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BDX on-beam background assess and MC validation

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Abstract

In response to the issue raised by JLAB-PAC44 about the experiment proposal *PR-16-001 Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab* [**?**] we propose to measure the prompt radiation produced by the interaction of the high intensity 11 GeV electron beam with the Hall-A beam dump. The muon and neutron flux will be sampled at different height (with-respect-to the beam line), positions and angles downstream of the beam dump to map out the radiation field in the location of the future hall hosting the BDX experiment. In order to realistically assess the beam-on background experienced by the BDX detector, a specimen of the CsI(Tl) crystal from the BDX electromagnetic calorimeter, will be exposed to the radiation as part of a plastic scintillator hodoscope built specifically for this measurement (BDX-Hodo). Although it will not be possible to directly compare results of this tests with the experimental set up proposed in PR-16-001 that will make use of a different and optimised shielding, the measurement will be extremely useful to validate the MonteCarlo simulation tools (GEANT4 and FLUKA) used to design the new underground facility and optimize the BDX detector.

This report is organised as follow: results of the simulation of the radiation field produced by the interaction of the beam with the dump are reported in Sec. **??**; the experimental set-up and the detector is described in Sec.**??**; the expected results of the measurement are reported in Sec. **??**. Details about cost estimate to run the test, work -and time-planes are reported in the Appendix.

Contents

1 MC simulations

1.1 The Hall-A high-power beam-dump

The Hall A and C use identical high-power absorbing (up to 1 MW) beam-dumps to stop the 11 GeV beam, remnant of beam/target interaction. The dump is made by a set of about 80 aluminum disks, each approximately 40 cm in diameter of increasing thickness (from 1 to 2 cm), for a total length of approximately 200 cm, followed by a solid Al cylinder 50cm in diameter and approximately 100 cm long. They are both cooled by circulating water. The full drawing of the beam-dump is shown in Fig. ??. To increase the radiation shielding, the thickness of the concrete tunnel surrounding the Al dump is about 4-5 m thick.

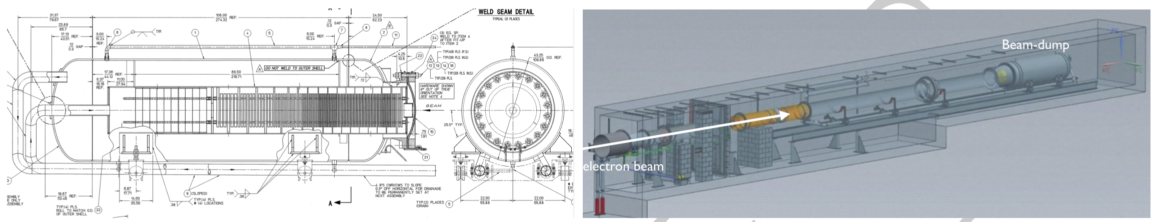

Figure 1: Hall-A beam dump and beam dump enclosure.

1.2 The beam-dump model in FLUKA

The beam-dump geometry and materials have been implemented in FLUKA-2011.2c.5 by the Jefferson Lab Radiation Control Department. Detailed are reported in Ref. [?]. The input card used to run the program includes all physics process and a tuned set of bias to speed up the running time not affecting the results integrity. The μ, n, and γ fluence (differential in angle and energy)

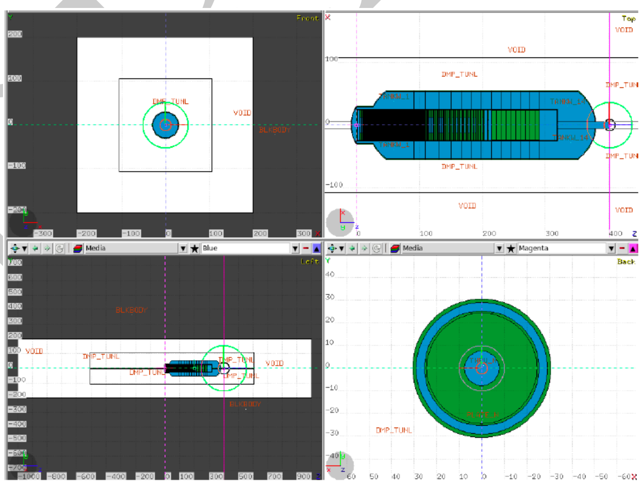

Figure 2: Hall-A beam-dump implementation in FLUKA.

per EOT were calculated at XXX cm downstream of the beam window, through a circular area of

105 cm^2. Figure ?? shows the FLUKA graphic representation and the location of the flux detector. An extension to also include the proper geometry and material composition downstream of the beam-dump has also been implemented. Figure ?? shows the geometry of of the concrete bunker surrounding the beam-dump and the soil as implemented in FLUKA.

`figs/fluka-bd-dwns.pdf`

Figure 3: The geometry/composition of the concrete bunker surrounding the beam-dump and the soil as implemented in FLUKA.

1.3 The beam-dump model in GEANT4 (GEMC)

The beam-dump model, as well as the geometry and composition of surrounding proximity, has also been implemented in GEANT4 using the GEMC tool [?]. This is a refined version with-respect-to the one used in PR-16-001 [?] that better matches the beam-dump geometry implemented in FLUKA. For a better description of muon transportation, the `G4GammaConversionToMuons` has been added to the standard physics list used in simulations of PR-16-001(`FTFP_BERT_HP + STD + HP`). Particles flunce has been sampled by mean of a a flux detector has been positioned in the same location as in the FLUKA model. Figure /ref shows the beam dump and vicinity implemented in GEMC.

1.4 Radiation of beam/dump interaction

A comparison of muon fluence downstream of the beam-dump (see above for details about the location) obtained by FLUKA and GEMC are reported in Fig. ??. Considering that low energy muons are absorbed by the bunker-head shielding, to keep the GEMC running time reasonable, only particles (all) with energy grater than 100 MeV (`ENERGY_CUT=100*MeV`) has been tracked and sampled. A total of $4{\times}10^9$ (9×10^6) EOT have been simulated with GEMC (FLUKA). The comparison of the two simulations shows a perfect agreement in the full energy range where data were generated. In figs/gemc-bd-dwns.pdf

Figure 4: The geometry/composition of the beam-dump, the sourraunding concrete bunker and the soil as implemented in GEMC.

spite of a factor of $\times 100$ less statistics, FLUKA shows, as expected, smaller error bars. This reflects the optimised sizes used by the simulation to generate high statistics for low probability processes keeping the total statistics limited. To penetrate the concrete shielding and the soil, minimum energy of $E_\mu > 4$ GeV is required. With this energy cut, the integrated number of muon per EOT results in $4.8 \pm 0.1 \times 10^{-7}$ ($5.5 \pm 0.2 \times 10^{-7}$) for GEMC and FLUKA respectively. Figure ?? show the correlation between the muon energy and the azimuthal angle (with-respect-to the beam-line): the regions that are populated by both simulations, show again, the same behaviour.

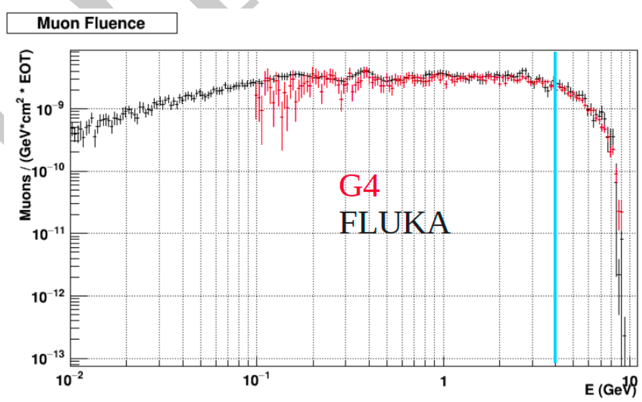

Figure 5: Muon fluence downstream of the beam-dump obtained by FLUKA (black) and GEMC (red). The GEMC simulations started at Eμ =100 MeV.

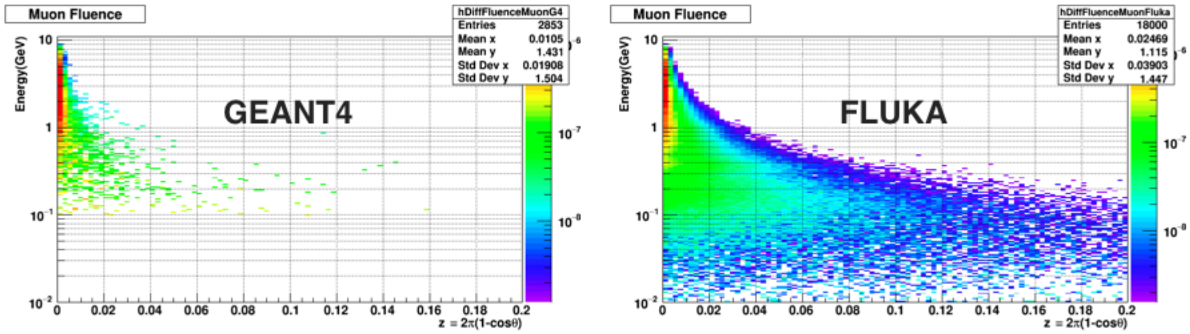

Figure 6: Energy vs. azimuthal angle of muons crossing the flux detector located downstream of the beam-dump obtained by FLUKA and GEMC.

1.5 Sampling and particle transport

The good agreement between two independent simulation tools (FLUKA and GEMC) gives us confidence about reliability of the obtained results. Both methods have pros and cons. FLUKA shows a superior speed in running but a complicated implementation and of selected results (e.g. the final output is given via *scores* such as fluence or distribution in specific location need to be pre-defined). GEMC (GEANT4) tracks particles in all volumes providing a straightforward output (particle four-momenta) in the desired flux detector but requires an un-practical running time to collect a reasonable statistics (in particular when an em shower is involved). In the following we describe how we overtook these difficulties.

1.5.1 Muons - GEMC

We used GEMC to simulate muons.To make the process more efficient, we defined the following procedure:

- use a low statistic sample of EOT to simulate the interaction of the 11 GeV electrons with the beam-dump;
- sample the muon flux and variables (momentum, azimuthal angle and transverse position) on a flux detector located downstream of the beam-dump;
- use the distributions from previous step as input of a custom event-generator to produce a high statistic muon sample;
- use GEMC to transport muons downstream of the beam dump all the way up the desired location of the BDX-Hodo;
- implement the BDX-Hodo response in GEMC to realistically describe the muon detection.

Figure **??** shows the muon distributions (energy vs azimuthal angle and radial distance from the beam line) downstream of the beam-dump, as obtained by the full GEMC simulation of 11 GeV electrons hitting the beam-dump. Figure **??** shows the comparison one of the two distributions as obtained by the GEMC with the result of the custom event generator. The difference in the error bar size indicates the improvement obtained by this procedure with-respect-to the limited statistic from GEMC.

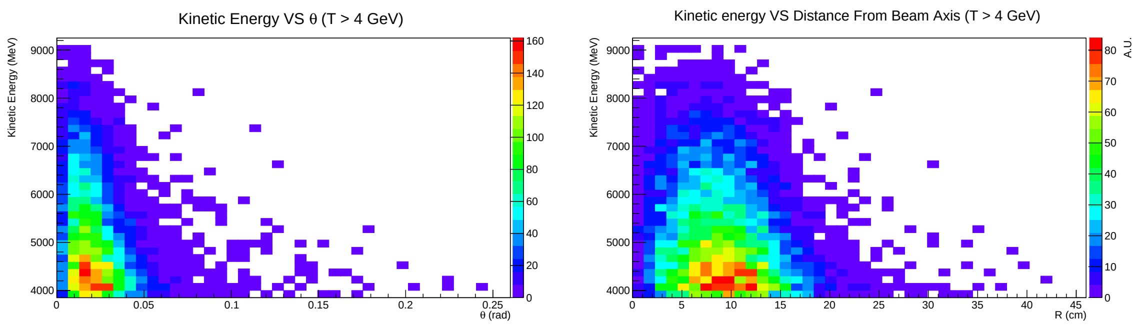

Figure 7: Muon kinetic energy vs. azimuthal angle (left) and distance (right) from the beam-line axes.

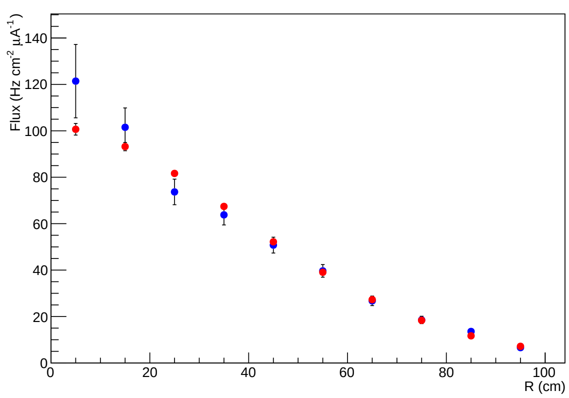

Figure 8: Muon kinetic energy vs. radial distance from the beam-line axes obtained by GEMC (blue) and by the custom event-generator (red).

1.5.2 Neutrons - FLUKA

Unfortunately the same procedure can not be applied to neutron simulation. Generation and propagation of low energy neutrons (down to thermal energy) prevent the use of a reasonable energy cut-off in GEMC. Moreover, a sizeble contribution to the neutron fluence at the location of interest (in the proximity of the future experimental hall) is given by neutron generated by high energy muons penetrating into the concrete shielding and soil. Given the difficulty in separate the generation (for the primary 11 GeV electron beam interaction and from secondary nuclear processes) from the neutron transport, we decided to only rely on FLUKA.

Muon and neutron flux at the location of interest will be presented in the Sec. **??** after discussing in the next Section, the proposed experimental set up and the BDX-Hodo detector.

2 Tests set-up

2.1 The background detector

2.2 Detector location

2.3 Detector simulation

3 Results

3.1 Expected muon rates

3.2 Expected neutron rates

3.3 The proposed set up

4 Appendix

4.1 Cost estimates

4.2 Work-plan, time-plan, ...