# Muon Absorption

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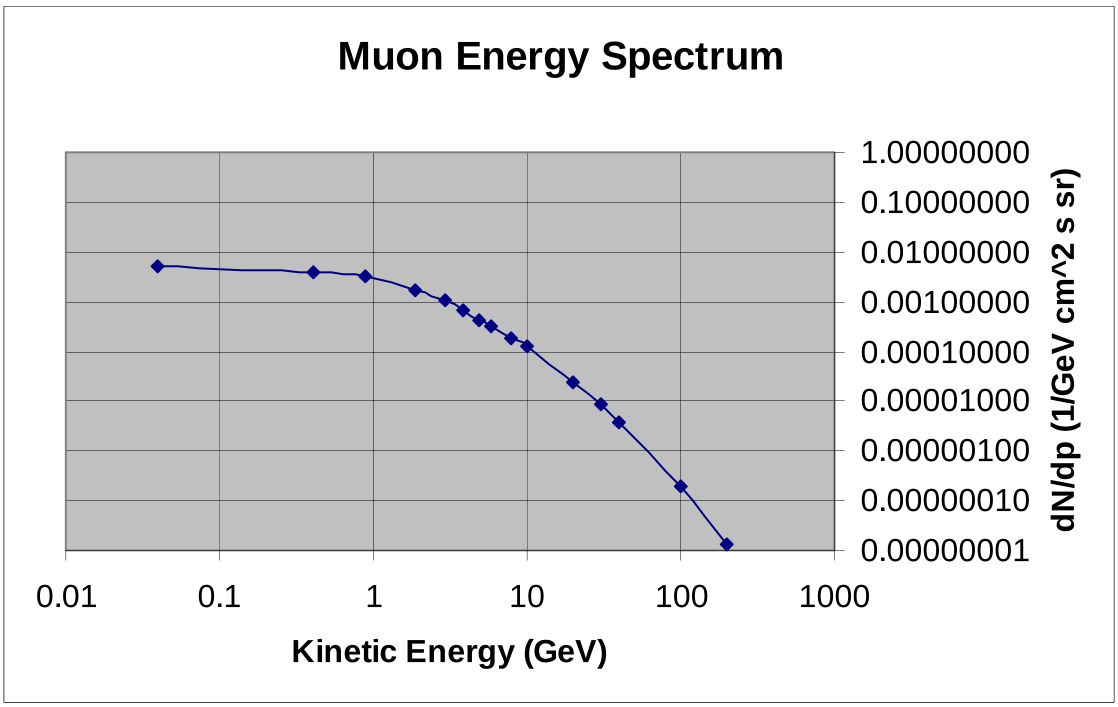
Excerpts from Physical Review D Chapters 24 and 27

### *Muon Energy Spectrum:*

The mean energy of muons at the ground is ~ 4 GeV. The energy spectrum is almost flat below 1 GeV, steepens gradually to reflect the primary spectrum in the 10-100 GeV range. The integral intensity of vertical muons above 1 GeV/c at sea level is ~ 70 $m^{-2}$ $s^{-1}$ $sr^{-1}$ . Experimentalists are familiar with this number in the form I ~ 1 $cm^{-2}$ $min^{-1}$ for horizontal detectors. [1]




Derived from fig. 24.4 [1]

### *Angular Distribution:*

The overall angular distribution of muons at the ground is $\propto \cos^2\theta$, which is characteristic of muons with $E_\mu$ » 3 GeV. At lower energy the angular distribution becomes increasingly steep, while at higher energy it steepens, approaching a sec θ distribution for high energies and θ < 70°. [1}

$\cos^2(45) = ½$
$\cos^2(60) = ¼$

## *Muon Stopping Power:*

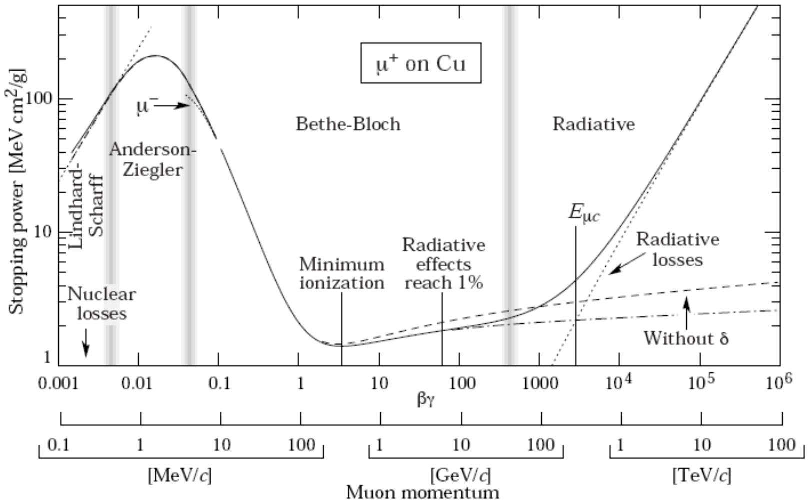



**Fig. 27.1:** Stopping power ($= \langle -dE/dx \rangle$) for positive muons in copper as a function of $\beta\gamma = p/Mc$ over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at $\beta\gamma \approx 0.1$ are taken from ICRU 49 [2], and data at higher energies are from Ref. 1. Vertical bands indicate boundaries between different approximations discussed in the text. The short dotted lines labeled "$\mu^-$" illustrate the "Barkas effect," the dependence of stopping power on projectile charge at very low energies [3].

November 30, 2006 15:59

## *Stopping Power at Minimum Ionization by Atomic Number:*

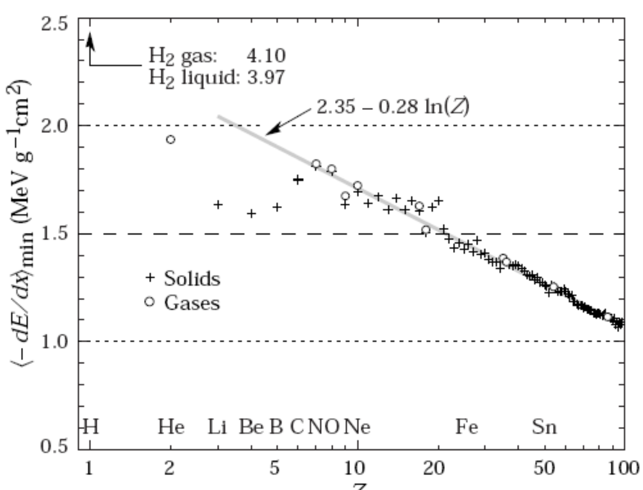



**Figure 27.2:** Stopping power at minimum ionization for the chemical elements. The straight line is fitted for $Z > 6$. A simple functional dependence on $Z$ is not to be expected, since $\langle -dE/dx \rangle$ also depends on other variables.

Eq. (27.1) may be integrated to find the total (or partial) "continuous slowing-down approximation" (CSDA) range $R$ for a particle which loses energy only through ionization

November 30, 2006 15:59

### ***Stopping Power by Element:***

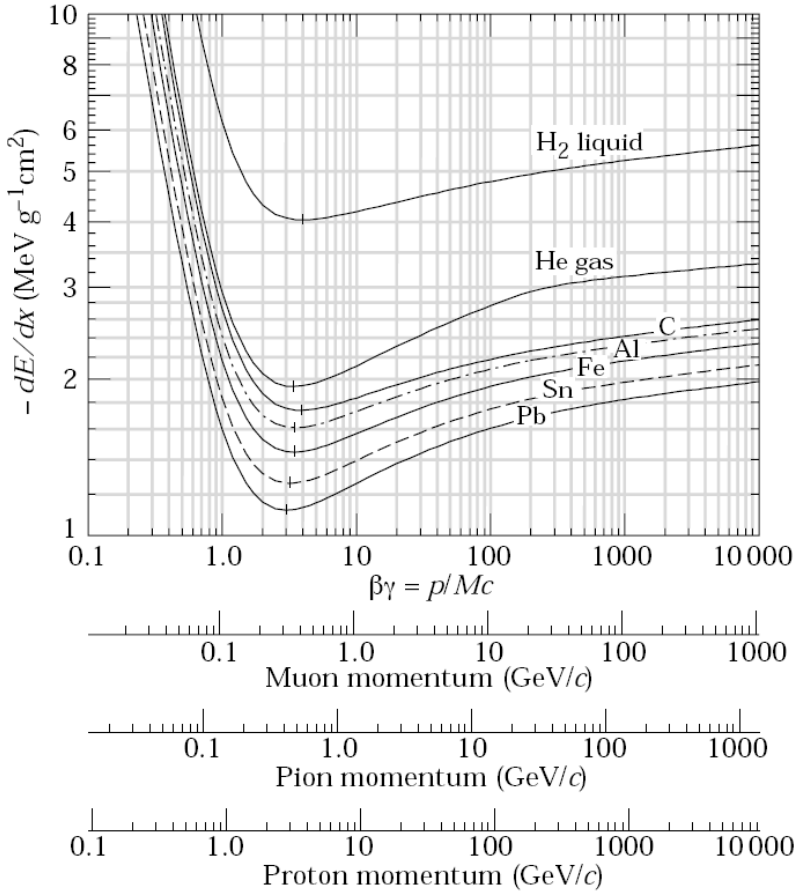



**Figure 27.3:** Mean energy loss rate in liquid (bubble chamber) hydrogen, gaseous helium, carbon, aluminum, iron, tin, and lead. Radiative effects, relevant for muons and pions, are not included. These become significant for muons in iron for $\beta\gamma \gtrsim 1000$, and at lower momenta for muons in higher-$Z$ absorbers. See Fig. 27.21.


1. T.K. Gaisser *et. al.*, Particle Data Review, chapter24: Cosmic Rays, http://pdg.lbl.gov/, cosmicraypp.pdf