Bertrand’s Wish List

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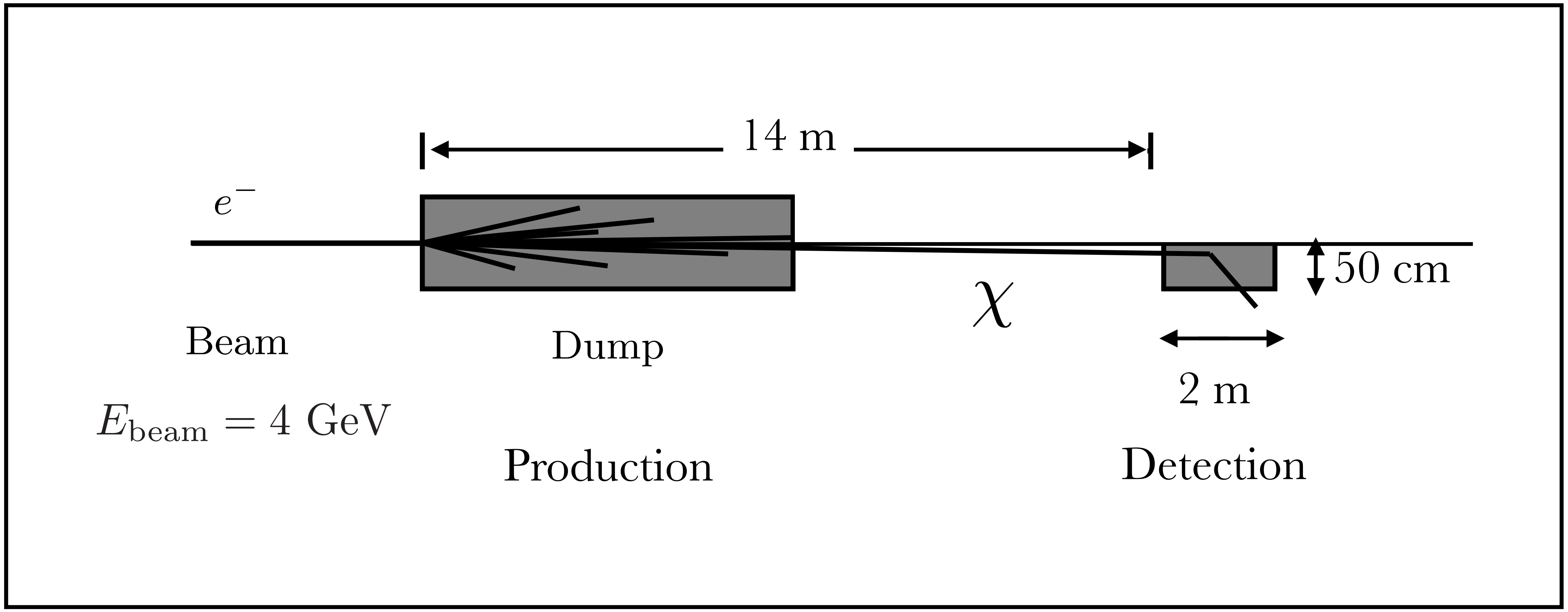
Fermilab

NEXT Meeting Jan 15, 2016

Overview

- **Setup Reminder**
- **Qualitative Signal Features**
- **NaI, CsI, LAr, LXe, Si, Plastic Scintillator**

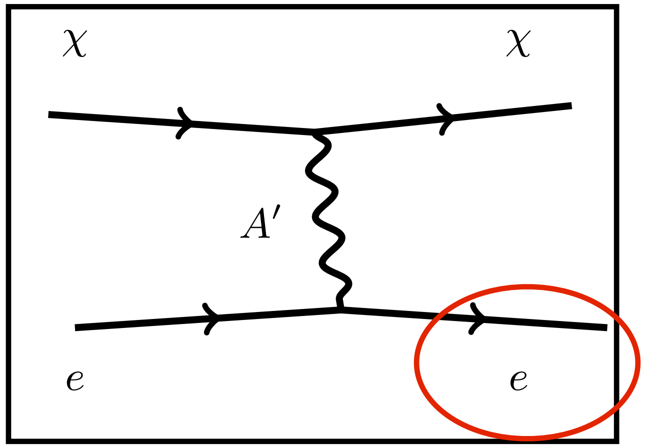
Setup Reminder



$$\mathcal{L}_{dark} = -\frac{1}{4}F'_{\mu\nu}F'^{\,\mu\nu} + \frac{\epsilon}{2}F'_{\mu\nu}F_{\mu\nu} + \frac{m^2_{A'}}{2}A'_{\mu}A'^{\,\mu} + \bar{\chi}(i\not{D} - m_\chi)\chi,$$

This talk: Rate comparison of different channels
Assuming elastic fermion DM scattering

Electron Recoils: Signal Characteristics



$$\frac{d\sigma}{dE_e} \simeq \frac{4\pi\epsilon^2\alpha\alpha_D[2m_e(E_\chi^2 - E_\chi E_e) - m_\chi^2 E_e]}{E^2(m_{A'}^2 + 2m_e E_e)^2}$$

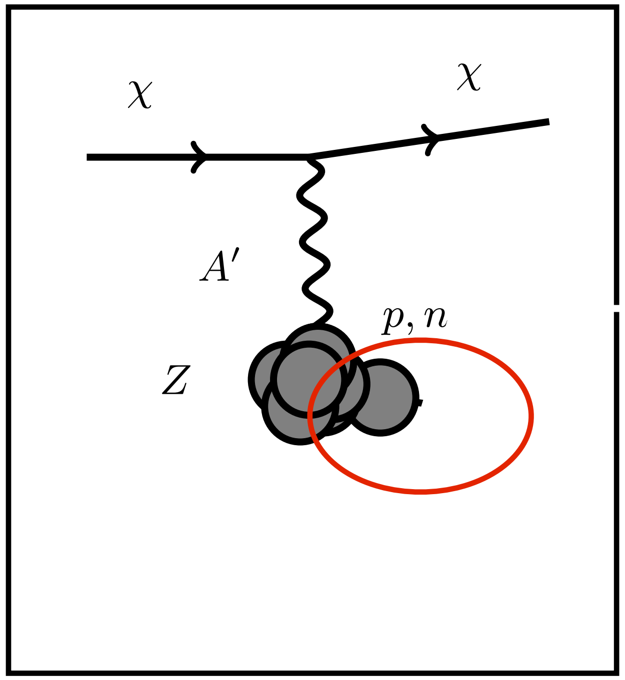
Flat & Forward Peaked

$$\cos\theta_e = \frac{E_\chi E_R - m_e(E_\chi + m_e - E_R)}{\sqrt{(E_\chi^2 - m_\chi^2)(E_R^2 - m_e^2)}}$$

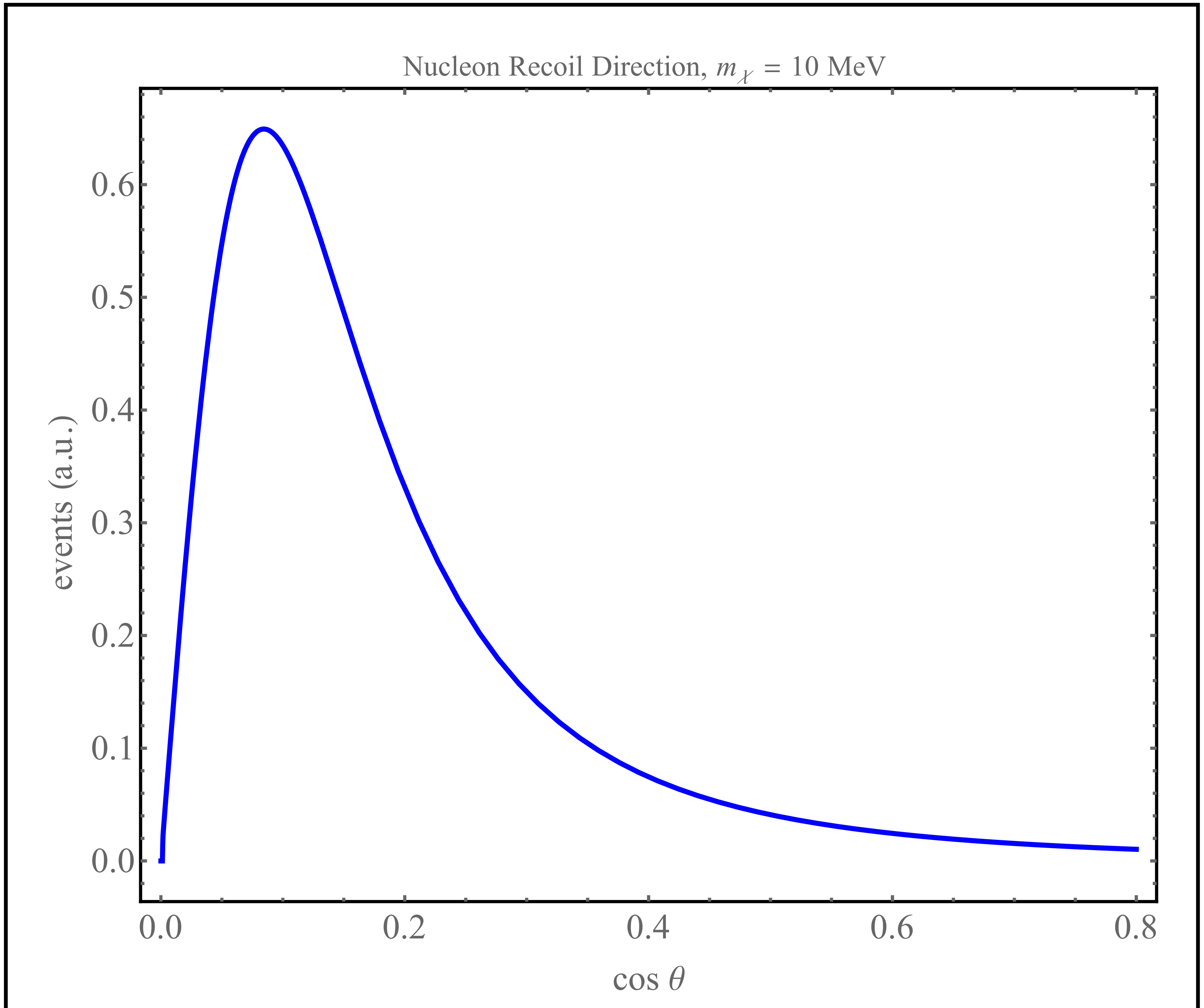
$$\cos\theta_e(E_{\chi,R} \gg m_e) \to \frac{E_\chi E_R}{E_\chi E_R} - \mathcal{O}\left(\frac{m_e}{E_\chi}\right) \approx 1$$

beam dump limit : light target, fast projectile $\theta_e \approx 0$

Nucleon Recoils: Signal Characteristics



$$\cos\theta_n = \frac{E_\chi E_R - m_n(E_\chi + m_n - E_R)}{\sqrt{(E_\chi^2 - m_\chi^2)(E_R^2 - m_n^2)}}$$

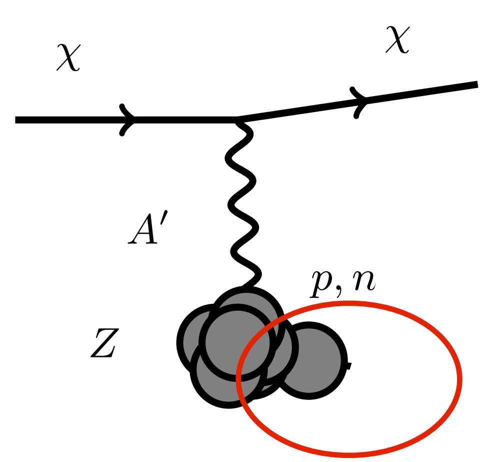


Relevant scales overlap

Nontrivial angular distribution

More orthogonal than electron recoils

Nucleon Recoils: Signal Characteristics



$$\frac{d\sigma}{dQ^2} \simeq (4\pi\epsilon^2\alpha\alpha_D)\frac{F_{1,N}^2 - \frac{Q^2}{4m_N^2}F_{2,N}^2(Q^2)}{[m_A^2+Q^2]^2}$$

$$F_{1,p} = \frac{1}{(1+Q^2/m_p^2)^2} \qquad F_{2,p} = \frac{1.79}{(1+Q^2/m_p^2)^2}$$

Distribution "breaks" near $Q^2 \sim m_{A'}^2 \implies T_{N,\text{knee}} \sim \frac{m_{A'}^2}{2m_p}$

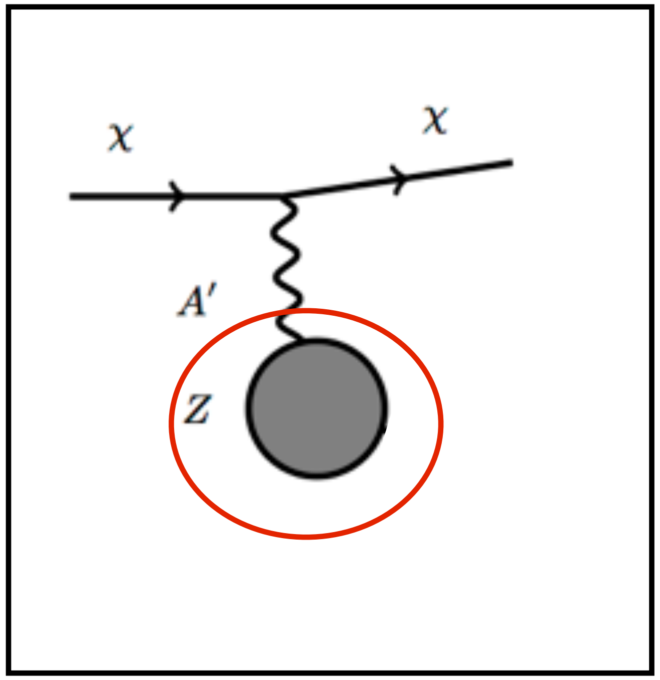
For benchmarks $m_{A'} = \ 3 \text{ MeV}, \ 30 \text{ MeV}, \ 150 \text{ MeV}$

$$T_{N,\text{knee}} \sim \ 5 \text{ keV} \ , \ 0.5 \text{ MeV} \ , \ 12 \text{ MeV}$$

To account for quasi-elastic binding effect, shift by~ O(MeV)

Coherent: Signal Characteristics

Most scattering is "glancing"



$$\cos\theta_N = \frac{E_\chi E_R - m_N(E_\chi + m_N - E_R)}{\sqrt{(E_\chi^2 - m_\chi^2)(E_R^2 - m_N^2)}}$$

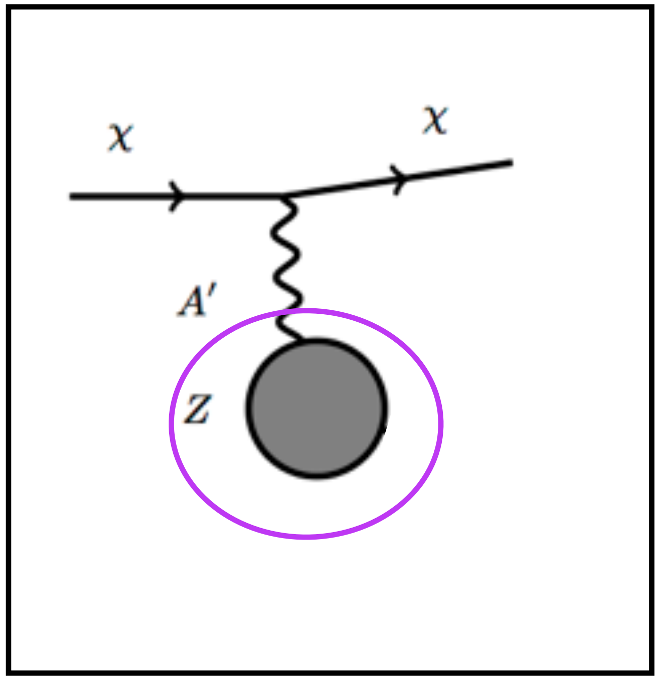
lab-frame scattering angle

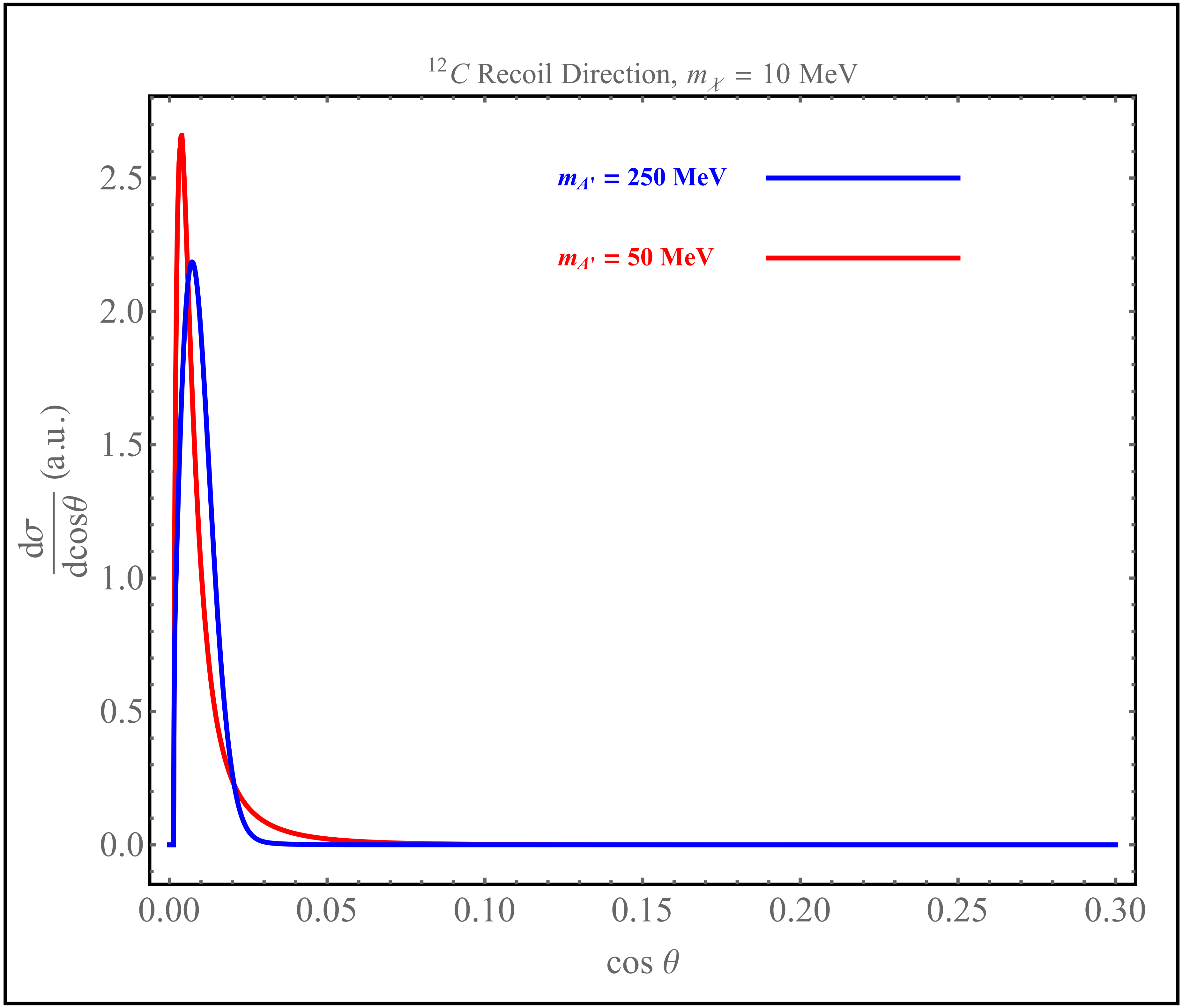
$$\cos\theta_N(m_N \gg E_\chi) \to \sqrt{\frac{E_R - m_N}{E_R + m_N}} \approx \frac{v_N}{c}$$

$$\theta_N \approx 90^\circ$$

beam dump limit (heavy target)

Coherent: Signal Characteristics

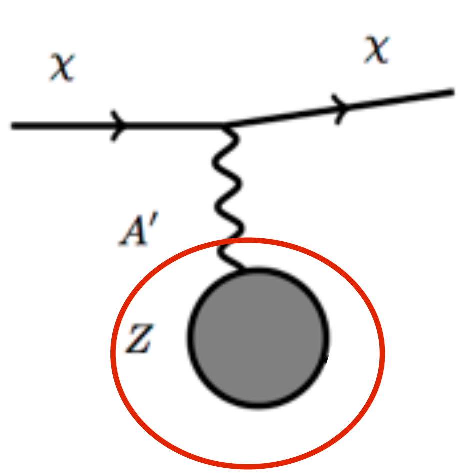




Difference due DM production variation for different mediator masses

Coherent: Signal Characteristics

Differential Cross Section



$$\frac{d\sigma}{dQ^2} \simeq (4\pi\epsilon^2\alpha\alpha_D)\frac{G_{\mathrm{Tsai}}}{[m_A^2+Q^2]^2}$$

$$T_{\mathrm{Knee}} \sim \frac{m_{A'}^2}{2m_{\mathrm{Nucleus}}}$$

Tsai Form Factor

(with atomic form factor)

$$G_{2,el}(t) = \left(\frac{a^2 t}{1+a^2 t}\right)^2 \left(\frac{1}{1+t/d}\right)^2 Z^2$$

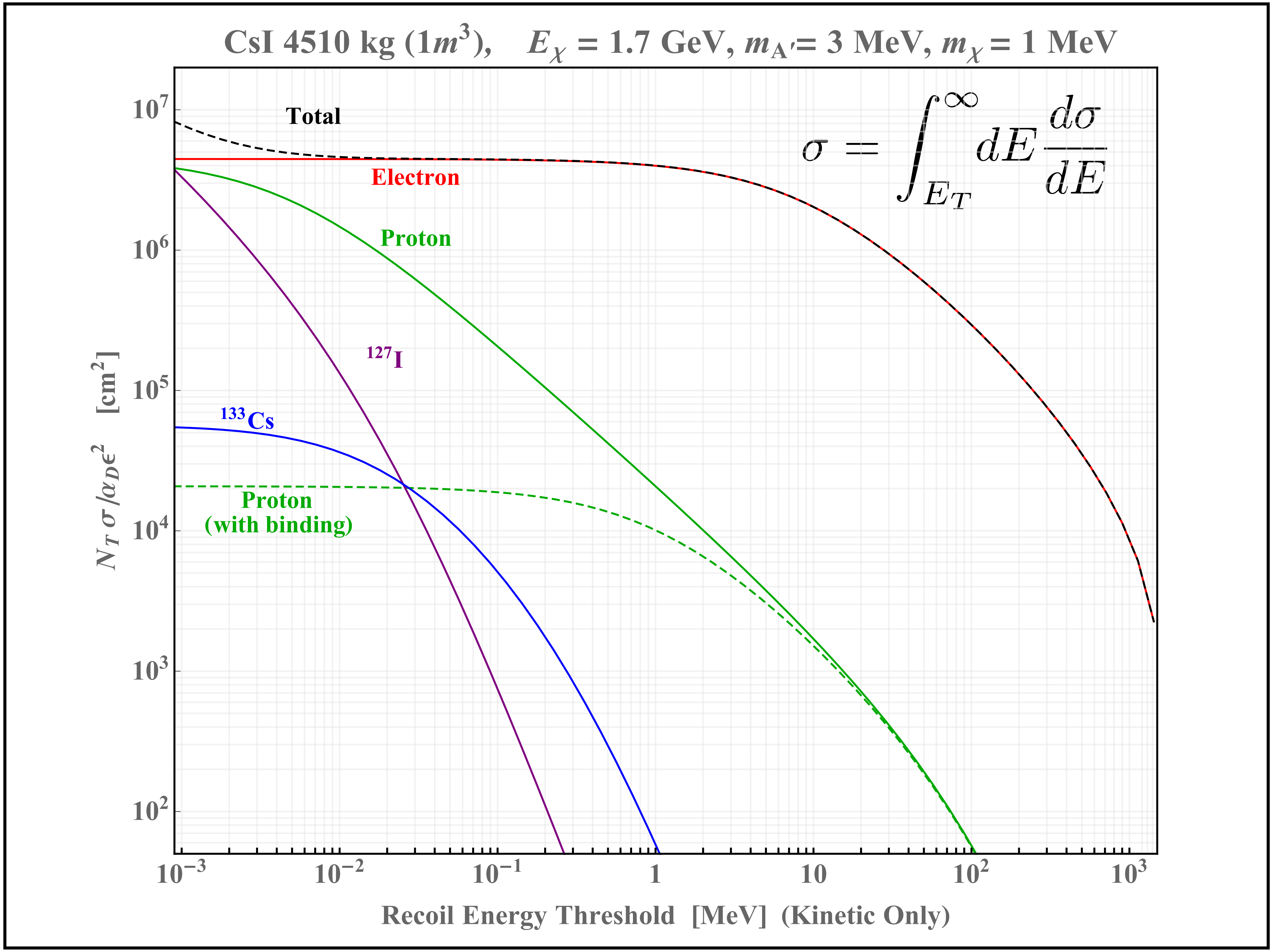
$$d = 0.164\ \mathrm{GeV}^2 A^{-2/3}$$

$$a = 111\, Z^{-1/3}/m_e$$

e.g. Carbon 12

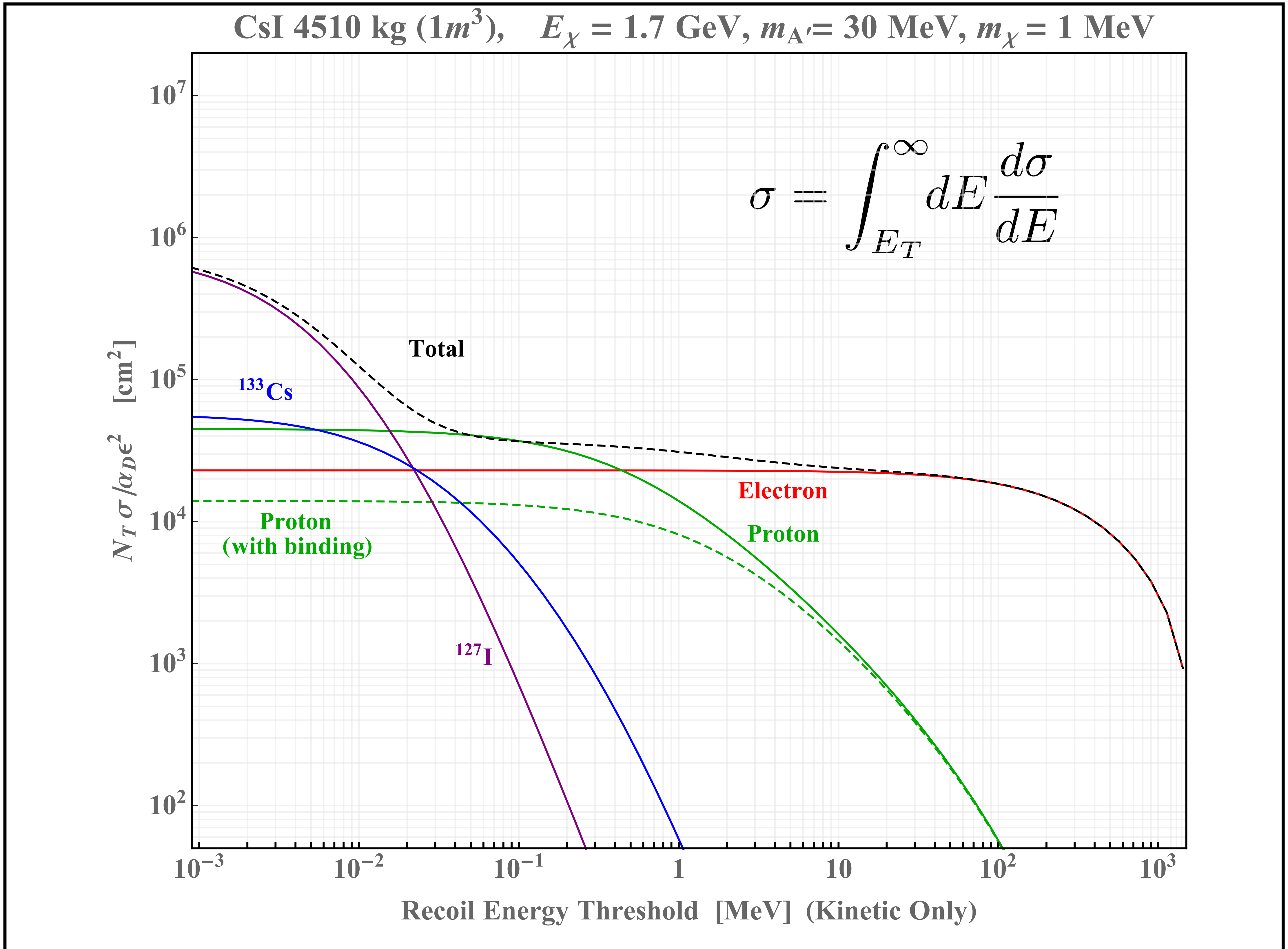
$$m_{A'} = \ 3\ \mathrm{MeV},\ 30\ \mathrm{MeV},\ 150\ \mathrm{MeV}$$
$$T_{N,\mathrm{knee}} \sim\ 0.4\ \mathrm{keV}\ ,\ 40\ \mathrm{keV}\ ,\ 1\ \mathrm{MeV}$$

Cross Section vs. Threshold, CsI



Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, CsI



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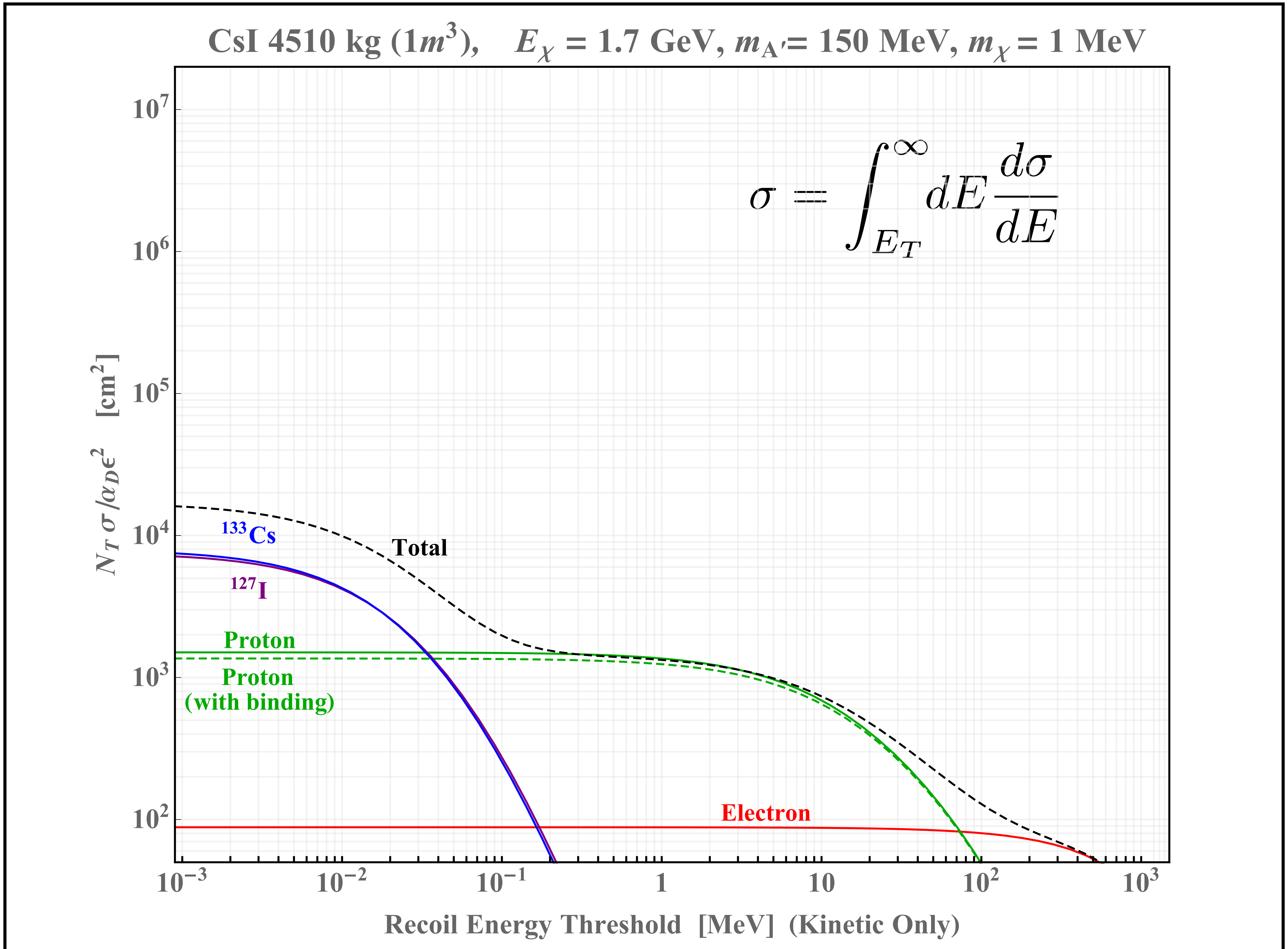
Cross Section vs. Threshold, CsI



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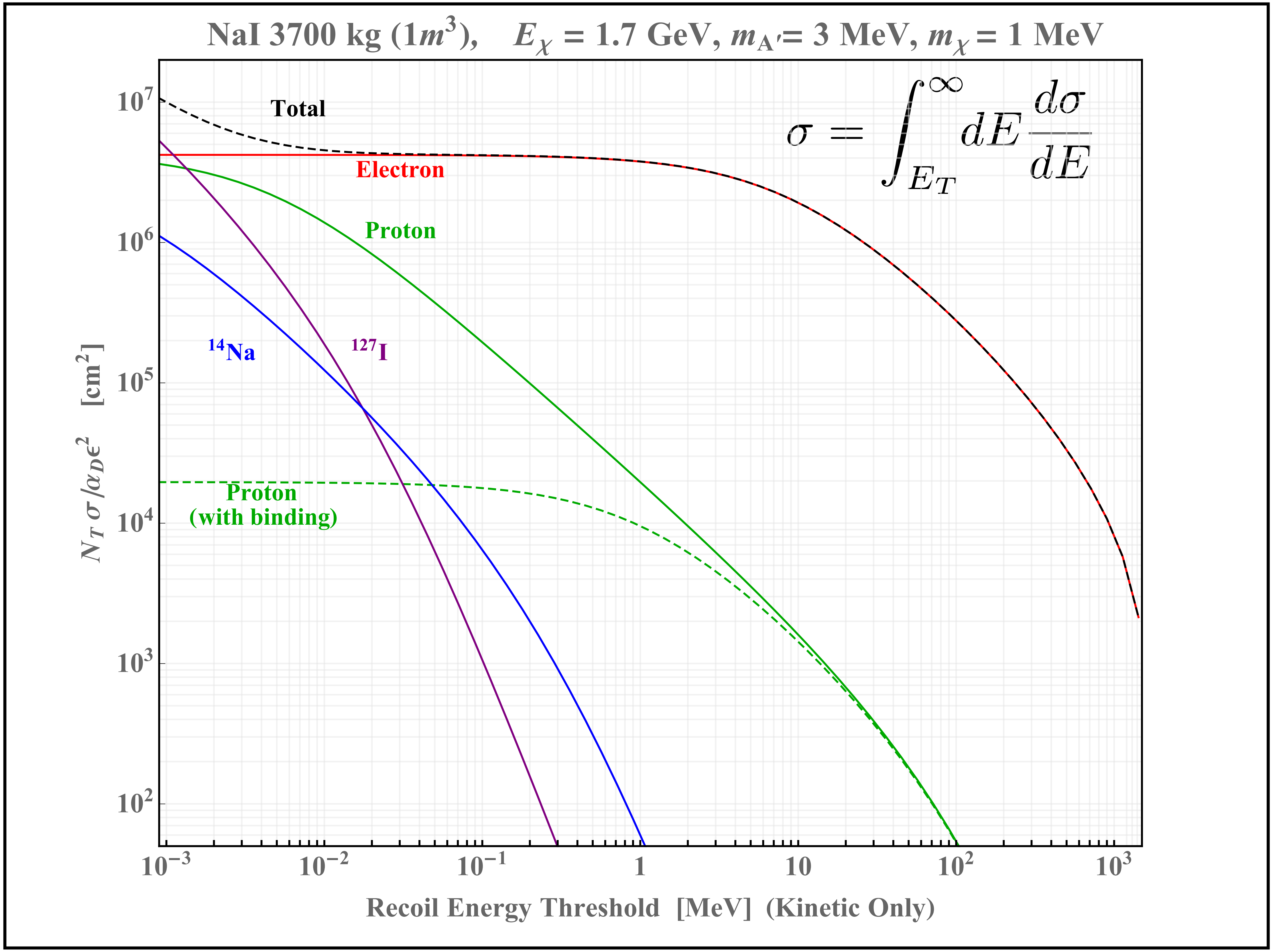
Cross Section vs. Threshold, NaI



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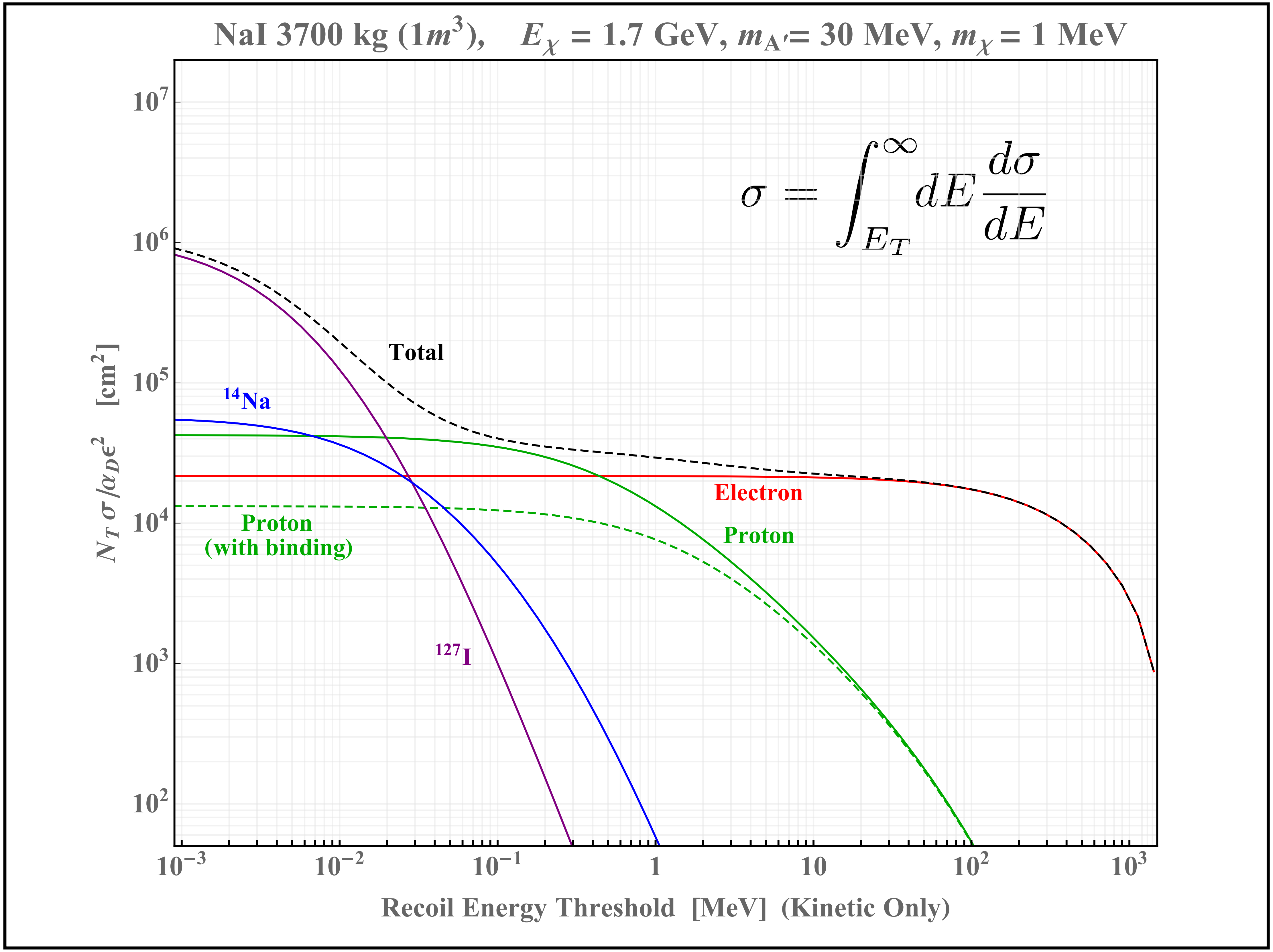
Cross Section vs. Threshold, NaI



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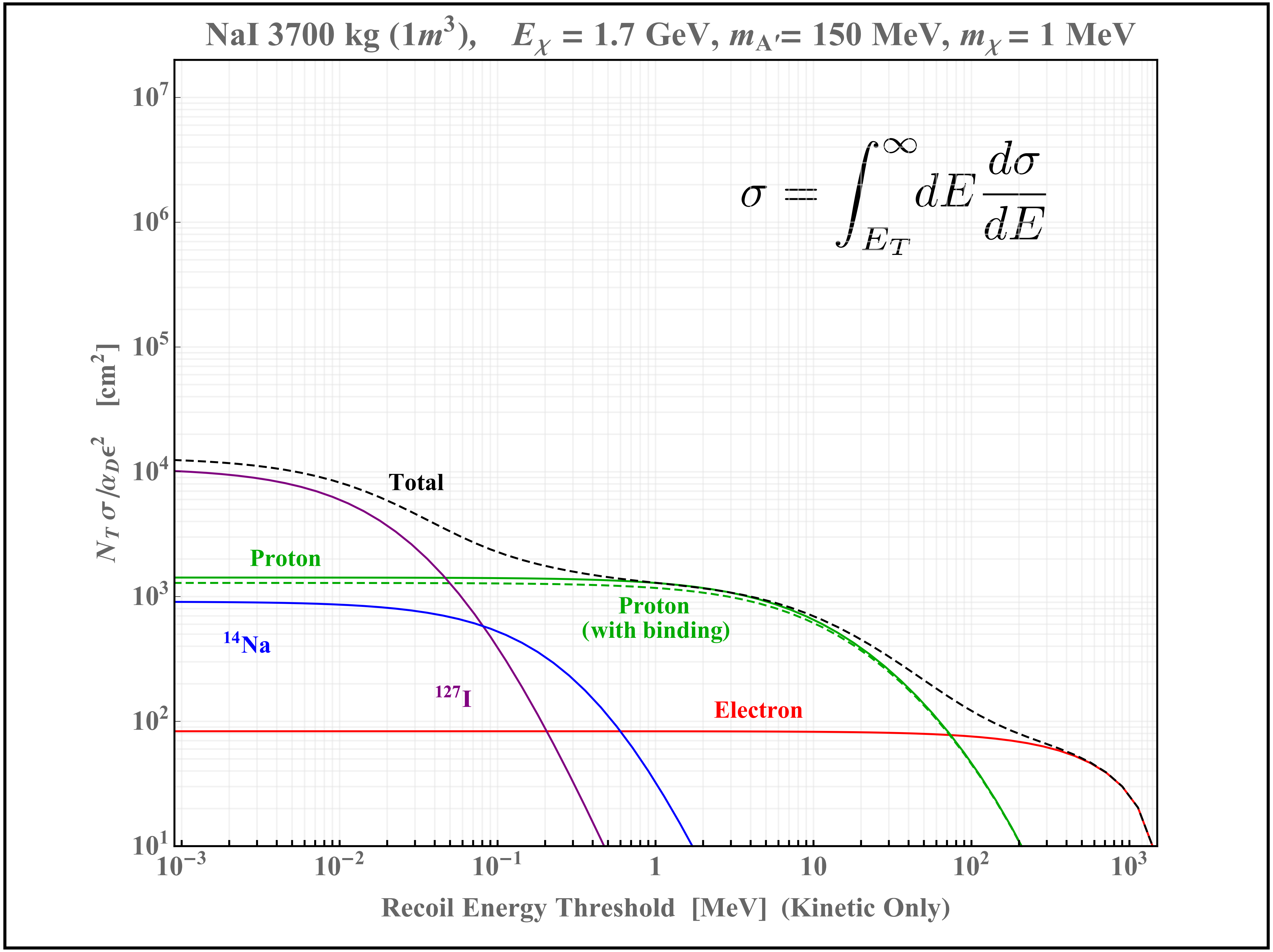
Cross Section vs. Threshold, NaI



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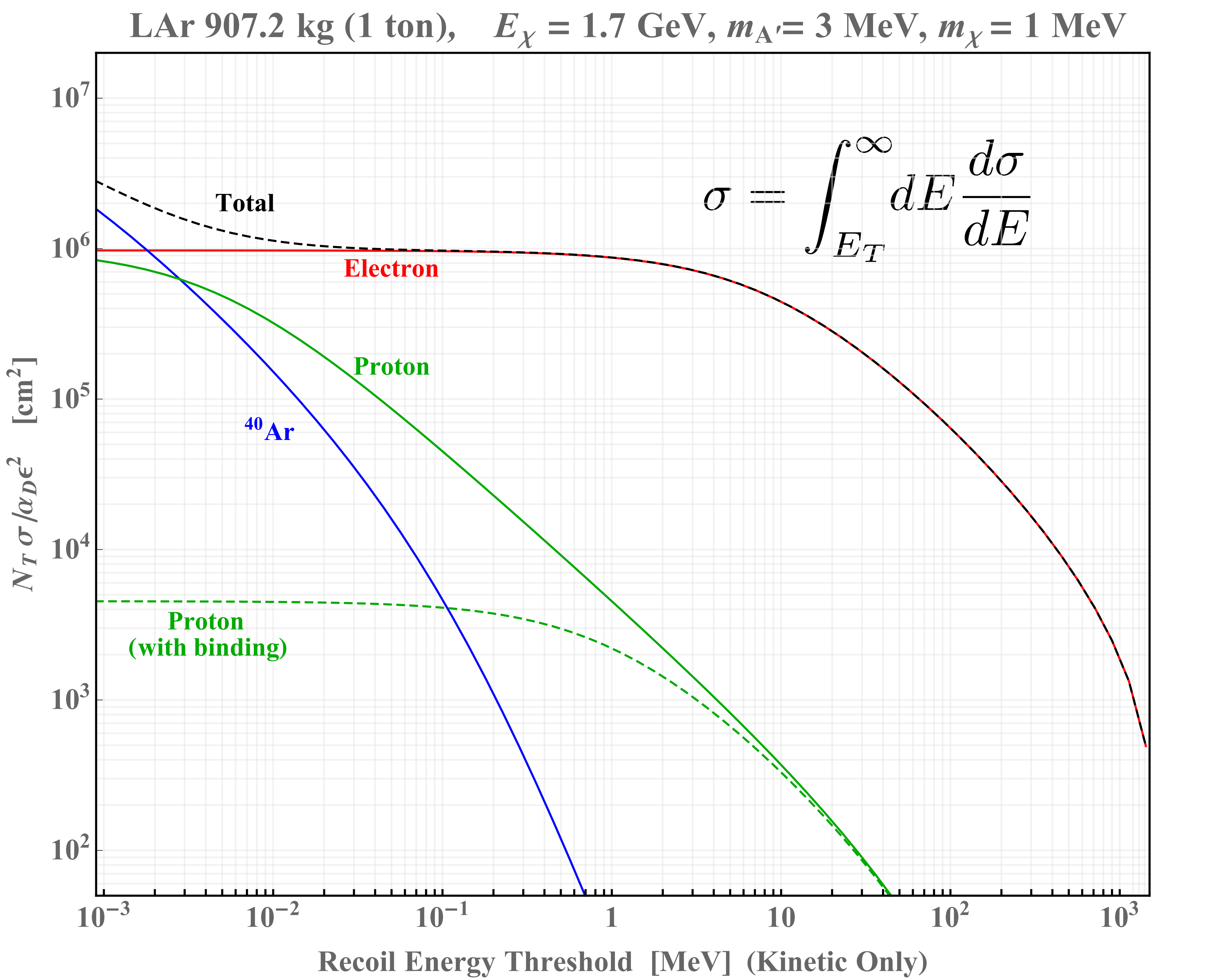
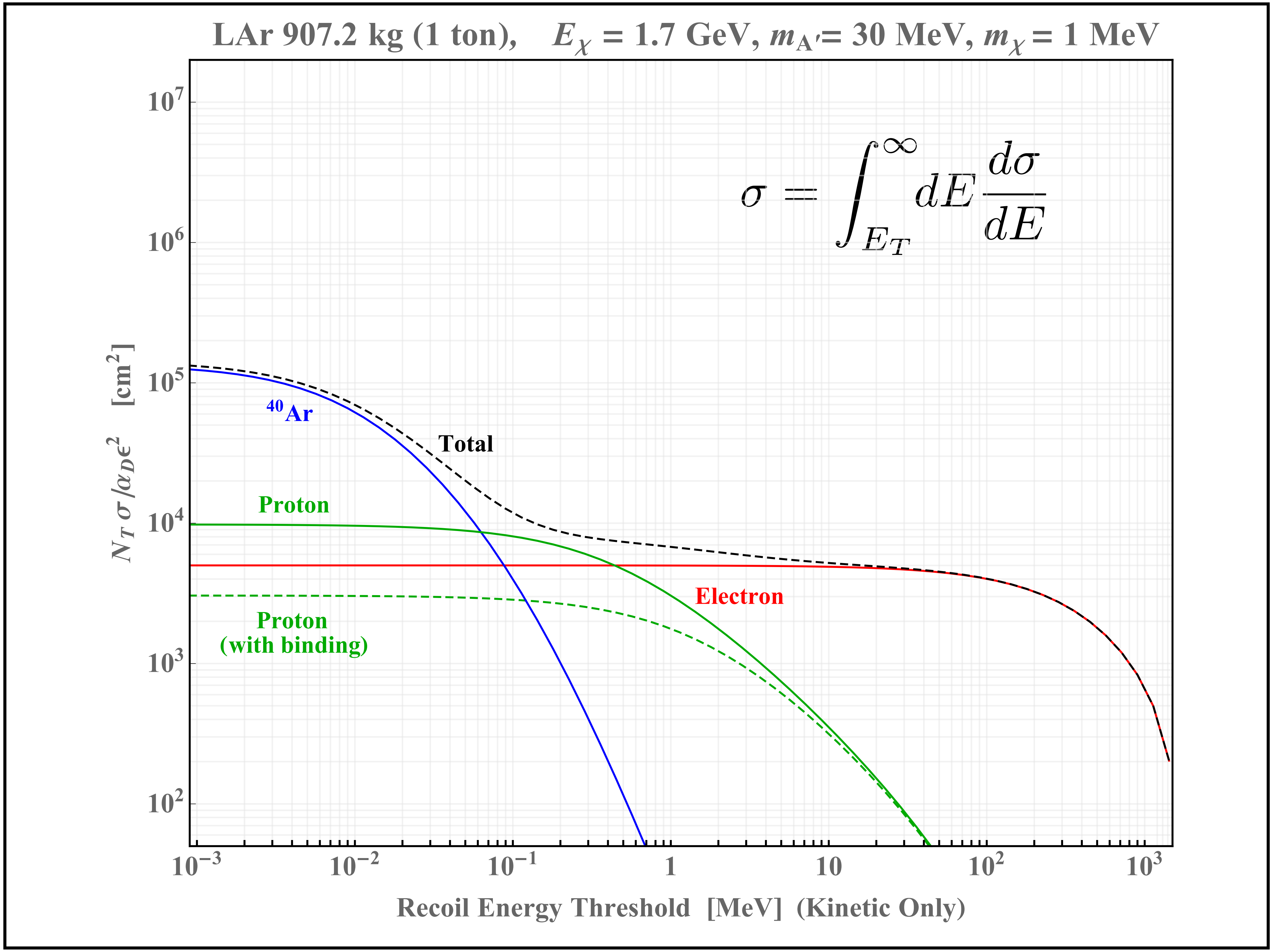
Cross Section vs. Threshold, LAr



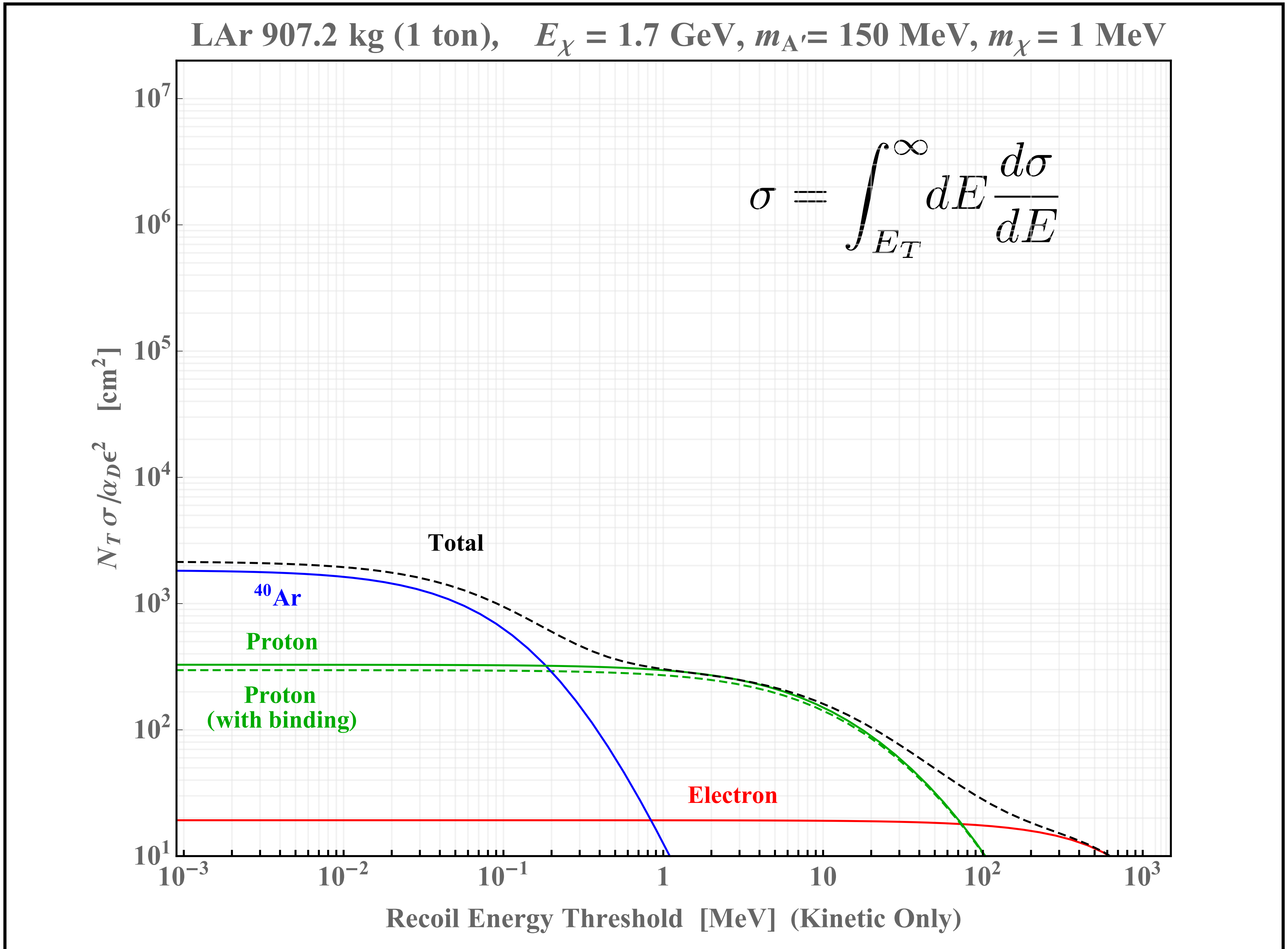
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, LAr



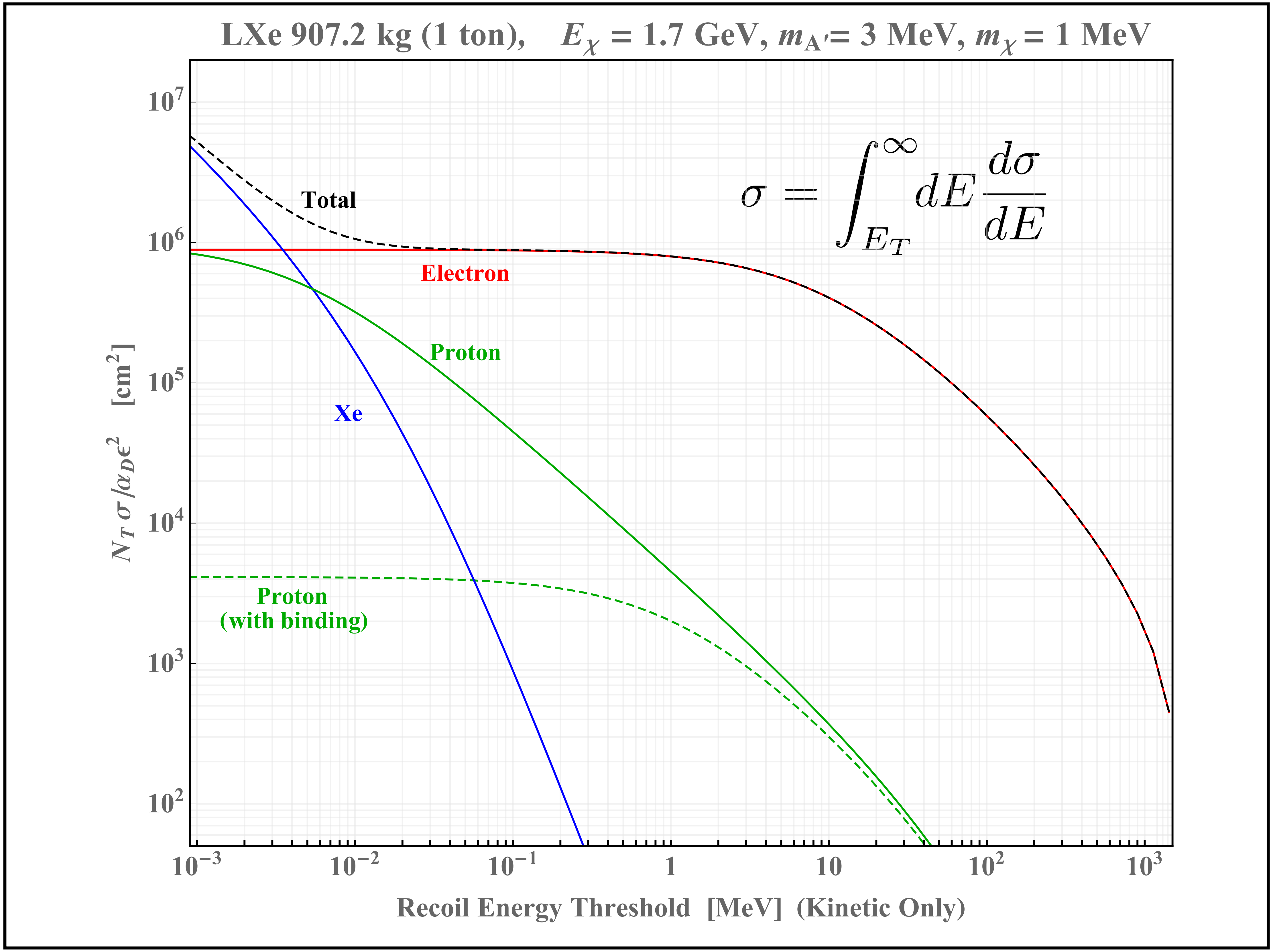
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, LAr



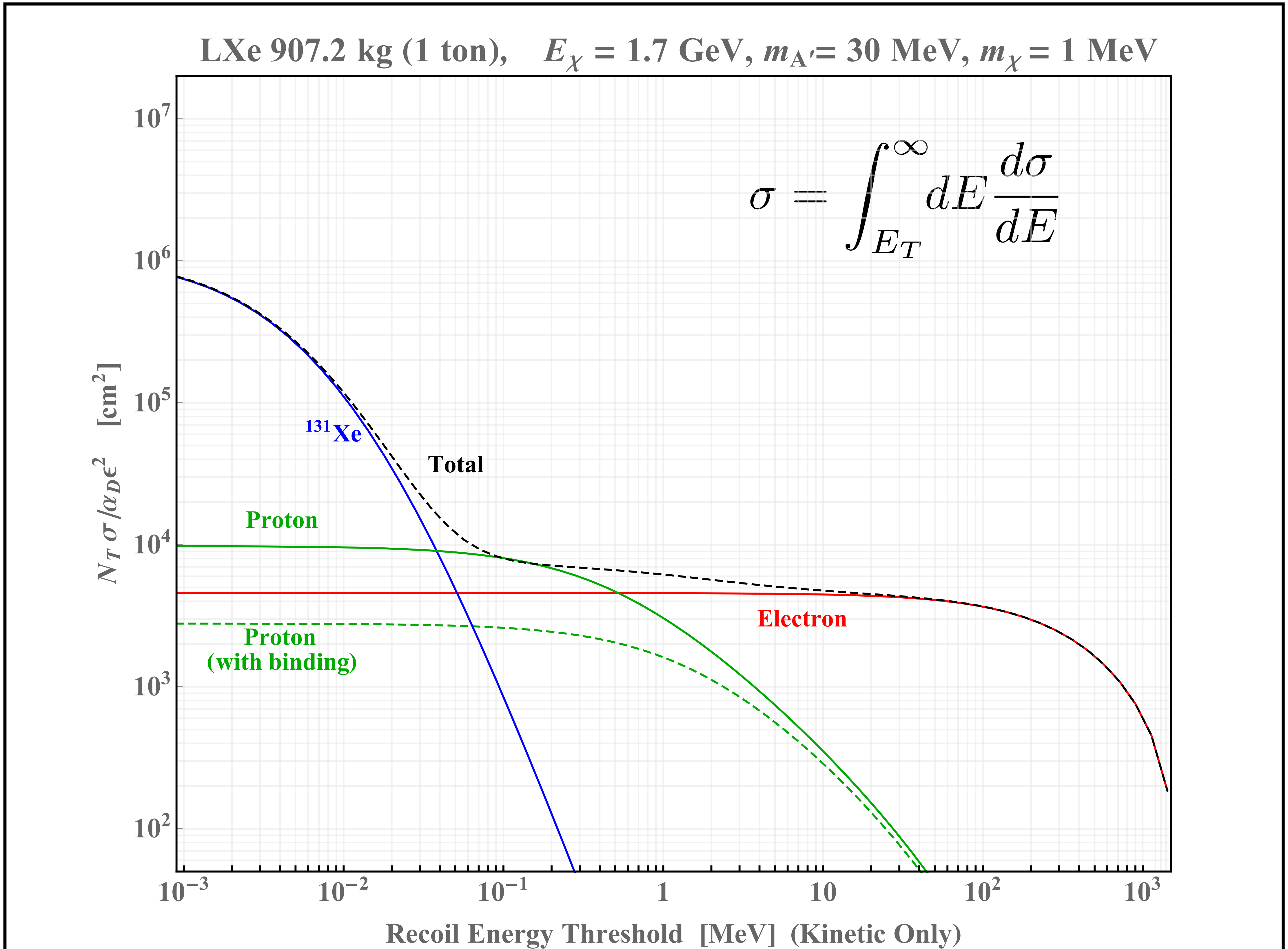
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, LXe



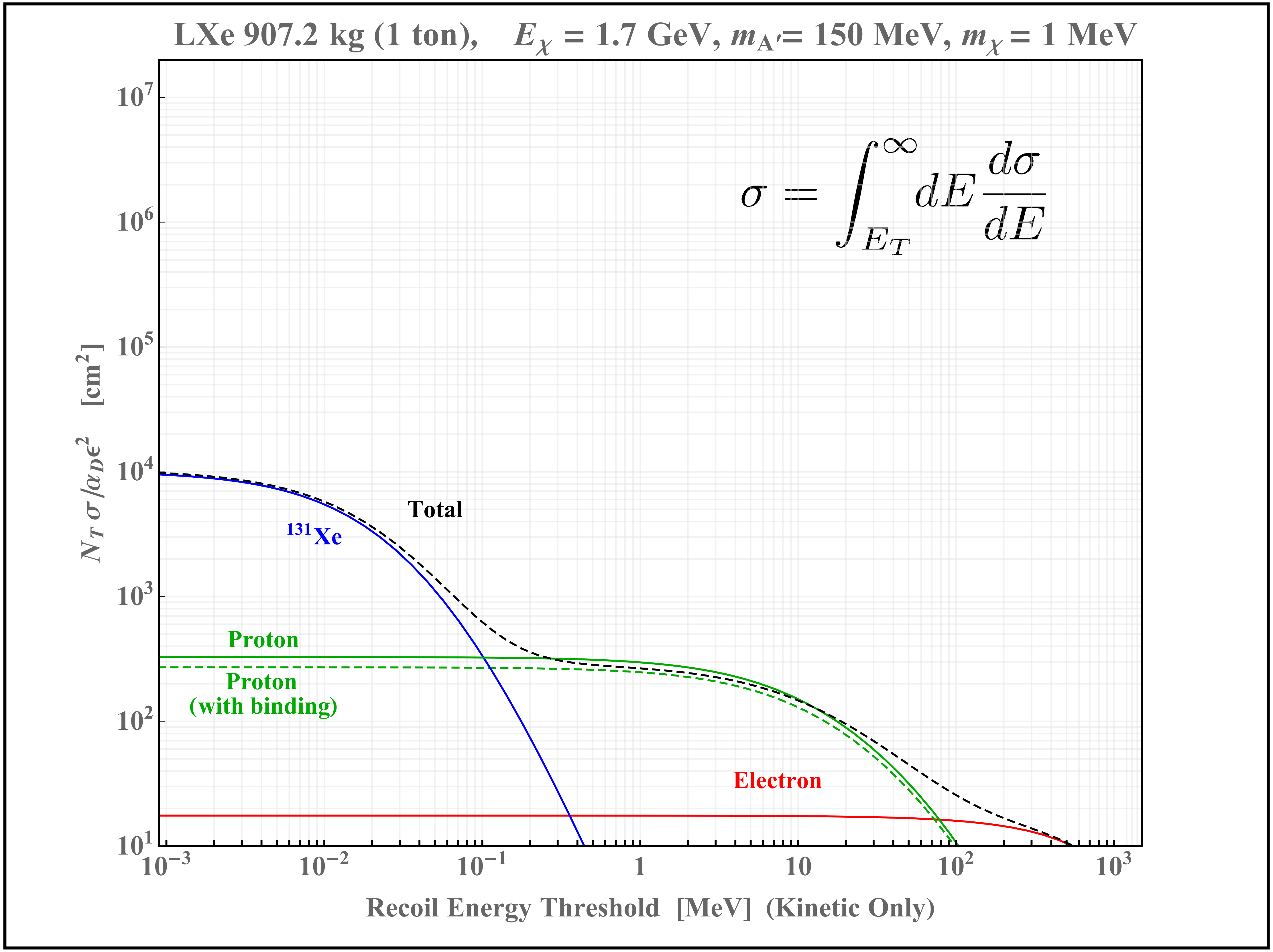
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, LXe



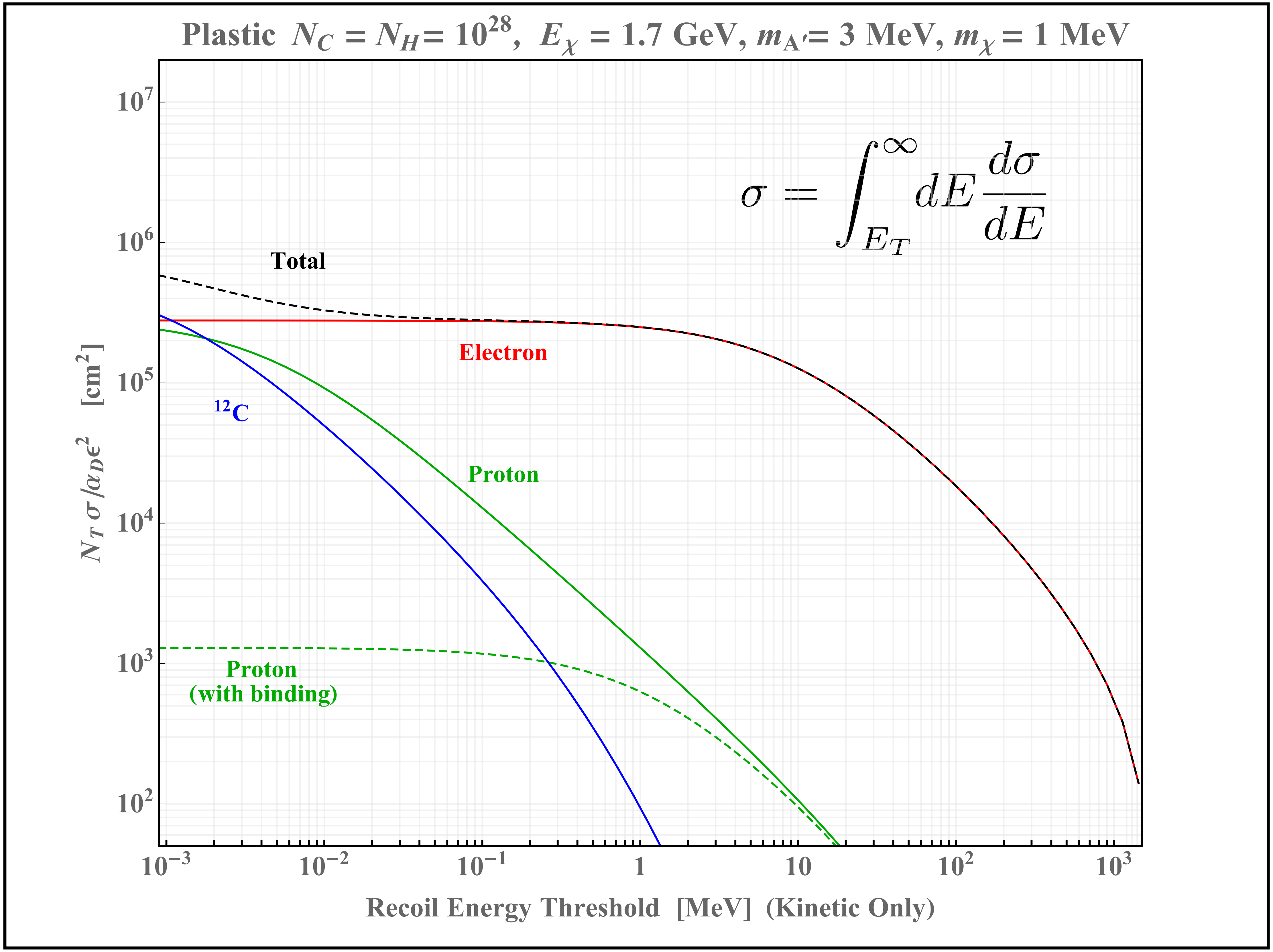
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, LXe



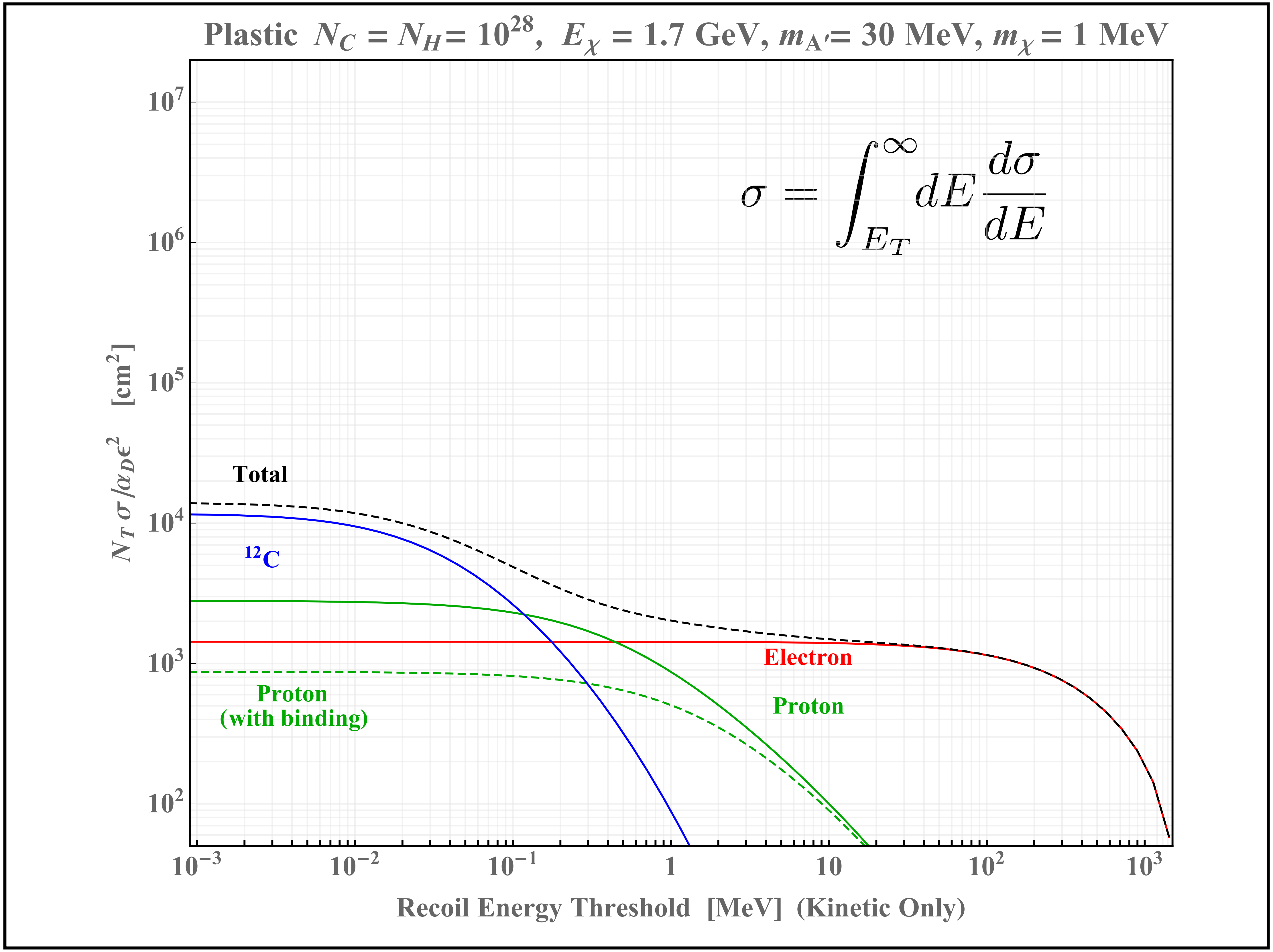
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, Plastic



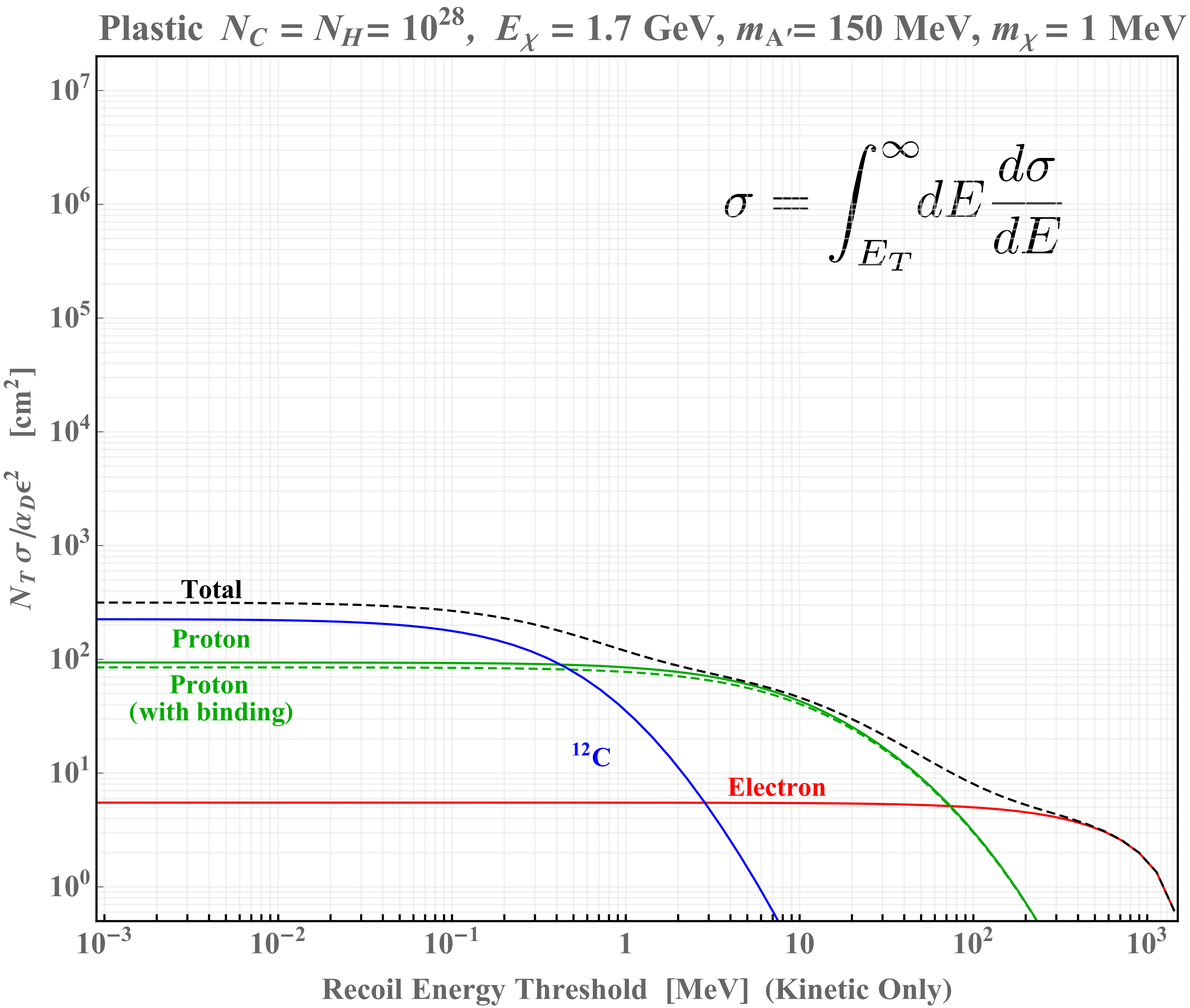
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, Plastic



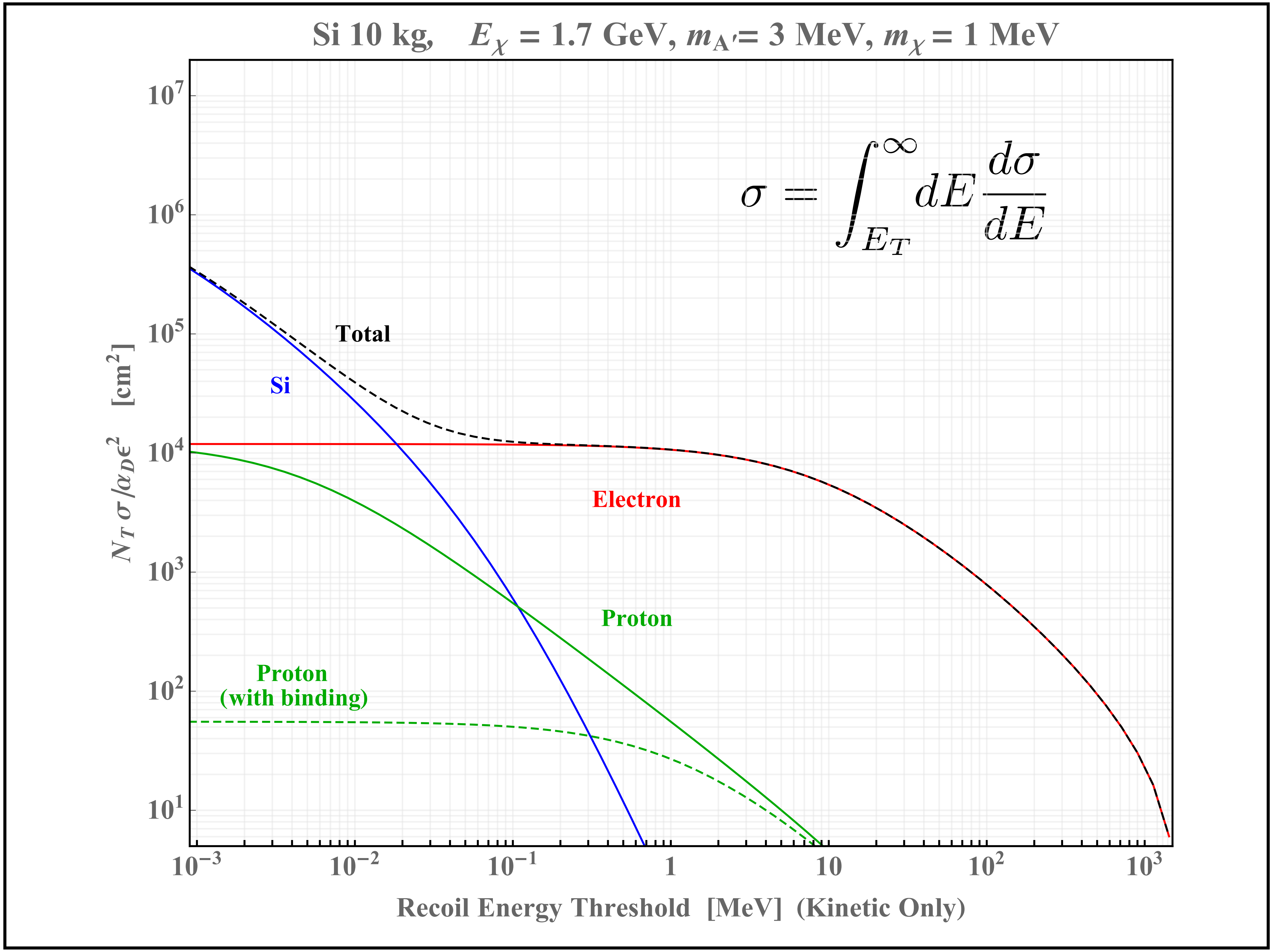
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, Plastic



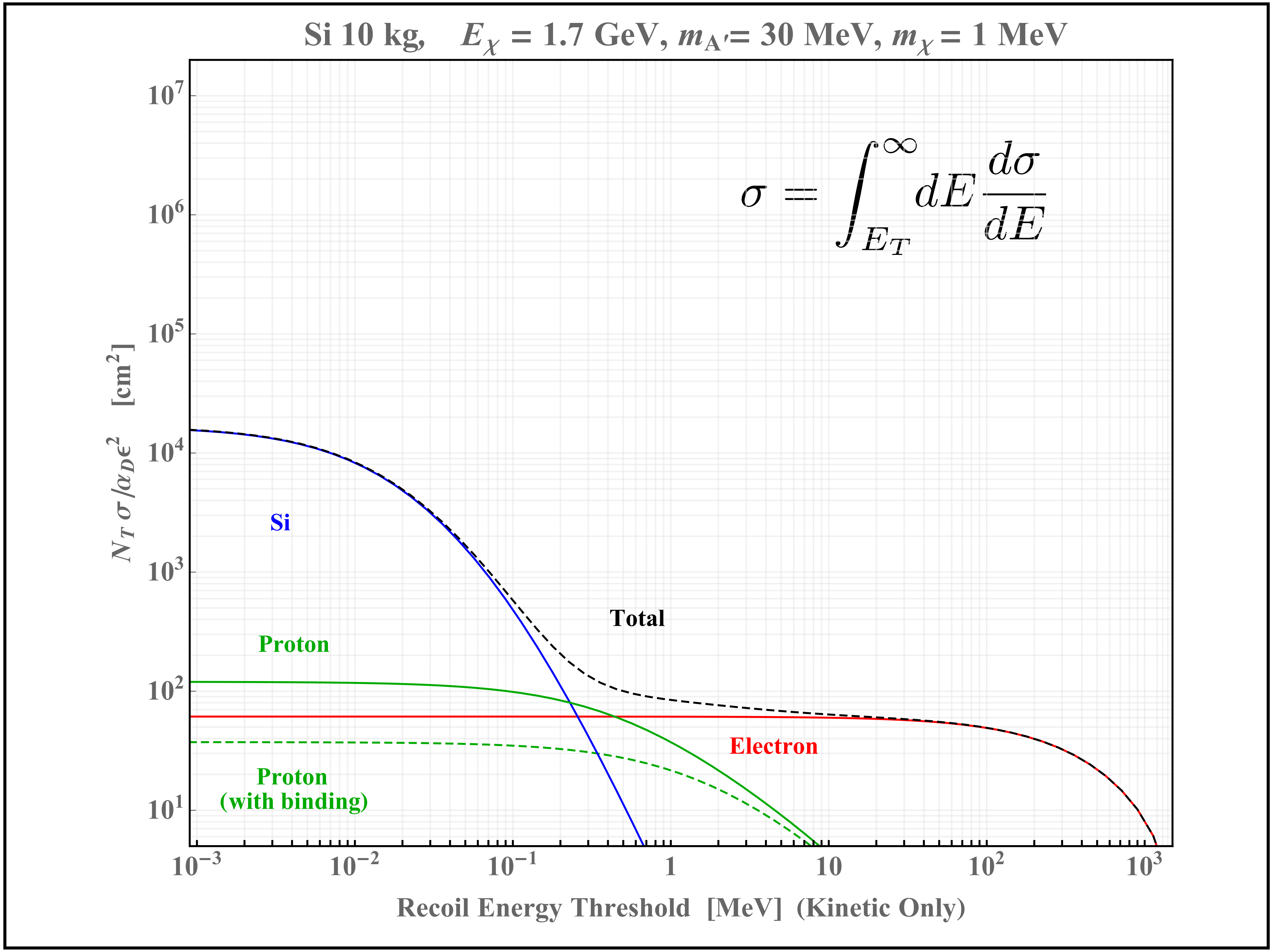
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, Si



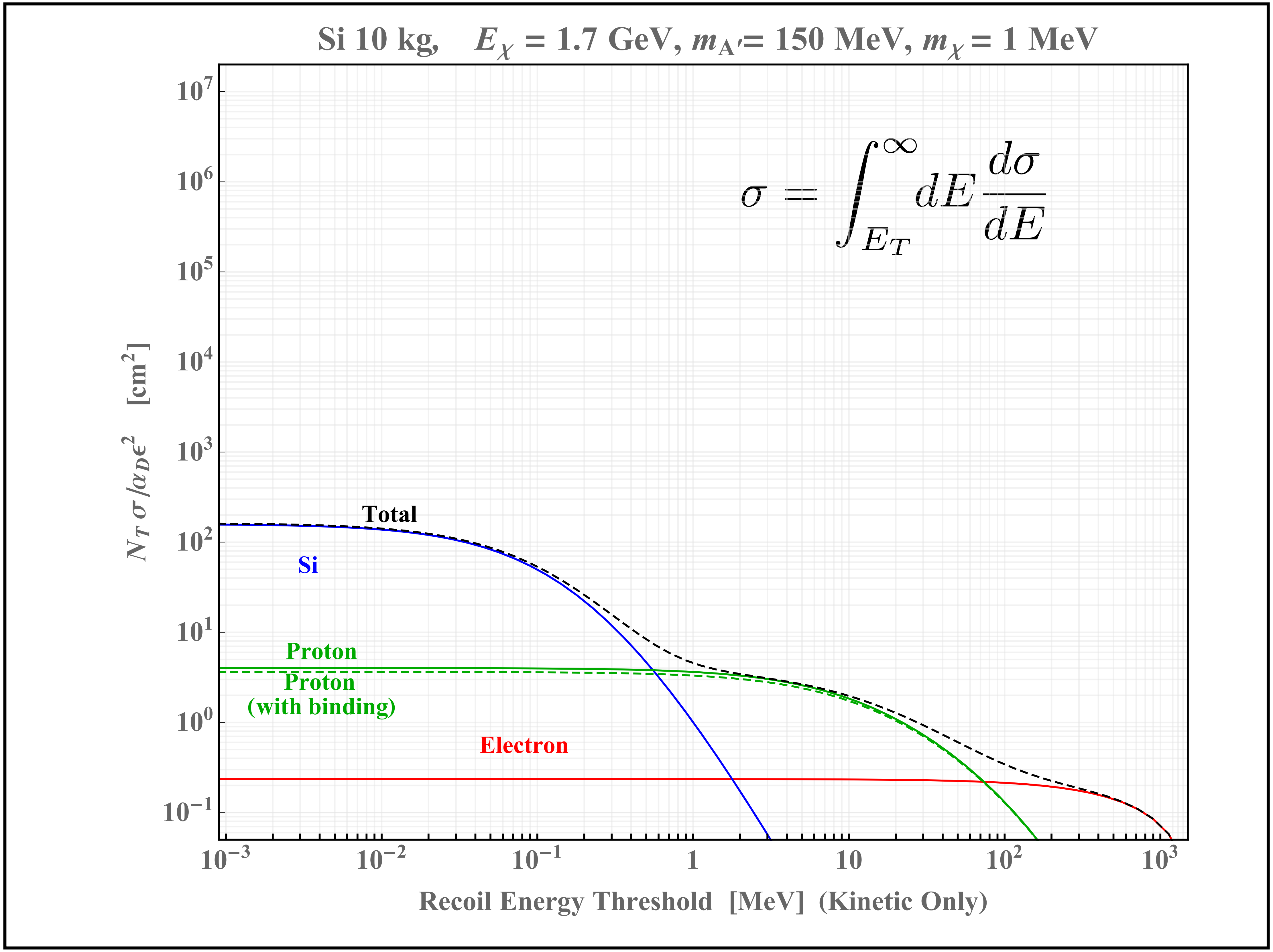
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, Si



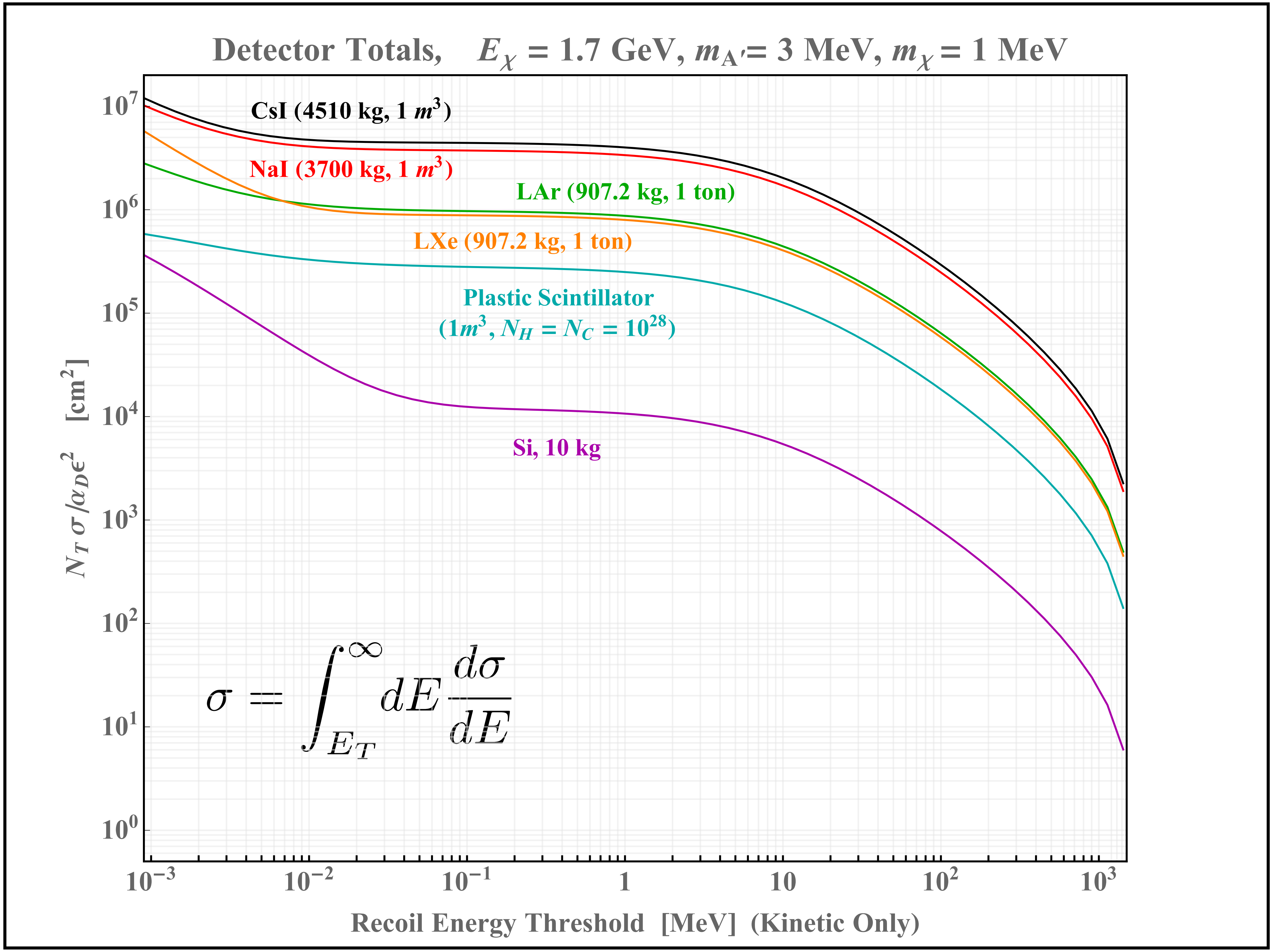
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, Si



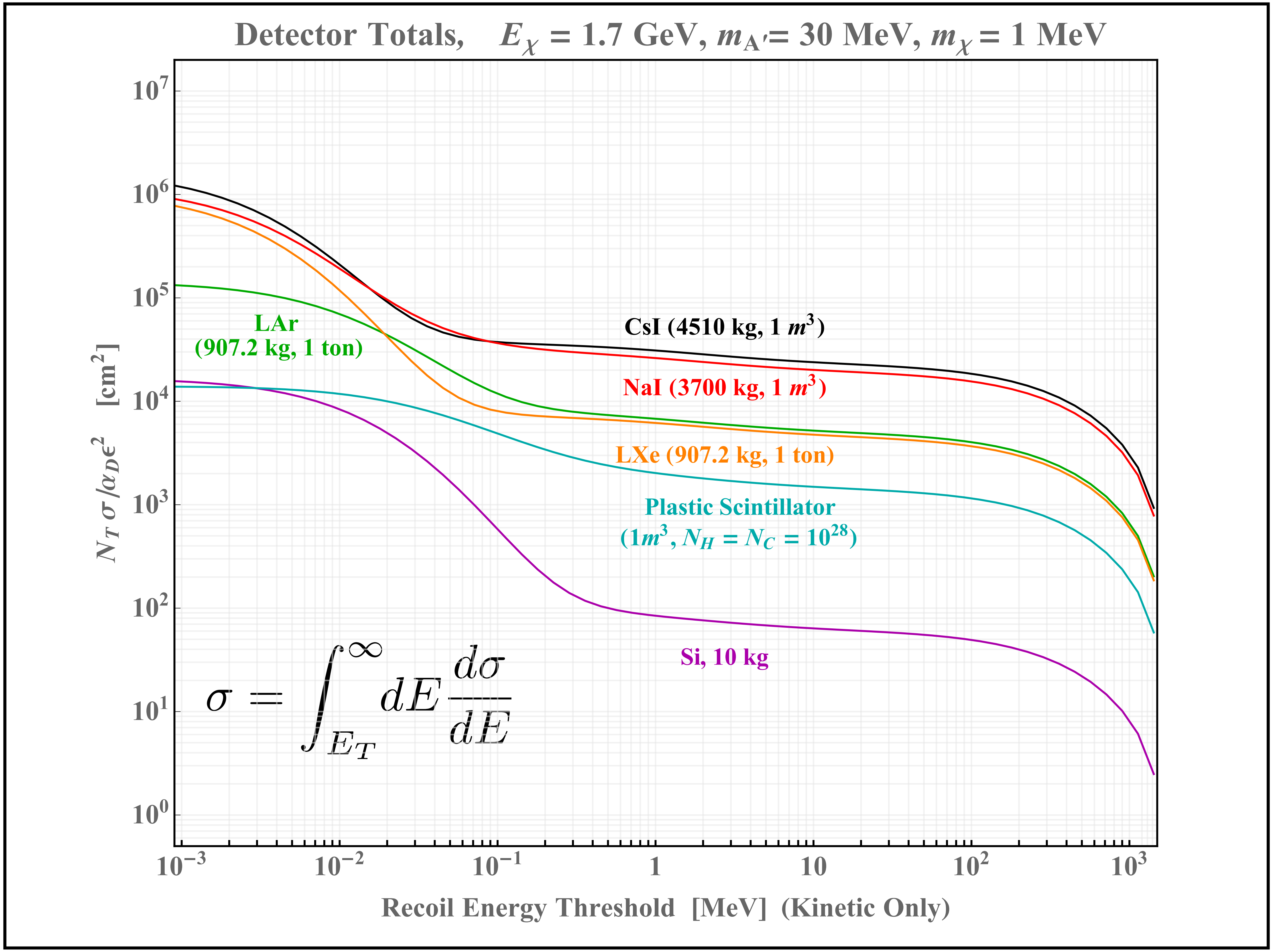
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, All



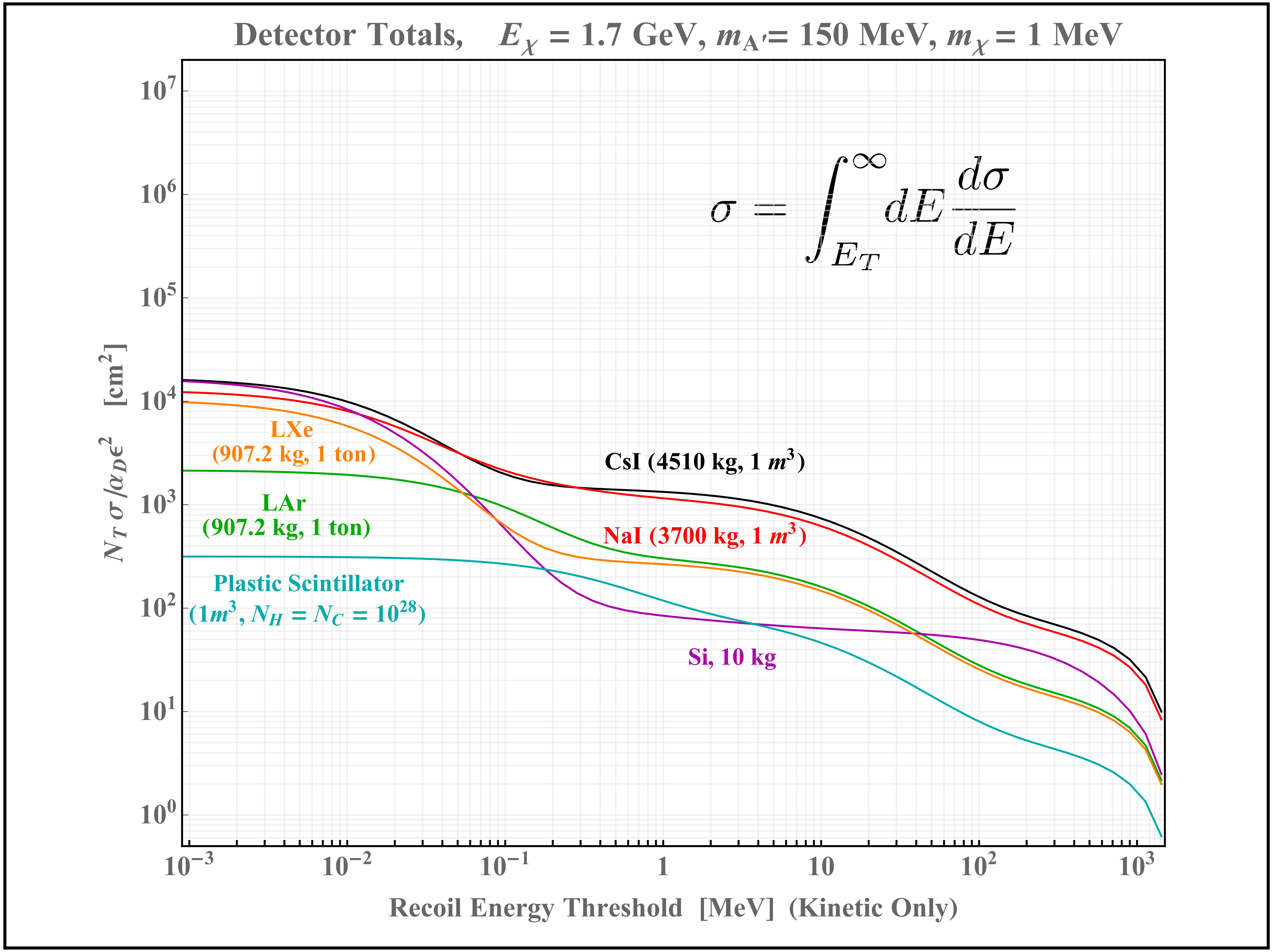
Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, All



Geometric Acceptance ~0.5% for Al dump, not included above

Cross Section vs. Threshold, All



Geometric Acceptance ~0.5% for Al dump, not included above

Caveats/Comments

- "Morally correct" to convolve with acceptance beam profile

Here we use single energy ~ 2 GeV, since this makes tiny difference

Mainly matters for heavy mediator & DM regime
(where we have less sensitivity)

- Computing rates requires relative Z/A factors for number densities of each species. May change ranking depending on detector molecules (easy to rescale)

- Here focus is 2-2 scattering cross sections only. Folding in acceptance is a factor in deciding detector material etc.

- Requests are welcome (materials, energies, data points etc.)