SNOLAB Linear Accelerator, Yay! (SLAY!)

TRISEP 2024

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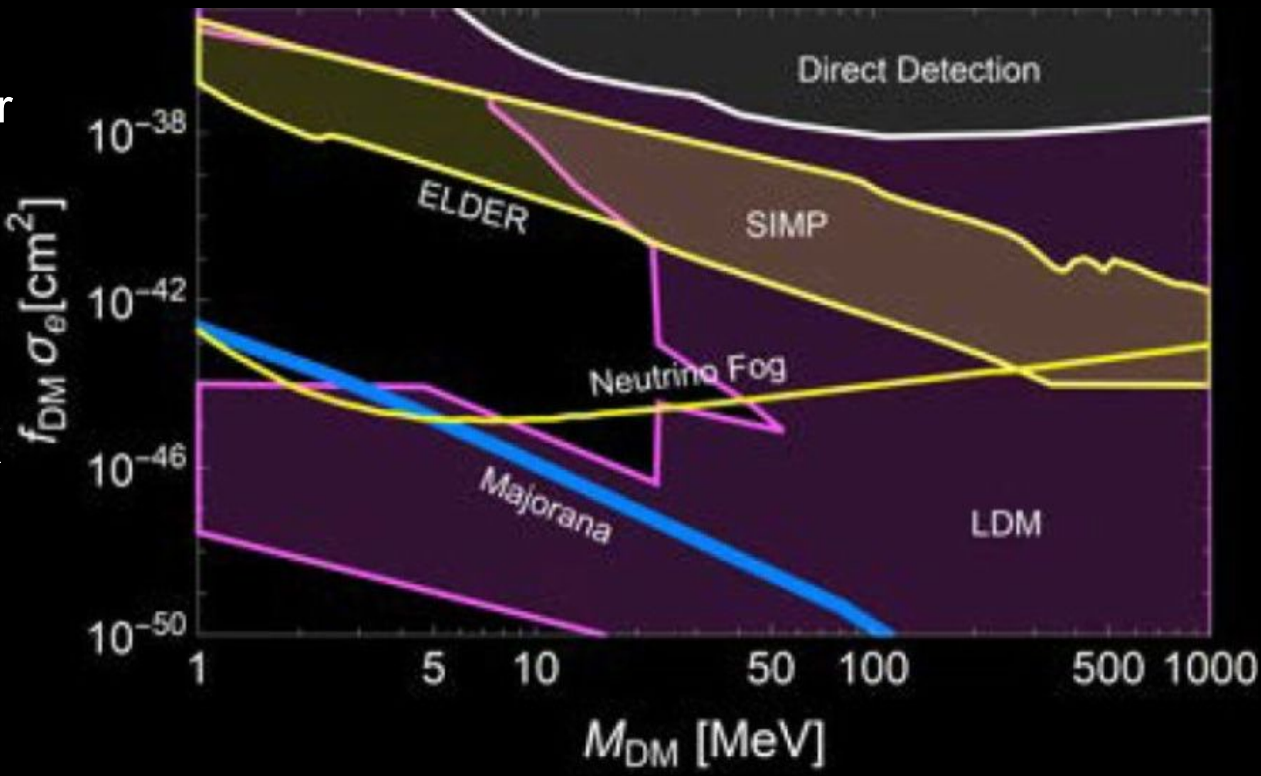
Motivation

- Light dark matter
  - New massive mediator
  - sub-GeV dark matter
- Accelerator based fixed-target experiment
  - BDX, Darklight, LDMX
- Direct detection based experiment
  - DAMIC-M, SENSEI



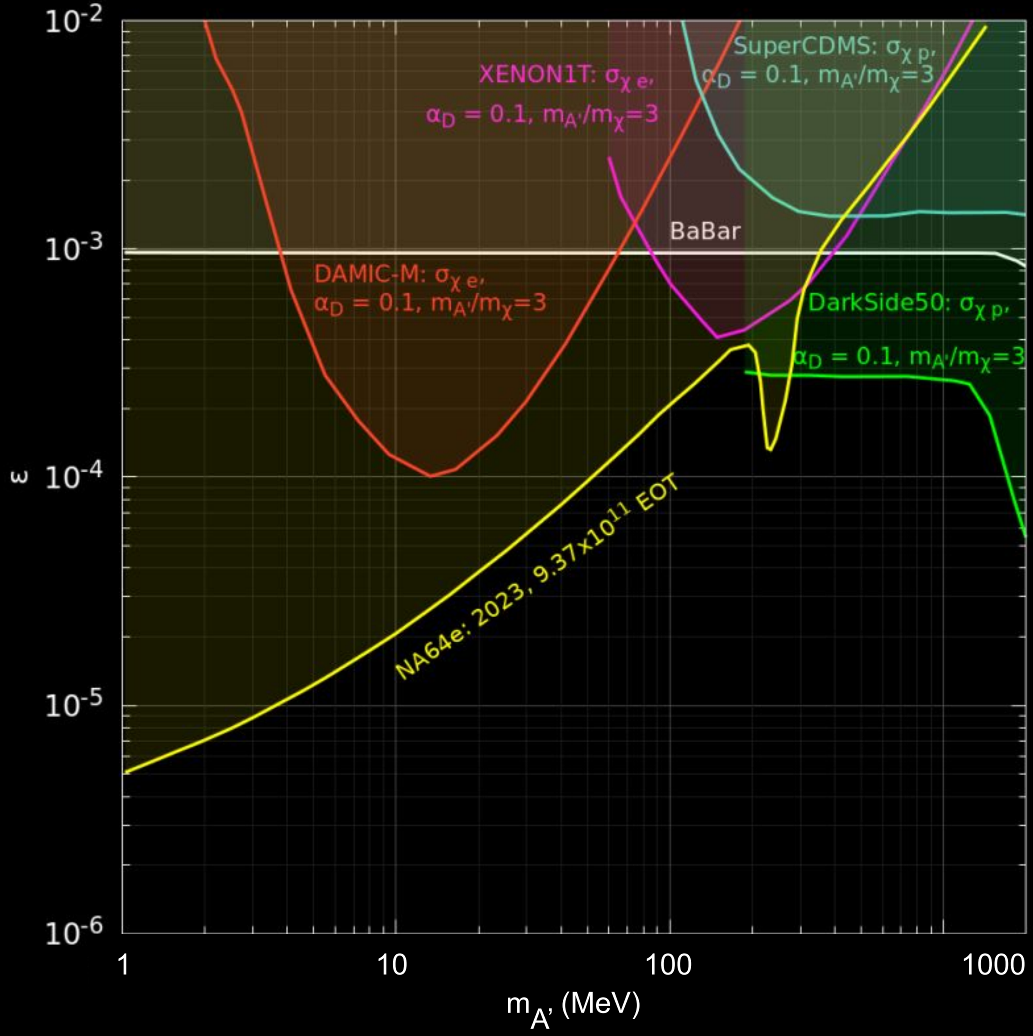
arXiv:2203.08084

Experiment Goals

Accelerator

+

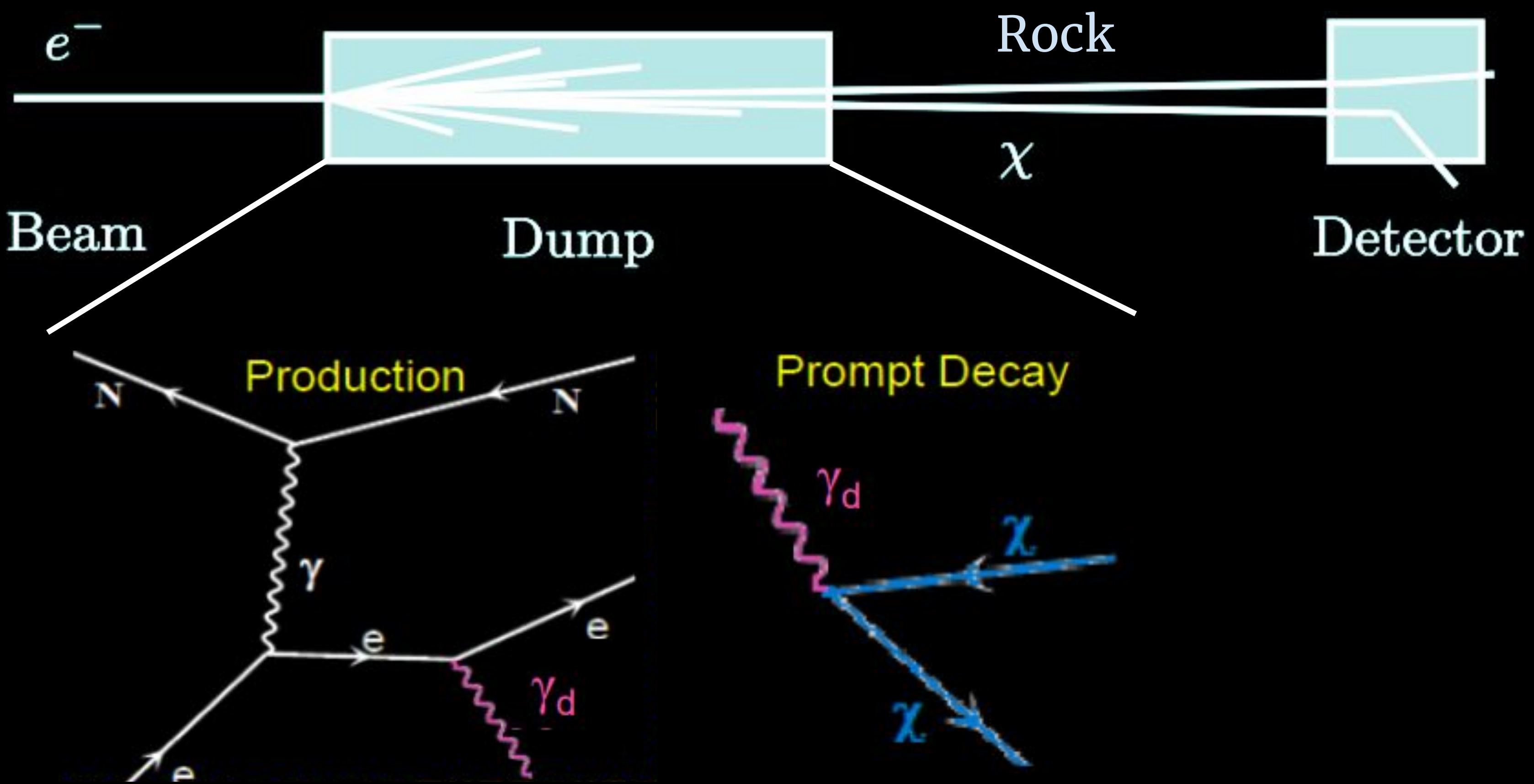
Direct Detection



arXiv:2307.14865v2

Riya, Simon, Lili, Shivansh

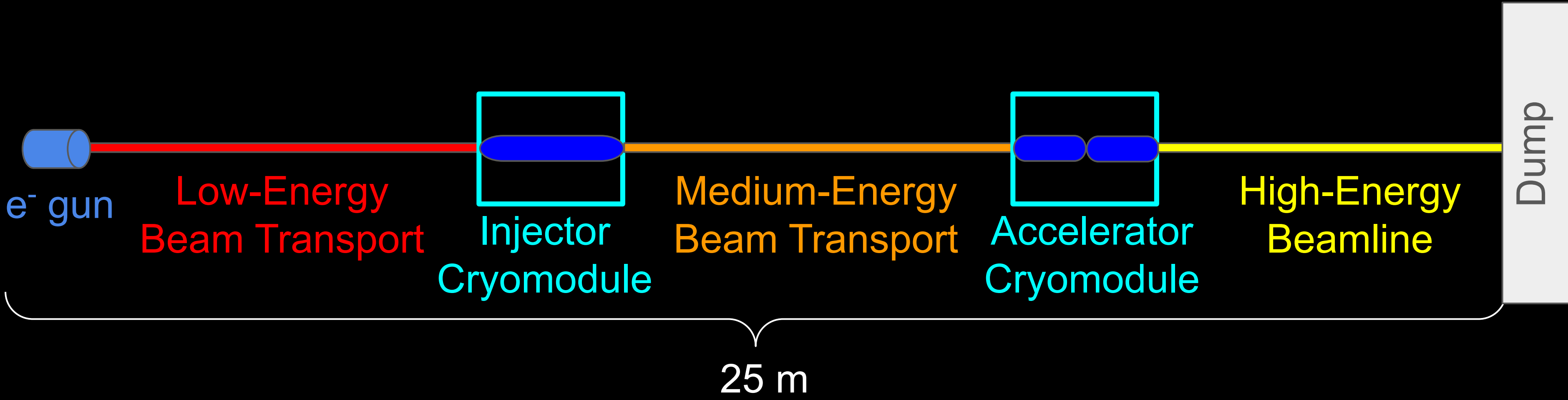
Light Dark Matter production in beam dump experiment



Phys. Rev. Lett. 111, 221803 (2013)

Accelerator Design

- Energy - 90 MeV
- High Luminosity - 10 mA
- Pulsed e⁻ beam



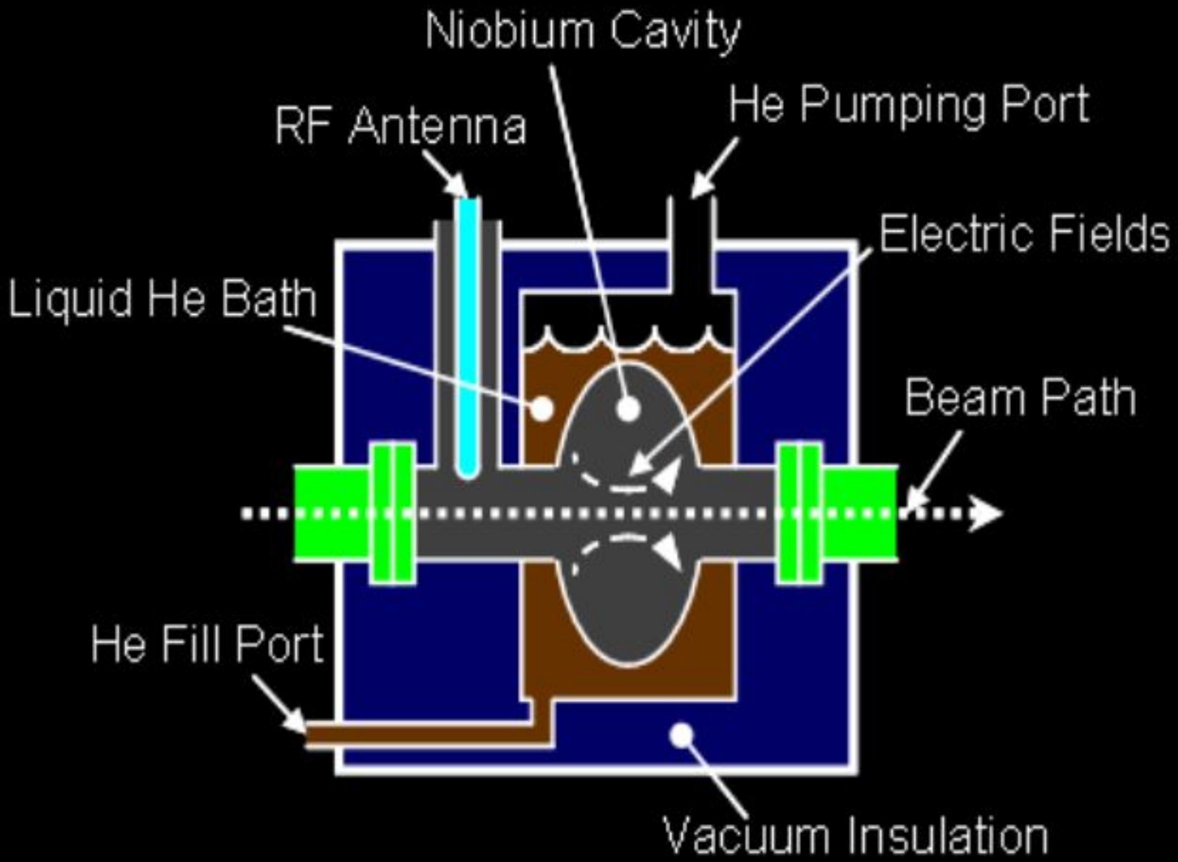
Accelerator Design

- Tungsten metal at 1000° C
- 10 mA

- Solenoid magnets focus e^- beam
- Scintillator foil monitor beam characteristics

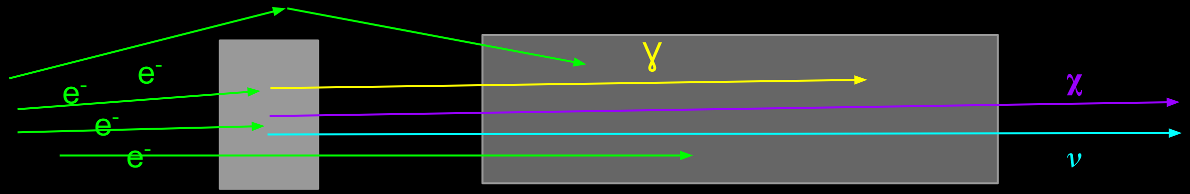
Accelerator Design

-



Oliver Kester, ALD accelerator division

Target and Shielding



- 1 cm tantalum foil
  - High melting point
  - Thick enough to block most electrons (maximize bremsstrahlung)
- Stopping photons:

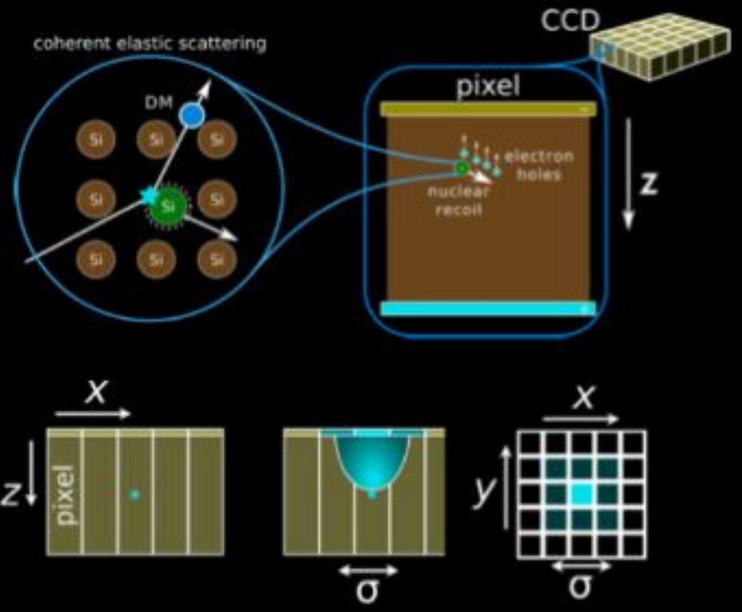
$$l_\gamma \approx \frac{1}{\mu\rho} = \frac{1}{0.02248\ \mathrm{cm}^2/\mathrm{g}*3\ \mathrm{g}/\mathrm{cm}^3} \approx 15\ \mathrm{cm}$$

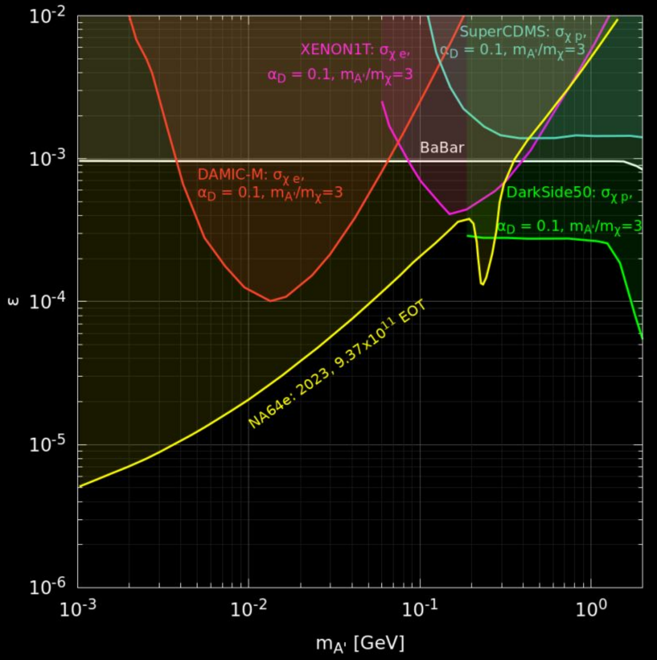
- Stopping electrons:

$$l_e \approx \frac{E}{dE/dx} = \frac{90\ \mathrm{MeV}}{5.212\ \mathrm{MeVcm}^2/\mathrm{g}*3\ \mathrm{g}/\mathrm{cm}^3} \approx 6\ \mathrm{cm}$$

- 20cm of rock should be sufficient to block background products
  - Still expect neutrinos to get through

Detector - DAMIC

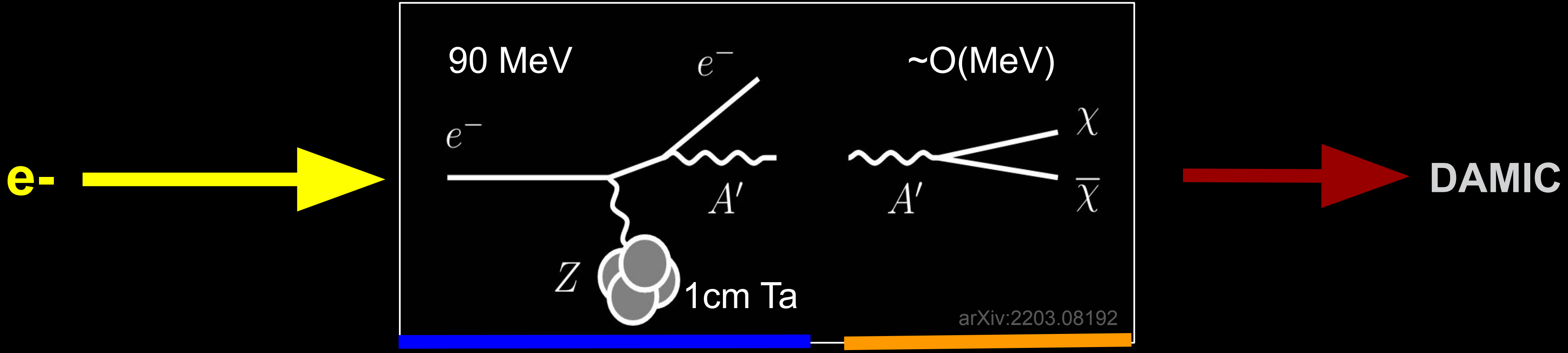




- Dark Matter in CCDs
- Sensitive to nuclear and electron recoils
- Best sensitivity for low mass DM among SNOLAB detectors
- Assuming DAMIC-M improvements

arXiv:2307.14865v2

Expected DM production rate



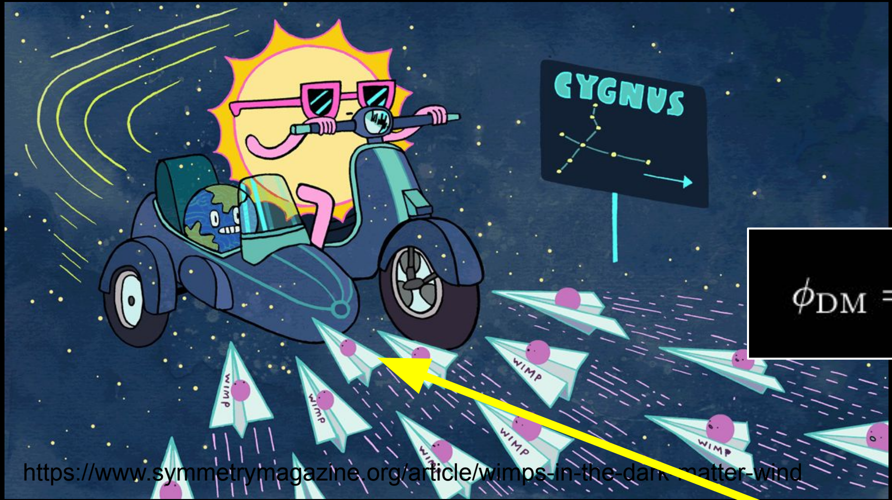
$$\frac{d\mathcal{R}_{\chi\chi}}{dt} \approx \underbrace{\mathcal{L}_{e^-}^{\text{DarkLight}} \frac{d\ell_{\text{SLAY!}}}{d\ell_{\text{DarkLight}}} \sigma_{\text{Brem}}}_{\approx 6\times 10^{16}\ \text{Hz}} \underbrace{P(m_{A'} \leq (\delta E)_{e^-})}_{\leq 1} \underbrace{\frac{\sigma_{e^- Z \to e^- Z A'_\mu}}{\sigma_{e^- Z \to e^- Z A_\mu}}}_{\sim \varepsilon^2} \underbrace{\frac{\Gamma_{A'_\mu \to \chi\chi}}{\Gamma_{A'_\mu \to \text{tot}}}}_{\leq 1}$$

$$\frac{d\mathcal{R}_{\chi\chi}}{dt} \lessapprox 10^{17}\varepsilon^2\ \text{Hz}$$

$$\epsilon = 10^{-4} - 10^{-2} \implies \frac{d\mathcal{R}_{\chi\chi}}{dt} \lessapprox 10^{9} - 10^{13}\ \text{Hz}$$

DarkLight luminosity ~ 5 $\text{nb}^{-1}\ \text{s}^{-1}$, for 150uA current on 1um Ta. Cross-section from EEDL evaluated electron data (1991).

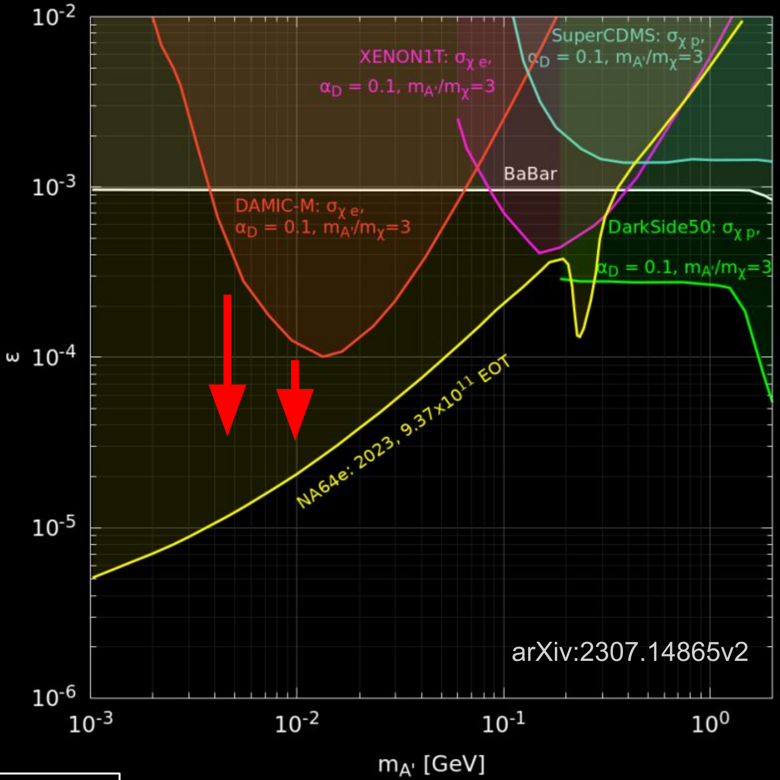
DAMIC DM flux



https://www.symmetrymagazine.org/article/wimps-in-the-dark-matter-wind

$$\phi_{\mathrm{DM}} = \frac{v\rho}{m}$$

v



$$v \approx 10^{-3}c,\ \rho \approx 0.3\ \mathrm{GeV\ cm^{-3}} \implies \phi_{\mathrm{DM}} \approx \frac{10^7}{\left[\frac{m}{\mathrm{GeV}}\right]}\mathrm{cm^{-2}s^{-1}}$$

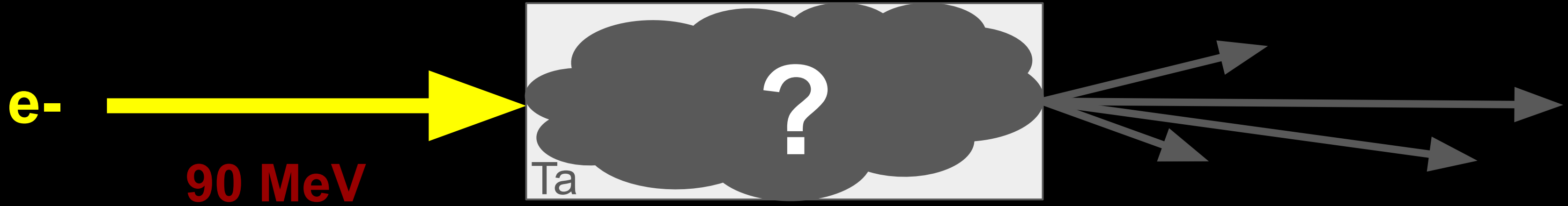
$$m \sim \mathcal{O}(\mathrm{MeV})$$

$$\Downarrow$$

$$\frac{d\mathcal{R}_{\chi\chi}}{dt} \lessapprox 10^{17}\varepsilon^2\ \mathrm{Hz}$$

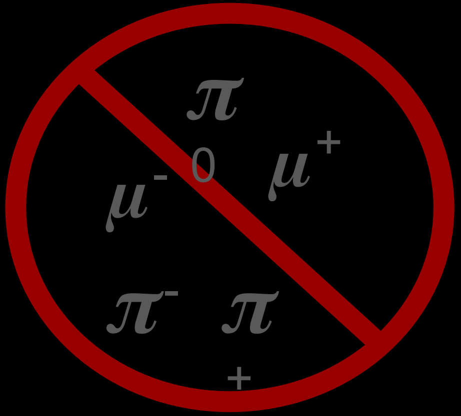
$$\phi_{\mathrm{DM}} \sim 10^{10}\mathrm{cm^{-2}\ s^{-1}}$$

Neutrino production



Infrequent ν production from:

1. Induced electron capture
2. Bremsstrahlung producing virtual Z, $W^{\pm}$
3. Photo-production of isotopes
4. Induced beta decays (1, 3)



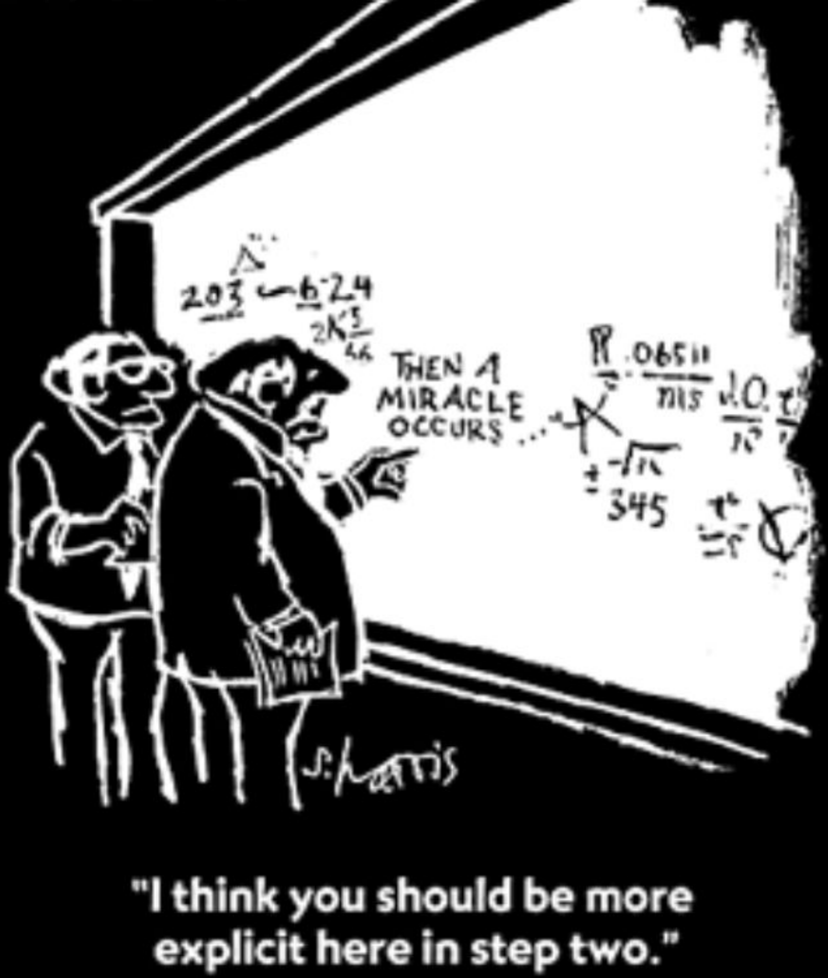
Expecting negligible ν background

Equity, Diversity, and Inclusion: Collaboration meetings

- Have DEI team in collaboration with 80 members
  - Talk to collaboration members who have dependents to understand their **individual needs** & priorities
- Group similar topics on the same day
- 1 meeting at experiment site, 2 other meetings at accessible location:
  - Rotate location according to proportion of people
  - Close to airports & with daycare facilities
- Decide location & dates in advance
- Hybrid meeting with zoom
- To accommodate different time-zones
  - Record Talks
  - Have a system for discussion

Summary

- Beam dump experiment for sub-GeV dark matter detection
- Compact e-linac at TRIUMF
  - Like ARIEL, but 90 MeV
- Tantalum target with rock shielding
- DAMIC-M as detector
- Expecting LDM flux to increase by orders of magnitude for some DM scenarios
- No significant increase in background



Extra slides

Expected DM production rate DETAILS

-
    - Consider rate an upper limit for MeV-scale dark photon production with a <100 MeV
    - Luminosity: 5.2 nb^-1 s^-1, e- beam incident on 1 micron Ta target. Luminosity proportional to target thickness so our luminosity = 5.2 nb^-1 s^-1 * 1 cm / 1 um = 5.2 * 10^4 nb^-2 * s^-1 = 5.2e4 (1e-9 barn)^-1 s^-1 = 5.2e13 barn^-1 s^-1
    - Cross-sec for Brem = 1.2e3 barn, so dR/dt = 5.2e13 (barn)^-1 s^-1 * 1.2e3 barn = 6.2e16 s^-1
    - Ratio probabilities producing DP vs SM photon via Brem is order epsilon^2
    - BR of DP into DM is maximally one (low mixing with SM + large coupling to DM)

Expected neutrino production - extra

- Beam O(10 MeV) can't produce muons or hadrons
- Electron capture on target produces neutrinos near the beam energy
  - Neutrino rate = (electron rate) * (probability EC on target)
  - Assuming energy transfer to nucleus is O(MeV), neutrino momentum = beam energy
  - Sufficiently high beam energy (50 MeV or so): most of these neutrinos should be distinguishable from solar ones for SNO (and very far above 130Te 0vbb signal)

- Higher-order (in coupling) processes producing additional neutrinos (continuous energy spectra) following e- Bremsstrahlung:

 - e- -> v e- v (via W)

 - e- -> e- e- v (via Z)

 - these processes are suppressed by (beam energy/mass W or mass Z)^4 so roughly O(1e-13) for 50 MeV beam

- Lowering rate of incident e- can mitigate produced neutrino background from point above, while sufficiently high beam energy

Backgrounds - Simon

- DAMIC Largest backgrounds H3 CCD contamination (~2.5 dru) and CCD Pb210 surface contamination (~4 dru)
- Total background rate ~12 dru
- Neutrinos created by SLAY could contribute to this background

Expected DM production rate DETAILS

-
    - Consider rate an upper limit for MeV-scale dark photon production with a <100 MeV
    - Luminosity: 5.2 nb^-1 s^-1, e- beam has FWHM of 1mm. FWHM contains 76% of Gauss distribution so in 2D 0.76*(e-rate) = luminosity * mm^2 = 7e31 Hz total e- rate
    - Number density Ta= N_Avogadro / (molecular mass) * (mass density) = 6e23/181 *16.65 cm^-3 = 5.5e22 cm^(-3)
    - Cross-section Brem. 90 MeV approx 1.2e3 barn, Macroscopic cross-sec = cross-sec * number density of Target = 1.2e3 (1e-24 cm^2) * 5.5e22 cm^-3 = 66 cm^-1
    - Probability of first interaction over distance x = 1 - exp(- macro_cross_sec * x) = approx 1 for cm-long detector. Unsurprising. Could also calculate total prob of any interaction over x with 4e6 barn microscopic cross-section, yielding macro cross-sec 4e6 (1e-24 cm^2) * 5.5e22cm^-3 = 2.2e5 cm^-1, and for 1cm tot probability =
    - Ratio probabilities producing DP vs SM photon via Brem is approximately epsilon^2
    - BR of DP into DM is maximally one (low mixing with SM + large coupling to DM)

$$\mathcal{R}_{\chi\chi} \approx \mathcal{R}_{e^-} \underbrace{\left(1 - e^{-\sigma_{\mathrm{Brem}} n_{\mathrm{Ta}} \ell_{\mathrm{Ta}}}\right)}_{\approx 1} \underbrace{P(m_{A'} \leq (\delta E)_{e^-})}_{\leq 1} \underbrace{\frac{\sigma_{e^- Z \to e^- Z A'_\mu}}{\sigma_{e^- Z \to e^- Z A_\mu}}}_{\sim \varepsilon^2} \underbrace{\frac{\Gamma_{A'_\mu \to \chi\chi}}{\Gamma_{A'_\mu \to \mathrm{tot}}}}_{\leq 1}$$