GATE
Optical Imaging Simulation

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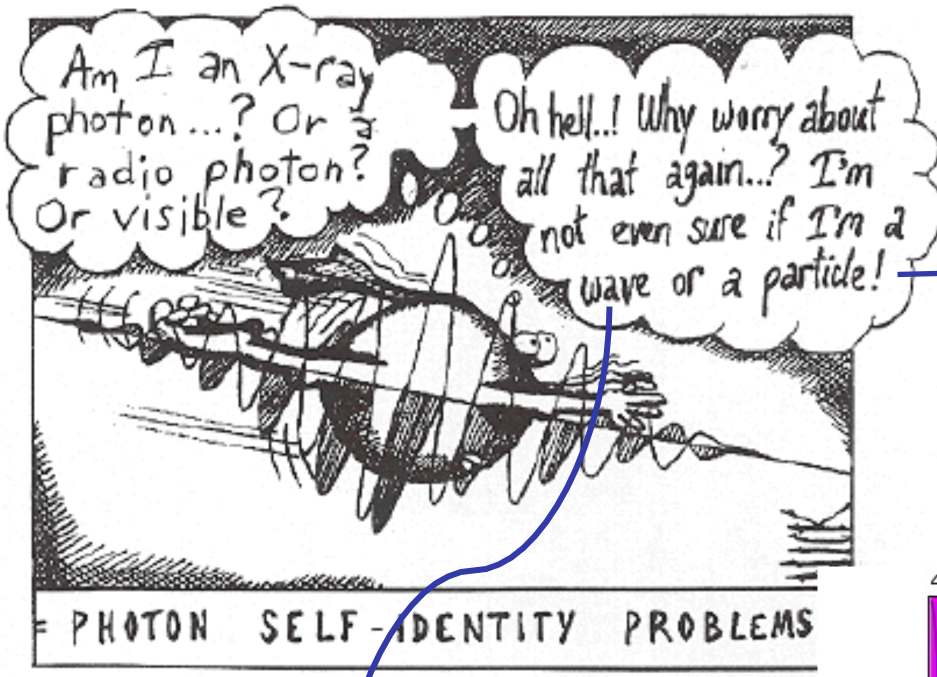
Optical Imaging : Fluorescence /Bioluminescence

* Non-invasive study of biological processes (optical biopsy)
* Non radioactive tracers
* Low cost technique (CCD – charged coupled device)

* But tissue optical properties have a strong dependence on depth

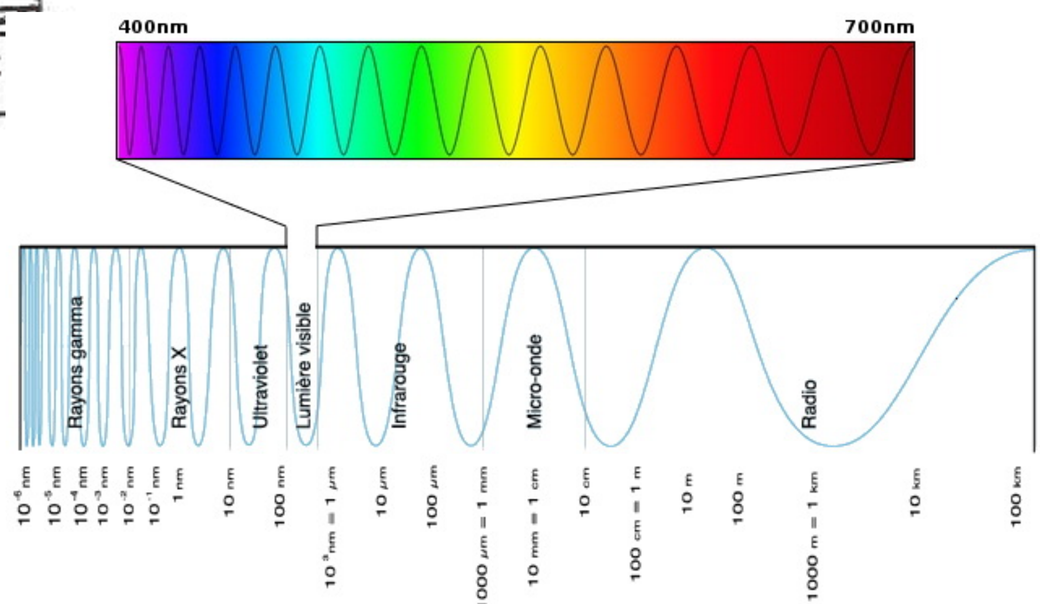
Photons in Geant4



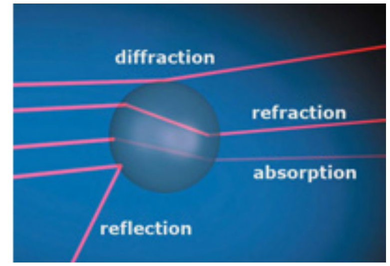
G4Gamma

G4OpticalPhoton

λ >> atomic spacing



Geant4 Processes at optical wavelengths

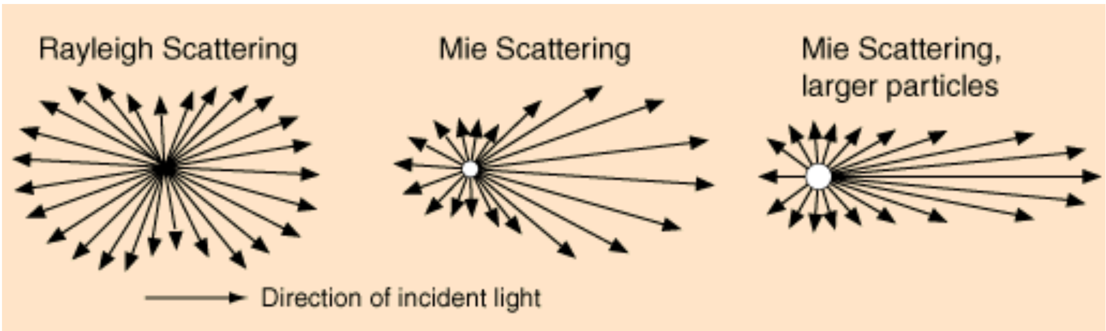


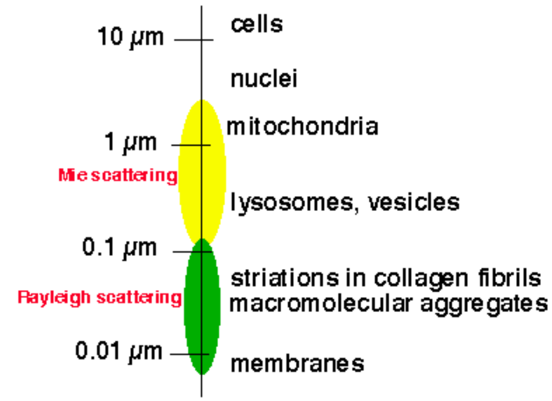
- Refraction and Reflection at medium boundary
- Bulk Absorption
- Rayleigh scattering
- Mie scattering (recently added in Gate but not in SVN yet)

- Optical properties of the medium (G4Material table)
- Properties are function of the photon Energy

- Absorption: absorption length
- Mie/Rayleigh: attenuation length + other parameters (Mie)
- At Boundaries: Reflection parameters, Reflectivity (fraction of incident radiation reflected by surface), transmission efficiency.

Mie and Rayleigh Scattering





- The Mie scattering implementation in Geant4 follows the Henyey-Greenstein approximation:

$$\tilde{P}_{HG}(\cos(\theta)) = \frac{1}{2}\frac{1-g^2}{(1+g^2-2g\ \cos(\theta))^{3/2}}.$$

$$\int_{-1}^{\cos(\theta)} \tilde{P}_{HG}(\cos(\theta'))\, d(\cos(\theta')) = \xi.$$

random number

$$g \equiv \langle\cos(\theta)\rangle$$

anisotropy

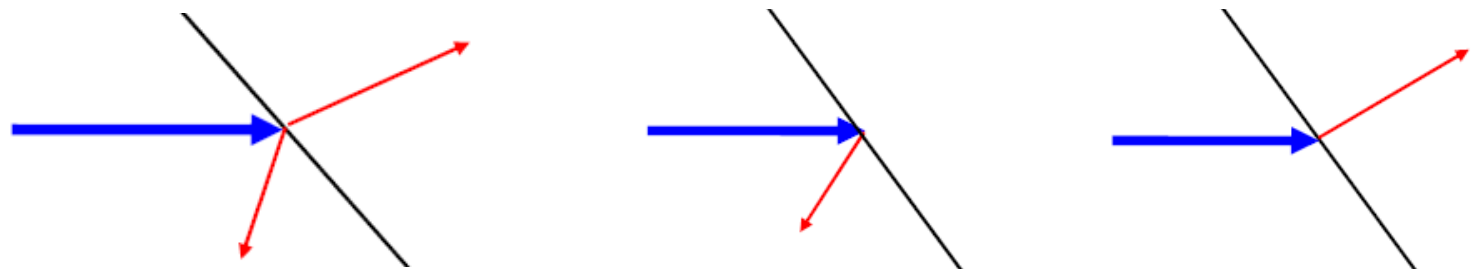
θ , angle between incident and scattered momentum direction

$$\cos(\theta) = \begin{cases} \frac{1}{2g}[1+g^2-(\frac{1-g^2}{1-g+2g\xi})^2], & \text{if } g \neq 0, \\ 2\xi - 1, & \text{if } g = 0. \end{cases}$$

- Final momentum, initial and final polarizations in the same plane.
- For small size parameter regime the Mie theory reduces to the Rayleigh approximation.

Processes at boundaries: Reflection and Refraction

Optical photons are treated as particles. With both Refraction and Reflection, at least two events are simulated. (no splitting)

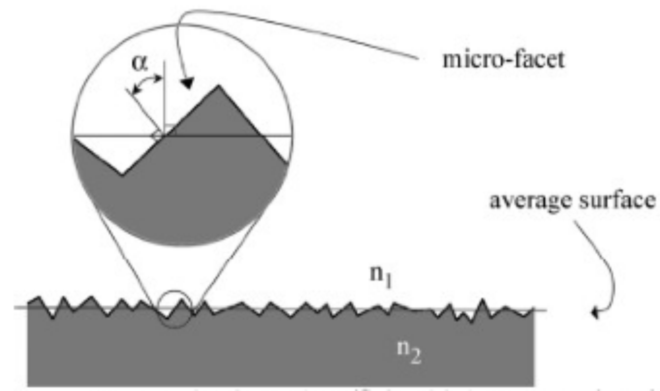


The coefficient of reflection depends on the refractive index difference, the angle of incidence and the initial polarization.

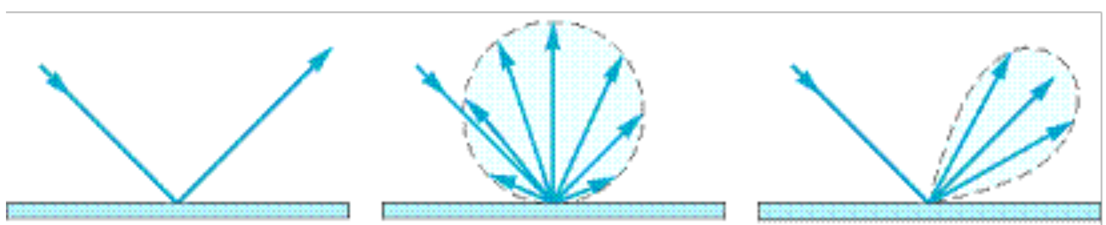
- Dielectric – Dielectric
  - total internal reflected
  - Fresnel refracted
  - Fresnel reflected
- Dielectric – Metal
  - absorbed (detected)
  - reflected

Surface Effects

- Polished (smooth) ➔ Default surface
- Polishedfrontpainted
- Polishedbackpainted
- Ground (rough) collection of micro-facets
- Groundfrontpainted
- groundbackpainted



- Specular Spike ➡ Photon reflected like in a perfect mirror about the average surface norma
- Lambertian reflection ➡ Photon will be reflected with a lambertian distribution
- Backscatter ➡ Photon reflected back into the direction the photon come
- Specular Lobe ➡ Specular reflection based on the micro-facet orientation



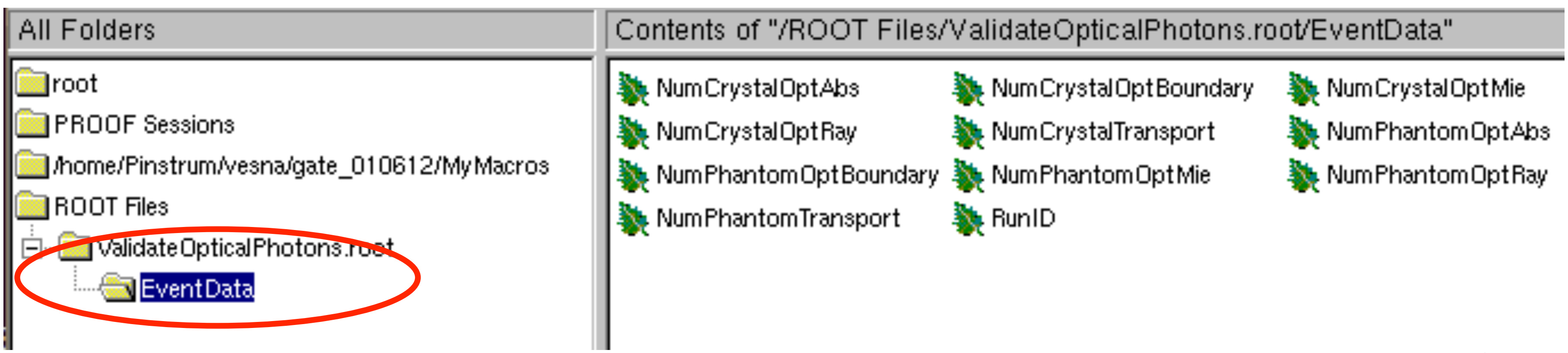
Status:

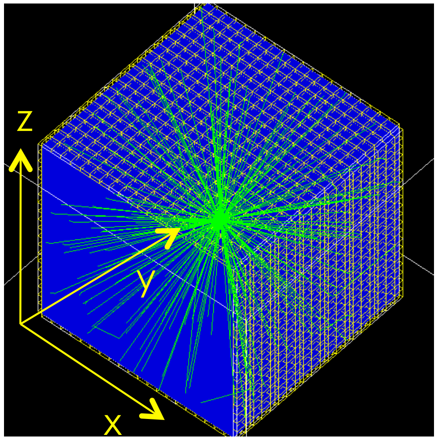
Generating and Tracking Optical Photons in Gate V6

New in ROOT output

- PhantomHits tree : Hit Global Position

- New file: ValidateOpticalPhotons.root
  - Number of Absorbed Optical photons
  - Number of Rayleigh scatter per Optical photon
  - Number of Mie scatter per Optical photon
  - Number of Boundary processes per Optical photon





Simple Test: Water
Rayleigh and Absorption

Phantom: water box $(5x5x5)mm^3$

Sensitive detector (4): array of pixels (LSO*)

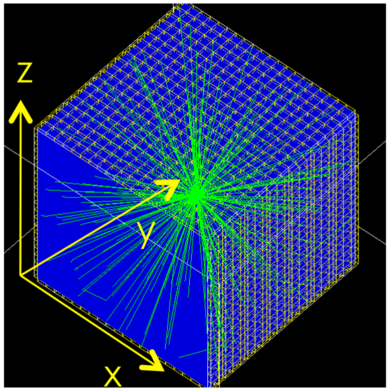
Isotrope optical photon source at (0,0,0)

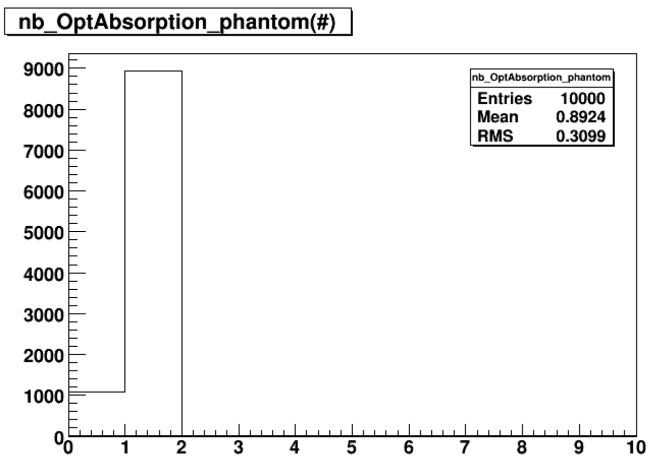
Water: ABSLENGTH = 0.004m and RINDEX = 1.33

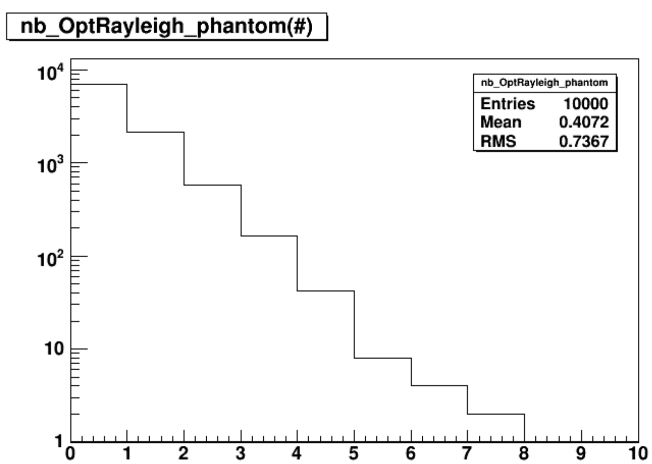
No surface were defined

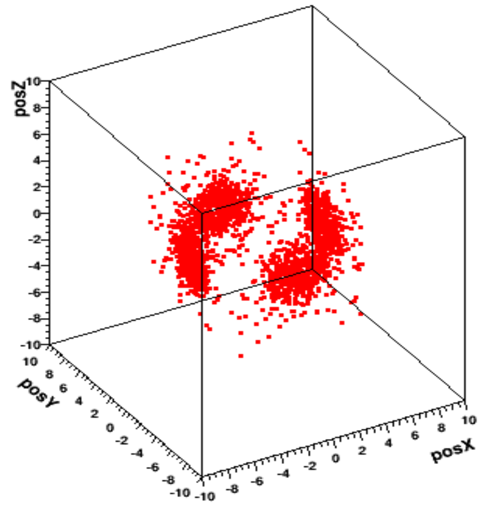
* Cerium-doped Lutetium Oxyorthosilicate

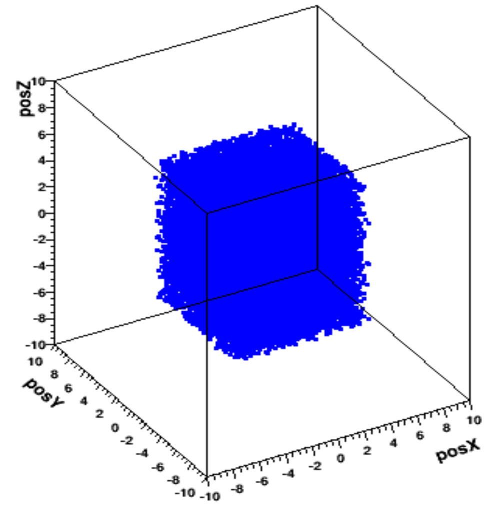
Simple Test Results

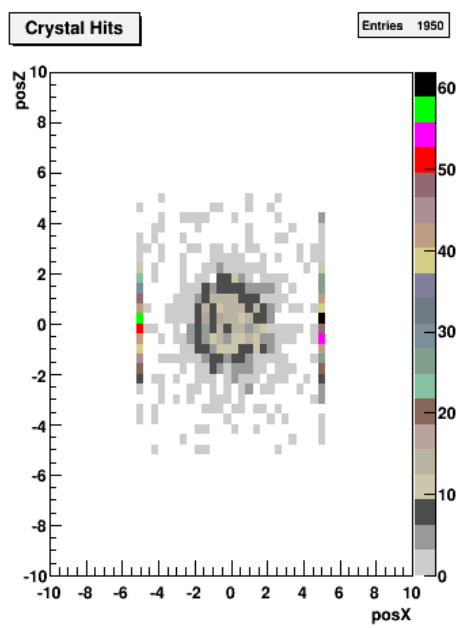


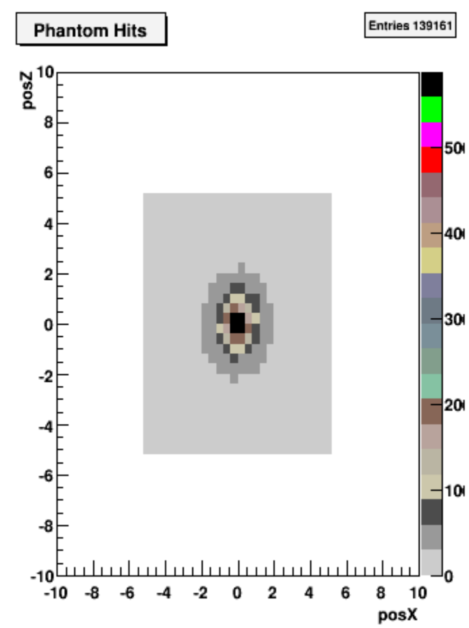






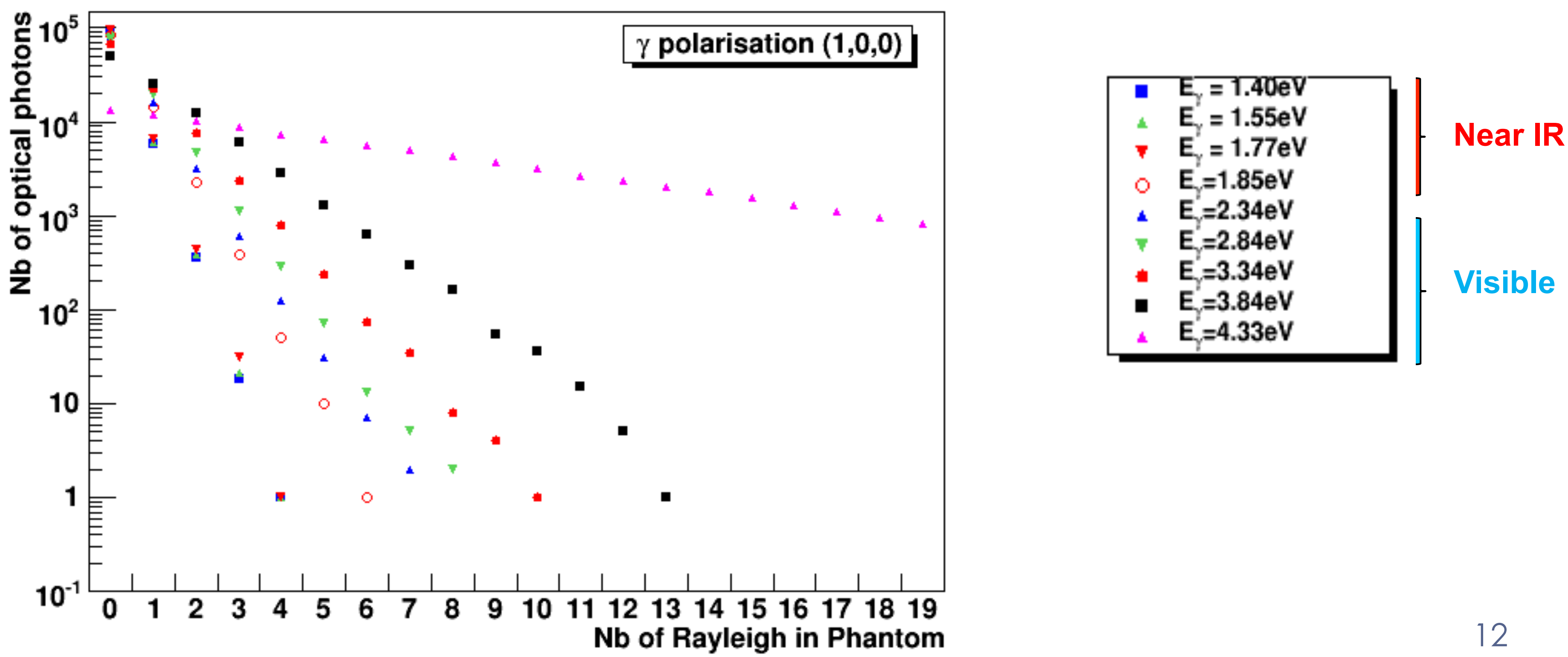






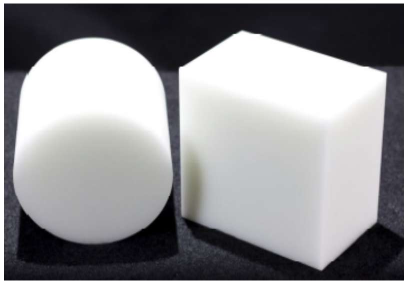
Rayleigh scatter in Water as function of Optical Photon Energy

Geant4: When RAYLEIGH property is not specified by the user, no Rayleigh scattering occurs in that material. Except for Water, for which it is internally calculated following the Einstein-Smoluchowski formula.



Validation of the Optical Module using a Reference Optical Phantom

Available at IMNC

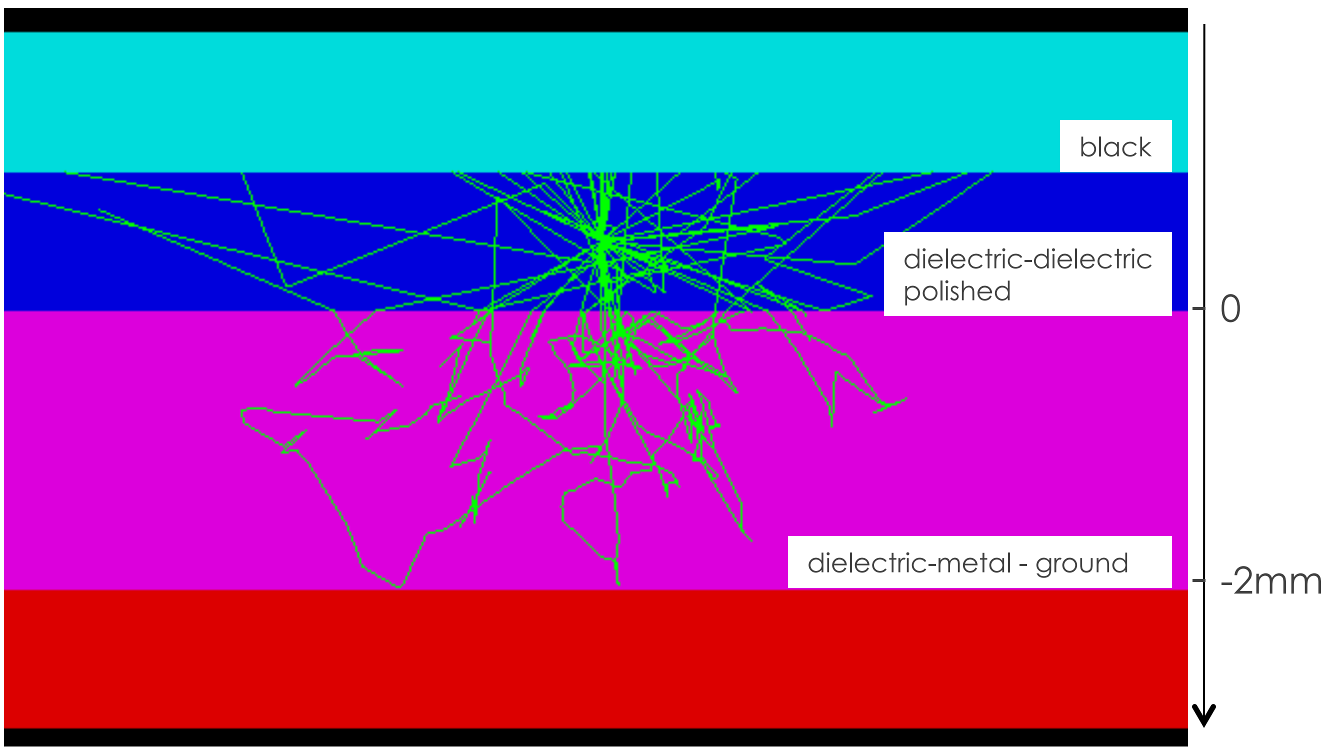


(National Optics Institute)

Preliminary benchmark

(was discussed last week at IMNC)

Biomimic phantom characterization:
RINDEX = 1.521 and anisotropie = 0.62
λ = 530 nm (E_γ = 2.34 eV) L_A = 0.847 cm L_S = 0.0113 cm
λ = 630 nm (E_γ = 1.97 eV) L_A = 0.926 cm L_S = 0.0104cm



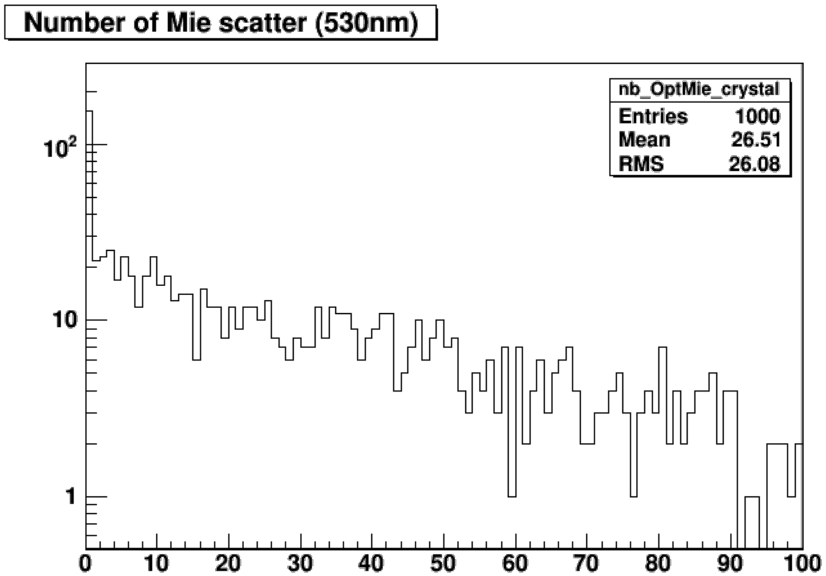
blackbox (water)

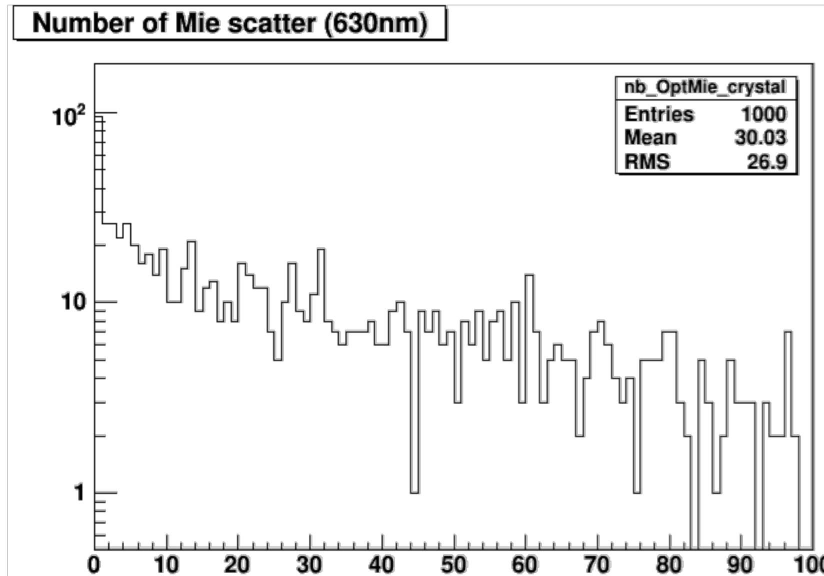
phantom (air)
Rindex=1.0

Plastic
$C_5H_8O_2$
d=1.18 g/cm^3

detector (water)

« Very » Preliminary Results





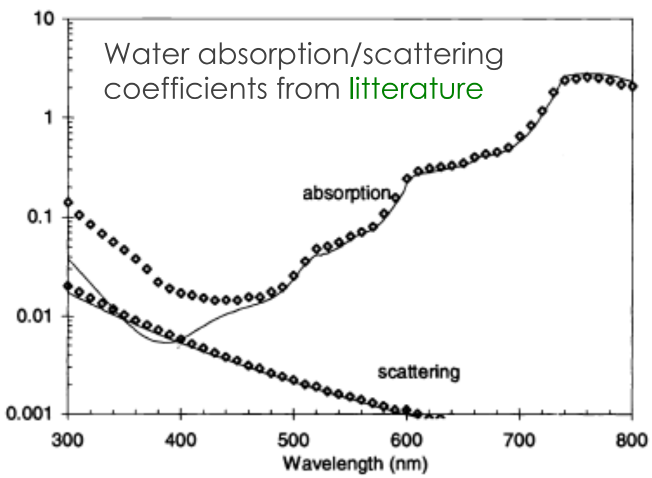
	Optical photon wavelength	Number of generated optical photons	Number of detected photons
plastic	530 nm	1000	498
plastic	630 nm	1000	487

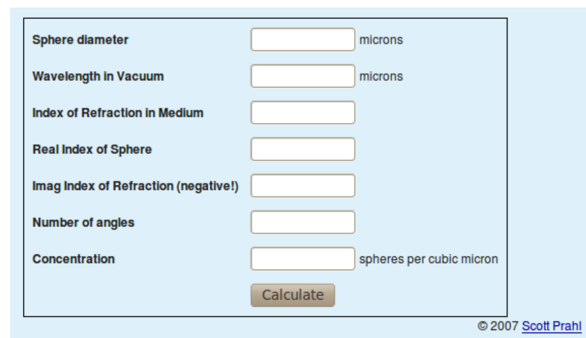
Some information are still needed from vendor:

- *chemical formula of the biomimic phantom*

Next Step

- Update previous table with more basic materials (Water, Blood…)
  - Inputs: density, chemical formula, Absorption/Scattering lengths, material anisotropy, Reflectivity…





Mie Scattering calculator (by Prahl)

Water molecule diameter 0.000275 µm
Hemoglobin diameter 0.0055 µm

- Update output Root file with Boundary status and scattering angle.

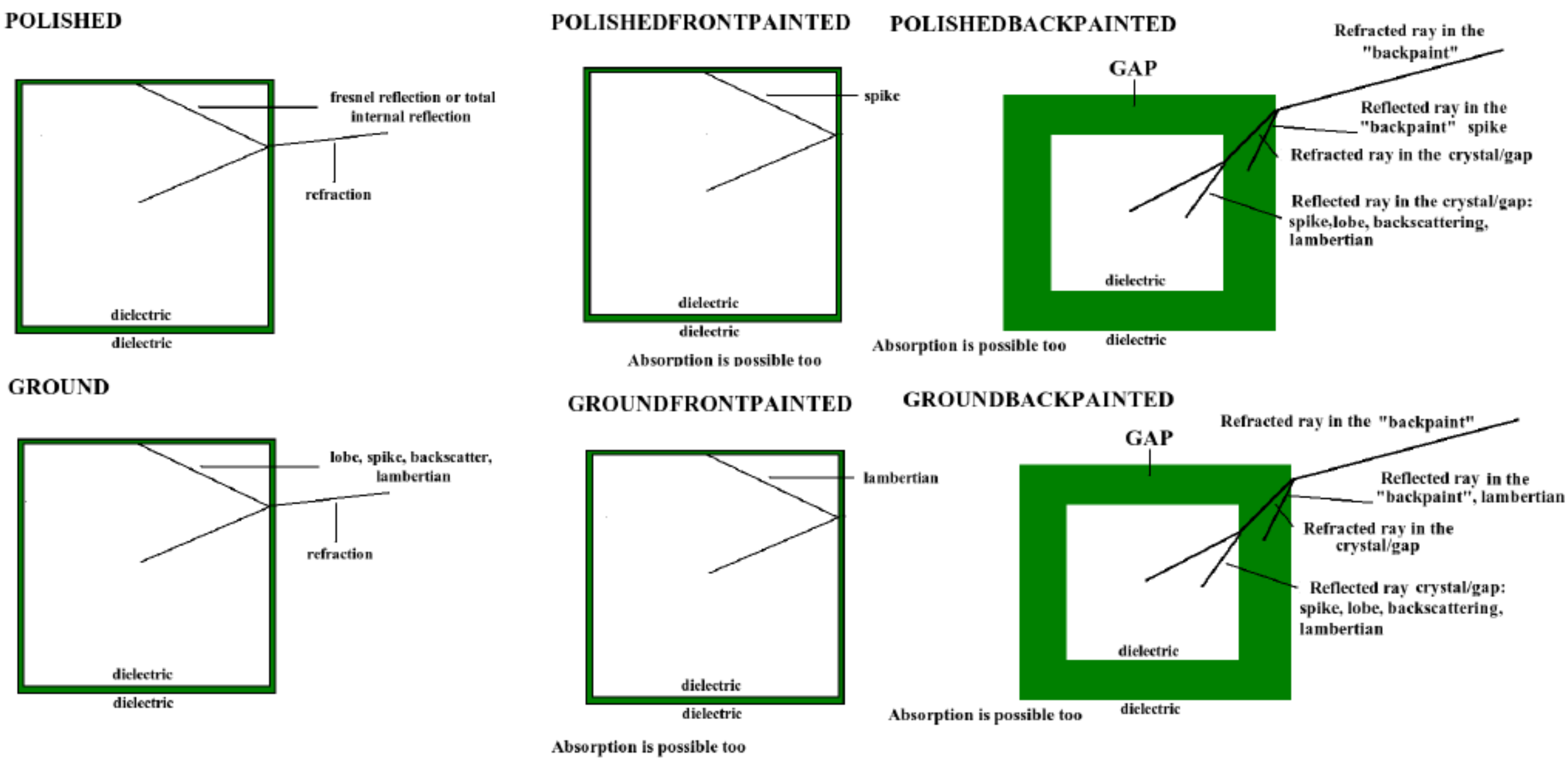
1: Fresnel refraction
2: Fresnel reflection
3: Total internal reflection
4: Lambertian reflection
5: Lobe reflection
6: Spike reflection
7: Backscattering
8: Absorption

Optical Module Plan

- Validate GATE optical photon (optical photon generated from a source) results :
  - Setup a common benchmark with Frederic Pain ✔
  - Materials with known/measured optical properties ✔
  - Validation **[We are here…]**
- Production of Optical Photons : G4Scintillation
  - Generate optical photons from Scintillation
  - Validation of Gate Scintillation Process
- Production of Optical Photons: G4AtomicDeexcitation (G4FluoTransition) :
  - Need to write the code in Gate **[February 2012]**
  - Validation of Gate Atomic Deexcitation Process
- Surface properties for Optical Boundary Processes :
  - Manpower in January/February with a Post-doc at IMNC (Mohamed Mesradi)
  - Caracterization/Measurements of optical properties of tissues **[starting February 2012]**
  - Validation of Gate Optical Boundary Processes

BACKUP

Surface Finish



Einstein-Smoluchowski formula for Water

```
// isothermal compressibility of water
G4double betat = 7.658e-23*m3/MeV;

// K Boltzman
G4double kboltz = 8.61739e-11*MeV/kelvin;

refsq = refraction_index*refraction_index;
xlambda = h_Planck*c_light/e;
```

```
c1 = 1 / (6.0 * pi);
c2 = std::pow((2.0 * pi / xlambda), 4);
c3 = std::pow( ( (refsq - 1.0) * (refsq + 2.0) / 3.0 ), 2);
c4 = betat * temp * kboltz;

Dist = 1.0 / (c1*c2*c3*c4);
```