Particle Interaction with Matter

Lecture 3

3.1 Charged Particles
3.2 Radiation
3.3 Ionisation
3.4 Photon Interactions
3.5 Hadron Interactions

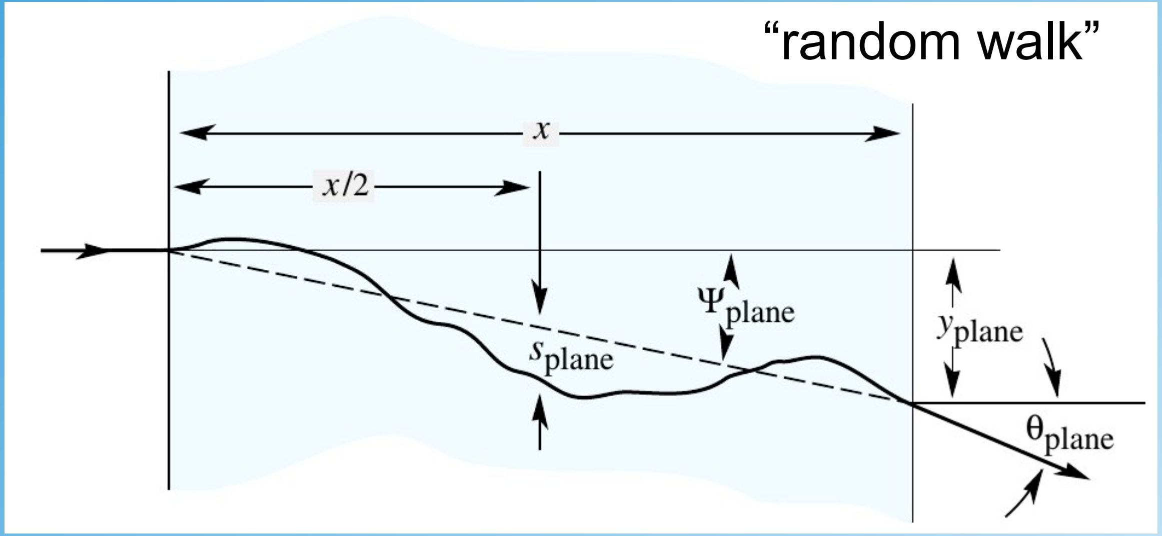
Multiple Coulomb Scattering

"Highland" formula describes the RMS of the core of the scattering distribution:

$$\theta_0 = \frac{13.6\ \mathrm{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big]$$

X_0=radiation length

$$dN = \frac{1}{\sqrt{2\pi}\,\theta_0} \exp\left(-\frac{\theta_{\mathrm{plane}}^2}{2\theta_0^2}\right) d\theta_{\mathrm{plane}}$$



$$\psi_{\mathrm{plane}}^{\mathrm{rms}} = \frac{1}{\sqrt{3}}\,\theta_0\ ,$$

$$y_{\mathrm{plane}}^{\mathrm{rms}} = \frac{1}{\sqrt{3}}\,x\,\theta_0\ ,$$

$$s_{\mathrm{plane}}^{\mathrm{rms}} = \frac{1}{4\sqrt{3}}\,x\,\theta_0\ .$$

Radiation Length X_0

Y.S.Tsai formula:

$$\frac{1}{X_0} = 4\alpha r_e^2 \frac{N_A}{A} \left\{ Z^2 \left[L_{\rm rad} - f(Z) \right] + Z\, L'_{\rm rad} \right\}$$

note: complicated form due to shielding effects

f(Z) is an infinite sum, can be approximated by:

$$f(Z) = a^2 \Big[(1+a^2)^{-1} + 0.20206 - 0.0369\, a^2 + 0.0083\, a^4 - 0.002\, a^6 \Big]$$

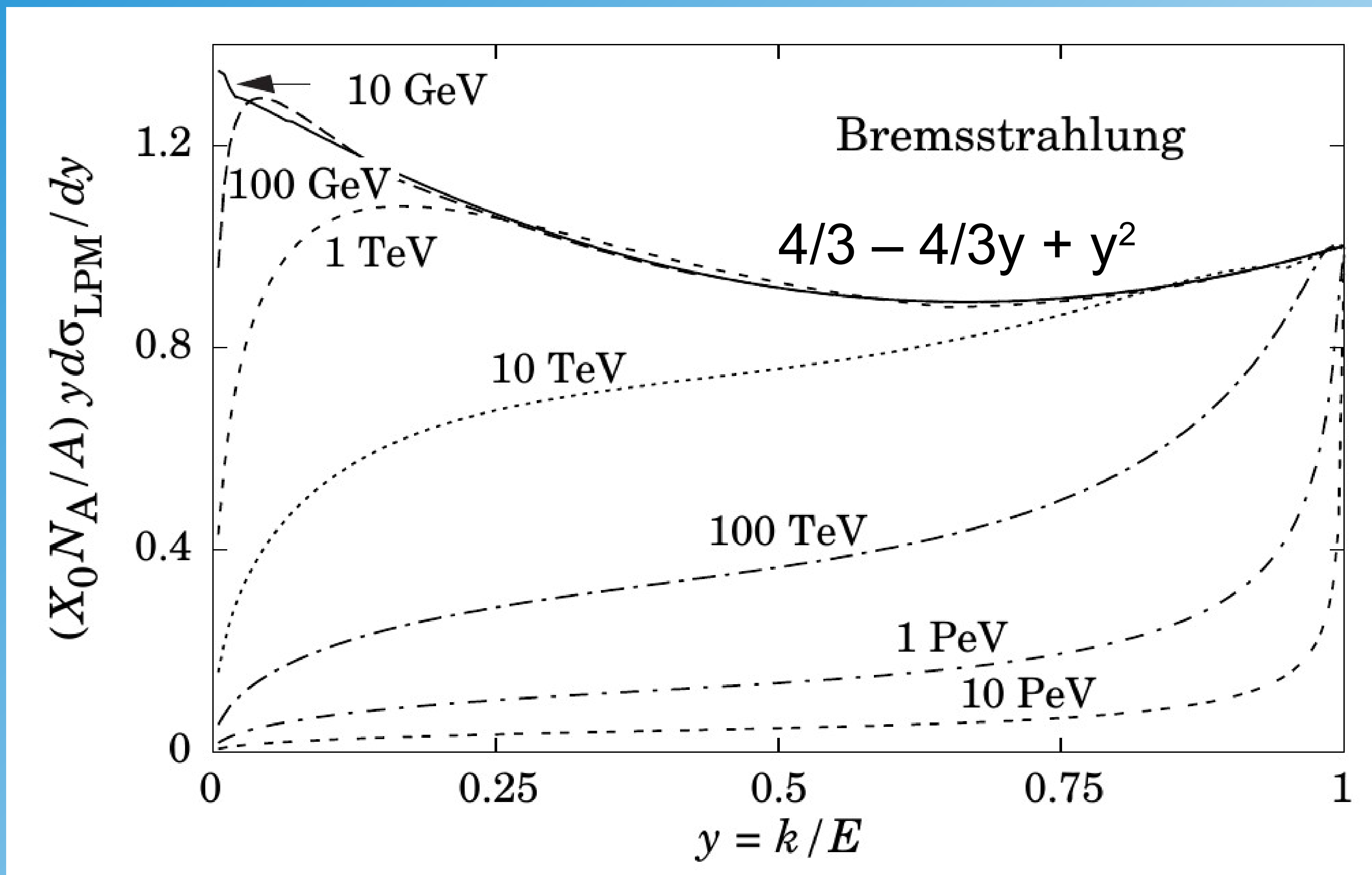
with $a = \alpha Z$

L_{rad} and L'_{rad} are tabulated:

Element	Z	$L_{\rm rad}$	$L'_{\rm rad}$
H	1	5.31	6.144
He	2	4.79	5.621
Li	3	4.74	5.805
Be	4	4.71	5.924
Others	> 4	$\ln(184.15\, Z^{-1/3})$	$\ln(1194\, Z^{-2/3})$

Bremsstrahlung

Normalised Bremsstrahlung cross section as function of ratio y



Transition Radiation

superpositions

200 mylar foils

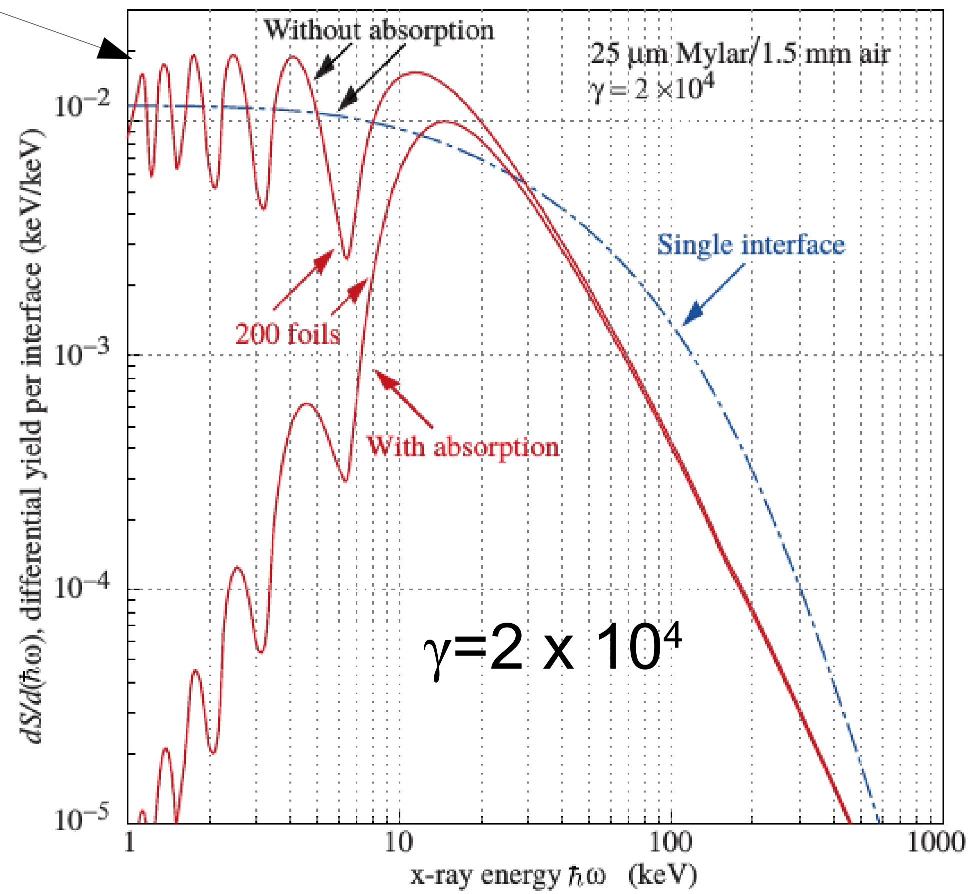
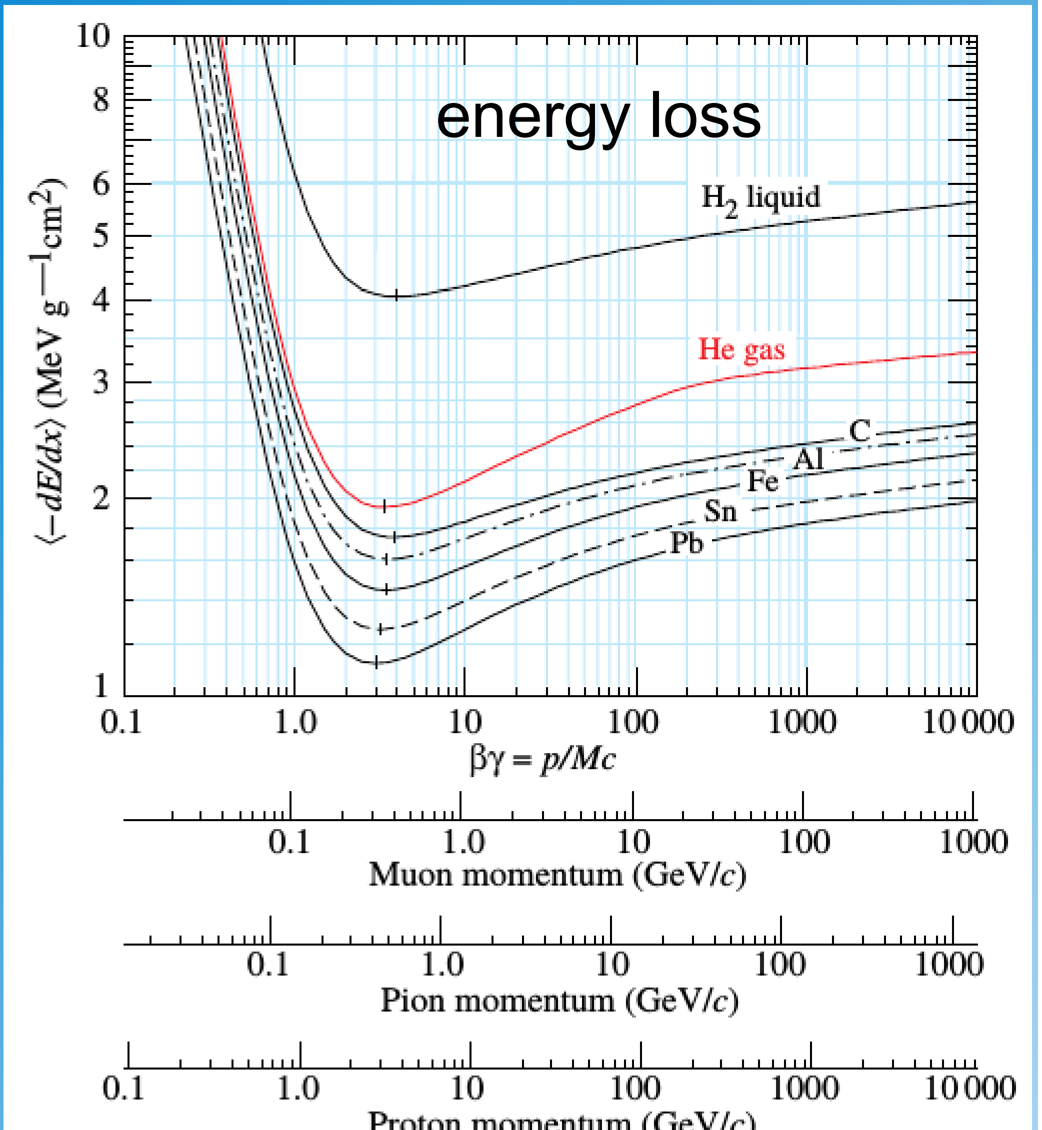
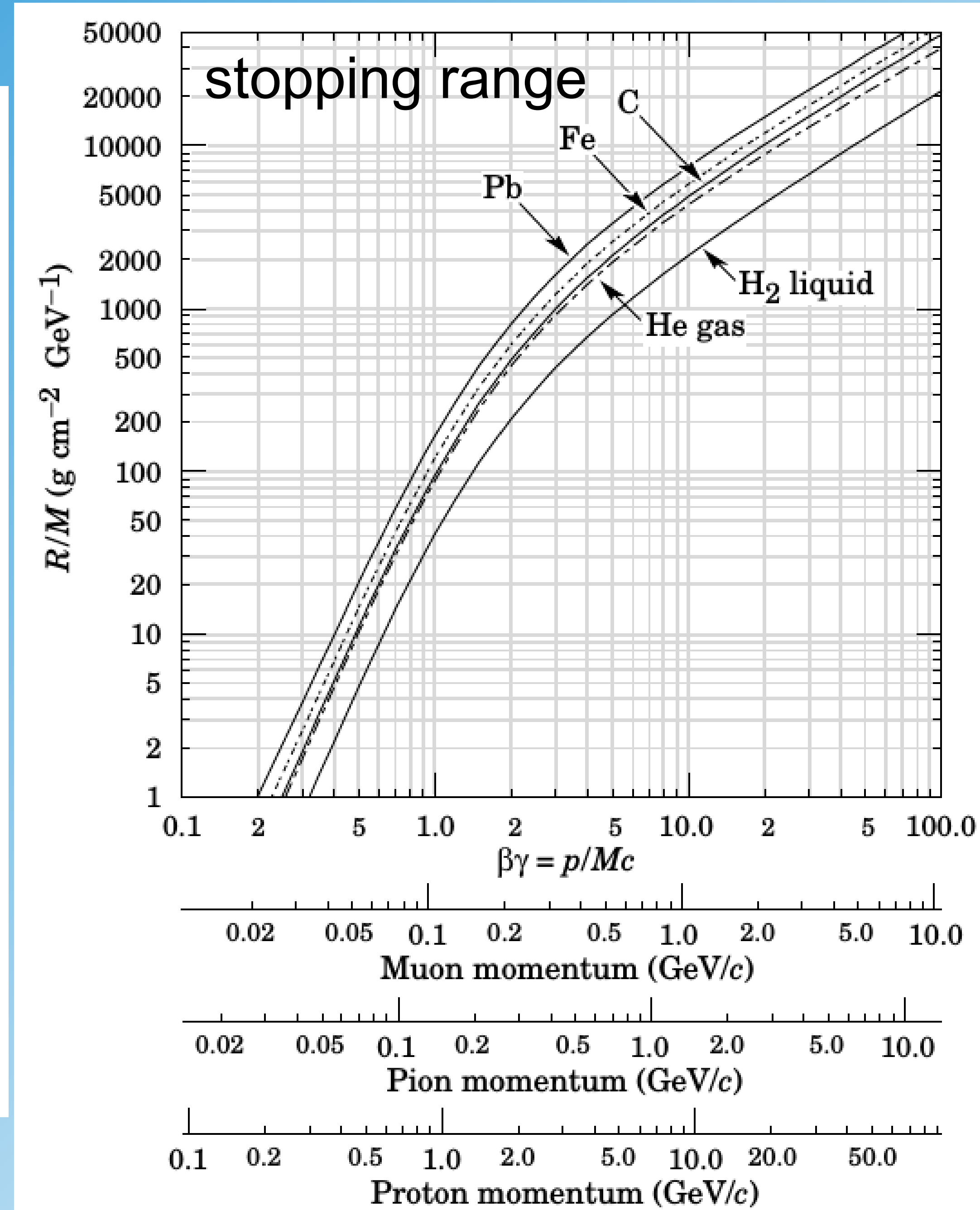


Figure 32.27: X-ray photon energy spectra for a radiator consisting of 200 25 μm thick foils of Mylar with 1.5 mm spacing in air (solid lines) and for a single surface (dashed line). Curves are shown with and without absorption. Adapted from Ref. 88.

Average Ionisation Loss in Matter





Excitation Energy I in Materials

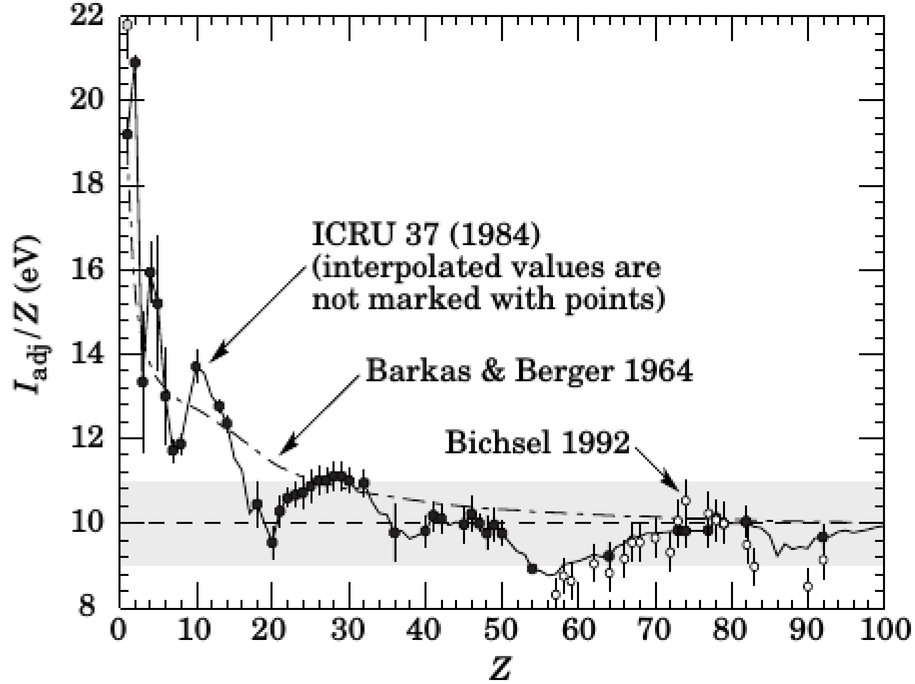
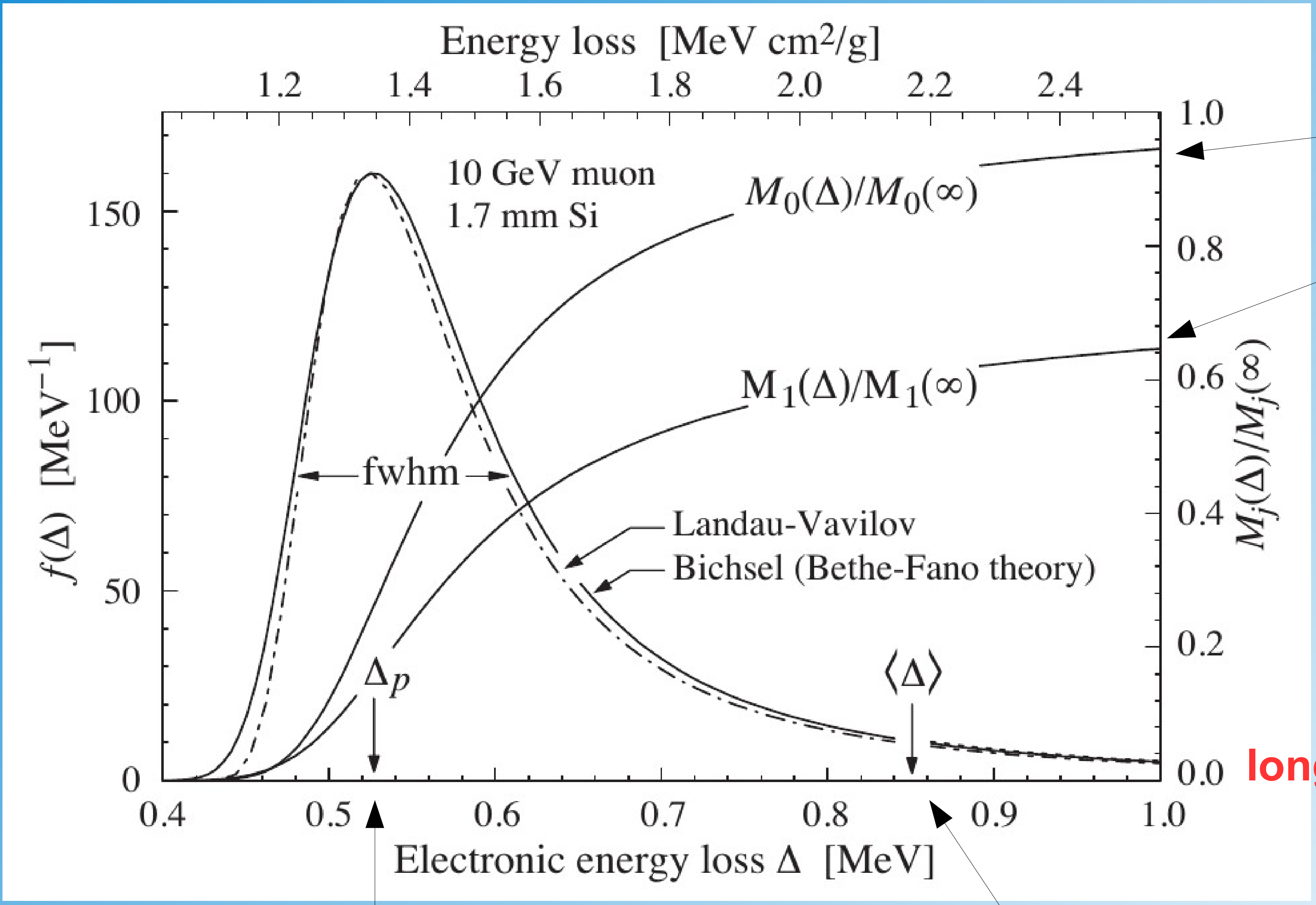


Figure 32.5: Mean excitation energies (divided by Z) as adopted by the ICRU [11]. Those based on experimental measurements are shown by symbols with error flags; the interpolated values are simply joined. The grey point is for liquid H_2; the black point at 19.2 eV is for H_2 gas. The open circles show more recent determinations by Bichsel [13]. The dash-dotted curve is from the approximate formula of Barkas [14] used in early editions of this *Review*.

Distribution of Energy loss



Most Probable Energy Loss

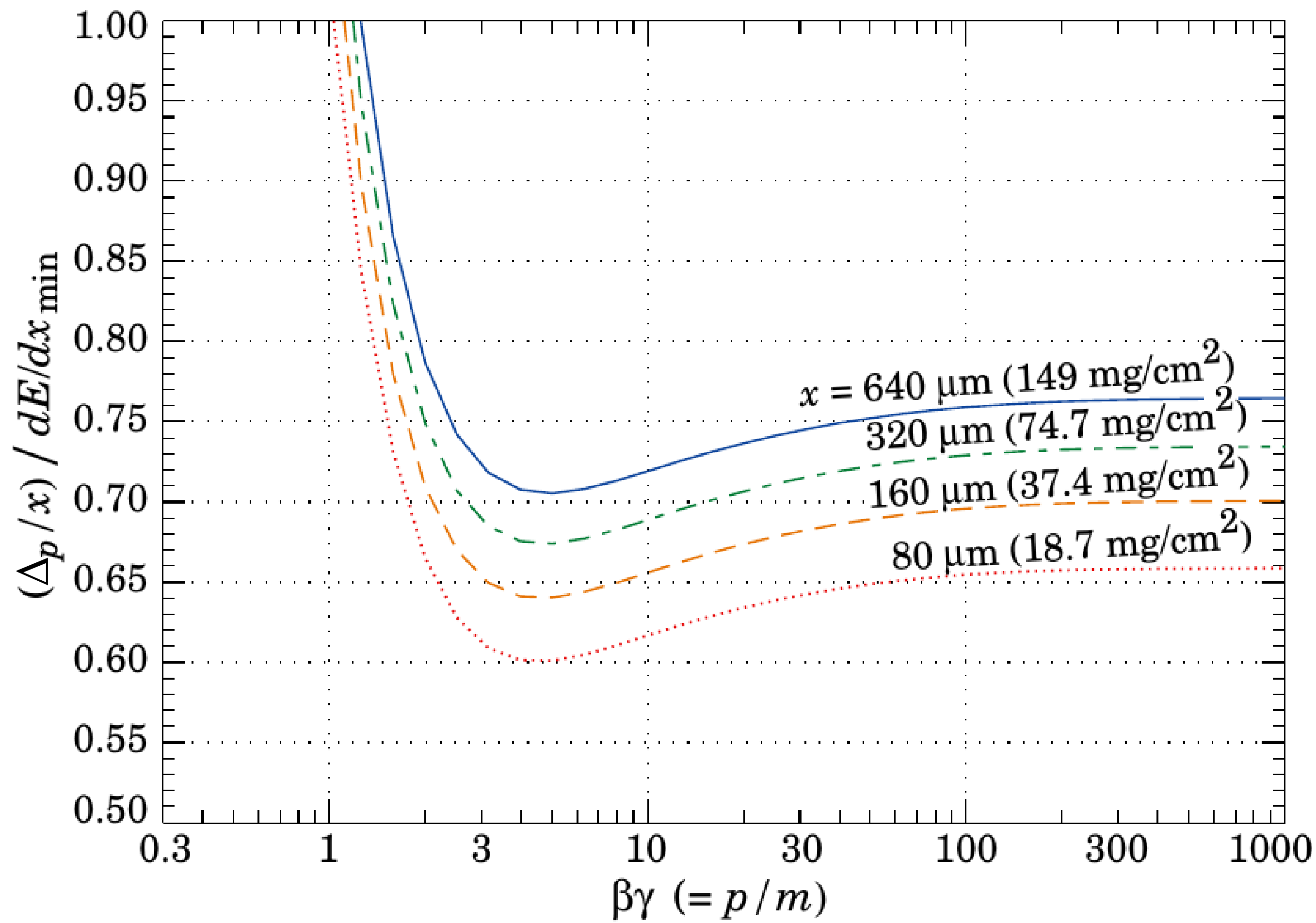
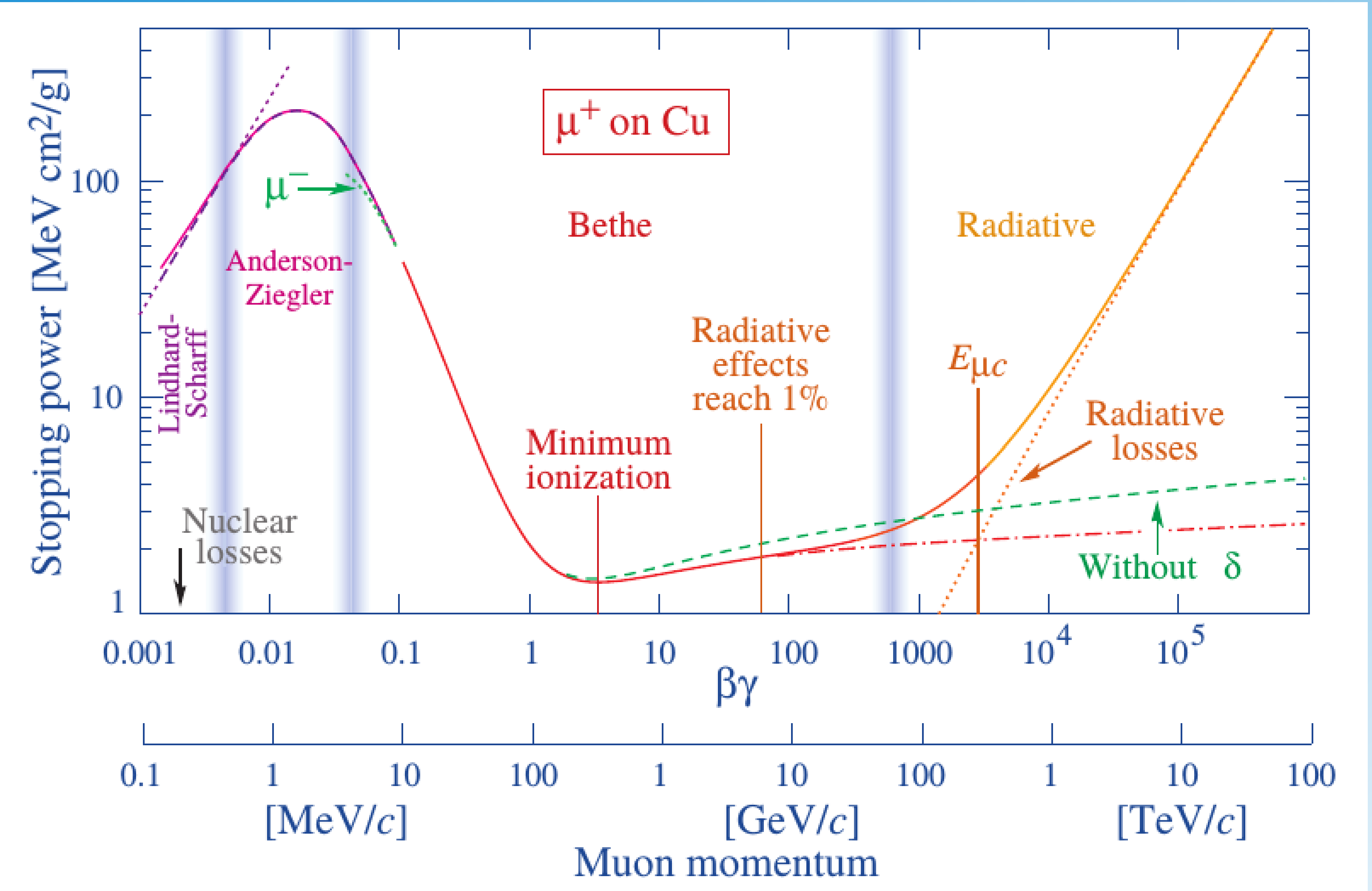


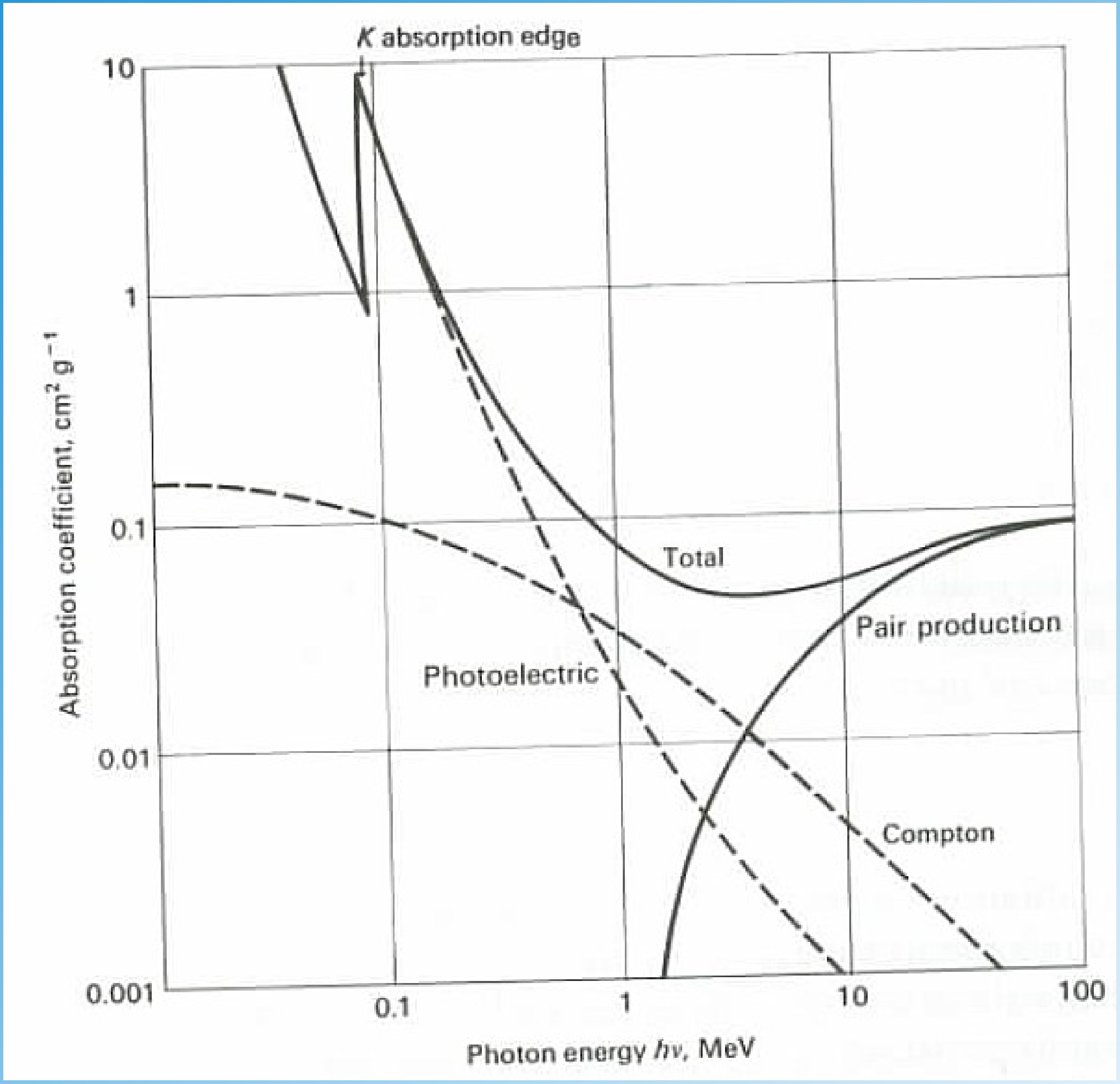
Figure 32.9: Most probable energy loss in silicon, scaled to the mean loss of a minimum ionizing particle, 388 eV/μm (1.66 MeV $\mathrm{g}^{-1}\mathrm{cm}^2$).

most probable energy loss per unit length varies!!!

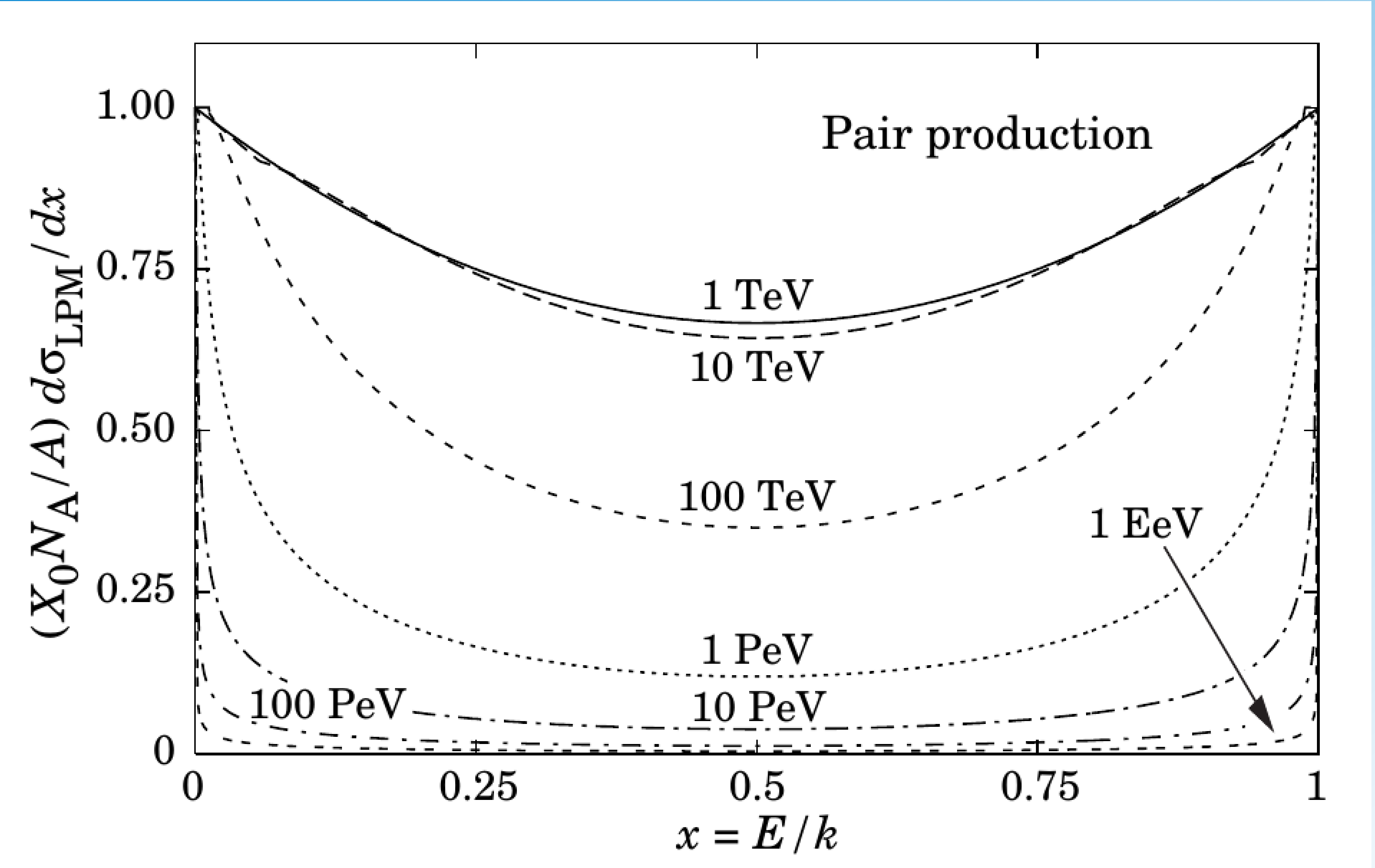
Summary Energy Loss of Muons



Photons Interactions in Matter



Photon Conversion



Photons Interactions in Matter

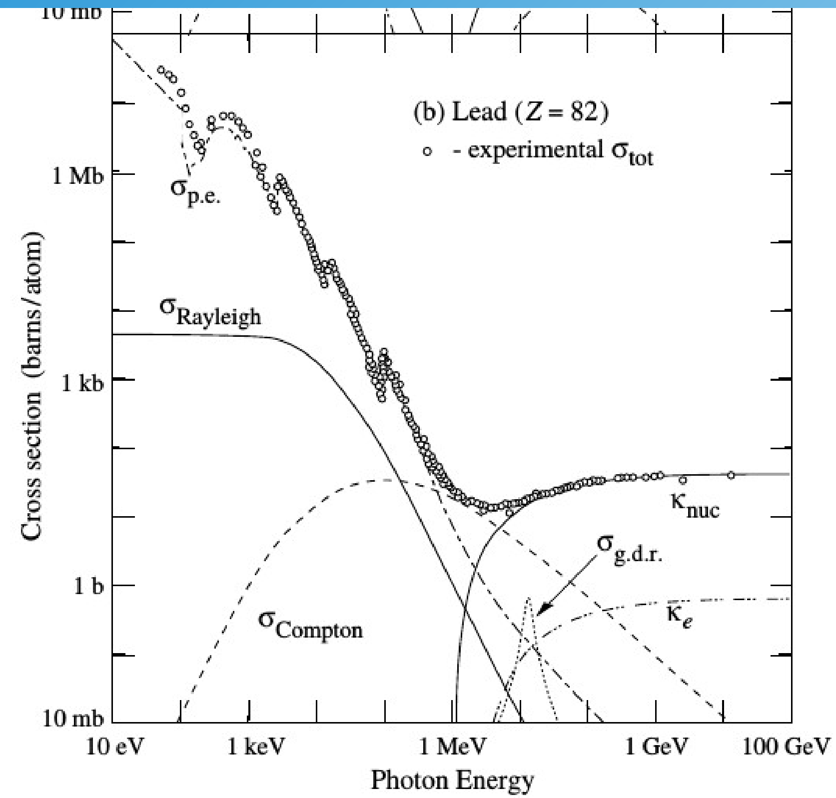


Figure 32.15: Photon total cross sections as a function of energy in carbon and lead, showing the contributions of different processes [51]:

$\sigma_{\text{p.e.}}$ = Atomic photoelectric effect (electron ejection, photon absorption)
σ_{Rayleigh} = Rayleigh (coherent) scattering–atom neither ionized nor excited
σ_{Compton} = Incoherent scattering (Compton scattering off an electron)
κ_{nuc} = Pair production, nuclear field
κ_e = Pair production, electron field
$\sigma_{\text{g.d.r.}}$ = Photonuclear interactions, most notably the Giant Dipole Resonance [52]. In these interactions, the target nucleus is broken up.

Original figures through the courtesy of John H. Hubbell (NIST).