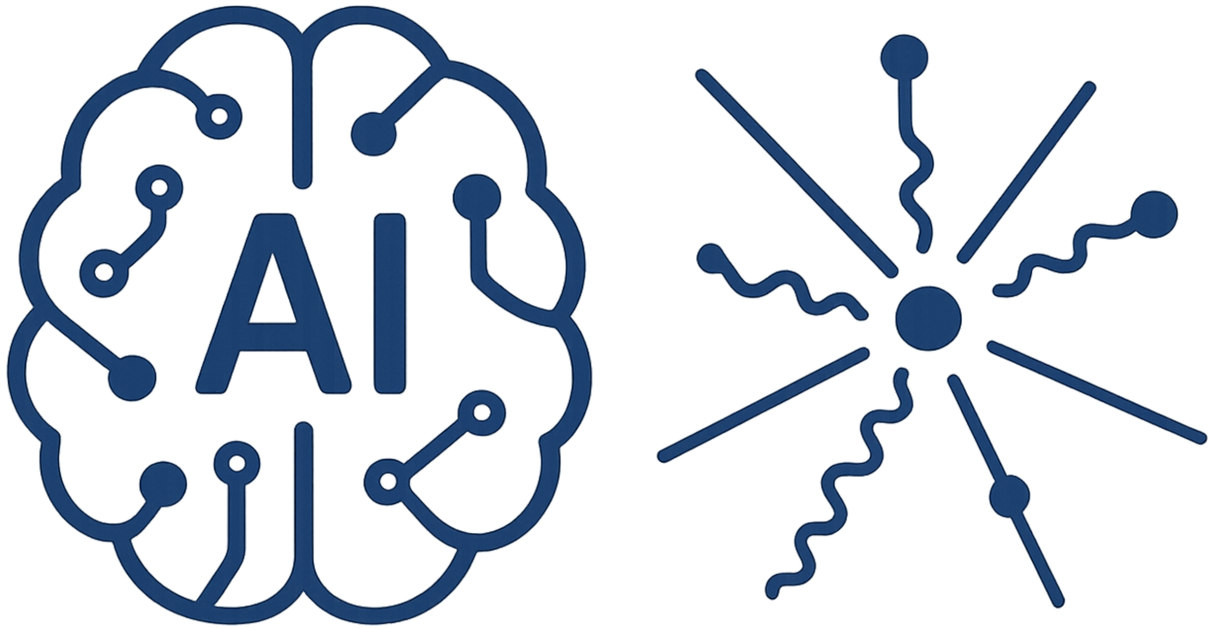
Introduction to

AI-Driven HEP

S. A. Fard - School of Physics (IPM)



Session 4

Instrument II

Grupen, Claus, and Boris Shwartz. Particle detectors. Cambridge university press, 2008.

Ade, Peter AR, Matthew J. Griffin, and Carole E. Tucker. Physical principles of astronomical instrumentation. CRC Press, 2021.

Karttunen, Hannu, et al., eds. Fundamental astronomy. Berlin, Heidelberg: Springer Berlin Heidelberg, 2007.

Instrument starts with Interaction & medium

Every interaction process can be used
as a basis for a detector concept

The main interactions

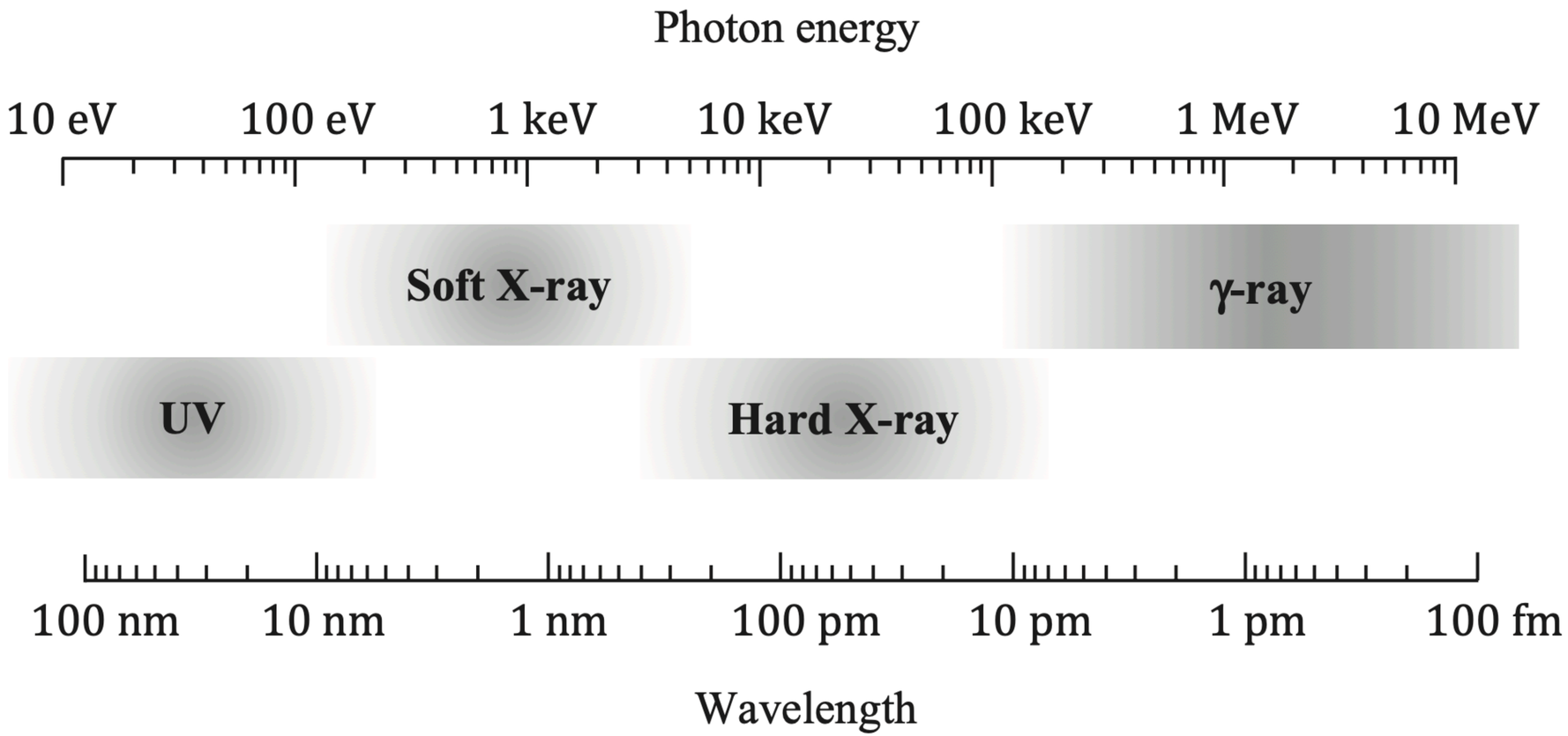
Ionisation , Excitation, Bremsstrahlung

Electron

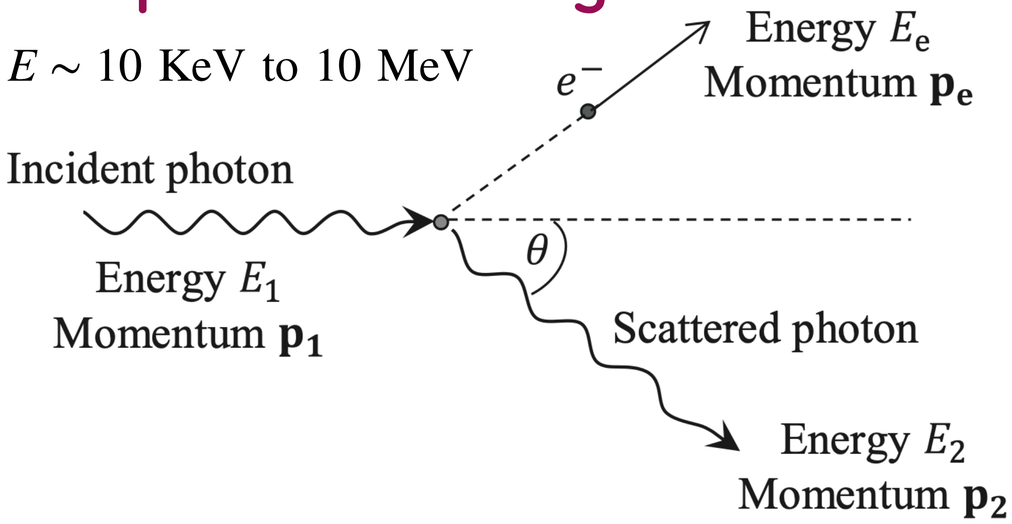
Neutral particles must produce
charged particles in an interaction

Photon - Neutrino

Instrument starts with Interaction & medium



Compton scattering



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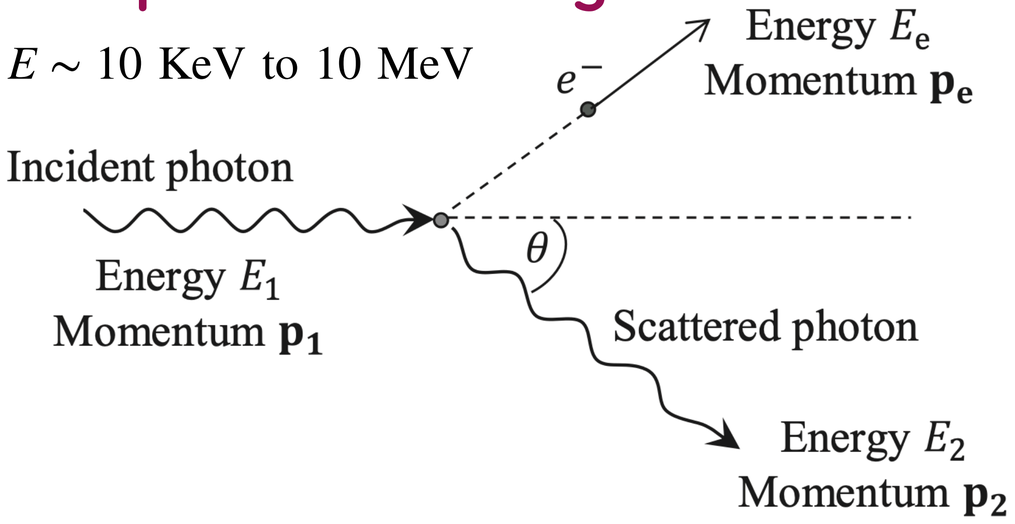
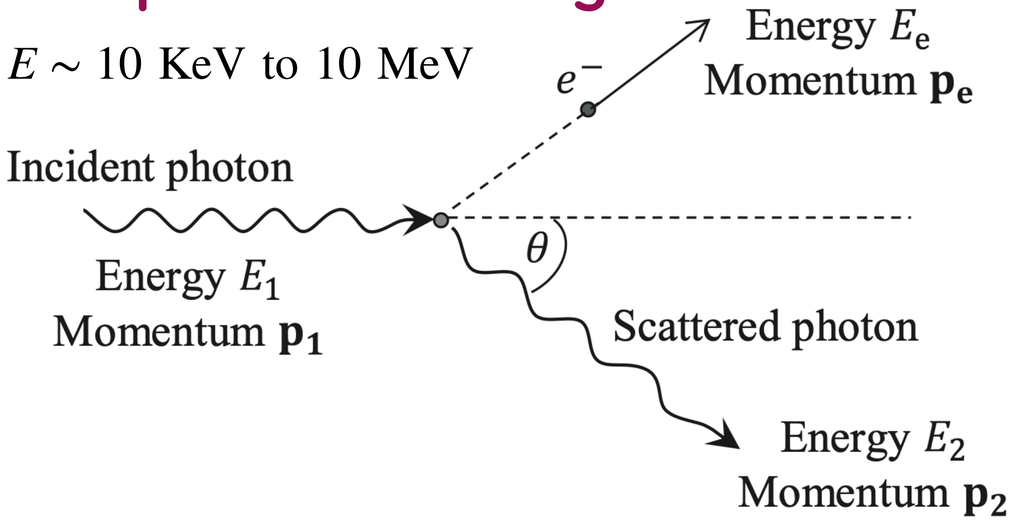


Increase in wavelength (decrease in energy) of (an X-ray or γ-ray) photon after it collides with a free or loosely bound electron

$$\Delta\lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

Compton scattering



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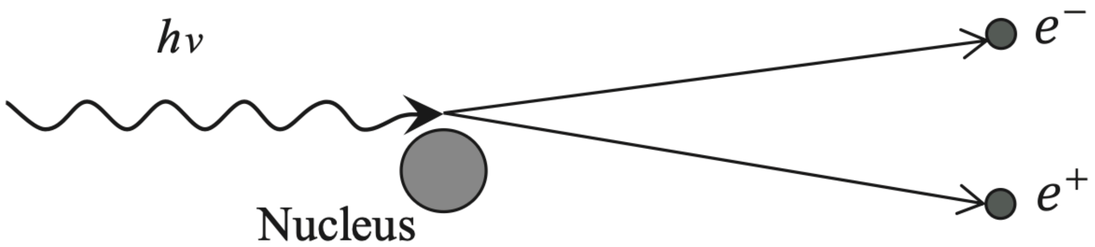
Inverse Compton scattering

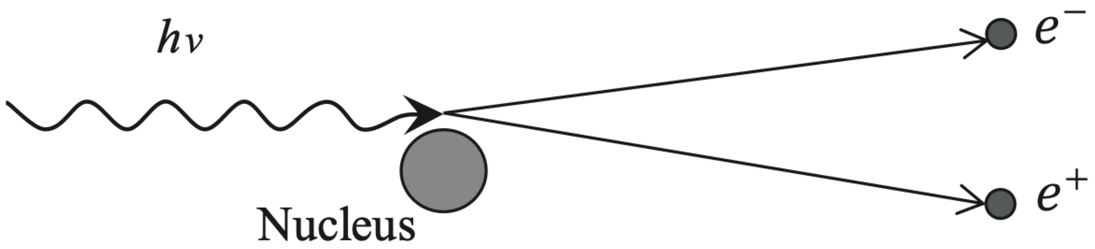
The process where a low-energy photon (e.g., microwave, optical) gains energy by scattering off a high-energy (relativistic) electron

Pair production



$E \sim 100$ MeV

Pair production



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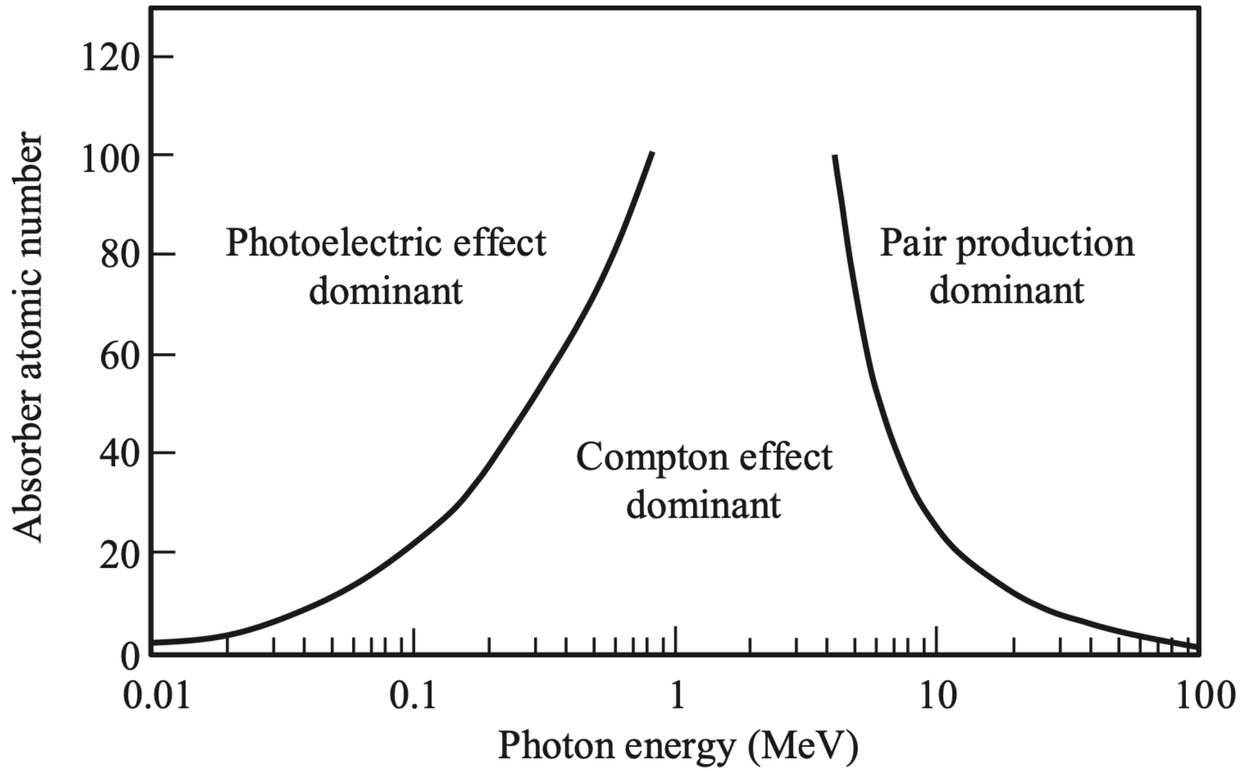

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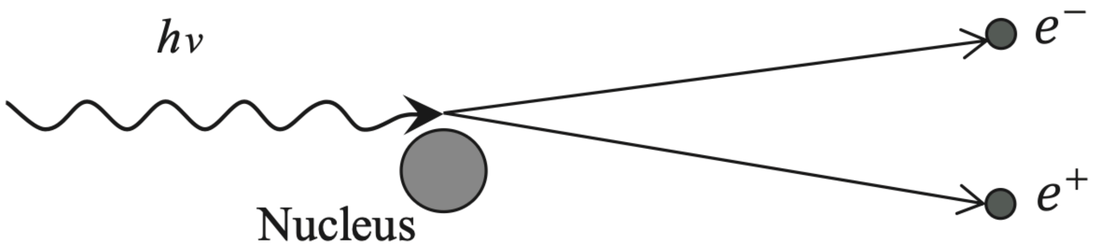

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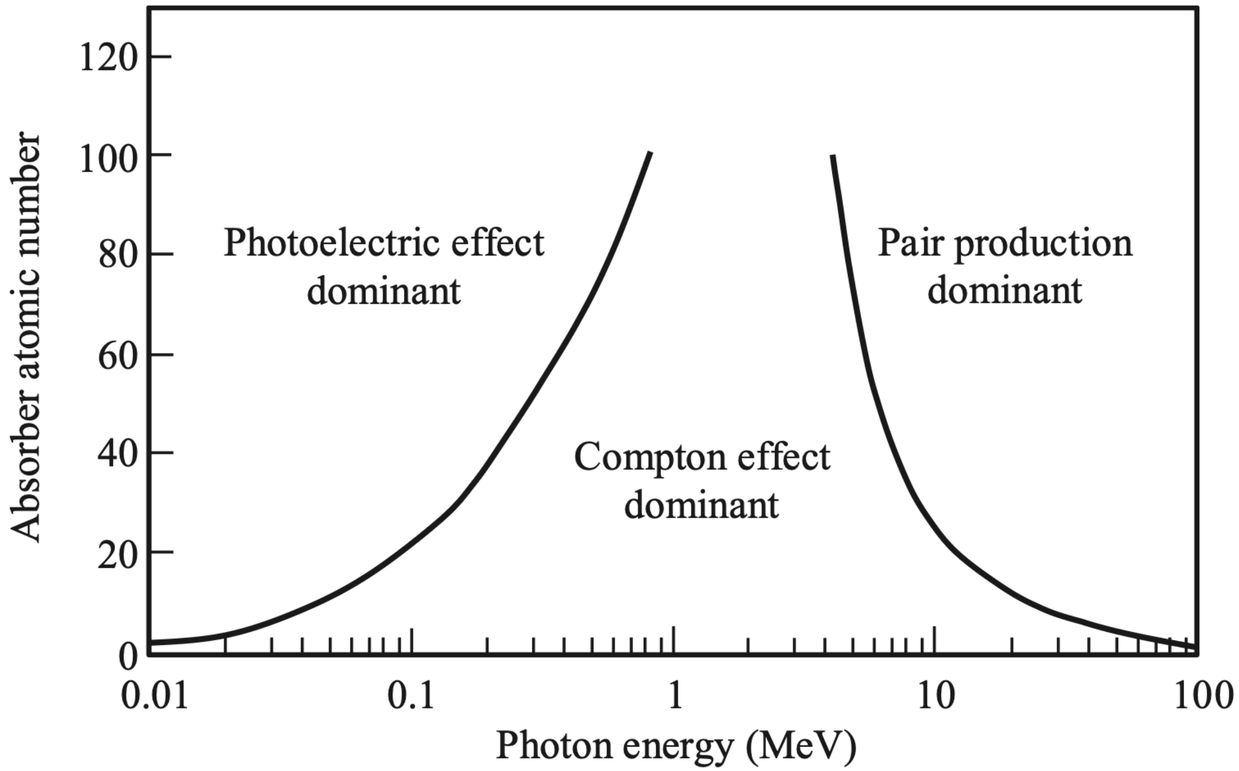
The electrons produced in these photon interactions can be observed through their ionisation in the sensitive volume of the detector.



Energy Loss

$$-\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\text{total}} = -\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\text{ionisation}} -\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\text{brems.}} -\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\text{pair pr.}} -\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\text{photonucl.}}$$

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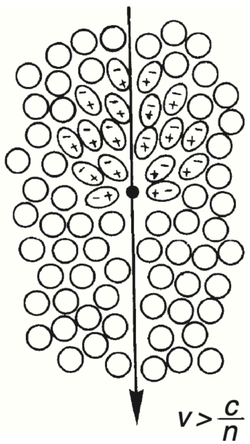
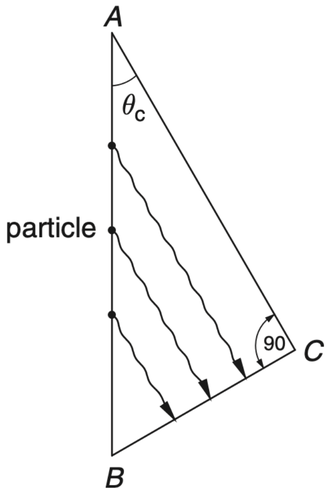
Cherenkov radiation





synchrotron radiation

Any charged particle accelerated in a straight line or on a curved path will emit electromagnetic radiation

Energy Loss

Charged particles passing through matter lose kinetic energy
by excitation of bound electrons and by ionisation

$$e^- + \text{atom} \rightarrow \text{atom}^* + e^-$$
$$\hookrightarrow \text{atom} + \gamma$$

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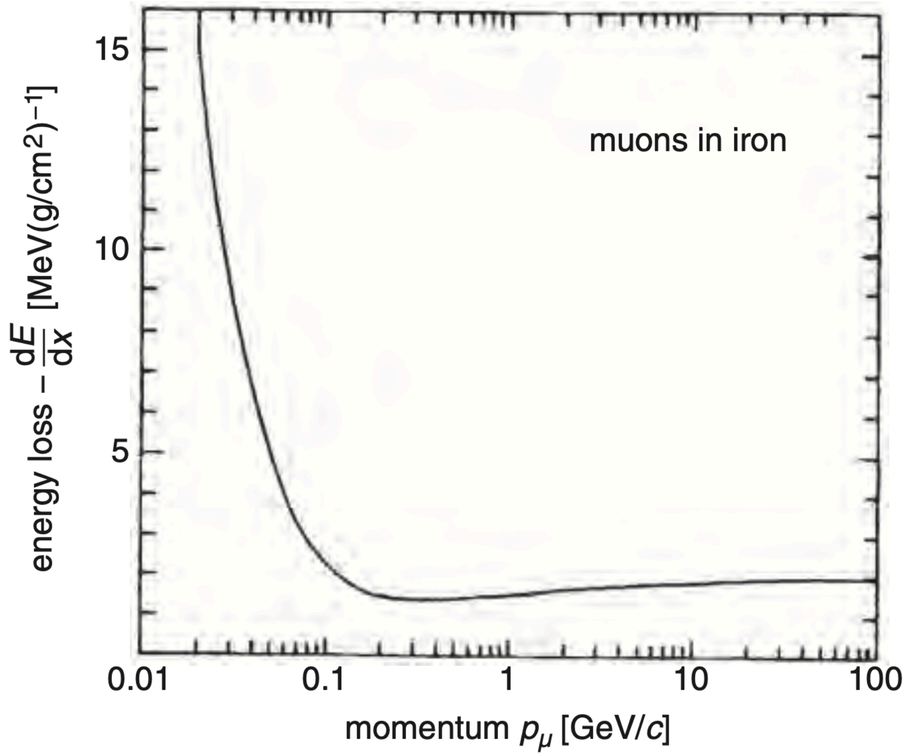

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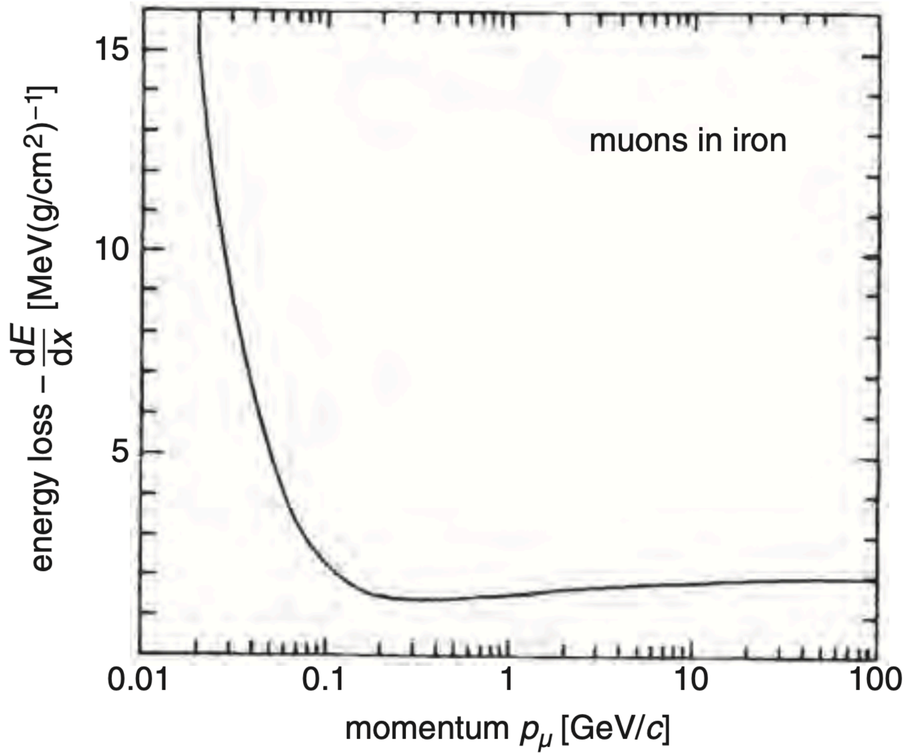

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$$-\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\text{min}} \approx 2\,\frac{\text{MeV}}{\text{g/cm}^2}$$

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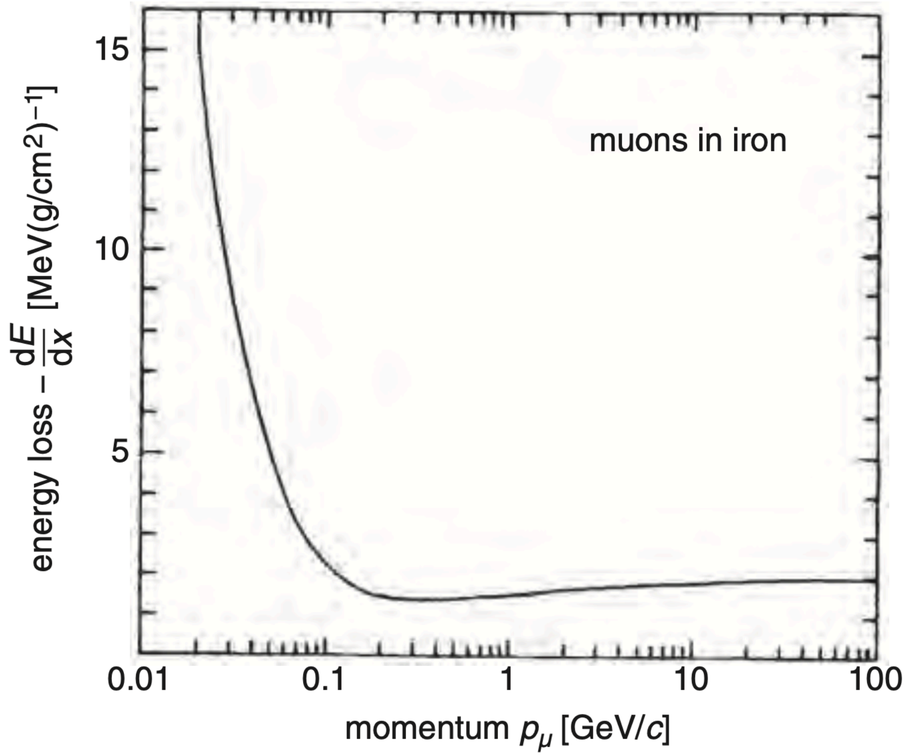

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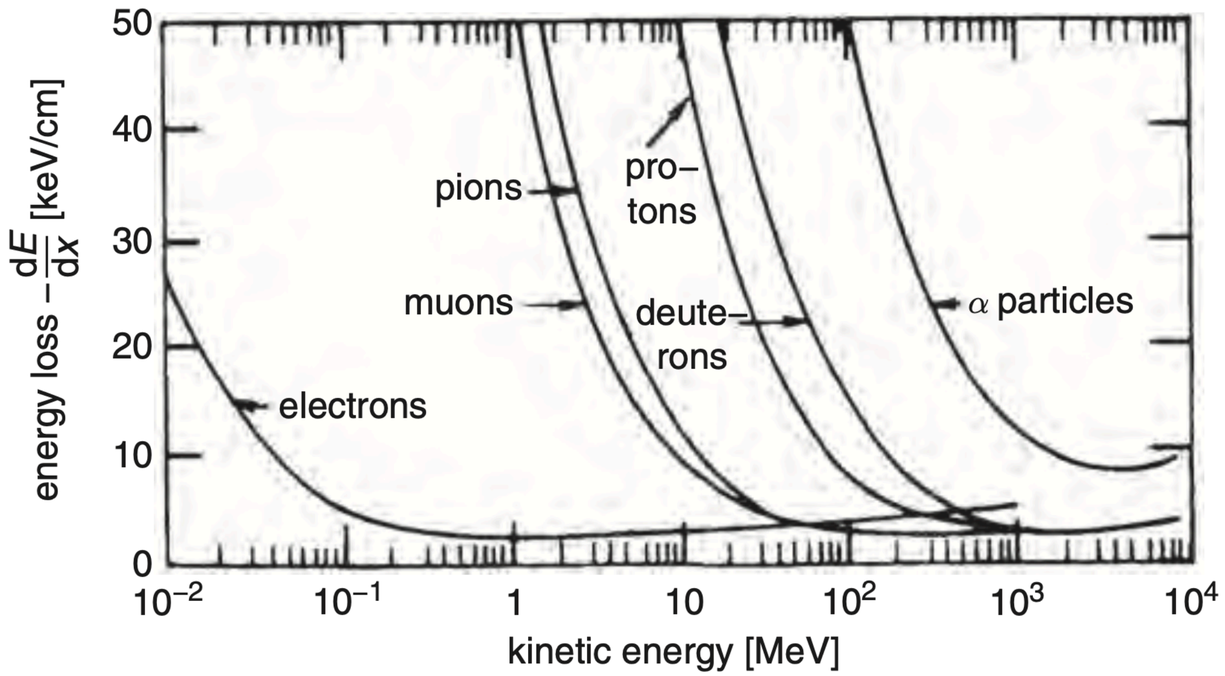
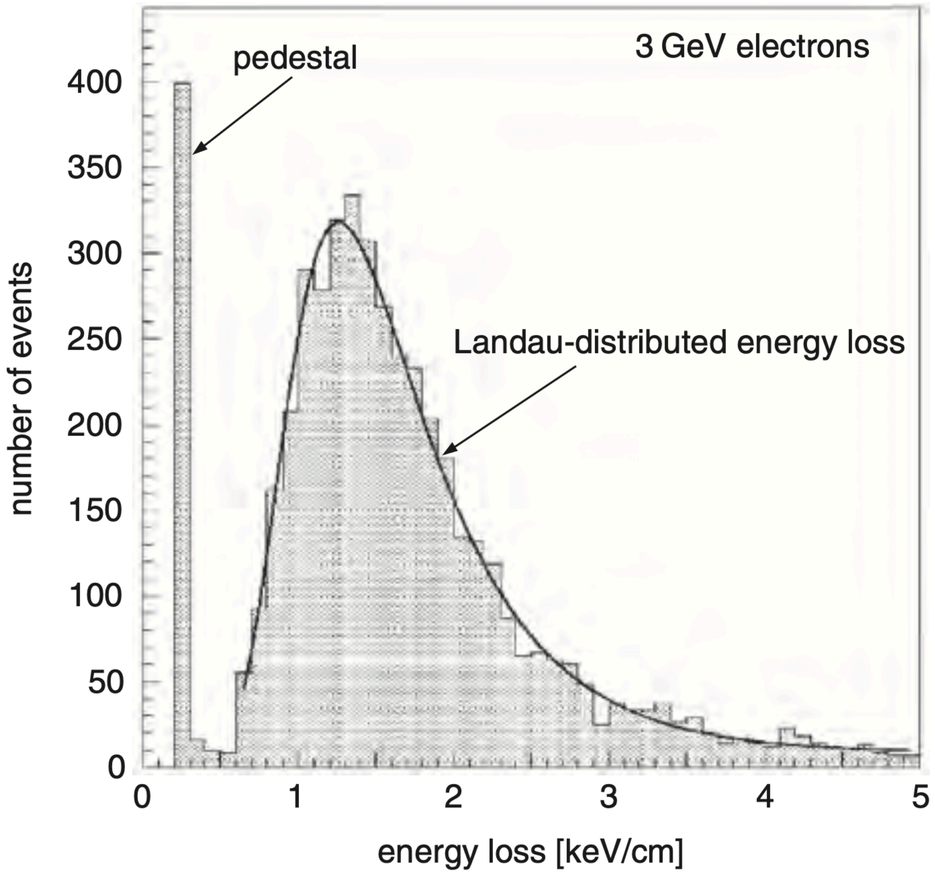
a muon (m_μ= 106 MeV) with a Lorentz factor of $\gamma = E/m_0$ = 10 corresponding to E = 1.06 GeV can transfer approximately 100 MeV to an electron

Energy Loss


energy loss $-\frac{dE}{dx}$ [keV/cm]
50
40
30
20
10
0
10^{-2}
10^{-1}
1
10
10^2
10^3
10^4
kinetic energy [MeV]
pions
muons
electrons
pro–
tons
deute–
rons
α particles

Energy Loss



Landau distribution

$$L(\lambda) = \frac{1}{\sqrt{2\pi}} \cdot \exp\left[-\frac{1}{2}(\lambda + \mathrm{e}^{-\lambda})\right]$$

Landau characterises the deviation from the most probable energy loss