Optical Physics

Andreas Schälicke (DESY, Zeuthen)
material adpted from P. Gumplinger / G. Santin

Optical Photons - Introduction

- Technically, should belong to electromagnetic category, but:
  - optical photon wavelength is >> atomic spacing
  - treated as waves -> no smooth transition between optical and gamma particle classes

- G4OpticalPhoton <> G4Photon

```
particleGun->SetParticleDefinition(G4OpticalPhoton::OpticalPhotonDefinition());
```

- UI command

```
/gps/particle opticalphoton
```

Processes producing optical photons

- Optical photons are produced by:
  - G4Cerenkov
  - G4Scintillation
  - G4TransitionRadiation

- Classes located in
  - processes/electromagnetic/xrays

- Warning: these processes generate optical photons without energy conservation

Optical Physics - Initialization

- since 9.3 a physics builder exists:

```
G4OpticalPhysics* opticalPhysics = new G4OpticalPhysics();

// adjust some parameters for the optical physics

// wave lenght shifting
opticalPhysics->SetWLSTimeProfile("delta");

// scintillation
opticalPhysics->SetScintillationYieldFactor(1.0);
opticalPhysics->SetScintillationExcitationRatio(0.0);

// cerenkov
opticalPhysics->SetMaxNumPhotonsPerStep(100);
opticalPhysics->SetMaxBetaChangePerStep(10.0);

// general
opticalPhysics->SetTrackSecondariesFirst(true);
```

Optical Photons - Interactions

- Optical photons undergo:
  - Rayleigh scattering
  - refraction and reflection at medium boundaries
  - bulk absorption
  - wavelength shifting
- Classes located in `processes/optical`
- Geant4 keeps track of polarization
  - but not overall phase -> no interference!
- Optical properties can be specified in G4Material by user
  - reflectivity, transmission efficiency, dielectric constants, surface properties
- Photon spectrum properties also defined in G4Material
  - scintillation yield, time structure (fast, slow components)

Absorption and Rayleigh Scattering

- G4OpAbsorption
  - uses photon attenuation length from material properties to get mean free path
  - photon is simply killed after a selected path length
- G4OpRayleigh
  - elastic scattering including polarization of initial and final photons
  - builds it own private physics table (for mean free path) using G4MaterialTable
  - may only be used for optical photons

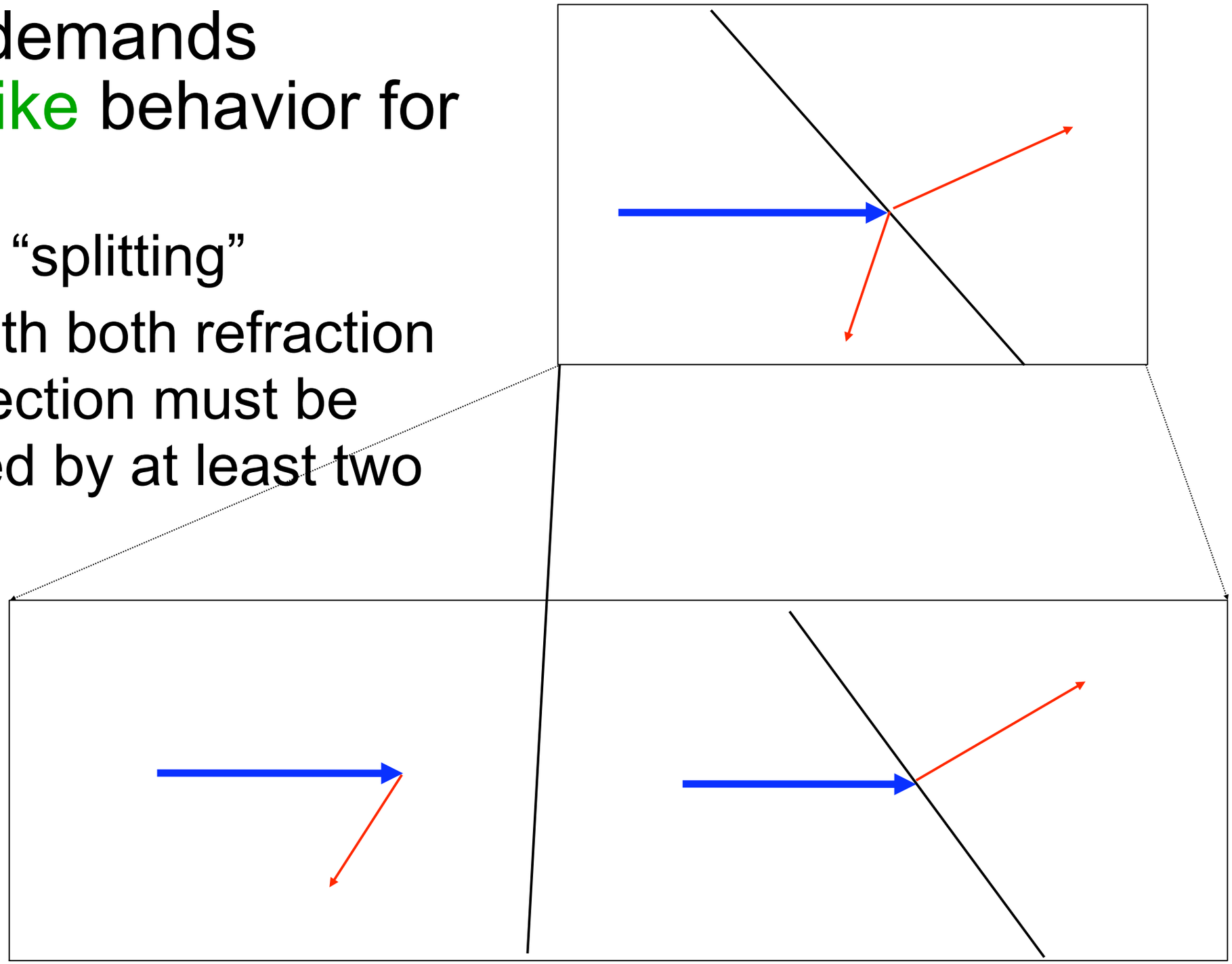
Optical Properties

- optical properties are stored in the `G4MaterialPropertiesTable`, Example:

```
// *** Material definition
G4NistManager *man = G4NistManager::Instance();
G4Material *LXe = man->FindOrBuildMaterial("G4_lXe");

// *** Material properties tables
const G4int nE = 3;
G4double LXe_energy[nE]    = { 7.0*eV , 7.07*eV, 7.14*eV };

G4double LXe_scint[nE] = { 0.1, 1.0, 0.1 };
G4double LXe_rindex[nE]  = { 1.59 , 1.57, 1.54 };
G4double LXe_abslength[nE]  = { 35.*cm, 35.*cm, 35.*cm};

LXe_mt = new G4MaterialPropertiesTable();
LXe->SetMaterialPropertiesTable(LXe_mt);

LXe_mt->AddProperty("FASTCOMPONENT", LXe_energy, LXe_scint, nE);
LXe_mt->AddProperty("SLOWCOMPONENT", LXe_energy, LXe_scint, nE);
LXe_mt->AddProperty("RINDEX",        LXe_energy, LXe_rindex, nE);
LXe_mt->AddProperty("ABSLENGTH",     LXe_energy, LXe_abslength, nE);
LXe_mt->AddConstProperty("SCINTILLATIONYIELD",12000./MeV);
LXe_mt->AddConstProperty("RESOLUTIONSCALE",1.0);
LXe_mt->AddConstProperty("FASTTIMECONSTANT",20.*ns);
LXe_mt->AddConstProperty("SLOWTIMECONSTANT",45.*ns);
LXe_mt->AddConstProperty("YIELDRATIO",1.0);
```

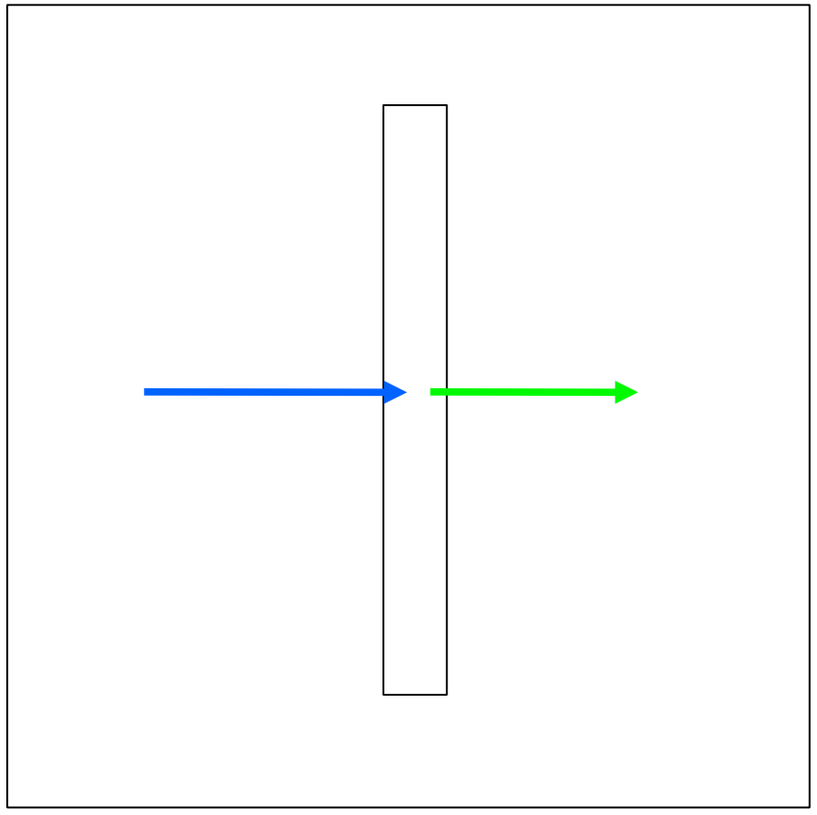
Optical Photons - Interactions (2)

- Geant4 demands particle-like behavior for tracking:
  - thus, no “splitting”
  - event with both refraction and reflection must be simulated by at least two events



Exampe: Wavelength Shifting

- Handled by G4OpWLS
  - initial photon is killed, one with new wavelength is created
  - builds it own physics table for mean free path
- User must supply:
  - absorption length as function of photon energy
  - emission spectra parameters as function of energy
  - time delay between absorption and re-emission



Exampe: Wavelength Shifting

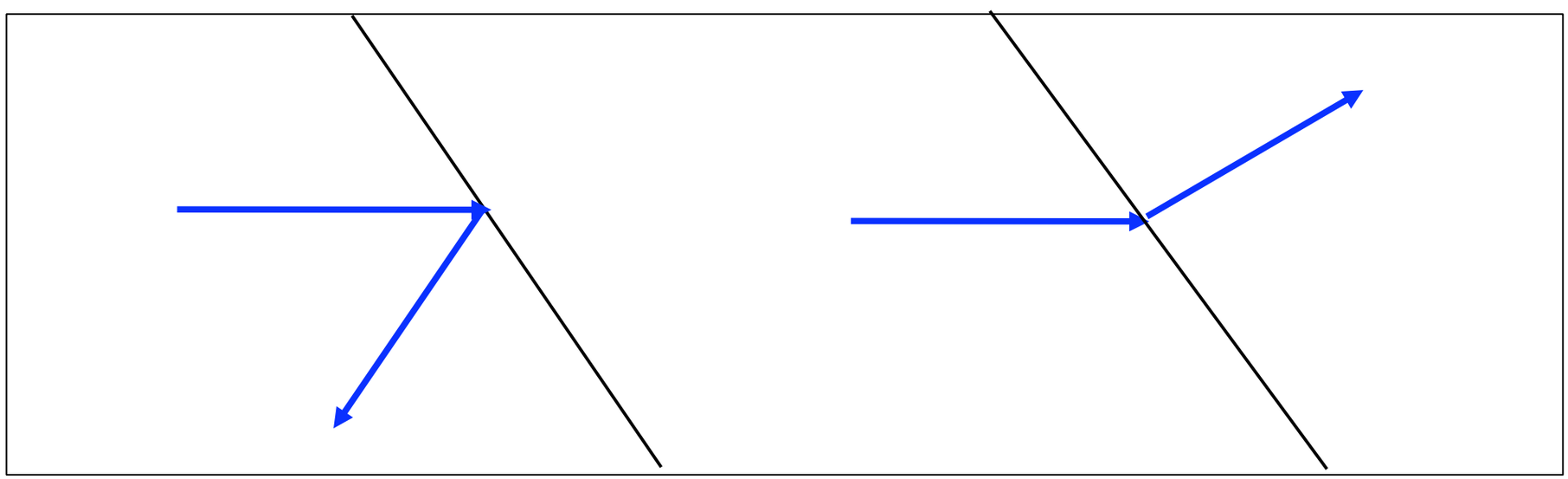
- Provide parameter

```
G4MaterialPropertiesTable* fiberMPT = new G4MaterialPropertiesTable();
const G4int ne = 4;
G4double Fiber_energy[] = {2.00*eV,2.87*eV,2.90*eV,3.47*eV};
G4double Fiber_rindex[ne]={ 1.60, 1.60, 1.60, 1.60};
G4double Fiber_abslength[ne]={9.00*m, 9.00*m, 0.1*mm, 0.1*mm};
G4double Fiber_emission[ne]={1.0, 1.0, 0.0, 0.0};
fiberMPT->AddProperty("RINDEX",        Fiber_energy, Fiber_rindex,ne);
fiberMPT->AddProperty("WLSABSLENGTH", Fiber_energy, Fiber_abslength,ne);
fiberMPT->AddProperty("WLSCOMPONENT", Fiber_energy, Fiber_emission,ne);
fiberMPT->AddConstProperty("WLSTIMECONSTANT", 0.5*ns);
```

- Time profile may be “delta” or “exponential”
  - set using `G4OpWLS::UseTimeGenerator`

Boundary Interactions

- Handled by G4OpBoundaryProcess
  - refraction or reflection
  - absorbed/detected
- User must supply surface properties using G4OpticalSurfaceModel (`glisur`, `unified`, `LUT`)
- G4SurfaceType
  - `dielectric-dielectric`
  - `dielectric-metal`
  - `dielectric-LUT`
- G4OpticalSurfaceFinish
  - `polished`
  - `ground`
  - `front-`, `back-painted`, ...



Boundary Interactions

- G4OpticalSurface
  - defines propeties
- G4LogicalSkinSurface or G4LogicalBorderSurface
  - defines boundary

```
G4OpticalSurface* wrapper = new G4OpticalSurface("wrapper");
new G4LogicalBorderSurface("wrapper", slab, expHall_phys, wrapper);

wrapper->SetType(dielectric_metal);
wrapper->SetFinish(polished);
wrapper->SetModel(glisur);

const G4int NUM = 2;

G4double pp[NUM] = {2.0*eV, 3.5*eV};
G4double reflectivity[NUM] = {1., 1.};
G4double efficiency[NUM] = {0.0, 0.0};

G4MaterialPropertiesTable* wrapperProperty = new G4MaterialPropertiesTable();

wrapperProperty->AddProperty("REFLECTIVITY", pp, reflectivity, NUM);
wrapperProperty->AddProperty("EFFICIENCY", pp, efficiency, NUM);

wrapper->SetMaterialPropertiesTable(wrapperProperty);
```

Boundary Interactions

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```
G4OpticalSurface* wrapper = new G4OpticalSurface("wrapper");
new G4LogicalBorderSurface("wrapper", slab, expHall_phys, wrapper);
wrapper
wrapper
wrapper
const G
G4doubl
G4doubl
G4doubl
G4Mater                                                    ertiesTable();
wrapperProperty->AddProperty("REFLECTIVITY", pp, reflectivity, NUM);
wrapperProperty->AddProperty("EFFICIENCY", pp, efficiency, NUM);
wrapper->SetMaterialPropertiesTable(wrapperProperty);
```

The surface concept is not needed, if perfectly smooth surface exists between two dielectic materials, the only relevant property is the index of refraction of both media.

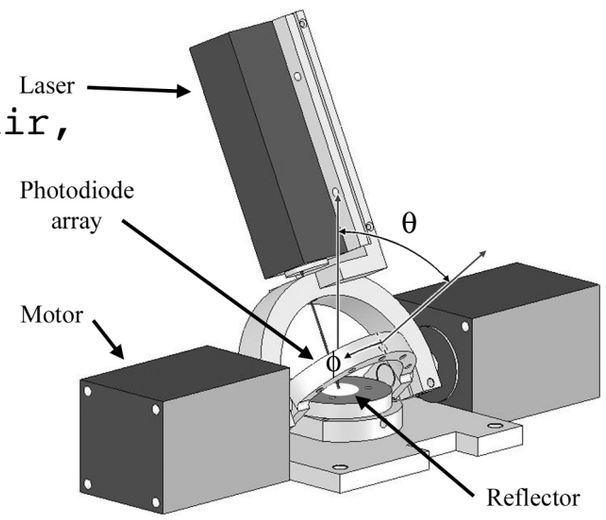
Look-Up-Tables (LUT)

- available since 9.3
- based on
  - M. Janecek, W. Moses IEEE Trans.Nucl. Sci.55 (2008)

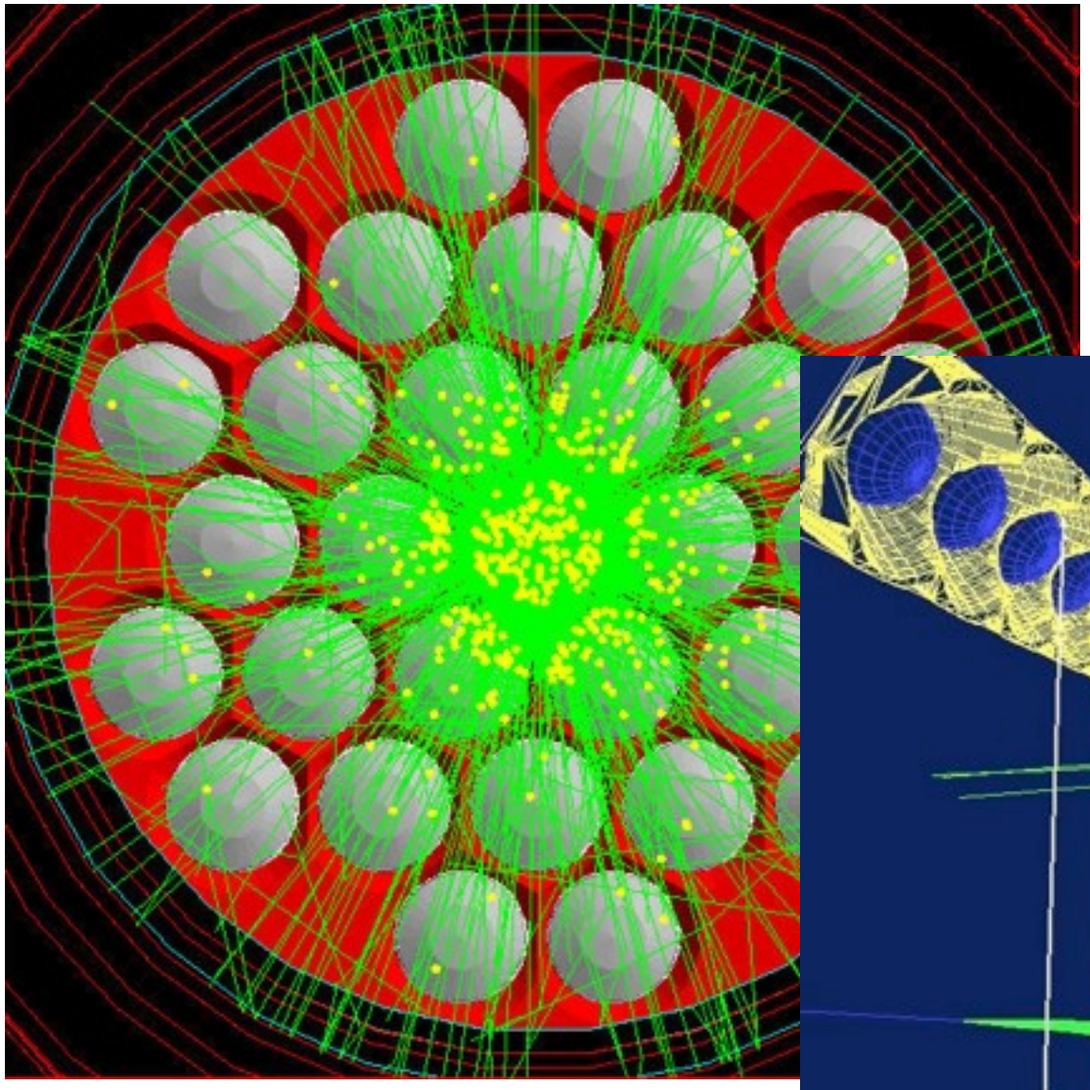
```
wrapper->SetType(dielectric_LUT);
wrapper->SetModel(LUT);
//mechanically polished surface, with tyvek
wrapper->SetFinish(polishedtyvekair);
```

- many typical HEP “finish” provided:

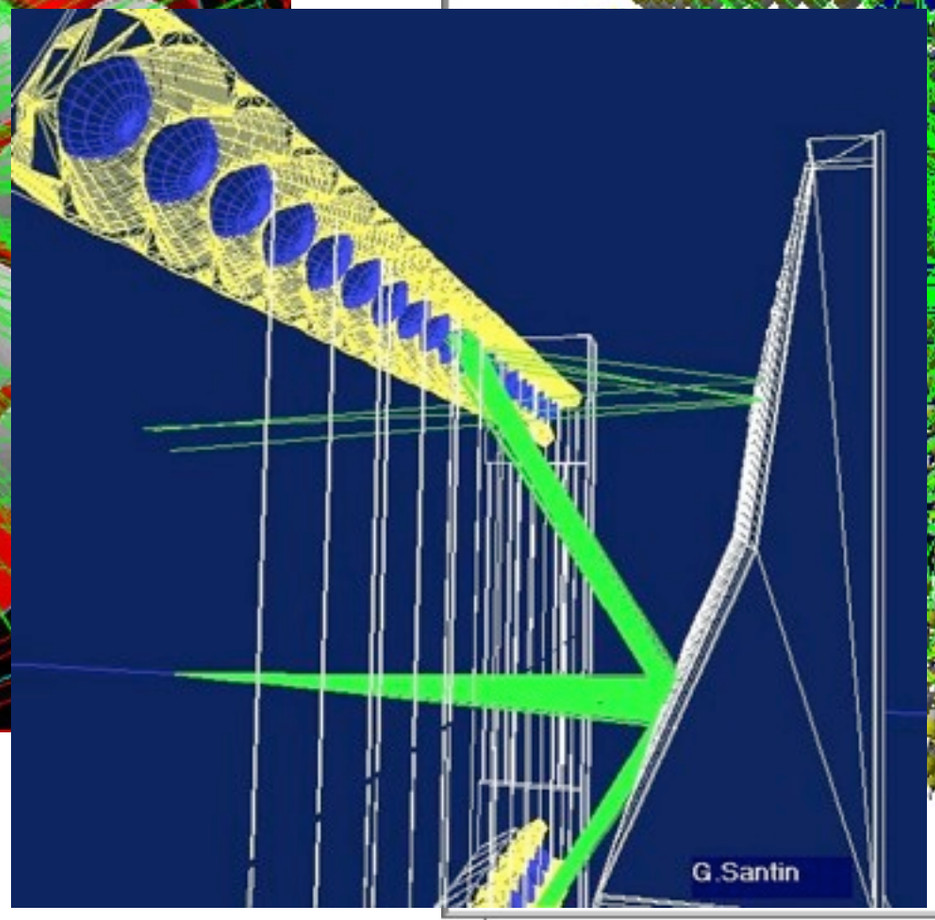
```
polishedlumirrorair,  polishedlumirrorglue, polishedair, polishedteflonair,
polishedtioair, polishedtyvekair, polishedvm2000air, polishedvm2000glue,
etchedlumirrorair, etchedlumirrorglue, etchedair, etchedteflonair,
etchedtioair, etchedtyvekair, etchedvm2000air, etchedvm2000glue,
groundlumirrorair, groundlumirrorglue, groundair, groundteflonair,
groundtioair, groundtyvekair, groundvm2000air, groundvm2000glue
```



Examples of user applications



Zeppelin III, courtesy of H.Araujo (Imperial College London & UK Dark Matter Collaboration)



G.Santin, HARP Cerenkov, CERN

Borexino, courtesy of A. Etenko, I. Machulin - Kurchatov Institute

Summary

- G4OpticalPhoton describles long-wavelength photons
- Optical processes handle
  - photon production by scintillation, Cerenkov and transition radiation, and
  - reflection, refraction, absorption, wavelength shifting
- A simulation may start with a charged particle and end with optical photons, all within the same event loop
- Documentation
  http://cern.ch/geant4 → User support
  → Application Developers Guide → Optical photon processes
  http://cern.ch/geant4 → User support
  → Physics reference manual → Optical photons
- Examples
  - **`examples/novice/N06`**
  - **`examples/extended/optical/LXe`**
- Forum
  http://cern.ch/geant4 → User support
  → User forum → Processes Involving Optical Photons