E12-16-001
E12-16-001 update to Jefferson Lab PAC51
July 27, 2023

BDX
Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab
An update for jeopardy process

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and the BDX Collaboration

E12-16-001 - BDX - Executive Summary

- The BDX experiment (E12-16-001) received an A-rating from PAC46 in 2018
- Since then, the BDX Collaboration has engaged in:
  - demonstrating the validity of the proposed experimental setup
  - seeking funding to build the necessary infrastructure (DOE, NSF, Gordon and Betty Moore Foundation, …)
- The BDX experiment concept has been fully validated with the BDX-MINI experiment
- Physics motivations to run the BDX experiment are even stronger than 5 years ago
- The BDX Collaboration is ready to run the experiment upon realization of the infrastructure to install shielding and the detector downstream of the Hall-A beam-dump

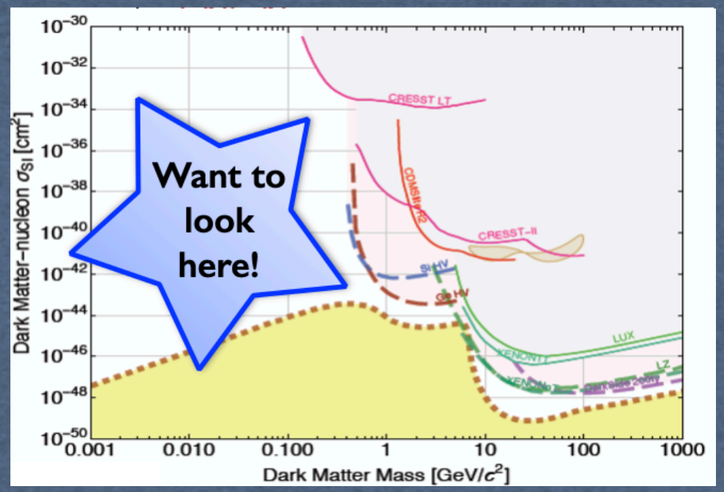
We seek the endorsement from PAC51 to recognise the compelling physics of BDX

Layout

- Summary of E12-16-001 BDX experiment
- The BDX-MINI experiment
- Results and perspectives

Light Dark Matter

- Compelling astrophysical indications of DM existence but no direct proof of particle-like behaviour
- An extensive experimental program based on WIMPS paradigm is searching for DM via nuclear recoil (Direct Detection)



- Negative results call for extending the DM hunting territory to unexplored regions

Dark/Hidden Sector
Light Dark Matter couples to SM with a new force

- Light Dark Matter (X) in 1-1000 MeV mass where (traditional) DD is (almost) impossible
- High intensity beam makes accelerator-based DM search highly competitive

Light Dark Matter | Direct Detection

1 MeV — 1 GeV — (Z boson mass) — 10 TeV

Dark Sector or Hidden Sector (DM not directly charged under SM interactions)

WIMPs

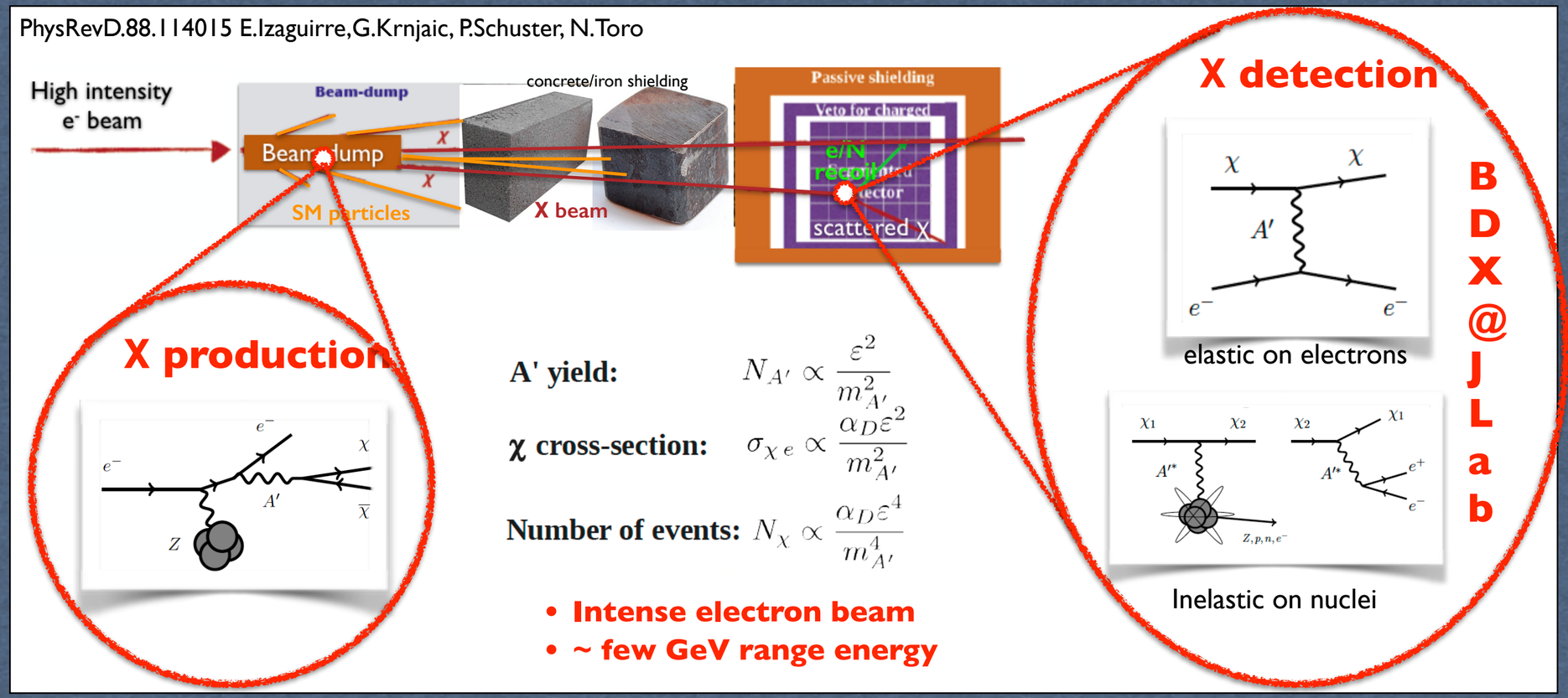
JLab is the world-leading facility for LDM search (HPS, APEX, X-17, positron beam, BDX, …)

The BDX experiment

Two-step process

I) An electron radiates an A' and the A' promptly decays to a χ\χ-bar (DM) pair

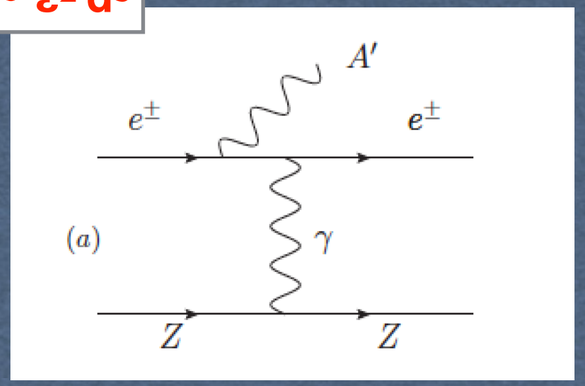
II) The χ (in-)elastically scatters on a e-/nucleon in the detector producing a visible recoil (GeV)



Experimental signature in the detector: **X-electron → EM shower ~GeV energy**

Theory update: *A'* Production mechanisms - $e^{\pm}$

~ $\varepsilon^2 \alpha^3$



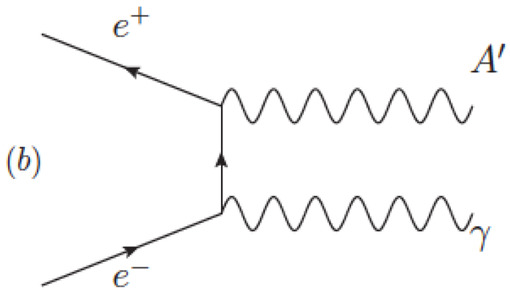
The Weizsacker-Williams approximation (*A'-strahlung*)

- The first tree-level mechanism proposed
- BDX sensitivity presented in E12-16-001 was based solely on this production mechanism

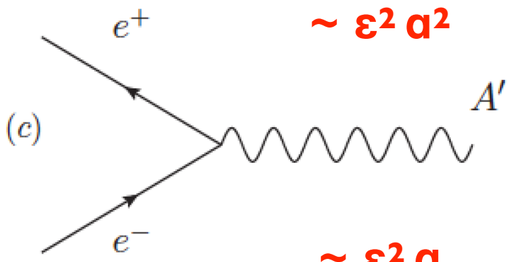
A' Production - resonant/non-resonant production

- Specific for positron annihilation
- A beam dump is a copious source of positrons
- Positrons in the EM shower may have any energy in the range of 0 - E_{beam}
- New BDX exclusion limits were calculated including the resonant production mechanism

L. Marsicano et al. Phys. Rev. Lett., 121(4) 041802, 2018
L. Marsicano et al. Phys. Rev. D, 98 (1) 015031, 2018



~ $\varepsilon^2 \alpha^2$



~ $\varepsilon^2 \alpha$

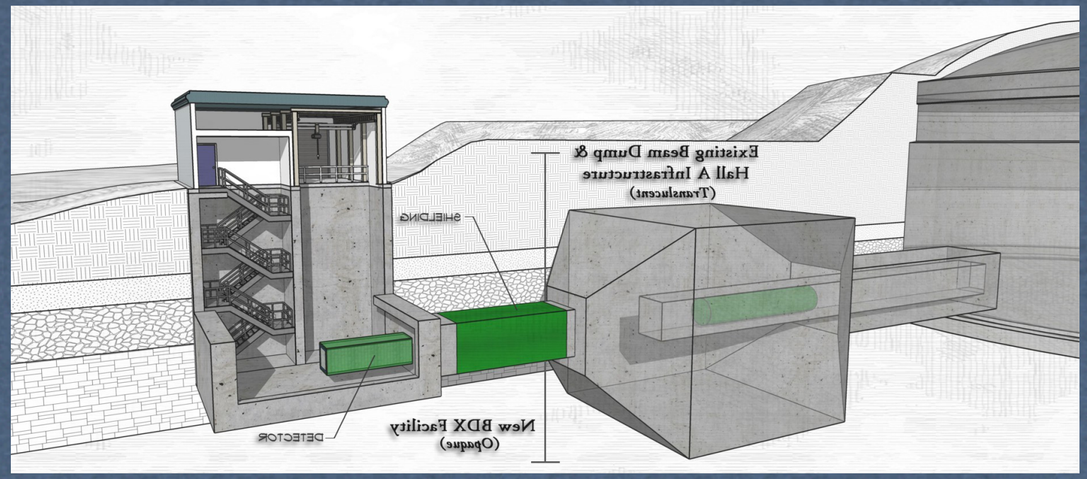
- **NON-RESONANT annihilation**

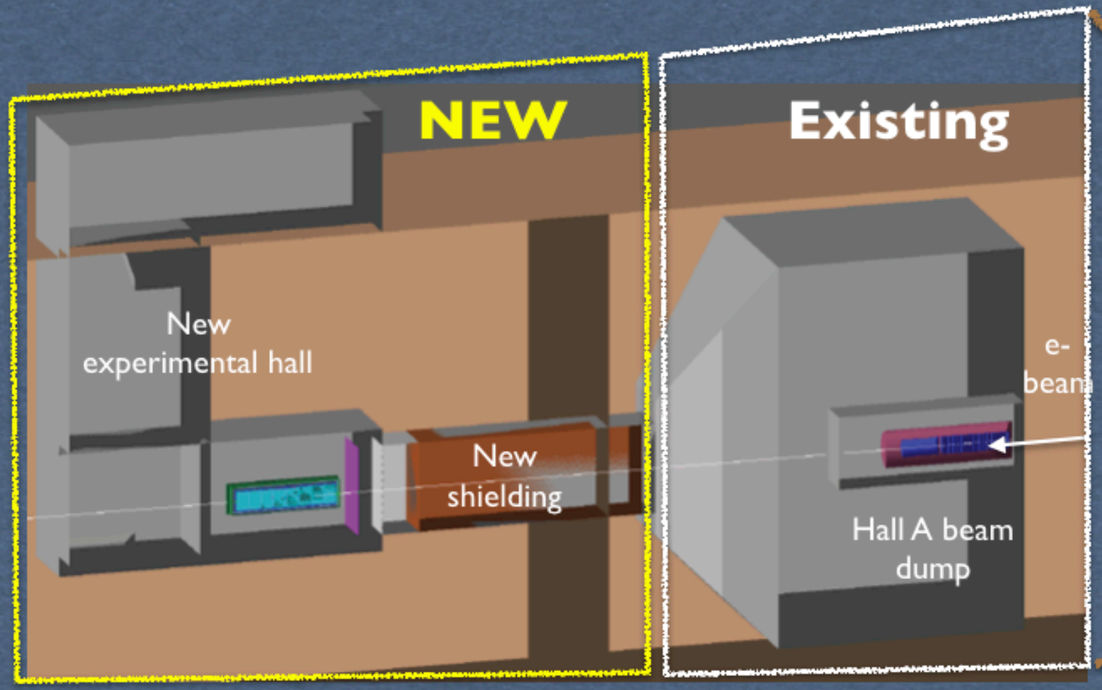
- **RESONANT annihilation**

$$\sigma_r = \sigma_{\text{peak}} \frac{\Gamma_{A'}^2/4}{(\sqrt{s} - m_{A'})^2 + \Gamma_{A'}^2/4} ,$$

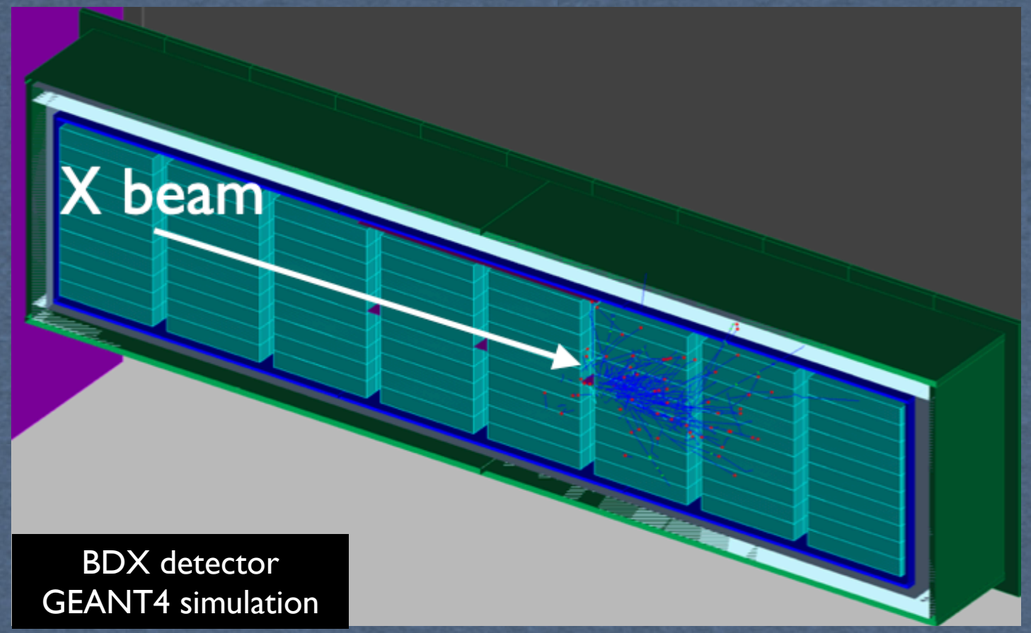
BDX @ JLab

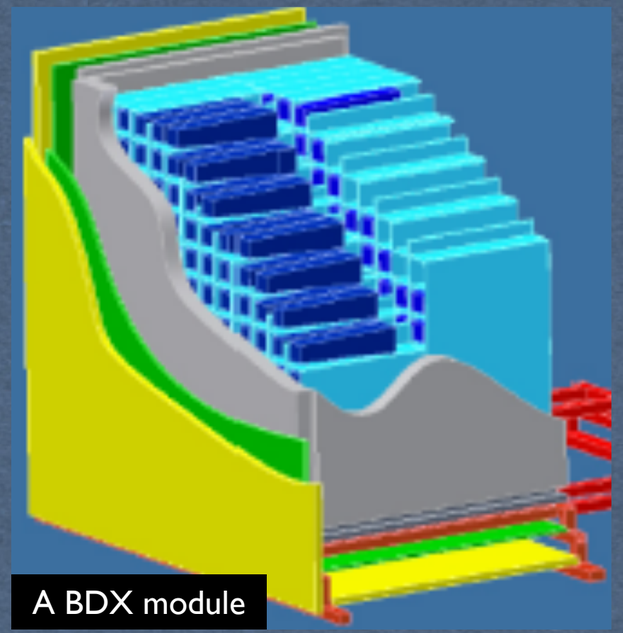
- Unique experiment able to PRODUCE and DETECT LDM
- High energy beam available: 11 GeV
- The highest available electron beam current: ~65 uA
- The highest integrated charge: 10^{22} EOT (41 weeks)
- BDX detector is granted (recycling BaBar CsI crystals)
- BDX infrastructure: new experimental hall and iron shielding
- The sweet spot: to run in parallel to the Moeller experiment (2026-2029)





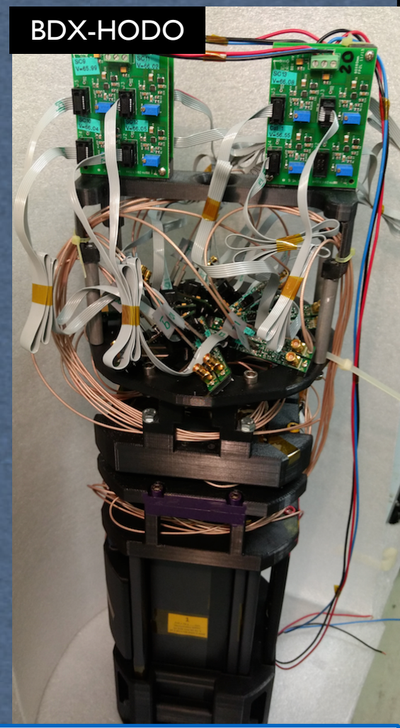
The BDX detector





Background assessment and detector concept validation:

- Cosmic rays: BDX prototype
- In-situ beam-on (n and muons): BDX-HODO
- High stat simulations (FLUKA and GEANT4) validated with measurements



M.Battaglieri et al. NIM.A, 925:116–122, 2019

BDX detector: E.M. Calorimeter + hermetic veto for bg rejection

- Modular design
- 8 modules each having 10x10 crystals
- 800 CsI(Tl) crystals (from BaBar EMCal)
- 6x6 mm^2 Hamamatsu SiPM readout + fADC electronics
- Inner and Outer veto: plastic scintillator + WLS fibres, SiPMs
- 50 x 55 x 295 cm^3

BDX (updated) sensitivity

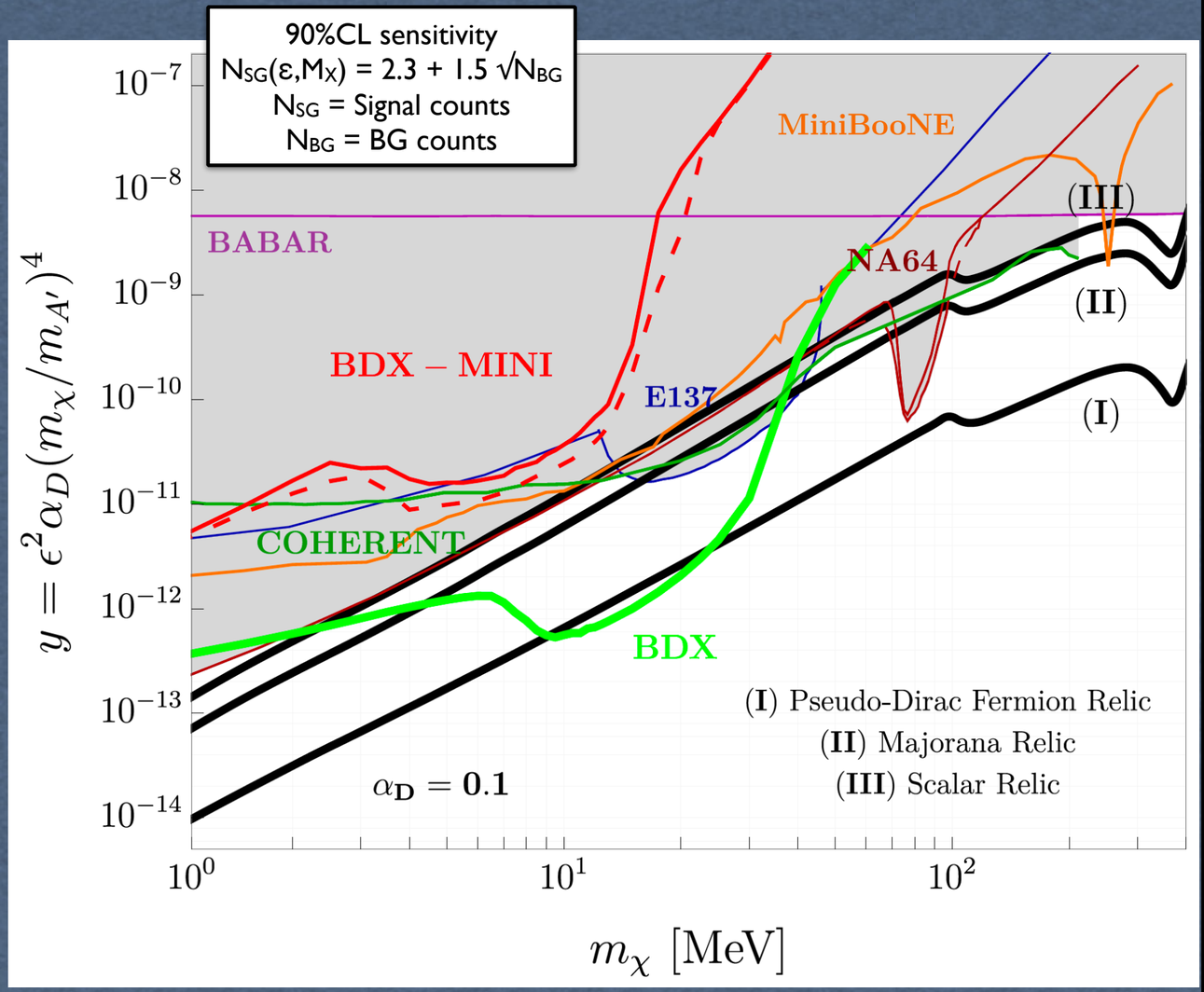
Beam time request (parasitic to Hall-A ops)

- 10^{22} EOT (65 uA for 285 days)
- BDX can run parasitically with any Hall-A E_{beam}>10 GeV experiments (e.g. Moeller)

Beam-related background	
Energy threshold	N_ν (285 days)
300 MeV	~10 counts

Cosmic background	
Energy threshold	$\sqrt{Bg}$ (285 days)
300 MeV	<2 counts

- Calculation includes resonant positron annihilation
- Sensitivity to inelastic LDM is not shown



The sensitivity of BDX exceeds more than 10x the existing limits on LDM production
Such tight exclusions will set limits on LDM mechanisms or render an important null result

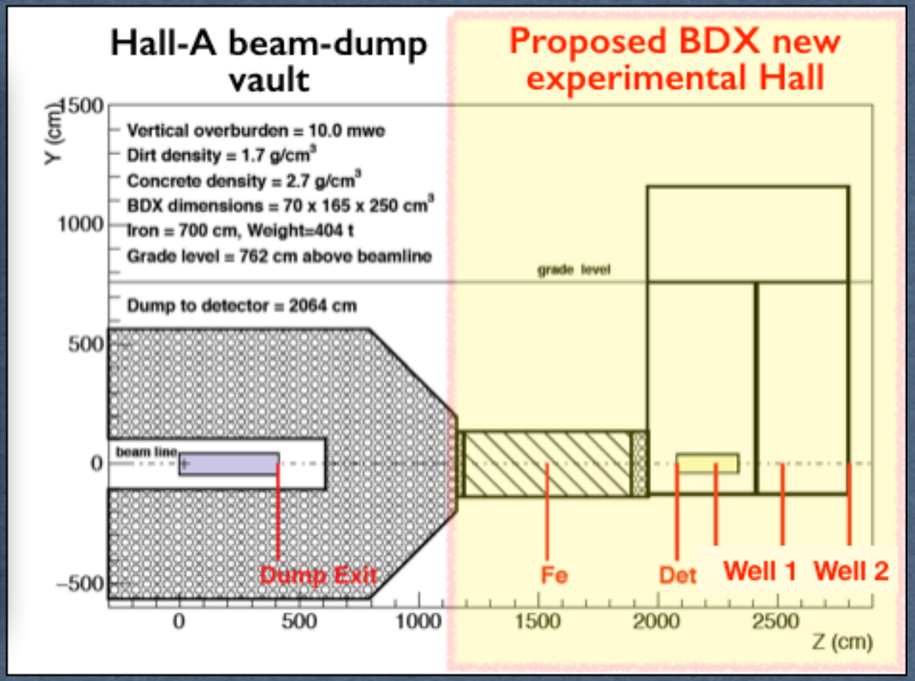
BDX-MINI @ JLab

BDX-MINI: pilot experiment to prove the validity and feasibility of the BDX experiment

- Two wells dug for background (muon) assessment
- E_{beam}=2.2 GeV, no muons
- BDX-MINI yielded the first physics result!

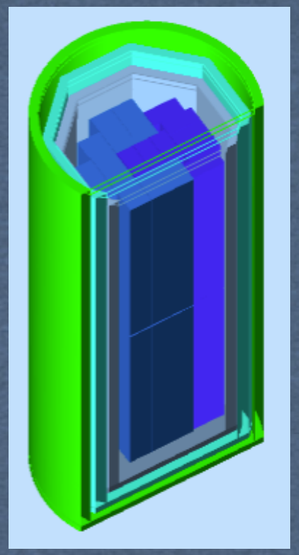
- Installed in March 2019
- Run form Dec 2019 to Aug 2020
- Collected $2.6 10^{21}$ EOT (25% BDX!) in ~6 months (+ cosmics)
- Good detector performance with high-duty factor

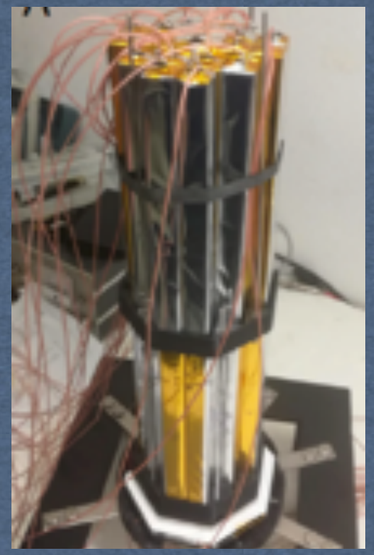
Downstream of the Hall-A beam dump
- TODAY -

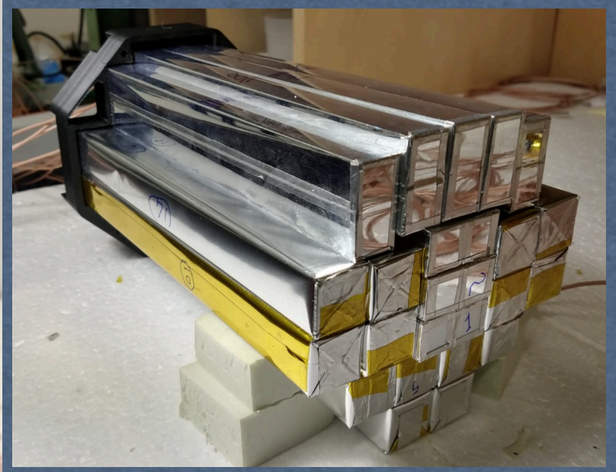


BDX-MINI reach

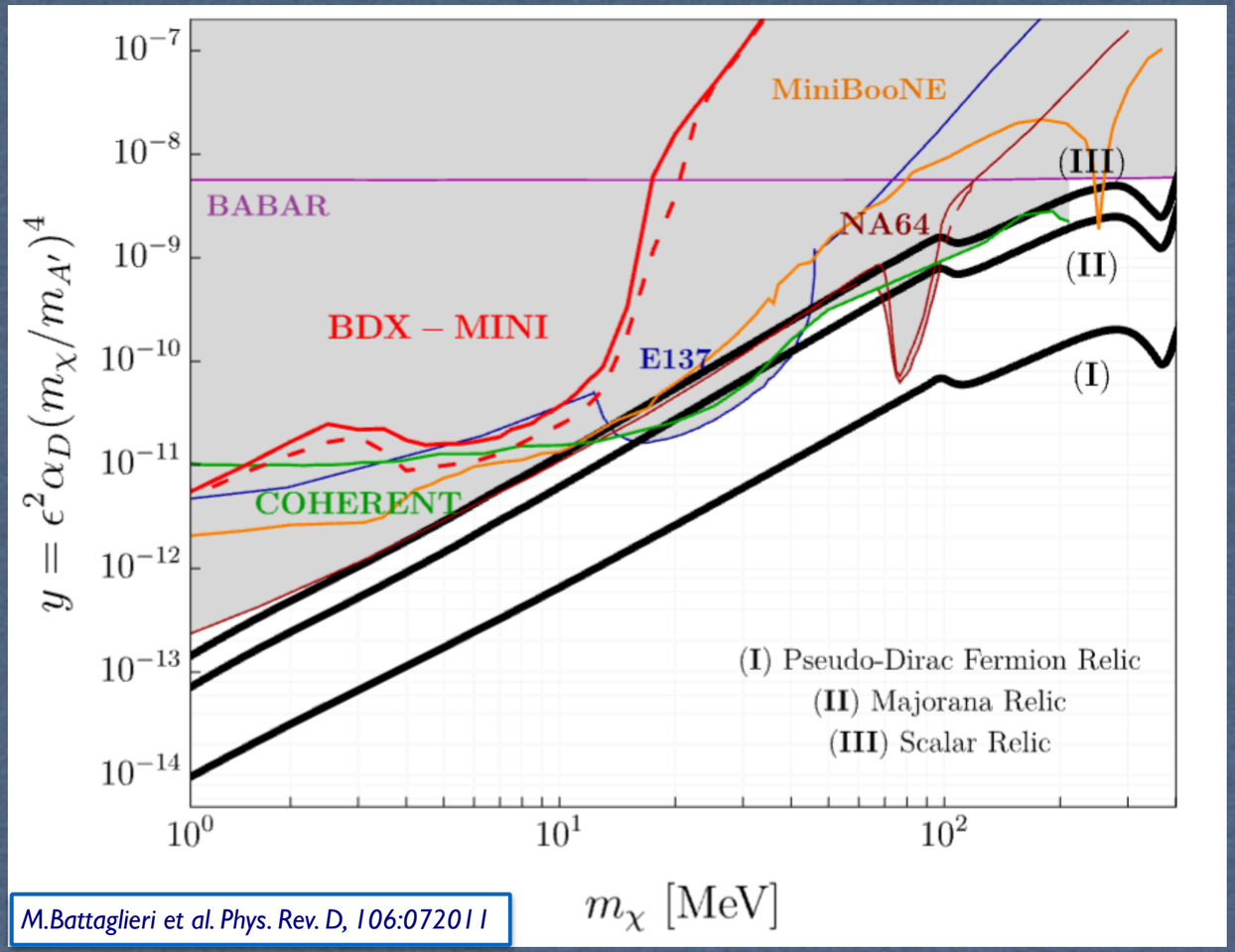
- Detector concept similar to BDX: EM calorimeter + active/passive vetos
- 44 $PbWO_4$ PANDA/FT-Cal crystals (~1% BDX active volume)
- 6x6 mm^2 SiPMs readout
- 2 active plastic scintillator vetos: cylindrical and octagonal (8 SiPMs each) + 2x lids + Passive W shielding







M.Battaglieri et al. EPJC (2021) 81: 164



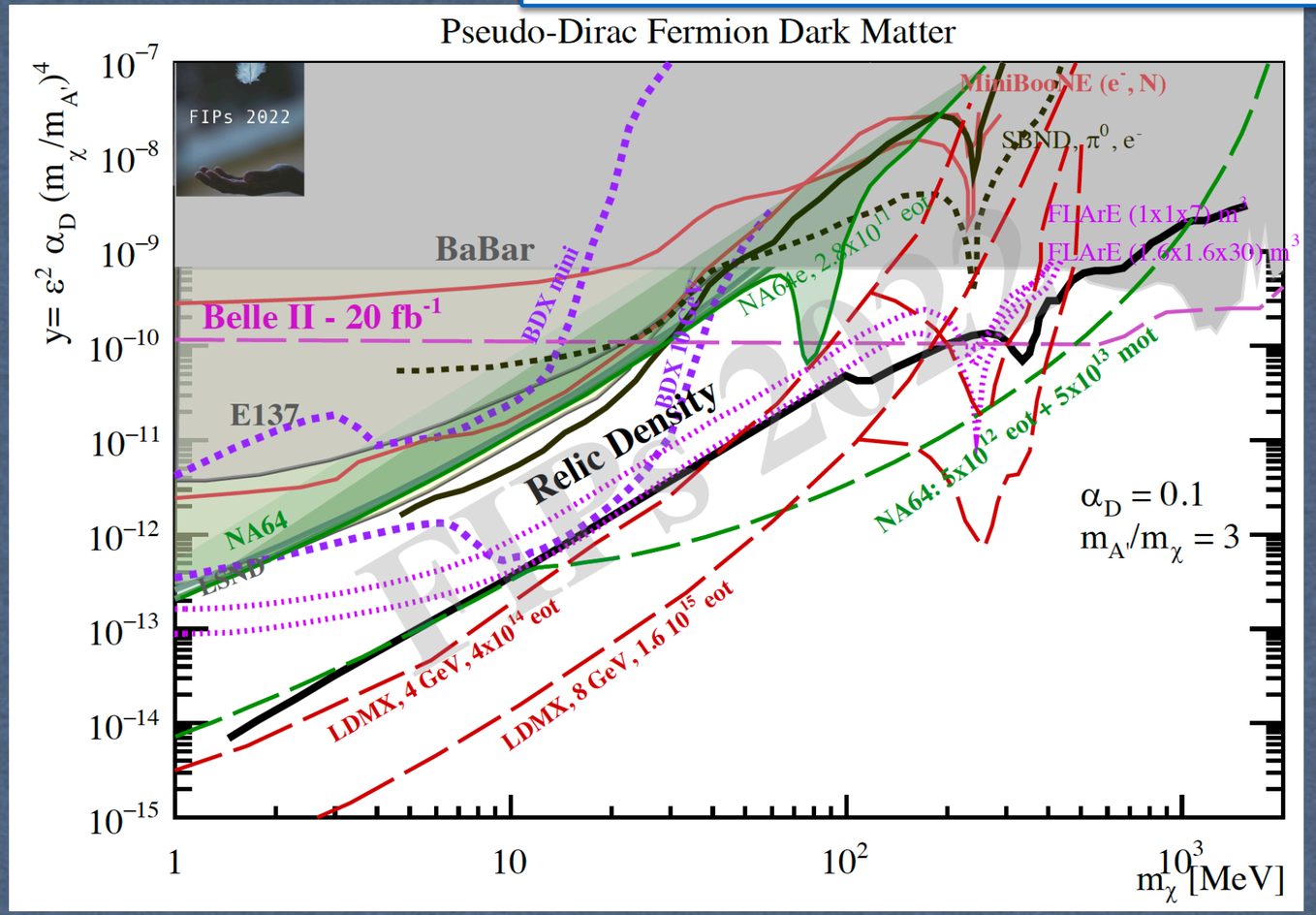
M.Battaglieri et al. Phys. Rev. D, 106:072011

Even with our pilot BDX-MINI experiment, we extended the exclusion limits beyond the dedicated and fully-instrumented experiments (E137, NA64, MiniBoone, …)

LDM searches status

L.G. Krnjaic et al. Snowmass 2021 Rare & Precision Frontier (RF6): 7 2022
C. Antel et al. Feebly interacting particles: Fips 2022 workshop report, 2023

- CERN-FIPs workshop report, (SNOWMASS22) shows that BDX offers great potential for discovering LDM (or disproving it, in a large area of parameter space)
- Several experiments planned/proposed (LHC, SLAC, Mainz, FNAL, KEK, PSI, LPARC) with a variety of beams (proton, leptons, photons), energies (from 150 MeV to 14 TeV) and experimental techniques (visible, invisible, recoil, ..) with a timeline that reaches ~2042
- BDX has the unique opportunity to be one of the first (significant) experiments to set limits and verify/falsify viable theoretical scenarios (relic LDM, inelastic DM, …)
- Over the last 5 years, NA64 has pushed the exclusion limit slightly down (it is scheduled to run more!)



BDX needs to run as soon as possible (in parallel to Moeller?)
(We risk missing a golden opportunity of detecting LDM!)

Conclusions

- Over the past few years, it has become clear that searching for LDM must employ high-intensity beams from accelerators (SNOWMASS 2022)
- The A-rated BDX physics case to assess the existence of Light Dark Matter remains valid and up-to-date
- The inclusion of a new LDM production mechanism (positron annihilation) will increase the BDX sensitivity
- The BDX concept has been tested with several prototypes and dedicated measurement campaigns
- The BDX-MINI successful pilot run has demonstrated the potential of the BDX (technique and physics reach)
- Collecting 10^{22} EOT in 285 days of parasitic running (in parallel to Moeller?) at 11 GeV, the BDX experiment would be >10 times more sensitive than previous experiments
- The BDX Collaboration will be responsible for seeking funding to build the detector/DAQ and is working with the lab leadership to design the BDX infrastructure (shielding + detector installation)

We ask PAC51 Committee to fully support the BDX experiment

BDX offers a golden opportunity to discover Light Dark Matter: do not miss it!