

Signatures of Composite Dark Matter in Bubble Chambers

Alex Hayes



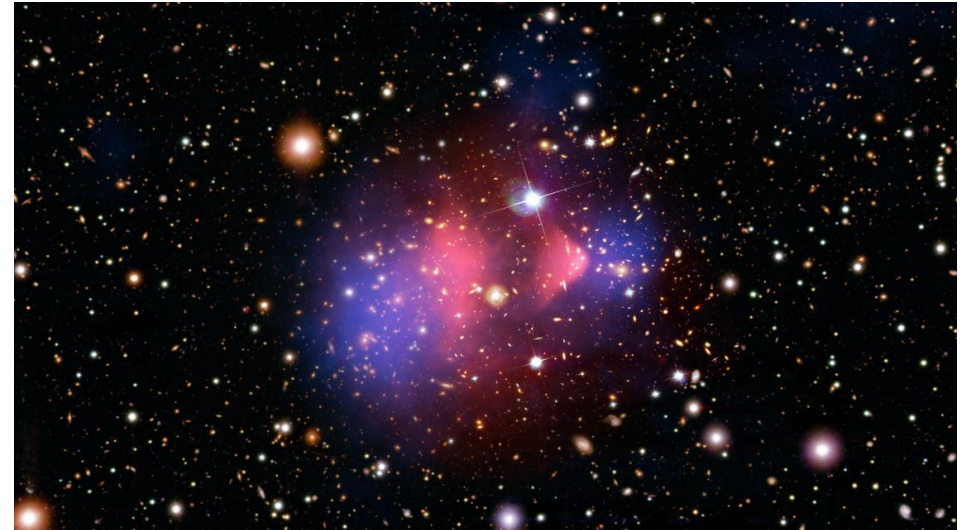
Outline

- Part I: Dark Matter
- Part II: Bubble Chambers
- Part III: Analysis & Results

Part I: Dark Matter

Part I – Dark Matter

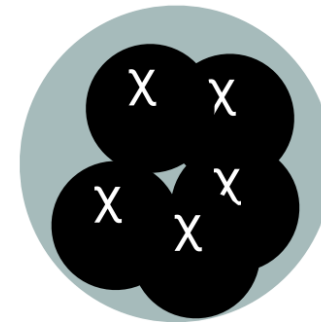
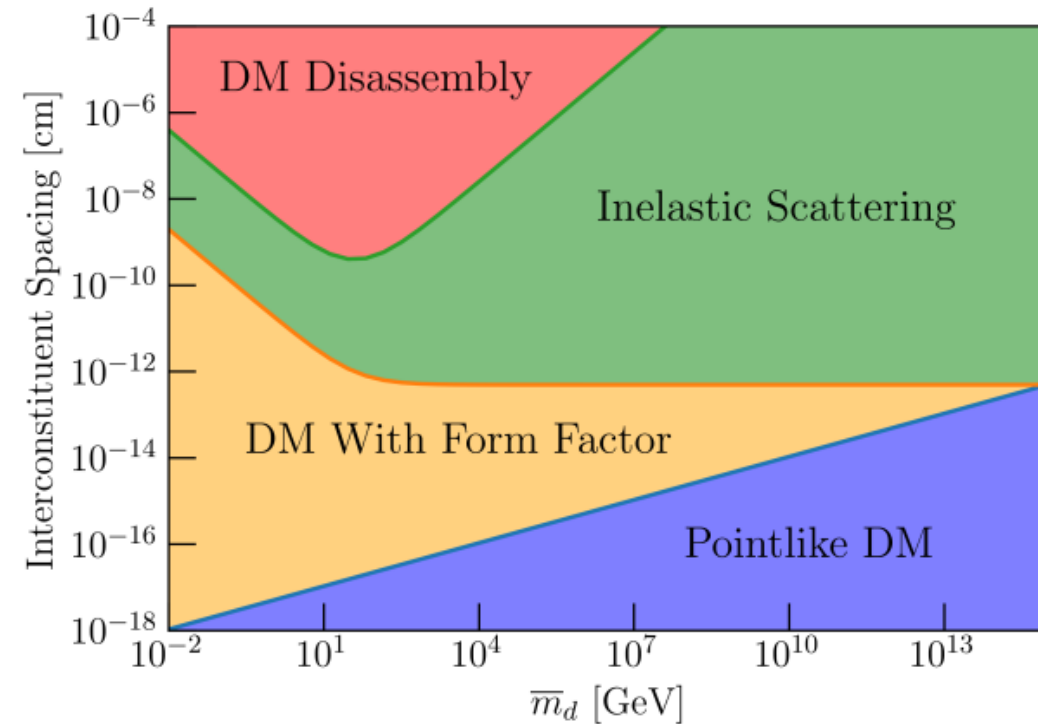
- New form of matter
- Motivated by various astrophysical phenomena
- Particle nature unknown



Credit: NASA

Part I – Composite Dark Matter

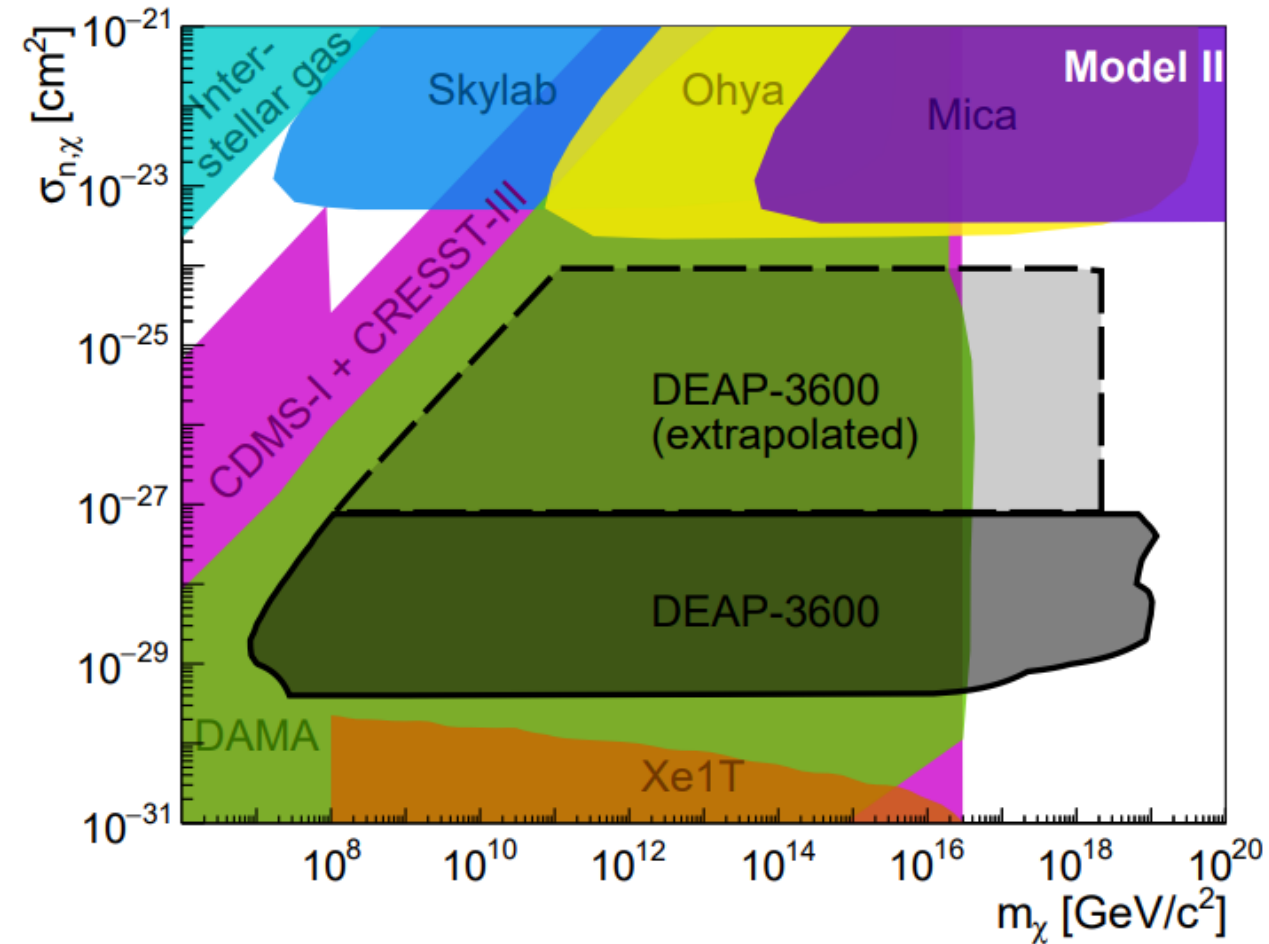
- Models with a binding force
- Clump into large composite states
- Can be very heavy, $\mathcal{O}(1 - 10^{45})$ GeV



Credit: Joe Bramante

Part I – DEAP-3600 Multi-scatter

- Used DEAP-3600's lack of multiple-scatter events
- Provided new limits on heavy dark matter



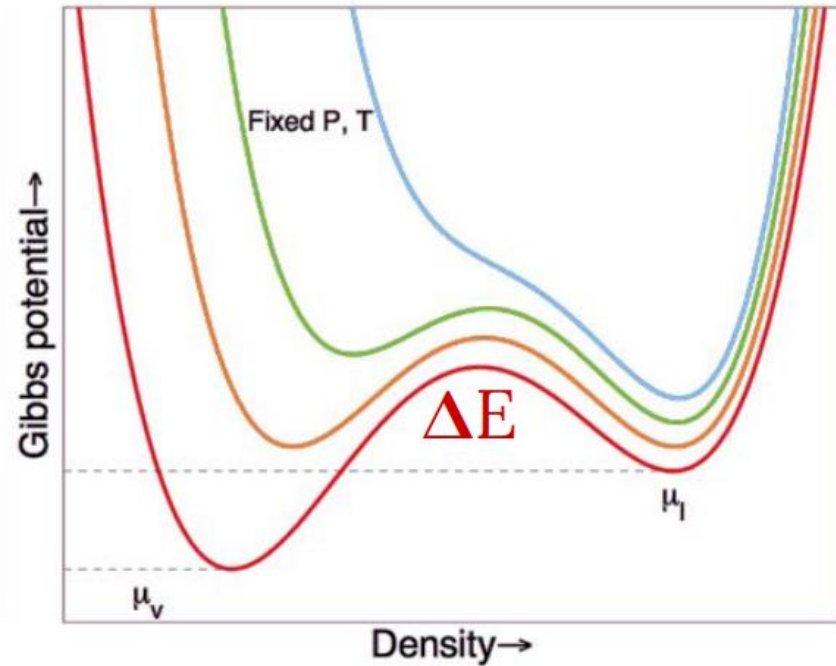
Credit: DEAP Collaboration

Part I – Summary

- Invisible, new type of matter
- Models with binding forces
 - Create large “composites”
- Direct detection can provide new limits

Part II: Bubble Chambers

Part II – Bubble Chambers

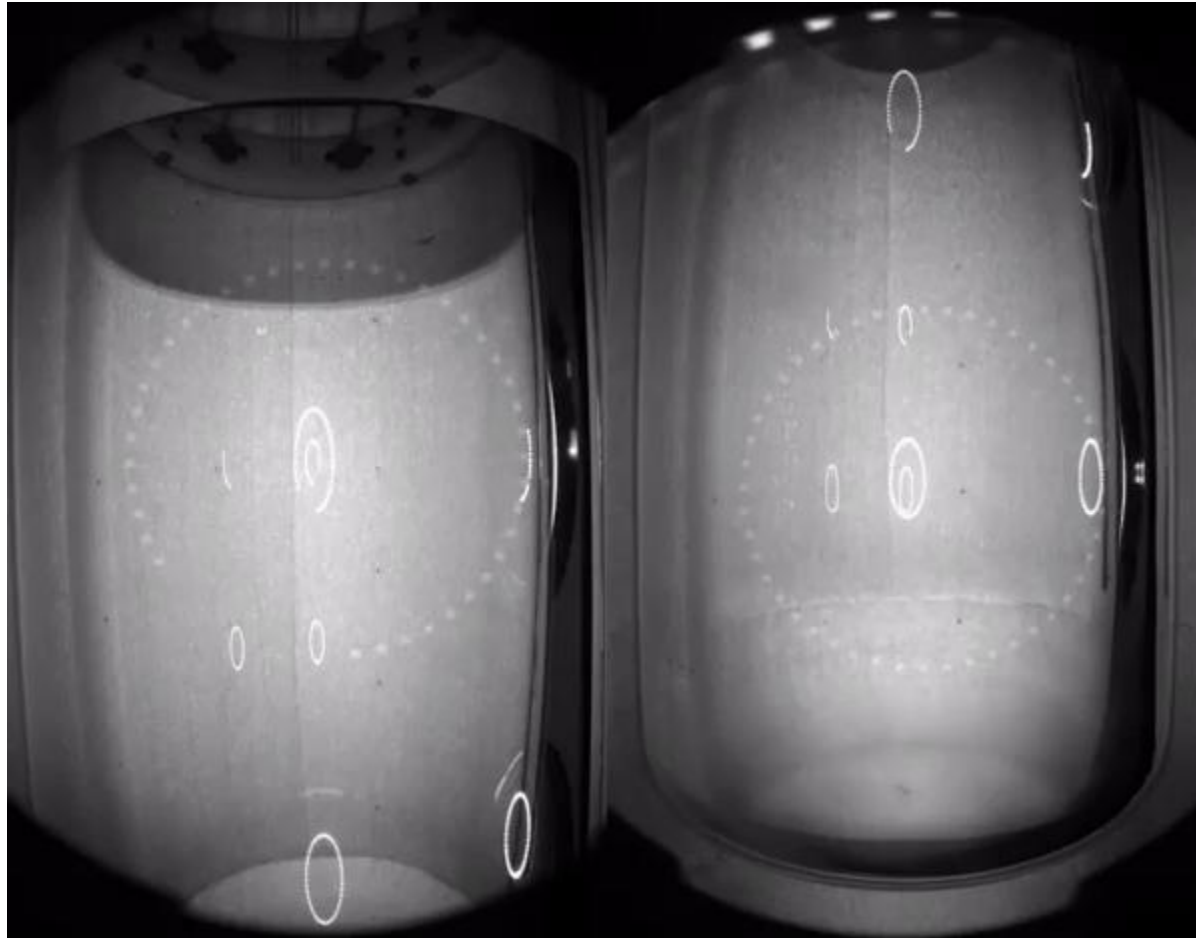


Credit: Ben Broerman, SBC



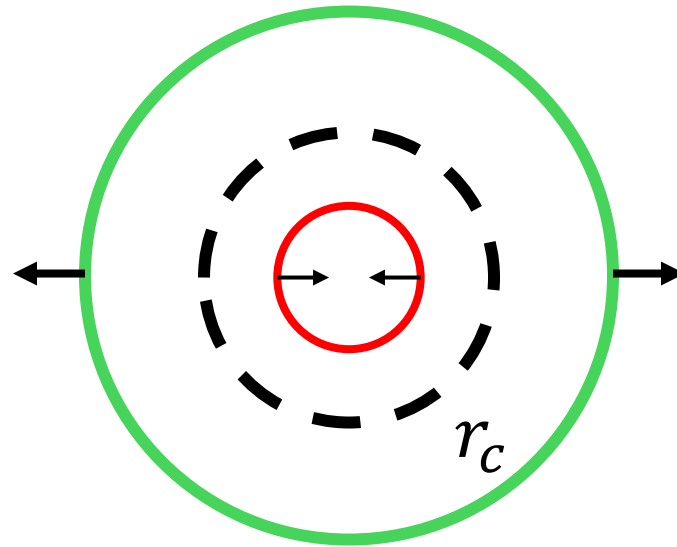
Credit: PICO Experiment

Part II – Bubble Chambers



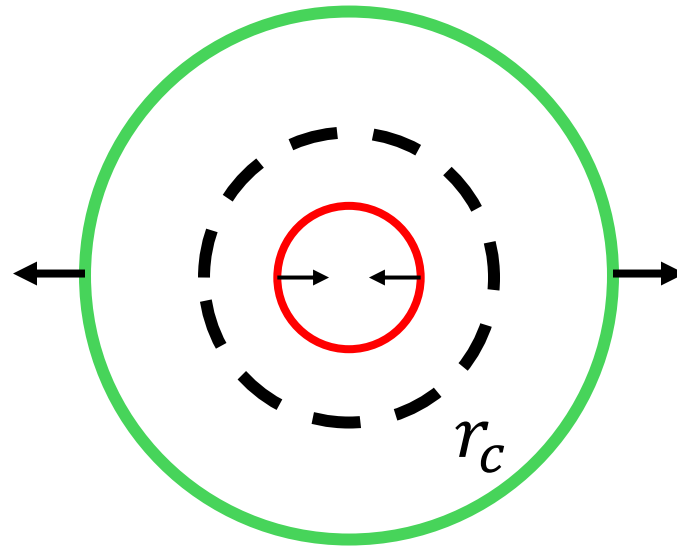
Credit: McDonald Institute

Part II – Energy Threshold



$$E_{thresh} =$$

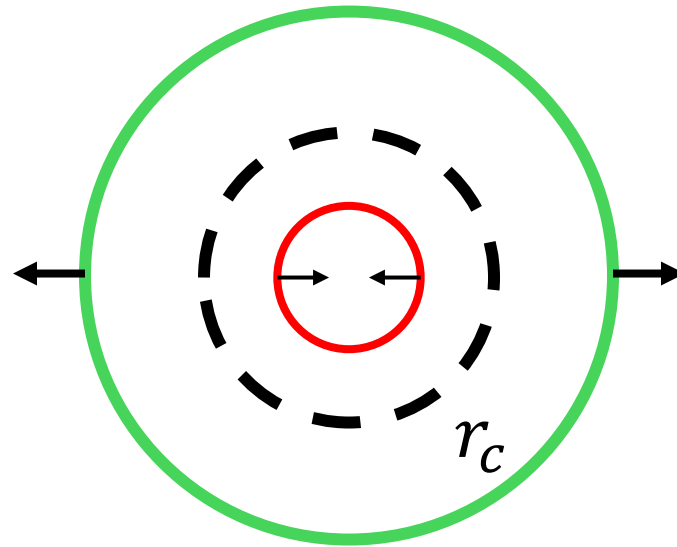
Part II – Energy Threshold



$$E_{threshold} = 4\pi \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) r_c^2$$

Surface tension

Part II – Energy Threshold

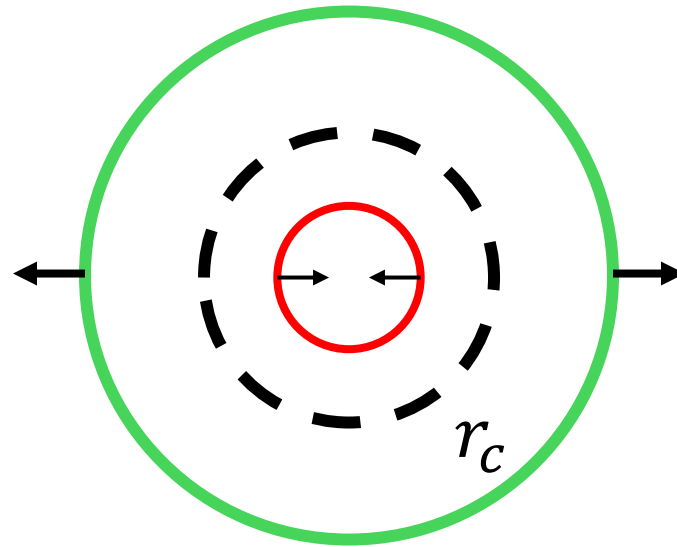


$$E_{thresh} = 4\pi \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) r_c^2 + \frac{4\pi}{3} \rho_b (h_b - h_l) r_c^3$$

Surface tension

Enthalpy

Part II – Energy Threshold



$$E_{thresh} = 4\pi \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) r_c^2 + \frac{4\pi}{3} \rho_b (h_b - h_l) r_c^3 - \frac{4\pi}{3} (P_b - P_l) r_c^3$$

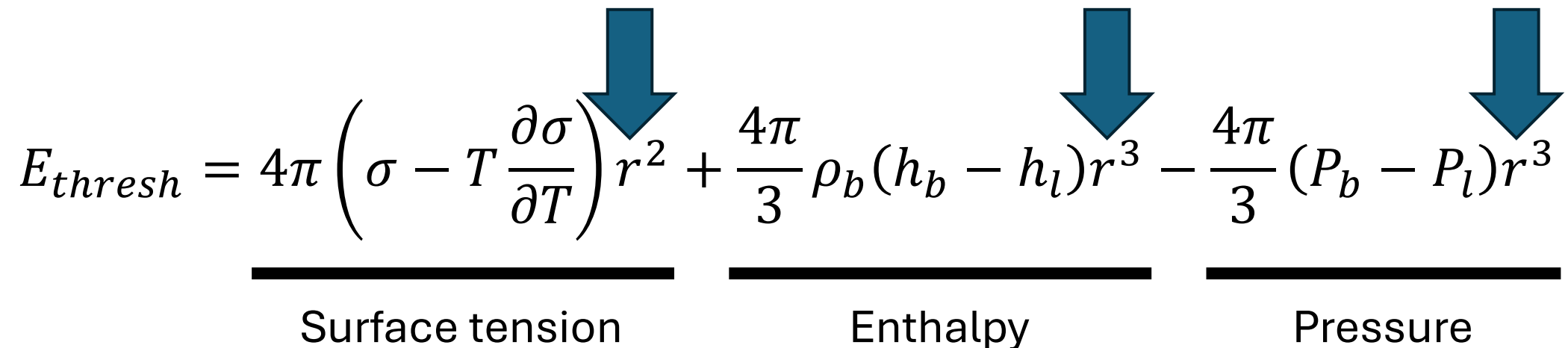
Surface tension

Enthalpy

Pressure

Part II – Energy Threshold

If $r > r_c$:

$$E_{thresh} = \underbrace{4\pi \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) r^2}_{\text{Surface tension}} + \underbrace{\frac{4\pi}{3} \rho_b (h_b - h_l) r^3}_{\text{Enthalpy}} - \underbrace{\frac{4\pi}{3} (P_b - P_l) r^3}_{\text{Pressure}}$$


Part II – Summary

- Macroscopic signal region
- Uniquely sensitive to composite interactions!

Part III: Analysis & Results

Part III – Velocity

- Flux:

$$\Phi = \frac{\rho_D}{M_D} v_{avg} A f_g$$

Part III – Velocity

- Flux:

$$\Phi = \frac{\rho_D}{M_D} v_{avg} A f_g$$

- Number of events:

$$N = \Phi t \int_{v_i}^{\infty} f(v) dv$$

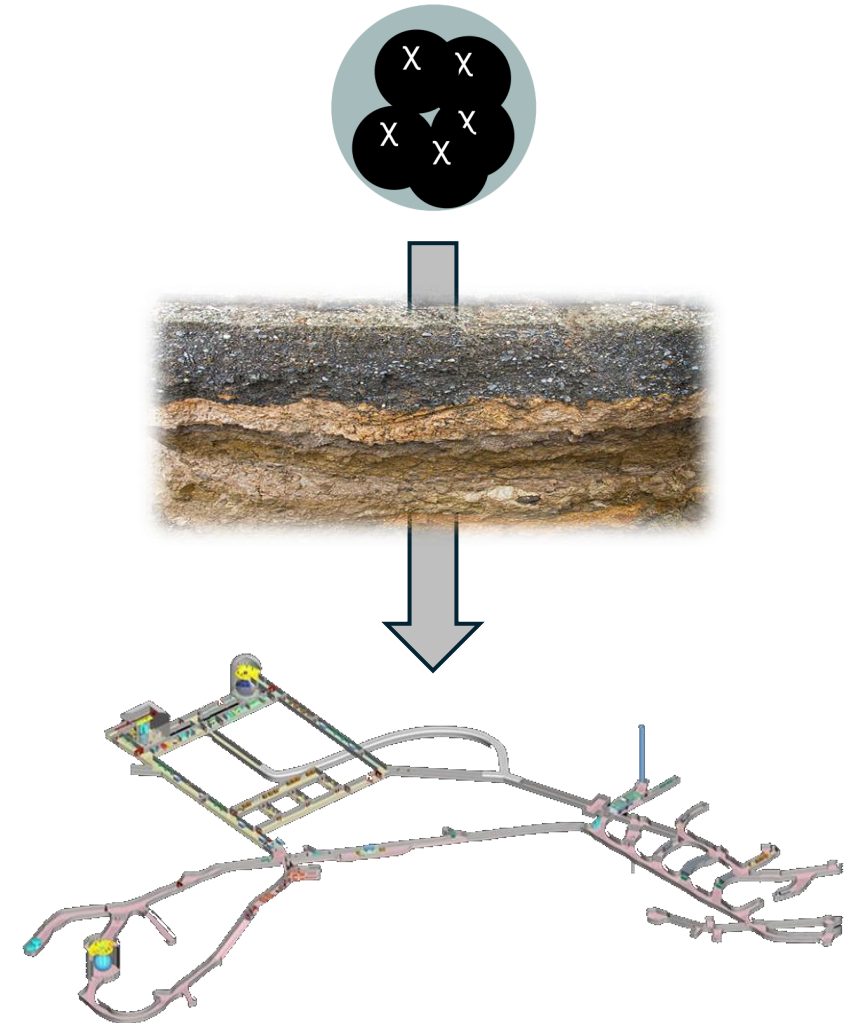
➤ This gives us v_i

Part III – Overburden

- Overburden slowdown:

$$\frac{v_f}{v_i} \sim \exp(-\sigma_{nd} \ell \sum \mu_{Nd}^4 n_N)$$

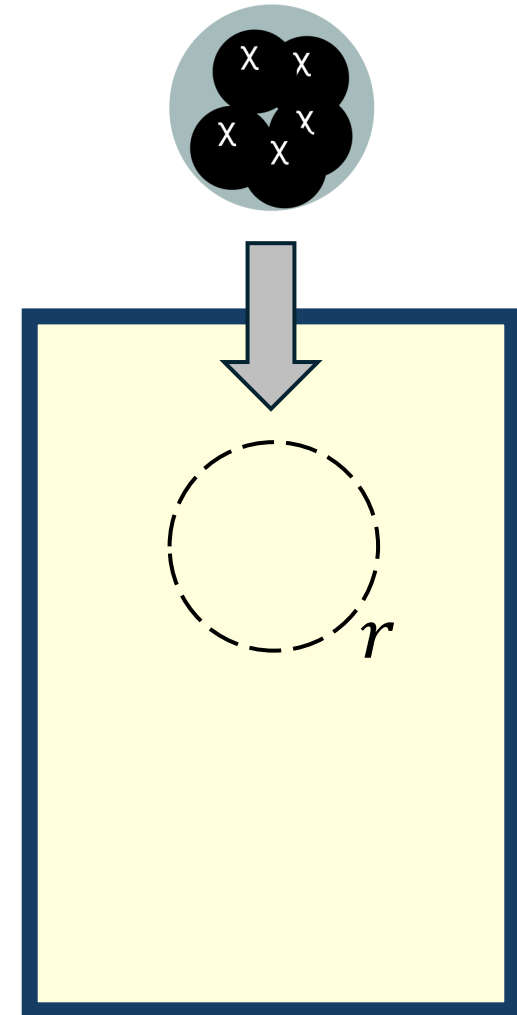
- Composite disassembly?



Part III – Total Energy Deposit

- Total energy deposited:

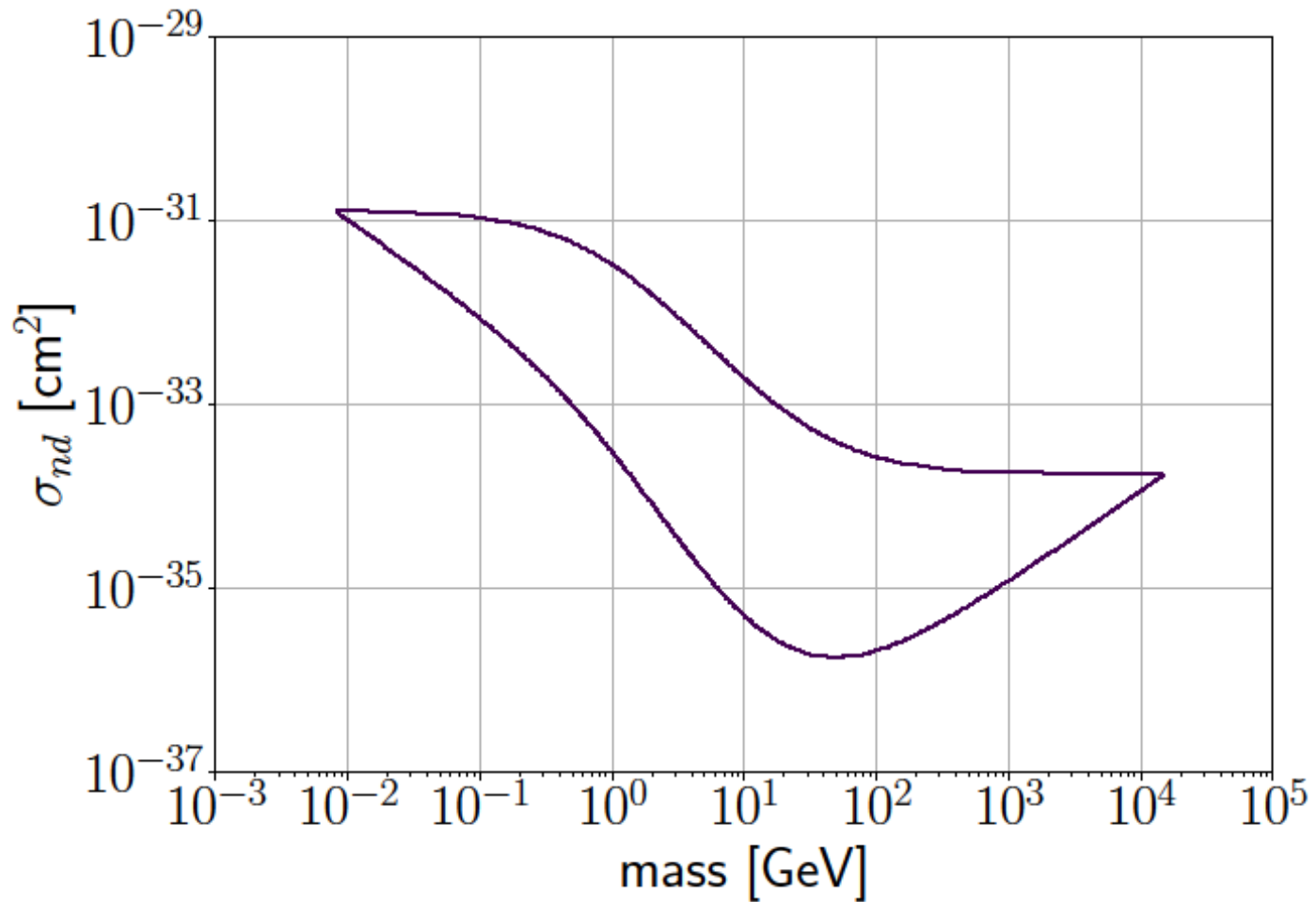
$$E_{dep} \sim rN\sigma_{nd}v_f^2 \sum \mu_{Nd}^4 n_N$$



Part III – Summary so far

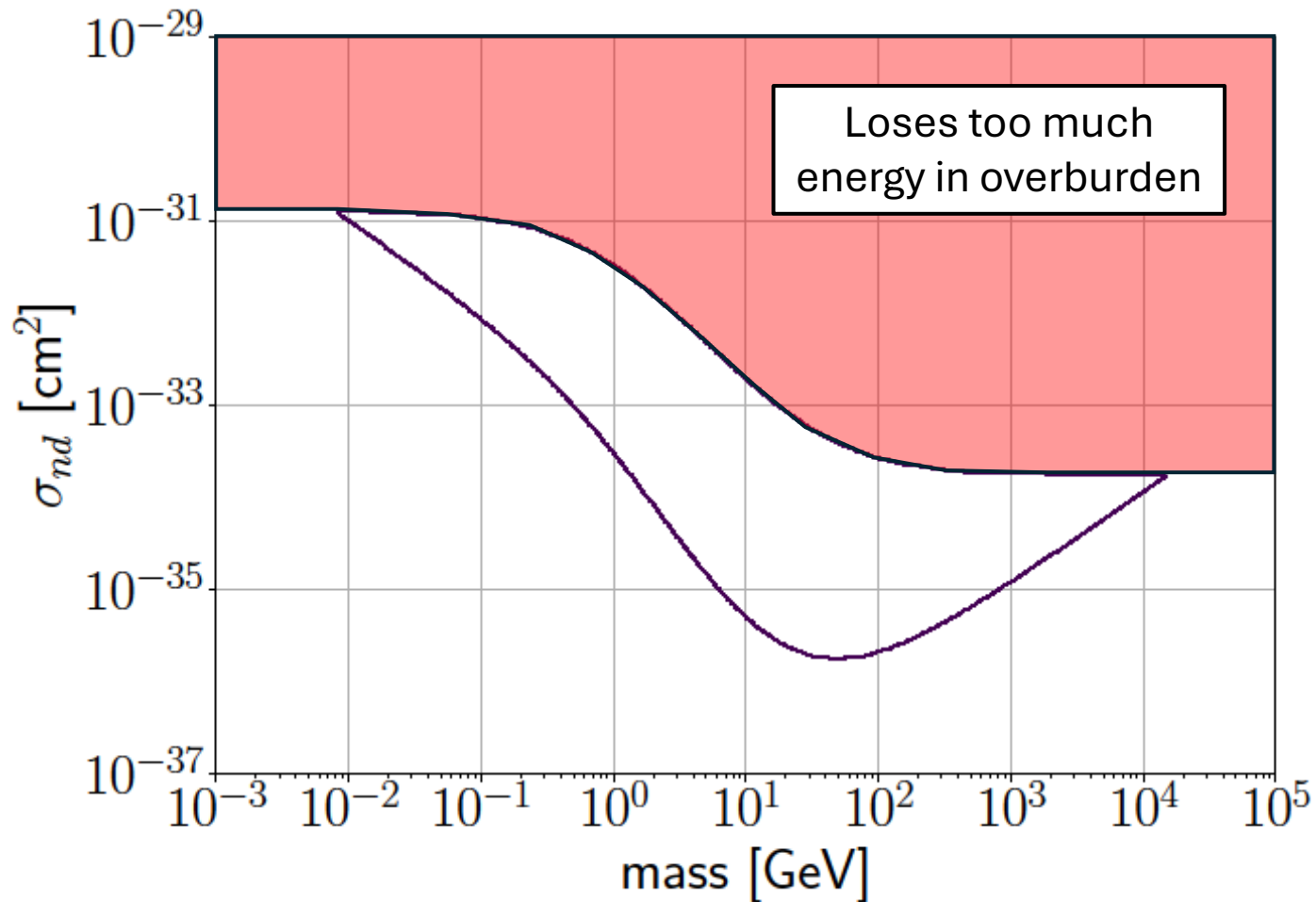
- Find ν to give enough events
- Calculate energy lost in overburden
- Bubbles when $E_{dep} > E_{thresh}$

Part II – Results (Preliminary) – PICO-40L



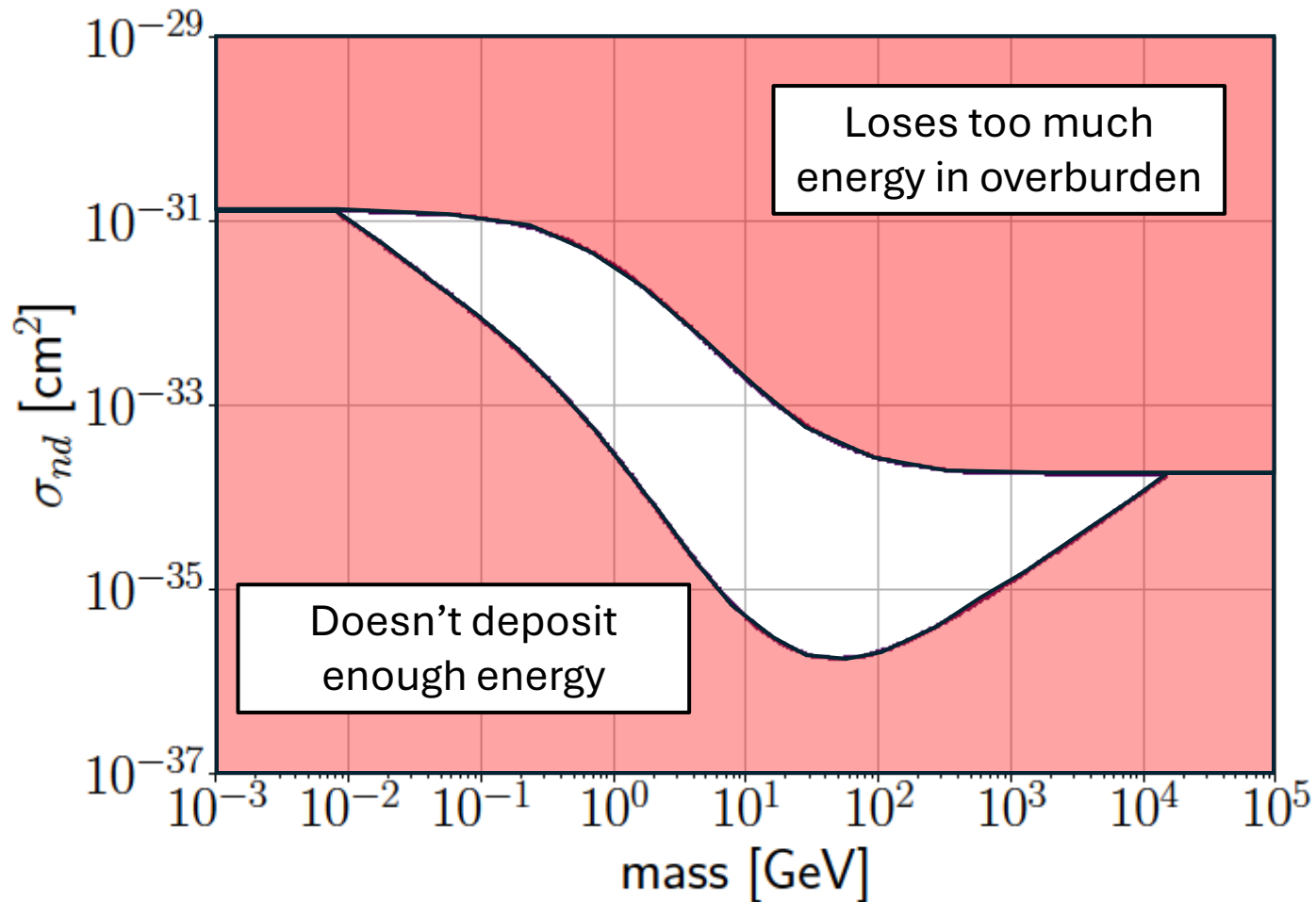
PICO-40L sensitivity at surface

Part II – Results (Preliminary) – PICO-40L



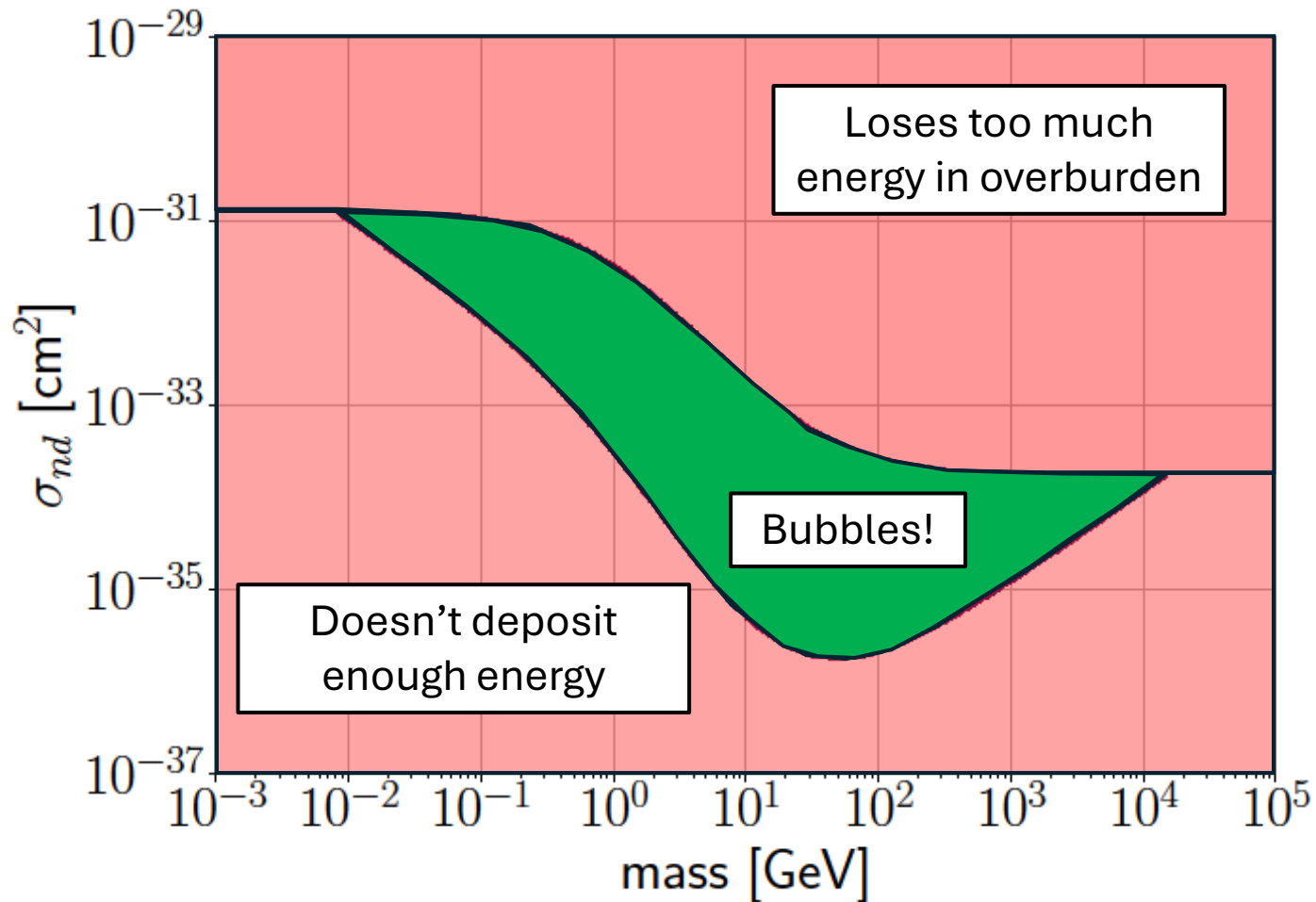
PICO-40L sensitivity at surface

Part II – Results (Preliminary) – PICO-40L



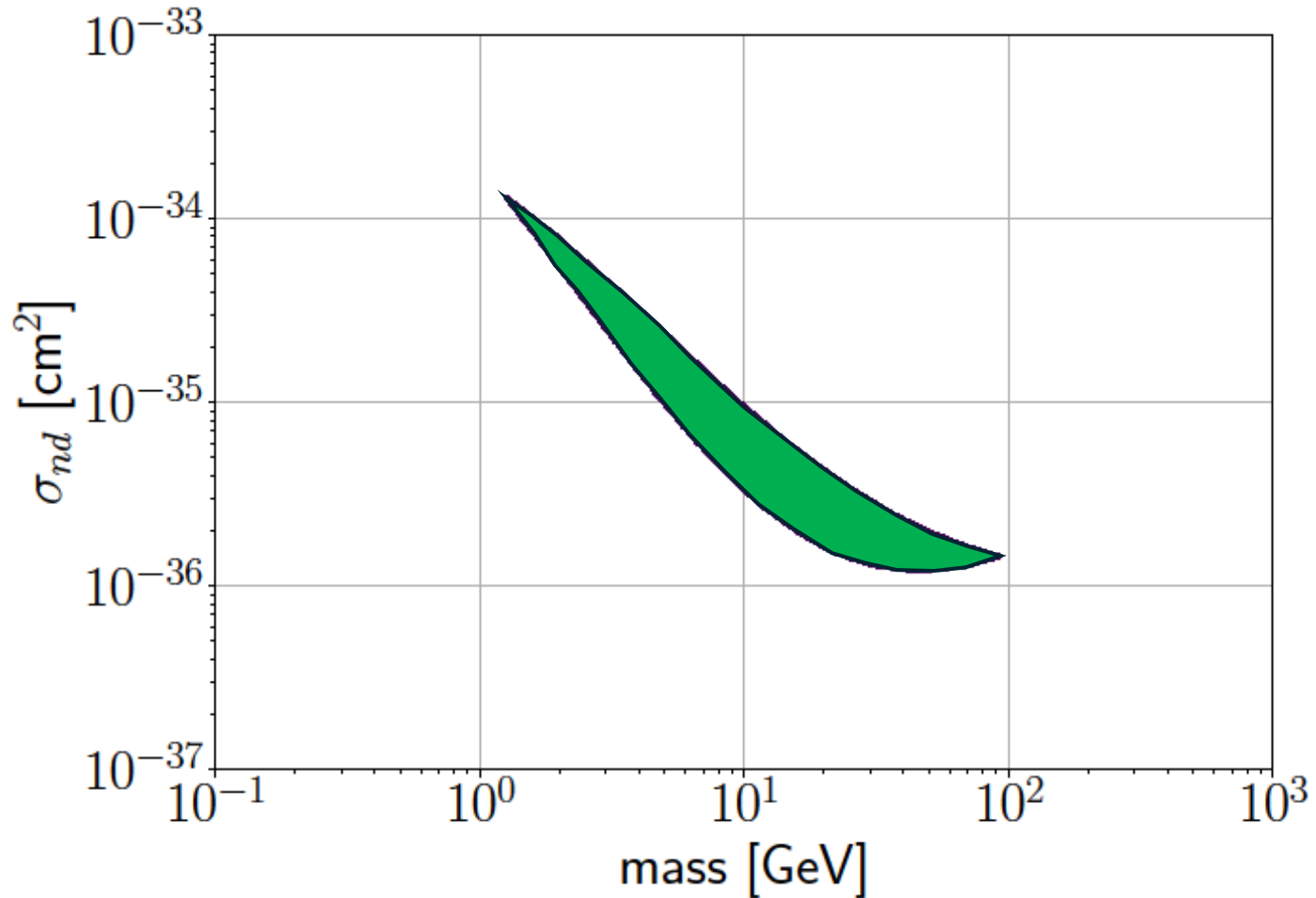
PICO-40L sensitivity at surface

Part III – Results (Preliminary) – PICO-40L



PICO-40L sensitivity at surface

Part II – Results (Preliminary) – PICO-500



PICO-500 sensitivity in SNOLAB

Part III – Summary

- Analyzed velocity distribution, overburden effects, and energy deposited by composite dark matter
- Calculated composite dark matter limits for PICO-40L (at surface) and PICO-500 (in SNOLAB)
- Paper in the works! Stay tuned for more bubbles

Thank you!

