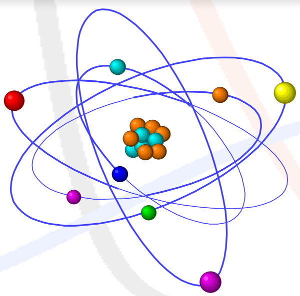
# Experimental Methods :
# Nuclear And Particle Physics



**Experiment – 3**
**Energy Loss**

IISER

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# Energy loss

- Particle loses its energy due to
  - ionization,
  - bremsstrahlung,
  - direct pair production
  - photo-nuclear interaction.

$$\boxed{-\frac{dE_\mu}{dx} = [a(E_\mu) + b(E_\mu)E_\mu]}$$

$a(E_\mu)$ is the ionization energy loss.

$$b(E_\mu) = b_{brem} + b_{pair} + b_{photo}$$

Radiative Processes

# Energy loss

**Ionization Energy Loss:** As we have already discussed that this energy losses are estimated by well-known Bethe-Bloch formula:

$$-\frac{dE}{dx} = \alpha^2 2\pi N \lambda_e^2 \frac{Z m_e}{A} \frac{1}{\beta^2} \left[ \ln \frac{2 m_e \beta^2 \gamma^2 E'_m}{I^2(Z)} - 2\beta^2 + \frac{1}{4} \frac{E'^2_m}{E^2} - \delta \right] \quad (1)$$

**Bremsstrahlung**: The high-energy muons predominantly lose energy in matter by bremsstrahlung. The energy loss by bremsstrahlung is given by

$$\frac{dE}{dx} = -E \frac{N}{A} \int_{v_{min}}^{v_{max}} \frac{d\sigma}{dv} dv \qquad \frac{d\sigma}{dv} = \alpha \left( 2 Z_e \frac{m_e}{m_\mu} \right)^2 \frac{1}{v} \left( \frac{4}{3} - \frac{4}{3} v + v^2 \right) \phi(\delta)$$

**Direct electron pair production:** The energy loss due to the direct pair production can be calculated by

$$\frac{dE}{dx} = -2E \frac{N}{A} \int_{v_{min}}^{v_{max}} v \int_0^{\rho_{max}} \frac{d^2\sigma}{dv d\rho} d\rho dv \qquad \frac{d^2\sigma}{dv d\rho} = \alpha^4 \frac{2}{3\pi} (2 Z_e)^2 \frac{1-v}{v} \left( \phi_e + \frac{m_e}{m_\mu} \phi_\mu \right)$$

Photo-nuclear Cross section

$$\frac{d\sigma}{dv} = \frac{\alpha}{2\pi} A \sigma_{\gamma N} v \left\{ \frac{3}{4} G(x) \left[ \kappa \ln \left( 1 + \frac{m_1^2}{t} \right) - \frac{\kappa m_1^2}{m_1^2 + t} - \frac{2 m_\mu^2}{t} \right] + \right.$$
$$+ \frac{1}{4} \left[ \kappa \ln \left( 1 + \frac{m_2^2}{t} \right) - \frac{2 m_\mu^2}{t} \right] +$$
$$\left. + \frac{m_\mu^2}{2t} \left[ \frac{3}{4} G(x) \frac{m_1^2}{m_1^2 + t} + \frac{1}{4} \frac{m_2^2}{t} \ln \left( 1 + \frac{t}{m_2^2} \right) \right] \right\},$$

# Task-3 (a)

Following tables shows the type of incident particle

| Particle | Symbol | Rest Mass $(MeV/c^2)$ | Mean Lifetime |
|---|---|---|---|
| Electron | $e^-, e^+$ | $m_0^{e^\pm} = 0.511$ | stable ( $> 6.6 \times 10^{28}$ yr) |
| Muon | $\mu^-, \mu^+$ | $m_0^{\mu^\pm} = 105.658$ | $2.197 \times 10^{-6}$s |
| Tauon | $\tau^-, \tau^+$ | $m_0^{\tau^\pm} = 1776.86$ | $2.903 \times 10^{-13}$ s |
| Pion | $\pi^-, \pi^+$ | $m_0^{\pi^\pm} = 139.57$ | $2.6 \times 10^{-8}$ s |
| Kaon | $K^-, K^+$ | $m_0^{K^\pm} = 493.677$ | $1.238 \times 10^{-8}$s |
| Proton | $p, \bar{p}$ | $m_0^{P,\bar{P}} = 938.272$ | stable ( $> 2.1 \times 10^{29}$ yr) |
| Neutron | $n, \bar{n}$ | $m_0^{n,\bar{n}} = 939.565$ | 879.4 s (free) |
| Hydrogen | $H$ | $m_0^{D} = 938.781$ | - |
| Deterium | $D$ | $m_0^{D} = 1875.6127$ | - |
| Hellium | $He$ | $m_0^{He} = 3727.379$ | - |

Task is to find out momentum vs energy-loss of each particle

Number of incidence per particle: 10,000

Incoming Energy; 1 MeV to 10 GeV (uniform distribution)

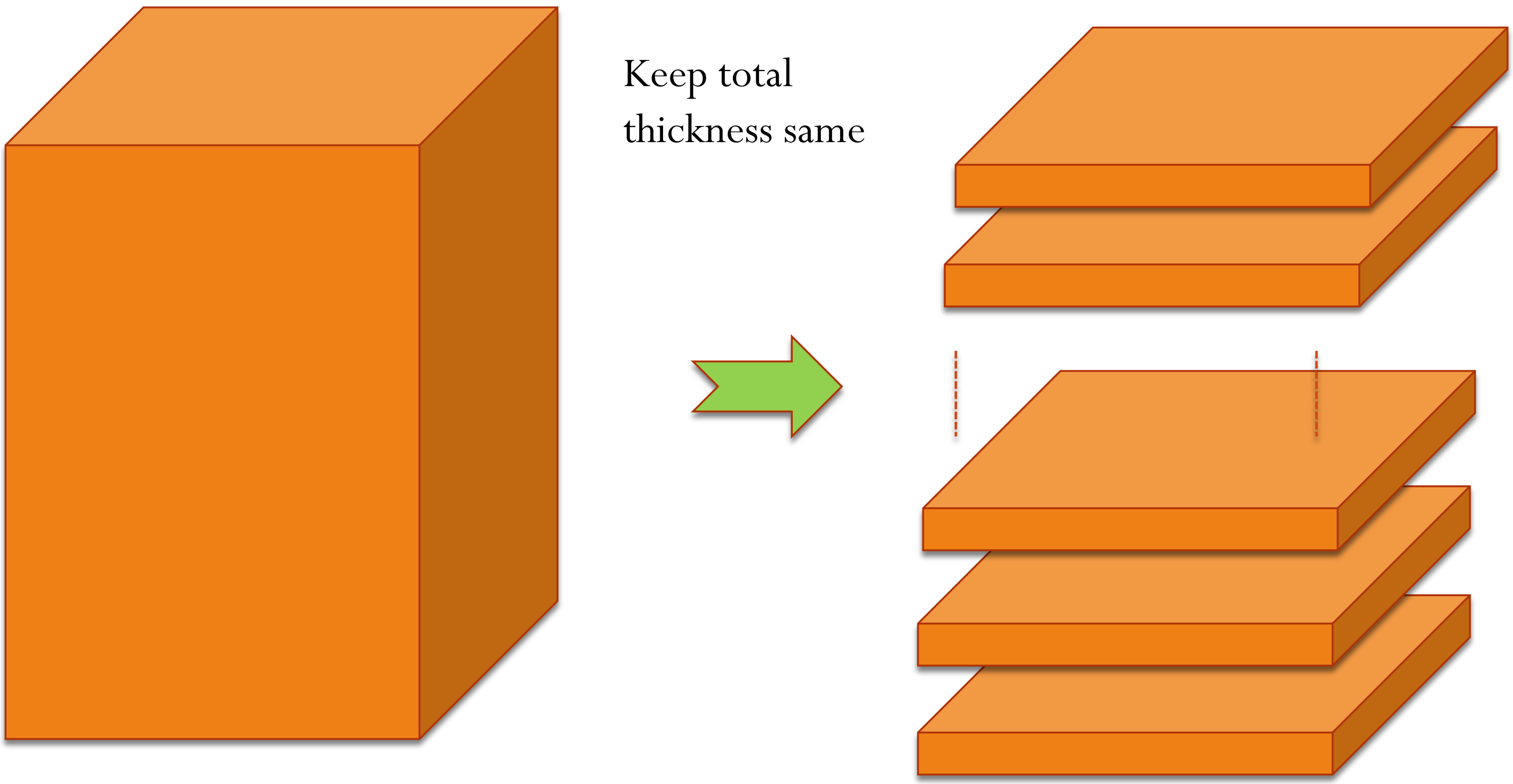
Material Volume: Cu (10 cm thick)

# How to start: Muon Interaction

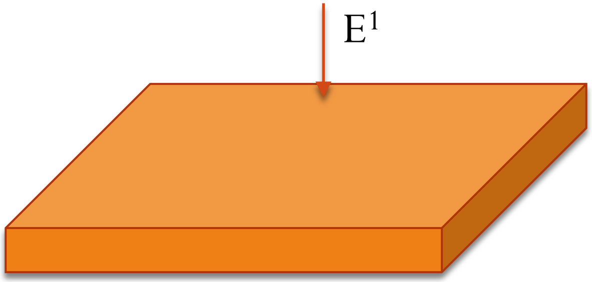
If you follow the approximation energy loss merely depends on the function dE/dx=a

=> every loss point you must recalculate the value of available E[1]

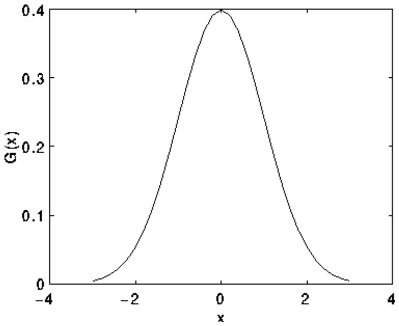
=> Make slices (how small you can make)



# How to start: Muon Interaction Experiment




Calculate $\Delta E^1$




If you conduct same experiment for several time, it will not give exactly same theoretical values for all observations

Gaussian Distribution

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

$f(x)$ = probability density function

$\sigma$ = standard deviation

$\mu$ = mean

Do not Use Landau Distributions

# What to plot

3. Plot energy spectrum of each particles.
4. Calculate energy loss for each particles (you should use the energy loss due to ionization alone)
   (a) Plot momentum vs $dE/dx$ plot for each particle
   (b) Plot momentum vs $dE/dx$ plot for all particles in single plot.

# Task -3 (b)

| Element | Symbol | AtomicNumber | NumberofNeutrons | AtomicMass |
|---|---|---|---|---|
| Hydrogen | H | 1 | 0 | 1.0070000000000000 |
| Helium | He | 2 | 2 | 4.002 |
| Lithium | Li | 3 | 4 | 6.941 |
| Beryllium | Be | 4 | 5 | 9.012 |
| Boron | B | 5 | 6 | 10.811 |
| Carbon | C | 6 | 6 | 12.011 |
| Nitrogen | N | 7 | 7 | 14.007 |
| Oxygen | O | 8 | 8 | 15.999 |
| Fluorine | F | 9 | 10 | 18.998 |
| Neon | Ne | 10 | 10 | 20.18 |
| Sodium | Na | 11 | 12 | 22.99 |
| Magnesium | Mg | 12 | 12 | 24.305 |
| Aluminum | Al | 13 | 14 | 26.982 |
| Silicon | Si | 14 | 14 | 28.086 |
| Phosphorus | P | 15 | 16 | 30.974 |
| Sulfur | S | 16 | 16 | 32.065 |
| Chlorine | Cl | 17 | 18 | 35.453 |
| Argon | Ar | 18 | 22 | 39.948 |
| Potassium | K | 19 | 20 | 39.098 |
| Calcium | Ca | 20 | 20 | 40.078 |
| Scandium | Sc | 21 | 24 | 44.956 |
| Titanium | Ti | 22 | 26 | 47.867 |
| Vanadium | V | 23 | 28 | 50.942 |
| Chromium | Cr | 24 | 28 | 51.996 |
| Manganese | Mn | 25 | 30 | 54.938 |
| Iron | Fe | 26 | 30 | 55.845 |
| Cobalt | Co | 27 | 32 | 58.933 |
| Nickel | Ni | 28 | 31 | 58.693000000000000 |
| Copper | Cu | 29 | 35 | 63.54600000000000 |
| Zinc | Zn | 30 | 35 | 65.38 |

*You need to estimate what is the minimum energy required for a muon and an electron to penetrate through an unit depth of the hypothetical active volume made out of each element.*

The data files are uploaded in moodle

1. When muon and electron Energies are 20 GeV (only ionization energy loss)

(a) Calculate and plot minimum energy loss vs atomic number

(b) Calculate and plot the minimum energy loss vs atomic mass

(c) (c) Plot dE/dx vs atomic number plot for muon and electron

2. Plot minimum required energy vs atomic number.

Hints: You need to use the approximation that we used in task-2