# Bubble Chamber Sensitivity to Composite Dark Matter

Alex Hayes

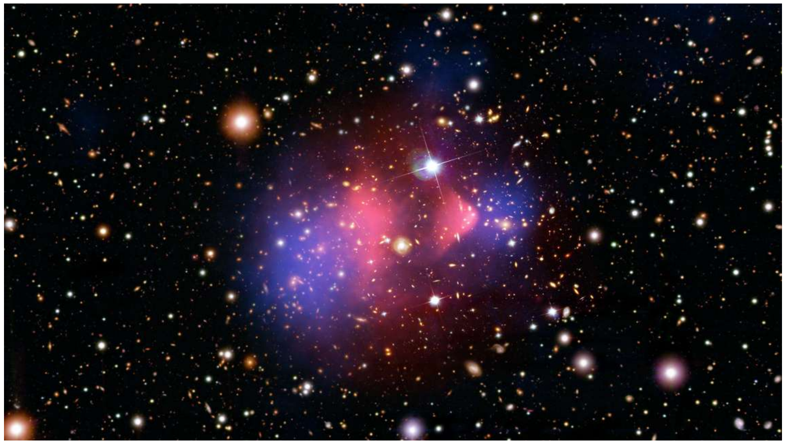
# Outline

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

# Part I: Dark Matter

# Part I – Dark Matter

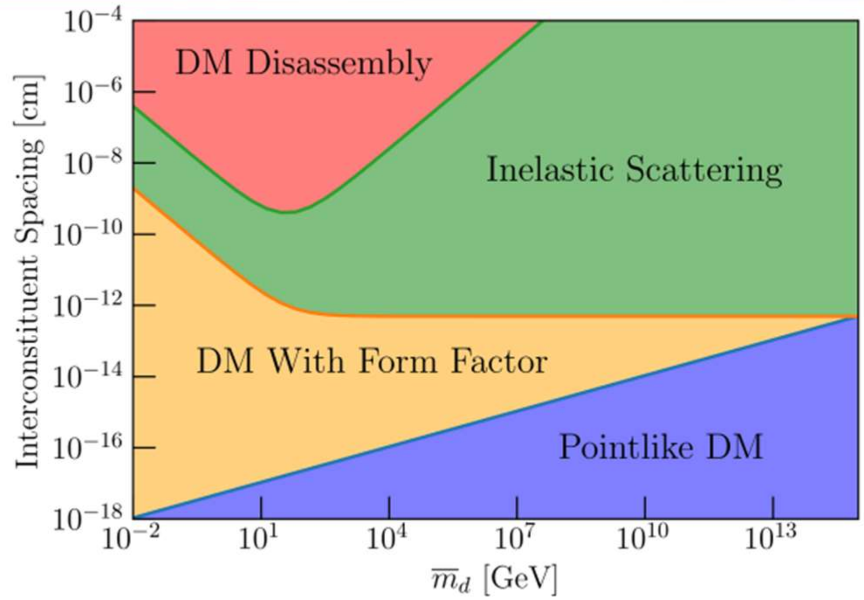
- New form of matter
- Motivated by various astrophysical phenomena
- Particle nature unknown

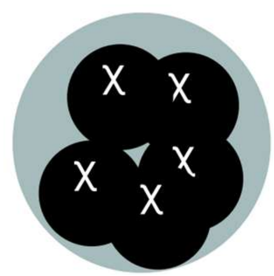


Credit: NASA

# 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

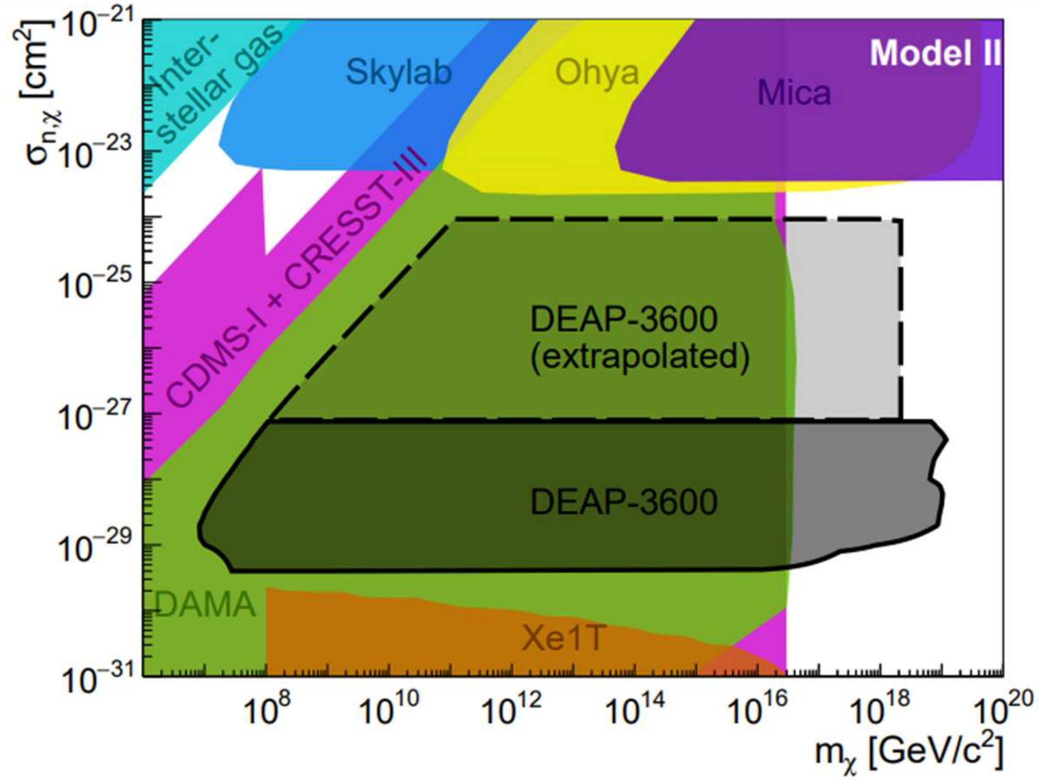



Credit: Joe Bramante

# 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

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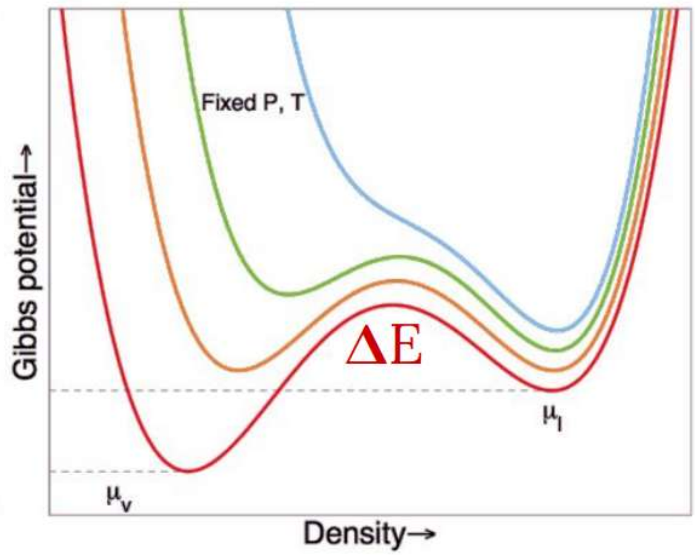
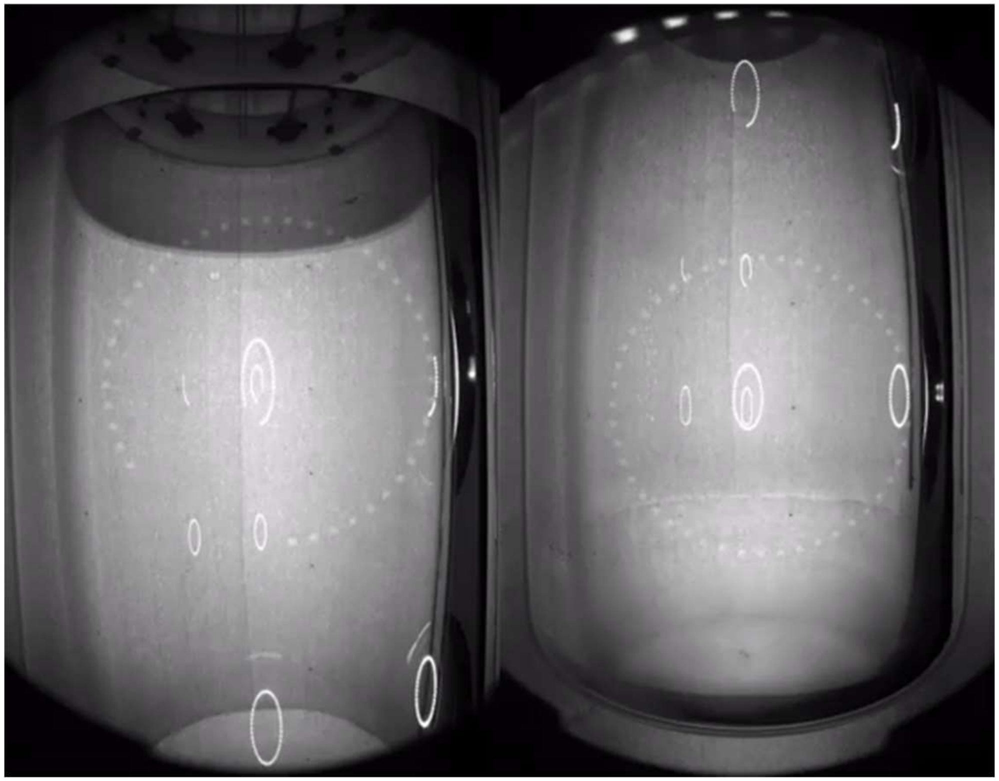



Credit: Ben Broerman, SBC

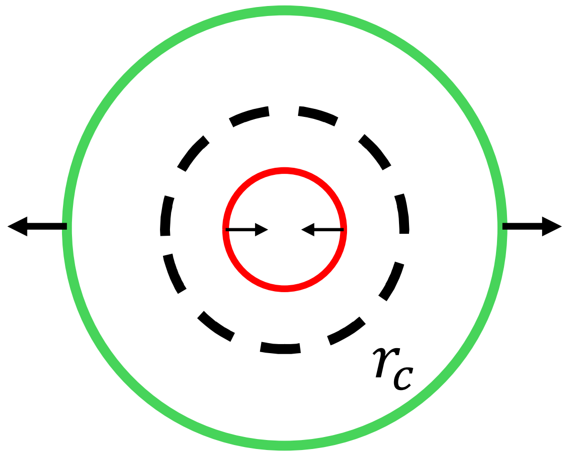
Credit: PICO Experiment

# Part II – Bubble Chambers



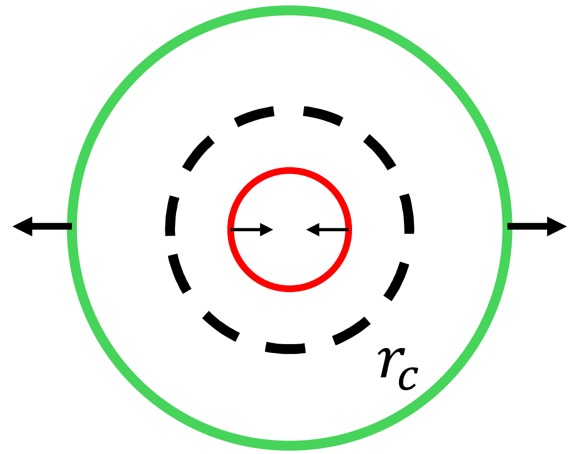
Credit: McDonald Institute

# Part II – Energy Threshold




$$E_{thresh} =$$

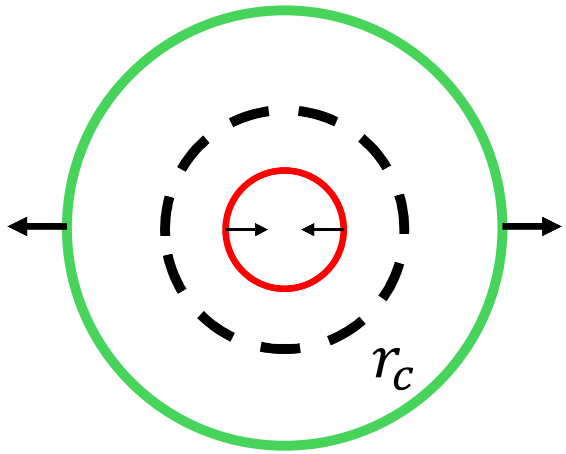
# Part II – Energy Threshold




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

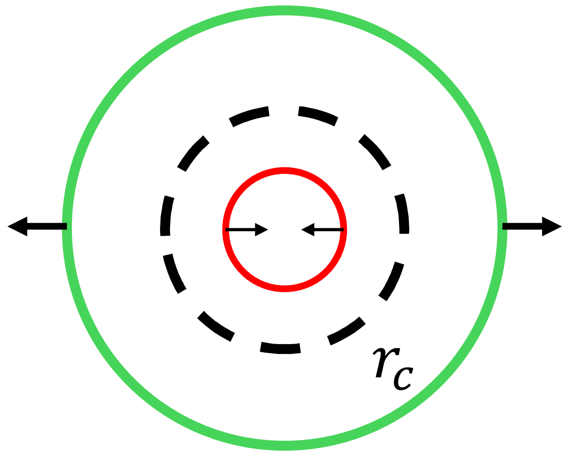
$$\underbrace{\hphantom{4\pi\left(\sigma - T\frac{\partial\sigma}{\partial T}\right)r_c^2}}_{\text{Surface tension}}$$

# Part II – Energy Threshold




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

# 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:

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

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- Flux:

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

- Number of events:

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

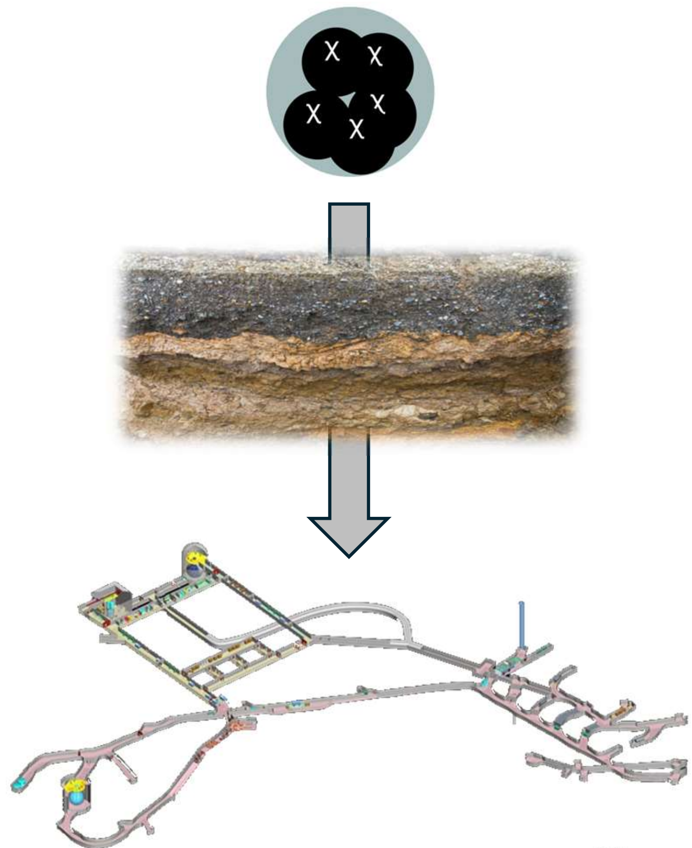
➢ This gives us $v_i$

# Part III – Overburden

- Overburden slowdown:

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

- Composite disassembly?

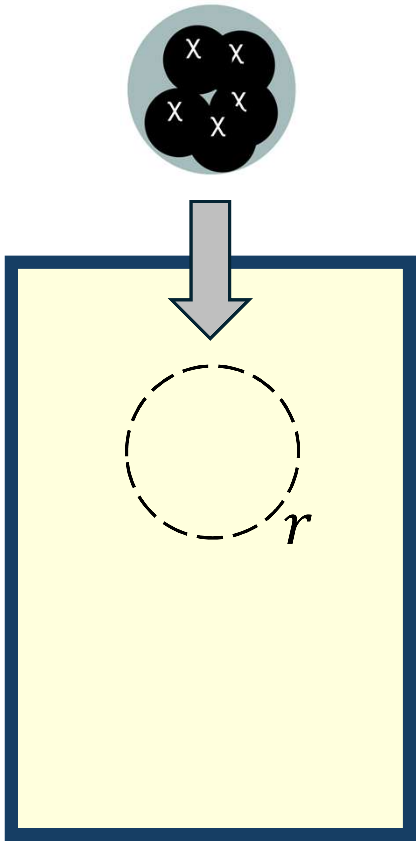


# Part III – Total Energy Deposit

- Total energy deposited:

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

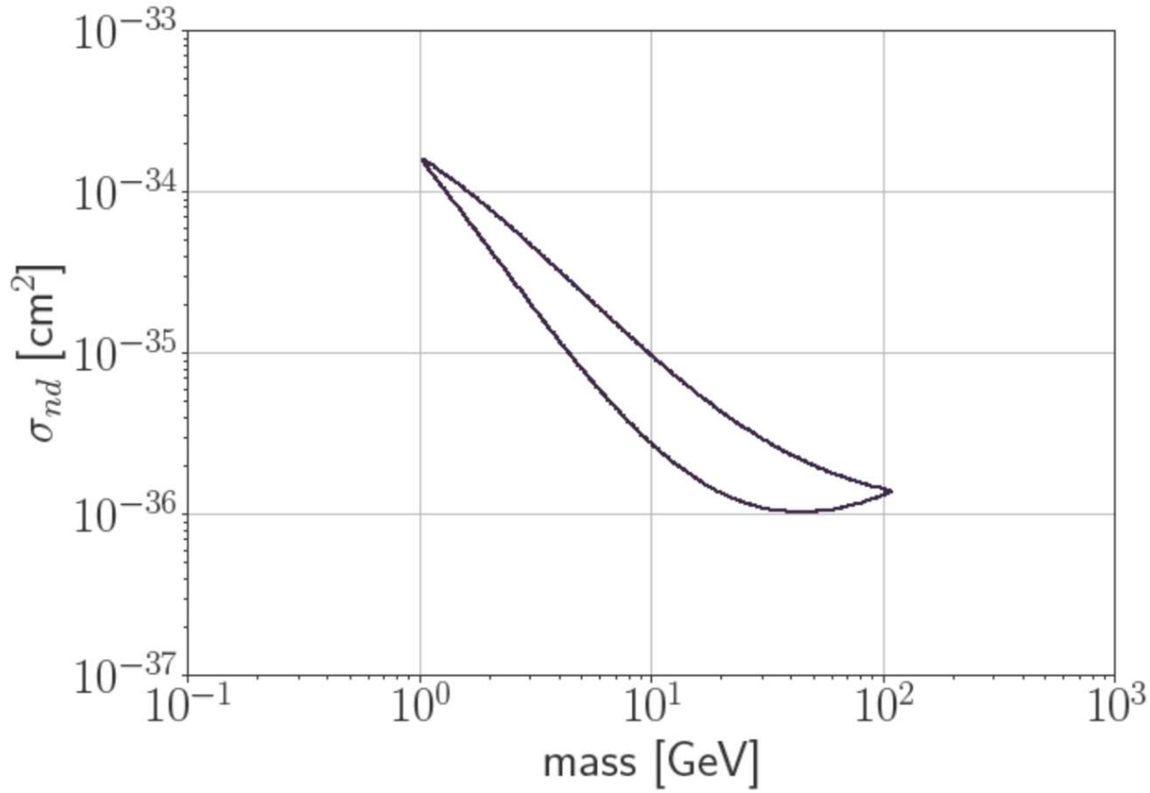
- Continuous bubble formation



# Part III – Summary so far

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

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




PICO-40L sensitivity at SNOLAB

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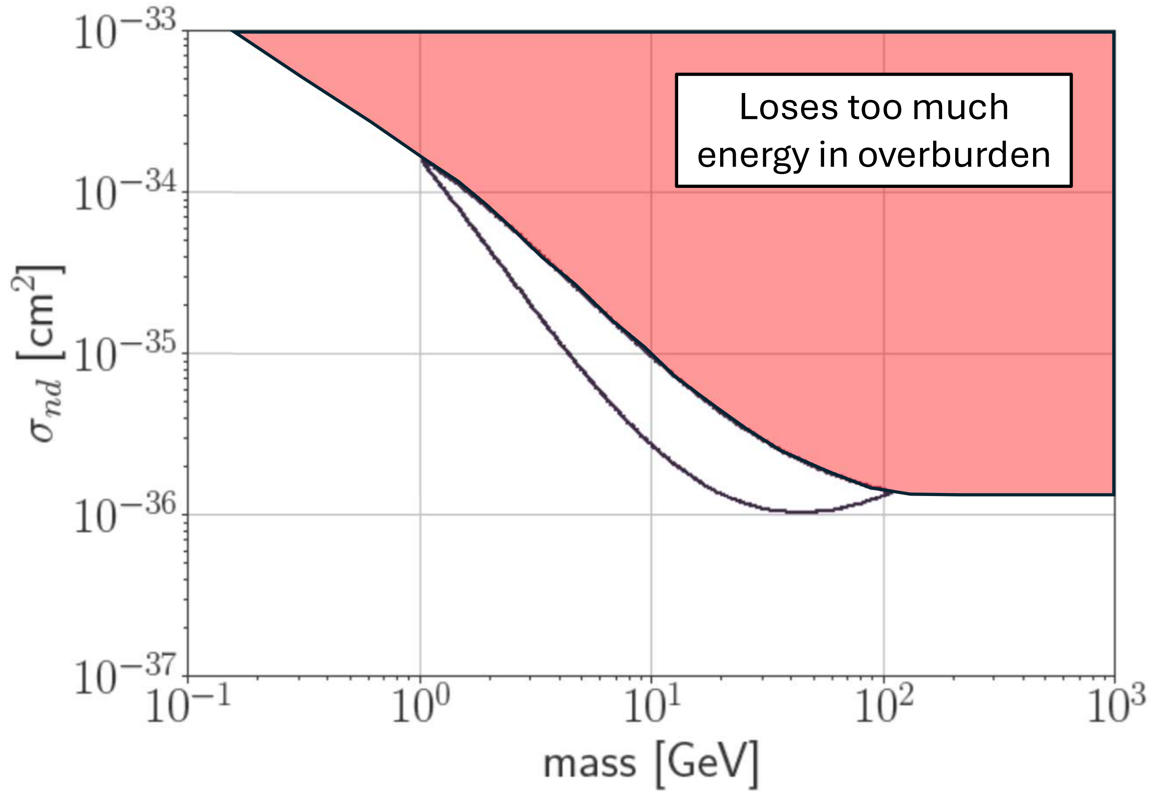


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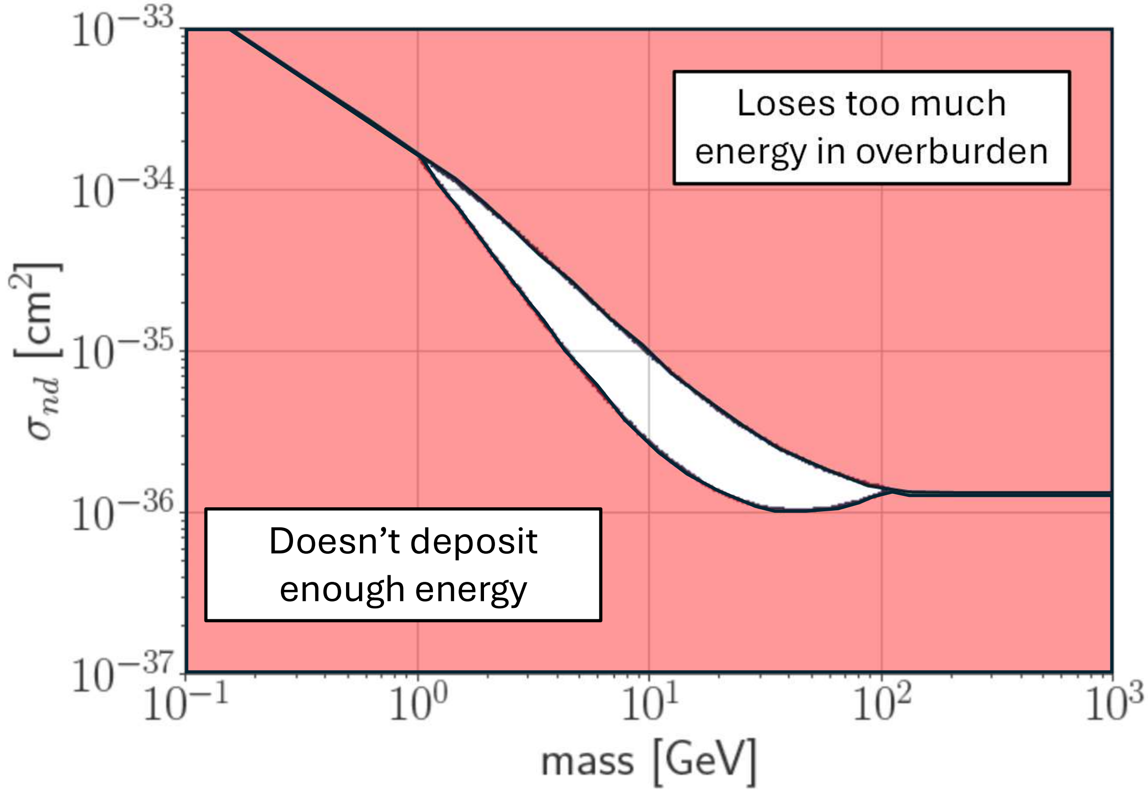


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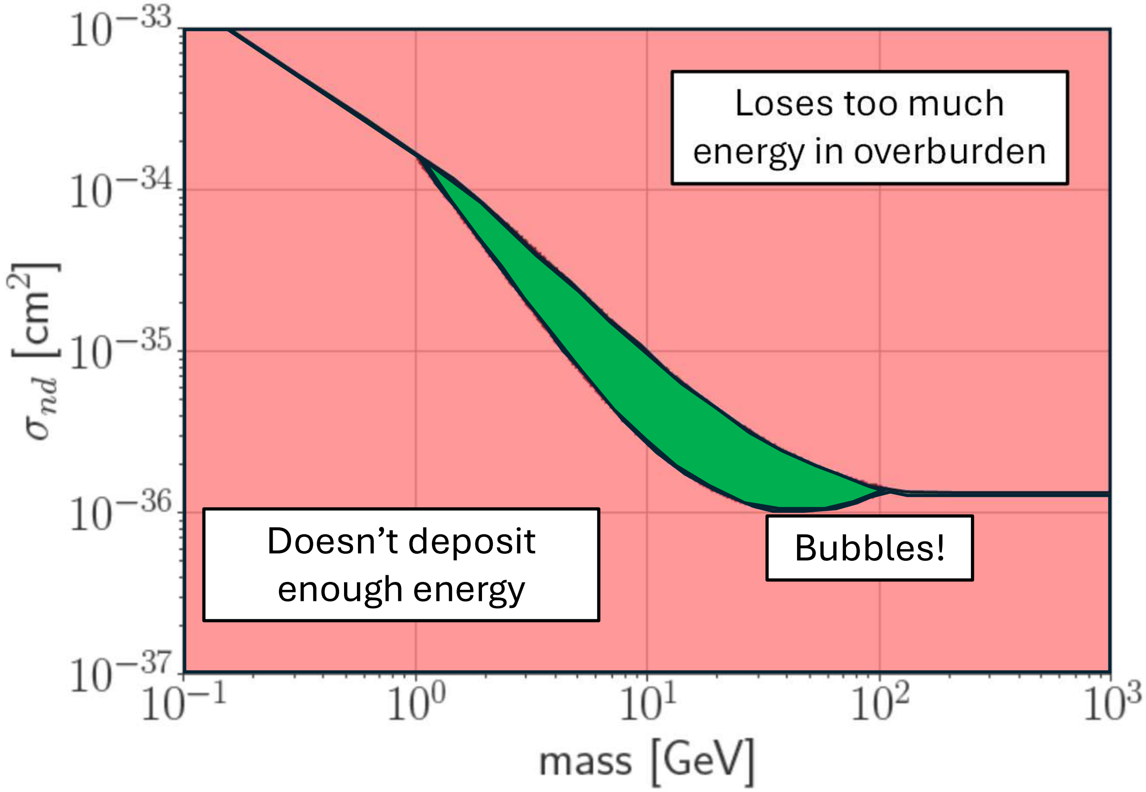


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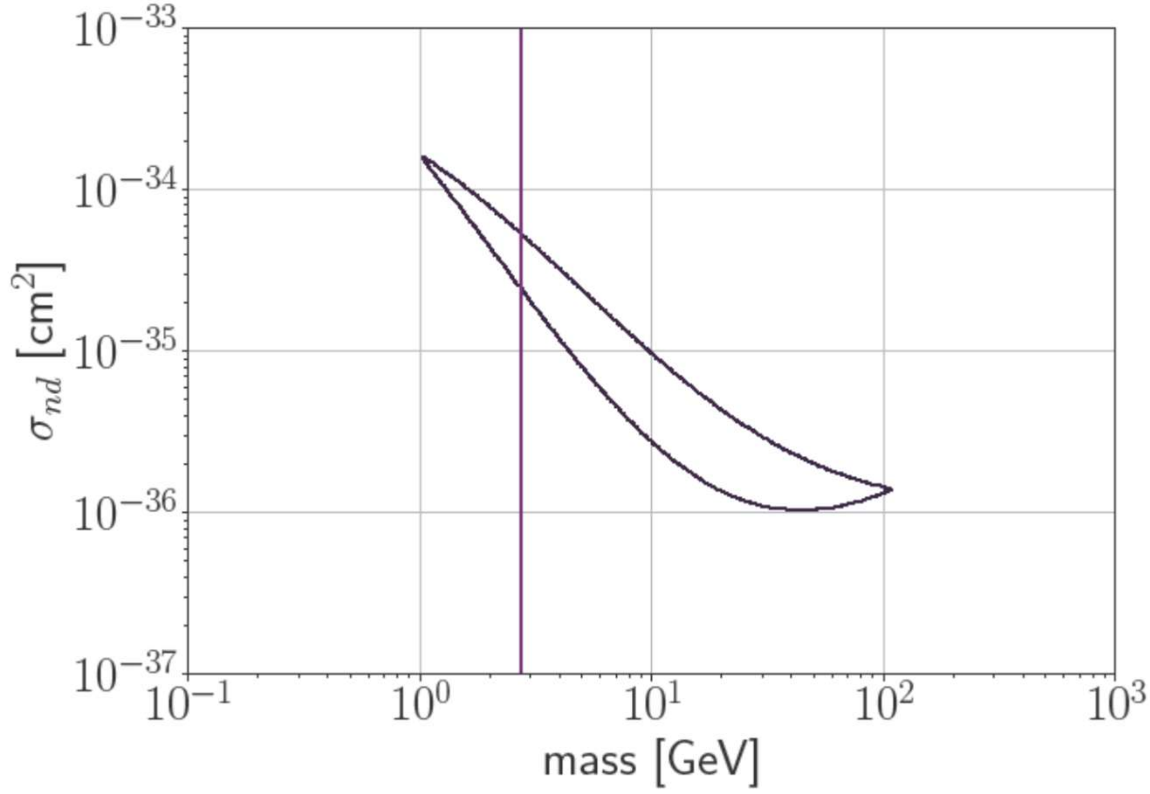


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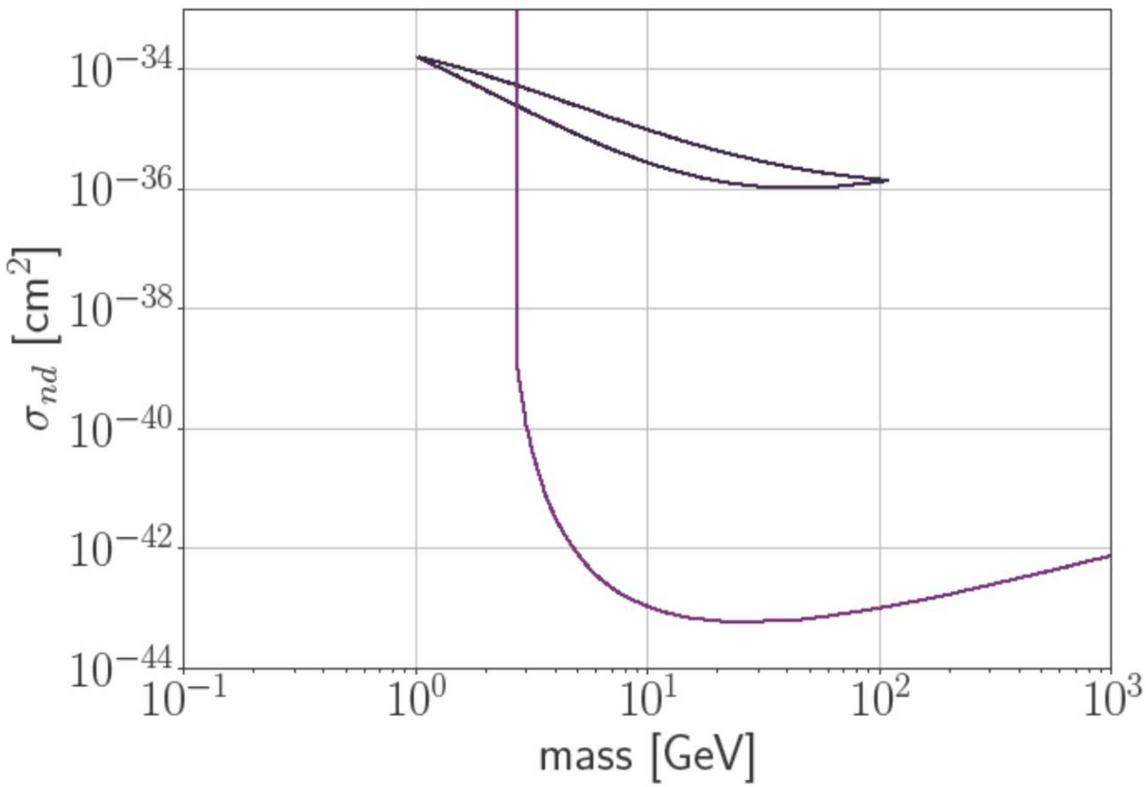
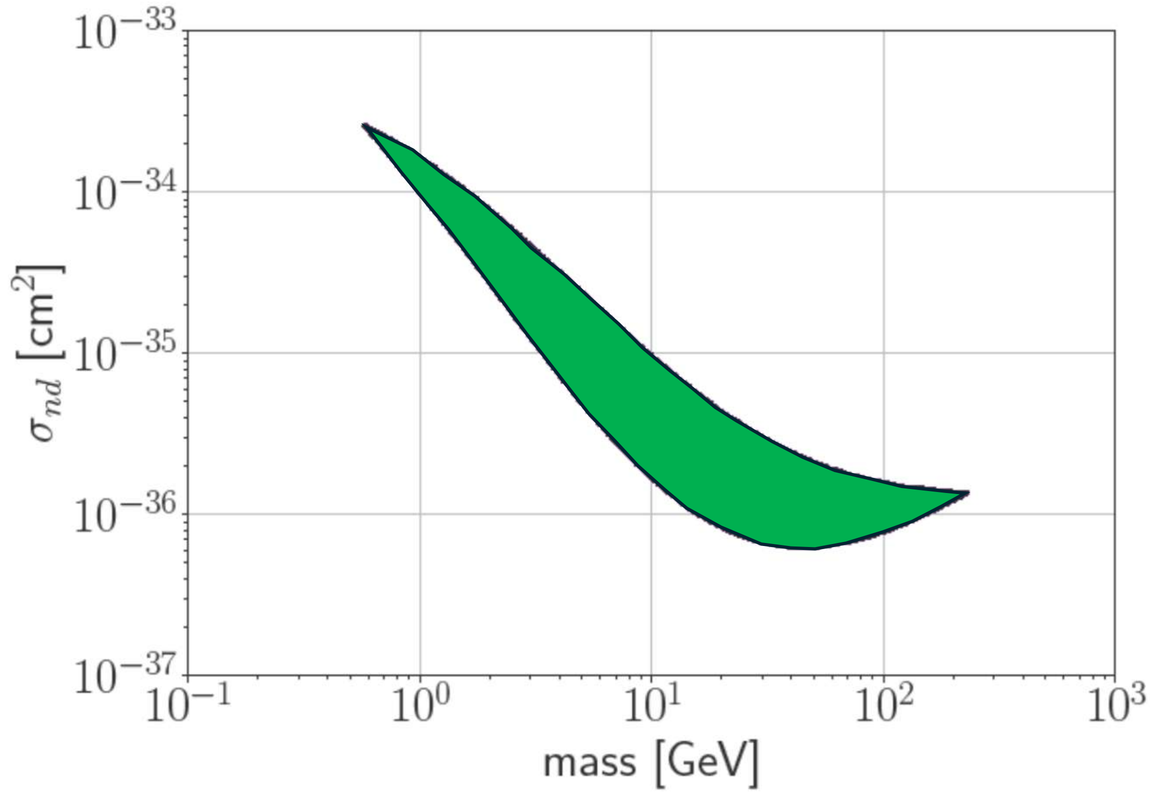


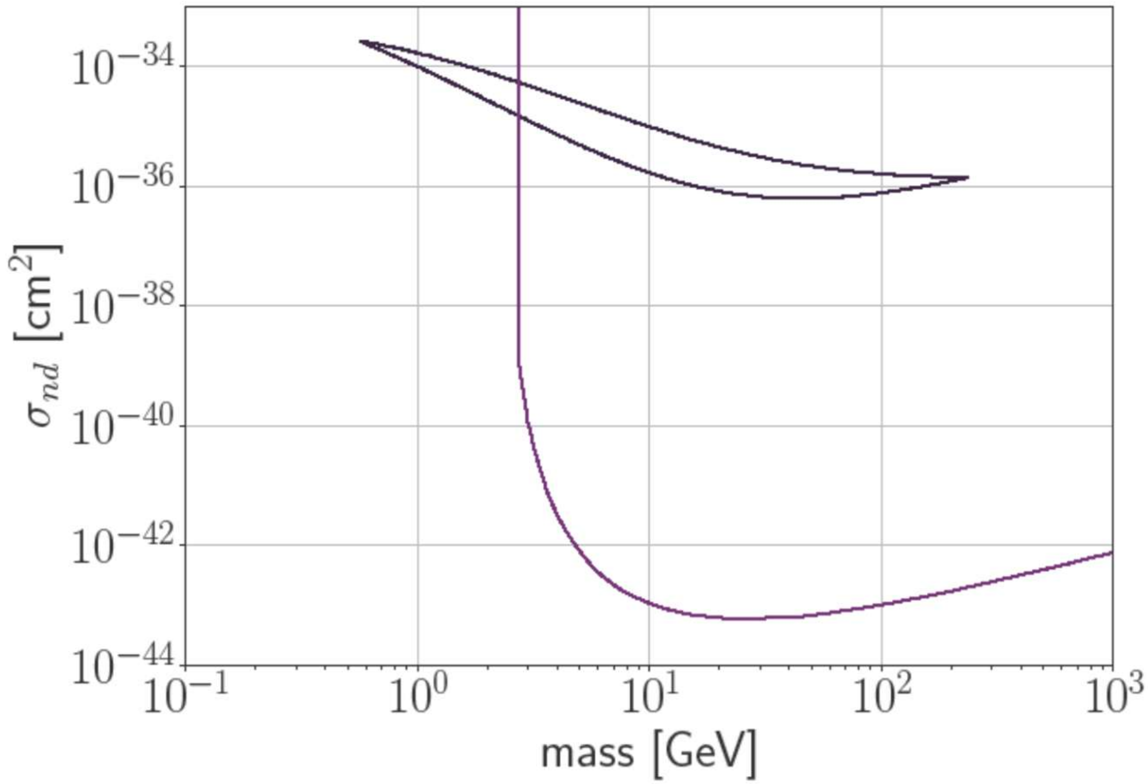

PICO-40L sensitivity at SNOLAB

# Part III – Results (Preliminary) – PICO-500




PICO-500 sensitivity in SNOLAB

# Part III – 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 and PICO-500
- Paper in the works! Stay tuned for more bubbles

Thank you!