The BDX experiment

Marco Spreafico

On behalf of BDX Collaboration

08 - 01 - 2022

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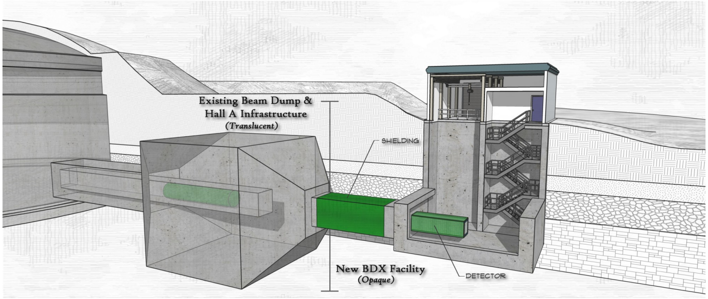
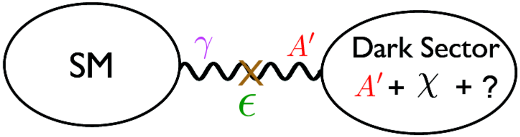


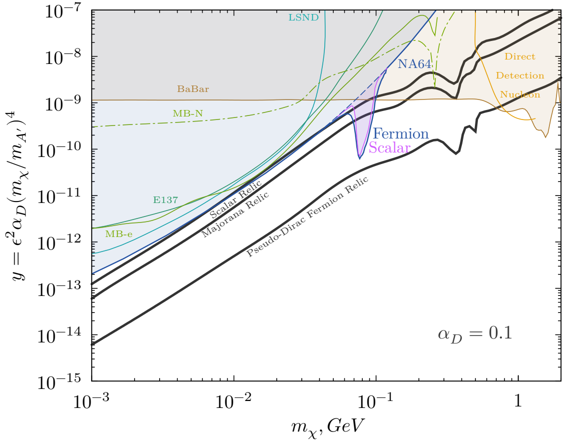
Light Dark Matter

The Light Dark Matter model predicts DM made by sub-GeV states interacting with SM via a new force



Simplest possibility: "vector portal"

→ U(1) gauge boson (*dark photon*) coupling to electric charge



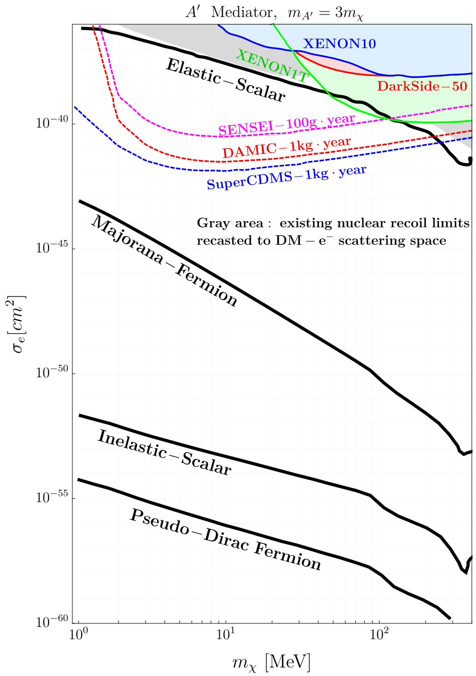
Model parameters:

- Dark Photon mass: $m_{A'}$
- Dark Photon coupling to SM ϵe
- Dark matter mass: m_χ
- Dark sector coupling: g_D ($\alpha_D \equiv g_D^2/4\pi$)

Light Dark Matter

Direct detection not well suited for sub-GeV DM searches:

- DD experiments optimized for $m_\chi >$ GeV (e.g. WIMPs)
  - $\rightarrow$ $E_R \propto m_\chi^2/m_N \Rightarrow$ recoil energy at the limit of current generation of detectors
- LDM-SM interaction cross section depends on impinging particle velocity
  - $\rightarrow$ DD sensitivity strongly model-dependent



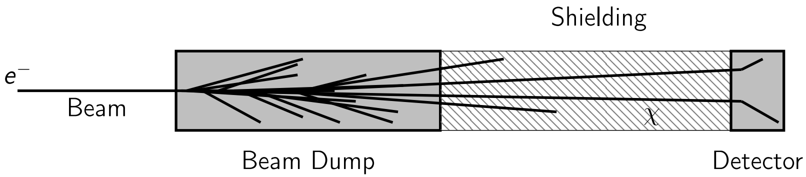
LDM at accelerators

Accelerator based experiments at the *intensity frontier* uniquely suited to search for LDM:

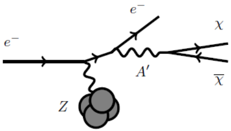
- $\rightarrow$ High intensity $\Longrightarrow$ increased possibility of DM production
- $\rightarrow$ Production of relativistic DM $\Longrightarrow$ testing different models

Beam dump Experiments

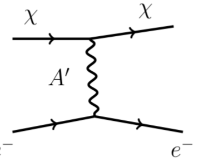
Beam dump experiments: direct detection of LDM produced by beam impinging on fixed target (beam dump)



- χ production:
  - High intensity e^- beam impinging on a dump
  - $\Rightarrow$ relativistic χ production



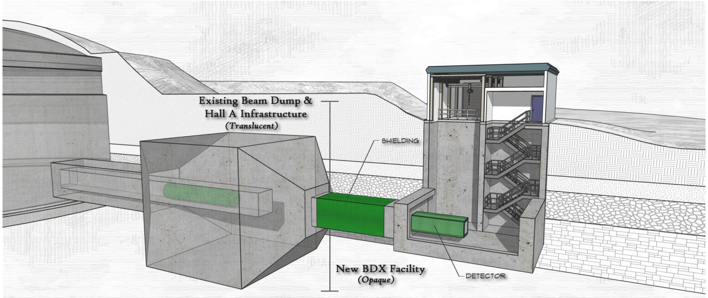
- χ detection:
  - Detector placed behind dump ($\sim 10 - 100$ m)
  - χ scattering through A' exchange $\Rightarrow$ recoil releasing detectable energy ($E_{beam} = 10$ GeV $\implies$ $E_R \gtrsim 100$ MeV)



BDX-Experimental Setup

BDX is a **JLab experiment** approved by PAC46

→ unique experiment able to produce and detect LDM



Experiment designed with two goals:

LDM production and detection

- → High-intensity CEBAF beam, 10^{22} EOT/y
- → Medium-high energy 10 GeV
- → $1m^3$ detector
- → EM showers detection capability

Minimize background

- → Shielding to filter beam-related background
- → Multi layer veto for cosmogenic background
- → Segmented detector
- → Time resolution for detector-veto coincidence

BDX-Experimental Setup

JLAB offers the best condition for BDX:

- High energy beam (11 GeV)
- High electron beam current (65 μA)
- Fully parasitic wrt Hall-A physic programme (Moeller)

A new facility must be built in front of Hall-A beam dump:

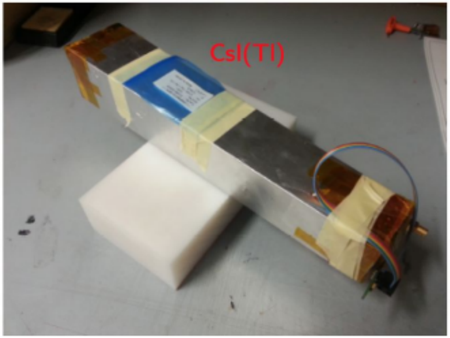
$\Rightarrow$ new underground ($\sim$ 8 m) hall 25 m downstream of Hall-A beam dump

- $\rightarrow$ passive shielding ($\sim$ 6.6 m iron) between dump and detector to reduce beam related background
- $\rightarrow$ sizable overburden ($\sim$ 10 m water-equivalent) to reduce cosmogenic background

BDX - Detector

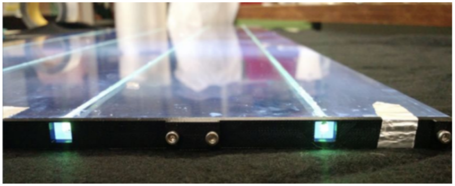
Electromagnetic Calorimeter:

- Requirement: sensitivity to high energy ($\gtrsim$ 100 MeV) EM shower
- Technology: homogeneous EM calorimeter made with CsI(Tl) crystals and SiPM readout
  - → Compact detector
  - → High crystal density ⇒ increase event yield
  - → Reuse BaBar calorimeter crystals ⇒ low cost



Veto System:

- Requirement:
  - High efficiency for charged particle detection
  - Hermeticity and compactness
- Technology:
  - → 2 layers of plastic scintillator counters read by WLS fibers and SiPM
  - → 5 cm lead vault between veto and calorimeter



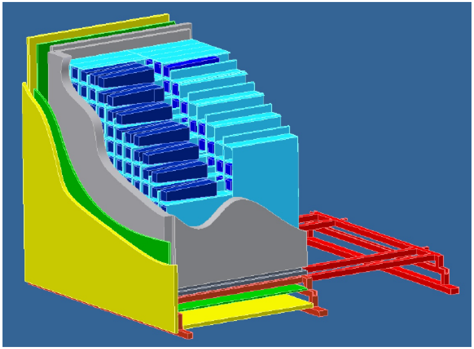
BDX - Detector Design

Detector design:

- 800 CsI(Tl) crystals (volume ~ 0.5 m^3)
- Modular detector

Modular detector arrangement:

- 1 module: 10×10 crystals
  - 30 cm long
  - 50×50 cm^2 front face
  - Crystals surrounded by a 5-cm thick lead shielding and two plastic scintillator counters
- 8 modules (~ 2.6 m length)



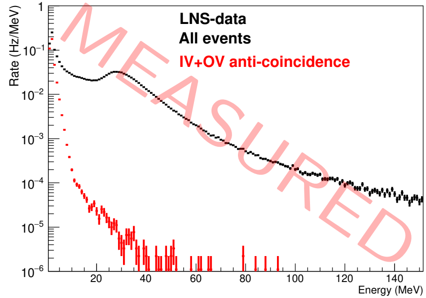
Signal detection:

- EM shower ($\gtrsim 100$ MeV) and no corresponding activity in the active veto
- Signal efficiency $\sim 20\%$

BDX - Backgrounds

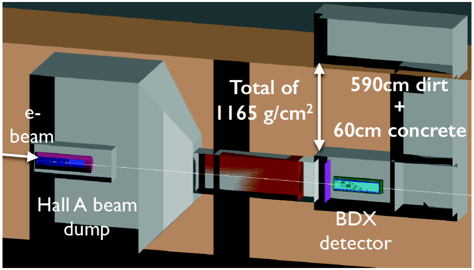
Cosmogenic:

- μ rejected by IV-OV
- low energy n absorbed by overburden
- Results extrapolated from data of BDX prototype installed at INFN-LNS (similar overburden as BDX)
  - $\rightarrow$ $E_{thr} = 300$ MeV $\rightarrow B_c \sim 5/y$



Beam-related:

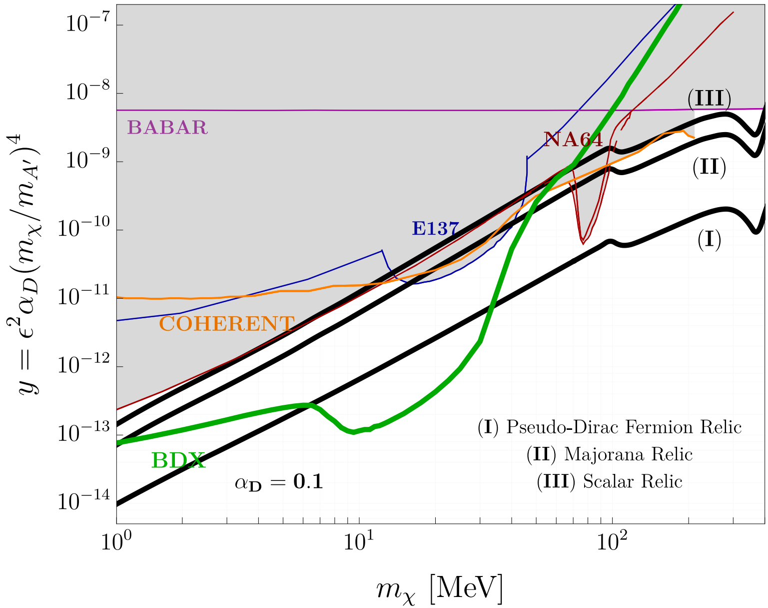
- ν_e CC interaction main background
- all other SM particles absorbed by 6.6 m of iron + 2 m of concrete
  - $\rightarrow$ simulation validated with beam-μ measure in situ (BDX-Hodo)
- Results obtained from MC simulations
  - $\rightarrow$ $E_{thr} = 300$ MeV $\rightarrow B_\nu \sim 10$ per 10^{22} EOT



BDX - Sensitivity

BDX will improve of 2 orders of magnitude current exclusion limits in LDM parameter space

$\rightarrow$ test relic target in mass range not accessible to higher energy experiments



BDX - Validation

BDX technology validated in a pilot run (BDX-MINI@JLab)

Experimental setup:

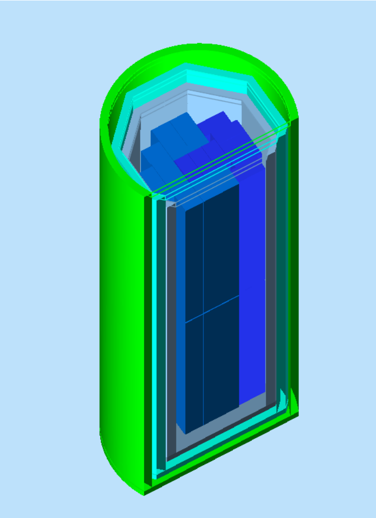
- 2.2 GeV, 150μA beam impinging on hall A
- Detector installed in a well 25 m downstream
- 20 % of BDX total charge collected (2×10^{21} EOT)

Detector:

- 0.15% of BDX active volume (44 $PbWO_4$ crystals, 4 dm^3), SiPM readout
- High efficiency hermetic multi layer veto (2 active vetoes + passive tungsten innermost layer)

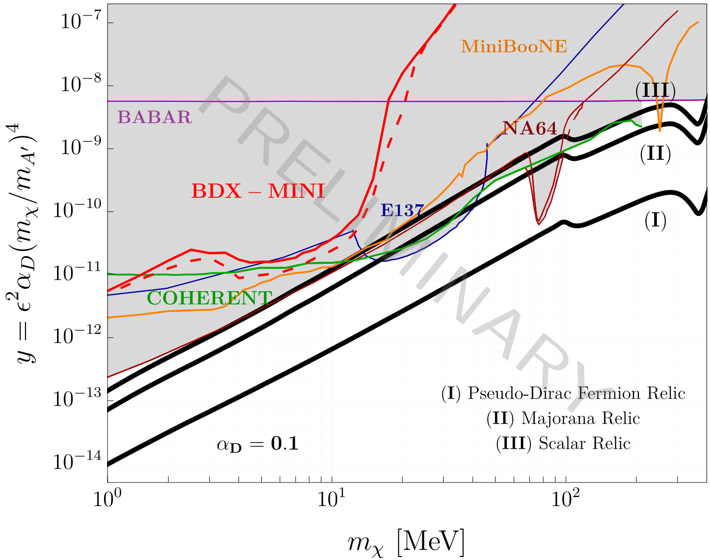
Analysis:

- Analysis optimization shown that reach can be improved over the 0 background condition



BDX- Validation

BDX-MINI results soon to be published:



⇒ Results comparable with flagship experiments

⇒ Confirmation of BDX high sensitivity

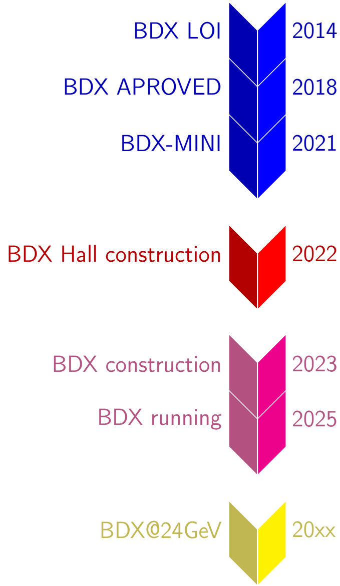
BDX - Status and perspective

→ 2014 - BDX Letter of Intent
→ 2015 - BDX Proto: study of cosmic background
→ 2017 - BDX Hodo: study of beam-related background
→ 2018 - BDX approved at PAC46 with the highest scientific rating
→ 2021 - BDX-Mini: test of BDX technology

→ 2022 - BDX Hall construction?

→ 2023 - BDX construction
→ 2025 - Moeller: BDX running parasitically

→ 20xx - BDX@24 GeV



BDX @ 24 GeV

How would BDX benefit from 24 GeV CEBAF upgrade?

Advantages

- Increased number of secondary particles in the dump $\Rightarrow$ enhanced DM production
- Some DM production mechanisms (resonant e^+e^- annihilation) are strongly dependent on the beam energy
  - $\Rightarrow$ enhanced reach in poorly explored DM parameter space

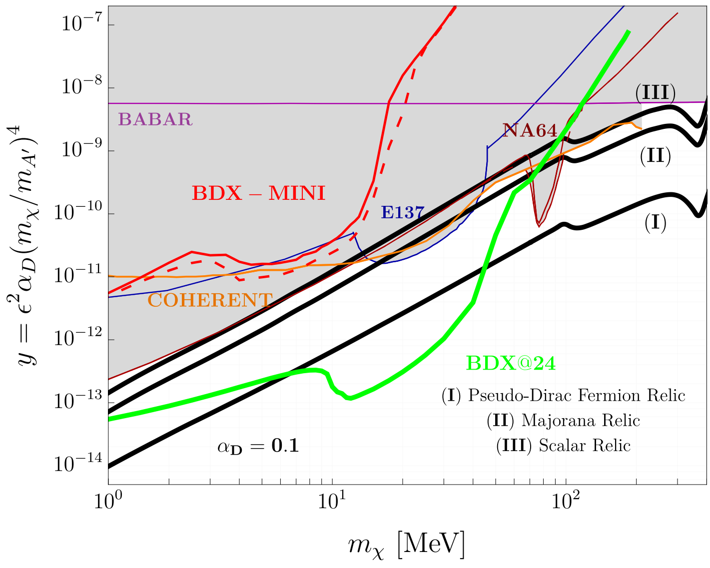
Drawbacks

- Increased beam-related background
  - $\rightarrow$ μ shielding may not be sufficient
    - $\rightarrow$ rethink experimental setup (more shielding, move away the detector)
  - $\rightarrow$ ν background increased
    - $\rightarrow$ need to study ν background rejection algorithm on real data

$\rightarrow$ BDX is meant to run with a 10 GeV beam but a 24 GeV measurement could benefit BDX results

BDX @ 24 GeV

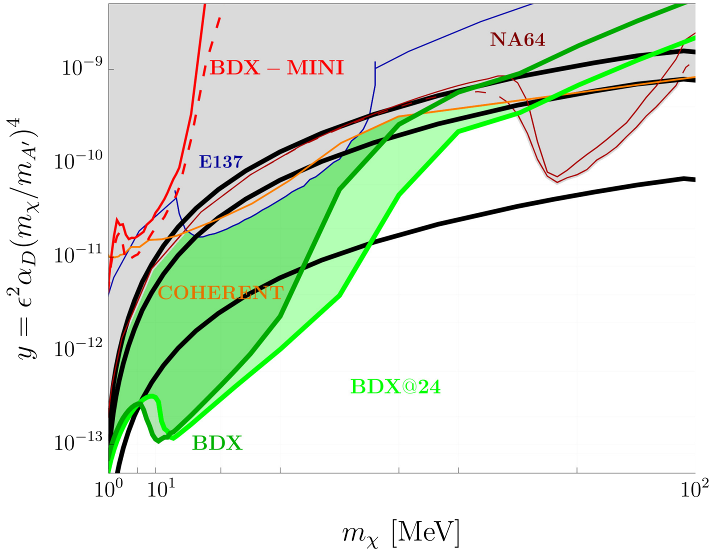
BDX@24 can complement BDX measure



- **Just an estimate!** Background needs to be evaluated

BDX @ 24 GeV

BDX@24 can complement BDX measure



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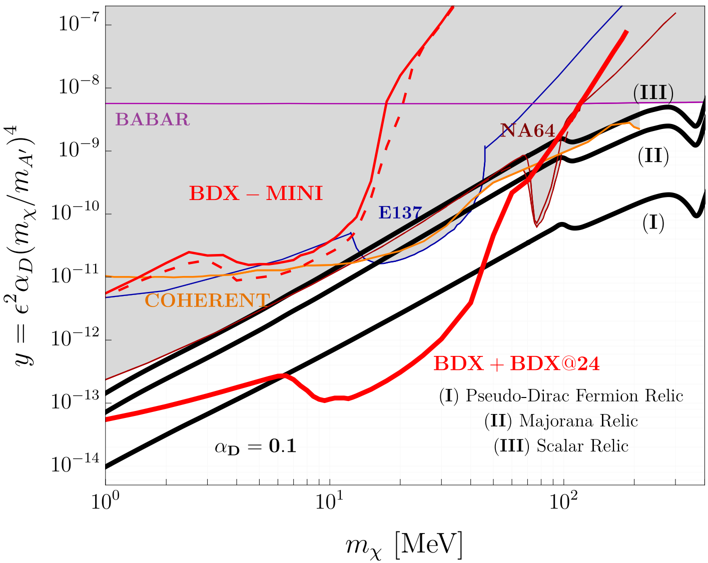
BDX @ 24 GeV

BDX@24 can complement BDX measure



- **Just an estimate!** Background needs to be evaluated

Summary

- Dark Matter in the MeV-GeV range is largely unexplored
- **Beam Dump eXperiment** at JLab: search for Dark Sector particles in the MeV-GeV mass range
  - High intensity (10^{22} EOT/y), high energy (11 GeV)
  - Detector: 800 CsI(Tl) calorimeter + 2-layer active veto + shielding
- BDX approved at JLAB PAC with the highest scientific rating
- BDX-MINI assessed BDX capabilities:
  - Technology validation
  - Feasibility of BDX
  - Corroboration of BDX expected sensitivity
- BDX is meant to run at 10 GeV
  - 24 GeV beam can be used to extend BDX reach