

Geant4 Simulation of the Pierre Auger Fluorescence Detector

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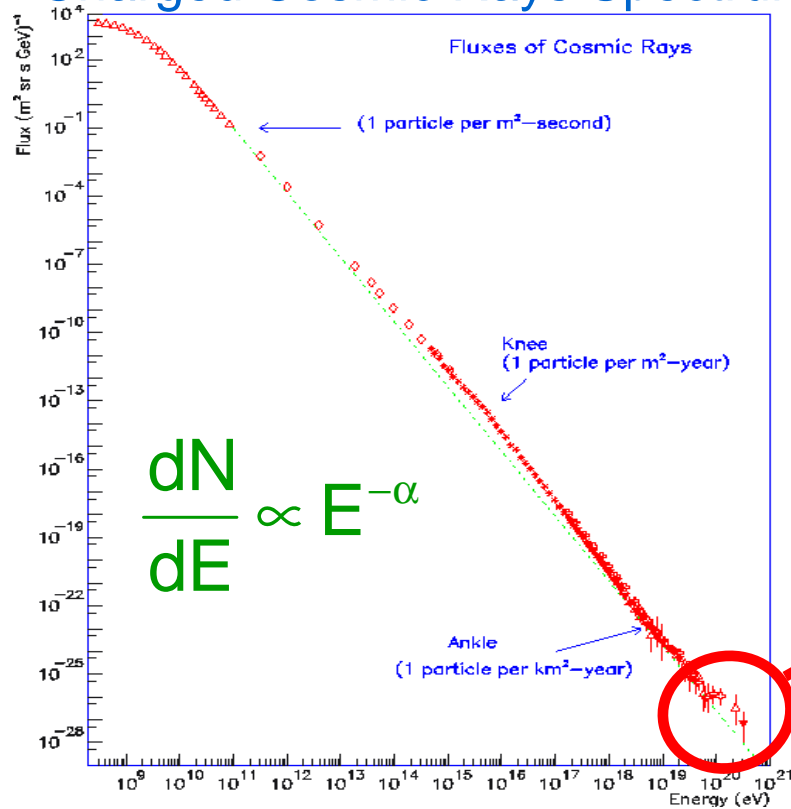
11th Geant4 Collaboration Workshop and Users Conference

9-14 October 2006

LIP - Lisboa & IST - Lisboa

Ultra High Energy Cosmic Rays (UHECR)

Charged Cosmic Rays Spectrum



Many questions:

Sources ? Acceleration mechanisms ?

GZK cutoff ?

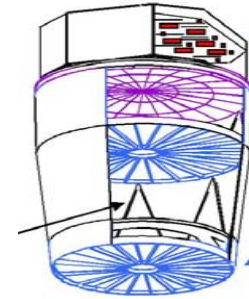
Same physics laws ?

$E > 10^{20}$ eV !

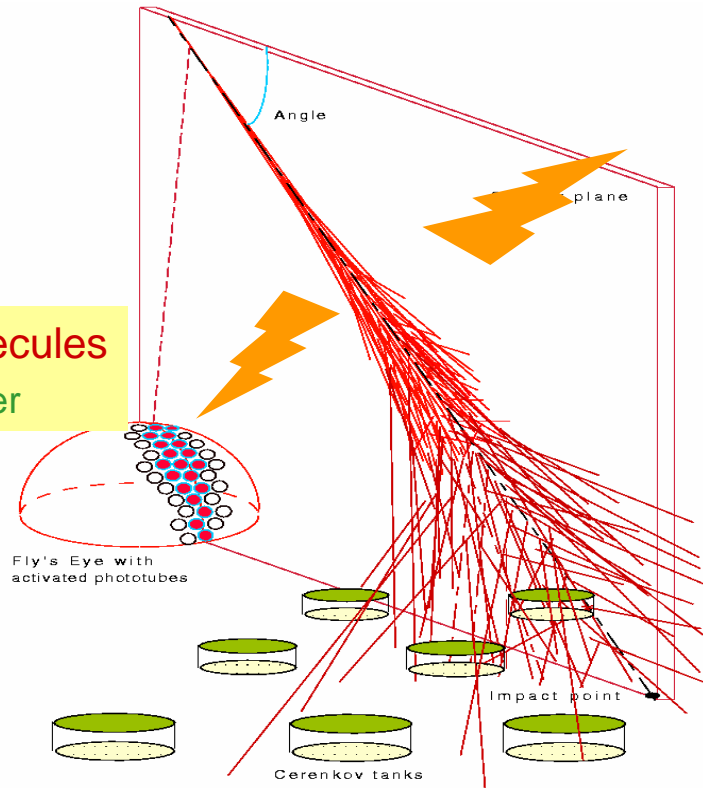
UHECR detection

Extensive Air Showers (EAS)

Light detection from space



Fluorescence from air N_2 molecules
isotropic emission along the shower



Cherenkov light
collimated with the shower

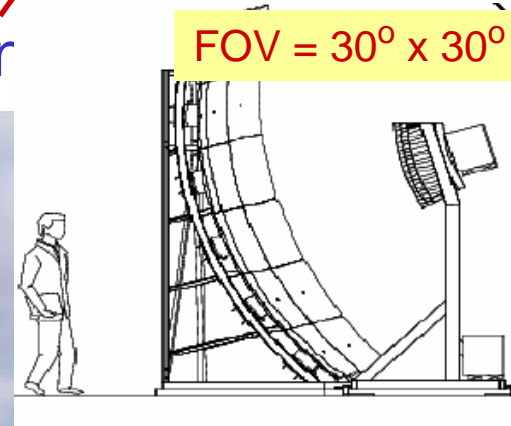
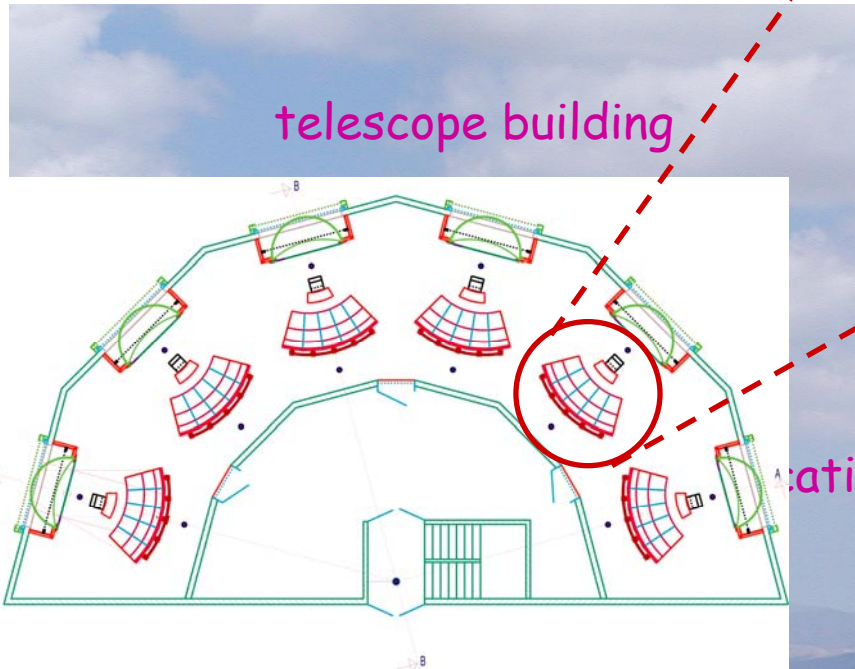


Direct detection of shower particles
Scintillators, Cherenkov radiators (e.g. water),...

The Southern Pierre Auger Observatory



- A giant hybrid detector in Argentina



observation tower

Cherenkov water tank

ay
or stations;
sing;

ectors
ch;

Schmidt optics

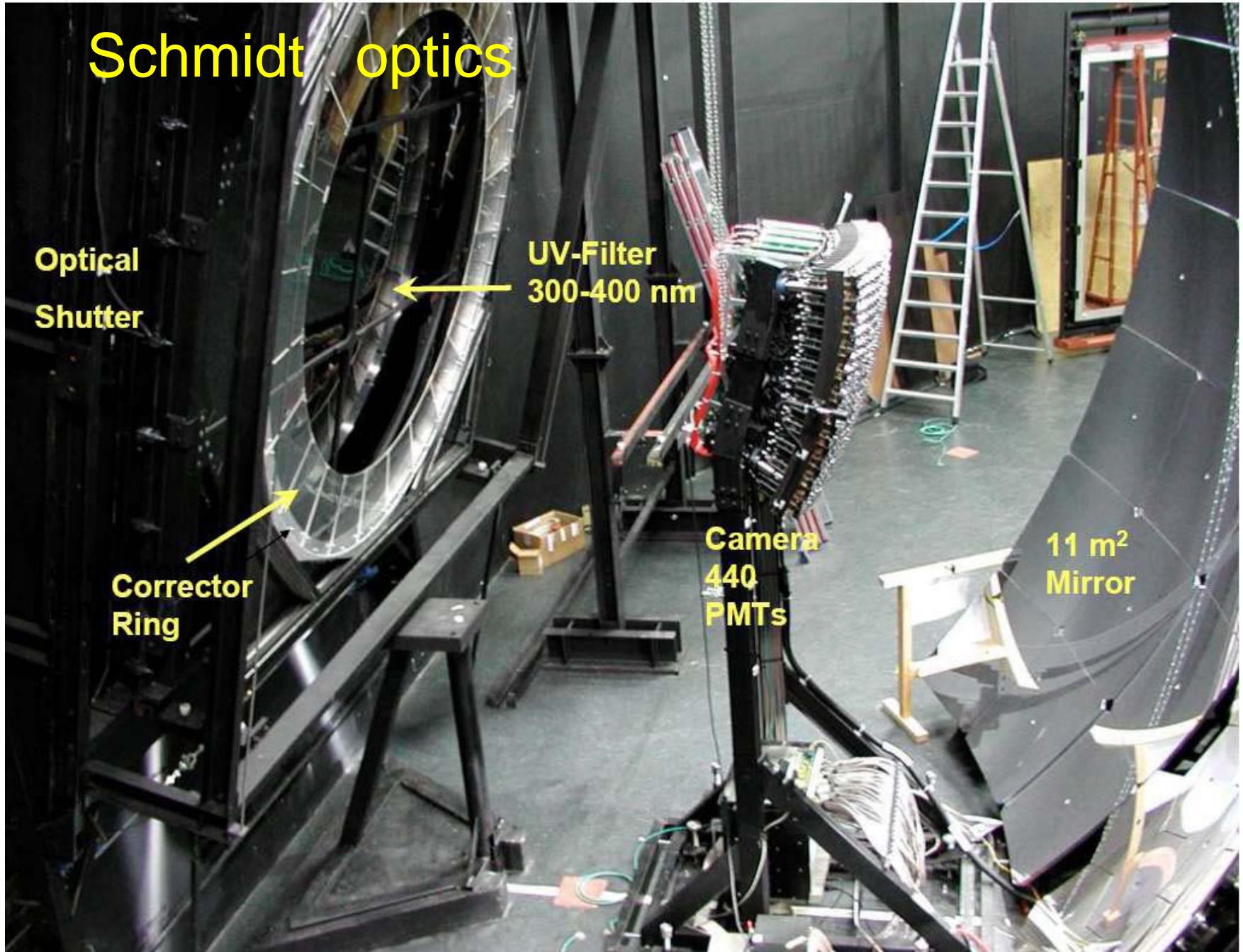
Optical
Shutter

UV-Filter
300-400 nm

Corrector
Ring

Camera
440
PMTs

11 m²
Mirror

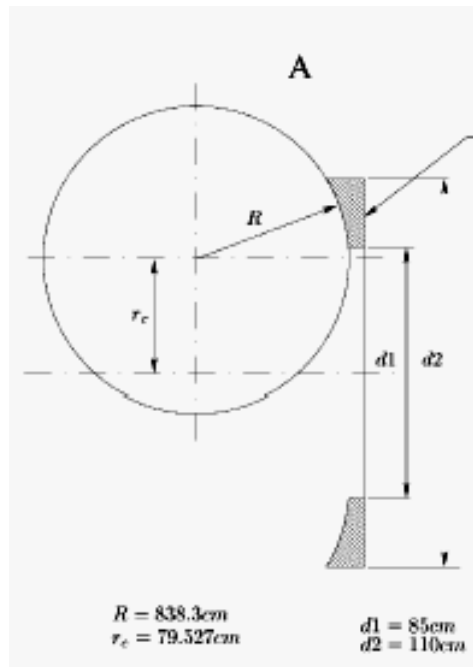


Corrector ring

Ring shaped lens to increase the telescope aperture ($\sim 2x$);

No significant degradation of optics performance.

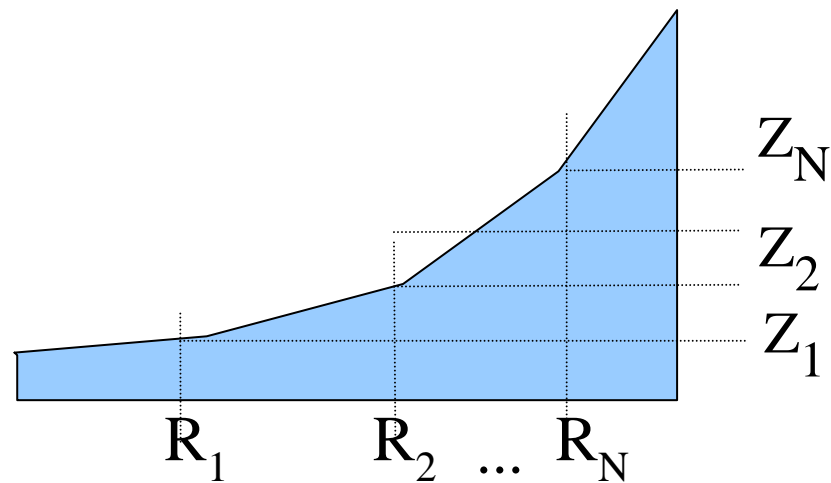
Toroidal profile



Corrector ring in Geant4

- G4Polycone;
- Discretization of ring profile:

Equidistant slices along Z ; R_i vs Z_i from ring profile equation.



N - to be optimized...

Corrector ring in Geant4

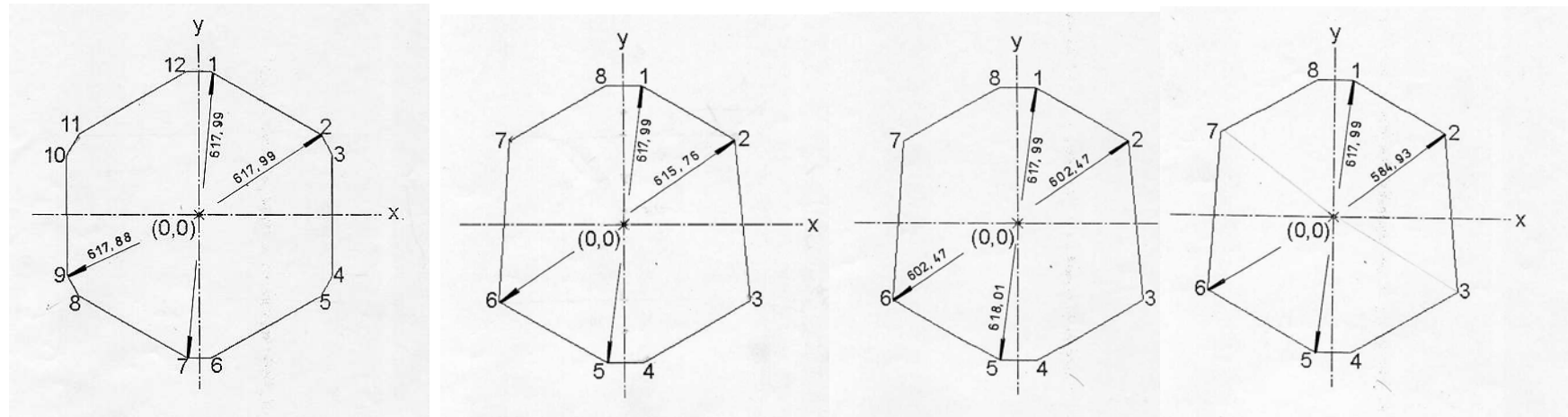


Mirror

- 3.5 x 3.5 m² spherical mirror;
- 3.4 m curvature radius;
- Made of square or hexagonal mirror segments (MS) with spherical curvature;
- Hexagonal MS mirror implemented in the simulation.



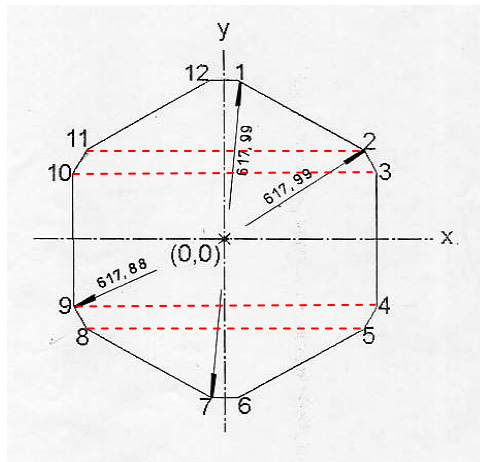
4 different MS shapes to fit the mirror curvature:



Each mirror is made of 60 mirror segments.

Mirror segments (MS) in Geant4

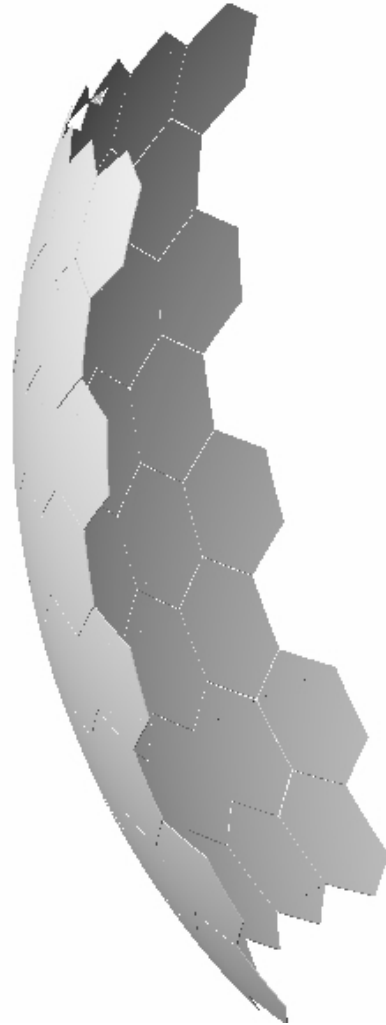
- 1) Union of G4Trd solids ;
- 2) Intersection of resulting boolean solid with a G4Sphere.
(Rmin = Radius of curvature; Rmax = Rmin + thickness)



The four MS types are described in the simulation.

- MS parameters (curvature, reflectivity, distance to camera) are read for each fluorescence telescope ;
- Access to a mirror segment DB is also possible.

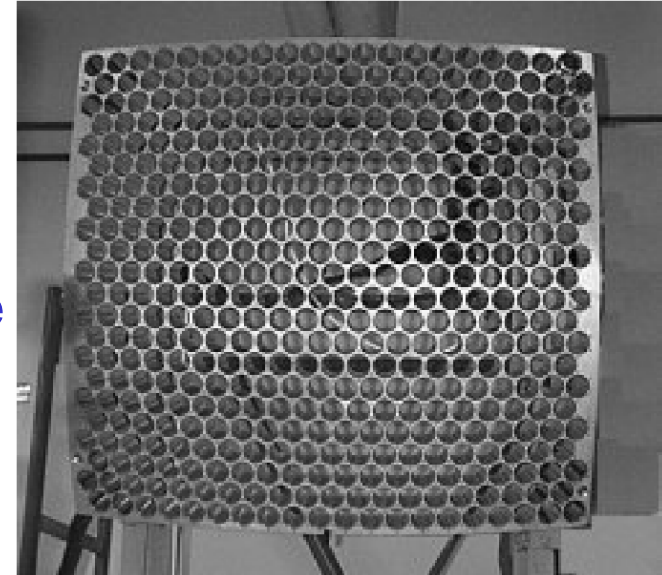
Assembled mirror



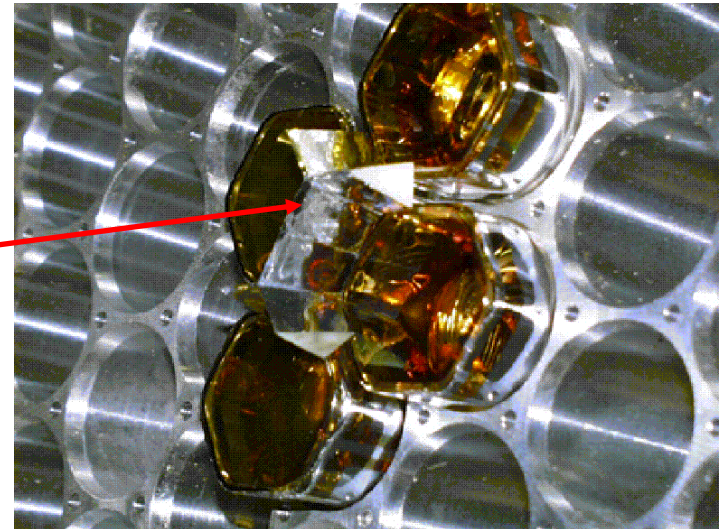
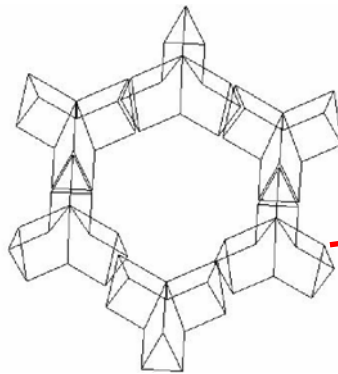
Camera

- Spherical focal surface;
- Hexagonal PMT's;
- Reflecting light guides (“Mercedes”) to maximize light collection.

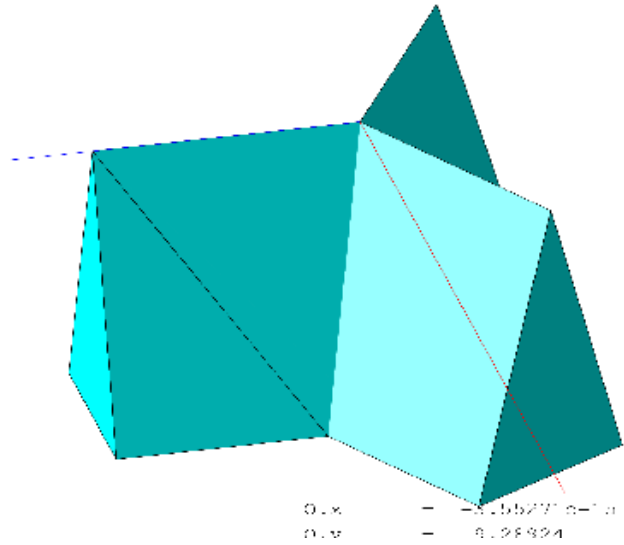
Camera frame



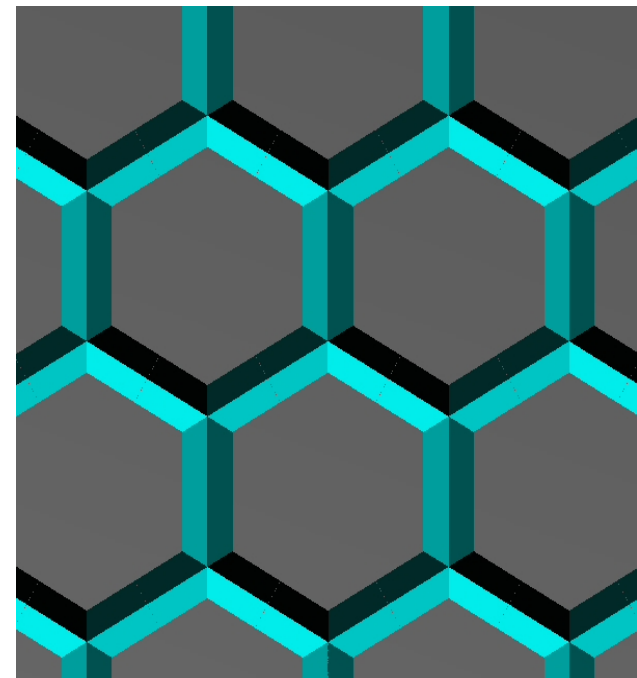
6 “Mercedes” light collectors



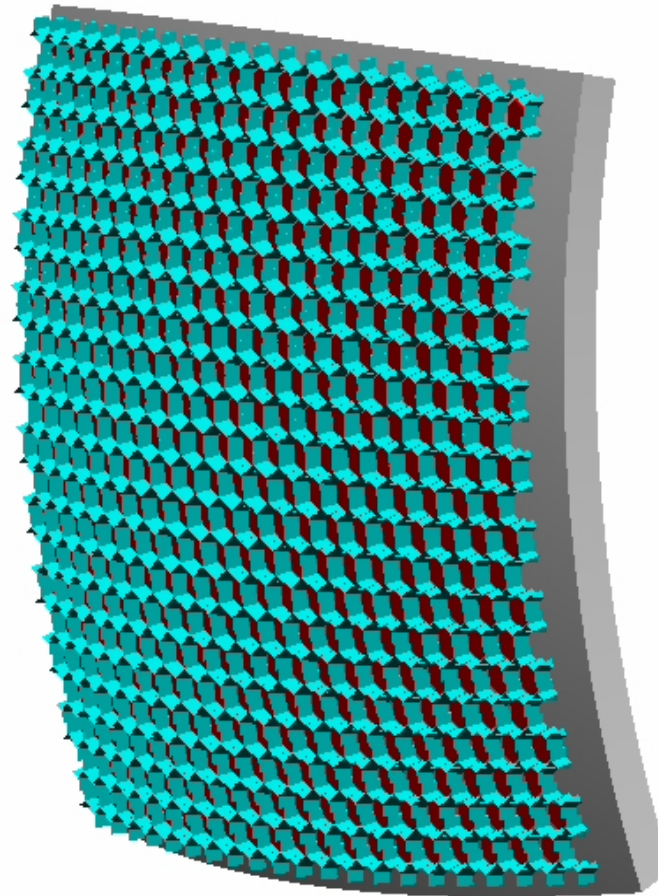
Mercedes light collectors in Geant4



Union of 3 G4Polyhedra solids

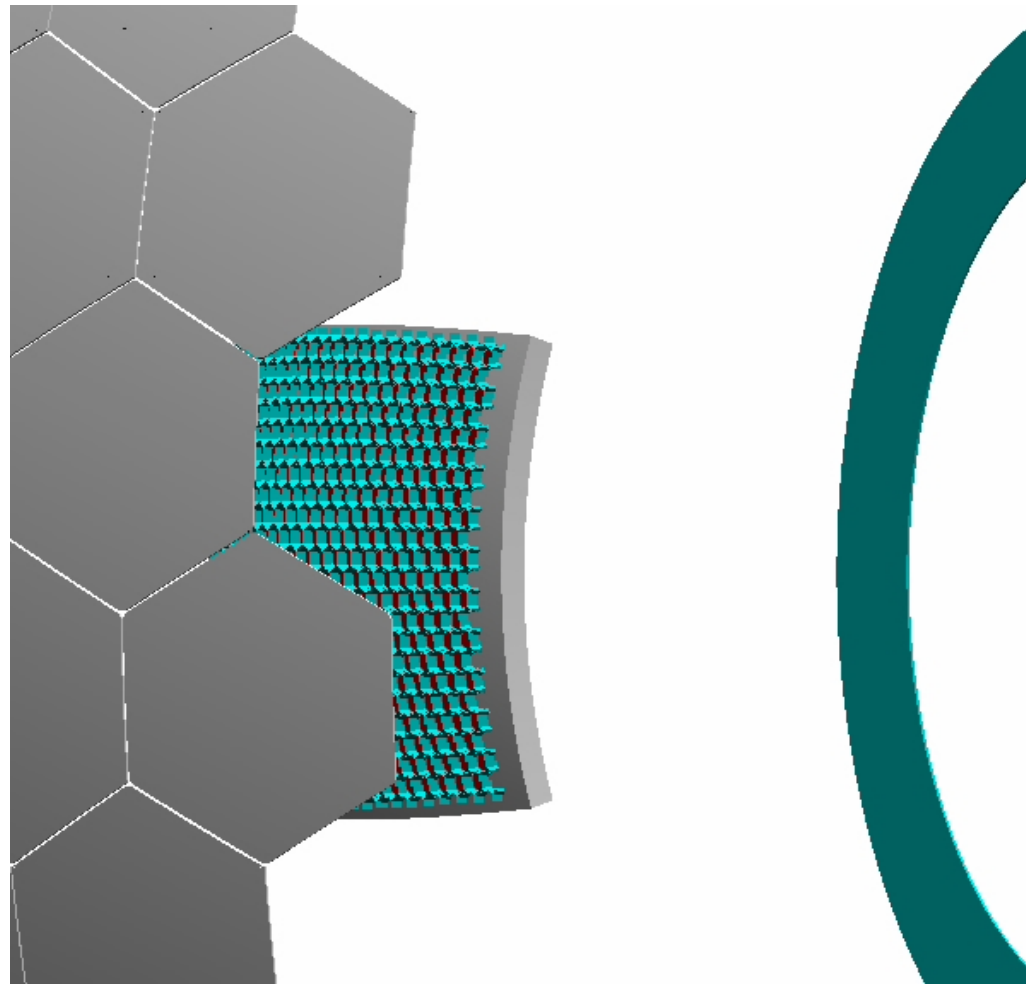


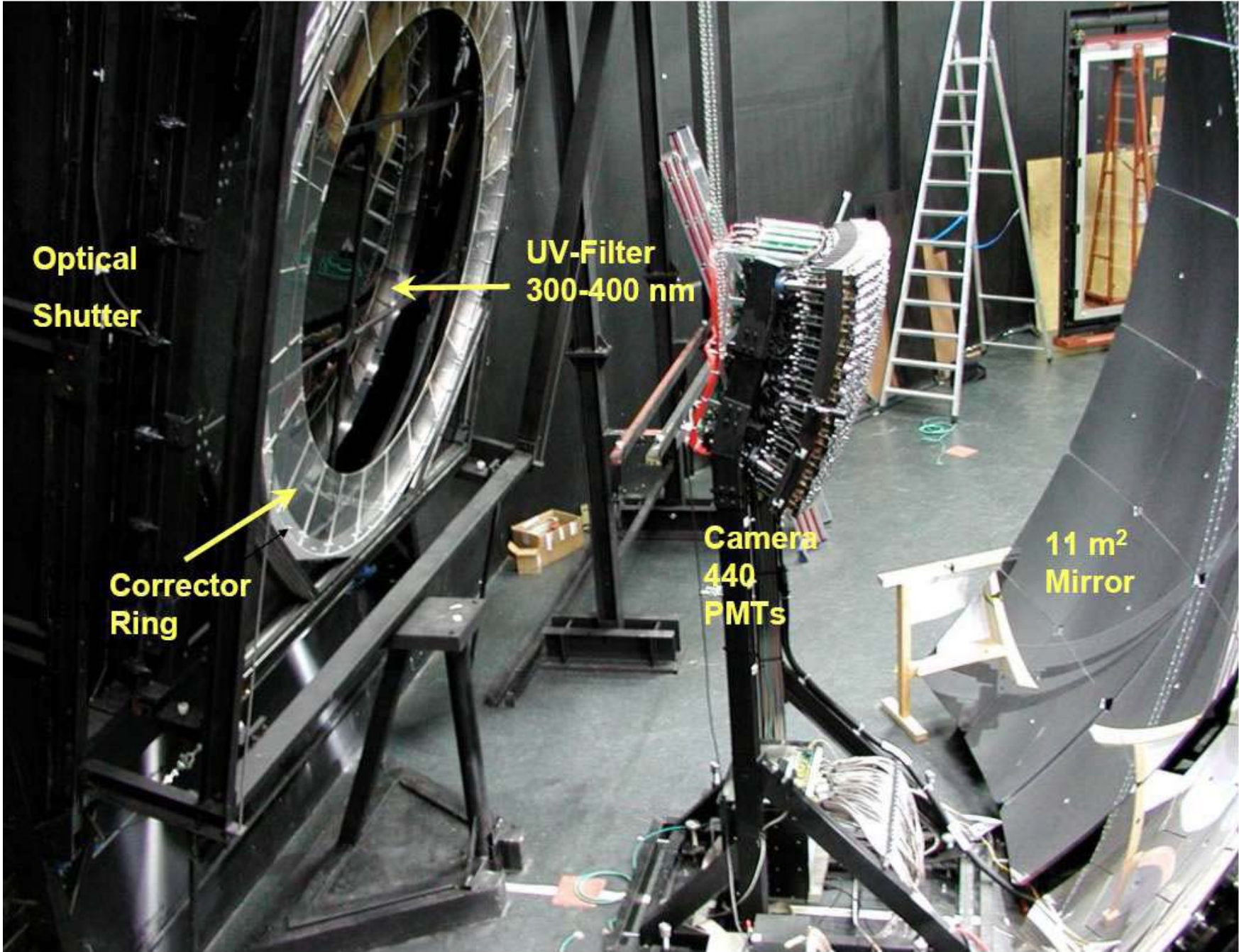
Assembled camera

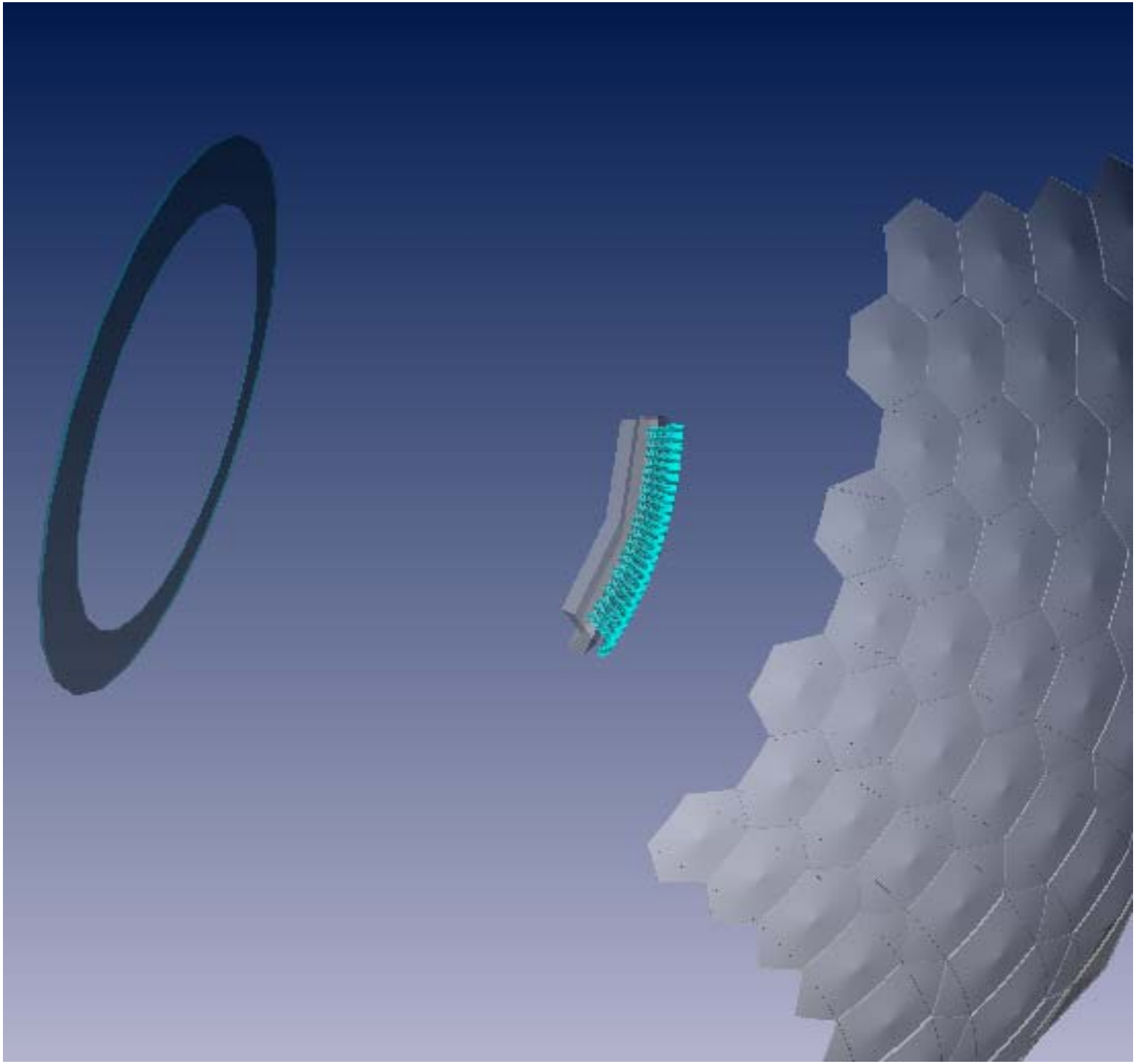


PMTs described as hexagonal volumes (shown in red) and defined as sensitive volumes.

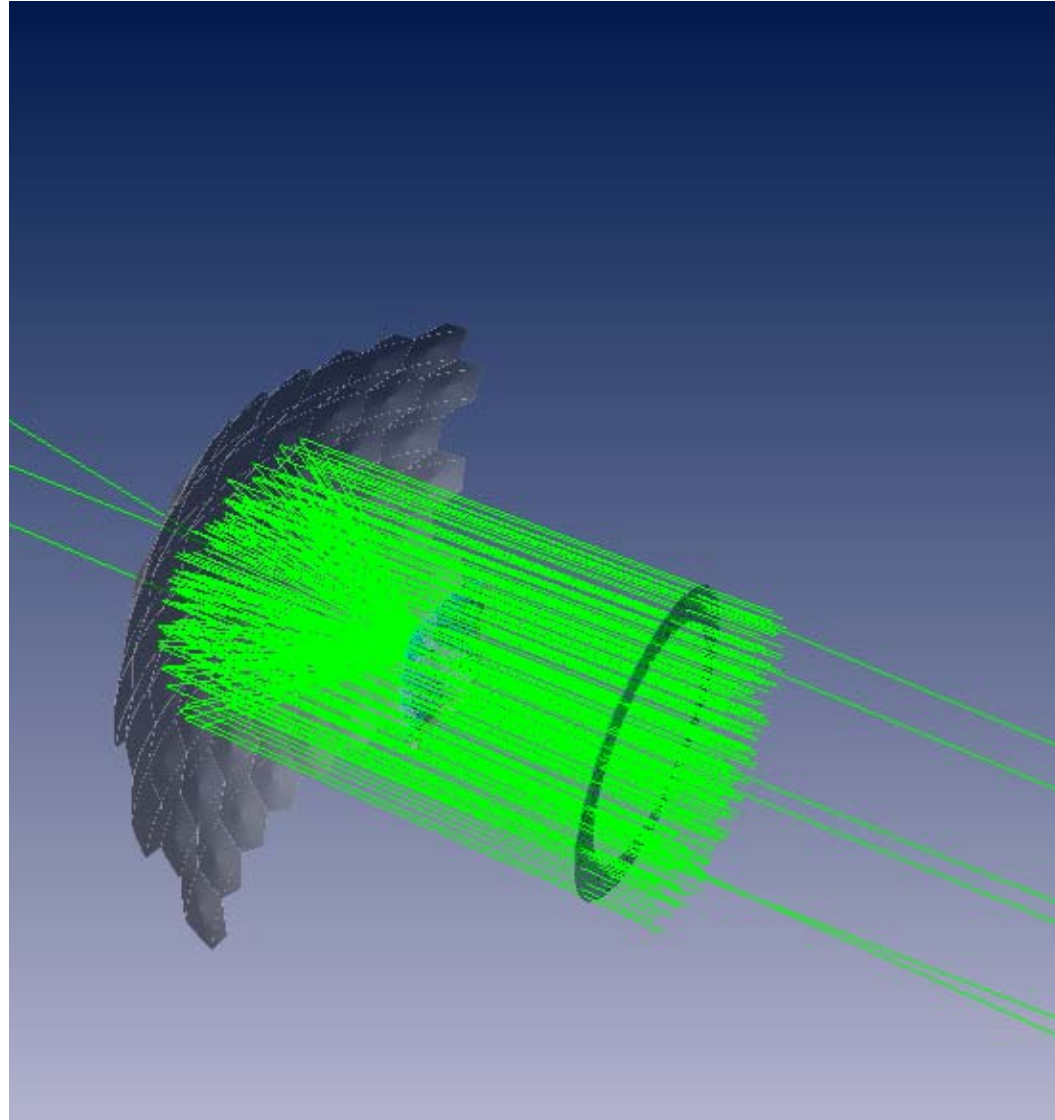
Assembled telescope

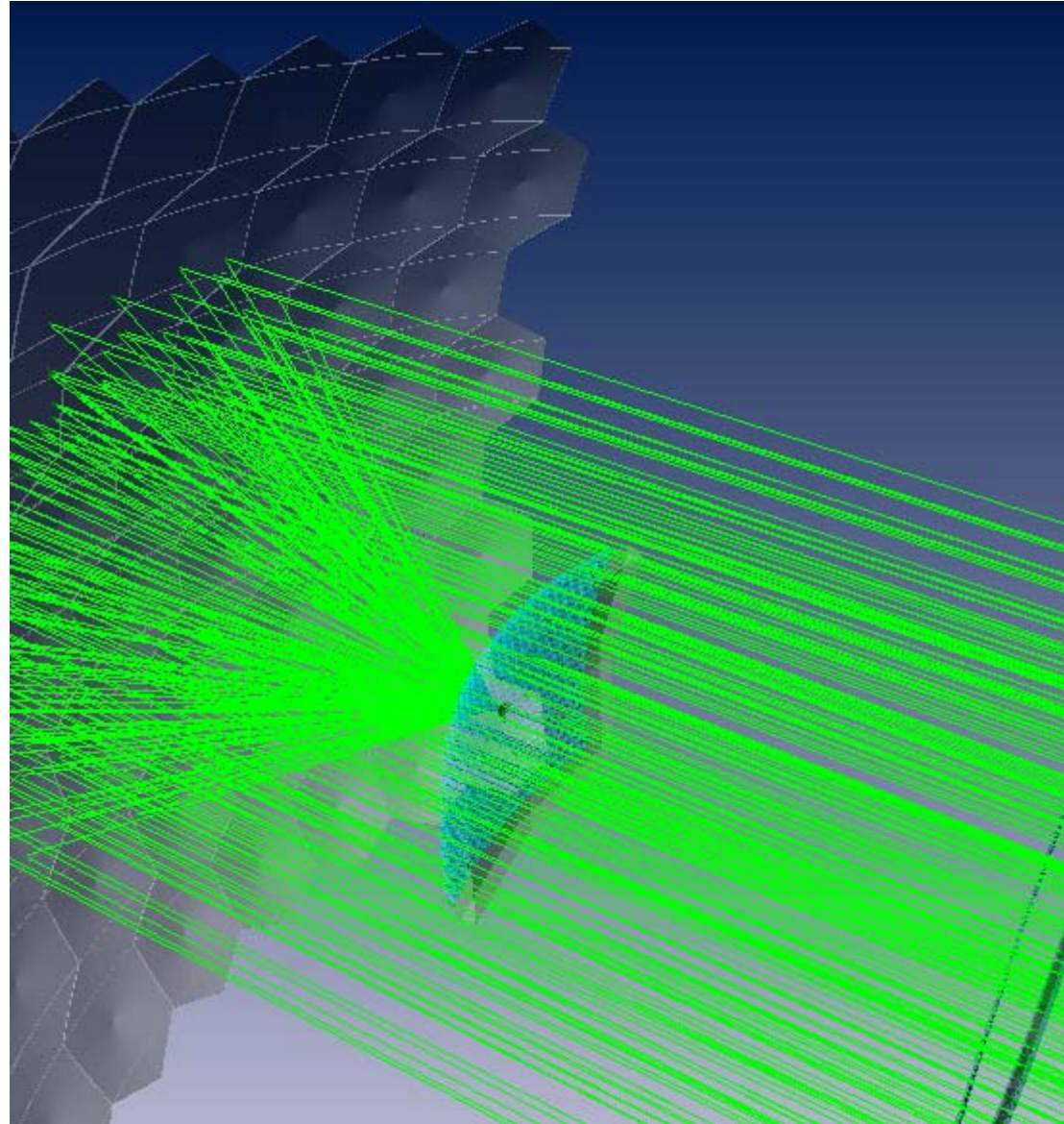


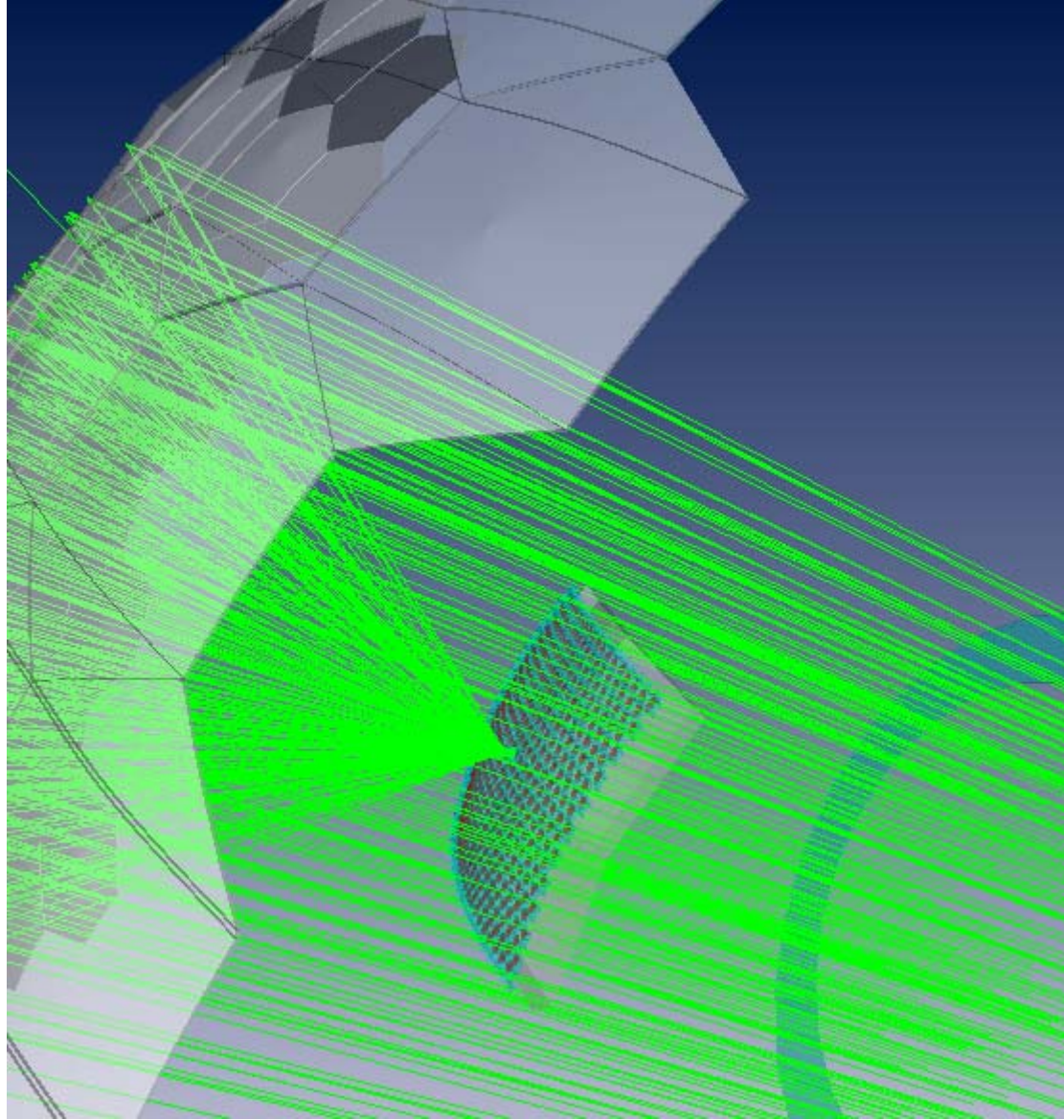




Seeing light...





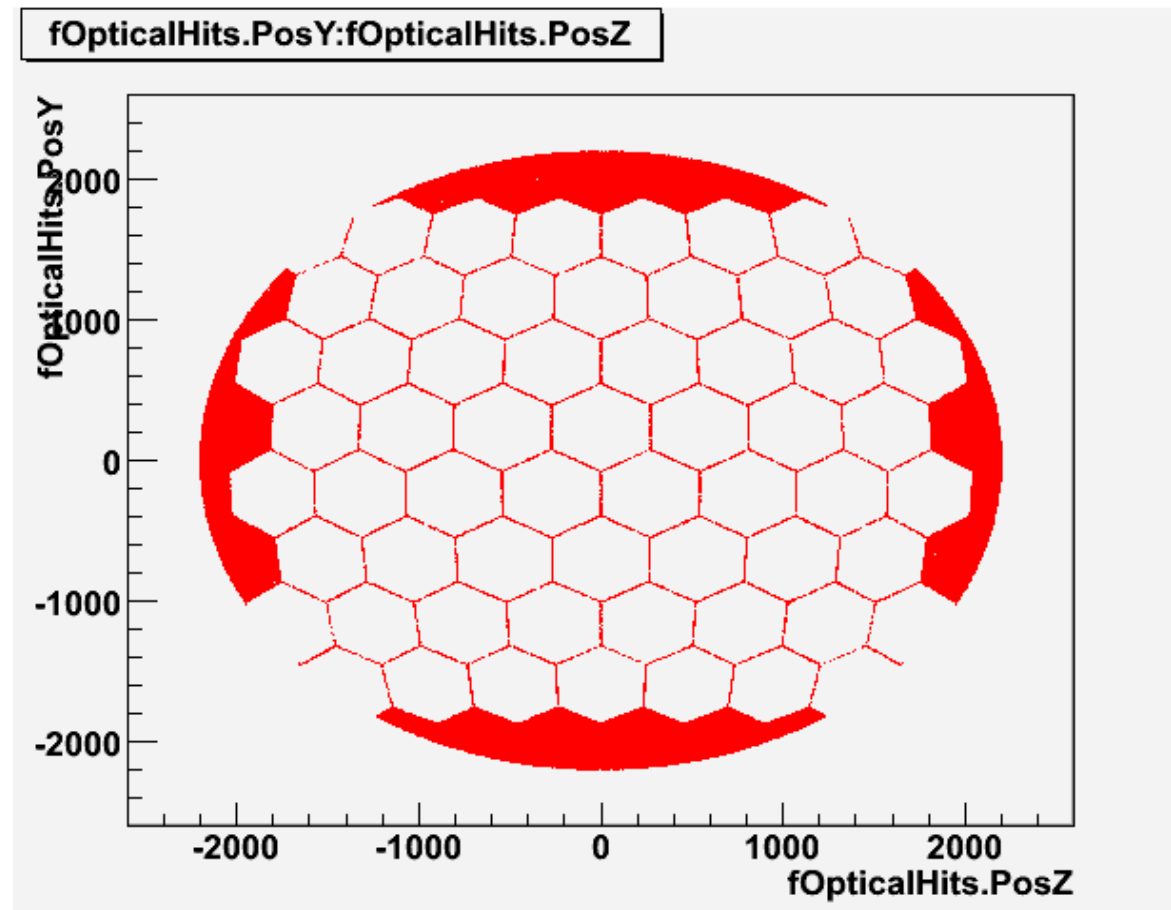


Some very preliminary results



Mirror “X-ray”

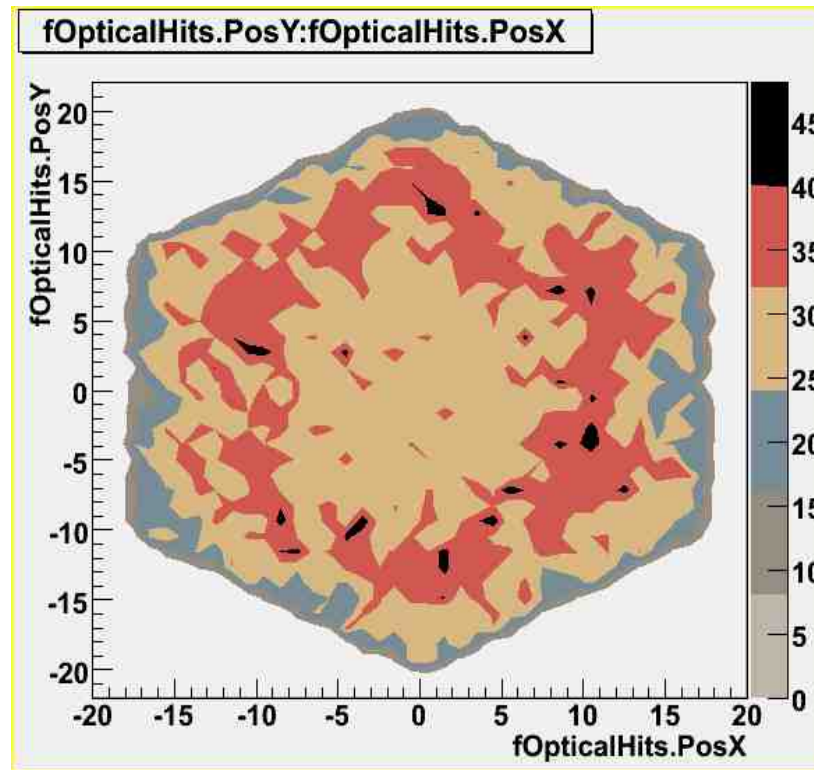
Uniform illumination of the mirror ($\theta=0^\circ$) ;
Photon positions detected behind the mirror.



Camera “X-ray”

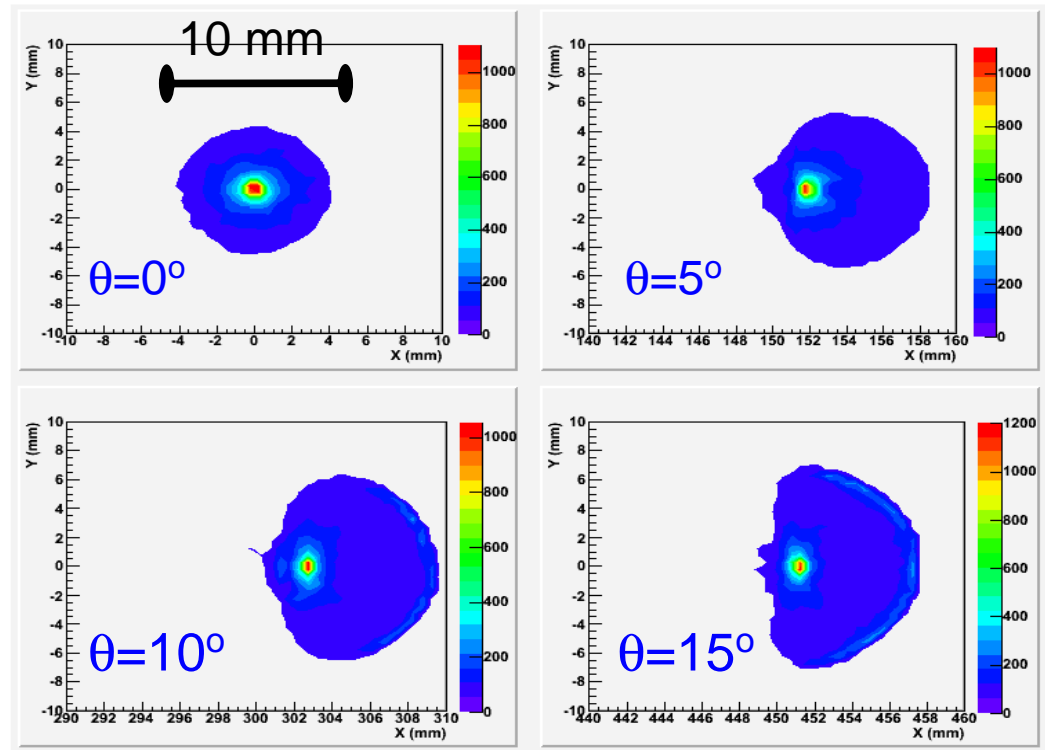
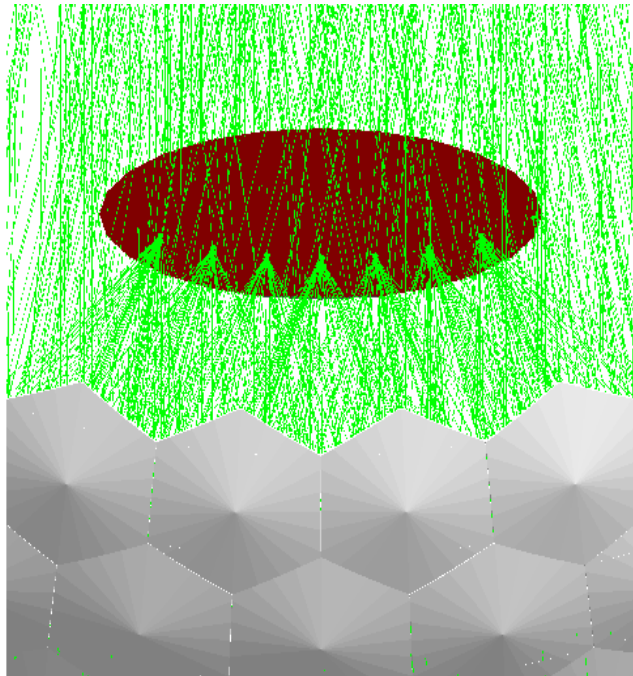
Uniform illumination of the camera ($\theta=0^\circ$);

Average photon distribution over the PMT surface:



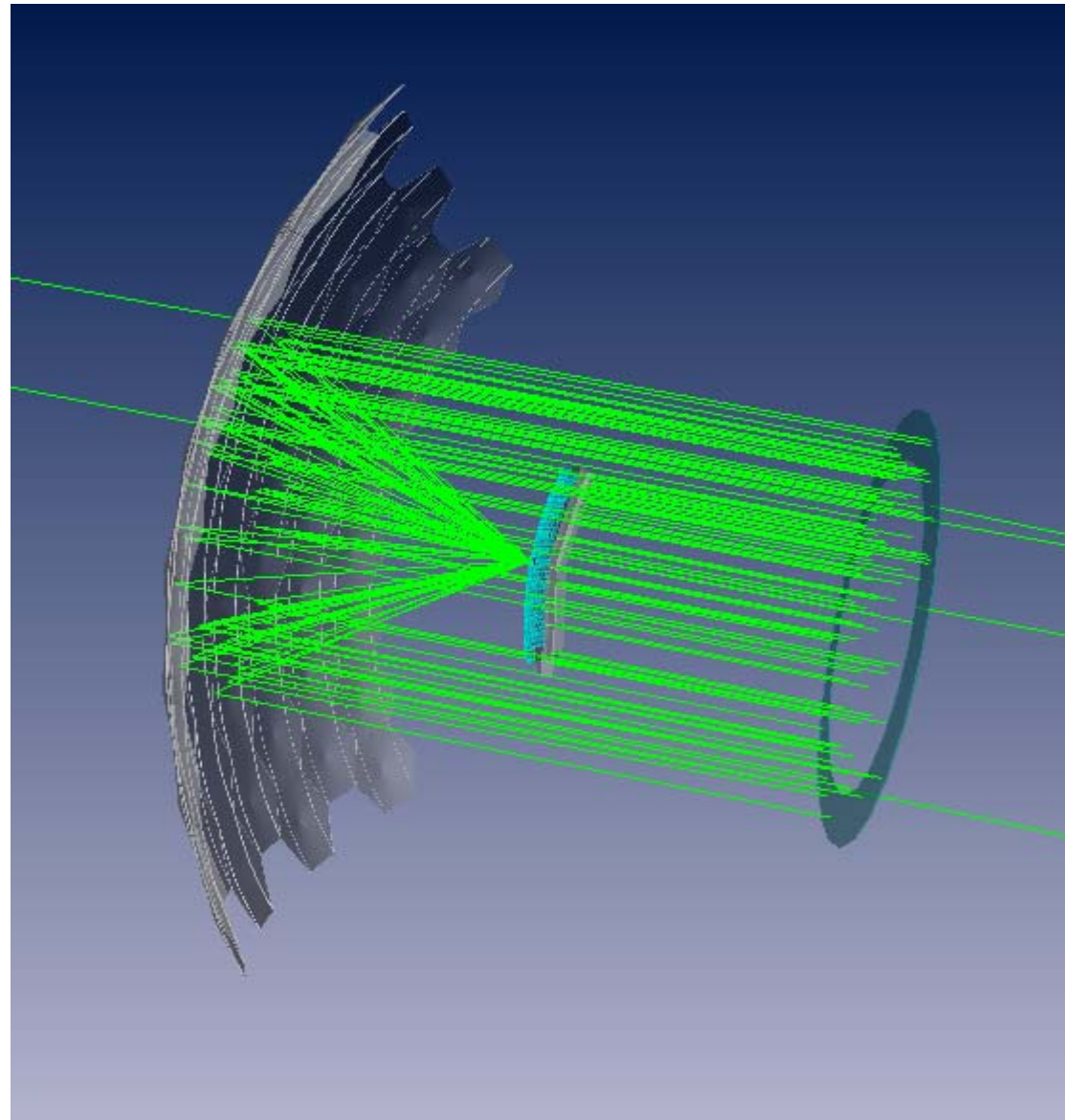
Effect of non-uniformities of photocathodes can be introduced in the simulation.

PSF vs theta – an example



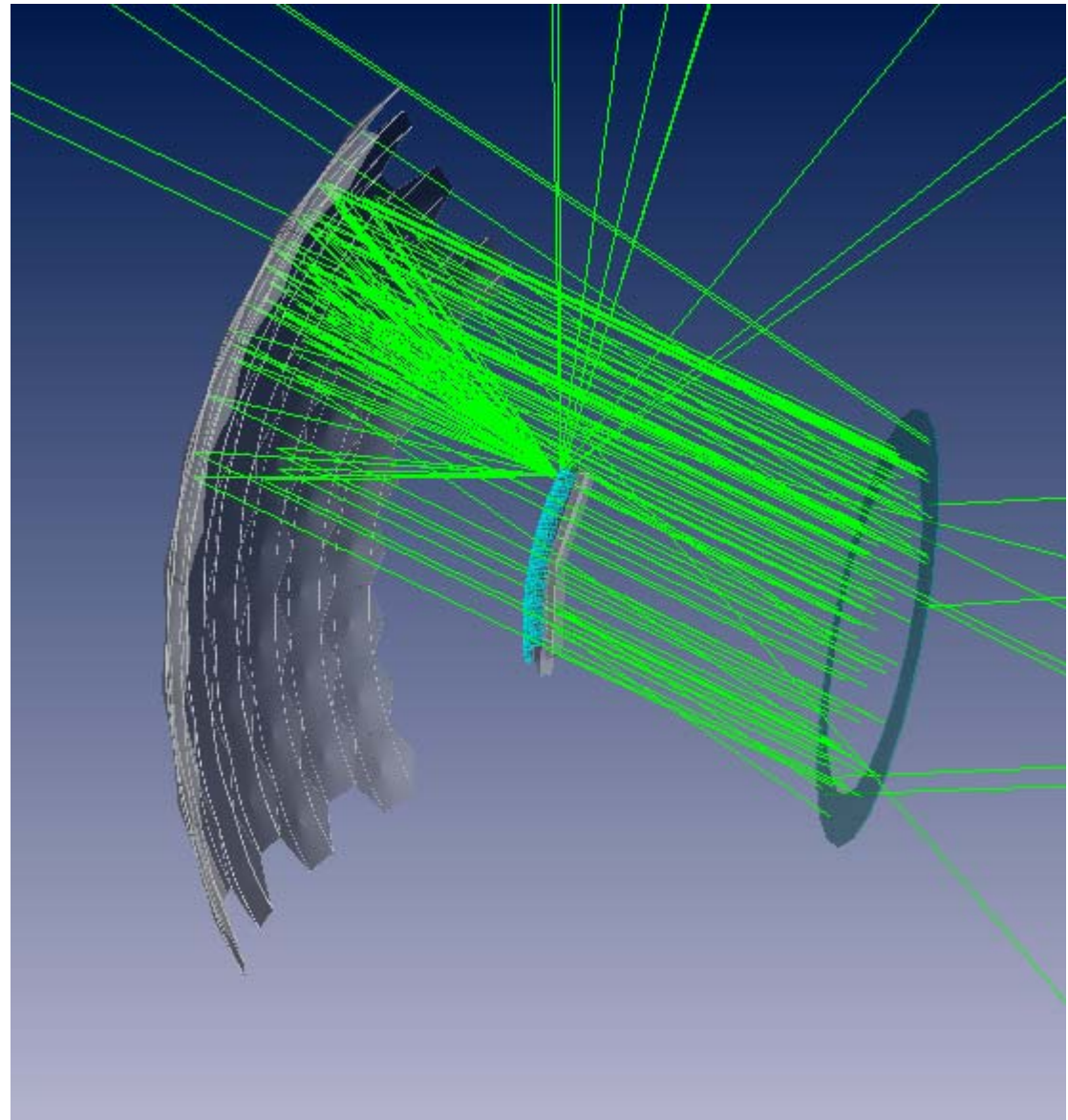
Direction Scans

$\Theta = 0^\circ$; $\Phi = 0^\circ$



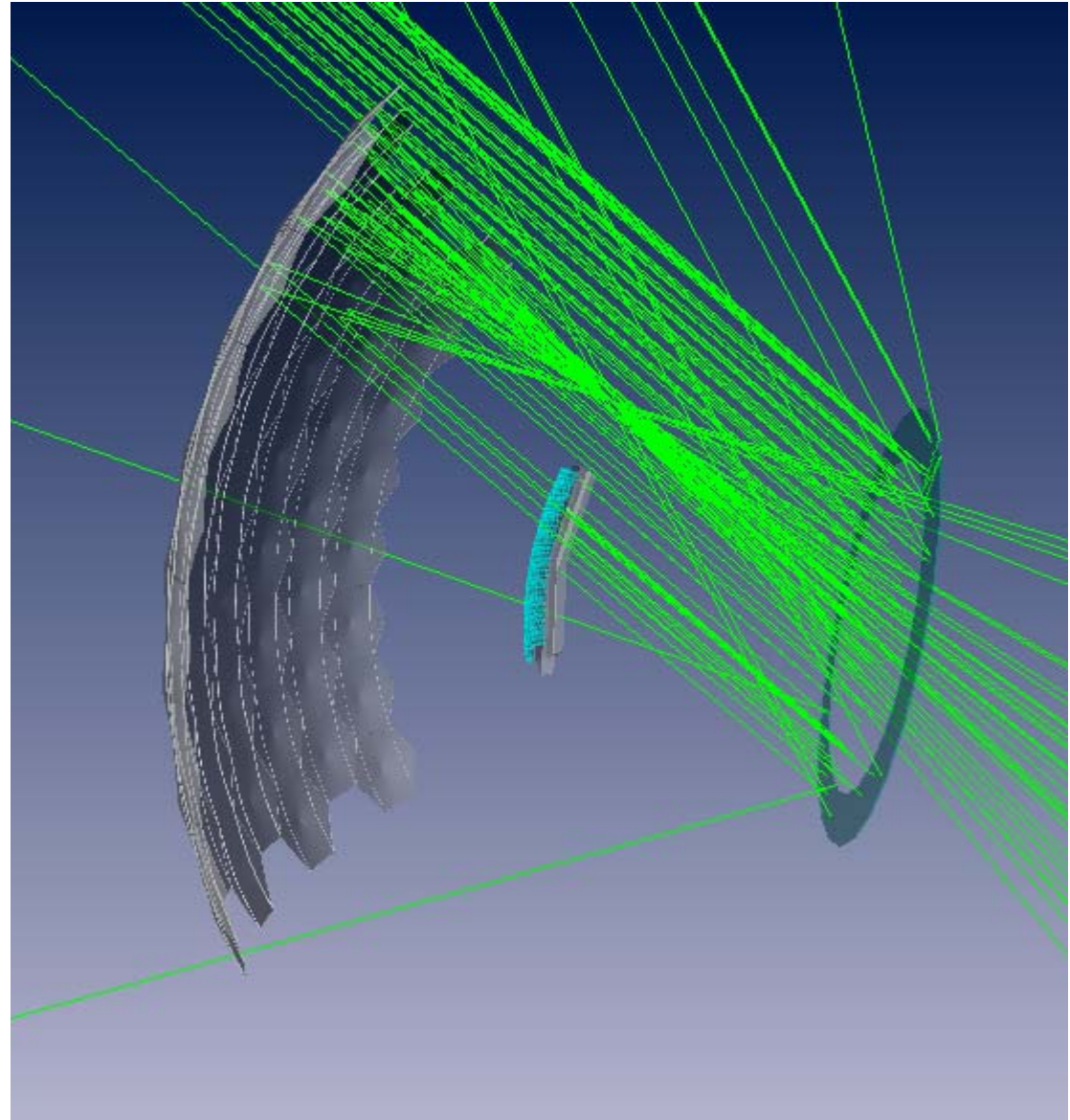
Direction Scans

Th=15°; Phi=0°



Direction Scans

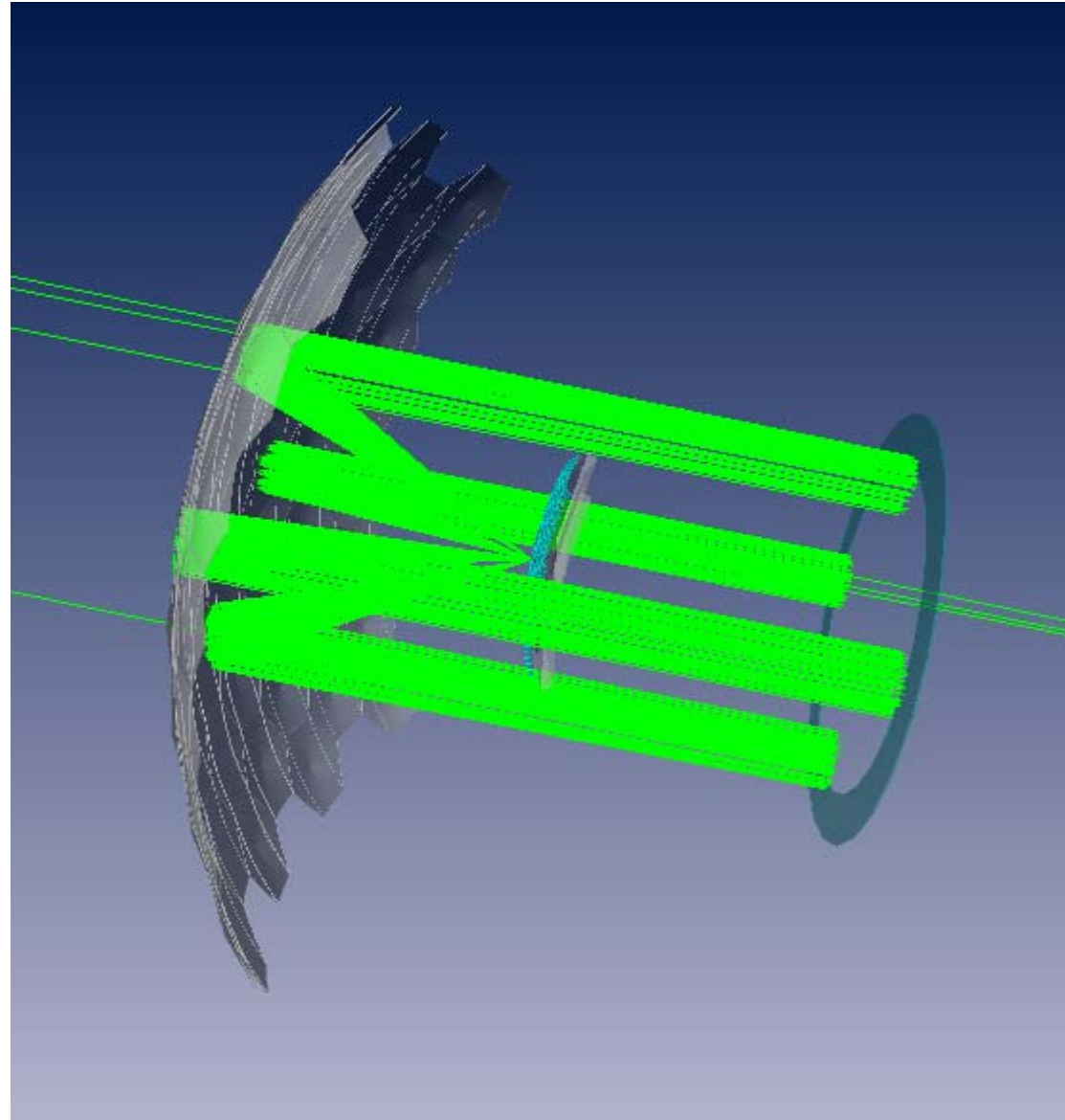
Th=30°; Phi=0°



Position Scans

Spots at
 $\Phi=0^\circ; 90^\circ; 180^\circ; 270^\circ$

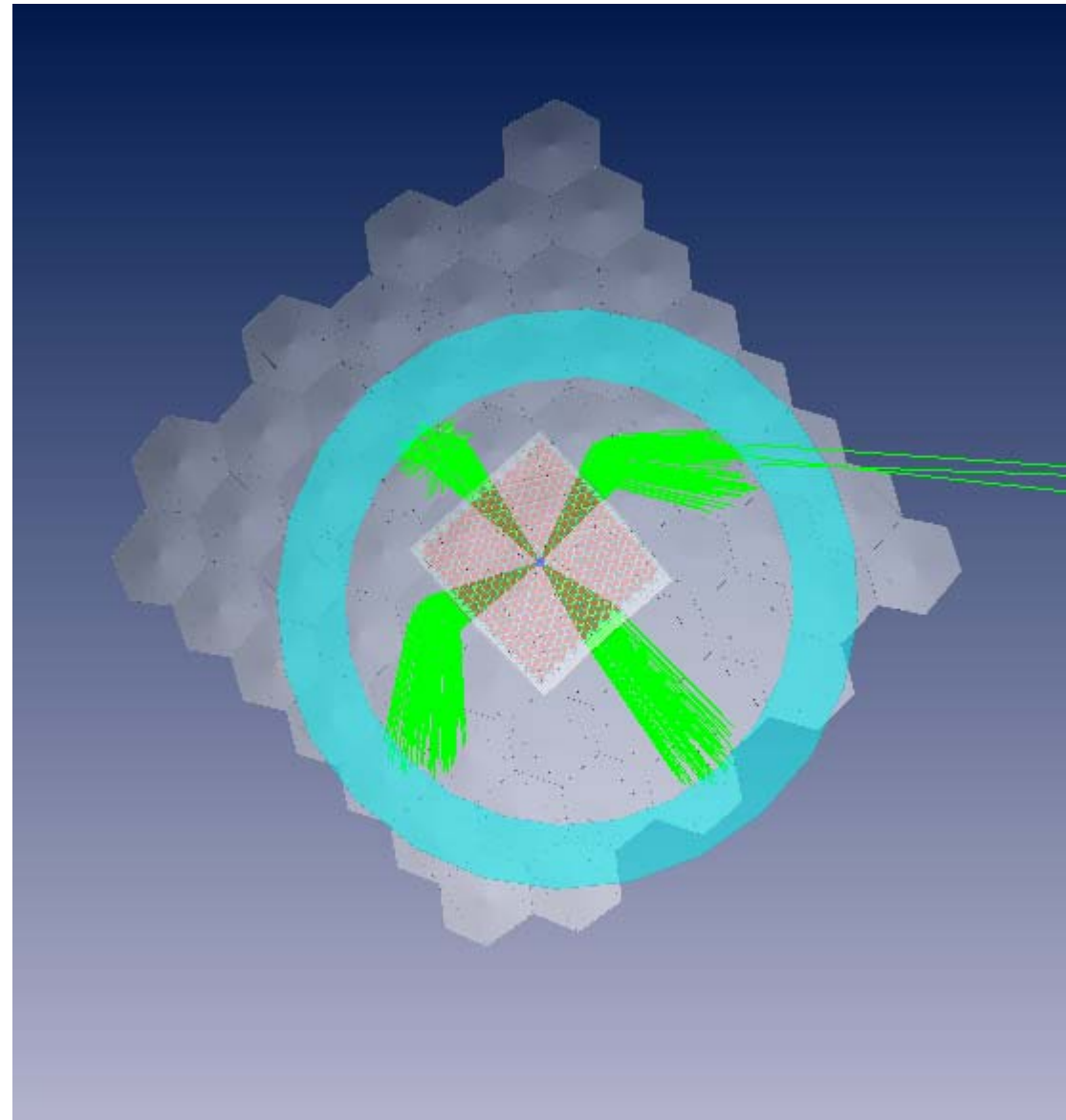
Photons direction:
 $\Theta=0^\circ; \Phi=0^\circ$



Position Scans

Spots at
 $\Phi=0^\circ; 90^\circ; 180^\circ; 270^\circ$

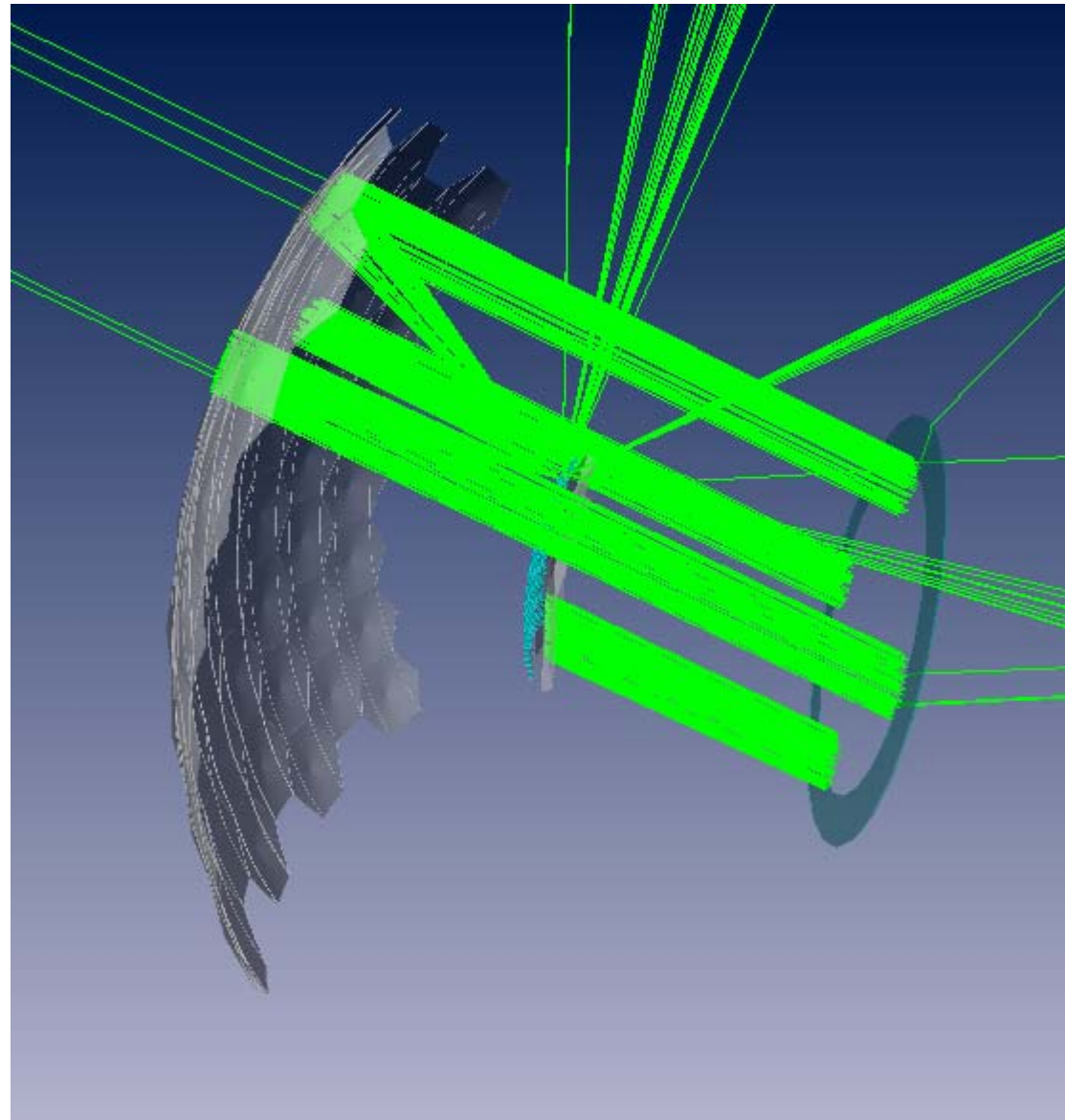
Photons direction:
 $\Theta=0^\circ; \Phi=0^\circ$



Position Scans

Spots at
 $\Phi=0^\circ; 90^\circ; 180^\circ; 270^\circ$

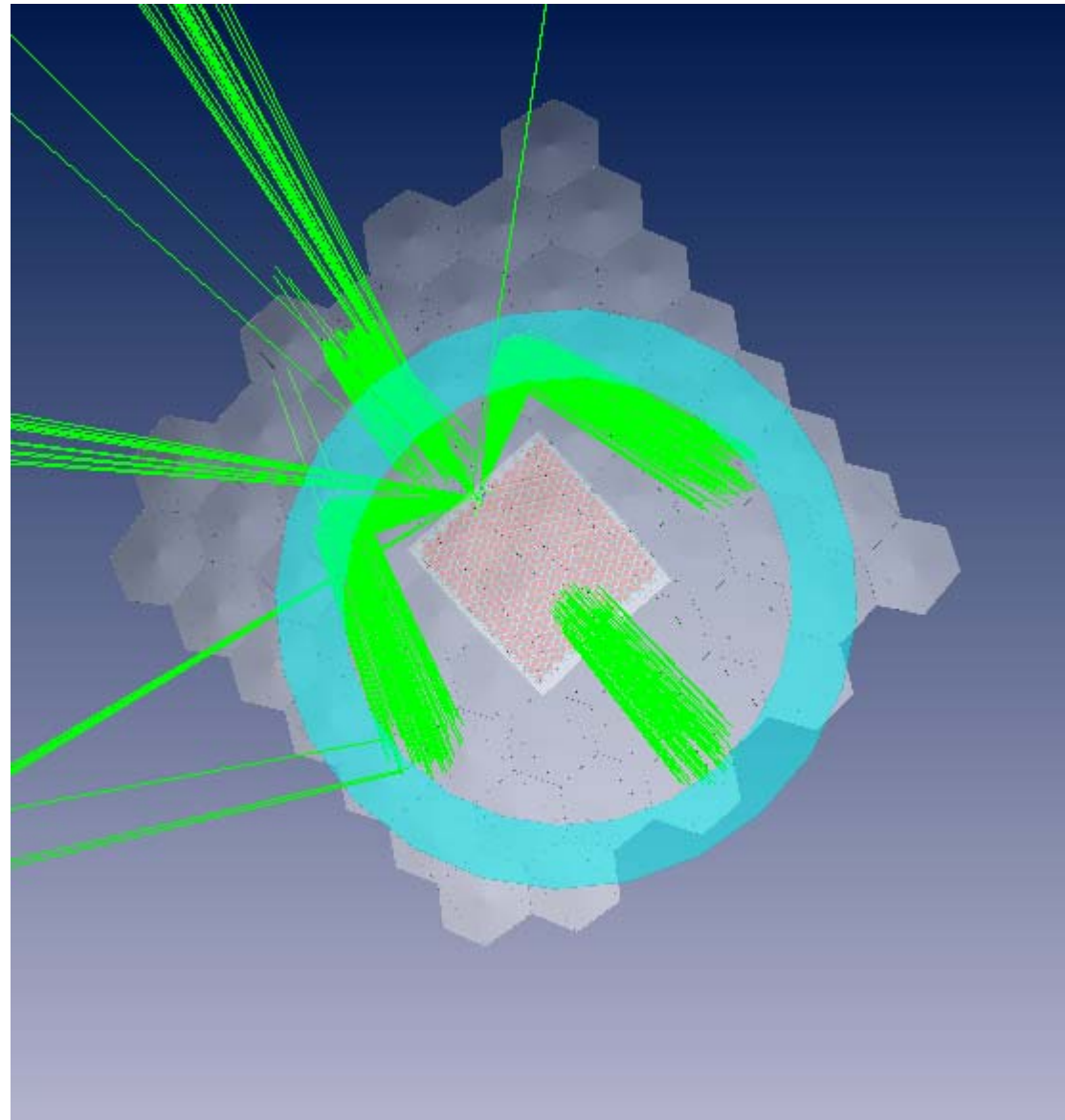
Photons direction:
 $\Theta=15^\circ; \Phi=0^\circ$



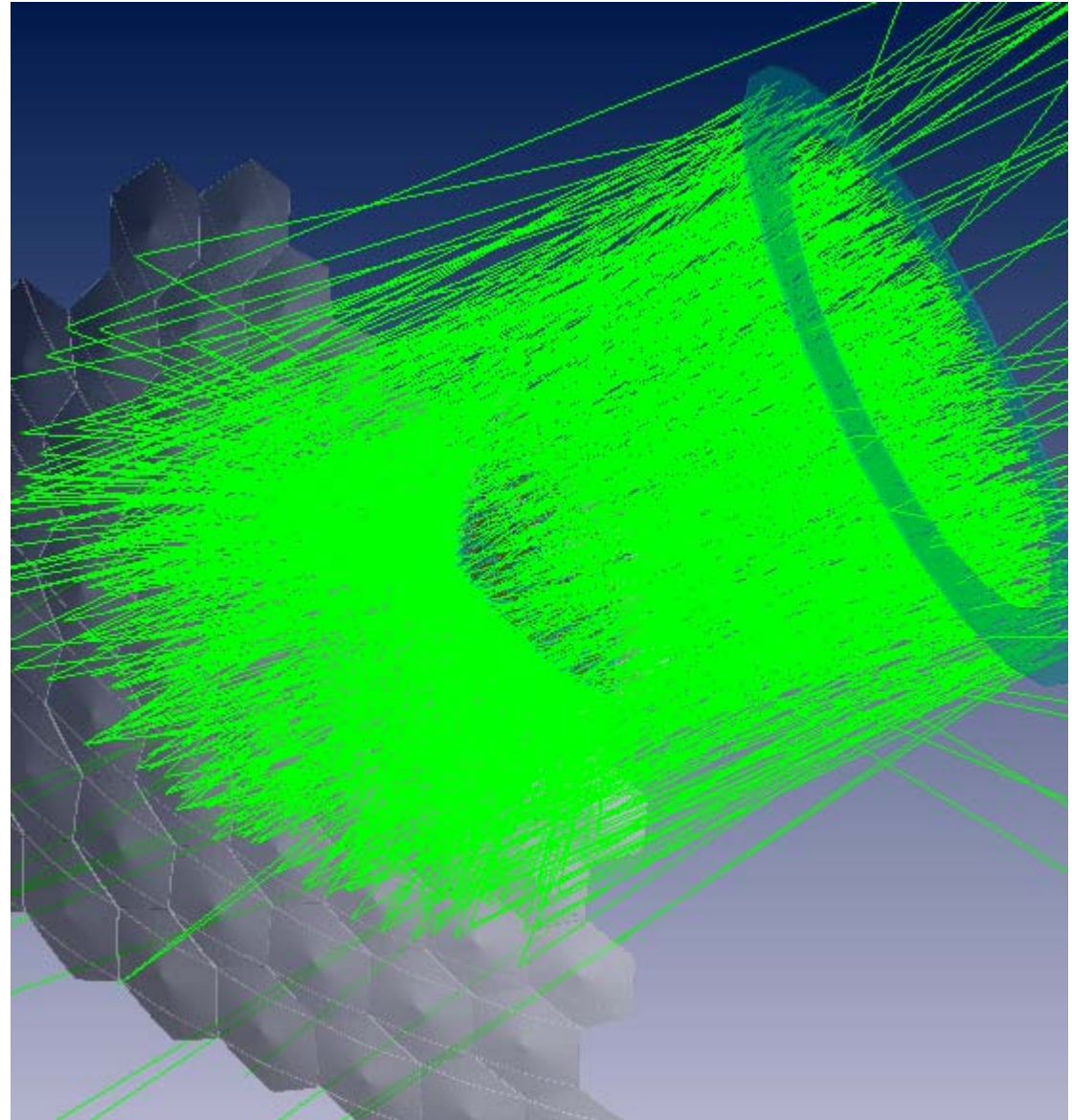
Position Scans

Spots at
 $\Phi=0^\circ; 90^\circ; 180^\circ; 270^\circ$

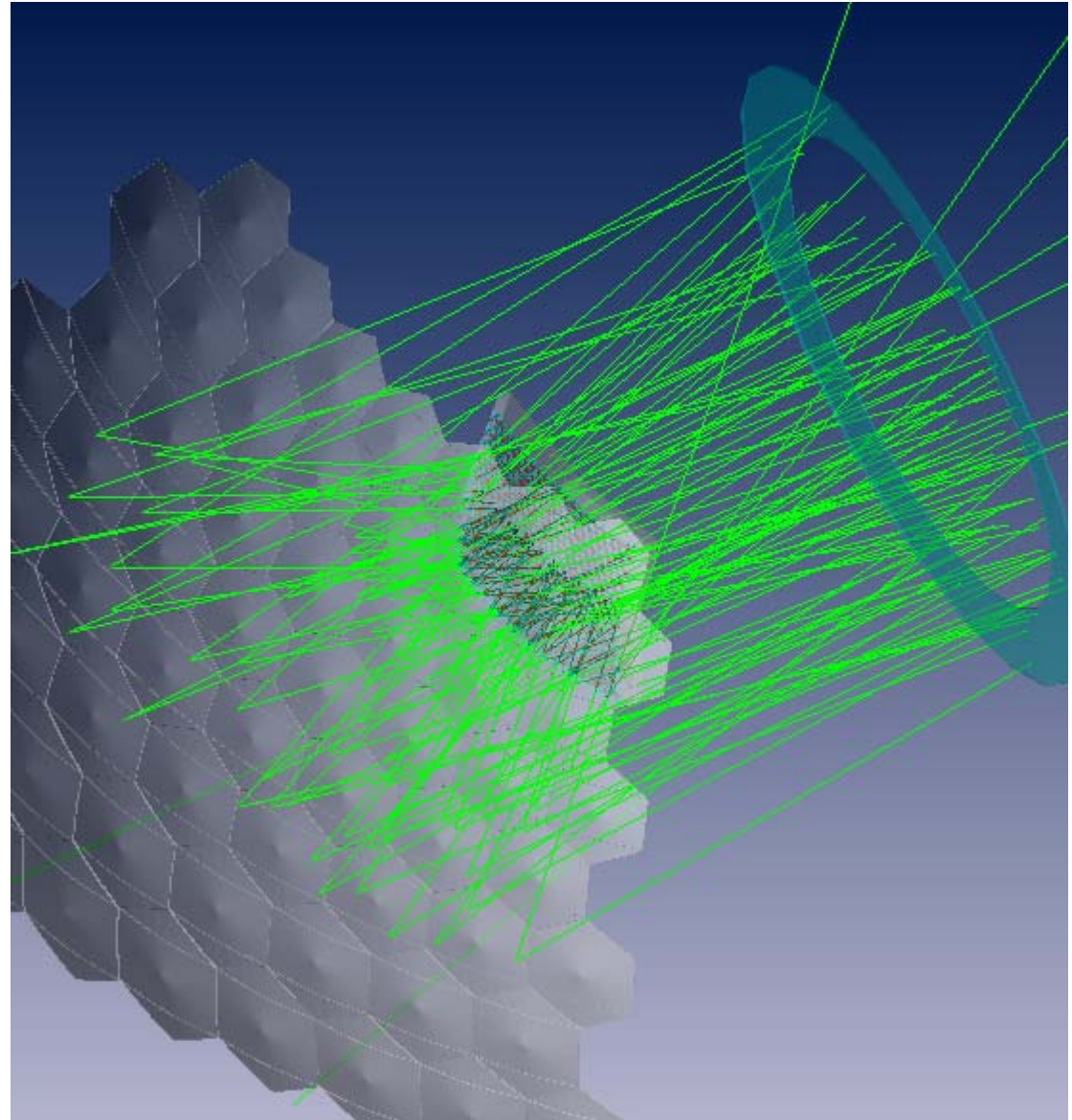
Photons direction:
 $\Theta=0^\circ; \Phi=0^\circ$



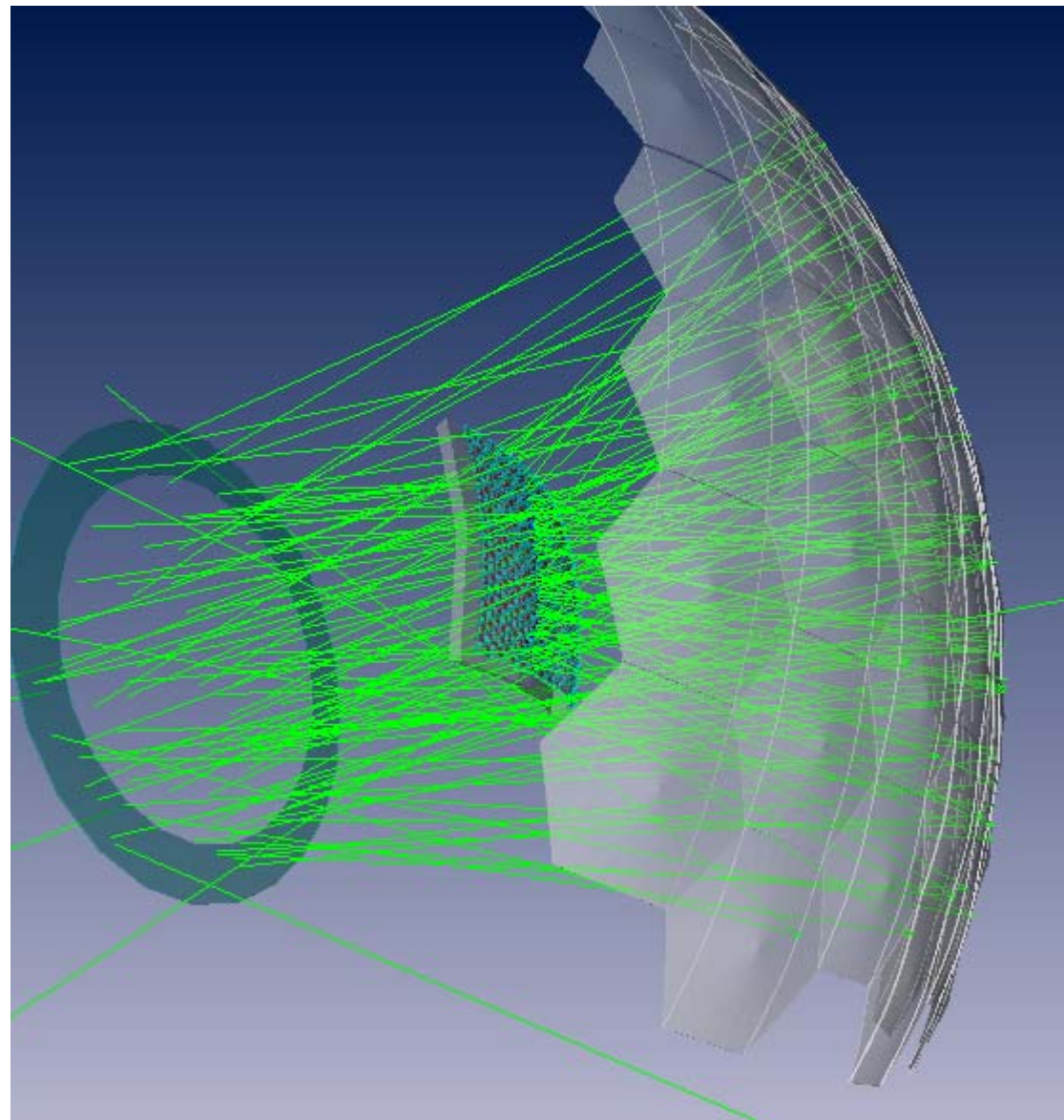
A SHOWER... 1000 Photons



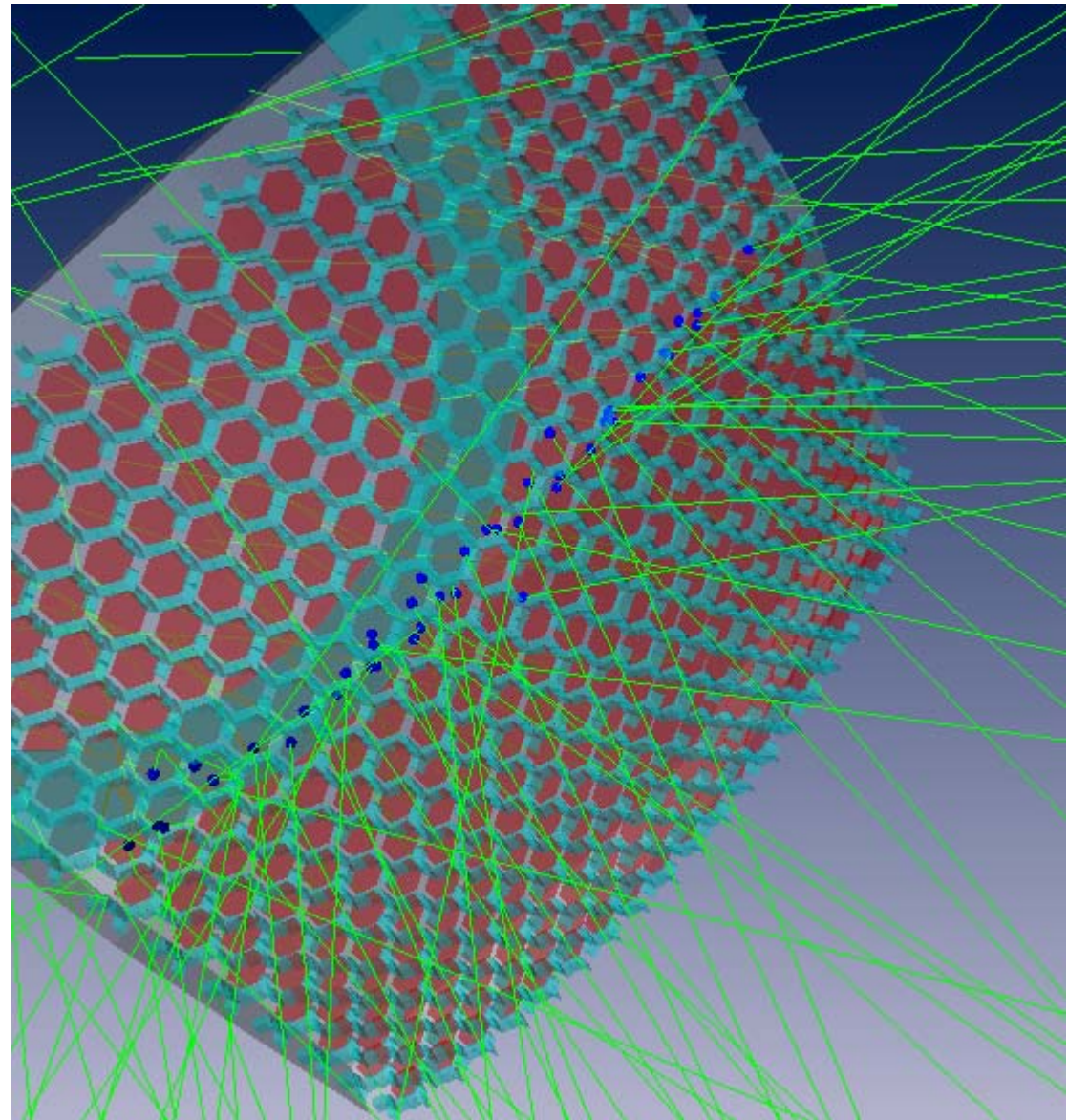
A SHOWER... 100 Photons



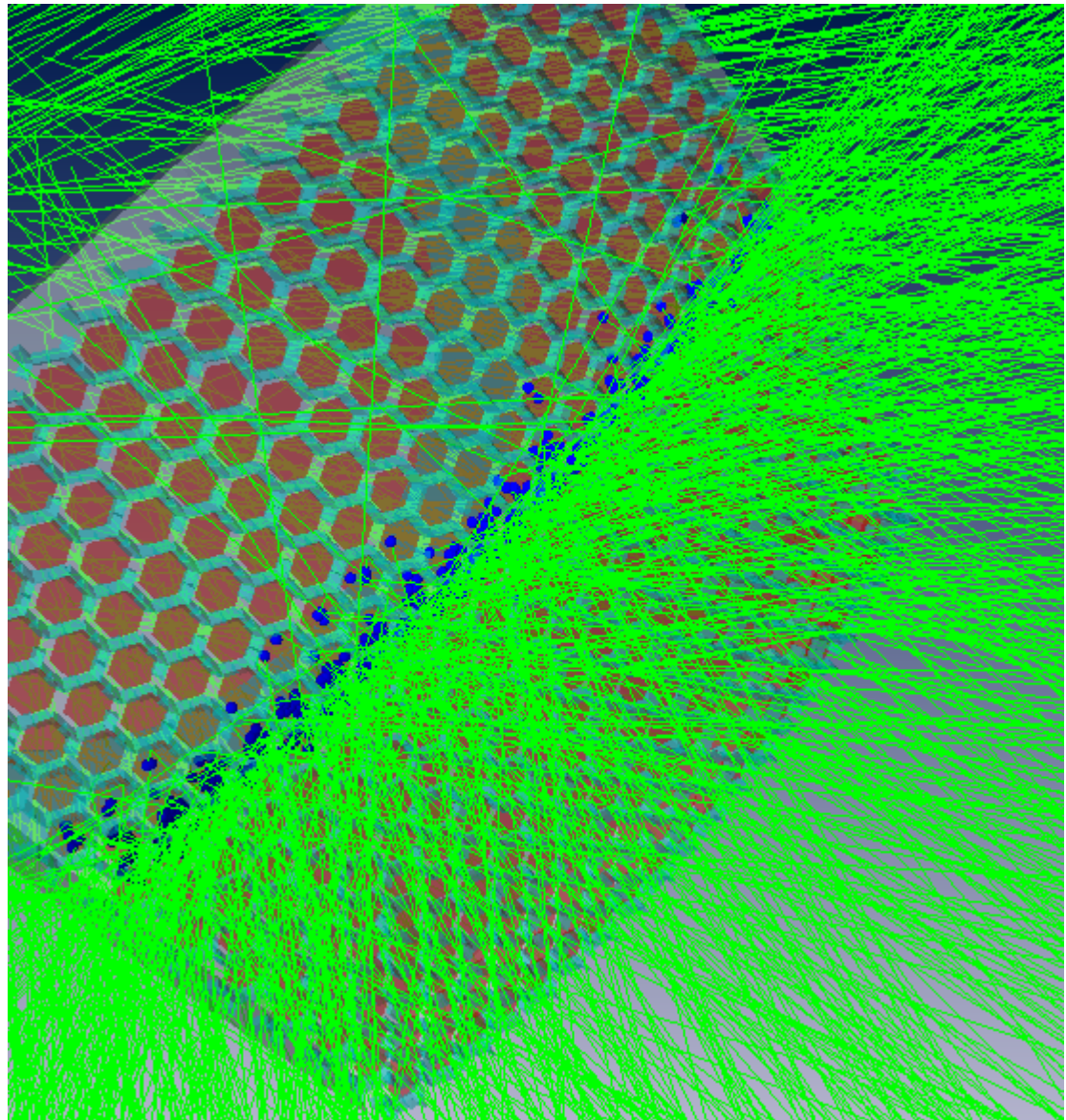
A SHOWER... 100 Photons



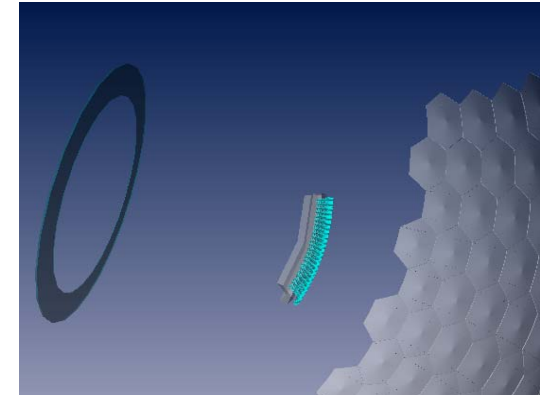
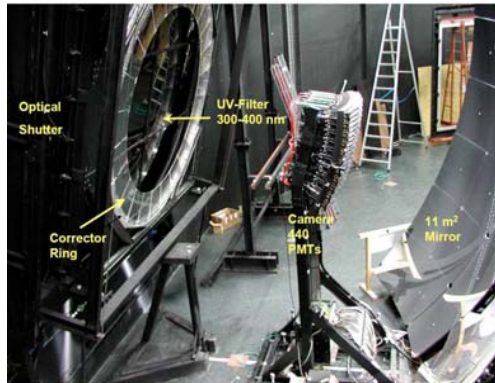
A SHOWER... 100 Photons



A SHOWER... 1000 Photons



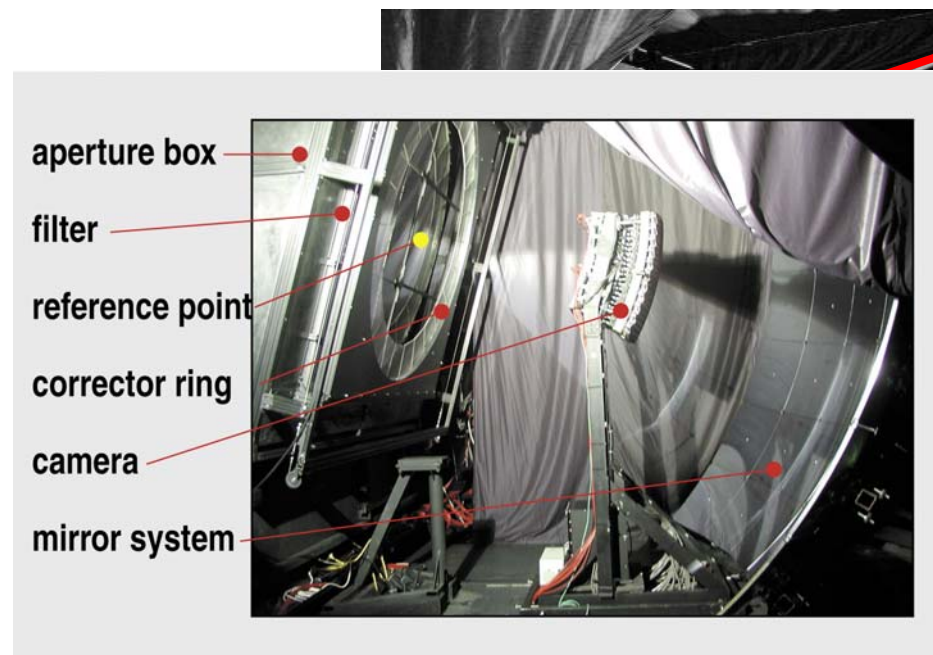
Summary



- ✓ A full Geant4-based simulation of the Auger fluorescence detectors was developed;
- ✓ Integration in the Auger simulation chain is being carried;
- ✓ Detailed comparisons with the ray-tracing software will be performed.

Optics of Auger Fluorescence

Schmidt optics telescope. Detectors



Mirror:
f/1 spherical mirror ;
3.5 m x 3.5 m;
PSF = 0.5° .

Camera:
440 hexagonal pixels/PMT's;
 $1.5^\circ \times 1.5^\circ$ pixel FOV;
Spherical focal surface.

- Full Geant4 simulation will be implemented at LIP.
- Other LIP activities:
 - Reconstruction and analysis of the Fluorescence Detectors data;