Biomedical Optics

Monte-Carlo Simulations

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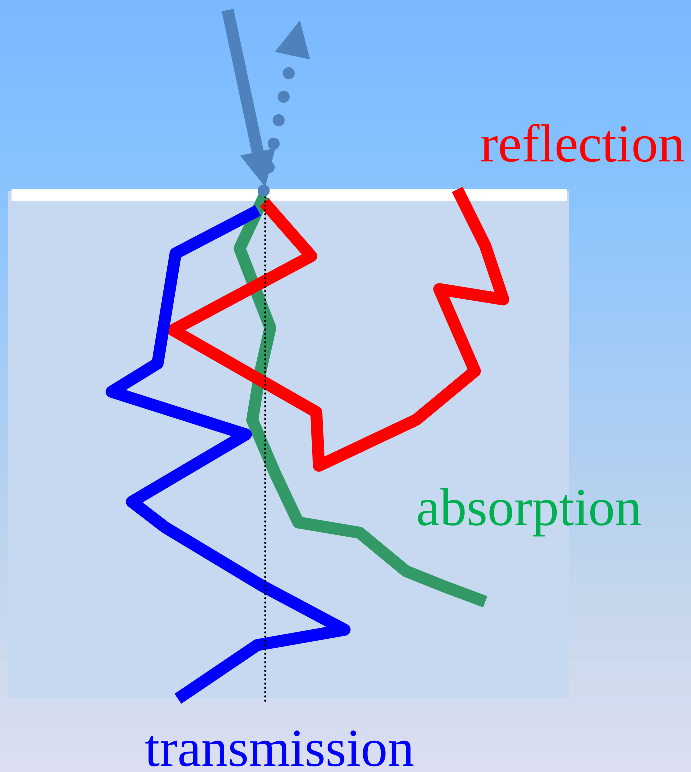
Monte-Carlo simulations: Principle

Principle :



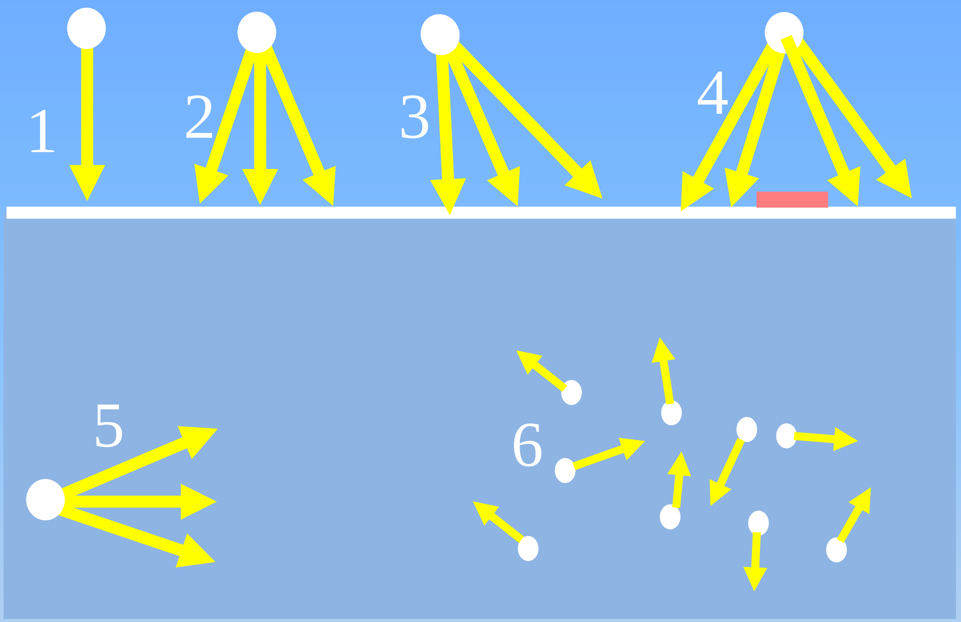
Steps: Photons will be:

1. **Emitted** towards tissue
2. **Reflected** at surface or:
3. **Injected** into tissue;
4. **Propagated** over distance related to "transport mean-free-path";
5. **Absorbed**, or:
6. **Scattered**;
7. **Propagated** again, as in 4.
8. **Reflected or refracted** at boundaries (external or internal).
9. **Detected,** when leaving the sample.

MC : Emission

Steps: Photons will be:

1. **Emitted,**
2. Reflected, or
3. Injected,
4. Propagated
5. Absorbed, or:
6. Scattered,
7. Propagated.
8. Reflected / refracted.
9. Detected.



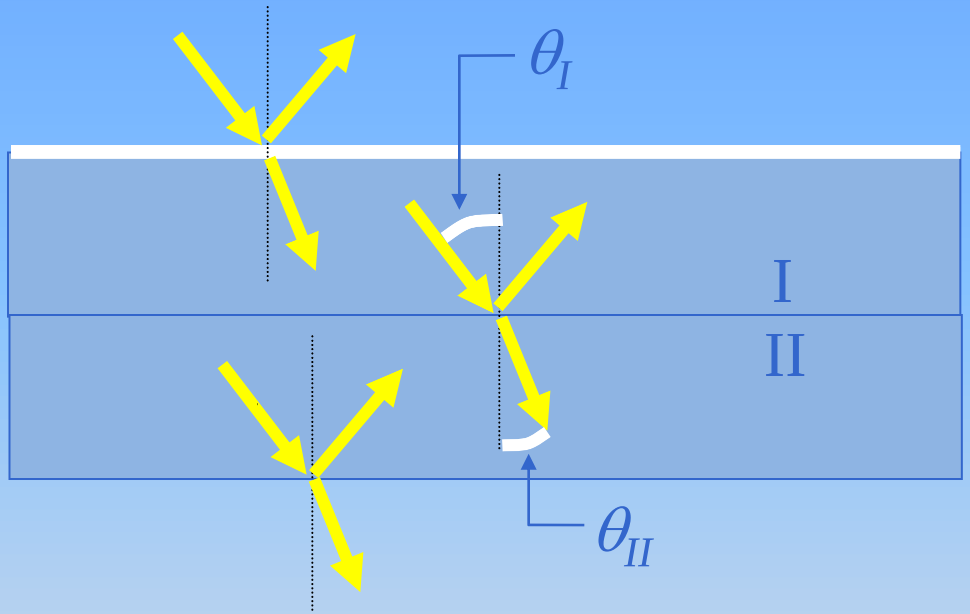
Photon sources:

1. Pencil beam
2. Divergent beam
3. Tilted beam
4. Ring-shaped beam
5. Internal focus
6. Distributed source

MC: Reflection or Injection

Steps: Photons will be:

1. Emitted,
2. **Reflected, or**
3. **Injected,**
4. Propagated
5. Absorbed, or:
6. Scattered,
7. Propagated.
8. Reflected / refracted.
9. Detected.



Reflection or refraction according to the Fresnel-relations:

Percentage of reflection $R = f\,(n_I / n_{II}\,;\ \theta_{I\,,}\ \theta_{II}\,)$

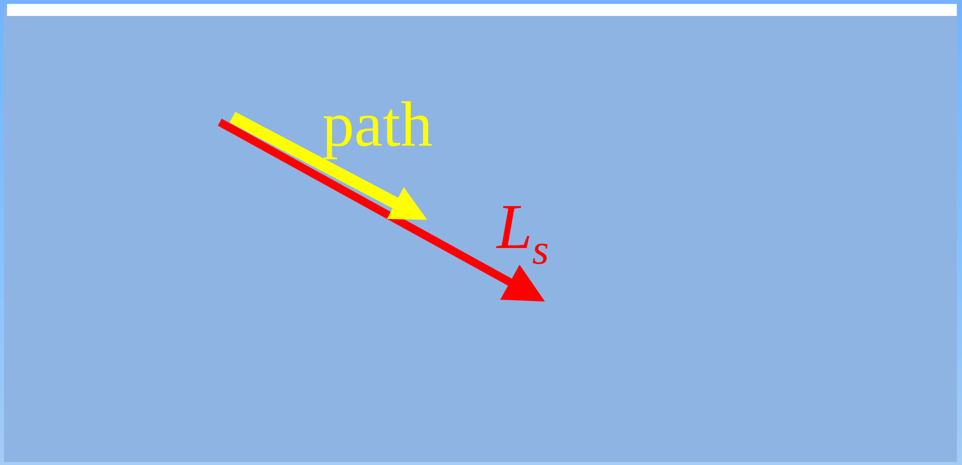
In program: reflection if : $Random * 100 \leq R$

$Random$ = random generator ($0 \leq random < 1$)

MC: Light Propagation

Steps: Photons will be:

1. Emitted,
2. Reflected, or
3. Injected,
4. **Propagated**
5. Absorbed, or:
6. Scattered,
7. Propagated.
8. Reflected / refracted.
9. Detected.



Propagation distance determined by Lambert & Beer's Law:

$I(x) = I(0).\ \exp(-\mu x)$; μ = attenuation coefficient

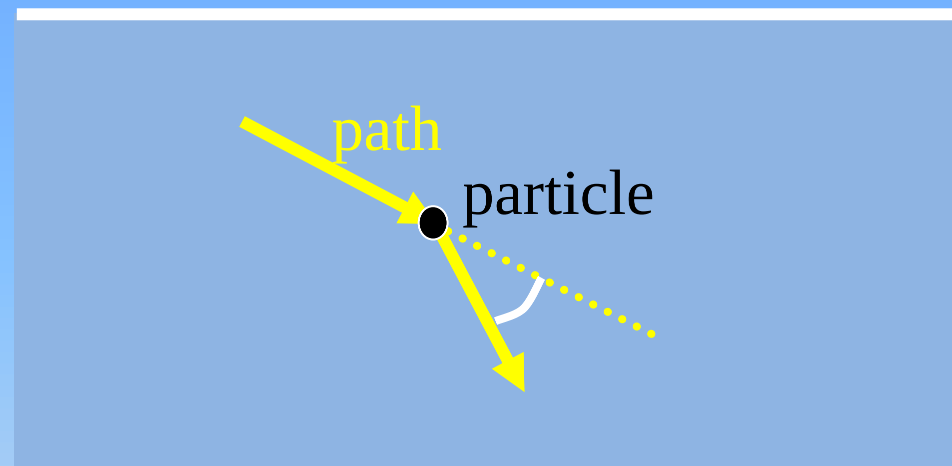
Average translation distance between scatter events:
$L_s = 1 / (\mu_s + \mu_a)$; μ_s and μ_a = coefficients of the *medium*.

In program: $path = -\ L_s\ .\ \ln(1-random)$; $0 \leq random < 1$

MC: Absorption or Scattering

Steps: Photons will be:

1. Emitted,
2. Reflected, or
3. Injected,
4. Propagated
5. **Absorbed, or:**
6. **Scattered,**
7. Propagated.
8. Reflected / refracted.
9. Detected.



After propagation: arrival at particle: Absorption or Scattering

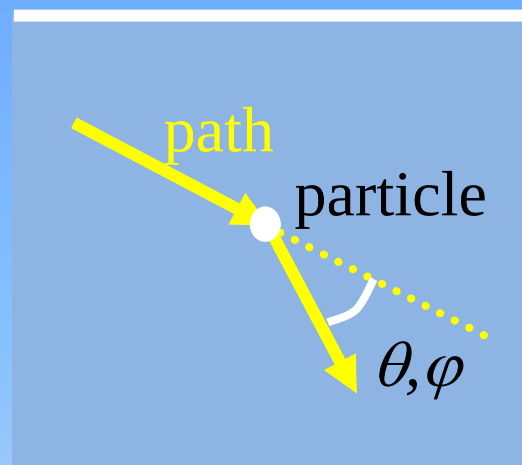
determined by absorption and scattering cross sections: σ_a and σ_s [m^2]
with $\mu_a = n\,\sigma_a$; $\mu_s = n\,\sigma_s$; n = nr. particles / m^3

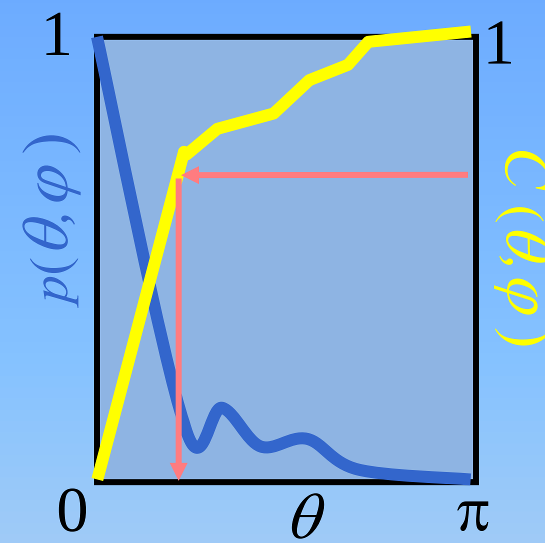
In program: absorption if: $random < \sigma_a / [\sigma_s + \sigma_a]$

MC: Scattering

Steps: Photons will be:

1. Emitted,
2. Reflected, or
3. Injected,
4. Propagated
5. Absorbed, or:
6. **Scattered,**
7. Propagated.
8. Reflected / refracted.
9. Detected.





Scattering by particle: angles θ,φ determined by scattering function $p(\theta,\varphi)$

Options: isotropic, dipolar, Rayleigh-Gans, Mie, ...

In program: θ determined by: $random = C(\theta,\varphi)$,

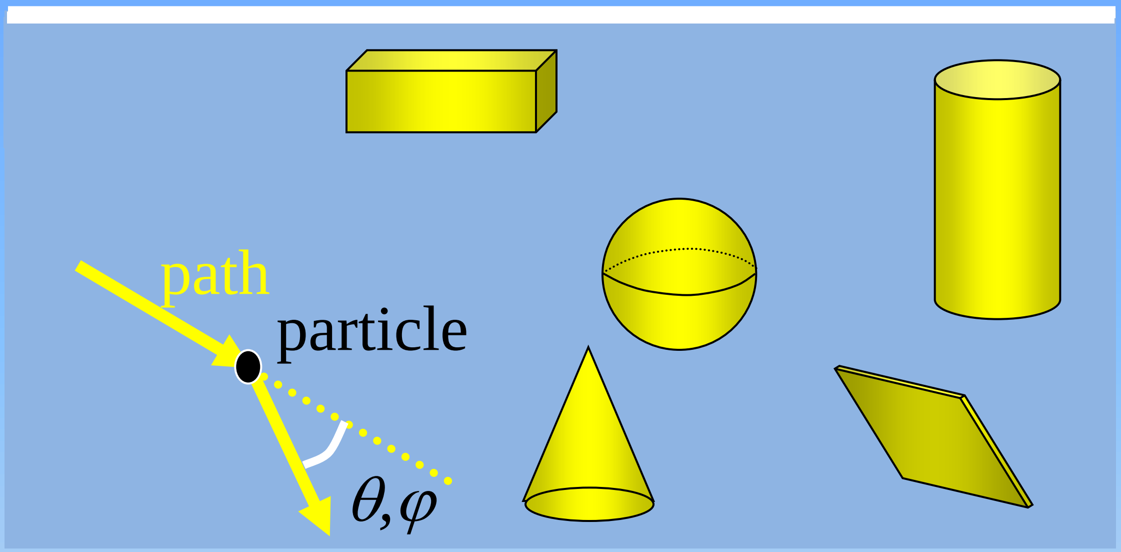
$C(\theta,\varphi)$ is cumulative scattering function

$$C(\theta,\varphi) = \int_0^{\theta} p(\theta',\varphi).\sin\theta'.d\theta'$$

φ determined by: $\varphi = random * 2\pi$

MC: Propagation

Steps: Photons will be:
1. Emitted,
2. Reflected, or
3. Injected,
4. Propagated
5. Absorbed, or:
6. Scattered,
7. **Propagated.**
8. Reflected / refracted.
9. Detected.



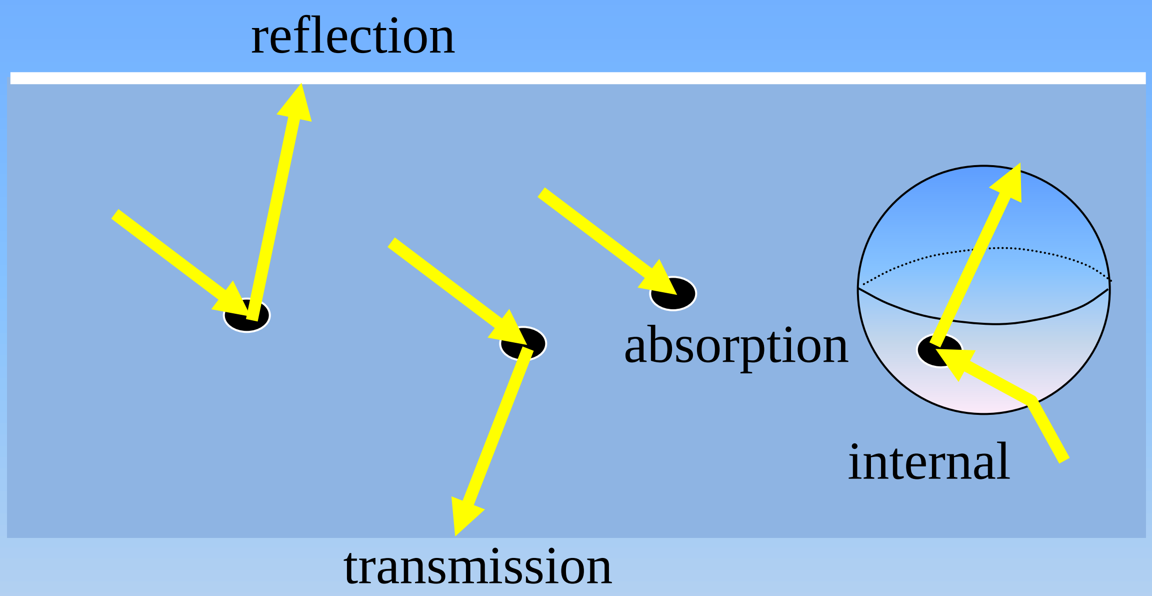
Propagation through layers and objects

Objects: options:
- rectangular blocks
- cylindrical tubes in X, Y, Z-directions or oblique
- spheres (fixed or randomly distributed)
- cones
- mirrors (one-surface only)
- torusses

MC: Detection

Steps: Photons will be:

1. Emitted,
2. Reflected, or
3. Injected,
4. Propagated
5. Absorbed, or:
6. Scattered,
7. Propagated.
8. Reflected / refracted.
9. **Detected**.



Detection: options: reflection, transmission, absorption, internal

Detection window: options: XY-grid; rings; internal (sphere)

MC: Optical properties

<u>Optical properties of tissue</u> (at 800 nm):

	μ_a [mm^{-1}]	μ_s [mm^{-1}]	$g = < \cos\theta >$	n [-]	Thickn. [mm]	Scatt. func.*)	n_{rel} +) [-]
Epidermis	0.01	10	0.875	1.5	0.1	HG	1.1
Dermis	0.01	10	0.82	1.4	2	HG	1.1
Blood °)	1.0	70	0.99	1.4	-	Mie	1.07
Fat (subcut.)	0.001	3	0.9	1.4	0-2	Mie	≈1.1
Glass	0	0	-	1.5	-	-	-
Water	0.001	0	0	1.33	-	-	-

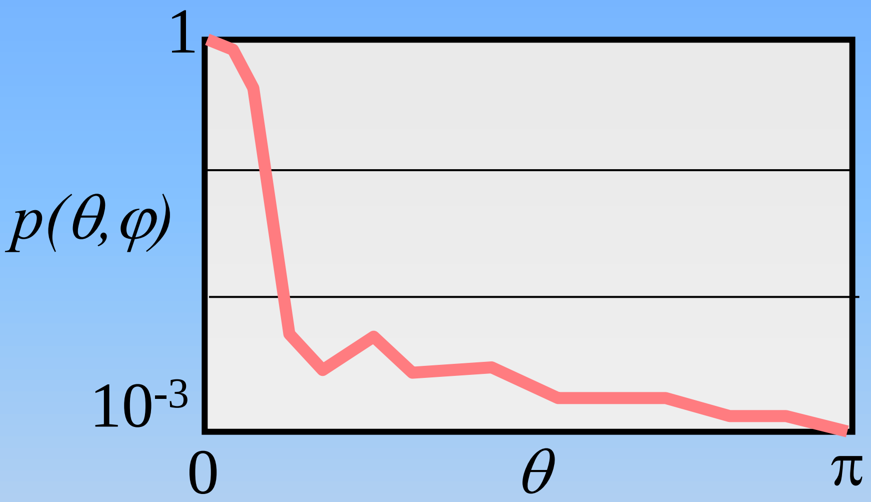
°) At hematocrit = 45 % ;
Blood ≈ 1.5 vol.% in tissue

*) HG = Henyey-Greenstein
+) relative refractive index of particles in medium

MC: Scattering functions

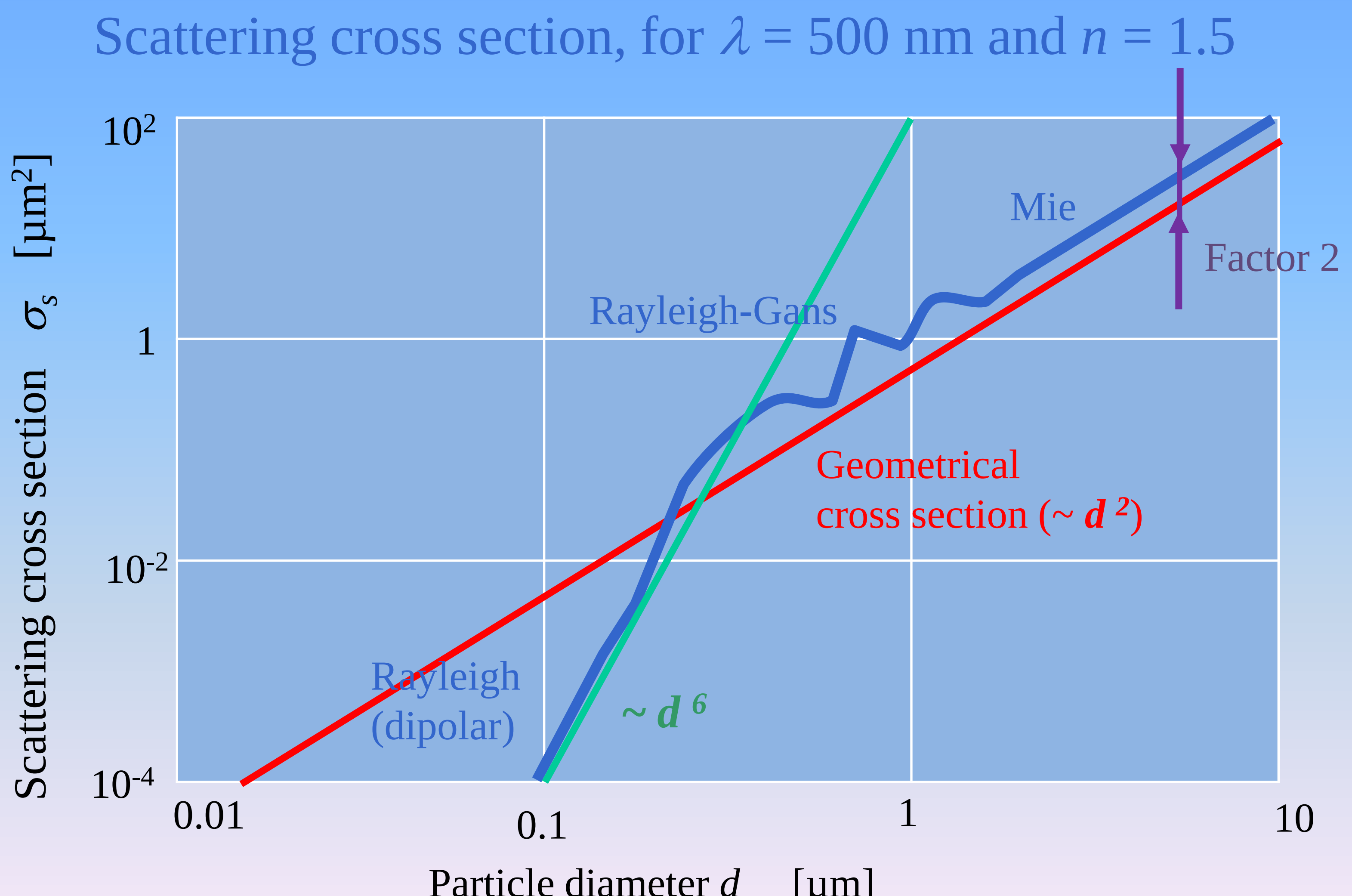
Scattering function: $p(\theta,\varphi)$
determined by:

- relative refractive index n_{rel}
  of scattering particles in medium
- aspect ratio x = ratio of
  - particle circumference,
  - wavelength in medium



Examples	Particle sizes (λ= 800 nm)
• isotropic	• << 0.1 µm
• dipolar (Rayleigh)	• 0.05 – 0.2 µm
• Rayleigh-Gans	• 0.2 – 2 µm
• Mie	• > 2 µm

MC: Scattering cross section



MC: Simulations

Numerical project:

- Depart from: basic tissue structure (2-layer system)
- Use pencil beam, λ = 800 nm
- Vary one of following variables by factors 2 and ½ :
    1. Thickness of epidermis
    2. Thickness of dermis
    3. Scattering coefficient of dermis
    4. Absorption coefficient of epidermis
    5. Scattering coefficient of epidermis, or
    6. Scattering function
- Calculate: $I(r)$ for source-detector distance r = 0...3 mm , normalize to 1 at r = 1 mm
- Plot: ln $I(r)$ vs. r and calculate μ_{eff}
- Compare μ_{eff} with monolayer situation (dermis only)

MC - program

How to handle the Monte-Carlo-program:

- Depart from: Creation of Scattering Functions (*.MIE-files)
- Create Input data-files (*.INP-files).
- If more (related) simulations wanted:
  create List of INP-files (*.LST-file)
- Start Simulations
- After completion of simulations: results in *.FOT-files
  Plot: ln I (r) *vs.* r for r = 0..3 mm
  (plot option available in program).
- Calculate μ_{eff} and
  compare with monolayer situation (dermis only)

Monte-Carlo simulations

The end