Validation of BDX Streaming Readout

EIC Streaming Readout Workshop

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L. Marsicano (INFN – Genova)


Farnesina

Ministero degli Affari Esteri
e della Cooperazione Internazionale

Search for light dark matter

Light dark matter (100-MeV range) is a new hypothesis to explain the gravitationally observed relic abundance, alternative to the traditional WIMP (10-GeV range) hypothesis

- LDM requires a new interaction mechanism between the SM and the dark sector. The simplest: DM-SM interaction through a new U(1) gauge-boson ("dark-photon")
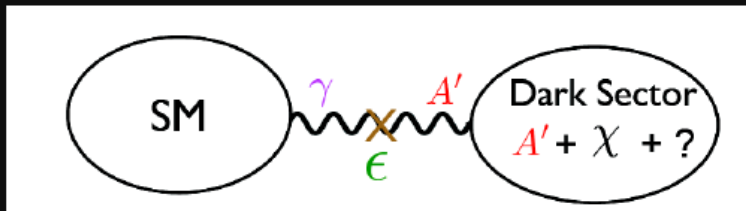
Accelerator based experiments in the GeV energy range are the ideal tool to search for LDM (direct-detection experiments have limited sensitivity to LDM – too low energy recoil)

At JLAB, a comprehensive LDM experimental program is running investigate both the existence of LDM particles and of dark photons
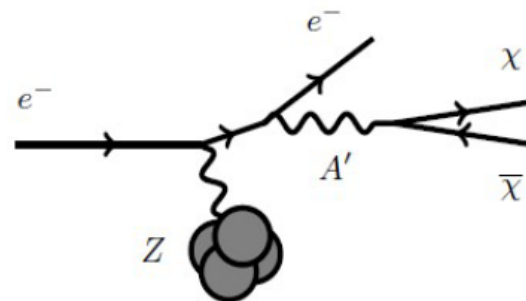
The BDX experiment

Beam Dump eXperiment: LDM direct detection in a e⁻ beam, fixed-target setup
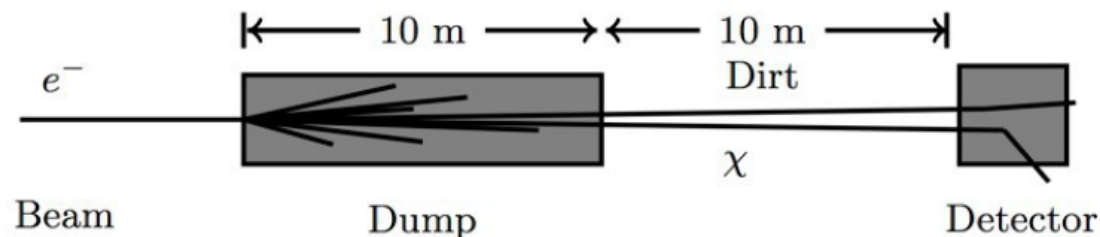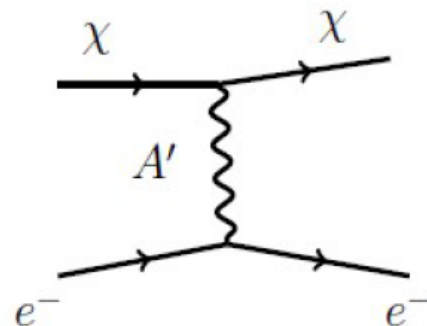
LDM production

- High-energy, high-intensity e⁻ beam impinging on the dump
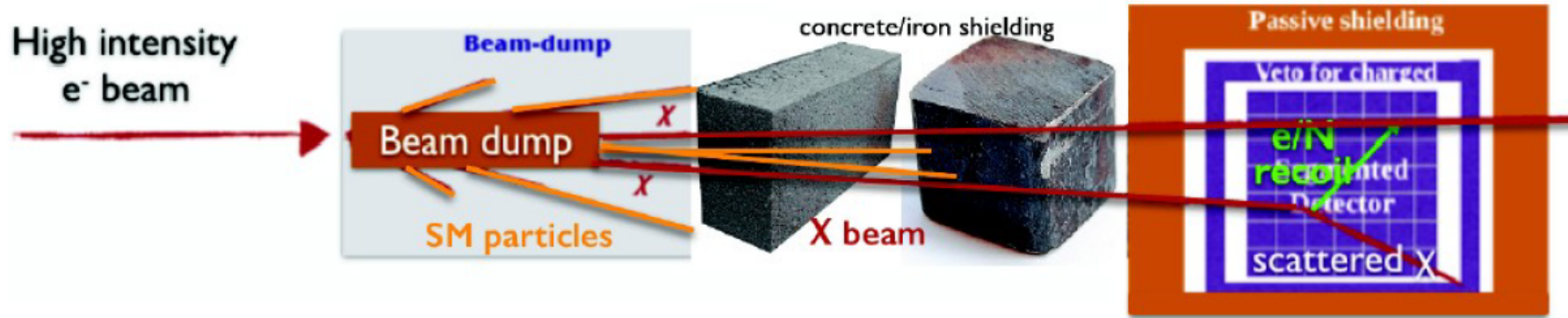- LDM particles pair-produced radiatively, through A' emission

LDM detection

- Detector placed behind the dump at ~ 20m
- Neutral-current scattering on atomic e⁻ through A' exchange, recoil releasing visible energy
- Signal: $O(100 \text{ MeV})$ - EM shower

BDX Experiment Layout

PRODUCE AND DETECT LDM

- High-intensity e⁻ beam, ~ 10^{22} electrons-on-target (EOT)/year
- Medium-high energy , >10 GeV
- ~ 1 m³ (1-5 tons) detector
- EM-showers detection capability

REDUCE BACKGROUNDS

- Passive shielding between beam-dump and detector to filter beam-related backgrounds
- Passive shielding and active vetos surrounding the active volume to reduce and identify cosmogenic backgrounds
- Segmented detector for background discrimination based on event topology

The BDX Detector

BDX detector: state-of-the-art EM calorimeter, CsI(Tl) crystals with SiPM-based readout

Detector design:
- 800 CsI(Tl) crystals, total interaction volume 0.5 m^3
- Dual active-veto layer, made of plastic scintillator counters with SiPM readout

Calorimeter arrangement:
- 1 module: 10x10 crystals, 30-cm long. Front face: 50x50 cm2
- 8 modules: interaction length 2.6 m

Signal:
- EM-shower, (threshold: 300 MeV), anti-coincidence with IV and OV
- Efficiency (conservative): O(10% – 20%) – dominated by EM shower splash-back to veto counters

BaBar CsI

~ 5 cm

~ 5 cm

Trapezoidal cross-section

~ 32 cm
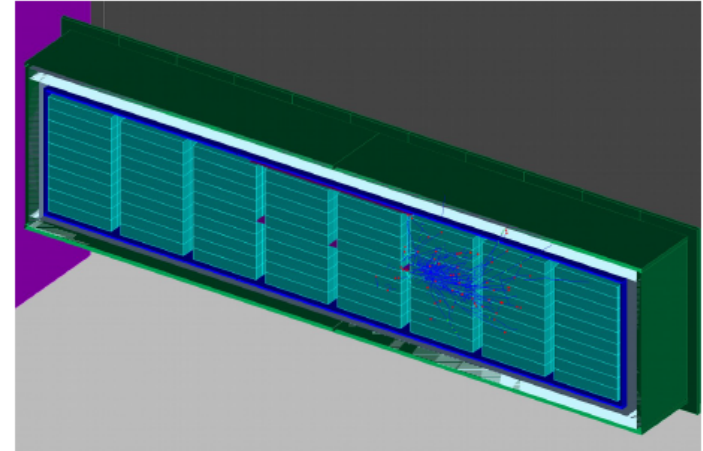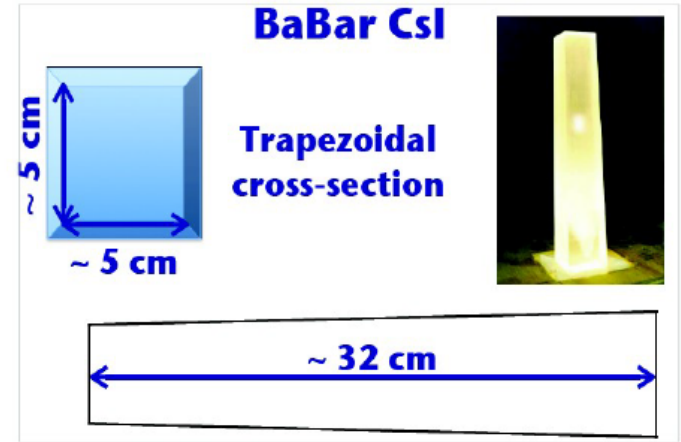
The BDX Setup At JLab

Jefferson Laboratory is home for the CEBAF electron accelerator, based on superconducting RF technology.

Plan to run BDX behind Hall-A beam-dump in a new, dedicated experimental Hall

- Ideal beam conditions for the experiment: $E_0 = 11GeV$, I up to ~ 60 μA
- Already-approved experiments with more than 10^{22} EOT (Moller, PVDIS)
- BDX is compatible with these planned experiments and can run parasitically with them

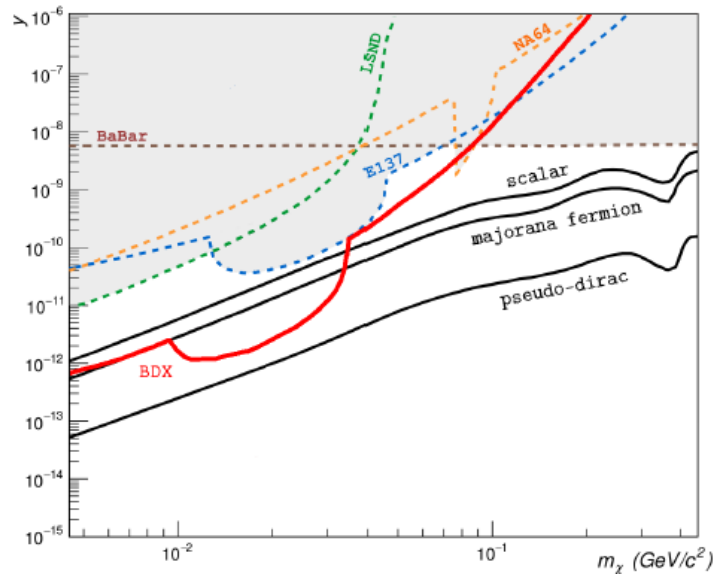The new BDX facility behind Hall-A at JLab
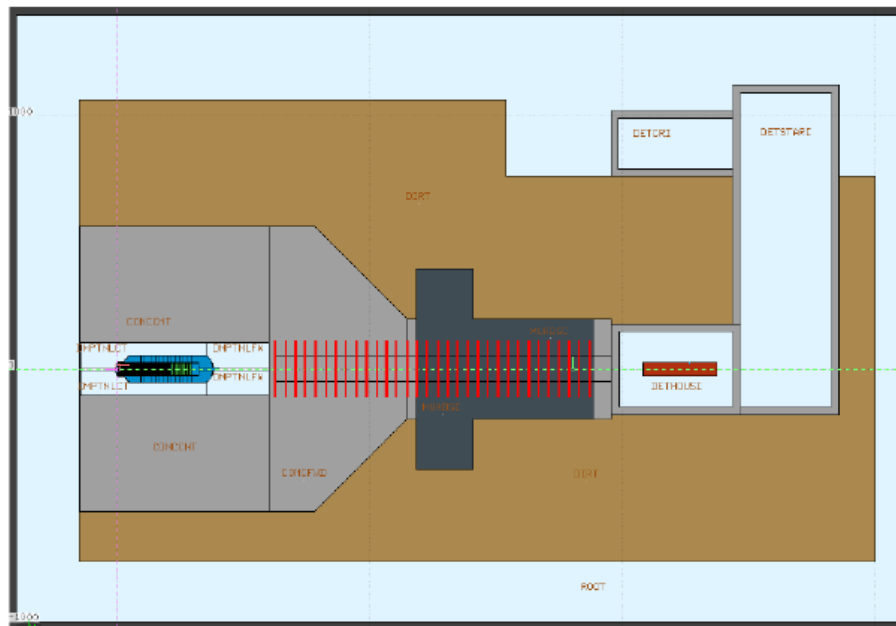
The BDX Experiment

BDX was officially approved by JLAB PAC46 in July 2018 with the highest scientific rating

The collaboration is currently working with JLab on designing the new facility and secure funding for the construction

Dark matter search in a
Beam-Dump eXperiment (BDX)
at Jefferson Lab

The BDX Collaboration

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The BDX reach after 1 year of measurement

The BDX DAQ System: Requirements

Number of channels and rates (results obtained from small-scale prototype characterization):

- 1000 CsI(Tl) crystals, each read by a SiPM. Signal rate: 5 Hz/crystal
- 100 active veto channels, each read by a SiPM. Signal rate: 30 Hz/counter

Background rejection requirements:

Whenever there is a EM shower the ECAL, all hits from all veto channels in a O(10 us) window before and after must be acquired to identify and reject backgrounds, including rare events as muon decays, delayed neutron hits, …

- First phase "learning": save all hits (waveforms) to disk. Perform offline analysis to find correlations and define events

- Second phase "production": implement event selection algorithms in the online software

The BDX DAQ System

BDX plans to adopt a streaming-readout DAQ system for the whole detector: CsI(Tl) crystals + plastic scintillator counters.

Key elements:

- **Digitization:** INFN "wave board" digitizer (250 MHz, 14 bit, 12 ch) for SiPM (see talk from Fabrizio Ameli)
- **Online reconstruction and event building:** TriDAS system – KM3 (see talk from Tommaso Chiarusi)
- **Run control/monitoring:** custom system based on REST APIs and web-based controls

General Readout scheme:

Detector

X beam

Amplification / Digitization

Online-data analysis

**Trigger decision/ event building (?)**
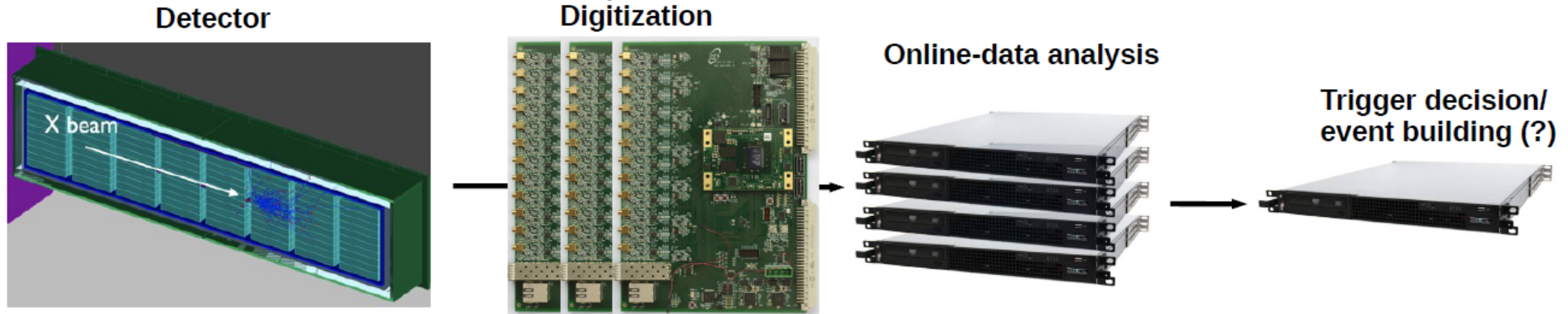
The BDX-mini Detector

Waiting for the new experimental hall...

→ **BDX-mini**: small scale prototype for detector design and technology validation

Detector Components:

- 44x PbWO$_4$ crystals read by SiPMs (total volume about 0.004 m^3)
- 0.8 cm thick tungsten shielding
- double plastic scintillator layer read by SiPM + WLS fibers (20 channels in total)
- water tight stainless steel vessel
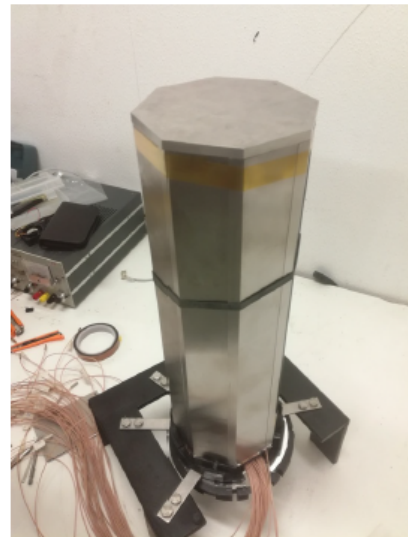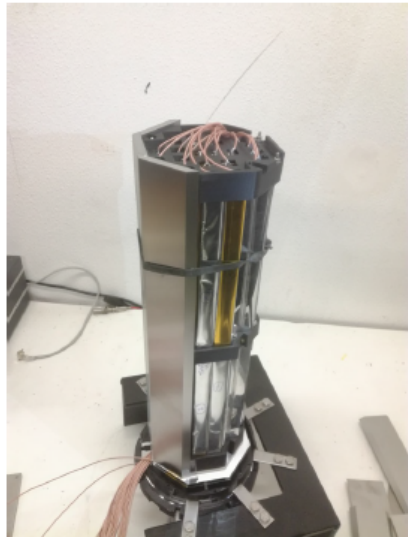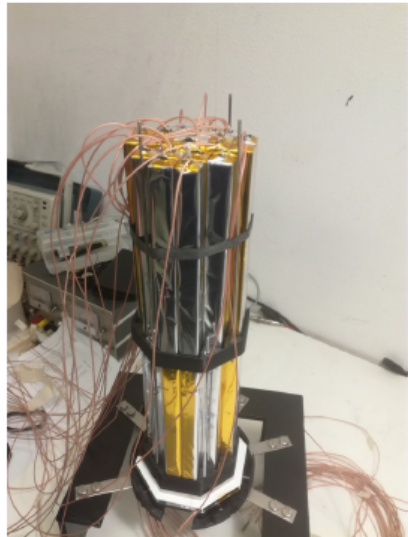
BDX-mini tests @JLab

BDX-mini measurement campaign @JLab:

- Detector lowered at beam height in a pipe drilled 25 m behind Hall A beam-dump
- Beam-on measurement foreseen fall 2019 (beam energy 2 GeV ; current 150 μA)
- Currently cosmic data-taking ongoing

BDX-mini setup is based on "traditional" triggered DAQ. **A test measurement run has been taken with the BDX triggerless system**

BDX-Mini Triggerless DAQ Validation

"Technical validation" process: Compare between BDX-mini data acquired with "standard" (triggered) and "triggerless" DAQ system BDX-mini (coincidence rates, spectra...)
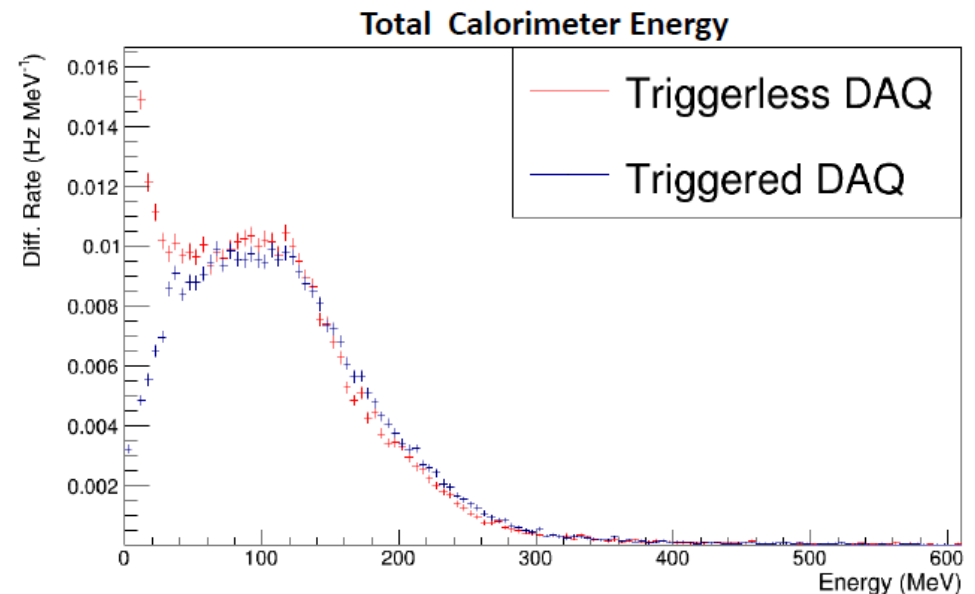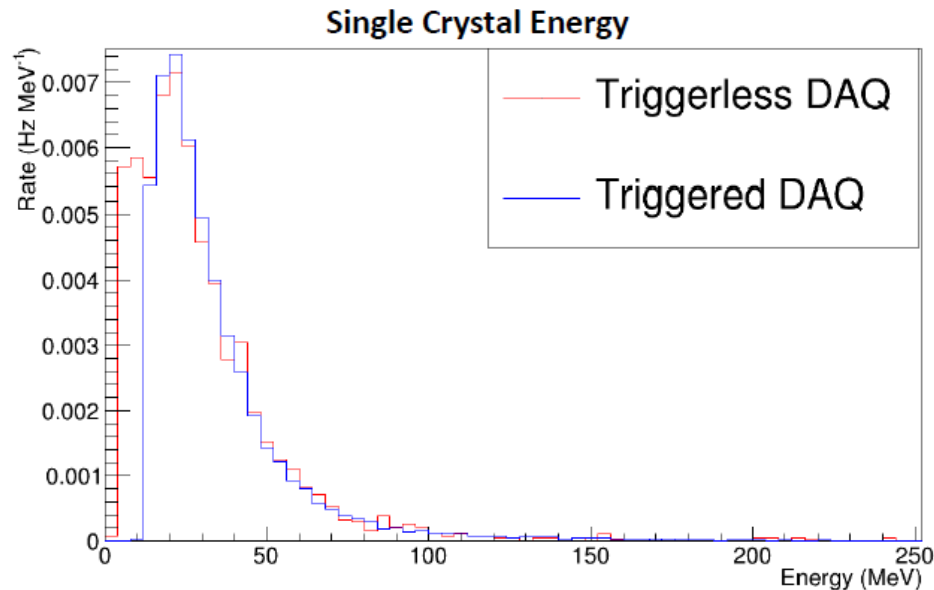
Triggerless DAQ Chain – wave board + TriDAS

I. Only signals over the wave-board hardware threshold are processed (Hits)

II. Event definition and construction by **Level 1 (L1)** low level software selection algorithm (e.g. OR of crystals Hits)

III. Event selection and tagging by **Level 2 (L2)** algorithm (e.g. clustering, trajectories selection)

Triggered DAQ Chain – Jlab FADC + CODA

I. All channels are passed to discriminators

II. Discriminator output passed to coincidence module for event definition (OR of crystals)

III. All channels waveforms acquired and saved for each trigger

DAQ Comparison: Rates

- For both DAQ systems, crystals were calibrated in energy with MC simulations

- No L2 selection used for this test

- Single crystal energy distributions show good agreement above the "triggered" DAQ energy threshold

- Total energy distributions present slight discrepancy in shape
  →**Wave board threshold effect**

**Single Crystal Energy**

Total Calorimeter Energy

- Hit multiplicity distributions confirm the discrepancy
- Triggerless DAQ: lower rate at high hit multiplicity
- Triggered DAQ: lower rate at low hit multiplicity
  → wave board threshold is lower than triggered DAQ threshold but
  high enough to cut very low energy hits

**DAQ Comparison: Multiplicity**
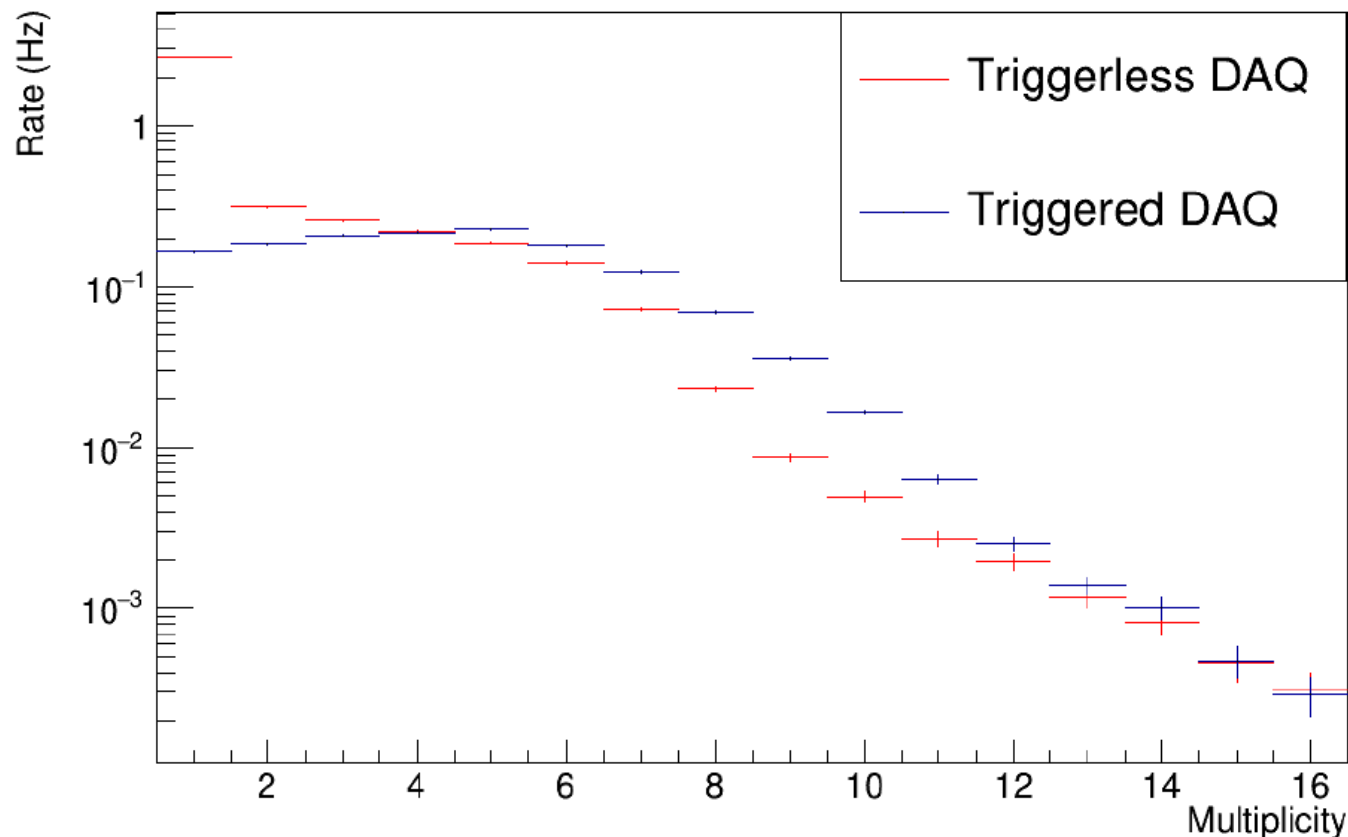
Wave Board Threshold Effect

- Wave board threshold effect is mitigated applying a threshold to hit energies during analysis
- Asking for at least 20 MeV per crystal to define a hit results in a much better agreement between the DAQ systems

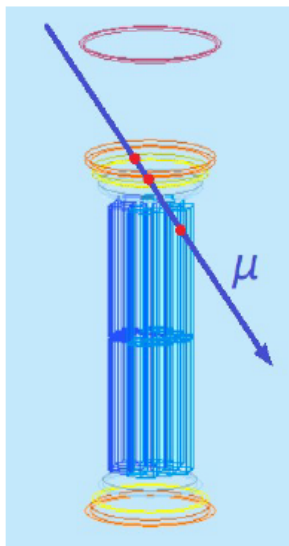→ wave board hardware threshold must be tuned carefully
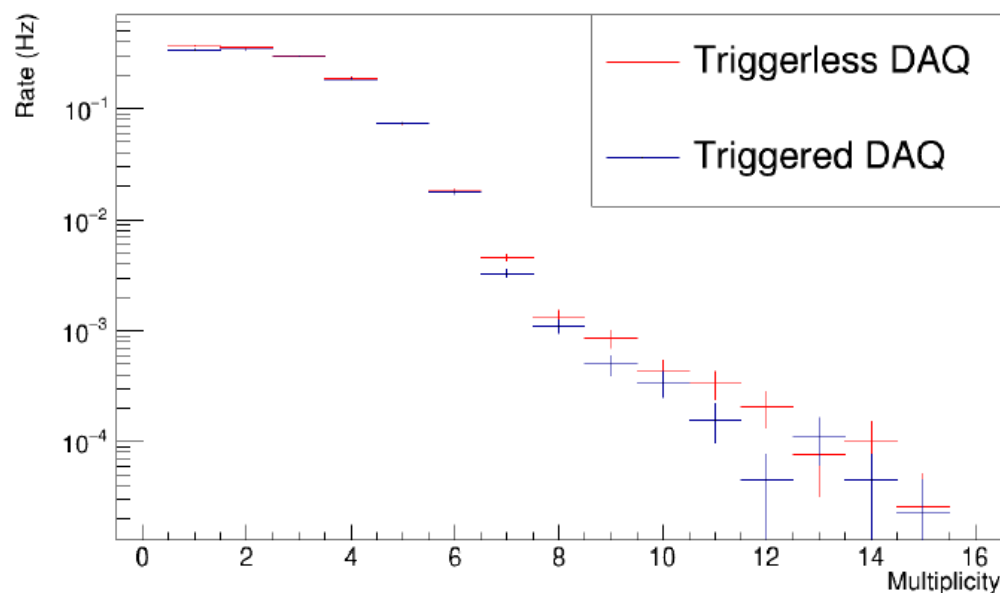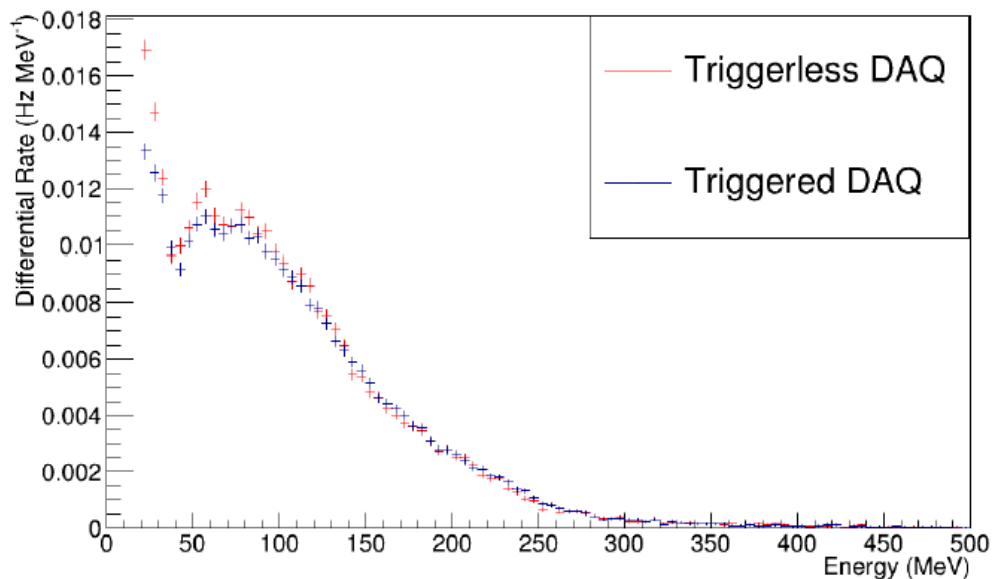
"Clustering" Trigger Efficiency

- L2 "clustering" selection trigger was tested
- Events selected online applying few MeV thresholds on Etot and Eseed
- Same cuts applied offline to unselected events
- Trigger efficiency is about 100 %
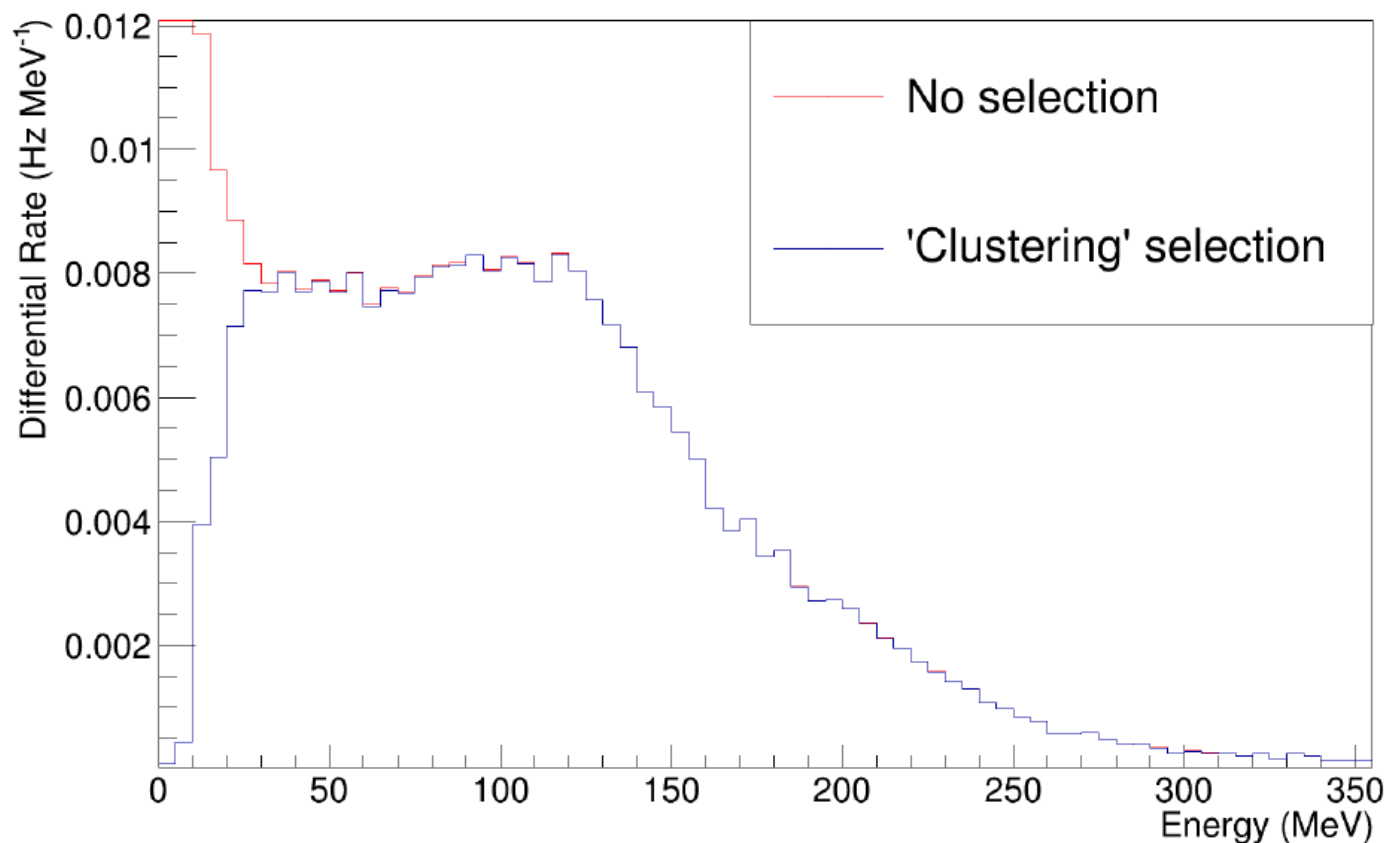
Cosmic Trajectory Selection

Selecting events with hits in well defined positions of the vetos can be used to identify cosmic muons trajectories (useful for crystals calibration)

- An online trajectory selection trigger was implemented
- Events defined applying conditions on veto channels charge distribution
- Online trajectory selection has comparable efficiency to the offline analysis
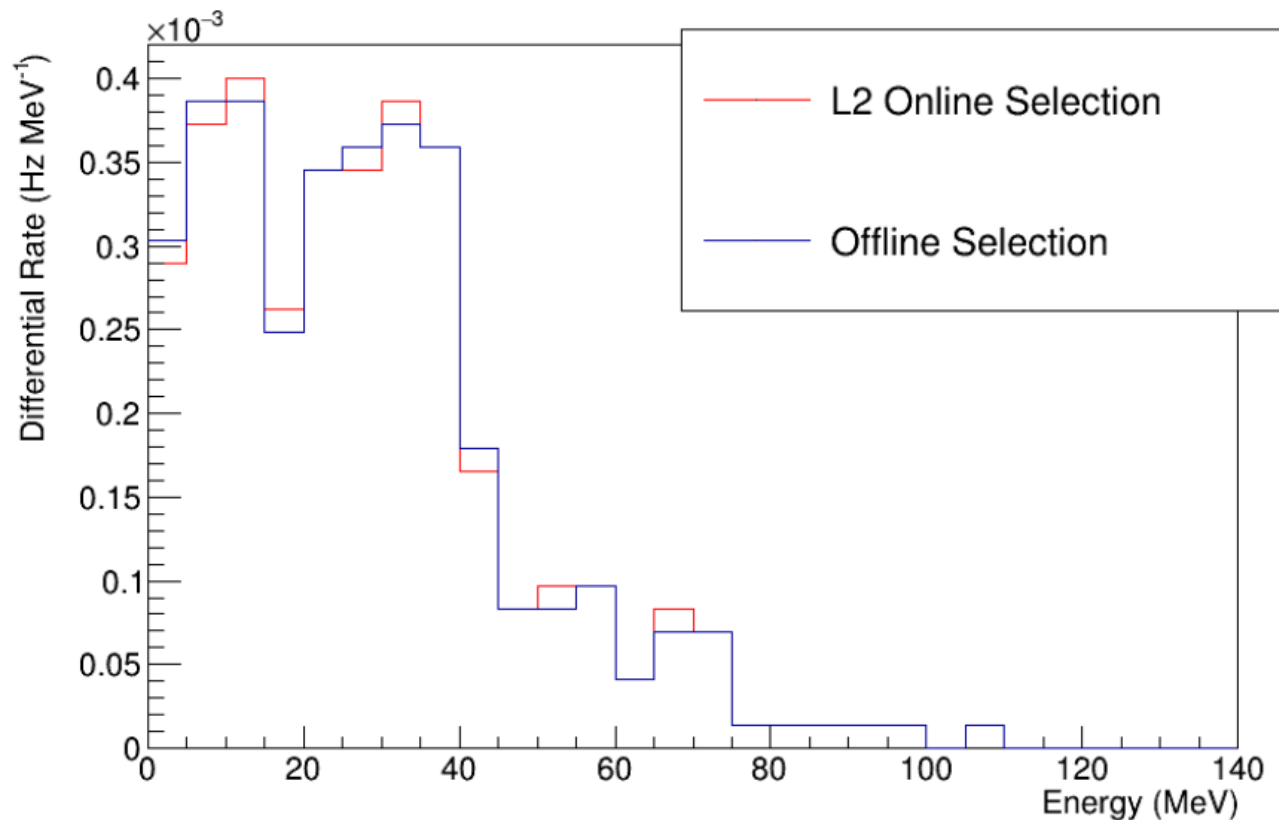
BDX tests as a first step toward EIC triggleress system validation

Tests and characterization measurements of a streaming readout system for the BDX setup can be a first step toward the validation of this technology for the full EIC detector – *starting from EM calorimetry*

- **Same technology:** $PbWO_2$ crystals + SiPM readout
- Number of channels for BDX-Mini large enough to study EM showers measurement and reconstruction
- Software system (TriDAS) adaptable to other detectors
- Readout board design can be extended to other front-ends
- Rate stress-test is possible by lowering local thresholds at few phe level

eRHIC

JLEIC
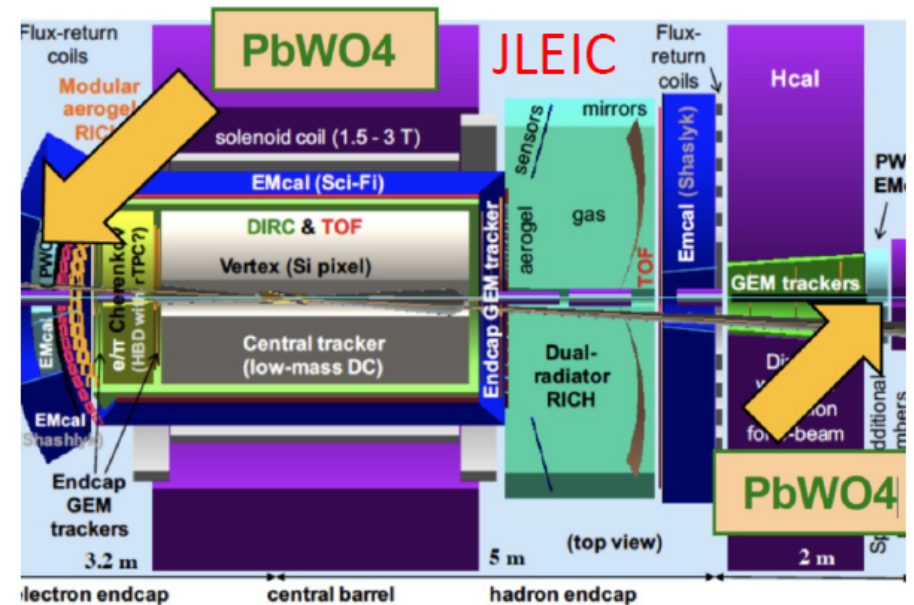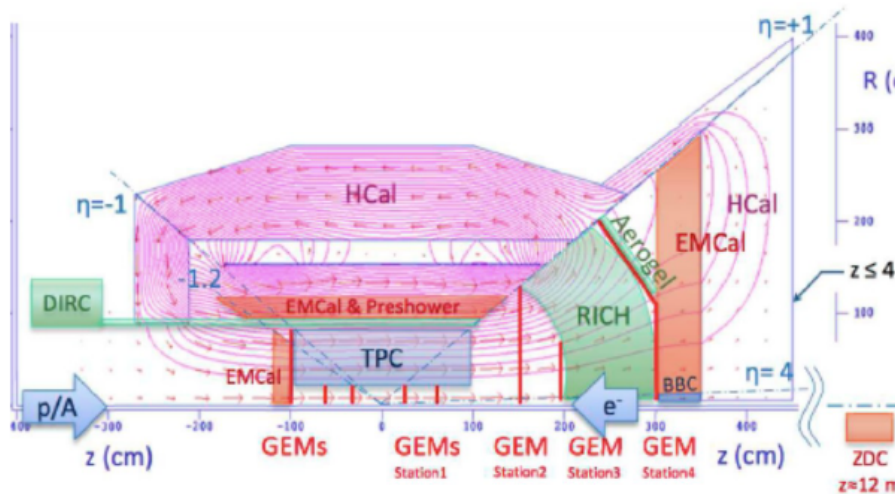
Conclusions

The BDX experiment at Jefferson Lab is a new search for light dark matter exploiting an e^- beam, fixed thick-target setup

- BDX will employ a triggerless DAQ system for the full detector readout (CsI(Tl) crystals / plastic scintillator counters, SiPM readout)
- System is based on a custom FEE/digitizer board and on the TriDAS software (KM3)

A measurement campaign is taking place at JLab with "BDX Mini" detector
- Main setup are based on traditional triggered DAQ. Test runs have be taken with the BDX triggerless system: this allowed to compare results for the same observables and validate the system
- The triggerless system tested proved to be a good option for BDX
- Further tests will be performed in future

BDX can be the first step toward the validation of the triggerless approach in EIC – starting from EM calorimetry

Backup: BDX expected data rate (300 MeV threshold)

- The overall trigger rate will be $R_{trg} = 5 \; Hz/\text{crystal} \cdot 1000 \text{ crystals} = 5 \text{ kHz}$.

- The data size of each crystal signal is: $D_{crs} = 2048 \text{ samples} \cdot 12 \text{ bit/sample} = 3$ kB. The total data rate from crystals is: $DR_{crs} = D_{crs} \cdot R_{trg} = 14 \text{ MB/s}$.

- The data size of a FADC-integrated pulse is $D_{veto} \simeq 12\text{B}$. Assuming (conservatively) that $N_{veto}/10$ veto counters report a pulse for each trigger, the total data rate from these is: $DR_{veto} = N_{veto} \cdot D_{veto} \cdot R_{trg} = 1 \text{ MB/s}$.

- The total event rate is: $DR_{tot} \simeq 1.1 \cdot (DR_{crs} + DR_{veto}) = 16 \text{ MB/s}$. A 10% overhead has been assumed for event-related information (event time, indexes of channels, ...)