Opportunities beyond hadronic physics @JLAB:
Future infrastructures

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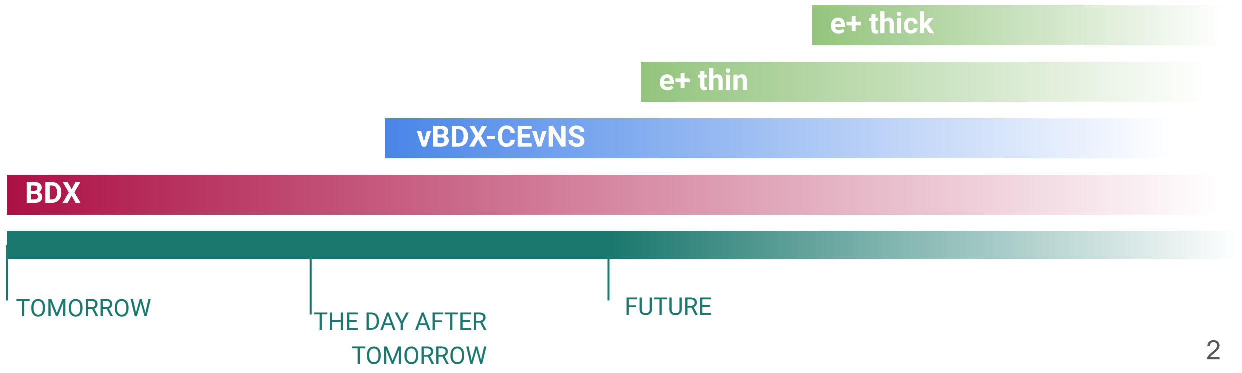
Outline

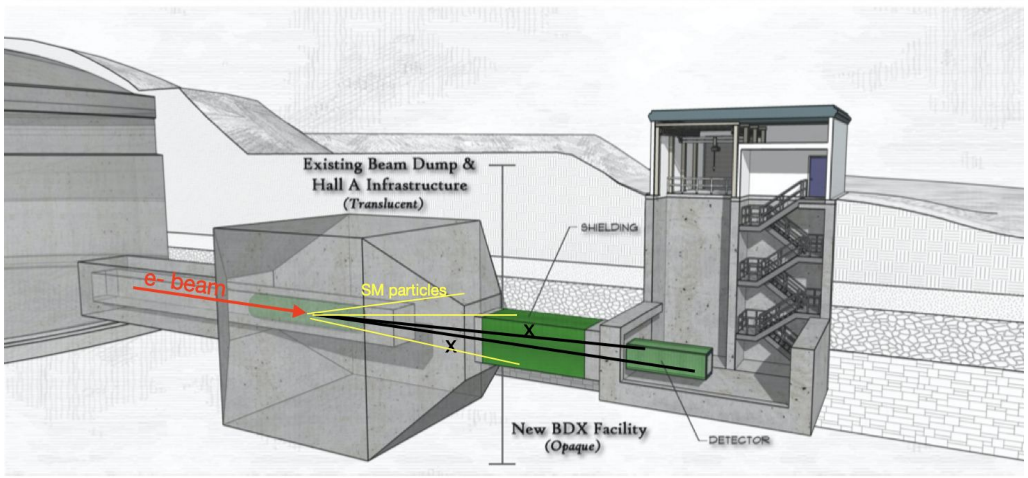
- ❖ New research lines using secondary beams produced by interaction of e- beam and dump:
  - ➢ Light Dark Matter beam: BDX experiment
  - ➢ Neutrino beam: Coherent elastic ν-Nucleus scattering measurement

- ❖ LDM search with positron beams:
  - ➢ thin target approach
  - ➢ thick target approach



The Beam Dump eXperiment - BDX

- BDX is a **JLAB experiment** approved by PAC46
- Unique experiment able to **PRODUCE** and **DETECT** light dark matter
- Two step experiment:
  - **production** of LDM beam
  - **detection** of LDM particle: χ scatters on e- in the detector realising visible signal



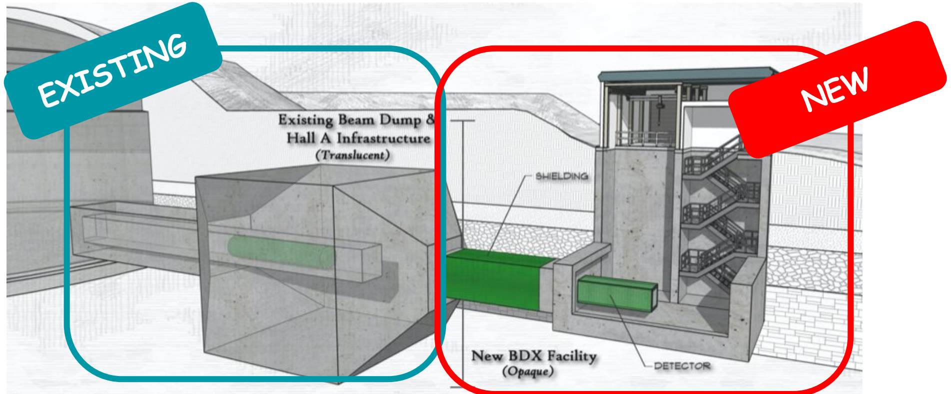
The experiment is designed with two goals

- **Maximize production and detection of LDM**
  - high intensity beam
  - ~1m3 detector - medium/high density material

- **Reduce backgrounds**
  - cosmic backgrounds
  - beam-related backgrounds
  - passive shielding material and active veto system

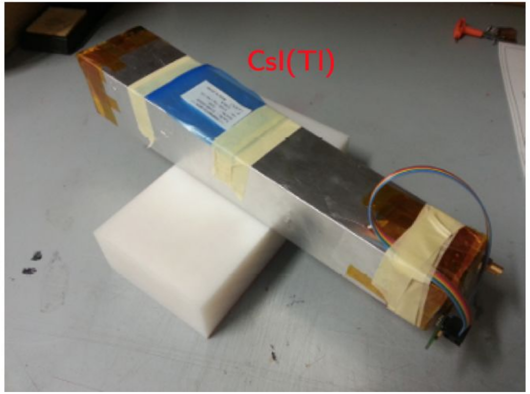
BDX @ JLAB

- **JLAB offers the best condition for BDX**
  - A high energy beam: 11 GeV
  - The highest available electron beam current: ~65uA (currently)
  - Charge : 10^22 EOT
  - Fully parasitic wrt Hall-A physics program
- **New facility to be built** in front of Hall-A beam dump
  - Passive shielding layer between beam dump and detector to reduce SM beam-related background
  - Sizeable overburden (~10 m water-equivalent) to reduce cosmogenic background
  - New underground hall (~8m) at 25 m downstream hall-A beam dump that will host the detector
- **Detector with 2 components:** Ecal + Veto system

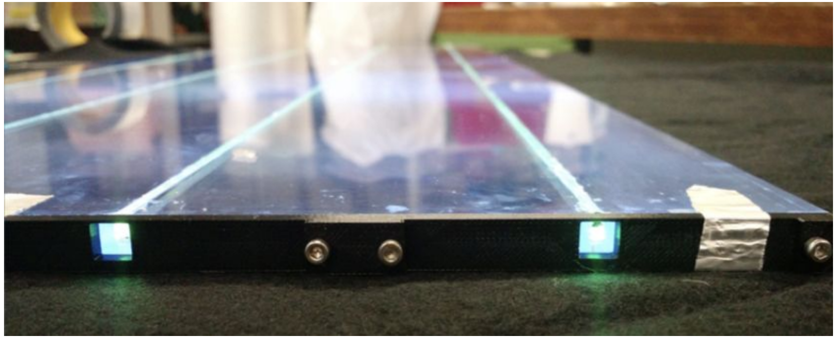


BDX detector

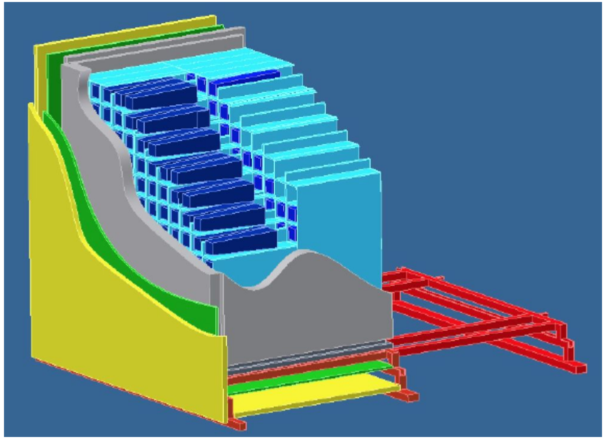
- **Inner detector**
  - **Active volume requirement:**
    - Sensitivity to high-energy EM shower
  - **Technology:** homogeneous EM calorimeter made with CsI(Tl) crystals and SiPM readout
    - High crystal density: maximize event yield with compact detector
    - Reuse BaBar crystals



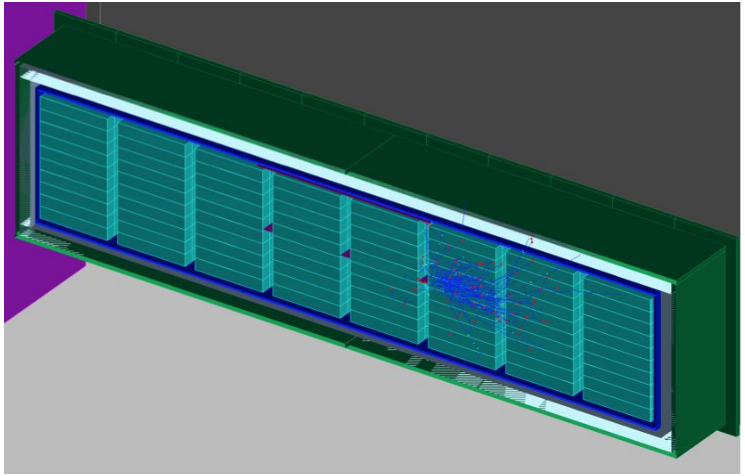
- **Veto System**
  - **Active volume requirement:**
    - high efficiency for charge particle detection
    - hermeticy and compactness
  - **Technology:**
    - two layers of plastic scintillator counters, made of different paddles each read by WLS fibers + SiPMs
    - 5 cm lead vault between active veto and calorimeter to shield photons



BDX detector assembly



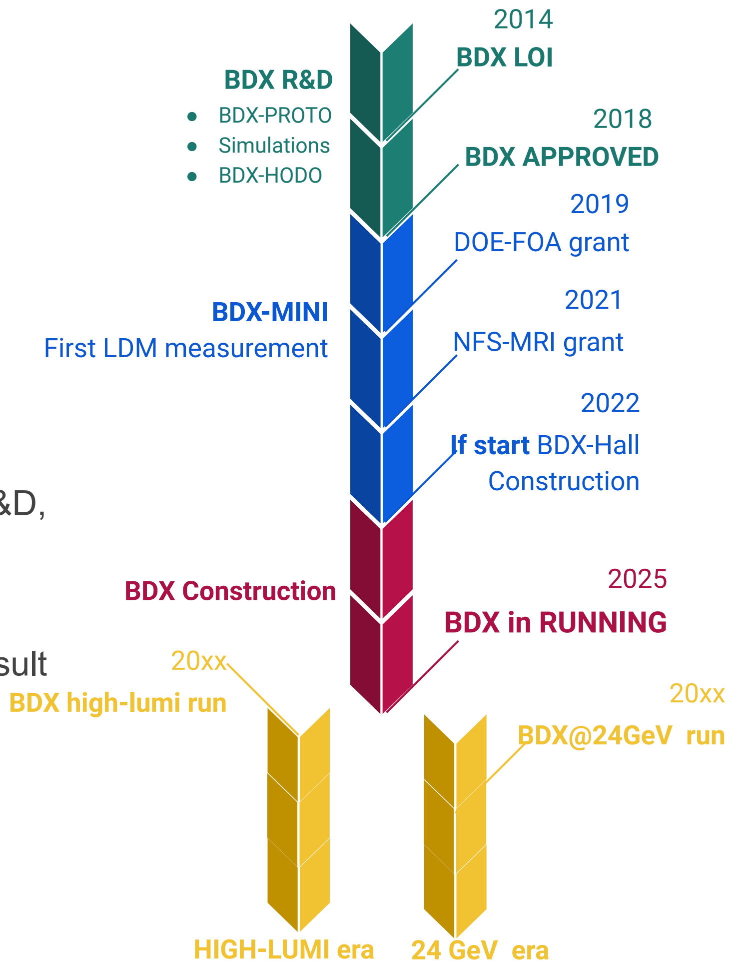
- ❖ **Detector design:**
  - ➢ 800 CsI(TI) crystals, total interaction volume ~0.5m3
  - ➢ modular detector
- ❖ **Arrangement:**
  - ➢ 1 module: 10x10 crystals, 30-cm long. Front face: 50x50 cm2
  - ➢ 8 modules: interaction length: ~2.6 m
- ❖ **DM signal:**
  - ➢ presence of an EM shower O(100MeV) coupled null activity in the active veto system



★ **BDX technology validated** in a 2 GeV e-beam test run (BDX-MINI@JLab) performed in 2020-21 with 0.15% of BDX active volume (~50 PbWO crystals) and 20% of BDX EOT (2 1021 EOT). Despite the reduced size of the experiment, the physics result is comparable to previous experiments (see L. Marsicano talk)

BDX Status & Prospective

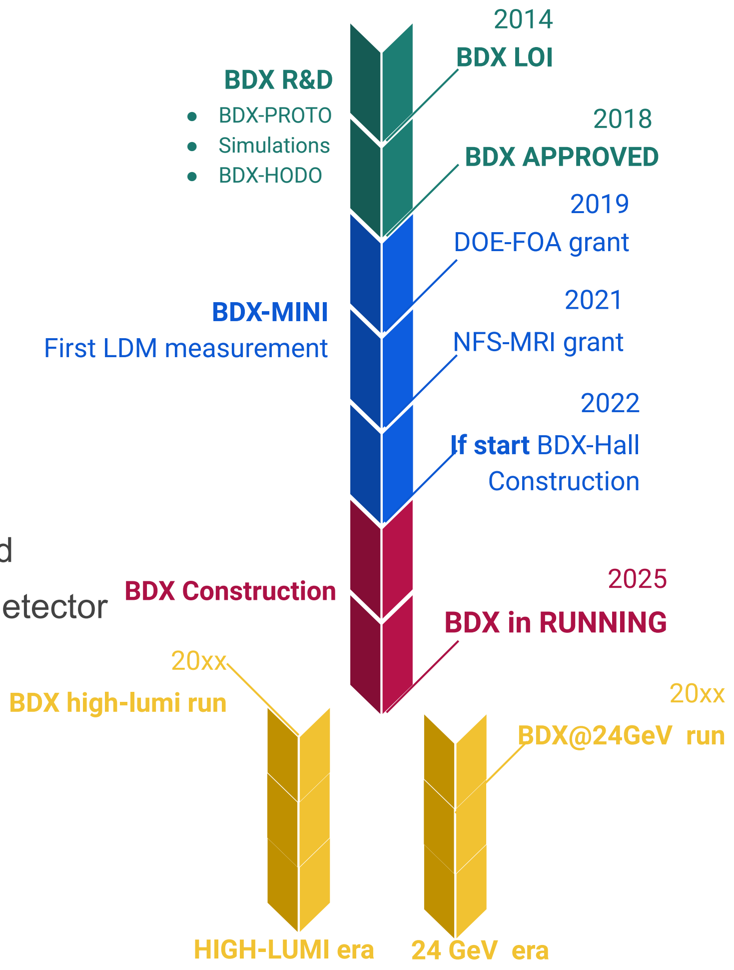
- ❖ BDX is a **JLAB experiment** approved by PAC46 with the **highest scientific rating**
- ❖ It is **part of FY 2021 Annual Laboratory Plan**
- ❖ JLAB has supported the several experimental initiatives proposed by BDX-collaboration
- ❖ BDX is a **mature** experiment: a lot of work on simulations, detector R&D, background rejection
- ❖ To run BDX a new hall is mandatory:
  - ➢ Application to DOE-FOA and NFS-MRI grants: no positive result obtained
- ❖ Parasitic run with MOLLER



BDX in the upgraded CEBAF era

- ❖ **CEBAF @ high-lumi**
  - ➢ No new infrastructures are necessary
  - ➢ BDX can take advantage of high-lumi beam immediately

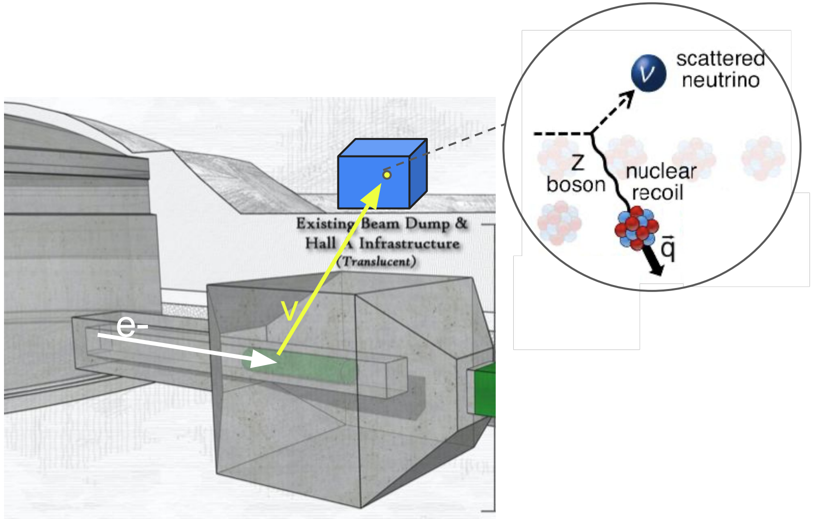
- ❖ **CEBAF @ 24 GeV**
  - ➢ New infrastructures could be necessary
  - ➢ Beam-related background has to be evaluated
    - ■ new shielding between dump and detector
  - ➢ BDX@24GeV reach has to be estimated



vBDX-CEvNS

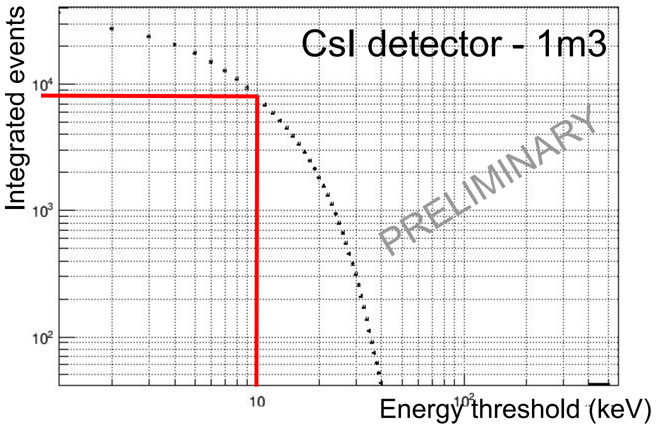
- **Coherent Elastic v-Nucleus Scattering**
  - The largest cross section among neutrino scattering channels for Ev < 100 MeV
  - Cross section is approximately proportional to N^2
  - Recoil energy transfer to the nucleus is O(10keV)
  - COHERENT has established the first detection of CEvSN

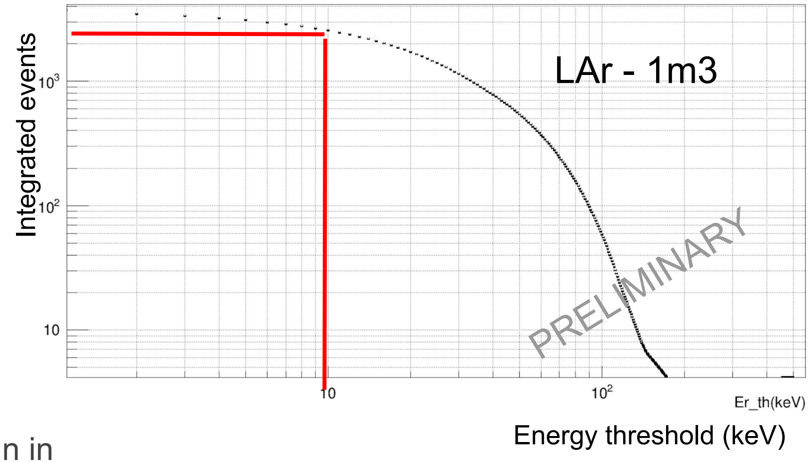
- **Requirements**:
  - High-intense v-flux
  - v-flux energy range: few MeV - few 100 MeV
  - detector has be sensitive to small energy depositions
  - backgrounds need to be sufficiently small to observe the signal.



νBDX-CEνNS

- **ν-beam @ JLAB**
  - Produced by the interaction between e- beam and Hall A dump in a energy range: 10MeV - 300 MeV
  - Neutrino flux : ~10^{18} ν/m^2 at ~10 m above the dump for 10^{22}EOT
- **Infrastructures**:
  - Detector located 10m on top of the dump
  - No peculiar civil construction is demanded
  - Two detection technology are under study:
    - CsI
    - LAr-TPC
  - Veto system: active (plastic …) and passive (lead, water, borate silicone and/or cadmium sheet layers…)
- **Backgrounds**:
  - beam-related background: neutron
  - beam-unrelated background: cosmic, radioactive detector contamination, environmental radioactivity
  - Extensive Monte-Carlo simulations and measurements campaign in situ are necessary



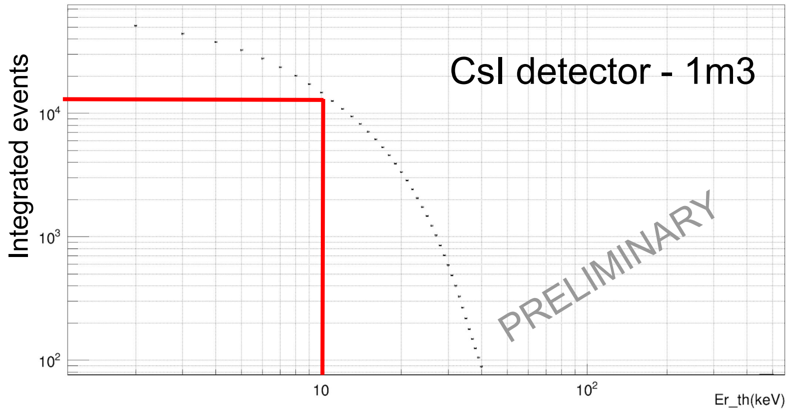


Credit to A. Fulci, S. Grazi, A. Pilloni

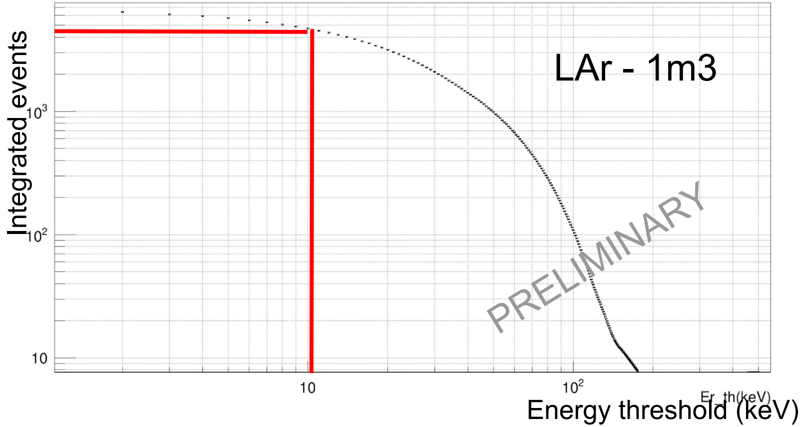
vBDX-CEvNS @ 24 GeV

- ❖ **CEBAF @ high luminosity**
  - ➢ Increasing of statistic
  - ➢ vBDX can take advantage of high-lumi beam immediately

CEBAF @ 24 GeV



- ❖ **CEBAF @ 24 GeV**:
  - ➢ neutrino flux : ~2*10^{18} v/m^2 at ~10 m on top of the dump for 10^{21}EOT
  - ➢ Increasing of a factor ~2 than CEBAF@12GeV case
  - ➢ Beam-related background has to be evaluated
  - ➢ Extensive Monte-Carlo simulation and measurements campaign in situ are necessary



Credit to A. Fulci, S. Grazi, A. Pilloni

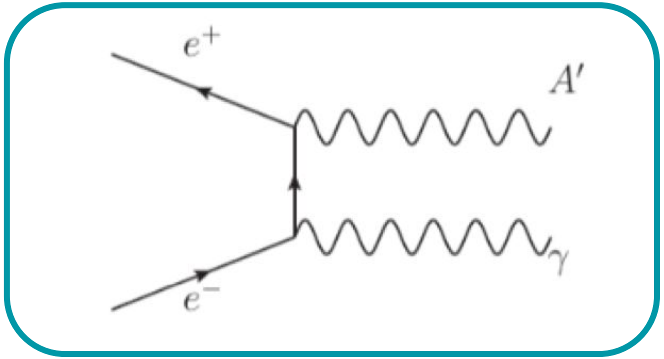
LDM searches with e+ beam: Thin Target approach

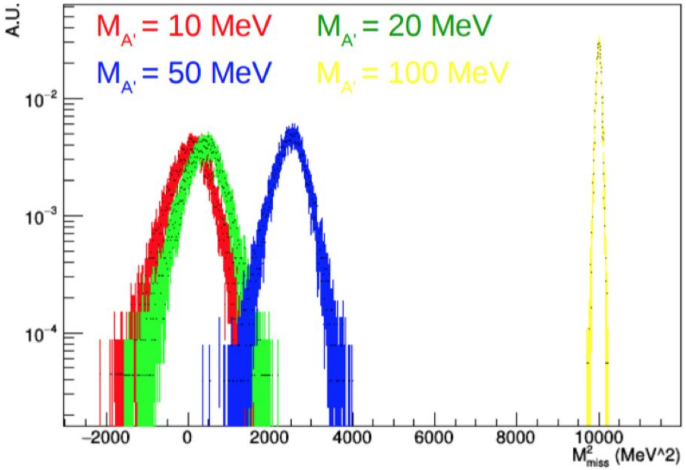
- **Approach:**
  - e+ beam on thin target
  - A' production via e+e- -> γA'
  - Produced *A'* leaves the detector volume without interacting
  - Detect the final-state γ in a EM calorimeter and compute the missing mass :

$$M^2_{MISS} = (P_{e^+} + P - P_\gamma)^2$$

- **Signal:**
  - a peak in the missing mass distribution over a smooth SM background

- **Backgrounds:**
  - All process resulting in a single γ hitting the calorimeter:
    - Bremsstrahlung
    - e+e- -> γγ ; e+e- ->γγγ

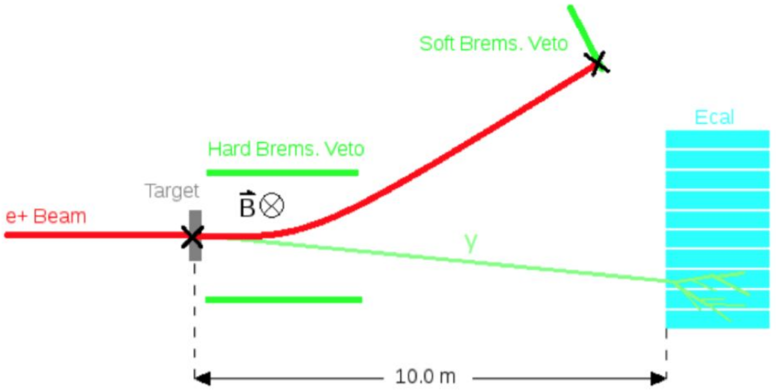


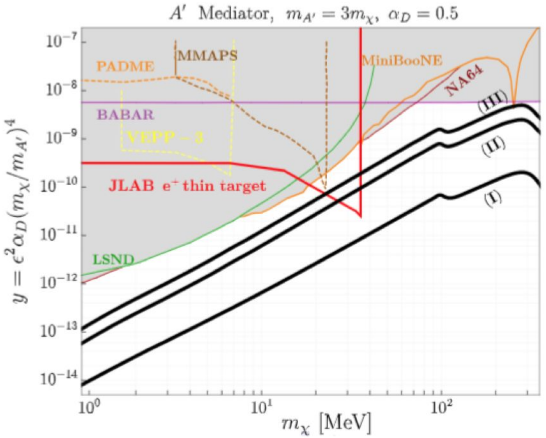


M. Battaglieri et al., Light dark matter searches with positrons *Eur. Phys. J. A* 57, 253 (2021)

LDM searches with e+ beam: Thin Target approach

- **Beam parameters:**
  - Energy : 11 GeV (max mA' ~ 100 MeV)
  - Current: 100 nA
  - Continuous structure
  - Momentum dispersion < 1%
  - Angular dispersion < 0.1 mrad
- **Apparatus:**
  - 100 um C target
  - Constant magnetic field of ~ 1 T over a 2m region downstream the target to bend charge particles
  - 50 cm radius EM calorimeter; energy resolution σ(E)/E~0.02/sqrt(2)
  - Crystal front face 1x1 cm2; angular resolution: 0.5 mrad
  - Veto system (plastic scintillator) to reject background events (mainlys breamstralung





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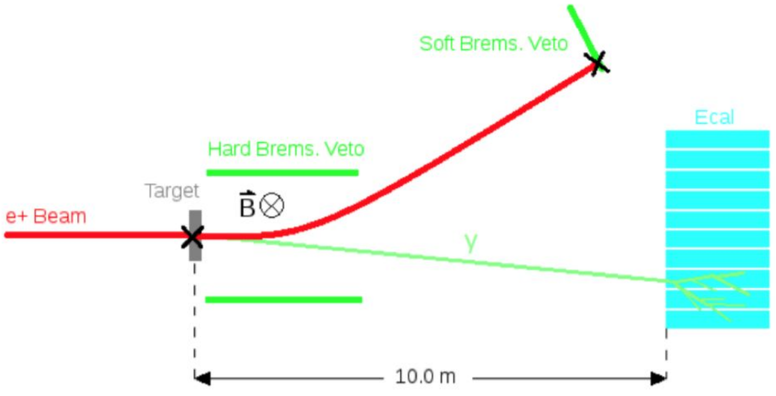
LDM searches with e+ beam: Thin Target approach

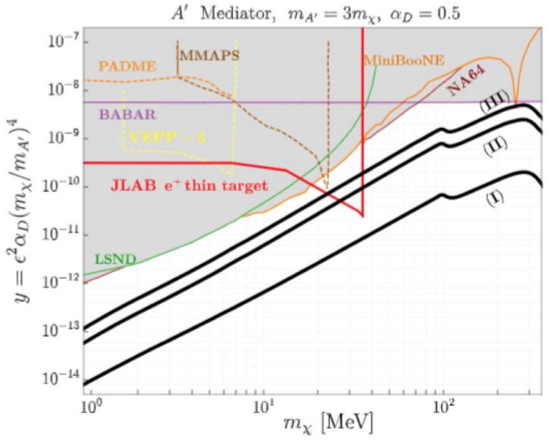
NEW

- **Beam parameters:**
  - Energy : 11 GeV (max mA' ~ 100 MeV)
  - Current: 100 nA
  - Continuous structure
  - Momentum dispersion < 1%
  - Angular dispersion < 0.1 mrad

EXISTING

- **Reusable PADME component:**
  - Target can be easily transferred and installed @JLAB
  - Calorimeter meets all requirement of the experiment (energy and angular resolution, dimension)
  - Technology and front-end of veto system can be reused
  - Crystal front face 1x1 cm2; angular resolution:
  - New DAQ is necessary





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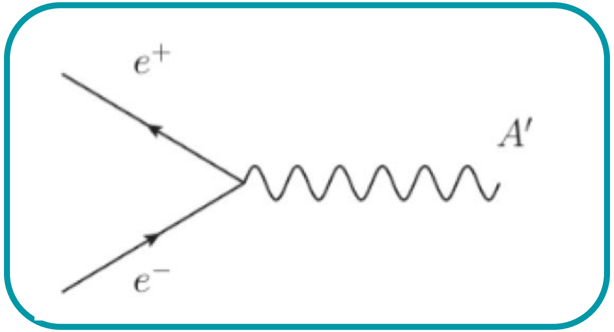
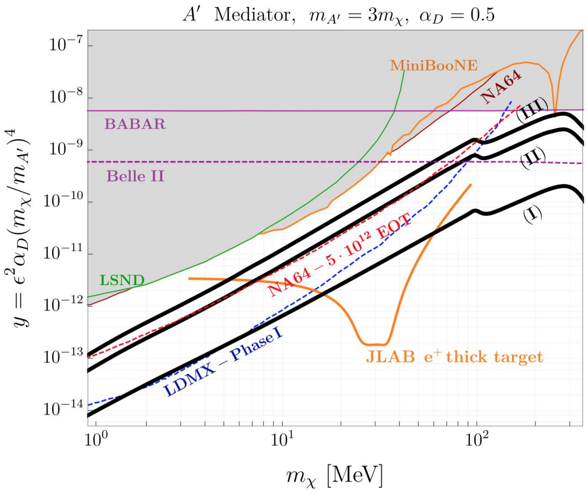
LDM searches with e+ beam: Thick Target

- **Approach:**
  - e+ beam on thick active target
  - Primary e+ produces an EM shower in the target (large number of secondary positrons produced)
  - A' production via e+e- -> A'->XX
  - Produced *A'* leaves the detector volume without interacting
  - Signal events are identified when the missing energy Emiss, exceeds a minimum threshold value.





- **Signal:**
  - a peak in the missing energy distribution at a value depending solely on the dark photon mass (mA' = 2meEmiss)

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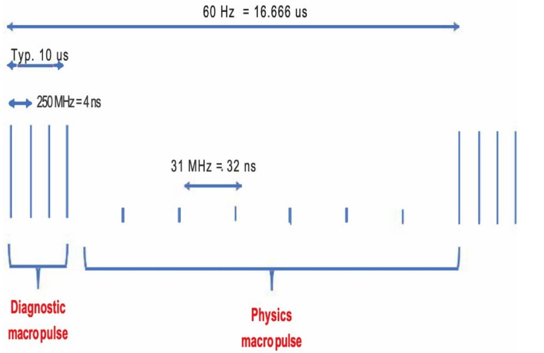
LDM searches with e+ beam: Thick Target setup

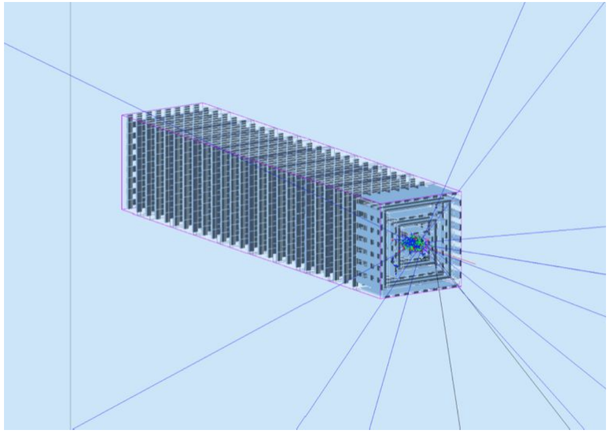
- **Beam parameters:**
  - Energy : 11 GeV
  - Low beam current : 1e+ per μs
  - **R&D necessary to achieve such beam structure**

NEW

- **Apparatus:**
  - EM calorimeter 10x10 matrix of 2x2x25 cm3 PbWO4 crystals (28X0 lenght)
  - Hadronic calorimeter modular iron/scintillator inhomogeneous calorimeter surrounding the ECAL to avoid any particle leakage
  - Fast magnetic deflector in front of detector, synchronized to the beam 60 Hz frequency, in order to transport the positrons belonging to the high-current pulses to a suitable beam-dump



A non-trivial time structure of the beam is required to avoid e^+ beam pile-up in the detector.



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Summary

- Several future initiatives to explore “hot” cases beyond hadron physics using the secondary beams and positron beams
  - new and/or modified infrastructures in terms of civil constructions and detectors are required.

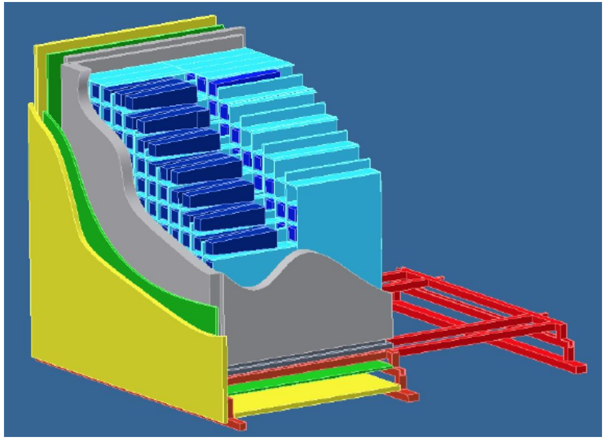
- **LDM secondary beam** will be used in BDX experiment. It will be performed in the nearby future provided the new hall is built

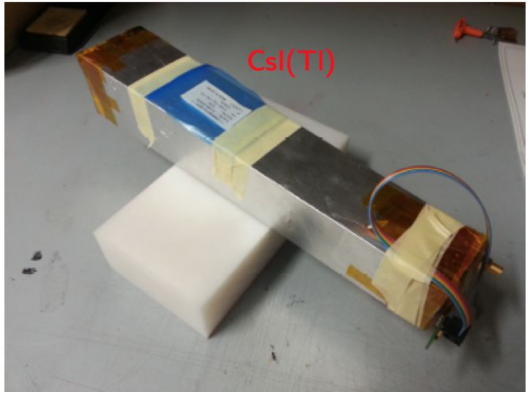
- A recent idea to measure CEvNS exploiting neutrino flux is under study.

- The availability of **e+ beams** will allow to perform two complementary measurements able to investigate vast unexplored regions in the LDM parameters space.
  - thin target approach: conceptual design is already mature
  - thick target approach: R&D activity on beam and detector

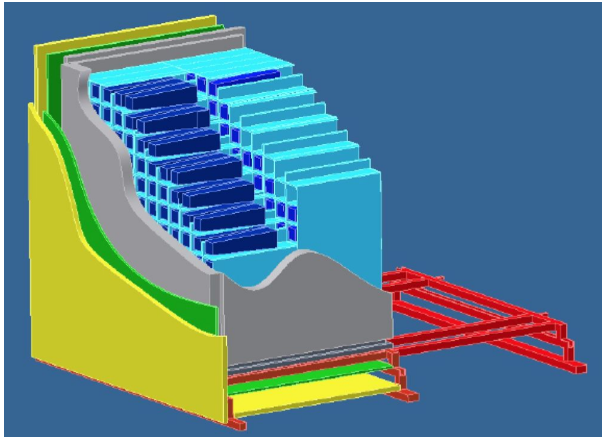
BDX inner detector

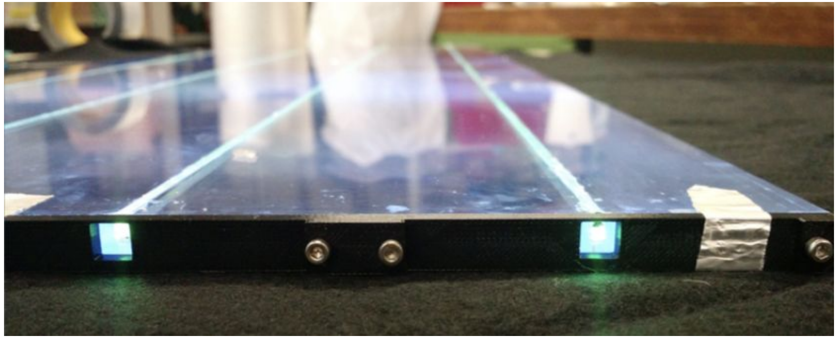
- ❖ **Active volume requirement:**
  - ➢ Sensitivity to high-energy EM shower
- ❖ **Technology:** homogeneous EM calorimeter made with CsI(Tl) crystals and SiPM readout
  - ➢ High crystal density: maximize event yield with compact detector
  - ➢ Homogeneous solution: minimize dead-spaces and passive materials
  - ➢ Detector segmentation implemented with modular design - each modulus being a matrix of crystals
  - ➢ SiPM readout: reduce dead spaces between moduli compared to traditional PMT readout





BDX veto system



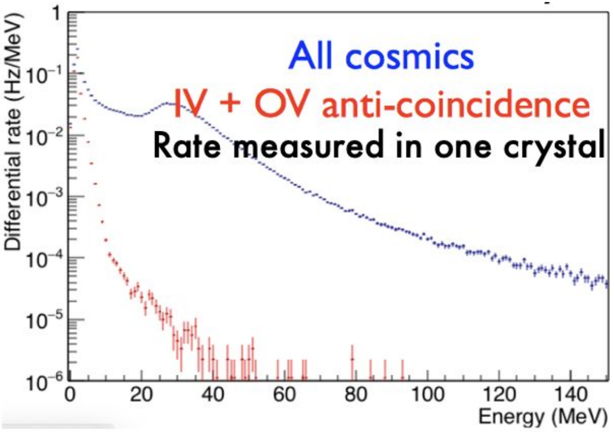


- **Active volume requirement:**
  - high efficiency for charge particle detection
  - hermeticy and compactness
- **Technology:**
  - two layers of plastic scintillator counters, made of different paddles each read by WLS fibers + SiPMs
  - 5 cm lead vault between active veto and calorimeter to shield photons

BDX Backgrounds

- **Cosmogenic Background**
  - Measured with the BDX prototype at INFN-LNS, with similar overburden as expected at JLAB
  - Using vetos in anti-coincidence and high energy threshold O(350MeV), cosmic background is negligible

BDX-PROTO



Threshold	Projected counts
250 MeV	(57 ± 25)
300 MeV	(4.7 ± 2.2)
350 MeV	(0.037 ± 0.022)

- **Beam-related Background**
  - Estimated through MC simulations
    - MC simulations validated with on-site measurement
  - 6.6 iron shield +2m concrete enough to range-out high energy muons
  - **Neutrinos**: only particles reaching the detector
    - High-energy ν from in-flight decays of pion and kaon
    - Possible background contribution from ve interaction via CC in the detector
    - Estimate: Nν = 5 counts for 10^22 EOT (optimal selection cuts)