The Beam Dump eXperiment and Secondary beams @ JLAB

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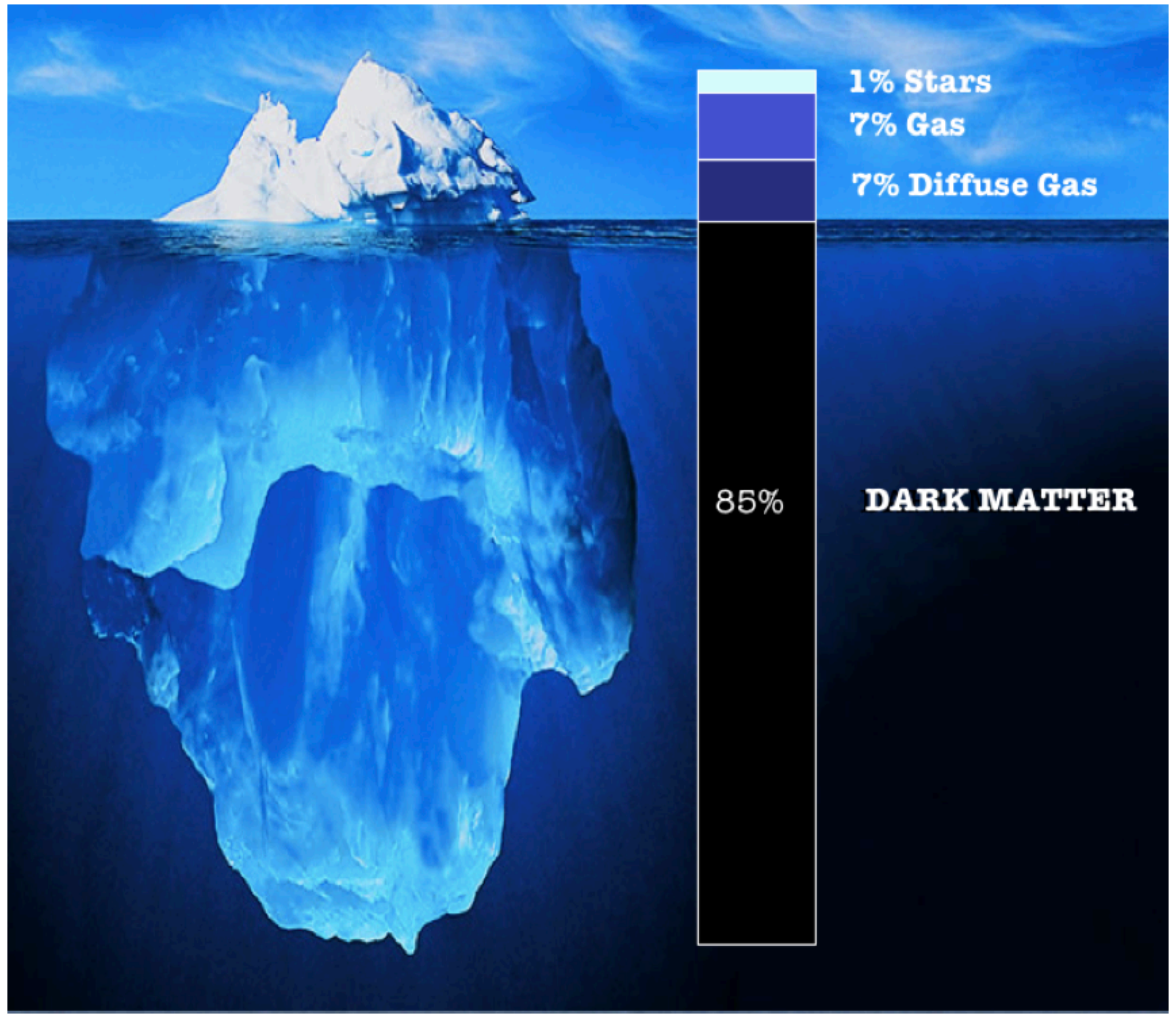
On Behalf of BDX Collaboration

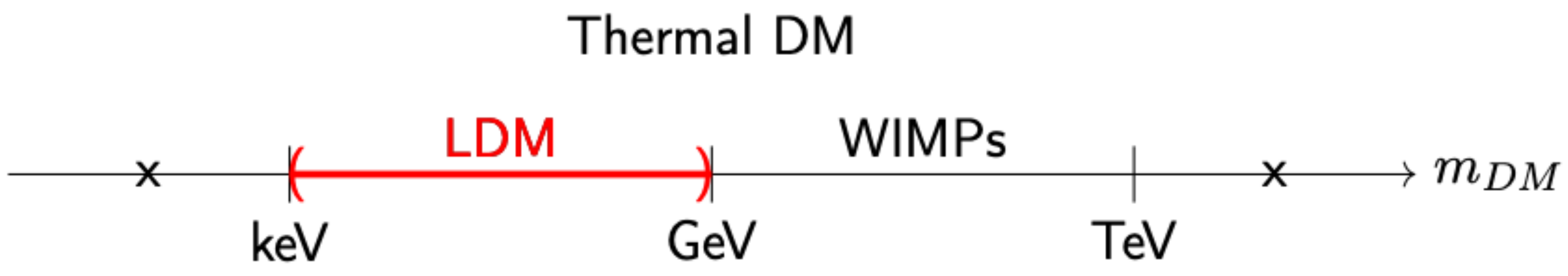
**INFN - Sezione di Catania*

2026 JLUO Annual meeting — 23 - 25 June 2026

Dark Matter

- **Dark Matter** is there but we know nothing about the particle content of DM
  - Plenty of cosmological and of cosmological/ astrophysical observations: CMB anisotropies, galaxy rotation curves, gravitational lensing…
- No hints on DM particles properties: mass, cross section..
- **Cosmological prior:** thermodynamical equilibrium between DM and SM states in early universe. DM relic abundance ρ_{DM} is connected to the macroscopic cross section for the annihilation $\chi\chi \to ll$ (freeze-out mechanism)





Constraint on DM mass and interaction:

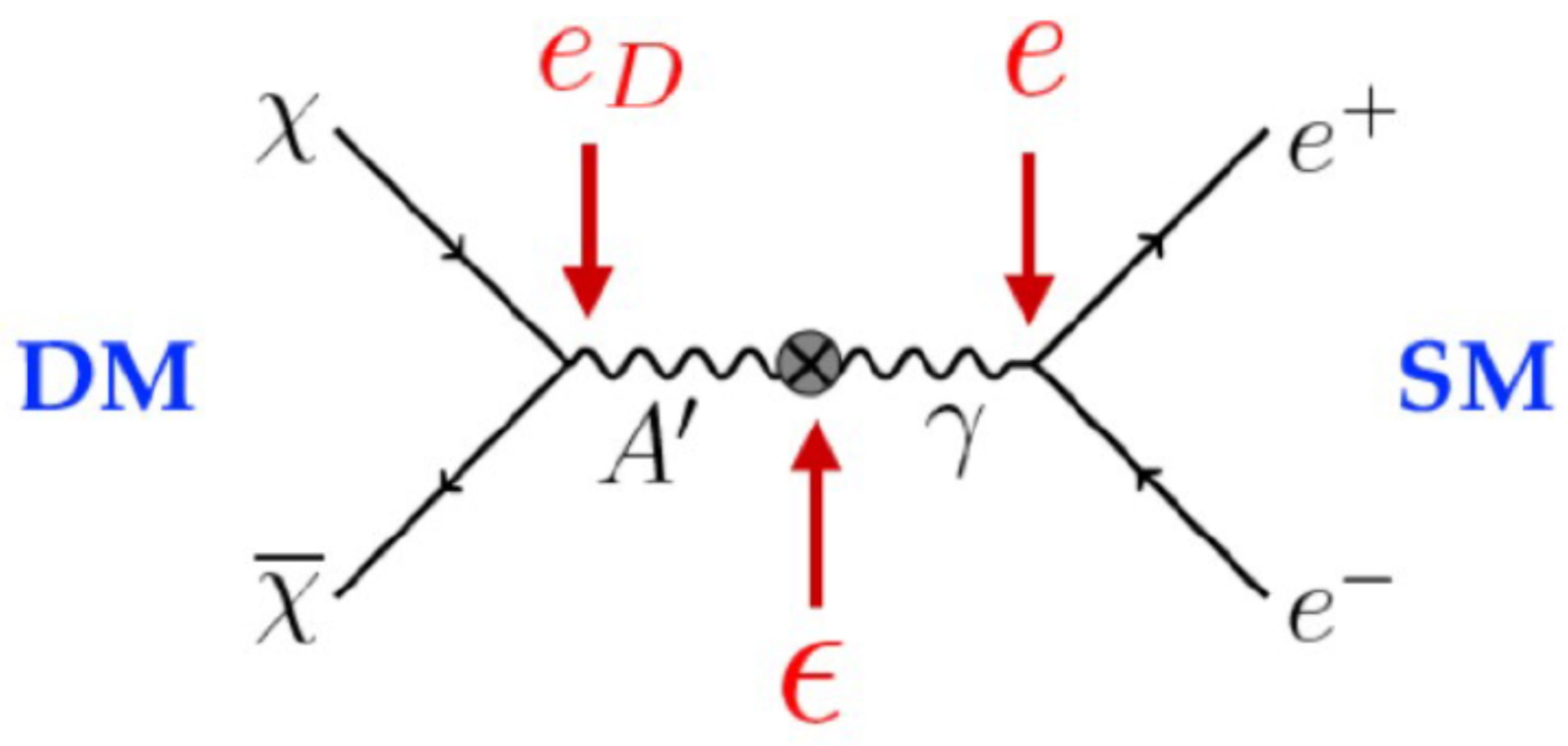
- Should be dark (no EM interaction)
- Should weakly interact with SM particles
- Should provide the correct relic abundance

The Light Dark Matter (LDM) physics case

- **Light Dark Matter**: DM made by sub-GeV particles (χ), the lightest stable state of a "new" Dark Sector.
- LDM particles **interact** with SM states via **"new pseudo-EM" force** mediated by a massive mediator
  - Simplest possibility: **vector-portal** DM-SM interaction through a new U(1) gauge-boson (dark photon) coupling to electric charge

Model parameters:

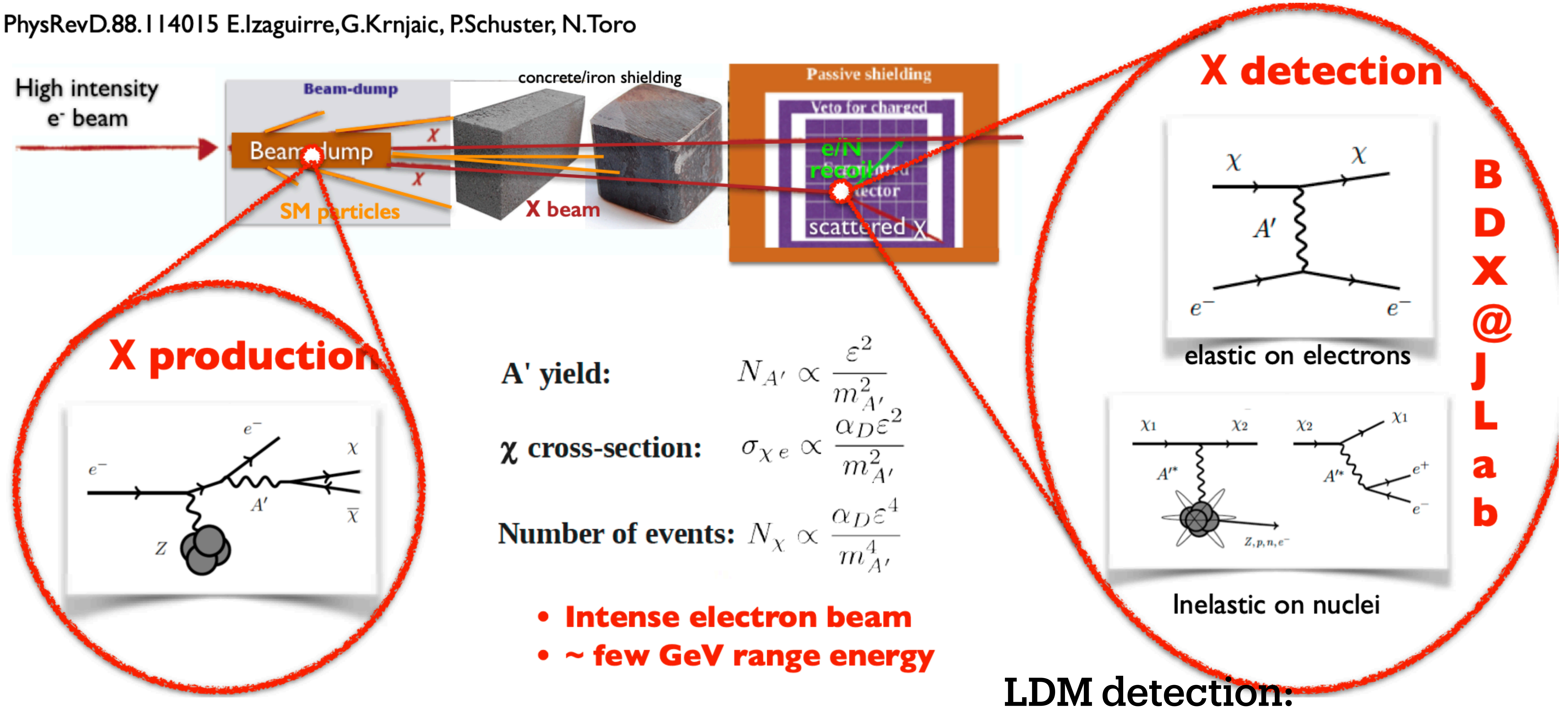
- Dark photon mass mA', coupling to SM state ε
- Dark matter mass m_χ, coupling to DM g_{DM}



$\langle \sigma v \rangle \propto \frac{y}{m_\chi^2} \qquad y \equiv \varepsilon^2 \alpha_D (m_\chi / m_{A'})^4$

For a comprehensive review: 1707.04591, 2005.01515, 2011.02157

Beam Dump Experiment



A' yield: $N_{A'} \propto \frac{\varepsilon^2}{m^2_{A'}}$

χ cross-section: $\sigma_{\chi e} \propto \frac{\alpha_D \varepsilon^2}{m^2_{A'}}$

Number of events: $N_\chi \propto \frac{\alpha_D \varepsilon^4}{m^4_{A'}}$

- **Intense electron beam**
- **~ few GeV range energy**

LDM production:

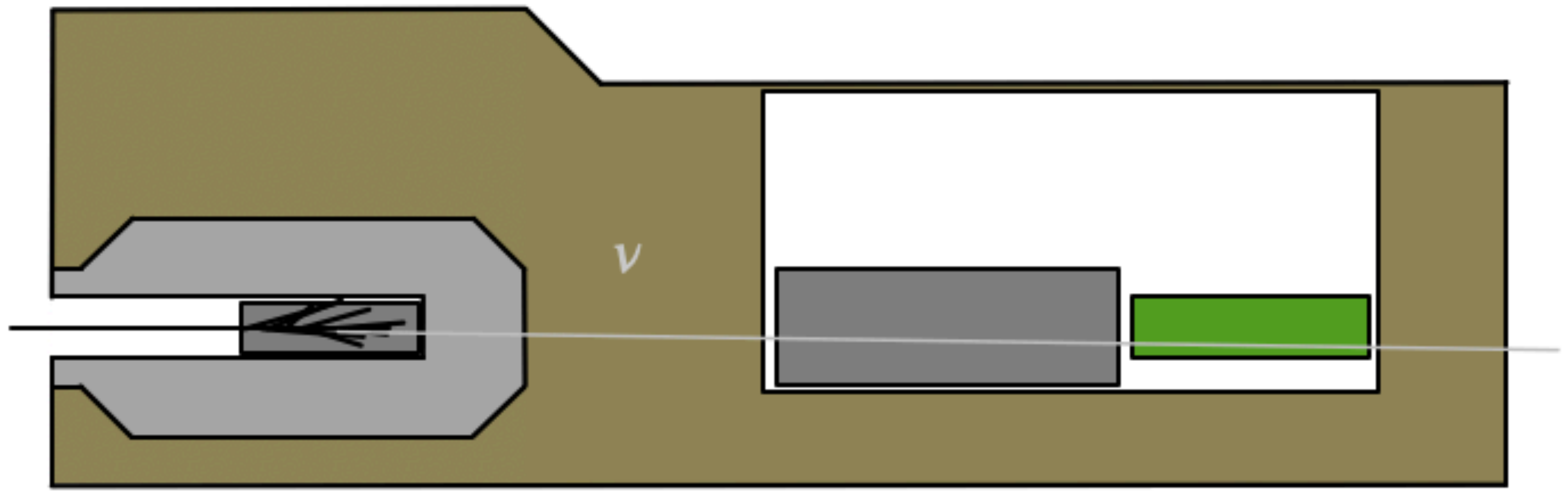
- **e- beam** impinging on thick target
- χ from decay of A' produced in the thick target

LDM detection:

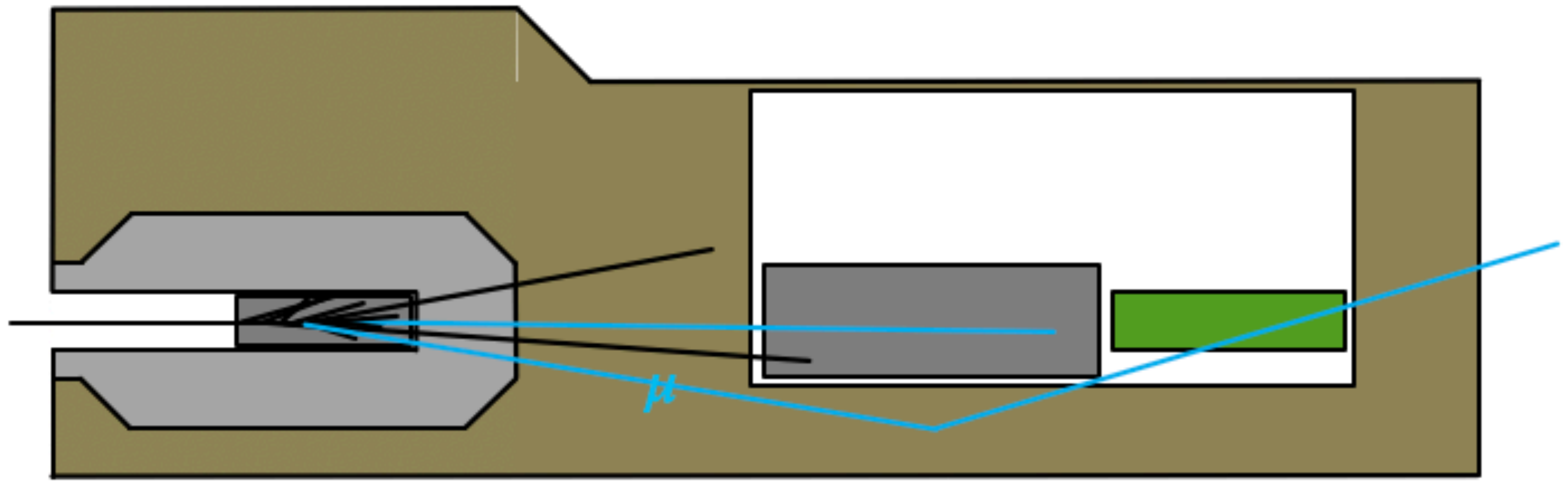
- χ propagate through shielding
- χ scattering through A' exchange
- Experimental signature: χ-e- -> EM shower ~ O(100 MeV)energy

Beam Dump eXperiment Background

- **Beam related background:**
  - **Neutrinos** can mimic DM interaction
  - High energy muons can propagate through shielding reaching the detector

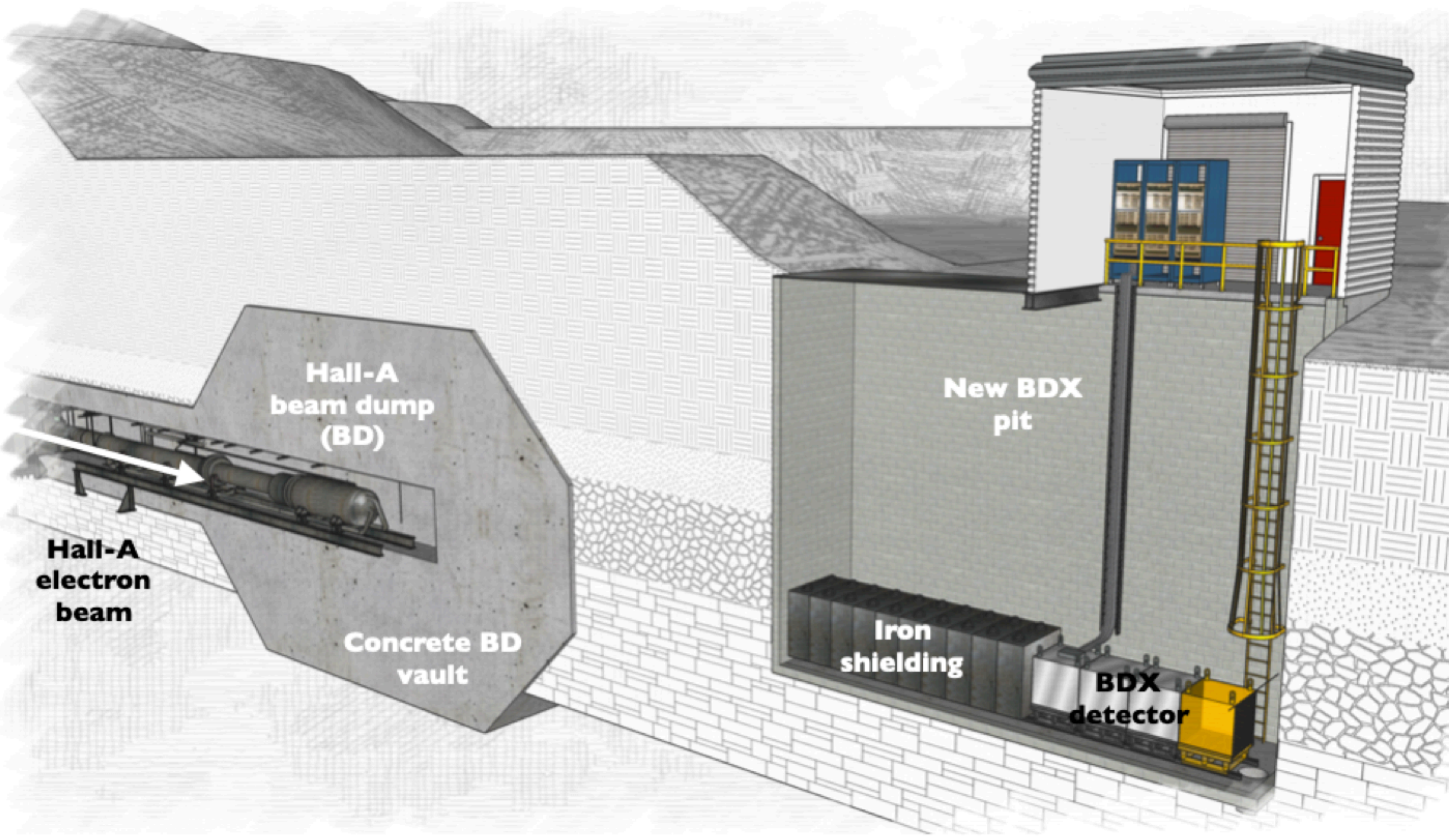


- **Cosmic background:**
  - Continuous beam does not allow for coincidence with beam bunch to remove cosmogenic background
  - Significant background from cosmic **muons**
  - Neutral poorly known background from **spallation** of cosmic muons near detector



Beam Dump Experiment @ JLAB

- **BDX is an approved JLAB experiment with highest scientific rating**
- **JLAB offers the best condition for BDX**:
  - Medium electron energy beam ~ 11 GeV
  - High electron beam current ~ 65 μA
  - Fully synergic wrt Hall-A physic program (Moeller)
- **New facility to be built in front of Hall-A beam dump:**
  - New underground (~8m) hall
  - 25 m downstream of Hall-A beam dump
  - Passive shielding to reduce beam related background ~12 m dirt +concrete and 6m steel
- **Detector with 2 components:** EM-Calorimeter + Veto systems
- **BDX reach complementary to DarkMesa**

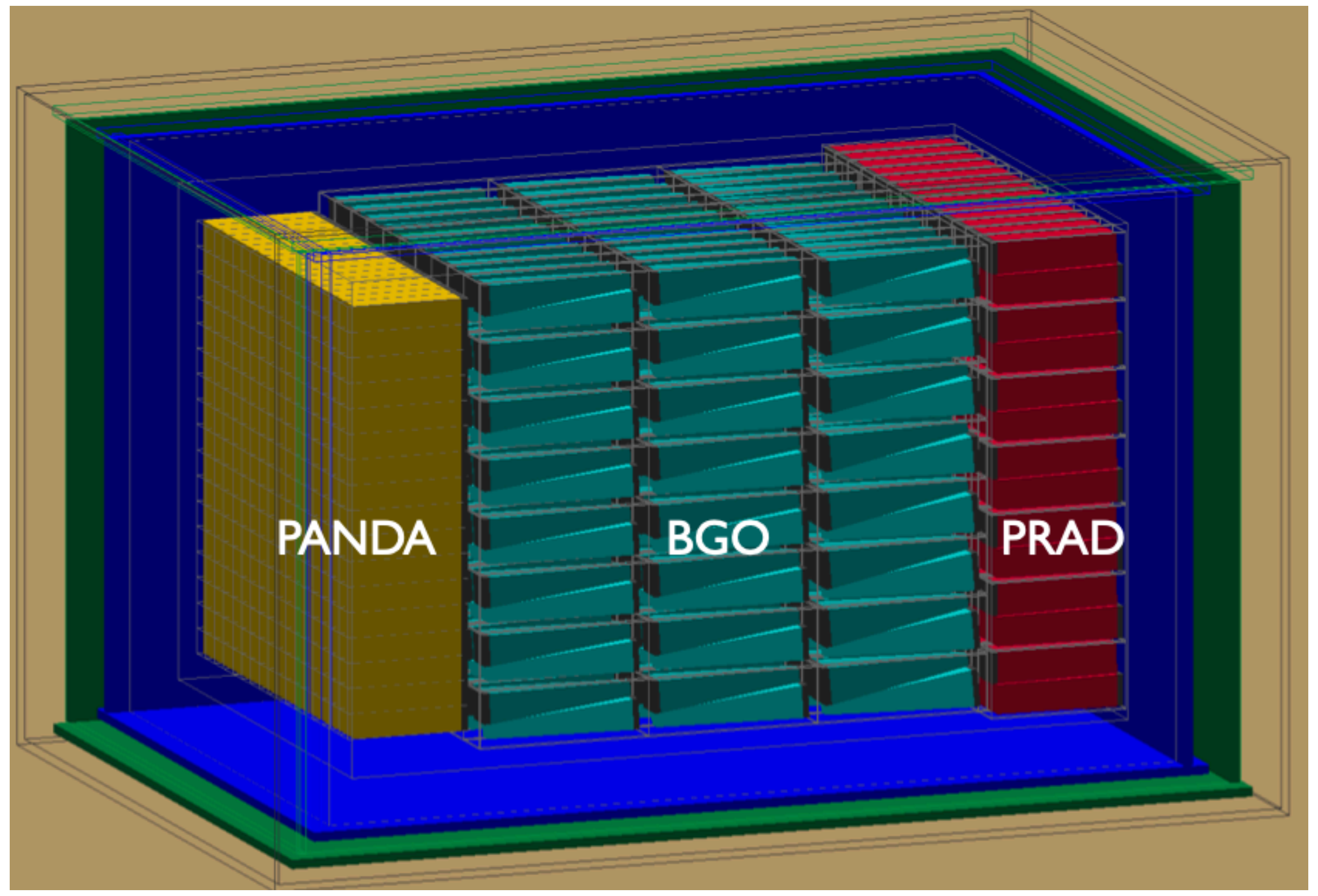


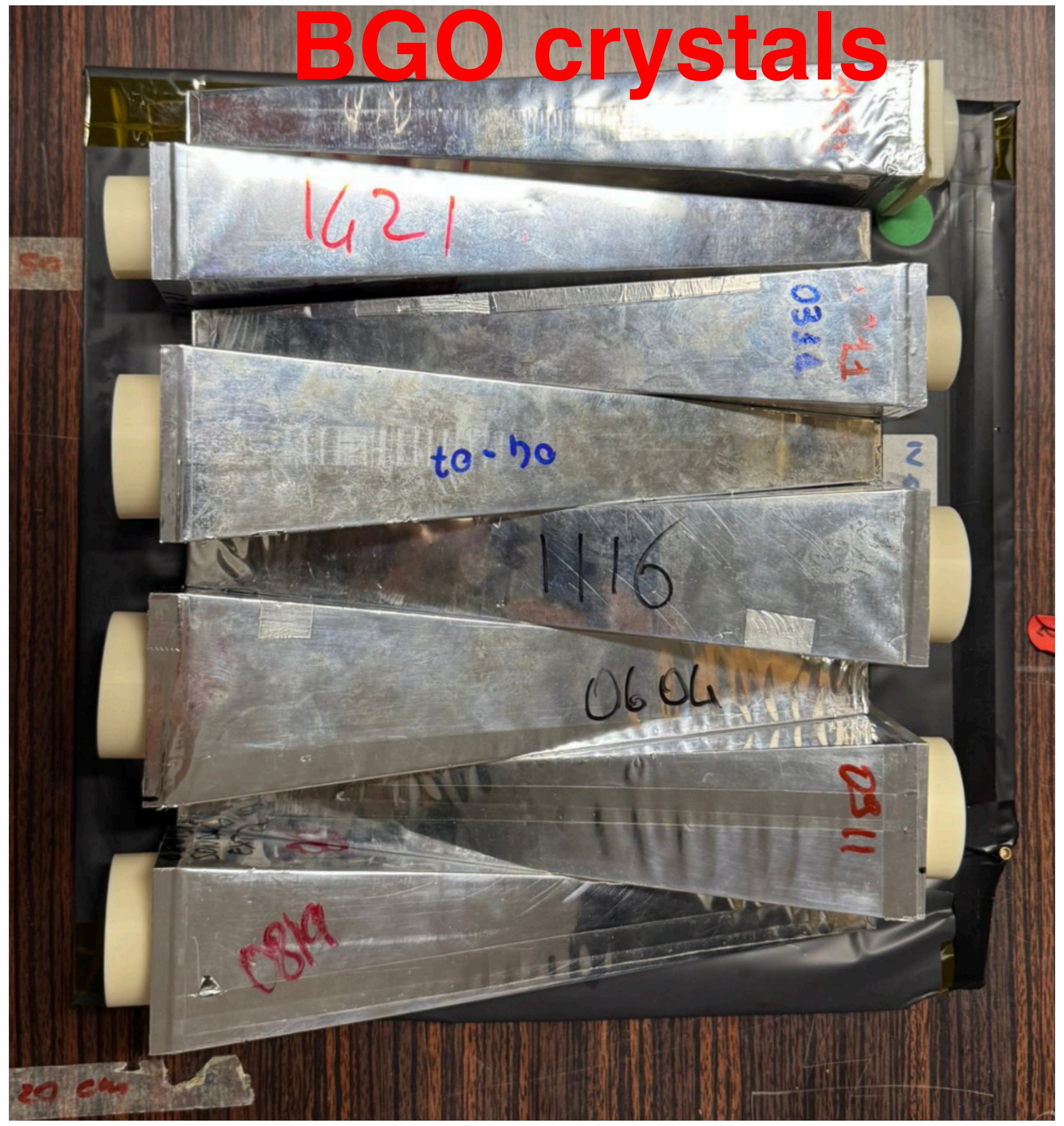
BDX detector

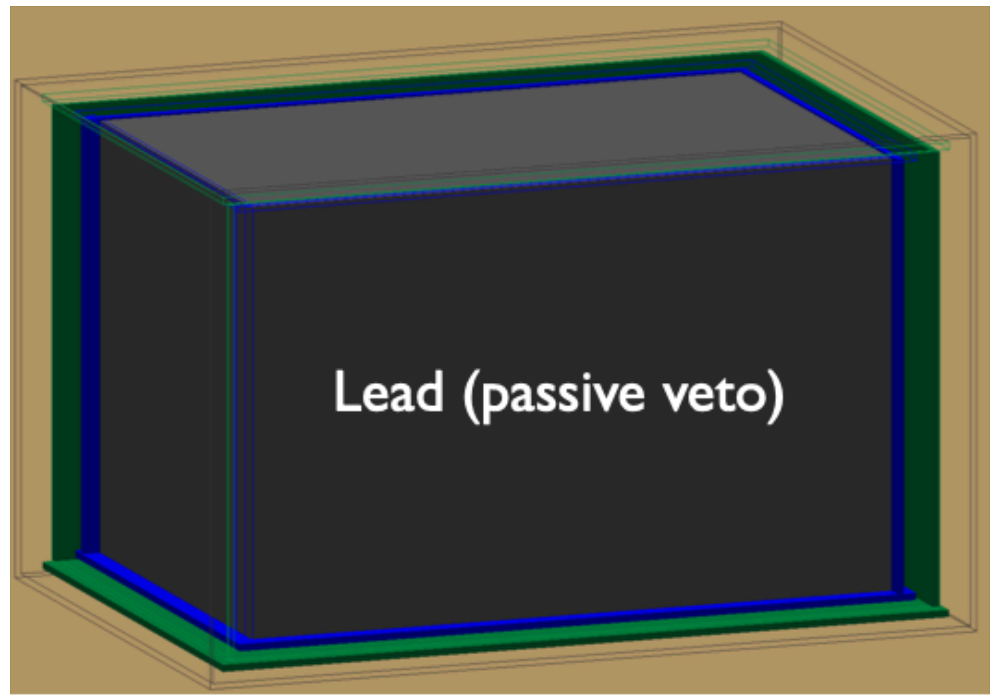
Expected signal: deposited energy (~100 MeV) in the active target and no corresponding activity on the veto system

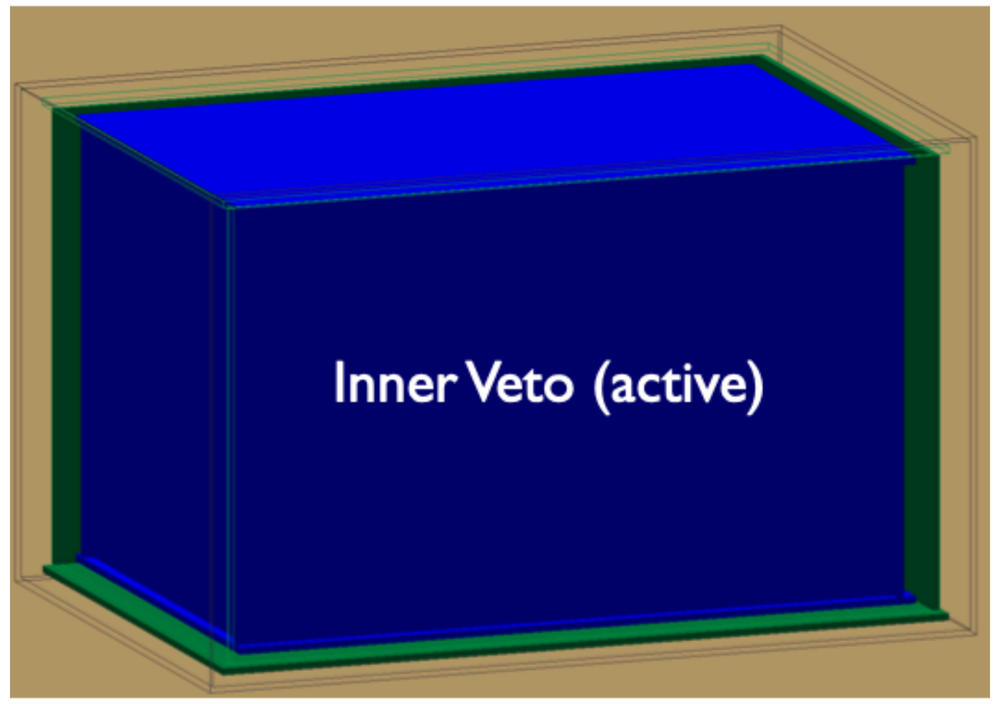
Detector Design:

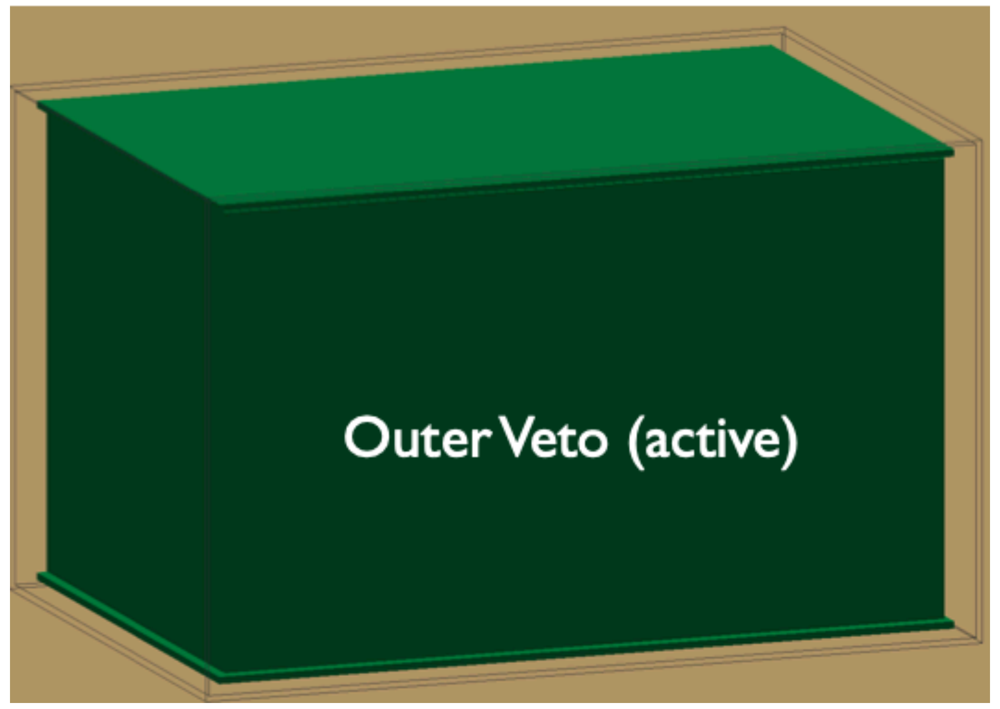
- **Electromagnetic Calorimeter**
  - Homogenus 3 tons Ecal
    - 480 BGO-OD BGO crystals (1/2 BDX volume)
    - Exploring if the 1200 PRAD PbWO crystals (1/4 BDX volume) are available
    - 800 PANDA PbWO crystals (1/4 BDX volume) which do not meet the PANDA's EM-calorimeter requirements in terms of radiation hardness.
  - 6x6 mm2 SiPM readout





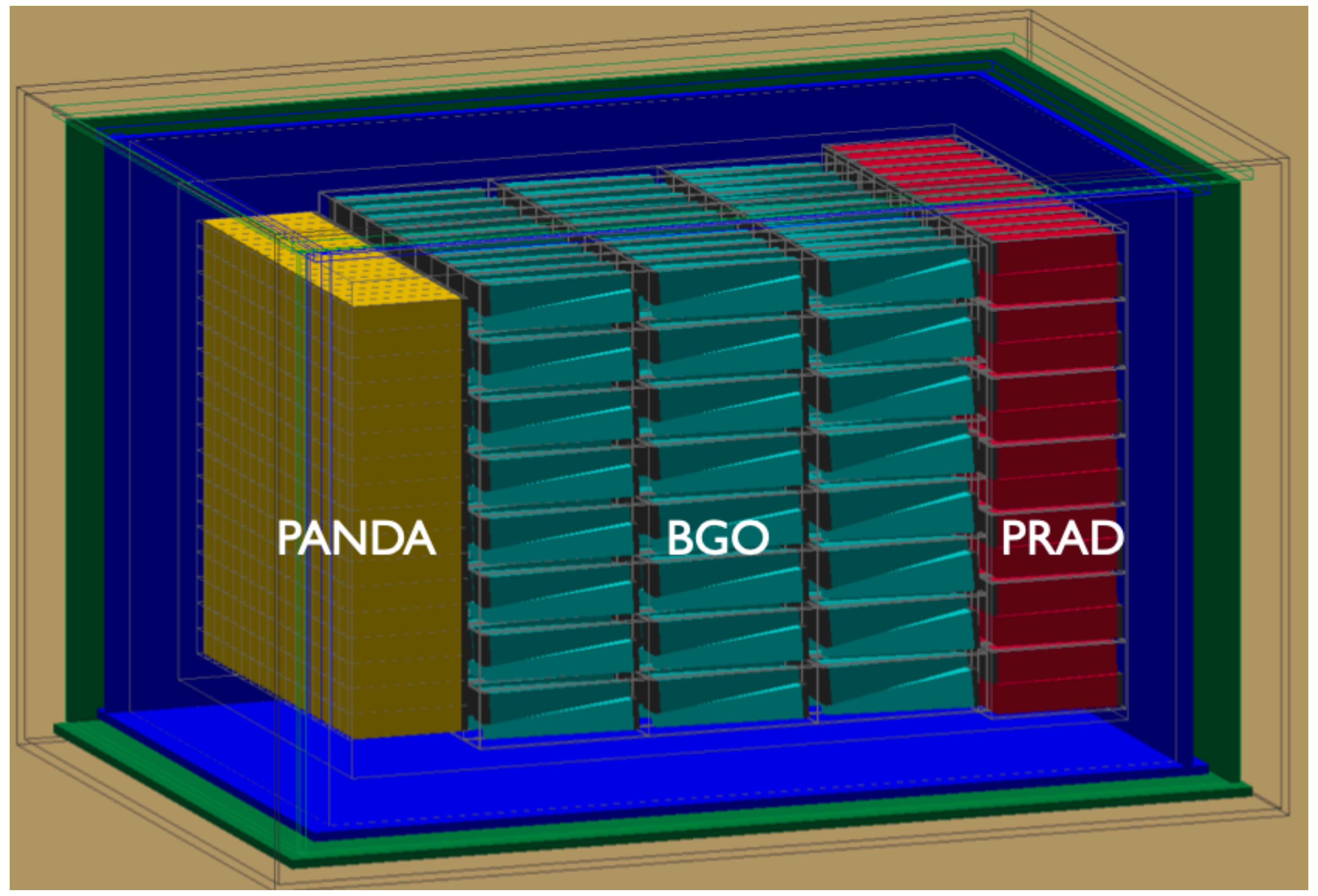


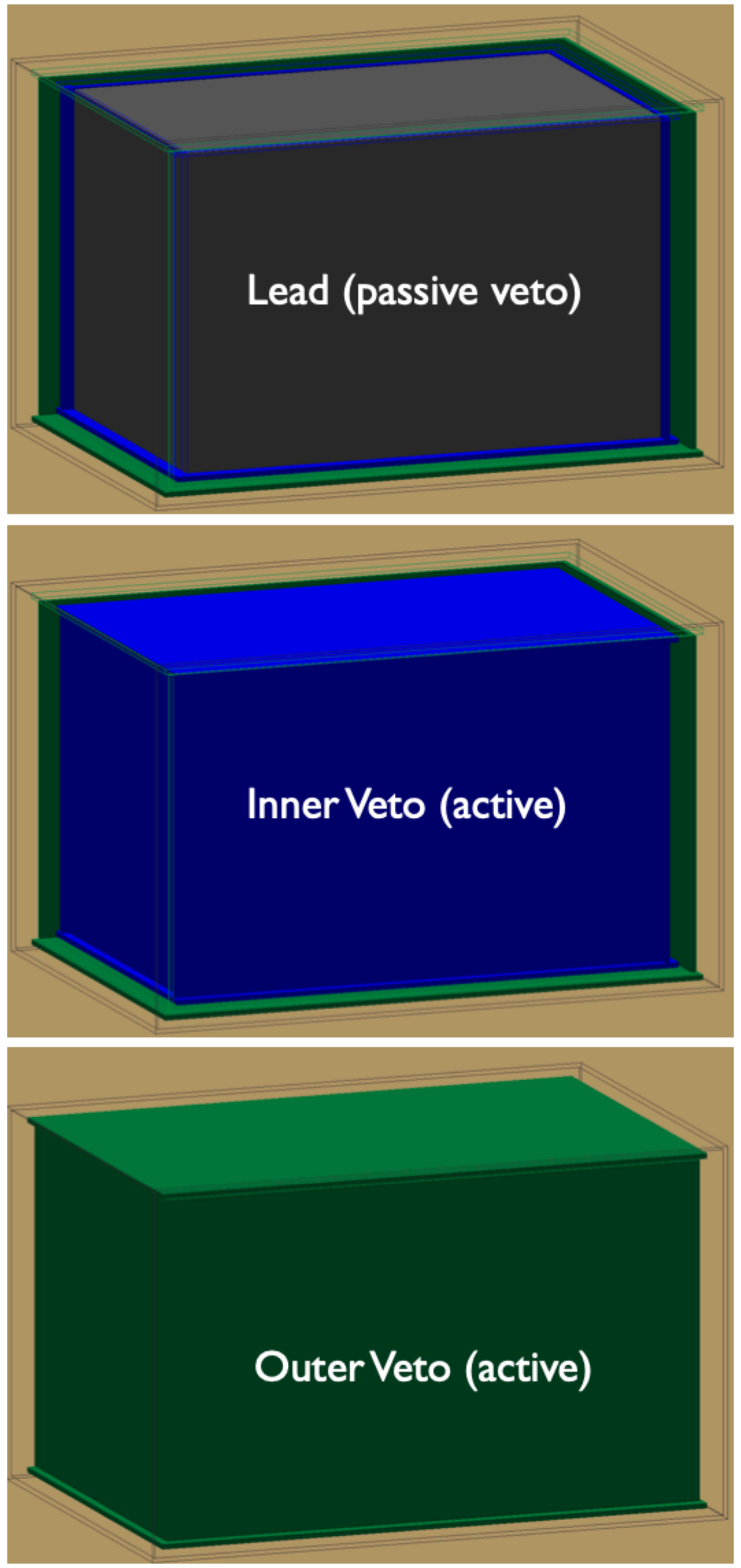




BDX detector

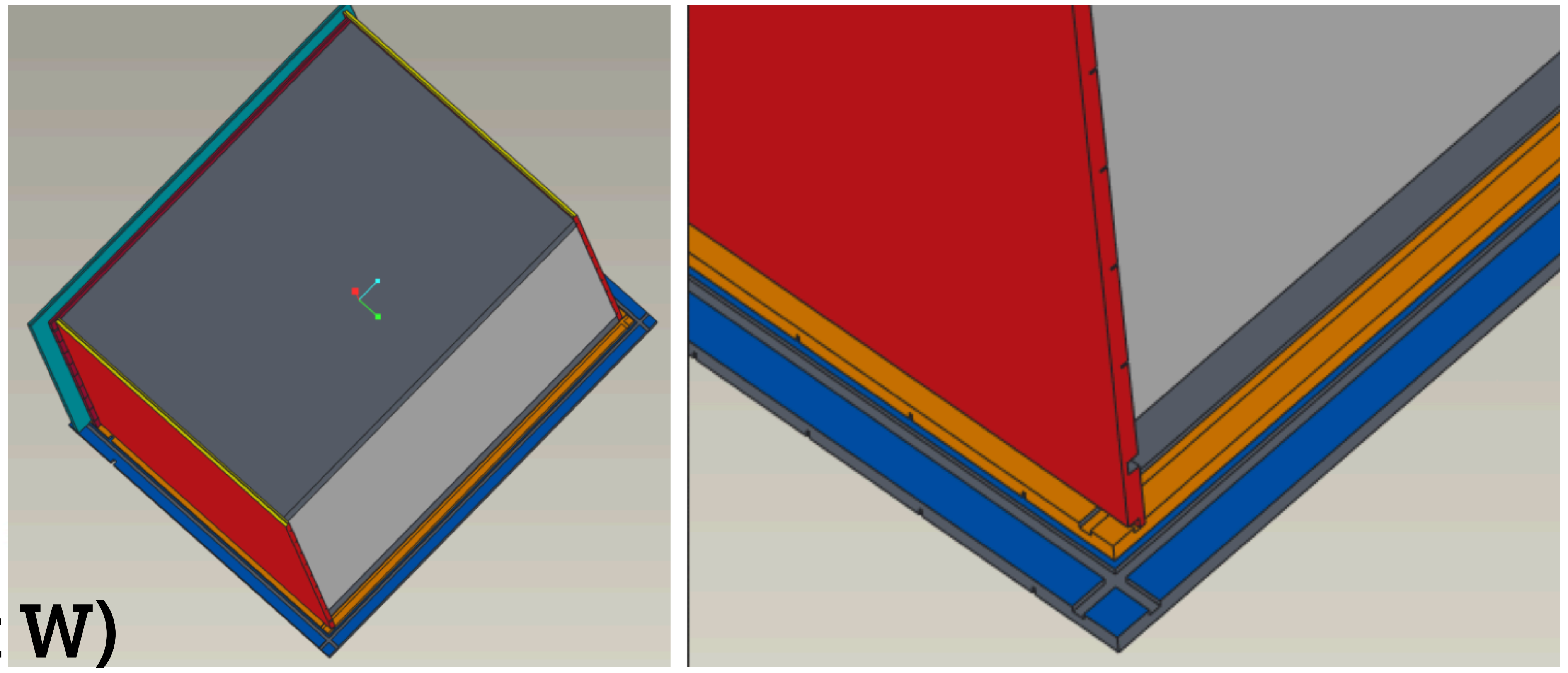
Expected signal: deposited energy (~100 MeV) in the active target and no corresponding activity on the veto system





Detector Design:

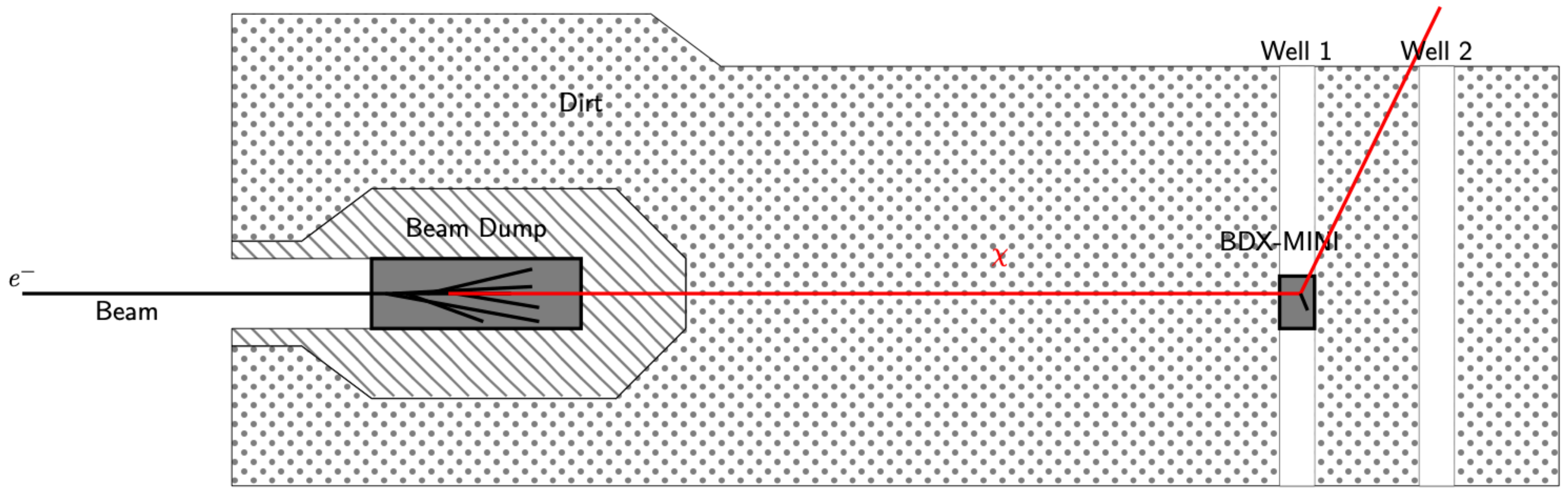
- **Veto systems:**
  - Hermetic multi layer veto
  - 2 active layer veto made of plastic scintillator counters
  - 5 cm thick lead vault
  - WLS fiber + 3x3mm2 SiPM readout



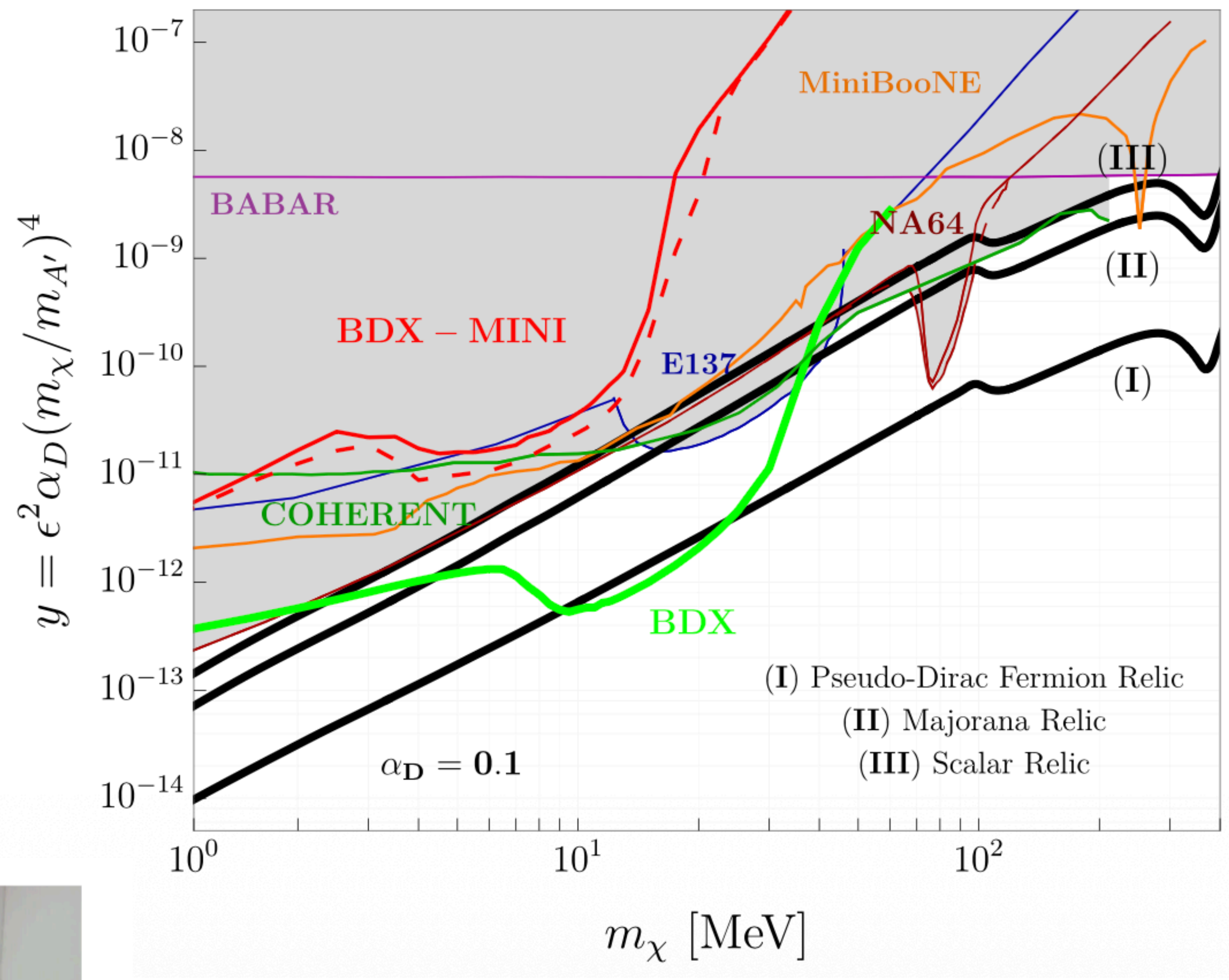
Detector Size: 1.6 x 1.2 x 1.1 m3 (L x H x W)

BDX - MINI @ JLAB

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

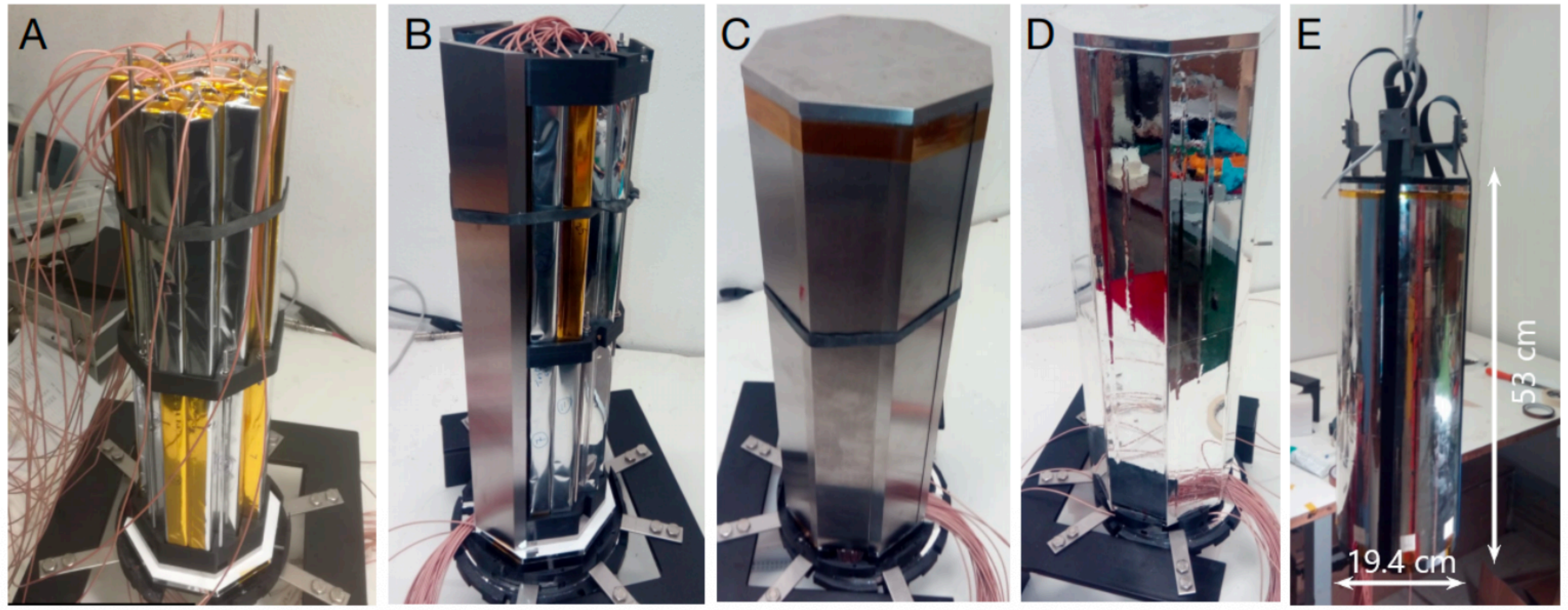


- Detector placed ~20m downstream beam dump
- 2.56 GeV e- beam, current ~ 150 uA
- Accumulated 2.5E21 EOT



Detector Design:

- 44 PANDA/CLAS12 PbWO crystals (~1% BDX active volume) - SiPM readout
- 2 plastic scintillator vetoes: cylindrical and octogonal and passive W shielding



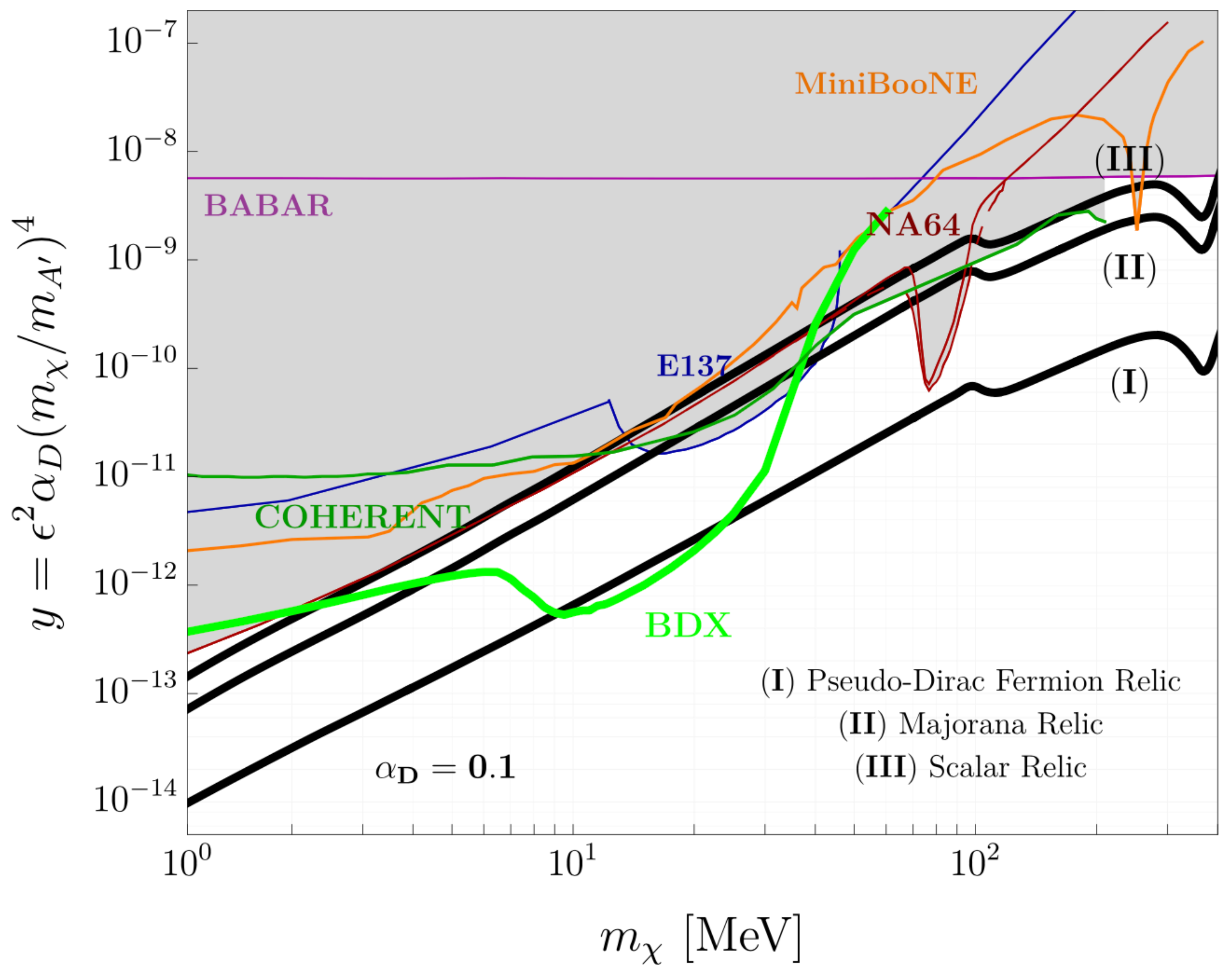
- No excess was observed
  - Evaluated 90% exclusion limit in the LDM parameter space
  - Results comparable with flagship experiments

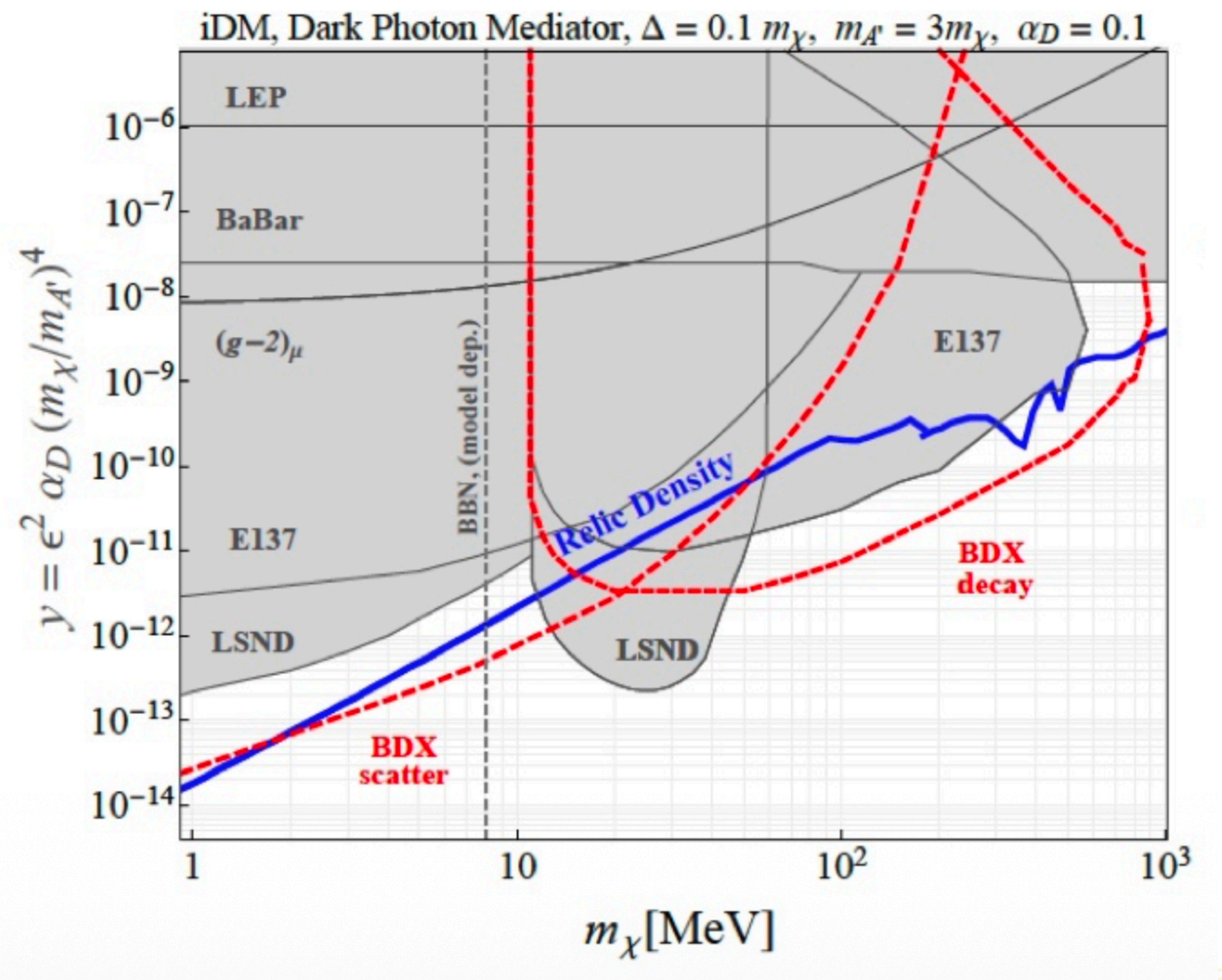
M. Battaglieri et al., Eur.Phys.J.C 81 (2021) 2, 164

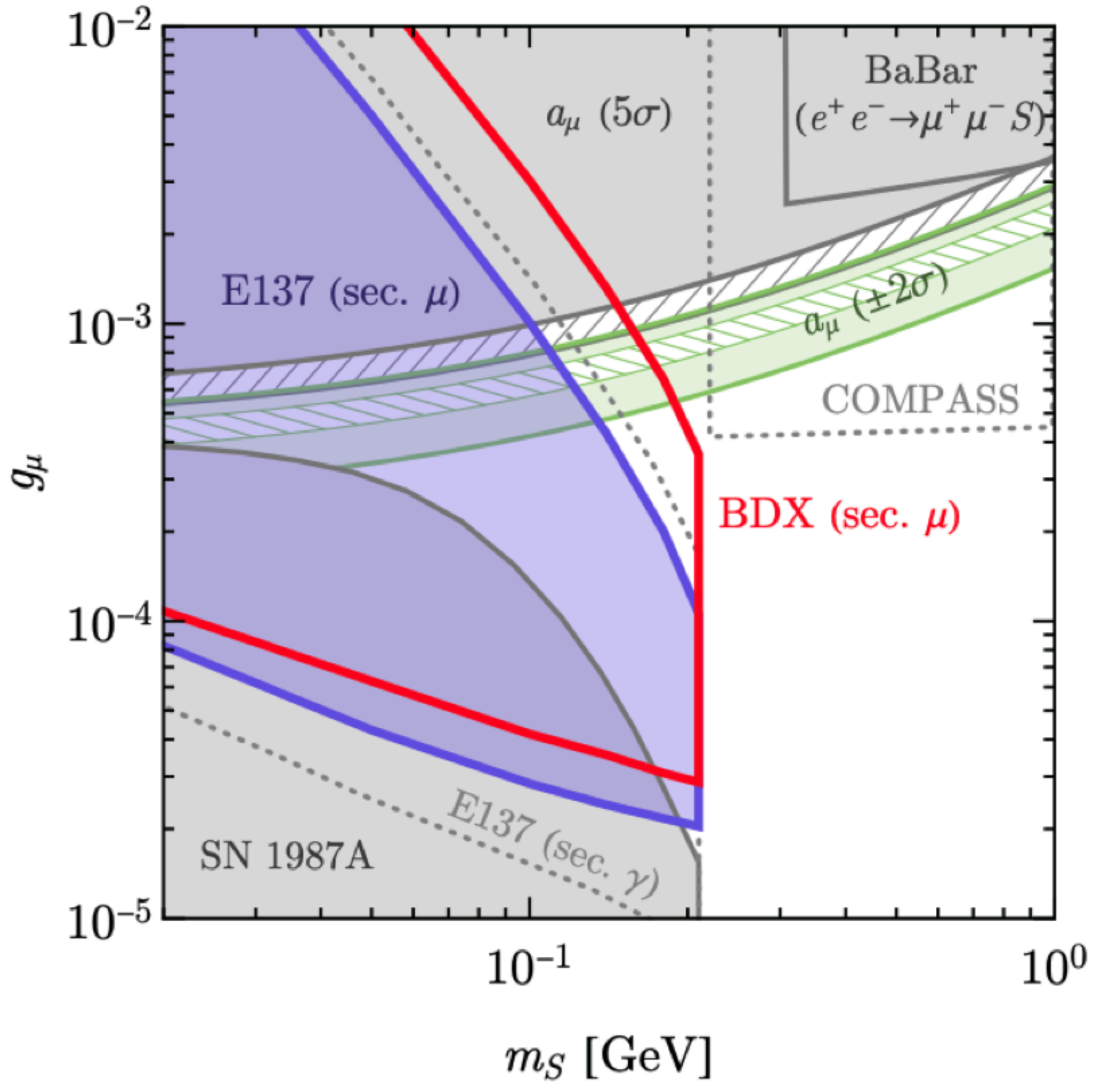
M. Battaglieri et al., Phys.Rev.D 106 (2022) 7, 072011

BDX Reach

Thanks to the CEBAF high luminosity and an optimized detector layout, BDX will be able to explore different LDM models





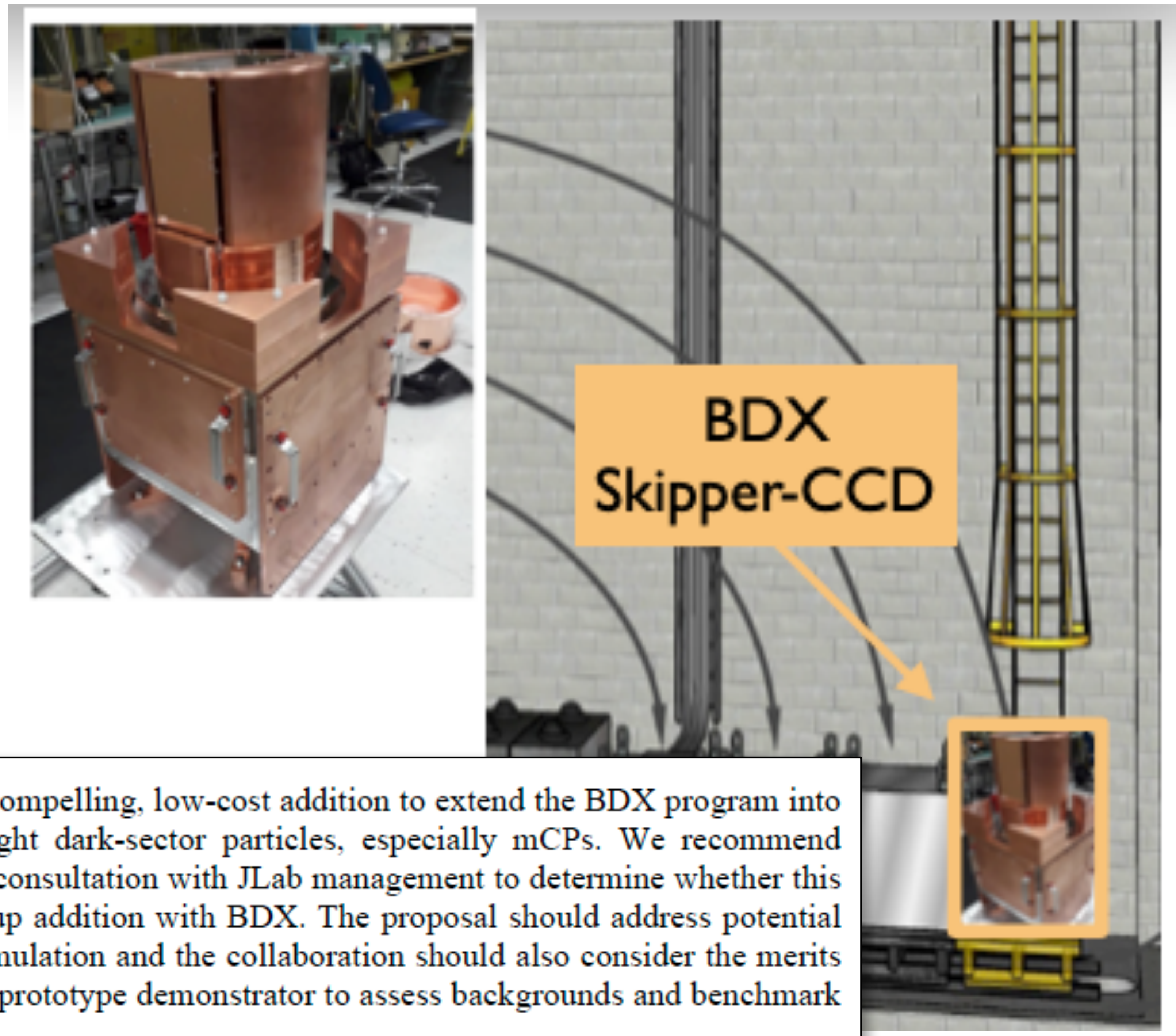


BDX @ JLAB: Status

- BDX approved by PAC46(2018)
- Waiting that JLAB will contract a company for the detailed hall drawings
- Calorimeter crystal procurement:
  - 480 BGO from BGOOD @Bonn - Done!
  - Request to PANDA collaboration to use 800 (or more) PbWO crystals (did not meet PANDA specs)
- Veto procurements:
  - Plastic scintillators ready to be machined
  - SiPMs available
- BDX is expected to run in parallel with Moller experiment

Extending BDX

Extending BDX detector to test other models
- Addition of Skipper-CCD by SBU/FNAL groups
- LOI presented at PAC53
- Full proposal encouraged



Summary: This LOI describes a compelling, low-cost addition to extend the BDX program into a new regime of sensitivity to light dark-sector particles, especially mCPs. We recommend proceeding to a full proposal after consultation with JLab management to determine whether this should be considered as a run group addition with BDX. The proposal should address potential backgrounds through continued simulation and the collaboration should also consider the merits of a staged plan with a small-scale prototype demonstrator to assess backgrounds and benchmark the simulations.

Extending BDX sensitivity to further models
- Axion-Like Particles (ALPS)
- Interest at HEP experiments (SHIP)

CALT-TH/2025-029 CERN-TH-2025-178

Long-lived axion-like particles from electromagnetic cascades

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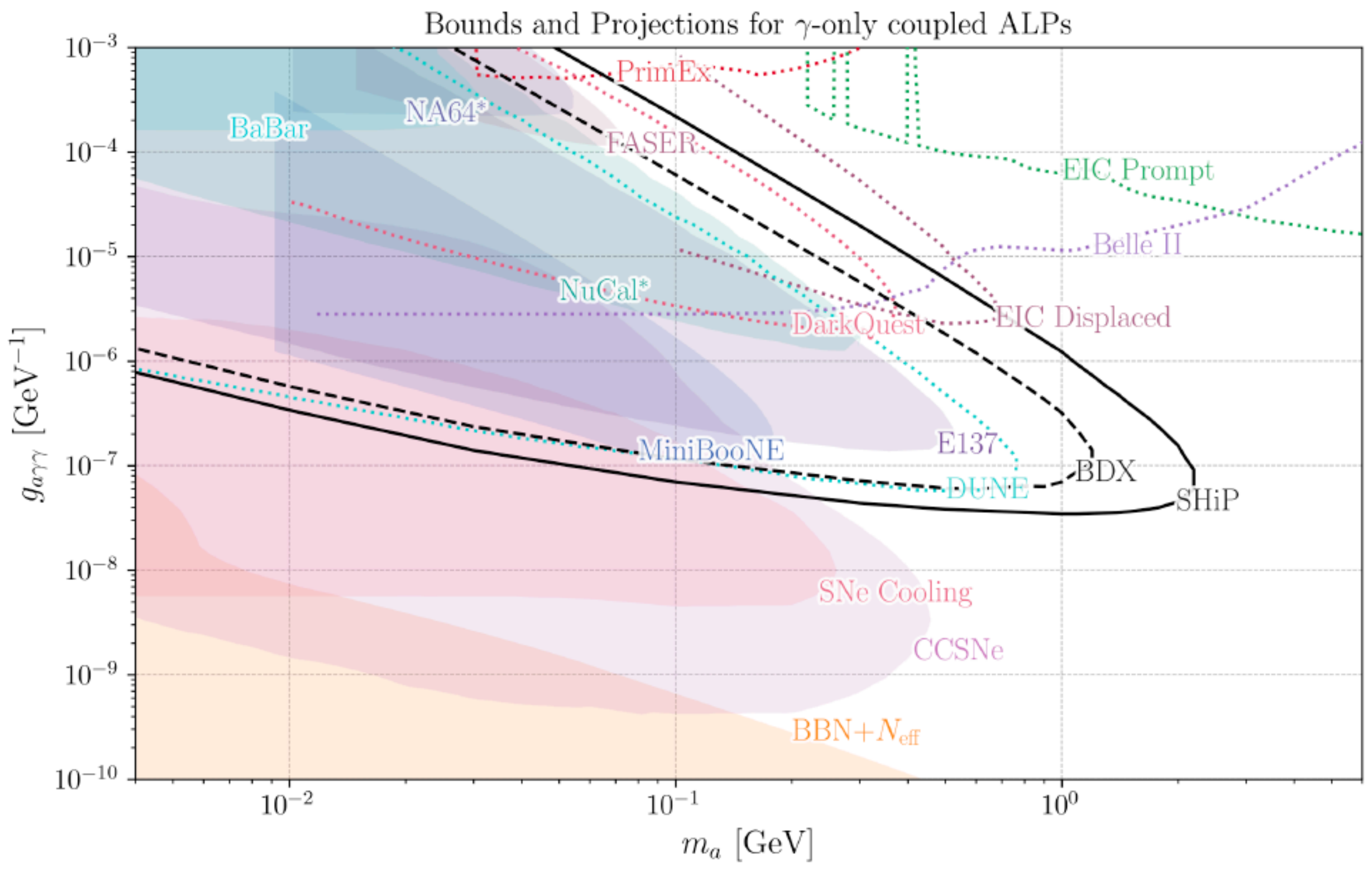
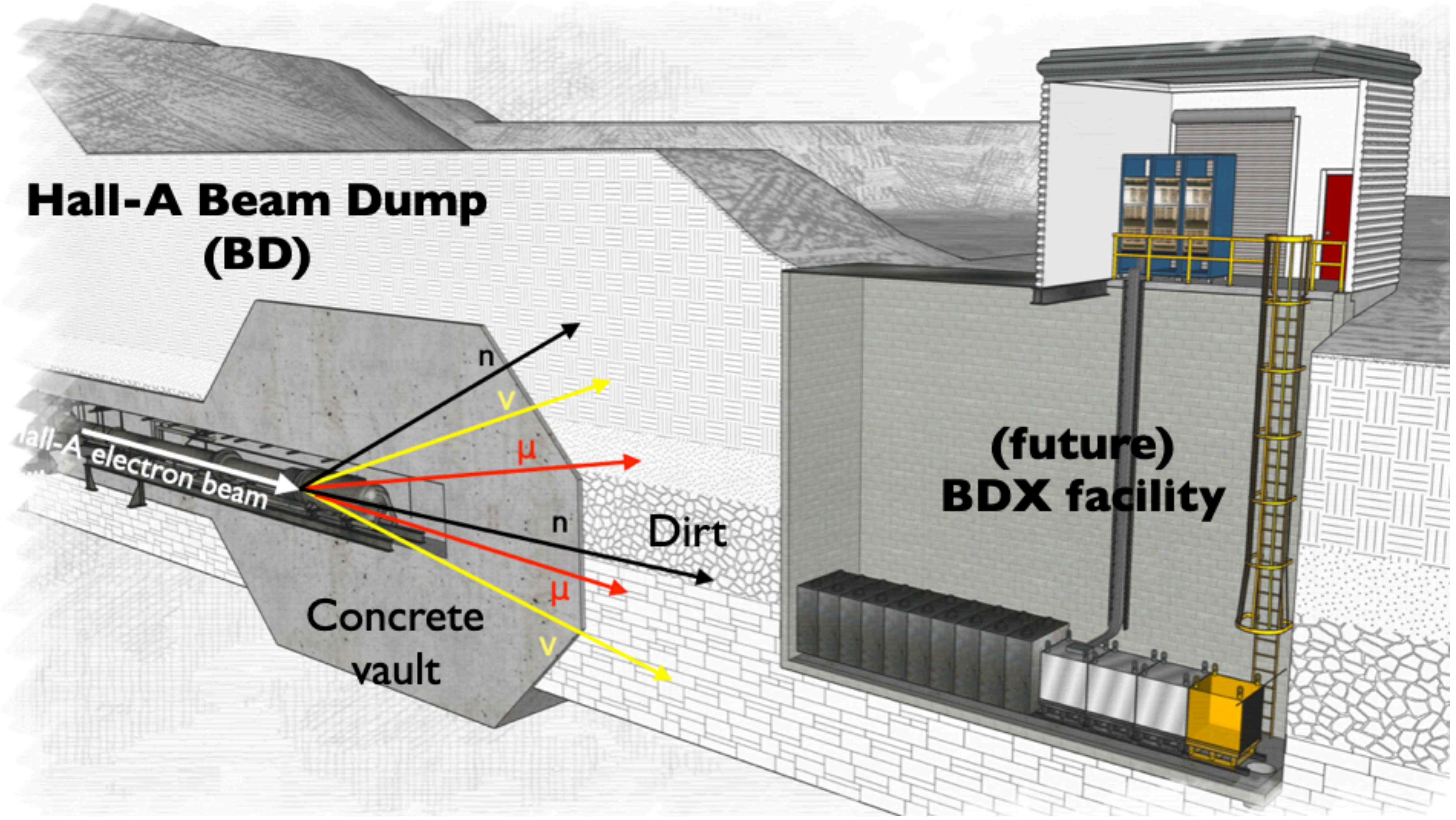
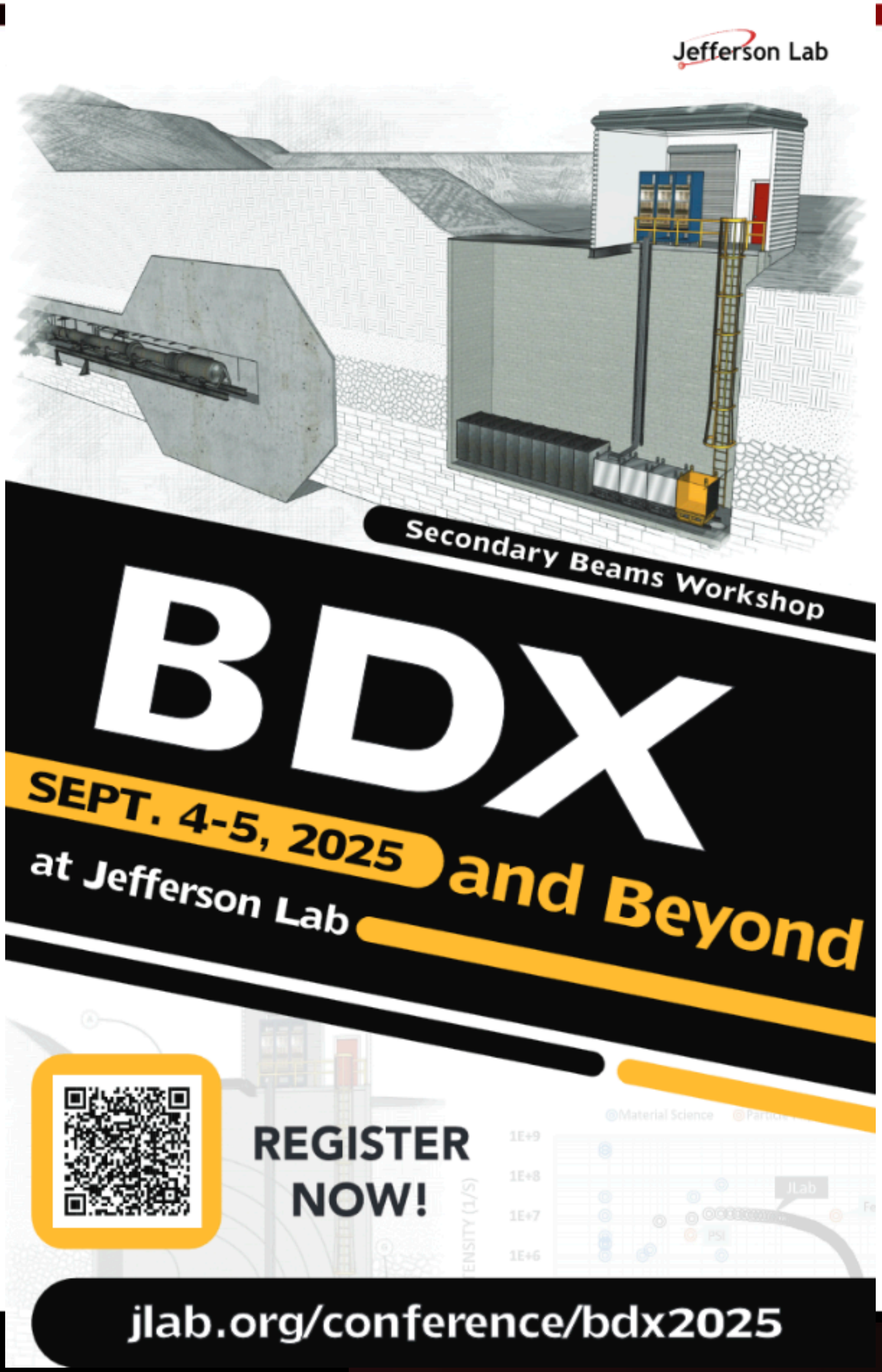
We study axion-like particles (ALPs) in beam dump experiments, focusing on the Search for Hidden Particles (SHiP, at CERN) experiment and the Beam Dump eXperiment (BDX, at JLab). Many existing projections for sensitivity to ALPs in beam dump experiments have focused on production from either the primary proton/electron beam, or - in the case of SHiP - the secondary (high-energy) photons produced by neutral meson decays (e.g., $\pi^0 \to \gamma\gamma$). In this work, we study the subsequent production of axions from the full electromagnetic shower in the target, finding order-of-magnitude enhancements in the visible decay yields across a wide range of axion masses. We update SHiP's sensitivity curve and provide new projections for BDX. Both experiments will be able to reach currently unexplored regions of ALP parameter space.



BDX & Beyond

- International Workshop on Secondary Beams at Jefferson Lab (BDX & Beyond) held at Jefferson Lab on 4-5 September 2025
- Explored the potential of intense muon and neutrino secondary beams to extend the BDX facility with some additional installations
- A parallel study is underway to evaluate the potential of secondary neutron beams.



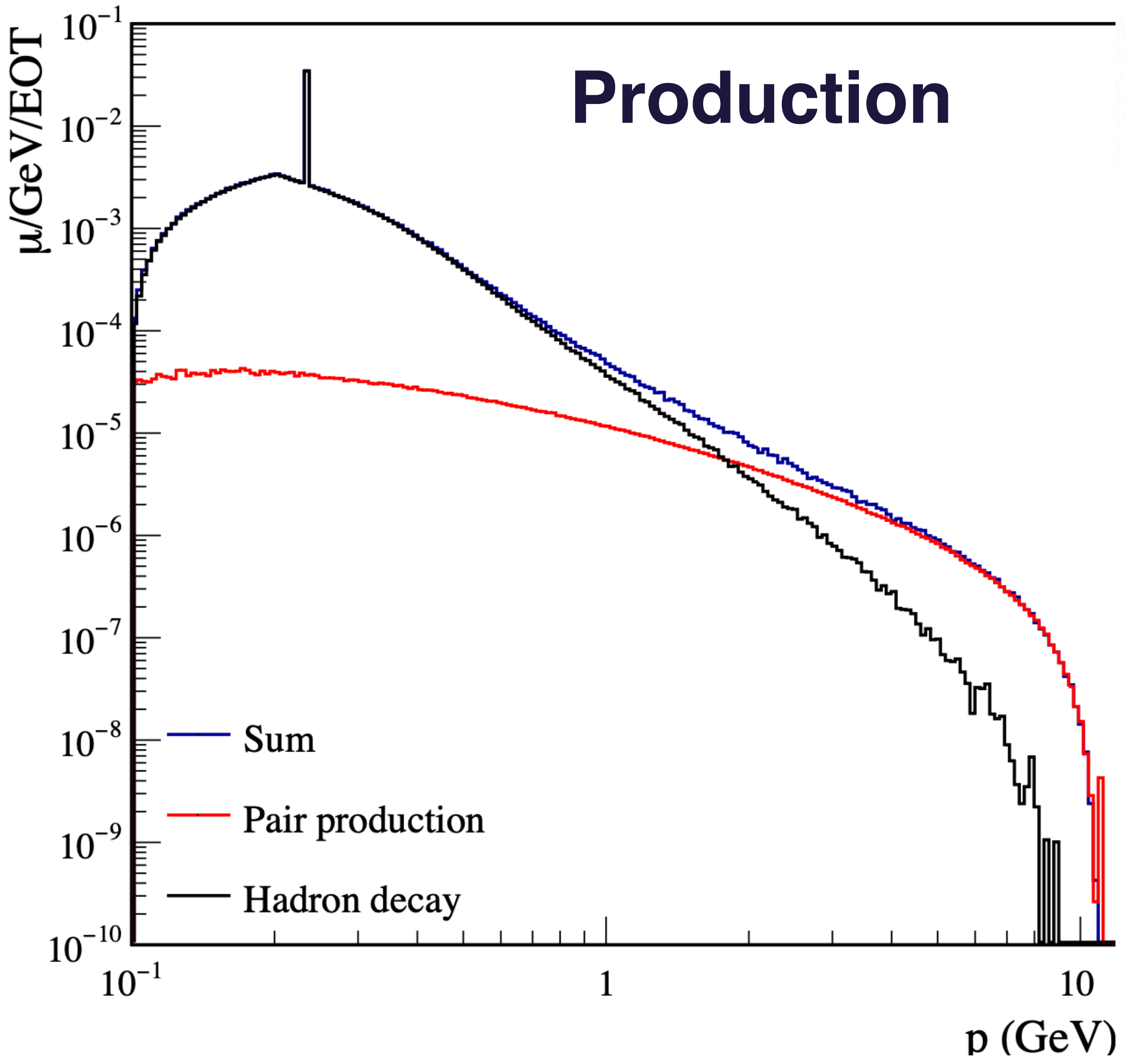


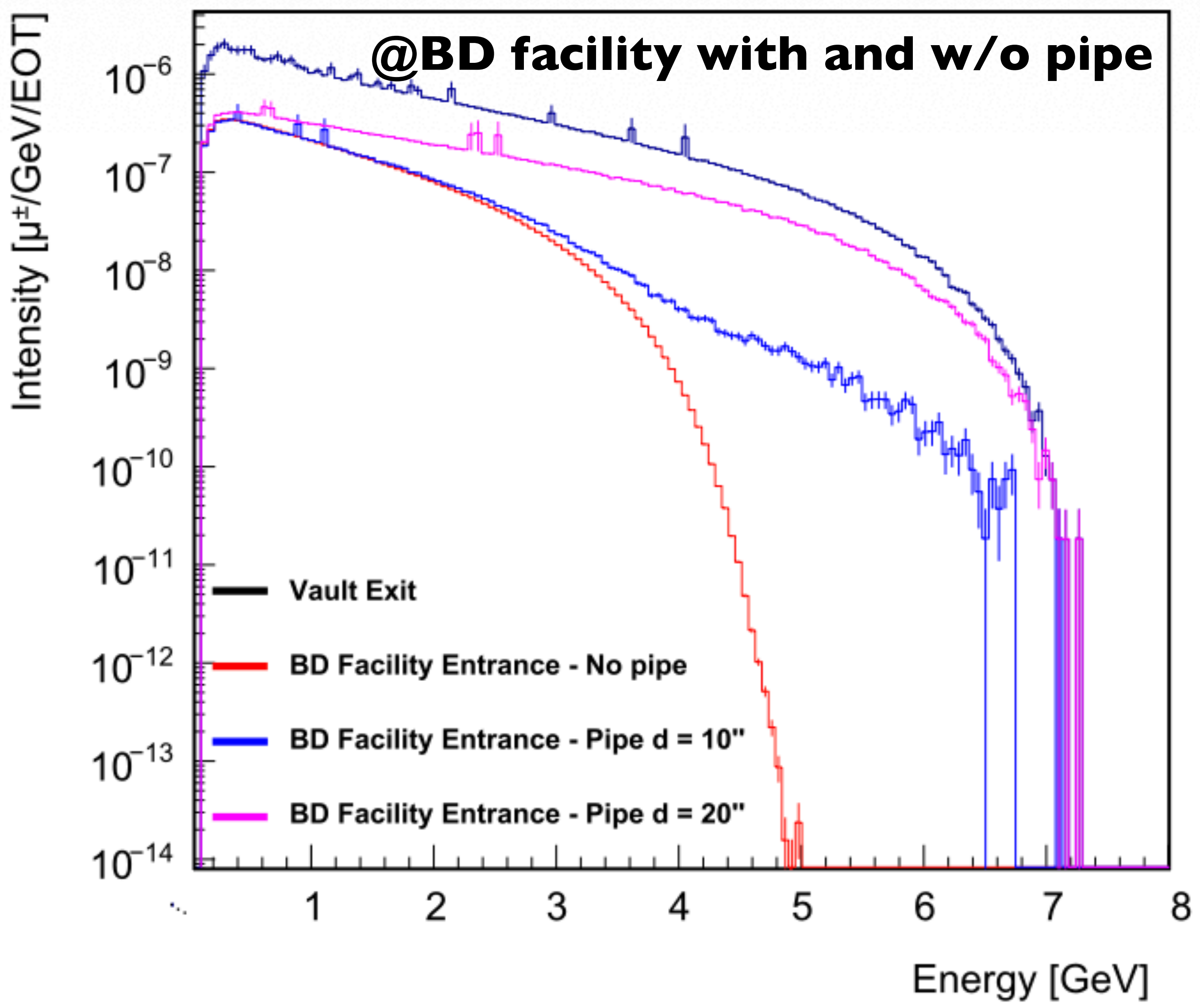
Muon beams @ BDX facility

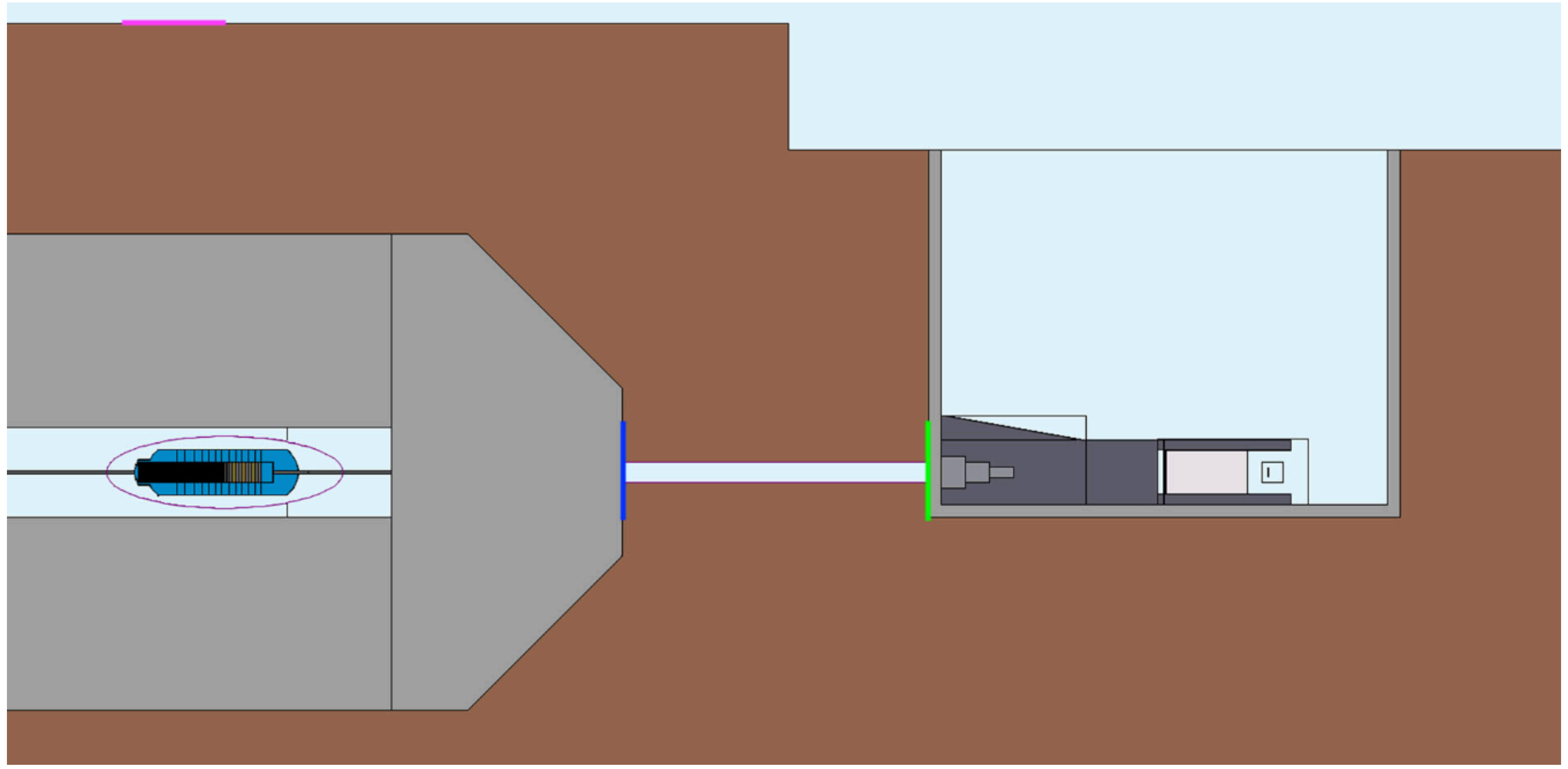
M. Battaglieri et al., Secondary beams at high-intensity electron accelerator facilities. Instruments 8, 1 (2024). https://doi.org/10.3390/instruments8010001

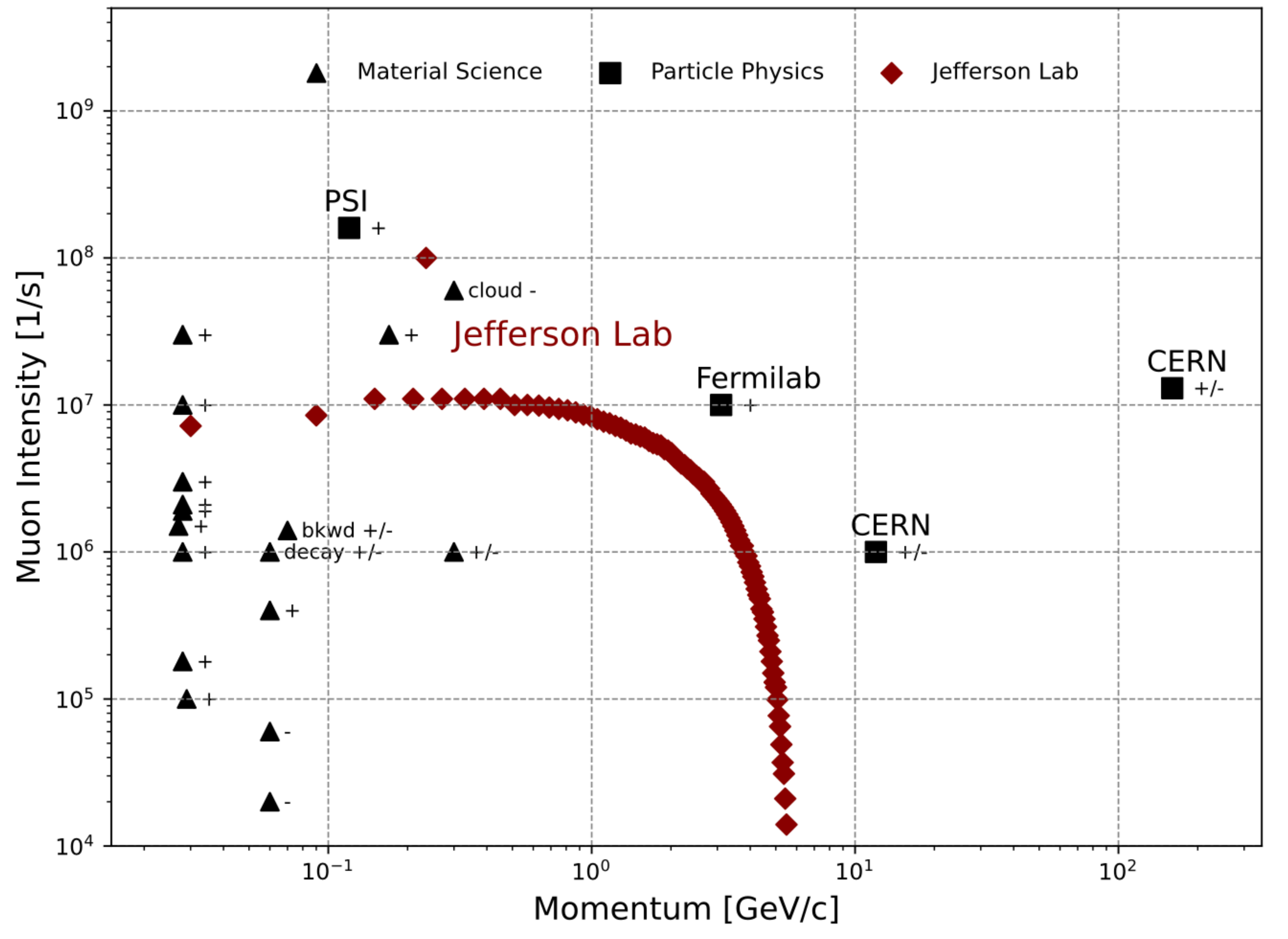
Achenbach, P., Afanasev, A., Ambrozewicz, P. et al. A Beamdump facility at Jefferson Lab. Eur. Phys. J. A 61, 285 (2025). https://doi.org/10.1140/epja/s10050-025-01748-6

- Muon flux estimated using FLUKA for 11 GeV e- beam (I~50uA) on Hall-A BD
- High-energy muon produced via two processes:
  - Photo-production of π and k and decay
  - Pair-production: $\gamma N \rightarrow \mu\mu N$
- At the entrance of BDX facility the muon flux is:
  - No pipe: 9E7 mu/s
  - Pipe 10'': 2E8 mu/s
  - Pipe 20'': 3E8 mu/s







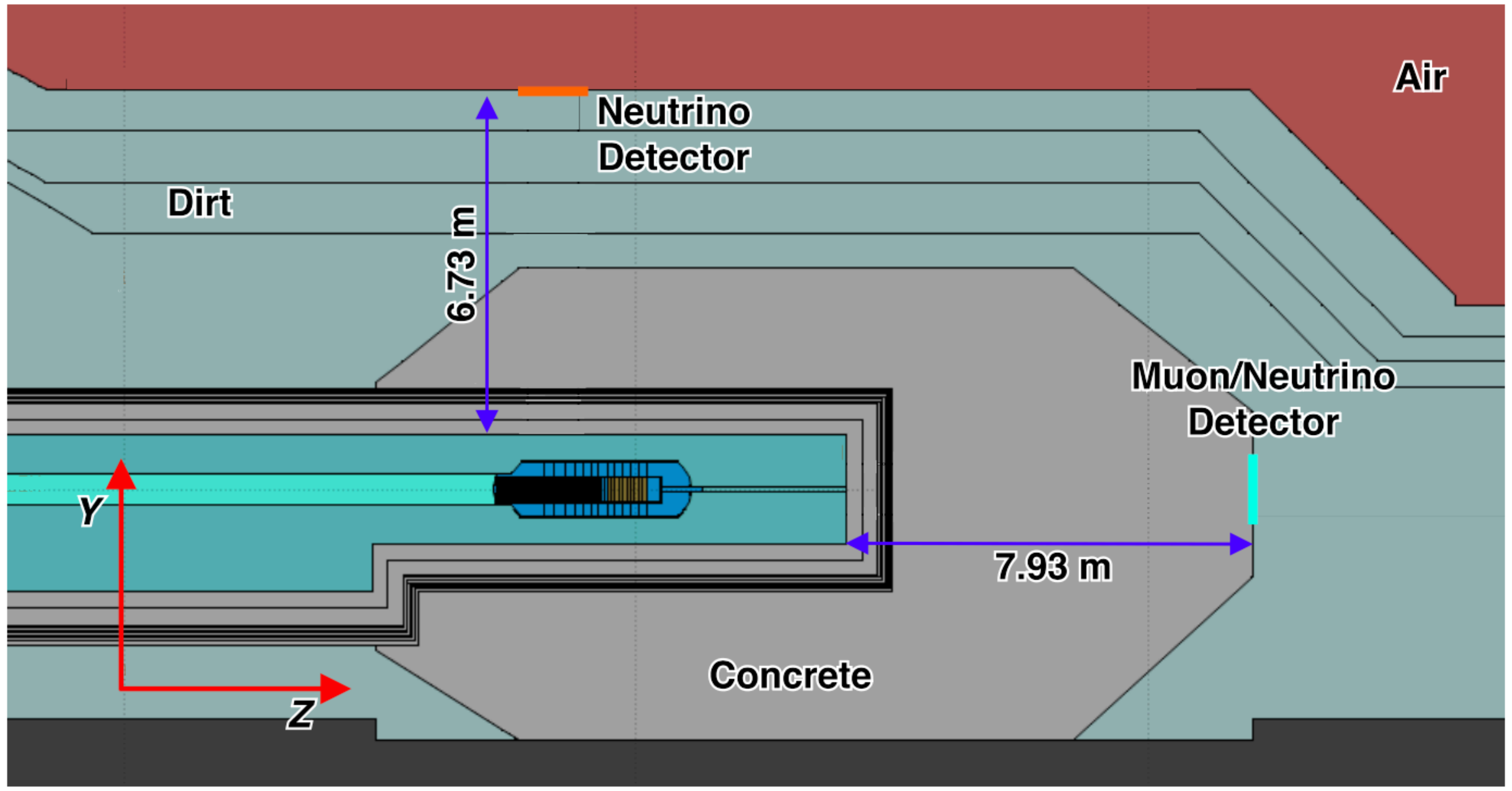


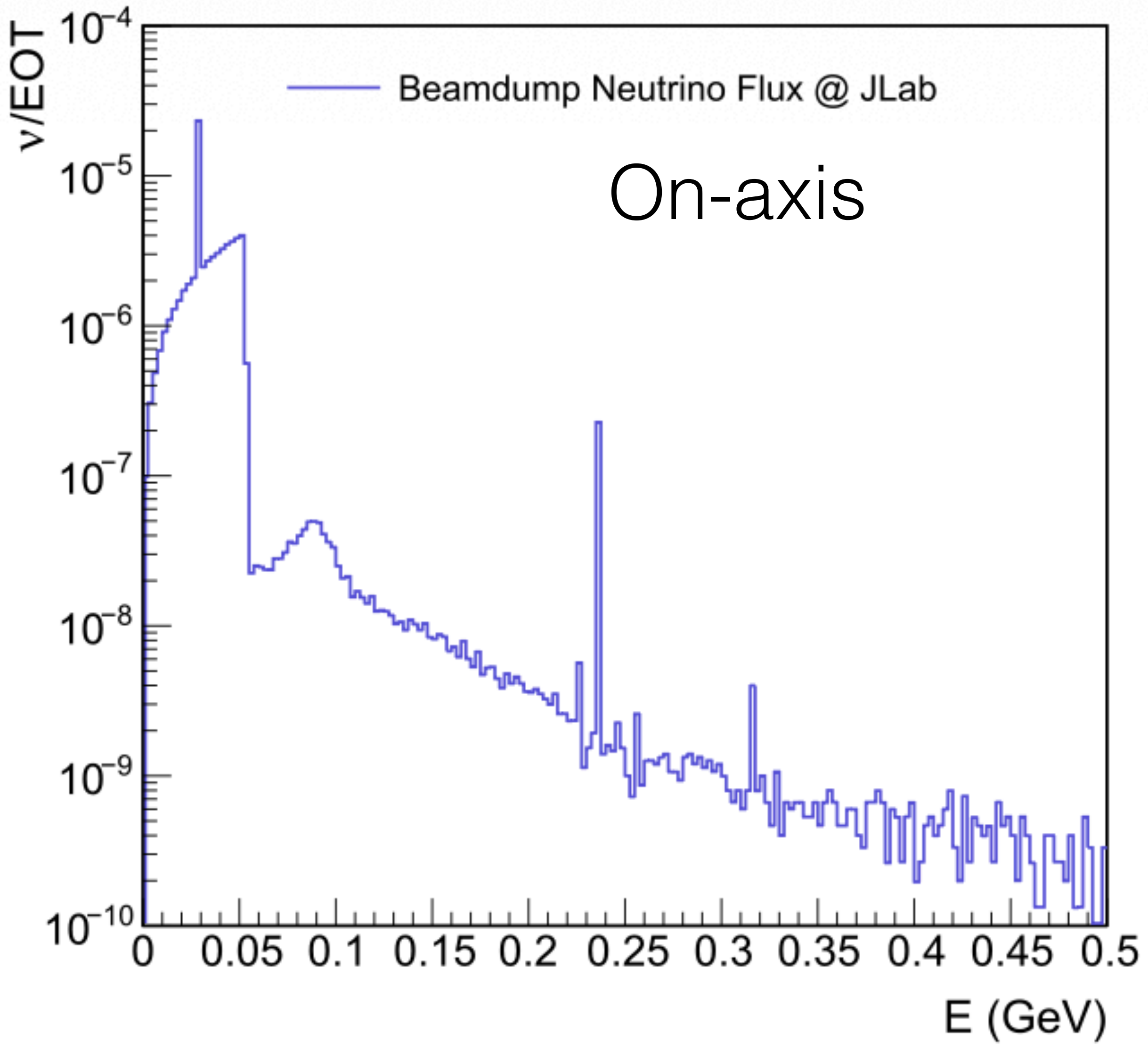
Neutrino beams @ BDX facility

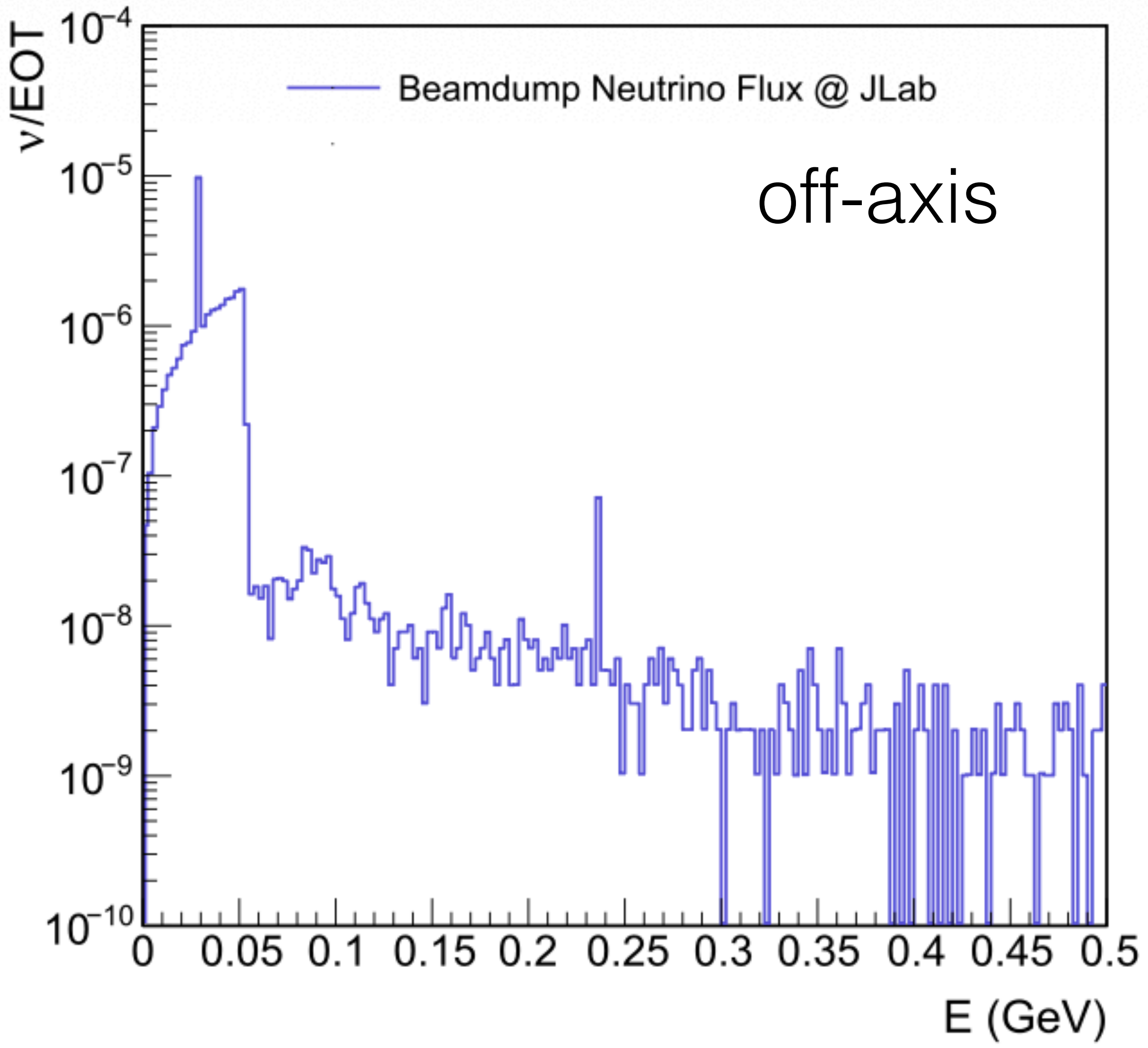
M. Battaglieri et al., Secondary beams at high-intensity electron accelerator facilities. Instruments 8, 1 (2024). https://doi.org/10.3390/instruments8010001

Achenbach, P., Afanasev, A., Ambrozewicz, P. et al. A Beamdump facility at Jefferson Lab. Eur. Phys. J. A 61, 285 (2025). https://doi.org/10.1140/epja/s10050-025-01748-6

- Neutrino flux estimated using FLUKA for 11 GeV primary e- beam (I~50uA) on Hall-A BD
- Low energy part due to pion and muon decay at rest
  - π decay produces a prompt 28.5 MeV ν_μ along with a μ witch subsequently decays producing a ν_e ν_μ
- High energy ν from in-flight pion and kaon decay





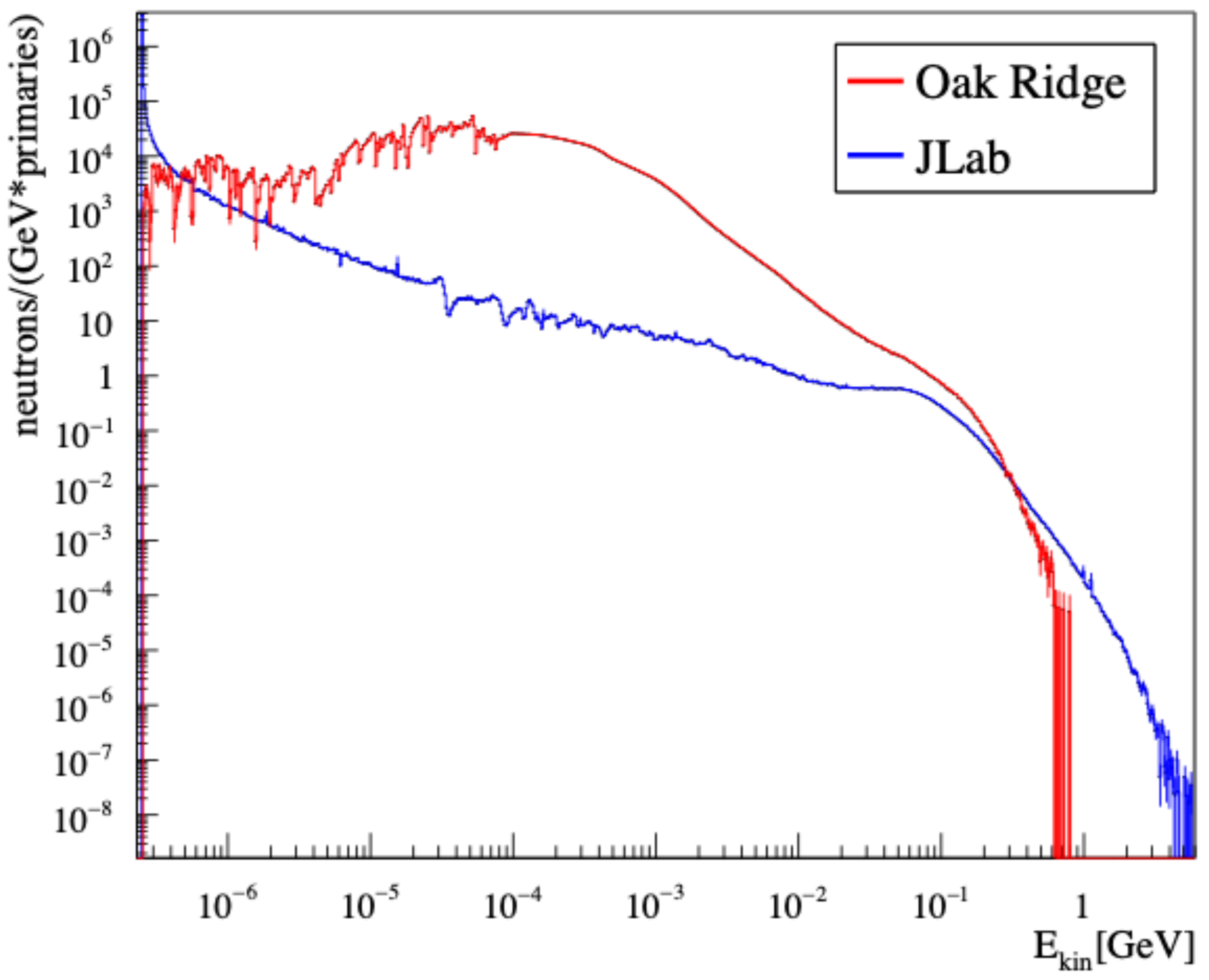


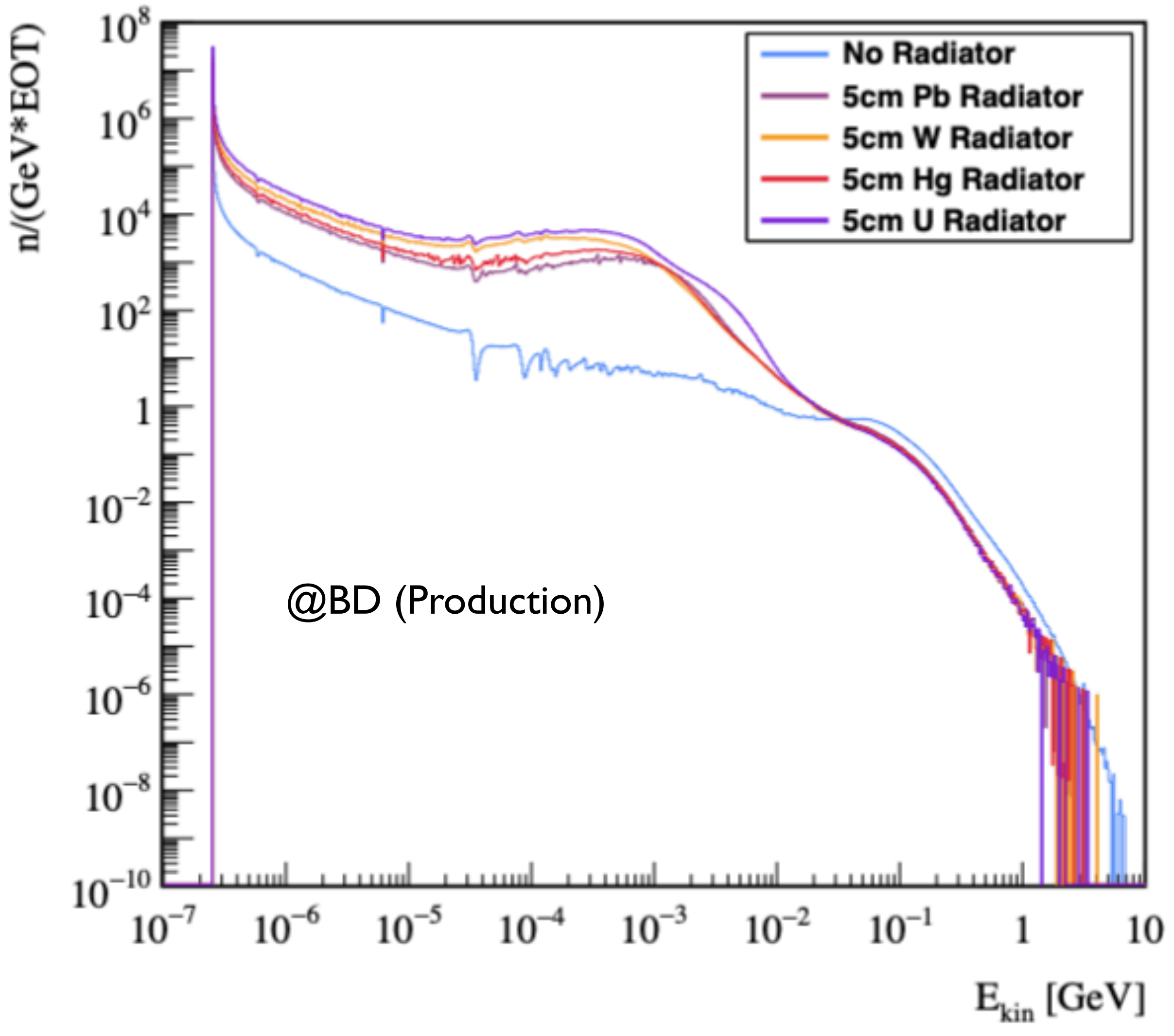
Beam Energy	Off-Axis Flux [ν/EOT/m^2]	On-Axis Flux [ν/EOT/m^2]
11 GeV	6.7×10^{-5}	2.9×10^{-5}
22 GeV	1.9×10^{-4}	6.3×10^{-5}

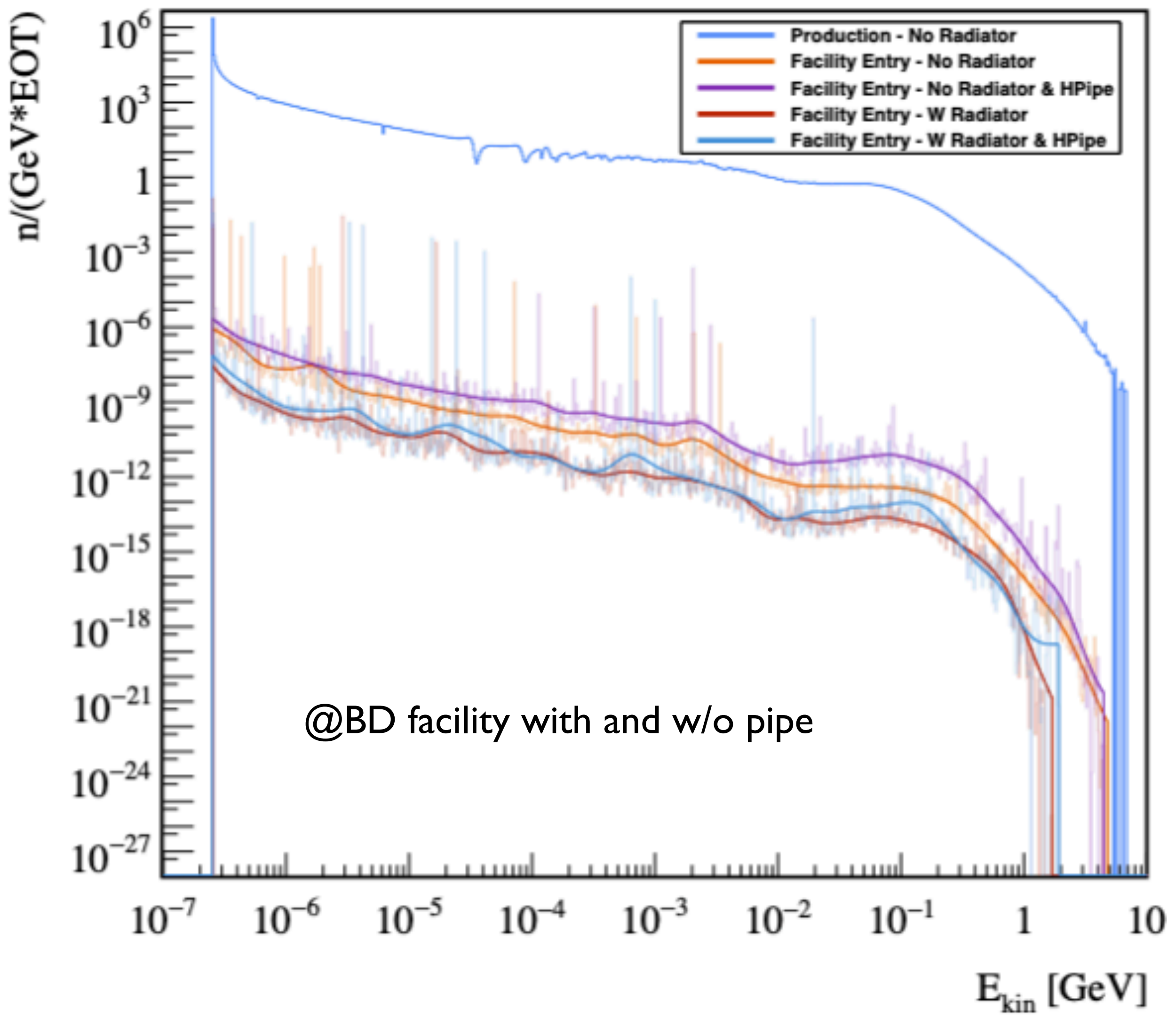
- Flux comparable the integrated flux of the flagship DAR-neutrino facility SNS@Oak Ridge National Lab

Neutron beams @ BDX facility

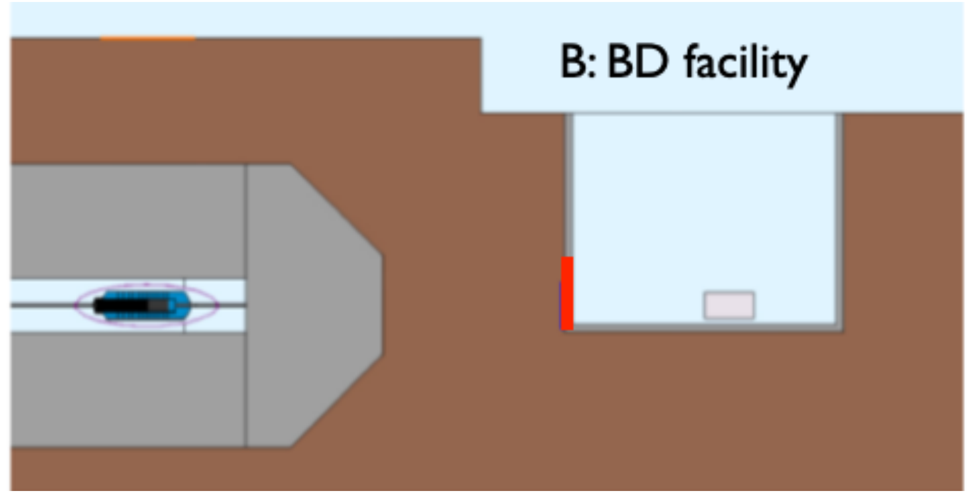
- Neutrons flux estimated using FLUKA for 11 GeV primary e- beam (I~50uA) on Hall-A BD
  - FLUKA simulation framework cross checked with SNS data
- Transport: three geometries studied: current, BD facility, BD facility + horizontal (air) pipe

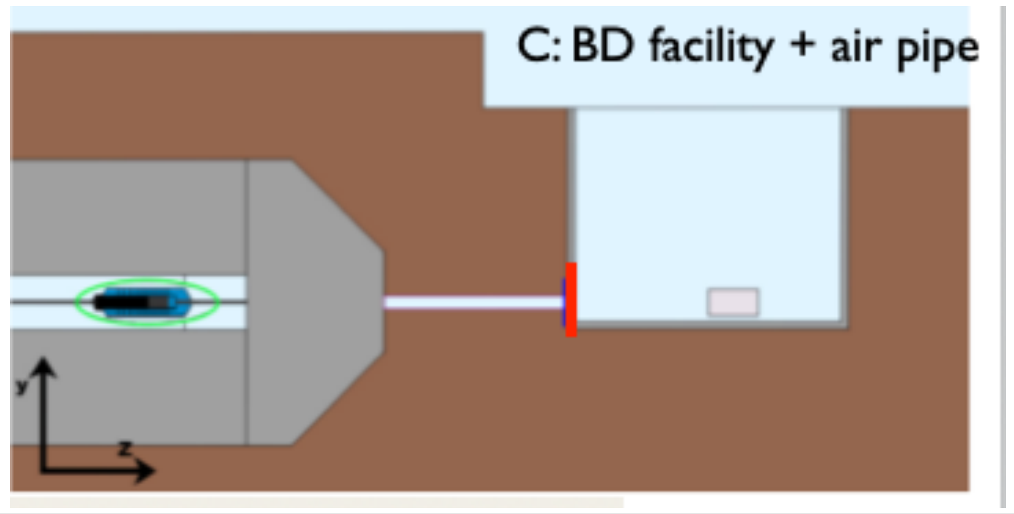






Config	100 keV – 1 MeV		1 – 100 MeV		100 MeV – 1 GeV		1 – 10 GeV	
	flux	x 3x10^{14}	flux	x 3x10^{14}	flux	x 3x10^{14}	flux	x 3x10^{14}
Production (no rad.)	5.70×10^{-03}	$1.71\times10^{+12}$	6.30×10^{-02}	$1.89\times10^{+13}$	1.80×10^{-02}	$5.40\times10^{+12}$	5.60×10^{-05}	$1.68\times10^{+10}$
Config B (no rad., no pipe)	1.10×10^{-12}	$3.30\times10^{+02}$	7.90×10^{-13}	$2.37\times10^{+02}$	5.90×10^{-16}	1.77×10^{-01}	2.70×10^{-19}	8.10×10^{-05}
Config C (no rad. + pipe)	1.10×10^{-12}	$3.30\times10^{+02}$	1.20×10^{-10}	$3.60\times10^{+04}$	1.20×10^{-14}	$3.60\times10^{+00}$	4.70×10^{-17}	1.41×10^{-02}
Config B (W rad., no pipe)	1.20×10^{-16}	3.60×10^{-02}	9.30×10^{-17}	2.79×10^{-02}	2.40×10^{-17}	7.20×10^{-03}	1.90×10^{-21}	5.70×10^{-07}
Config C (W rad. + pipe)	1.90×10^{-11}	$5.70\times10^{+03}$	1.10×10^{-11}	$3.30\times10^{+03}$	7.40×10^{-16}	2.22×10^{-01}	2.40×10^{-20}	7.20×10^{-06}





Conclusions

- Existence of Dark Matter is a compelling reason to investigate new forces and matter over a broad range of mass
- Extensive experimental plans at high intensity e-facility to search for LDM: JLab, LNF, Mainz, SLAC
- Jefferson Lab is the world-leader facility for present and near-future LDM searches
- The BDX concept has been tested with prototypes, dedicated measurement campaigns and running a pilot experiment (BDX-MINI) demonstrating the technique and the physics reach
- Collecting 10^22 EOT in 285 days of parasitic running at 11 GeV, the BDX experiment would be >10 times more sensitive than previous experiments
- The high intensity (~50uA), medium energy (~10 GeV) CEBAF electron beam at Jefferson lab is ideal for producing secondary beams
- Secondary beams offer new opportunities to complement hadron physics at lepton-beam facilities fully parasitically