A Study of Muon Production Using Electron Beams and iRPC Detection Techniques

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1. Introduction

Muons are unstable charged leptons continuously produced by cosmic-ray interactions in the atmosphere. Their high penetration capability makes them valuable for muon tomography (muography), with applications in geology, archaeology, nuclear inspection, and security. However, the atmospheric muon flux at sea level is relatively low ($\sim 1\ \mathrm{muon\,cm^{-2}\,min^{-1}}$).
Laser-Wakefield Acceleration (LWFA) [1] can generate compact, high-energy electron beams, offering a potential alternative muon source for portable muography systems with enhanced flux. In this work, we simulate muon production from electron beams interacting with a lead and tungsten target then investigate their detection using Resistive Plate Chambers (RPCs) [2].

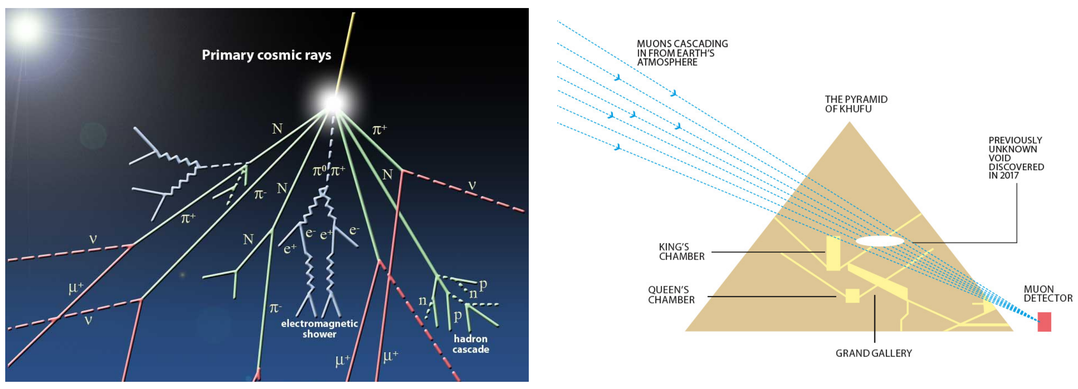


Figure 1: *Cosmic shower (left), muography applications (right)*

2. Simulation Framework

The study was performed using the FLUKA Monte Carlo code. Electron beams of 2 and 10 GeV were directed onto lead and tungsten targets to investigate muon production.

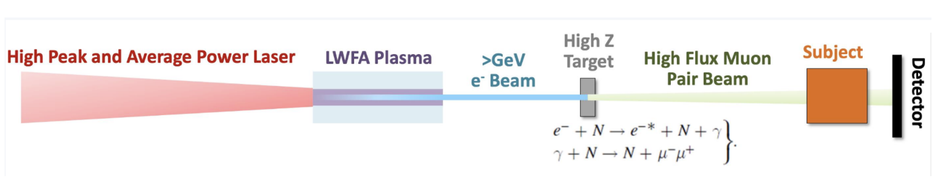


Figure 2: *Schematic layout of the laser-wakefield acceleration (LWFA) setup for muon production.*

The simulation geometry included the target, 2 m concrete shielding, and a downstream $30 \times 30\,\mathrm{cm}^2$ iRPC detector used to evaluate muon spatial and energy distributions.
Muon production was modeled through Bremsstrahlung and Bethe–Heitler pair production paths:

$$e^- + \mathrm{Pb} \rightarrow e^- + \gamma + \mathrm{Pb} \tag{1}$$

$$\gamma + \mathrm{Pb} \rightarrow \mathrm{Pb} + \mu^+ + \mu^- \tag{2}$$

Particle fluence, energy spectra, and trajectory distributions were systematically analyzed across different operational beam setups and target configurations.

3. Particles Produced from the Electron Beam

The results show that muon yield strongly depends on beam energy. While the yield remains low for 2 GeV and 5 GeV beams, it increases significantly at 10 GeV due to enhanced electromagnetic shower development.

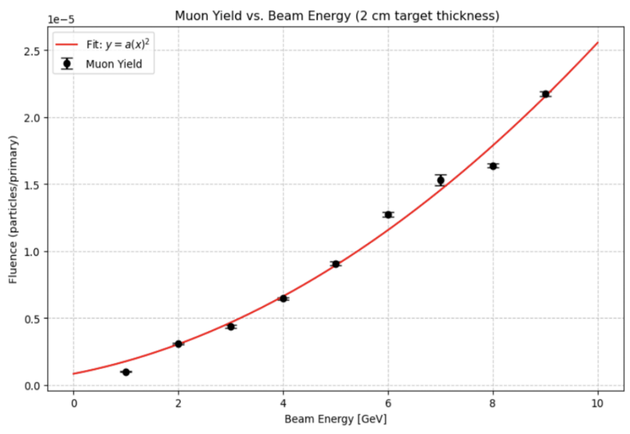


Figure 3: *Muon yield versus beam energy for a lead target.*

Figure 3 shows a non-linear dependence of muon yield on beam energy, well described by a quadratic relation ($y = ax^2$), reflecting the fundamental two-step muon production chain inside the lead target block.

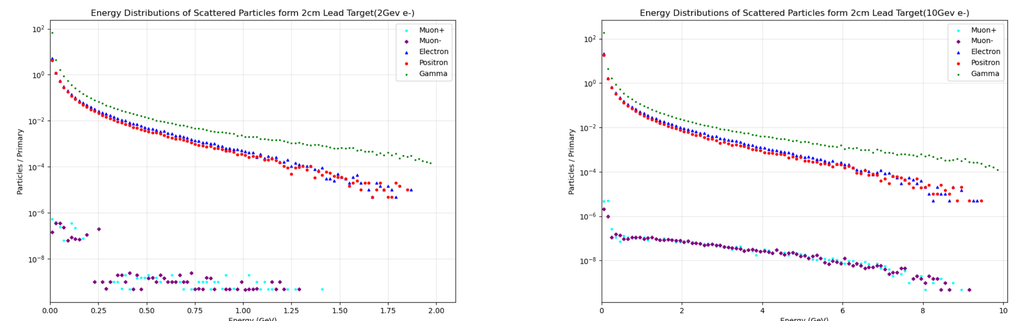


Figure 4: *Energy spectra of secondary particles (γ, e^-, e^+) exiting a $2\,\mathrm{cm}$ lead target for incident beam energies of $2\,\mathrm{GeV}$ (left) and $10\,\mathrm{GeV}$ (right).*

At $\sim 3.5\,X_0$, the target supports a fully developed electromagnetic shower. However, muons remain 4–5 orders of magnitude below the electromagnetic background, requiring strong filtering layouts.

4. Simulation Results - Interaction with iRPC

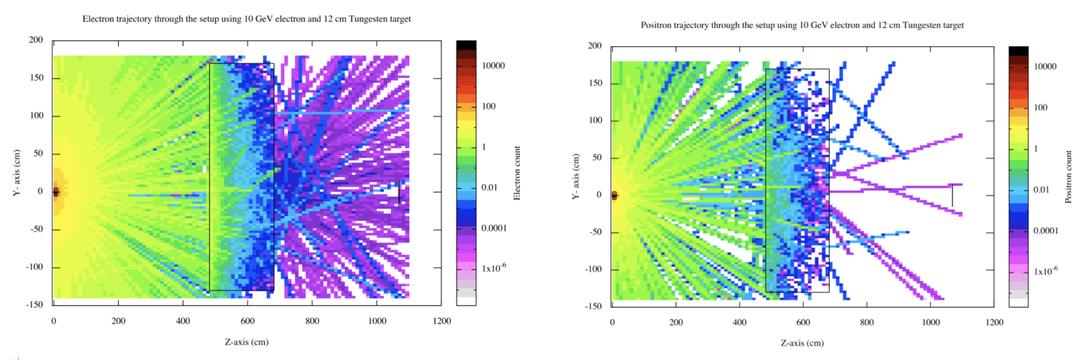


Figure 5: *Simulated tracking trajectories of secondary electrons (e^-, left) and positrons (e^+, right) through the setup of $12\,\mathrm{cm}$ thickness tungsten target, 200 cm concrete shielding and $1.4\,\mathrm{mm}$ gap iRPC at $10\,\mathrm{GeV}$ electron beam.*

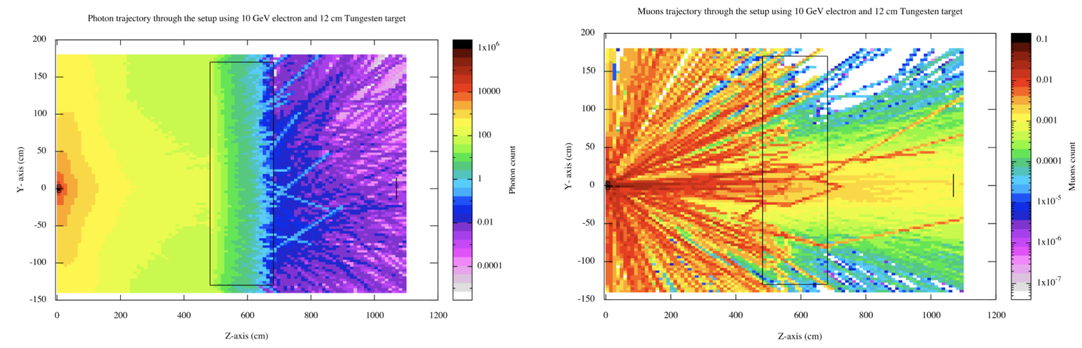


Figure 6: *Tracking trajectories through the $12\,\mathrm{cm}$ tungsten target and $200\,\mathrm{cm}$ concrete block layout for background photons (γ, left) versus the highly penetrating muon signal ($\mu^{\pm}$, right).*

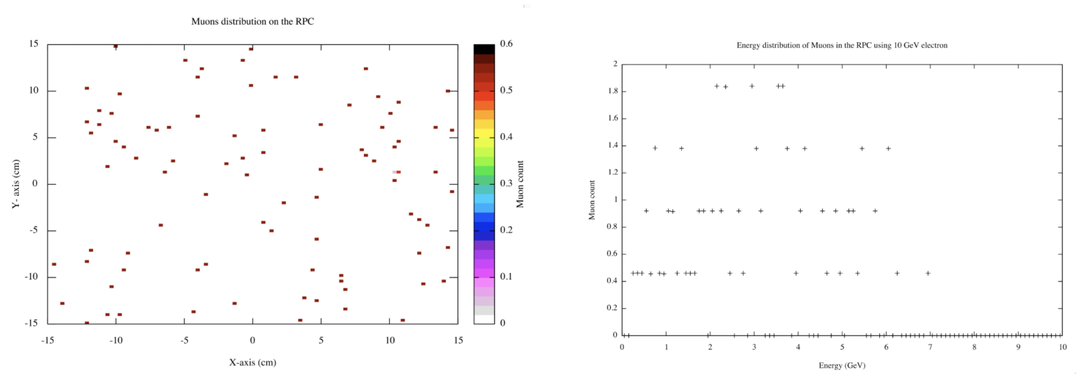


Figure 7: *Downstream analysis at the active detector area: 2D spatial hit distribution of muons hits across the iRPC tracking grid (left) alongside the corresponding simulated muon energy spectrum (right).*

The results show that the $200\,\mathrm{cm}$-thick concrete shielding block strongly attenuates the electromagnetic background ($e^{\pm}, \gamma$) while muons pass through with minimal interaction. This provides clean hit mapping across the iRPC grid, peaking safely beneath $3.0\,\mathrm{GeV}$.

5. Conclusions

In this work, muon production from electron beams interacting with a lead and tungsten target was simulated using FLUKA, and the response of a downstream iRPC detector was studied. The results show that muon yield increases strongly with beam energy, with $10\,\mathrm{GeV}$ beams producing the highest yields. An approximately quadratic dependence on beam energy is observed. The simulated tracking setup demonstrates clean spatial distributions, successfully recording localized muon hit counts across the active iRPC geometry after background suppression.

References

[1] ZHANG, F. et al. High Power Laser Sci. Eng., 2017, vol. 5, p. e16.
[2] PESKOV, V. et al. Resistive gaseous detectors. John Wiley & Sons, (2018).