Ch 4.
Physics of Particle and Radiation Detection

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2021.04.02.Fri

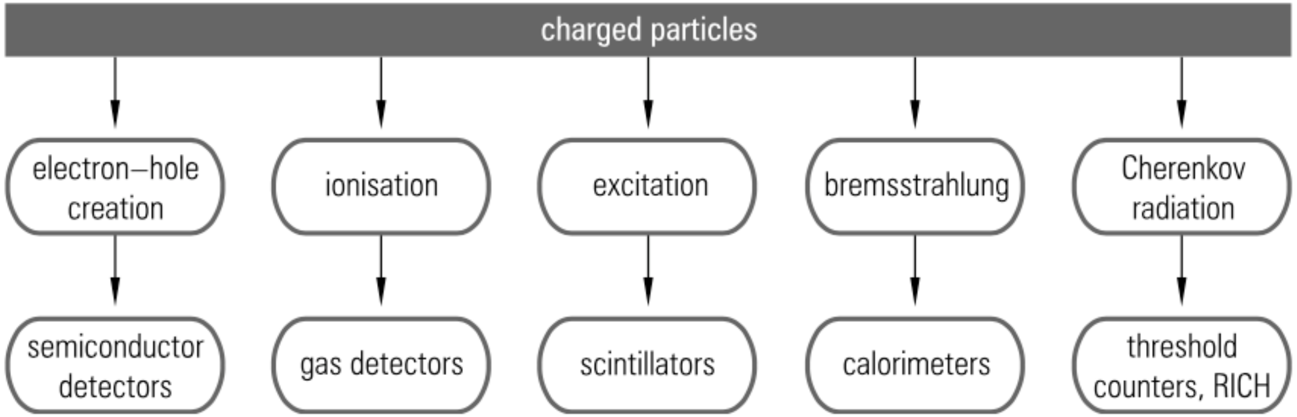
NSRI 1(a) Study

Contents

0. Overview

FUNDAMENTAL PRINCIPLE :: Transfer all or part of the particle energy to the detector!!

Cosmic Rays

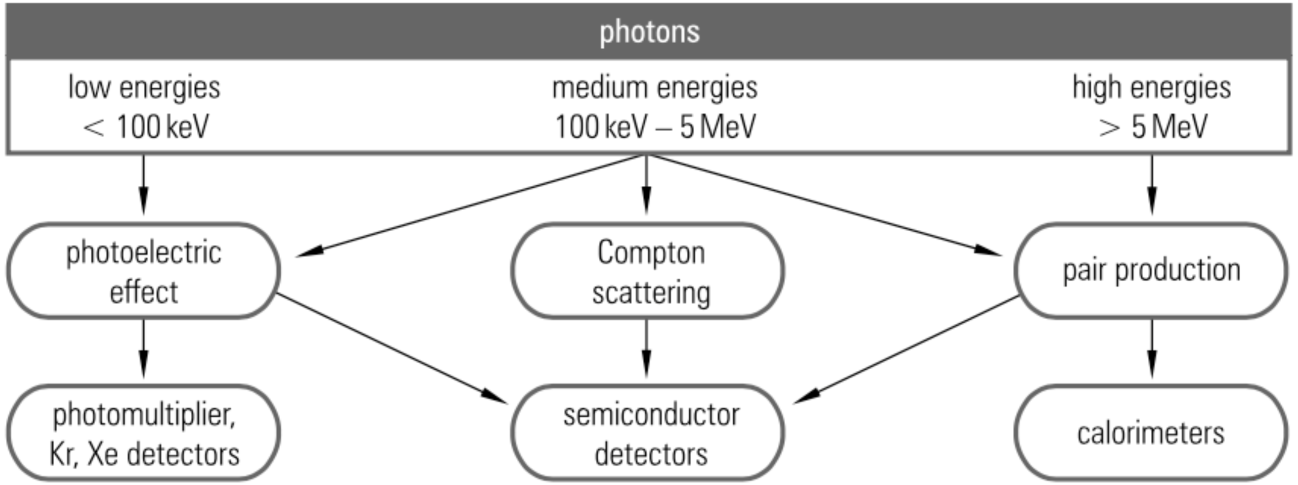


charged particles

electron–hole creation
ionisation
excitation
bremsstrahlung
Cherenkov radiation

semiconductor detectors
gas detectors
scintillators
calorimeters
threshold counters, RICH

Photons



photons

low energies
< 100 keV

medium energies
100 keV – 5 MeV

high energies
> 5 MeV

photoelectric effect
Compton scattering
pair production

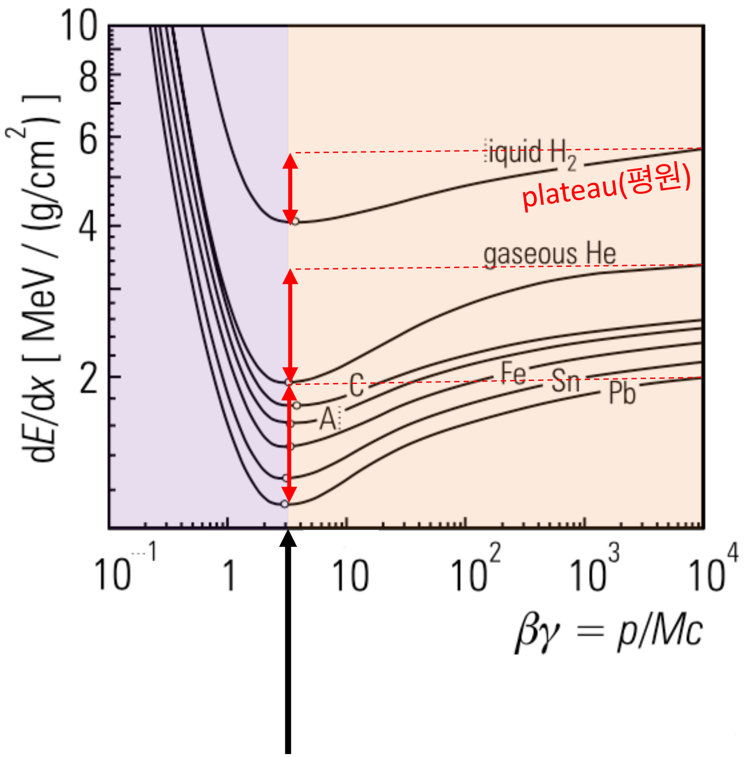
photomultiplier, Kr, Xe detectors
semiconductor detectors
calorimeters

1. Cosmic Ray Detection

1.0. Cosmic Ray Energy Loss

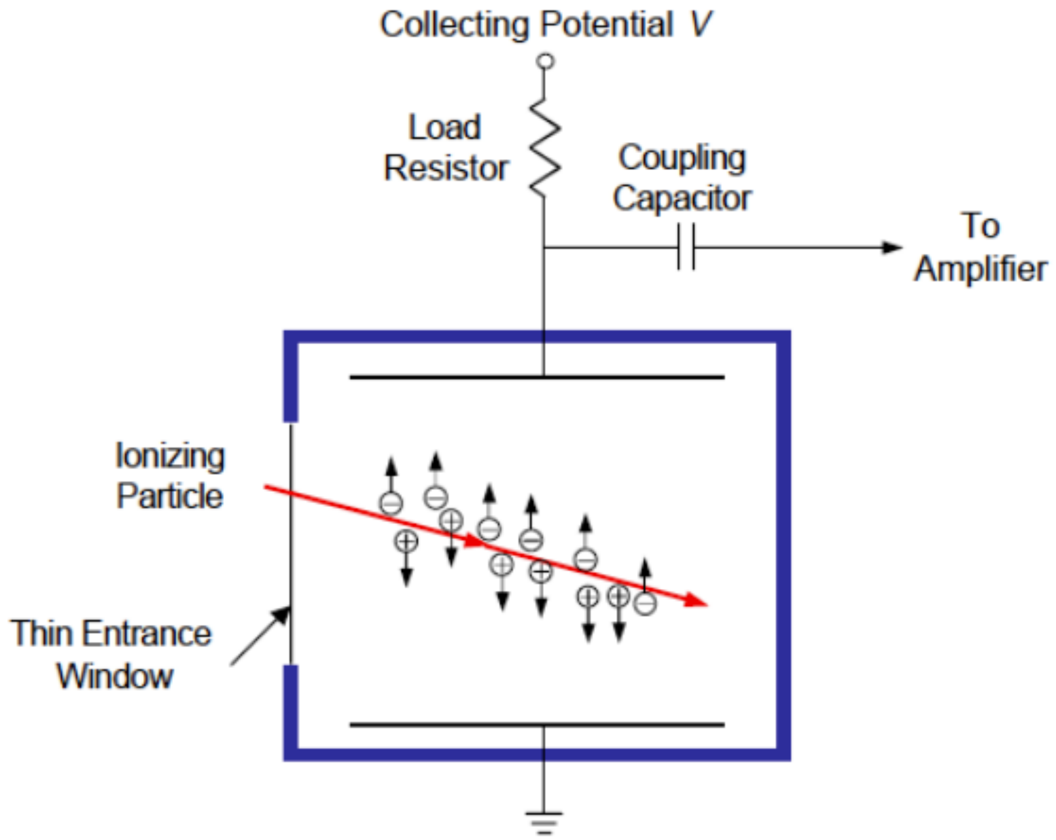
	Energy Loss
Ionization Loss	Bethe-Bloch formula $-\frac{dE}{dx} = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta}{2} \right]$ 🍇 For low energy particles, high energy means less energy loss. 🍊 For high energy particles, high energy means more energy loss.
Bremsstrahlung	$-\frac{dE}{dx} = 4\alpha N_A \frac{Z^2}{A} r_e^2 E \ln \frac{183}{Z^{1/3}} = \frac{E}{X_0} \propto E$
Pair production	$-\frac{dE}{dx} \propto E$

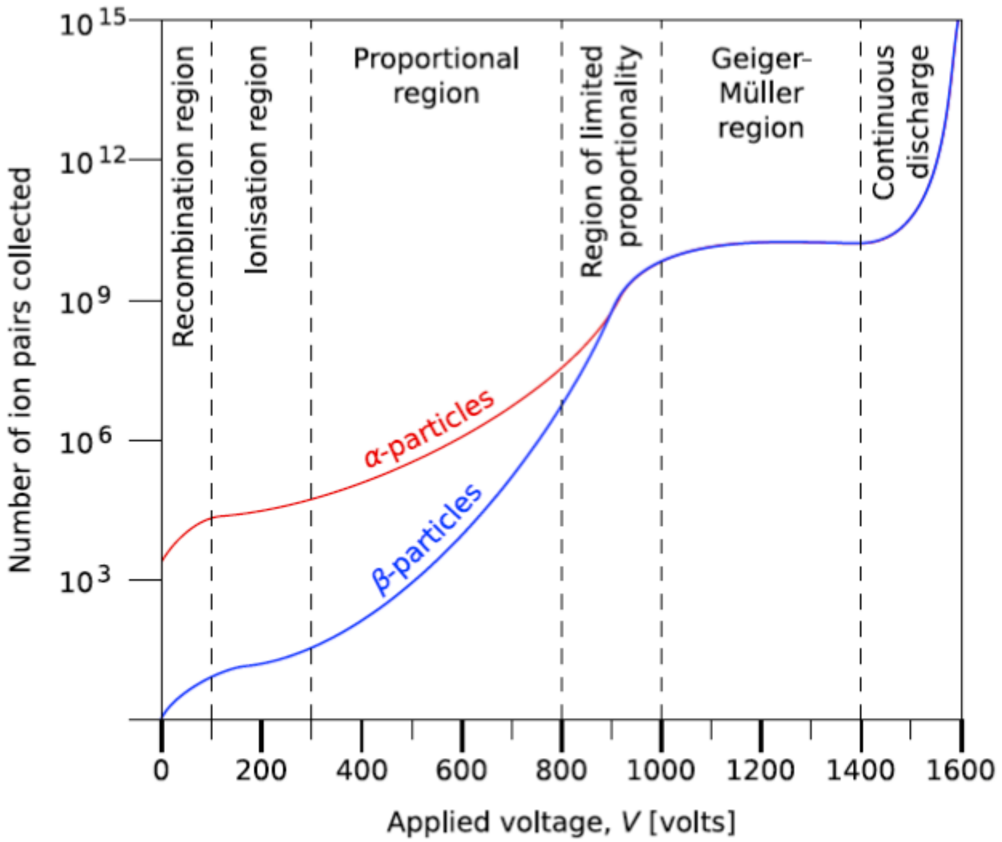
$$-\frac{dE}{dx} = \overset{\text{ionization}}{a(E)} + \overset{\text{bremsstrahlung}}{b(E)E}$$



Minimum ionization($\beta\gamma \approx 3.5$)

1.1. Gas Detector

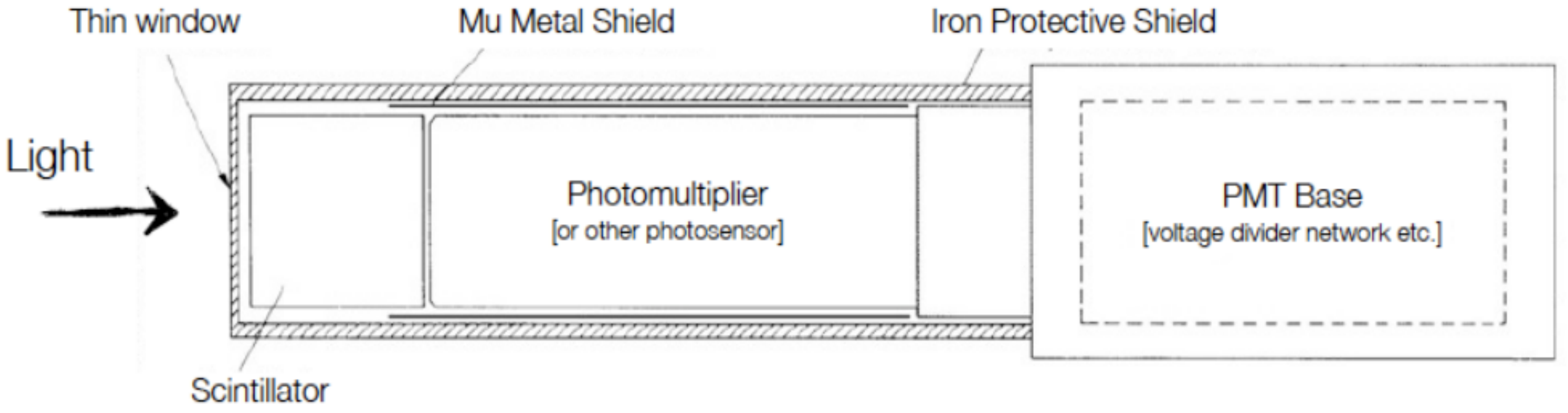




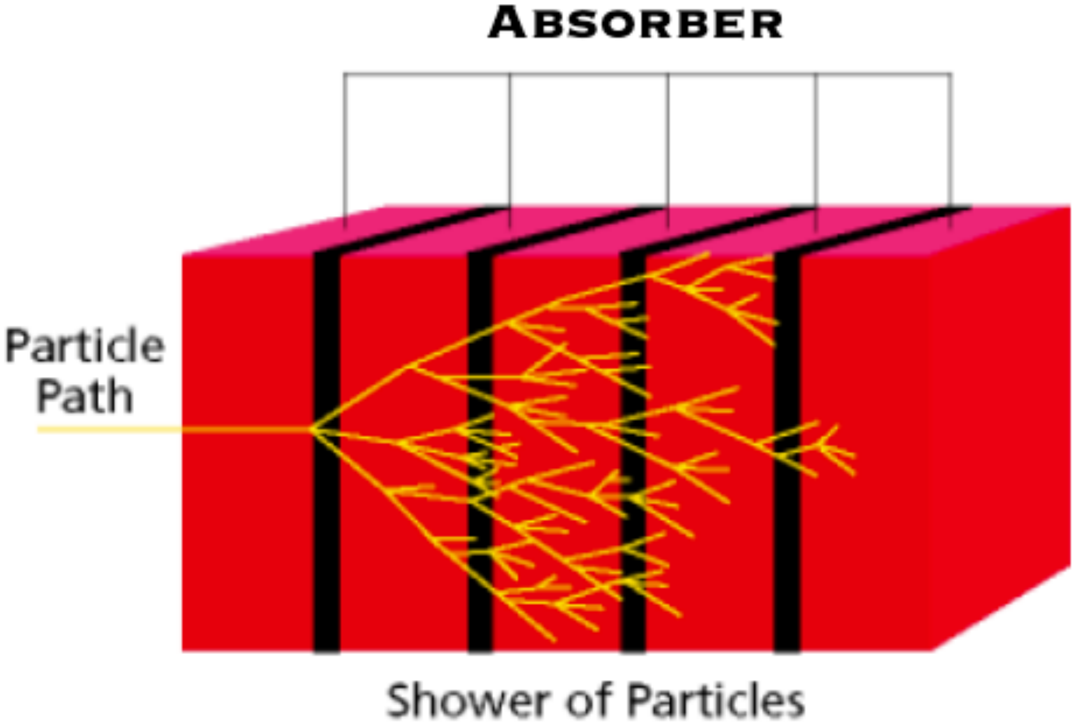
1. Cosmic Ray Detection

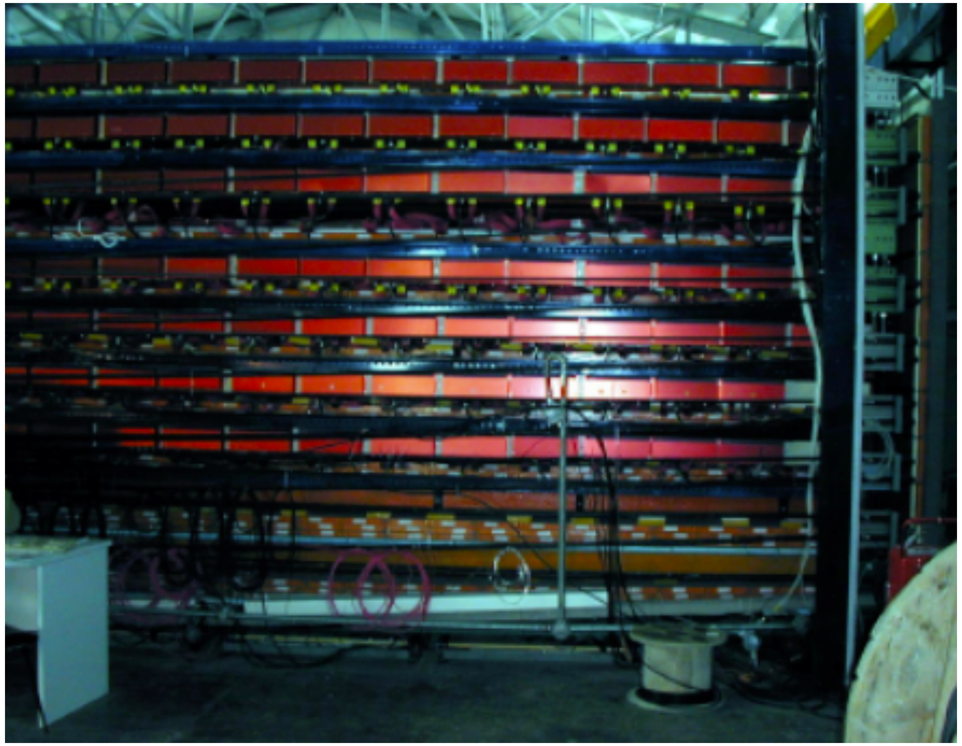
1.2. Scintillator

* scintillation : 발광, 번쩍임



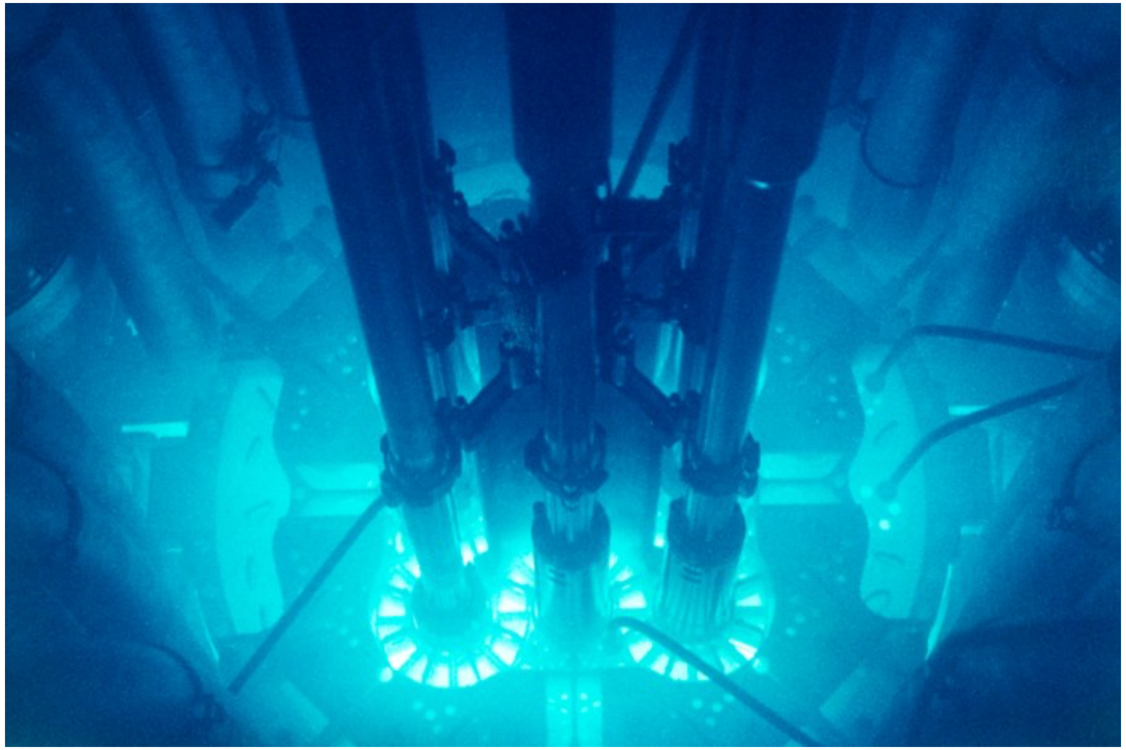
1.3. Calorimeters

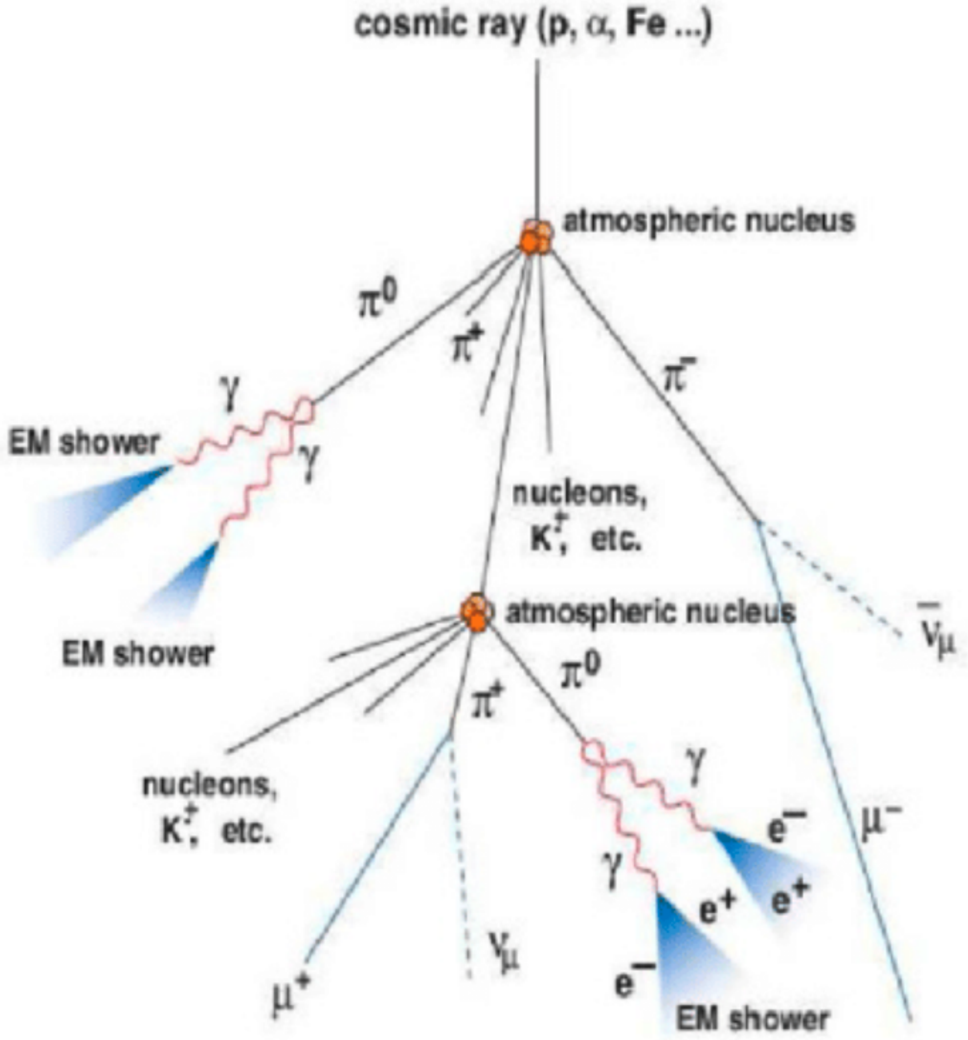




1. Cosmic Ray Detection

1.4. Cherenkov Detector



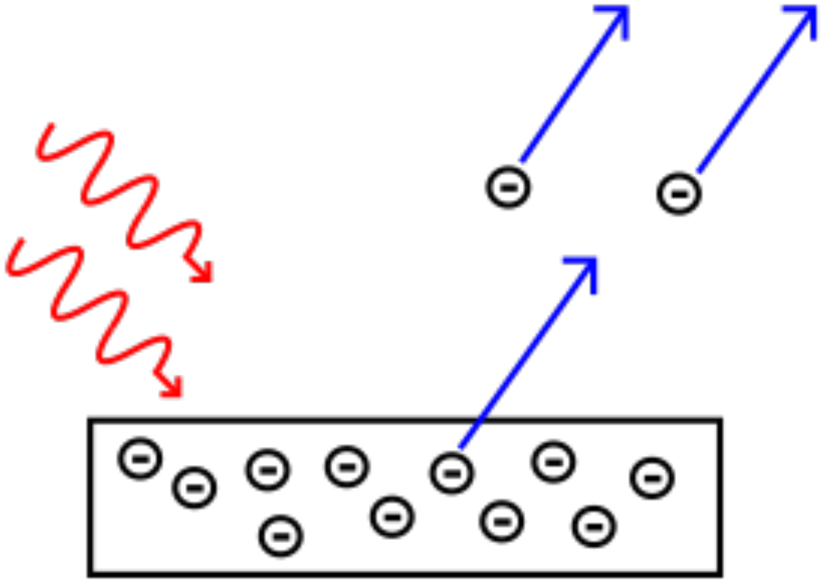


2. Gamma Ray Detection

2. Gamma Ray Detection

2.1. Detection of Low Energy Photons

Photoelectric Effect



2. Gamma Ray Detection

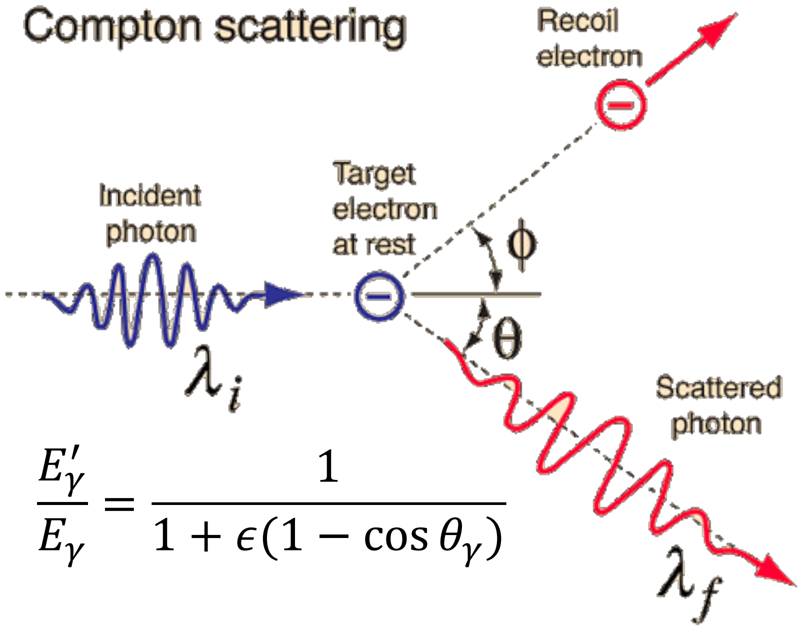
2.2. Detection of High Energy Photons

Compton Scattering

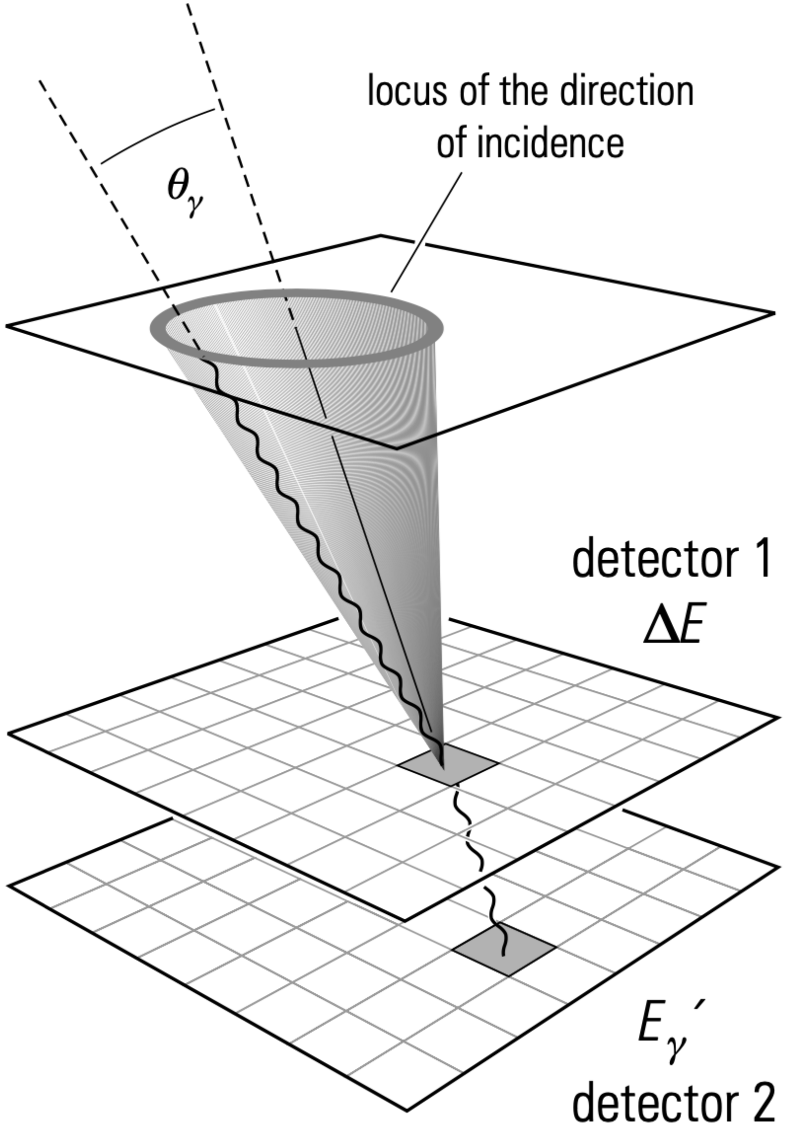
Pair Production(e, e^{+})

2.2. Detection of High Energy Photons

Compton Scattering



$$\frac{E'_\gamma}{E_\gamma} = \frac{1}{1 + \epsilon(1 - \cos\theta_\gamma)}$$



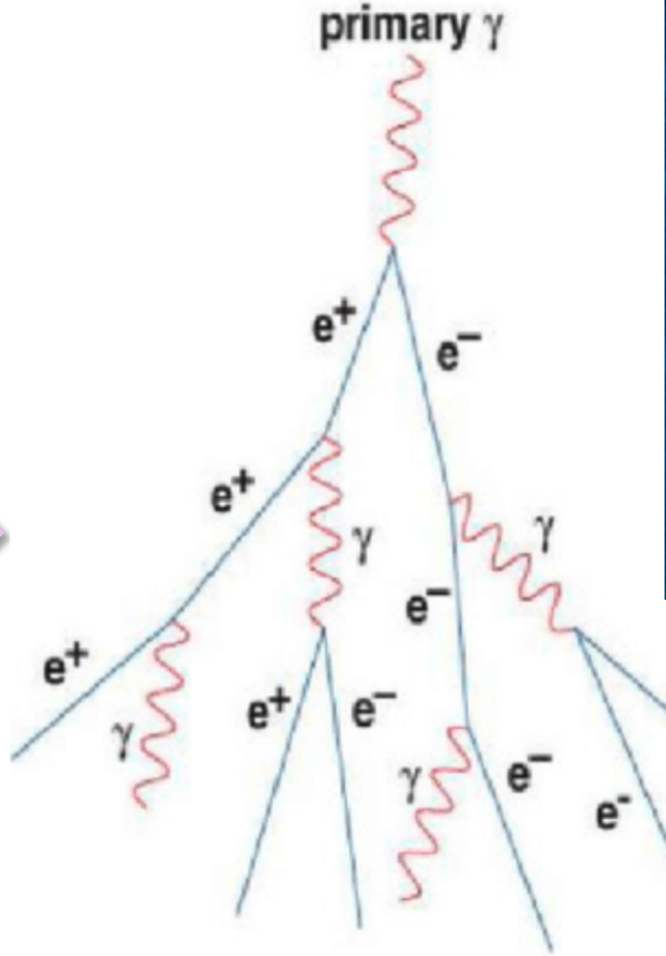
Pair Production(e, e^+)

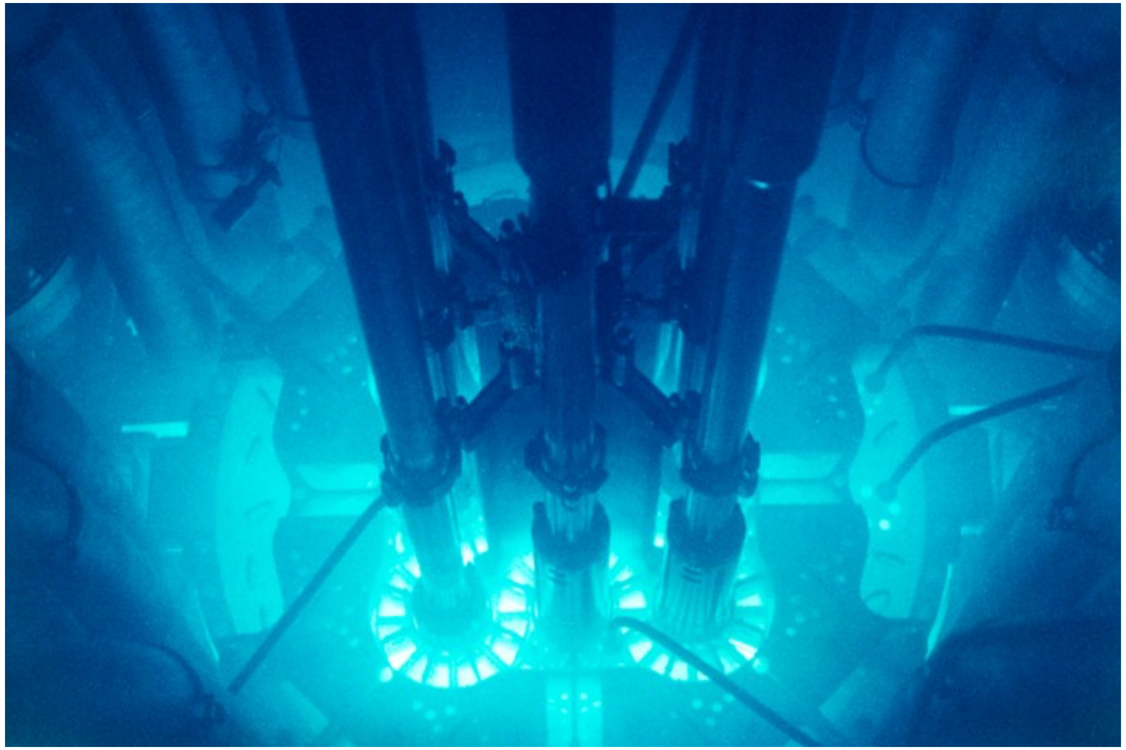
2. Gamma Ray Detection

2.2. Detection of High Energy Photons

Compton Scattering

Pair Production(e, e^+)





Ch 5. Acceleration Mechanisms

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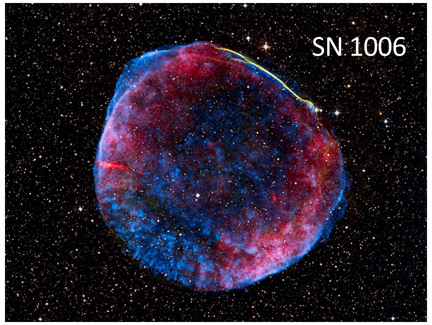
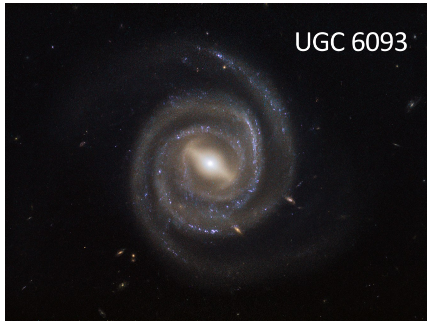
2021.04.02

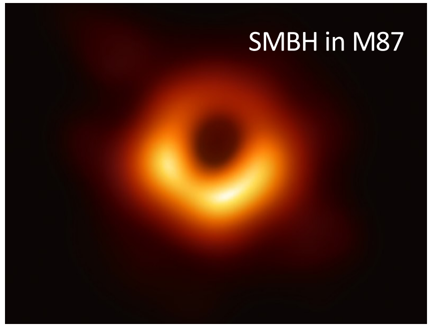
Contents

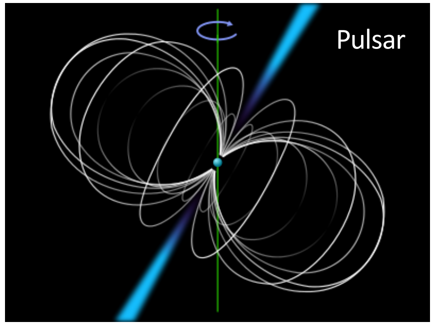
How are CRs accelerated?

Sources

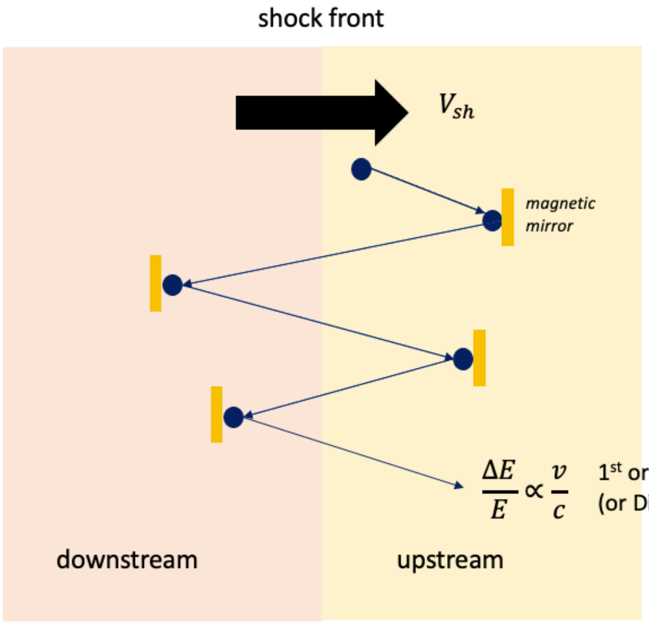




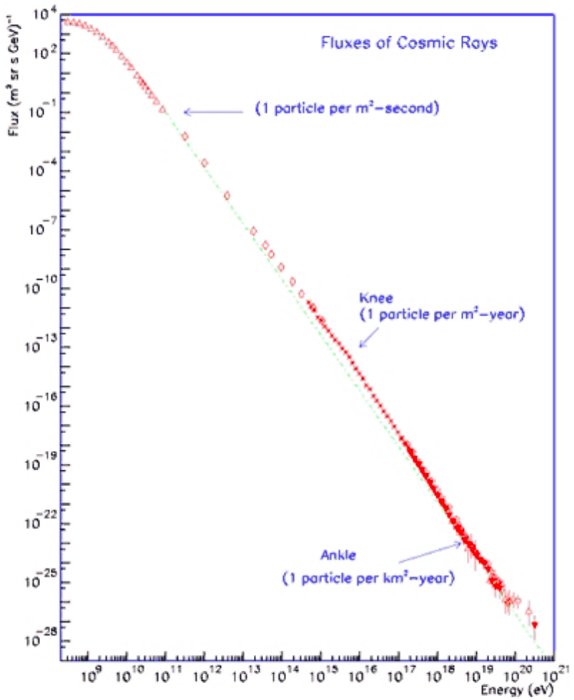




Acceleration

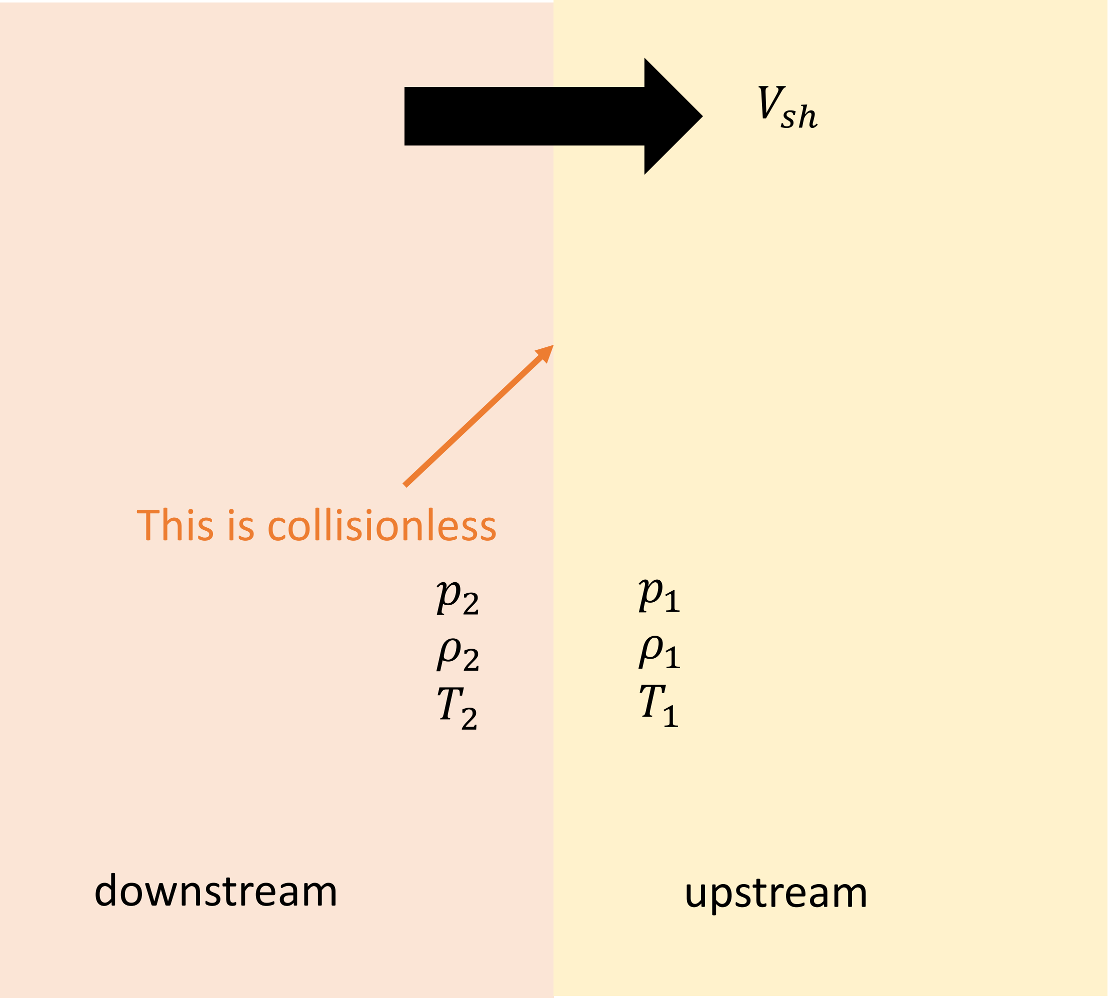


$\frac{\Delta E}{E} \propto \frac{v}{c}$ 1st order Fermi Acceleration
(or Diffusive Shock Acceleration)



5.1. Shock structure

Fast-moving($V_{sh} > v_{sound}$) discontinuity



V_{sh}

This is collisionless

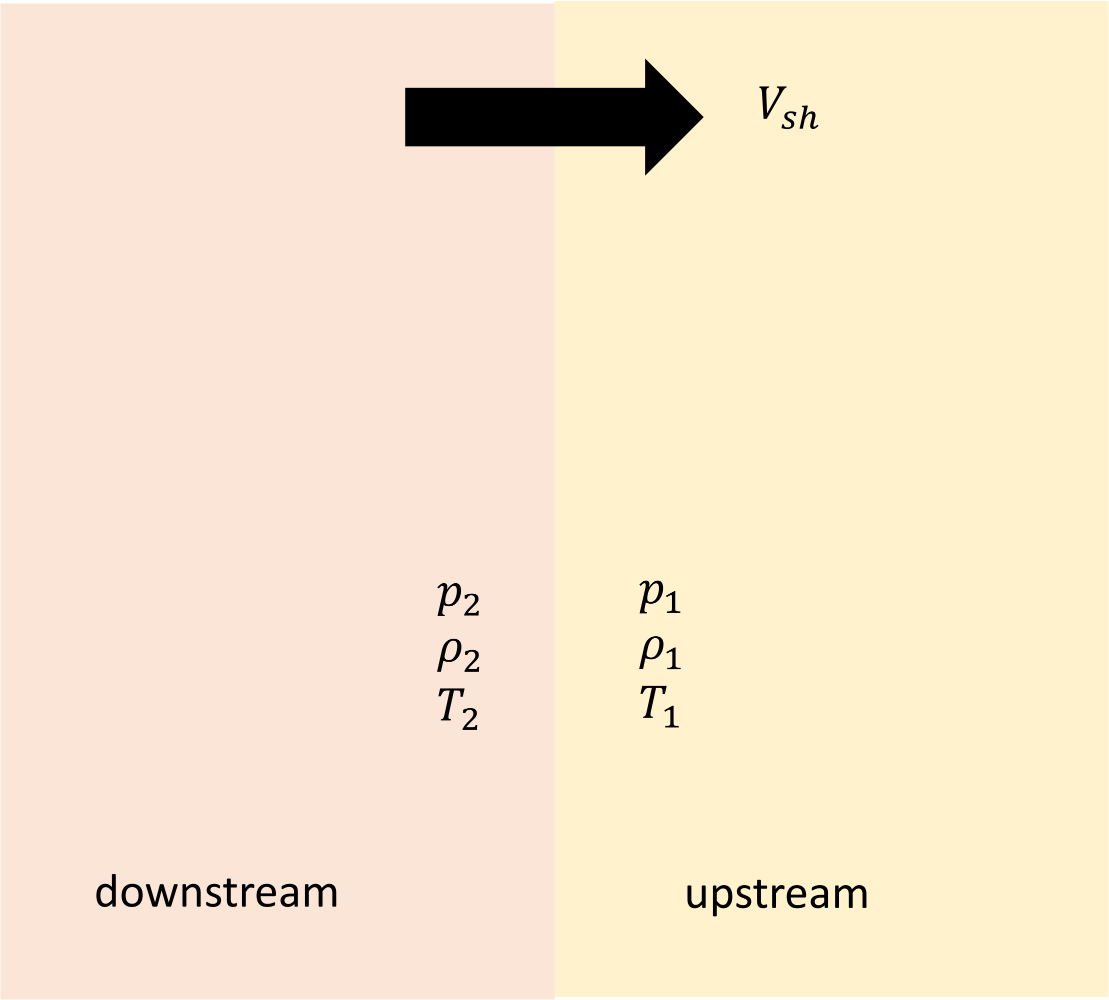
p_2
ρ_2
T_2

p_1
ρ_1
T_1

downstream

upstream

5.1. Shock structure



V_{sh}

p_2
ρ_2
T_2

p_1
ρ_1
T_1

downstream

upstream

Rankine-Hugoniot Jump Condition

In a 1-dimensional stationary shock,

a) the mass conservation,

$$\rho_1 v_1 = \rho_2 v_2$$

b) the momentum conservation,

$$p_1 + \rho_1 v_1^2 = p_2 + \rho_2 v_2^2$$

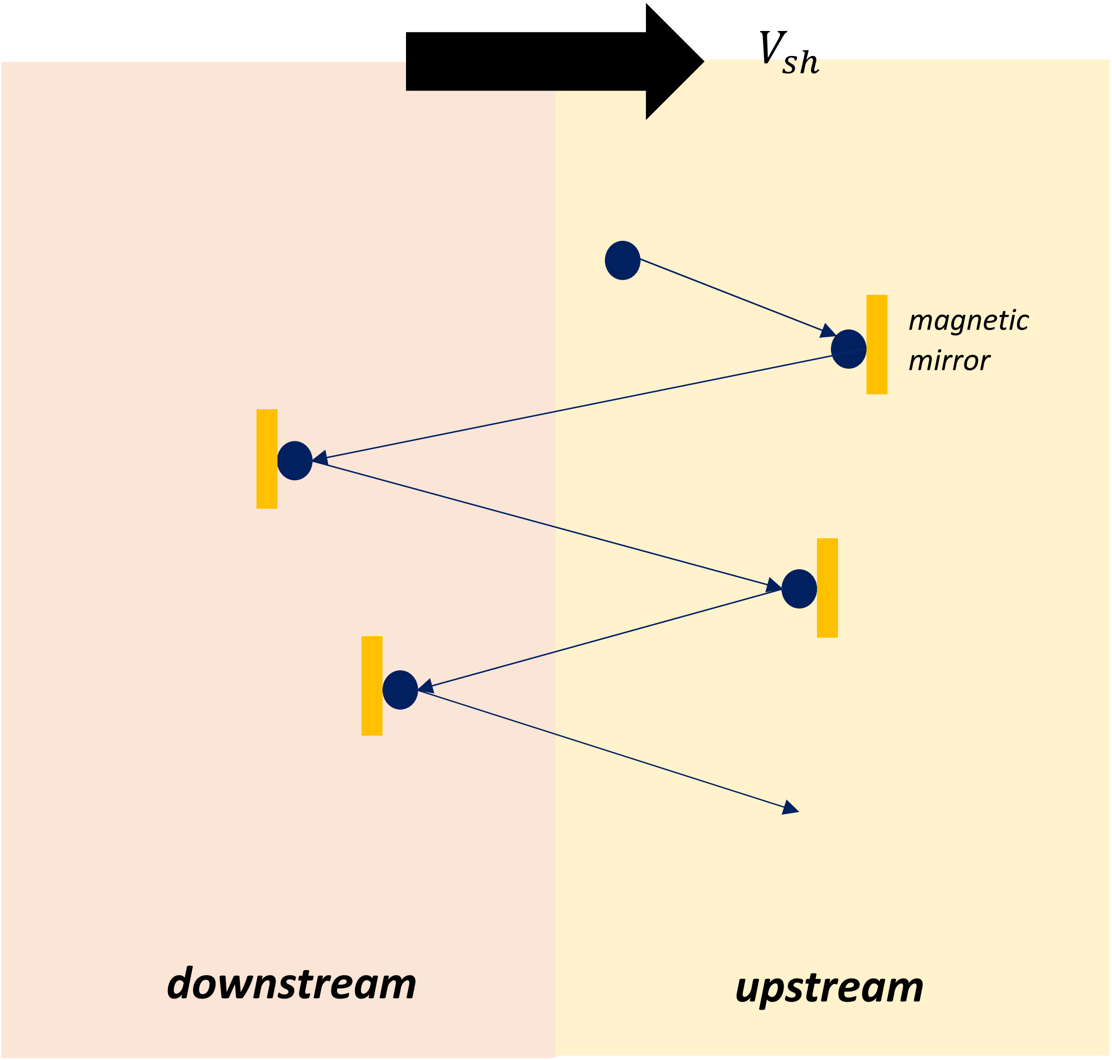
and (c) energy conservation

$$\frac{1}{2} v_1^2 + \frac{\gamma}{\gamma - 1} \frac{p_1}{\rho_1} = \frac{1}{2} v_2^2 + \frac{\gamma}{\gamma - 1} \frac{p_2}{\rho_2}$$

holds.

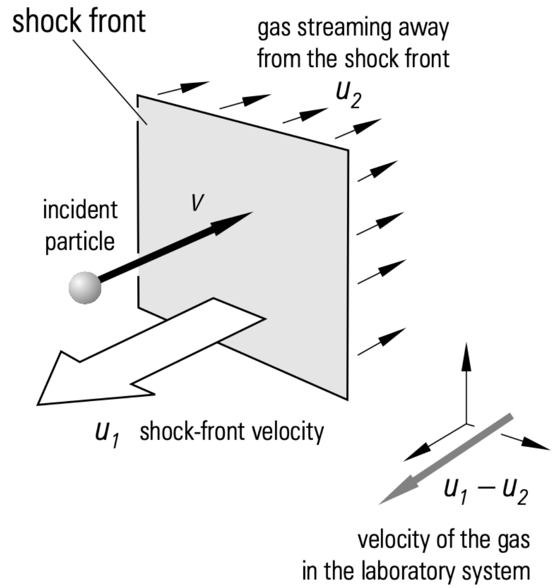
5. Acceleration Mechanism

5.2. 1st Order Fermi Acceleration



$$
\begin{aligned}
\Delta E &= \frac{1}{2}m[v+(u_1-u_2)]^2 - \frac{1}{2}mv^2 \\
&= \frac{1}{2}m\{[v+(u_1-u_2)]^2 - v^2\} \\
&= \frac{1}{2}m[(u_1-u_2)^2 + 2v(u_1-u_2)]
\end{aligned}
$$

$$
\begin{aligned}
\frac{\Delta E}{E} &\approx \frac{(u_1-u_2)^2 + 2v(u_1-u_2)}{v^2} \\
&\approx \frac{2(u_1-u_2)}{v}
\end{aligned}
$$



5. Acceleration Mechanism

5.2. 1st Order Fermi Acceleration

Energy Spectrum

Initial particle energy : E_0

- At initial : $E = E_0$
- At 1st cross : $E_1 = E_0 + \epsilon E_0 = (1+\epsilon)^1 E_0$

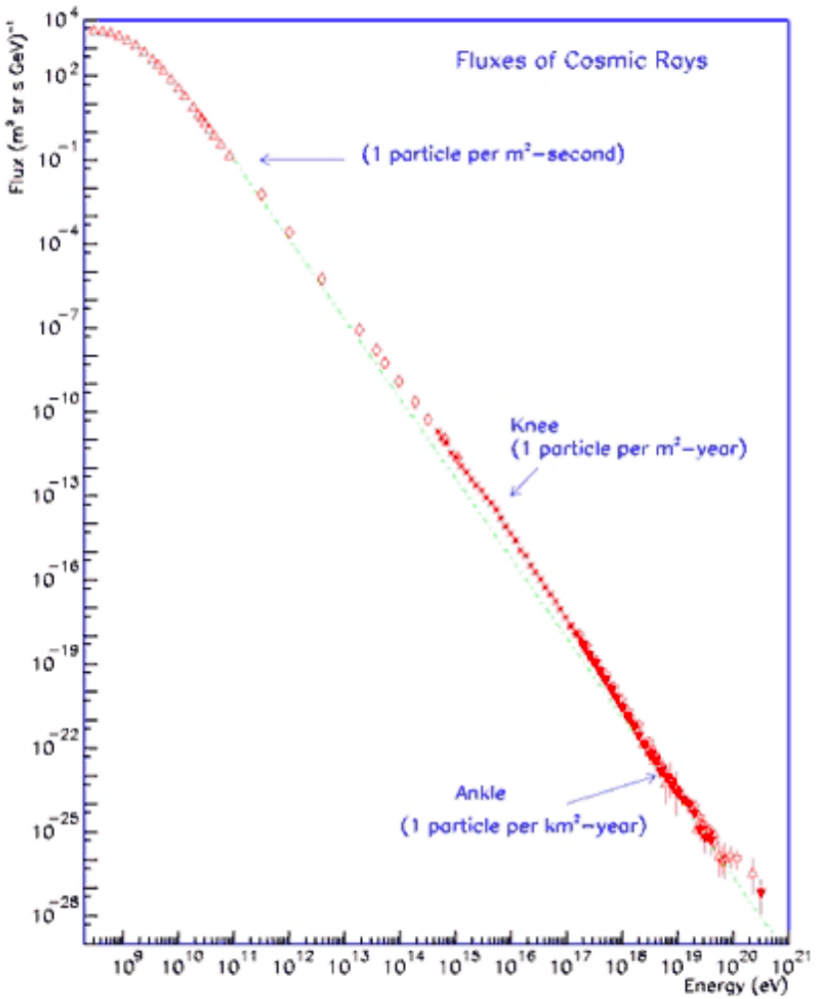
  …
- At n-th cross : $E_n = (1+\epsilon)^n E_0 \longrightarrow \boxed{n = \frac{\ln(E_n/E_0)}{\ln(1+\epsilon)}}$

$$\boldsymbol{N \propto E^{-\alpha}}$$

Escape probability p, then

$$N(>E_n) \sim \sum_{m=n}^{\infty} (1-p)^m = \sum_{k=0}^{\infty} (1-p)^{k+n}$$

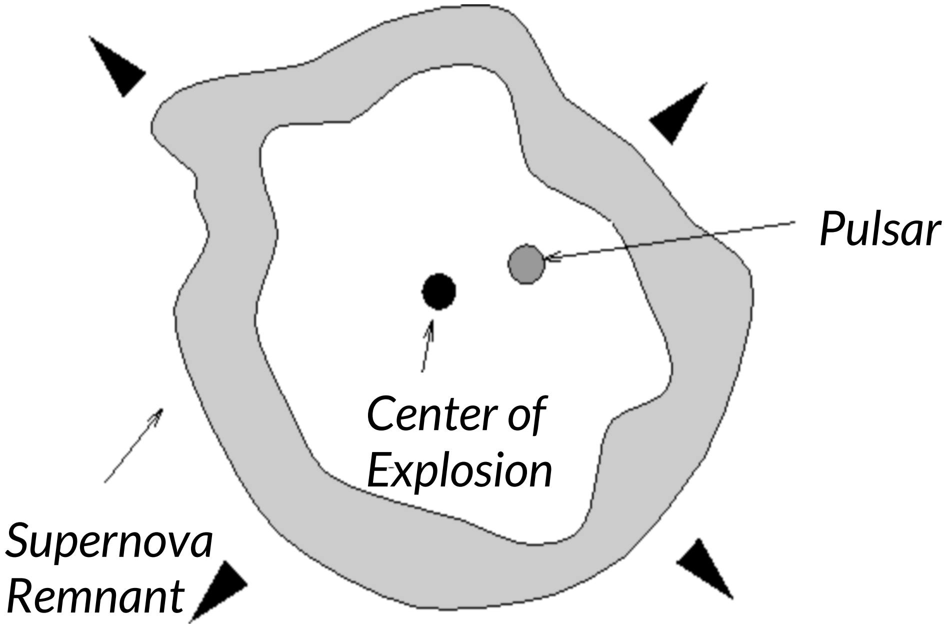
$$= (1-p)^n \sum_{k=0}^{\infty} (1-p)^k = \boxed{\frac{(1-p)^n}{p}}$$



5. Acceleration Mechanism

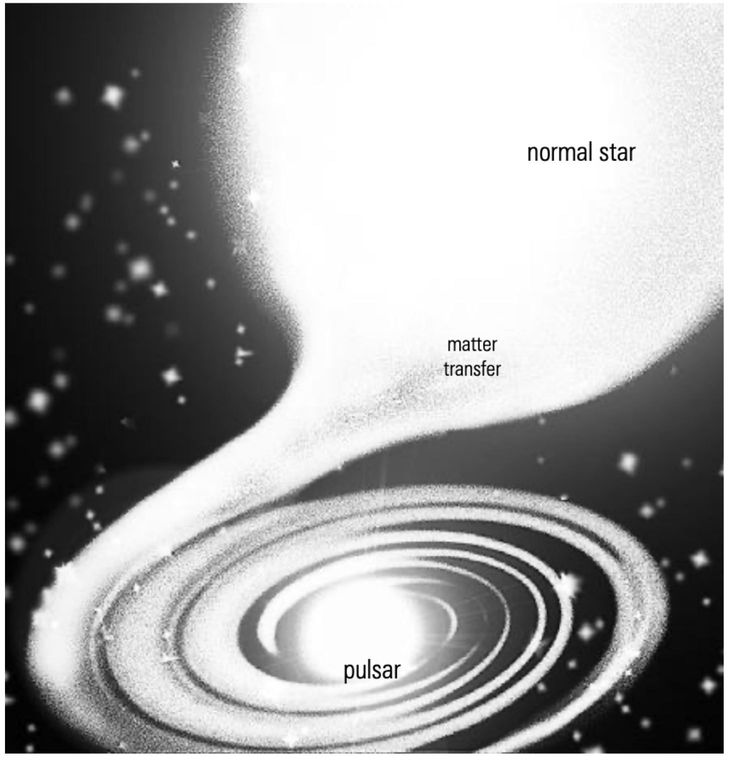
5.3. Examples of Astrophysical Objects

Pulsar



$$B_{pulsar} = B_{star} \frac{R_{star}^2}{R_{pulsar}^2}$$

Binaries ::



AGN or SMBH