PARTICLE DECAYS and NONELEMENTARY PARTICLES

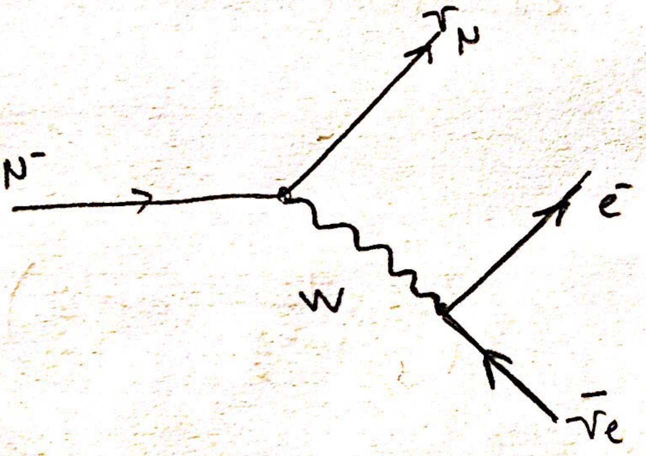
Elementary Particle Decay

* All decays of elementary matter particles go via weak charged current ($W^{\pm}$): (changes flavour)

* For a decay to be occur, there need to be particles with lower mass.

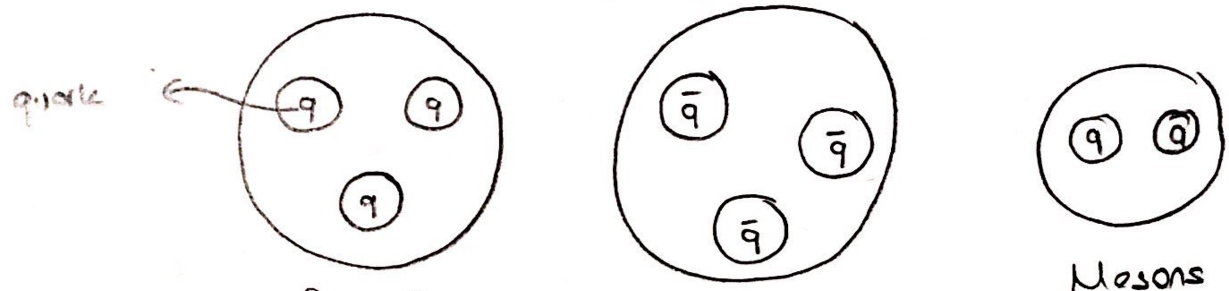
* Electron is stable since it is the lightest charged particles. Neutrinos are also stable.

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$



$\bar{\nu}_e \rightarrow$ to conserve lepton numbers.

Nonelementary Particles



Baryons → half-integer spin

Antibaryons

Mesons → integer spin

$\underbrace{\hspace{10em}}_{\text{Hadrons}}$

Hadrons

Proton: $|p\rangle = |uud\rangle$ → Stable

* Baryon conservation in SM

Neutron: $|n\rangle = |udd\rangle$ → Decay down to proton

$$n \rightarrow p e^- \bar{\nu}_e$$

Pions $\pi^{\pm}$, → $|\pi^+\rangle = |u\bar{d}\rangle$

→ $|\pi^-\rangle = |\bar{u}d\rangle$

→ $|\pi^0\rangle = \frac{1}{\sqrt{2}}|u\bar{u} - d\bar{d}\rangle$

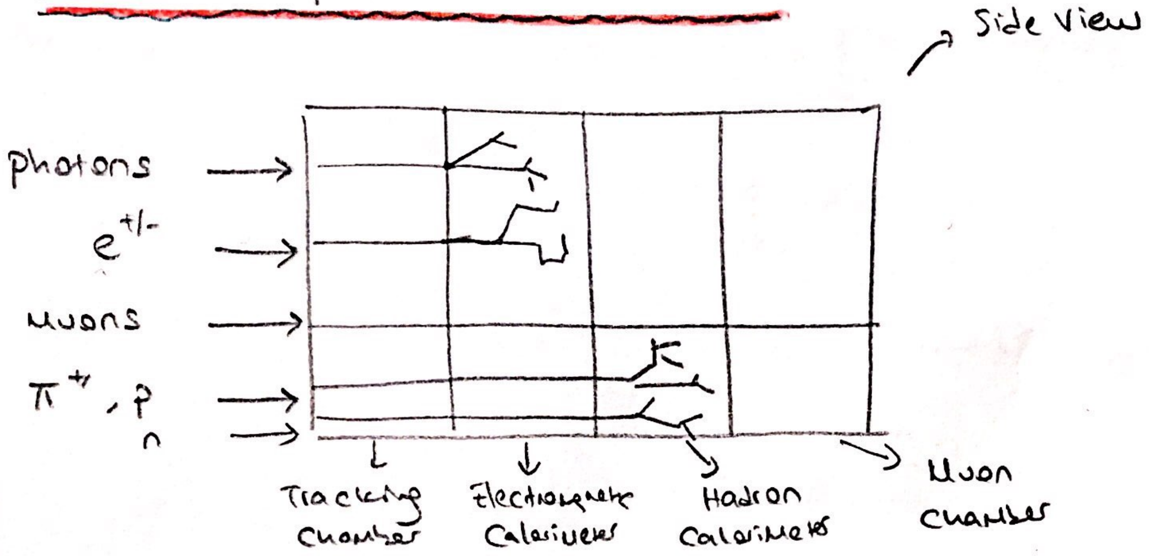
Particle Lifetime

Weak → Large lifetimes, long-lived

Electromagnetically → Intermediate Lifetime

Strong → Short-lived

Particle Properties Measurement



- Charge
- Energy & momentum
- Particle Identification (PID)
- Point where the particle was produced or decayed.
  (production) vertex (decay) vertex
- what was the mother particle

Having these properties, try to reconstruct an initial process in a collision.

Reconstruction with kinematics

$$M^2 = \left(\sum E_i\right)^2 - \left|\sum \vec{p_i}\right|^2$$

→ Usually it is not possible to measure both energies and momenta.

→ Measure a combination: energy + mass or momentum + mass

Decay Length $L = \beta\gamma c\tau$ where τ is particle lifetime.

$$\beta\gamma = \frac{p}{m}$$

Many different types of particle detecters:

- Scintillators
- Bubble or Cloud Chamber
- Wire chambers ...

★ They all rely on the detection of a perturbation induced in matter

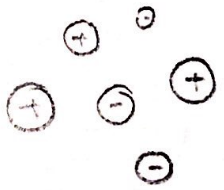
- Ionization (electrical signal)
- Excitation (scintillation) of atoms via light

works only for charged particles and a photon ← EM interactions btw incident particle and the atomic elections.

Sensitive volumes in which the perturbations occur

- gas
- liquid
- solid

Ionization



Bethe - Bloch equation:

$$\frac{dE}{dx} \approx -4\pi\hbar^2 c^2 \alpha^2 \frac{nZ}{m_e v^2} \left\{ \ln\left[\frac{2\beta^2\gamma^2 c^2 m_e}{I_e}\right] - \beta^2 \right\}$$

$v = \beta c$ is a speed of the traversing particle

Z: atomic number of the material

n its number density

$$n = \frac{\rho}{A m_u}$$

ρ → Material density

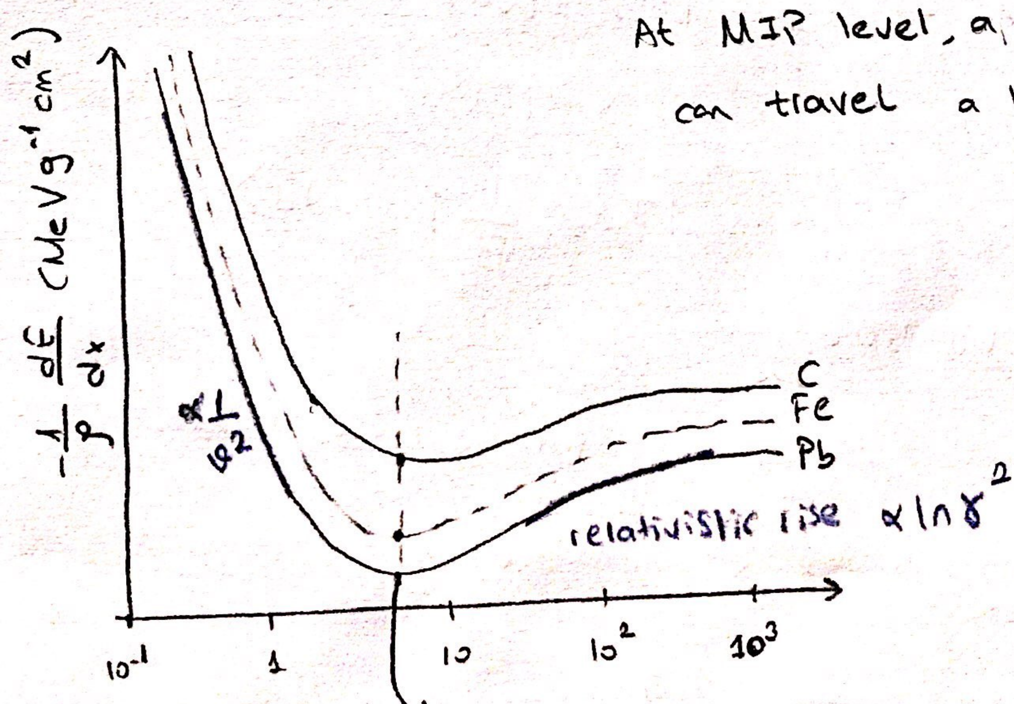
A → atomic mass number

m_u → $1{,}66 \times 10^{-27}$ → unified atomic mass unit

$I_e \sim 10Z$ eV → effective ionization potential of the material

$$\frac{1}{\rho}\frac{dE}{dx} \propto \frac{Z}{A} \approx \text{const}$$

At MIP level, a particle can travel a long distance.



MIP (minimum ionizing particles $\beta\gamma = 3$)

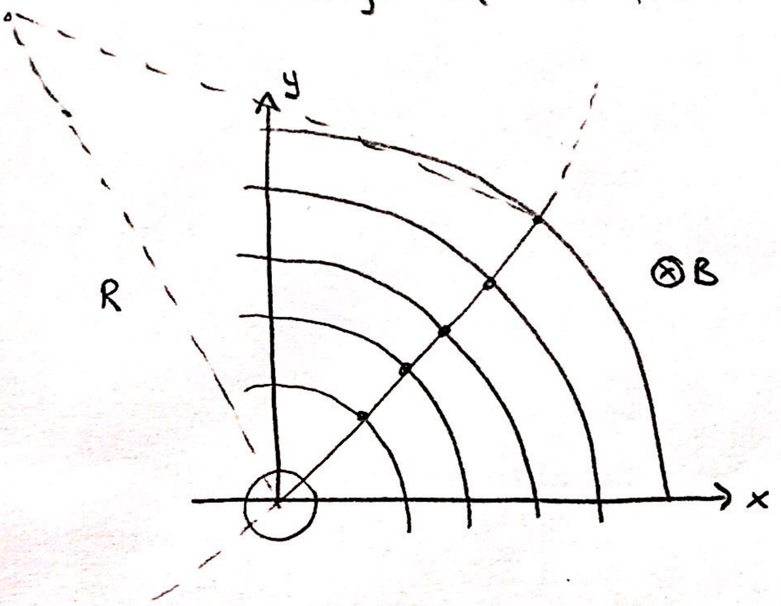
Momentum Measurement

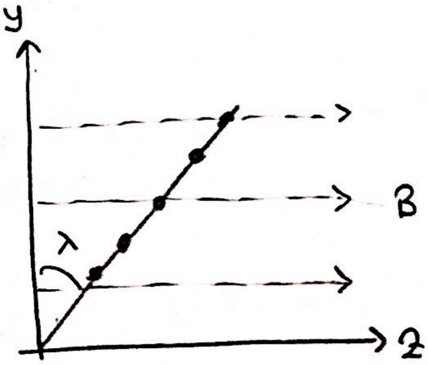
$$F = \frac{Mv^2}{R} = q(\vec{v} \times \vec{B})$$

$$p\cos\lambda = qBR$$

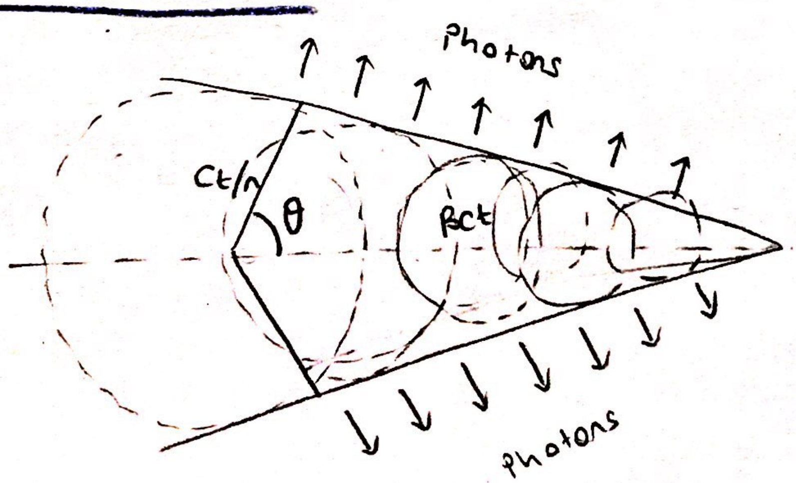
$$p\cos\lambda\ [GeV/c] = 0.3\,BR\ [Tm]$$

Obtain R and $\cos\lambda$ from constructed particle trajectory and knowledge of B-field.





Cerenkov Radiation



Occurs when $v > c/n$

$$\cos\theta = \frac{1}{n\beta}$$

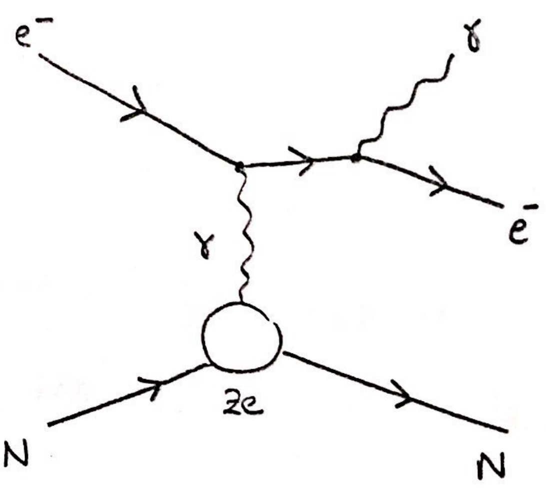
Light is emitted if:

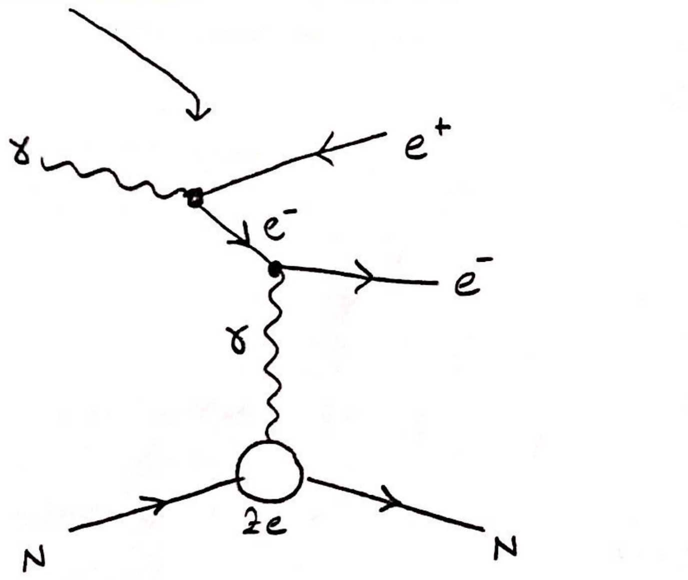
$$\beta > 1/n$$

$$\beta = \frac{pc}{E} = \frac{p}{\sqrt{p^2 + m^2c^2}}$$

$$\boxed{mc < p\sqrt{n^2 - 1}}$$

Bremsstrahlung and e^+e^- production





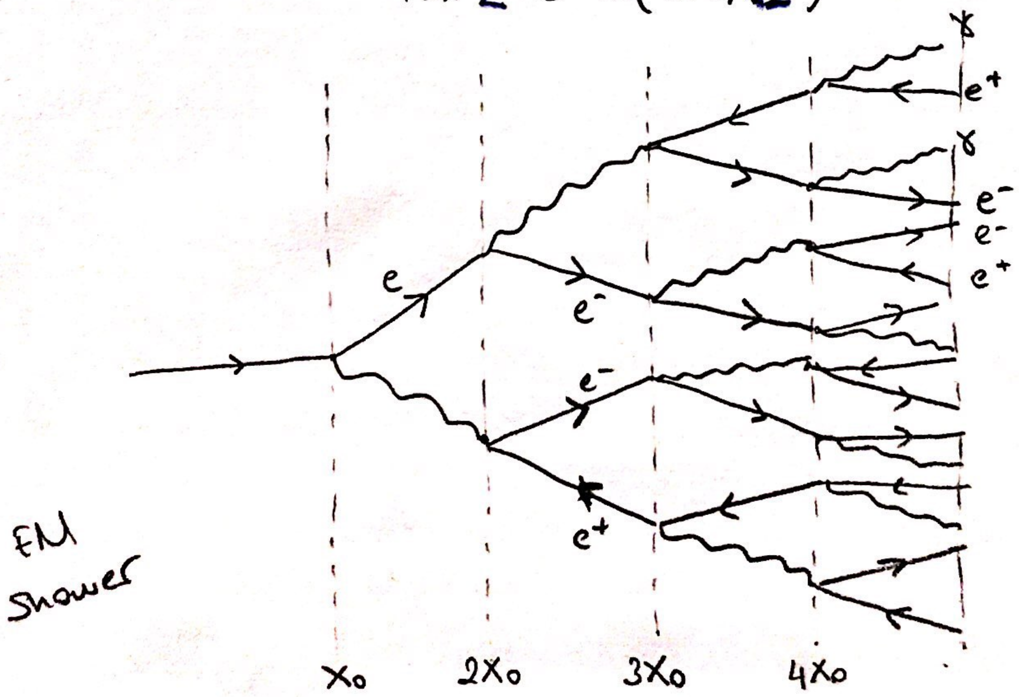
↳ Main energy loss mechanism for $e^\pm$ with $> E_c$ (800/Z MeV)

Dominant energy loss mech for γ with $E_\gamma > 10$ MeV

Radiation Length (X_0)

Avg. distance over which the energy of an electron is reduced by bremsstrahlung by a factor of $1/e$.

$$X_0 \approx \frac{1}{4\alpha n Z^2 r_e^2 \ln(287/\sqrt{Z})} \quad , r_e = \frac{e^2}{4\pi\epsilon_0 m_e c^2} = 2.8\times10^{-15}\,m$$



☆ Number of particles doubles after every X_0.

After $x X_0$ avg. energy

$$\langle E\rangle \approx \frac{E}{2^x}$$

Shower development stops after $\langle E\rangle < E_c$

$$x_{max} = \frac{\ln(E/E_c)}{\ln 2}$$