The Beam Dump eXperiment

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Dark Matter Search

- 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

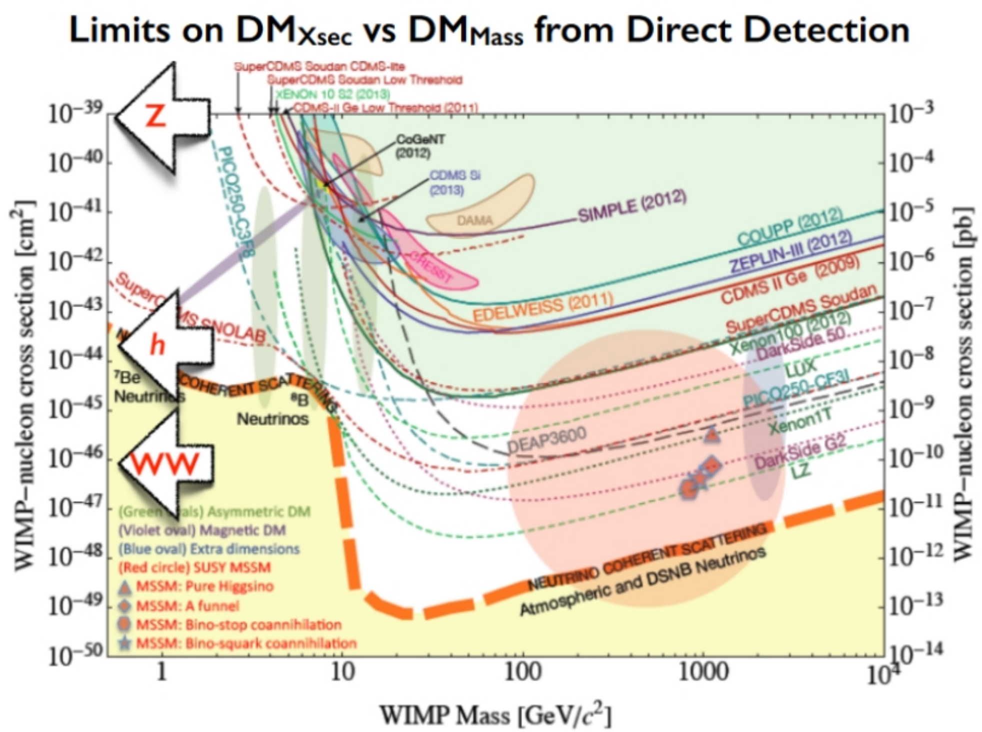
  → Present DM density depends on DM-SM interaction properties

  → DM mass and interaction cross section are bound

  If $m_{DM} \sim 100$ GeV → typical Weak Interaction cross section: "WIMP Miracle"

From WIMPs to Dark Sector

- 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



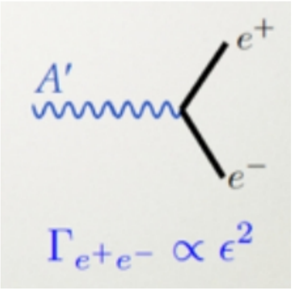
- To preserve DM thermalization: lower DM mass → higher interaction cross section
  → new force necessary
- Simplest Model: Dark Sector of χ (MeV-GeV mass range) particles coupled to SM through a U(1) massive gauge boson, the Dark Photon (*A'*), kinetically mixed with SM photon:

$$\mathcal{L} = -\frac{1}{4}F'_{\mu\nu}F'^{\,\mu\nu} + \frac{\epsilon}{2}F'_{\mu\nu}F_{\mu\nu} + \frac{m_{A'}^2}{2}A'_{\mu}A'^{\,\mu} + g_D A'_{\mu}J^{\mu}_{D}$$

A' Decays

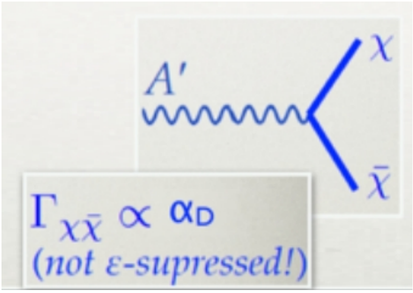
Visible: $A' \rightarrow e^+e^-$

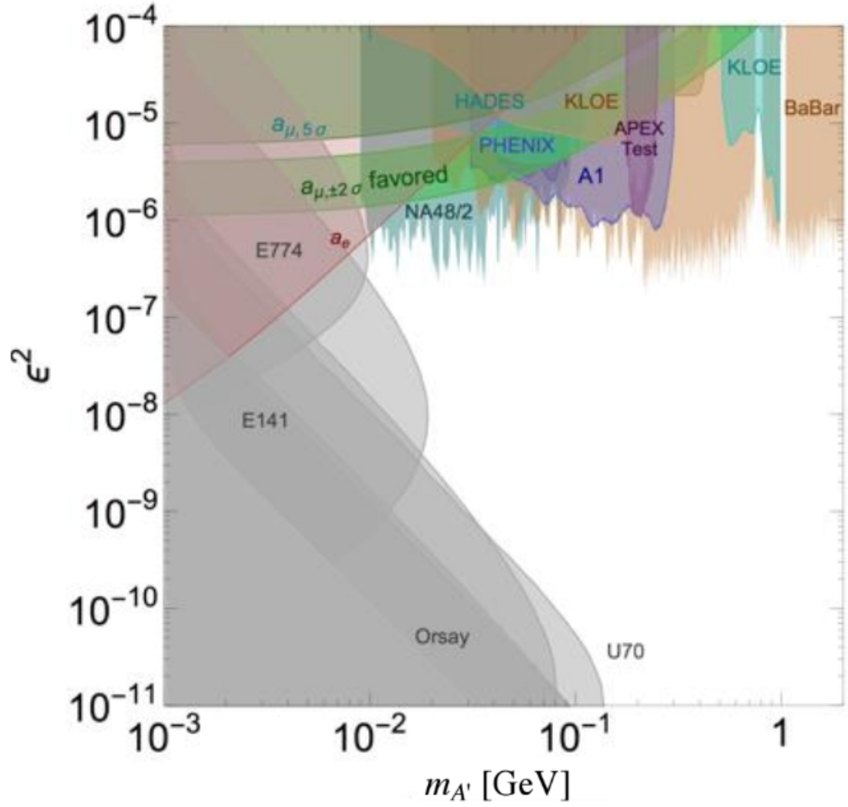
- $m_{A'} < 2m_\chi$
- Decay time depending on ε^2

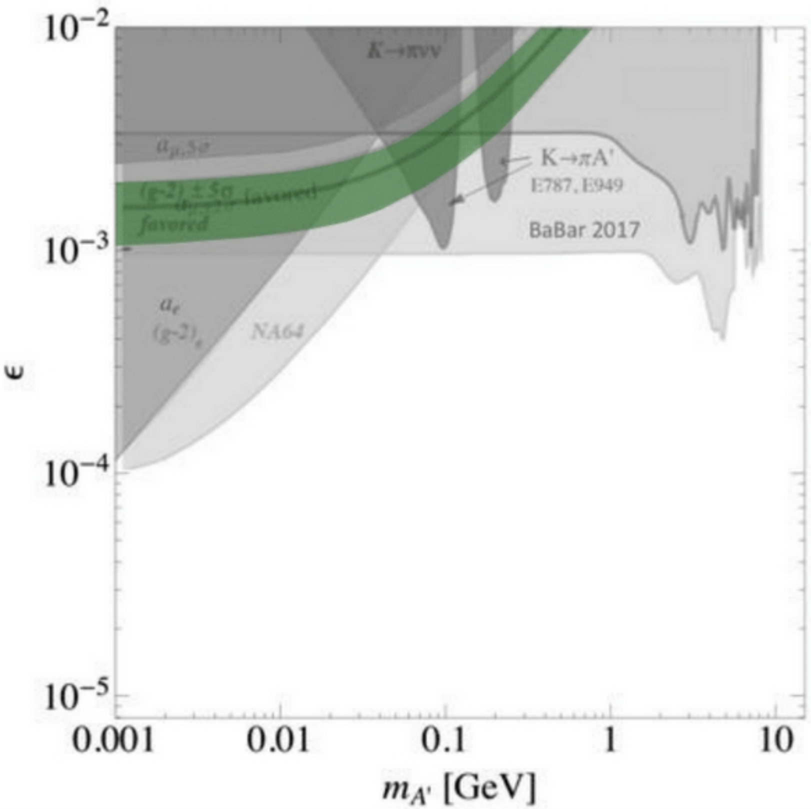


Invisible: $A' \rightarrow \chi\chi$

- $m_{A'} > 2m_\chi$
- Not depending on ε



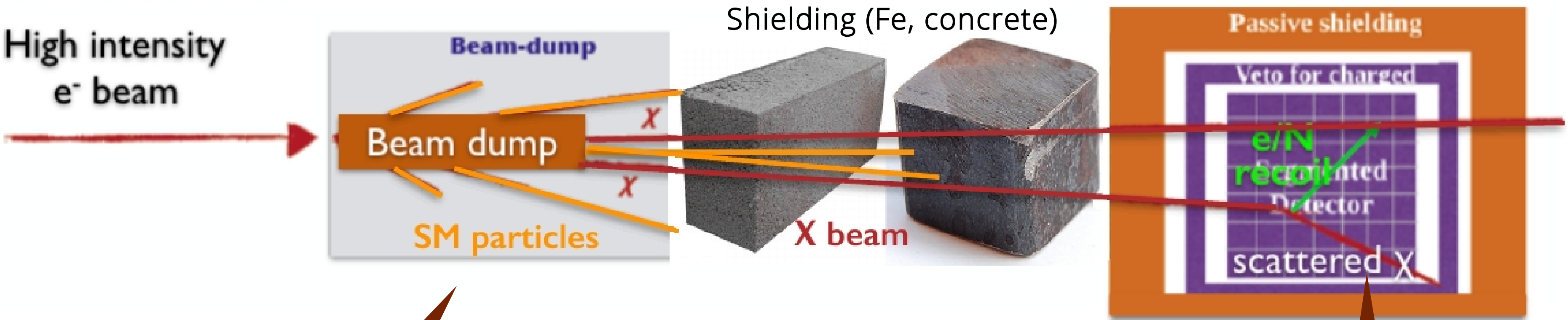


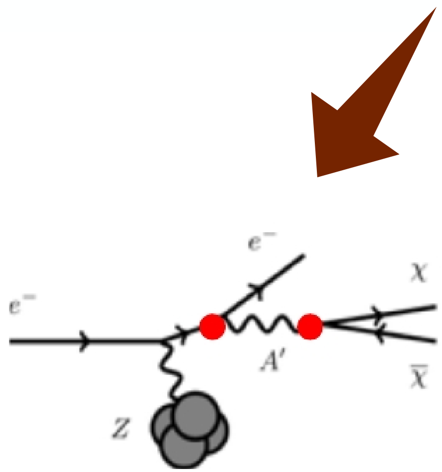


<u>This is the scenario addressed by BDX</u>

The Beam Dump eXperiment

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

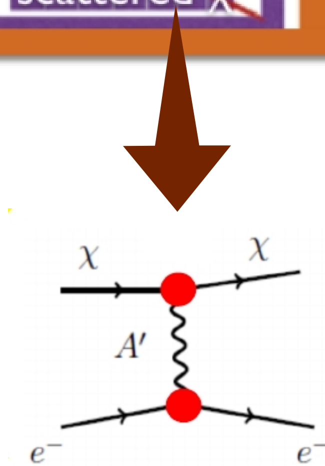




A' yield: $N_{A'} \propto \frac{\varepsilon^2}{m_{A'}^2}$

χ cross-section: $\sigma_{\chi e} \propto \frac{\alpha_D \varepsilon^2}{m_{A'}^2}$

Number of events: $N_\chi \propto \frac{\alpha_D \varepsilon^4}{m_{A'}^4}$



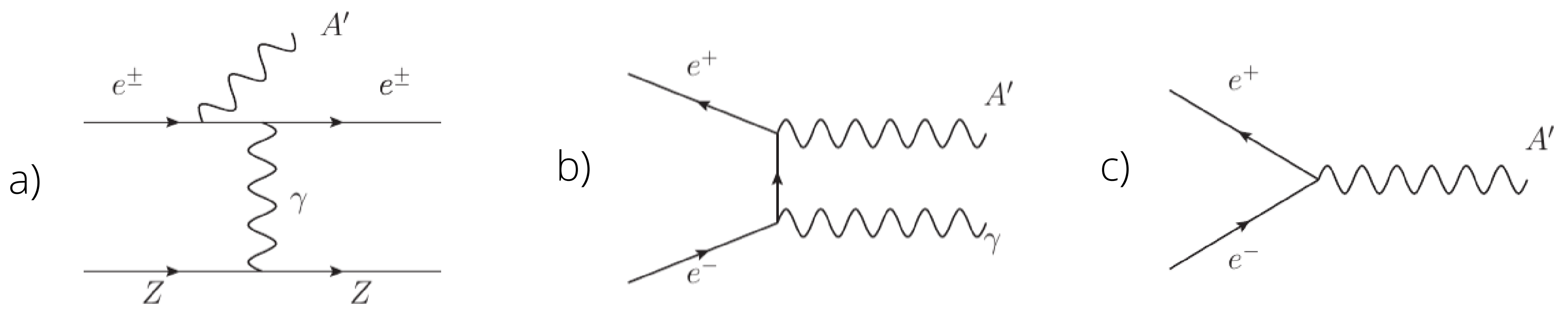
Production:

χs produced via A' emission (*A'-strahlung*) and subsequent decay

Detection:

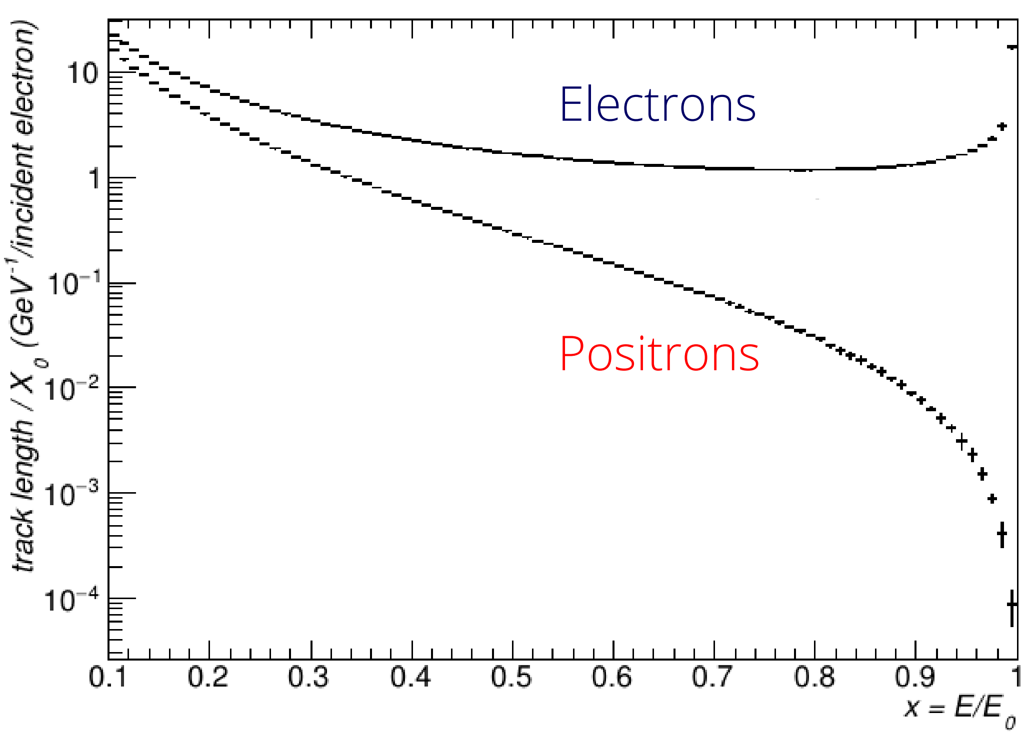
χs scatter off detector electrons, resulting in a detectable signal

e^+ contribution to A' production



- An electron beam-dump is a positron-rich environment
- e^+ can contribute to the total χ 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



Jefferson Lab Facility

Beam Dump eXperiment proposed at Jefferson Laboratory, behind Hall-A Beam-dump

CEBAF Beam Parameters:

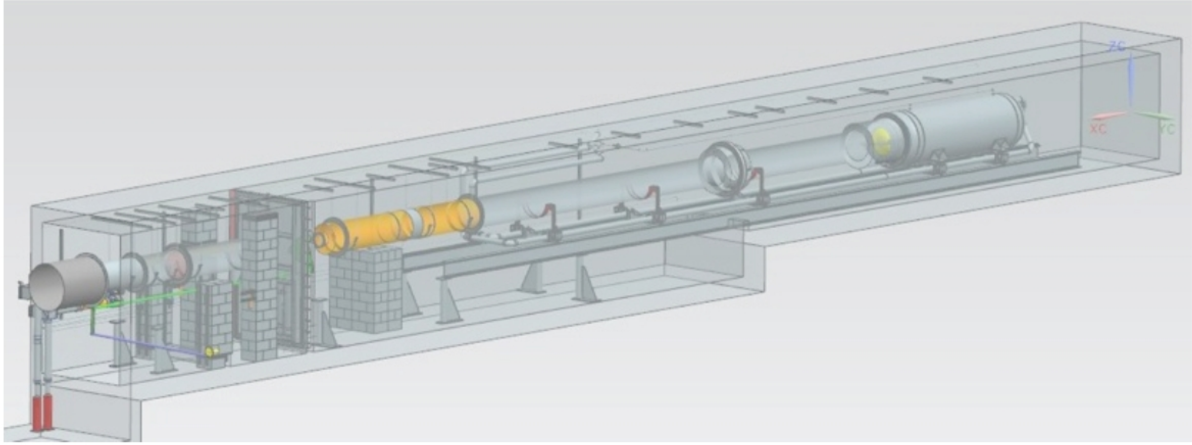
- Energy: 11 GeV
- CW beam
- Current: 65 μA

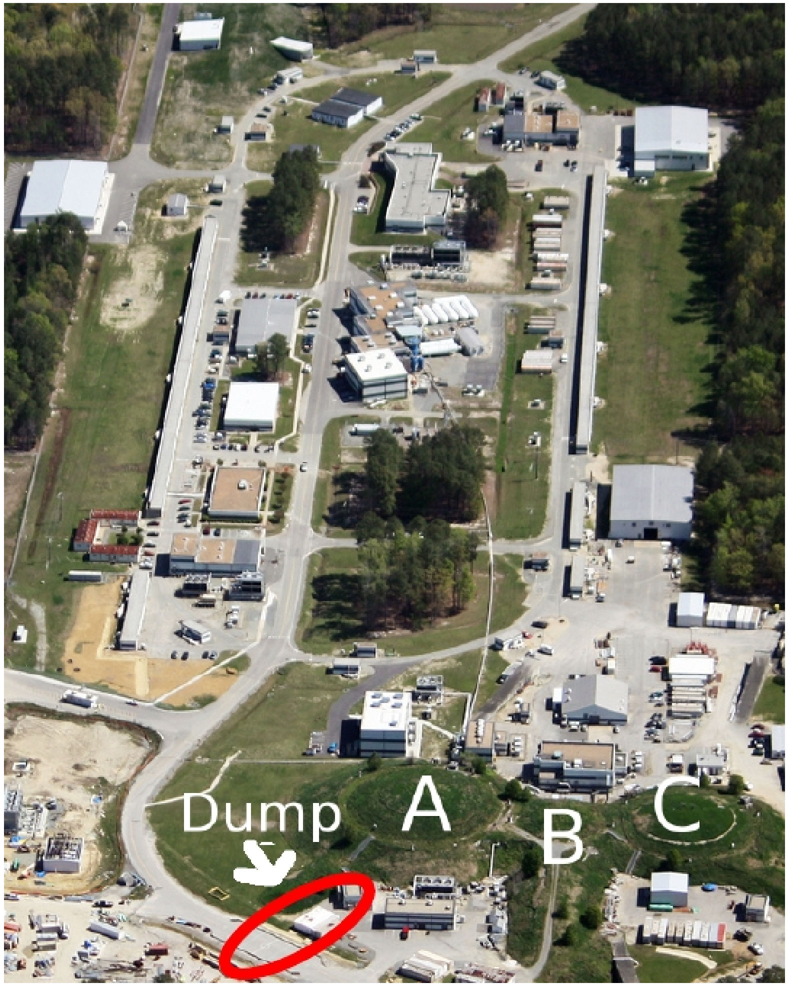
→ **Possible to achieve 10^{22} EOT/yr**

Necessary to build a new hall behind Hall-A beam dump;

- estimated cost: ~2M $
- time-scale for construction: ~2 yr

JLab Hall A beam-dump



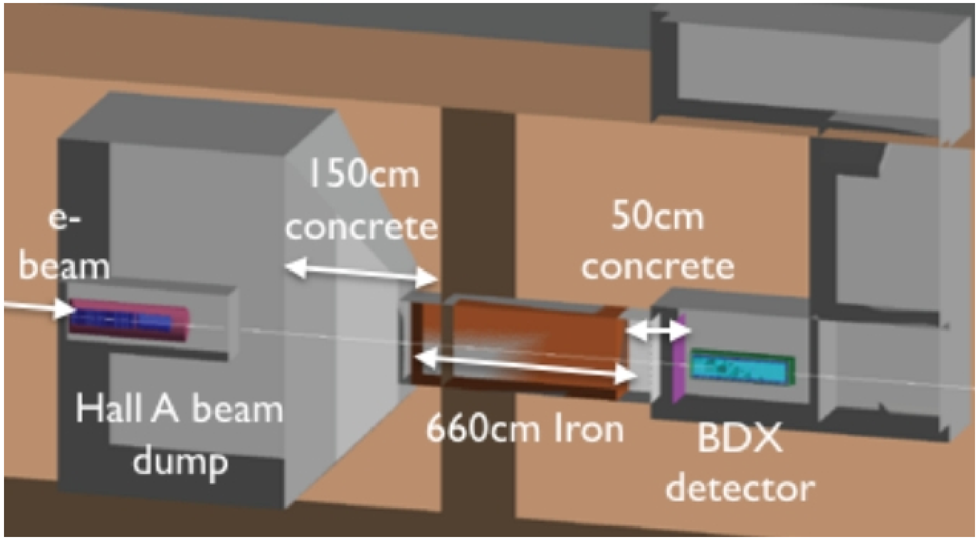


Background Reduction Strategies

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:

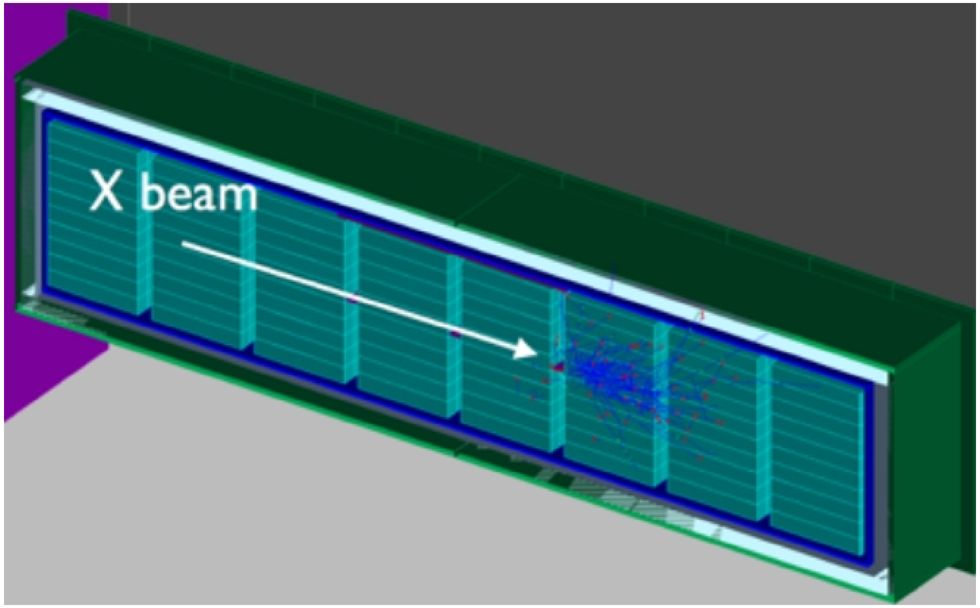
- 800 CsI(Tl) crystals from BaBar> Ecal (~1m^3 total)
- 8 modules 10X10 crystals each
- 6X6 mm^2 SiPM readout

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

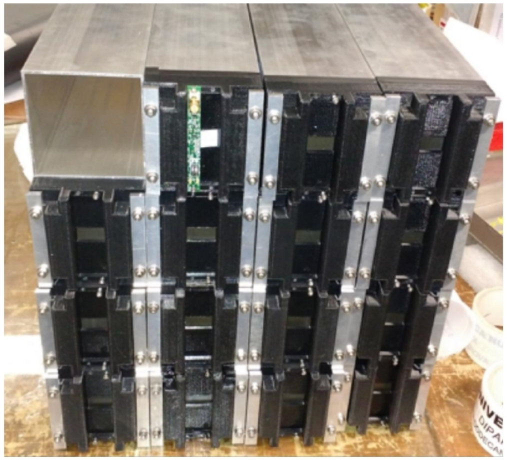


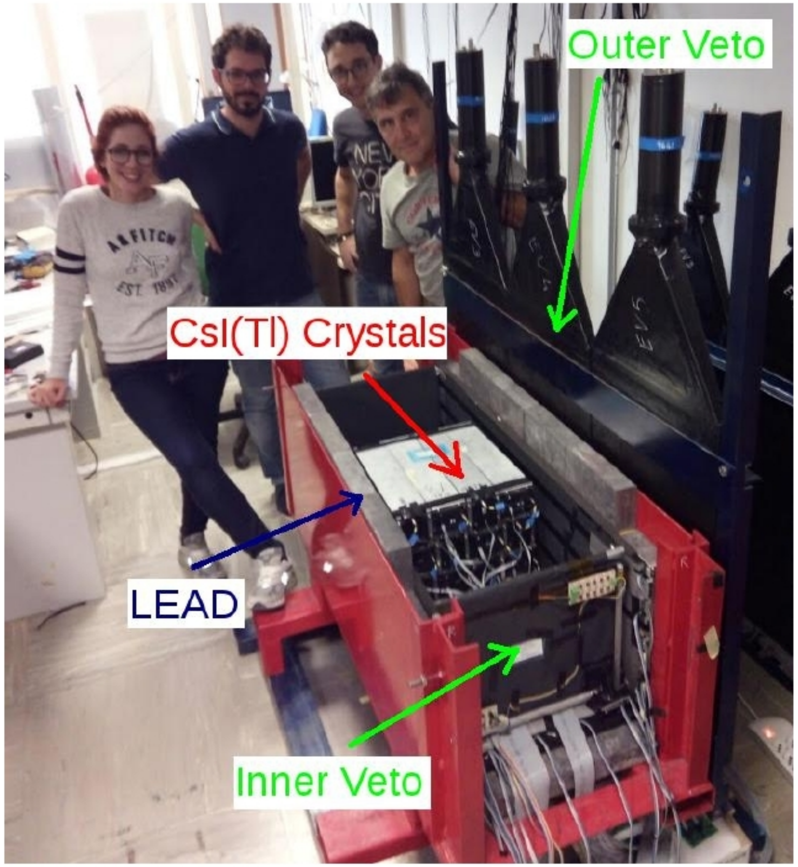
BDX Prototype

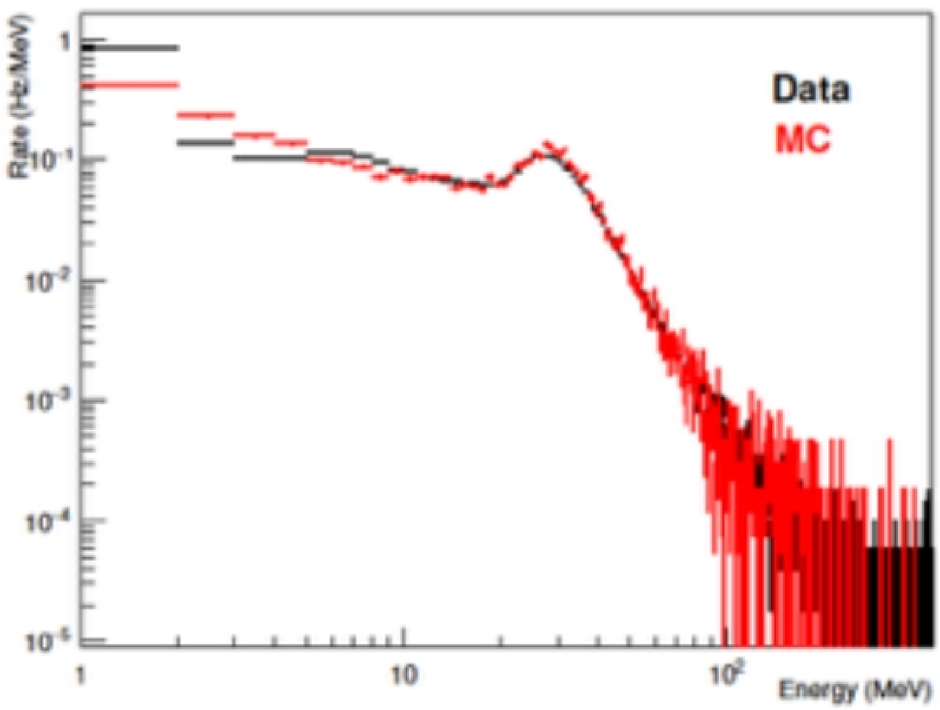
Goals:

- 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

4X4 CsI(Tl) Matrix







Result:

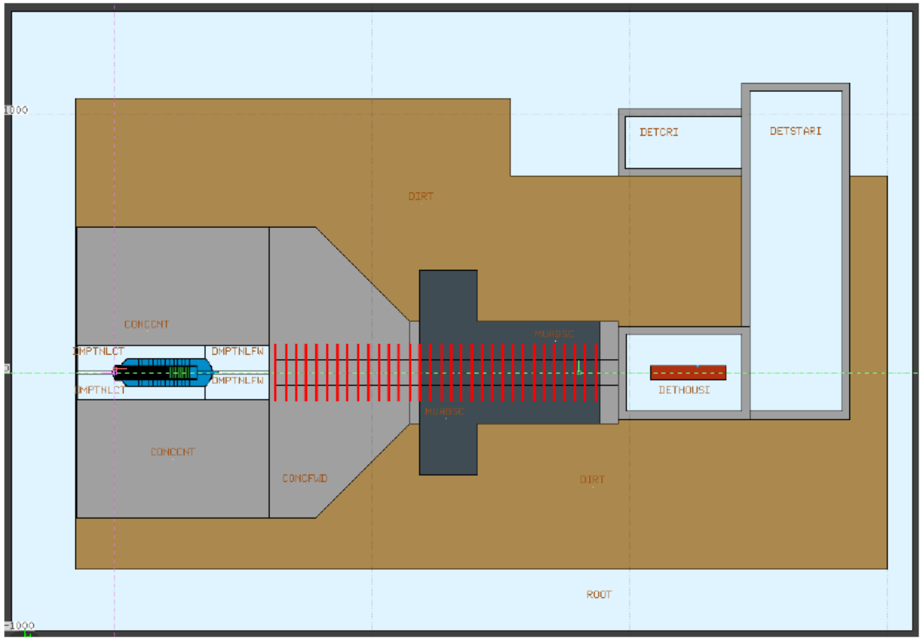
with E_{th}= 350 MeV,

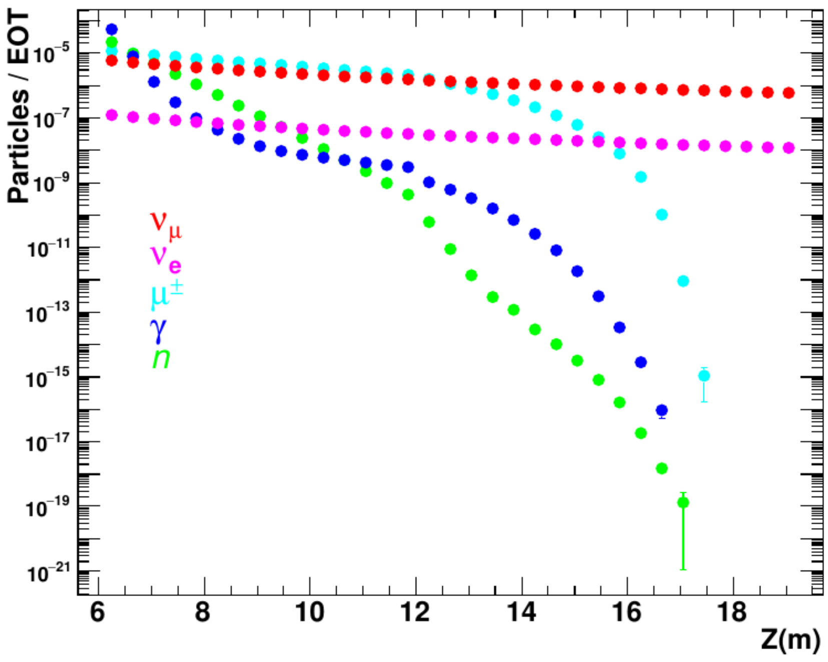
Expected O(0) cosmic background events for the full experiment

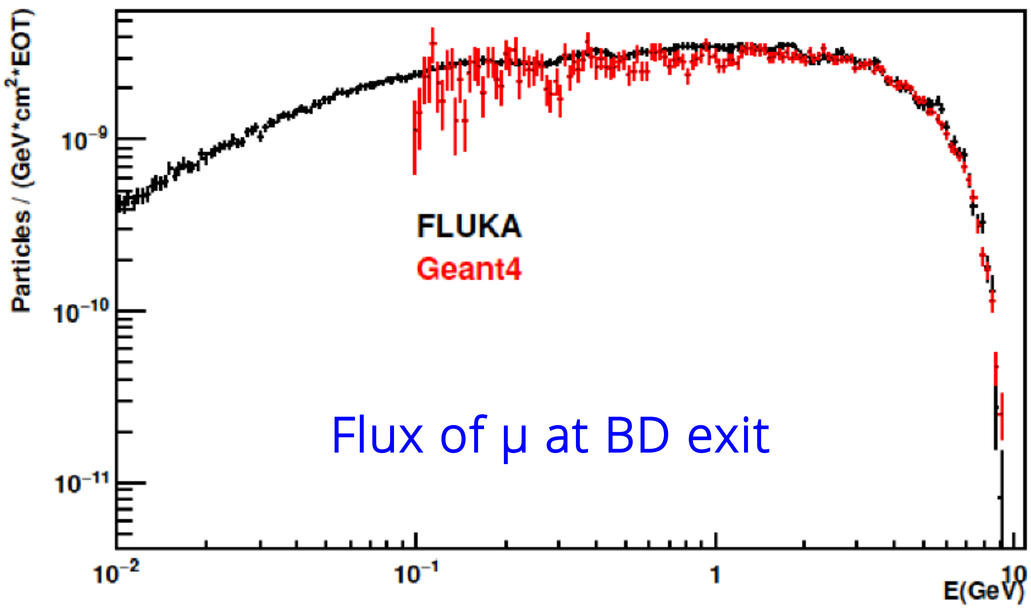
Beam-related background

- 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)







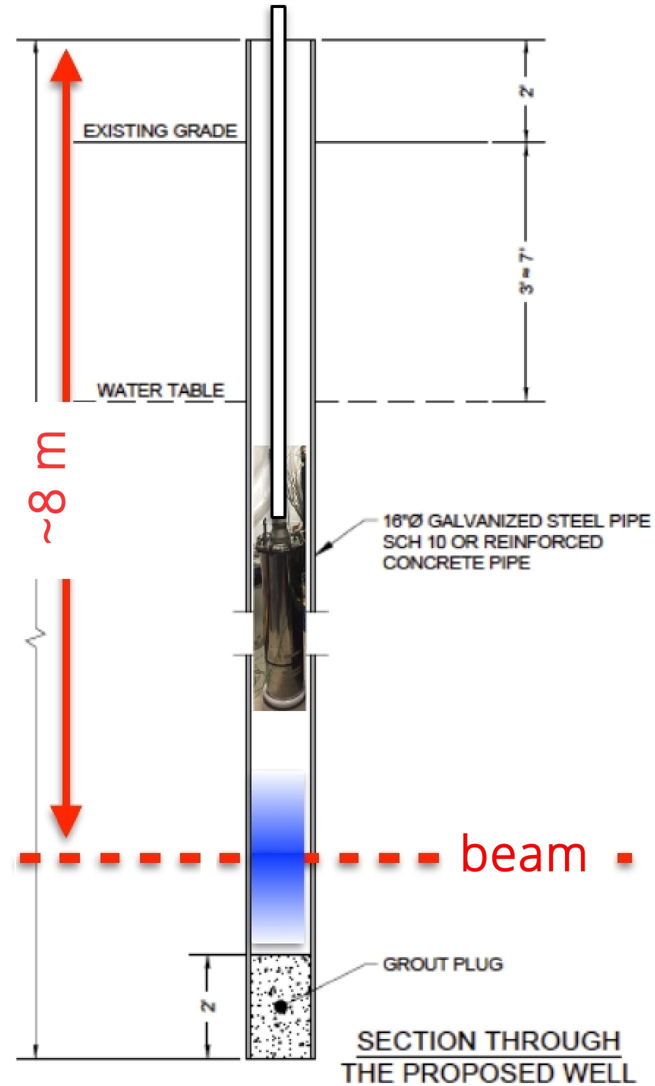
BDX muon test

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



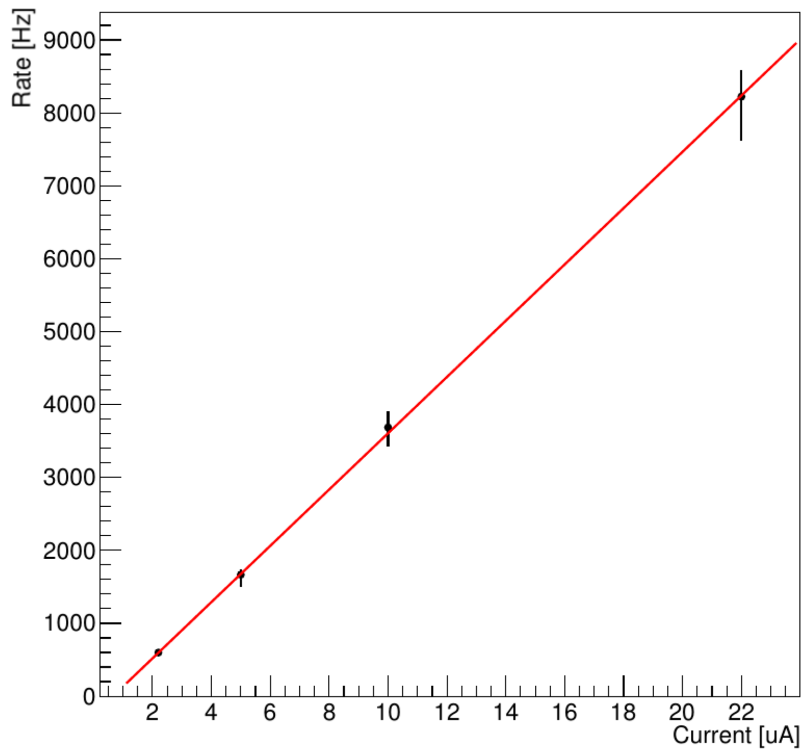
BDX muon test - results

- Muon rate was measured in the two wells at different depth and varying the beam current
- Simulated rates shows critical dependence on the dirt density ρ_D
- ρ_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

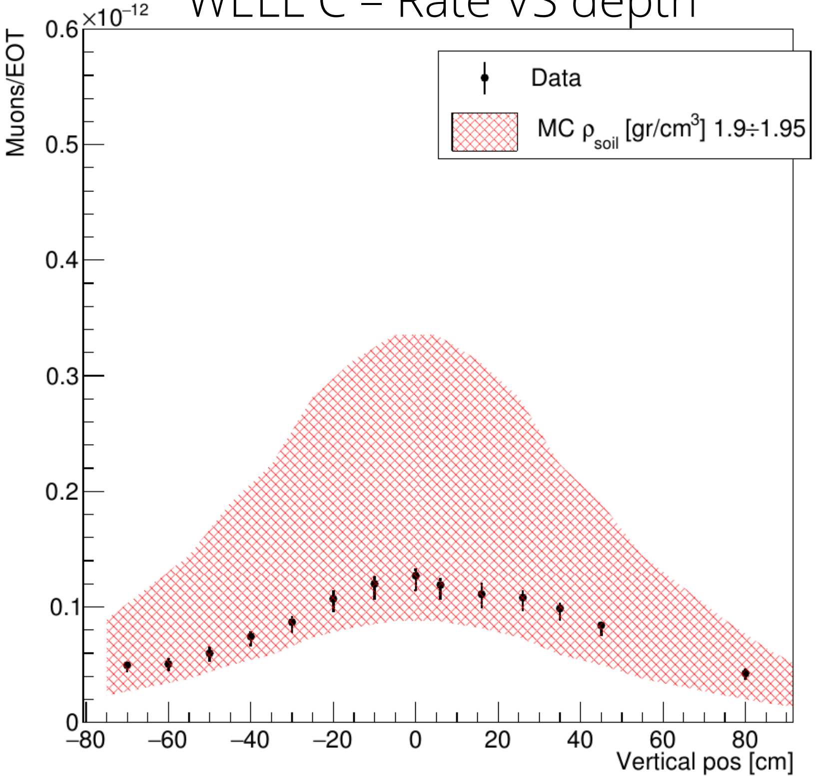
✖ Accounting for dirt and concrete density uncertainty, the agreement between data and simulations is reasonable

✖ NO neutrons pile-up effect was observed

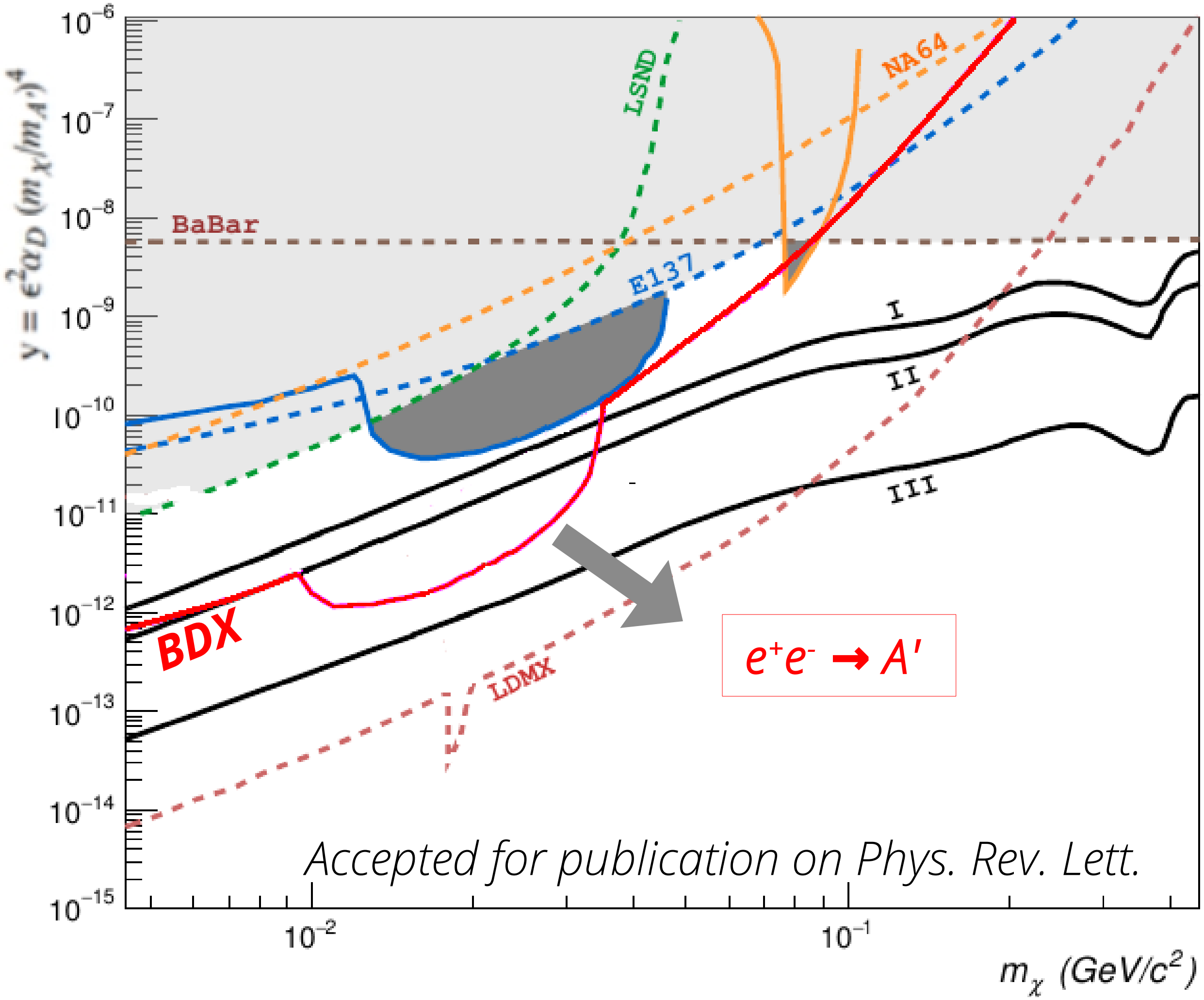
WELL B – Rate VS Current



WELL C – Rate VS depth



BDX Reach



Beam time request:

- 10^{22} EOT (65 μA X 285 days)
- Possible to run parasitically to any Hall-A 11 GeV experiment

Expected Backgrounds:

- Energy threshold: 350 MeV
- Neutrino background events: ~5 ev.
- Cosmic background events: ~0 ev.

BDX sensitivity is 10-100 times better than existing limits on LDM

BDX status

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

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

The BDX Collaboration

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Conclusions

- 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 μA 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 ~100 existing limits on LDM parameter space and providing directions for future activities in the field

BDX Collaboration

Thank you for your attention!