Streaming readout system for the BDX experiment

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e della Cooperazione Internazionale

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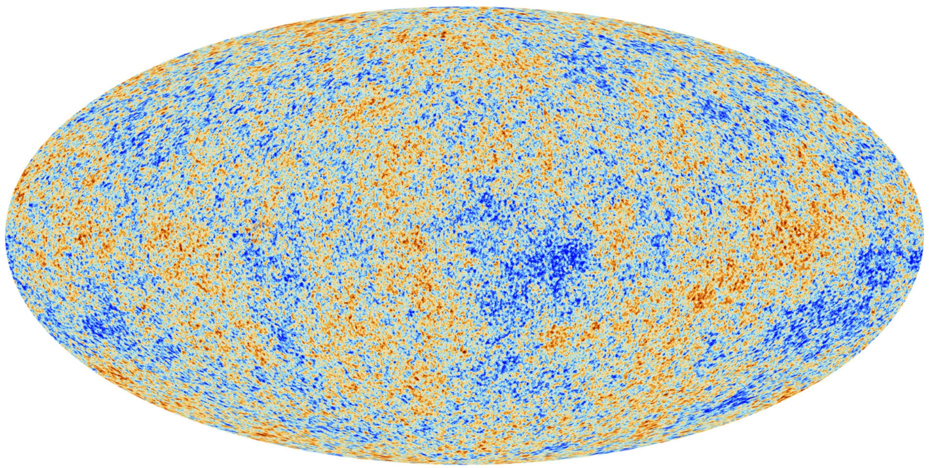
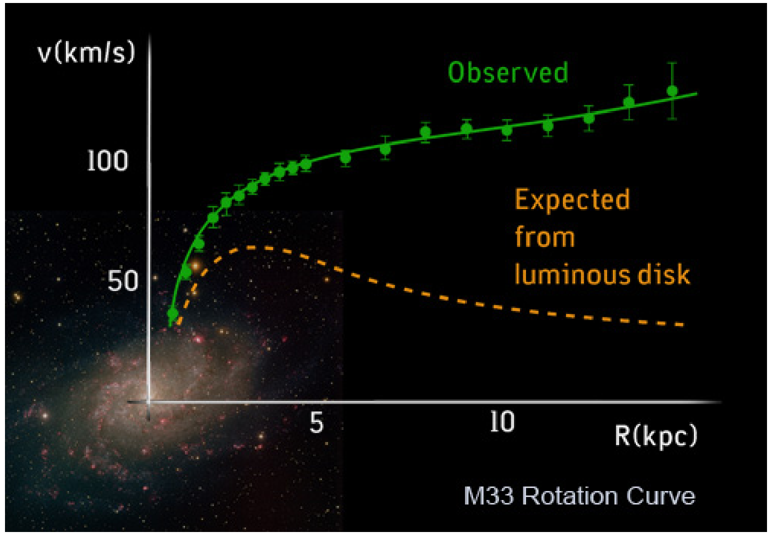
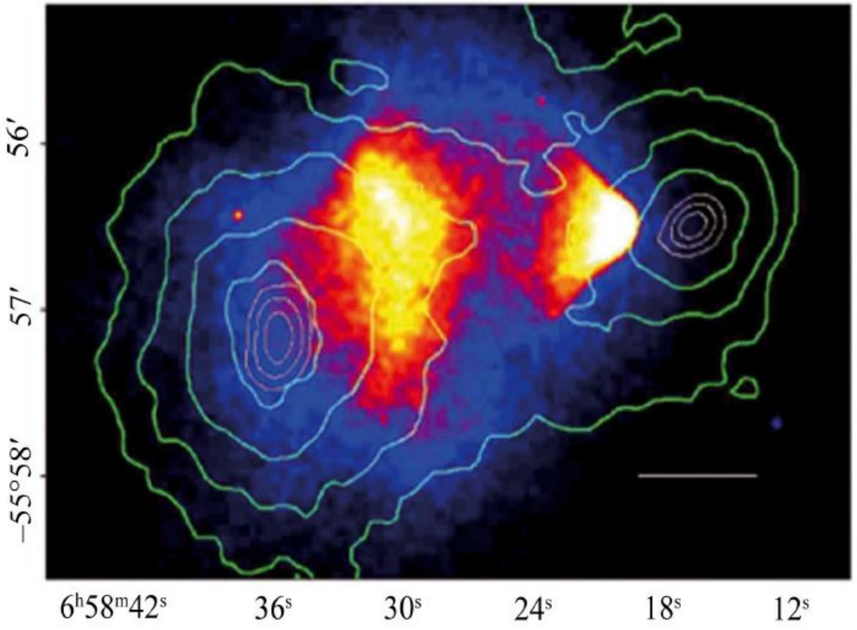
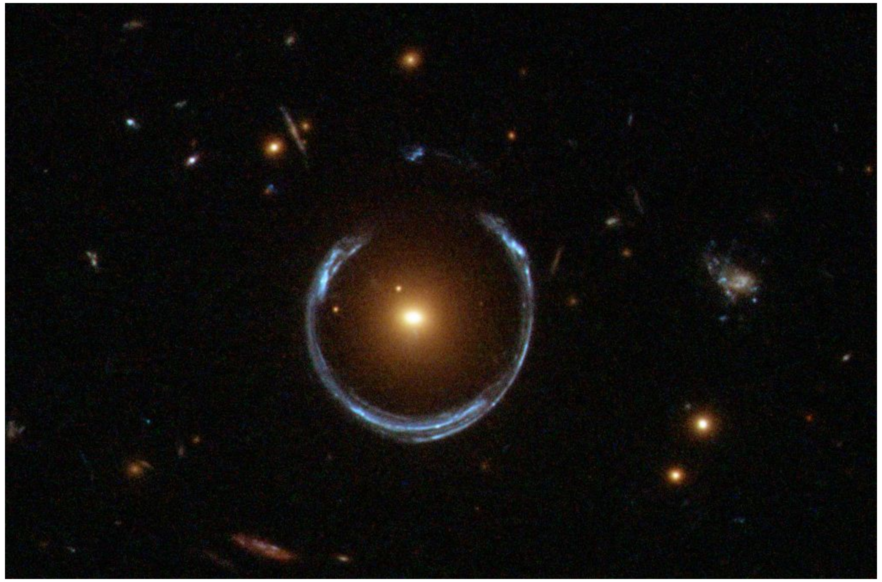
Why Dark Matter?





Plenty of **cosmological/ astrohpisical** observations: **CMB anisotropies**, **galaxy rotation curves**, **gravitational lensing**,**cluster collisions**...

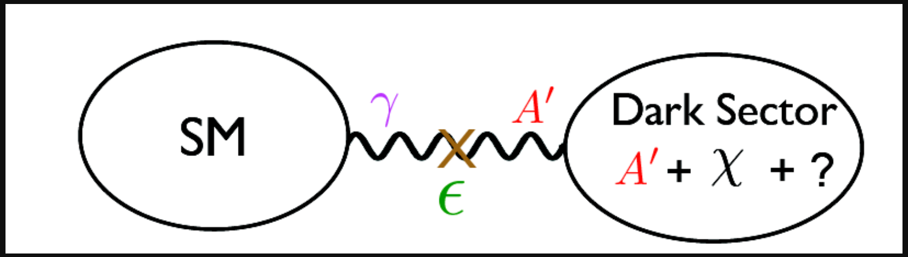




Search for light dark matter (LDM)

Light dark matter (1-1000 MeV range) is a new hypothesis to the explain the gravitationally observed relic abundance, alternative to the traditional WIMP (10-GeV range) hypothesis

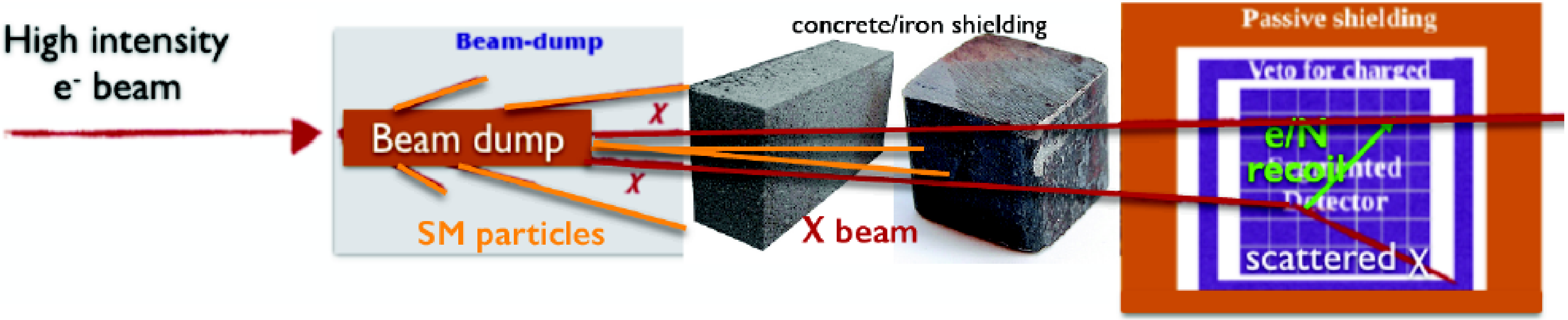
- LDM requires a new interaction mechanism between the SM and the **dark sector**. The simplest: DM-SM interaction through a new U(1) gauge-boson (“**dark-photon, *A'*** ”)



Accelerator based experiments in the GeV energy range are the ideal tool to search for LDM

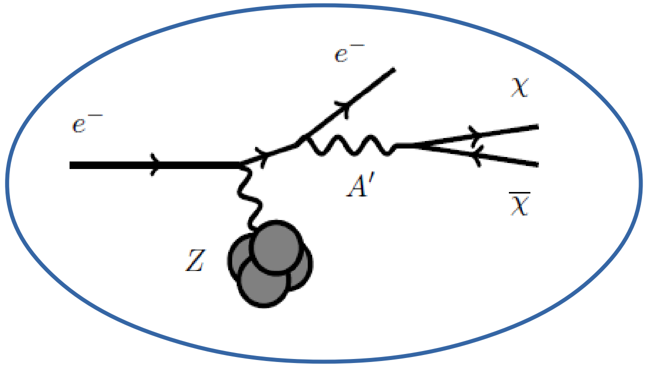
At **Jefferson Lab**, a comprehensive LDM experimental program is running investigate both the existence of LDM particles and of dark photons

The BDX Experiement



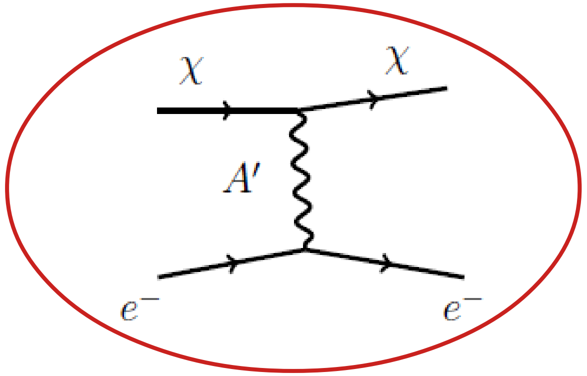
LDM production

- 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 MeV) - EM shower



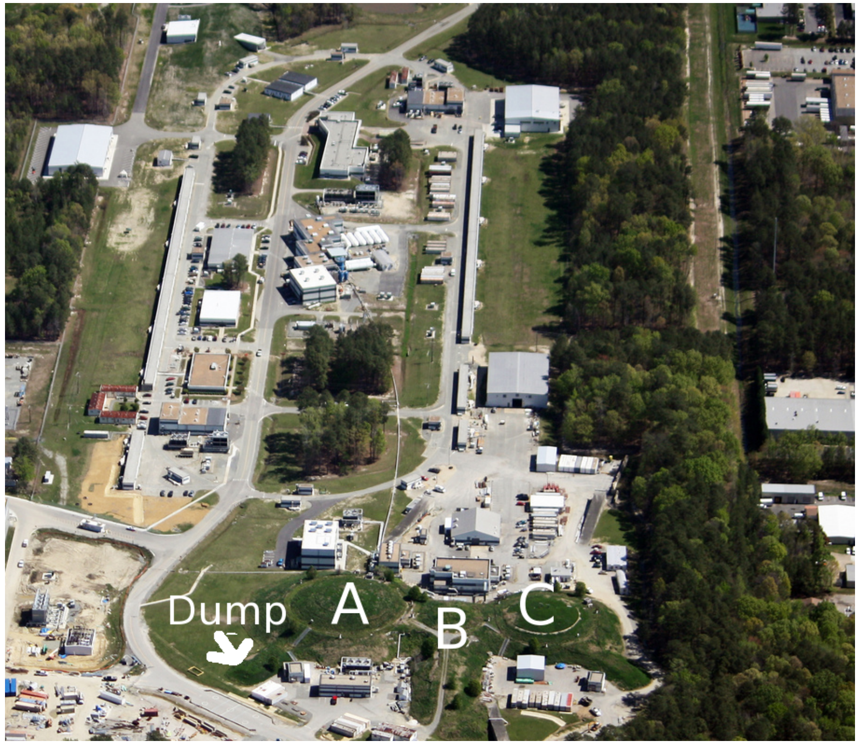
BDX at JLab

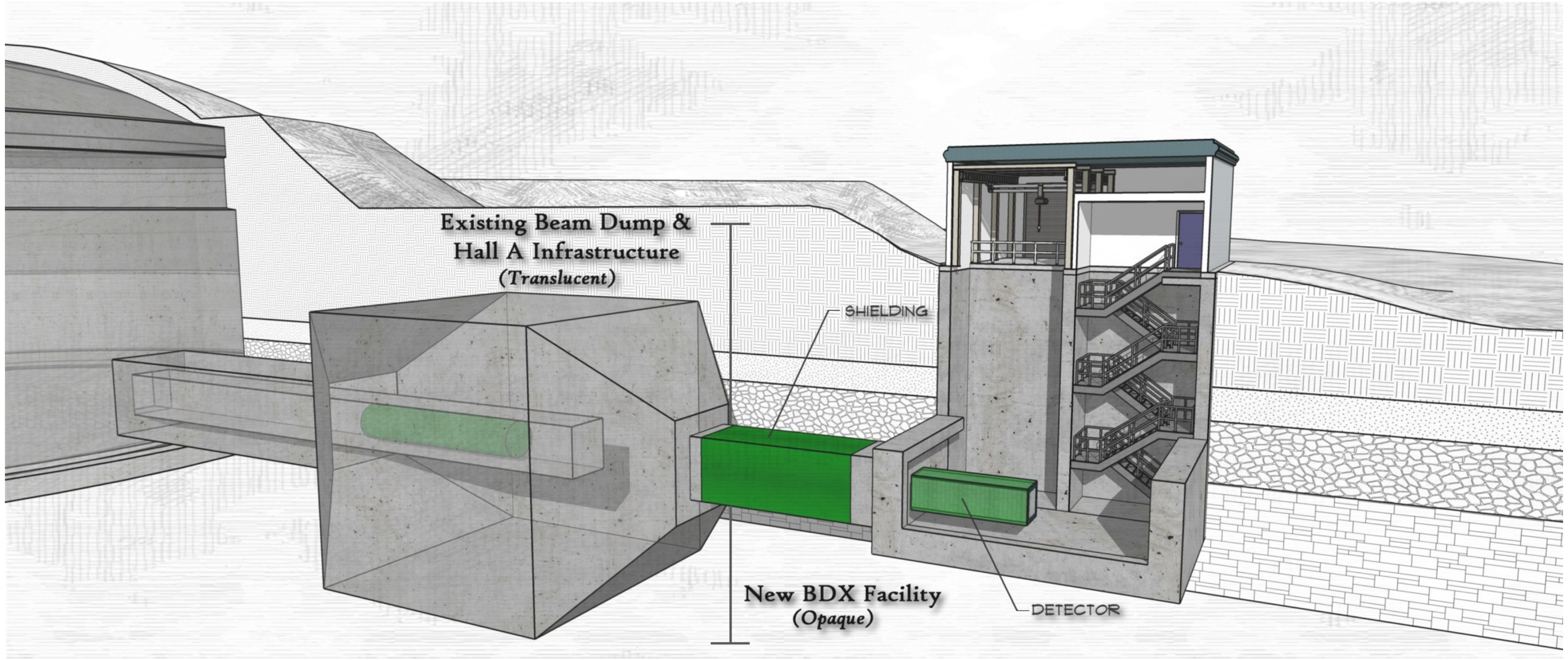
Jefferson Laboratory is home for the CEBAF electron accelerator, based on superconducting RF technology.

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

- Ideal beam conditions for the experiment: E_{beam} = 11GeV , I up to ~ 60 μA, 10^{22} EOT in ~1 year measurment
- Already-approved experiments with more than 10^{22} EOT (Moller, PVDIS)
- BDX is compatible with these planned experiments and can run parasitically with them

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





The BDX DAQ system: requirements

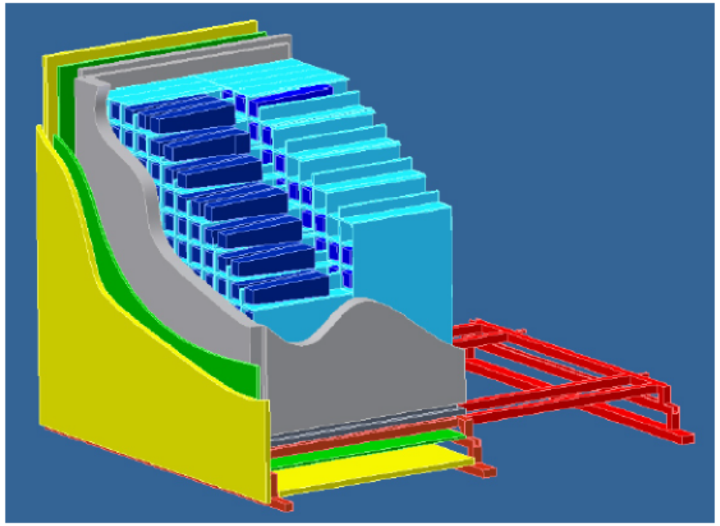
BDX detector: state-of-the-art EM calorimeter, CsI(Tl) crystals with SiPM-based readout, surrounded by active veto layers and a passive lead shielding to reduce cosmic background

ECAL:

- 800 CsI(Tl) crystals, total interaction volume 0.5 m^3 - SiPM readout

VETO:

- Dual active-veto layer (IV and OV), made of plastic scintillator counters - SiPM readout



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

- 800 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, …

The BDX DAQ system

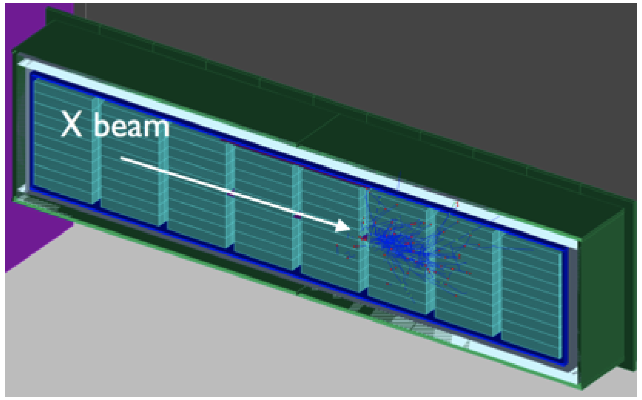
BDX plans to adopt a streaming-readout DAQ system for the whole detector: CsI(Tl) crystals + plastic scintillator counters.

Key elements:

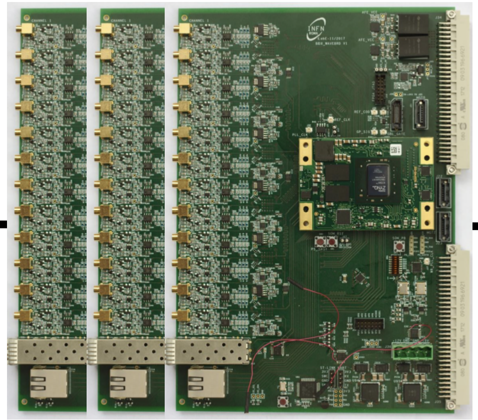
- **Digitization:** **INFN “wave board” digitizer** (250 MHz, 14 bit, 12 ch) for SiPMs
- **Online reconstruction and event building:** **Trigger-less Data Acquisition (TriDAS)** (already used by KM3net experiment)
- **Run control/monitoring:** custom system based on REST APIs and web-based controls

General Readout scheme:

Detector Digitization



Amplification / Digitization



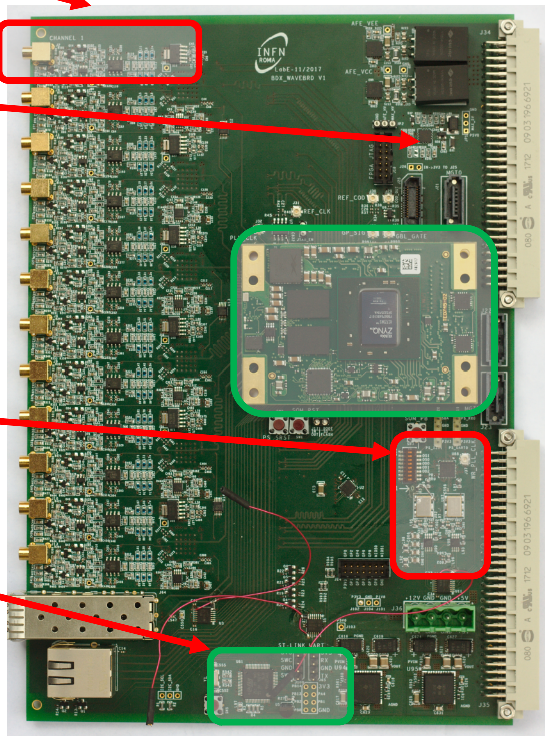
Online-data analysis

Trigger decision/ event building

The BDX *WaveBoard* digitizer

- The board is based on a Commercial-Off-The-Shelf (COTS) System On Module (SOM) mezzanine card hosting a **Zynq-7030**
- There are 12 analog front end channels
  - 6 dual-channel ultra low-power ADCs (**12/14** bit up to **250MHz**)
  - Pre-amplifier on board: **selectable gain** (either 2 or 50)
  - **HV** provided and monitored on-board
  - pedestal set by DAC
- Timing interfaces:
  - PLL to clean, generate, and distribute clocks
  - External clock and reference signals
  - White Rabbit enabled board
- ARM-M4 controls on-board peripherals (ADCs, DACs, PLL, …)
- On board peripherals:
  - High speed: GbE, SFP, USB OTG
  - Low Speed: serial, I2C, temperature monitor

Single Channel
Front End
w/ High Voltage



F. Ameli et al. *"A low cost, high speed, multichannel analog to digital converter board"*, *Nucl. Instum. Meth,* **A936,** (2018)

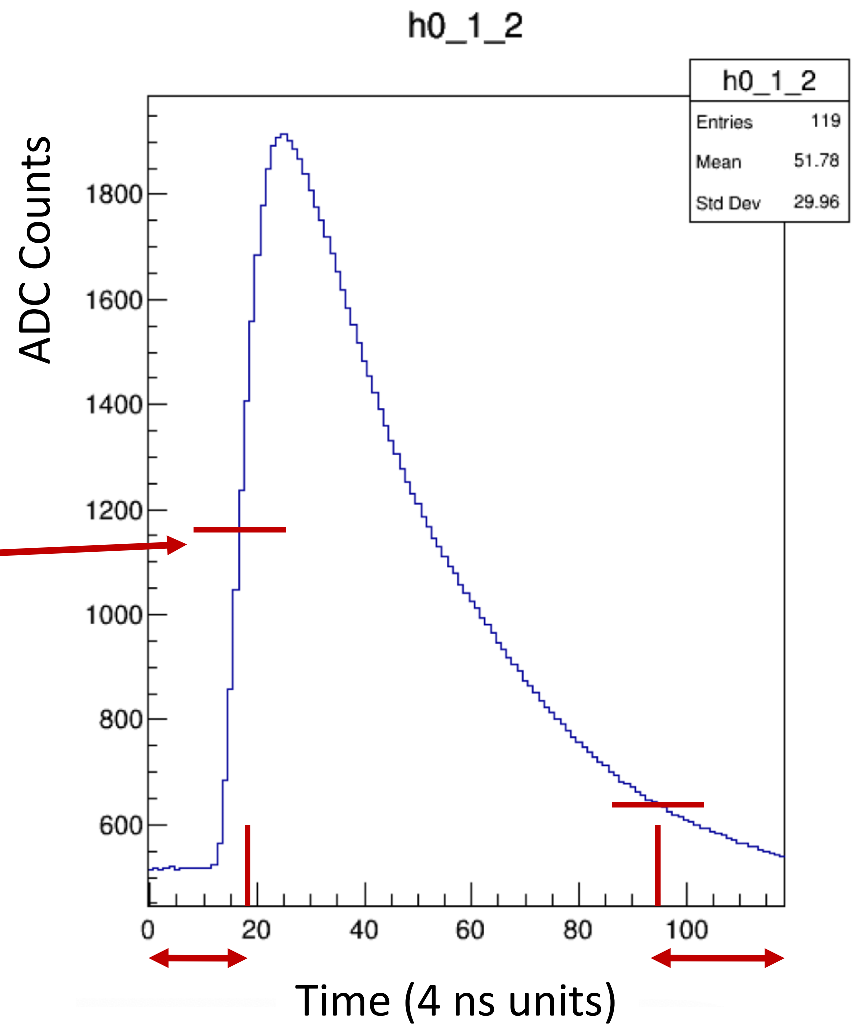
Digitization example: BDX crystal read by SiPM

DAQ Setup Procedure

- Set over and under thresholds
- Set Leading samples number
- Set Trailing samples number

Acquisition Process

- Time stamp is set on first over threshold sample
- A packet with channel ID, charge, time stamp and samples is pushed through Ethernet interface
- Dead time happens when output link speed is too low wrt hit rate



The BDX-Mini Detector test at Jlab

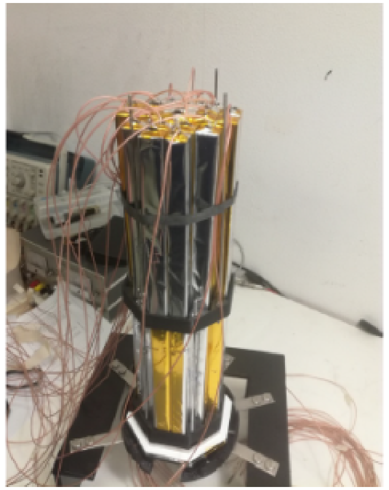
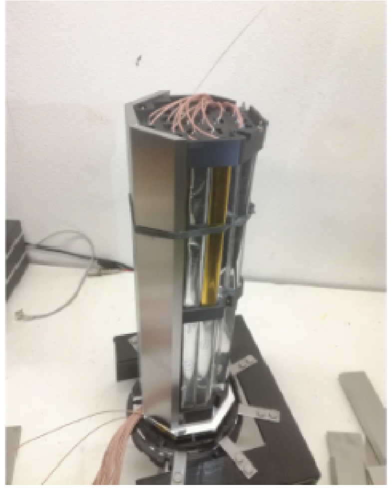
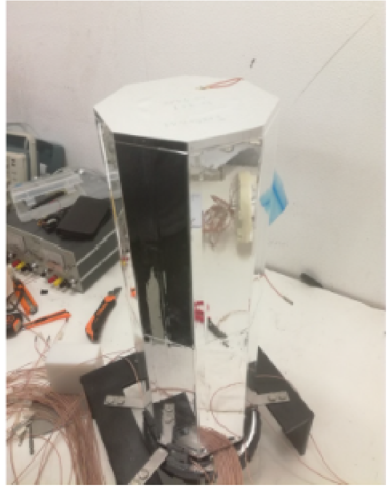
Waiting for the new experimental hall…
→ **BDX-mini:** small scale prototype for detector design and technology validation

Detector Components:

- 44x $PbWO_4$ crystals read by SiPMs (tot. volume 0.004 m^3)
- 0.8 cm thick-tungsten shielding
- Double plastic scintillator veto read by SiPM (20 channels)

Measurement Campaign @ Jlab:

- Detector lowered in a pipe drilled in the location of the future BDX hall
- Beam on measurement performed between fall 2019 – summer 2020 with **E_{beam}= 2 GeV, I = 150 μA**

BDX-mini Triggerless DAQ Validation

BDX-mini measurement campaign @Jlab allowed to test the BDX “triggerless” DAQ chain and to assess its performance in comparison with a traditional “triggered” DAQ chain

“Technical validation” process:

- Acquisition of two cosmic background data sets, with the BDX streaming DAQ system and with a triggered system
- Compare the data acquired with standard and triggerless DAQ system (coincidence rates, energy spectra...)

Triggerless DAQ Chain – waveboard + TriDAS

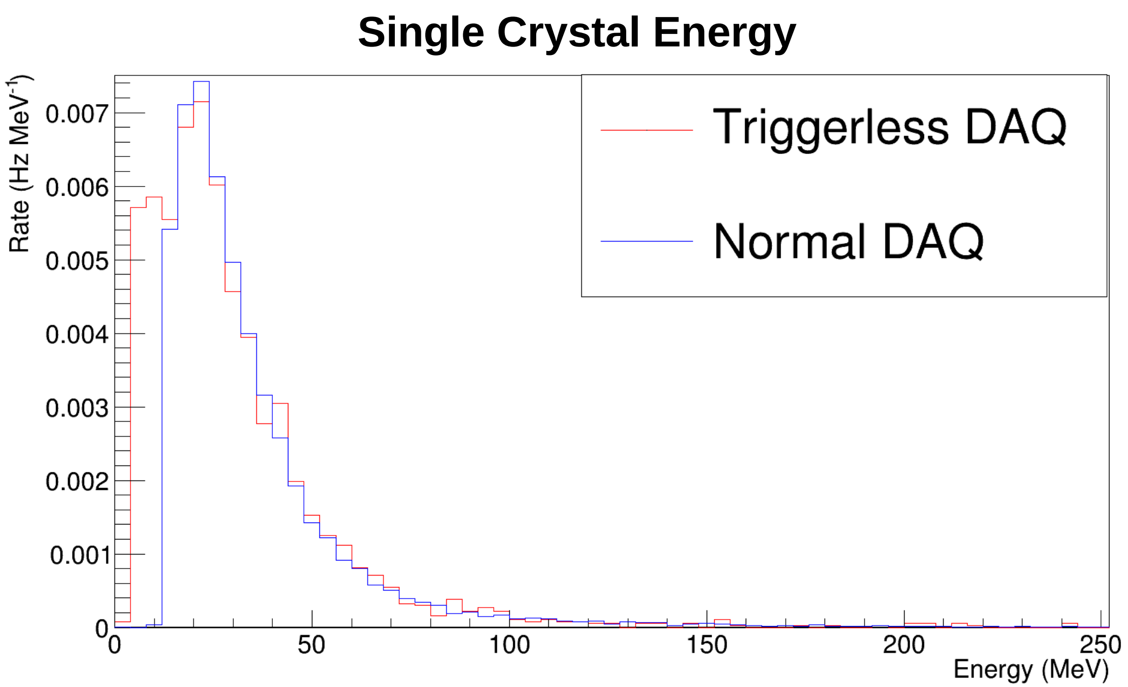
1. Only signals over the wave board hardware threshold are processed (hits)
2. Event Definition by Level 1 low level software selection algorithm (e.g. OR of crystal hits)
3. Event selection and tagging by Level 2 algorithm (e.g. clustering, trajectory selection)

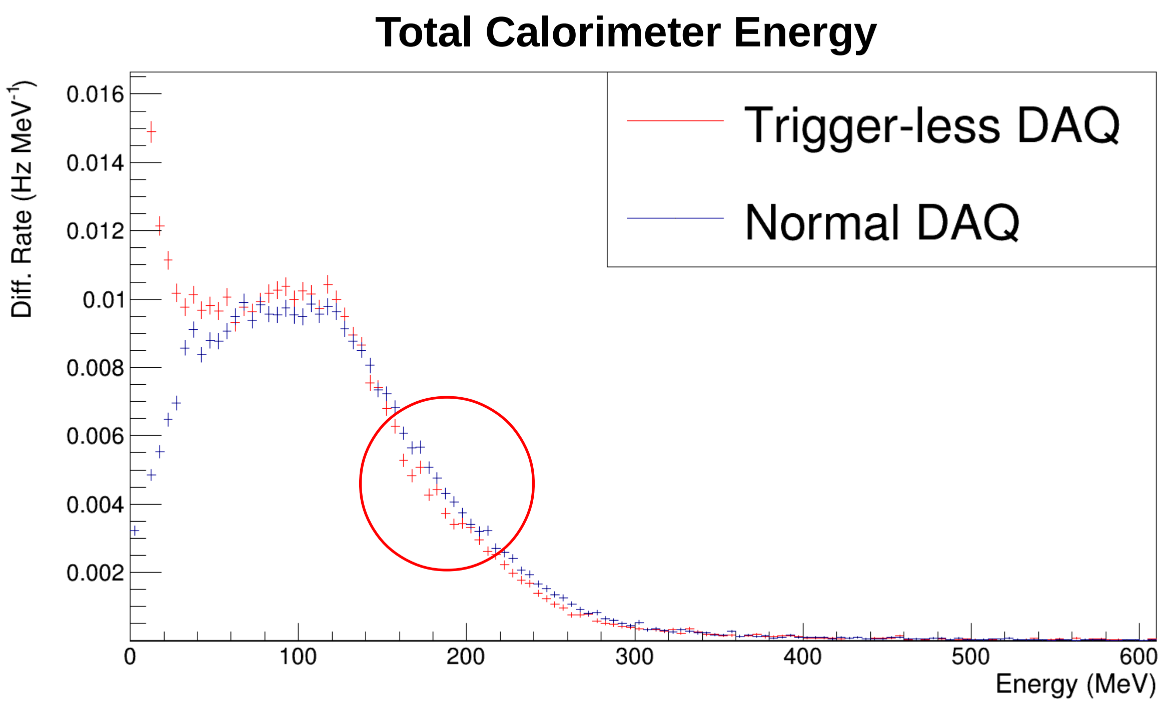
Triggered DAQ Chain – Jlab FADC + CODA

1. All channels are passed to discriminators
2. Discriminator output passed to coincidence module for event definition (OR of crystals)
3. All channels waveform acquired and saved for each trigger

DAQ Comparison: Rates

- For both DAQ systems, crystals were calibrated using MC simulations
- NO Level 2 selection used for this test
- Single crystal Rates are in good agreement above the "triggered" DAQ energy threshold
- Total energy distributions present slight discrepancy effect
  → Waveboard threshold effect

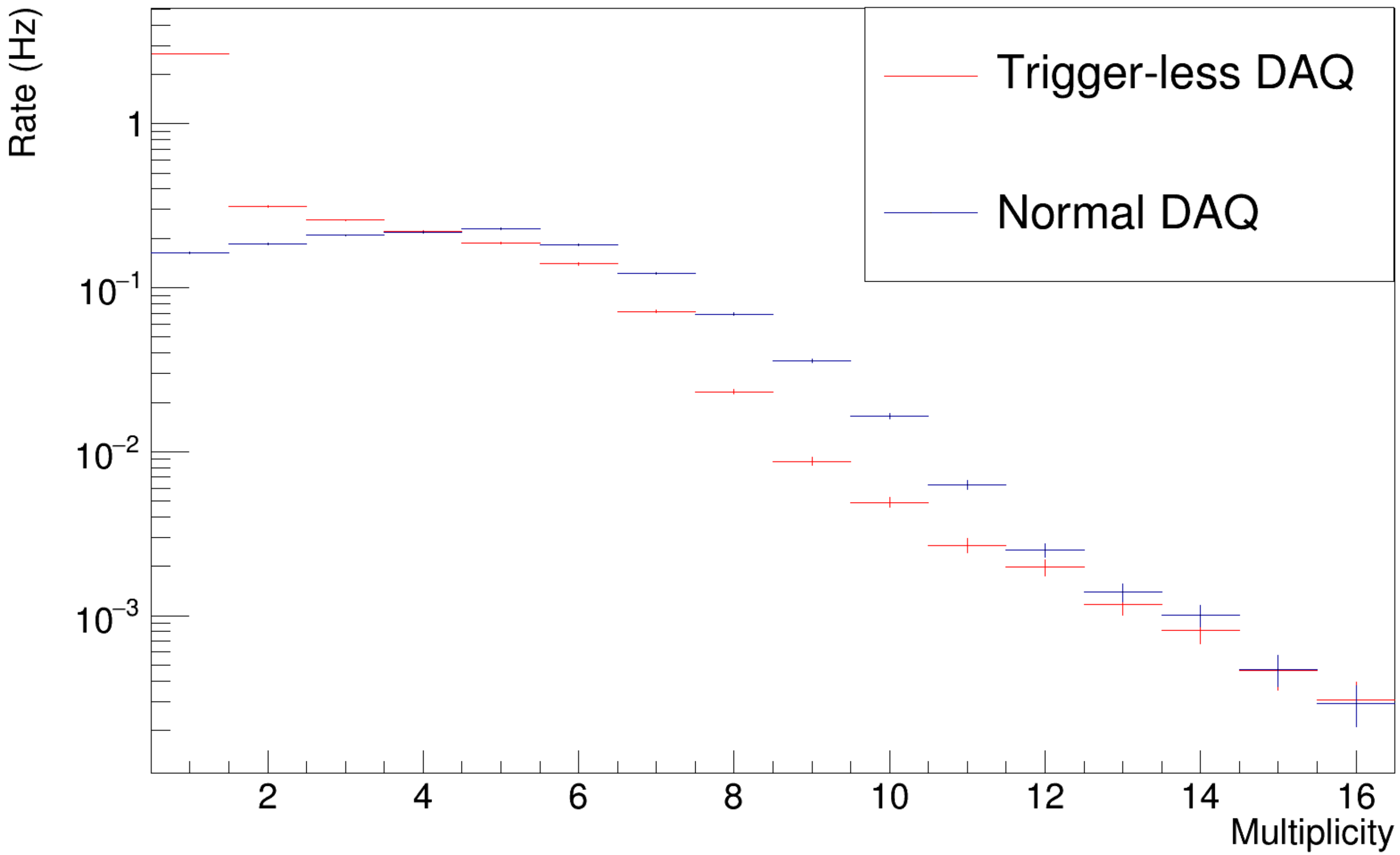




DAQ Comparison: Multiplicity

- Hit multiplicity distribution confirms discrepancy
- Triggerless DAQ: lower rate at high hit multiplcity
- Triggered DAQ: lower rate at low hit multiplicity

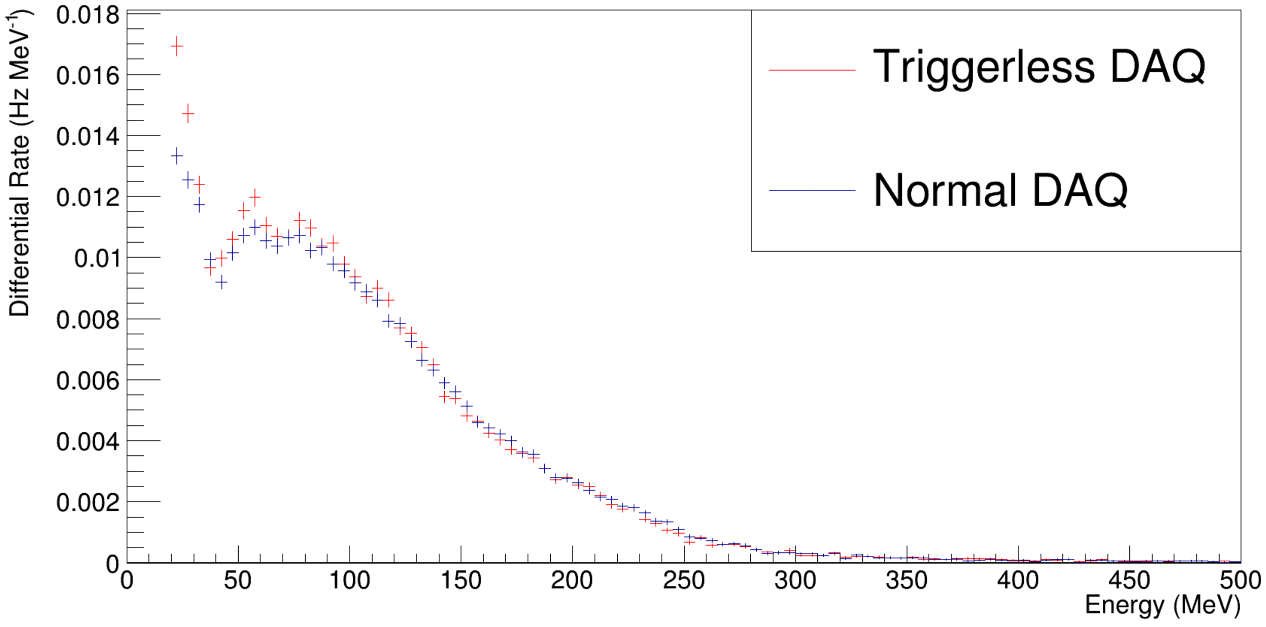
  → Wavebard threshold is lower than triggered DAQ threshold but high enough to cut very low energy hits

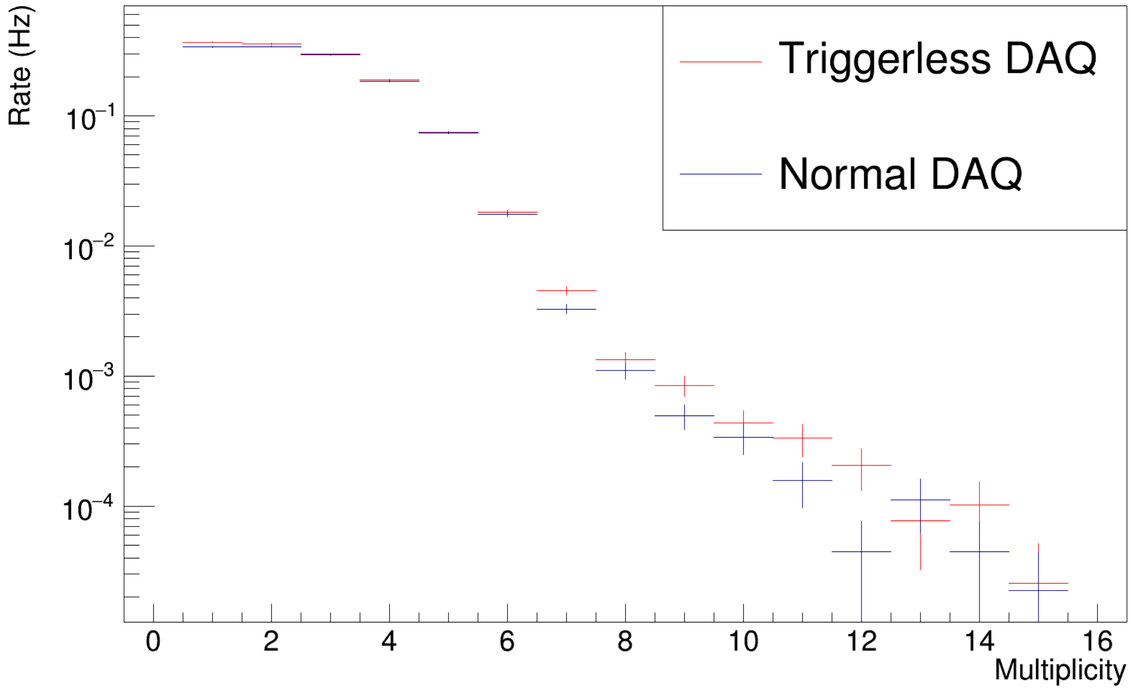


Wave Board treshold effect

- Threshold effect discrepancy is mitigated applying a threshold to hit energies in offline analysis
- With a single hit energy threshold of 20 MeV the agreement is reasonable

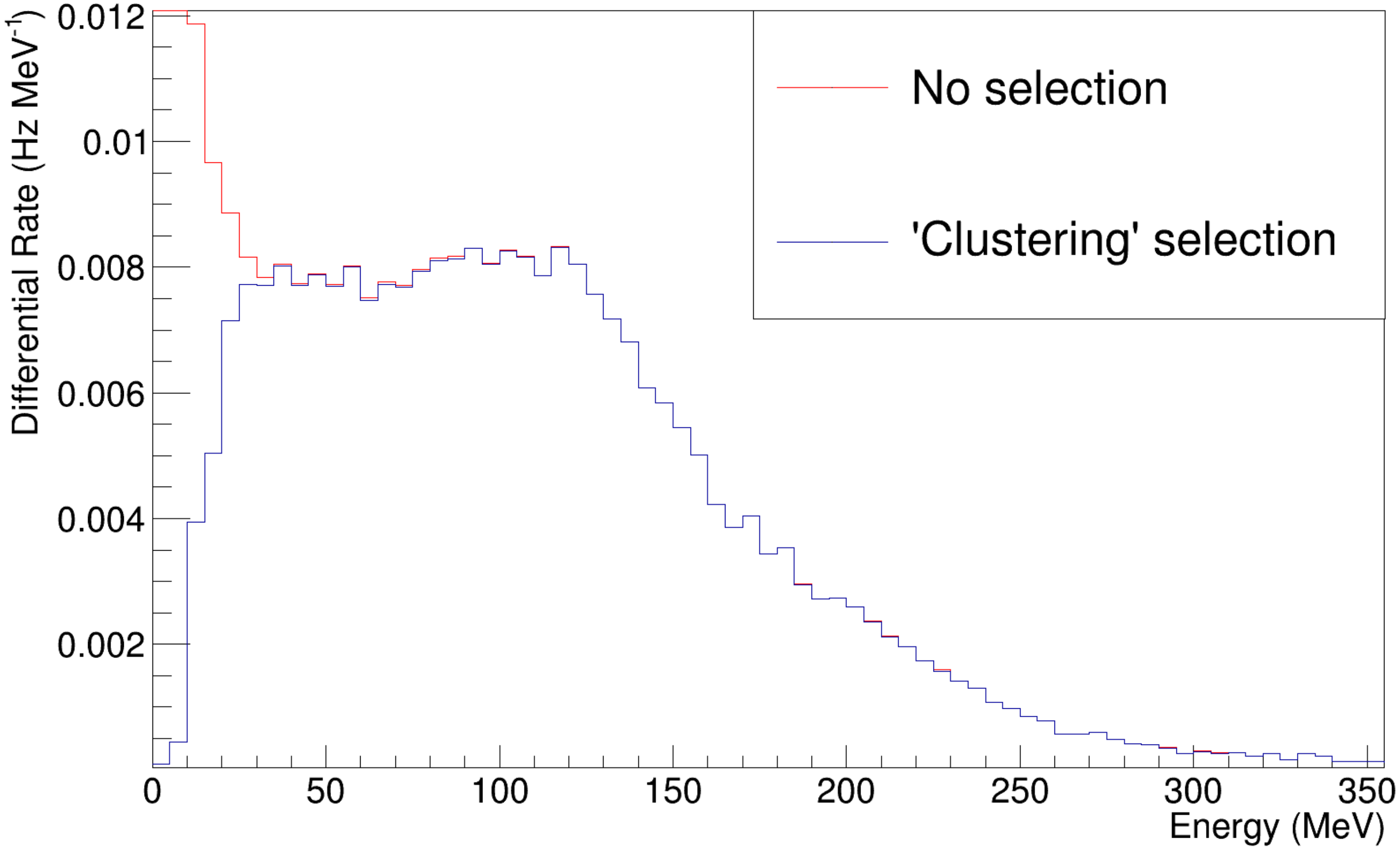
→ Wave board hardware threshold mast be tuned carefully





“Clustering” Trigger Efficiency

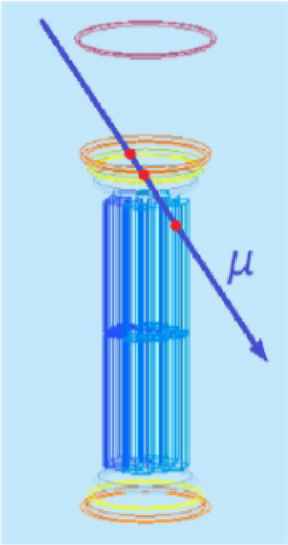
- Level 2 online “clustering” selection trigger was tested
- Events selected online applying a few MeV threshold on Etot and Eseed
- Same cut applied offline to unselected events
- Trigger efficiency is about 100%

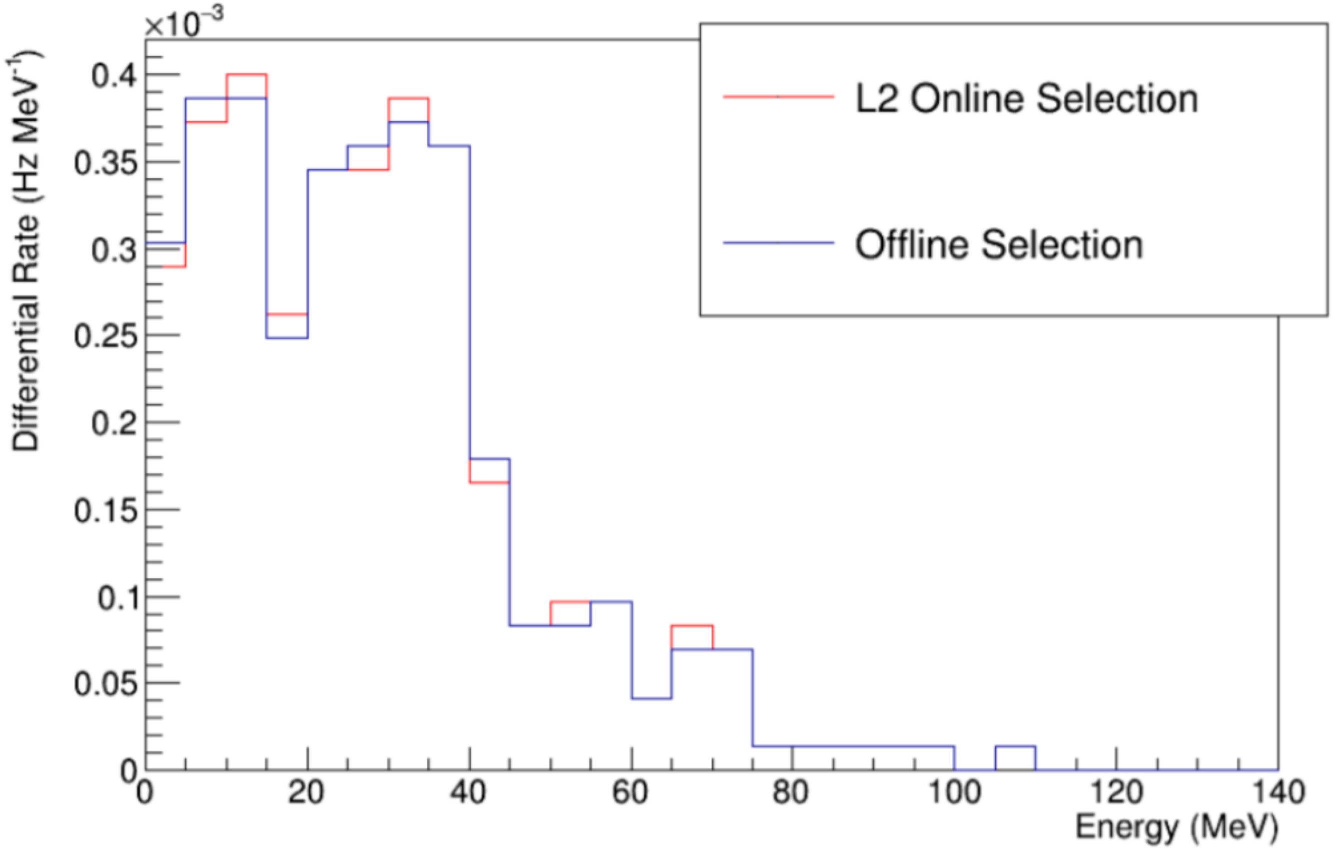


Cosmic Trajectory Selection

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

- An online trajectory selection algorithm was implemented (Level 2)
- Events defined applying conditions on veto channels charge distributions
- Online trajectory selection has comparable efficiency to the offline analysis





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 a streaming readout system for the full detector readout (CsI(Tl) crystals / plastic scitillator counters, SiPM readout)
- System is based on a custom digitizer board developed by INFN and on the TriDAS software (KM3net)

A measurement campaign with a small scale detector (BDX-mini) has been performed at Jefferson Lab

- Test runs ave been taken with the BDX triggerless system: this allowed to validate the DAQ chain and assess its performance
- The triggerless system proved to be a good system for BDX
- Further test will be performed in future

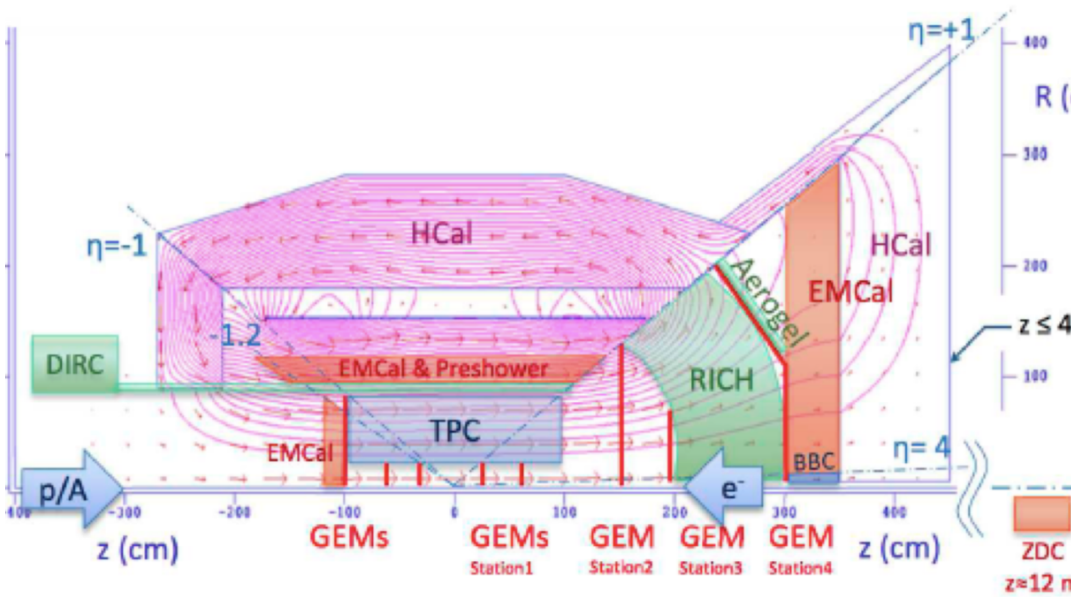
Thanks For The Attention!

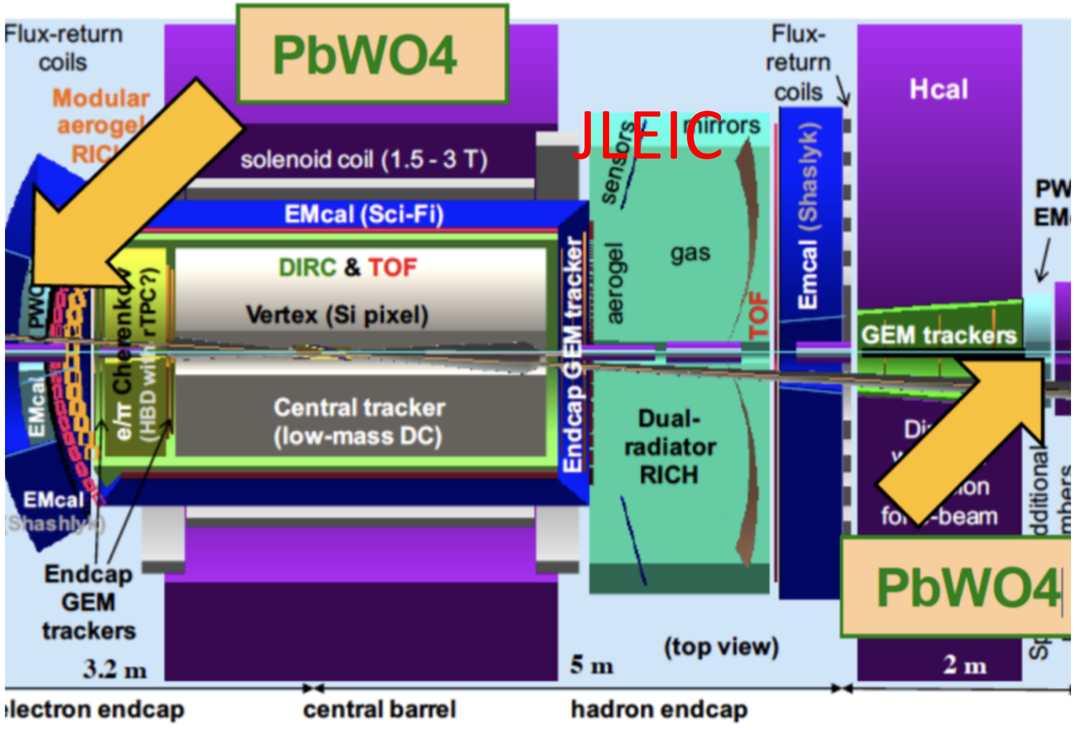
BDX tests as a first step toward EIC triggleress system validation

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:** PbWO4 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





The project 'Un sistema di acquisizione triggerless per l'Electron Ion Collider (EIC) / A triggerless DAQ for the Electron Ion Collider (EIC', in collaboration with the Massachusetts Institute of Technology (MIT), is funded by the Italian Ministry of Foreign Affairs (MAECI) as Projects of great Relevance within Italy/US Scientific and Technological Cooperation under grant n. MAE0065689 - PGR00799.

Backup: BDX expected data rate (300 MeV threshold)

- The overall trigger rate will be $R_{trg} = 5\ Hz/\text{crystal} \cdot 1000$ crystals $= 5$ kHz.
- The data size of each crystal signal is: $D_{crs} = 2048$ samples $\cdot 12$ bit/sample $= 3$ kB. The total data rate from crystals is: $DR_{crs} = D_{crs} \cdot R_{trg} = 14$ MB/s.
- The data size of a FADC-integrated pulse is $D_{veto} \simeq 12$B. Assuming (conservatively) that $N_{veto}/10$ veto counters report a pulse for each trigger, the total data rate from these is: $DR_{veto} = N_{veto} \cdot D_{veto} \cdot R_{trg} = 1$ MB/s.
- The total event rate is: $DR_{tot} \simeq 1.1 \cdot (DR_{crs} + DR_{veto}) = 16$ MB/s. A 10% overhead has been assumed for event-related information (event time, indexes of channels, ...)