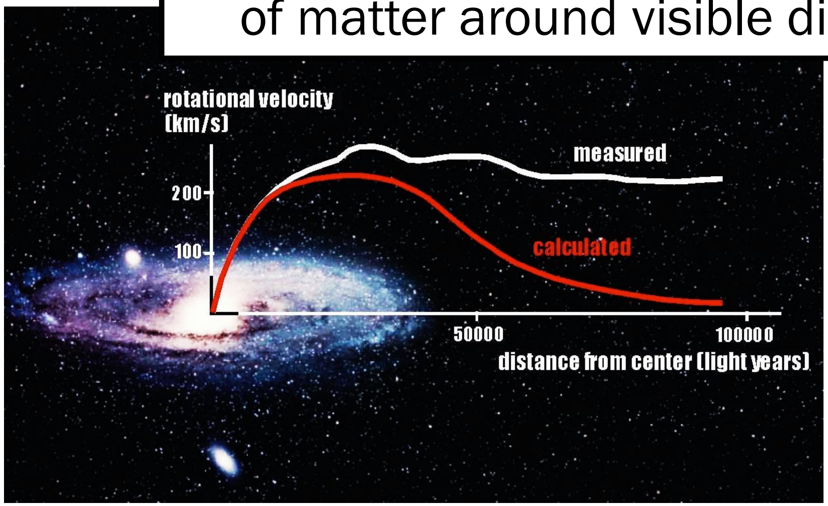
- constitutes ~85% of all matter
- is non-luminous & non-baryonic
- interacts gravitationally

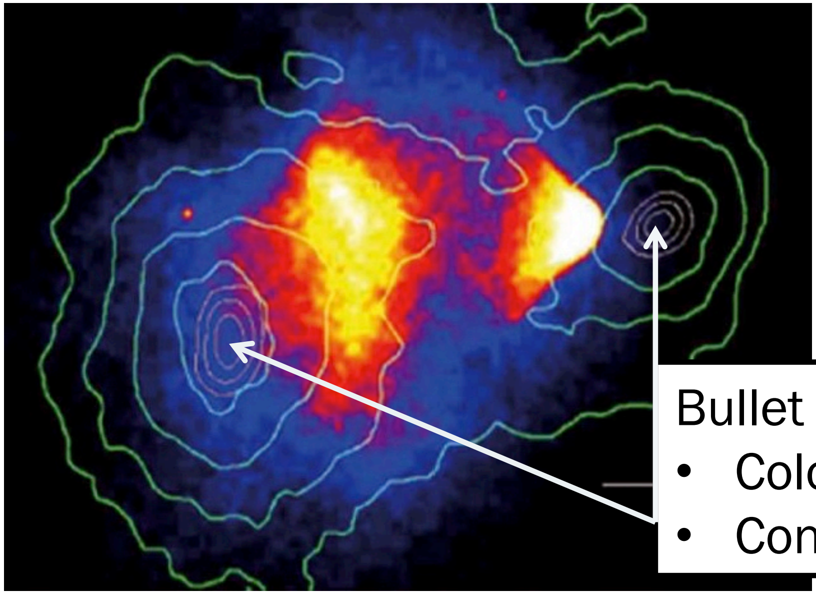
Galactic Rotation Curves

- Expect rotational velocity:

$$v_c \sim 1/R$$

- Flat distribution indicates halo of matter around visible disk





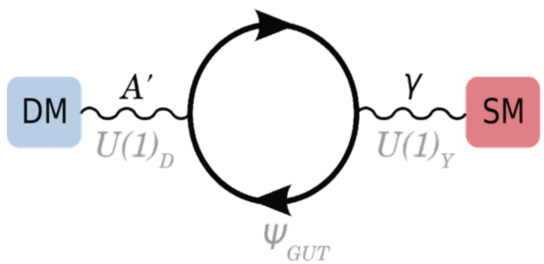
Bullet Cluster (two cluster collision):

- Colour map – visible matter (X-rays)
- Contours – gravitational centre (lensing)

Electron Interacting DM

Dark Photon (DP)

- Vector boson (V) associated with new $U(1)_D$ gauge symmetry
- Hypothetical mediator between dark and visible sector, may itself be the DM
- May kinetically mix with Standard Model photon



- Dark Photon mass: m_V

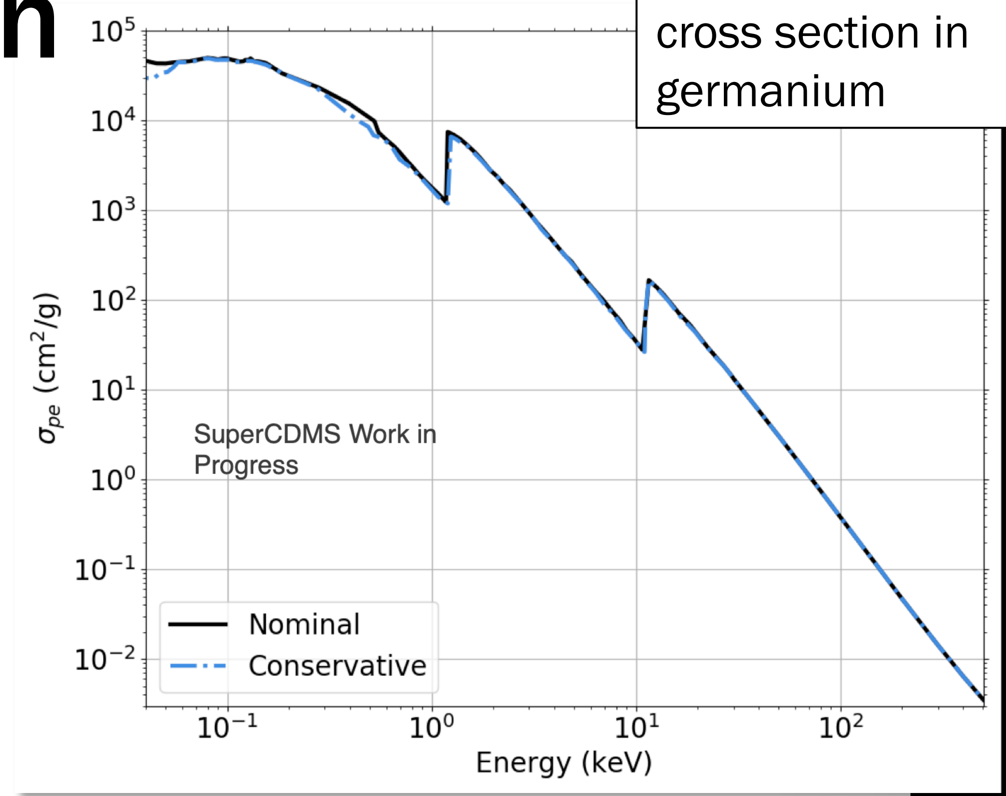
Axion-Like Particle (ALP)

- Pseudo-scalar Goldstone boson (a) associated with spontaneous breaking of some new symmetry
- Electrically neutral
- May have interactions with electrons
- Canonical axion: proposed to solve the strong CP problem
- ALP mass: m_a

Dark Absorption

ALPs/DPs may be absorbed by bound electrons in process analogous to photoelectric effect

- Assumption: either ALPs or DPs constitute all of the galactic dark matter
- Galactic ALPs/DPs are nonrelativistic
- Interaction rates are:

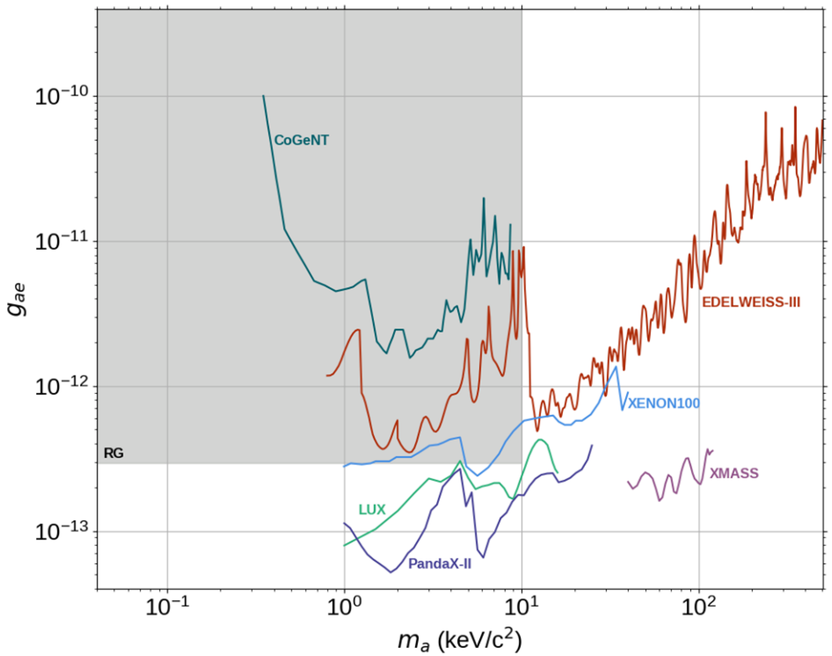


Photoelectric cross section in germanium

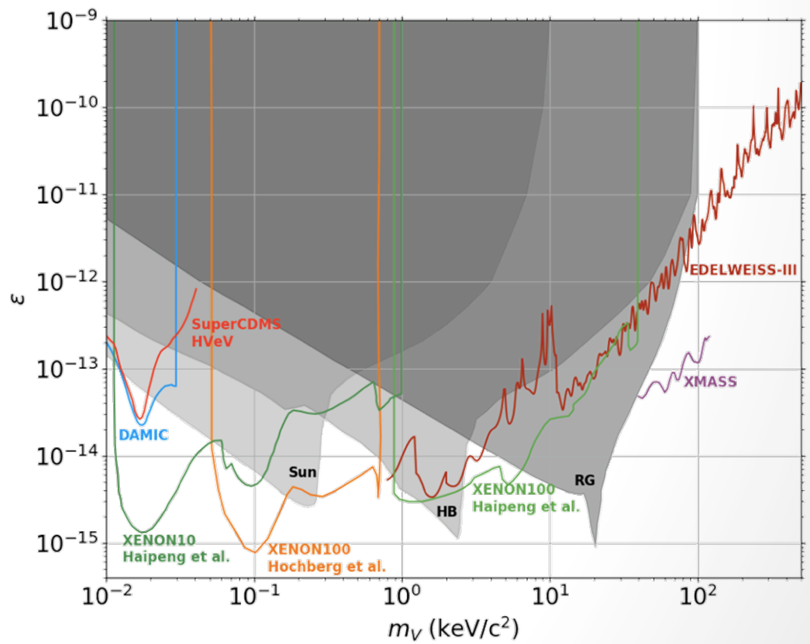
$$R_{DP} \approx \frac{\varepsilon_{eff}^2 c}{m_V c^2} \rho_{DM} \sigma_{pe}(m_V c^2) \qquad R_{ALP} \approx \frac{3 g_{ae}^2 c}{16\pi\alpha} \frac{m_a}{m_e} \rho_{DM} \sigma_{pe}(m_a c^2)$$

- Expected signal shape: Dirac-delta at DM mass (m_a or m_V) folded with detector resolution

Current Parameter Space



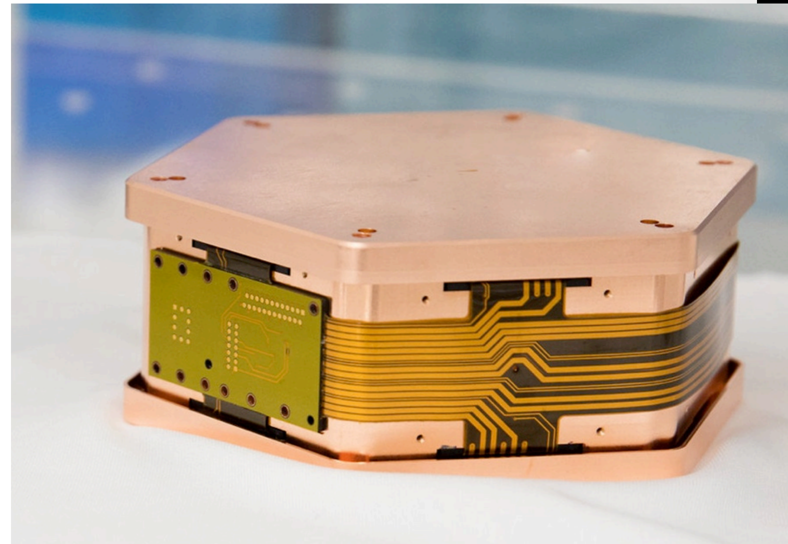
Current direct detection (lines) and astrophysical (shaded) exclusion limits for ALPs and DPs in coupling constant vs. mass plane



Shaded regions and area above lines are excluded

Our analysis range:
40 eV - 500 keV

SuperCDMS



A SuperCDMS SNOLAB detector

Search for DM using cryogenic semiconductor detectors instrumented with transition edge sensors (TESs) and charge electrodes – measure both phonon and ionization signals

Past (2012-2015)

- At Soudan, MN (~700m below ground)
- 15 Ge detectors (~9 kg)

Future (2020 - ?)

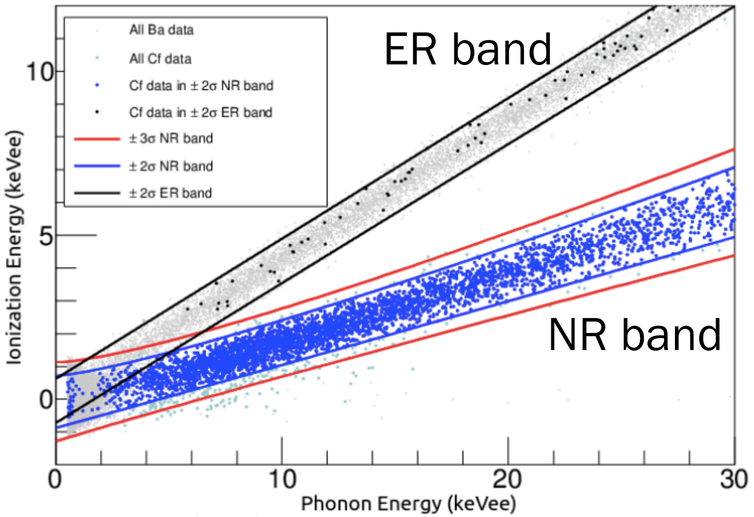
- Deeper (SNOLAB)
- Larger (~30kg)
- Lower threshold

Traditionally search for WIMPs (interact via nuclear recoils (NRs))

Past searches for electron recoil (ER) DM: CDMS II, HVeV detectors

Here we set ER DM limits using data from SuperCDMS Soudan

SuperCDMS Soudan

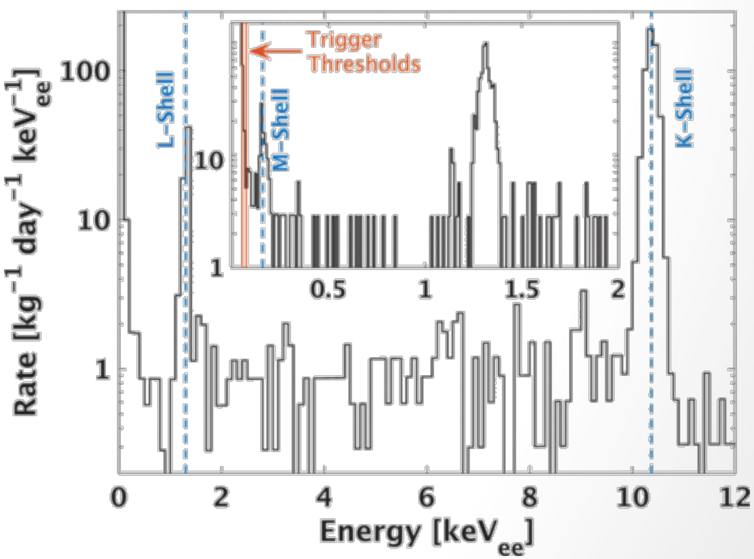


iZIP: Standard operational mode

- 4V bias voltage across detector
- Measure both phonon + ionization signals
- Discrimination between ER vs. NR

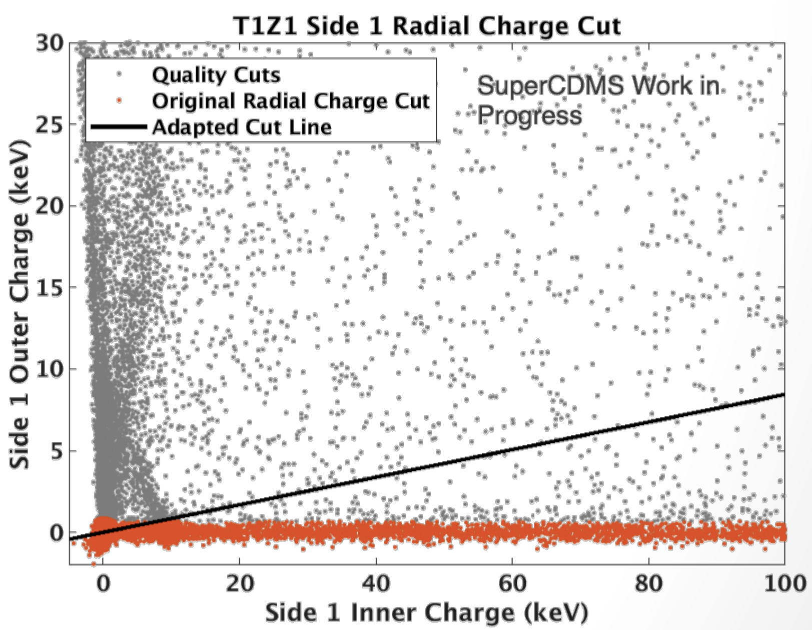
CDMS low ionization threshold experiment (CDMSlite)

- Higher bias voltage (~70V): drifting charges produce large extra phonon signal (NTL amplification)
- Measure phonon signal only
- ER vs. NR discrimination is lost
- Much lower energy thresholds!



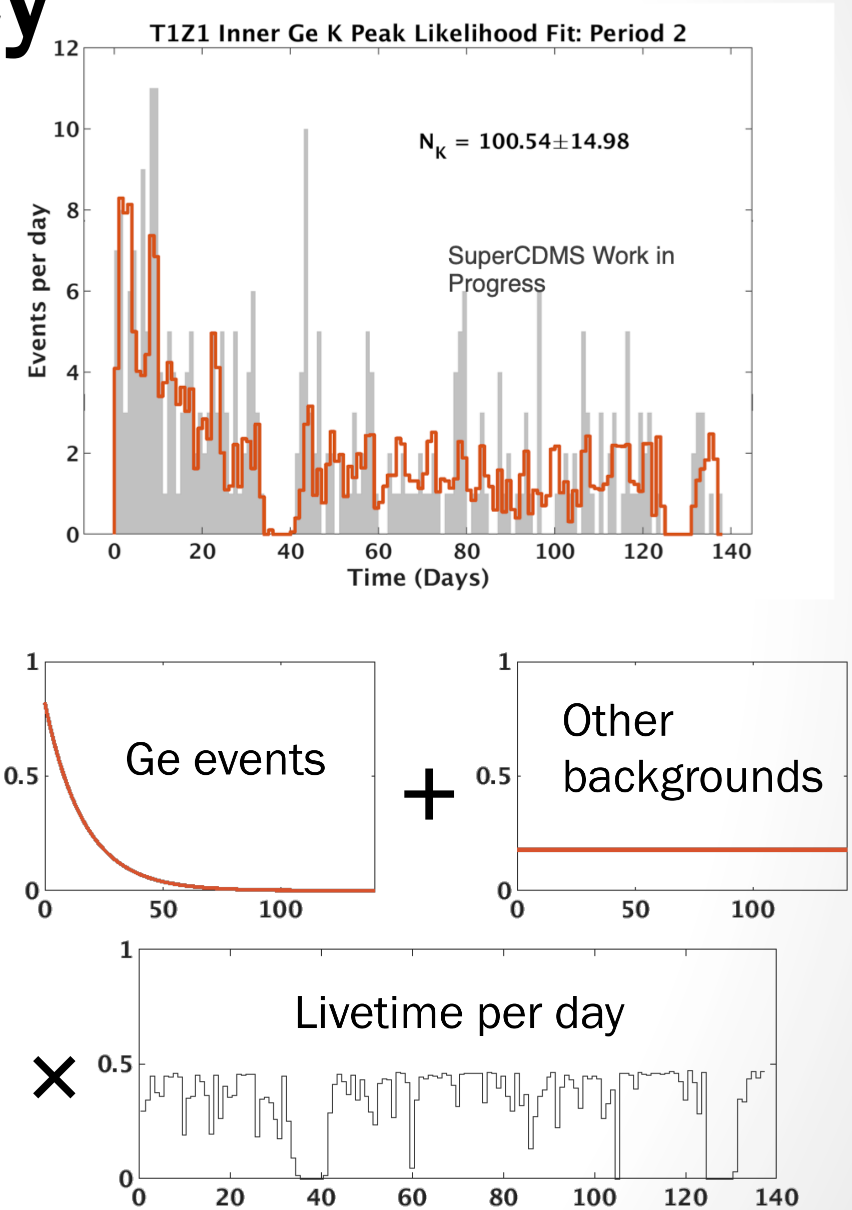
iZIP Fiducial Volume

- Inhomogenous electric field across detector - particularly at sidewalls
- Fiducial Volume (FV) cuts remove events with:
  - reduced NTL amplification
  - trapped charges on the detector faces/sidewalls
- FV was defined for NR, but we need it for ER
- Gammas are not a good proxy due to multiple scatters
- Use the ^{71}Ge electron capture and make sure our FV cuts are energy independent (only have the one calibration point)

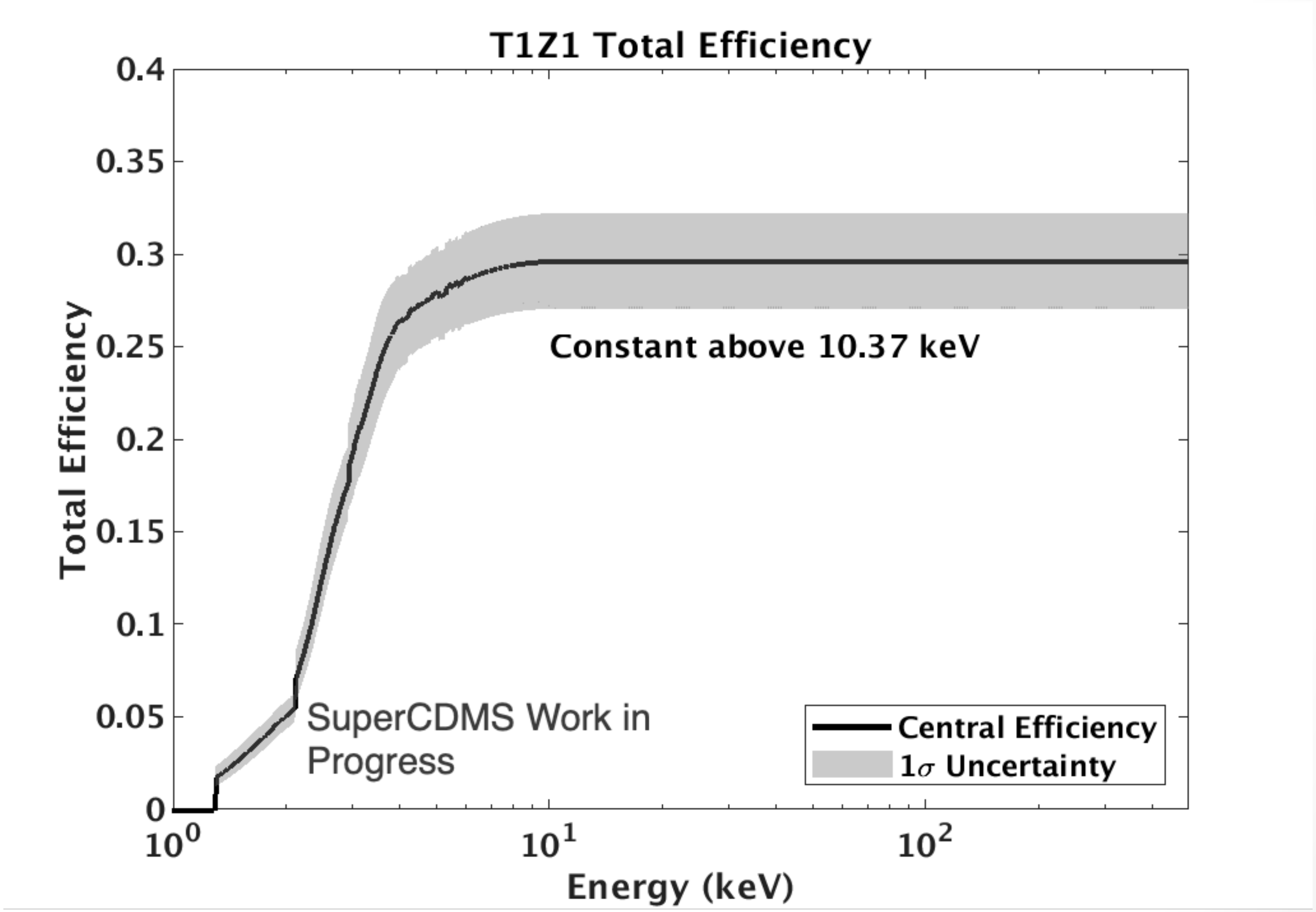


iZIP FV Efficiency

- ^{71}Ge produced in neutron calibrations
- Decay via electron capture; produces pointlike events (like dark absorption)
- Identify Ge events as decaying component (11 day half life) in the spectrum
- Ratio of number of ^{71}Ge events passing the FV cuts to all ^{71}Ge events gives the FV efficiency



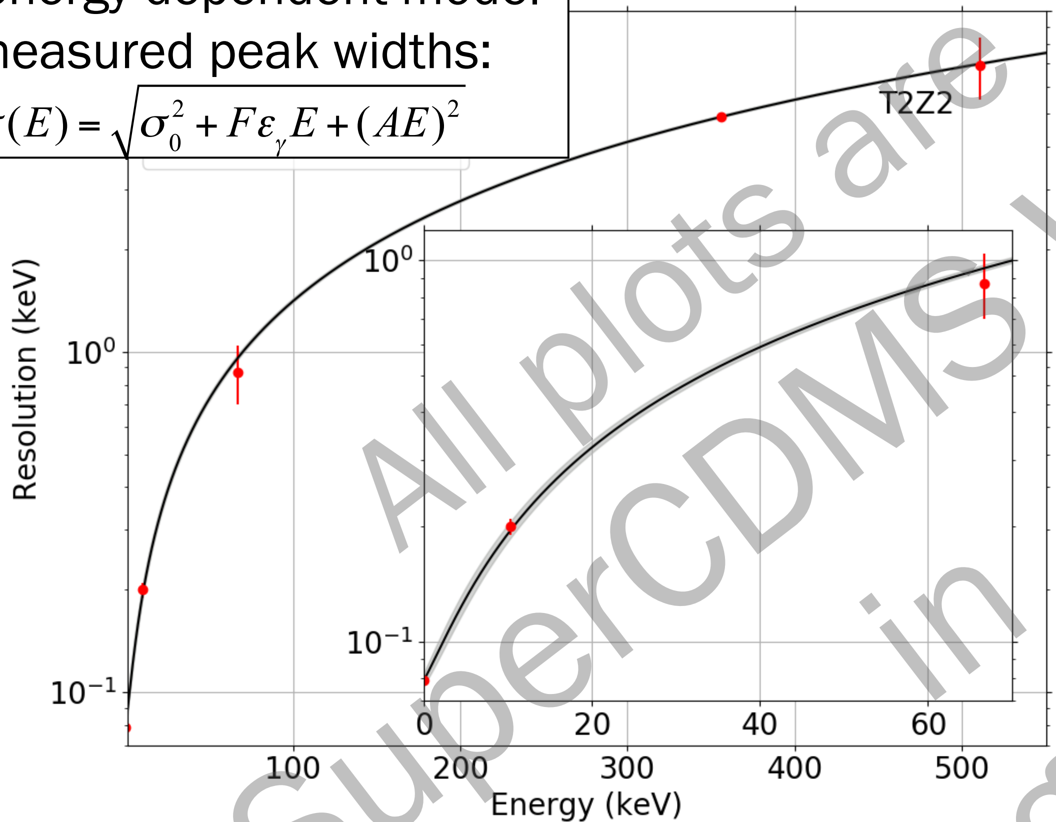
iZIP Total Signal Efficiency



iZIP Resolution Model

Fit energy dependent model to measured peak widths:

$$\sigma(E) = \sqrt{\sigma_0^2 + F\varepsilon_\gamma E + (AE)^2}$$



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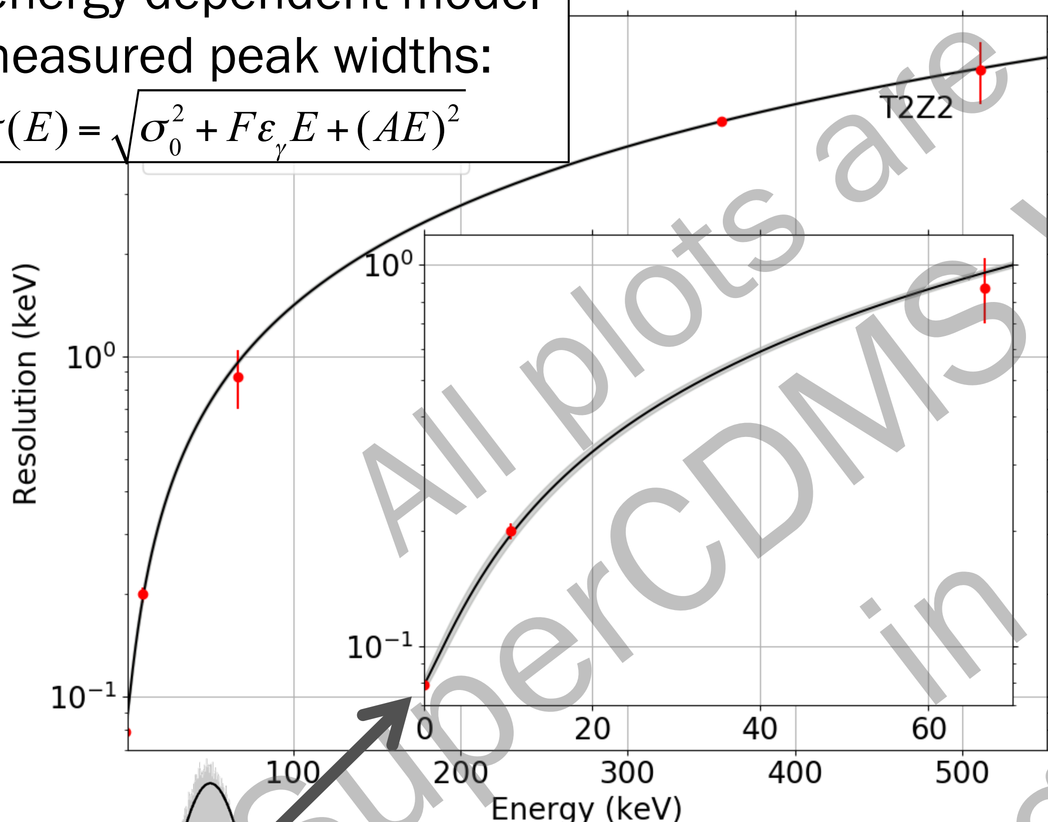

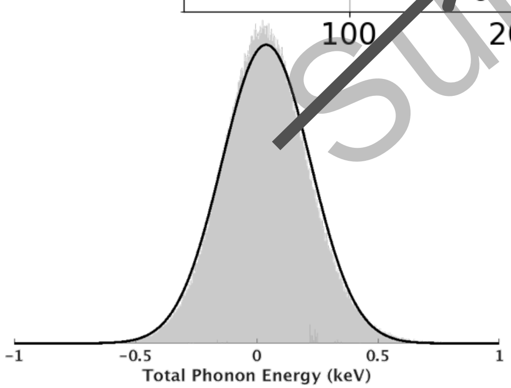

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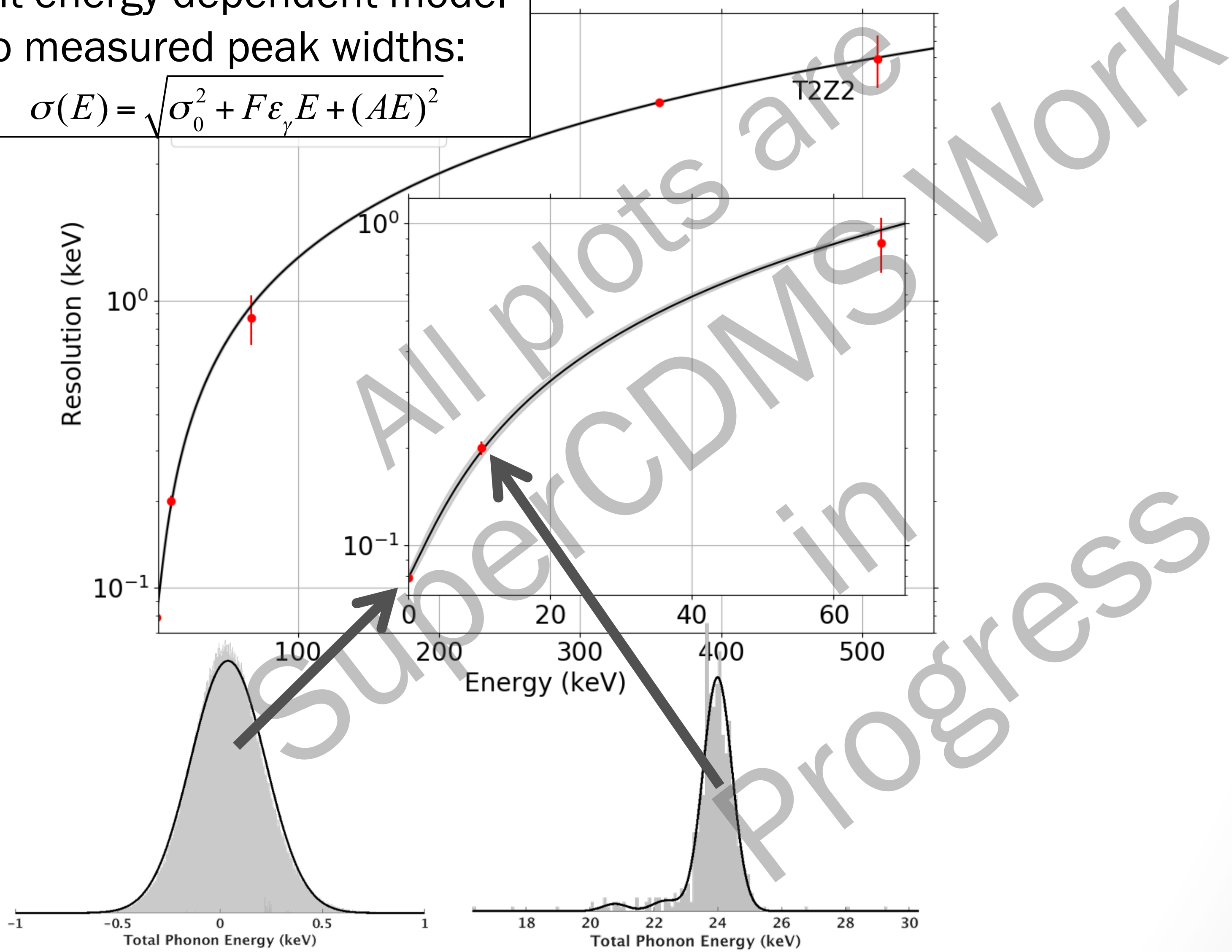

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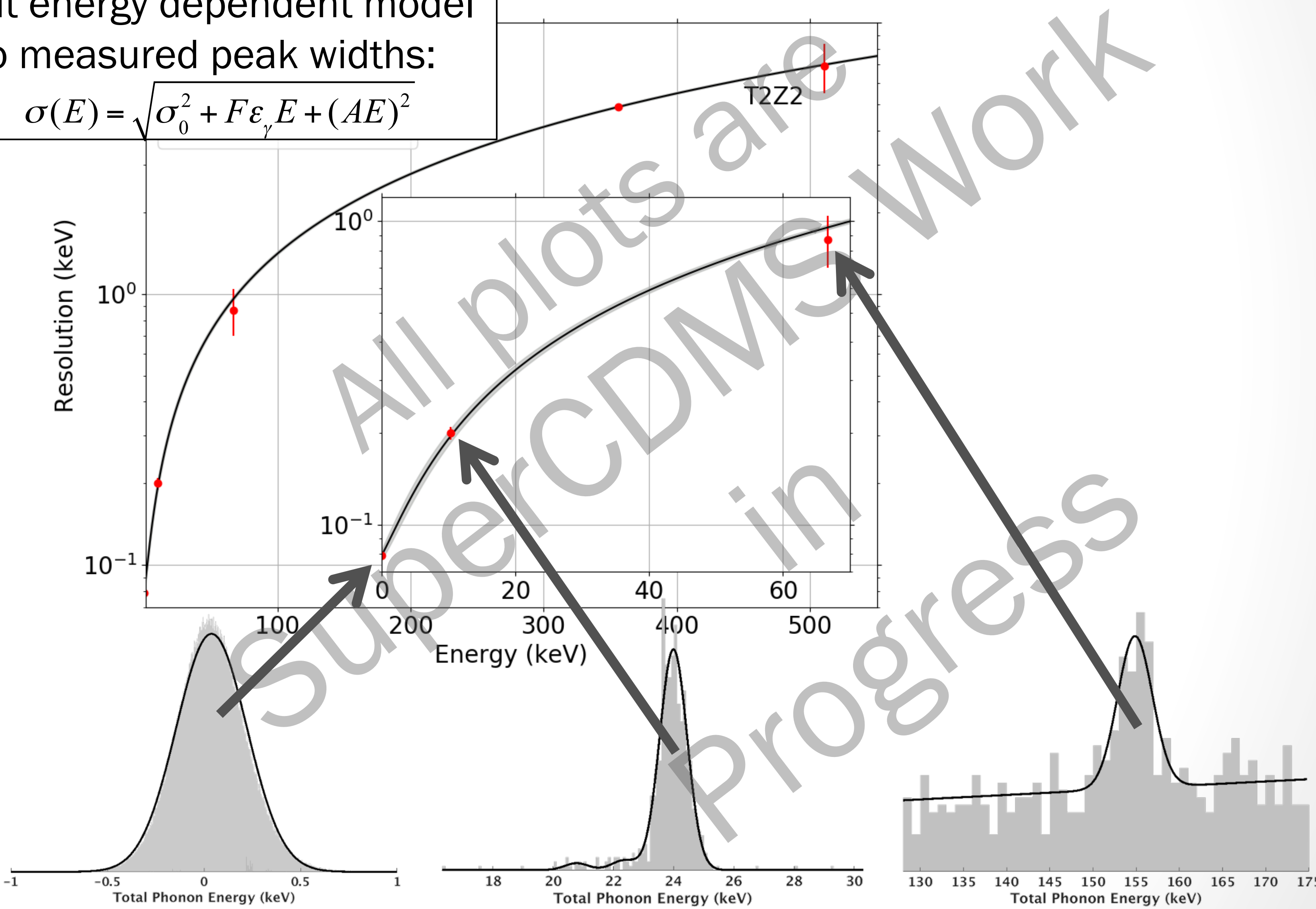

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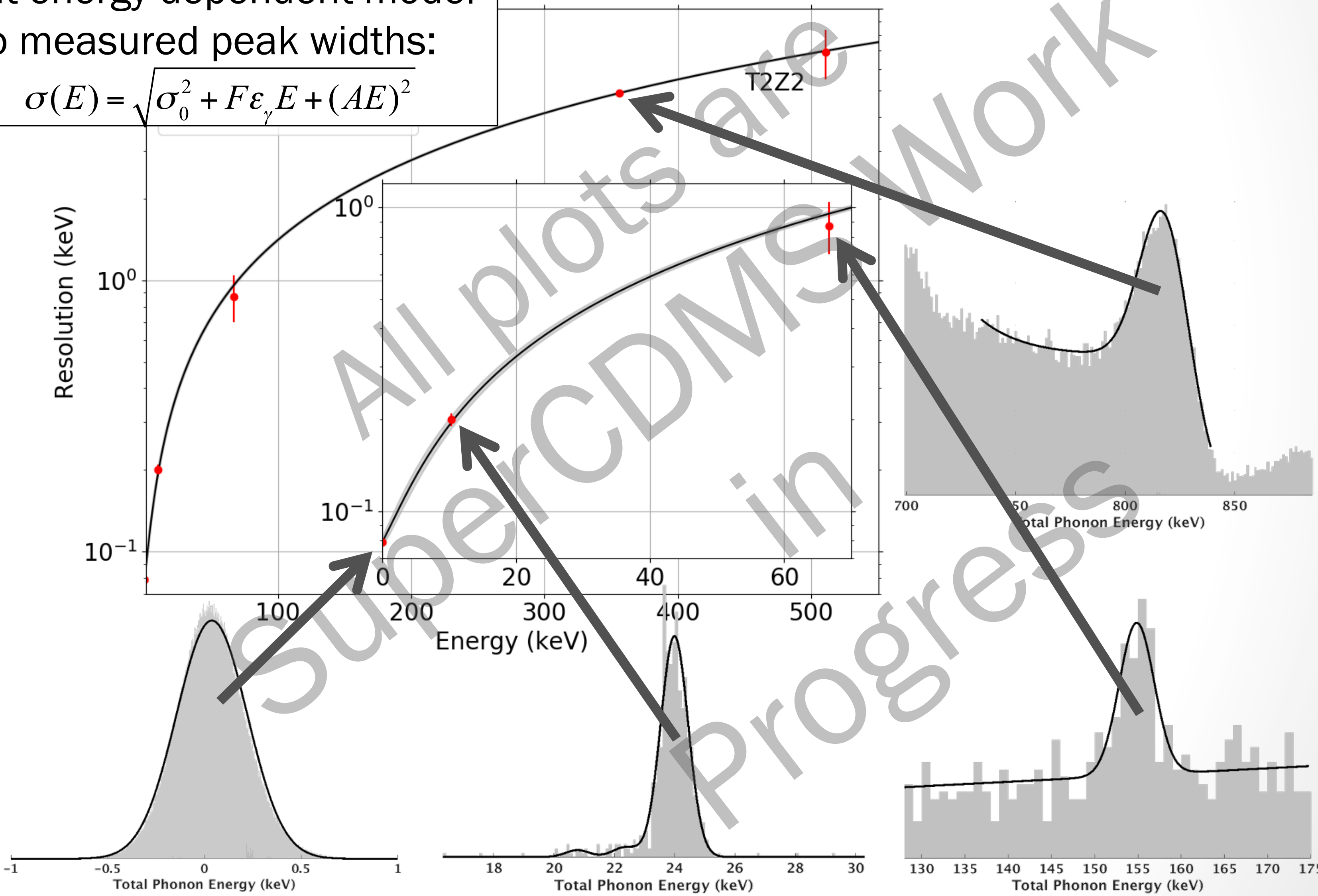

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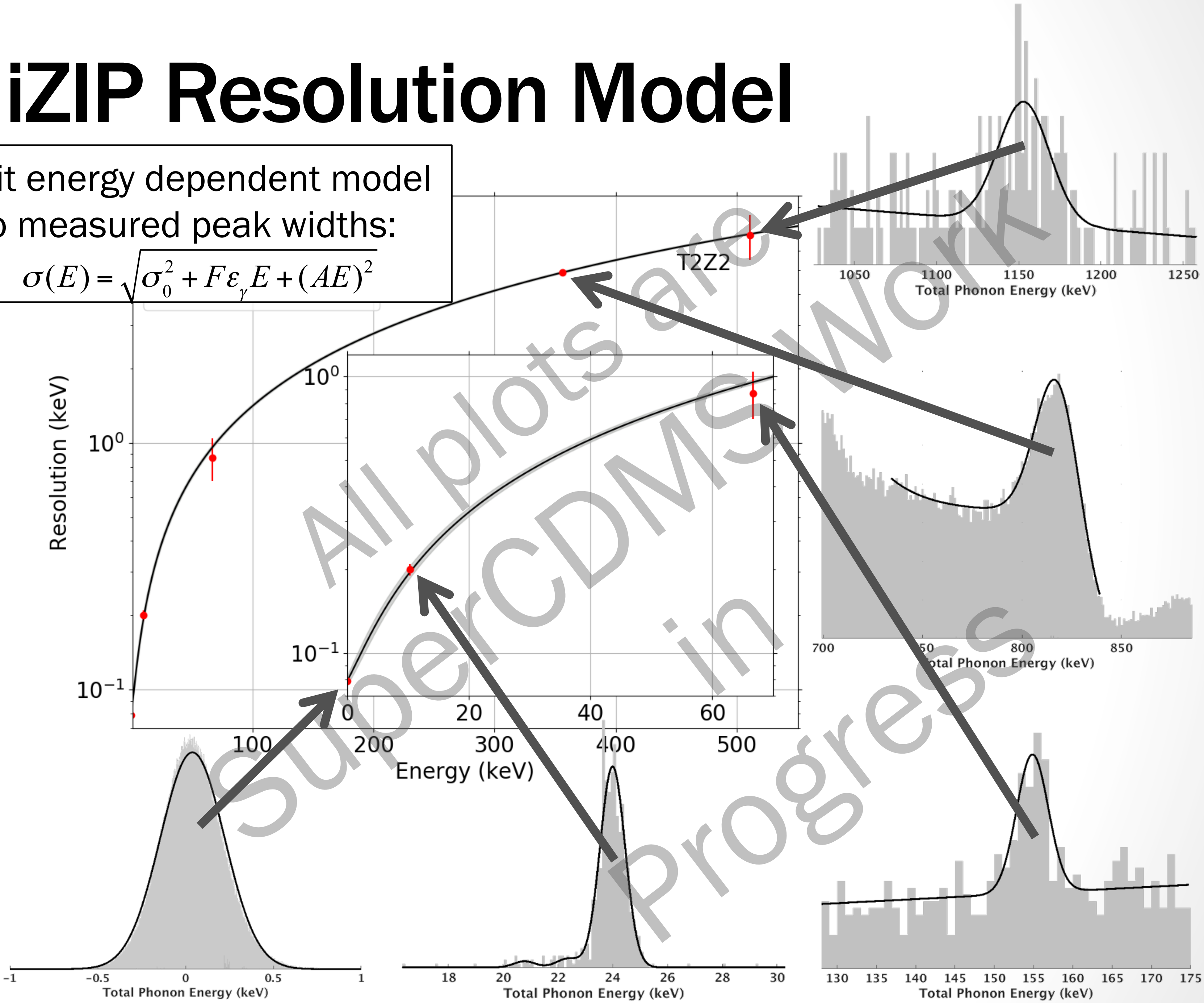

Limit Setting

For DM, mass M, expected signal is a Gaussian at energy $E_M = Mc^2$

Set limit using Poisson counting statistics (0 background assumption):

- Count number of events, N, in range $E_M \pm \sigma(E_M)$, where $\sigma(E_M)$ is the detector resolution at E_M
- Determine the Poisson 90% upper limit on N, N_{90}
- Calculate upper limit on rate, R, using exposure-weighted efficiency, $\xi(E_M)$:

$$R = {N_{90}}/{\xi(E_M)}$$

- Determine coupling constant (g_{ae} or ε) from rate

Combining Datasets

We would pay a big penalty if we simply average datasets and include detectors with higher backgrounds

To combine datasets at a given dark matter mass:

- Take lowest measured rate r_{min} and compare all other rates
- Discard a dataset if the measured rate is >3σ above r_{min}
- Combined rate calculated from remaining datasets:

$$R = \frac{P_{90}\left(\sum_i N_i\right)}{\sum_i \xi_i}$$

i = sum over kept datasets
N_i = measured events in dataset i
ξ_i = exposure-weighted efficiency
$P_{90}(N)$ = 90% Poisson upper limit on N

Limits on the two different couplings are then calculated using the combined rate

Results

- Limits calculated for ALP and dark photon couplings in mass range 40 eV – 500 keV
  - CDMSlite Run 2 + Run 3 combined limit
  - iZIP Run 133 combined limit
  - SuperCDMS Soudan (CDMSlite + iZIP) combined limit
- Look for results on arXiv in the near future!

The SuperCDMS Collaboration