Lepton beam facilities at the intensity frontier

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ABSTRACT

The Thomas Jefferson National Accelerator Facility (JLab) is a national laboratory in the United States. It houses "CEBAF", an high intensity electron accelerator that can reach energies up to 12 GeV at up to 100 µA, which is used to investigate the building blocks of matter. Once used for the experiment, the electrons are absorbed into a beam-dump, here they interact producing particles from which secondary beams are formed and that can be used to explore new physics frontiers *in parallel* to already existing experiments. The most relevant secondary beams produced are: a neutrino beam, a muon beams and (if it exist) a light dark matter beam.

SIMULATION TOOLS

Detailed description of the beam-dump and Hall-A geometry with their materials was implemented in GEMC (a C++ framework developed at JLAB that uses GEANT4 to simulate the passage of particles through matter that provides several advantages) and FLUKA (a general purpose tool for calculations of particle transport and interactions with matter).

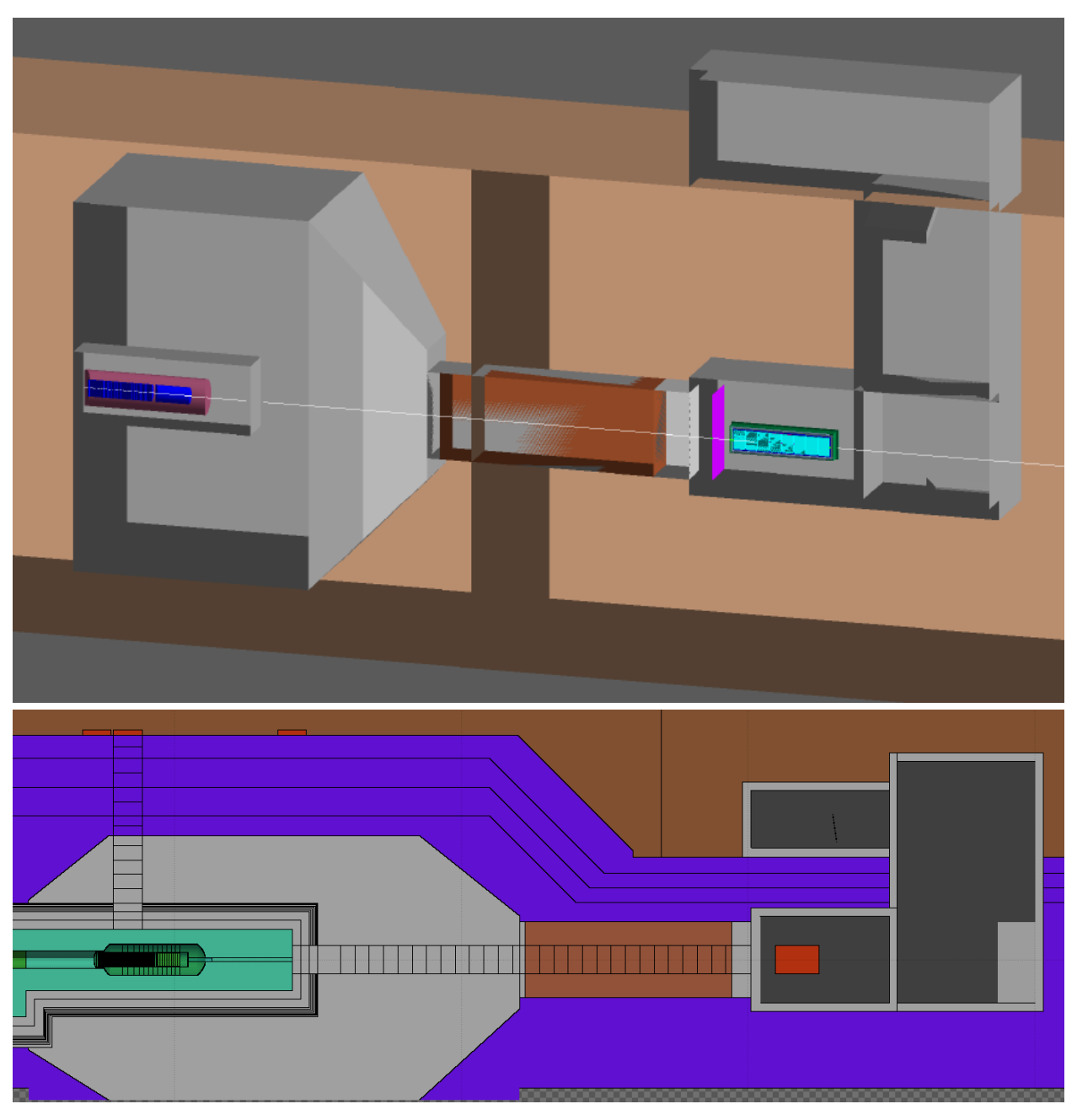

Figure 2: Beam-dump geometry in GEMC (up) and in FLUKA (down).

The two software were used to validate the simulation results with each other. With GEMC more focused on the simulation of detector response and FLUKA focused on producing more extensive simulations with the help of several biasing techniques.

NEUTRINO BEAM: νBDX-CEνNS

Coherent elastic neutrino-nucleus scattering (CEνNS) is a process in which neutrinos scatter on a nucleus which acts as a single particle. In 2017 the COHERENT collaboration announced the detection of CEνNS using a stopped-pion source with CsI detectors, followed up by the detection of CEνNS using an Ar target.

- Measurements of the CEνNS process will provide information that can be used to test the presence of new physics
- Even though the total cross section is large by neutrino standards, CEνNS has long proven difficult to detect, since the deposited energy into the nucleus is ~ keV.
- CEνNS events can be measured with the same detectors used to search for dark matter since they are already sensible to small energy depositions.
- The neutrino beam produced @JLab thorugh e^--dump interaction shows a typical DAR spectrum, with a flux of $\sim 9 \times 10^{17} \nu \cdot year/m^2$ at ~ 10 m above the dump
- Two detection technology are under study: CsI crystals, LAr-TPC; also an active and passive veto system to reduce the background is currently being studied.
- The CEvNS interactions expected in $1m^3$ active volume located in the position in Fig. 1 are $\sim 1.5 \times 10^3$ for a threshold of 10 keV recoil energy.

RESEARCH LINES

The interaction between the electron beam and the beam dump produces several particles like neutrinos, muons and light dark matter particles that can be used to perform experiments beyond the scope of hadron physics.

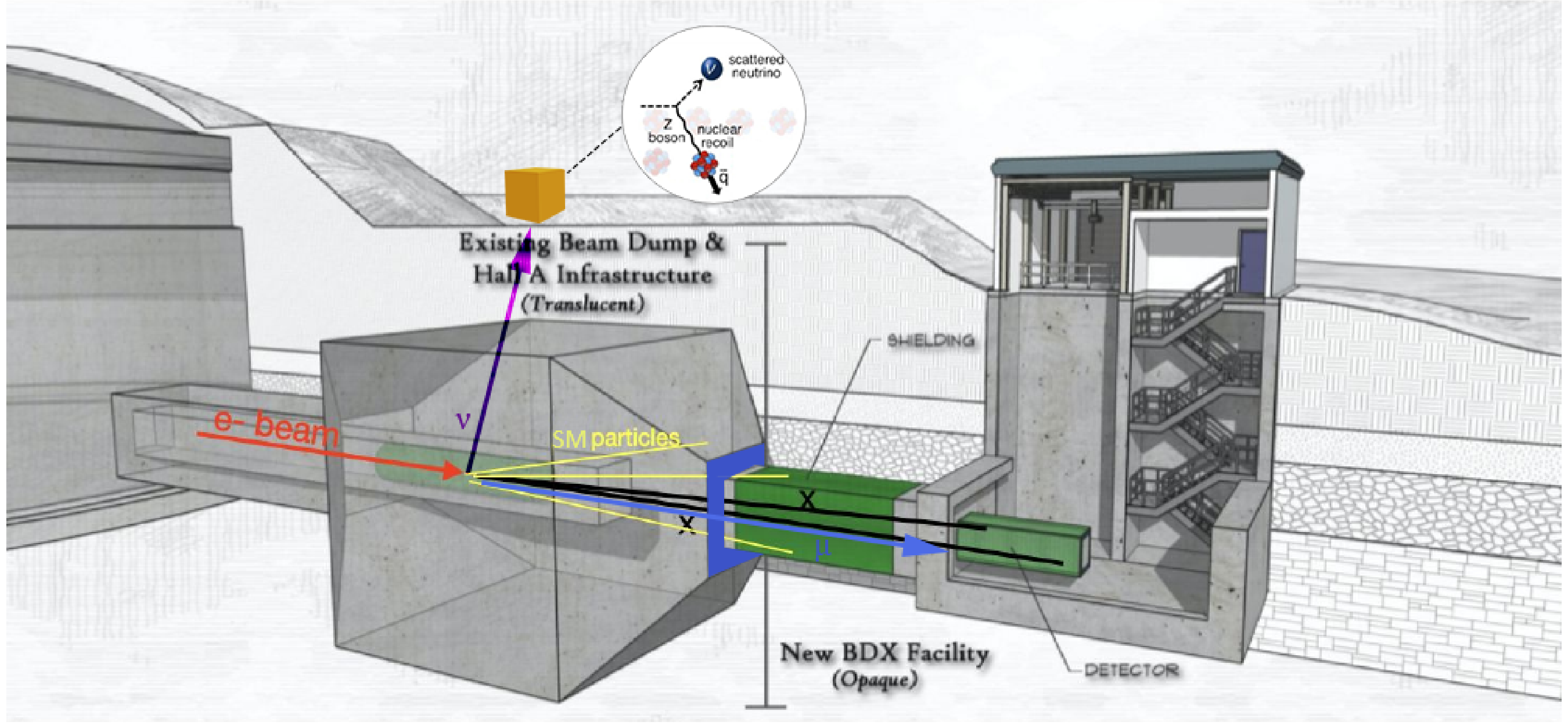

Figure 1: Schematic view of the interaction of the e^- beam and the beam-dump producing neutrinos, light dark matter and muons.

This opens new research lines:

- **Light dark matter beam** → BDX experiment
- **Neutrino beam** → Coherent Elastic v-Nucleus Scattering (CEvNS) measurement
- **Muon beam** → Proton radius measurement

LIGHT DARK MATTER BEAM: THE BEAM DUMP EXPERIMENT (BDX)

The Beam Dump eXperiment (BDX) is a JLAB experiment approved by PAC46, it will be able to produce and detect light dark matter (LDM). The physics motivation for this experiment are principally the search of dark matter in extended mass range (1 MeV - 1 GeV) and the testing of its thermal origin.
In BDX, LDM particles will be produced through the e^--dump interaction. Then, they will traverse unimpeded sufficient material that eliminates all standard model (SM) particles aside from neutrinos and, in the end, they will scatter in the detector downstream of the dump. The experimental signal will be an electromagnetic shower induced by the χ-electron scattering. Moreover, low-energy scattered nucleons could be detected as a secondary goal to provide an alternative probe of LDM production. The BDX detector is made by two main components: an electromagnetic calorimeter sensitive both to $\chi - e$ and χ-nucleon scatterings and a veto detector used to reduce the cosmic background. The veto detector consists of a passive layer of lead sandwiched between two instrumented layers of scintillators.
BDX at JLab offers a series of unique possibilities:

- can reach ever smaller couplings between the mediator and the SM thanks to CEBAF's intense beam;
- it is sensitive to models with A' with leptophilic coupling;
- a beam-dump setup can offer superior sensitivity to Majorana DM models than missing energy/mass experiments

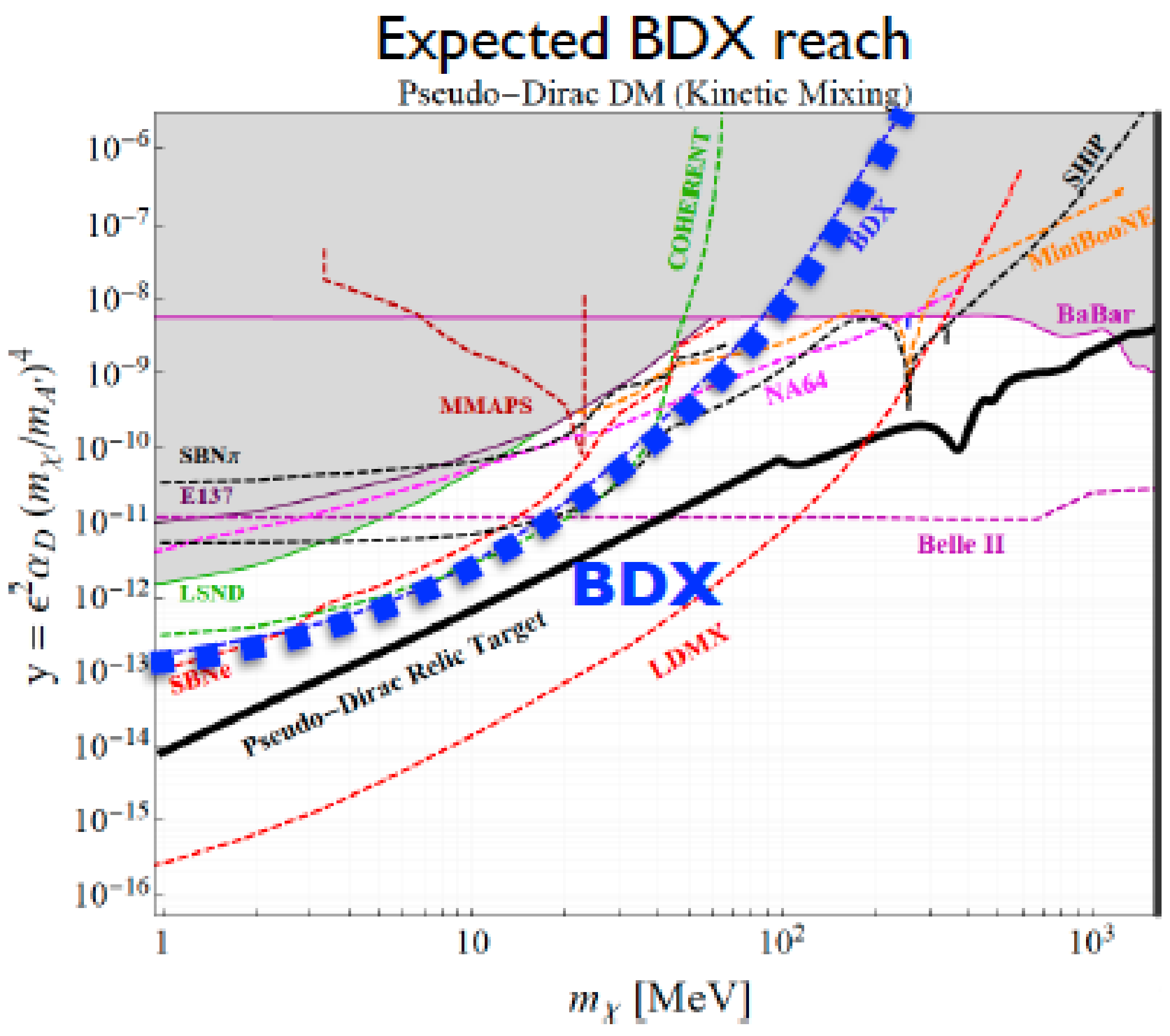

Figure 3: Expected BDX reach.

MUON BEAM: PROTON RADIUS PUZZLE

The simulation performed using FLUKA & GEANT4 showed that an intense muon flux is produced downstream of the concrete vault surrounding the beam-dump. This muon beam has the following characteristics:

- it is mainly produced by EM pair production;
- has a characteristic bremsstrahlung spectrum;
- has a narrow spatial distribution.

This beam can be further focused using a dedicated infrastructure and tagged to perform precision physics experiments such as the proton radius measurements. The use of muons, instead of electrons, comes with a significant advantage: a reduction in the corrections related to lepton EM radiation thanks to the greater muon mass. The number of muons partially forward focused (with a $\sigma_x \approx \sigma_y \approx 20$ cm) and in a year of data acquisition ($\sim 10^{22}$ eot) are $\sim 2 \times 10^{15} \mu \cdot year$.

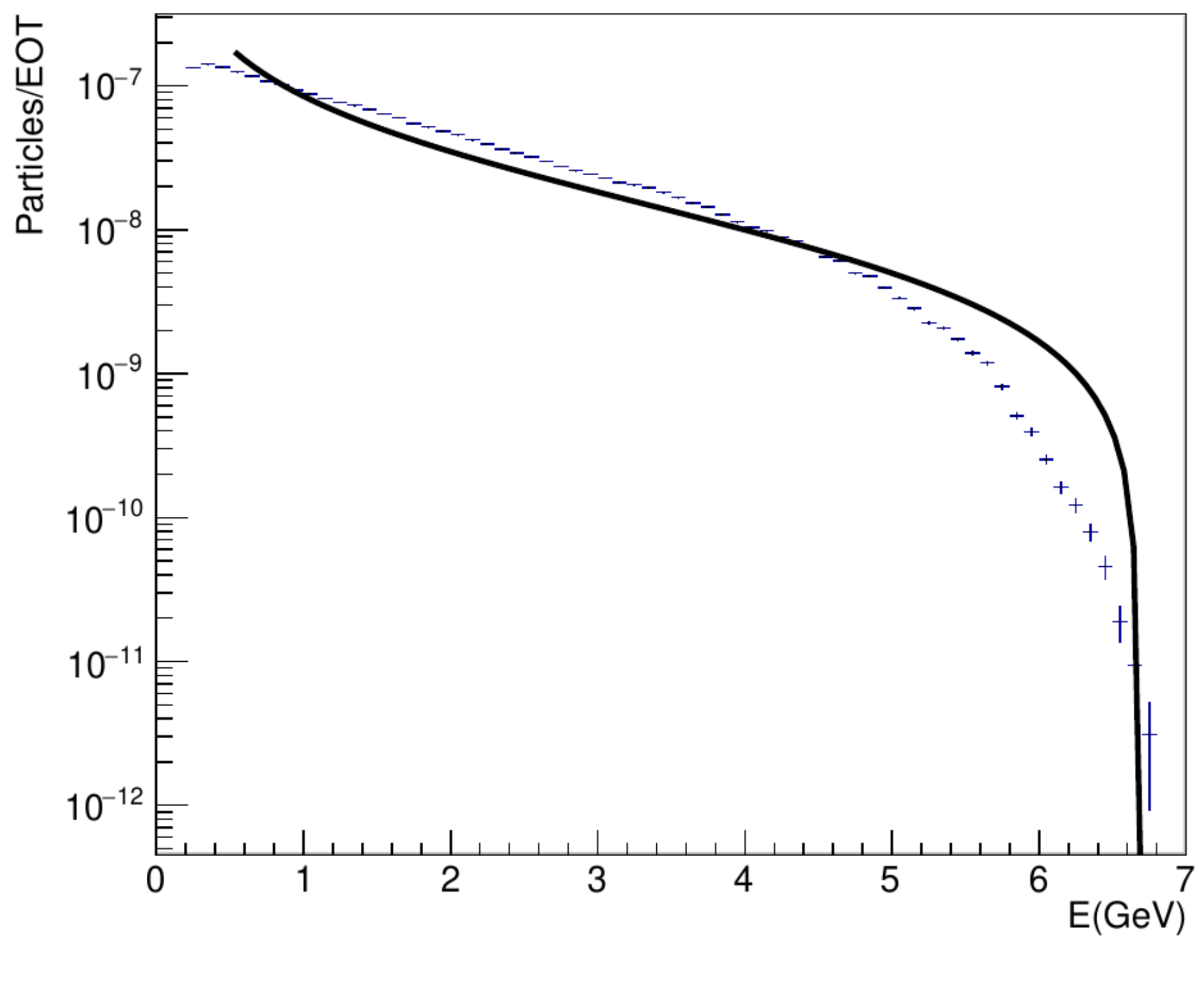

Figure 4: Muon energy distribution at the exit of the concrete downstream the beam dumpn fitted with s simple function $1/E$.

CONCLUSION

The interaction of the JLab intense electron beam and the beam dump opens different research lines beyond hadron physics. Simulations made using FLUKA and GEMC showed that:

- a neutrino beam (of $\sim 9 \times 10^{17} \nu \cdot year/m^2$ at 10 m above the dump) with a typical DAR spectrum is produced and that could be used to detect CEνNS events with 1.5 $\times 10^3$ expected interaction in 1m^3 active volume;
- a partially forward focused muon beam ($\sim 9 \times 10^{15} \mu \cdot year$) is produced at the exit of the concrete downstream of the dump, and that could be used to perform a proton charge radius measurement;

Moreover, if LDM is produced in the dump, it can be detected at $\sim 20m$ downstream through an EM calorimeter.

REFERENCES

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