The Beam Dump eXperiment

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Dark Matter (DM) existence is highly motivated by various astrophysical observations (Galaxy Rotation Curves, CMBR fluctuations, collisions between galaxy clusters...)

DM properties remain to date unknown (interactions with Standard Model, mass...)

DM Thermalization hypothesis: thermal equilibrium with primordial Universe and decoupling due to Universe cooling

→ Present DM density depends on DM-SM interaction properties
→ DM mass and interaction cross section are bound

If $m_{DM} \sim 100$ GeV → typical Weak Interaction cross section: “WIMP Miracle”
WIMPs search: detectors made of large volumes of active materials to detect cosmogenic DM scattering over nuclei - low sensitivity to light DM candidates (<1 GeV)

NO evidence of WIMP to date
→ Search for lower mass candidates

To preserve DM thermalization: lower DM mass → higher interaction cross section
→ new force necessary

Simplest Model: Dark Sector of χ (MeV-GeV mass range) particles coupled to SM through a U(1) massive gauge boson, the Dark Photon ($A'$), kinetically mixed with SM photon:

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu}^\prime F^\prime_{\mu\nu} + \frac{\epsilon}{2} F_{\mu\nu}^\prime F_{\mu\nu} + \frac{m_{A'}^2}{2} A_{\mu}' A_{\mu}' + g_D A_{\mu}' J_D^\mu$$
A’ Decays

Visible: $A' \rightarrow e^+e^-$
- $m_{A'} < 2m_\chi$
- Decay time depending on $\varepsilon^2$

Invisible: $A' \rightarrow \chi\chi$
- $m_{A'} > 2m_\chi$
- Not depending on $\varepsilon$

This is the scenario addressed by BDX
The Beam Dump eXperiment

- **BDX**: Light Dark Matter production and detection using a high intensity e⁻ beam:

  **Production:**
  χₕ produced via A' emission (A'-strahlung) and subsequent decay

  **Detection:**
  χₛ scatter off detector electrons, resulting in a detectable signal
An electron beam-dump is a **positron-rich** environment.

- $e^+$ can contribute to the total $\chi$ yield with the resonant and non-resonant annihilation processes b) and c):
- **Positron annihilation into $A'$** scales as $\varepsilon^2 \alpha^2$ (b) or $\varepsilon^2 \alpha$ (c) compared to the $\varepsilon^2 \alpha^3$ scaling of the $A'$-strahlung.

→ $e^+$ contribution can be relevant and must be considered in beam-dump experiment analysis.
CeBAF Beam Parameters:
- Energy: 11 GeV
- CW beam
- Current: 65 µA

→ Possible to achieve $10^{22}$ EOT/yr

Necessary to build a new hall behind Hall-A beam dump;
- estimated cost: ~$2M$
- time-scale for construction: ~2 yr
Critical background for the experiment: cosmic rays (muons, neutrons...) and SM particles produced in the beam-dump (neutrons, muons, neutrinos..)

→ Setup optimized for background reduction:
  ▶ Passive shielding between the dump and the detector filters beam-related background (except for neutrinos)
  ▶ Segmented detector for background discrimination based on event topology
  ▶ Passive shielding and active veto surround the detector for cosmic background reduction

Electromagnetic Calorimeter:
  • 800 CsI(Tl) crystals from BaBar> Ecal (~1m³ total)
  • 8 modules 10X10 crystals each
  • 6X6 mm² SiPM readout

Active Veto Sistem:
  • Double plastic scintillator layer
  • WLS fibers + SiPM readout

Passive shielding:
  • ~6.6 m of iron and ~4.5 m of concrete between the dump and the detector
  • ~4 m concrete overburden to reduce cosmic background
**Goals:**
- Measure cosmic background in a similar condition to the final experiment
- Validate the proposed design of the BDX detector
- Check the capability of background rejection and project the measured data to the full scale experiment

**Result:**
with $E_{th} = 350$ MeV,
Expected O(0) cosmic background events for the full experiment
Beam-related background evaluated through massive simulations with FLUKA and GEANT4

- Heavy use of biasing with FLUKA to achieve the highest possible statistic (~$10^{17}$ equiv. EOT)
- GEANT4 simulations used as a benchmark

Result: with optimized shielding only neutrinos can produce background (~5 events)
**BDX muon test**

Test to measure the beam-on background:
- Measure muon flux in the proposed BDX location
- Use results to validate simulations
- Check effects of beam-on background not accounted for in the simulations (low energy neutrons pile-up?)

**BDX hodo:**
- 1 CsI(Tl) crystal readout by a 6X6 mm$^3$ Hamamatsu SiPM
- 13 scintillator paddles 1 cm thick (readout by 3X3 mm$^3$ SiPM + WLS fibers)
- Water-tight cylindrical vessel
Muon rate was measured in the two wells at different depth and varying the beam current.

- Simulated rates show critical dependence on the dirt density $\rho_D$
- $\rho_D$ measured in the position of the two wells, at beam height: 1.93-1.95 g/cm$^3$
- No measured value of the beam-dump bunker concrete was available.

* Accounting for dirt and concrete density uncertainty, the agreement between data and simulations is reasonable
* NO neutrons pile-up effect was observed
Beam time request:
- $10^{22}$ EOT (65 $\mu$A X 285 days)
- Possible to run parasitically to any Hall-A 11 GeV experiment

Expected Backgrounds:
- Energy threshold: 350 MeV
- Neutrino background events: $\sim$5 ev.
- Cosmic background events: $\sim$0 ev.

BDX sensitivity is 10-100 times better than existing limits on LDM
Status:
- R&D effort ongoing from 2014 (first LOI presented to JLab PAC42)
- Full proposal presented to PAC44 (2016) approved conditionally to benchmarking simulation with on-site measurement (bdx-hodo) and to detector optimization
- Measurement of the muon flux have been performed on site (spring 2018) with the endorsement and support of JLab; simulations proved to be in reasonable agreement with data
- Results have been presented to PAC46 seeking for full approval of the BDX proposal

Collaboration:
- BDX proposal signed by more than 100 researchers
- Connections with groups involved in similar activities at SLAC, CERN, Mainz, and LNF
BDX is a beam-dump experiment searching for Dark Sector particles in the 1-1000 MeV mass range

- Beam parameters: $10^{22}$ EOT/year, 11 GeV energy
- Detector: ~800 CsI(Tl) crystals calorimeter (SiPM readout) + double-layer active veto + shielding

BDX can be ready to run in 2 years (time-scale for the building of the new hall)

The experiment is conditionally approved (PAC44) to run parasitically at Jefferson Lab for 41 week at 11 GeV and 65 $\mu$A current

Following PAC44 indications, measurements of the muon flux behind Hall-A beam dump have been performed

PAC46 request full approval

BDX can produce important physics results, improving by up to a factor $\sim$100 existing limits on LDM parameter space and providing directions for future activities in the field
Thank you for your attention!