BDX Muon Rate Prediction and Measurement Memo

Dan Snowden-Ifft

May 28, 2019

I recently received and read the nice BDX experimental results from JLab.

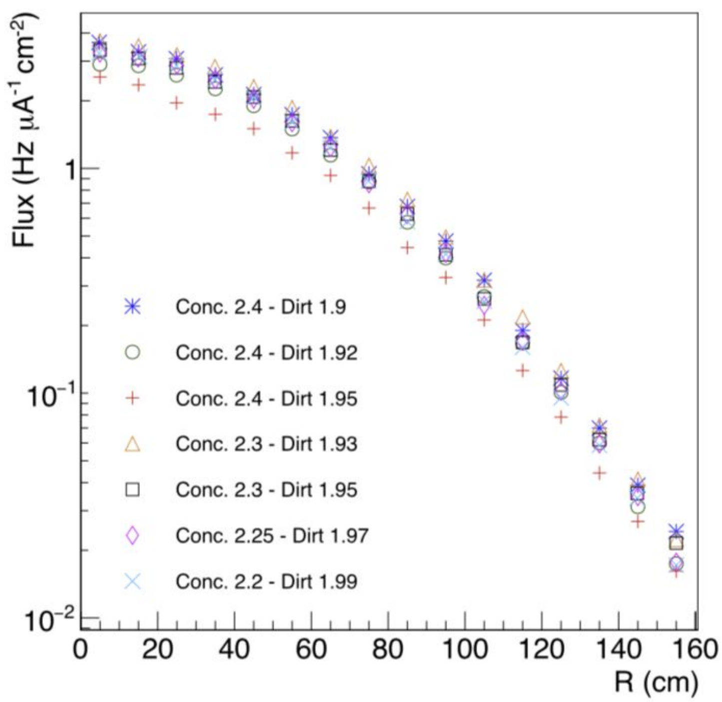

Figure 1 - From "Measurements of the muon flux produced by 10.6 GeV electrons in a beam dump” [1].

Coincidentally, through Andrea, I became aware of a muon production model for JLab.

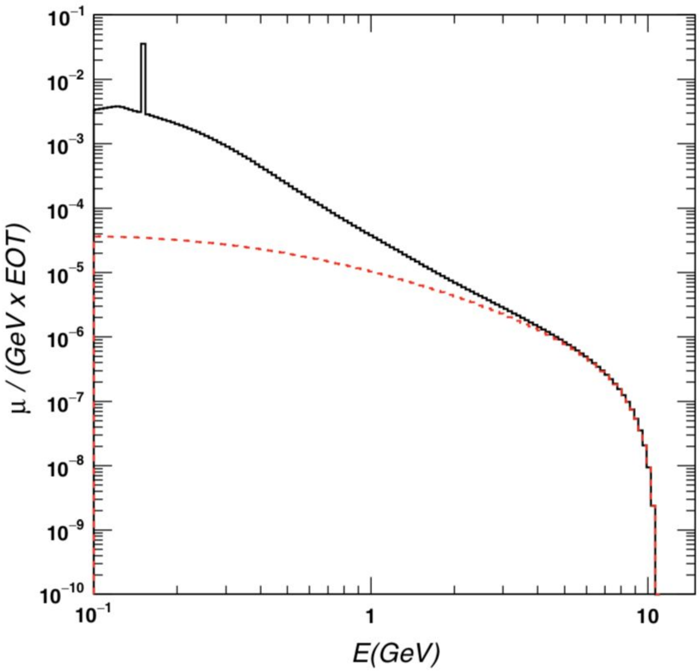

Figure 2 - From "Probing leptophilic dark sectors at electron beam-dump facilities" [2].

I wanted to see, for myself, whether these two results were consistent.

1) I calculated the range of a 10.6 GeV muon in the dirt.

a) Kinetic energy top of Al = 10.6 GeV, Momentum = 10.7 GeV/c, R/M top of Al = 50,000 g cm^-2 GeV^-1 from,

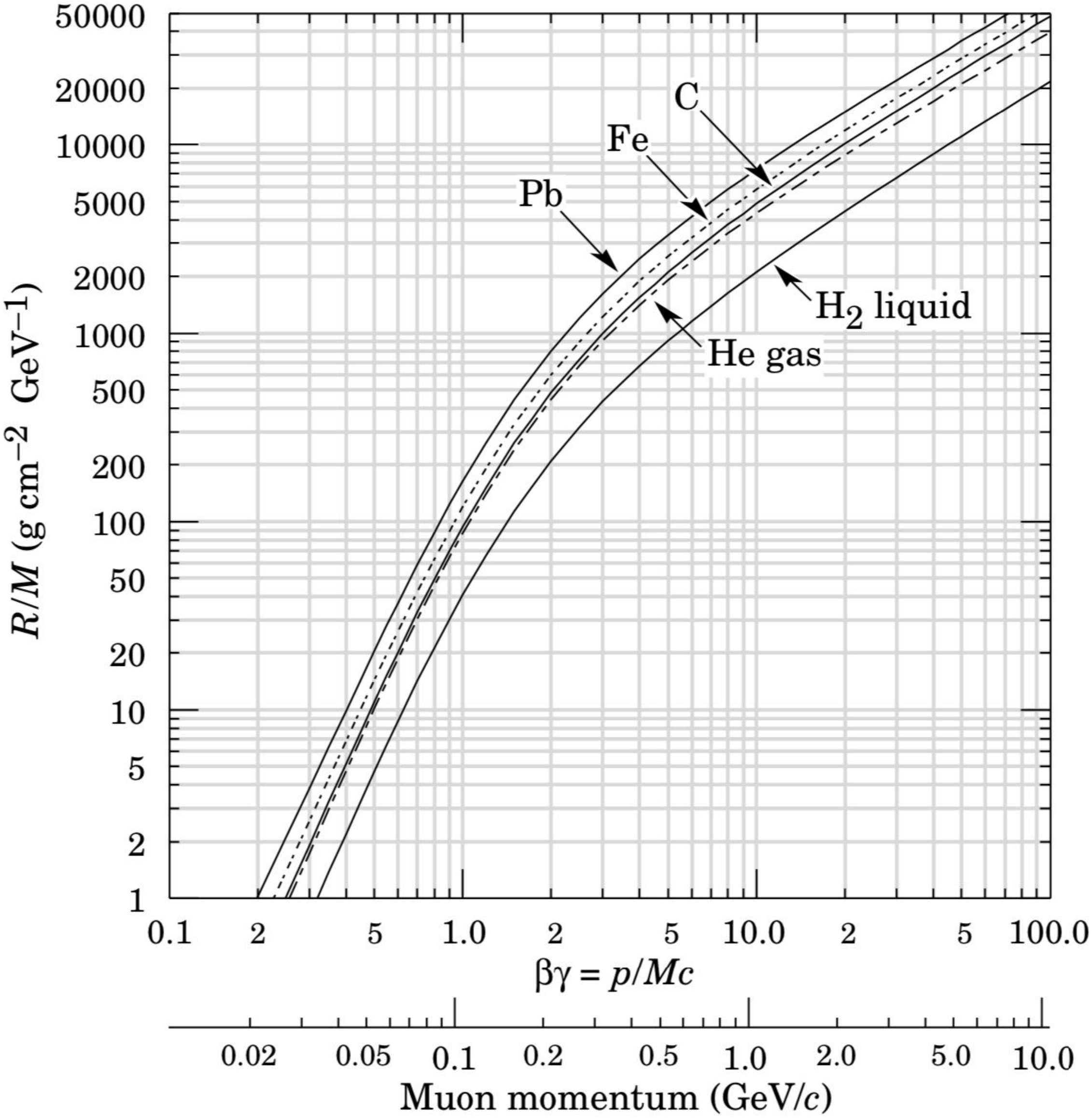

Figure 3 - Range energy graph from Particle Data Book [3]

Note I use the C curve for this calculation.

b) Length of Al beam dump = 325 cm from this diagram

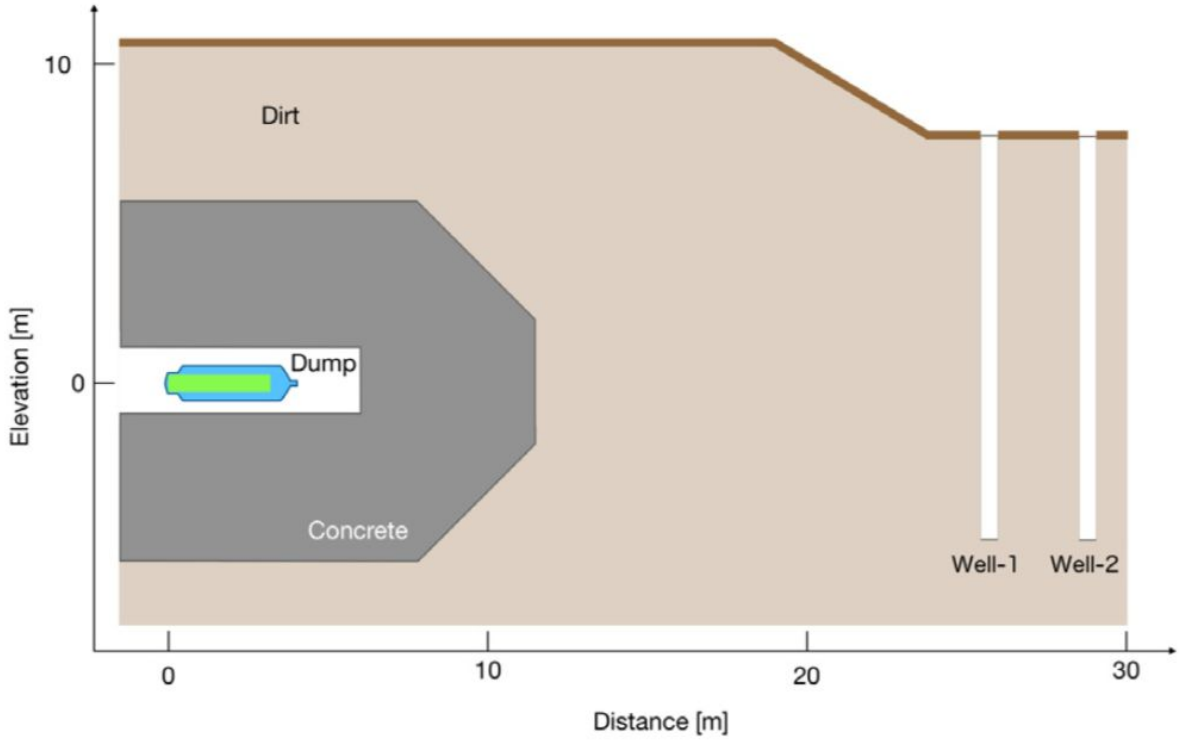

Figure 4 - From "Measurements of the muon flux produced by 10.6 GeV electrons in a beam dump" [1]

with density 2.699 g/cm^3. R/M decrease of Al beam dump = 8301.992 g cm^-2 GeV^-1. Note that I assume the muons are produced at the beginning of the dump. Note also that all measurements below were taken from this diagram.

c) Concrete shielding = 550 cm, density = 2.4 g/cm^3, R/M decrease of concrete = 12493.09 g cm^-2 GeV^-1

d) Remaining R/M in dirt = 50000 - 8301.992 - 12493.09 g cm^-2 GeV^-1 = 29204.91 g cm^-2 GeV^-1

e) Real range in dirt with density 1.94 g cm^-3 = 1590.59 cm. Note that Dirt to Well 1 = 1410 cm and Dirt to Well 2 = 1730 cm so this is consistent with the measurements, the muons ranged out somewhere between the wells.

f) I'm ignoring the water and air in the dump.

2) Well 1 is 180.5895 cm upstream of the calculated end of range or, in the strange units of Figure 3, 3315.816 g cm^-2 GeV^-1. Using Figure 3 this corresponds to a residual momentum of 0.80 GeV/c for a kinetic energy of 0.70 GeV.

3) The muons which just make it to Well 1 started out with 10.6 - 0.7 GeV = 9.9 GeV. So to get the muons passing the Well 1 position I integrate Figure 1 above from 9.9 GeV to 10.6 GeV. This gives me 4.9e-09 per EOT. I am ignoring straggling in this calculation.

4) 1 microA is 6.25e+12 EOT Hz. So I predict 30,457.15 Hz uA^-1 at the location of Well 1.

5) These are spread out in a 2D Gaussian of width,

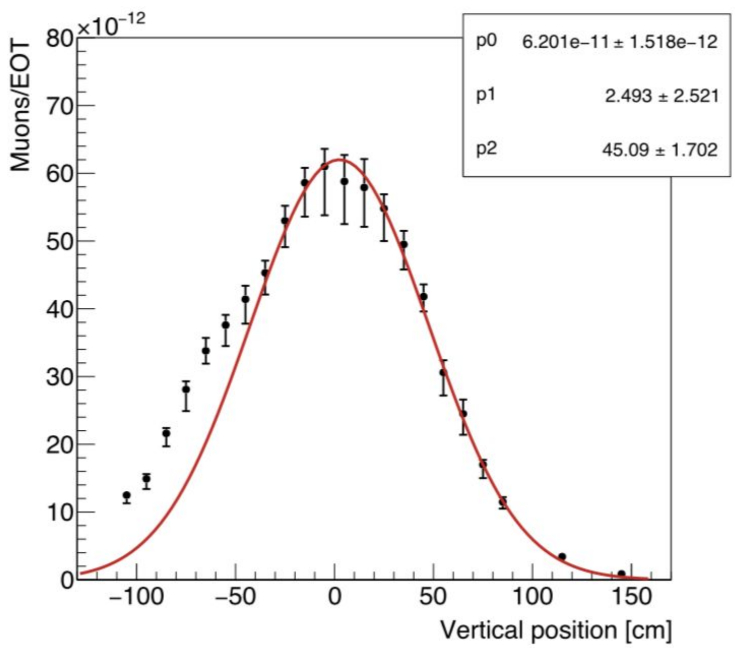

Figure 5 - From "Measurements of the muon flux produced by 10.6 GeV electrons in a beam dump" [1]

sigma = 45.09 cm. A normalized 2D Gaussian has an amplitude of 1 / (2 * pi * sigma^2). So I would predict a central density of 89,000 Hz uA^-1 / (2 * pi * sigma^2) = 2.4 Hz uA^-1 cm^-2

6) Figure 2 above seems to indicate a central density of 2.5 Hz uA^-1 cm^-2, 5% bigger.

7) To do a better job I would include the water and air in the dump. I would make a better guess as to where the mean muon production location would be for the highest energy muons. I would include straggling. And finally energy deposition in the detector.

Bottom line - The BDX muon model and the BDX muon measurements seem to agree to 5%.

References -

[1] M. Battaglieri, M. Bondí, A. Celentano, M. De Napoli, R. De Vita, S. Fegan, L. Marsicano, G. Ottonello, F. Parodi, N. Randazzo, E. S. Smith, and T. Whitlatch, Nucl. Instrum. Methods Phys. Res. Sect. Accel. Spectrometers Detect. Assoc. Equip. **925**, 116 (2019).

[2] L. Marsicano, M. Battaglieri, A. Celentano, R. De Vita, and Y.-M. Zhong, Phys. Rev. D **98**, 115022 (2018).

[3] M. Tanabashi, P. D. Grp, K. Hagiwara, K. Hikasa, K. Nakamura, Y. Sumino, F. Takahashi, J. Tanaka, K. Agashe, G. Aielli, C. Amsler, M. Antonelli, D. M. Asner, H. Baer, S. Banerjee, R. M. Barnett, T. Basaglia, C. W. Bauer, J. J. Beatty, V. I. Belousov, J. Beringer, S. Bethke, A. Bettini, H. Bichsel, O. Biebel, K. M. Black, E. Blucher, O. Buchmuller, V. Burkert, M. A. Bychkov, R. N. Cahn, M. Carena, A. Ceccucci, A. Cerri, D. Chakraborty, M.-C. Chen, R. S. Chivukula, G. Cowan, O. Dahl, G. D'Ambrosio, T. Damour, D. de Florian, A. de Gouvea, T. DeGrand, P. de Jong, G. Dissertori, B. A. Dobrescu, M. D'Onofrio, M. Doser, M. Drees, H. K. Dreiner, D. A. Dwyer, P. Eerola, S. Eidelman, J. Ellis, J. Erler, V. V. Ezhela, W. Fetscher, B. D. Fields, R. Firestone, B. Foster, A. Freitas, H. Gallagher, L. Garren, H.-J. Gerber, G. Gerbier, T. Gershon, Y. Gershtein, T. Gherghetta, A. A. Godizov, M. Goodman, C. Grab, A. V. Gritsan, C. Grojean, D. E. Groom, M. Grunewald, A. Gurtu, T. Gutsche, H. E. Haber, C. Hanhart, S. Hashimoto, Y. Hayato, K. G. Hayes, A. Hebecker, S. Heinemeyer, B. Heltsley, J. J. Hernandez-Rey, J. Hisano, A. Hocker, J. Holder, A. Holtkamp, T. Hyodo, K. D. Irwin, K. F. Johnson, M. Kado, M. Karliner, U. F. Katz, S. R. Klein, E. Klempt, R. V. Kowalewski, F. Krauss, M. Kreps, B. Krusche, Y. V. Kuyanov, Y. Kwon, O. Lahav, J. Laiho, J. Lesgourgues, A. Liddle, Z. Ligeti, C.-J. Lin, C. Lippmann, T. M. Liss, L. Littenberg, K. S. Lugovsky, S. B. Lugovsky, A. Lusiani, Y. Makida, F. Maltoni, T. Mannel, A. V. Manohar, W. J. Marciano, A. D. Martin, A. Masoni, J. Matthews, U.-G. Meissner, D. Milstead, R. E. Mitche, K. Moenig, P. Molaro, F. Moortgat, M. Moskovic, H. Murayama, M. Narain, P. Nason, S. Navas, M. Neubert, P. Nevski, Y. Nir, K. A. Olive, S. P. Griso, J. Parsons, C. Patrignani, J. A. Peacock, M. Pennington, S. T. Petcov, V. A. Petrov, E. Pianori, A. Piepke, A. Pomarol, A. Quadt, J. Rademacker, G. Raffelt, B. N. Ratcliff, P. Richardson, A. Ringwald, S. Roesler, S. Rolli, A. Romaniouk, L. J. Rosenberg, J. L. Rosner, G. Rybka, R. A. Ryutin, C. T. Sachrajda, Y. Sakai, G. P. Salam, S. Sarkar, F. Sauli, O. Schneider, K. Scholberg, A. J. Schwartz, D. Scott, V. Sharma, S. R. Sharpe, T. Shutt, M. Silari, T. Sjostrand, P. Skands, T. Skwarnicki, J. G. Smith, G. F. Smoot, S. Spanier, H. Spieler, C. Spiering, A. Stah, S. L. Stone, T. Sumiyoshi, M. J. Syphers, K. Terashi, J. Terning, U. Thoma, R. S. Thorne, L. Tiator, M. Titov, N. P. Tkachenko, N. A. Tornqvist, D. R. Tovey, G. Valencia, R. Van de Water, N. Varelas, G. Venanzoni, L. Verde, M. G. Vincter, P. Voge, A. Vogt, S. P. Wakely, W. Walkowiak, C. W. Walter, D. Wands, D. R. Ward, M. O. Wascko, G. Weiglein, D. H. Weinberg, E. J. Weinberg, M. White, L. R. Wiencke, S. Willocq, C. C. Woh, J. Womersley, C. L. Woody, R. L. Workman, W.-M. Yao, G. P. Zeller, O. V. Zenin, R.-Y. Zhu, S.-L. Zhu, F. Zimmermann, P. A. Zyla, J. Anderson, L. Fuller, V. S. Lugovsky, and P. Schaffner, Phys. Rev. D **98**, 030001 (2018).