

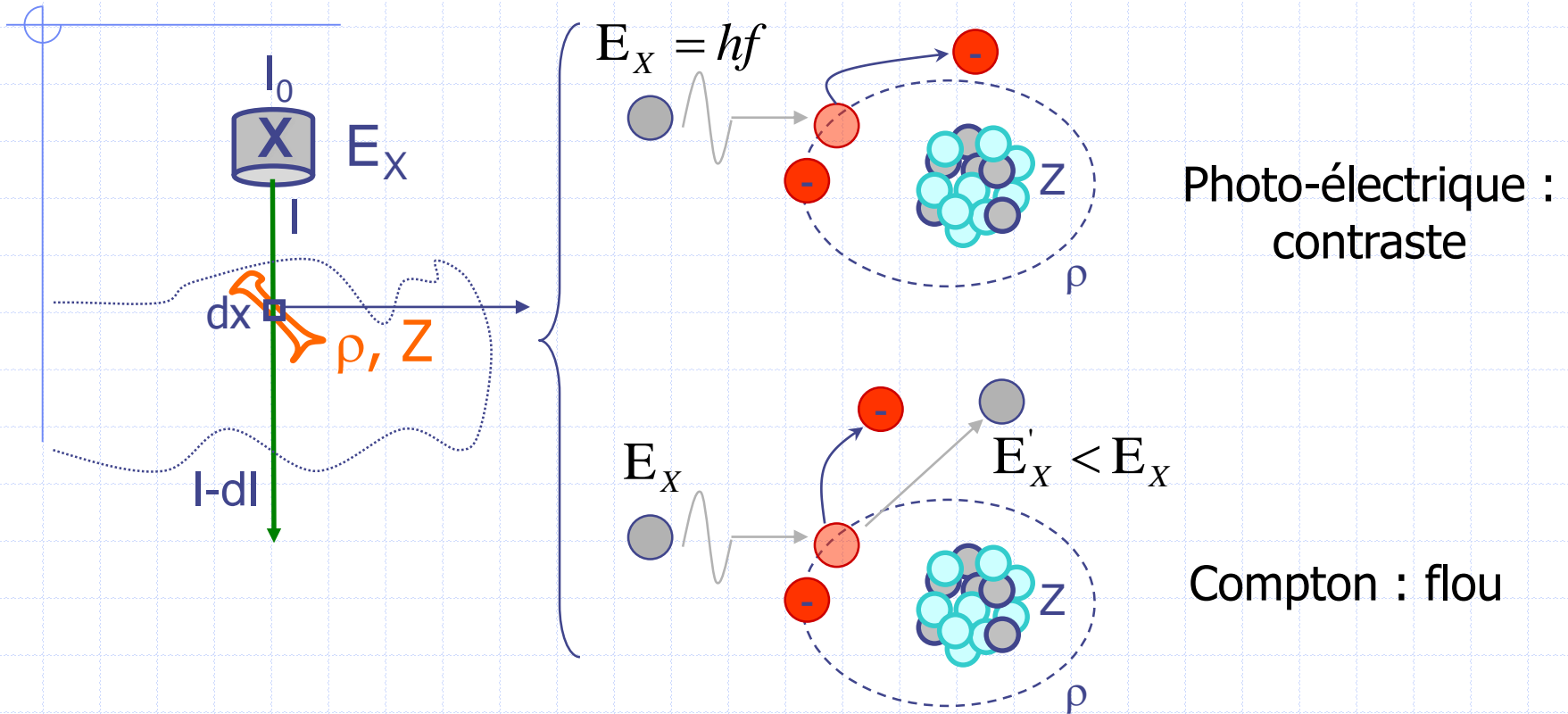
FORMATION TIC (Phymed)

FORMATION DES IMAGES X et GAMMA

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<http://scinti.etud.univ-montp1.fr>

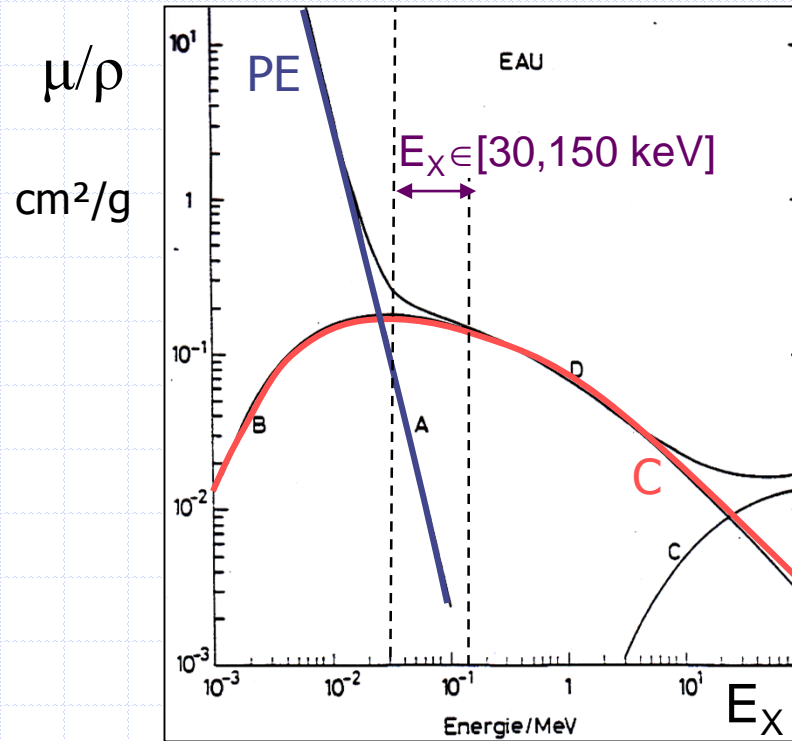
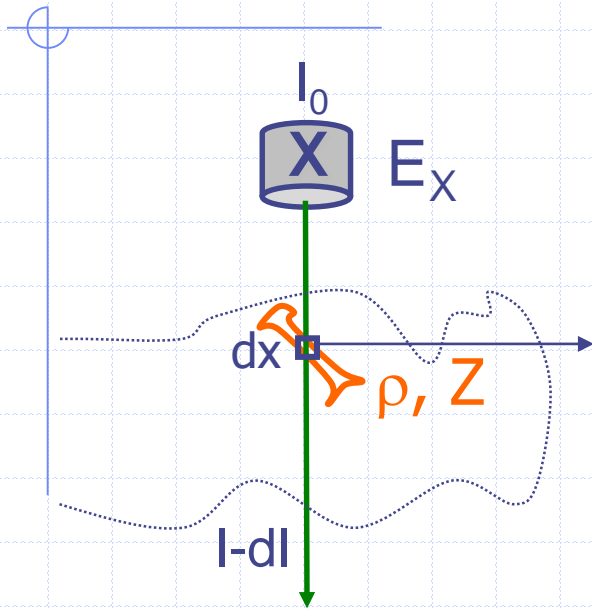
IMAGERIE DE TRANSMISSION X



Interaction aléatoire $\Rightarrow \mu = -\frac{dI}{I dx} \text{ cm}^{-1}$

μ = coef. linéique d'atténuation
= probabilité d'atténuation par cm

IMAGERIE DE TRANSMISSION X



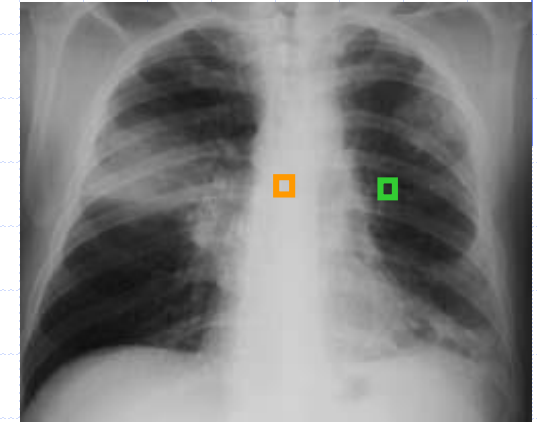
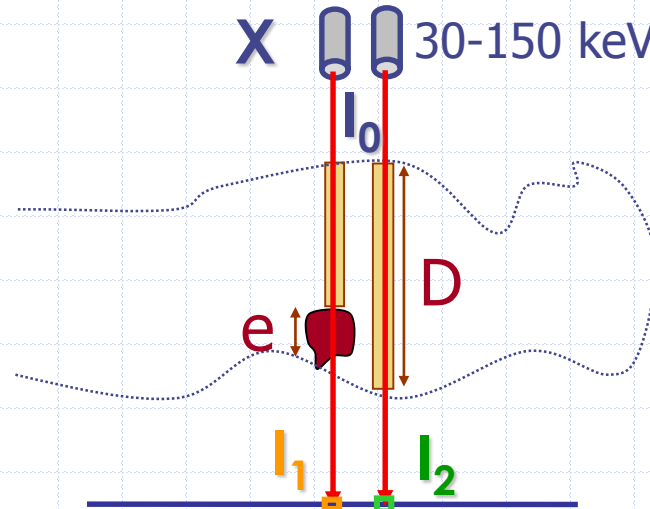
$\mu =$
coef. linéique
d'atténuation
= probabilité
d'atténuation
par cm

$$\mu = -\frac{dI}{I dx} \text{ cm}^{-1} \Rightarrow I = I_0 \cdot e^{-\mu \cdot x}$$

$$\mu_C / \rho \approx \text{constante}$$

$$\mu_{PE} / \rho \approx \text{cste. } (Z/E_X)^3$$

IMAGERIE DE TRANSMISSION X



$$I_1 = I_0 e^{-\mu(D-e) - \mu'e}$$

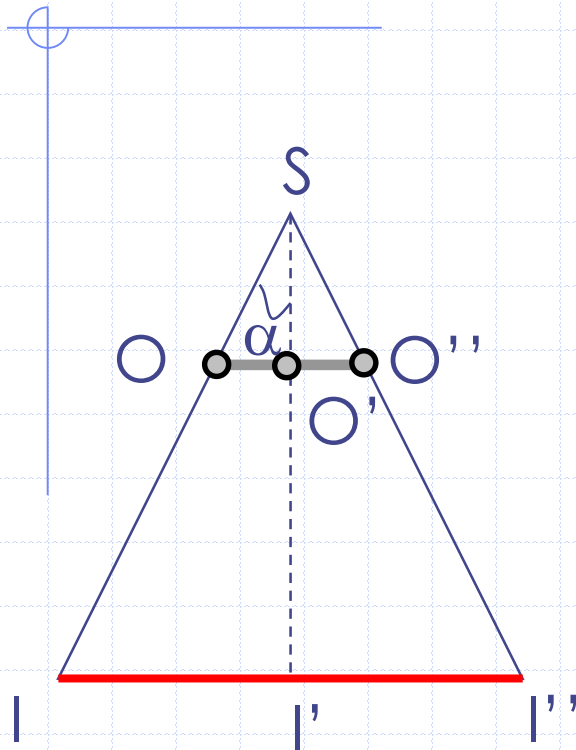
$$\approx I_0 (1 - \mu(D-e) - \mu'e)$$

$$I_2 = I_0 e^{-\mu D}$$

$$\approx I_0 (1 - \mu D)$$

$$C = \frac{|I_1 - I_2|}{I_1 + I_2} = \frac{|\mu' - \mu| \cdot e}{2} \propto \Delta\mu \Rightarrow C \propto \frac{e}{E_x^3} \Delta(\rho \cdot Z^3) : \text{différence de densité}$$

GRANDISSEMENT EN IMAGERIE X



Source de X = S

Objet absorbant

Détecteur (film)

$$\sin \alpha = \frac{II'}{SI} = \frac{OO'}{SO}$$

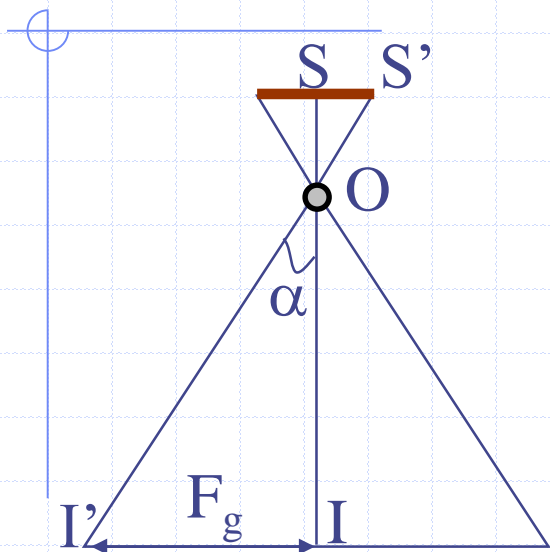


$$\frac{SI}{SO} = \frac{II'}{OO'} = G$$

Donc le grandissement G dépend :

- de la distance de la source de X au film (SI)
- de la **distance de la source à l'objet** (SO)

FLOUS EN IMAGERIE X (I)



Foyer $F = SS'$

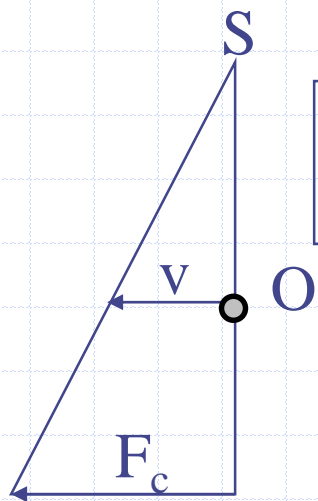
Objet absorbant

$$\text{tg} \alpha = \frac{II'}{IO} = \frac{SS'}{SO}$$

$$\Rightarrow F_g = F \cdot \frac{IO}{SO} = F \cdot \left(\frac{IS - OS}{SO} \right)$$

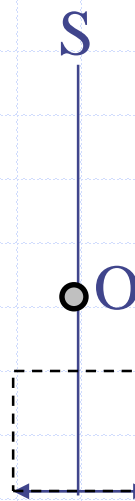
Flou géométrique :

$$F_g = F \cdot (G - 1)$$



Flou cinétique :

$$F_c = G \cdot v \cdot t$$

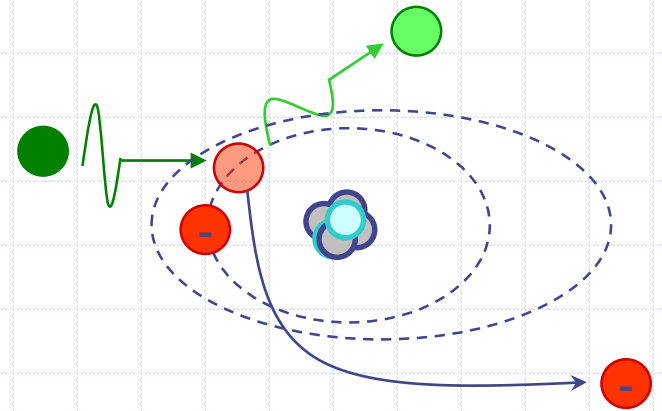
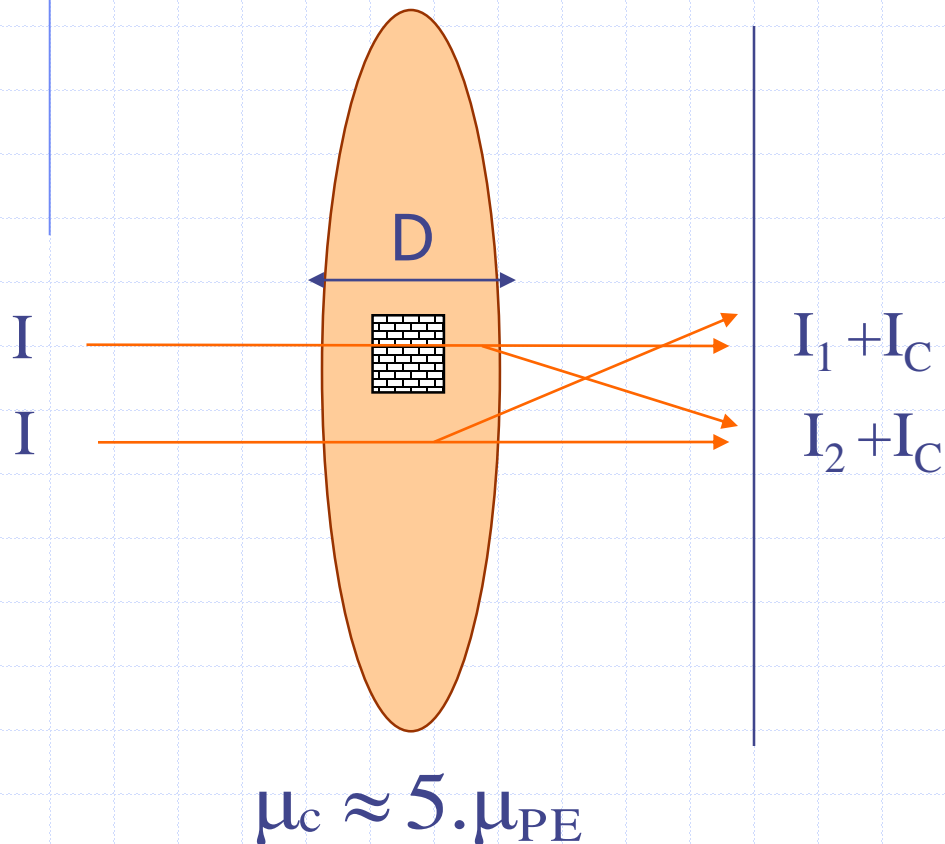


Flou d'écran :

$$F_e = \text{Grain, pixel}$$

FLOUS EN IMAGERIE X (II)

Flou par diffusion Compton :



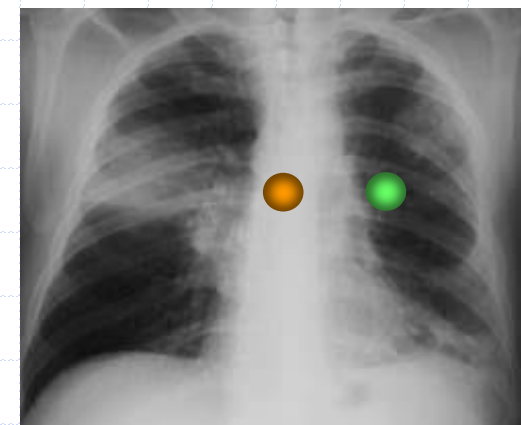
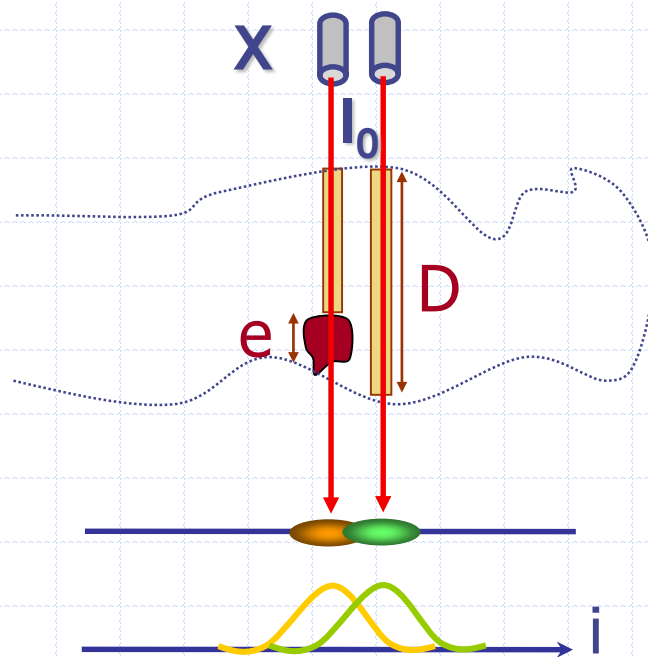
$$C = \frac{|I_1 - I_2|}{I_1 + I_2 + 2I_c}$$

- ✓ Compression : $D \downarrow$
- ✓ Diaphragme
- ✓ Grille
- ✓ Radio-protection

REPONSE EN IMAGERIE X 2D



ANALOGIQUE

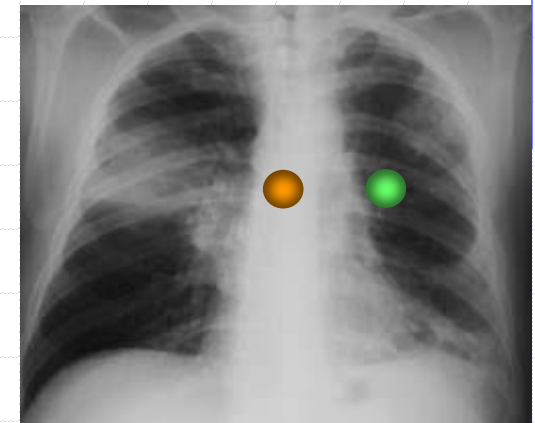
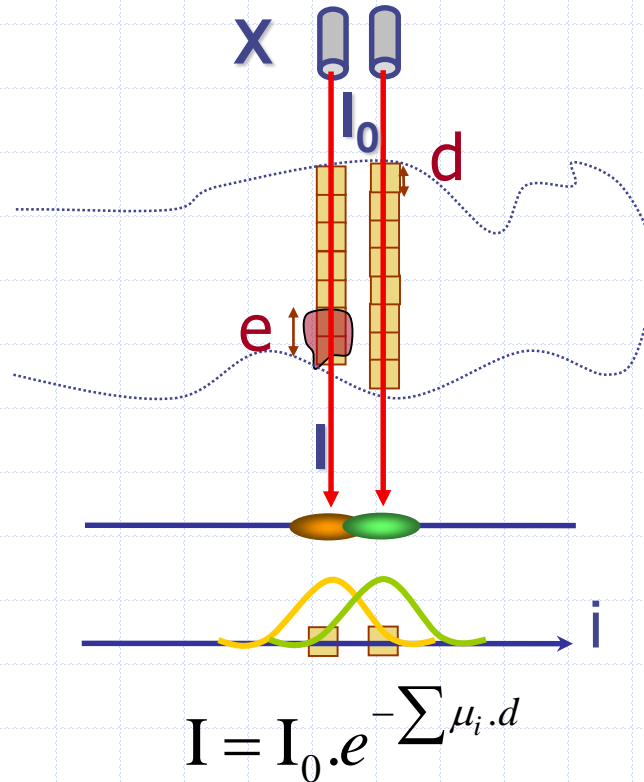


$$h(i) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{i^2}{2\sigma^2}}$$

REPONSE EN IMAGERIE X 2D



NUMERISE



$$I = I_0 \cdot e^{-\sum \mu_i \cdot d}$$

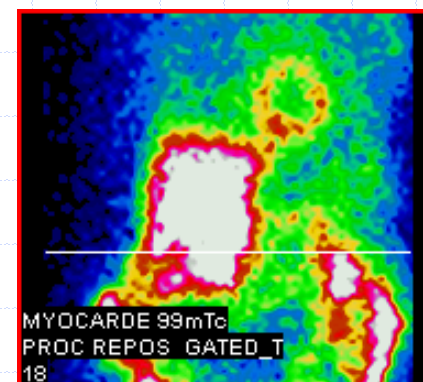
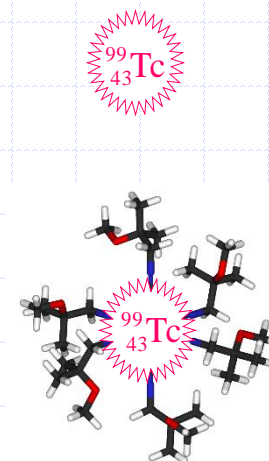
$$h(i) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{i^2}{2\sigma^2}}$$

$$p = \mu_1 + \mu_2 + \dots + \mu_n$$

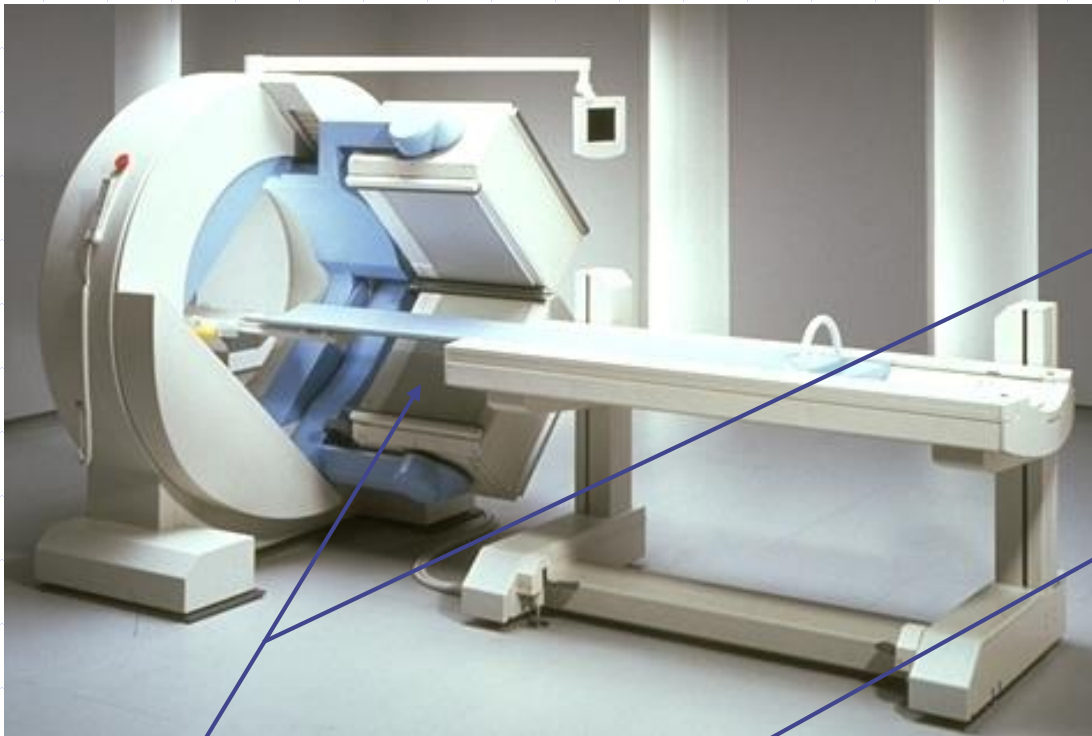
avec $p = -\frac{1}{d} \ln \frac{I}{I_0}$

IMAGERIE D'EMISSION GAMMA

- ◆ Principe : lier un isotope radioactif γ ou β^+ (marqueur) à une molécule d'intérêt biologique (vecteur) pour obtenir un traceur.
- ◆ Produire une cartographie de la radioactivité (scintigraphie) pour suivre le devenir du traceur dans un organisme humain.



γ -CAMERA



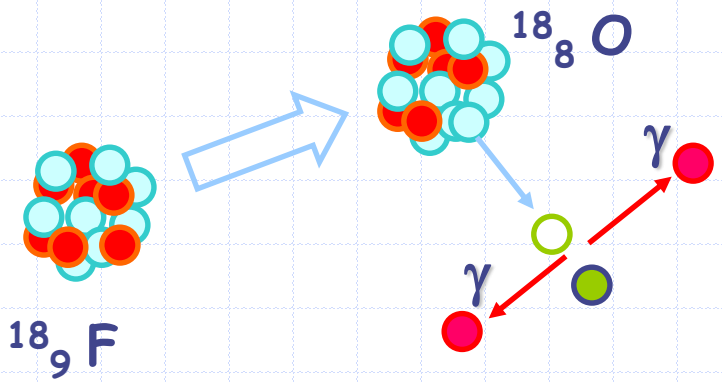
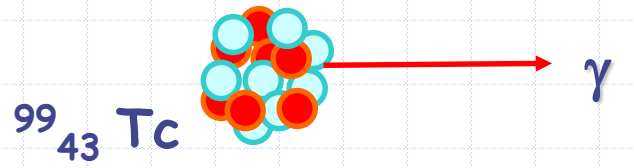
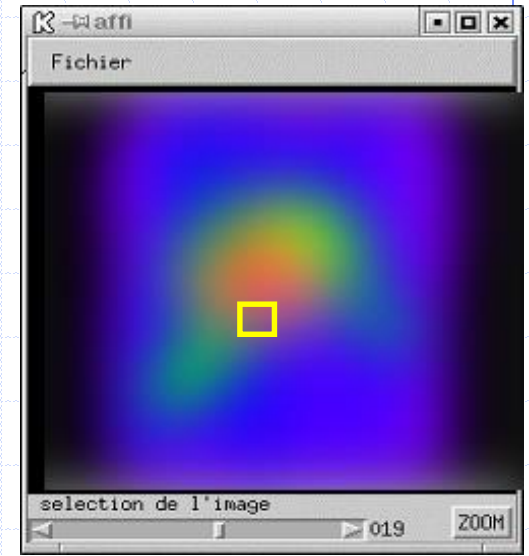
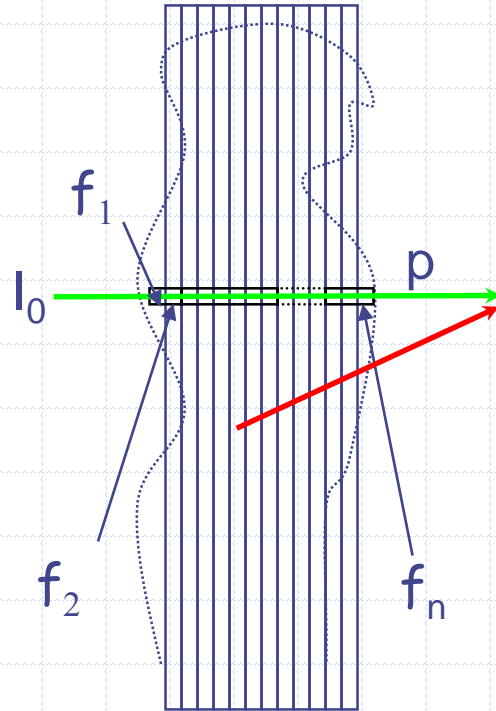
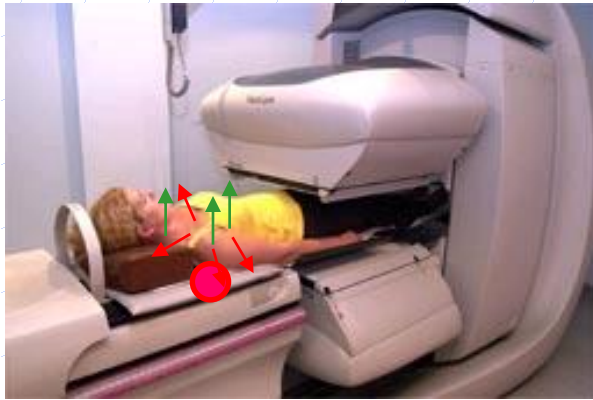
Collimateur

Scintillateur

Photo-multiplicateur

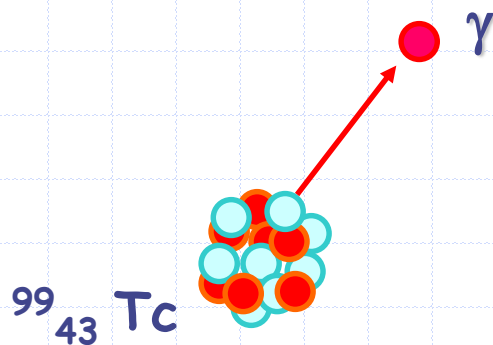
Localisation

ACQUISITION 2D

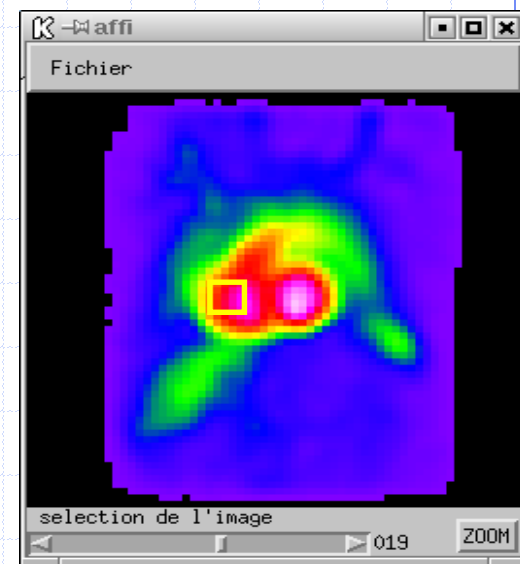
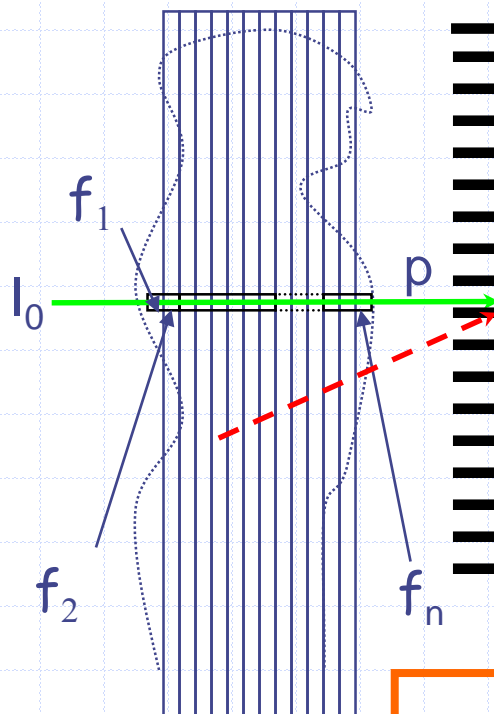


Isotopes émetteurs γ ou β^+

ACQUISITION 2D



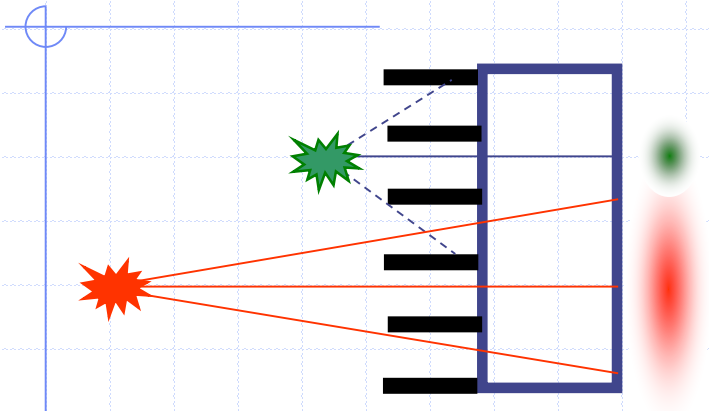
COLLIMATEUR



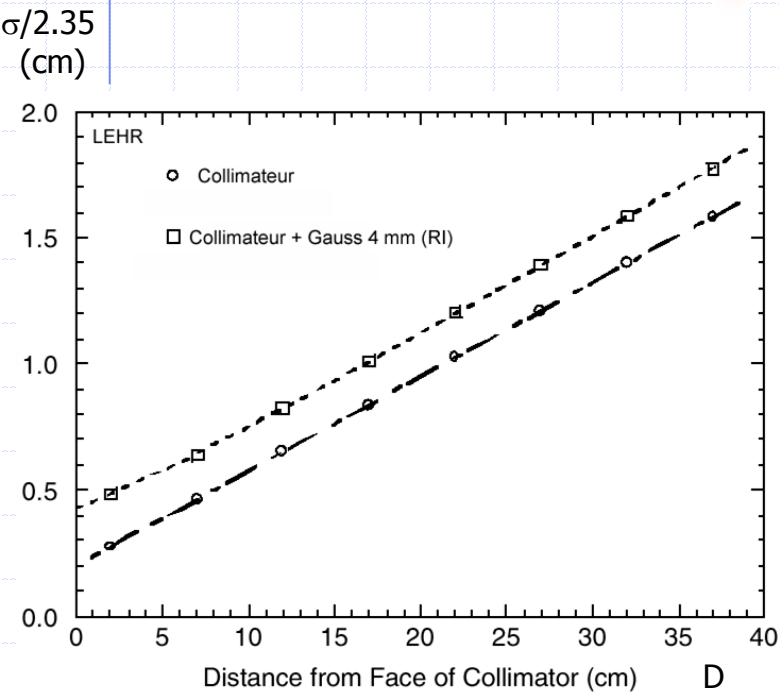
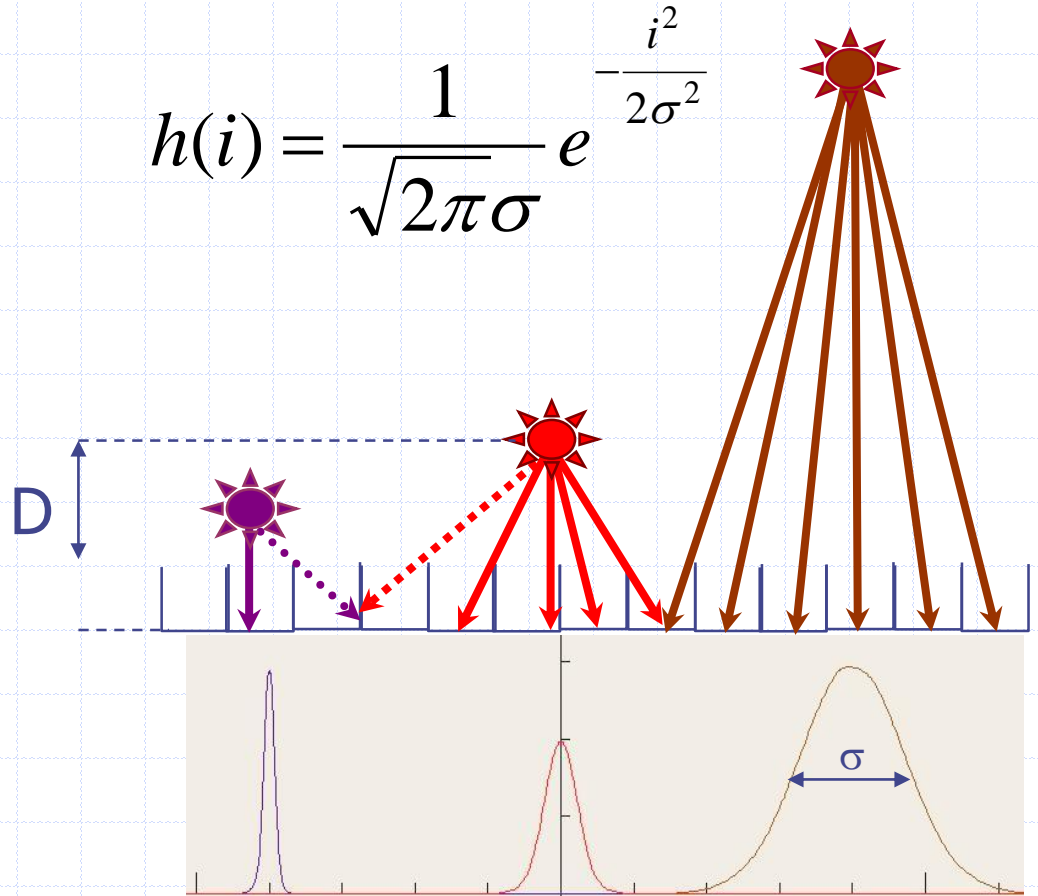
$$p = R_1 f_1 + R_2 f_2 + \dots + R_n f_n$$

résolution \approx cm
bruit de Poisson

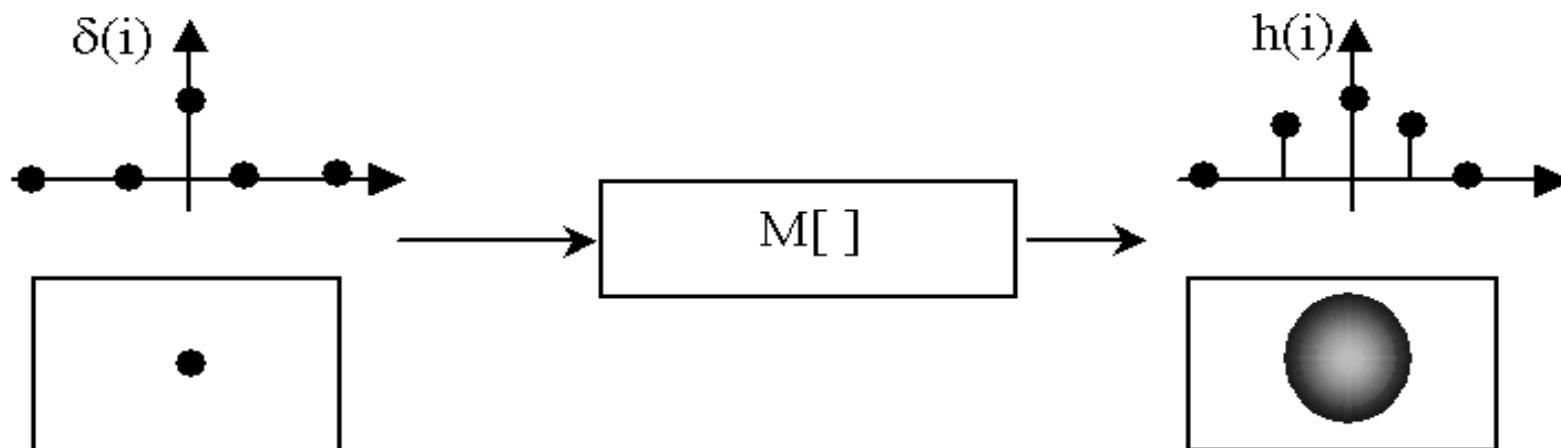
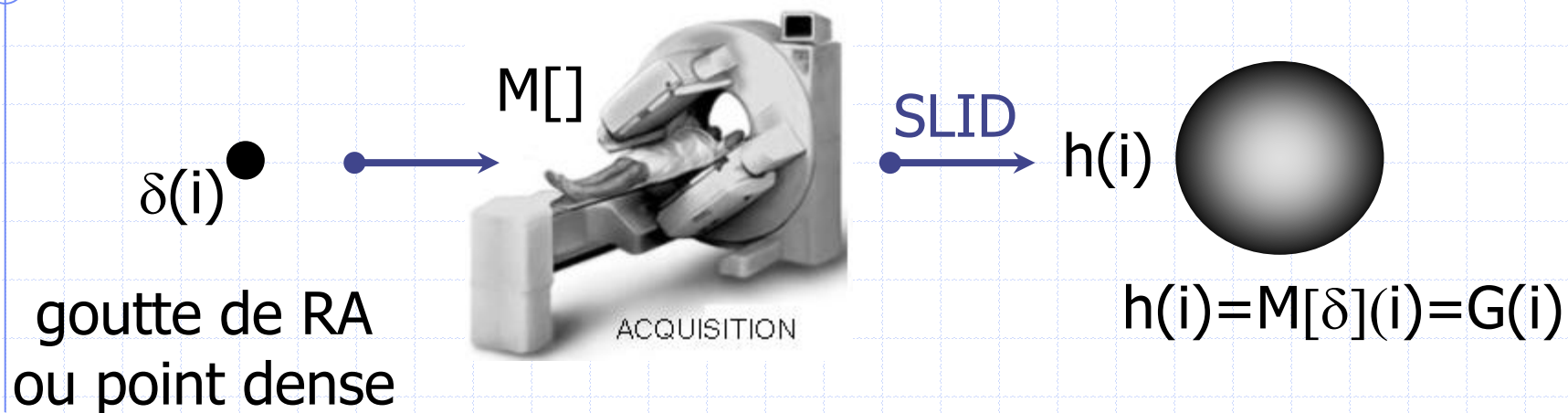
FLOU LIE AU COLLIMATEUR



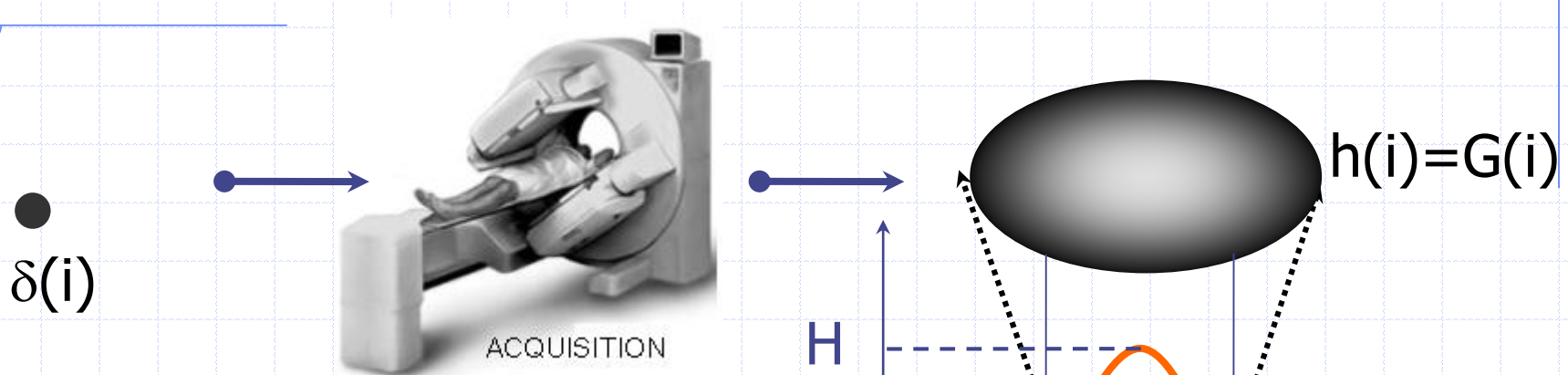
$$h(i) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{i^2}{2\sigma^2}}$$



REPONSE D'UNE CAMERA X, γ



LARGEUR A MI-HAUTEUR



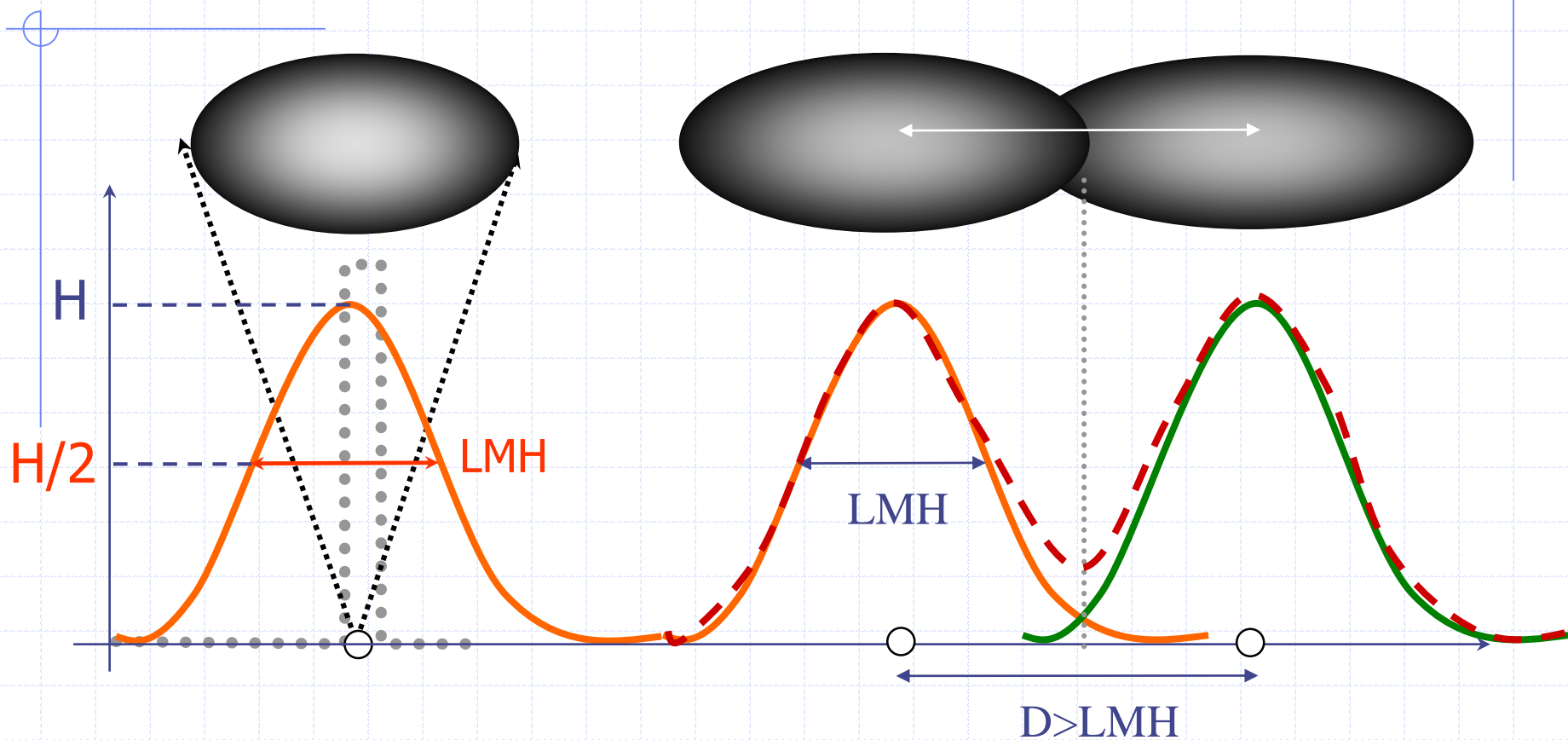
- Réponse intrinsèque

- ◆ X : LMH = 0,1 à 1 mm
- ◆ γ : LMH \approx 4 mm

- Réponse du collimateur (seulement pour l'imagerie γ)

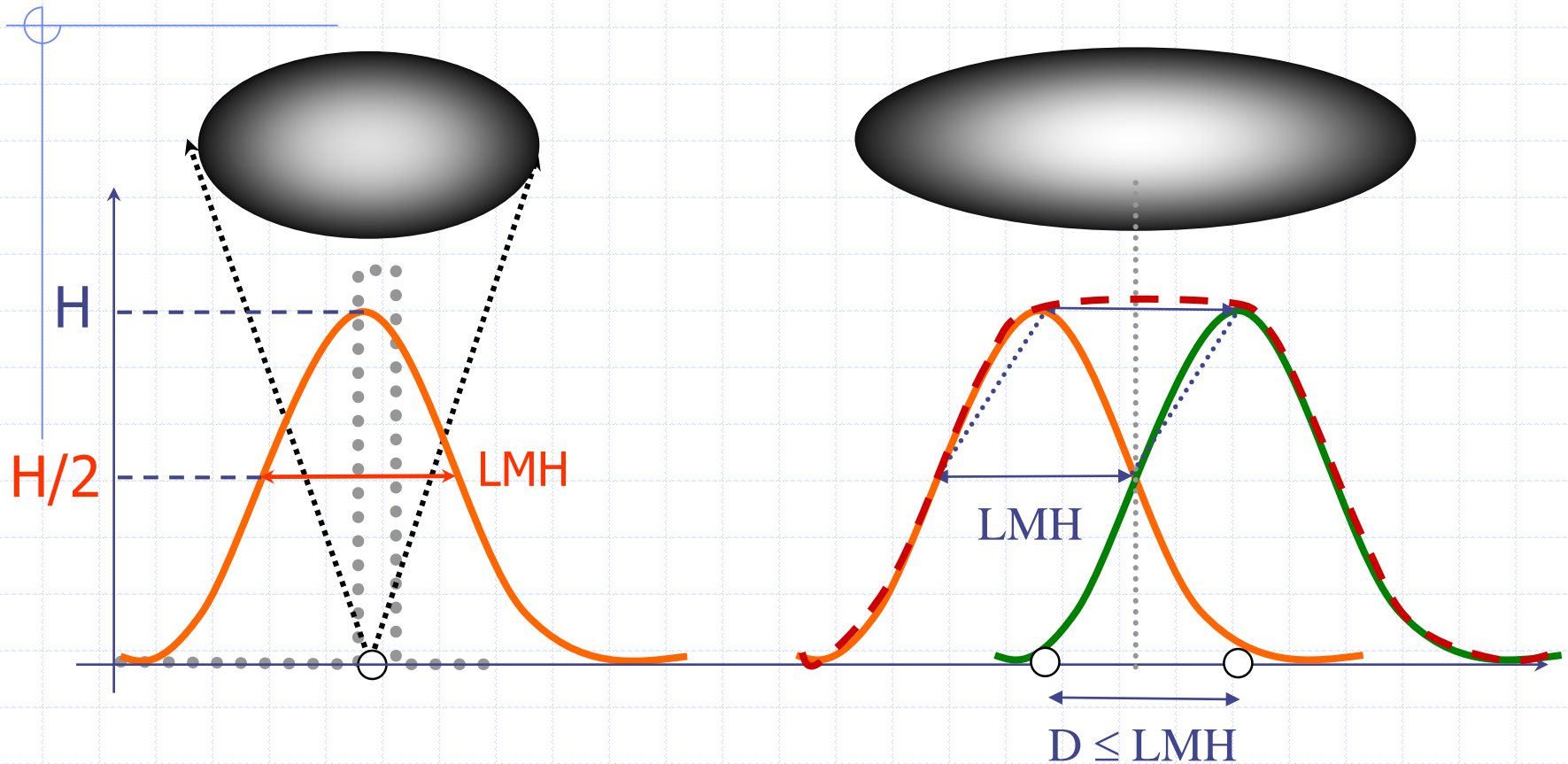
- ◆ LMH supplémentaire qui dépend de la distance source-détecteur

INTERPRETATION



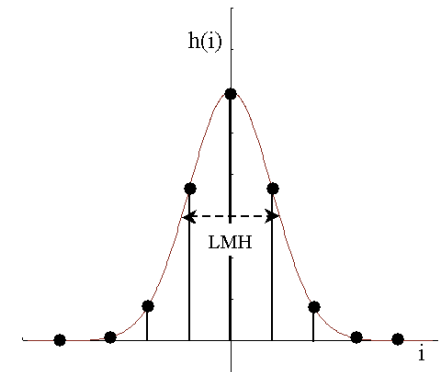
Si $D > LMH$, les deux objets sont discernables sur l'image

INTERPRETATION

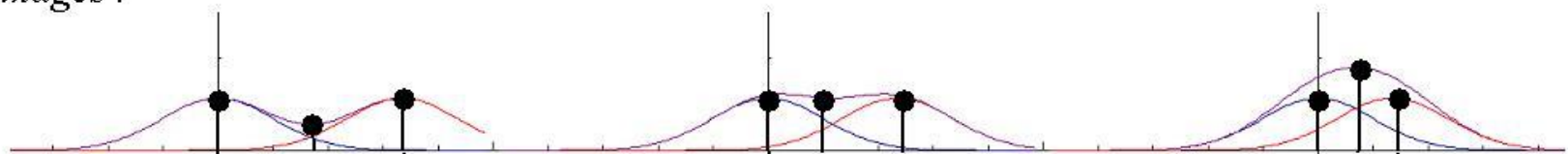


Si $D < LMH$, les deux images fusionnent :
 $LMH = \text{résolution} = \text{pouvoir séparateur}$

INTERPRETATION



Images :

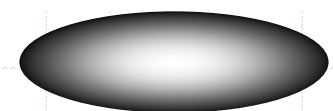
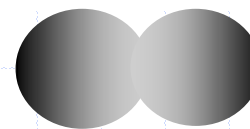
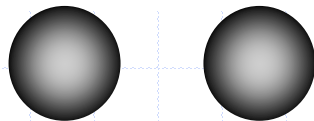


Objets :

$d > \text{LMH}$

$d = \text{LMH}$

$d < \text{LMH}$

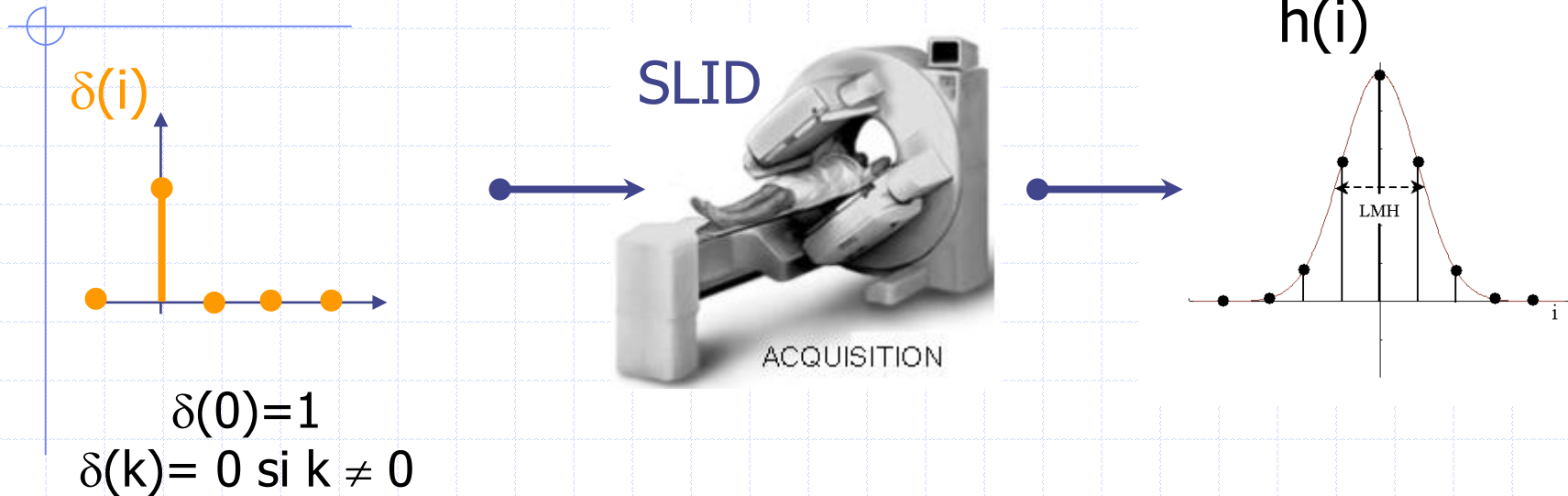


LMH = pouvoir séparateur = résolution de l'imageur

LMH = période minimale observable sur l'image

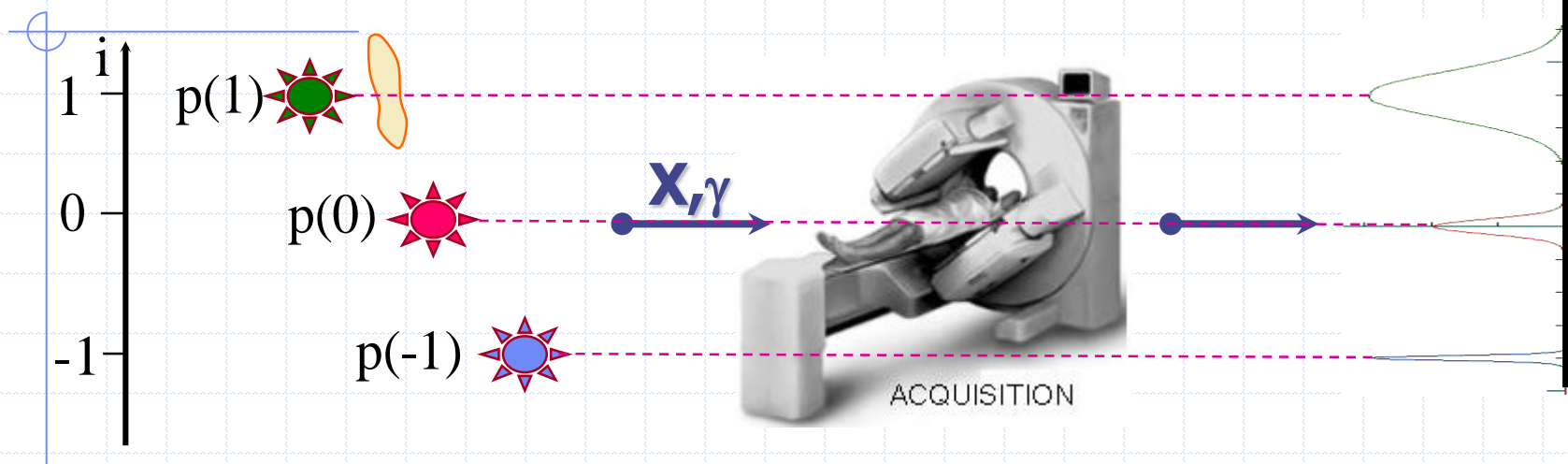
$1/\text{LMH}$ = fréquence spatiale maximale dans le signal

FORMATION DE L'IMAGE



$$h(i) = M[\delta](i)$$

FORMATION DE L'IMAGE

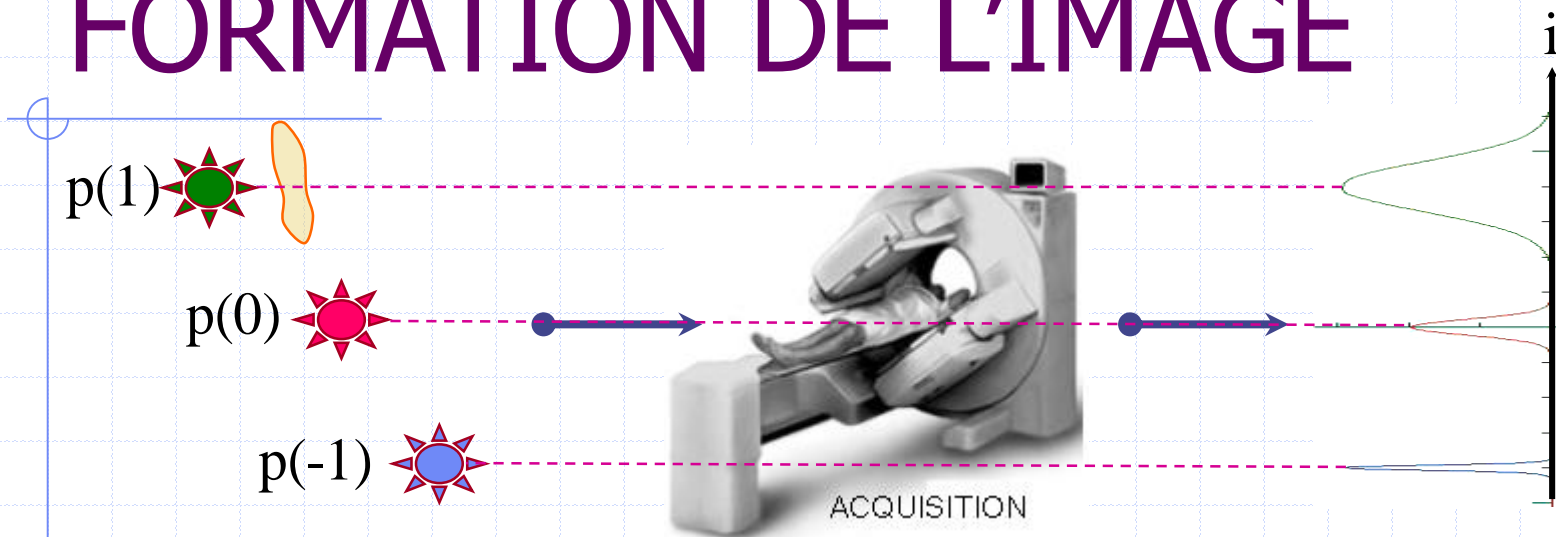


$$p(i) = \sum_{k=-\infty}^{+\infty} p(k) \cdot \underbrace{\delta(i-k)}_{= 0 \text{ sauf si } k=i \text{ où } \delta(0)=1}, \quad i \text{ fixé}$$

$$\sum_{k=-\infty}^{+\infty} p(k) \cdot \delta(i-k) = p(-1) \underbrace{\delta(i+1)}_0 + p(0) \underbrace{\delta(i)}_0 + p(1) \underbrace{\delta(i-1)}_{p(1)}$$

Exemple si $i = 1$:

FORMATION DE L'IMAGE

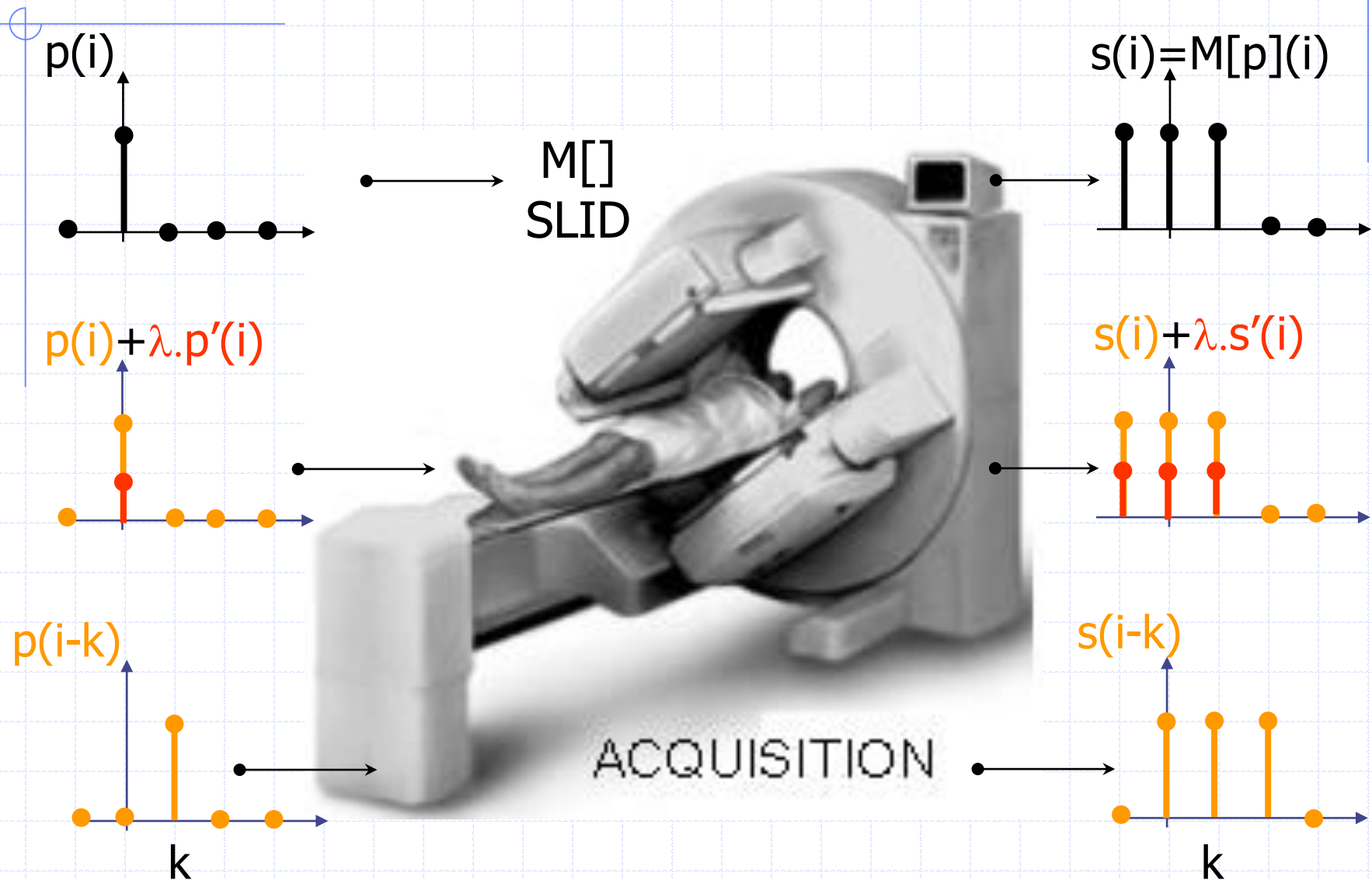


$$p(i) = \sum_{k=-\infty}^{+\infty} p(k) \cdot \underbrace{\delta(i-k)}_{= 0 \text{ sauf si } k=i}, \quad i \text{ fixé} \quad \Rightarrow \quad s(i) = M[p](i) = ?$$

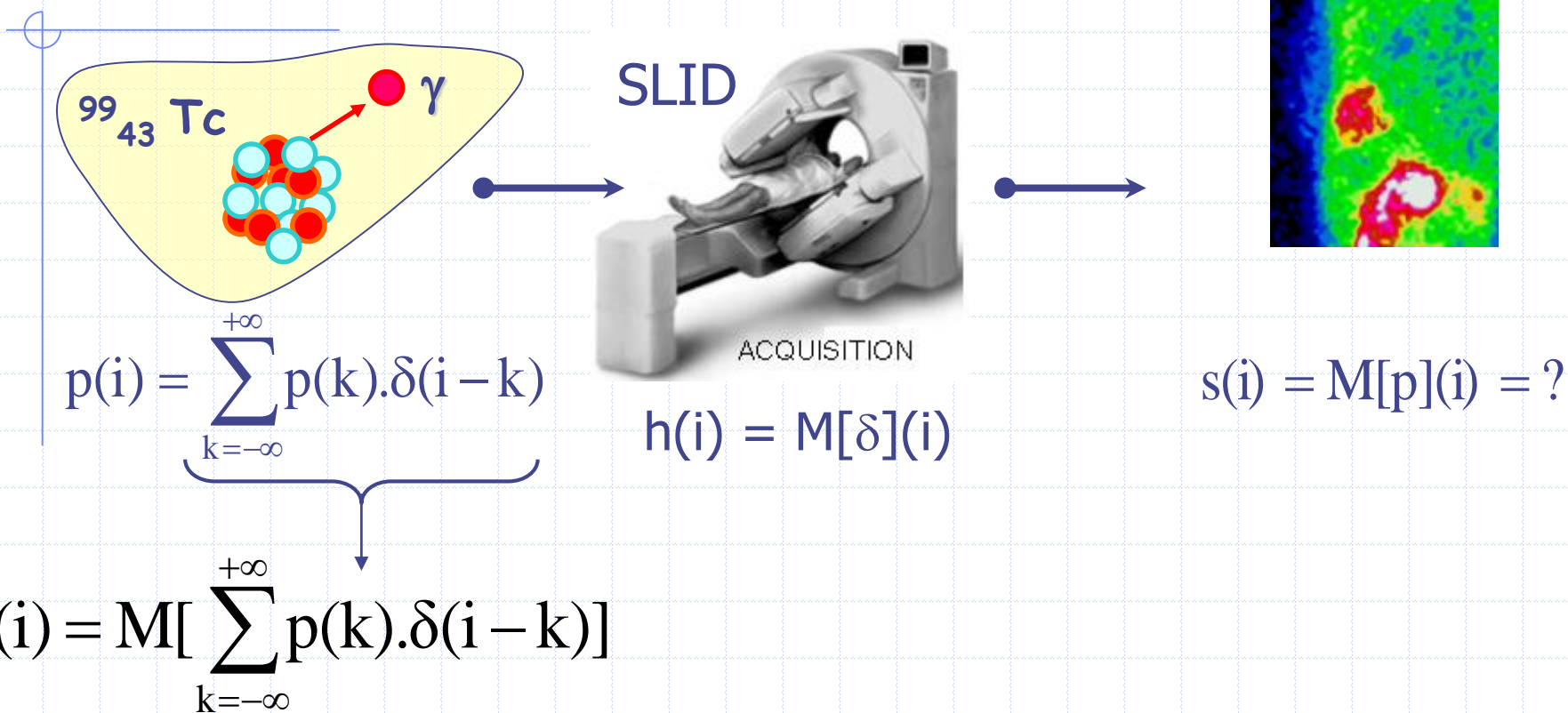
$$\delta(0) = 1$$

Pour déterminer s , il faut faire des hypothèses sur M , donc sur les caractéristiques de la caméra...

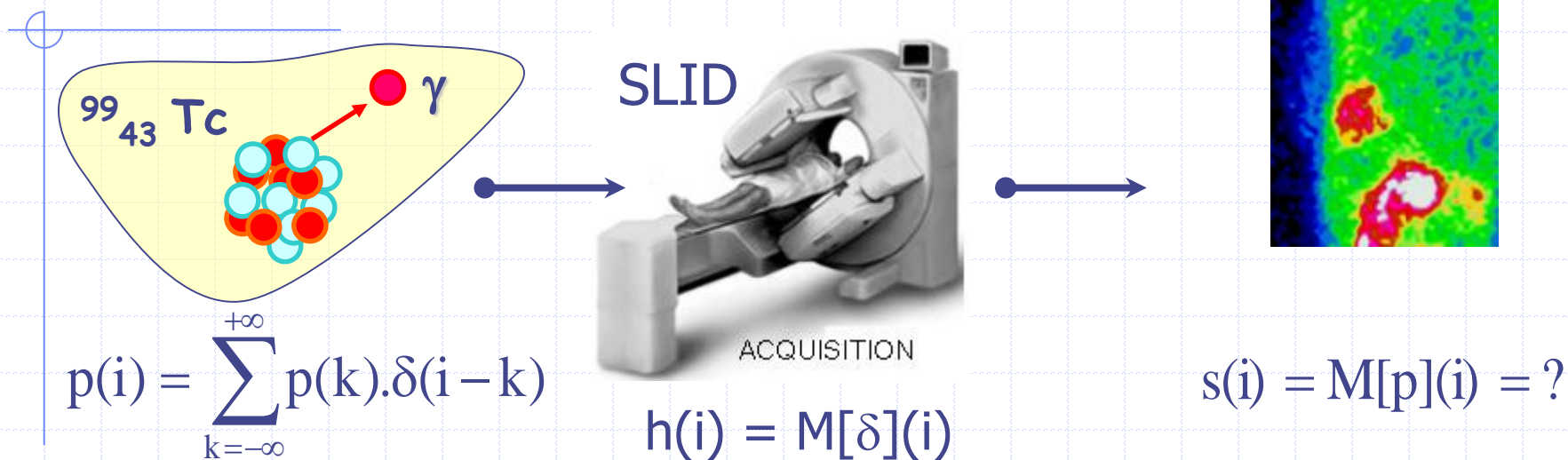
CAMERA \approx LINEAIRE & INVARIANTE



FORMATION DE L'IMAGE



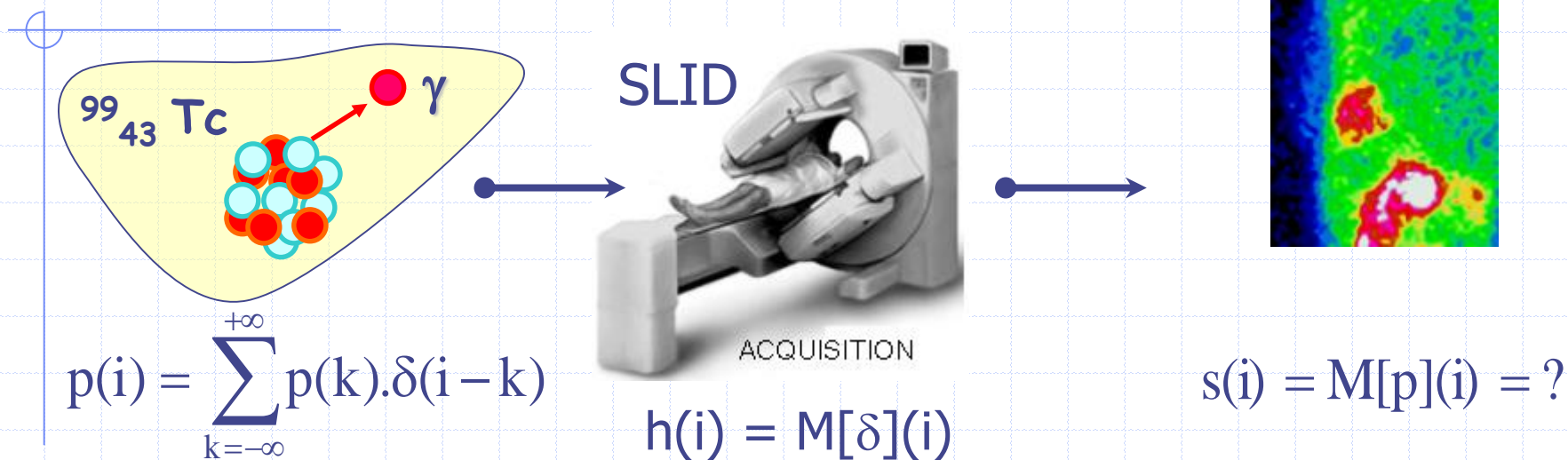
FORMATION DE L'IMAGE



$$s(i) = M\left[\sum_{k=-\infty}^{+\infty} p(k) \cdot \delta(i-k)\right] = \sum_{k=-\infty}^{+\infty} p(k) \cdot M[\delta(i-k)]$$

linéarité

FORMATION DE L'IMAGE



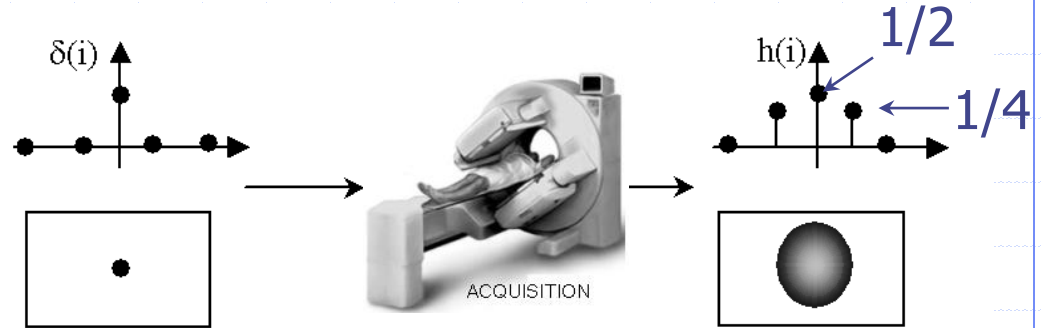
$$s(i) = M\left[\sum_{k=-\infty}^{+\infty} p(k) \cdot \delta(i-k)\right] = \sum_{k=-\infty}^{+\infty} p(k) \cdot \underbrace{M[\delta(i-k)]}_{h(i-k)} = \sum_{k=-\infty}^{+\infty} p(k) \cdot h(i-k)$$

Invariance dans le décalage

$$s(i) = \sum_{k=-\infty}^{+\infty} p(k) \cdot h(i-k) = \sum_{k=-\infty}^{+\infty} h(k) \cdot p(i-k) = (p * h)(i)$$

produit de convolution

EXEMPLE

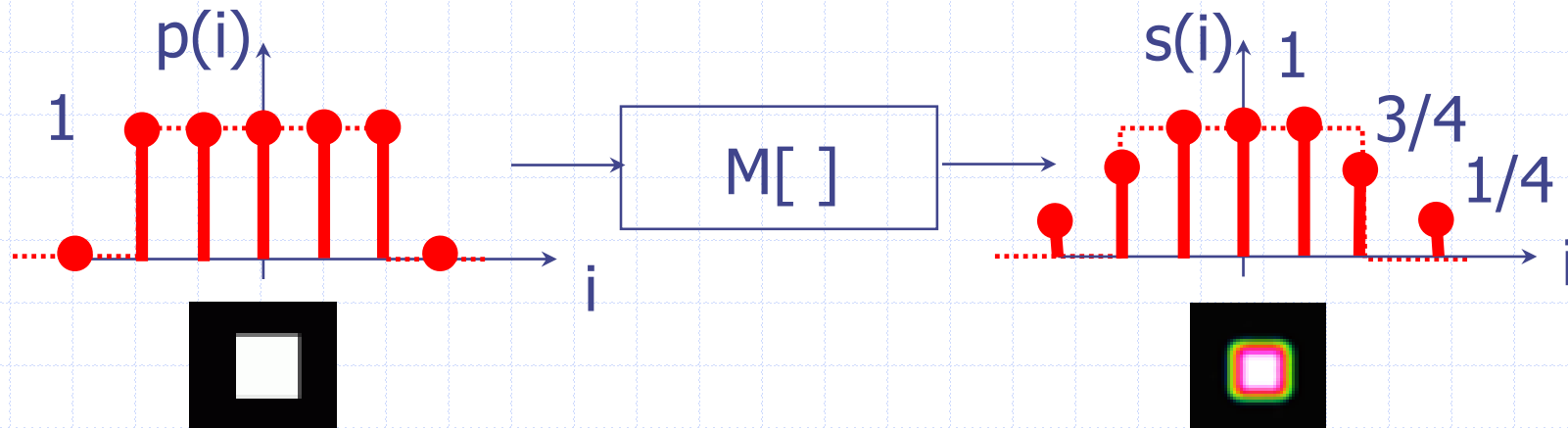


$$s(i) = \sum_{k=-1}^{+1} h(k).p(i-k)$$

$$s(i) = h(-1).p(i+1) + h(0).p(i) + h(1).p(i-1)$$

$$s(i) = \frac{1}{4}p(i+1) + \frac{1}{2}p(i) + \frac{1}{4}p(i-1) = \frac{2.p(i) + p(i+1) + p(i-1)}{4}$$

s = moyenne pondérée par h de la grandeur physique p



THEOREME DE CONVOLUTION

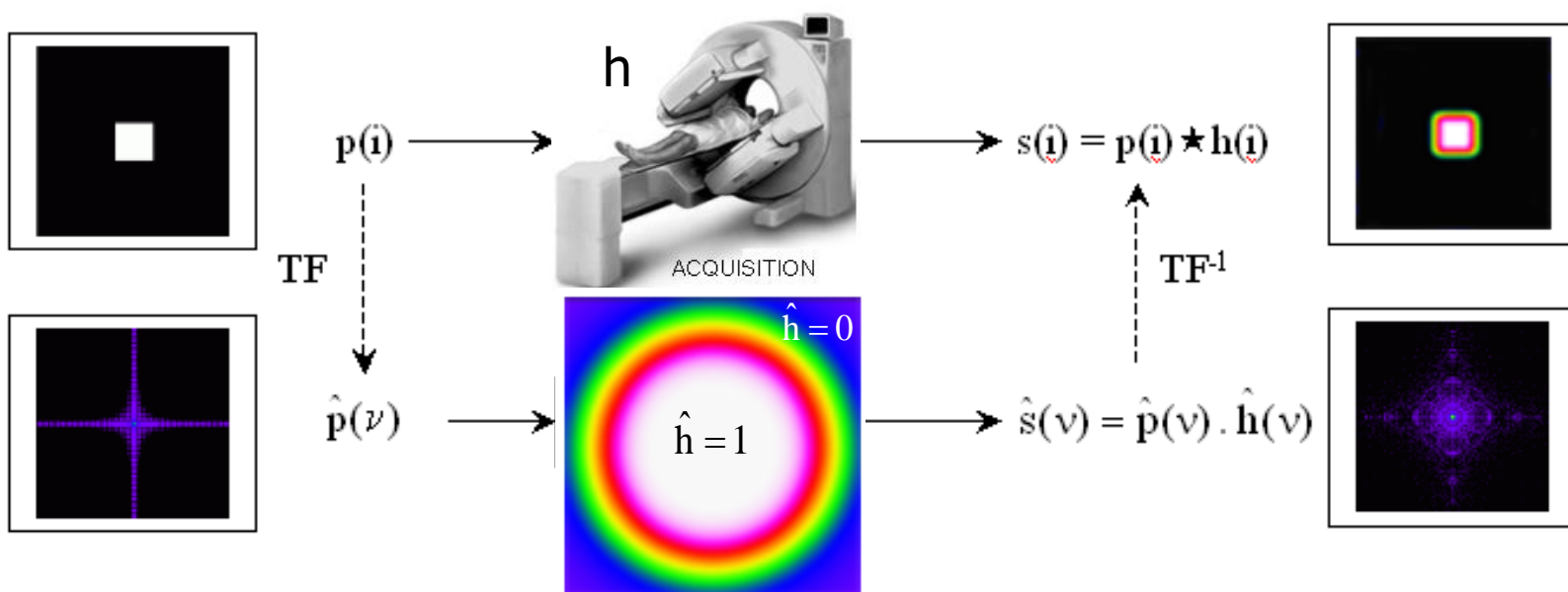
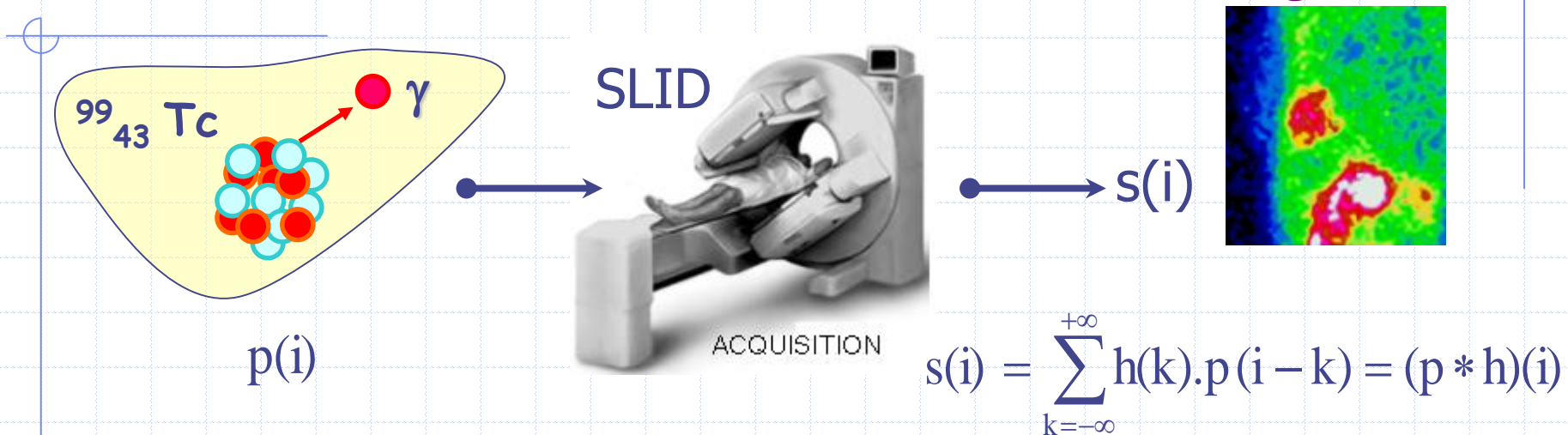
$$p(i) = e^{j.v.i} \rightarrow \boxed{M[\]} \longrightarrow s(i) = \sum_{k=-\infty}^{+\infty} h(k).p(i-k)$$

$$s(i) = \sum_{k=-\infty}^{k=+\infty} h(k).e^{j.v.(i-k)} = \underbrace{e^{j.v.i}}_{p(i)} \underbrace{\sum_{k=-\infty}^{k=+\infty} h(k).e^{-j.v.k}}_{\hat{h}(v)}$$

$$p(i) = e^{j.v.i} \implies s(i) = \hat{h}(v).p(i)$$

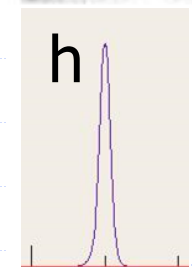
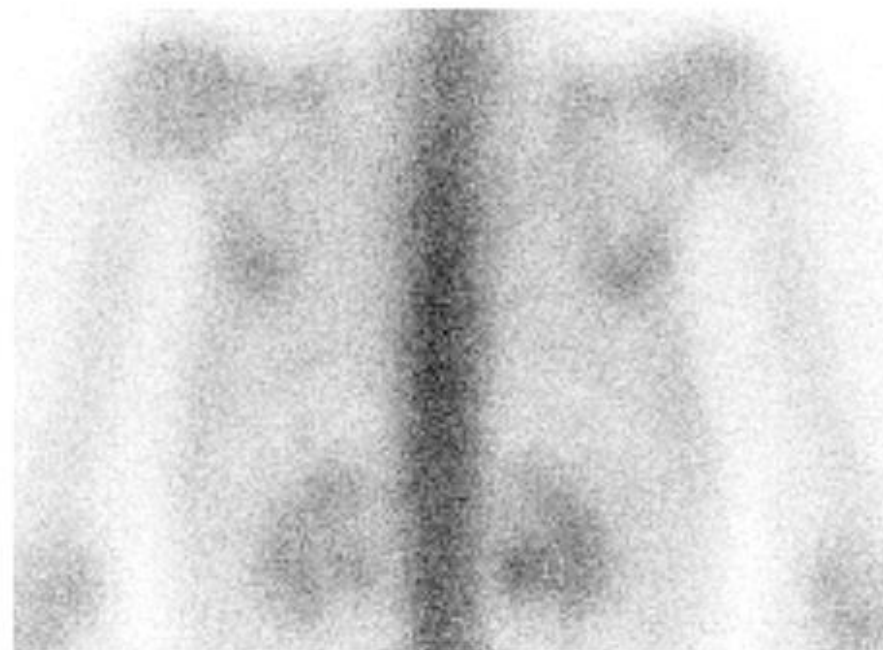
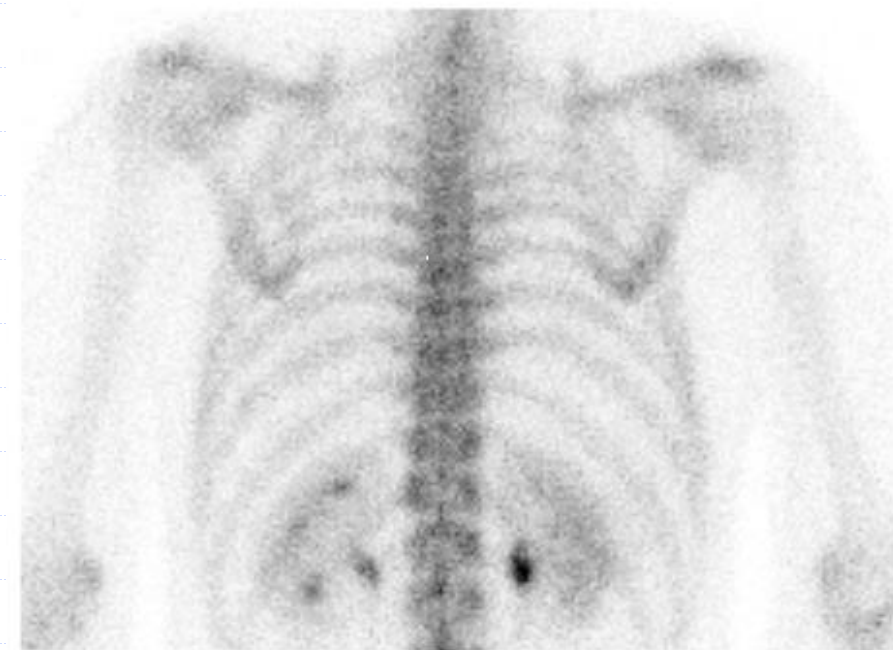
Un SLID agit sur l'harmonique v en l'amplifiant par la **réponse en fréquence** en v : $\hat{h}(v)$

REPONSE IMPULSIONNELLE / EN FREQUENCE



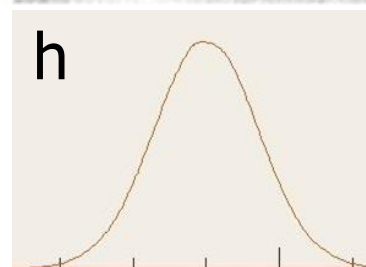
RESOLUTION ET DISTANCE (γ)

$s =$ moyenne pondérée par h de la grandeur physique p



FP
AU CONTACT

DT

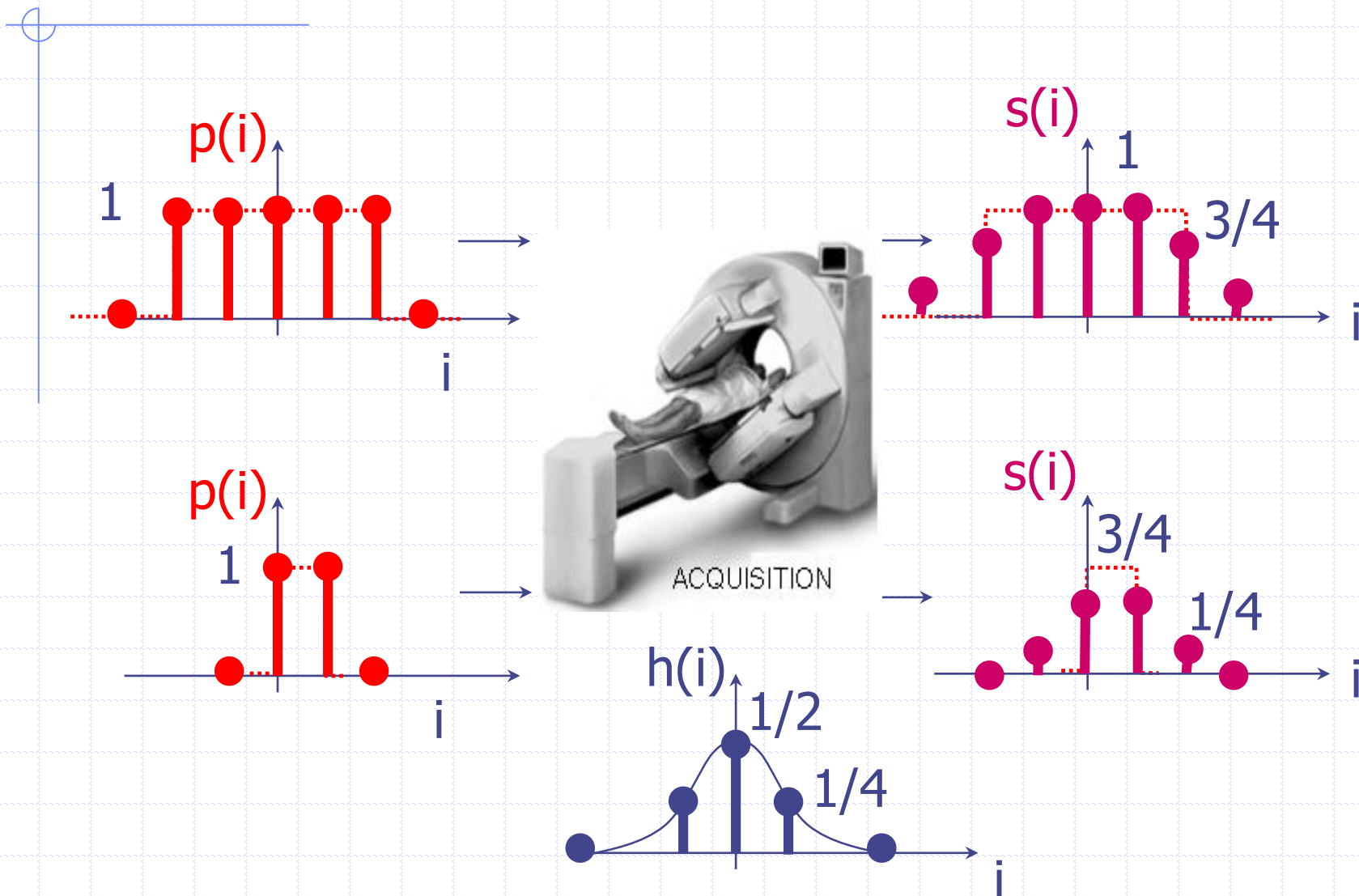


50 cm

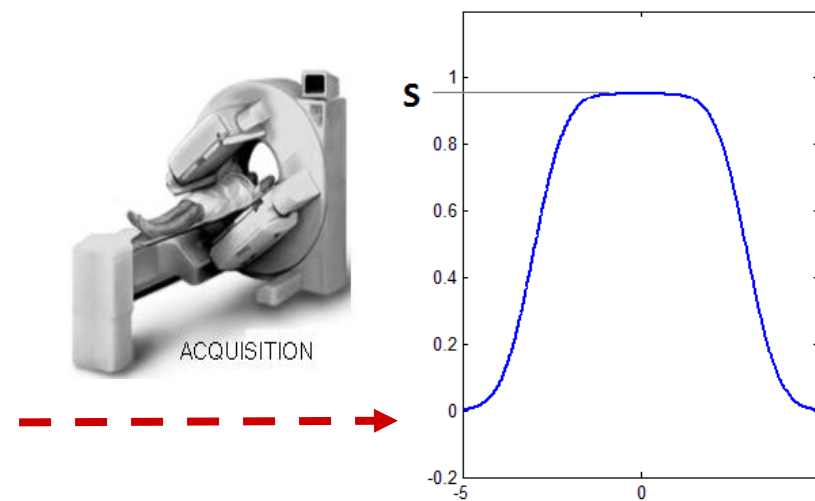
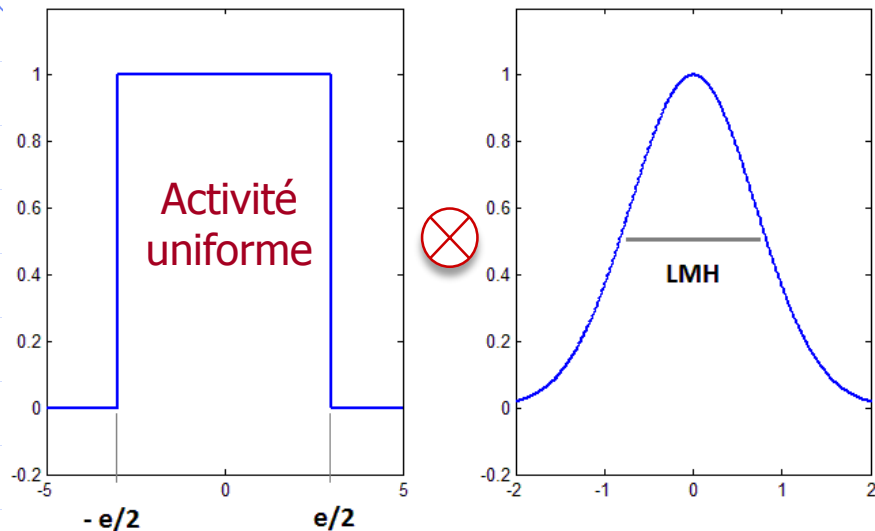
50 cm

DT

EFFET DE VOLUME PARTIEL

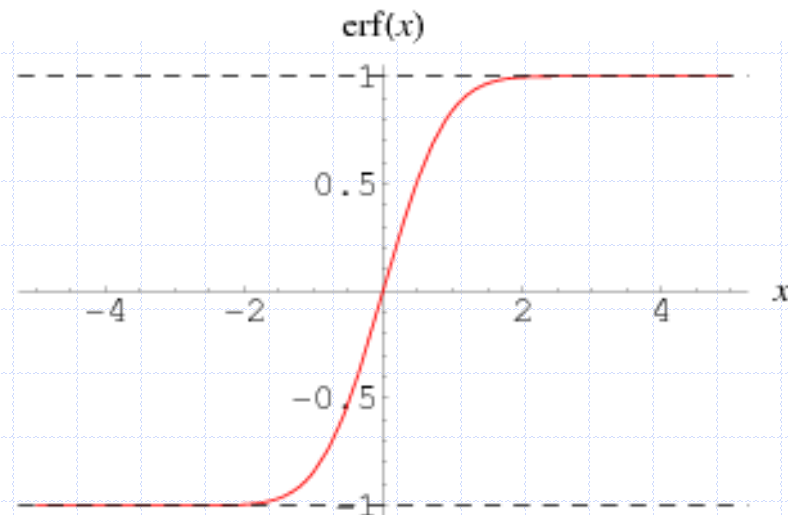


EFFET DE VOLUME PARTIEL

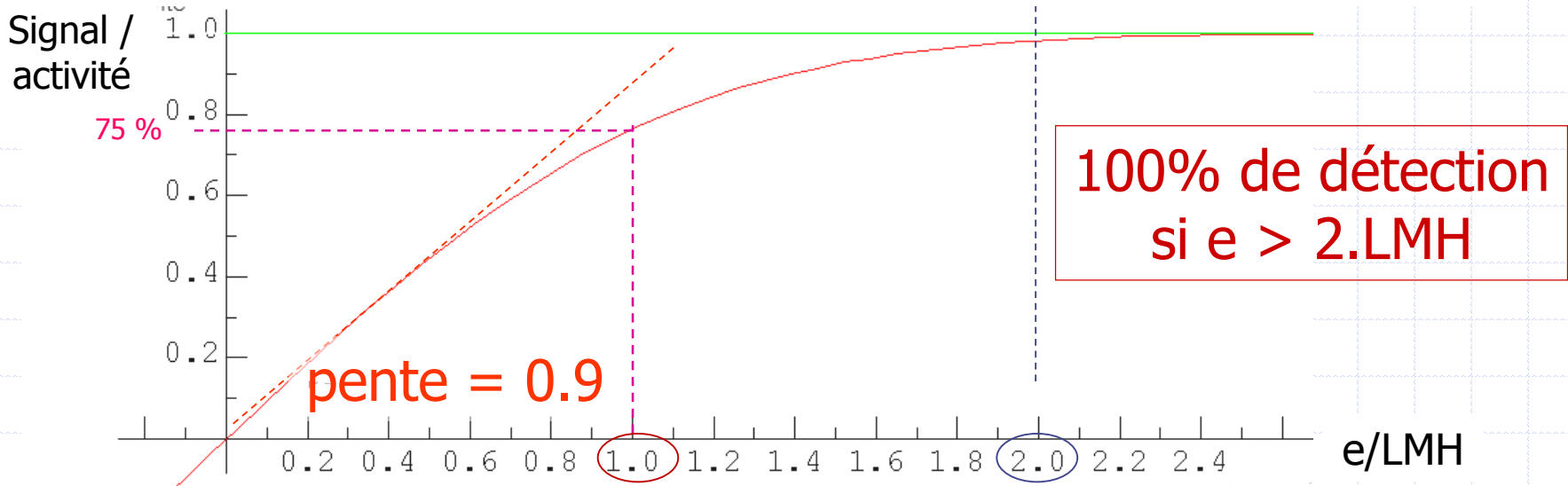
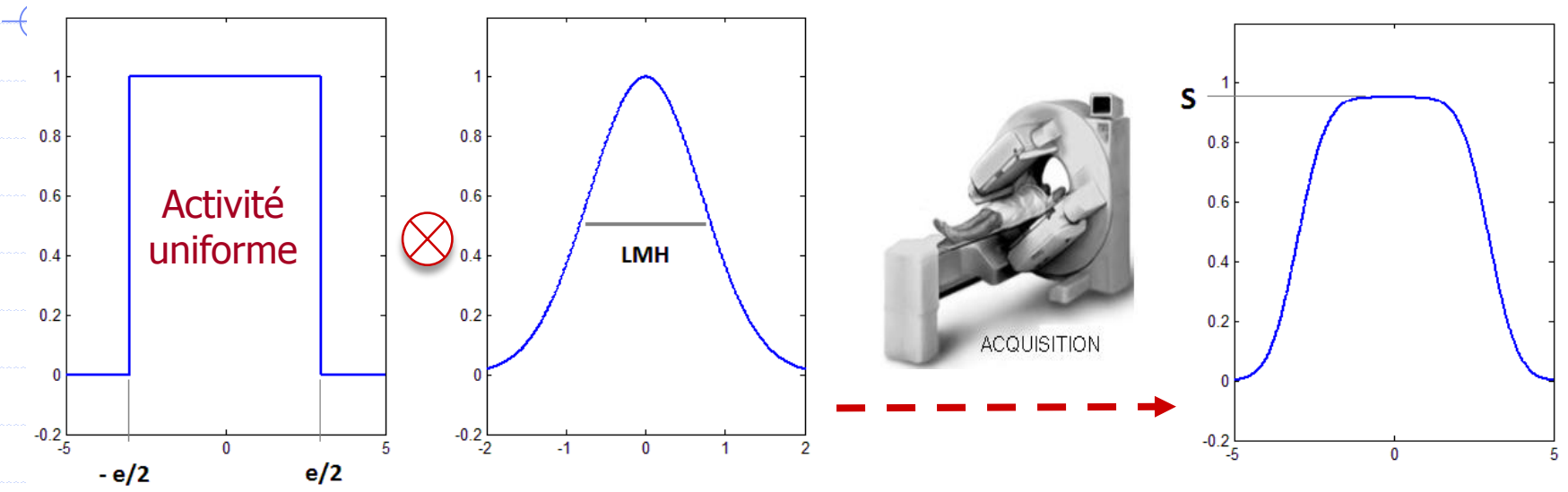


$$S = \int_{-e/2}^{e/2} G(x) dx$$

$$S = \frac{(\ln 2 / \pi)^2}{LMH} \int_{-e/2}^{e/2} e^{-\frac{4 \cdot \ln 2}{LMH^2} z^2} dx$$



EFFET DE VOLUME PARTIEL



IMPORTANCE DE LA LMH

- ◆ LMH = **Pouvoir séparateur** = résolution
- ◆ LMH = **Période minimale** des harmoniques
- ◆ LMH forme l'image par convolution
- ◆ LMH **limite les fréquences** dans l'image
- ◆ LMH conditionne l'effet de volume partiel
 - ◆ 100 % de détection si $e > 2 \times \text{LMH}$
- ◆ LMH conditionne l'échantillonnage (cf. suite)

RESOLUTIONS EN MEDECINE

0.1 mm

1 mm

5 mm

10 mm

15 mm



Mammo-
graphie

Radiographie

Scintigraphie γ

IRM et TDM X
Echographie

TEP
CZT

SPECT

