Simulation of optical processes in GEANT4

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DESY - ZEUTHEN

Outline

First part

- Results of experiments to measure the lightyield of two different material samples

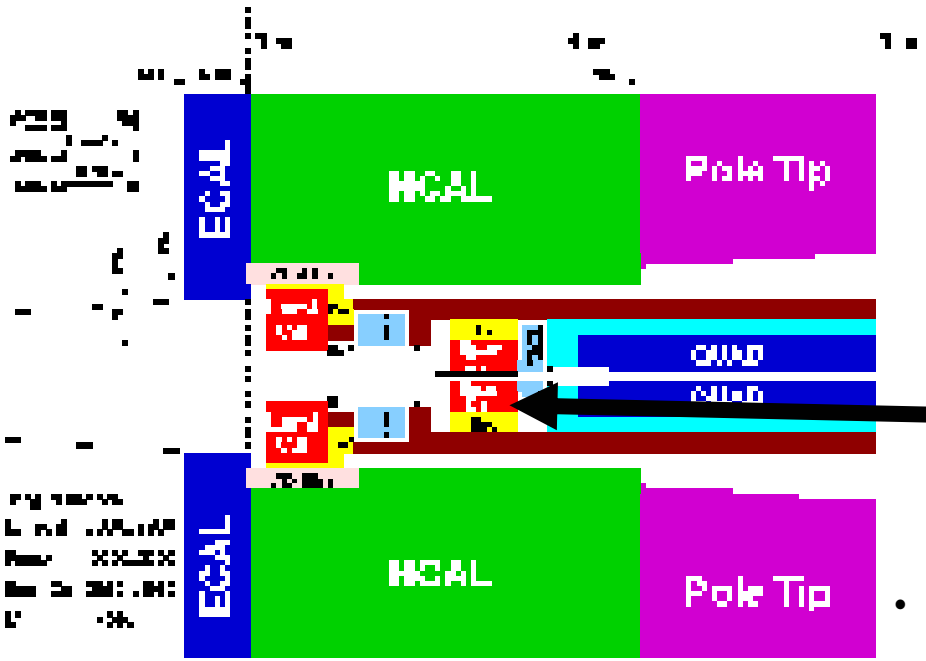
Second part

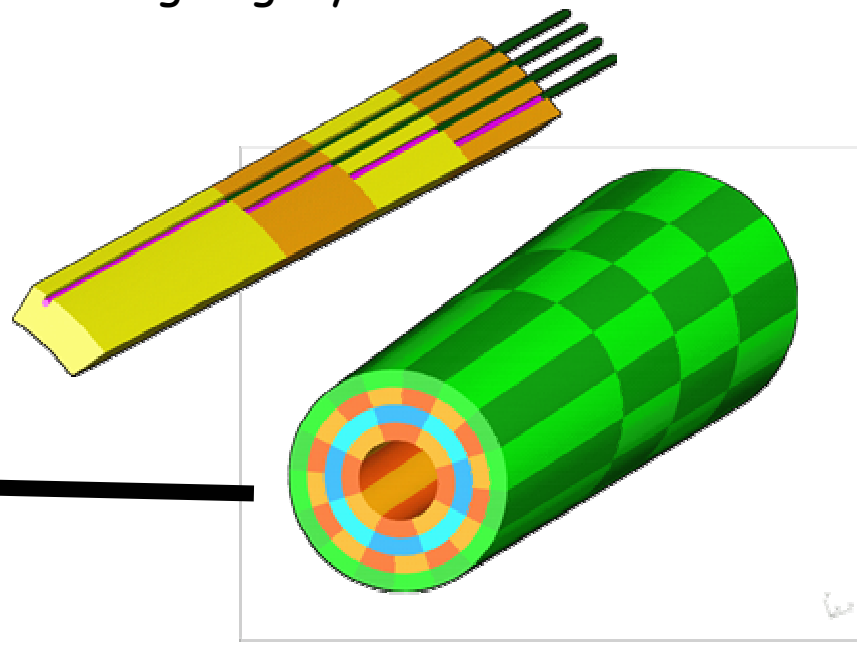
- Simulations of the Photontransport in scintillator/leadglass samples and wavelenghtshifting fibers with GEANT4

Longitudinal Segmentation

- Crystal cutted into segments in depth
- Optical isolated fibers
- Readout with photodetectors

Material:
- radiationhard
- dense
- high lightyield





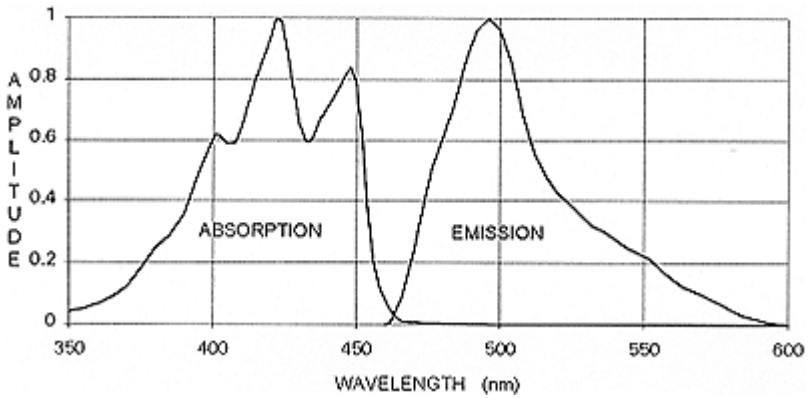
- Lightyield reduction due to fiber readout ?
- Crosstalk ?

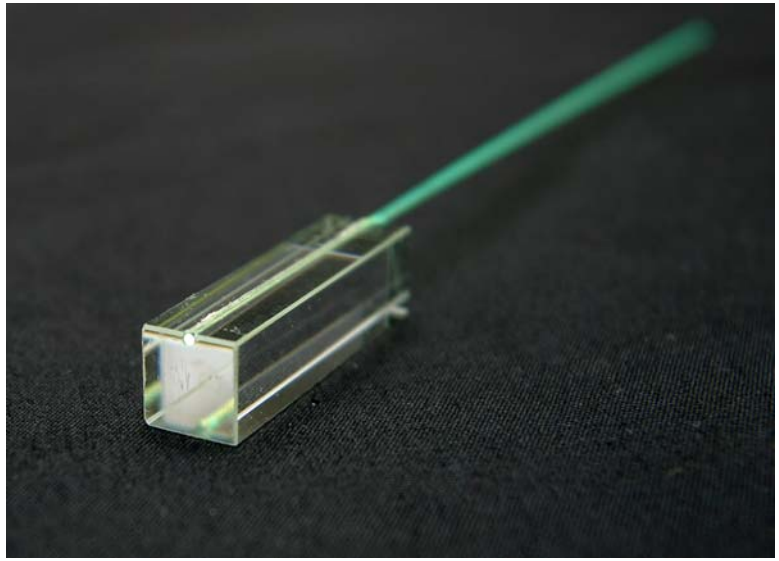
BICRON BCF-91A - Fibers

BCF-91A:

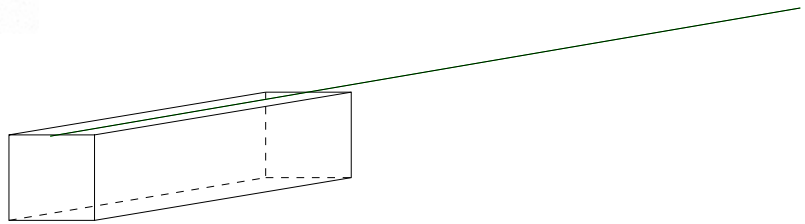
Λ(max. emission) = 494 nm

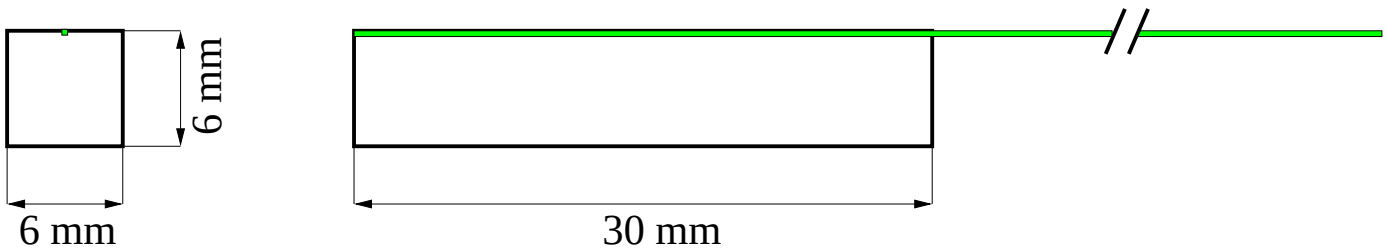
-> QE(PMT-XP1911) 13 ± 2 %



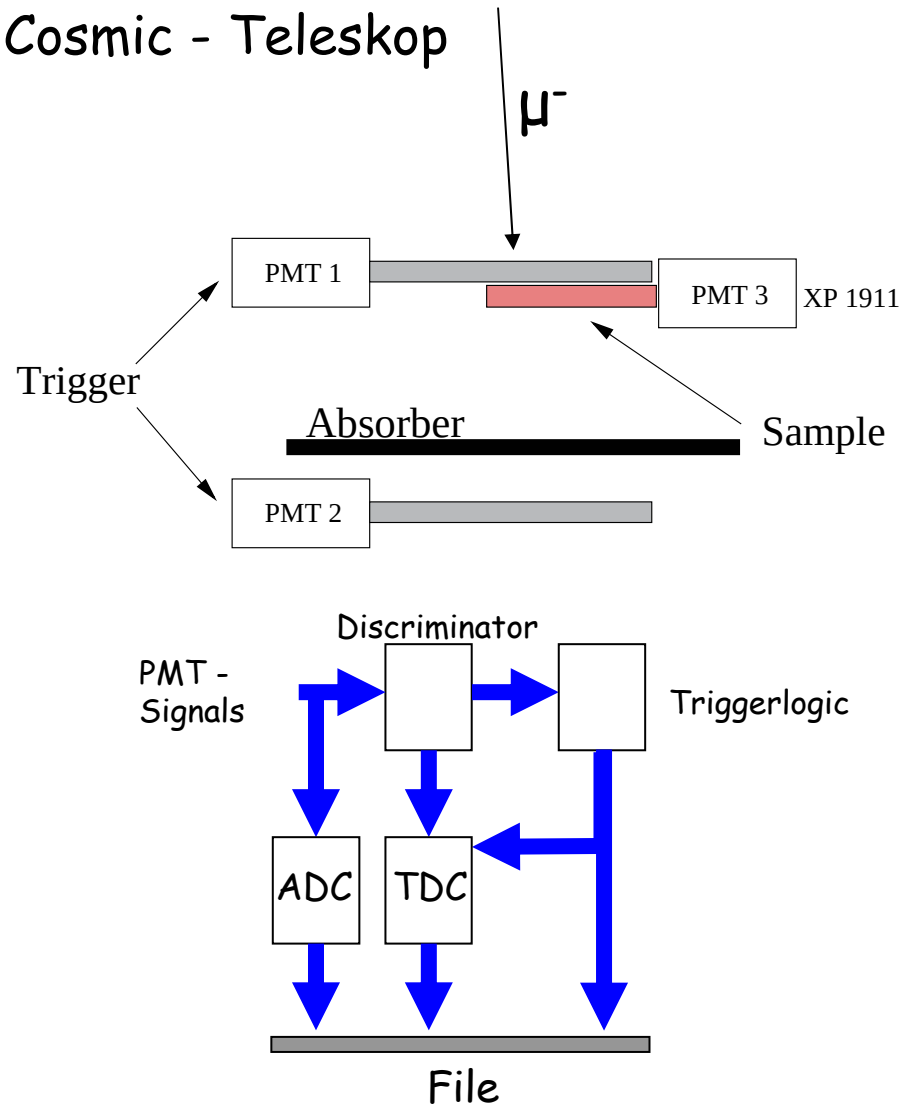


BC−408 Scintillator−Sample





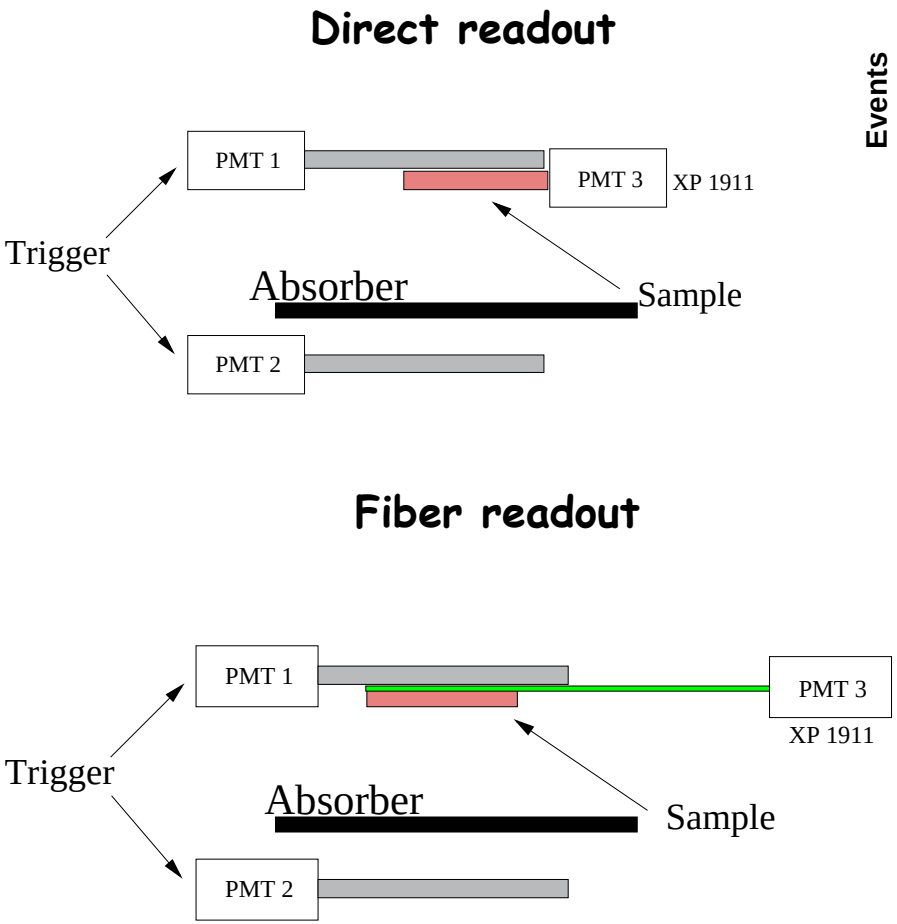
Experiment

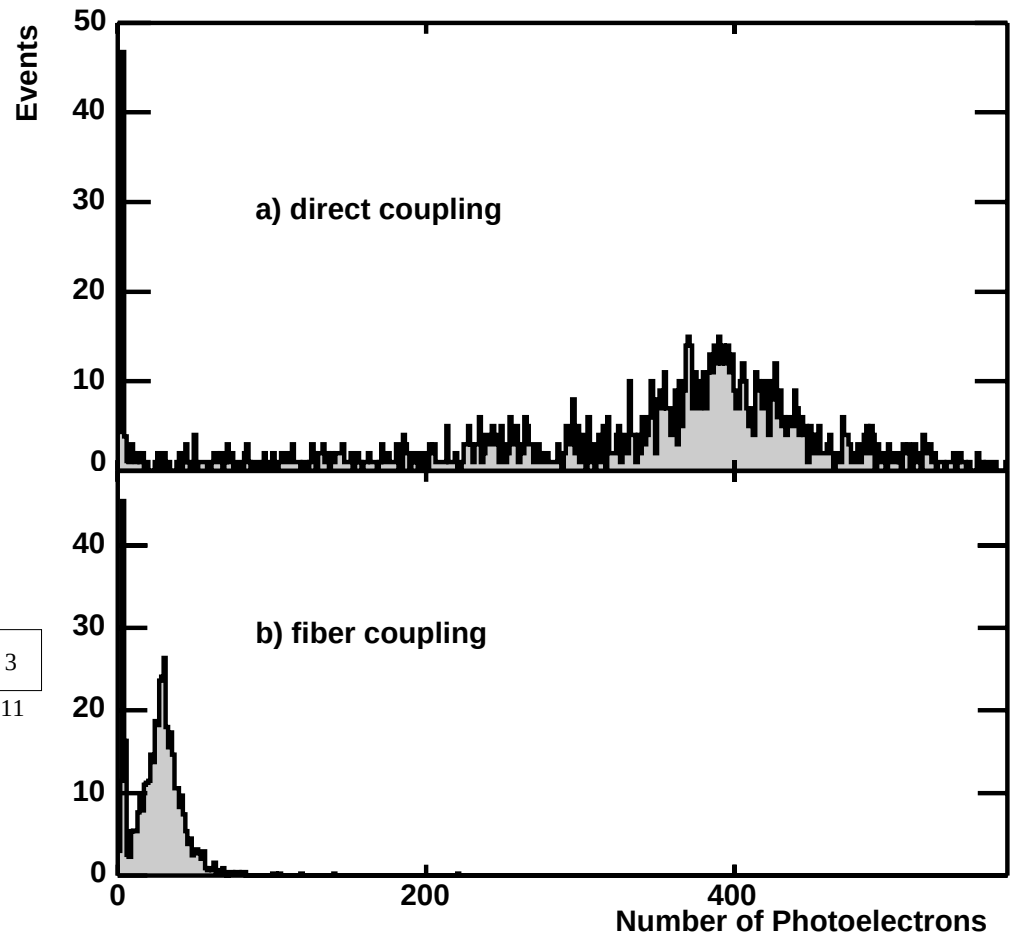

Cosmic - Teleskop
μ⁻
PMT 1
PMT 3
XP 1911
Trigger
Absorber
Sample
PMT 2
Discriminator
PMT - Signals
Triggerlogic
ADC
TDC
File


12/01/2004


12/01/2004

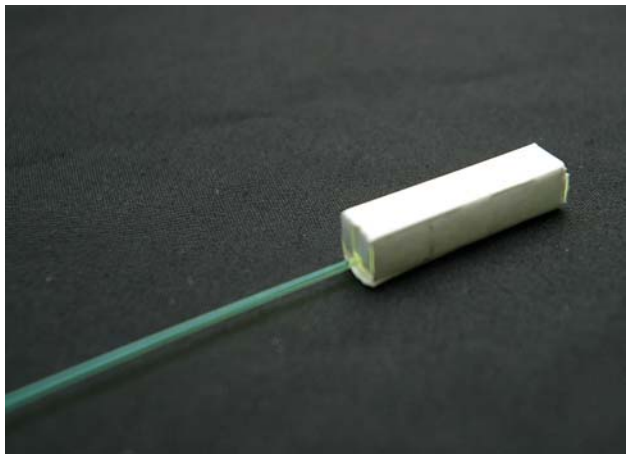
Direct readout vs. fiber readout (BC-408)





Experimental - Results

Plastic Scintillator

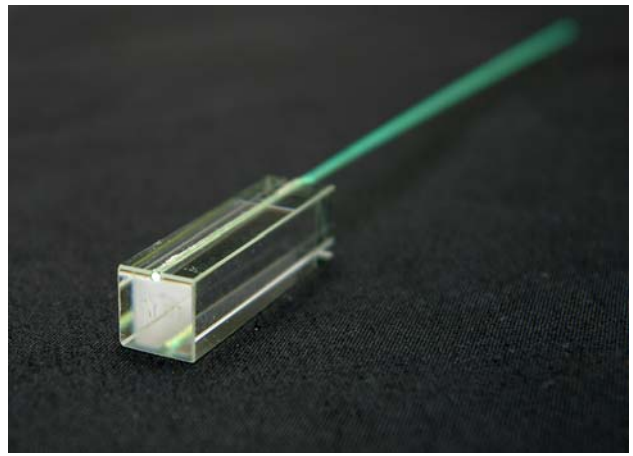


Direct readout : (QE_{PMT} 25 ± 1 %)
Photoelectrons : 390 ± 50 p.e. / μ
Lightyield : 1560 ± 260 photons / μ

Fiber readout : (QE_{PMT} 13 ± 2 %)
Photoelectrons : 27 ± 4 p.e. / μ
Lightyield : 210 ± 60 photons / μ

Lightyield reduced to 14 ± 4 %

Leadglass



Direct readout : (QE_{PMT} 15 ± 2 %)
Photoelectrons : 18.2 ± 2.2 p.e. / μ
Lightyield : 120 ± 30 photons / μ

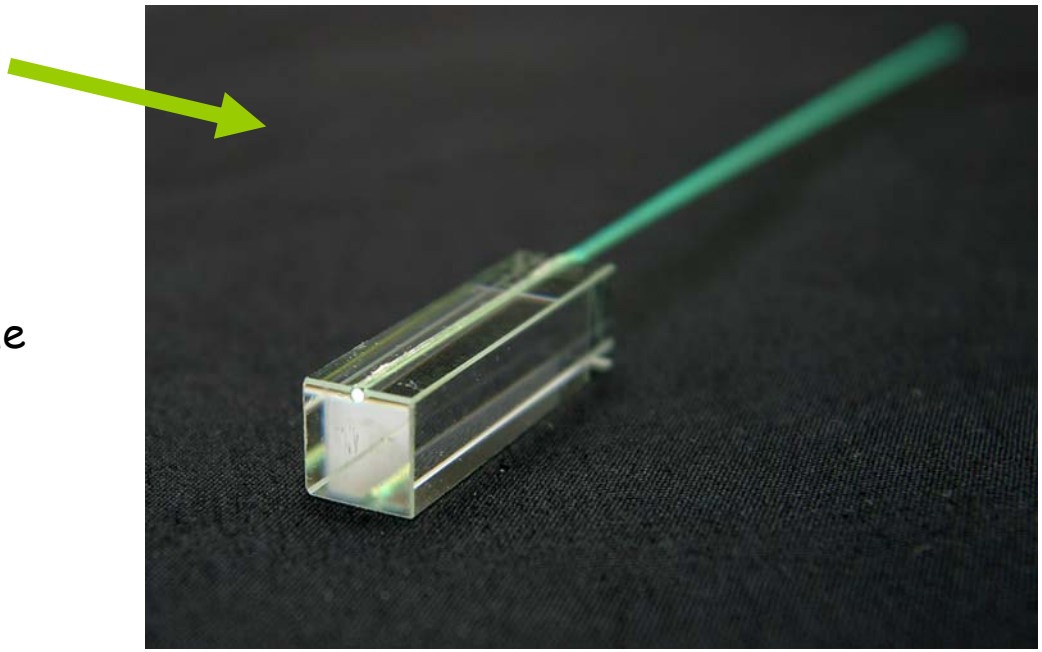
Fiber readout : (QE_{PMT} 13 ± 2 %)
Photoelectrons : 2.4 ± 0.5 p.e. / μ
Lightyield : 19 ± 7 photons / μ

Lightyield reduced to 16 ± 7 %

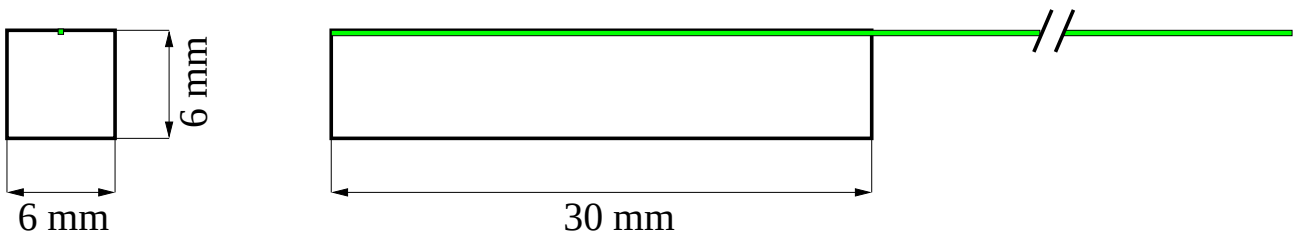
Simulation - Motivation

To simulate the behavior of Scintillator-samples, optical processes provided by GEANT4 have to be understood:

- Scintillation
- Čerenkov radiation
- Transport of optical photons in the medium
- Reflection
- Scattering
- photons at material boundaries
- Absorption
- Reemission
- wavelength shifting



BC−408 Scintillator−Sample



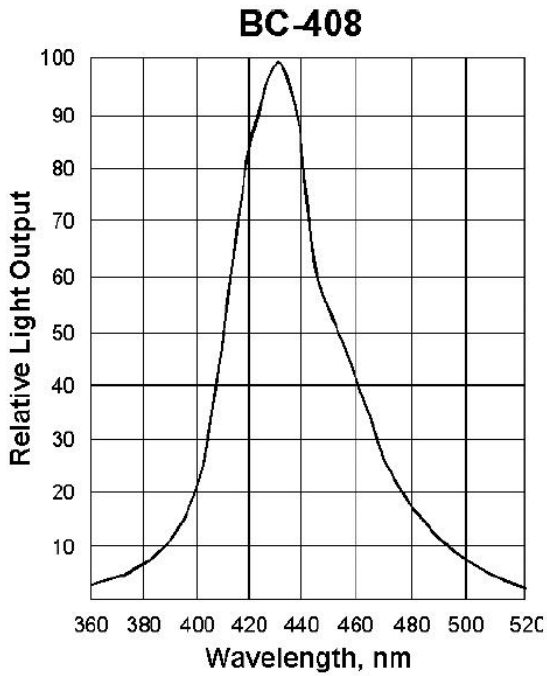
Relevant processes for optical photons

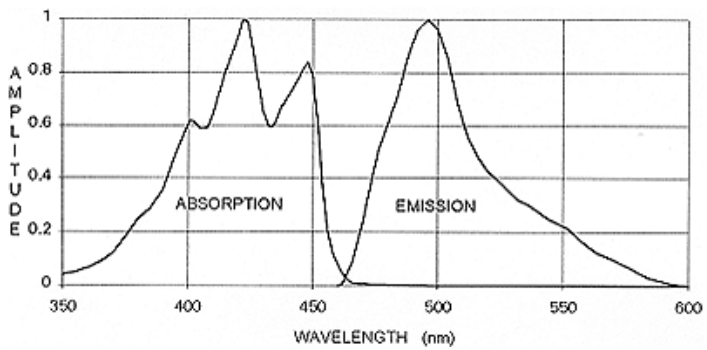
Process	Geant4 source	
Cerenkov	`processes/electromagnetic/xray -> G4Cerenkov`	
Scintillation	`processes/electromagnetic/xray -> G4Scintillation`	
OpBoundary	`processes/optical -> G4OpBoundary`	
OpAbsorption	`processes/optical -> G4OpAbsorption`	
OpRayleigh	`processes/optical -> G4OpRayleigh`	
OpWLS	`processes/optical -> G4OpWLS`	since GEANT4 6.0
(Transportation)		

Needed

Material properties:

- atomic composition of the materials used
- refractive index
- absorption length (-spectrum)
- scintillation yield (slow/fast)
- scintillation time constant (slow/fast)
- absorption-, emission-spectra of WLS-materials
- time constants of WLS-materials





Known:

- over all refractive index
- over all absorption length
- (rel. Emission-, Absorption spectrum)
- (scintillation yield)
- time constants

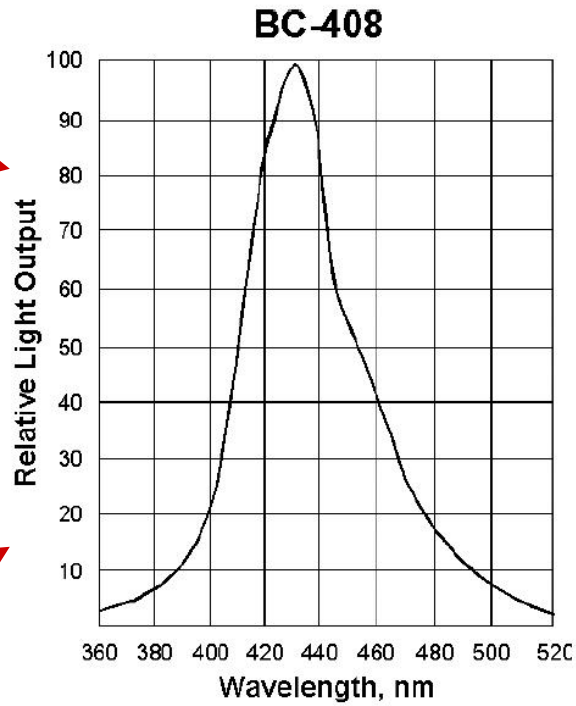
Scintillation

```
const G4int NUMENTRIES = 12;

  G4double PhotonEnergy[NUMENTRIES] =
    { 3.44*eV, 3.26*eV, 3.1*eV, 3.02*eV, 2.95*eV,
      2.92*eV, 2.82*eV, 2.76*eV, 2.7*eV, 2.58*eV,
      2.38*eV, 2.08*eV };

  G4double RINDEX_Bc408[NUMENTRIES] =
    { 1.58, 1.58, 1.58, 1.58, 1.58,
      1.58, 1.58, 1.58, 1.58, 1.58,
      1.58, 1.58 };

  G4double ABSORPTION_Bc408[NUMENTRIES] =
    { 210*cm, 210*cm, 210*cm, 210*cm, 210*cm,
      210*cm, 210*cm, 210*cm, 210*cm, 210*cm,
      210*cm, 210*cm };
```



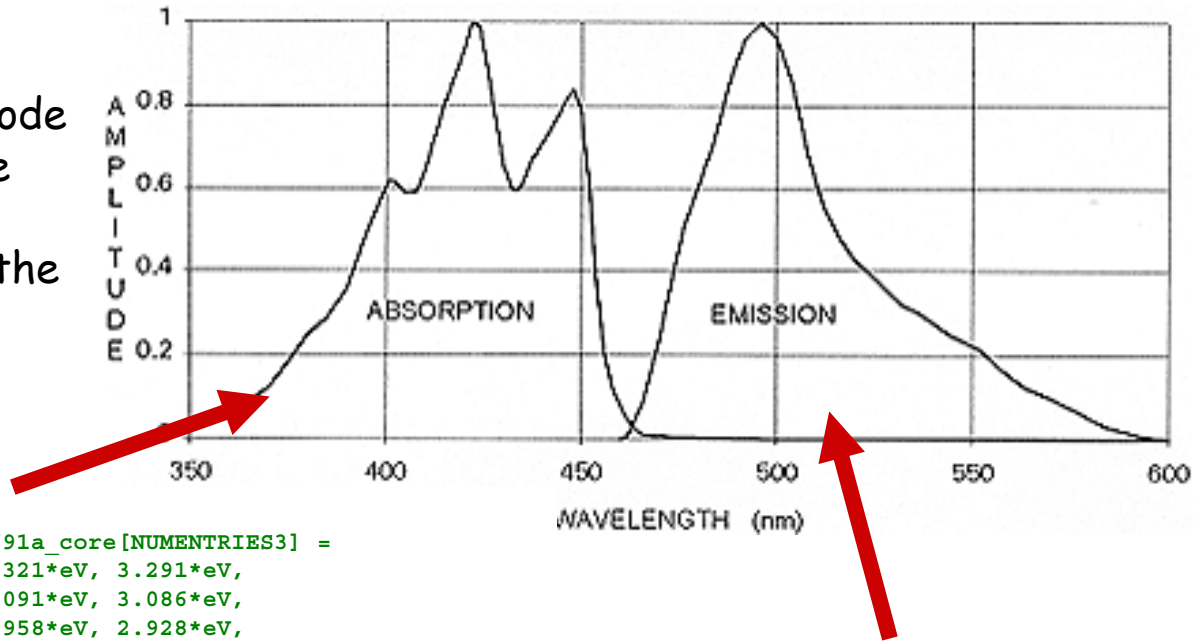

```
G4double SCINTILLATION_Bc408[NUMENTRIES] =
    { 0.04, 0.07, 0.20, 0.49, 0.84,
      1.00, 0.83, 0.55, 0.40, 0.17,
      0.03, 0 };

G4MaterialPropertiesTable *Bc408_mt = new G4MaterialPropertiesTable();
  Bc408_mt->AddProperty("RINDEX", PhotonEnergy, RINDEX_Bc408,  NUMENTRIES);
  Bc408_mt->AddProperty("ABSLENGTH", PhotonEnergy, ABSORPTION_Bc408,  NUMENTRIES);
  Bc408_mt->AddProperty("FASTCOMPONENT", PhotonEnergy, SCINTILLATION_Bc408, NUMENTRIES);

  Bc408_mt->AddConstProperty("SCINTILLATIONYIELD",500./MeV);
  Bc408_mt->AddConstProperty("RESOLUTIONSCALE",1.0);
  Bc408_mt->AddConstProperty("FASTTIMECONSTANT", 1.*ns);
  //Bc408_mt->AddConstProperty("SLOWTIMECONSTANT",1.*ns);
  Bc408_mt->AddConstProperty("YIELDRATIO",1.);
  Bc408->SetMaterialPropertiesTable(Bc408_mt);
```

WLS

Absorptionlength from Code Hugh Gallagers Web Page (Tufts University), (Scintillator studies for the MINOS-Experiment)



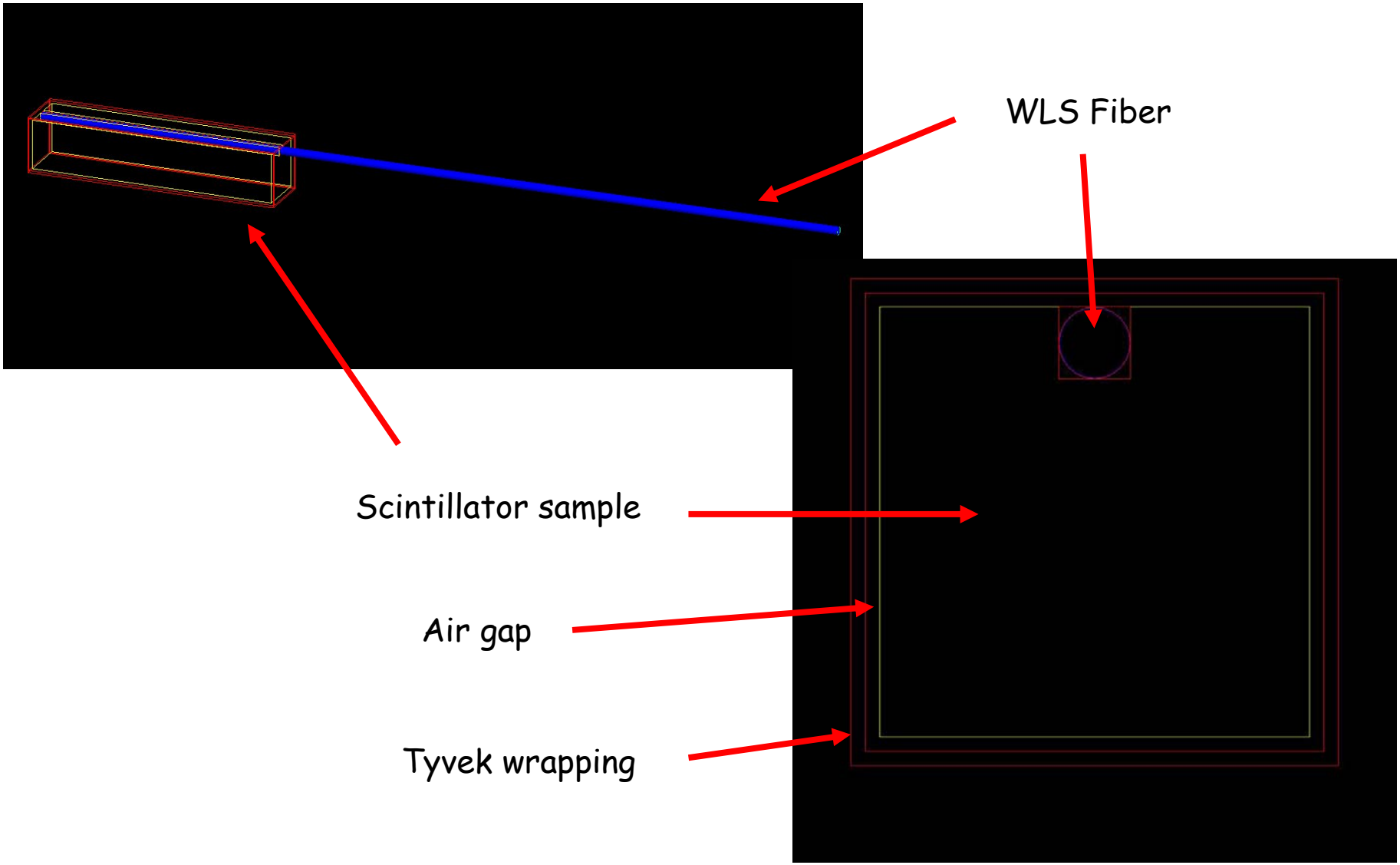

```
const G4int NUMENTRIES3 = 42;
    G4double PhotonEnergy_WLS_ABS_Bcf91a_core[NUMENTRIES3] =
   { 3.539*eV, 3.477*eV, 3.340*eV, 3.321*eV, 3.291*eV,
     3.214*eV, 3.162*eV, 3.129*eV, 3.091*eV, 3.086*eV,
     3.049*eV, 3.008*eV, 2.982*eV, 2.958*eV, 2.928*eV,
     2.905*eV, 2.895*eV, 2.890*eV, 2.858*eV, 2.813*eV,
     2.774*eV, 2.765*eV, 2.752*eV, 2.748*eV, 2.739*eV,
     2.735*eV, 2.731*eV, 2.723*eV, 2.719*eV, 2.698*eV,
     2.674*eV, 2.626*eV, 2.610*eV, 2.583*eV, 2.556*eV,
     2.530*eV, 2.505*eV, 2.480*eV, 2.455*eV, 2.431*eV,
     2.407*eV, 2.384*eV };

  G4double WLS_ABSLENGTH_Bcf91a_core[NUMENTRIES3] =
   { 0.28*cm, 0.28*cm, 0.26*cm, 0.25*cm, 0.24*cm,
     0.21*cm, 0.19*cm, 0.16*cm, 0.13*cm, 0.13*cm,
     0.14*cm, 0.11*cm, 0.08*cm, 0.05*cm, 0.02*cm,
     0.05*cm, 0.08*cm, 0.10*cm, 0.13*cm, 0.10*cm,
     0.08*cm, 0.07*cm, 0.08*cm, 0.11*cm, 0.13*cm,
     0.16*cm, 0.19*cm, 0.21*cm, 0.24*cm, 0.27*cm,
     0.30*cm, 2.69*cm, 3.49*cm, 3.99*cm, 5.00*cm,
     11.6*cm, 21.6*cm, 33.1*cm,  175*cm,  393*cm,
     617*cm, 794*cm };
```

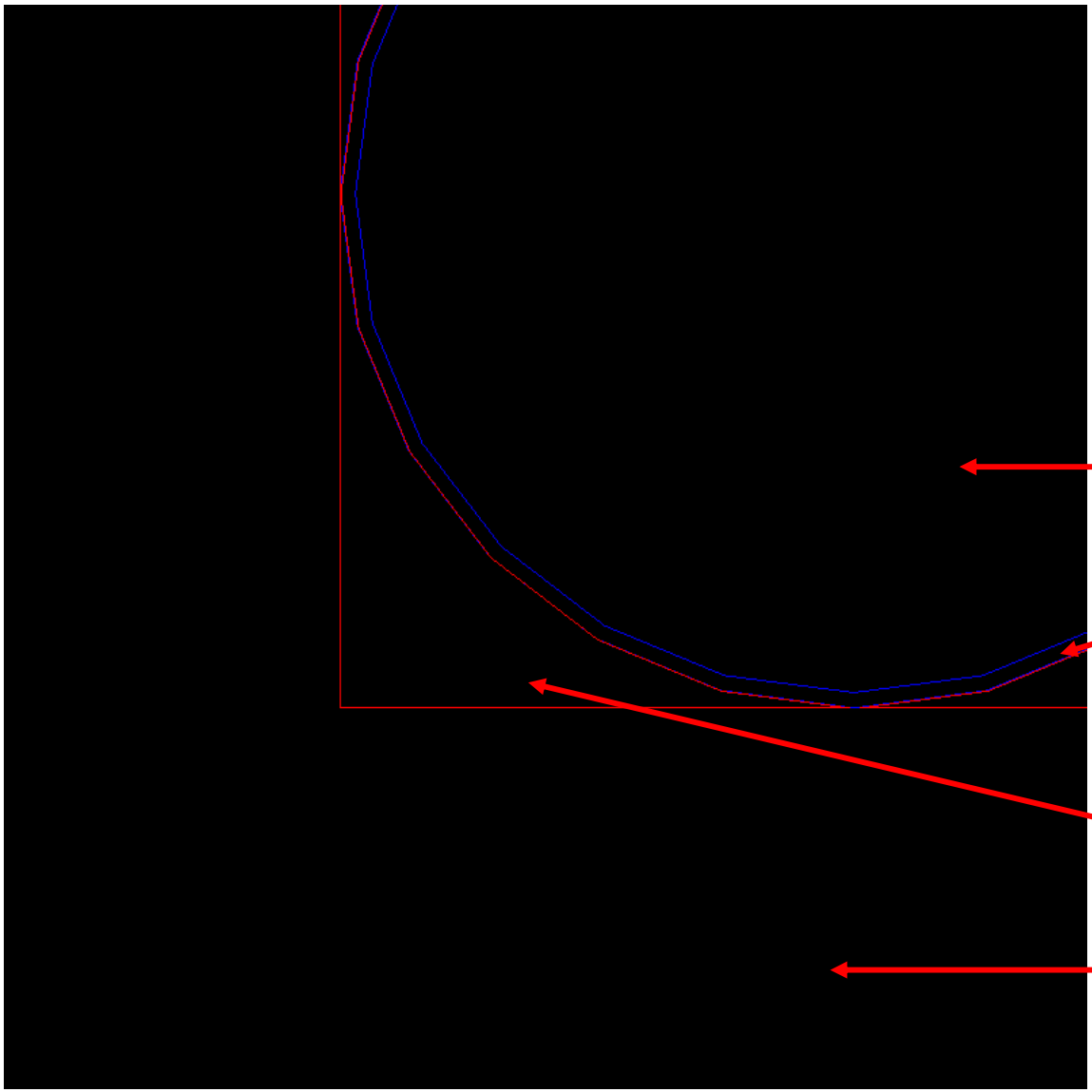
```
const G4int NUMENTRIES2 = 24;
   G4double PhotonEnergy_WLS_EM_Bcf91a_core[NUMENTRIES2] =
    { 2.69*eV, 2.67*eV, 2.66*eV, 2.64*eV, 2.63*eV,
      2.61*eV, 2.58*eV, 2.56*eV, 2.55*eV, 2.53*eV,
      2.50*eV, 2.48*eV, 2.46*eV, 2.45*eV, 2.44*eV,
      2.43*eV, 2.41*eV, 2.37*eV, 2.33*eV, 2.25*eV,
      2.24*eV, 2.19*eV, 2.15*eV, 2.08*eV };

   G4double WLS_EMISSION_Bcf91a_core[NUMENTRIES2] =
    {0, 0.02, 0.09, 0.20, 0.29,
     0.40, 0.59, 0.70, 0.80, 0.89,
     1.00, 0.96, 0.88, 0.79, 0.69,
     0.59, 0.50, 0.40, 0.31, 0.22,
     0.19, 0.10, 0.06, 0 };
```

Geometry



Frontview



Fiber diameter: 1mm,

Cladding thickness:
3% of core Ø

Channel: 1mmx1mm

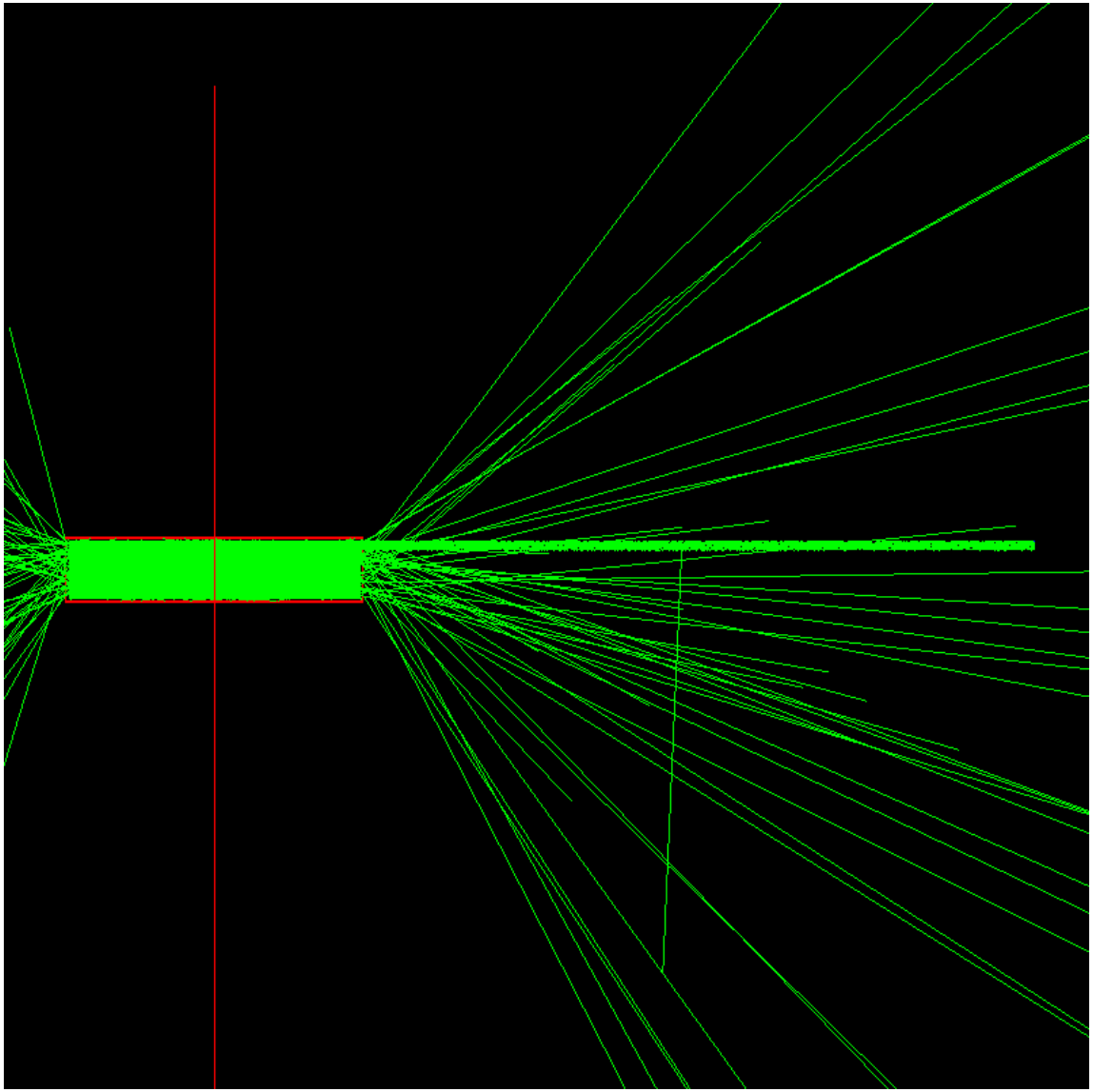
Fiber core:
Polystyrene, n=1.6

Fiber cladding:
Acrylic, n=1.49

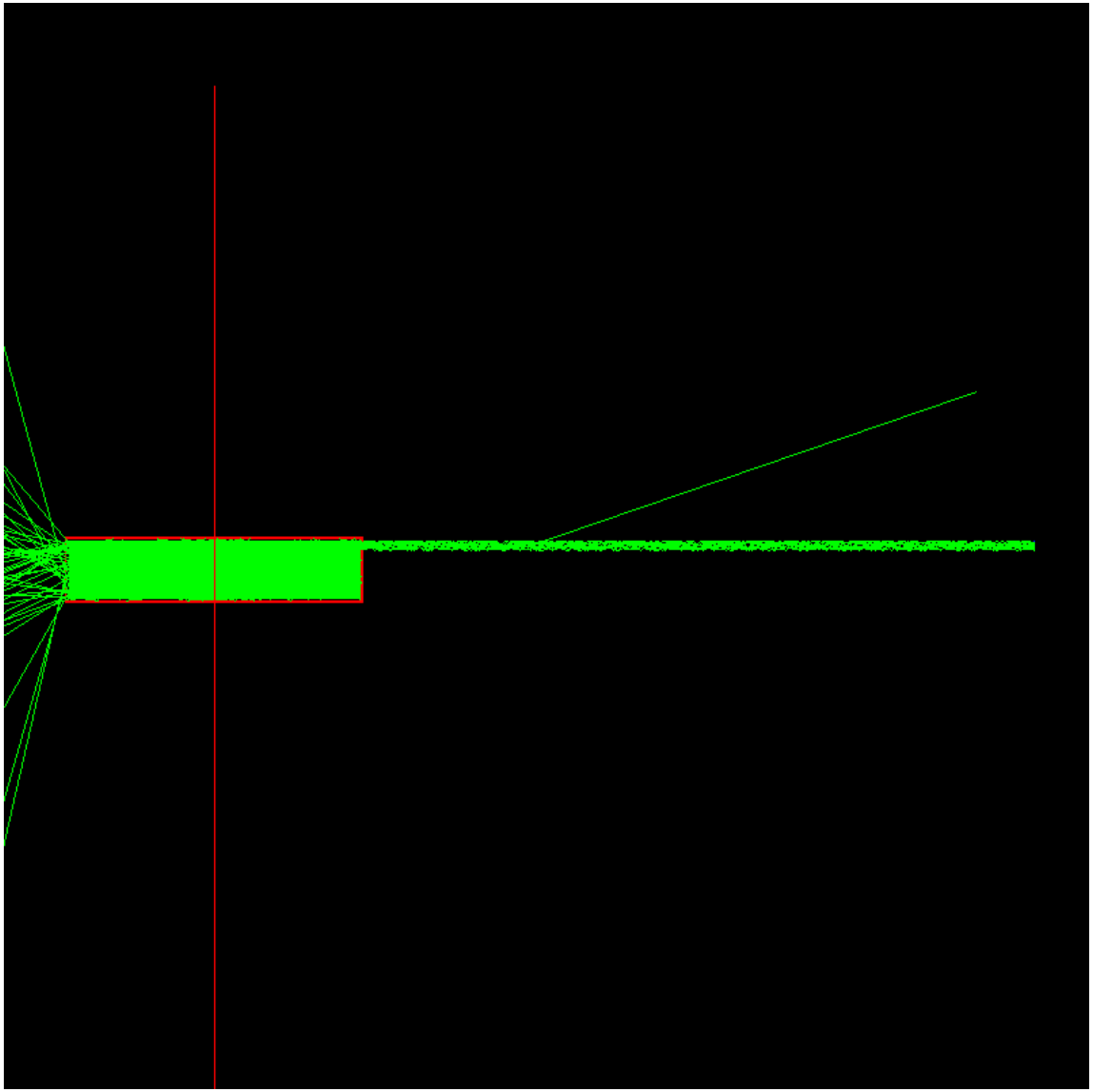
Optical glue:
Epoxy, n=1.56

Scintillator:
Polyvinyltoluene, n=1.58

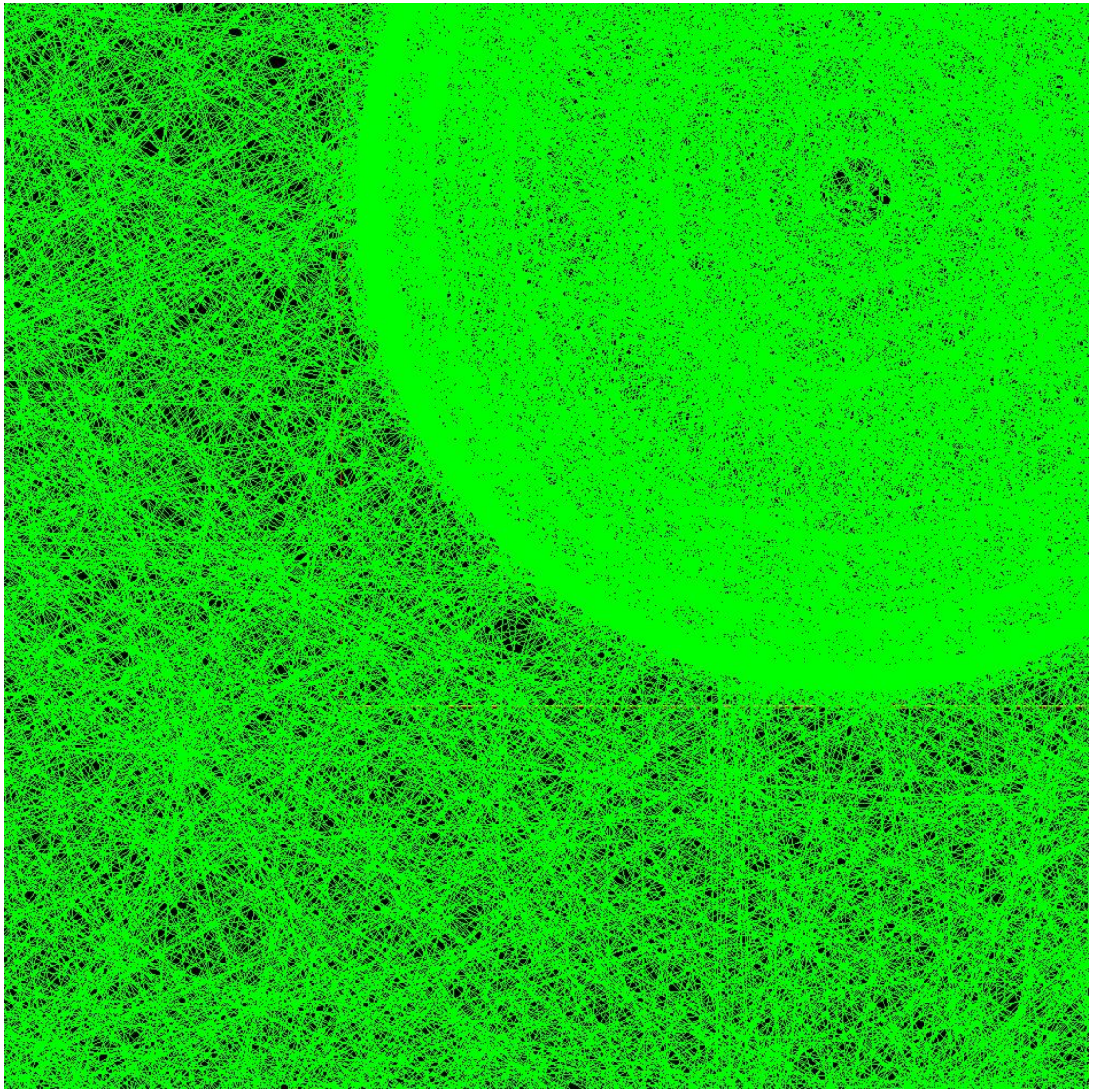
Sideview, both sides open



Sideview, one side open

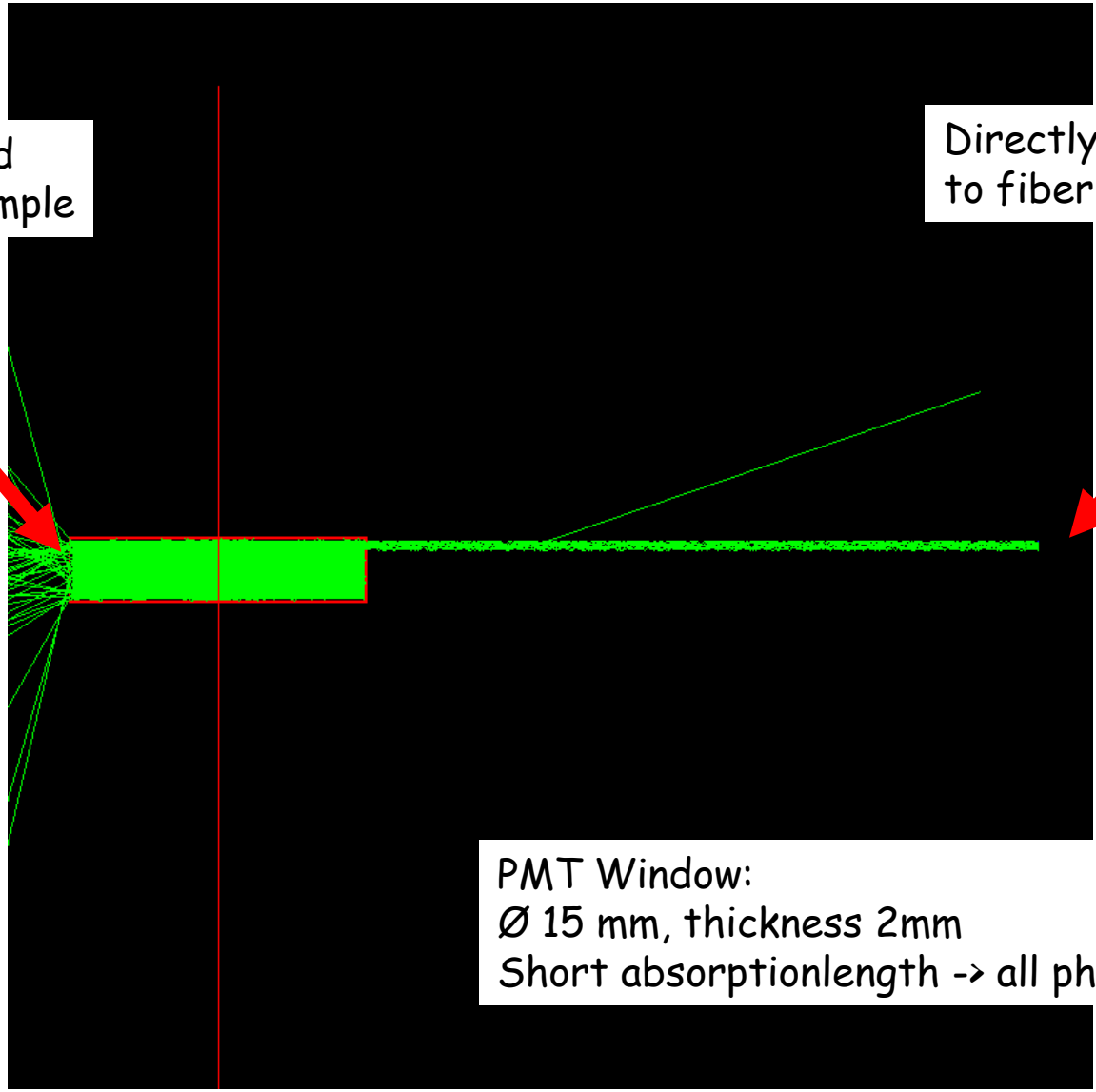


Front view - Photons in the Fiber

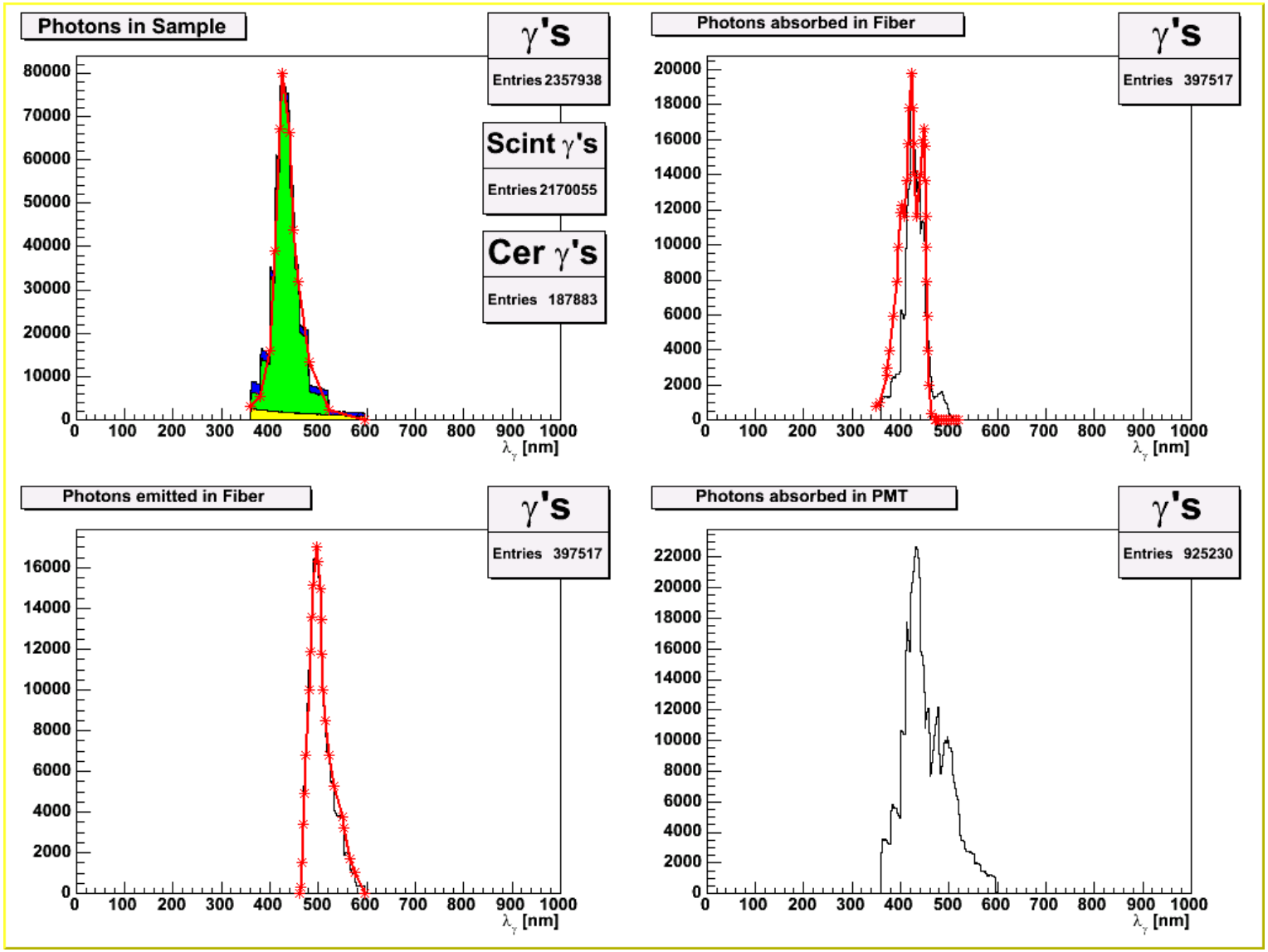


Scintillation yield ~50/MeV

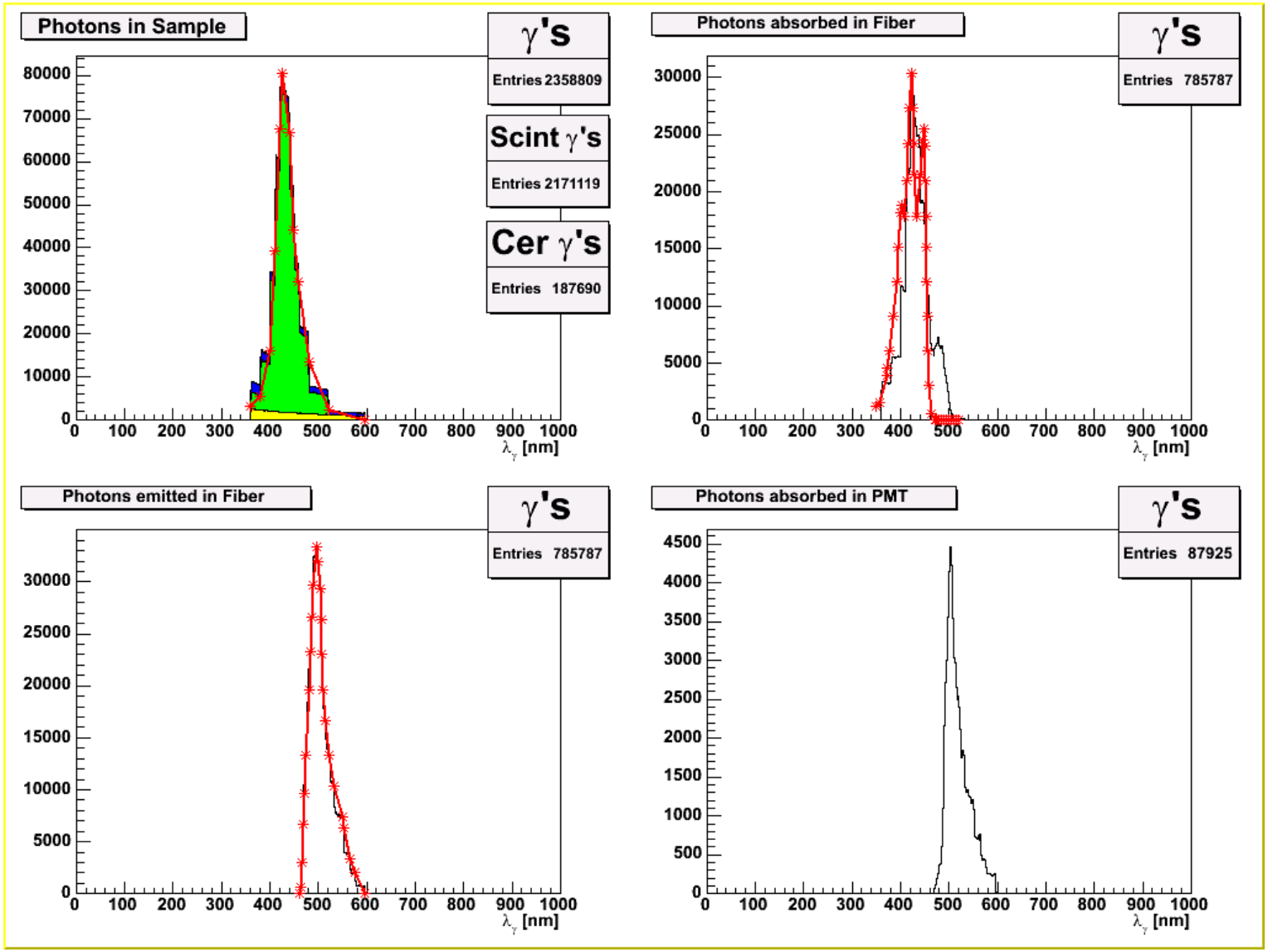
PMT positions



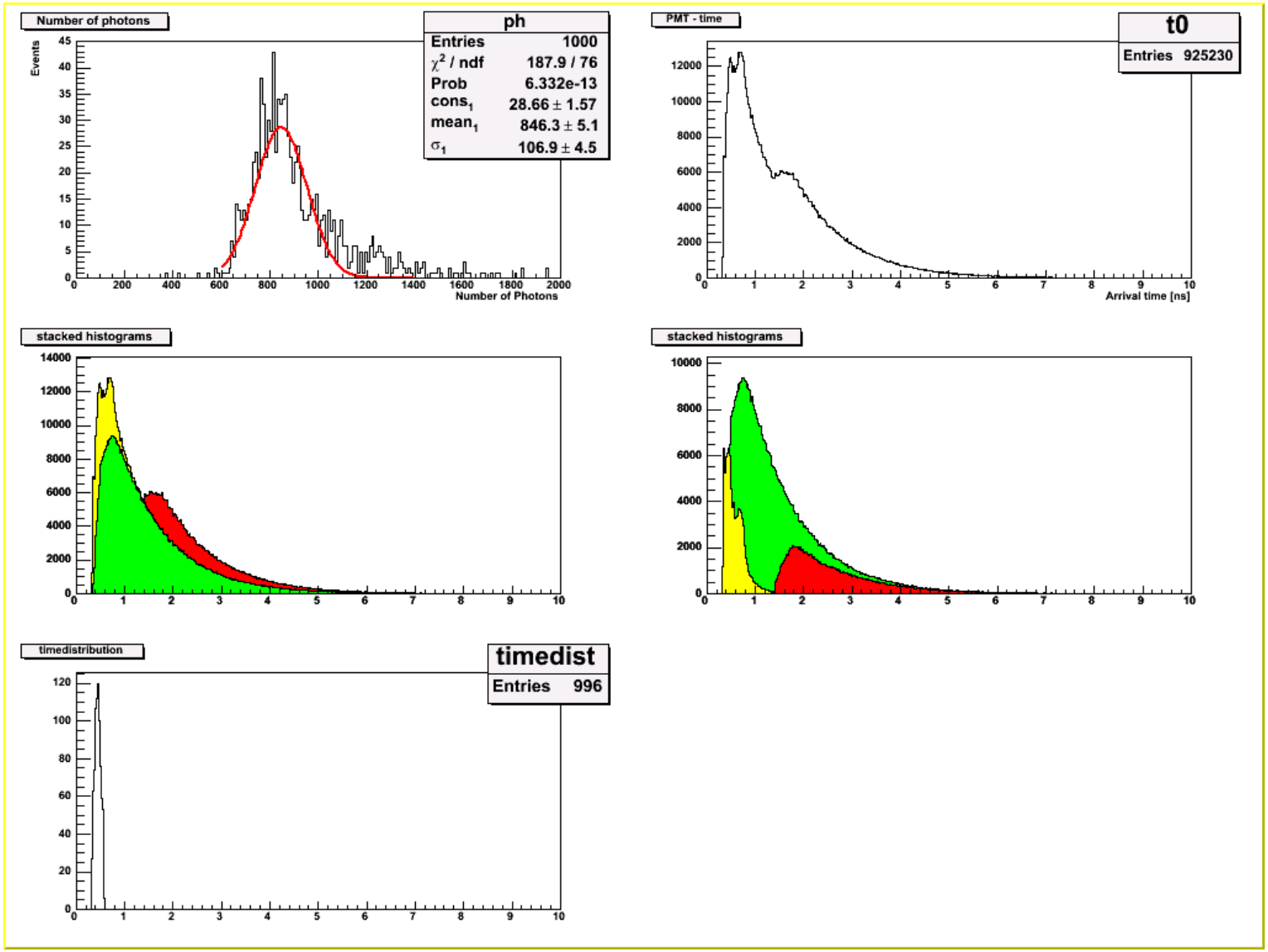
Bc_direct_3a


Photons in Sample
γ's
Entries 2357938
Scint γ's
Entries 2170055
Cer γ's
Entries 187883
λγ [nm]
Photons absorbed in Fiber
γ's
Entries 397517
λγ [nm]
Photons emitted in Fiber
γ's
Entries 397517
λγ [nm]
Photons absorbed in PMT
γ's
Entries 925230
λγ [nm]

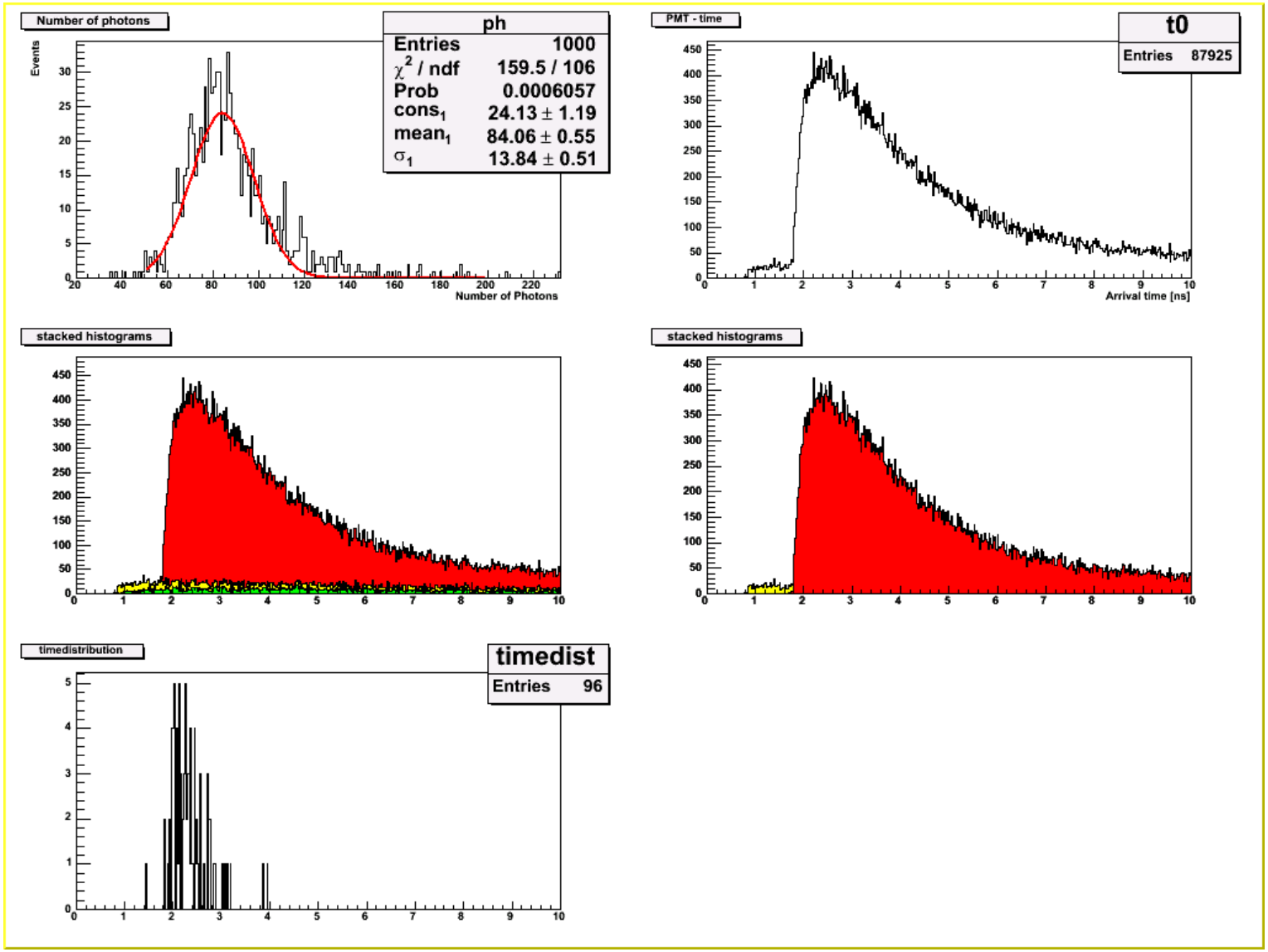
Bc_fiber_3a


Photons in Sample
γ's
Entries 2358809
Scint γ's
Entries 2171119
Cer γ's
Entries 187690
λγ [nm]
Photons absorbed in Fiber
γ's
Entries 785787
λγ [nm]
Photons emitted in Fiber
γ's
Entries 785787
λγ [nm]
Photons absorbed in PMT
γ's
Entries 87925
λγ [nm]

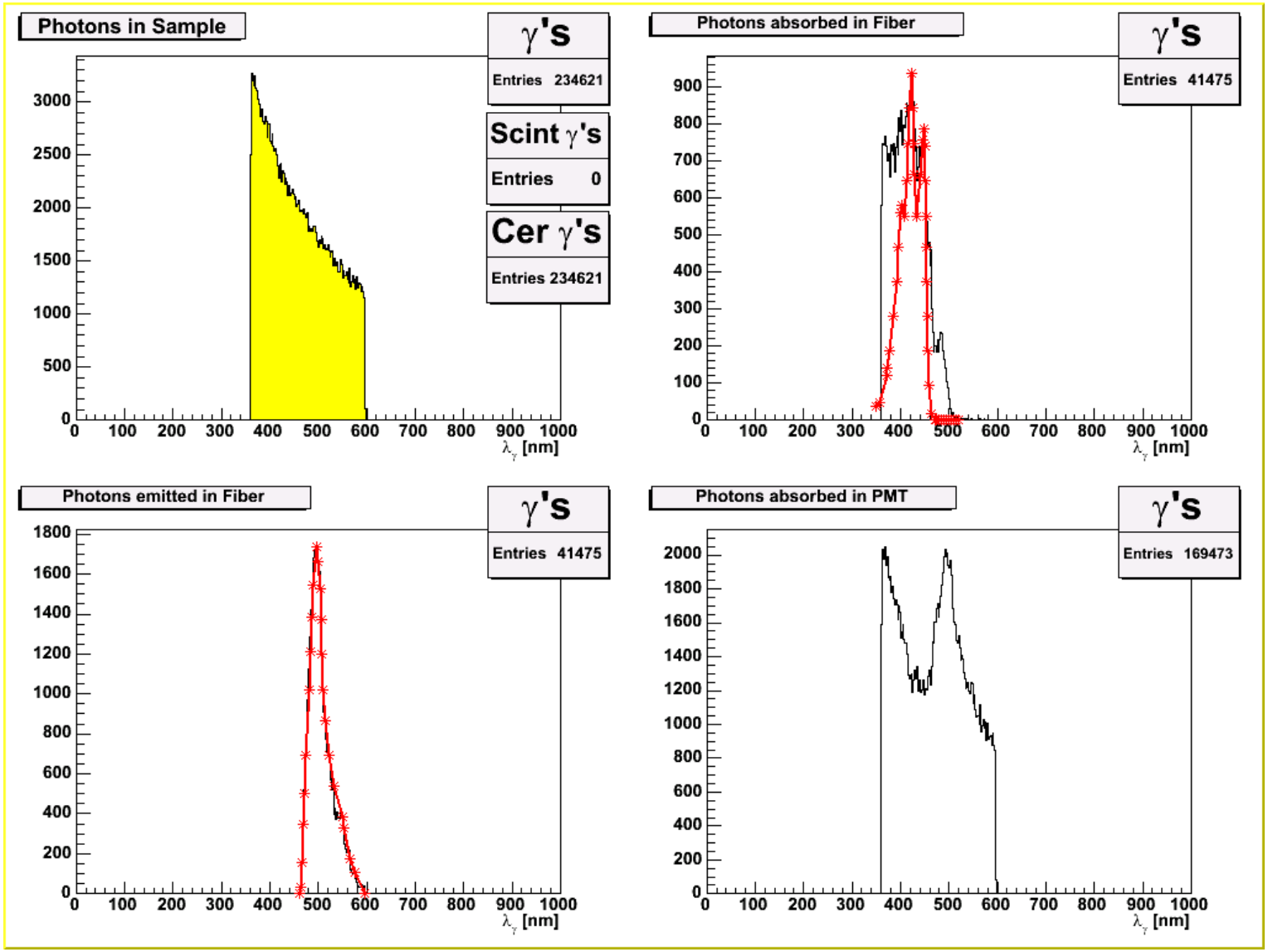
Bc_direct_3a_pmt



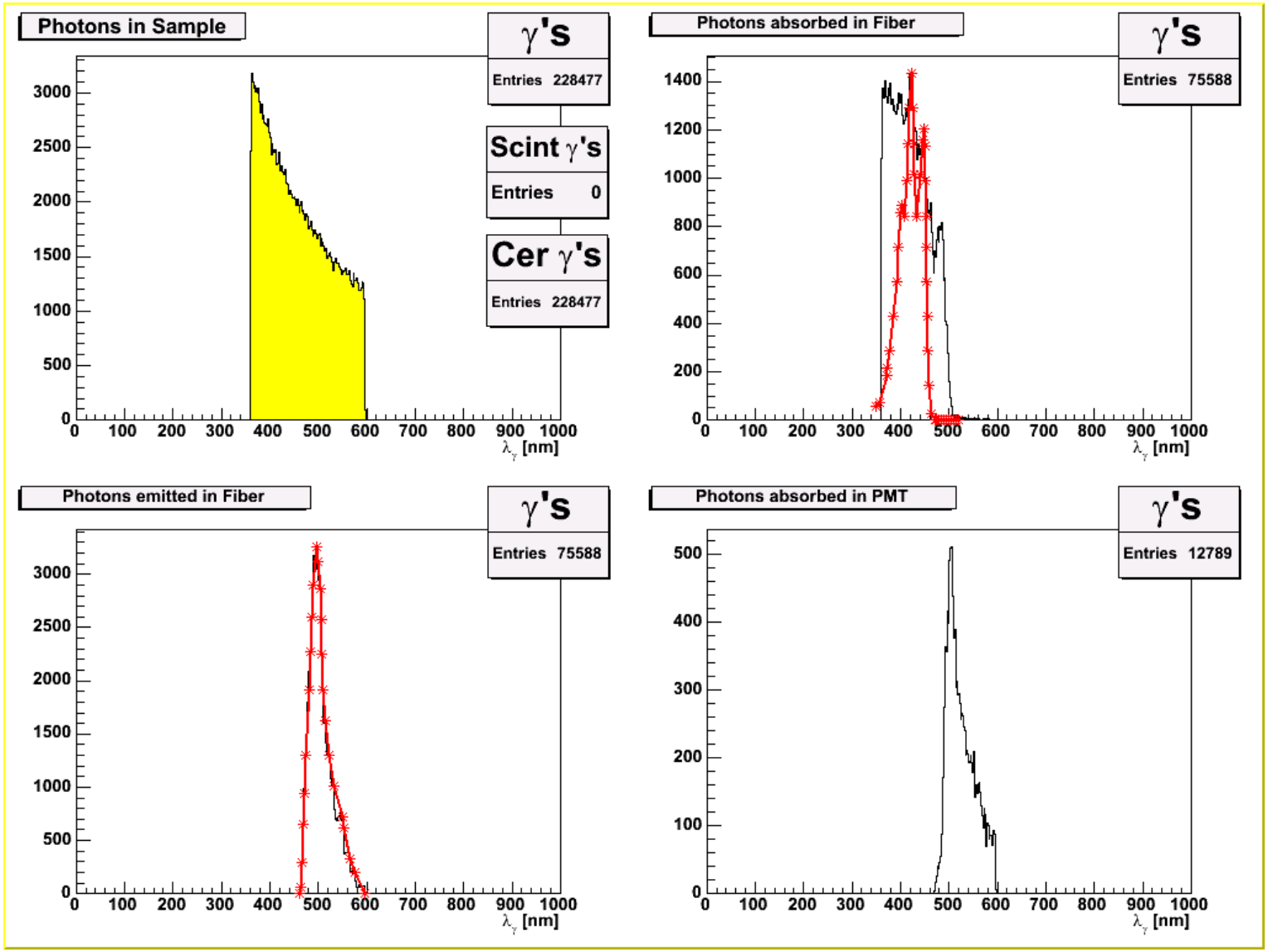
Bc_fiber_3a_pmt



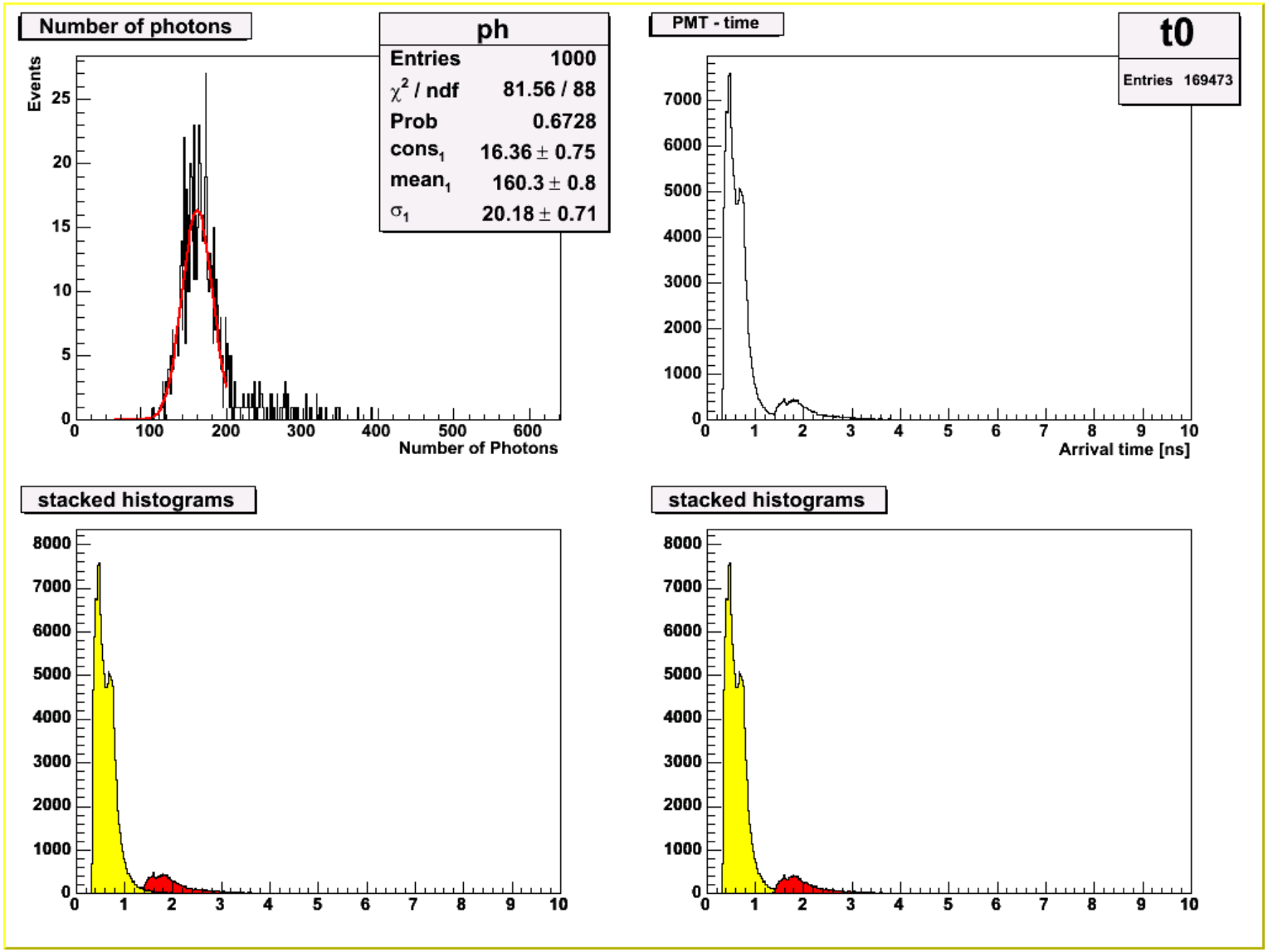
Lg_direct


Photons in Sample
γ's
Entries 234621
Scint γ's
Entries 0
Cer γ's
Entries 234621
λγ [nm]
Photons absorbed in Fiber
γ's
Entries 41475
λγ [nm]
Photons emitted in Fiber
γ's
Entries 41475
λγ [nm]
Photons absorbed in PMT
γ's
Entries 169473
λγ [nm]

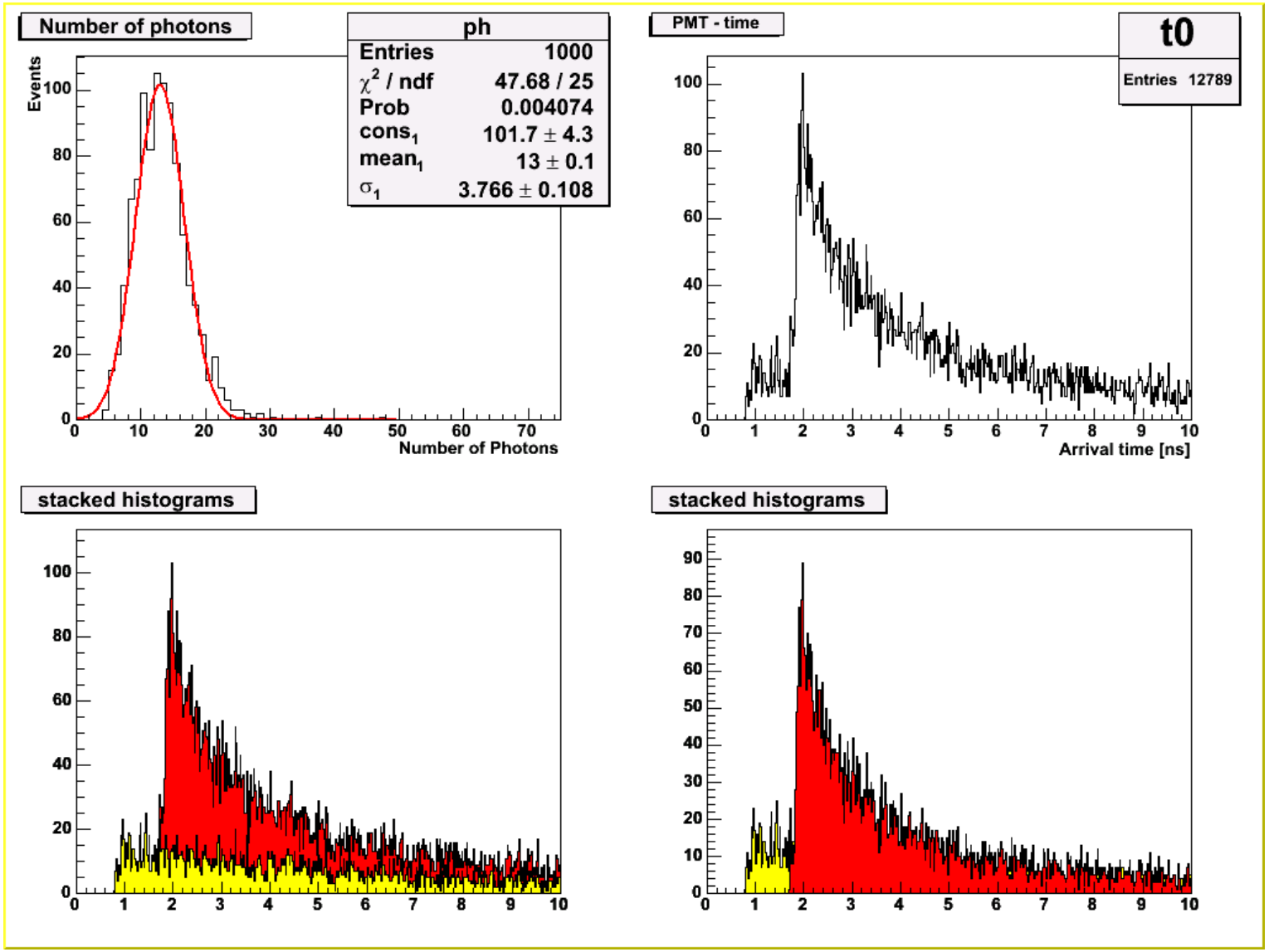
Lg_fiber


Photons in Sample
γ's
Entries 228477
Scint γ's
Entries 0
Cer γ's
Entries 228477
λγ [nm]
Photons absorbed in Fiber
γ's
Entries 75588
λγ [nm]
Photons emitted in Fiber
γ's
Entries 75588
λγ [nm]
Photons absorbed in PMT
γ's
Entries 12789
λγ [nm]

Lg_direct_pmt

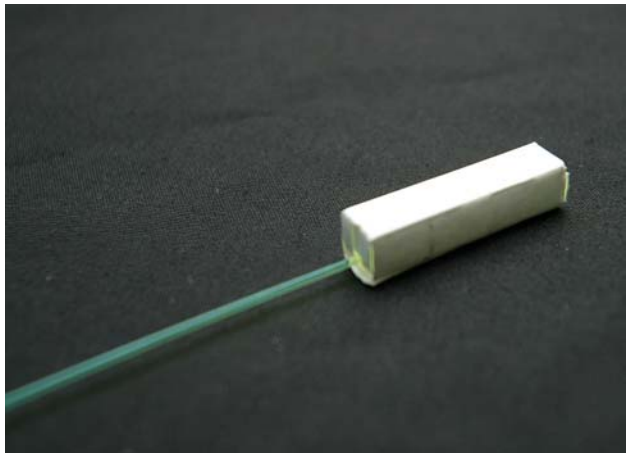


Lg_fiber_pmt


Number of photons
ph
Entries 1000
χ^2 / ndf 47.68 / 25
Prob 0.004074
$cons_1$ 101.7 ± 4.3
$mean_1$ 13 ± 0.1
σ_1 3.766 ± 0.108
Events
Number of Photons
PMT - time
t0
Entries 12789
Arrival time [ns]
stacked histograms
stacked histograms

Simulation - Results

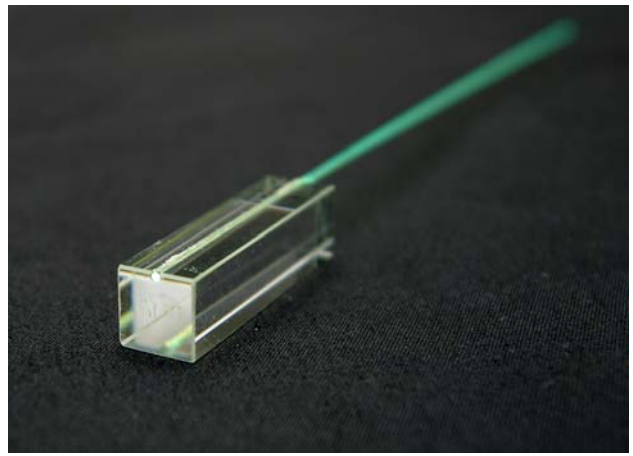
Plastic Scintillator



(exp.):
Lightyield reduced to 14 ± 4 %

(sim.):
Lightyield reduced to 9.3 – 9.8 %

Leadglass



(exp.):
Lightyield reduced to 16 ± 7 %

(sim.):
Lightyield reduced to 8.3 - 12 %

Summary

This is a first look – can be improved !!!

- for a first naive look – nice agreement between exp. and sim. results

For a realistic Simulation:

- implementation of realistic boundary and surface conditions of the materials/samples
- exact WLS-Absorption spectrum
- good knowledge of Absorption-, Emission behaviour of the materials
- material composition data

- these simulation studies continue

- V. Drugakov –> Simulation of a block of crystals