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# Diffuse Optical Tomography For Tumour Detection Diffuse Optical Tomography For Tumour Detection

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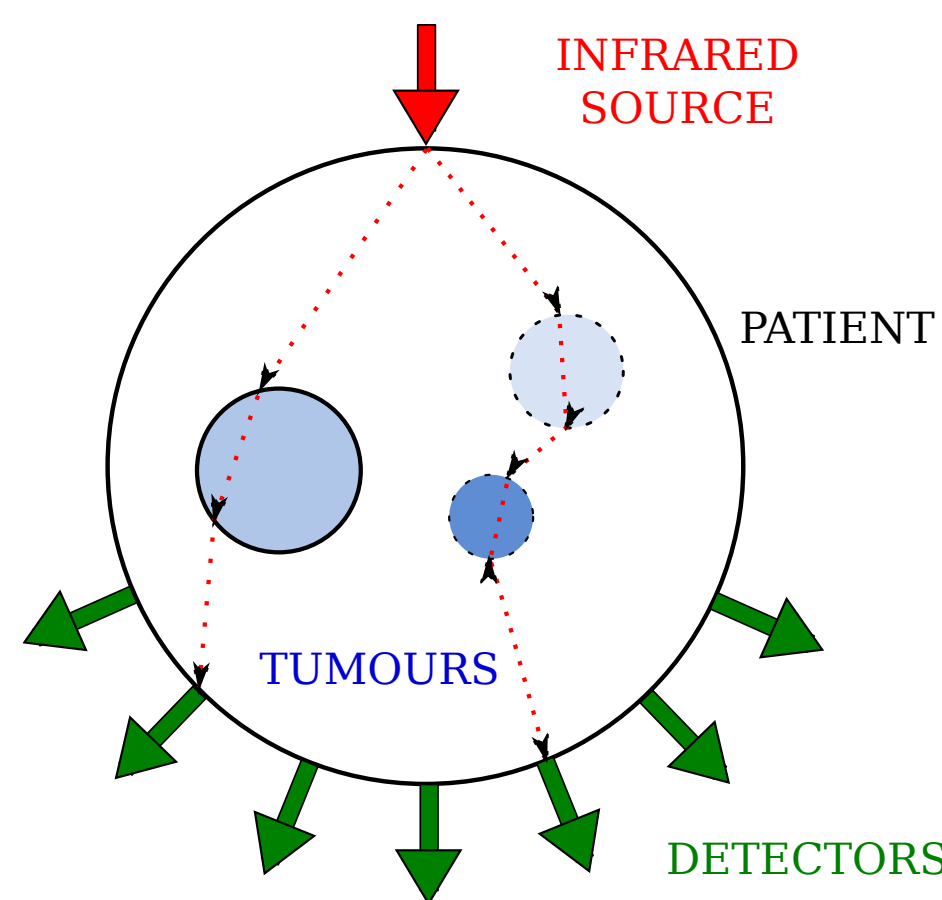


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## What is optical tomography?

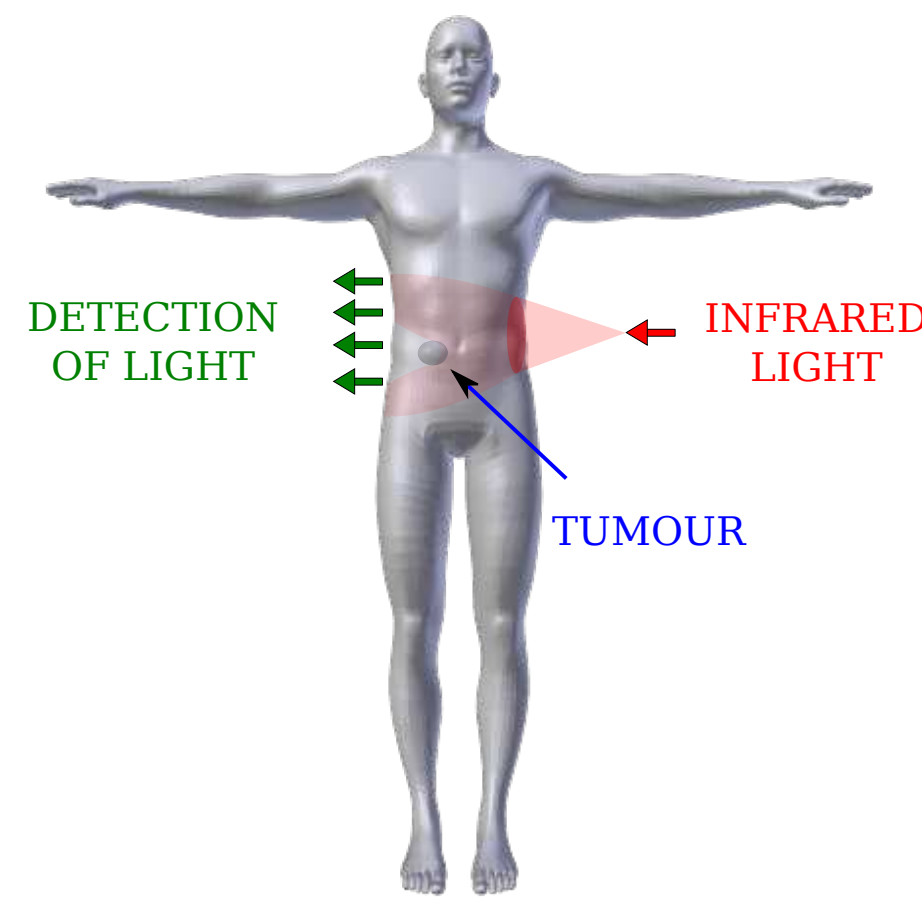
### Principle :

- Pulse an infrared light (IR) on the skin of a patient and measure at the opposite side the photon density diffused across the body.
- Add a fluorescent marker (Indocyanine green ICG) to improve the contrast.



### Goals ?

- Reconstruct the absorption and diffusion maps to understand the photon propagation and determine "opaque areas" assimilated to tumours.
- Provide a good image resolution to be put into practice in hospitals.



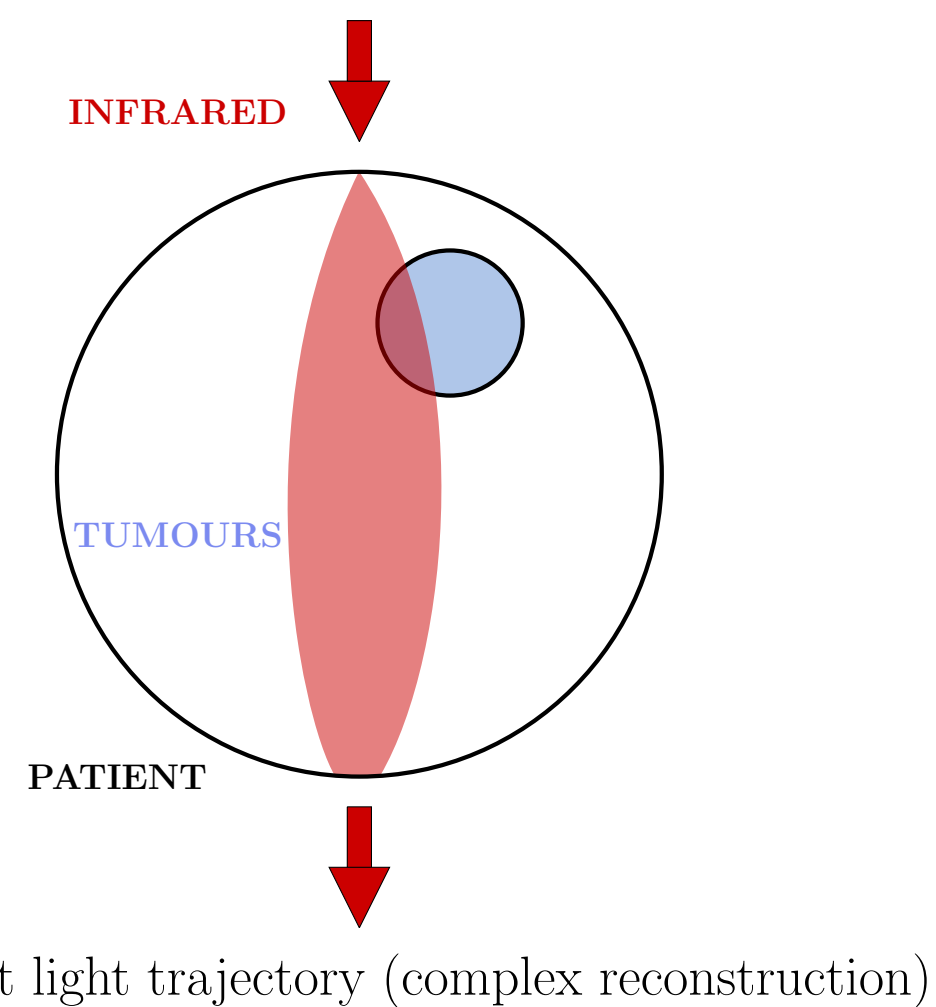
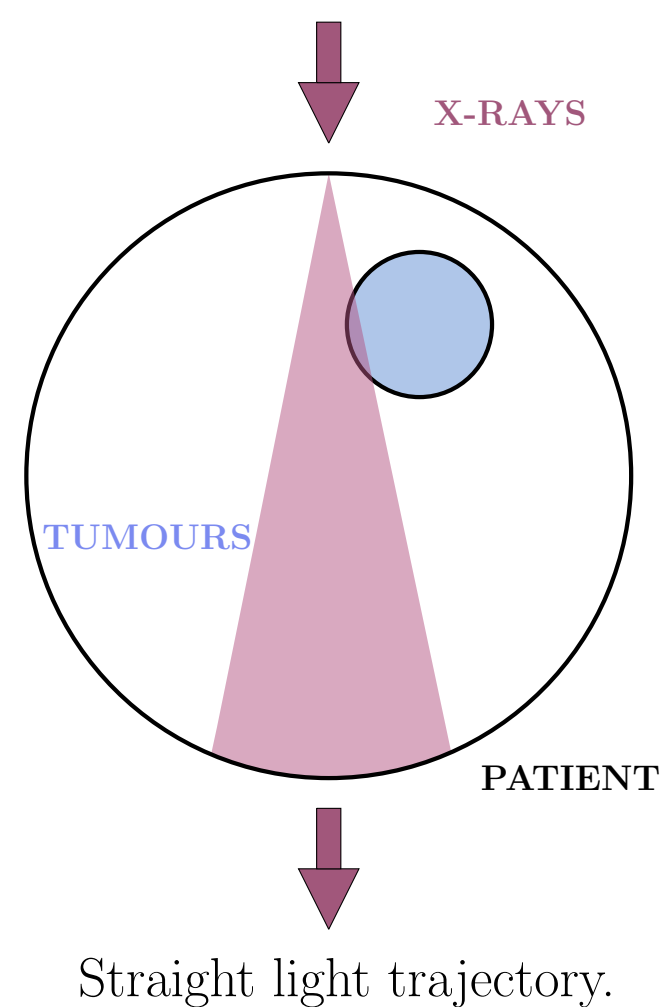
## What interests for healthcare?

### Advantages:

- Low cost (contrary to MRI, ...).
- Non ionizing (contrary to Xrays, ...).
- Non invasive (non-contact measure, painless,...).
- Complementary to existing imaging systems.

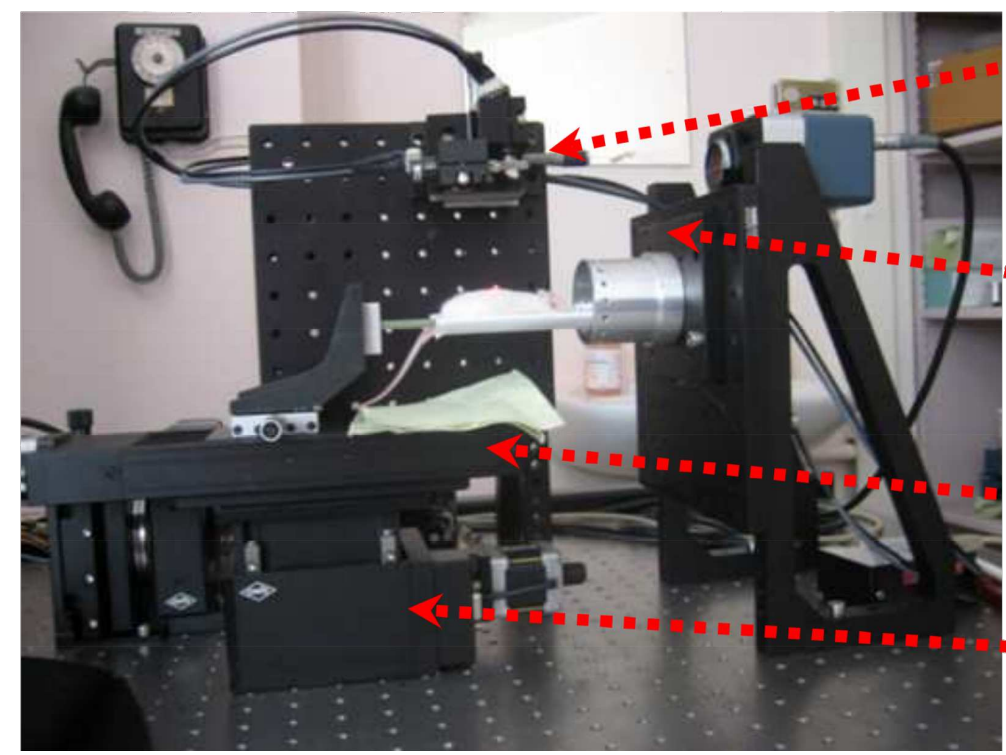
### Drawbacks:

- IR light does not propagate in straight line (contrary to Xrays).
- Image reconstruction involves non linear inverse problem.
- Setup of the acquisition protocol.

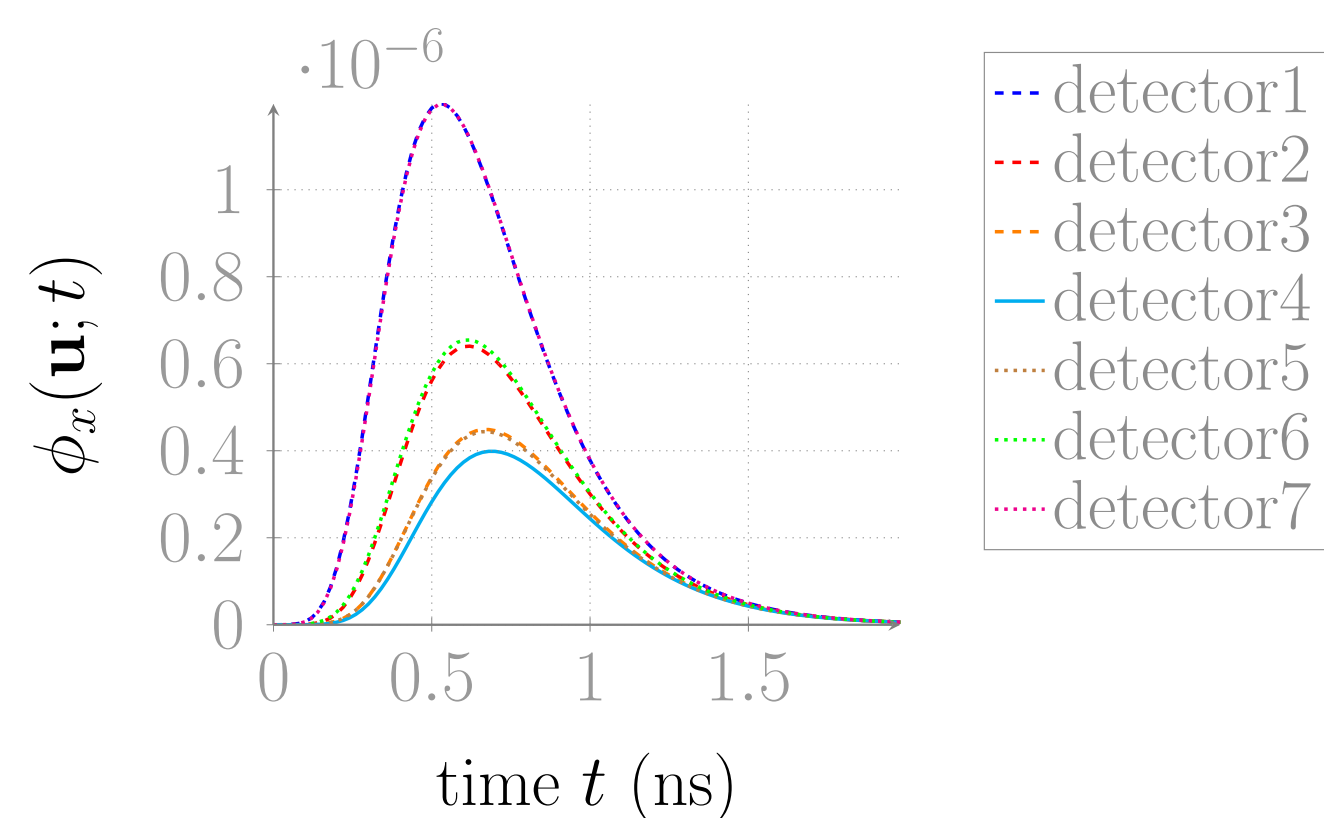
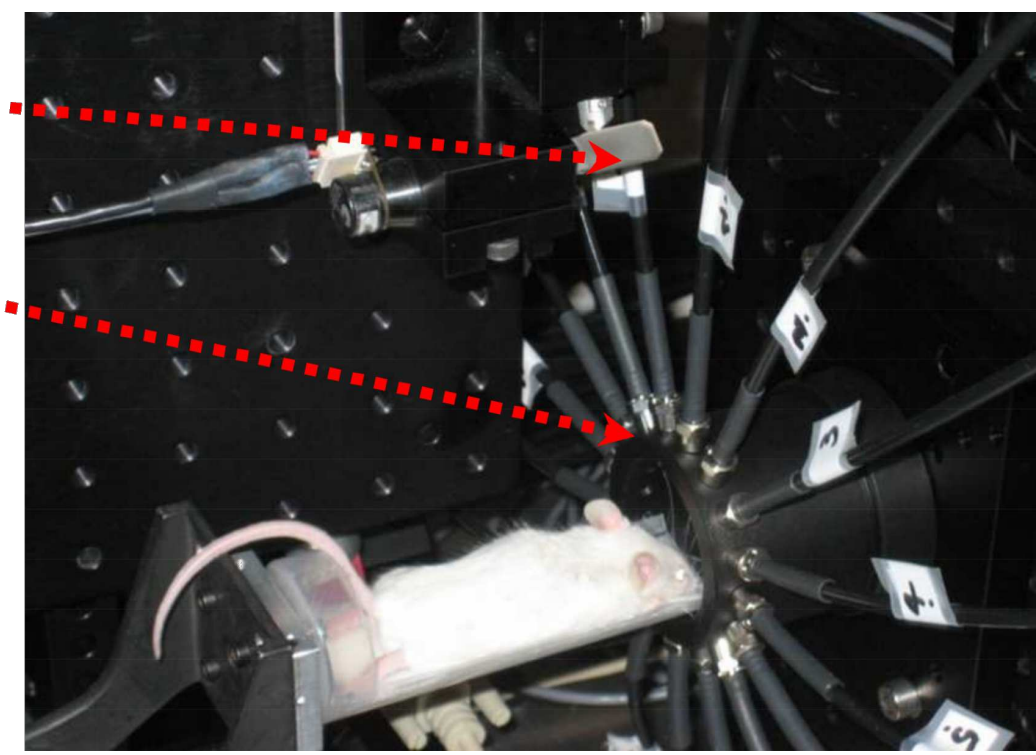


## Tomograph and measures

- A scanner system (conoscope and mirrors) retrieves a surfacic point cloud data set.
- A ring made of 16 fibers placed regularly around the object detects photons over time.
- A mechanical multiplexor aligns fibers with laser diodes which pulse or detect the IR light depending on the operating mode.



Mirrors  
 Fiber ring  
 Mount Engine 1  
 Mount Engine 2



### Acquisition process:

- 1 pulse per fibers.
- 7 measures (TPSF) per pulse at the opposite side and over time.

## Numerical tools

- FEEL++, a library for FEM methods providing a variational form language embedded in C++ and developed at the university of Strasbourg and other research centers (high order methods, reduced basis, level set methods, ...).
- Highly parallelized to work with supercomputers (MPI, OpenCL, ...).
- Interface with mesh generators (GMSH).
- Interface with linear and non linear solvers (PETSc, SLEPc, MUMPS, ...).
- Post processing software for visualization (Paraview, Ensight, ...).

## Mathematical model

- The physical phenomenon is modeled by the diffusion and fluorescence equations coupled on  $\Omega \times [0, T]$

$$\begin{cases} -\text{div}(\kappa_x \nabla \phi_x) + c_e \mu_{a,x} \phi_x + \frac{\partial \phi_x}{\partial t} = q_0, \\ -\text{div}(\kappa_m \nabla \phi_m) + c_e \mu_{a,m} \phi_m + \frac{\partial \phi_m}{\partial t} = \frac{\gamma}{\tau} \int_0^t \phi_x(s) e^{-\frac{t-s}{\tau}} ds, \end{cases}$$

where  $\phi_\ell$  are photon densities for  $\ell \in \{m, x\}$ .  $\mu_{a,\ell}$ ,  $\kappa_\ell$  are optical properties,  $\gamma, \tau$  fluorescence properties, and  $c_e$  the speed of the light respectively in the turbid medium.

- The Robin boundary condition on  $\partial\Omega \times [0, T]$

$$\phi_\ell + 2A\kappa_\ell \nabla \phi_\ell \cdot \mathbf{n} = 0$$

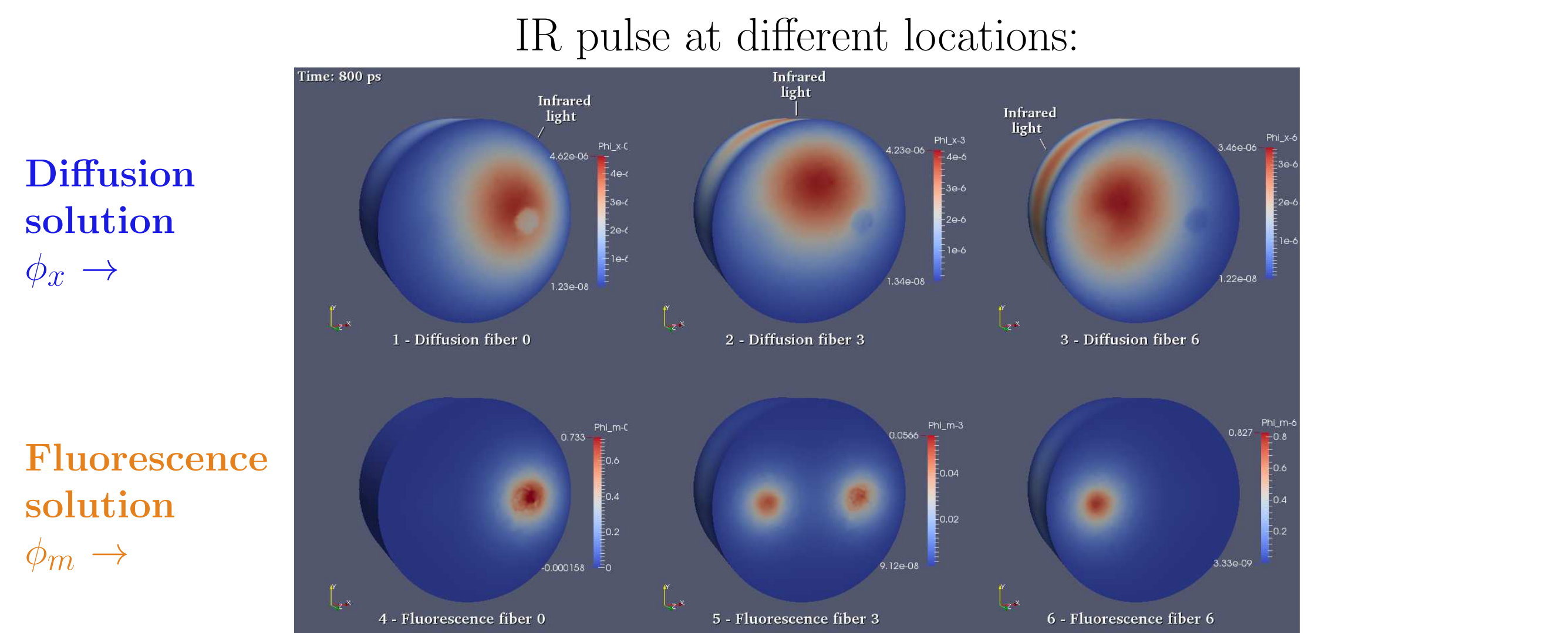
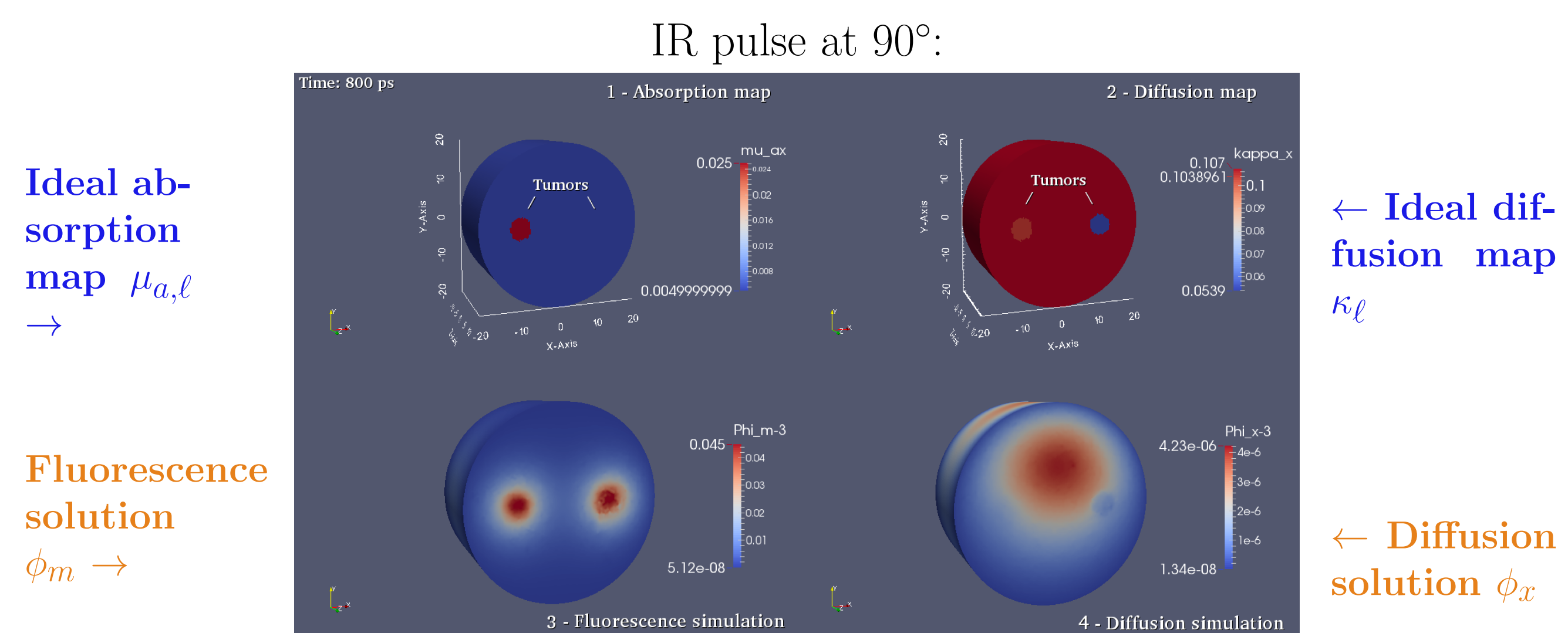
- The source term  $q_0$  can be a pointwise (regularized or not) dirac in contact mode, and regularized surfacic dirac for the non-contact.

$$q_0^{\text{regularized}} = \begin{cases} \frac{1 + \cos(\pi d(\mathbf{r}))}{2\epsilon} & \text{if } d(\mathbf{r}) < \epsilon = O(h) \quad (h \text{ characteristic mesh size}), \\ 0 & \text{else} \end{cases}$$

- Finite Element Method (FEM) strategy is used to solve the forward and inverse problems.

## Forward simulation examples

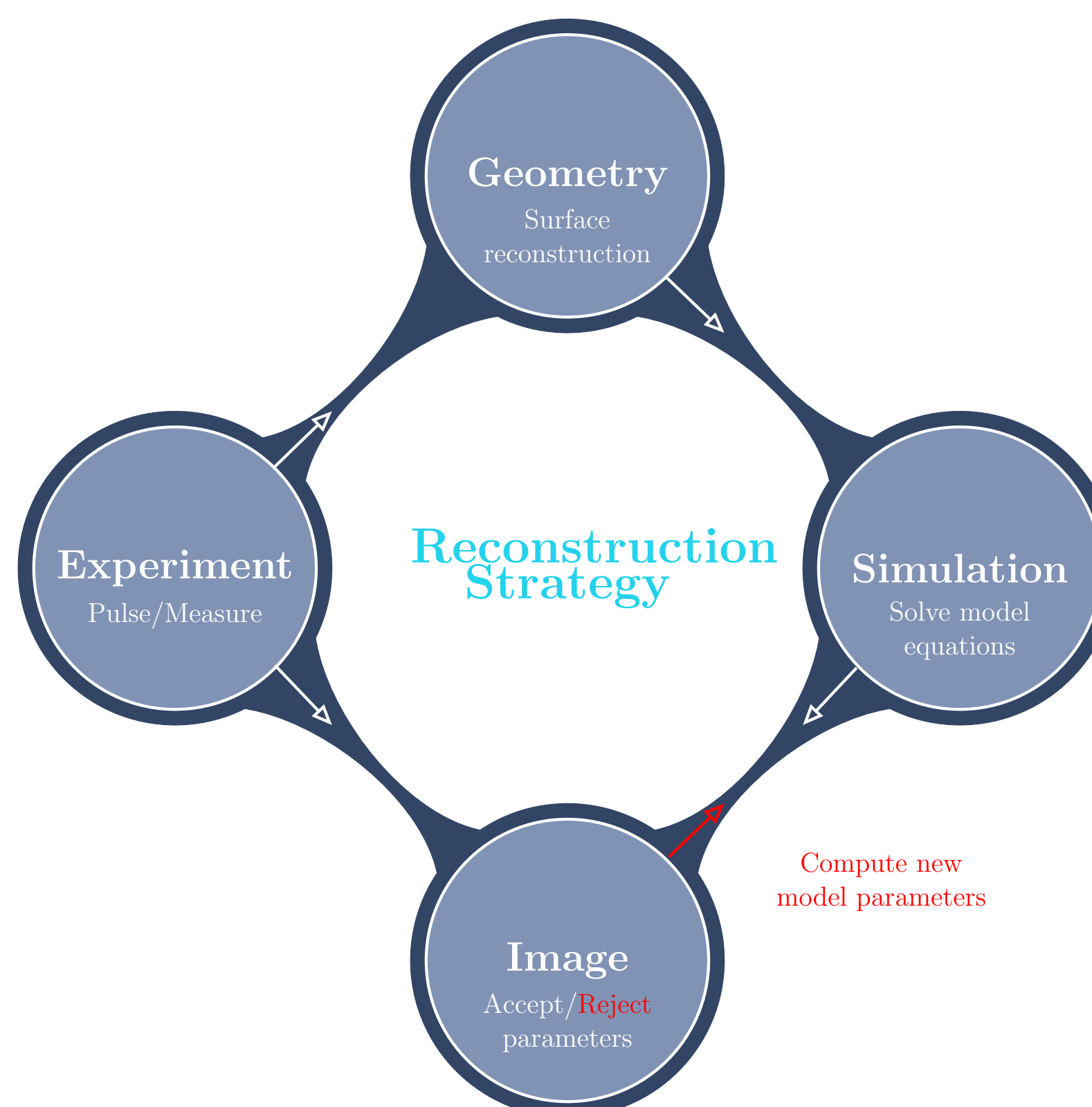
- Solution for the mathematical model on a cylindric test case containing two inclusions with different optical properties.



- ICG is located at the tumours (inclusions) due to their biological properties (hemoglobin oxygen saturation).

## Inverse problem

- Image reconstruction process which includes the physical data is required to deduce all the optical and fluorescent parameters.



- The image reconstruction consists in determining the best parameters  $\mu_{a,\ell}$ ,  $\kappa_\ell$ ,  $\gamma$ ,  $\tau$  such that the error between the computed and real data is sufficiently small

$$\|\phi_\ell^{\text{sim}} - \phi_\ell^{\text{real}}\| < \epsilon, \quad \epsilon > 0.$$

- The inverse problem is highly non linear. Known data on a subset of  $\delta\Omega$  does not necessary ensure the unicity of the solutions in  $\Omega$ .
- The number of detectors and the setting strongly influence the convergence and the stability of the solutions.

