DM Scattering Signals
@ Electron Beam Dump Experiments

Gordan Krnjaic

Fermilab

w/ Eder Izaguirre, Philip Schuster, Natalia Toro

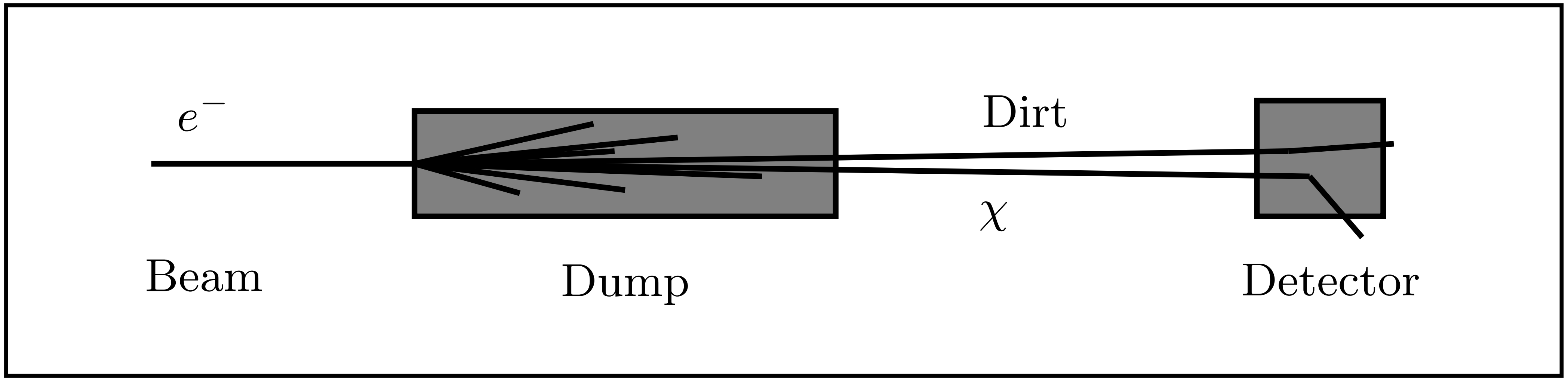
NEXT Meeting Nov 20, 2015

Overview

- **Easy:** Electrons
- **Medium:** Quasi-Elastic Nucleon
- **Hard:** Coherent Nuclear
- **Bonus:** Dark-Inelastic Scattering

- **Sneak Preview:** Missing Momentum @ SLAC

Setup Reminder

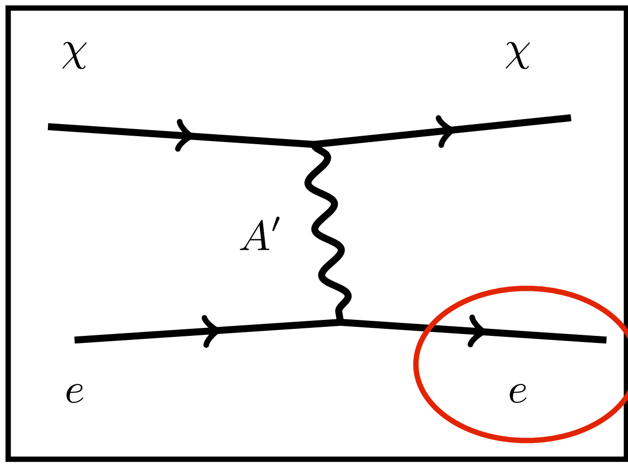


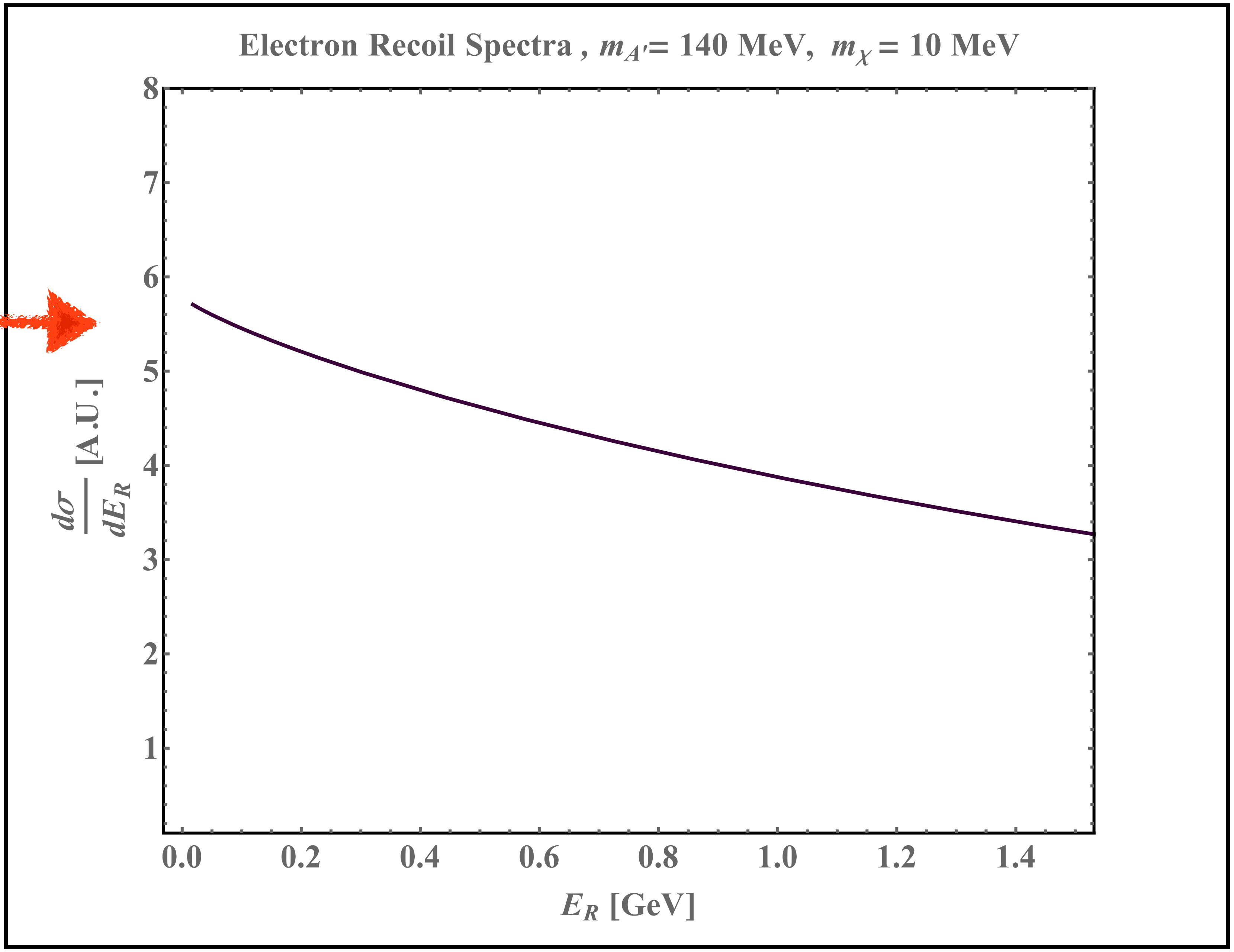
- E(beam) ~ O(few) GeV
- Baseline ~ O(10 m)
- Detector ~ O(m^3)
- Luminosity ~ O(10^22) EOT

Ultimate goal: optimizing for different signatures

This talk: essential features of each channel

"Easy" Case: Electron Target





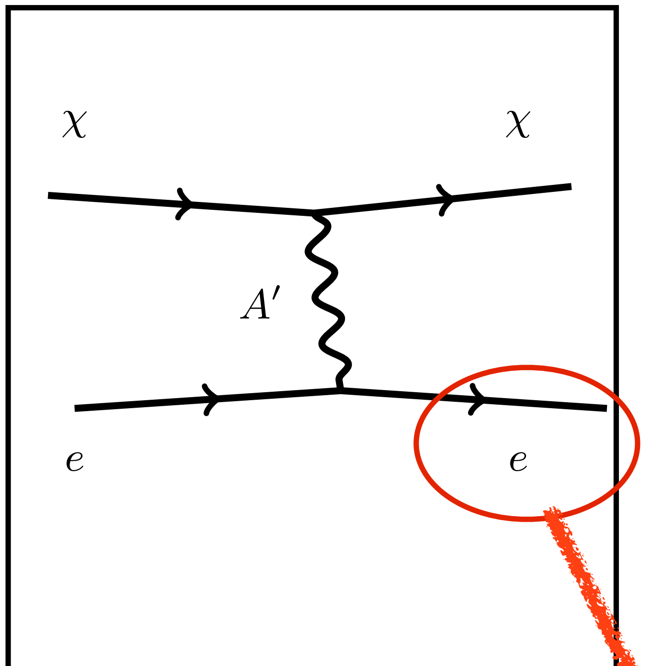
note scaling!

Key Features

- Nearly flat distribution
- Can cut away from BG
- Nearly indep. of material
- Similar to neutrino NC scattering (e.g. LSND)
- **Very forward recoil (bus vs. pebble)**

"Easy" Case: Electron Recoils

Why Forward Peaked?



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

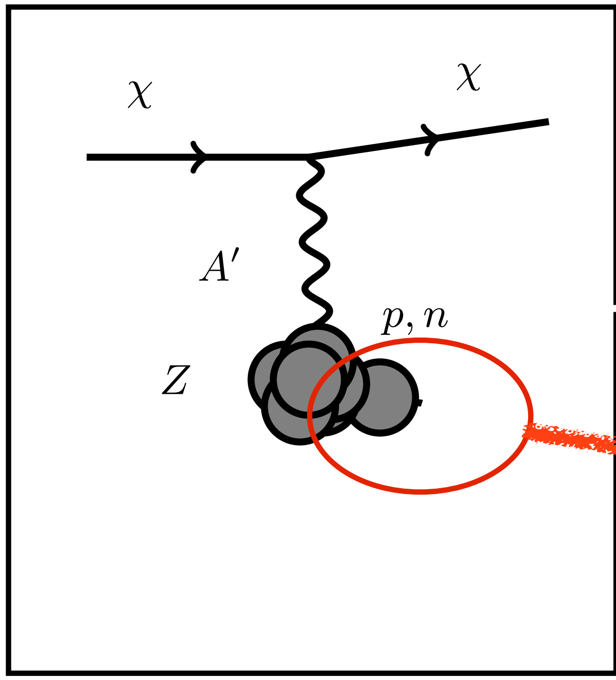
lab-frame scattering angle

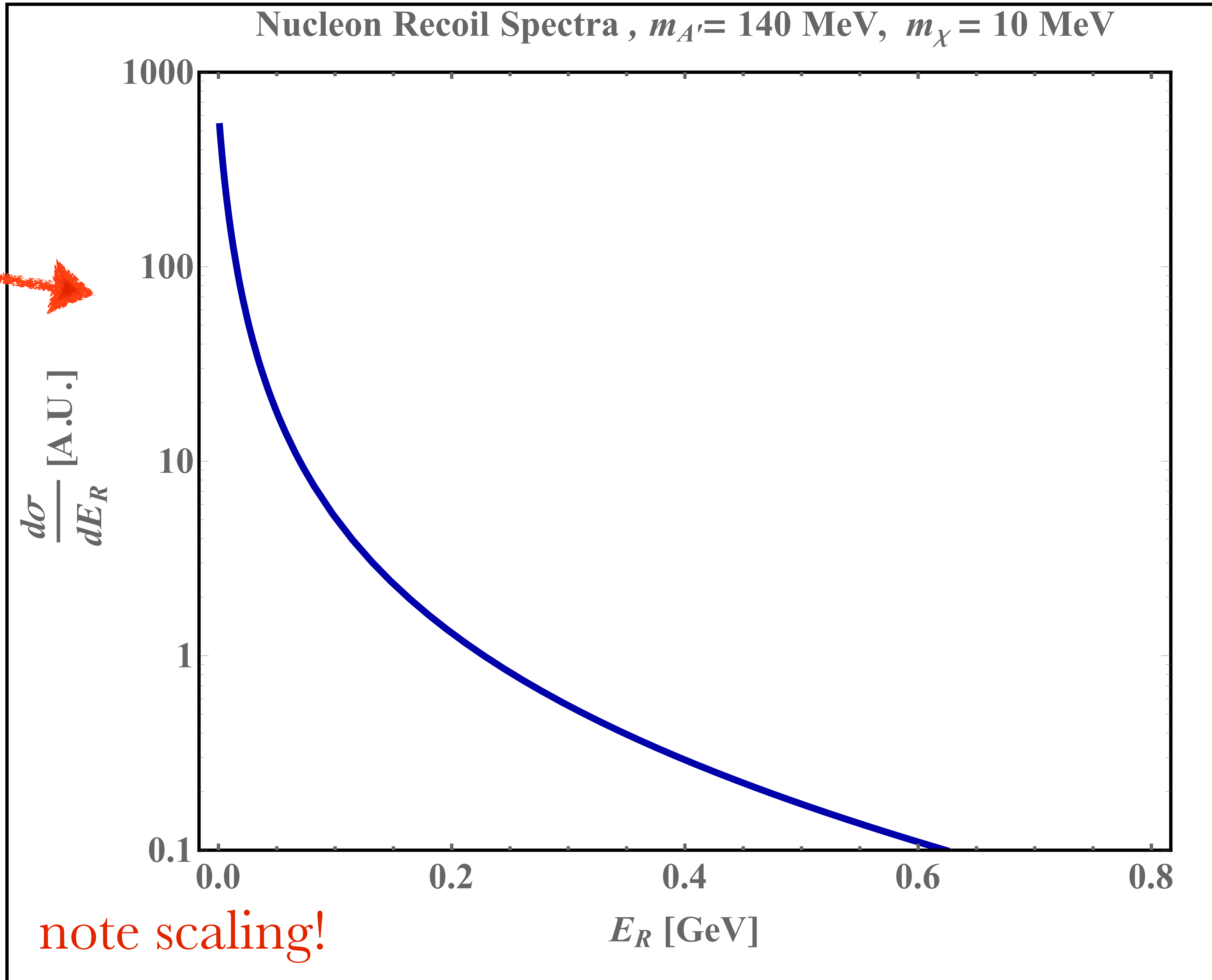
$$\cos\theta_e(E_{\chi,R} \gg m_e) \to \frac{E_\chi E_R}{E_\chi E_R} - \mathcal{O}\left(\frac{m_e}{E_\chi}\right) \approx 1$$

$$\theta_e \approx 0$$

beam dump limit (light target)

"Medium" Case: Nucleon Recoils



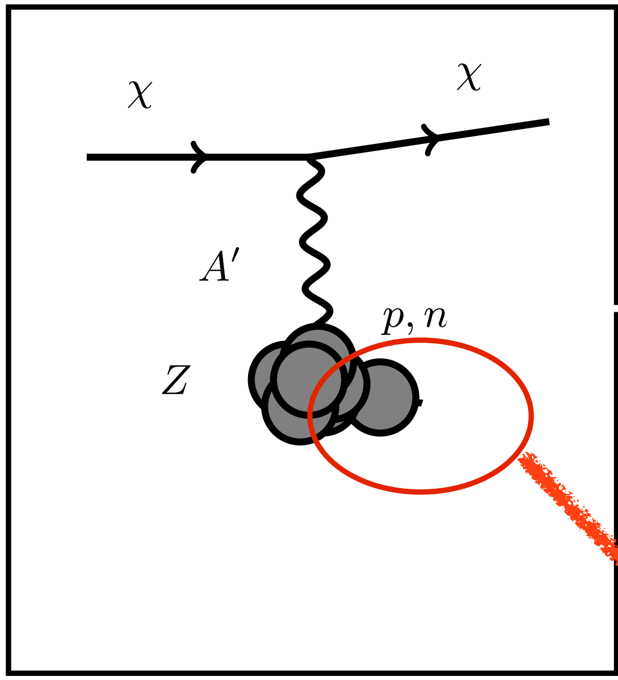


mono/dipole form factors

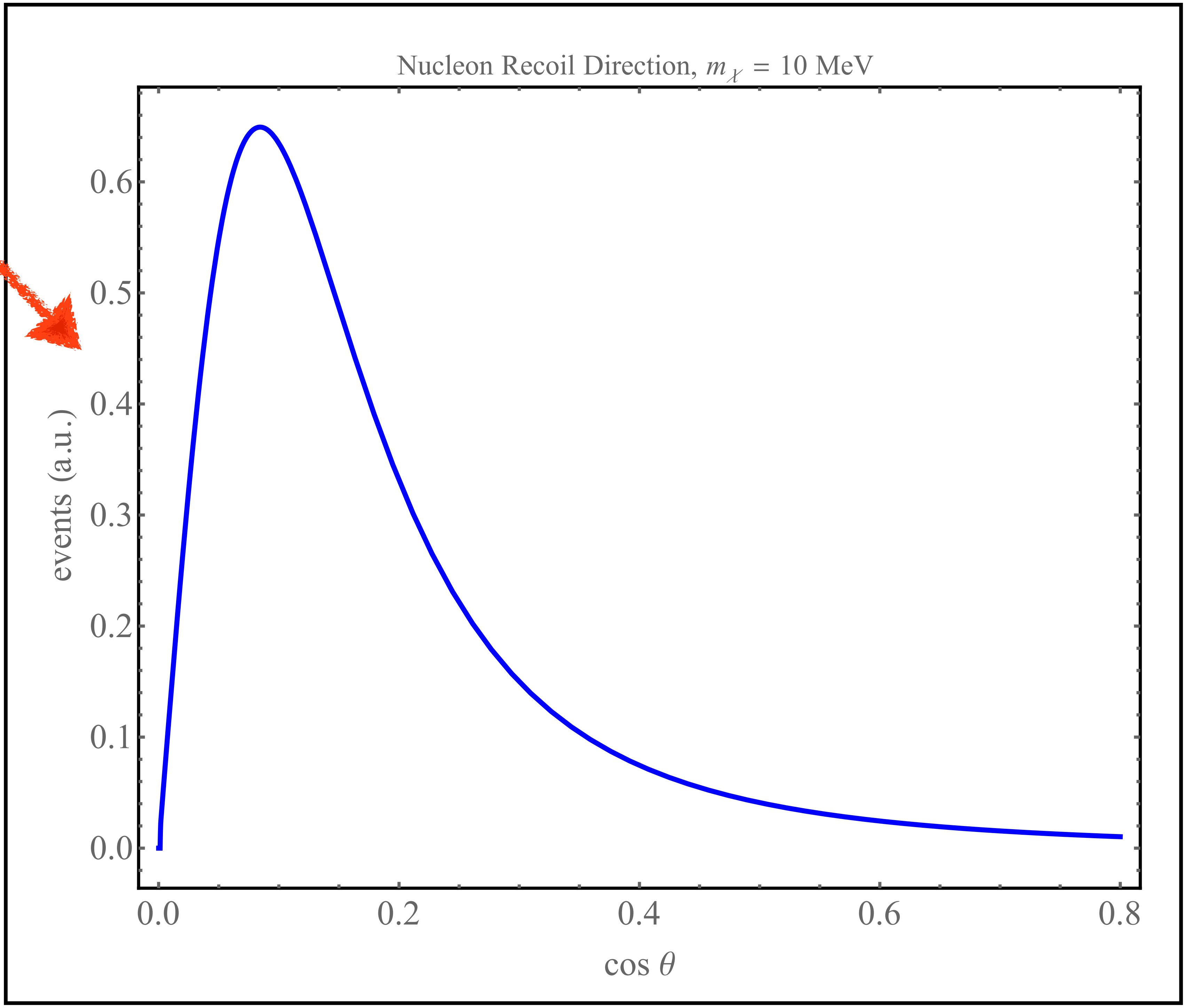
$$F_{1,N}(E_f) = \frac{q_N}{(1+2E_f/m_N)^2}$$

$$F_{2,N}(E_f) = \frac{\kappa_N}{(1+2E_f/m_N)^2}$$

"Medium" Case: Nucleon Recoils



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

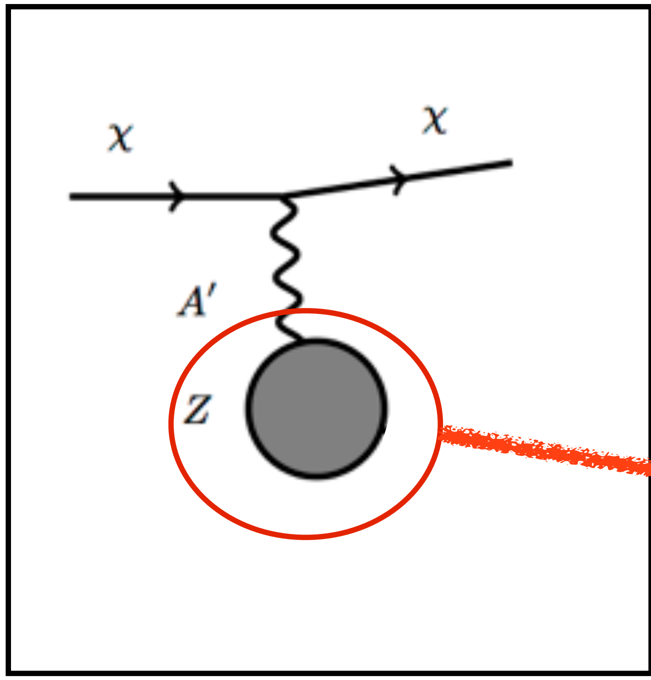


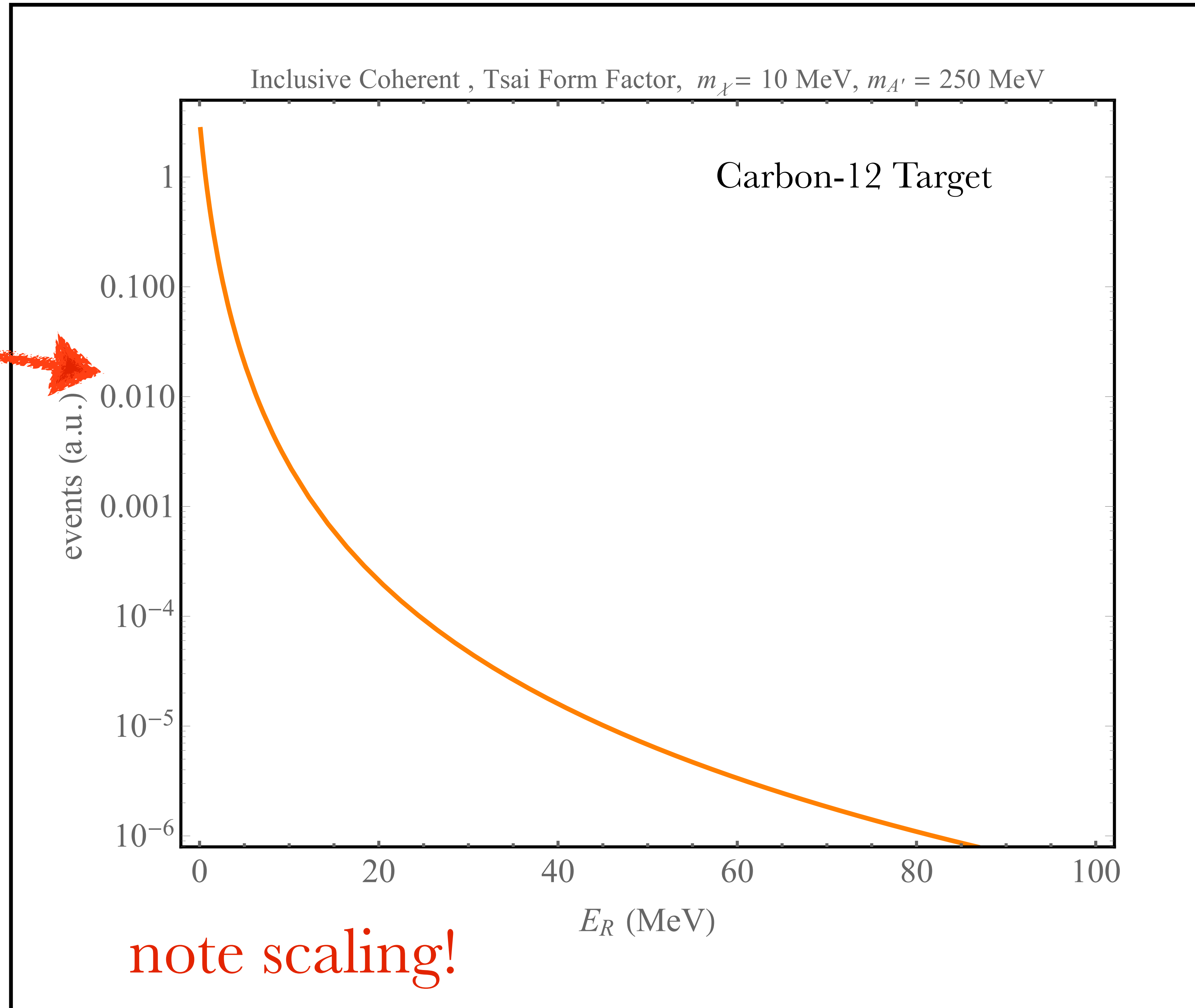
Relevant scales overlap

Nontrivial angular distribution

More orthogonal than electron recoils

"Hard" Case: Coherent Nuclear



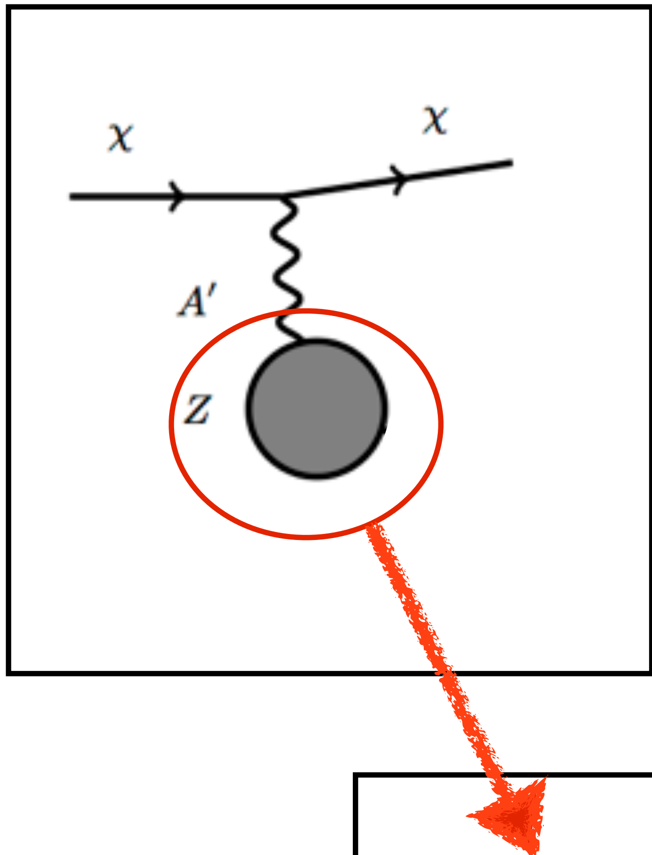


Key Features

- Exponentially falling
- Need very low BG
- Depends on material!
- **Orthogonal nuclear recoil**

"Hard" Case: Coherent Nuclear

Most scattering is "glancing"



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

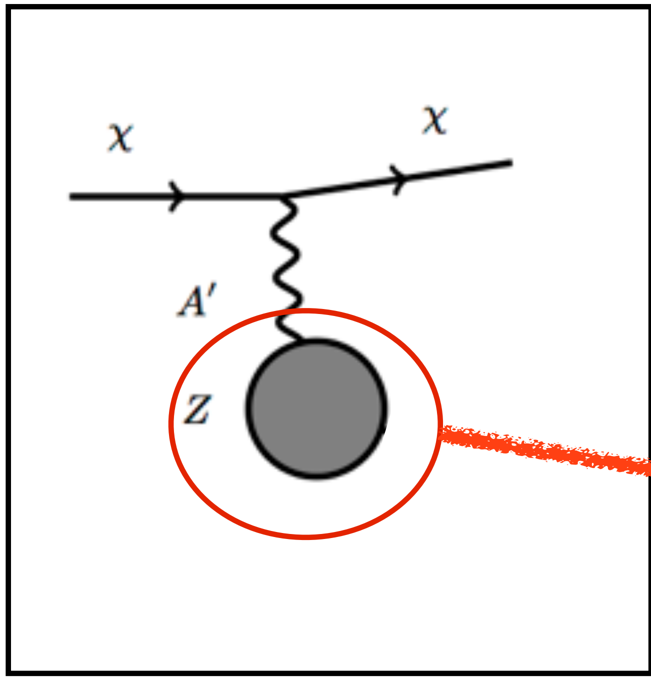
lab-frame scattering angle

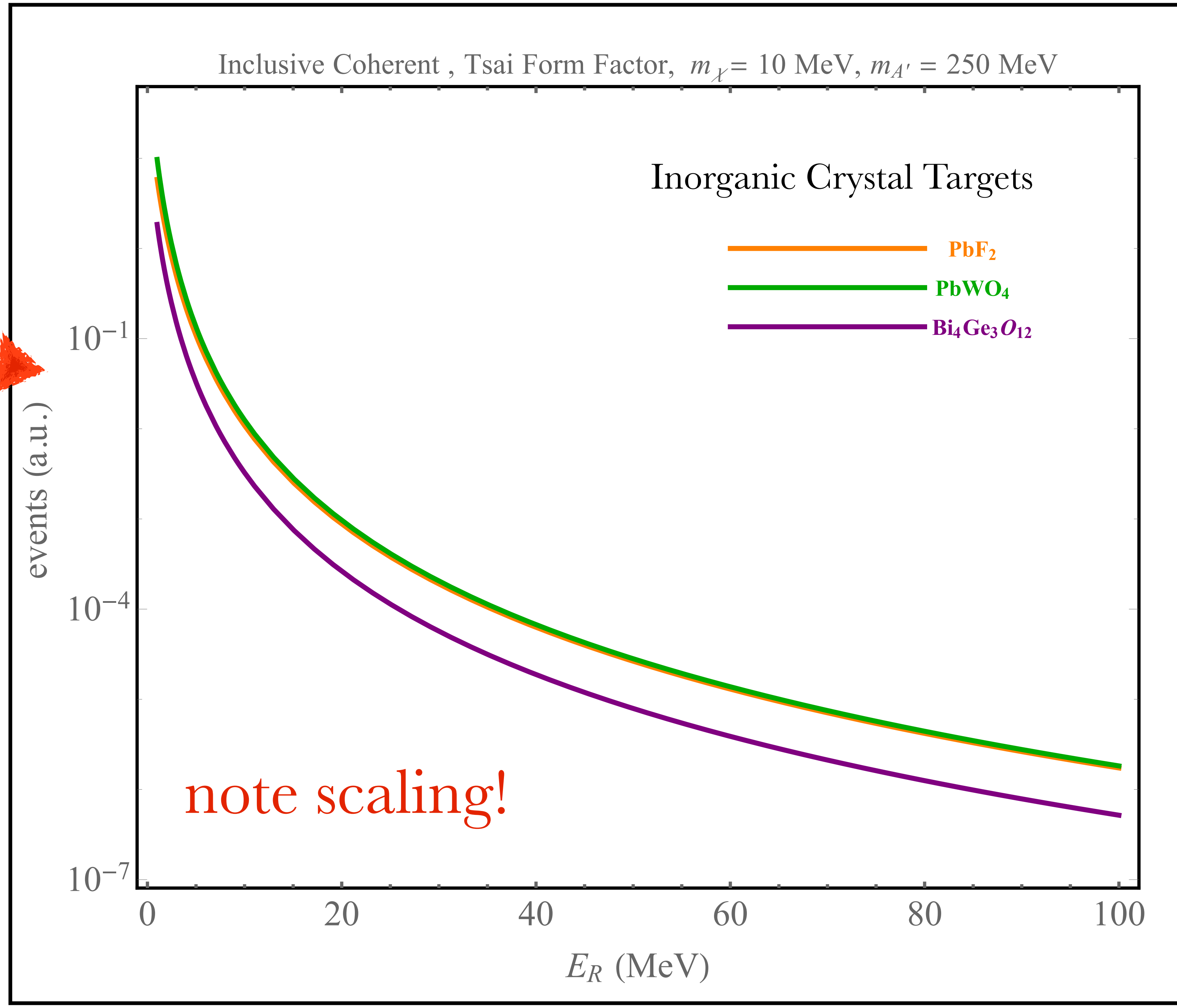
$$\cos\theta_N(m_N \gg E_\chi) \to \sqrt{\frac{E_R - m_N}{E_R + m_N}} \approx \frac{v_N}{c}$$

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

beam dump limit (heavy target)

"Hard" Case: Coherent Nuclear





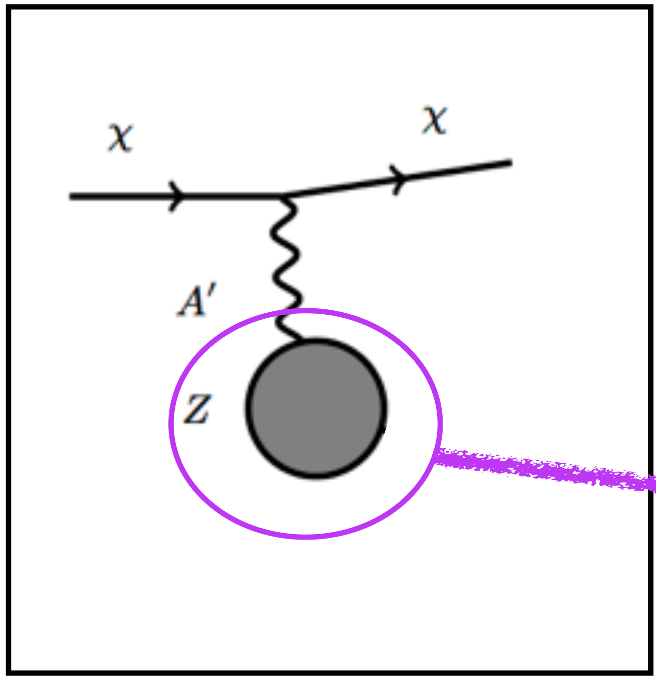
Tsai Form Factor

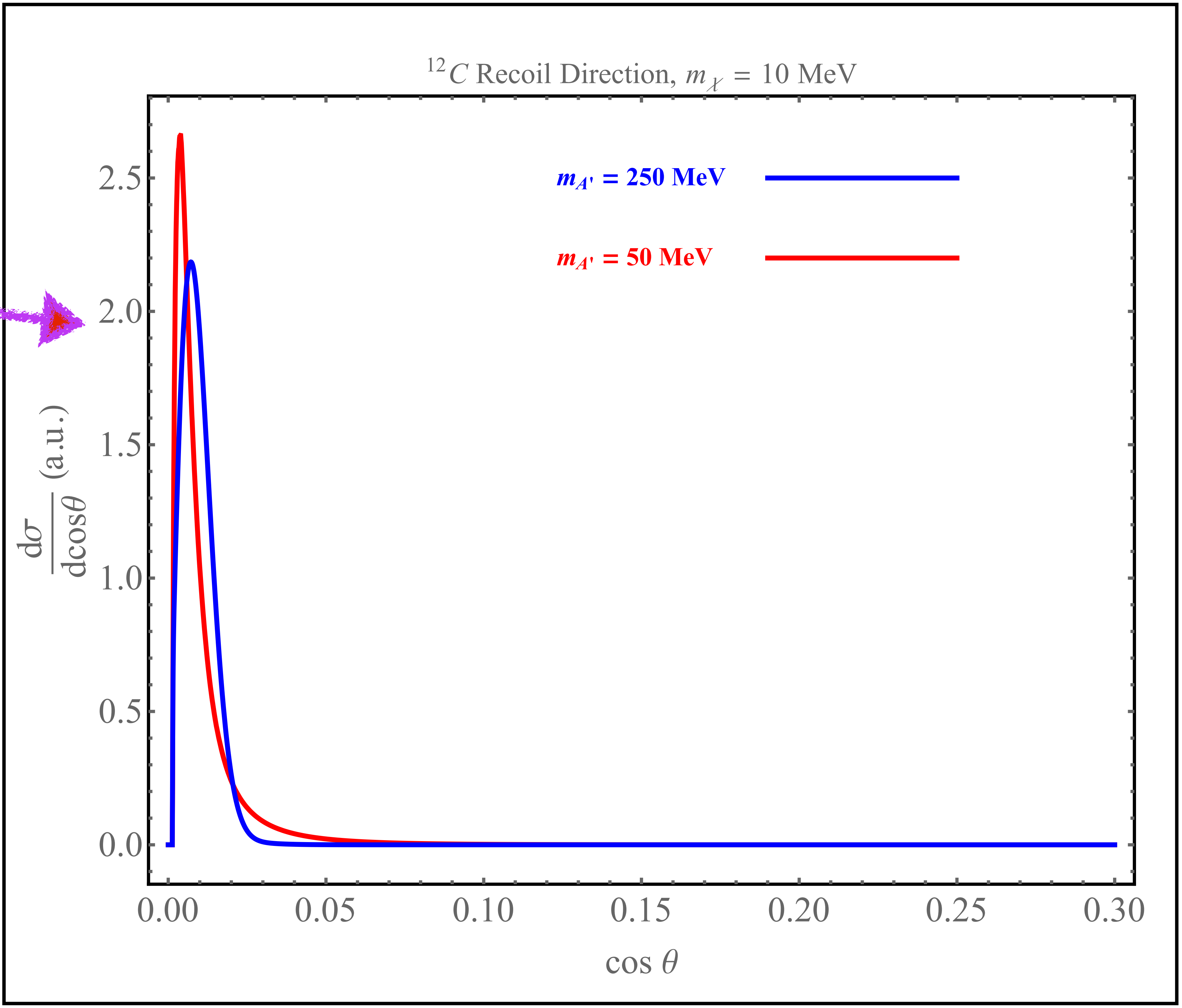
$$G_{2,el}(t) = \left(\frac{a^2 t}{1 + a^2 t}\right)^2 \left(\frac{1}{1 + t/d}\right)^2 Z^2$$

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

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

“Hard” Case: Coherent Nuclear

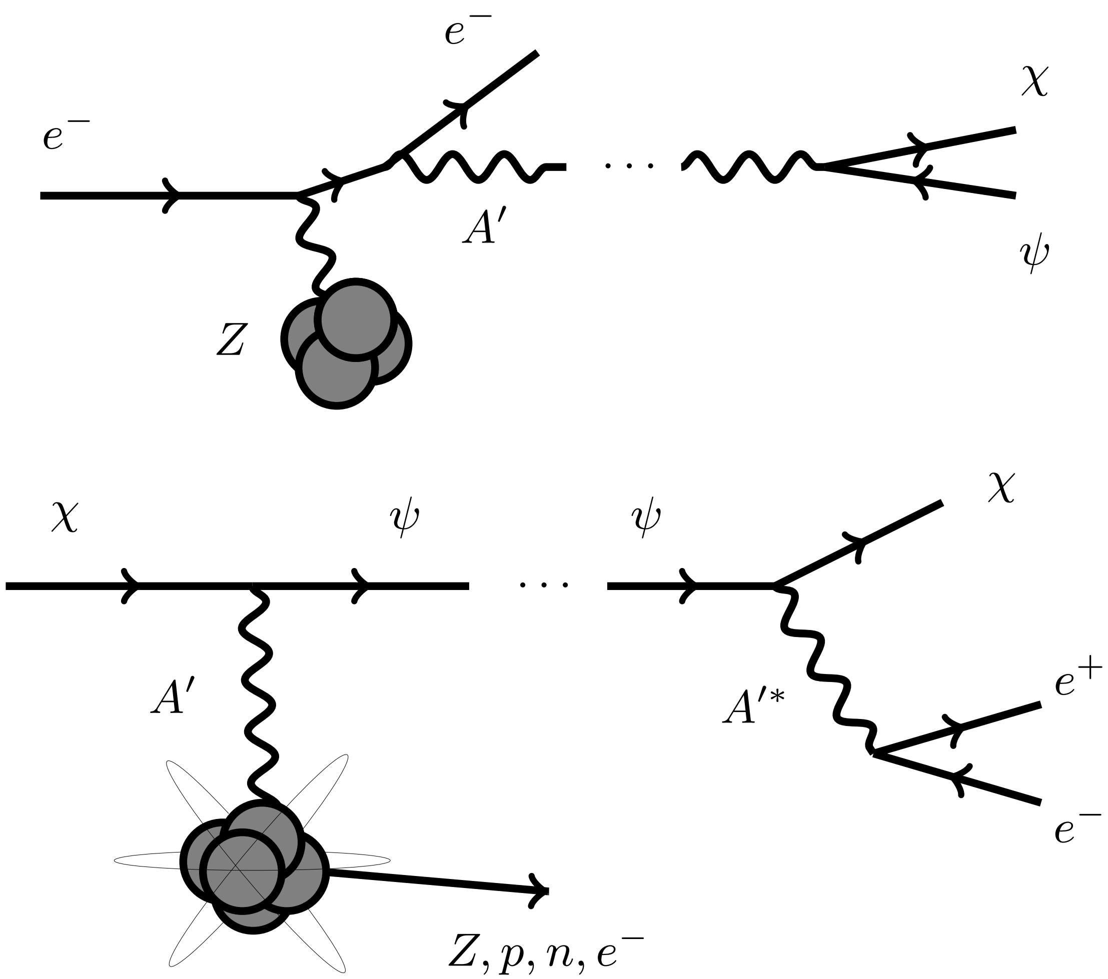




Difference due DM production variation for different mediator masses

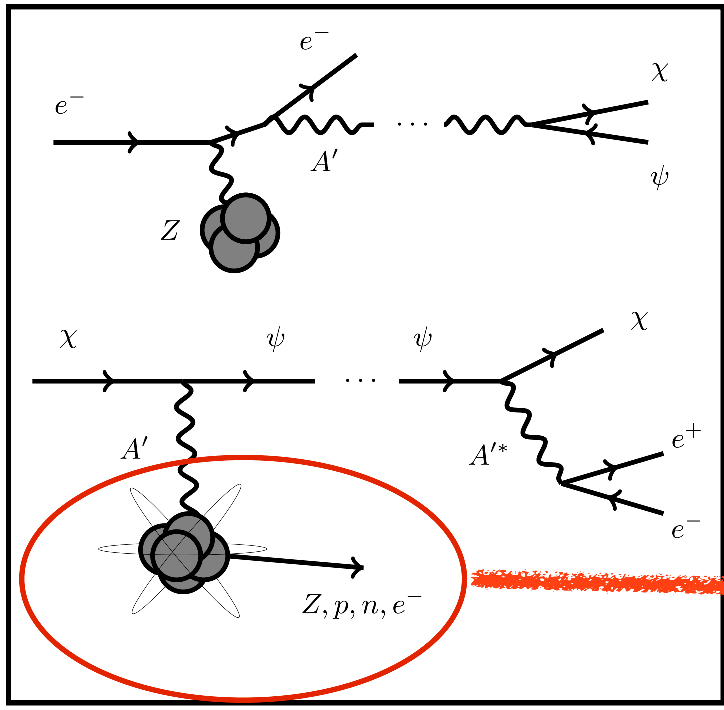
Bonus: Inelastic DM (iDM)

Step 1: Produce DM states with mass splitting
Step 2: Lighter state upscatters, produces heavier one
Step 3: Heavier state decays semi-visibly

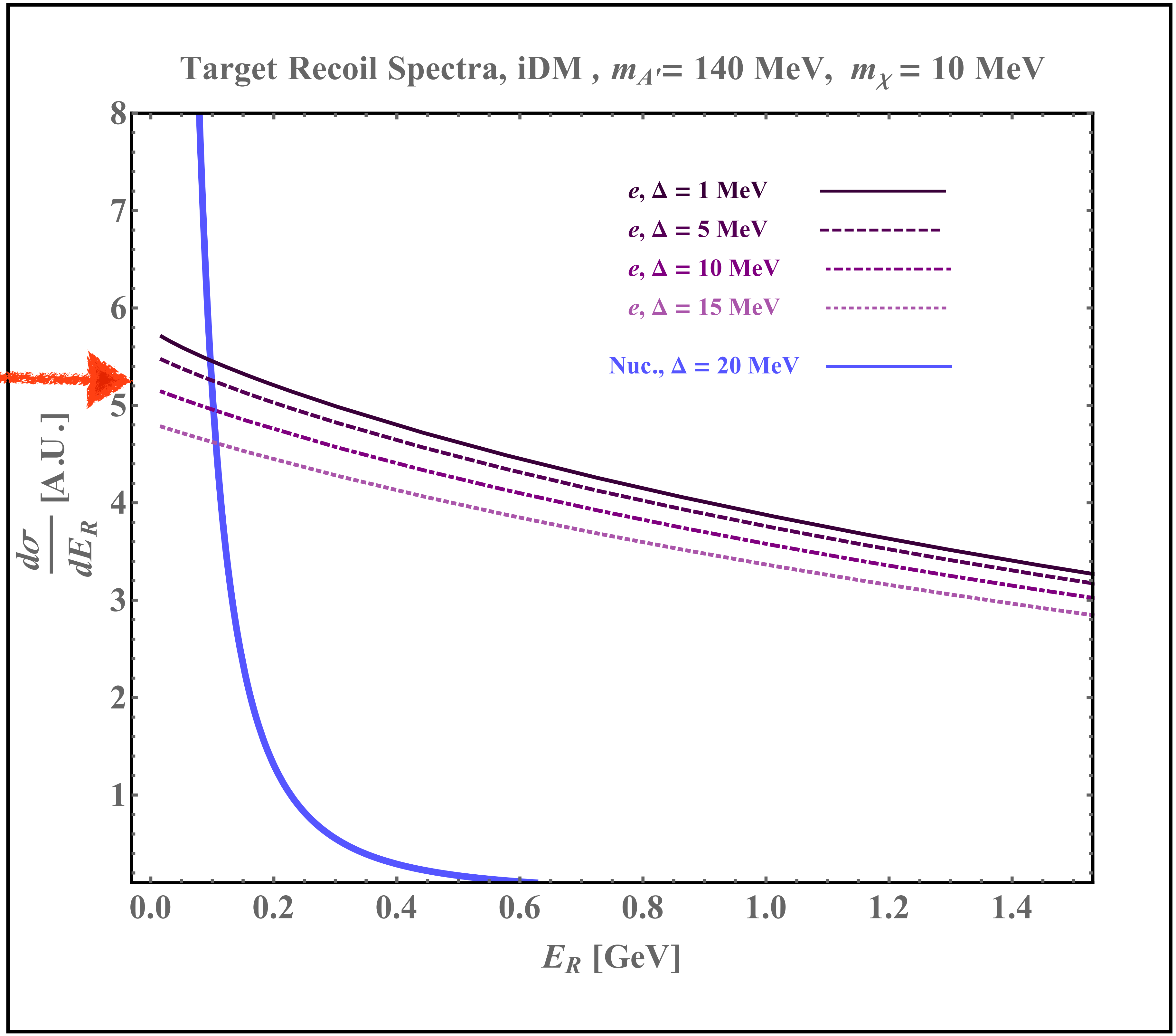


- Signal from de-excitation decay
- Striking signature, low BG
- Insensitive to recoil threshold
- Add all scattering channels

Bonus: Inelastic DM (iDM)

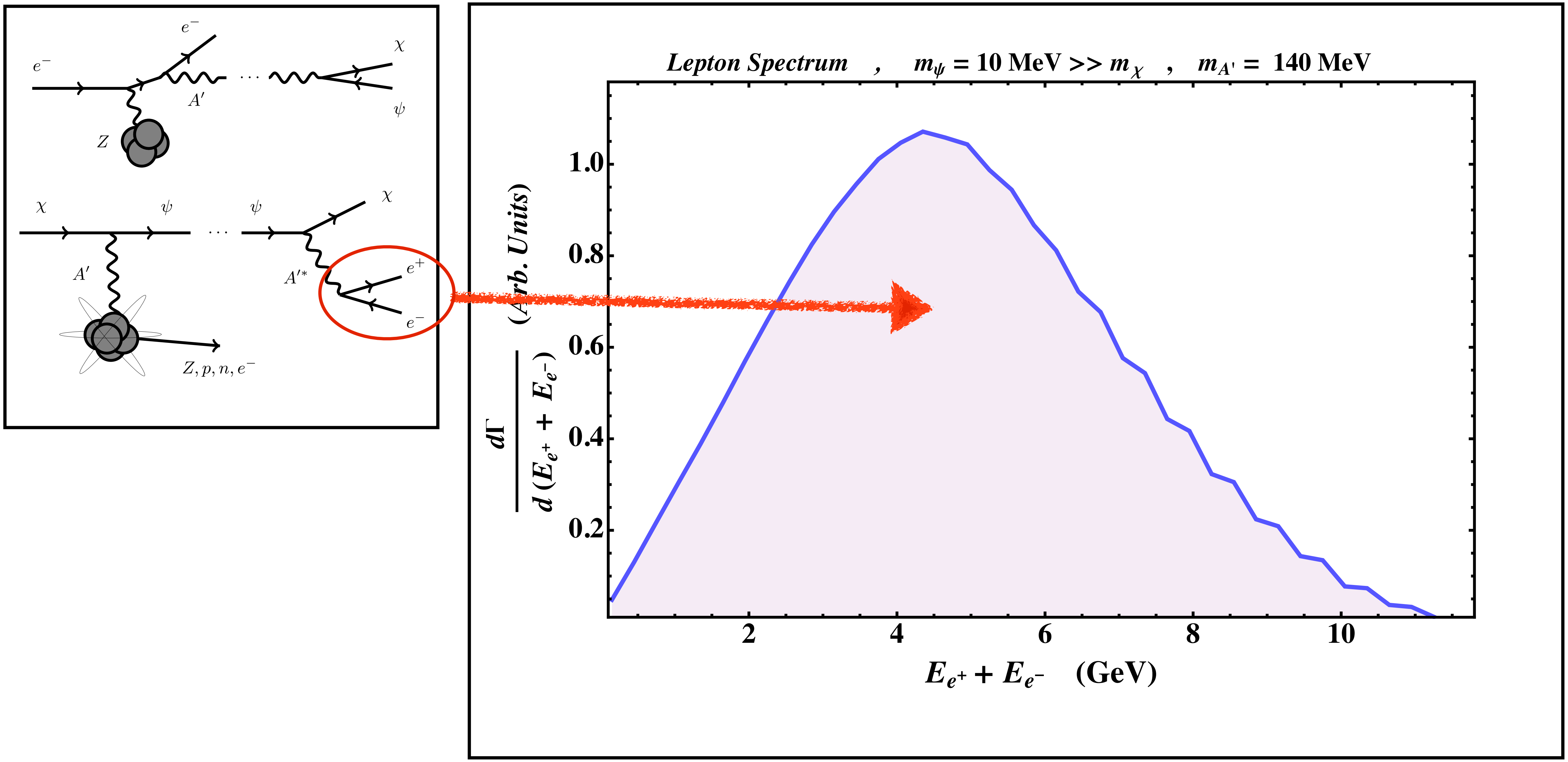


- Integrate from 0
- Rate insensitive to splitting
- Striking if decay is meter scale



Bonus: Inelastic DM (iDM)

$$\Gamma(\psi \to \chi\, e^+e^-) = \frac{4\epsilon^2\alpha\alpha_D\Delta^5}{15\pi m_{A'}^4}.$$

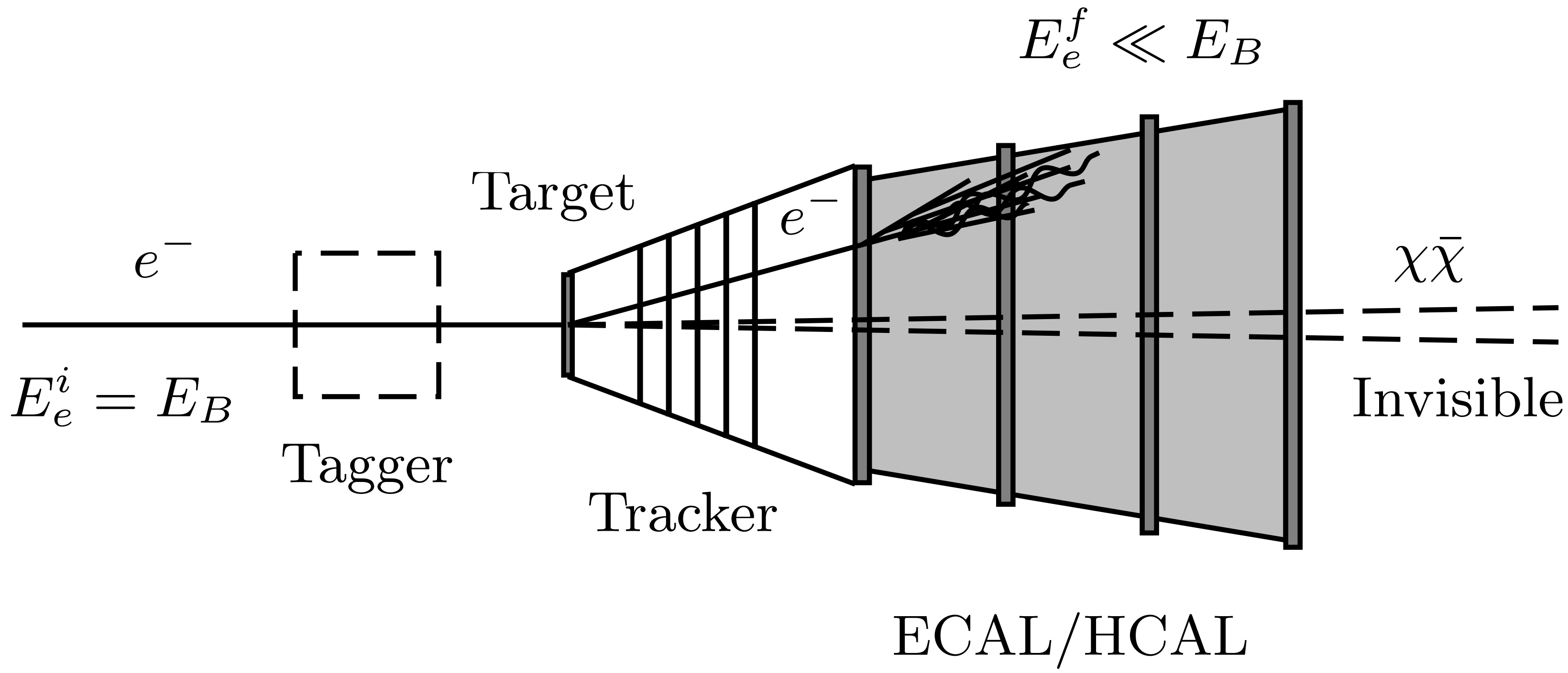


NB: plot made for 12 GeV beam, but qualitatively similar at lower energy, equally striking!

Summary

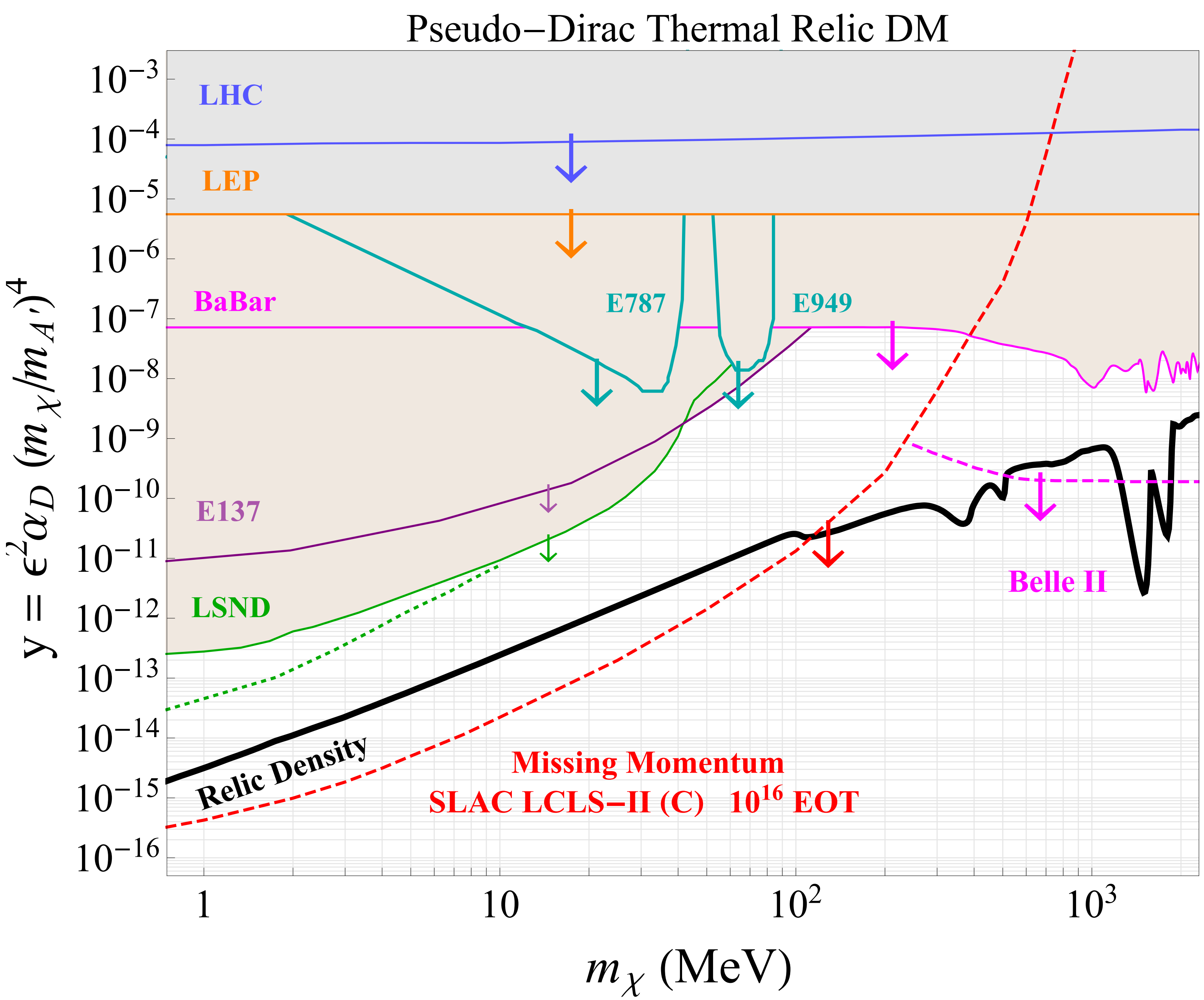
- **Easy:** Electrons
  Distribution flat, forward recoils
- **Medium:** Quasi-Elastic Nucleon
  Distribution falling, nontrivial angular distribution
- **Hard:** Coherent Nuclear
  Distribution sharply falling, orthogonal recoils
- **Bonus:** Dark-Inelastic Scattering
  Distribution irrelevant, Striking signal

Missing Momentum @ SLAC



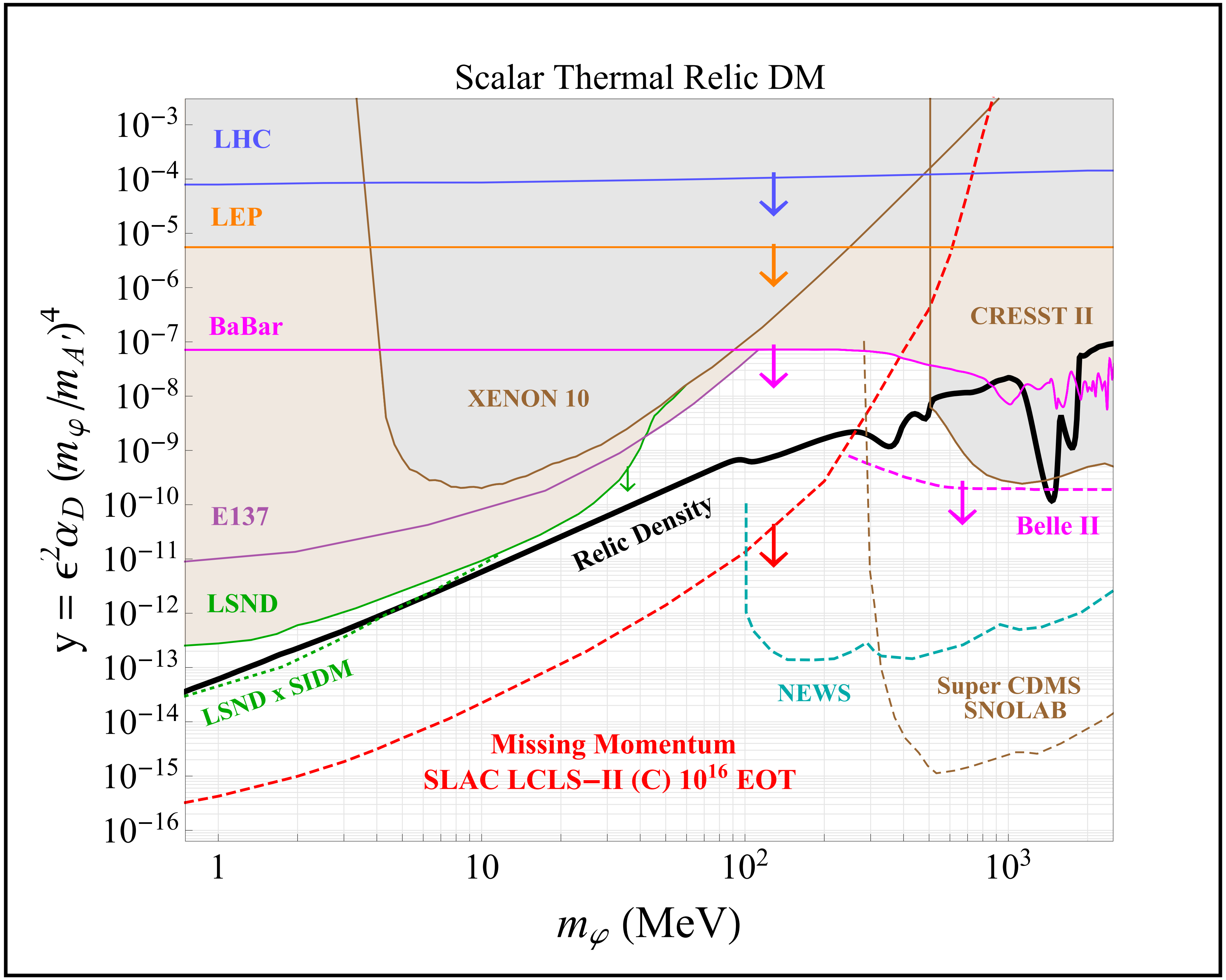
- Thin C12 target ~ 0.1 radiation length
- 4 GeV electron beam
- 10^16 EOT

Missing Momentum @ SLAC



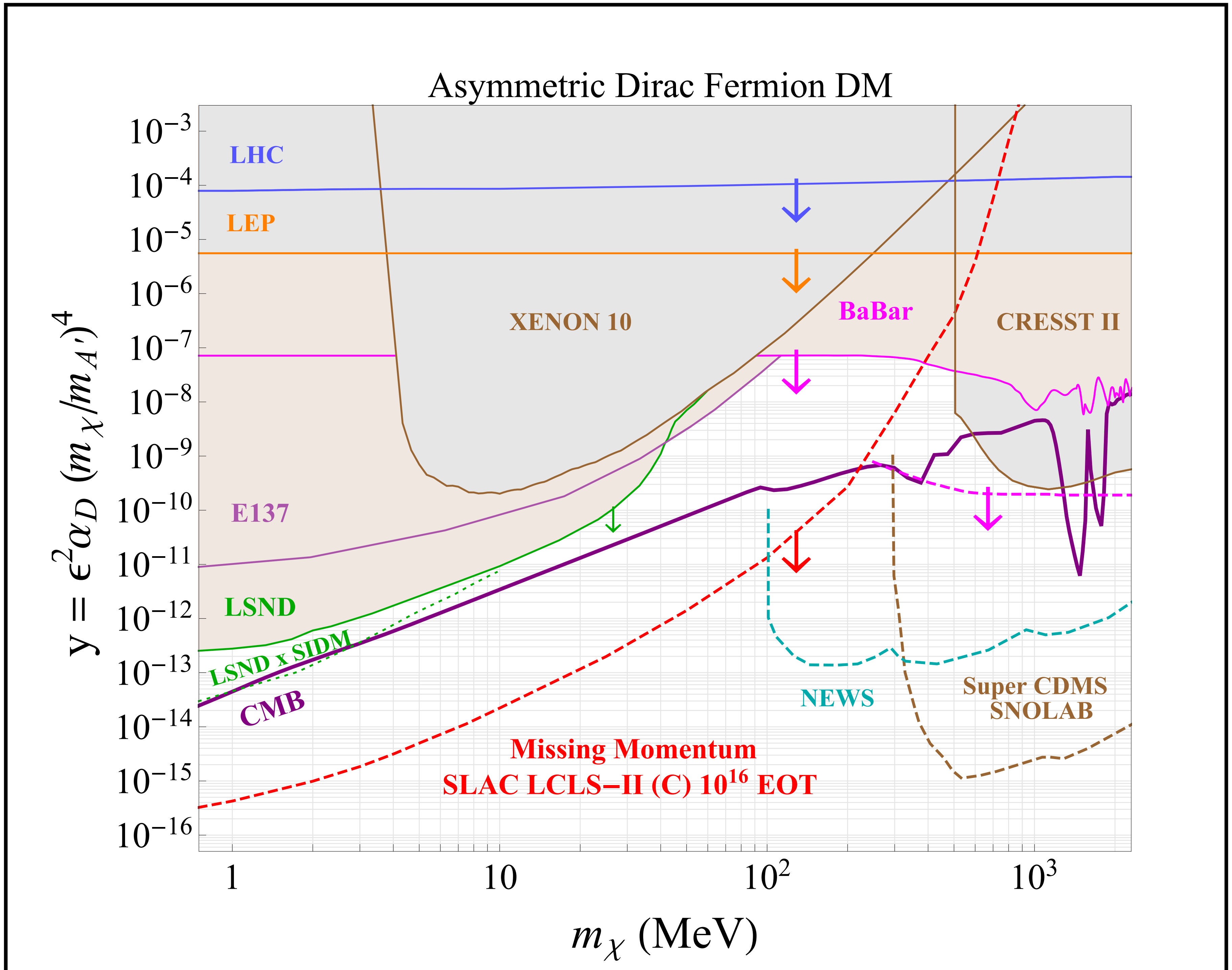
2.3 event yields, clean experiment limit

Missing Momentum @ SLAC



2.3 event yields, clean experiment limit

Missing Momentum @ SLAC



2.3 event yields, clean experiment limit