Radiation studies for Mu2e-II update. Energy station

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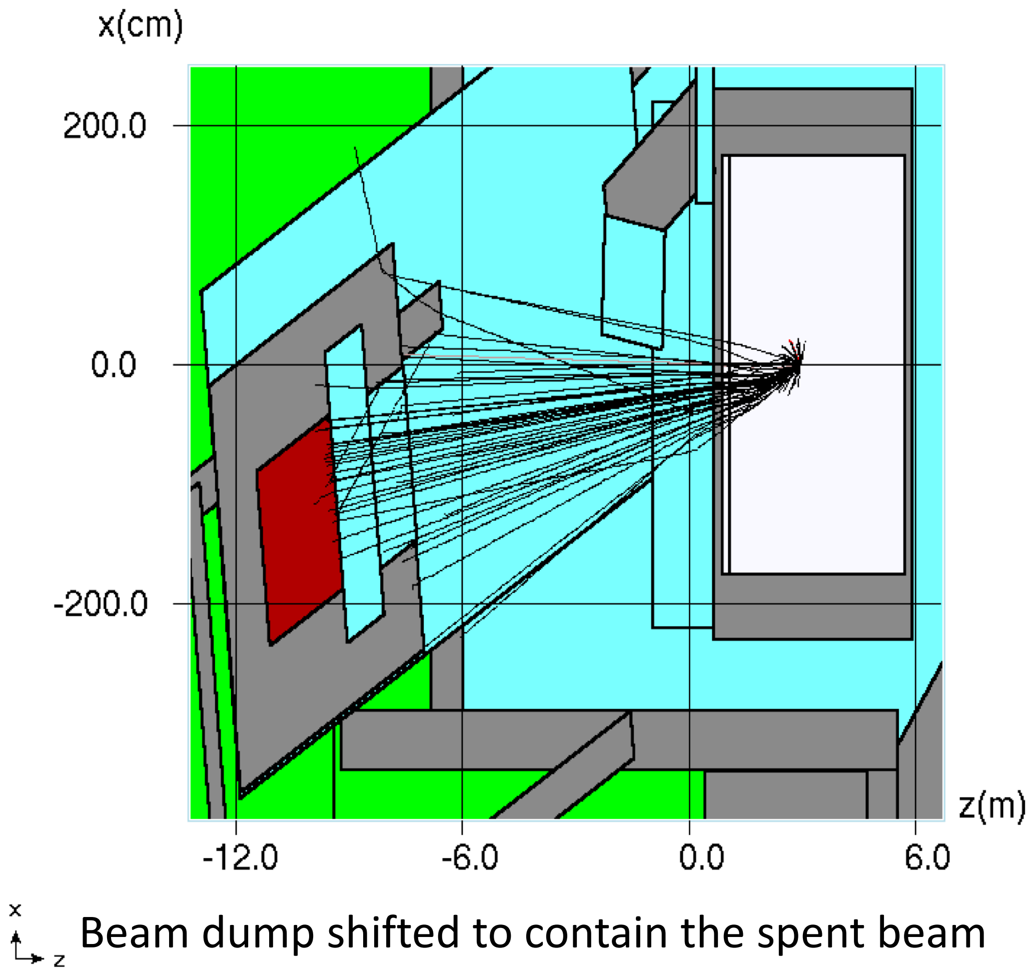
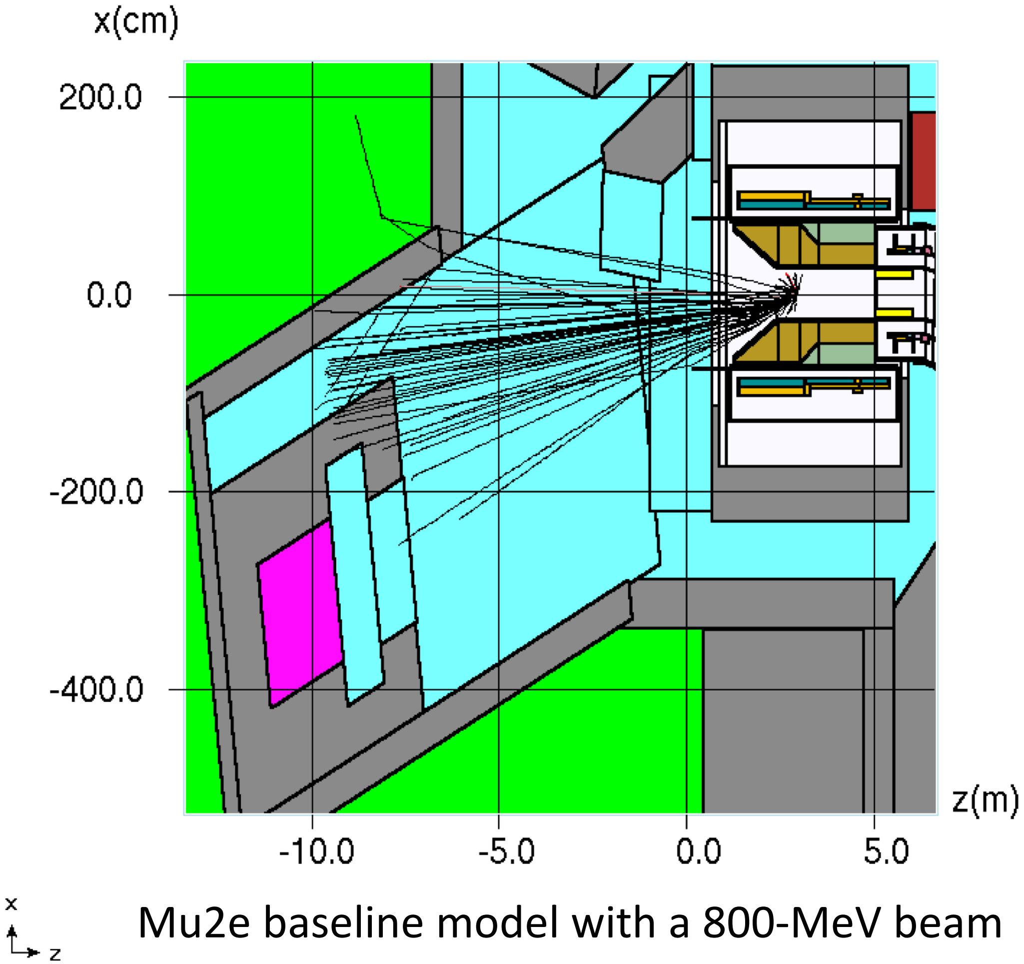
Mu2e-II Workshop

Beam dump for Mu2e-II: new location required



Beam dump shifted to contain the spent beam

Aspect Ratio z/x = 3.1648; y0 = 150.0000; -600.0000 < y < 600.0000 (cm)



Mu2e baseline model with a 800-MeV beam

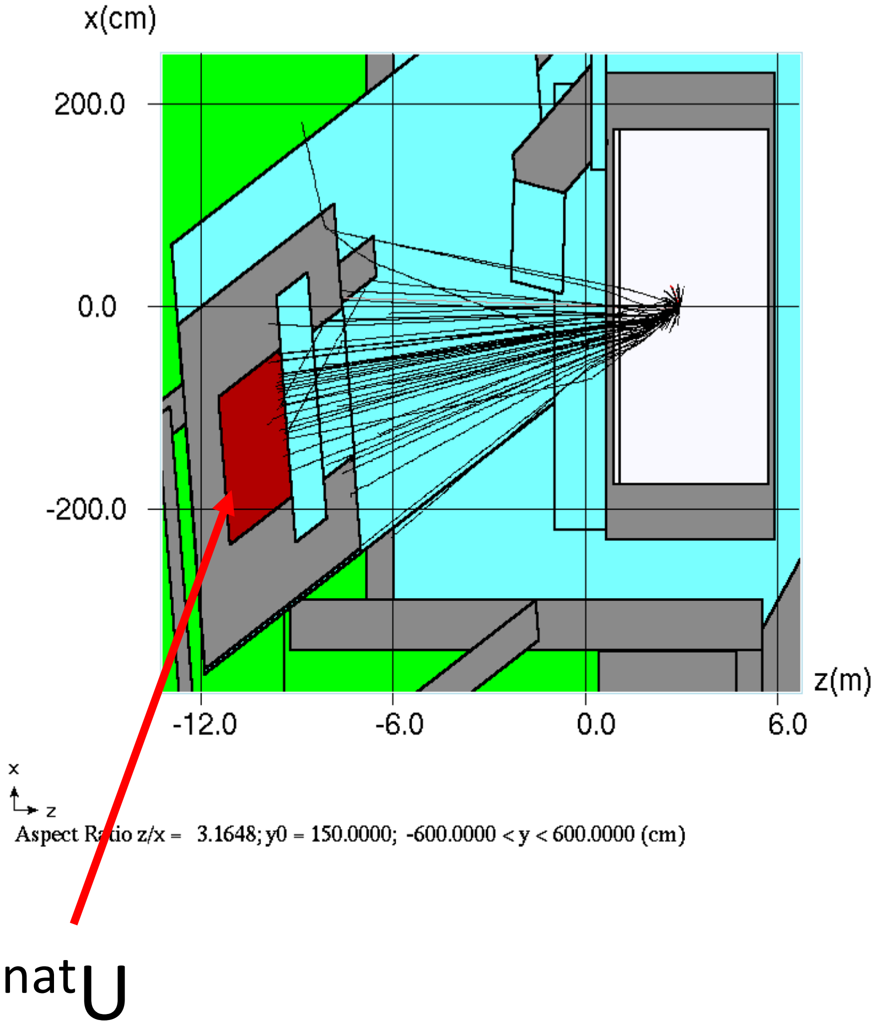
Aspect Ratio z/x = 2.6319; y0 = 0.0000; -550.0000 < y < 550.0000 (cm)

Even if only the proton beam energy changes from 8 GeV to 800 MeV, a relocation of beam dump by ~2m North and 1.5 m up will be required.

Using U-238 energy amplifier as a beam dump

- Idea: Uranium and transuranic elements when irradiated by energetic particles release fission energy (0.2 GeV per fission): an ADS principle
- Besides its broad application in energy production systems, depleted uranium has been successfully utilized in high-energy physics experiments. For example, in the D0 experiment, ^{238}U plates with the total mass 144.4 tons, were employed in the hadron calorimeter.
- Depleted uranium, having the 4.5-million-year half-life, emits α, β, and γ-radiation, however, due to self-attenuation in bulk material, despite large quantities, emission of radiation outside is quite modest because the detector mass eliminates any radiation exposure concerns. Also, uranium oxidation is seriously limited by inert gas atmosphere under which the D0 detector plates are stored.
- Hence, depleted uranium even in significant quantities was found to be a feasible material for long-term accelerator-based physics experiments.

Energy amplification in a ^{nat}U dump. MARS15 simulations



$$G = \frac{\chi_s \cdot \phi^* \cdot k_{eff} \cdot E_f}{\nu \cdot (1 - k_{eff})}$$

: $k_{eff} = 0.98$ (a typical number assumed for ADS), $\phi^* = 1$ (importance of the source of neutrons with respect to that of the fission neutrons, see [29] for details). This factor can be larger than 1 if other neutron sources than fission exist in the system; in our case a conservative assumption is made. The number of fissions per neutron ν was taken to be 2.5, and $E_f = 0.2$ GeV is the energy released per one fission.

Details are in V.S. Pronskikh, N. V. Mokhov, I. Novitski, S.I. Tyutyunnikov, Annals of Nuclear Energy, V. 109, 2017, pp. 692-697.

Simulated neutrons per proton = 34; Pth=Edep*G
for keff=0.98, G=133.3, and Pth= 2MW
for keff=0.99, G=269.3, and Pth= 4 MW
For a 400-kW beam, Pth = 8 MW and 16 MW, respectively
May be economically beneficial for energy saving

Further considerations for energy amplification

- Thermal power of ~10-20 MW is the energy production of typical small modular nuclear reactors (comparable to Fermilab Main Injector power)
- Thermal to electric conversion efficiency ~ 0.45
- Further work necessary:
  - Magnetic field optimization and focusing the spent beam on the dump (currently only 116 MeV/p (out of 800 MeV beam energy) is released in the dump
  - Simulations and precise determination of the keff and the required level of enrichment
  - ES&Q and radiation safety requirements and considerations
  - Can we check this result with FLUKA or Geant4 ?

Energy amplification/conservation station may be feasible for Mu2e-II and PIP-II