

# Geant4 Simulation of the Pierre Auger Fluorescence Detector

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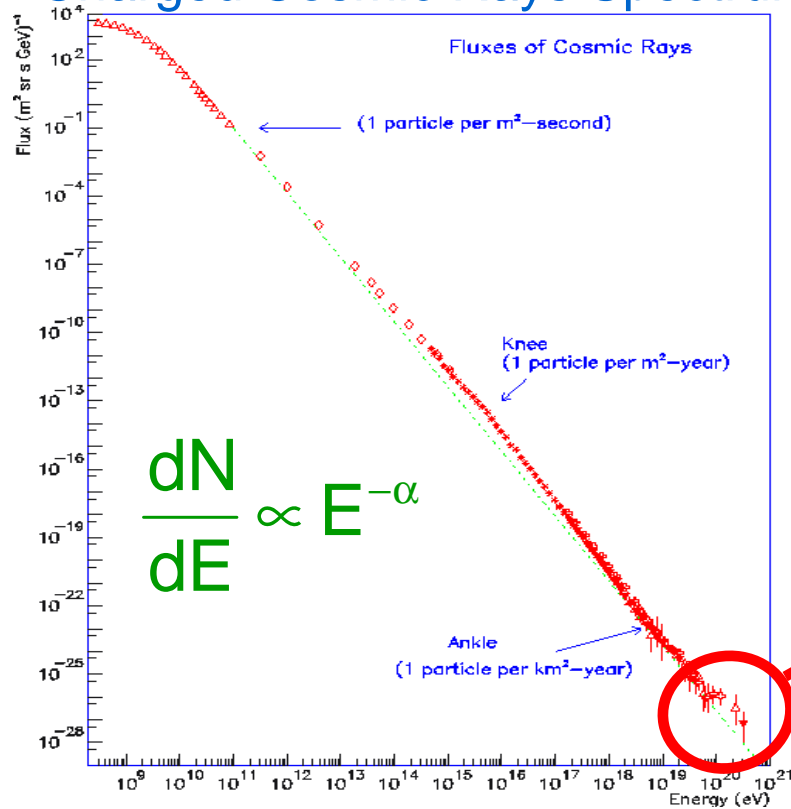
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LIP - Lisboa & IST - Lisboa

# Ultra High Energy Cosmic Rays (UHECR)

## Charged Cosmic Rays Spectrum



Many questions:

Sources ? Acceleration mechanisms ?

GZK cutoff ?

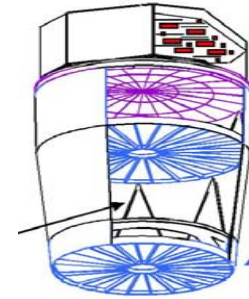
Same physics laws ?

$E > 10^{20}$  eV !

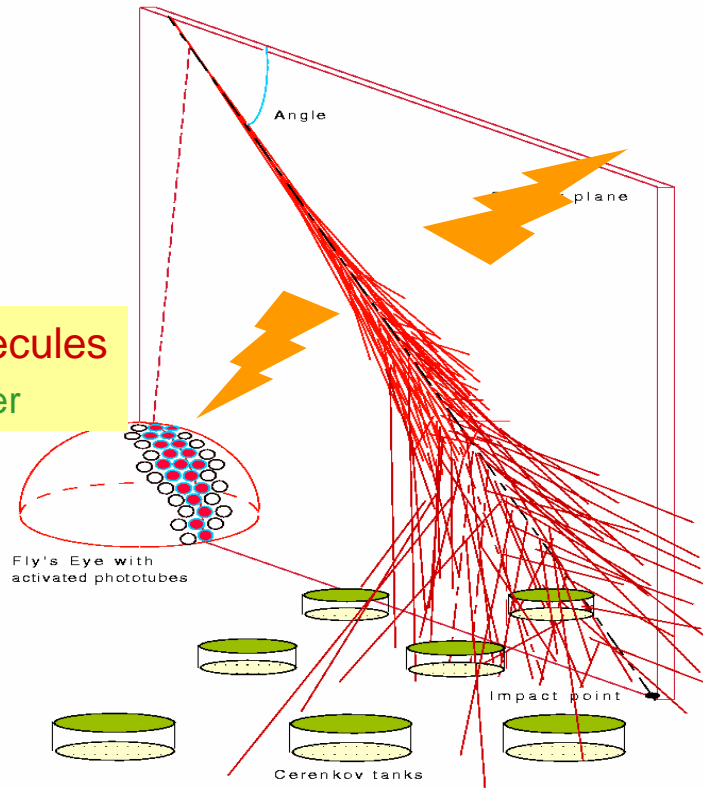
# UHECR detection

## 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

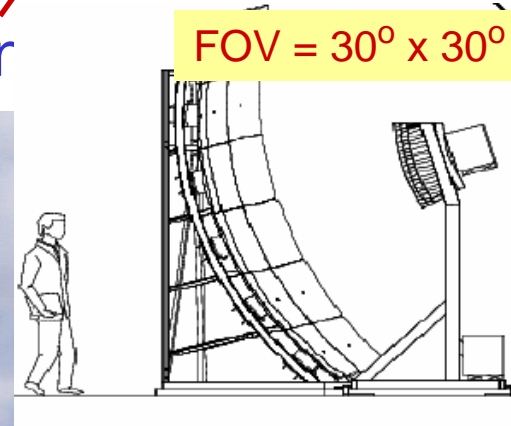
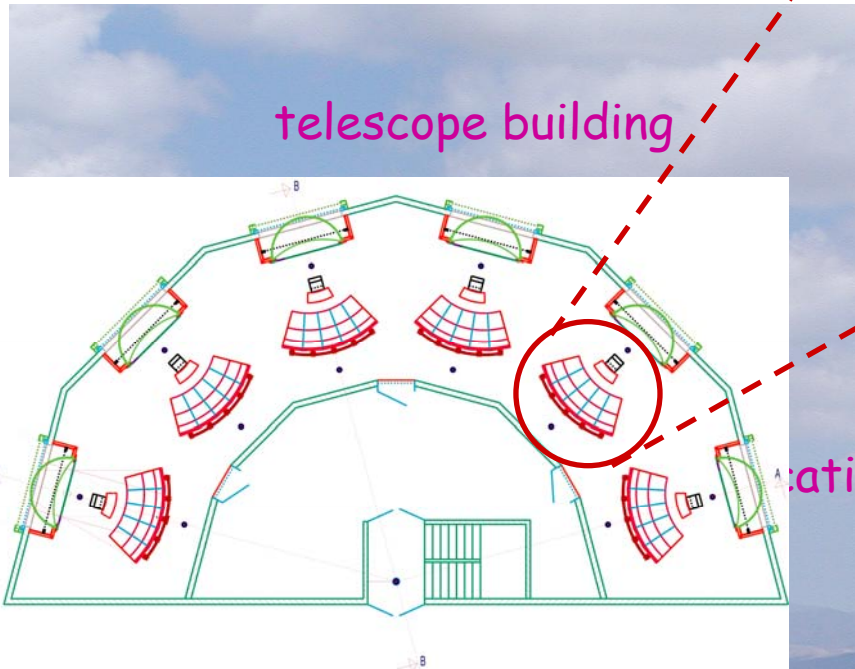


Direct detection of shower particles  
Scintillators, Cherenkov radiators (e.g. water),...

# The Southern Pierre Auger Observatory



- A giant hybrid detector in Argentina



ay  
or stations;  
sing;

ectors  
ch;

# Schmidt optics

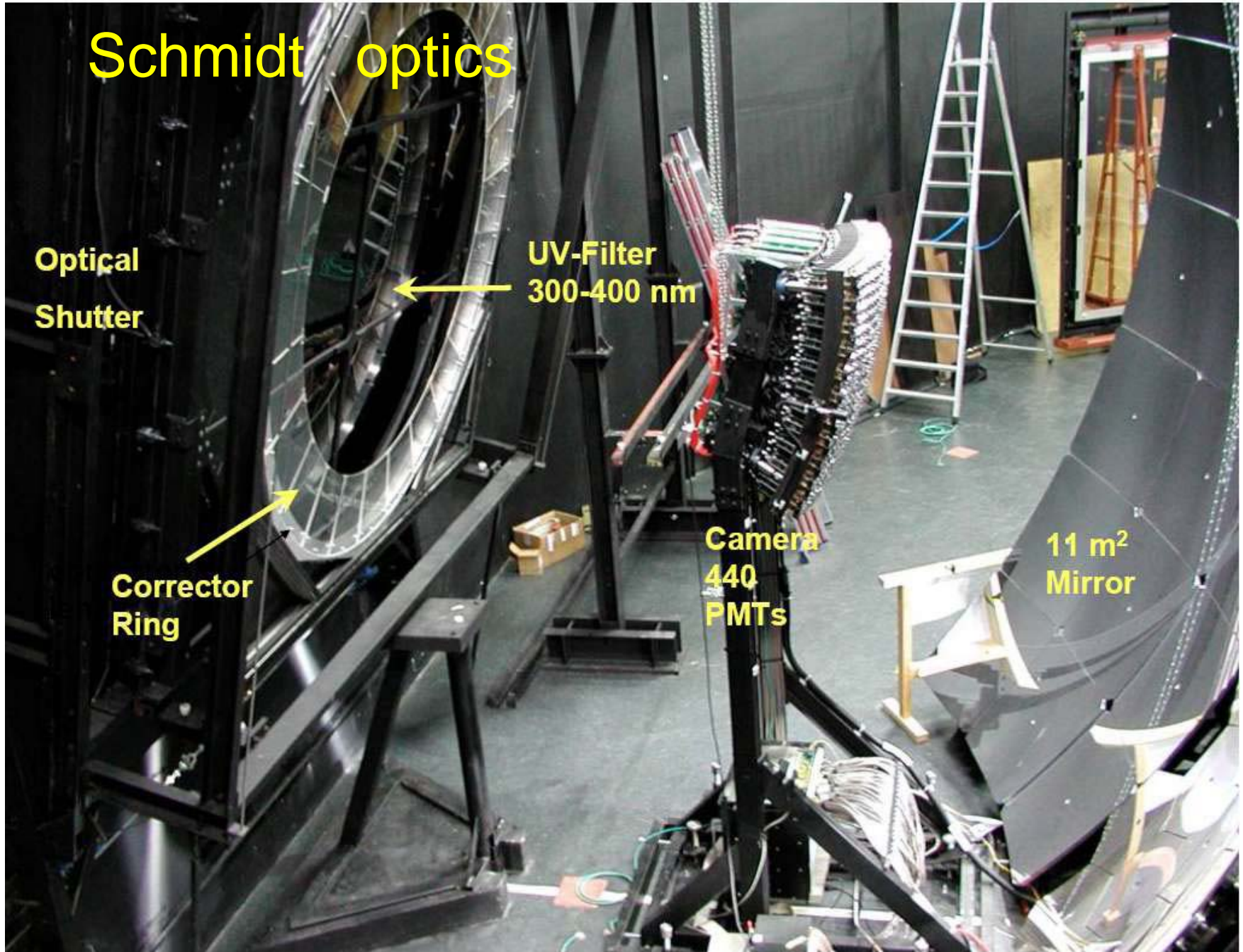
Optical  
Shutter

UV-Filter  
300-400 nm

Corrector  
Ring

Camera  
440  
PMTs

11 m<sup>2</sup>  
Mirror

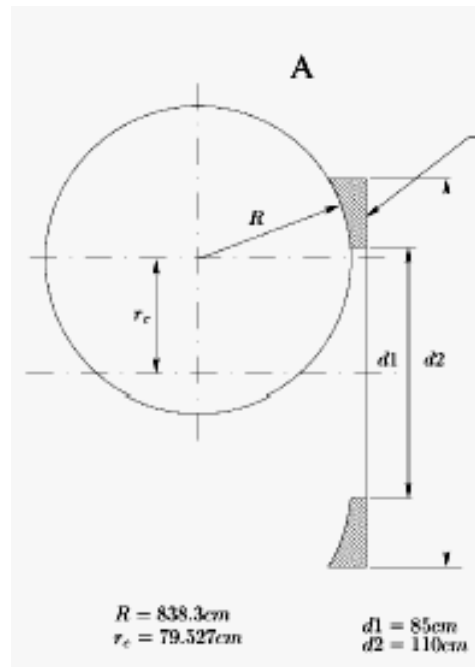


# Corrector ring

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

No significant degradation of optics performance.

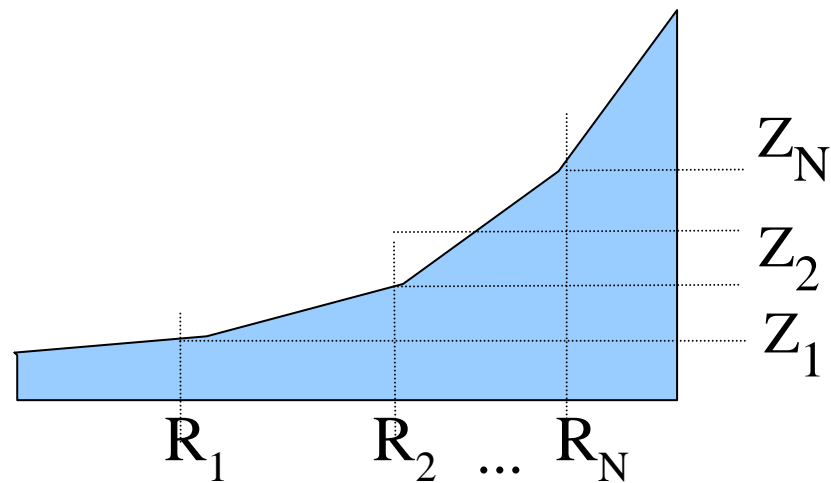
## Toroidal profile



# 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



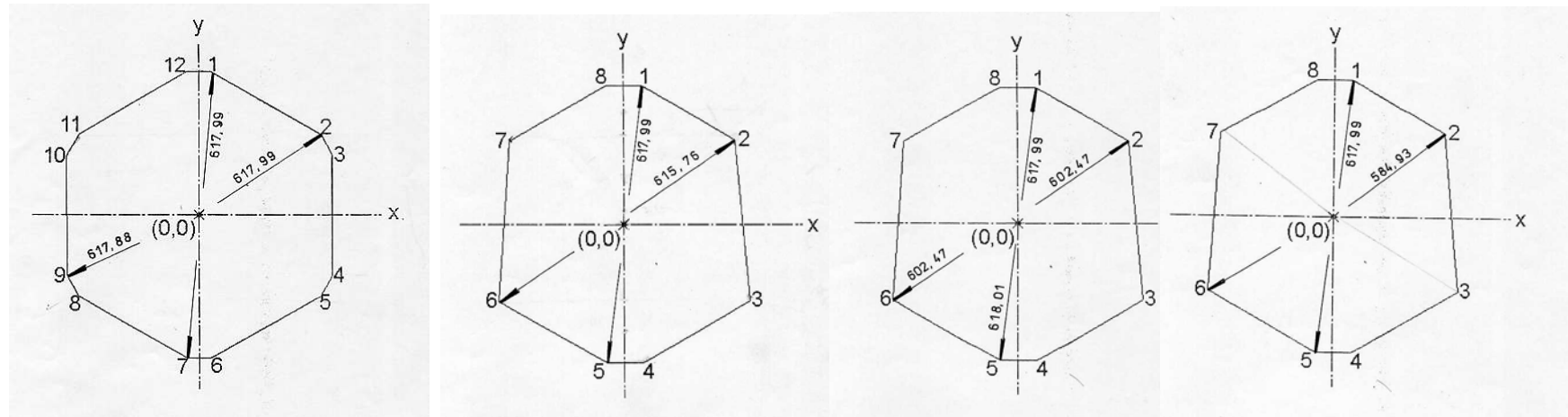


# Mirror

- 3.5 x 3.5 m<sup>2</sup> 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.



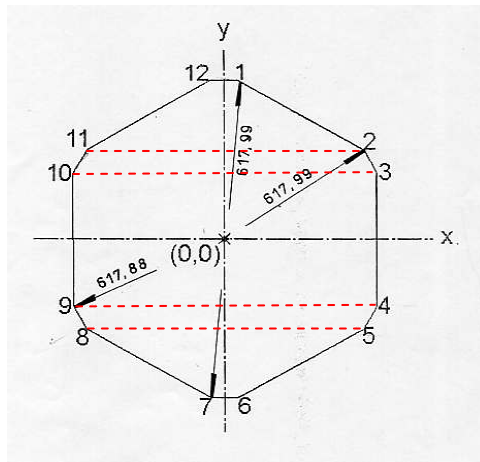
4 different MS shapes to fit the mirror curvature:



Each mirror is made of 60 mirror segments.

# Mirror segments (MS) in Geant4

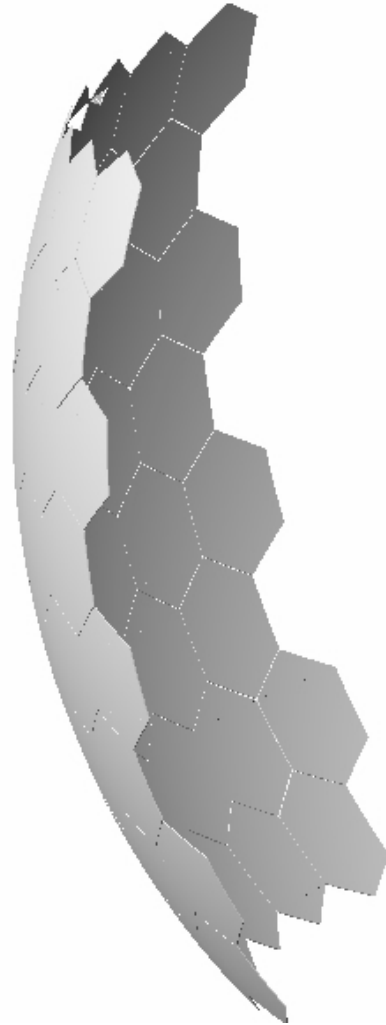
- 1) Union of G4Trd solids ;
- 2) Intersection of resulting boolean solid with a G4Sphere.  
(Rmin = Radius of curvature; Rmax = Rmin + thickness)



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.

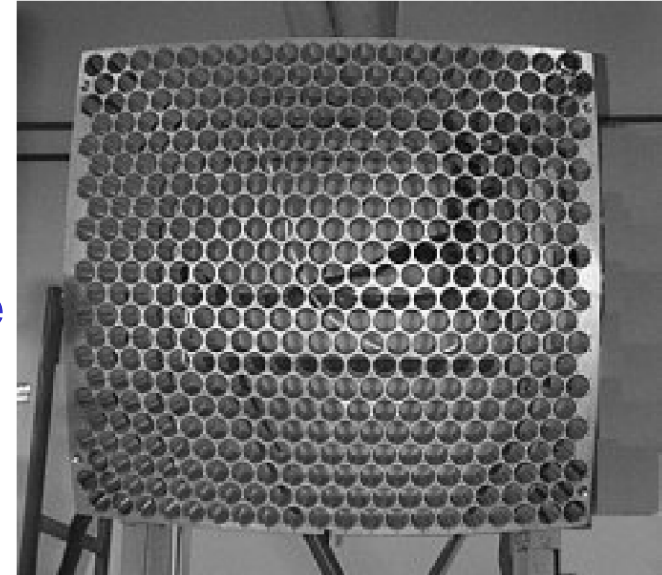
# Assembled mirror



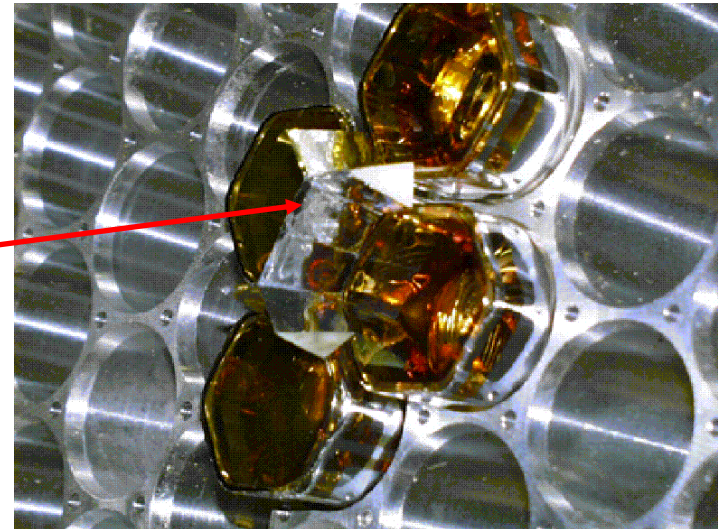
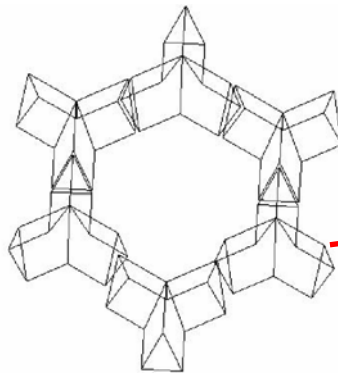
# Camera

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

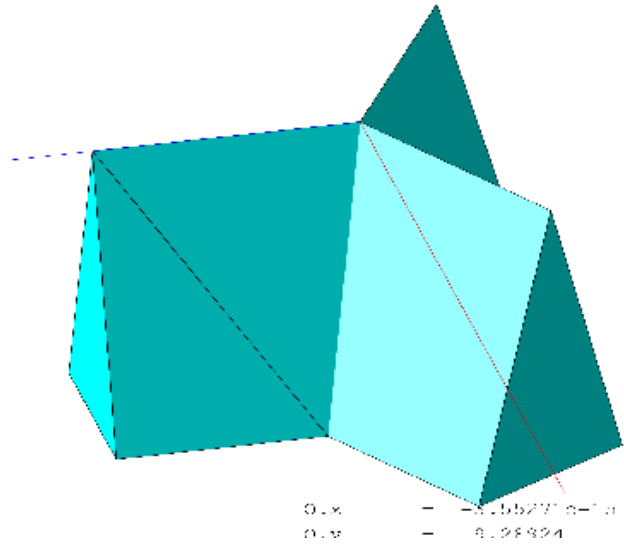
Camera frame



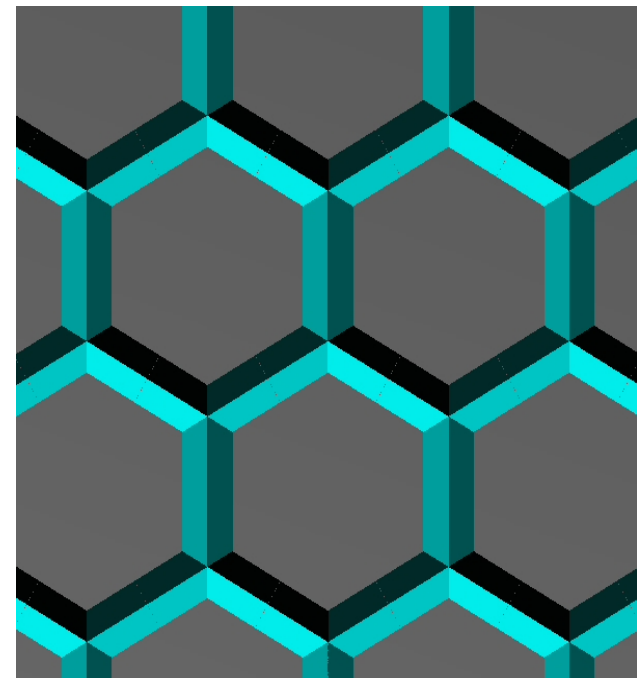
6 “Mercedes” light collectors



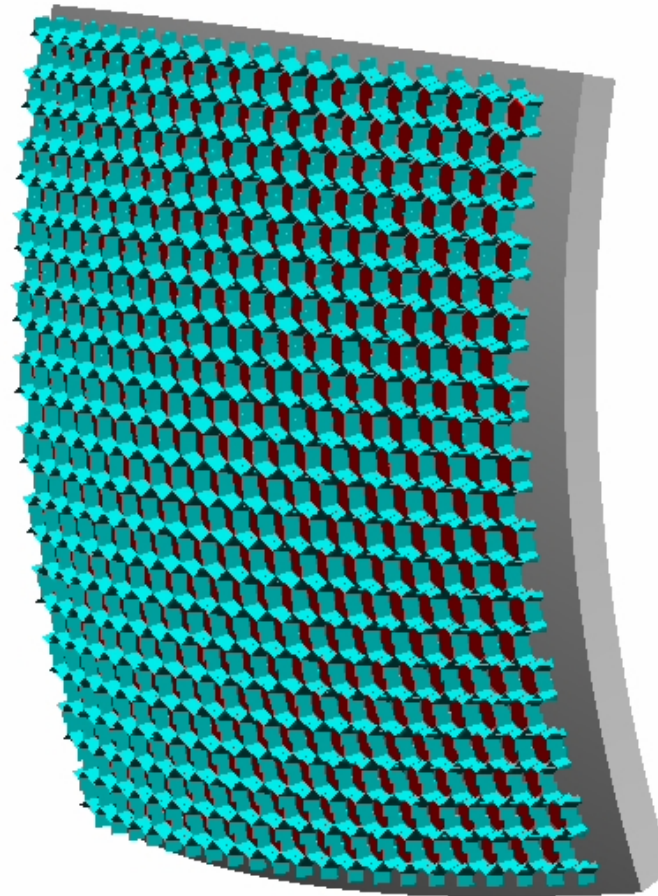
# Mercedes light collectors in Geant4



Union of 3 G4Polyhedra solids

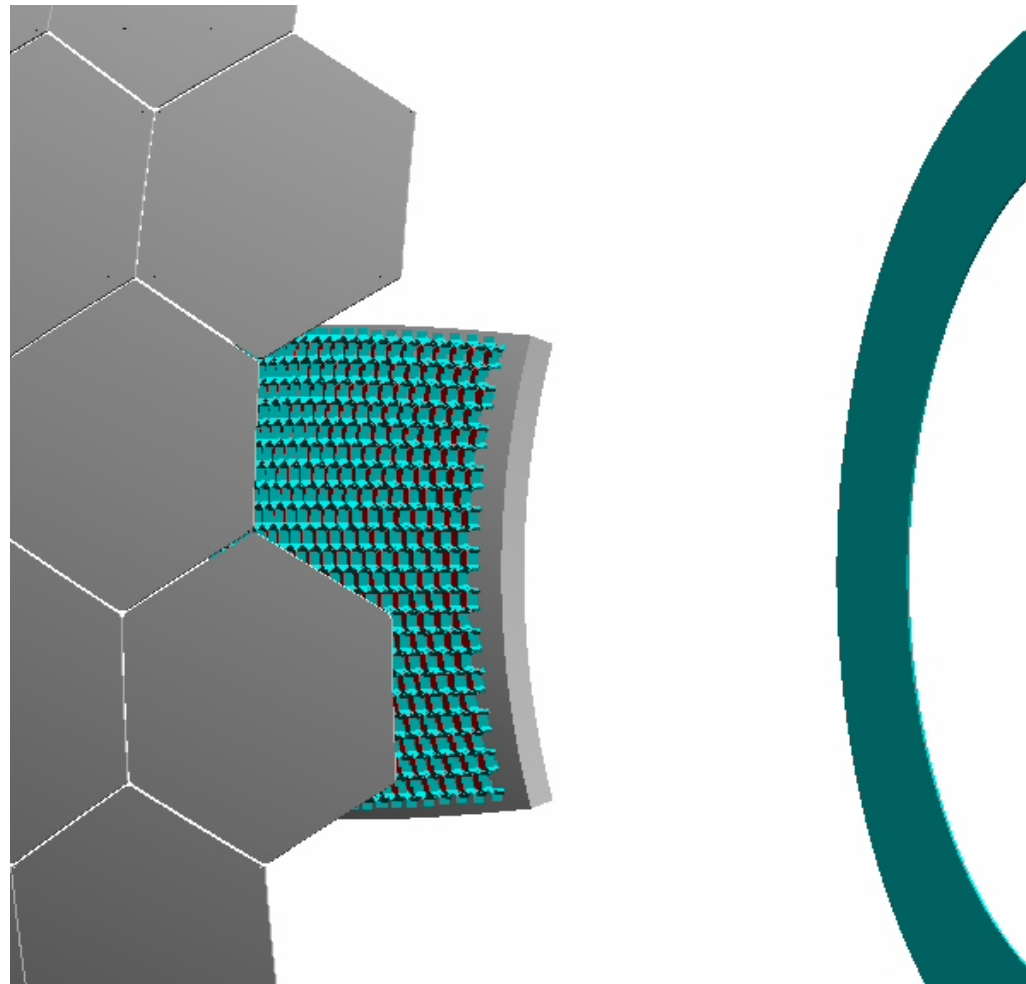


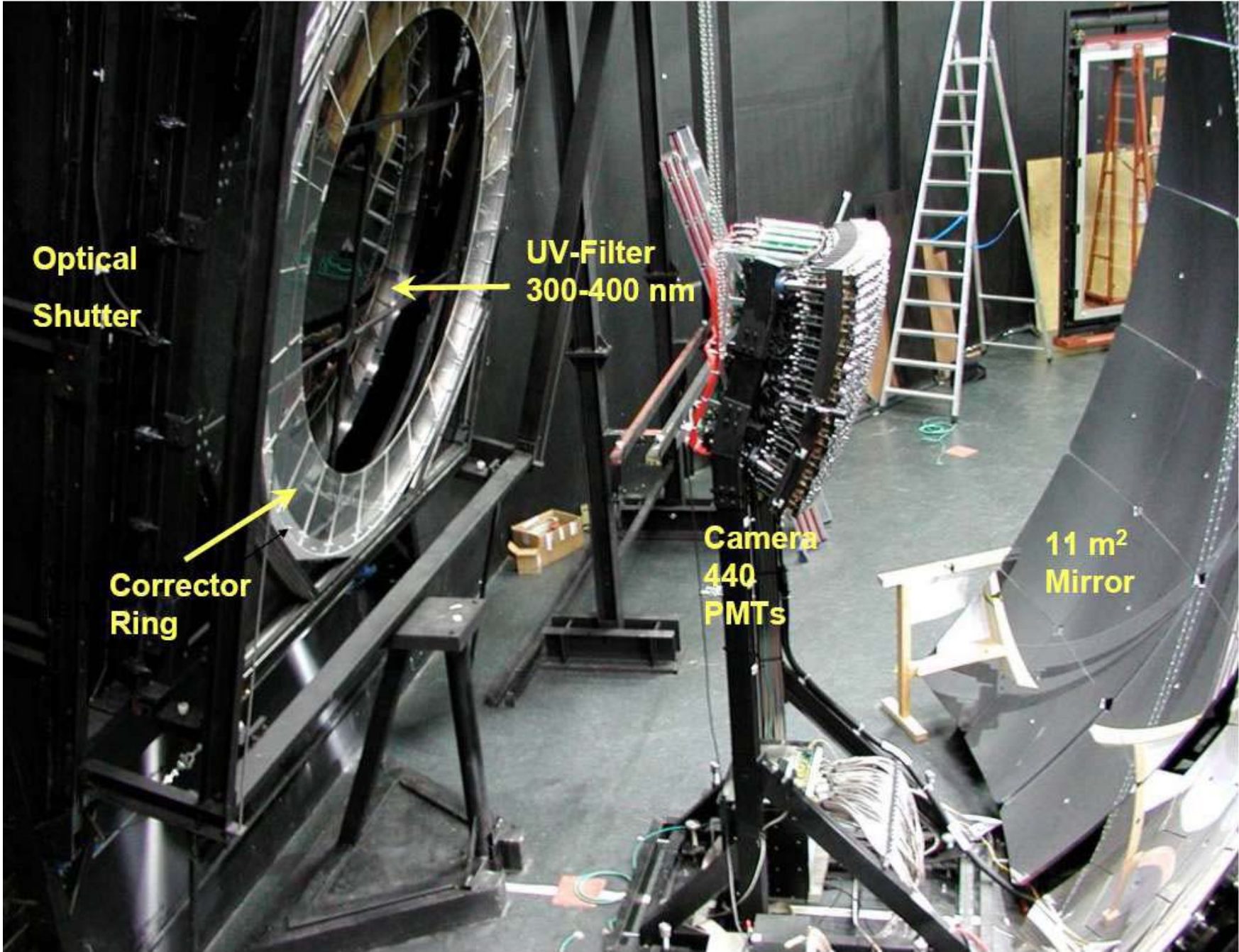
# Assembled camera



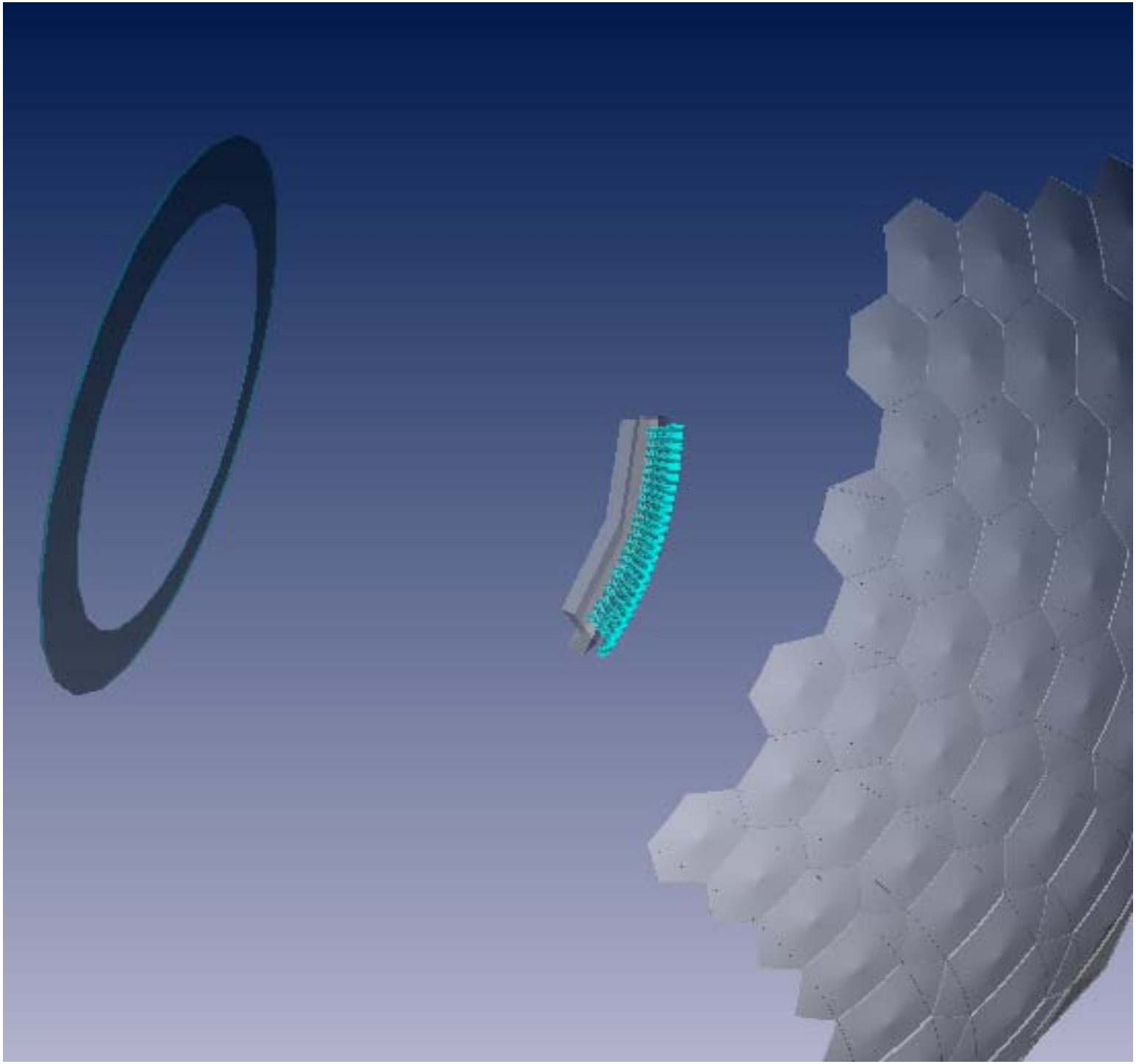
PMTs described as hexagonal volumes (shown in red) and defined as sensitive volumes.

# Assembled telescope

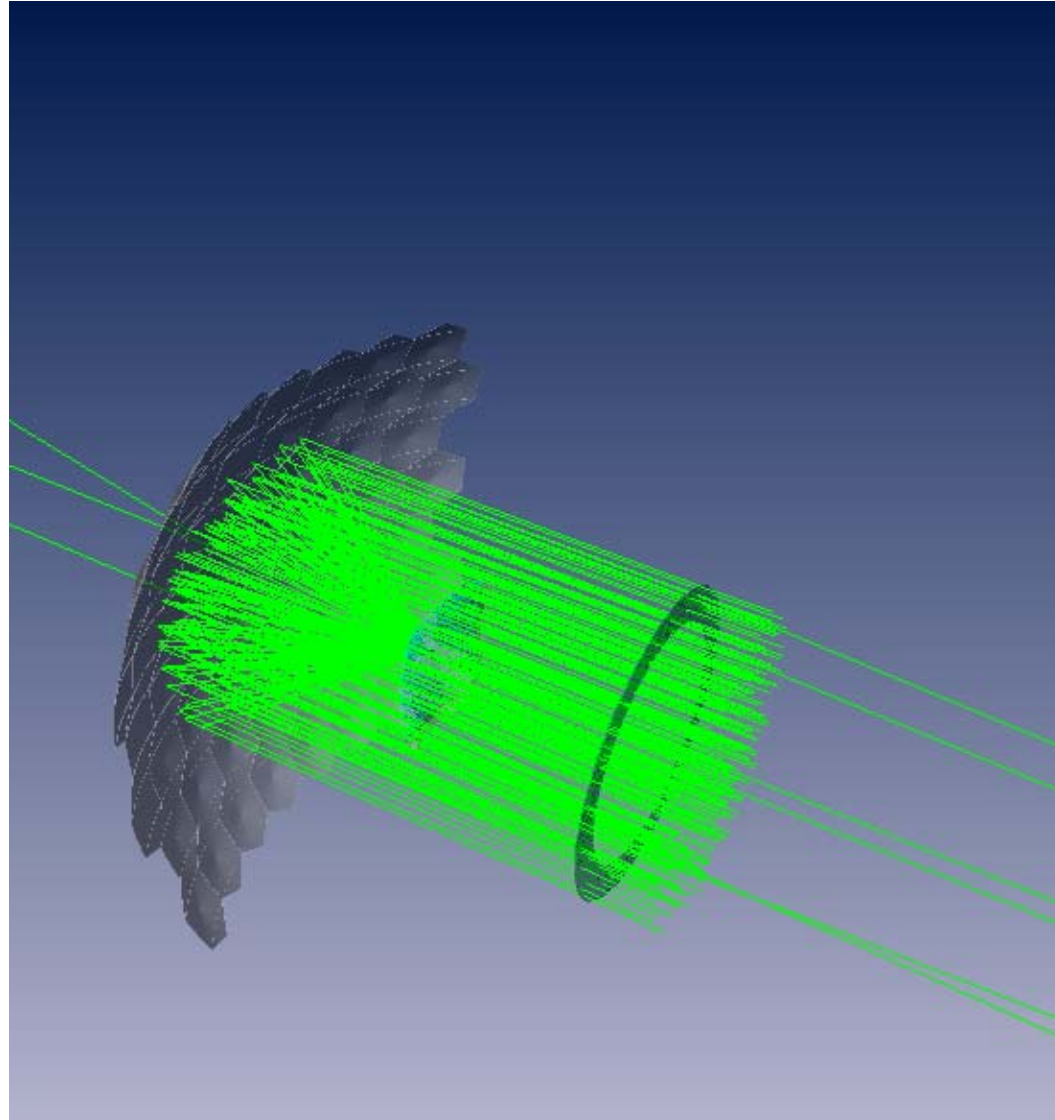


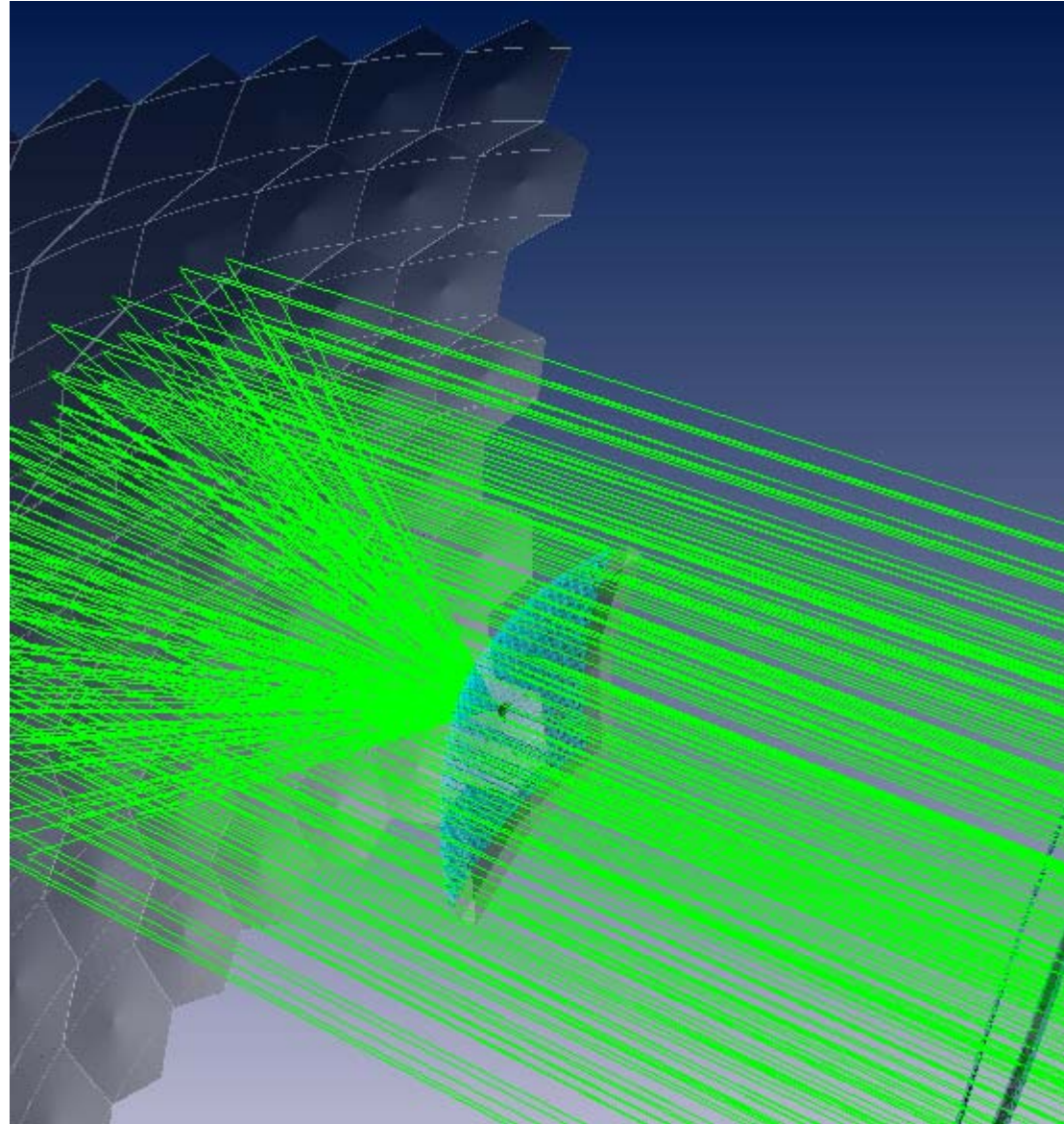


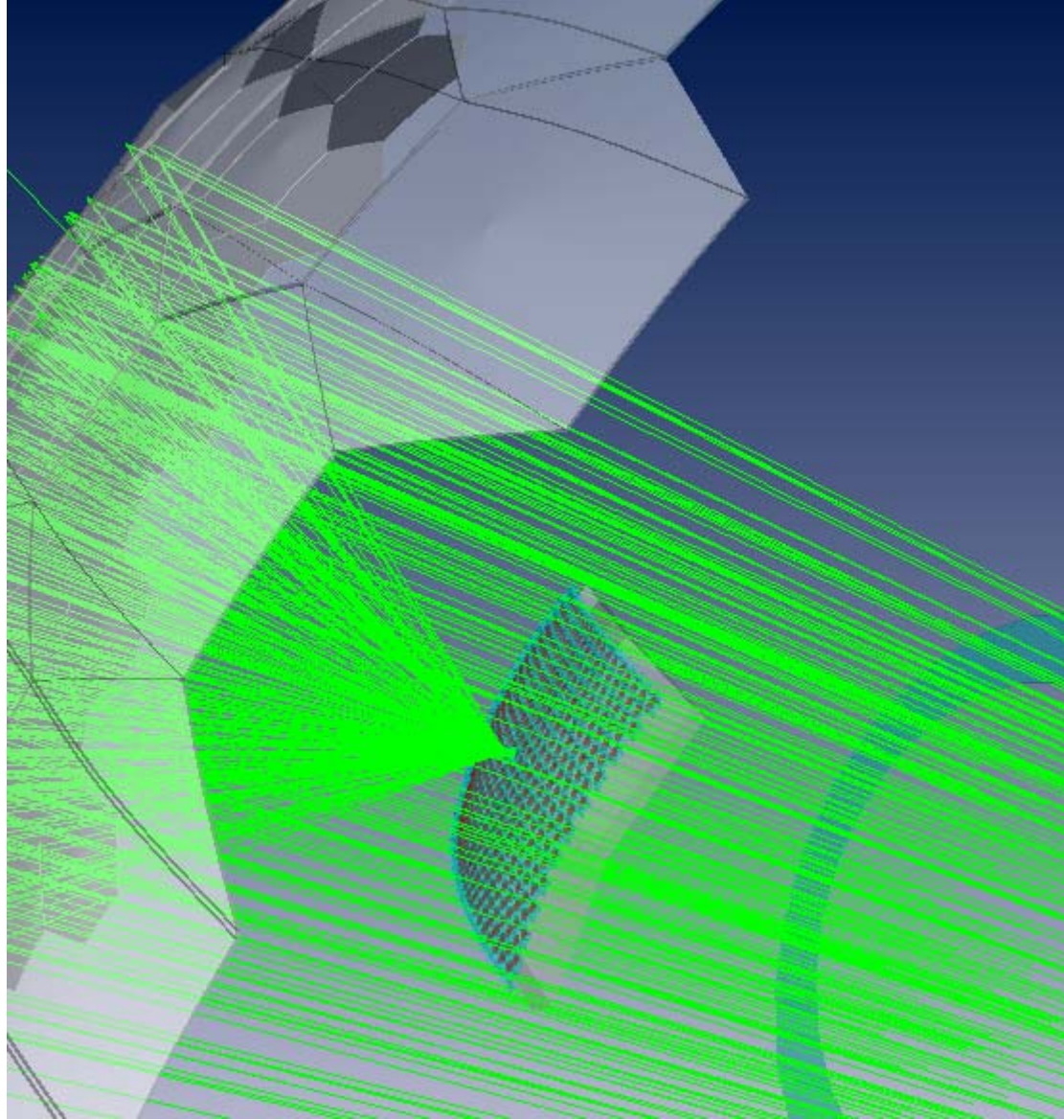




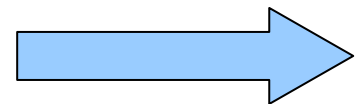
# Seeing light...





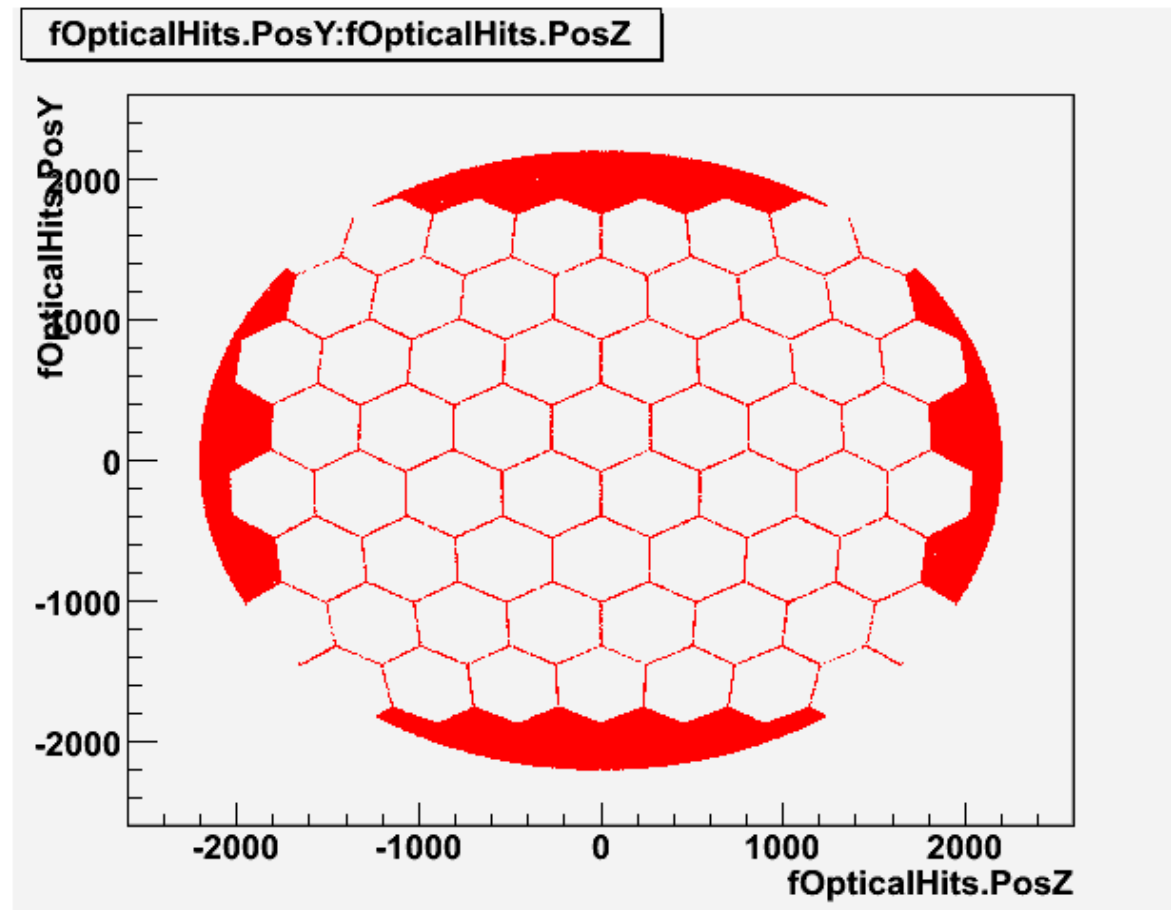


Some very preliminary results



# Mirror “X-ray”

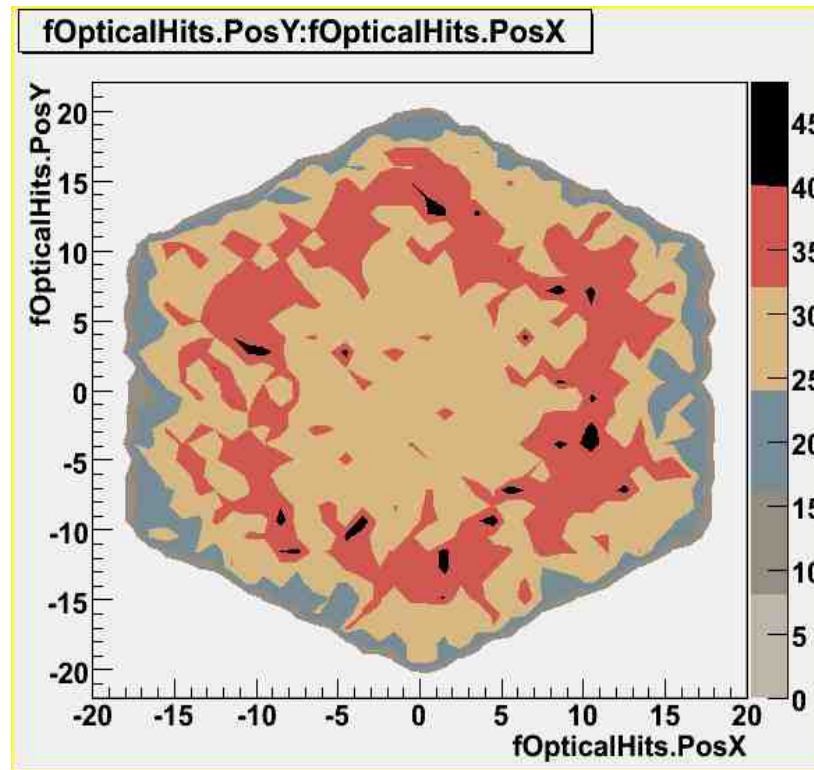
Uniform illumination of the mirror ( $\theta=0^\circ$ ) ;  
Photon positions detected behind the mirror.



# Camera “X-ray”

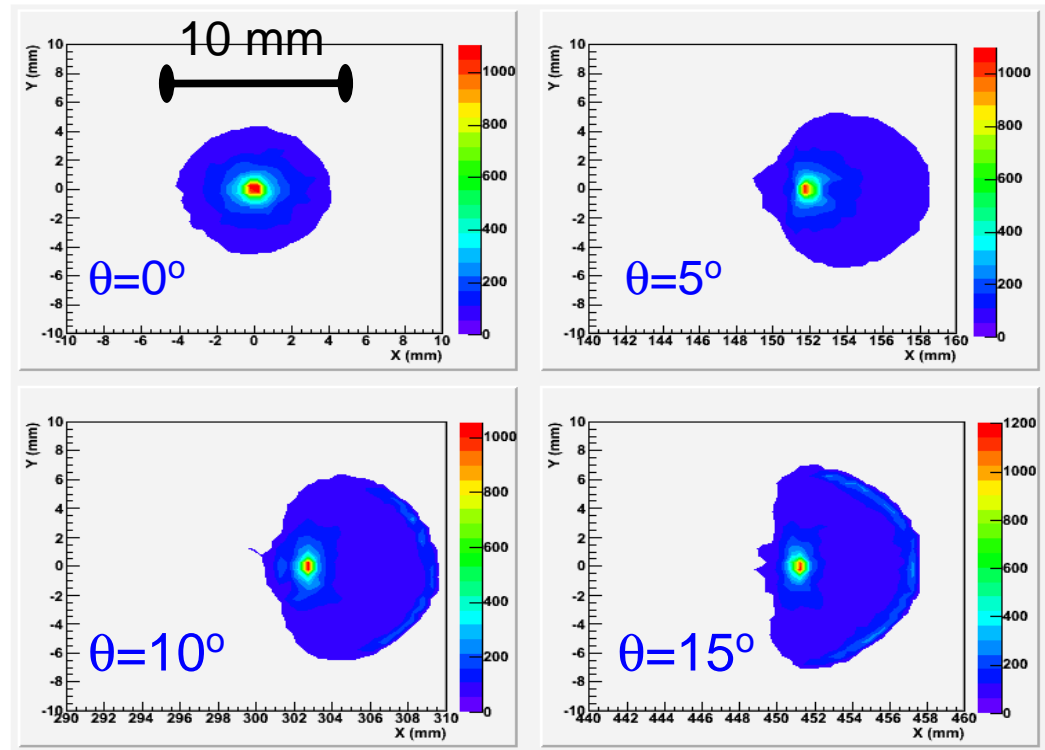
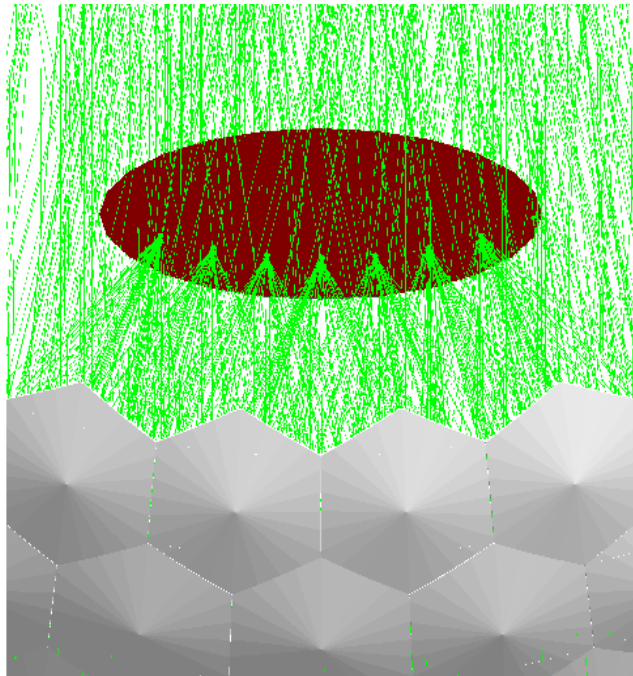
Uniform illumination of the camera ( $\theta=0^\circ$ );

Average photon distribution over the PMT surface:



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

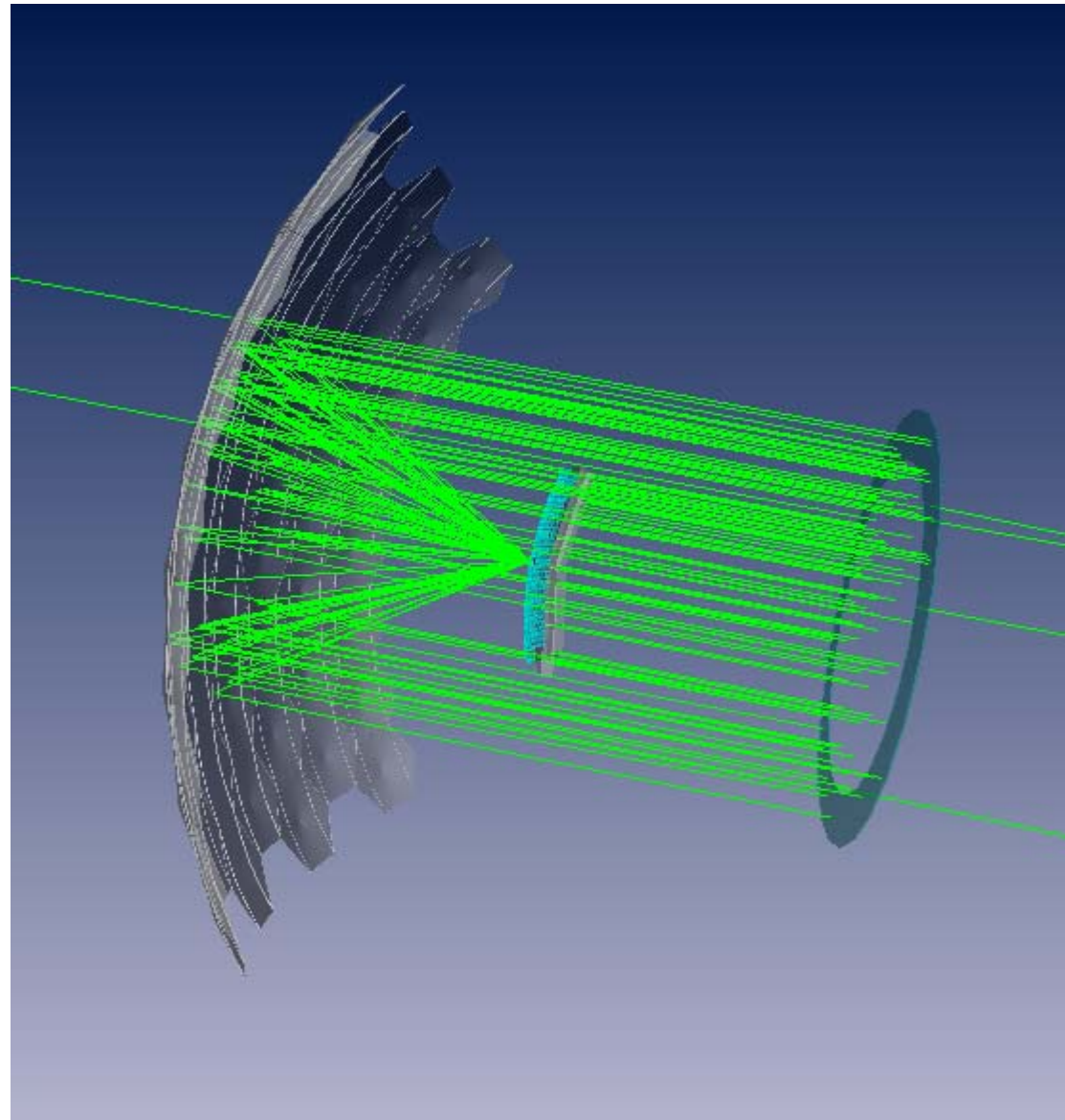
# PSF vs theta – an example





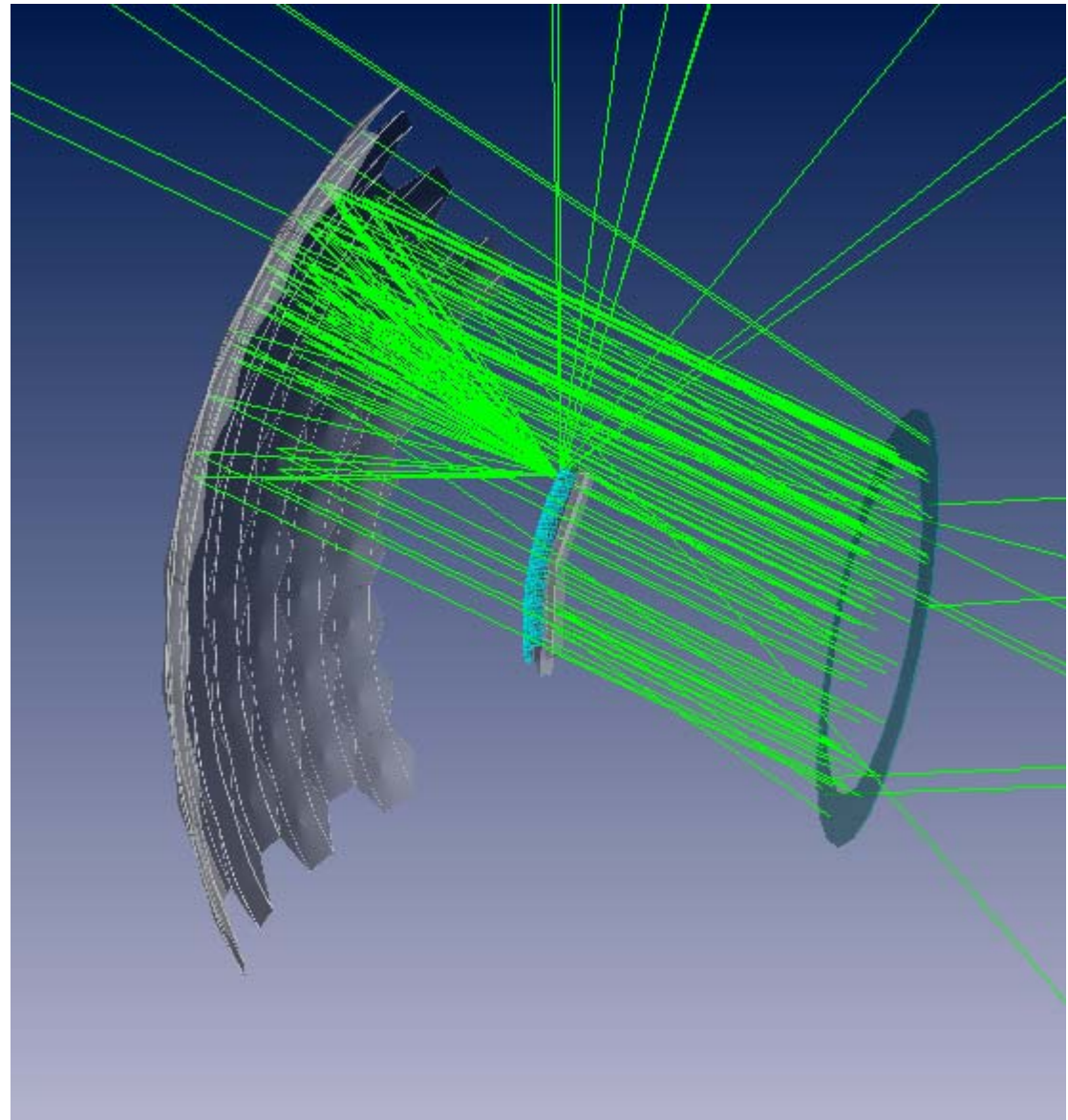
# Direction Scans

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



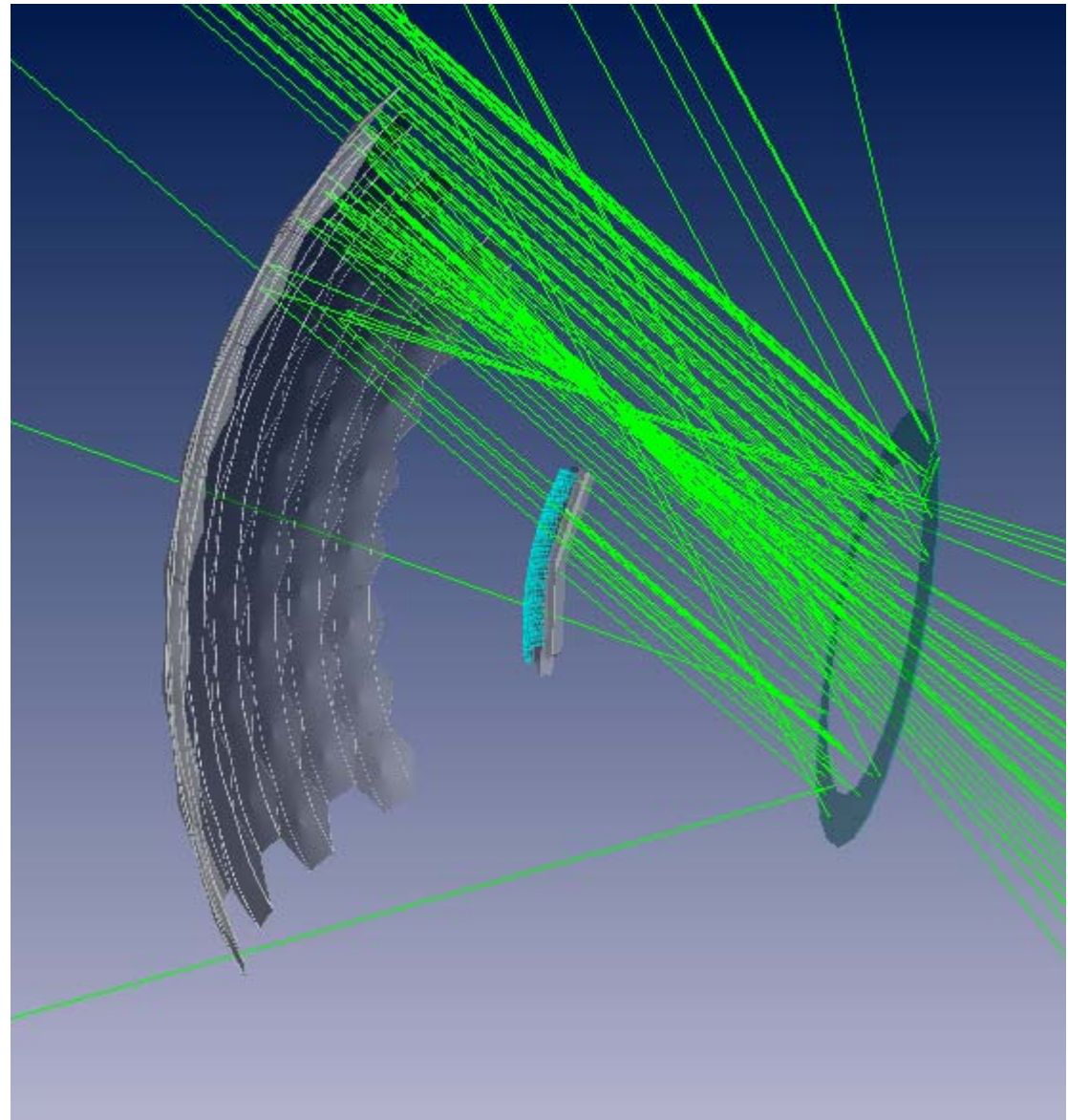
# Direction Scans

Th=15°; Phi=0°



# Direction Scans

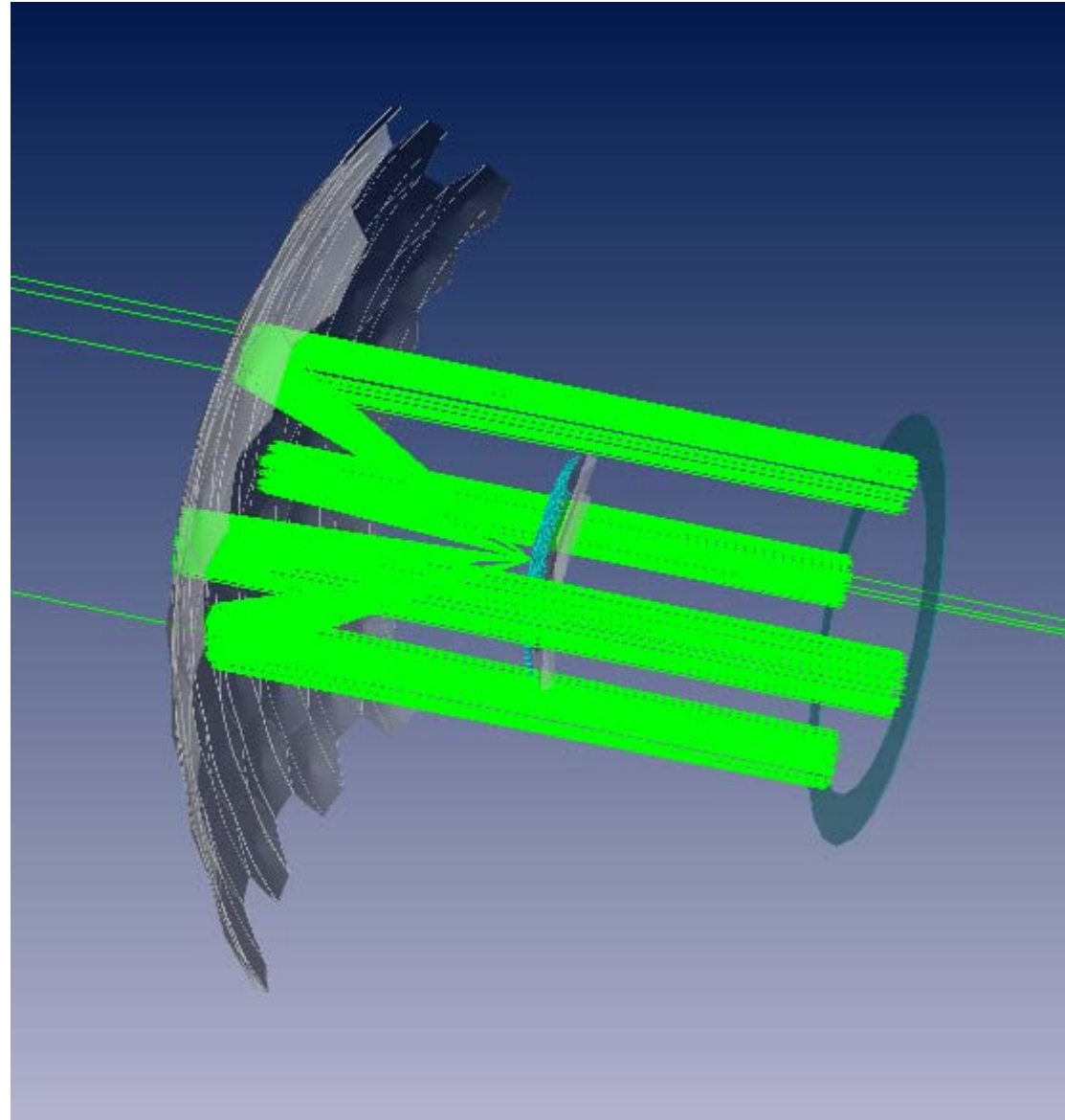
Th=30°; Phi=0°



# Position Scans

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

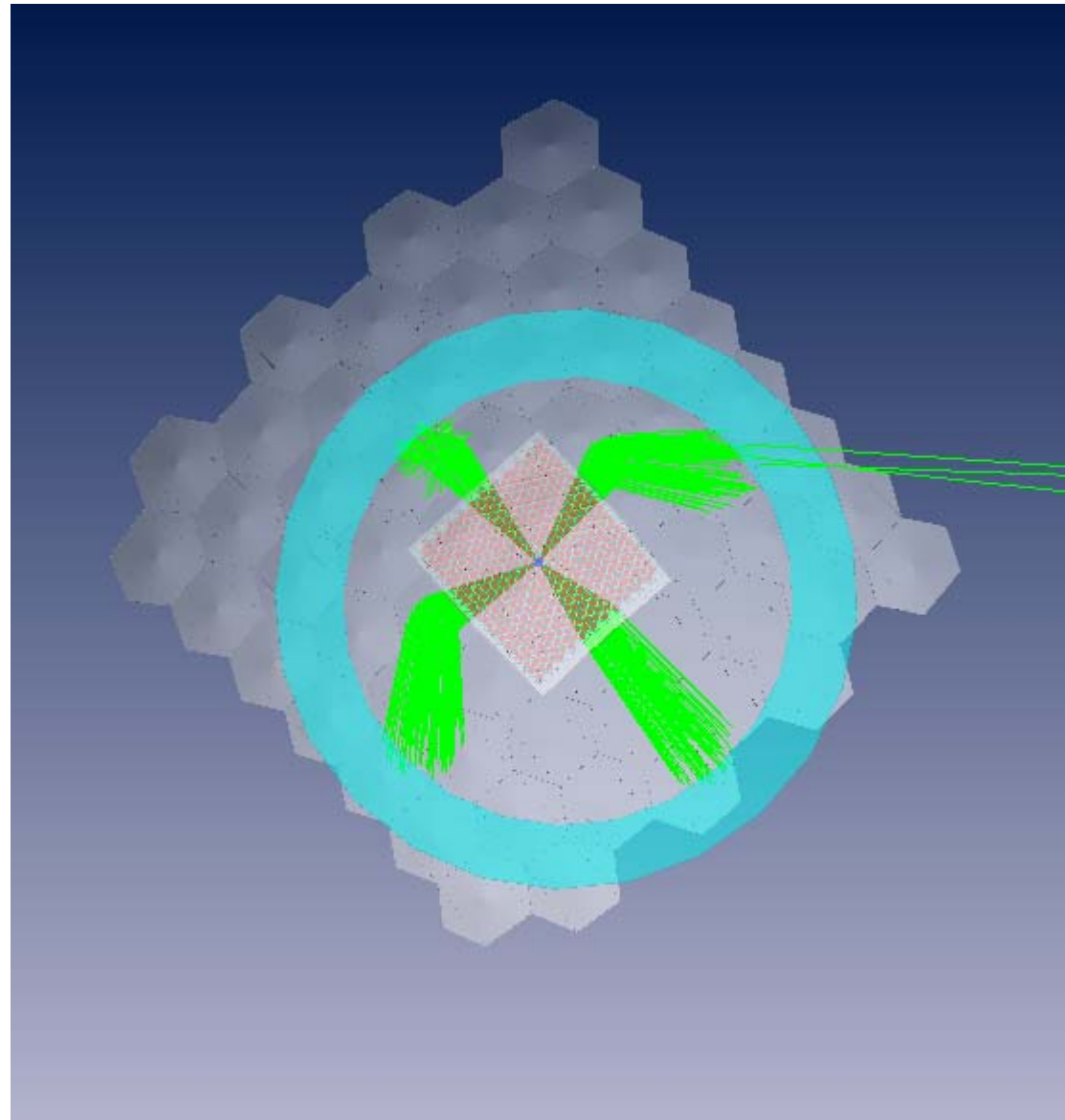
Photons direction:  
 $\text{Th}=0^\circ; \text{Phi}=0^\circ$



# Position Scans

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

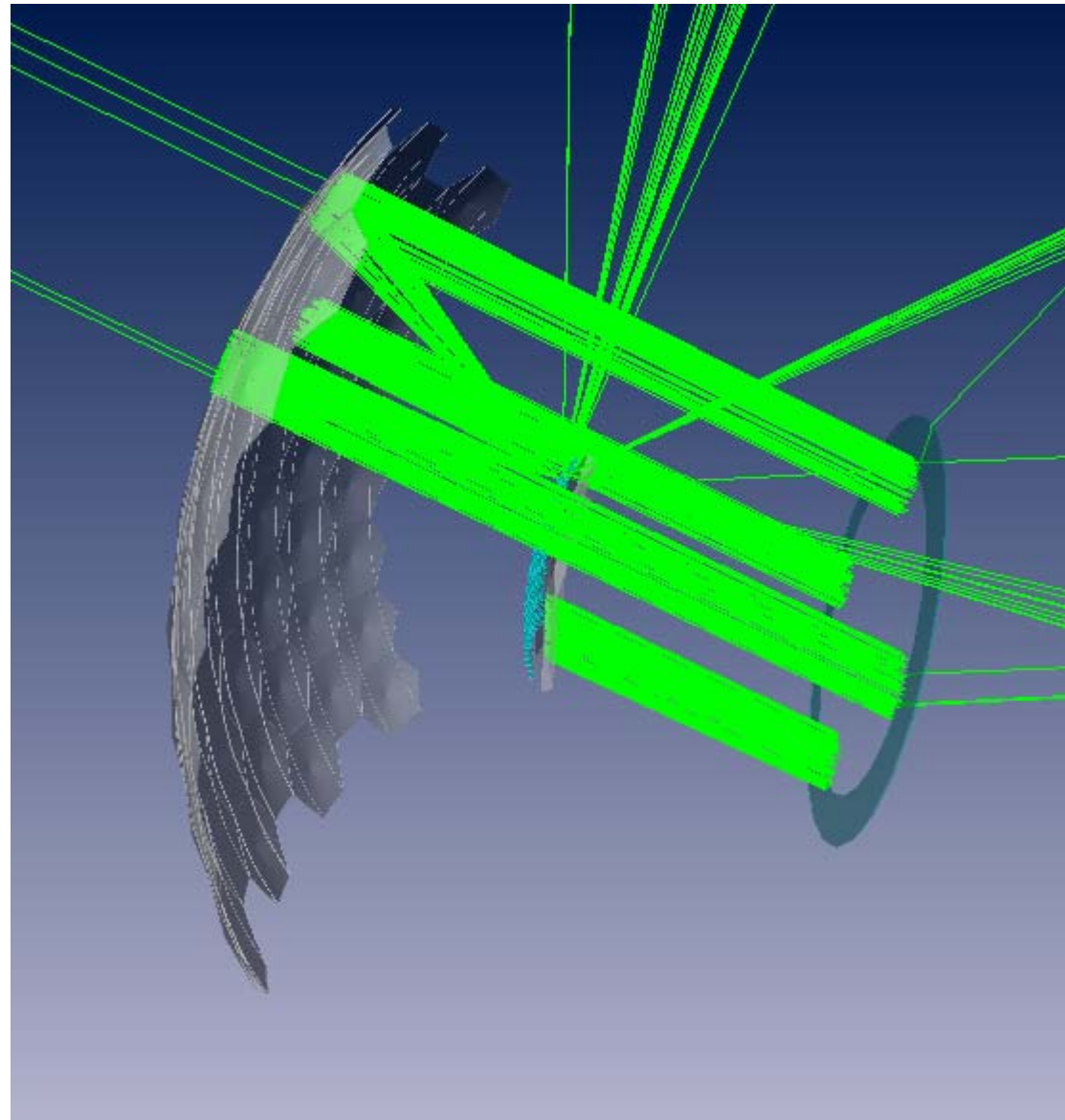
Photons direction:  
 $\Theta=0^\circ; \Phi=0^\circ$



## Position Scans

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

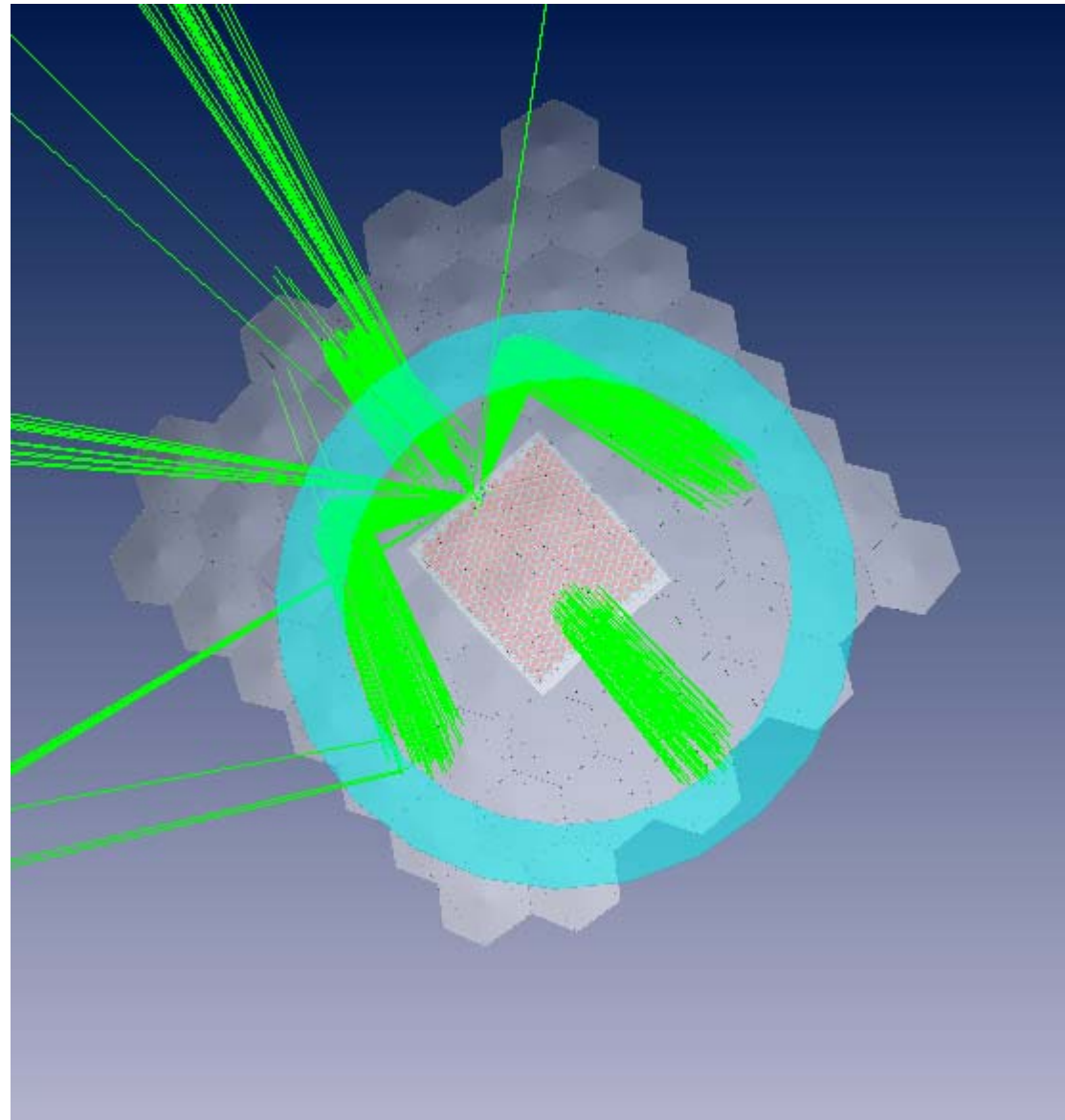
Photons direction:  
 $\Theta=15^\circ; \Phi=0^\circ$



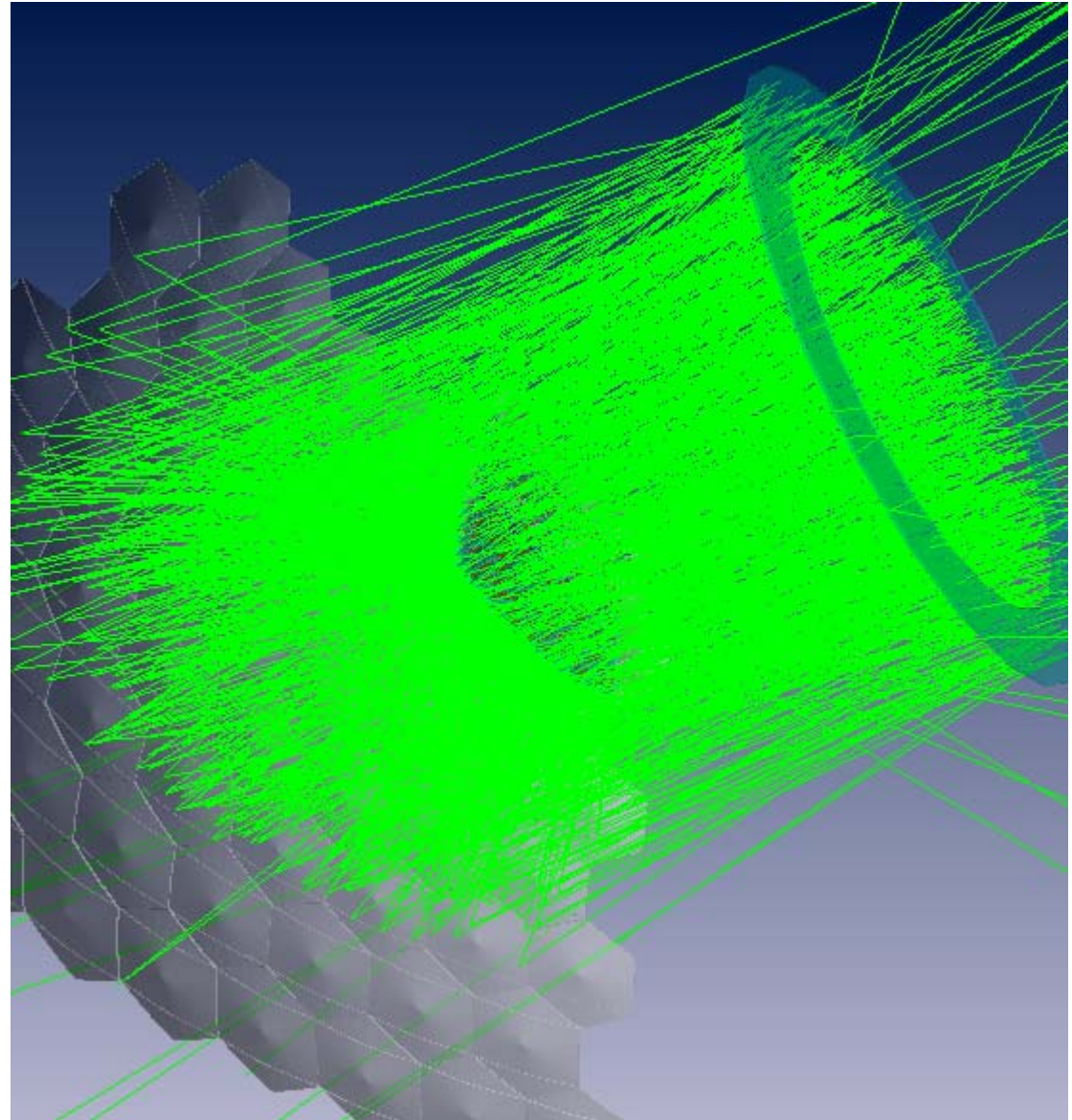
## Position Scans

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

Photons direction:  
 $\text{Th}=0^\circ; \text{Phi}=0^\circ$

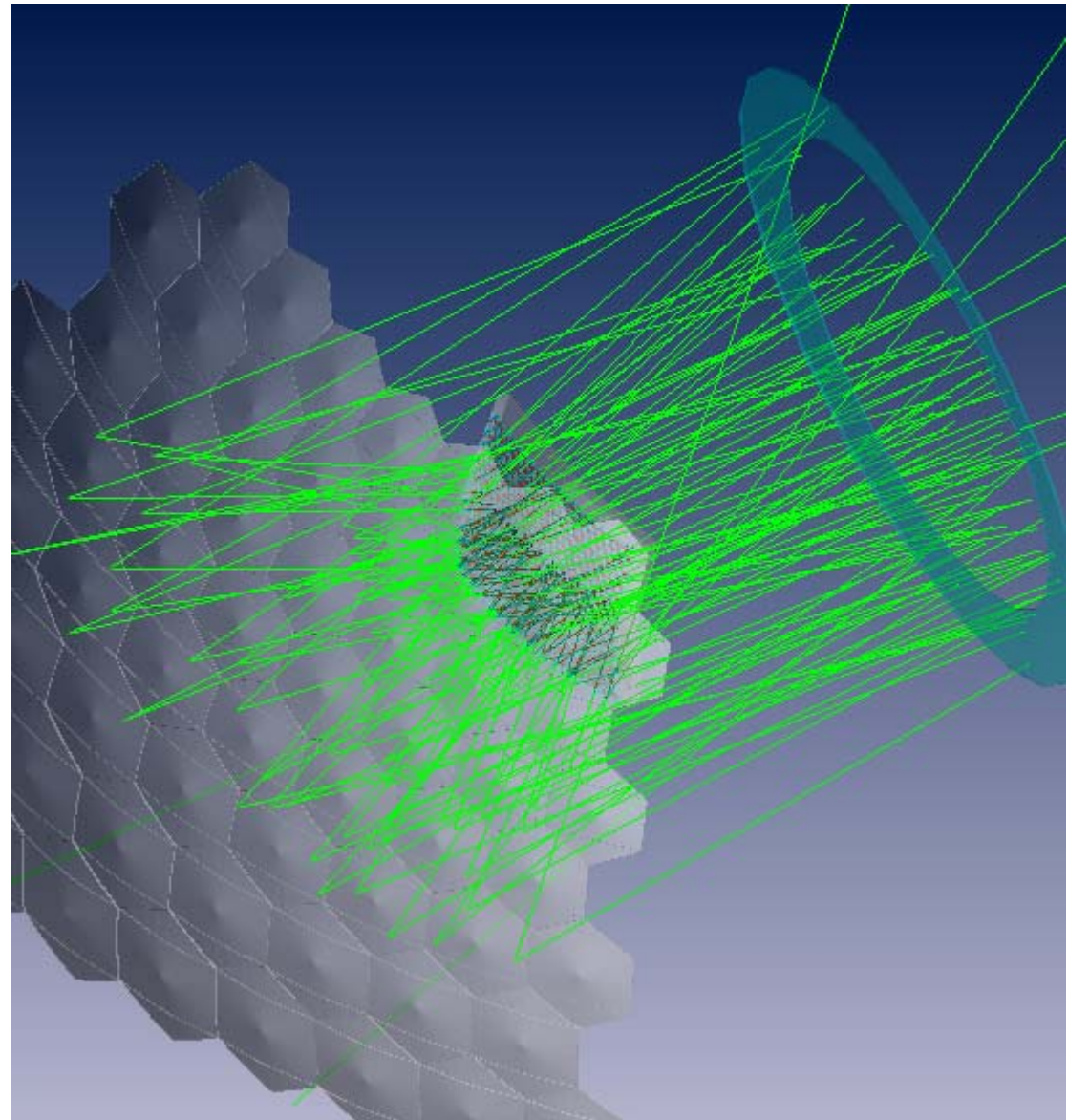


# A SHOWER... 1000 Photons

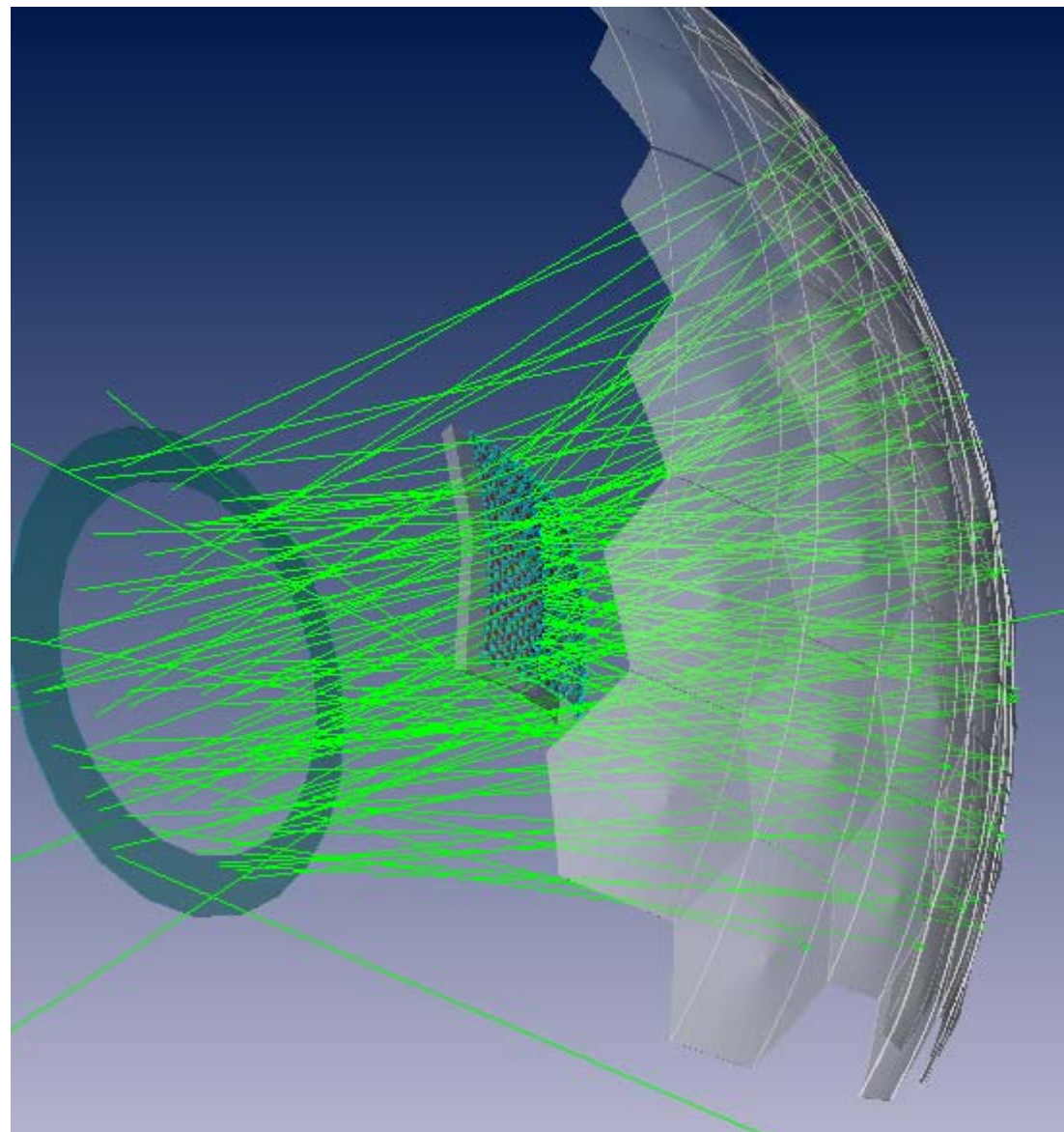




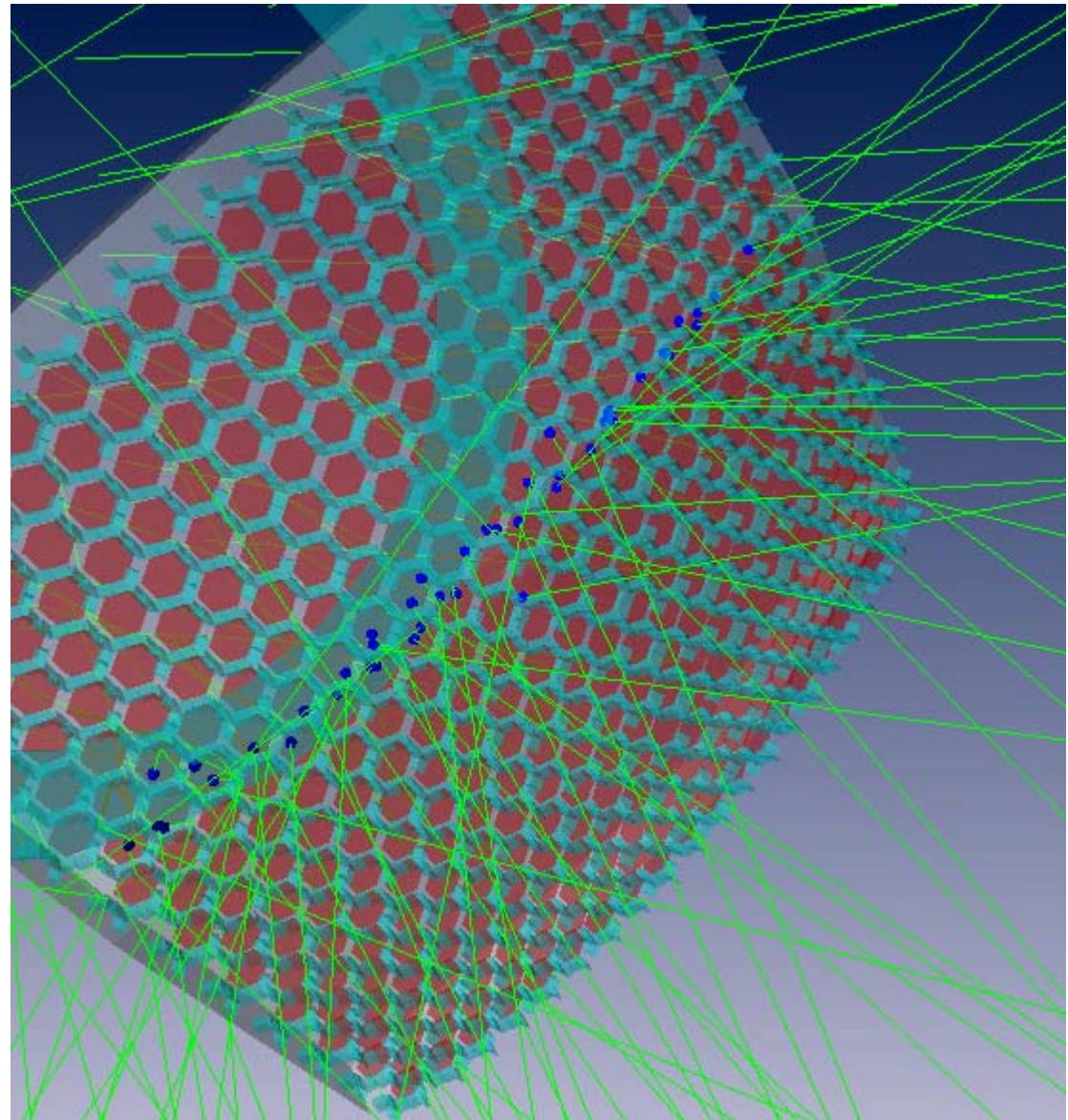
# A SHOWER... 100 Photons



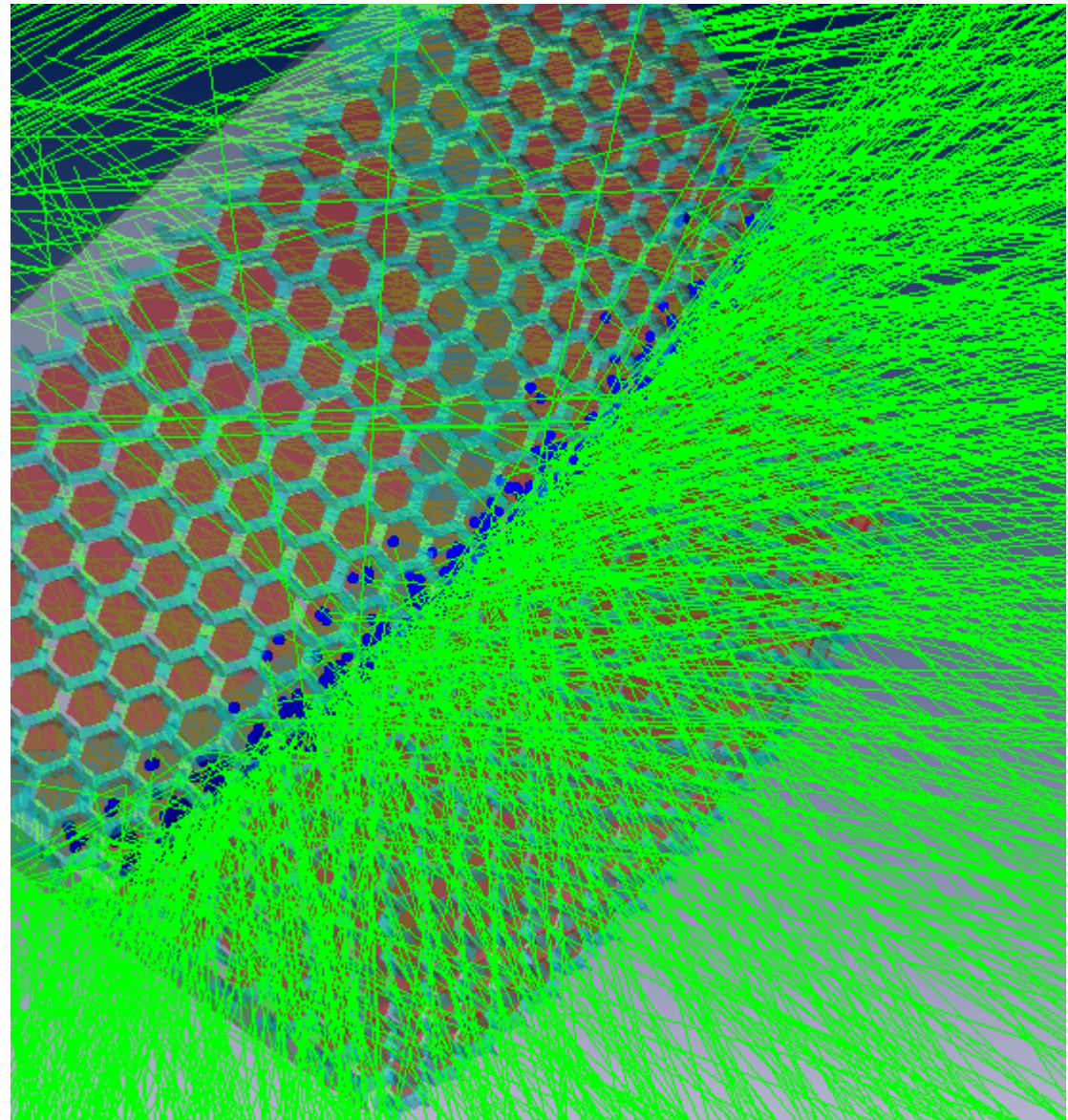
# A SHOWER... 100 Photons



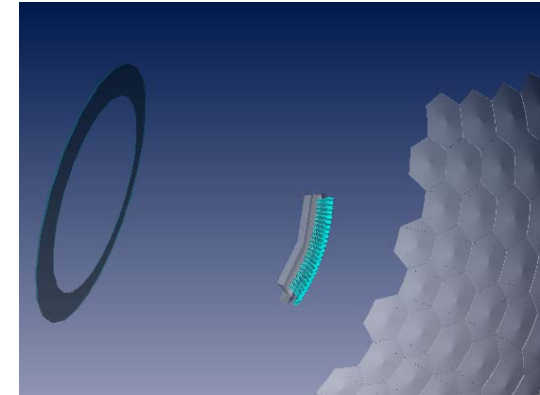
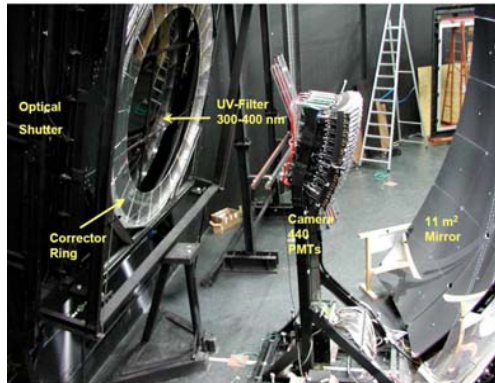
# A SHOWER... 100 Photons



# A SHOWER... 1000 Photons



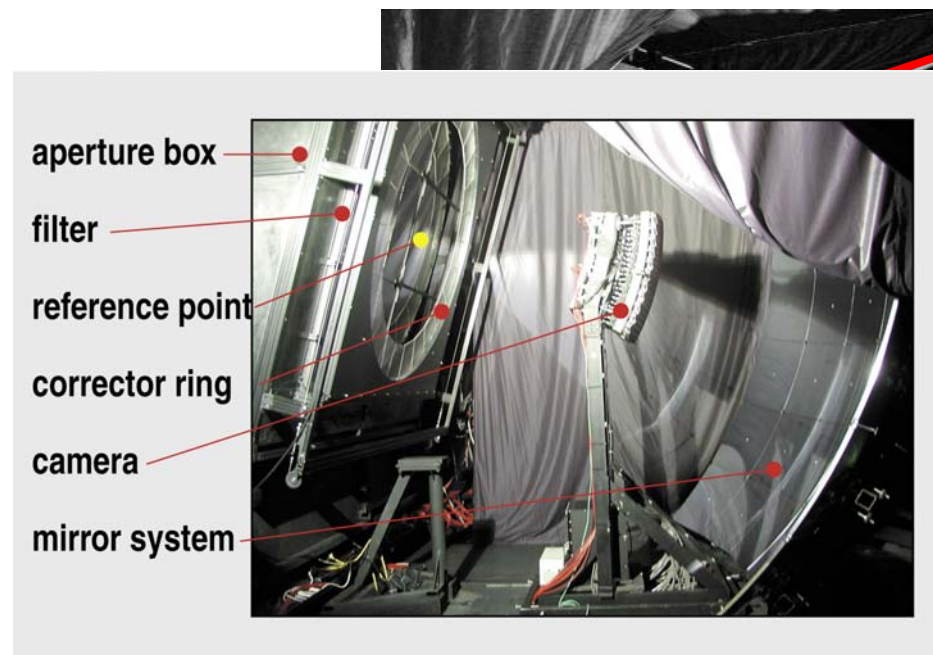
# Summary



- ✓ 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 =  $0.5^\circ$ .

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;