

# ANR HIGH-TUNE

## WP-2 : « Rayonnement et Biologie »

Jérémi Dauchet, **Institut Pascal**, Clermont-Ferrand

J.-F. Cornet, **Institut Pascal**, Clermont-Ferrand

Stéphane Blanco et Richard Fournier, **LAPLACE**, Toulouse

M. El Hafi, **RAPSODEE**, Albi

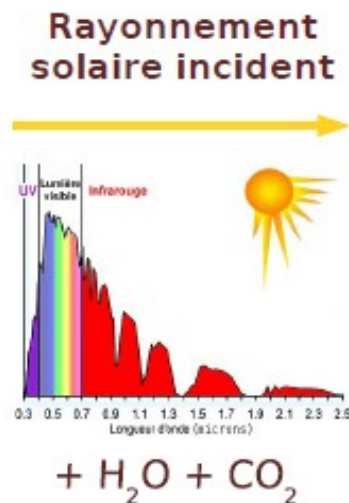
MésoStar SA

*Axe Photo-procédés de la fédération CNRS FédESol*

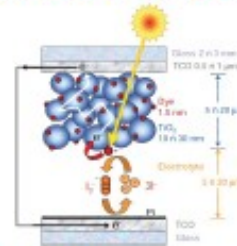
# Ingénierie de la photosynthèse



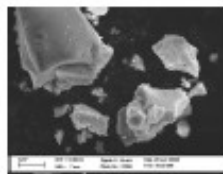
## Génie des systèmes photoréactifs



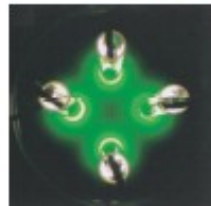
### Cellules photoélectrochimiques



### Photoreacteurs



### Photobioreacteurs



### Photosynthèse artificielle

↓  
Hydrogène,  
syngas, méthanol

### Photosynthèse naturelle

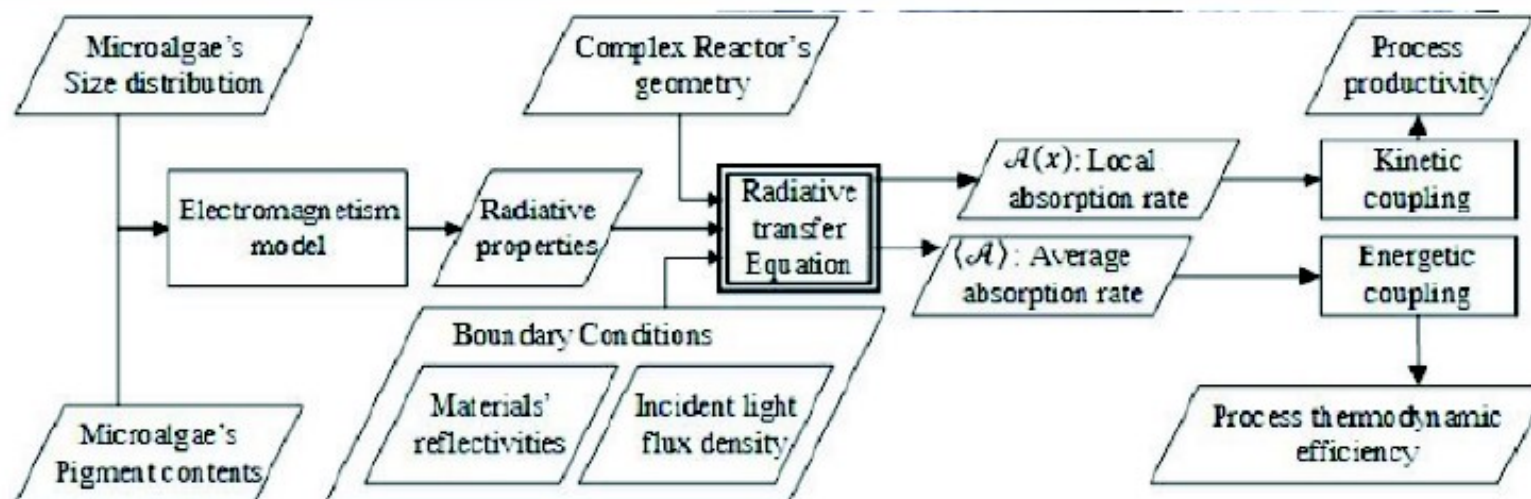
↓  
Biomasse convertie  
au sein de  
bio-raffineries

↓  
biocarburants,  
intermédiaires  
chimiques, etc



Procédés limités par le transfert de rayonnement

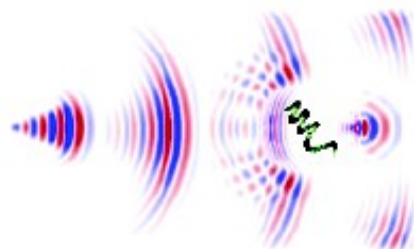
# Conception optimisée de photo-procédés



## Procédés contrôlés par la répartition de la lumière en leur sein

### Électromagnétisme & Biologie

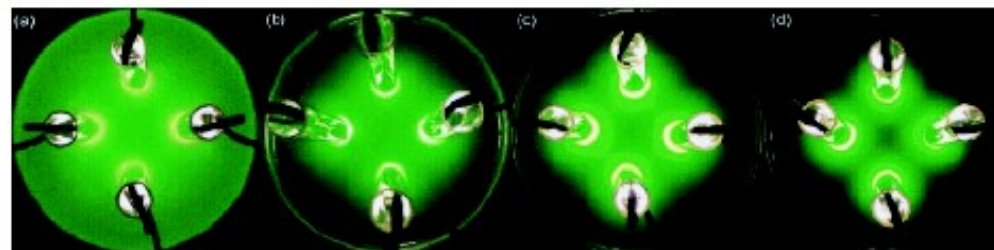
Interaction élémentaire  
lumière - microorganisme



micromètre

### Transfert radiatif

Lumière localement disponible à la photosynthèse



millimètre

### Génie des procédés

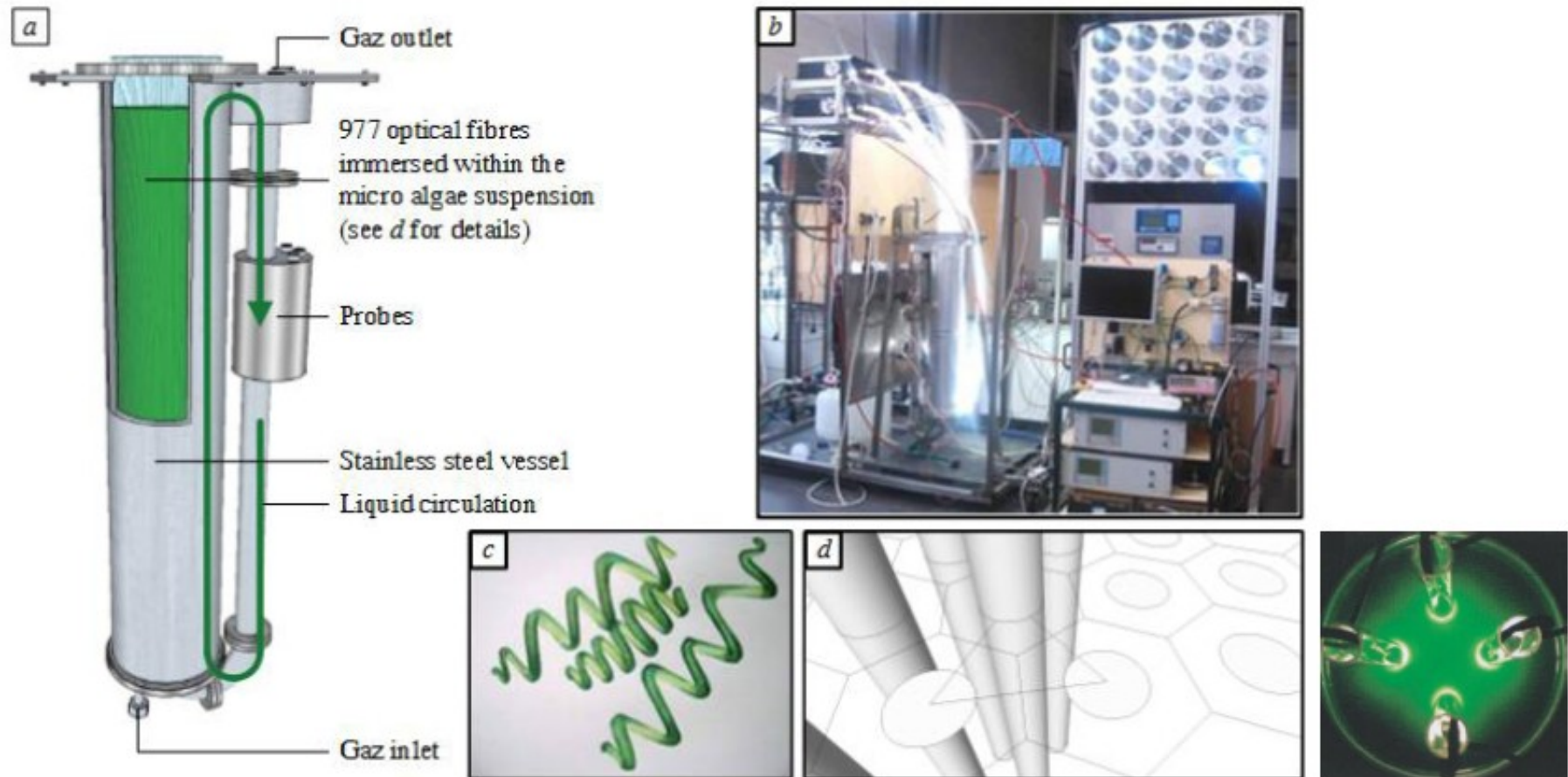
Moyenne sur le volume de réaction :  
performances du procédé



mètre

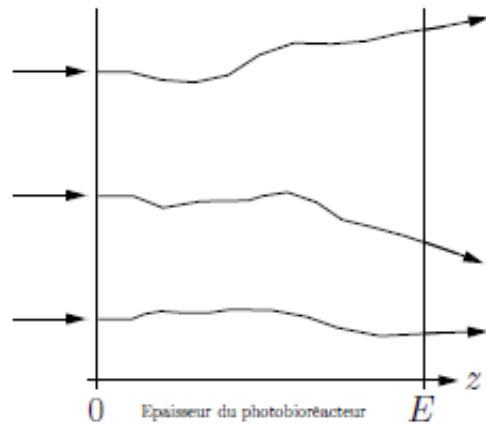
# Résultat de l'approche de conception : prototype DiCoFluV

Dilution Contrôlée du Flux en Volume : facteur 4 à 5 sur l'efficacité

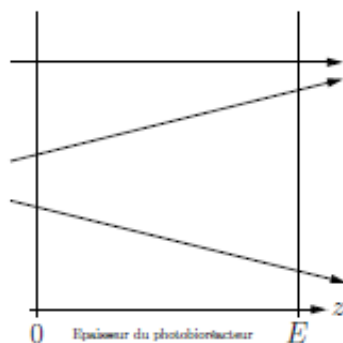


Brevet : J. F. Cornet et al. 2012 International Patent N° WO/2012/069622

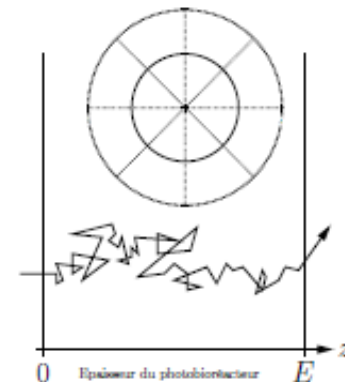
# Configurations radiatives adressées



- Régime stationnaire pour le transfert.
- Fonction de phase fortement anisotrope, orientée vers l'avant.
- Sources aux limites, souvent collimatées.
- Sensibilité des observables, à la fois aux conditions d'incidence et à la diffusion.



Mince  $e_d^* \ll 1$       Intermédiaire      Epais  $e_d^* \gg 1$



# Sensitivity evaluation

$$A(\mathbf{x}_0) = \int_{\nu_{min}}^{\nu_{max}} p_{\nu}(\nu) d\nu \int_{4\pi} p_{\Omega_0}^{\nu}(\omega_0) d\omega_0 \int_0^{\infty} p_{L_0, \nu}(l_0) dl_0 \dots \times \hat{w}$$

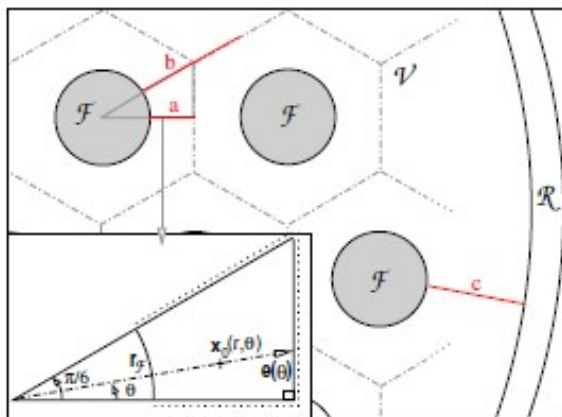
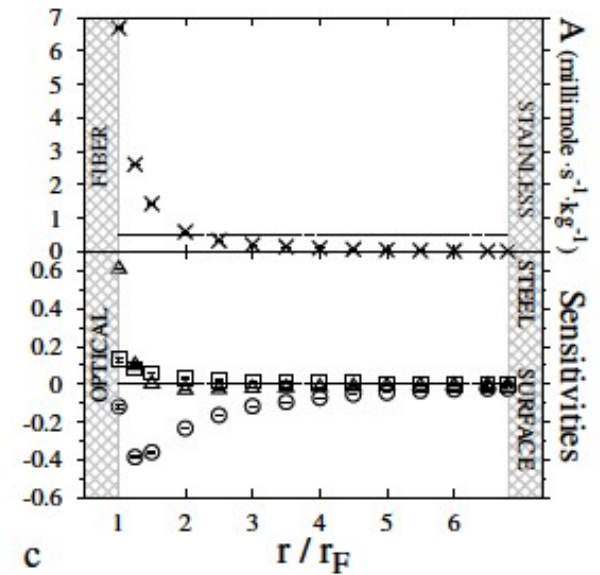
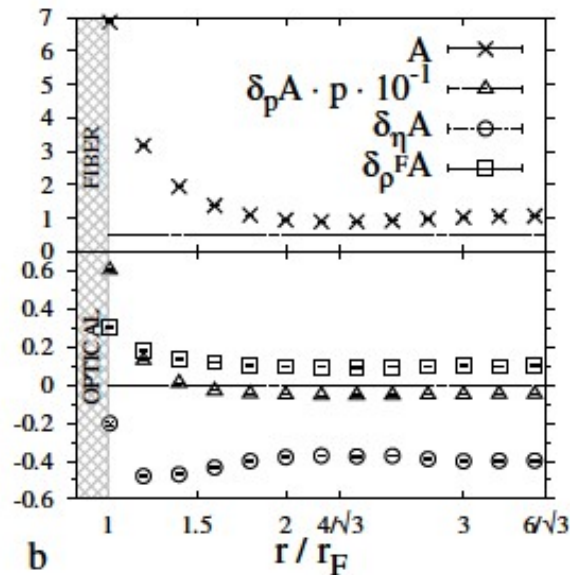
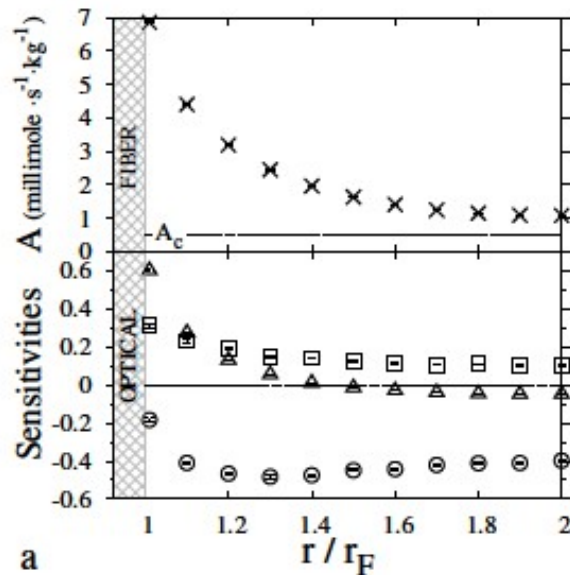
$$\partial_{\pi} A(\mathbf{x}_0) = \partial_{\pi} \left[ \int_{\nu_{min}}^{\nu_{max}} p_{\nu}(\nu) d\nu \int_{4\pi} p_{\Omega_0}^{\nu}(\omega_0) d\omega_0 \int_0^{\infty} p_{L_0, \nu}(l_0; \pi) dl_0 \dots \times \hat{w}(\pi) \right]$$

$$\begin{aligned} \partial_{\pi} A(\mathbf{x}_0) = & \int_{\nu_{min}}^{\nu_{max}} p_{\nu}(\nu) d\nu \int_{4\pi} p_{\Omega_0}^{\nu}(\omega_0) d\omega_0 \int_0^{\infty} p_{L_0, \nu}(l_0; \pi) dl_0 \dots \\ & \times \left( \partial_{\pi} [\hat{w}(\pi)] + \hat{w}(\pi) \sum \frac{\partial_{\pi} [p_{L_i, \nu}(l_i; \pi)]}{p_{L_i, \nu}(l_i; \pi)} \right) \end{aligned}$$

Domain deformation sensitivities:

Roger M., Blanco S., El Hafi M. and Fournier R. 2005 *Physical Review Letters* **95** 180601

# Analysis of the studied photobioreactor prototype



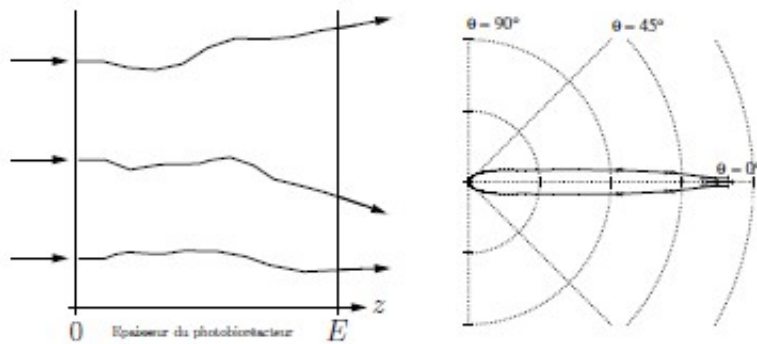
## Sensitivities to:

- $\triangle$  photosynthetic pigment content  $p$
- $\circ$  microorganisms density  $\eta$
- $\square$  fibers reflectivity  $\rho^{\mathcal{F}}$

# Approximations du transport : P1 et diffusion simple

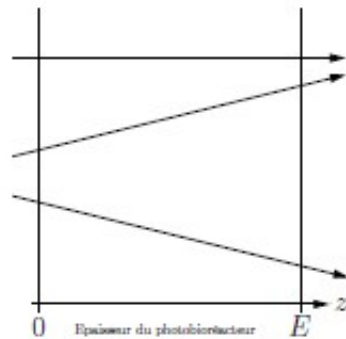
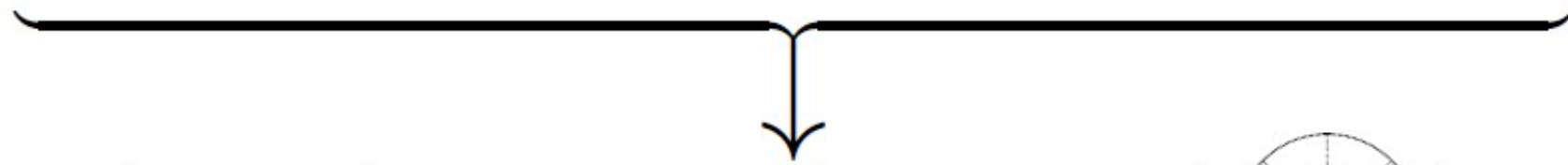
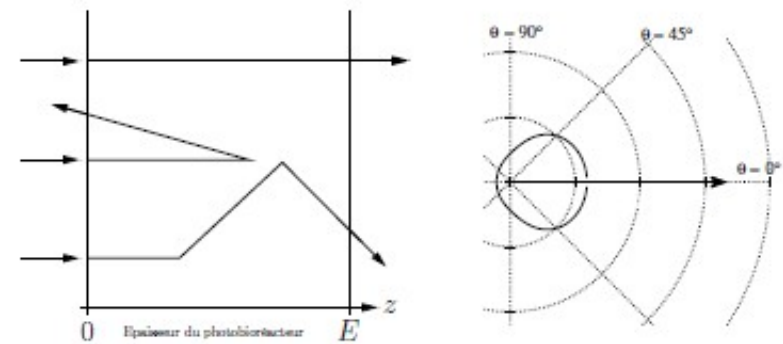
$$e_d = E/\lambda_d \simeq 20$$

$$g \simeq 0.95$$

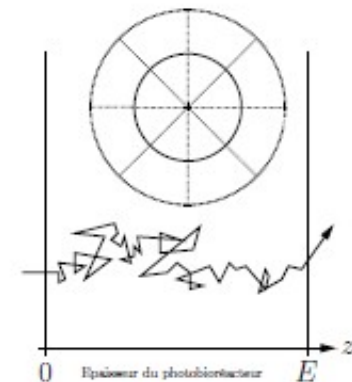


$$e_d^* = e_d(1 - g) \simeq 1$$

Fonction de phase isotrope



Mince  $e_d^* \ll 1$       Intermédiaire      Epais  $e_d^* \gg 1$

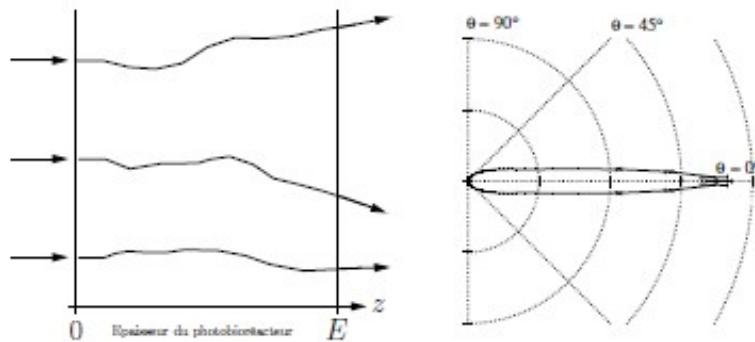




# Approximations du transport : P1 et diffusion simple

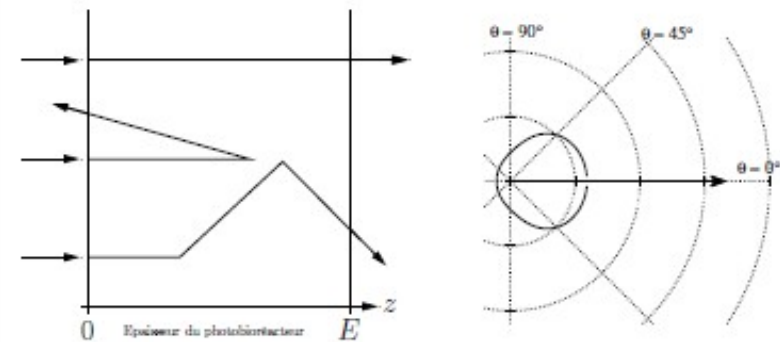
$$e_d = E/\lambda_d \simeq 20$$

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Fonction de phase isotrope



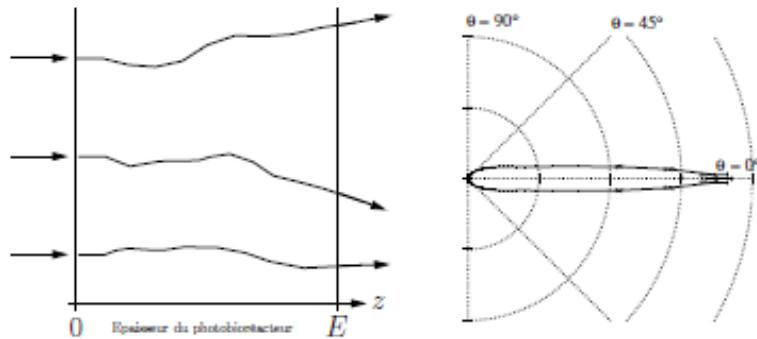
Dans le problème de transport équivalent :

- Balistiques  $\sim 80\%$
- 1 diffusion  $\sim 15\%$
- $> 1$  diffusion  $\sim 5\%$
- Balistiques : atténuation exponentielle
- Diffus :
  - Diffusion simple
  - P1

# Approximations du transport : P1 et diffusion simple

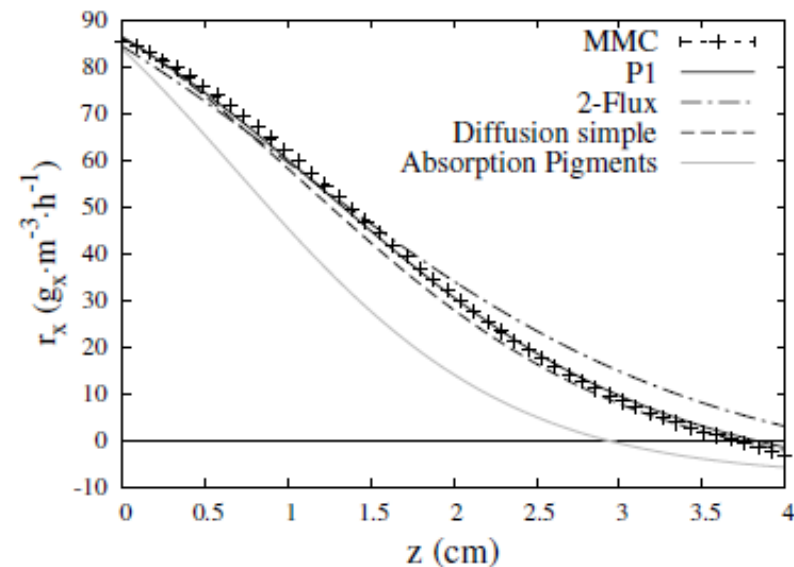
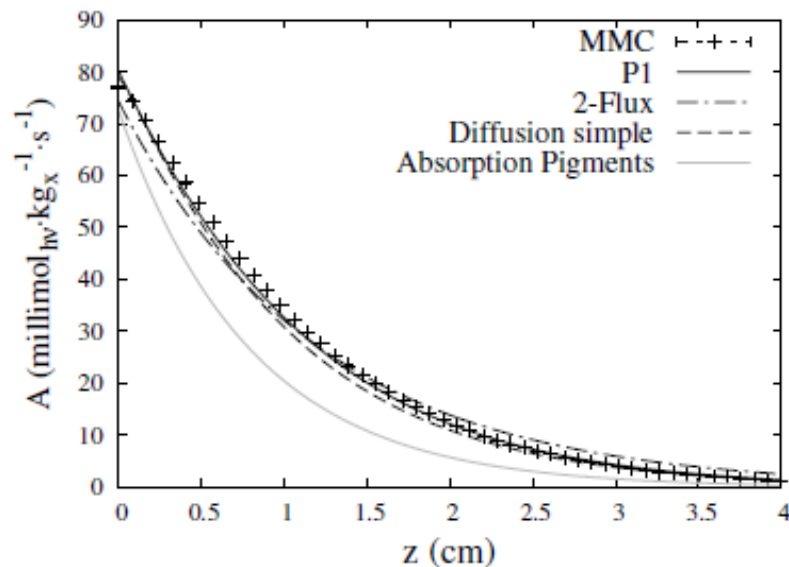
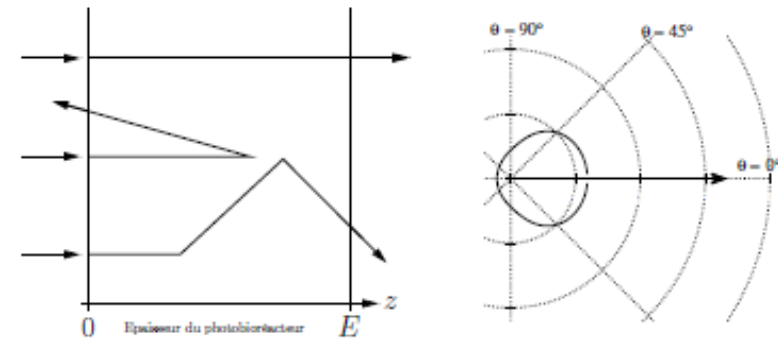
$$e_d = E/\lambda_d \simeq 20$$

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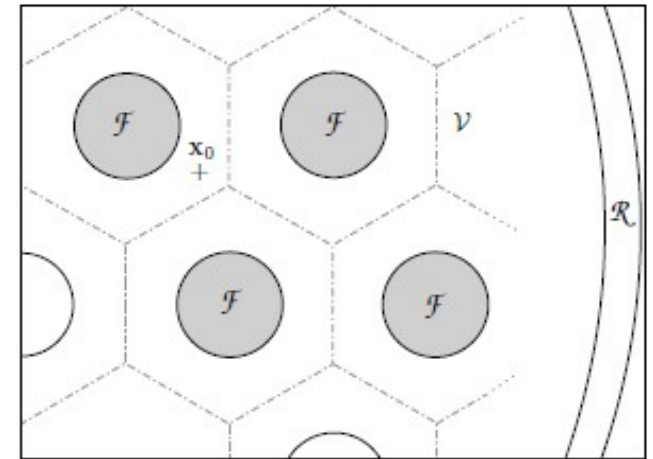
Fonction de phase isotrope



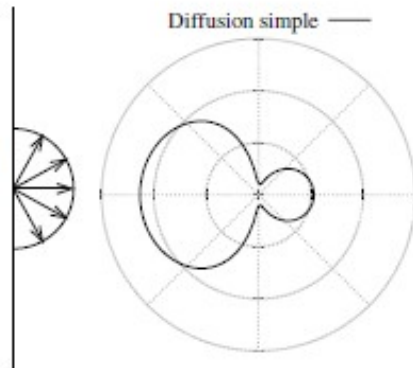
# Monte Carlo : concept de zéro variance

$$A(\mathbf{x}_0) = \int_{\nu_{min}}^{\nu_{max}} d\nu \sigma_{a,\nu} \int_{4\pi} d\omega_0 \hat{L}_\nu(\mathbf{x}_0, -\omega_0)$$

$$p_{\Omega_0}^{\nu, opt}(\omega_0 | \nu, \mathbf{x}_0) = \frac{\hat{L}_\nu(\mathbf{x}_0, -\omega_0)}{\hat{G}_\nu(\mathbf{x}_0)}$$



Fibre :  
Rayonnement  
incident  
lambertien



Miroir  
spéculaire

