BDX triggerless DAQ and validation

EIC streaming readout workshop

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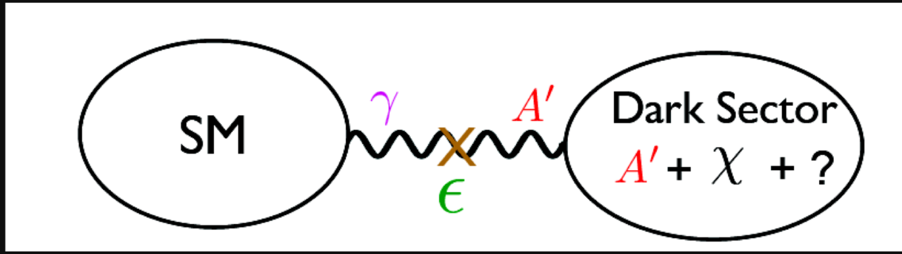
Search for light dark matter

Light dark matter (100-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")



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

BDX @ JLAB

DARKLIGHT

APEX

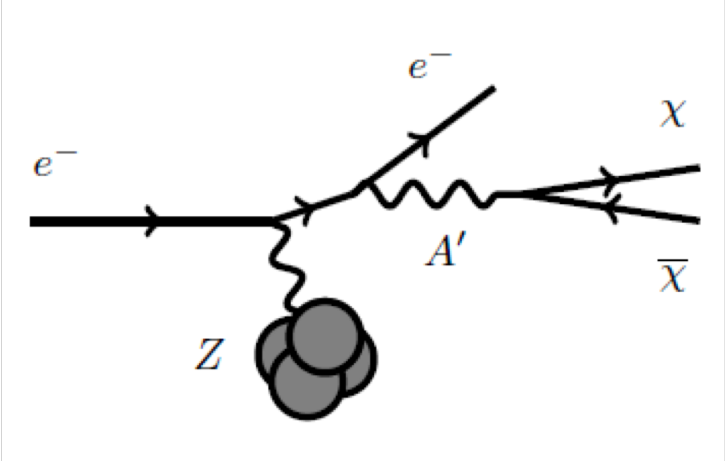
HEAVY PHOTON SEARCH

The BDX experiment

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

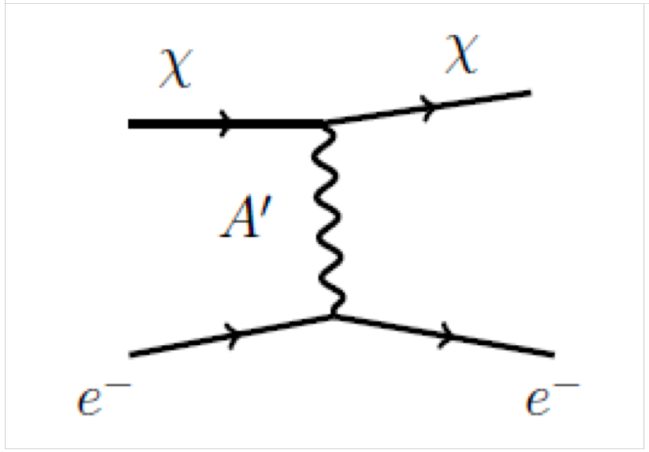
LDM production

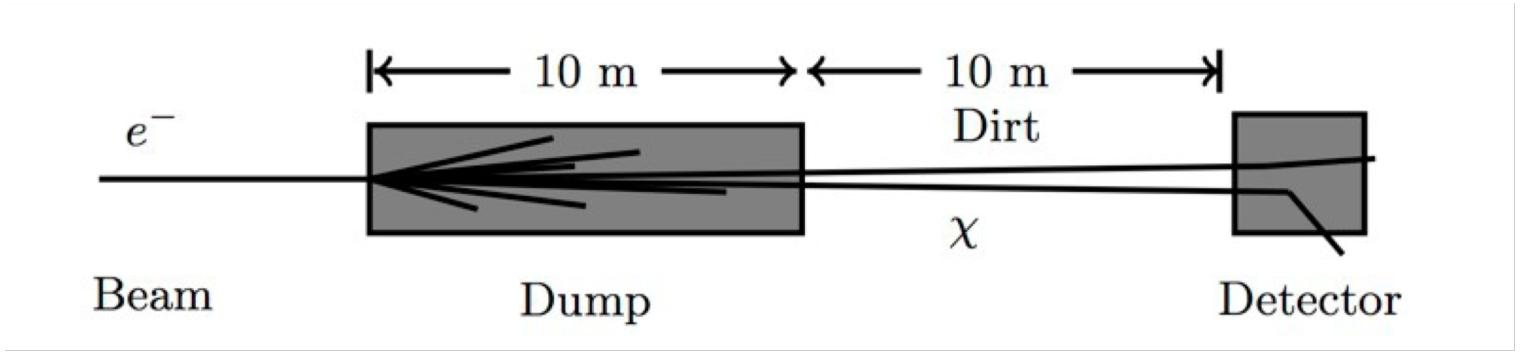
- High-energy, high-intensity e^- beam impinging on the dump
- LDM particles pair-produced radiatively, through A' emission



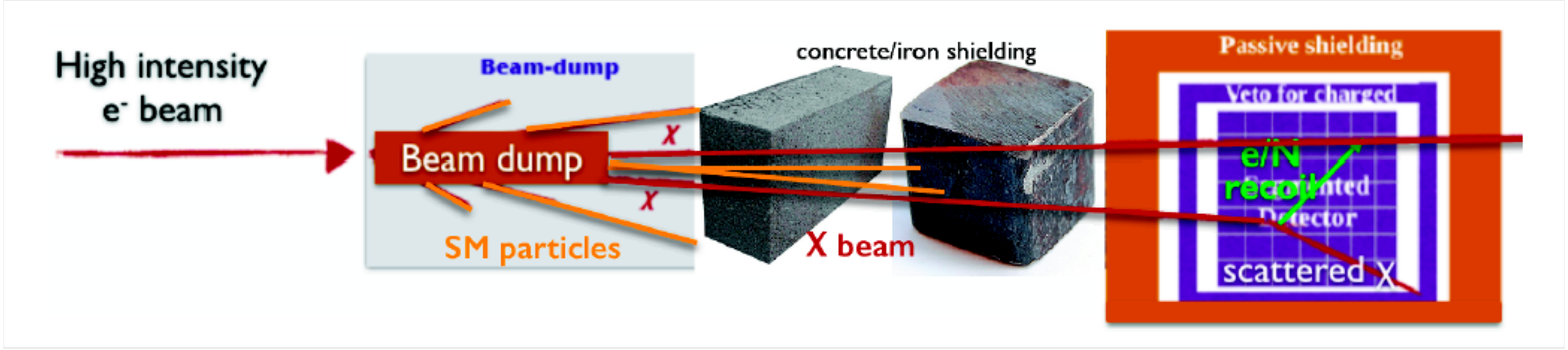
LDM detection

- Detector placed behind the dump at ~ 20m
- Neutral-current scattering on atomic e^- through A’ exchange, recoil releasing visible energy
- Signal: *O*(100 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 m^3 (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

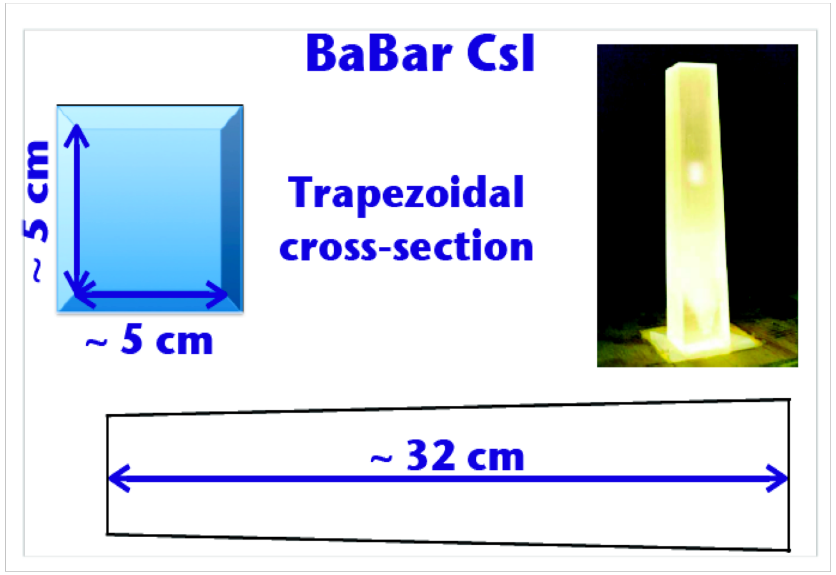
The BDX detector

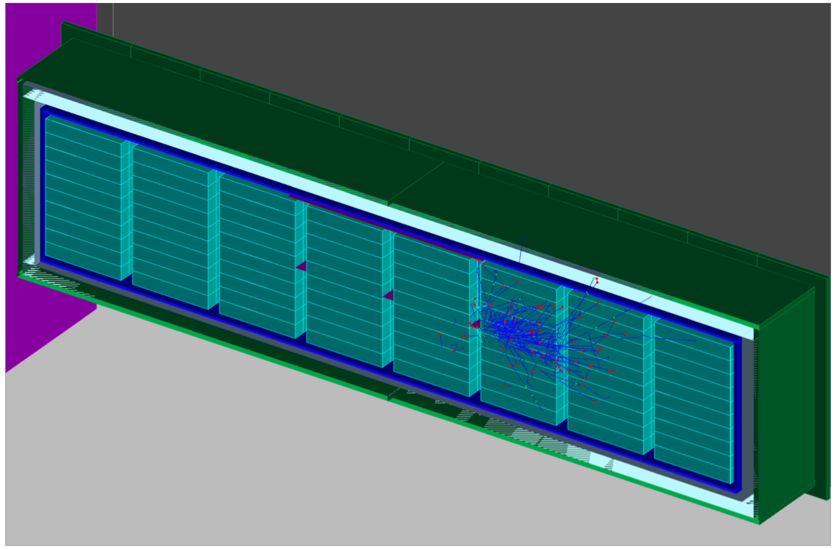
BDX detector: state-of-the-art EM calorimeter, CsI(Tl) crystals with SiPM-based readout

Detector design:
- 800 CsI(Tl) crystals, total interaction volume 0.5m^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





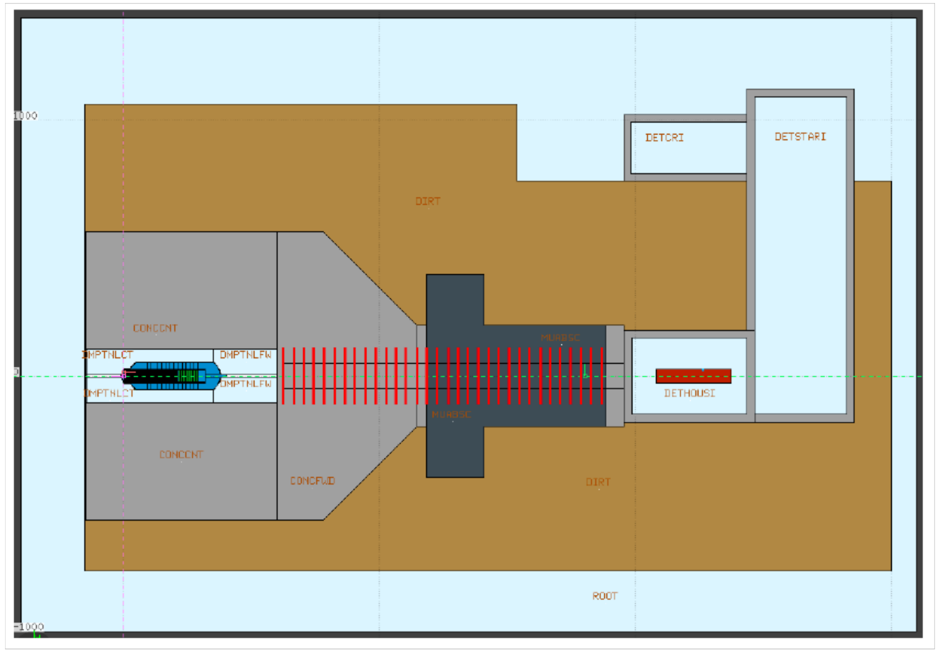
The BDX setup at JLab

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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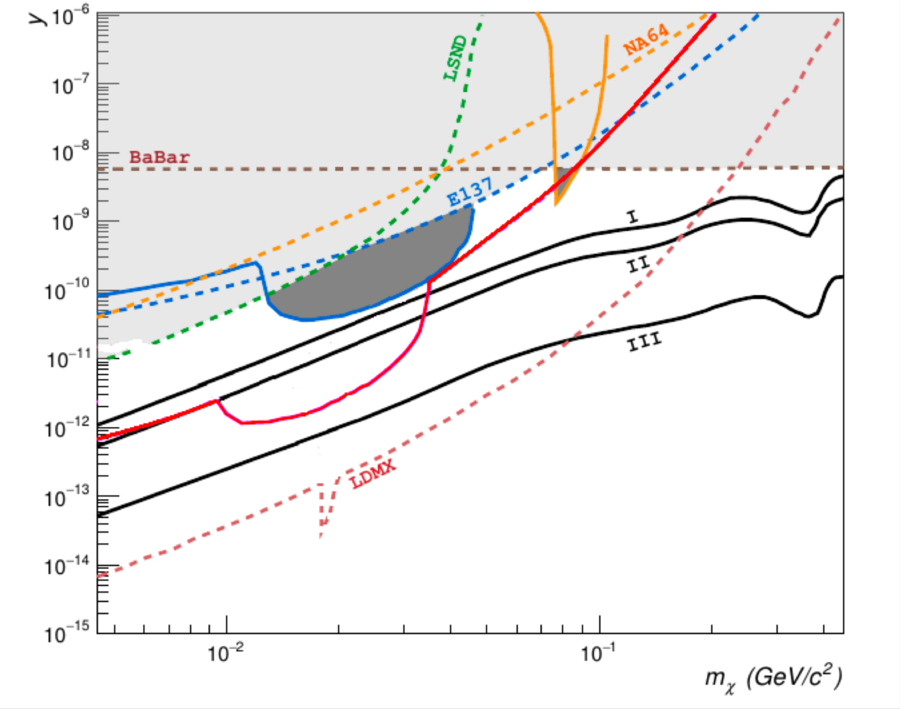
The BDX reach after 1 year of measurement



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

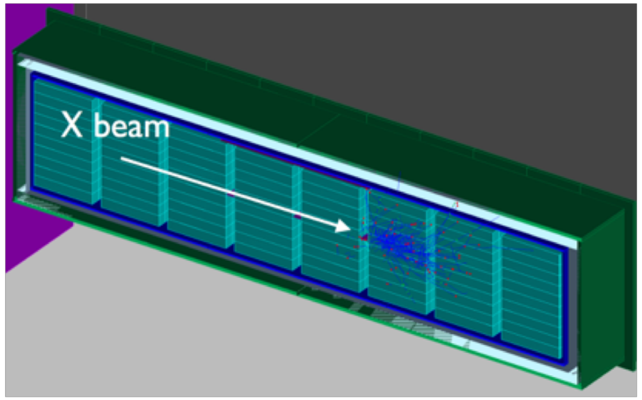
BDX plans to adopt a streaming-readout DAQ system for the whole detector: CsI(Tl) crystals + plastic scintillator counters.

Key elements:

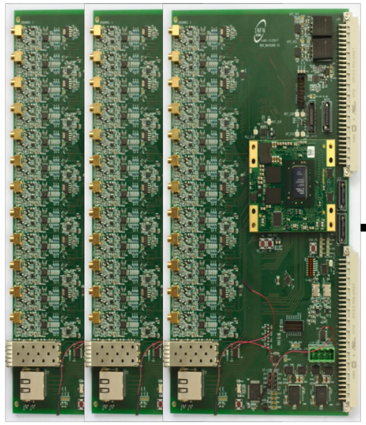
- **Digitization:** INFN “wave board” digitizer (250 MHz, 14 bit, 12 ch) for SiPM (see F. Ameli talk)
- **Online reconstruction and event building:** Tridas system – KM3 (see T. Chiarusi talk)
- **Run control/monitoring:** custom system based on REST APIs and web-based controls

General Readout scheme:

Detector



Amplification / Digitization



Online-data analysis

Trigger decision/ event building (?)

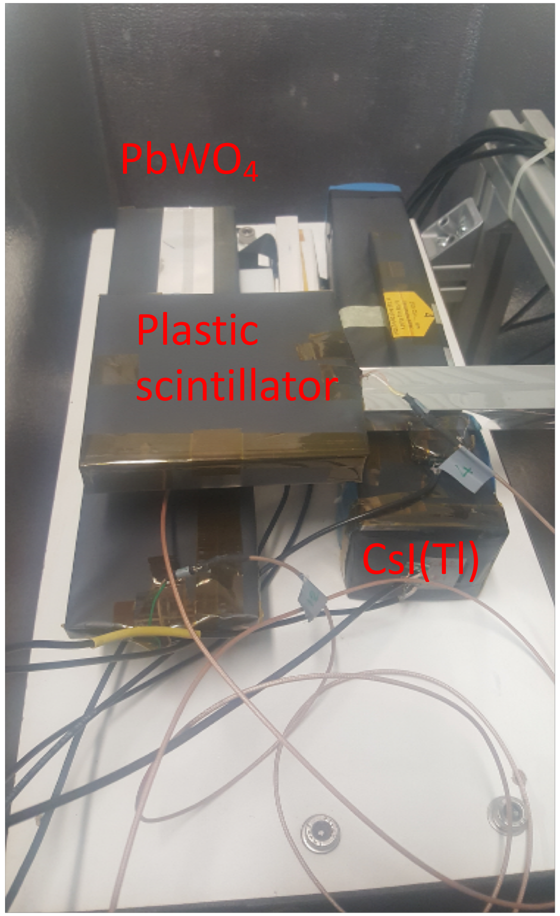
BDX DAQ system validation

"Technical validation" process:

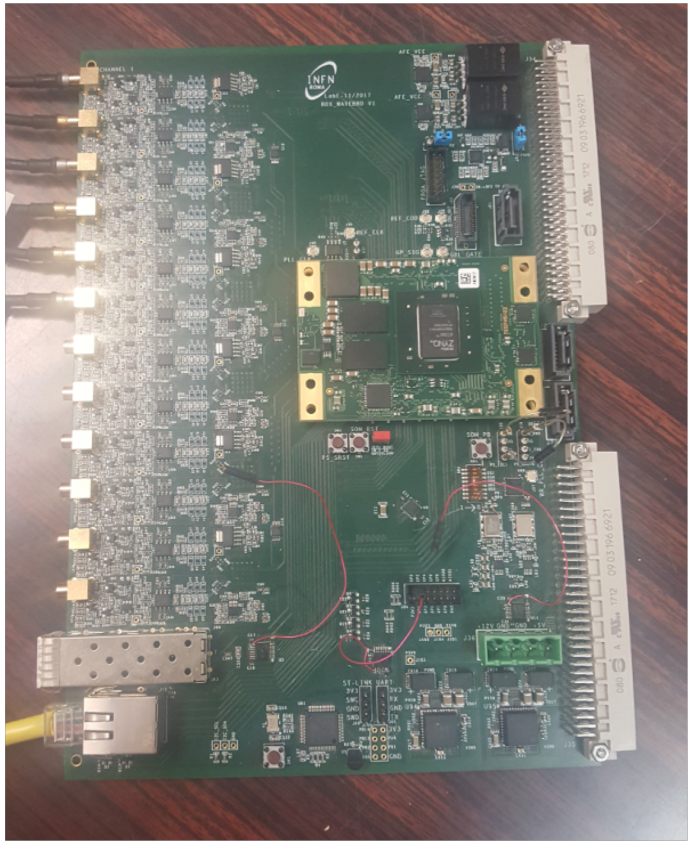
- Compare between "standard" (triggered) and "triggerless" DAQ system in a well controlled laboratory setup using cosmic rays
  - Setup the triggerless chain
  - Verify performances: coincidences rate / charge spectra / **timing** / …

A test laboratory at INFN-Genova is currently being set up:

- Different samples available: crystals (CsI(Tl) and **$PbWO_4$** with SiPM readout) + plastic scintillator with SiPM readout
  - PMT readout will be implemented next
- Triggerless DAQ based on wave-board + Tridas
- Triggered DAQ based on JLab FADC + CODA



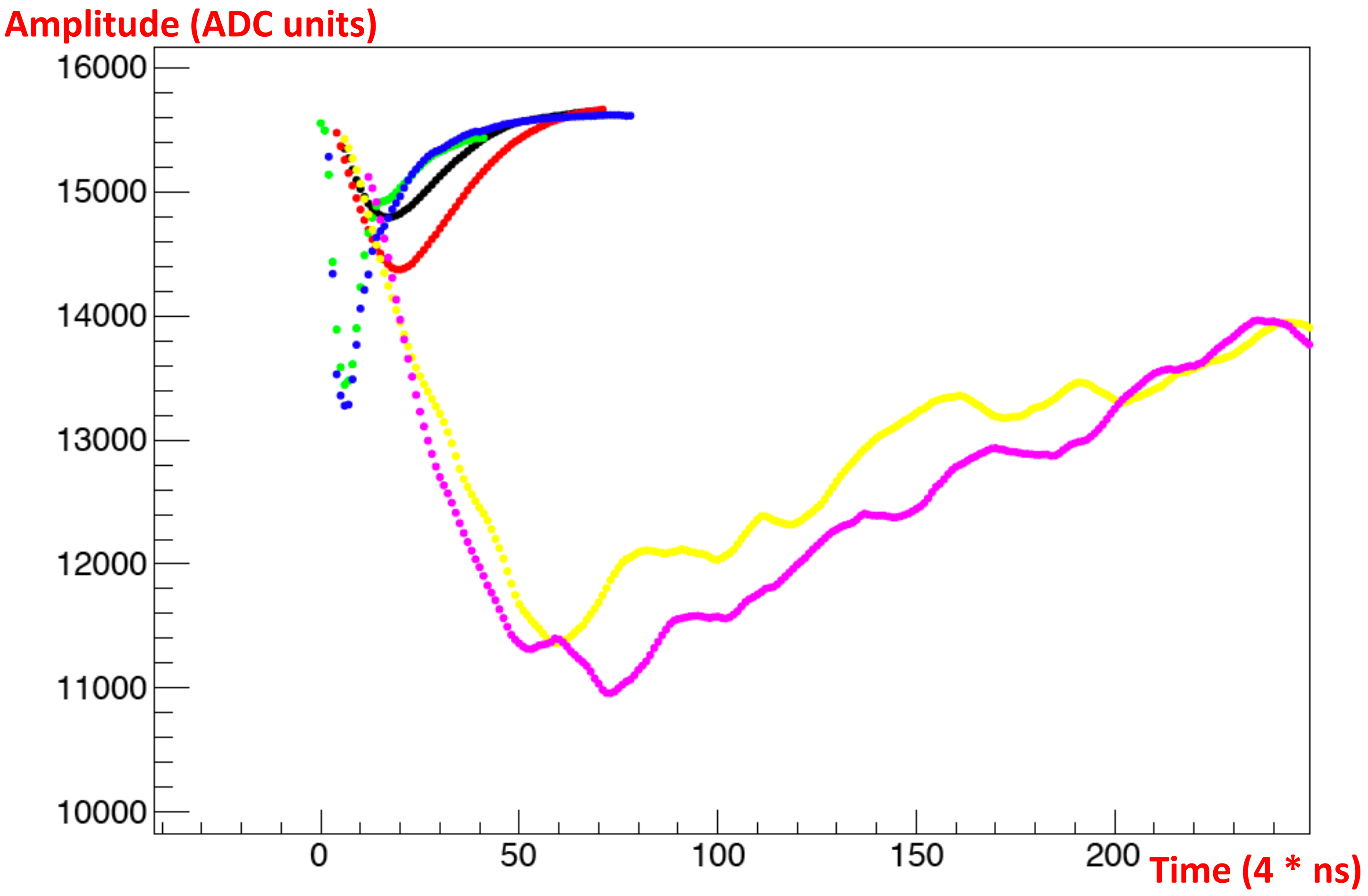
Wave-brd



BDX DAQ system validation

A first result: 6-fold coincidence from wave-brd between

- Two plastic scintillator counters (green/blue)
- Two PbWO4 crystals (red/black)
- One CsI(Tl) crystal with dual SiPM readout (purple/yellow)



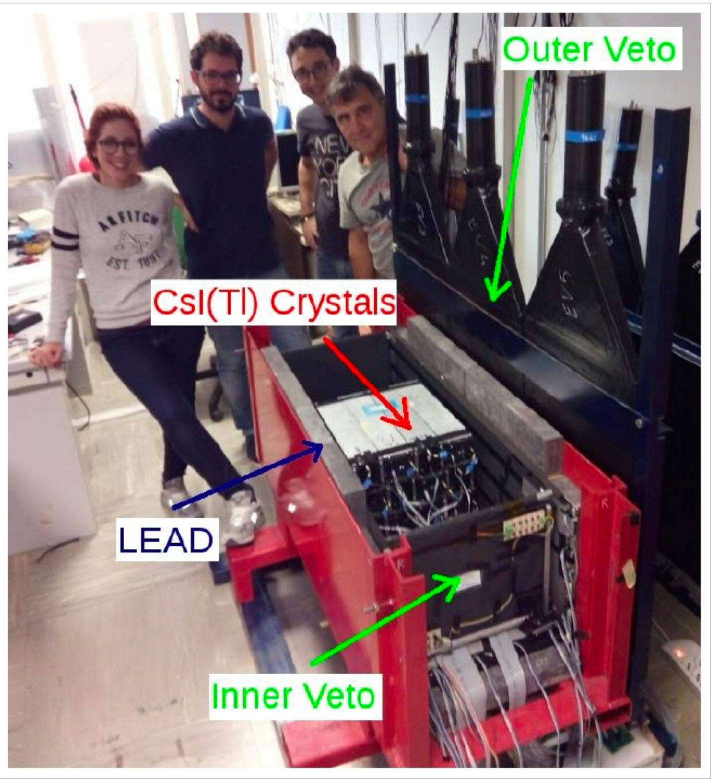
“Physical validation” process:

Compare between “standard” (triggered) and “triggerless” DAQ system in a real measurement: perform the analysis of the **same observable** in the two cases and **compare results**

BDX DAQ system validation

BDX-proto measurement @ JLab:

- Place a small scale prototype of one BDX module in a setup with similar overburden configuration as in the final setup
- Measure cosmogenic rate and evaluate foreseen backgrounds



BDX-proto detector:

- 16x CsI(Tl) crystals, SiPM readout
- 2 plastic scintillator veto layers, SiPM readout
- Setup to be modified to be compatible (cabling, ...) with wave-brd readout

Tests foreseen in 2019

“Physical validation” process:

Compare between “standard” (triggered) and “triggerless” DAQ system in a real measurement: perform the analysis of the same observable in the two cases and compare results

BDX DAQ system validation -2

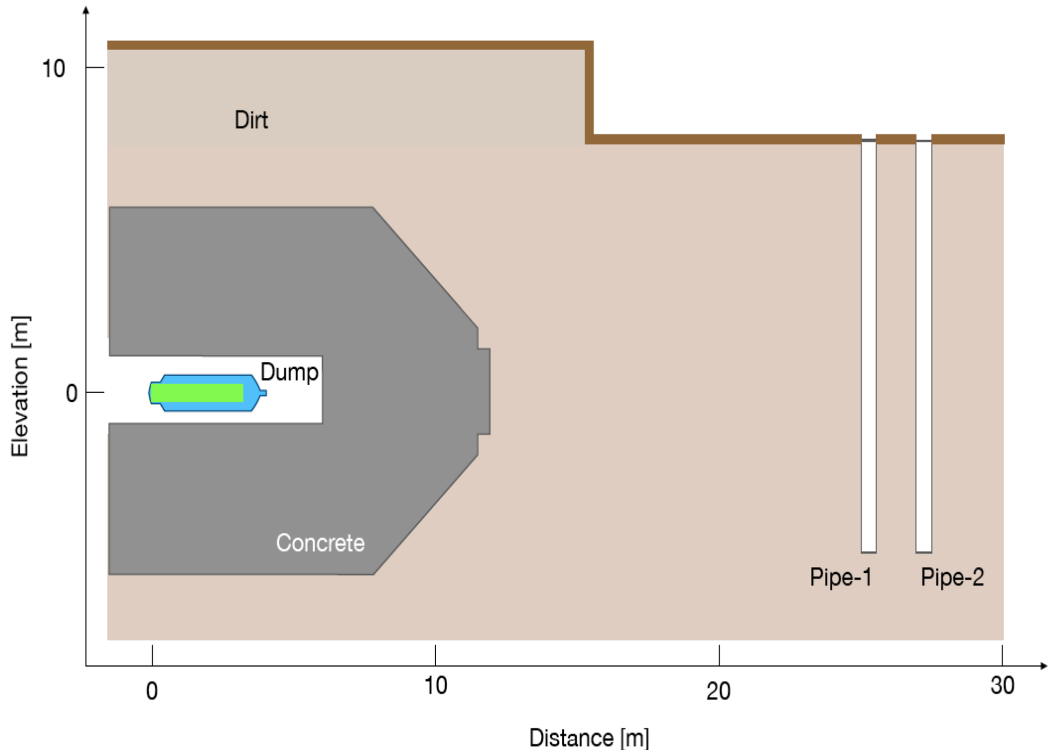
BDX-mini measurement:

- Exploit the setup used for MC validation @ JLab: 2 pipes behind Hall-A
- Place a small-scale detector in one pipe
- Take data alternately with both DAQ systems

BDX-mini detector:

- 50x **PbWO4** crystals, SiPM readout
- 2 plastic scintillator veto layers, SiPM readout
- Setup compatible (cabling, ...) with wave-brd readout / traditional triggered readout

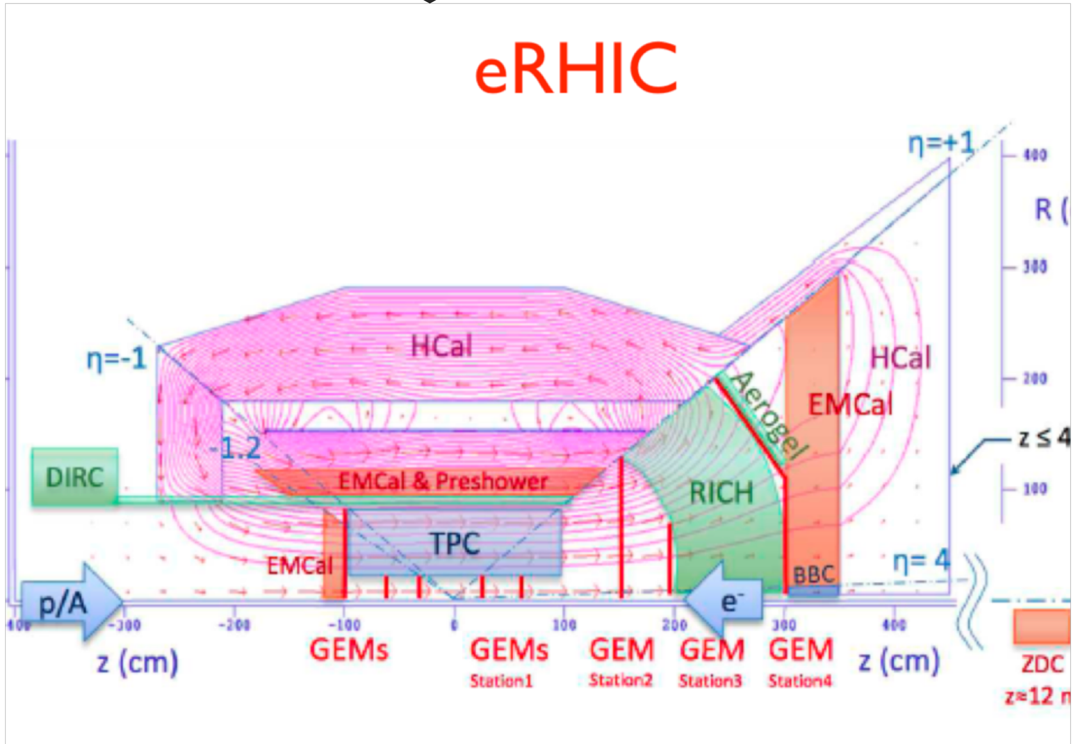
Tests foreseen from Gen 2019

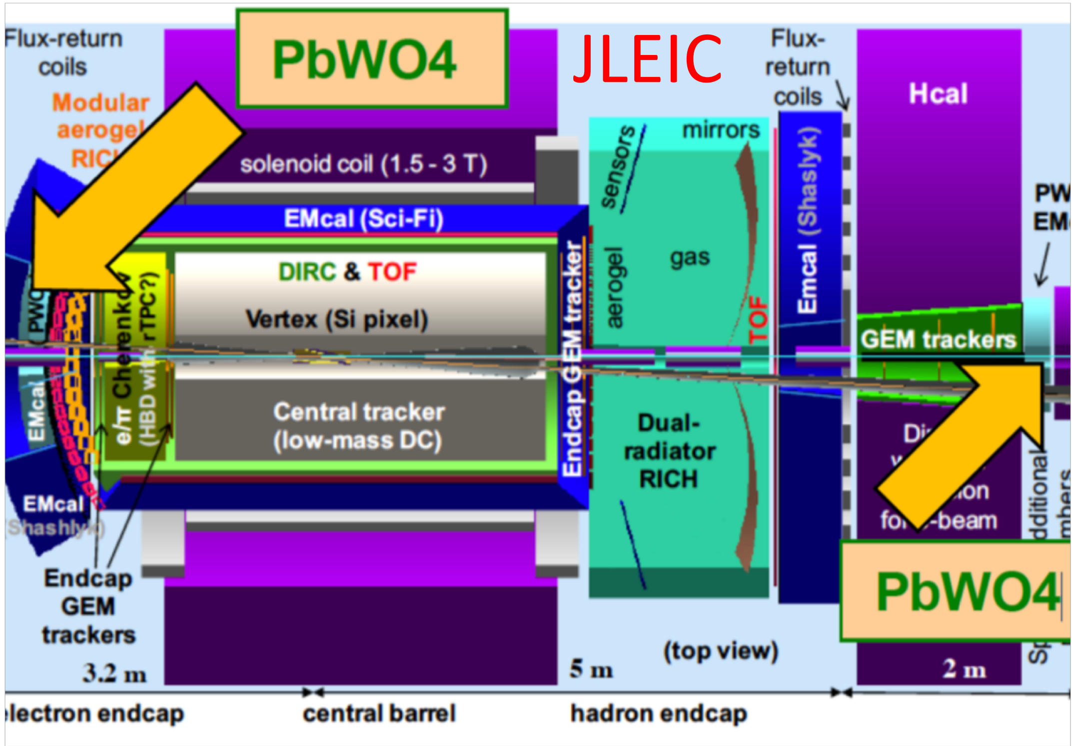


BDX tests as a first step toward EIC triggleress system validation

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





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 test lab has been set up at INFN-Genova for a "technical" validation of the new system
- Two measurement campaigns will take place in 2019 at JLab, with "BDX-Proto" and "BDX-Mini" detectors
  - Main setup are based on traditional triggered DAQ. Two measurements will be taken with the BDX triggerless system: this will allow to compare results for the same observables and validate the system
- BDX can be the first step toward the validation of the triggerless approach in EIC – starting from EM calorimetry

ATTRACT

A proposal to the EU-ATTRACT call has been submitted to support the BDX triggerless activity

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, ...)