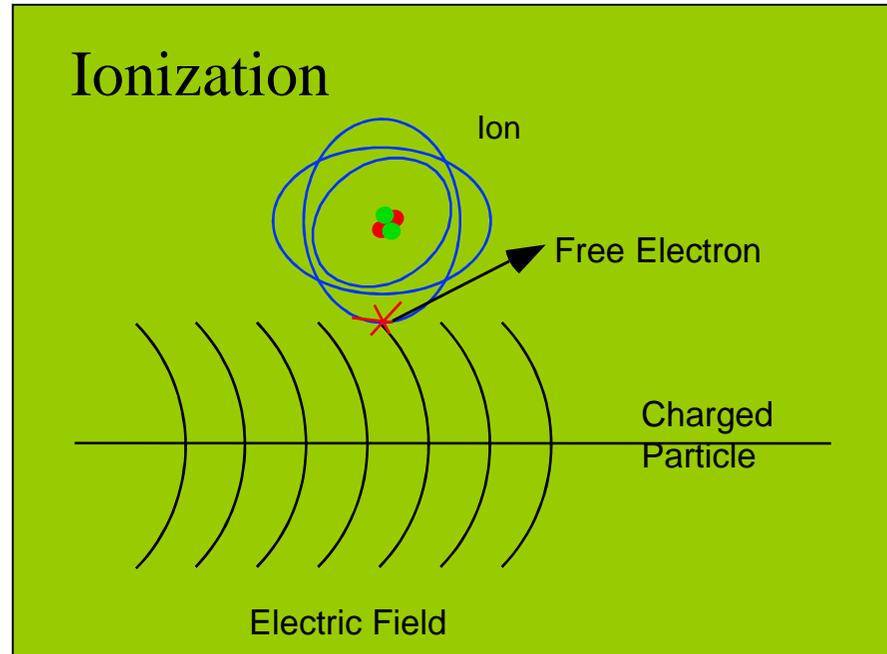


Quelques notions de base sur les techniques de détection en physique des particules

Excitation et Ionisation des particules chargées

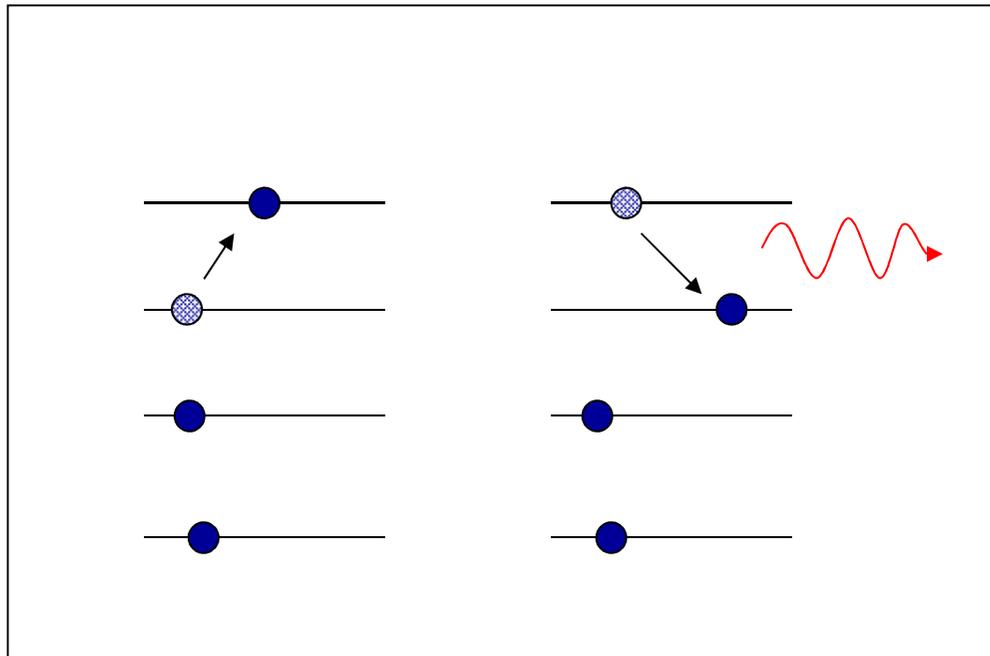


Le passage d'une particule chargée près d'un atome ionise celui-ci ou produit une excitation qui est suivie par une émission électromagnétique

Transfert d'énergie au milieu par le champ électrique

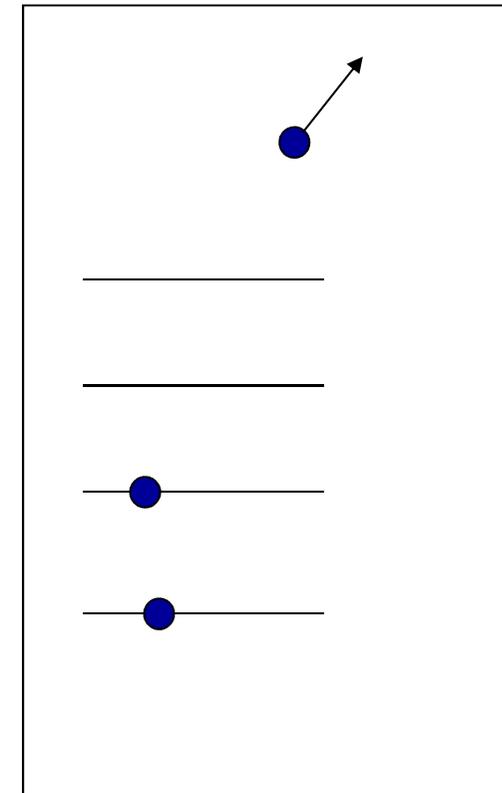
$$E_{\text{Tranfert}} < E_{\text{ion}}$$

excitation

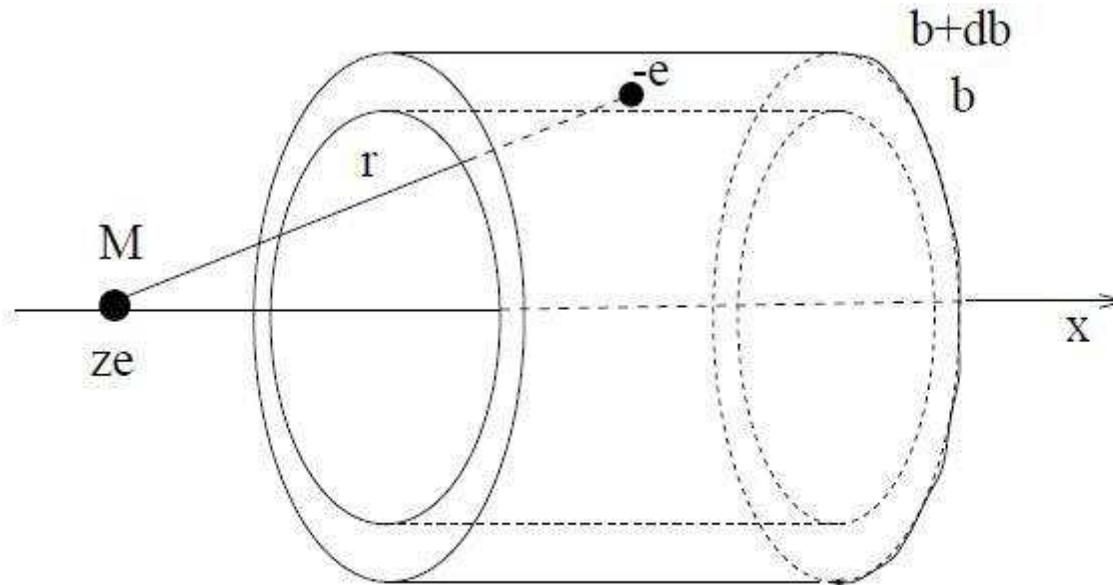


$$E_{\text{Tranfert}} > E_{\text{ion}}$$

ionisation



Principe de base

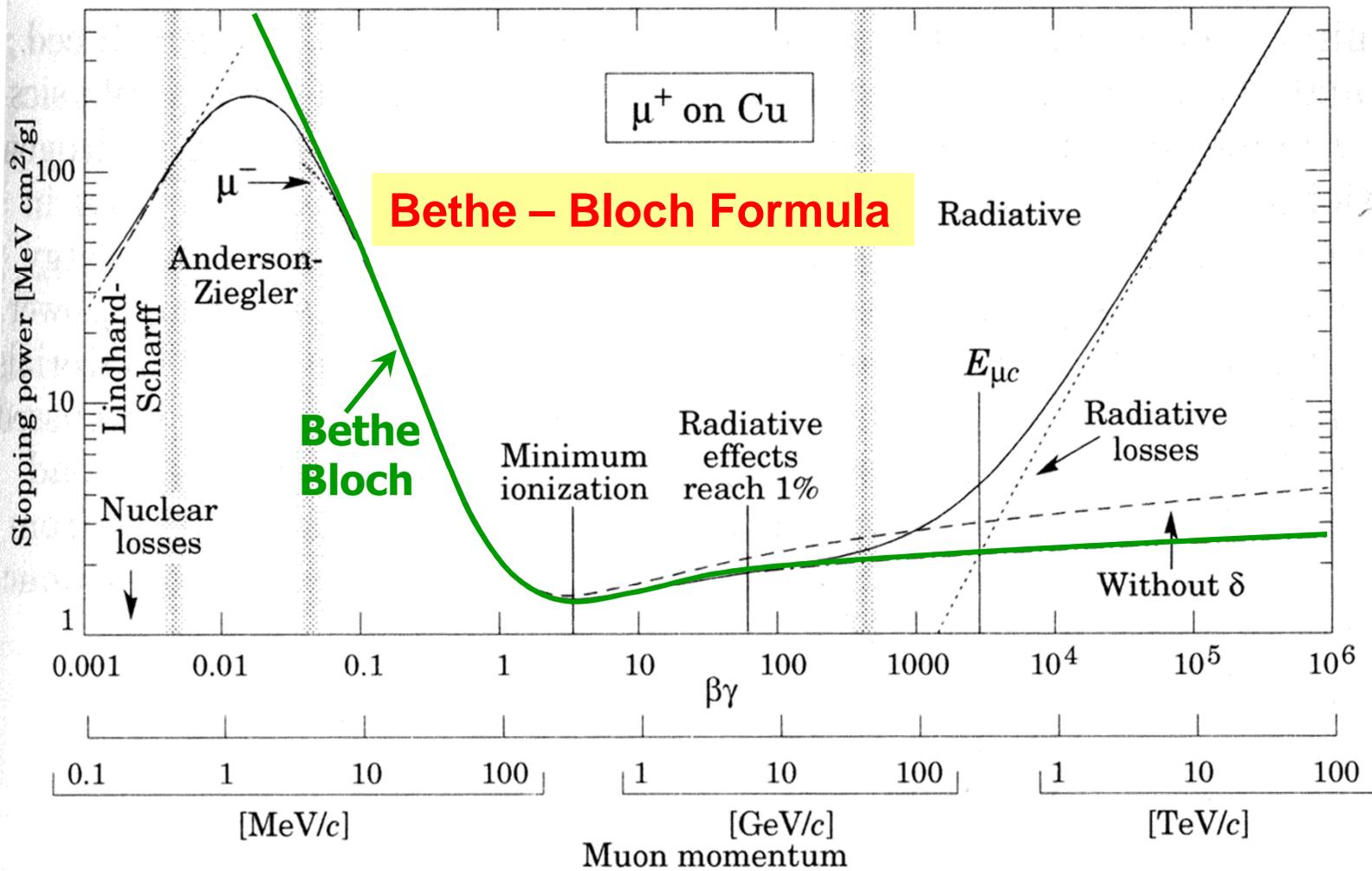


Stopping power

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln \left(\frac{2m_e c^2 \beta^2}{I(1-\beta^2)} \right) - \beta^2 \right]$$

$$\beta = v/c$$

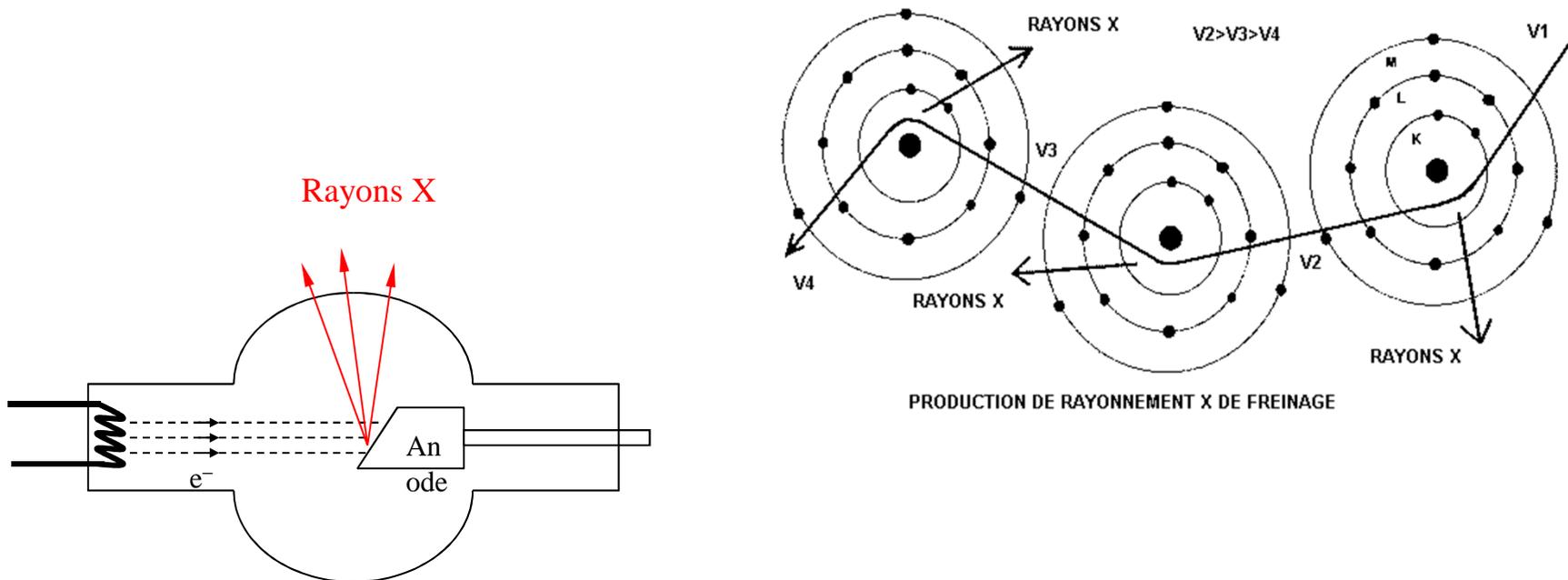
$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln \left(\frac{2m_e c^2 \beta^2}{I \cdot (1 - \beta^2)} \right) - \beta^2 \right]$$



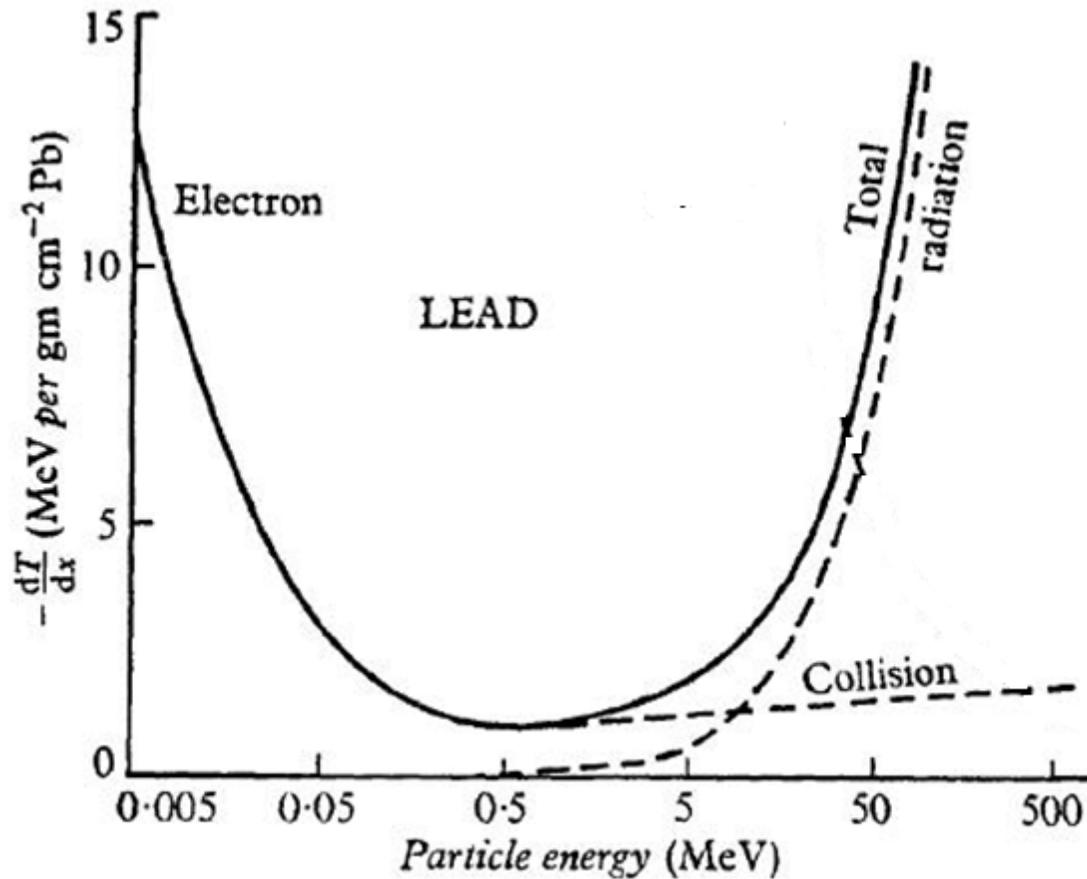
Rayonnement électromagnétique par des particules chargées

➤ Rayonnement primaire (cohérent et non isotrope)

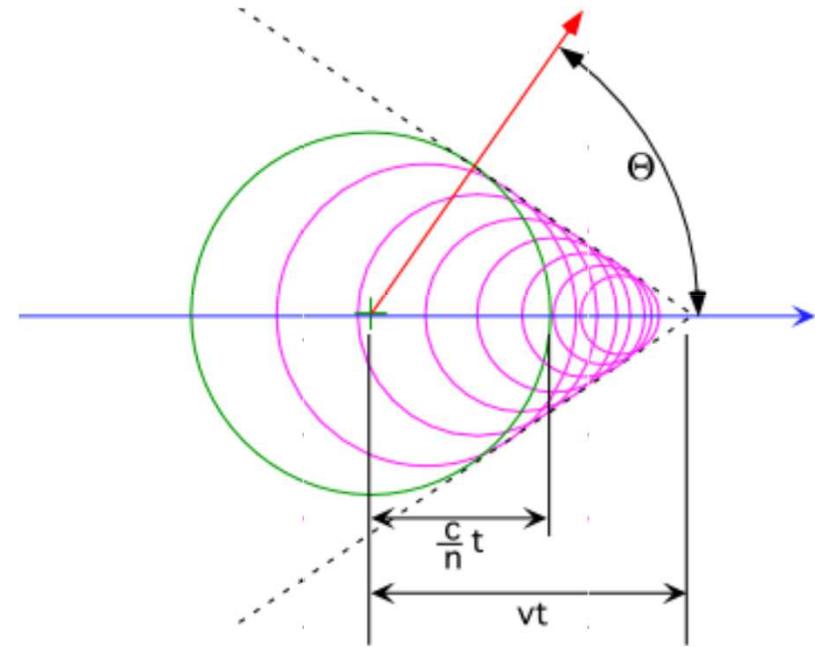
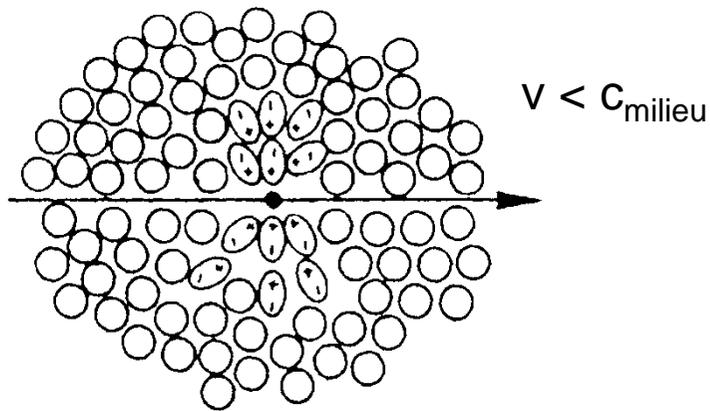
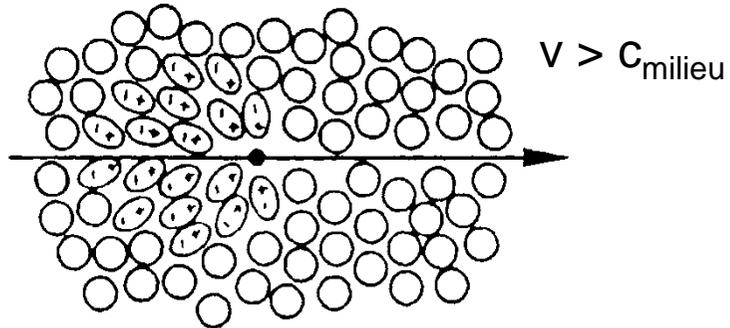
□ Bremsstrahlung (freinage → accélération)



Probabilité Bremsstrahlung : $\sigma \propto Z^2$

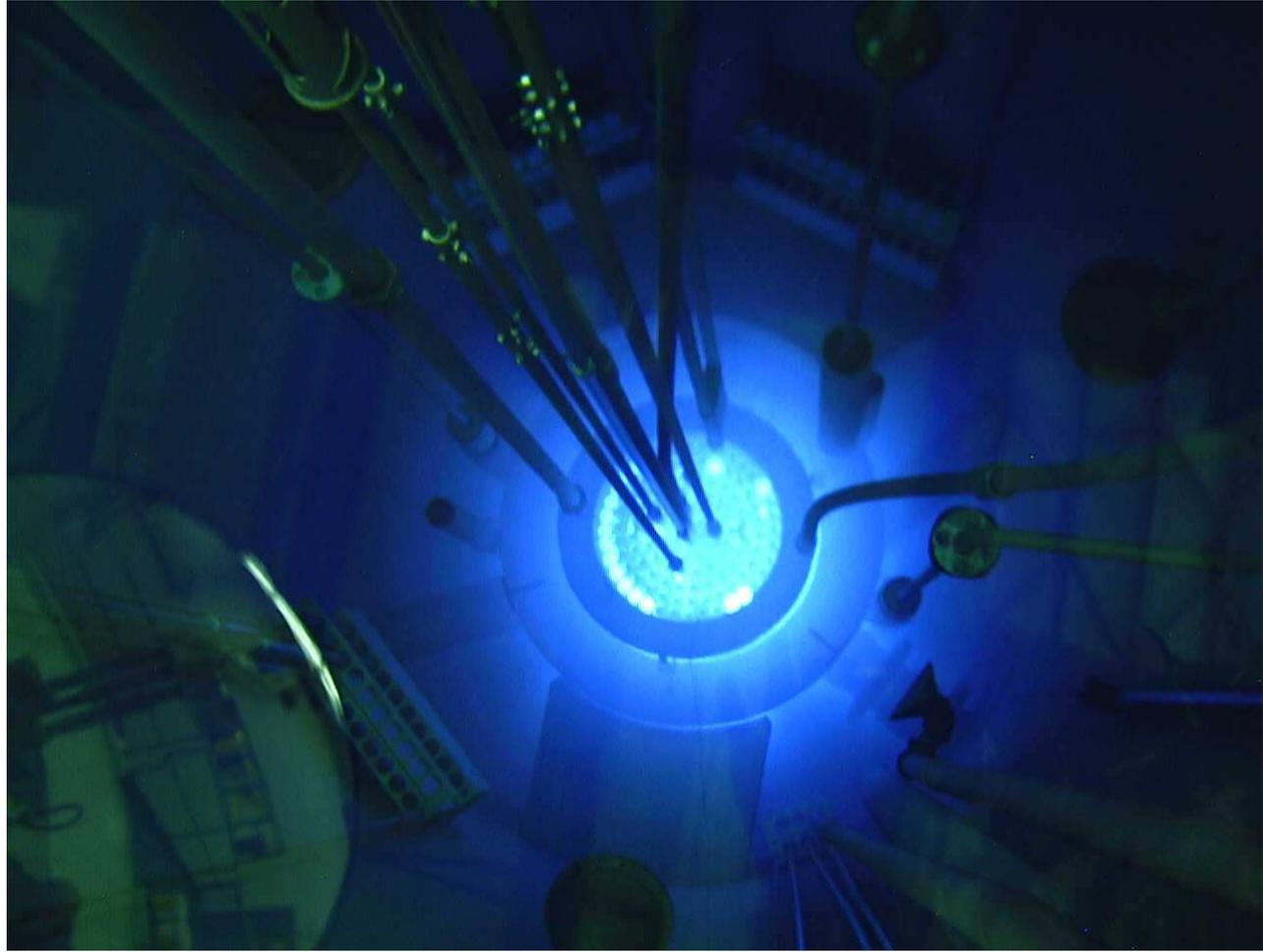


Cherenkov - Effect



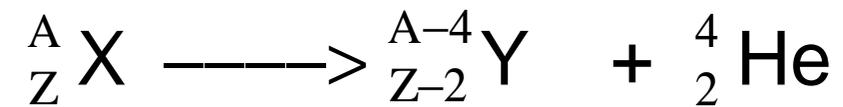
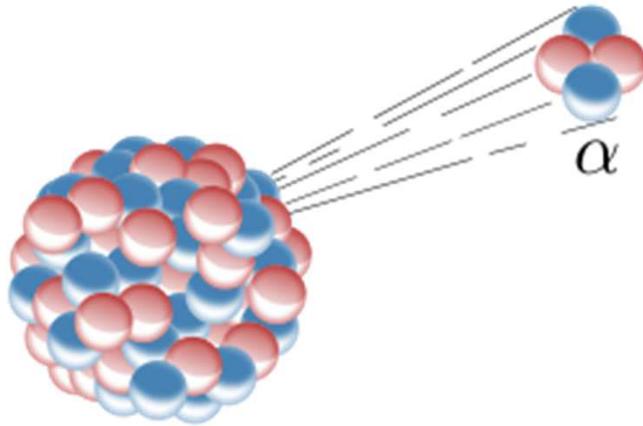
$$\cos \theta = \frac{1}{\beta n}$$

$$v > \frac{c}{n} \iff \beta > \frac{1}{n}$$



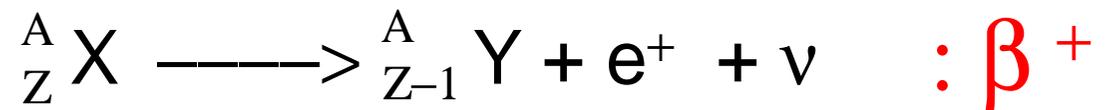
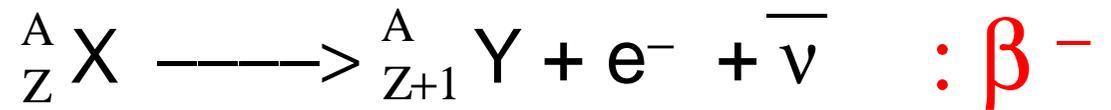
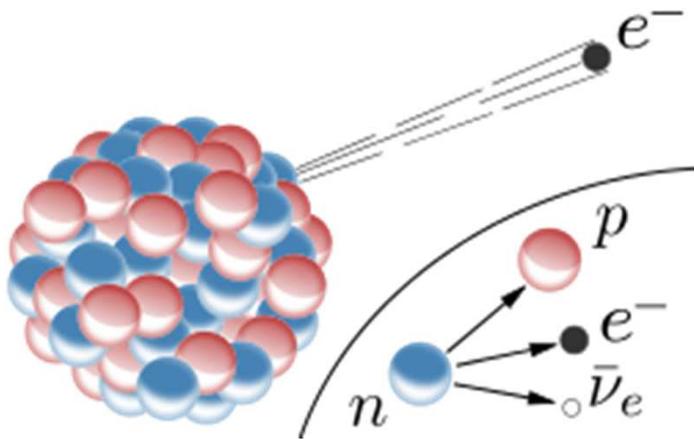
La radioactivité

La radioactivité alpha



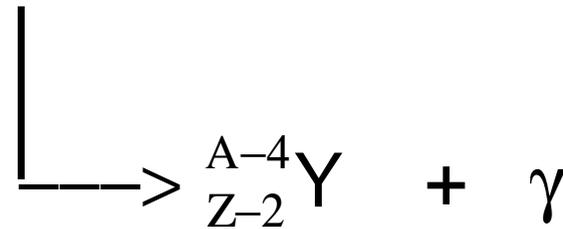
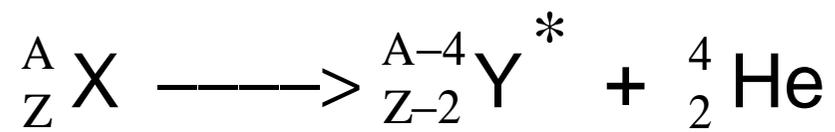
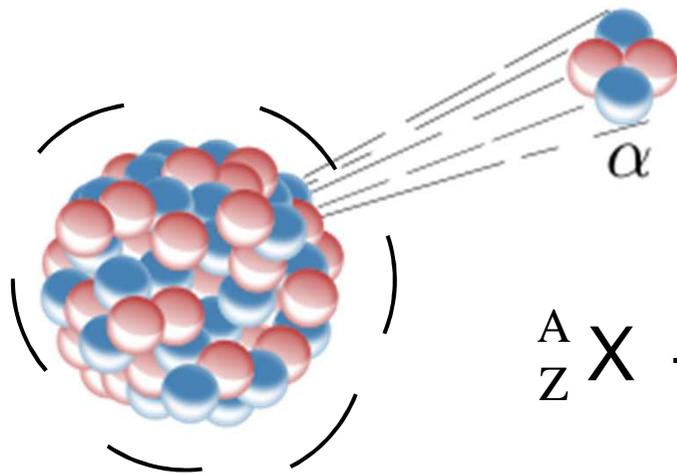
« Marche » pour des noyaux avec $A > \sim 150$

La radioactivité beta



Tous noyaux

La radioactivité gamma

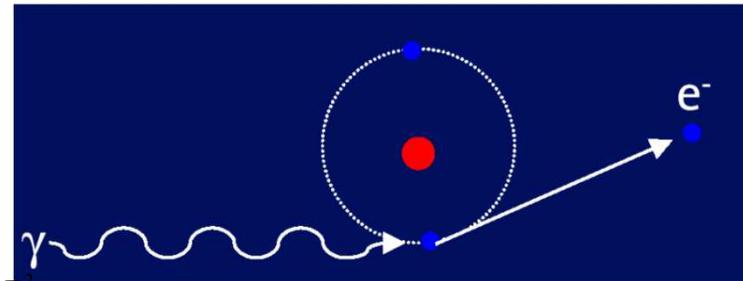


Interaction du rayonnement électromagnétique

➤ Effet photoélectrique

$$E_{\text{photoelec}} = E_{\gamma} - E_{\text{couche atom}}$$

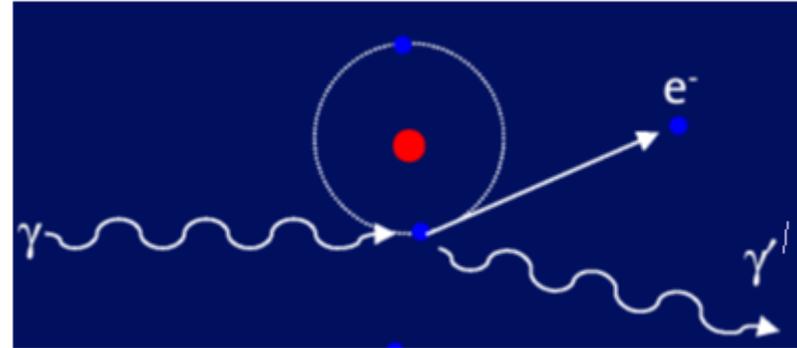
$\sigma_{\text{Compton}} \propto Z^2$



Interaction du rayonnement électromagnétique

➤ Effet Compton : $\gamma \rightarrow \gamma' + e^-$

Diffusion incohérente des γ sur des électrons quasi stationnaires



$$E_{\gamma} = h\nu$$
$$E_{\gamma'} = h\nu'$$

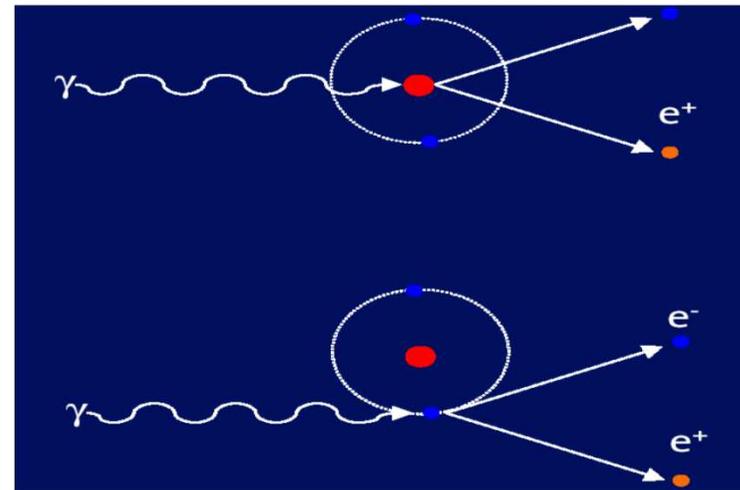
$$\left\{ \begin{array}{l} h\nu' = \frac{h\nu}{1 + \gamma(1 - \cos \theta)} \\ T = h\nu - h\nu' = h\nu \left(\frac{\gamma(1 - \cos \theta)}{1 + \gamma(1 - \cos \theta)} \right) \end{array} \right.$$

Interaction du rayonnement électromagnétique

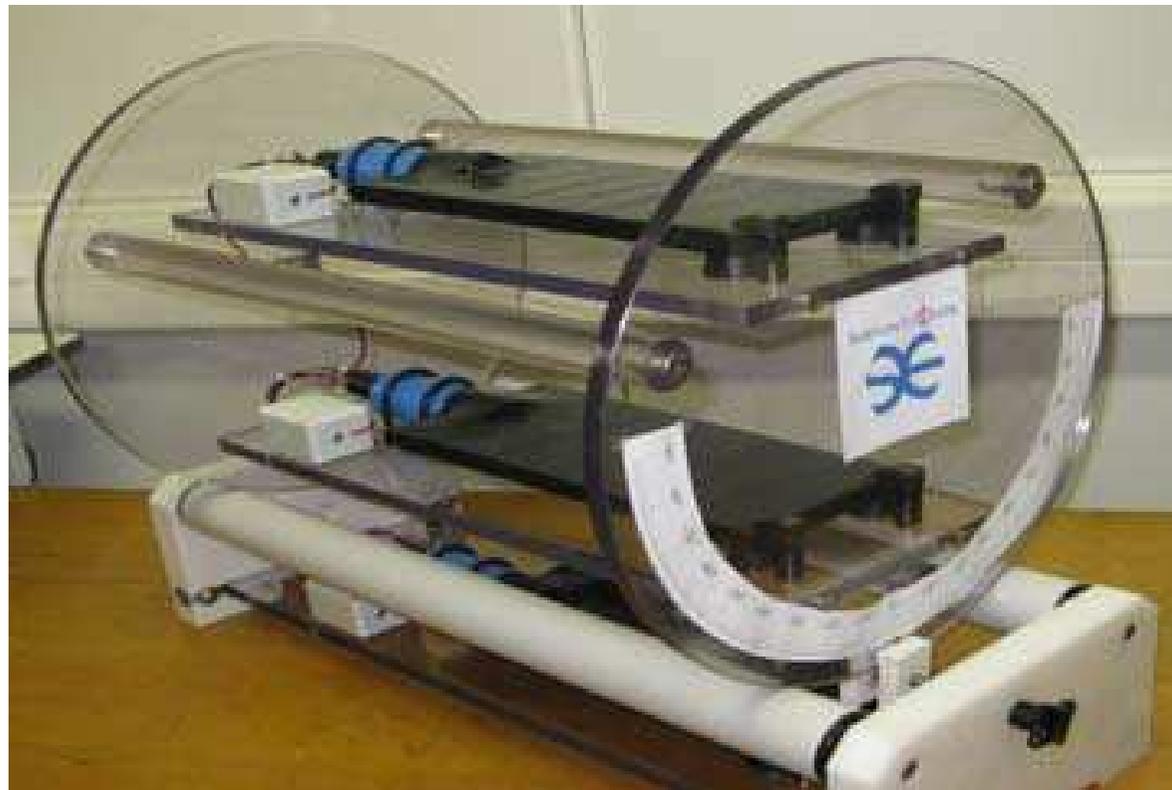
➤ Creation des paires

$$(E = m c^2)$$

$$E_{\gamma} > 2 \times m_e \text{ (1.022 MeV)}$$



Roue Cosmique



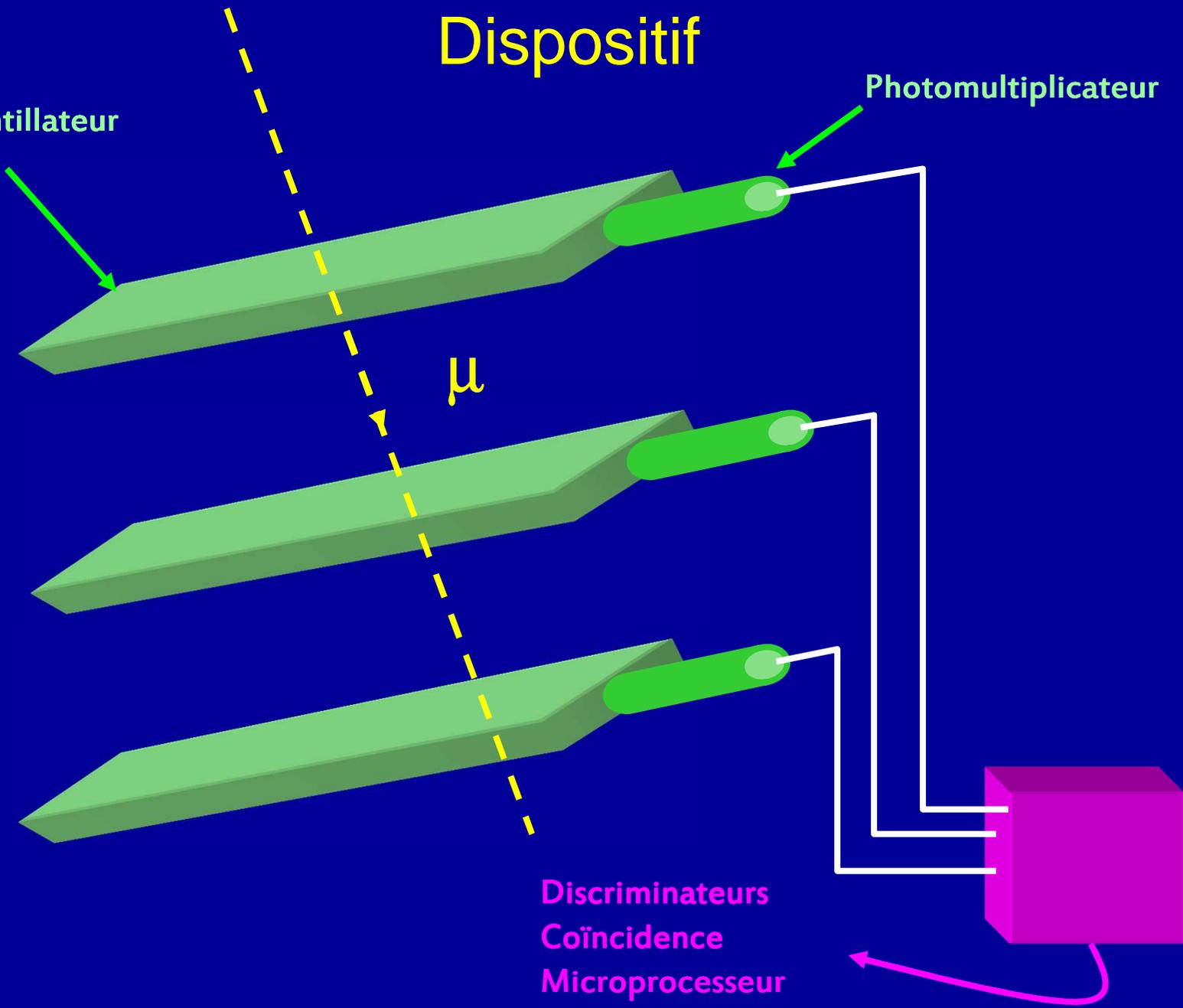
Dispositif

Scintillateur

Photomultiplicateur

μ

Discriminateurs
Coïncidence
Microprocesseur

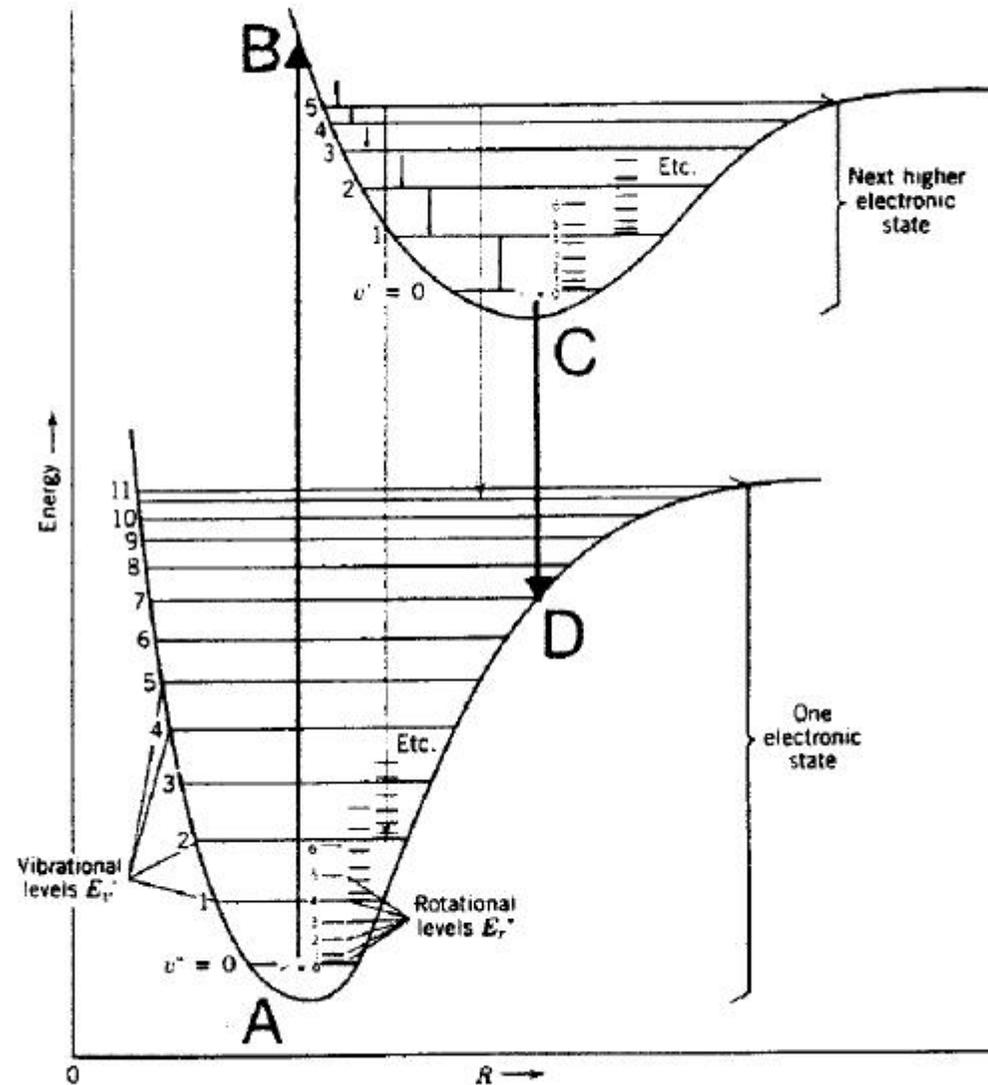


Scintillateur

Structure en bandes

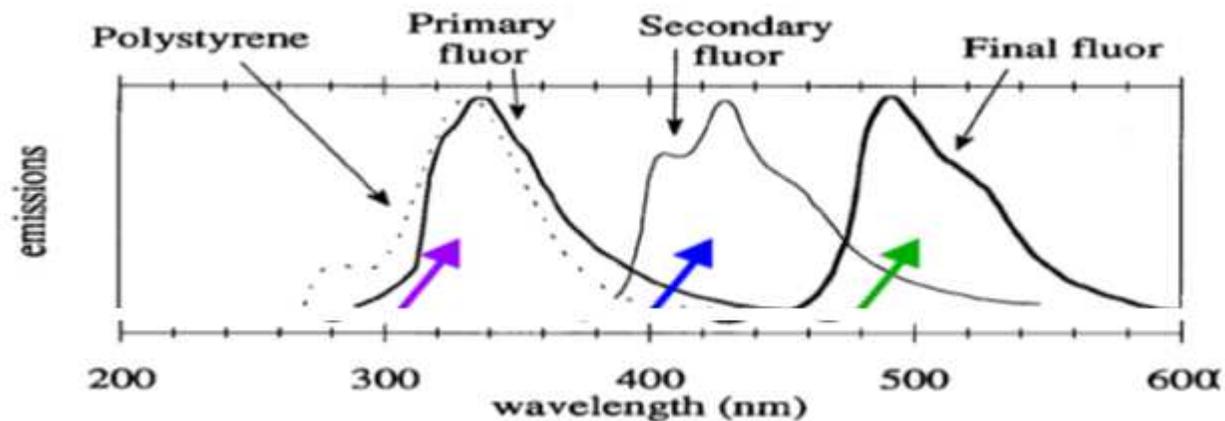
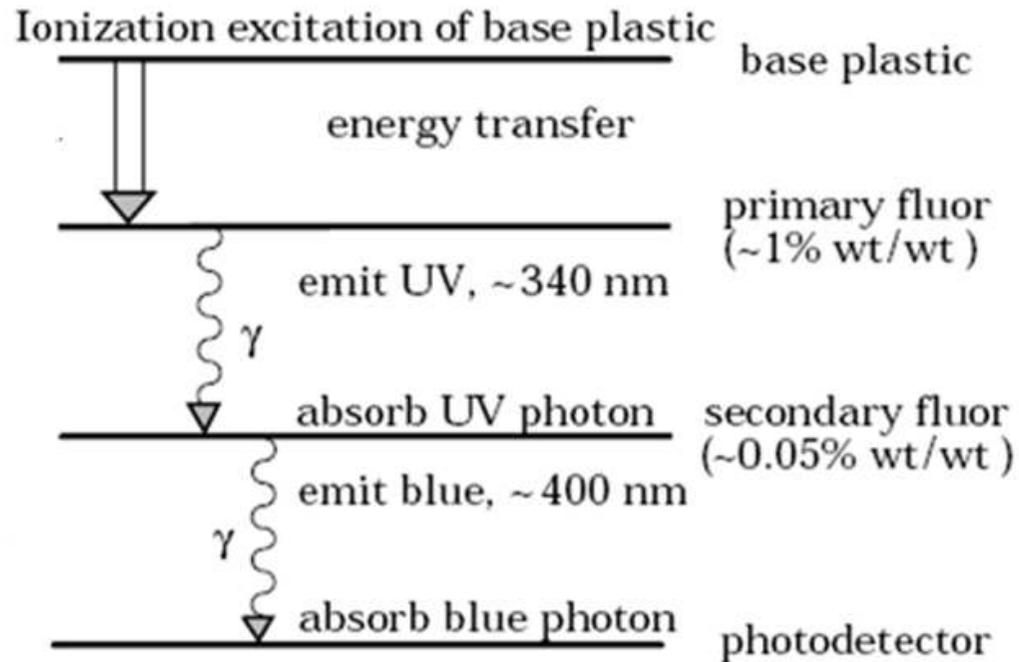
A → B : Absorption

C → D : Emission

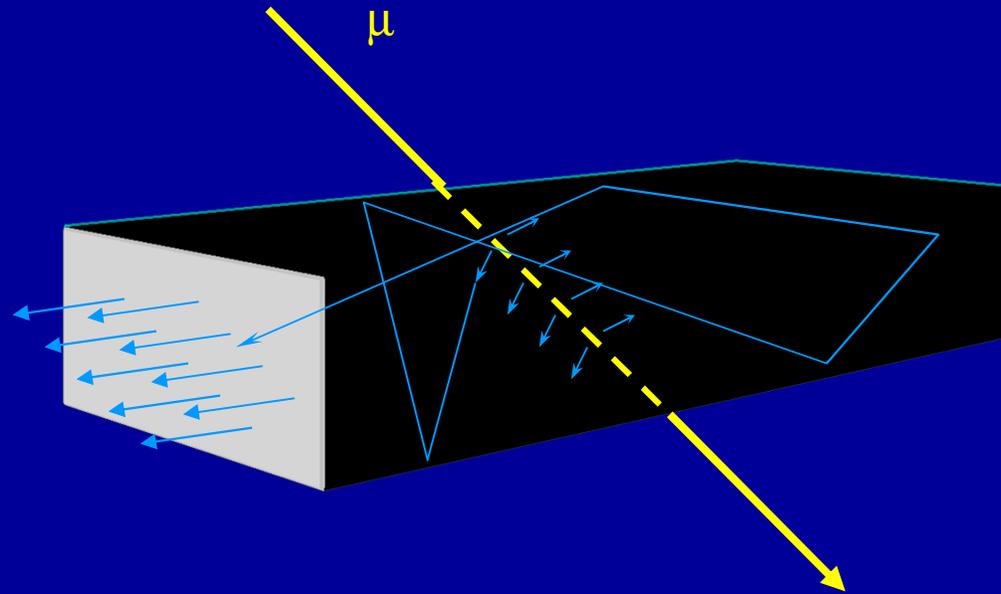


$E_{AB} > E_{CD} \Rightarrow$ Matériau transparent a sa propre lumière

Plusieurs composants => Scintillateurs



Scintillateurs



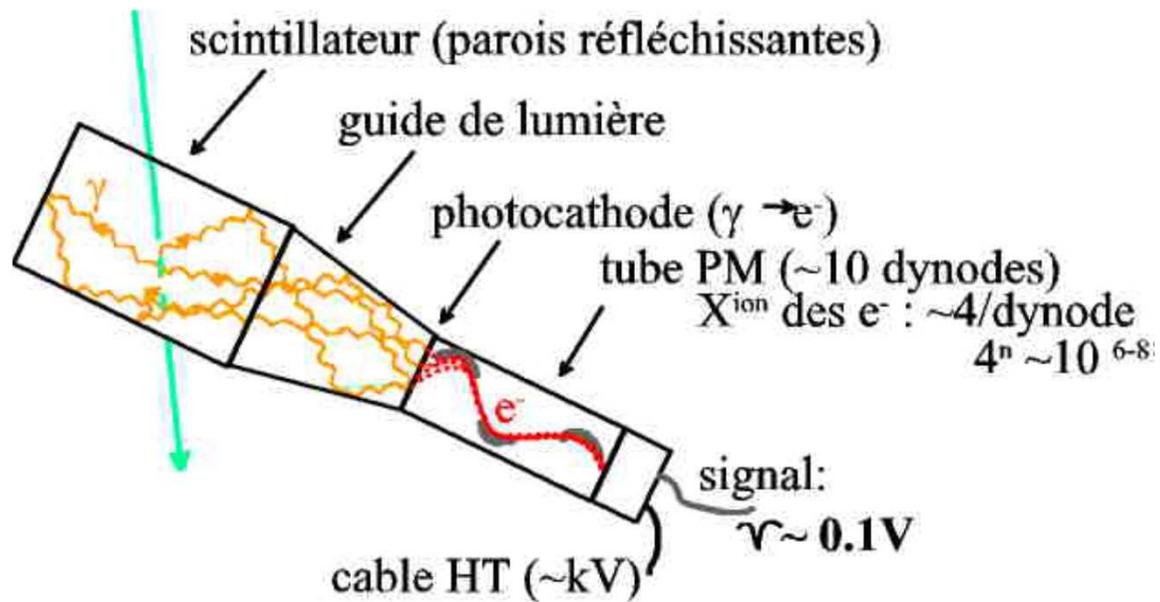
Milieux organiques aromatiques (polystyrène, polyvinyltoluène, ...)

Réflecteur

Protection

Les scintillateurs

- Dans certains matériaux : excitation des molécules par particule ionisante
→ luminescence
- Les γ produits ($\lambda \sim$ visible) atteignent la photocathode d'un tube photomultiplicateur (P.M)



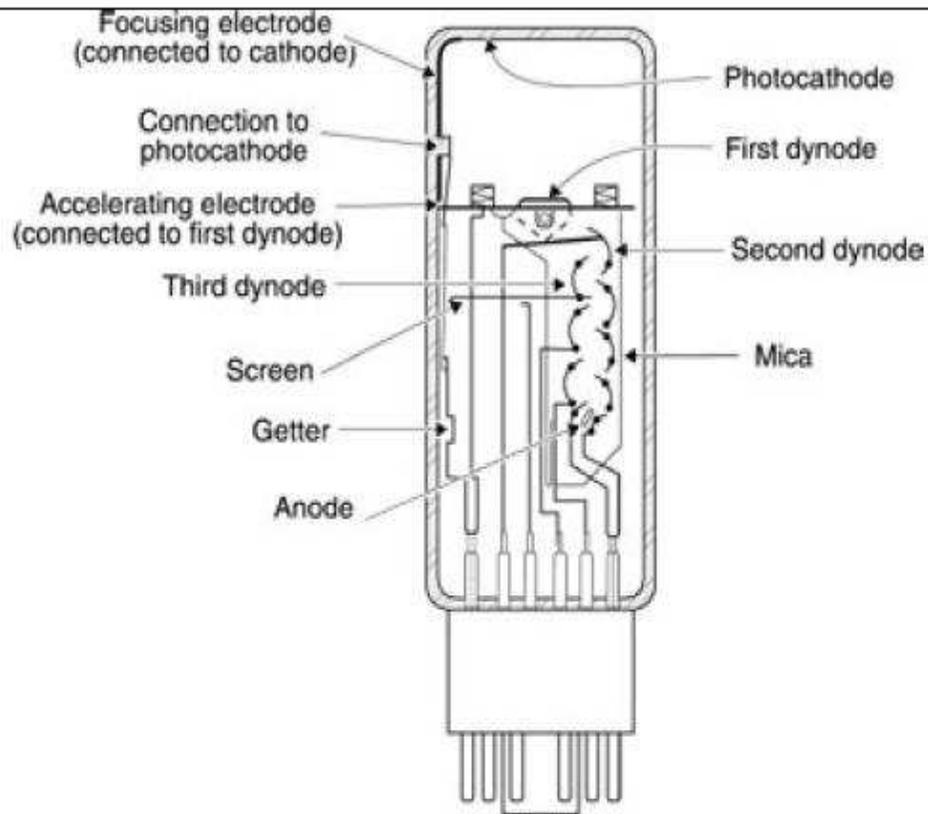


Figure 1 : Coupe d'un photomultiplicateur.

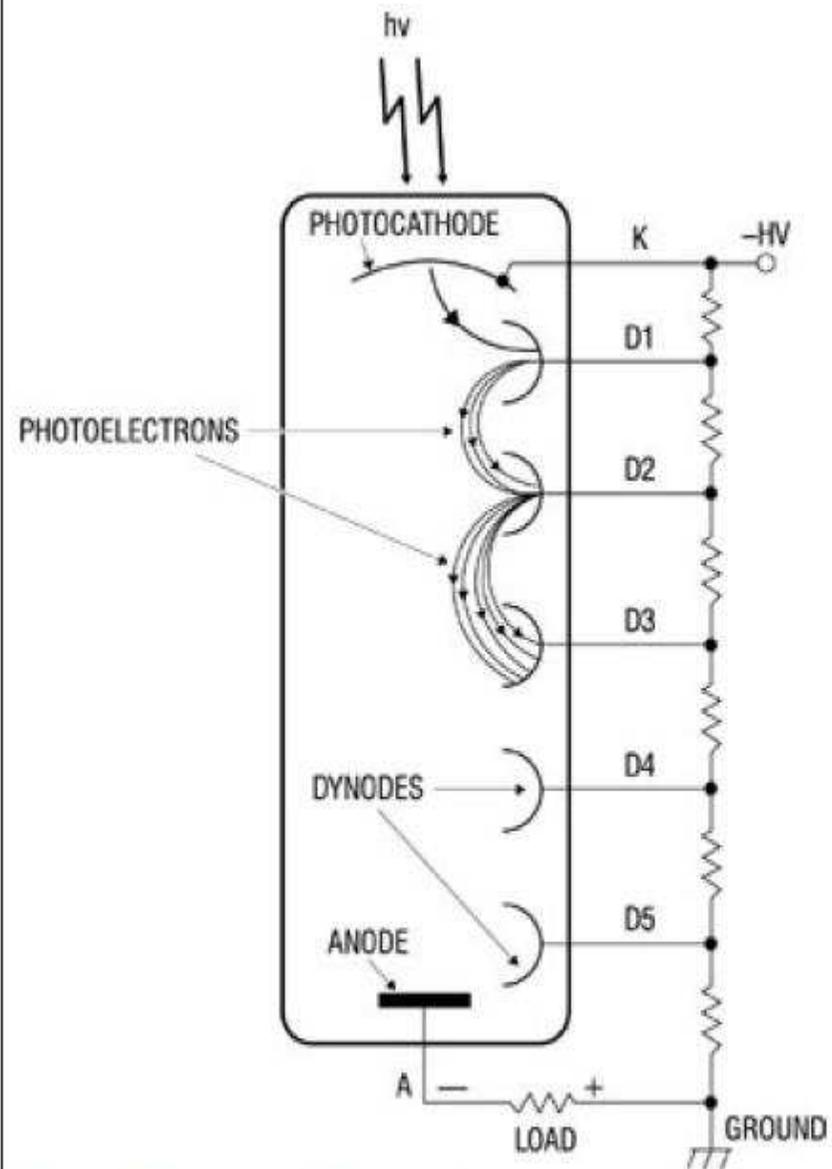
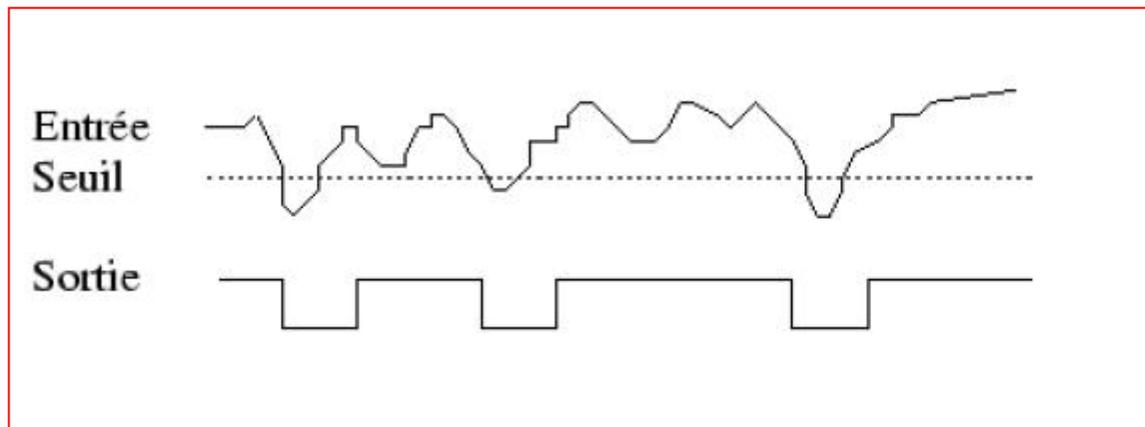
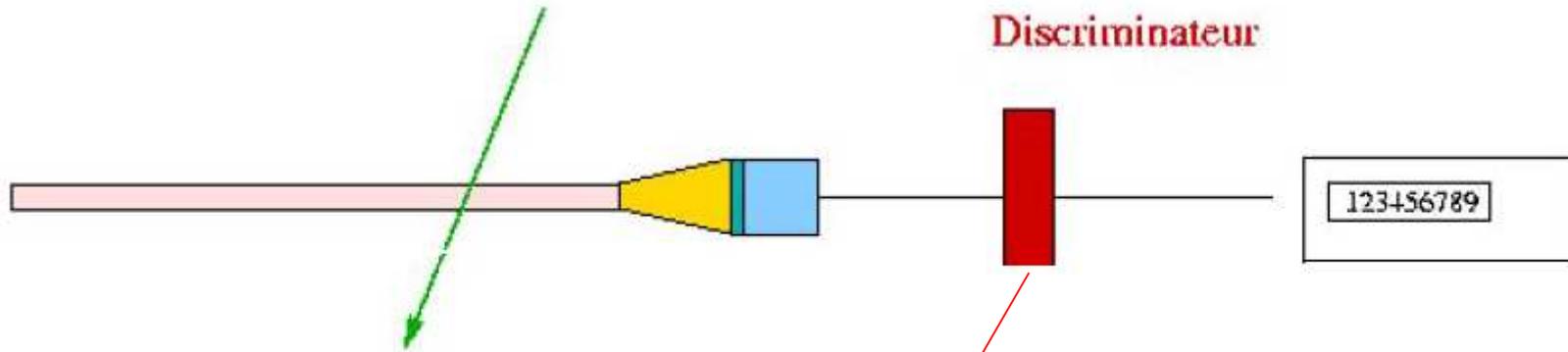
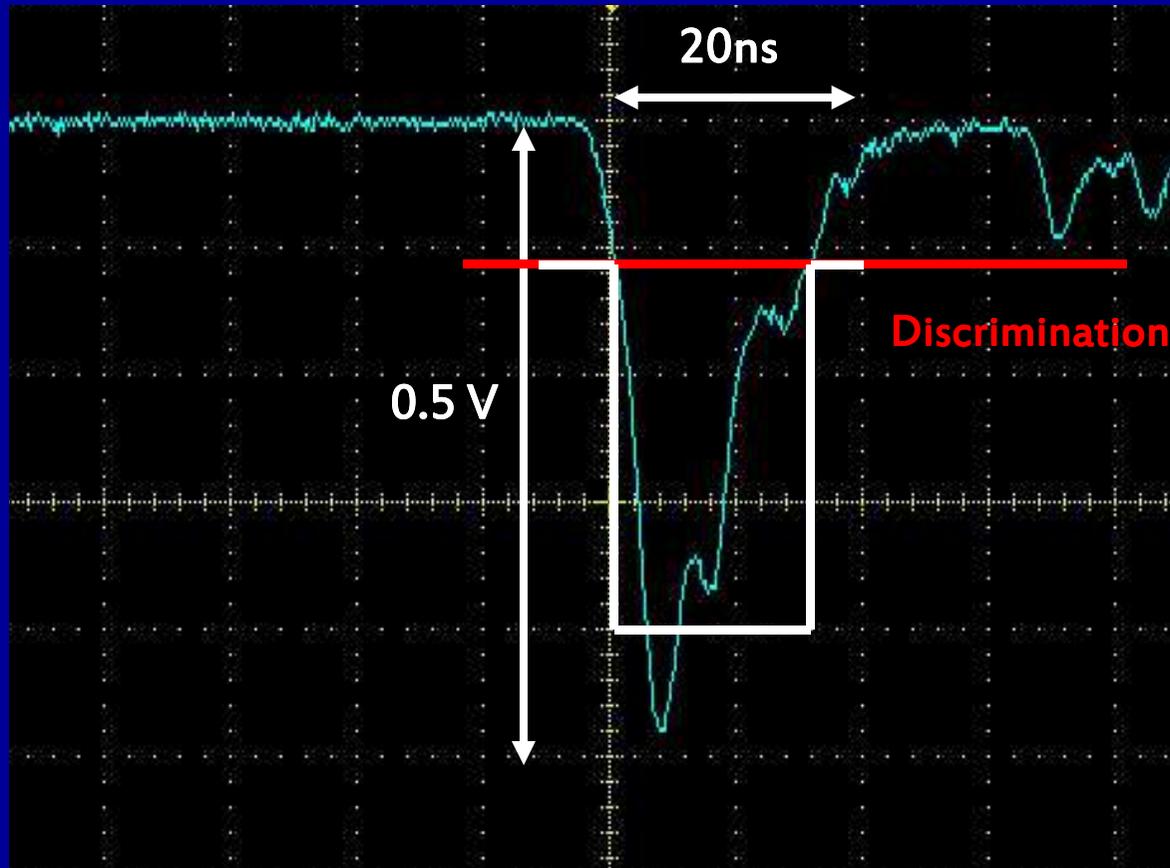


Figure 2 : Conversion des photons issus du cristal de NaI et multiplication des électrons par les dynodes.

Simple arrangement

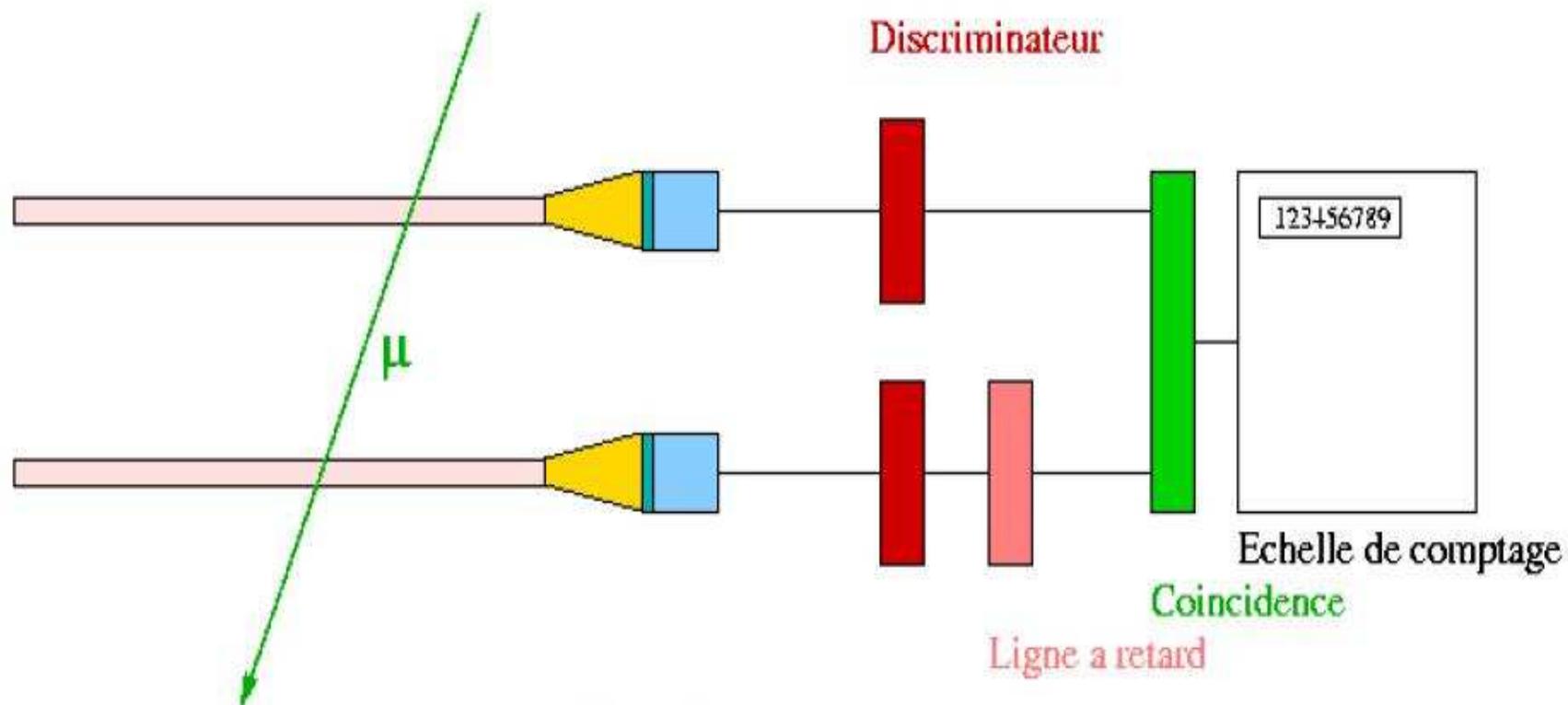


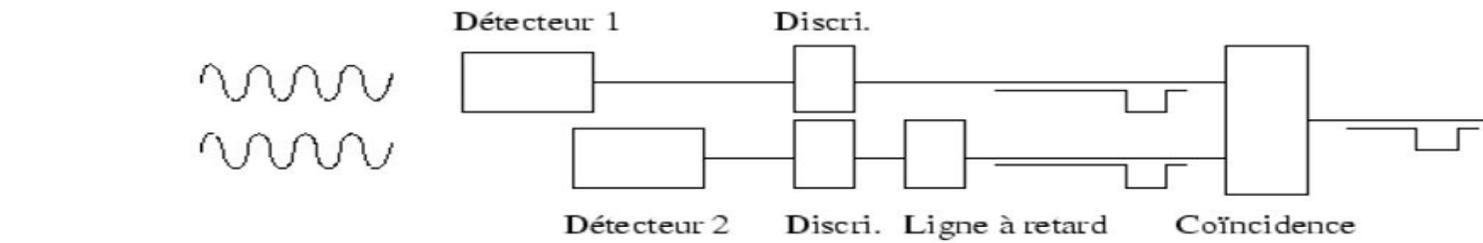
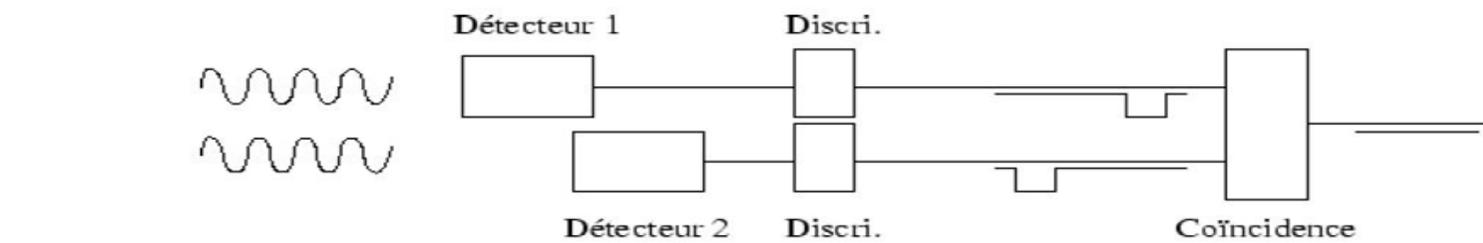
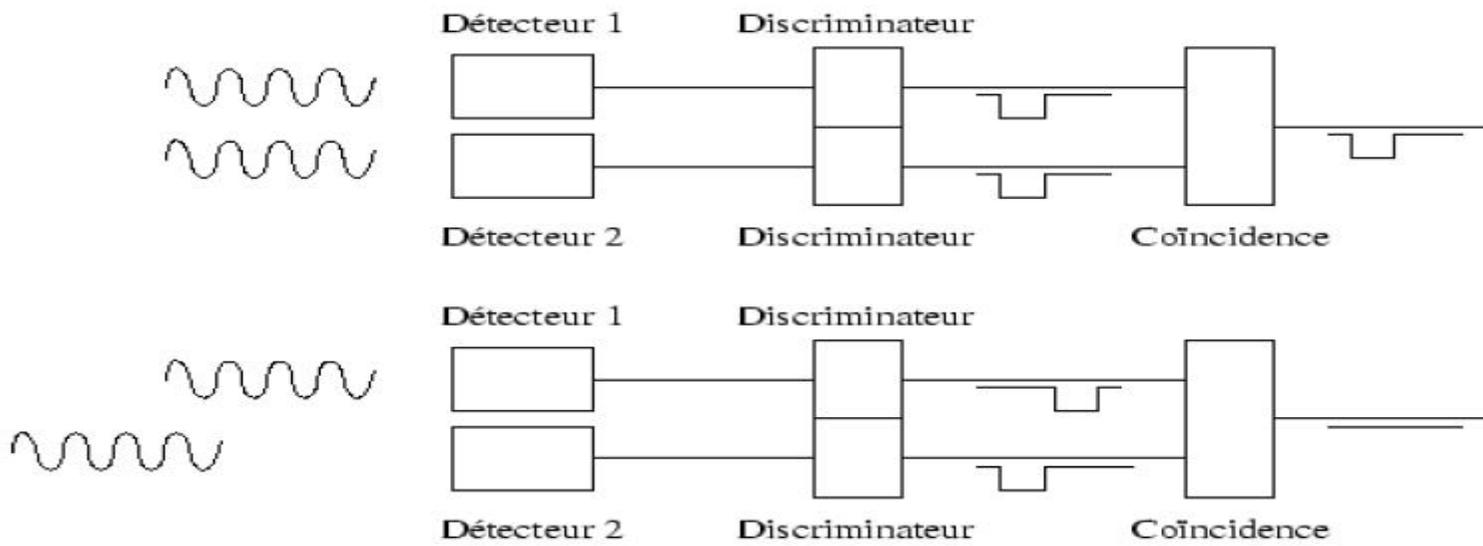
Forme du signal ...



- ⇒ Timing
- ⇒ pas d'énergie

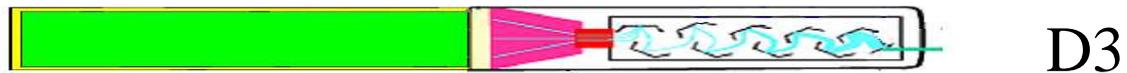
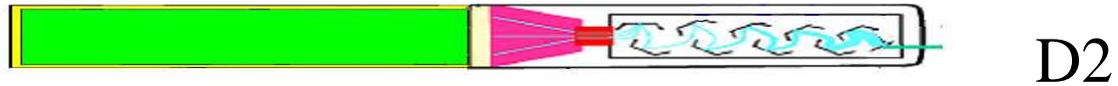
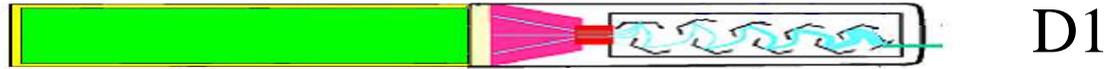
La détection en coïncidence





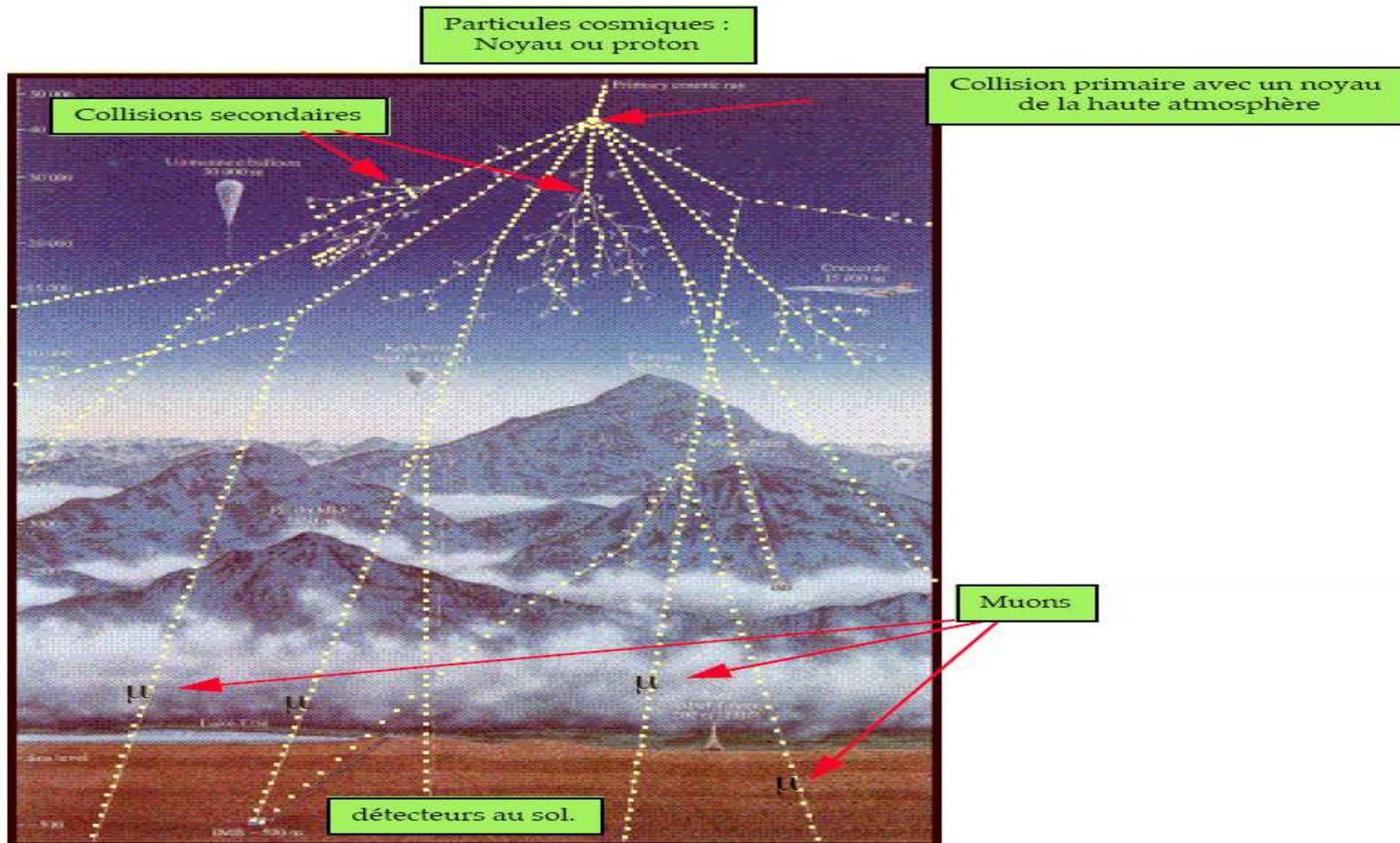
La Roue Cosmique

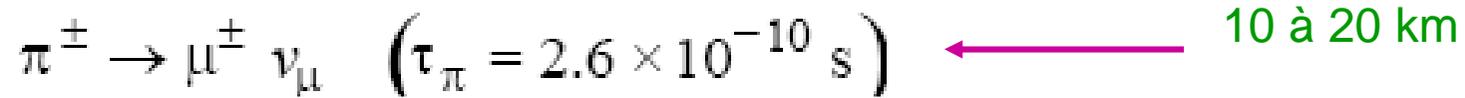
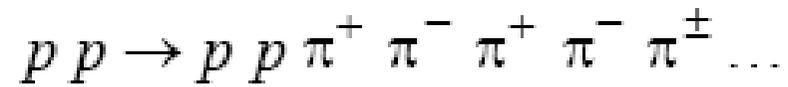
3 raquettes (30 cm X 10 cm X 1 cm)



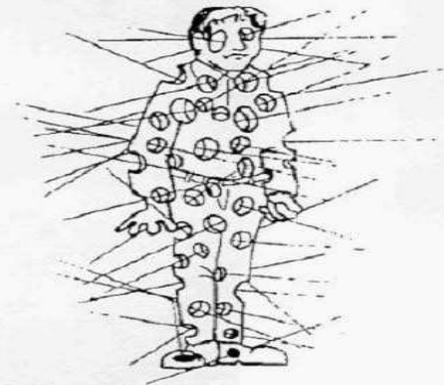
Coïncidences : D1 + D2,
: D2 + D3,
: D1 + D3,
: D1 + D2 + D3

Les Muons atmosphériques





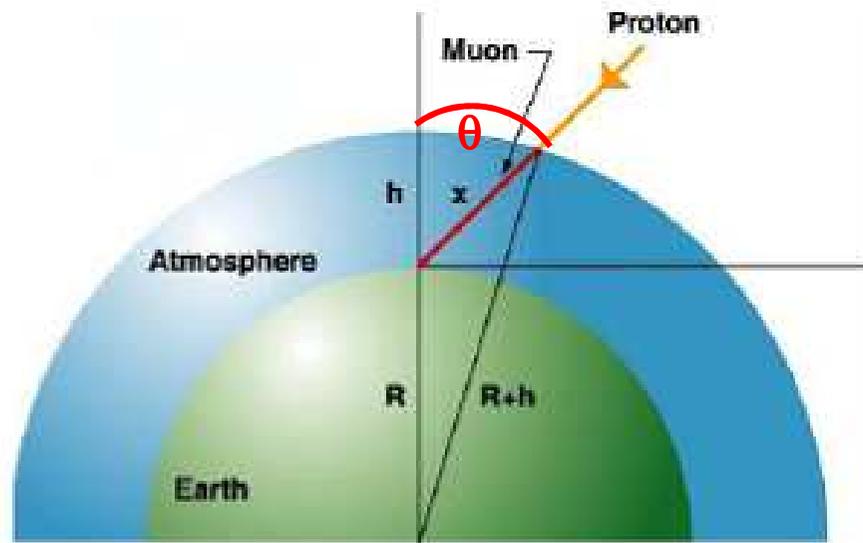
- Flux $\sim 180 \mu / \text{m}^2 / \text{s}$



**100,000 COSMIC RAYS WILL
HIT YOU IN THE NEXT HOUR!**

- $\tau_\mu = 2.2 \mu\text{s}$

Distribution angulaire



$$j(\theta) = 110 \cos^2(\theta) [m^{-2}s^{-1}sr^{-1}]$$

Vérifiée
expérimentalement
pour $E_m \sim 4 \text{ GeV}$

Distribution angulaire

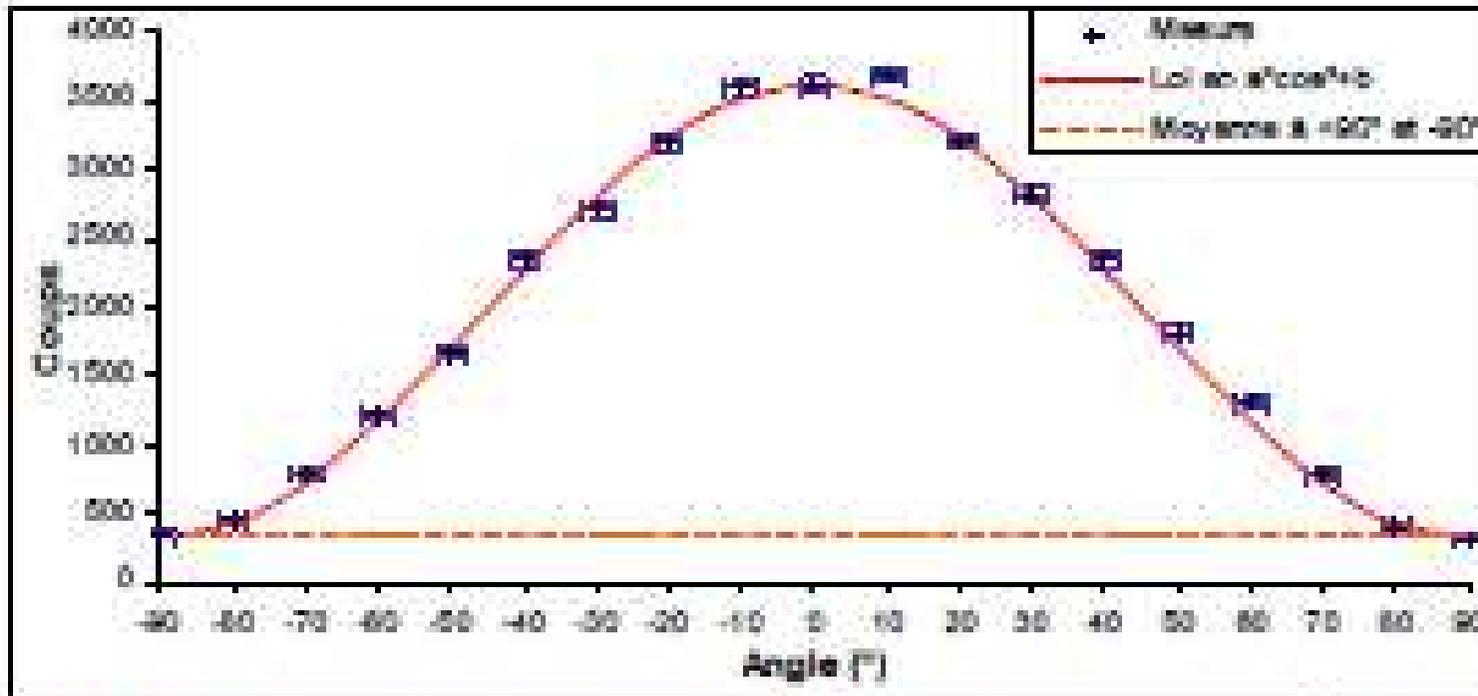
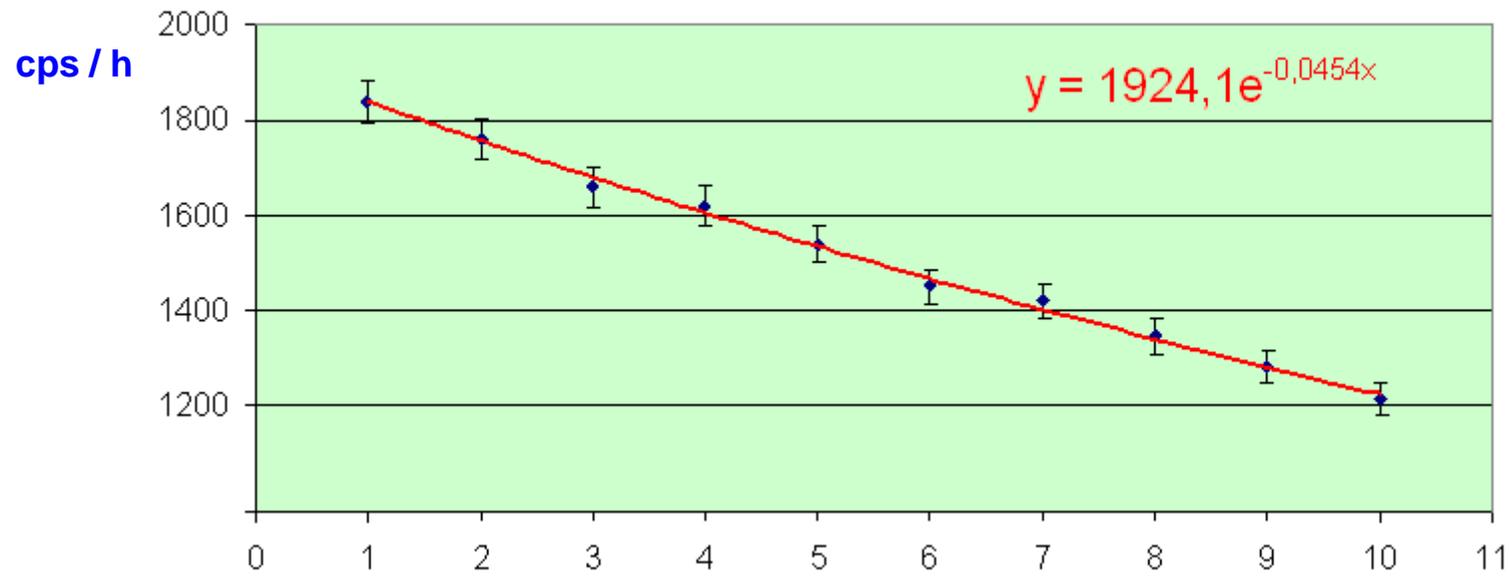


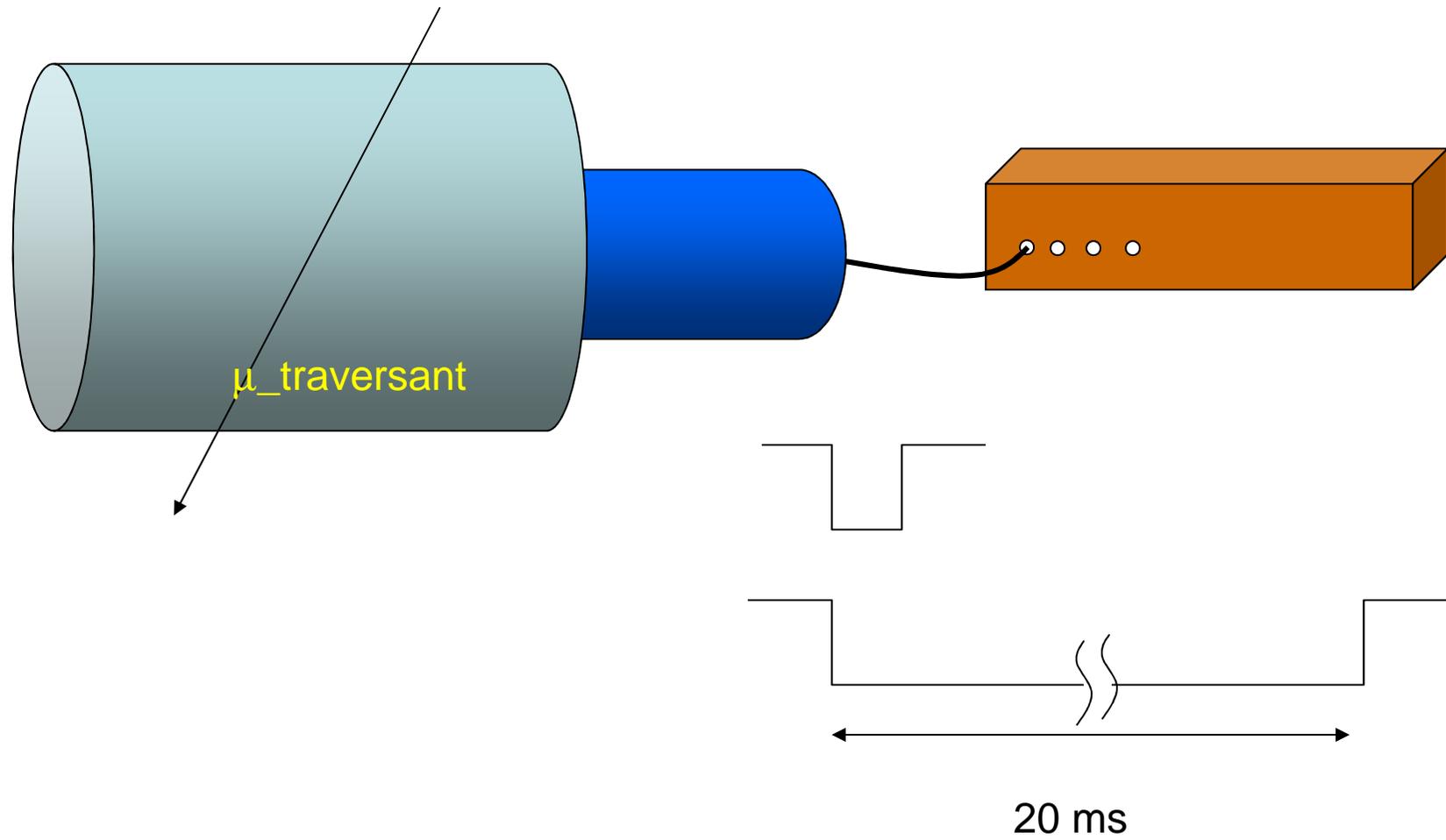
Fig. 4.2. Distribution angulaire du flux de muons atmosphériques

Variation du flux de muons avec l'épaisseur de béton

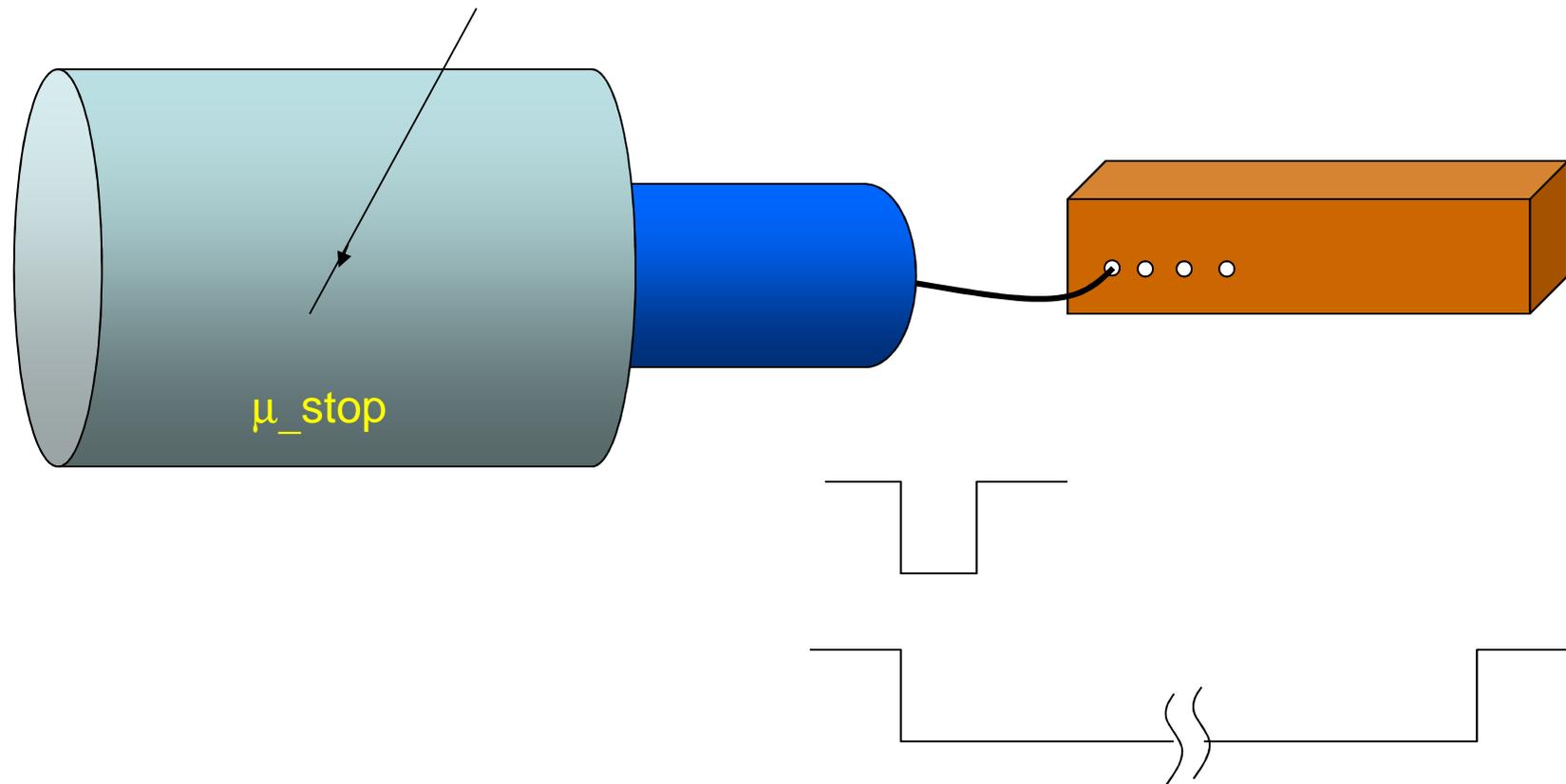


Etage TPR2

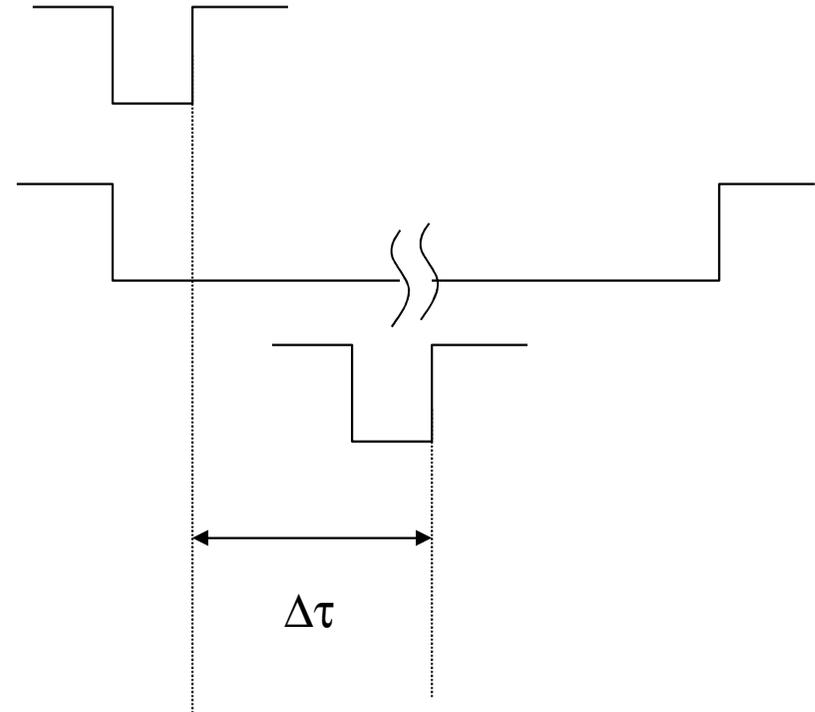
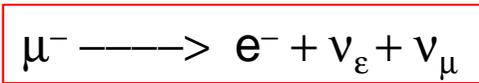
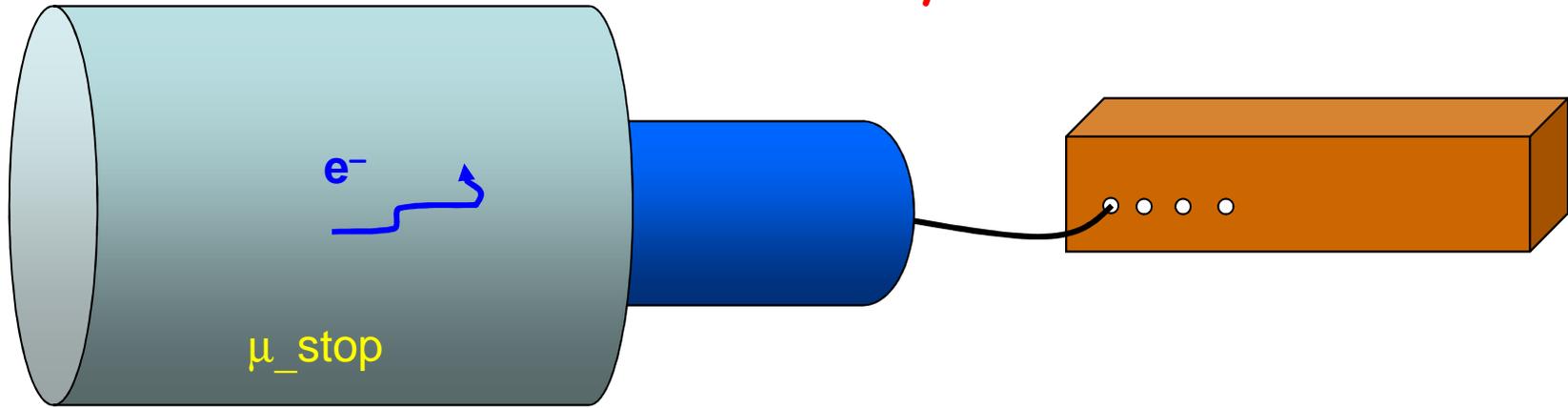
Vie moyenne du muon



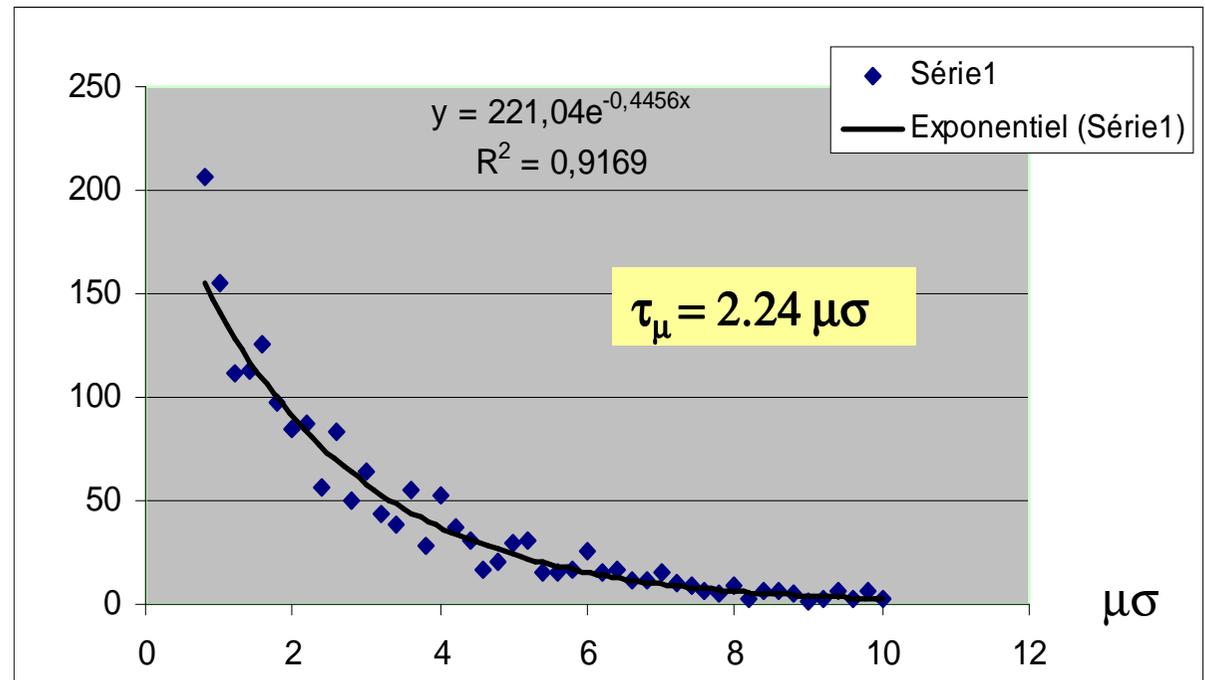
Vie moyenne du muon



Vie moyenne du muon



Vie moyenne du muon X

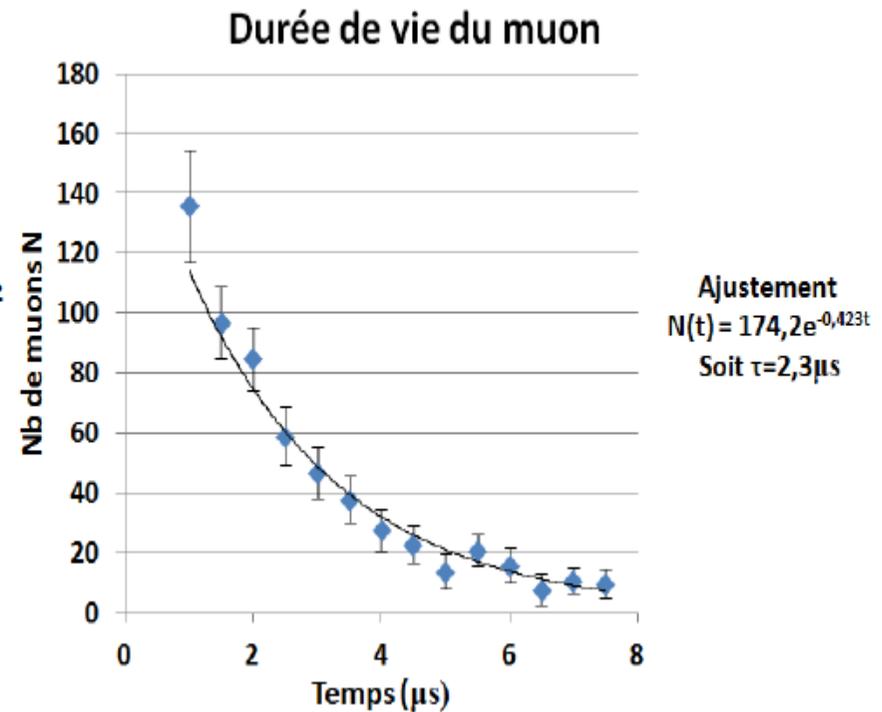
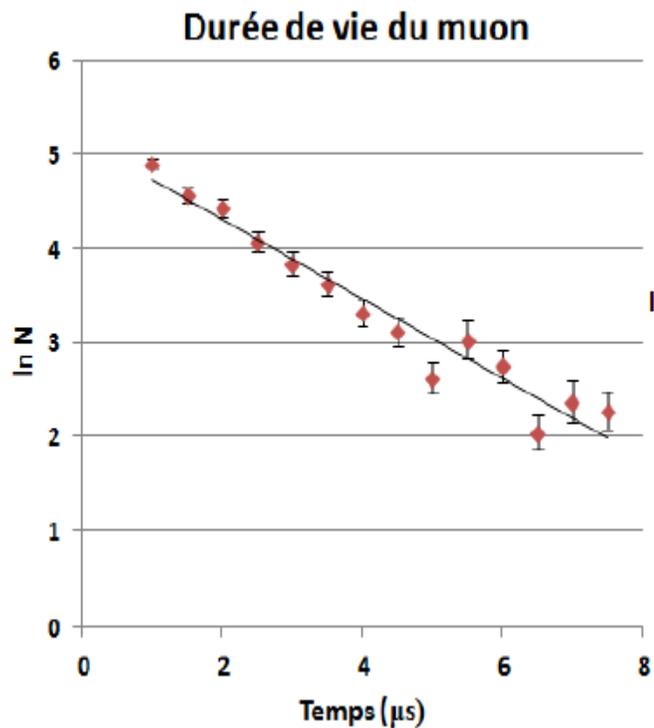


Vie moyenne du muon

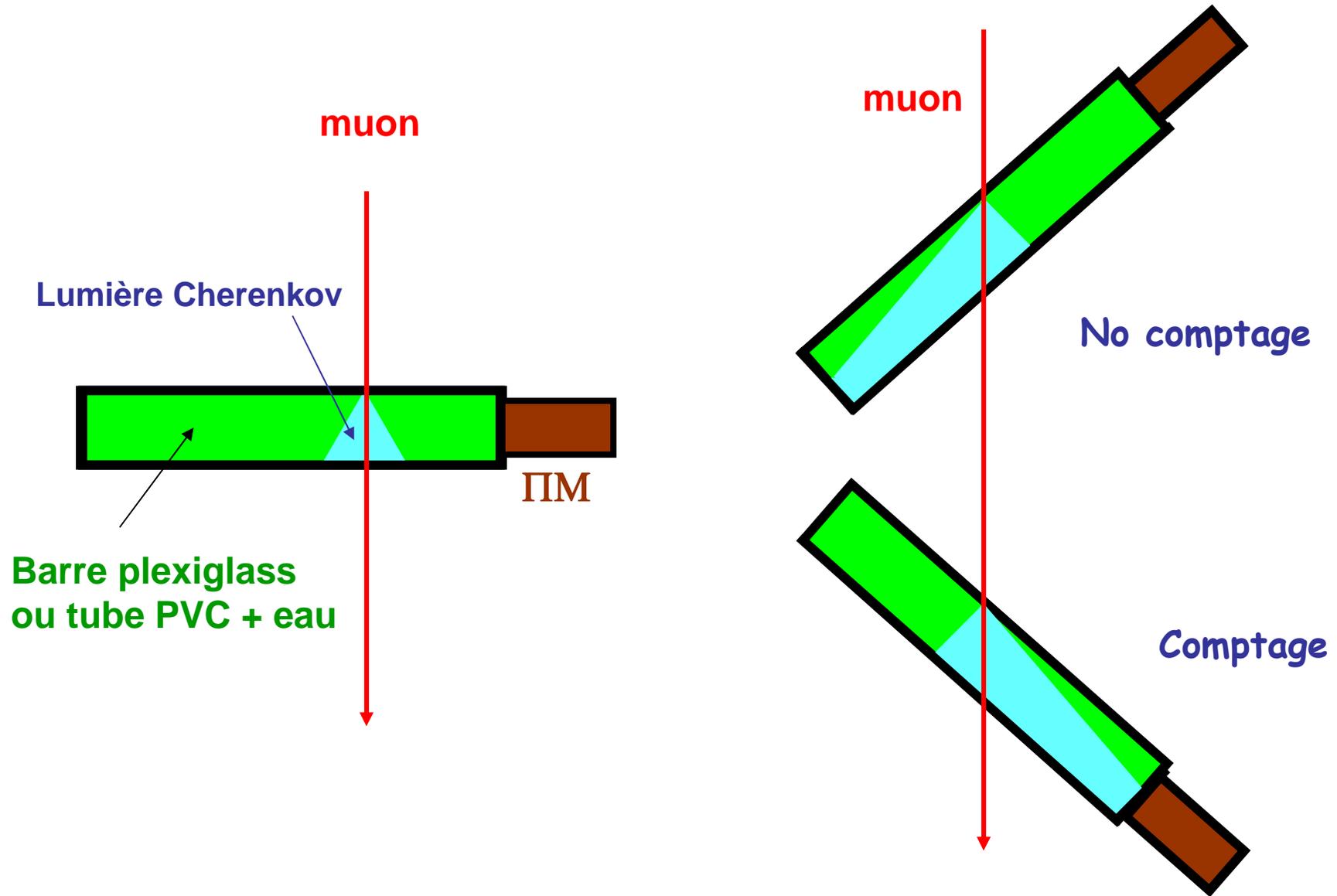
→ Muon_Stop

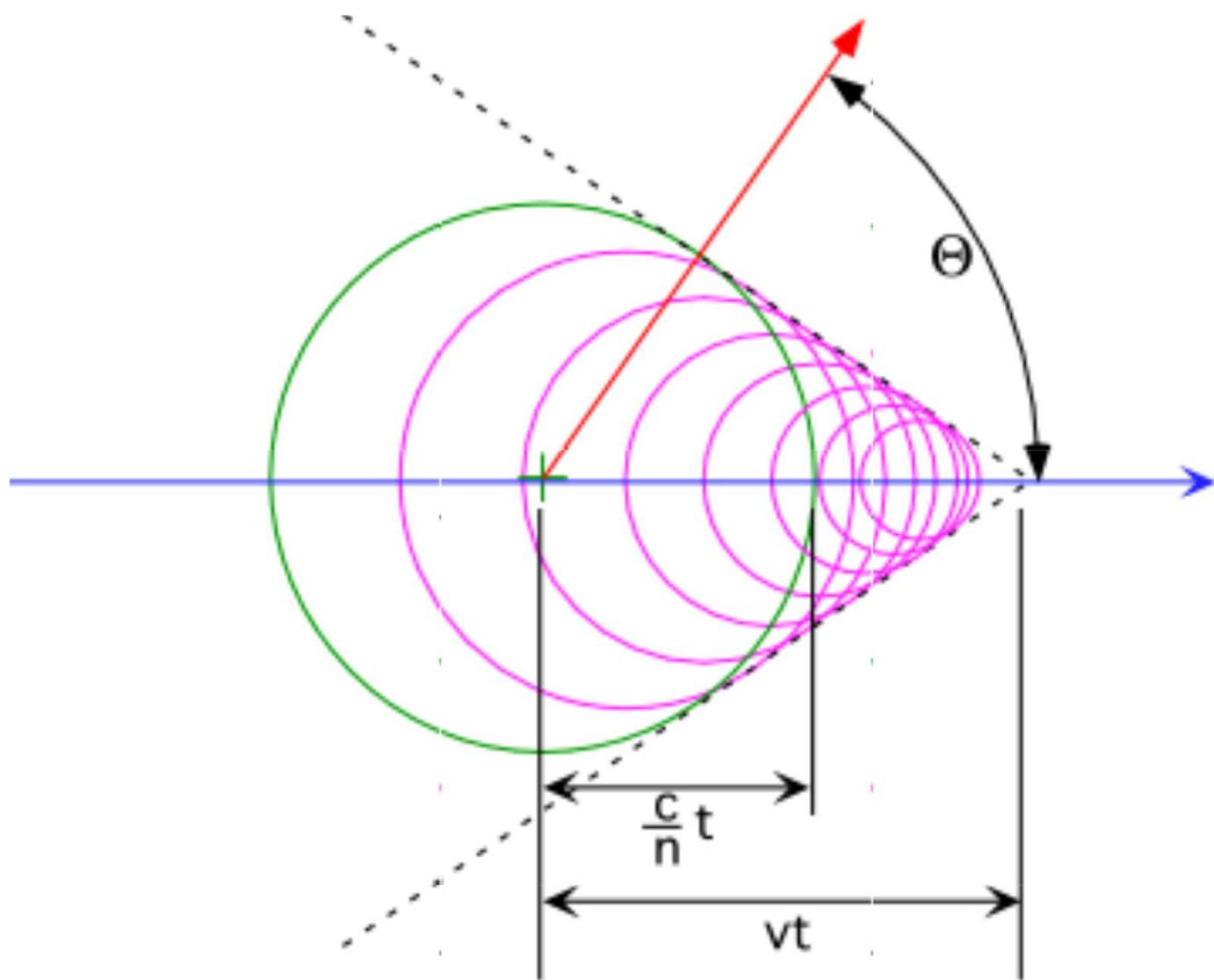


Allure des courbes obtenues :

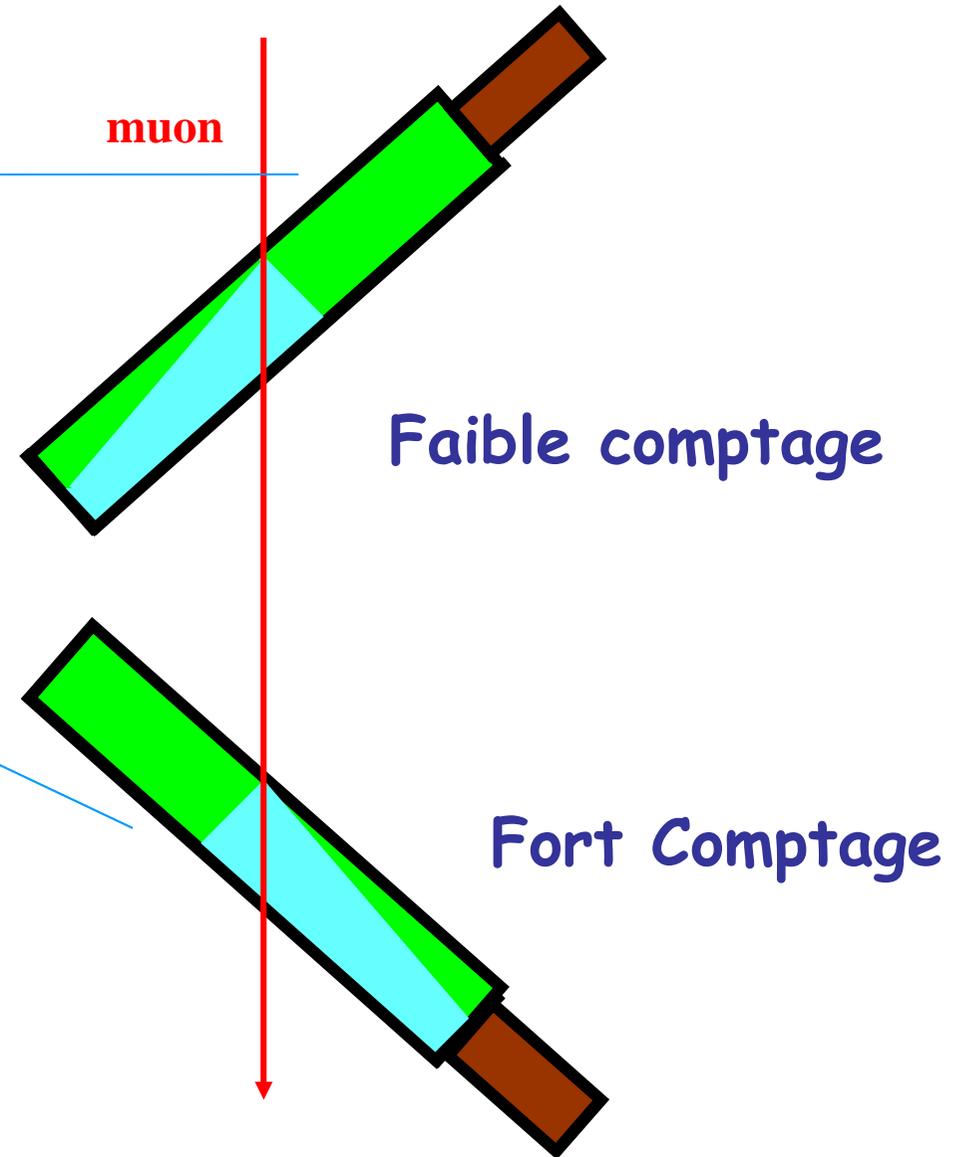
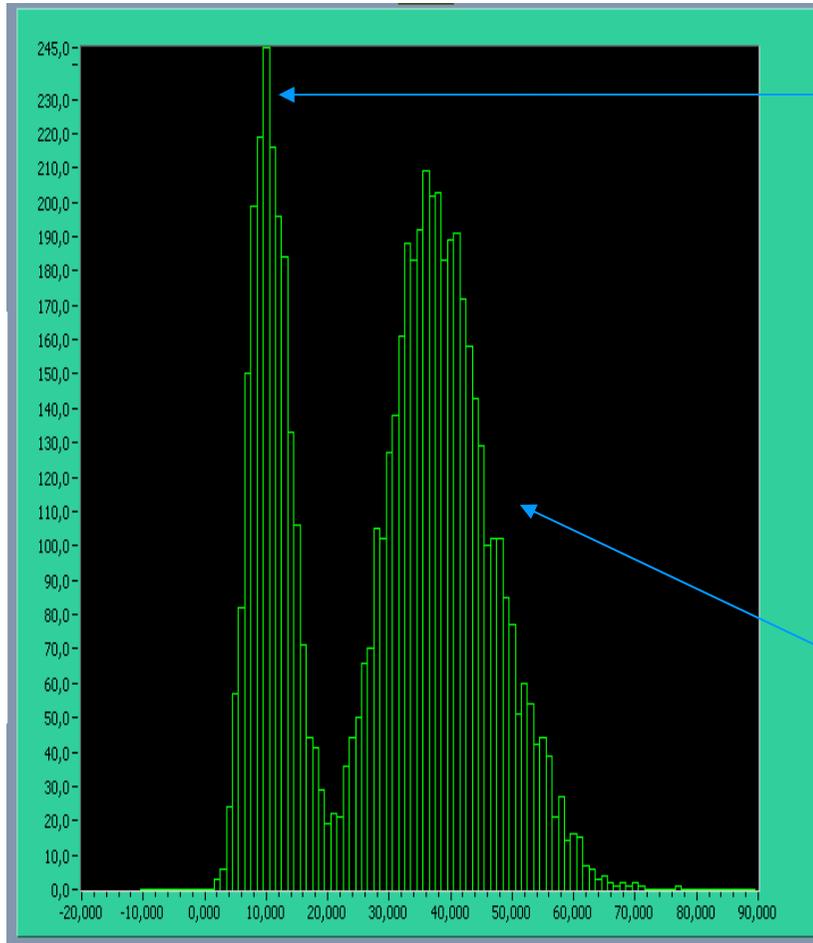


Effet Cherenkov (sens des muons)

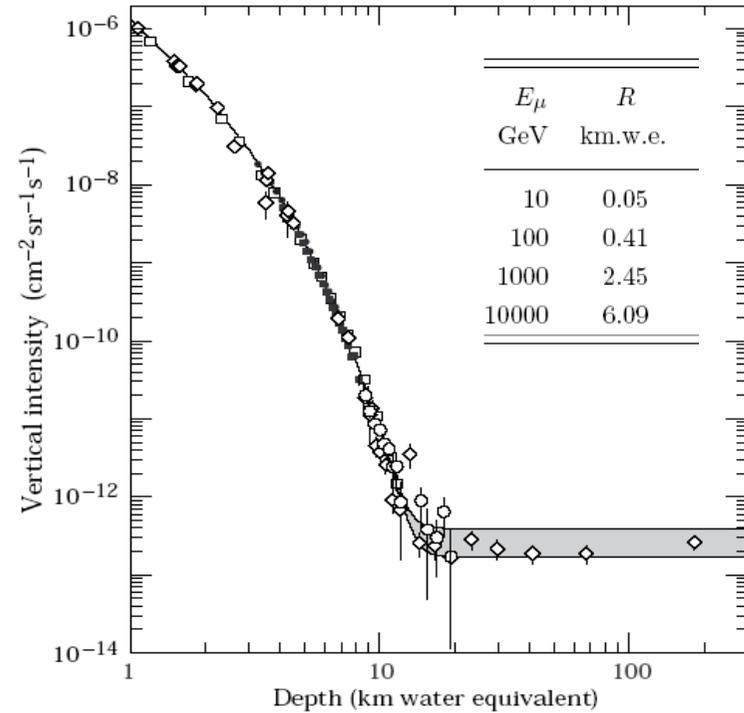




Effet Cherenkov (sens des muons)



- Grande pénétration dans la matière ($\mu_\mu \sim 200 \mu_\epsilon$)



- Spectre en énergie

$\langle E (0^\circ) \rangle = 10 \text{ GeV}$
 $\langle E (75^\circ) \rangle = 200 \text{ GeV}$

