Search for Light Dark Matter with the Beam Dump eXperiment (BDX) at Jefferson Lab

- Intro to Dark matter
- BDX at Jefferson Lab
- Data from a pilot experiment (BDX-MINI)
- Limits from BDX-MINI

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Dark Matter

Possibilities for Dark Matter?

- Primordial black holes
- Axions
- Heavy neutrinos
- Light supersymmetric particles
- Weakly Interacting Massive Particles (WIMPs)
- Light Dark Matter (LDM)
- ...........

Dark matter is

- Non-luminous
- Non-absorbing
- Gravitationally active

$\Omega_{DM} \sim \frac{1}{4}$

See PDG Review of Dark Matter

Thermal cosmological origin

As the Universe cools below dark matter (DM) mass, density decreases as $e^{-m/T}$.

Eventually, dark matter particles can’t find each other to annihilate.

Dark matter interacts with the Standard Model (SM) to stay in equilibrium...

Eventually, the density of DM and a (minimal) DM abundance is left over to the present day.

Slide Credit: Phillip Schuster
Covering the possibilities

LDM Regime

Finite class of models and mediators
(fixed targets, b-factories, $e^-$ direct detection)

$\sim 10$ keV

“WIMP” Regime

Large multiplicity of models
(direct detection, indirect detection, colliders)

GeV

$\sim 10$ TeV

- “No room for a new Standard Model charged matter at the GeV scale.”
- LDM requires new additional forces with light sub-GeV force carriers to produce the observed DM abundance.
- Extensions of Standard Model can provide DM candidates (WIMPs) which freeze out via SM gauge interactions.
- But... No candidates found so far
Standard Model - Dark Sector

Portal
(Kinetic Mixing)

\[ \alpha = \frac{e^2}{4\pi} \]

\[ \alpha_D = \frac{g_D^2}{4\pi} \]
DM with thermal cosmological history

\[ y \sim \sigma v \times m_{\chi}^2 \]

\[ \Omega_{DM} = 0.24 \propto \frac{1}{\sigma v} \]

\[ \sigma v \geq 3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1} \]
Decays to dark matter “invisible decays”

Izaguirre PRD 96 (2017) 055007
Beam Dump Experiments

- Parasitic to experimental program. Use electrons that are otherwise thrown away
- Produce “invisible decays” of heavy photon (Beam Dump)

\[ A' \rightarrow \chi \bar{\chi} \]

- Detect dark matter particle interaction (Experiment Detector)
- Signature is EM shower \( E > 0.5 \) GeV

\[ y = \epsilon^2 \alpha_D \left( \frac{m\chi}{m_{A'}} \right)^4 \]

Yield \( \sim y^2 \times \frac{1}{\alpha_D} \times \left( \frac{m_{A'}}{m\chi} \right)^4 \)

\( (m_{A'} > 2 m\chi) \)
Location of BDX at Jefferson Lab

- New underground facility behind Hall A
- Increased shielding from beamdump
- Beam energy ~ 11 GeV
- Beam current ~ 65 µA
- Integrated charge ~ $10^{22}$ EOT (41 weeks)
**Expected BDX backgrounds**

**Cosmogenic: data-driven estimate**
- Cosmic muons rejected by vetoes
- Neutrons absorbed by overburden
- Based on data at INFN-LNS (Catania): $B_c = 5$ (Th = 0.3 GeV)

**Beam-related backgrounds**
- Detailed simulations (FLUKA+GEANT4+GENIE)
- $B_v = 10$ for EOT=$10^{22}$
- All other SM particles absorbed by 6.6 m Fe and 2 m of concrete
Reach of existing and proposed experiments
Pilot experiment: BDX-MINI

- Operated for about 6 months in 2020
- Experimental Parameters: $E_e = 2.2$ GeV, $I = 150$ $\mu$A, EOT = $2.5\times10^{21}$
- Shielding: 5.4 m concrete and 14.2 m of earth
Detector based on BDX modular design

- **Signal requirements**
  - Sensitivity to EM showers
  - Low thresholds
  - Compact footprint and good segmentation

- **Background rejection**
  - High efficiency, fast timing
  - Hermetic
  - Three layers

Crystal based detector

Battaglieri NIMA 925 (2019) 116
Beam on and Beam off, response to veto

Ratio beam on/off

All data consistent with cosmogenic background
Parameter space excluded by BDX-MINI
Summary

- Beam-dump experiments are sensitive to **Dark Matter** with masses ~ 1-1000 MeV and probe regions of the parameter space that are not covered by visible decays of dark photons.

- The **BDX experiment is approved** to run parasitically at Jefferson Lab for 41 weeks at ~11 GeV, which will allow it to collect ~10^{22} electrons on target. The full experiment is awaiting funding.

- A pilot experiment, **BDX-MINI**, took data for 6 months while Hall A was operating a low energy (2.2 GeV), which has allowed us to set limits close to existing boundaries in the parameter space.