The BDX experiment at Jefferson Laboratory

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WORKSHOP ON DARK 2016 SECTORS

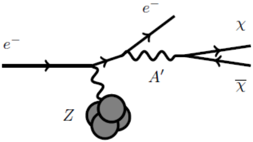
Outline

A fixed target LDM experiment

Beam Dump eXperiment: LDM direct detection in a e^- beam, fixed-target setup[1]

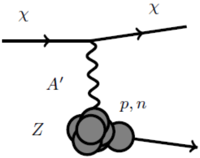
χ **production**

- High-energy, high-intensity e^- beam impinging on a dump
- χ particles pair-produced radiatively, trough A' emission (both on-shell or off-shell).

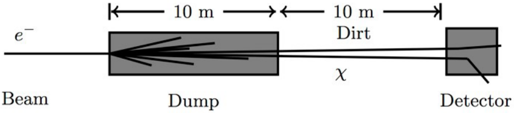


χ **detection**

- Detector placed behind the dump, O(10m)
- Neutral-current χ scattering trough A' exchange,recoil releasing visible energy
- Different signals depending on the interaction (e^- elastic, p quasi-elastic,. . .)



Number of events scales as (on-shell): $N \propto \frac{\alpha_D \varepsilon^4}{m_A^4}$



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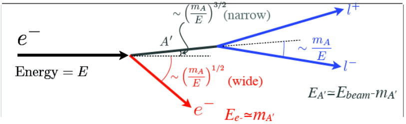
[1] For a comprehensive introduction: E. Izaguirre *et al*, Phys. Rev. D 88, 114015

LDM production

Main features of χ production in the beam dump follows from thin-target kinematics $*$ e^- energy loss and secondaries emission in the dump



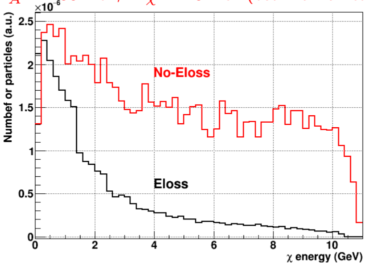
Thin target kinematics (on-shell A'):

- A' emitted forward, $E_A \simeq E_0$
- χ beam with very sharply peaked-forward kinematics

e^- in the dump:

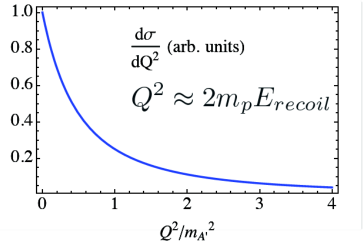
- e^- loses energy by ionization and Bremsstrahlung: χ kinematics gets broader
- Secondary (low-energy) e^- are produced: more χ particles are emitted

χ energy distribution for $E_0 = 11$ GeV
$M_A = 100$ MeV, $M_\chi = 10$ MeV (both normalized to 1)



LDM detection

Two main processes are considered (altough others may be possible)



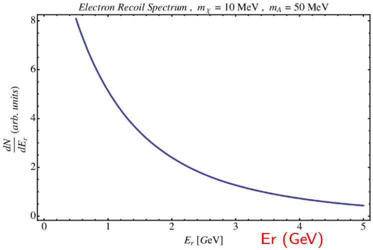
χ-p quasi-elastic scattering

- Nucleon recoil: sizeable cross section for T_N>1-10 MeV
- Signal in a single detector channel
- Low energy background rejection capability is required

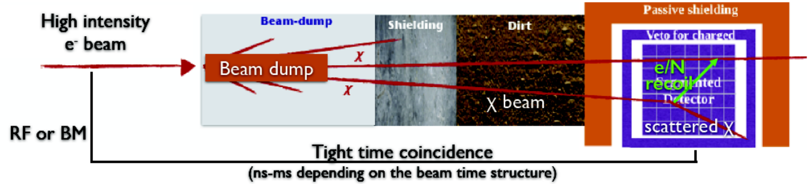
χ-e elastic scattering

- e^- recoil: EM shower (O(GeV)) with signals in multiple channels
- Background rejection is not critical

The simultaneous measurement of **both** e^- and p signals would provide a strong evidence of LDM existence.



BDX experiment layout



The experiment is designed with two goals:

Producing and detecting LDM

- High-intensity e^- beam, O(10^{21}-10^{22}) EOT/year
- Medium-high energy, O(5-10) GeV
- $\simeq 1\ m^3$ (1-5 tons) detector
- Low-energy thresholds
- EM-showers detection capability

Reducing background

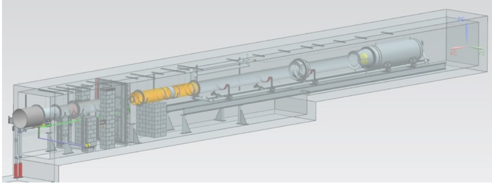
- Passive shielding and active vetos
- Segmented detector for events discrimination
- Good time resolution
- Different technologies for systematic checks

JLab facility

Beam Dump eXperiment at Jefferson Laboratory: ideal location is behind the Hall-A beam dump

- ☺ About 350 C/year ($2.2 \cdot 10^{21}$ EOT) of beam will be delivered to the Hall-A beam-dump with expected running of 25 weeks/year at $\simeq$ 50 μA
- ☹ Almost-continuous beam (4 ns time period): very good detector time resolution is required to make a beam coincidence

Hall-A beam-dump: Aluminum plates immersed in water for cooling.



BDX detector concept

Requirements

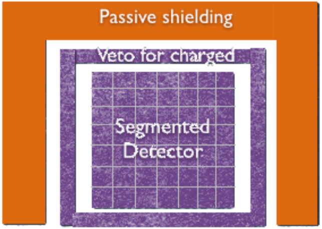
- High-density to maximize event yield
- Low threshold for nucleon recoil detection (MeV) + EM showers detection capability
- Segmentation for background rejection
- Active veto and passive shielding

BDX design

- EM calorimeter made with CsI(Tl) crystals+SiPM-based readout
- Two active-veto layers, made with plastic-scintillator counters read by SiPM and PMTs
- 5-cm thick lead layer betwen inner and outer veto

Total active volume: $\simeq 0.5\ m^3$

BDX detector sketch



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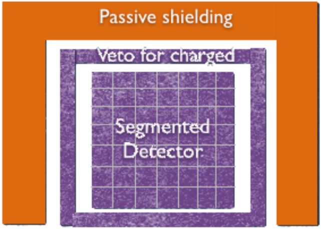

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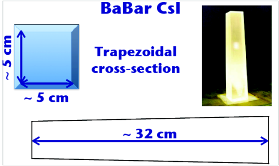
Calorimeter layout

BDX calorimeter: use the existing BaBar CsI(Tl) crystals with improved SiPM-based readout



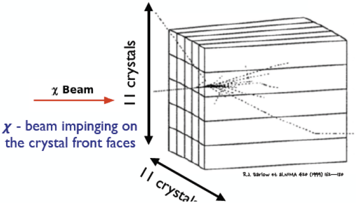
Detector design:

- $\simeq$ 800 CsI(Tl) crystals, total interaction volume $\simeq 0.5m^3$
- Simplified assembly mechanics
- Modular detector: change front-face dimesions and total lenght by re-arranging crystals

Possible arrangement:

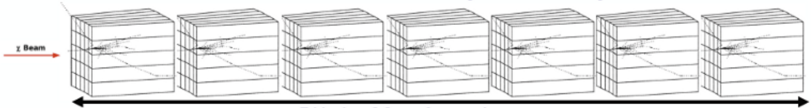
- 1 module: 11x11 crystals, 30-cm long. Front face: $50x50$ cm^2
- 7 modules: interaction length 2.1 m

Single module layout



R.J. Barlow et al.,NIMA 420 (1999) 162—180

TOT = 7 Blocks x 121 crystals = 847 crystals

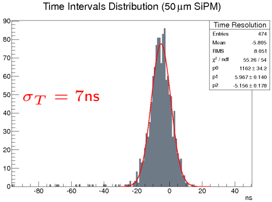


7 blocks ~ 2.2 m of active detector

Calorimeter R&D

Characterization campaign to measure crystal+SiPM properties

- Light-yield with SiM readout : $\simeq 1$ phe / MeV / mm^2
- Time resolution @ 30 MeV: $\sigma_T = 7$ ns



• Signals at MeV level are detectable

→ • Despite a long scintillation time a few ns time coincidence is possible.

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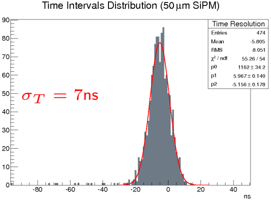
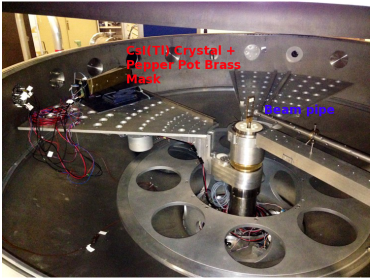
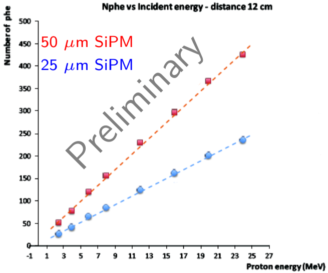


Time Intervals Distribution (50 µm SiPM)

Response to low-energy p has been measured with p beam at INFN-LNS: low-energy LY, light-quenching, detection efficiency, ...



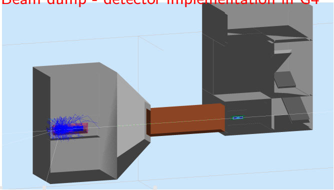


Nphe vs Incident energy - distance 12 cm

Beam-related background

Backgrounds created by beam interaction with the dump: estimated via MC

Beam dump - detector implementation in G4



Challenges:

- Computing: high EOT and energy
- Physics: modelling GeV to eV, low energy nuclear reactions, neutron transport

- **Brute-force G4-approach**
- **Combined approach**

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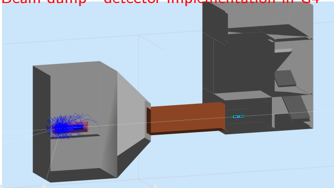

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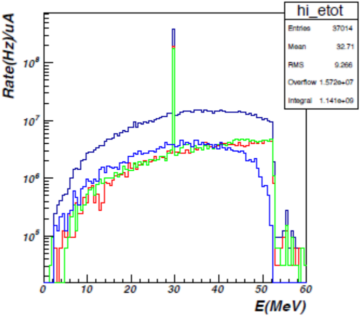

- Model beam dump geometry and materials
- High precision physics lists: QGSP_BERT_HP + EM_HP
- Determine fluxes of particles exiting from the dump and reaching the detector locations

⟶ O(10^9-10^{10}) EOT (μs @ 100 μA): only ν from π decay reach the detector

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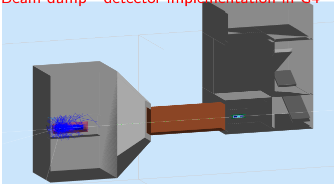

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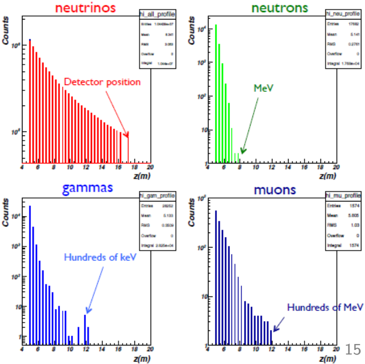


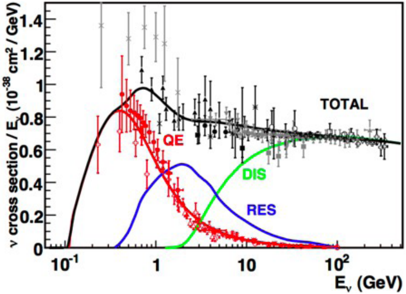
- G4 for treatment of high energy (GeV to MeV) interactions: sample particle fluxes at different depths within the dump, and extrapolate non-zero values to full luminosity
- Validate results for low energy n/γ with MCNP

⟶ Beam-related background (except ν) can be reduced to 0 with sizable shielding ($\simeq$ 8 m iron + concrete)

Cosmogenic background

Neutrinos:

- Considering flux, interaction cross sections and detection threshold the number of detected cosmic neutrinos is negligible



Neutrons:

- A high energy neutron can penetrate the shielding and interact inside the detector mimicking a χ-N scattering
- 1m iron shield + detection energy threshold introduce a neutron energy cutoff (detection efficiency = 0 for $T_n < 50 \div 100$ MeV)

Muons: different background topologies

- Crossing muons not rejected by veto / crystals multiplicity
- Muons decaying inside the detector (missing prompt signal)
- Muons decaying inside the lead shielding
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- Rare muon decays

Preliminary MC simulations shows cosmogenic bck is $\simeq (100)^2$ events / year

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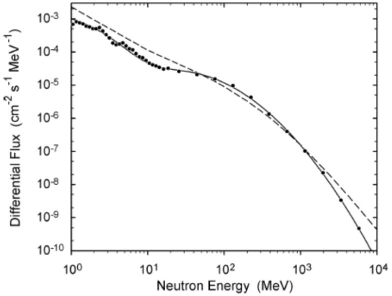
Neutron energy spectrum @ sea-level



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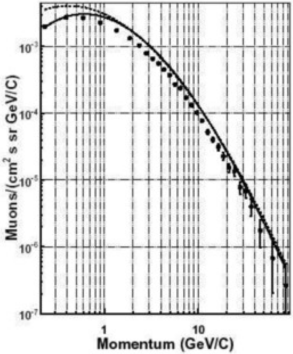

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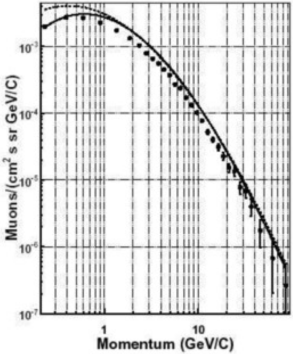

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Cosmogenic background measurement

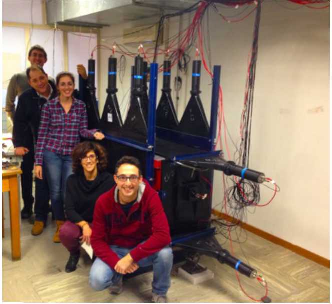
BDX-proto measurement campaign at INFN-LNS (Catania)

- Measure cosmogenic background in a configuration similar to the final detector setup.
- Project results to the full BDX-detector and obtain background rate estimate
- Validate MC

Prototype setup:

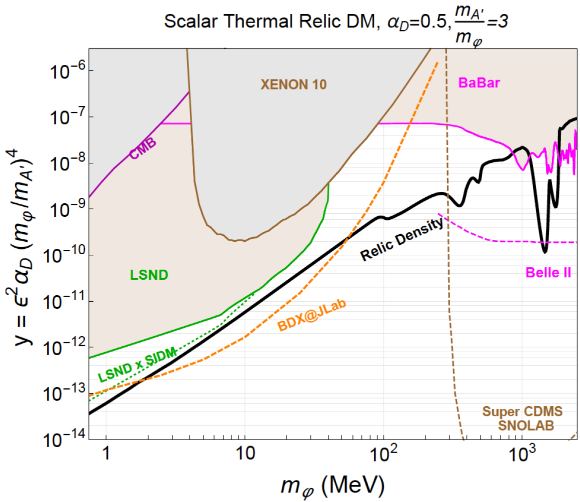
- 1 CsI(Tl) crystal (BaBar endcup), 2 x MPPC readout (25 μm, 50 μm)
- Inner-veto layer: plastic scintillator + WLS-fibers/SiPM readout
- 5-cm lead layer
- External-veto layer: plastic scintillator + PMT readout

BDX-proto at LNS



BDX@JLab: reach

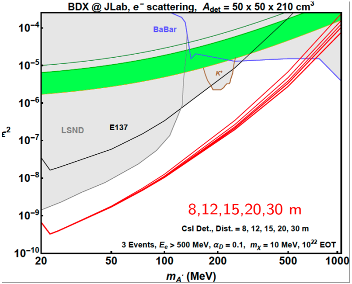
BDX can be a conclusive experiment to rule-out some Light Dark Matter scenarios



BDX@JLab: optimization

On-going effort to optimize the detector setup: minimize background and verify the effect on the signal

- Weak dependence on the dump-detector distance
- No sizeable effect by varying the detector footprint (with fixed active volume)
- No sizeable effect by varying the electron energy threshold: 500 MeV vs 50 MeV



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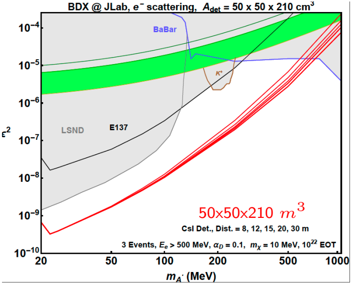

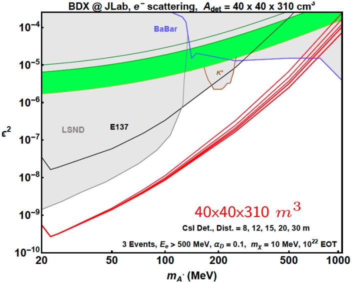

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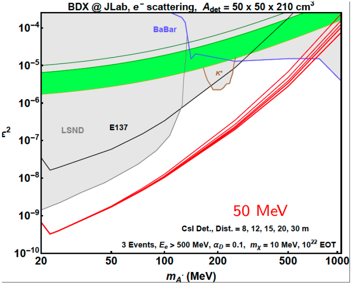

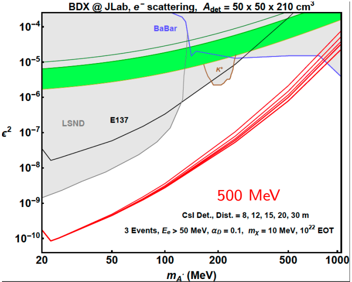

Conclusions

- Dark matter in the MeV-to-GeV range is largely unexplored.
- **Beam Dump eXperiment** at JLab: search for light DM particles in the 10 ÷ 1000 MeV mass range
  - High intensity (O(10^{21}-10^{22} EOT/year), high energy (11 GeV) e^- beam
  - Detector: CsI(Tl) calorimeter + 2-layers active veto + shielding. Can be assembled in reduced time and reduced cost, by re-using BaBar crystals
- Within 1 year, BDX can rule-out some Light Dark Matter scenarios
- Current experiment status:
  - LoI submitted to JLab PAC (2014): positive feedback, preparation of a full Proposal undergoing
  - Interesting opportunities for a phase-1 run @ other facilities
  - Dedicated cosmogenic background measurements @ LNS-CT

Backup slides

χ kinematics in the beam-dump