Linear Attenuation Coefficient for Cosmic-Ray Muons in Lead

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Abstract

The cosmic-ray muon attenuation coefficient in lead was measured using two vertically aligned scintillation detectors in a coincidence setup. After a two-day background measurement confirmed a stable muon rate, lead shielding was added in layers above the detectors, and count rates were recorded for each thickness over approximately two days to reduce statistical uncertainty. The measured count rates were normalized by active detection time and analyzed using the exponential attenuation model. The experimental attenuation coefficient was found to be μ = 0.007646 cm^{-1}, within 1.67% of the theoretical value of 0.00752 cm^{-1}[3]. At greater lead thicknesses, count rates plateaued, likely due to background noise and secondary particles produced within the lead.

Methodology

Cosmic-ray muon attenuation through lead was measured using two vertically aligned scintillation detectors in a coincidence setup, as seen in Fig. 1. A count was recorded when a muon passed through both detectors, which helped reduce random background events.

Before adding the lead bricks, the background muon count rate was recorded for approximately 1.5 days to confirm that the natural muon rate was mostly constant, as seen in Fig.2.

Lead bricks were then placed above the scintillation detectors, increasing the shielding thickness up to five layers. For each lead thickness, data was collected for approximately two days. The count rate was calculated as follows:

$$R = \frac{N}{t}$$

where N is the total number of counts and t is the collection time.

The attenuation coefficient was determined by plotting $\ln(I_0/I)$ as the dependent variable and x as the independent

$$\ln(I_0/I) = \mu x$$

where I_0 is the background rate, I is the count rate, x is the thickness of lead, and μ is the linear attenuation coefficient determined the slope of the linearized graph.

Figure 1. Experimental set-up exhibiting lead bricks above two scintillation detectors

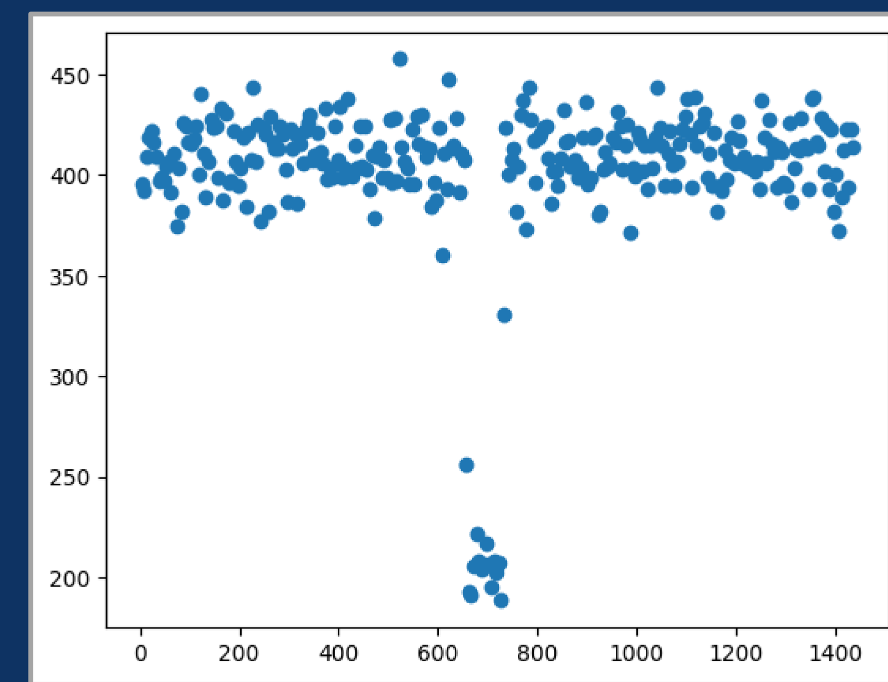

Figure 2. Background muon count rate measured over approximately 1.5 days.

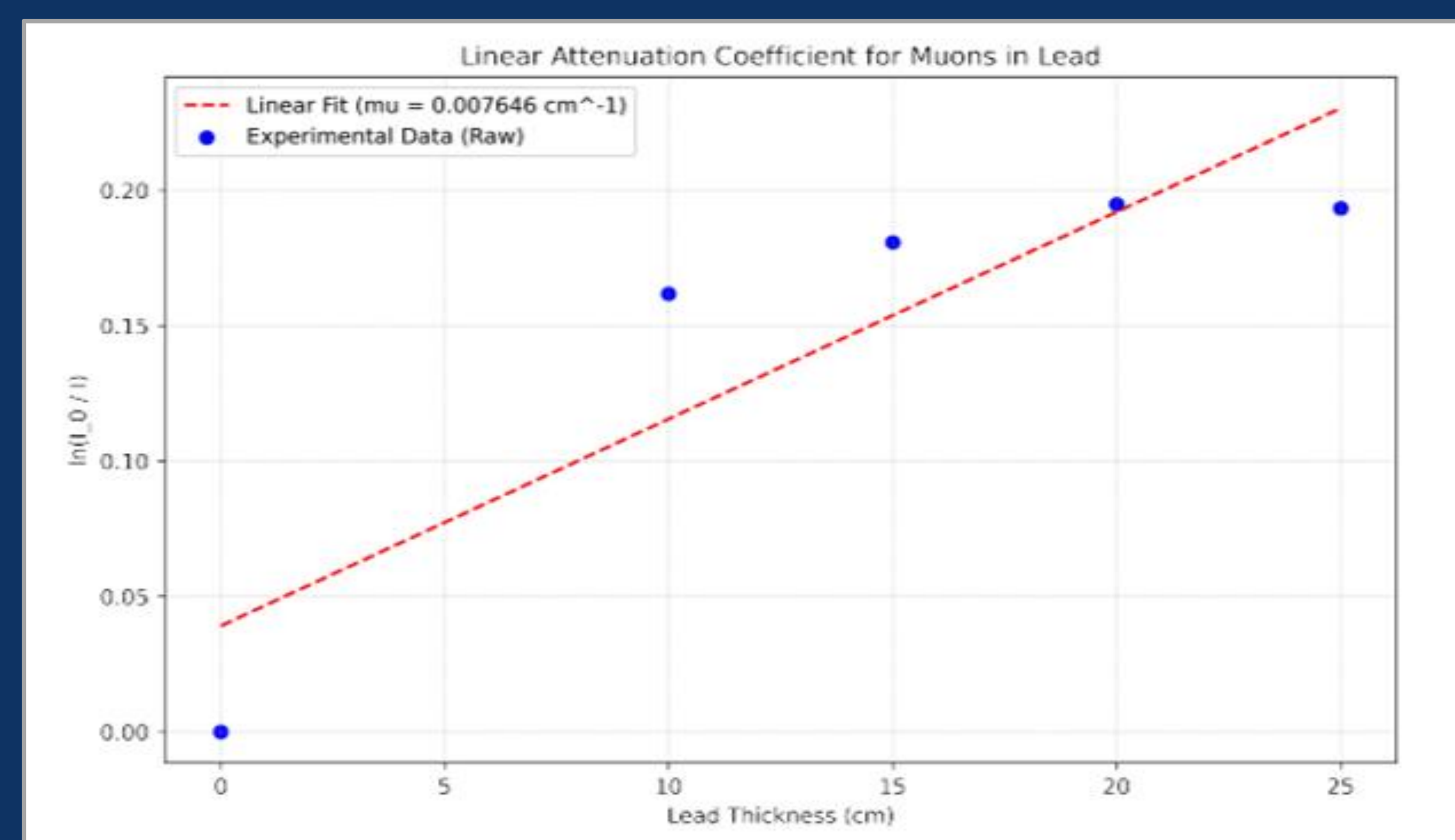

Figure 3. Standard OLS linear regression of the natural log ratio versus lead thickness.

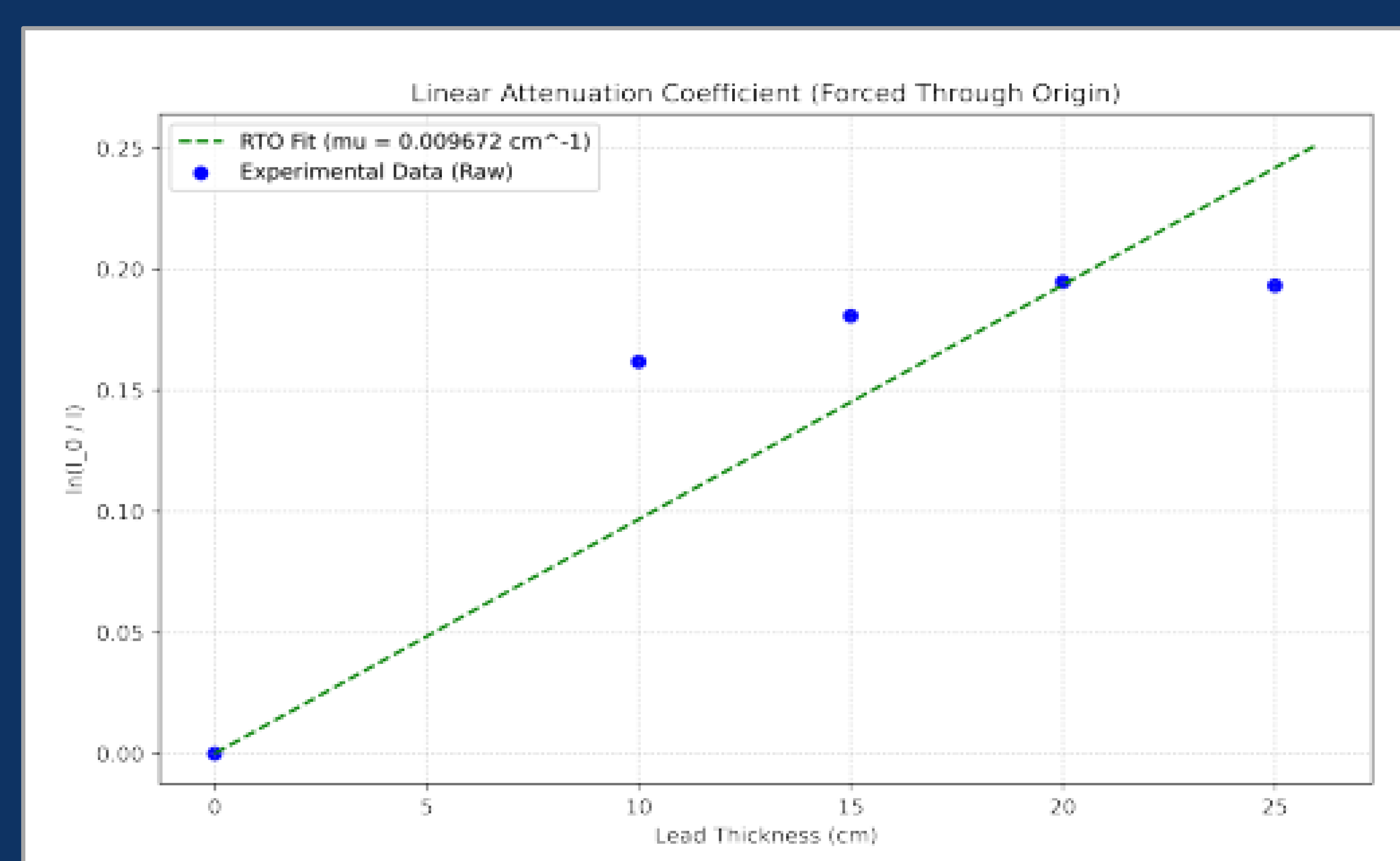

Figure 4. RTO fit illustrating the influence of the detection noise floor.

Results

Lead Thickness (cm)	Count Rate (counts/day)
0.0	115,185.57
10.0	97,982.42
15.0	96,138.86
20.0	94,795.47
25.0	94,940.43

Table 1. Experimental muon count rates normalized to counts per day

Table 1 displays how the muon rate decreases as lead thickness increased. This matches what was expected, since thicker lead should block or absorb more muons. To find the attenuation coefficient, the data were analyzed using the linear equation $\ln(I_0/I) = \mu x$. An Ordinary Least Squares regression gave an experimental value of μ = 0.007646 cm^{-1}, with R^2 = 0.7896. This was very close to the theoretical value of 0.00752 cm^{-1}[3], with only 1.67% error. A second fit, called Regression Through the Origin, forced the line to pass through zero. This gave μ = 0.009672 cm^{-1} with a lower R^2 = 0.7132, meaning it did not fit the data as well. At higher lead thicknesses, especially 20–25 cm, the count rate started to level off. This was likely due to background noise and secondary particles reaching the detectors, rather than a true stop in muon attenuation.

Conclusion

The linear attenuation coefficient for cosmic-ray muons in lead was determined to be μ = 0.007646 cm^{-1}, with only 1.67% error from the theoretical value. The decreasing count rate with added lead confirmed that muon flux depends on material thickness and density. These results support the basis of muographic imaging, where changes in detected muon counts can be used to non-invasively study the internal structure of dense objects.

References

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