A Geant4 based simulation for Fresnel lenses

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LIP

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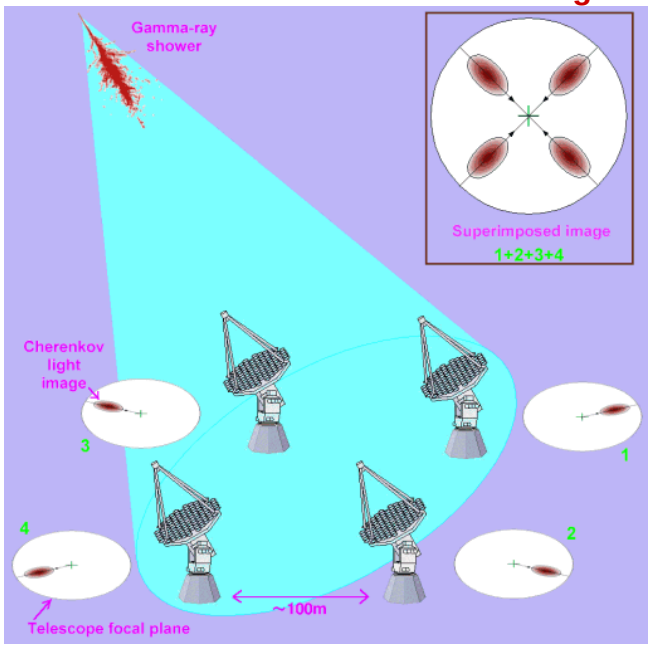
Outline

- Fresnel lenses in Air Shower Telescopes
- Fresnel lens description with Geant4
- Lens performance and optimization studies
- Air Shower Telescope simulation

Extensive Air Shower (EAS) telescopes

- Detection of Fluorescence and Cherenkov UV light from the EAS produced by Cosmic Rays in the atmosphere.
- Imaging Atmospheric Cherenkov Telescopes (IACT):
  - Very High Energy Gamma rays detection.
  - Beamed pulse of Cherenkov light emmited by the $\beta>1$ charged particles in the EAS.
  - Gamma - proton separation by analysis of the Cherenkov image shape.
  - Direction from stereoscopic observations with telescope arrays.

Stereo observation of Cherenkov images

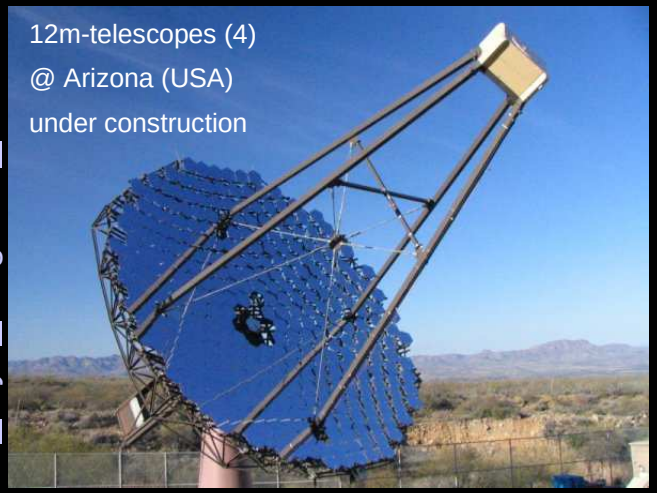


by CANGAROO Collaboration

IACTs World Wide

Imaging Telescope Array System

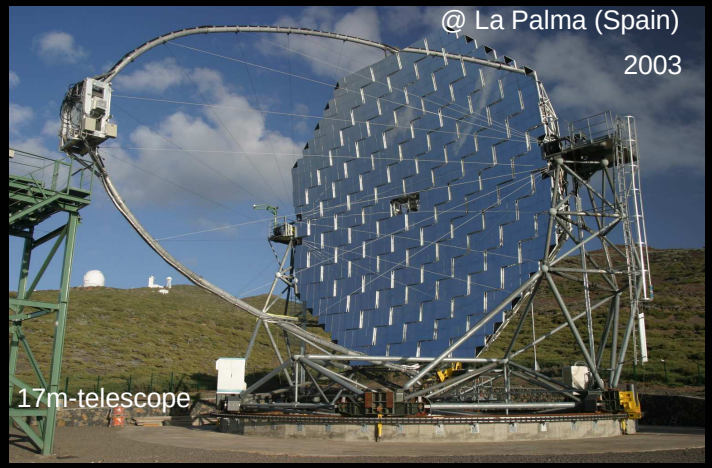
Very Energetic Radiation



V E R I T A S

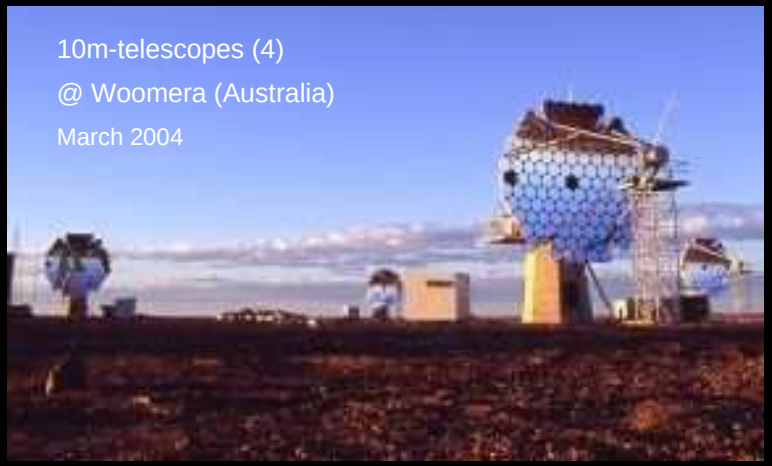
M A G I C Major Atmospheric Gamma

Imaging Cherenkov

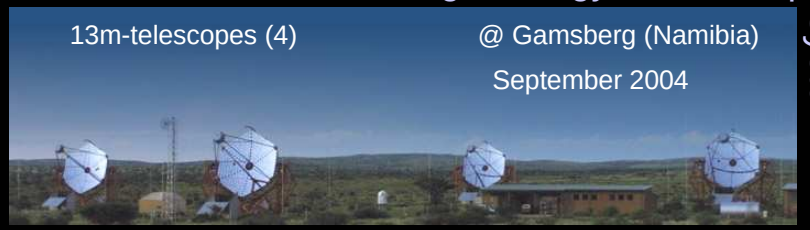


CANGAROO III

Collaboration of Australia and Nippon for a GAmma Ray Observatory in the Outback

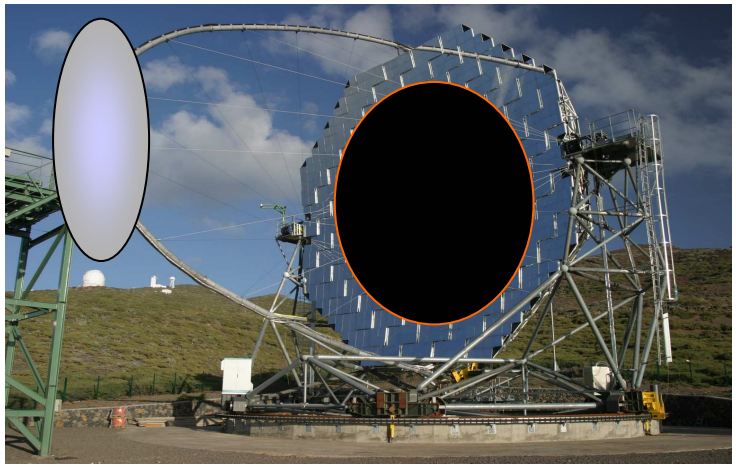


H.E.S.S. High Energy Stereoscopic System



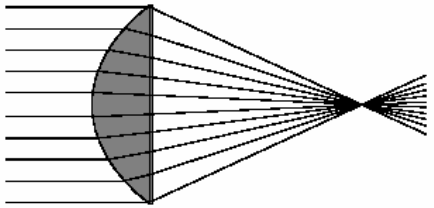
Large Field of View IACTs

- Limited Field Of View (FOV) in reflective optics due to :
  - **Image degradation for off-axis imaging**
  - **Shadow of the focal surface**

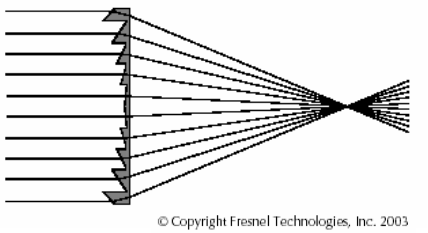


by Teresa Mineo

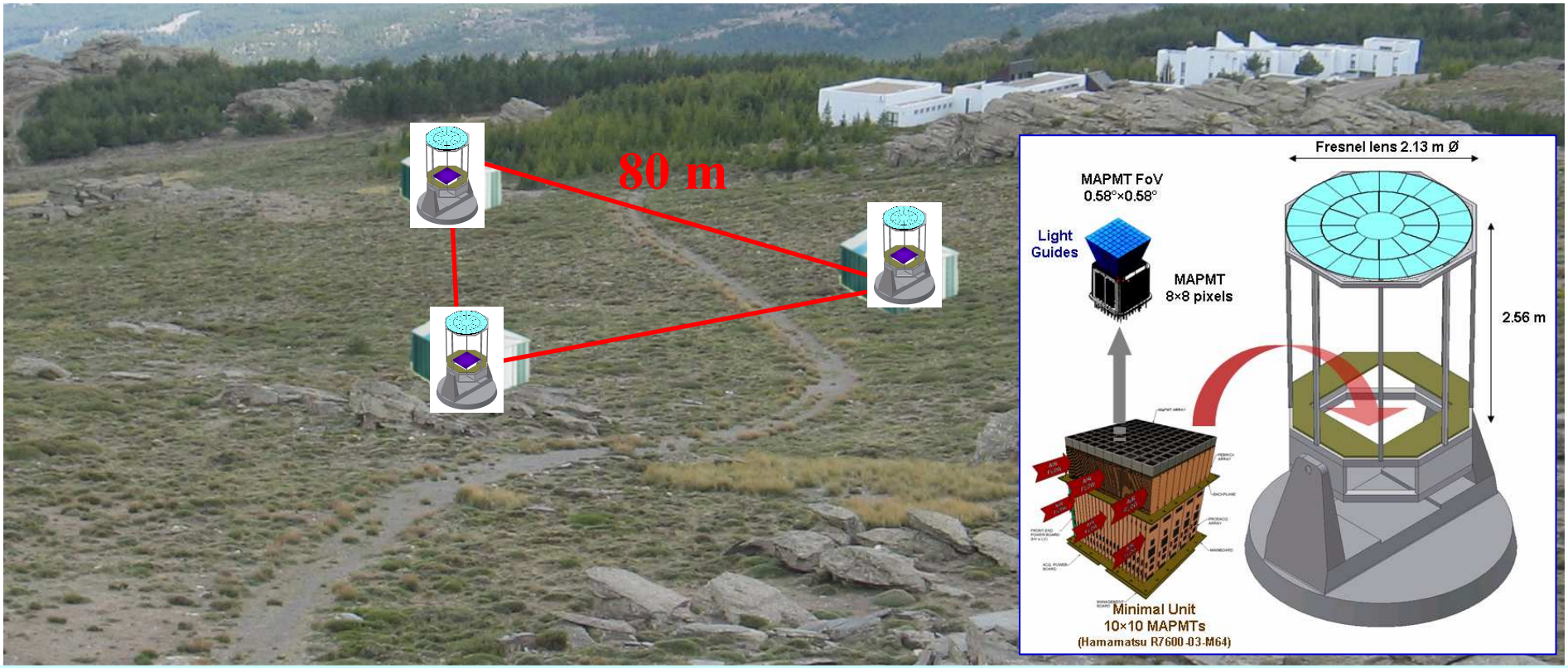
- Refractive optics allows for large FOV



- Novel technique using Fresnel lenses
  - **Small thickness**
  - **Low light absorption**



GAW – Gamma Air Watch



- GAW is a pathfinder gamma ray experiment, sensitive in the 1-10 TeV energy region.
- Array of 3 IACT with refractive Fresnel lens optics, joining high flux sensitivity with large FoV capability.
- The R&D telescope array is planned to be located at Calar Alto Observatory (Sierra de Los Filabres - Andalucía, Spain), at 2150 m a.s.l.

Fresnel lens simulation with Geant4

- Geant4 geometry description capabilities and availability of optics physics processes provide the necessary tools to set a simulation of Fresnel lenses.

- Description of Fresnel lenses geometry allows for detailed performance & optimization studies of IACT´s.

- An end to end simulation, covering air shower, lens and readout simulation can be implemented.

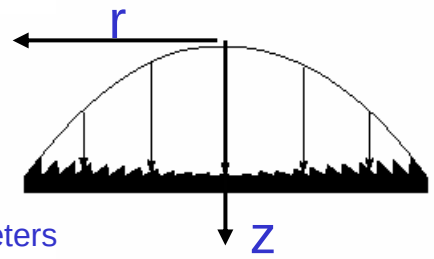
Fresnel lens implementation in Geant4 (1)

- Dedicated class to define the geometry of Fresnel lenses.
- Lens grooves are frustra of cones.
- Lens defined through a parameterised replication of G4Cons.
- Slope of each conic facet is computed from the lens surface sagita equation z(r) .

e.g. : Even aspheric lens

$$\frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \alpha_2 r^4 + \alpha_3 r^6 + \alpha_4 r^8$$

c - curvature ; k - conic const.; a – asphericity parameters



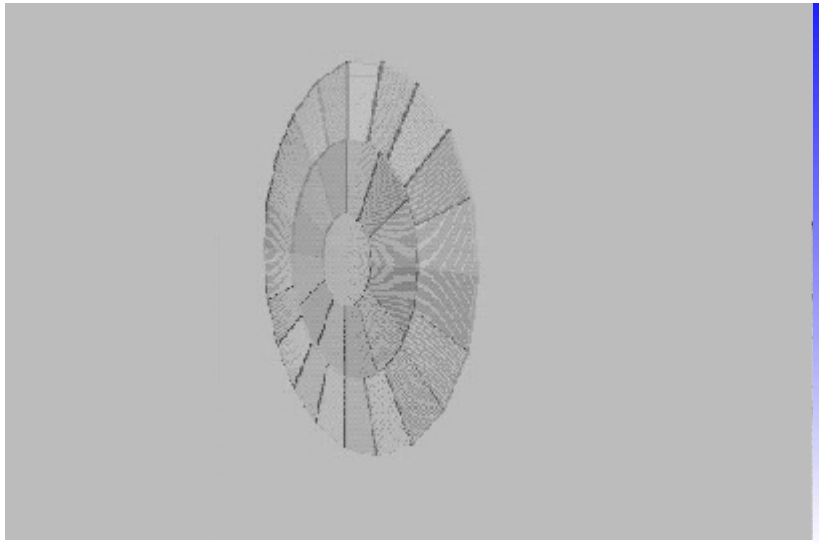
Optical physics list includes:

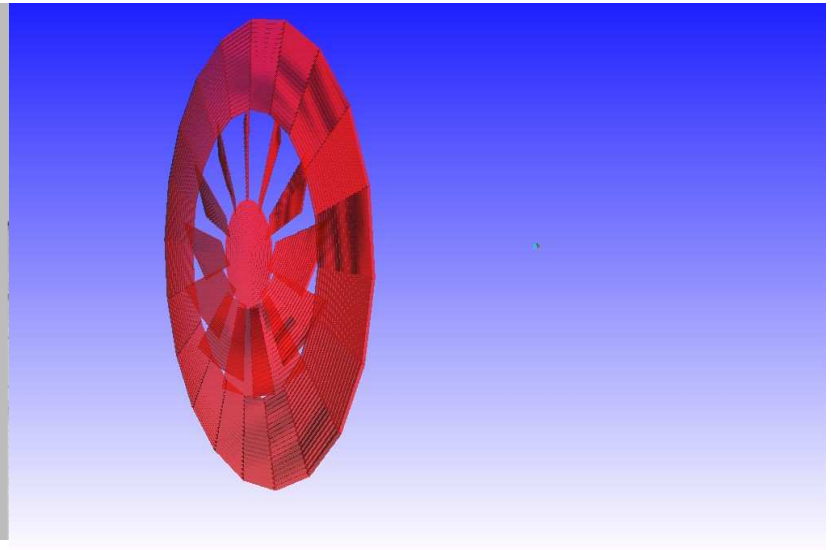
- **Cherenkov**
- **Refraction, reflection**
- **Rayleigh scattering**
- **Absorption**

Fresnel lens implementation in Geant4 (2)

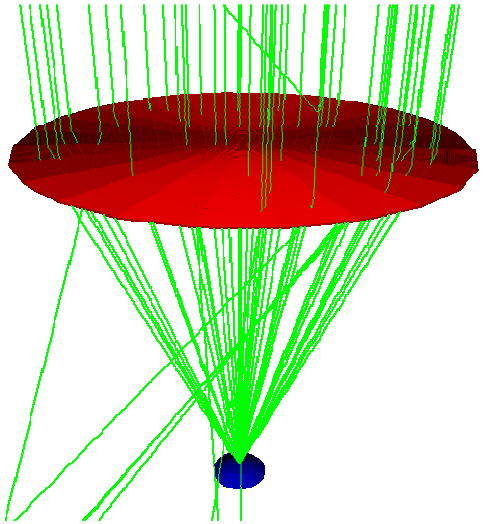
A FresnelLens object is defined by specifying:

- **Min,max radius;**
- **Min, max azimuthal span;**
- **Number of grooves;**
- **G4Material;**
- **Rotation axis, rotation angle;**
- **Surface sagita equation.**

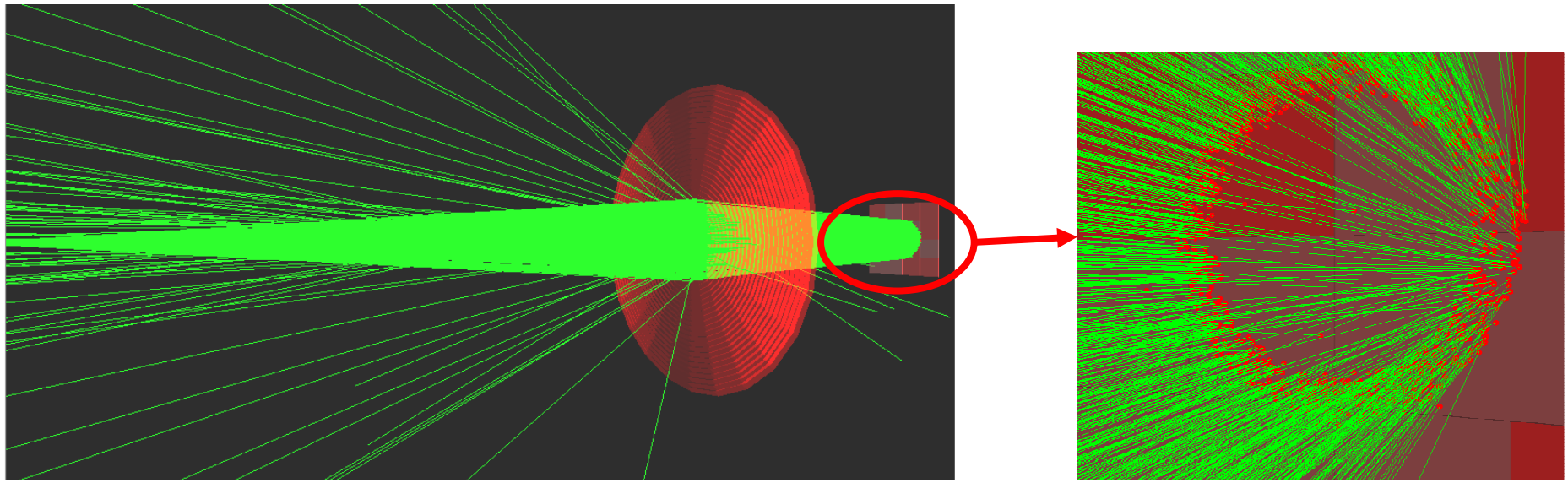




Fresnel lens implementation in Geant4 (3)



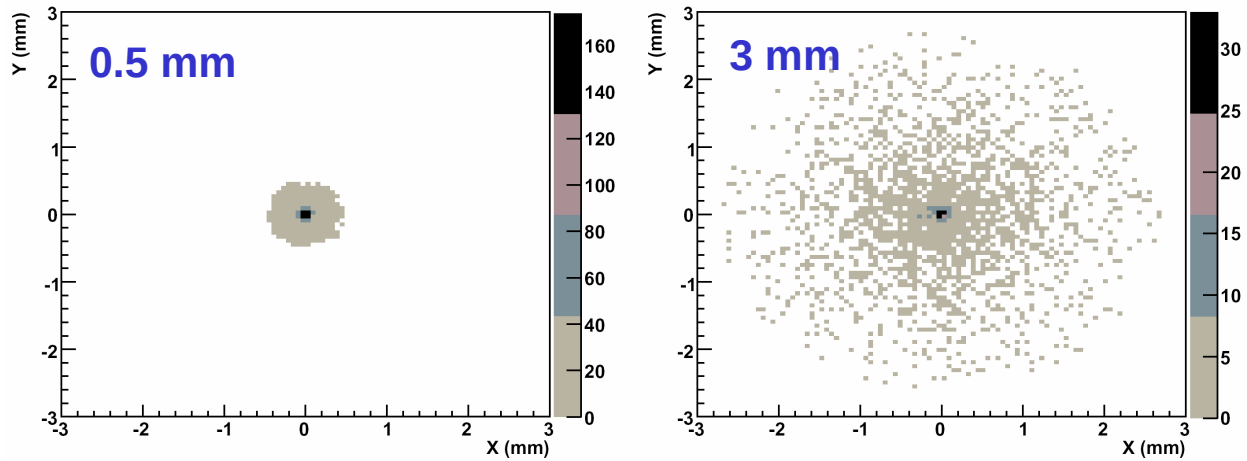
Cherenkov light from a muon



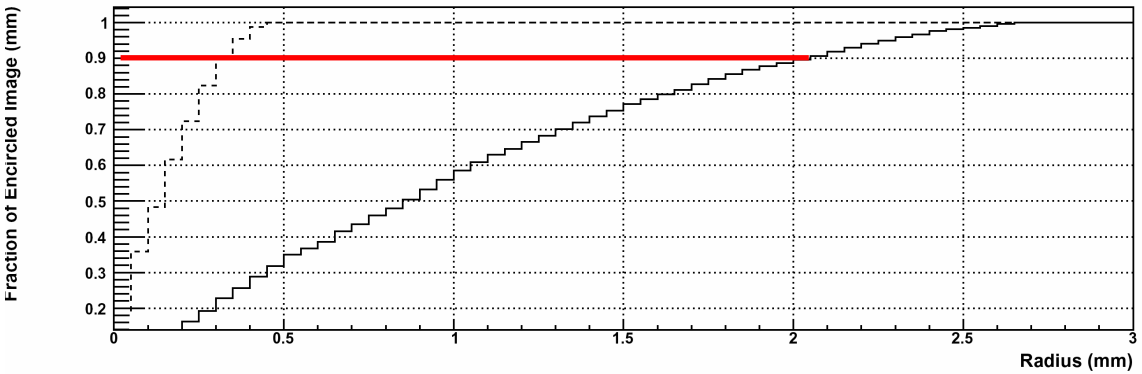
Studies of Fresnel optics performance

Point spread function vs groove size

On-axis, monochromatic light (λ=320 nm)



Fraction of encircled photons vs radius

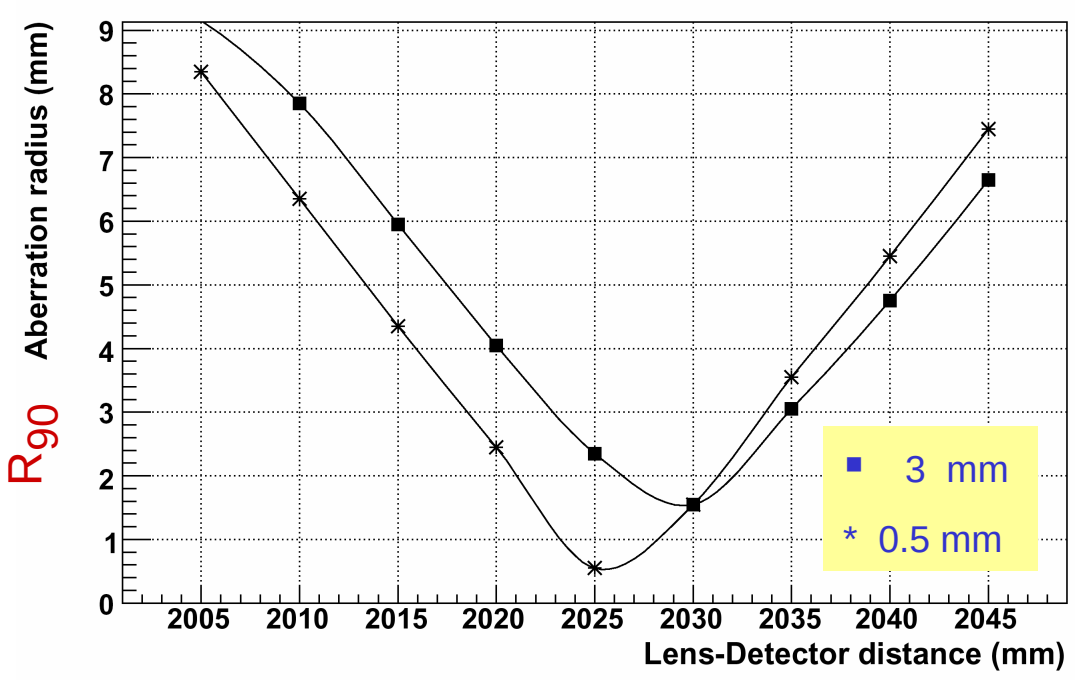


Studies of Fresnel optics performance

Optimal focal distance vs groove size

R_{90} vs Focal distance

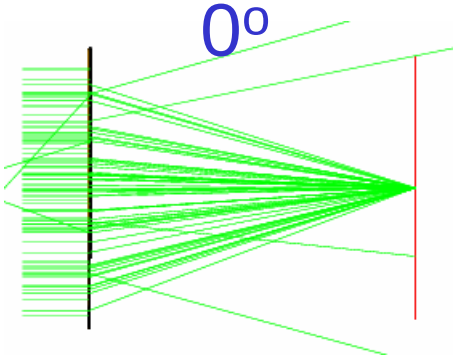
On-axis, monochromatic light (λ=320 nm)



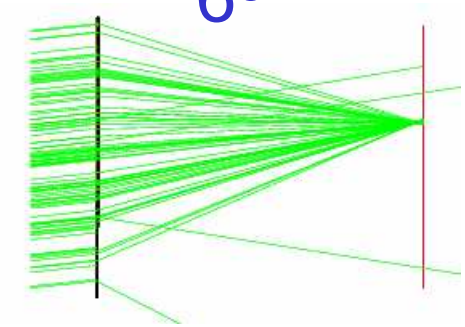
Studies of Fresnel optics performance

Off-axis performance

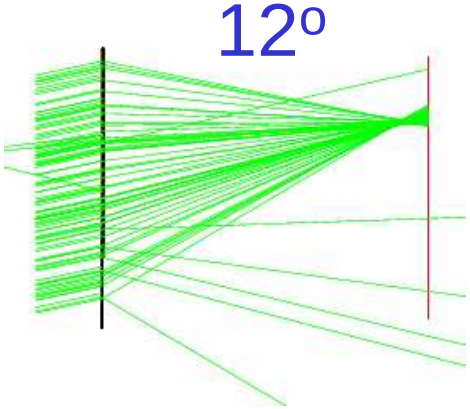
0º



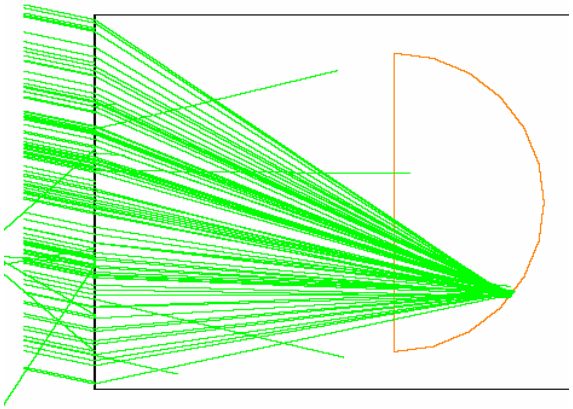
6º



12º



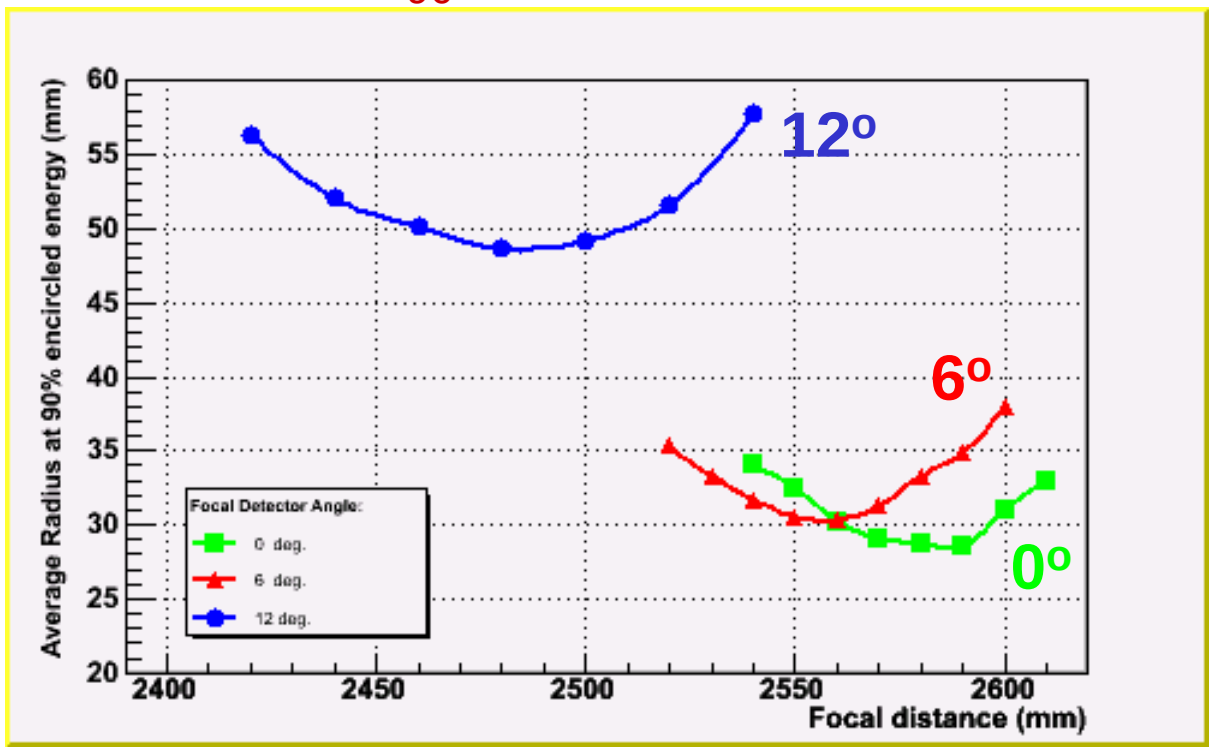
Curved Focal Surface



Studies of Fresnel optics performance

Off axis performance optimization

R_{90} vs Focal distance

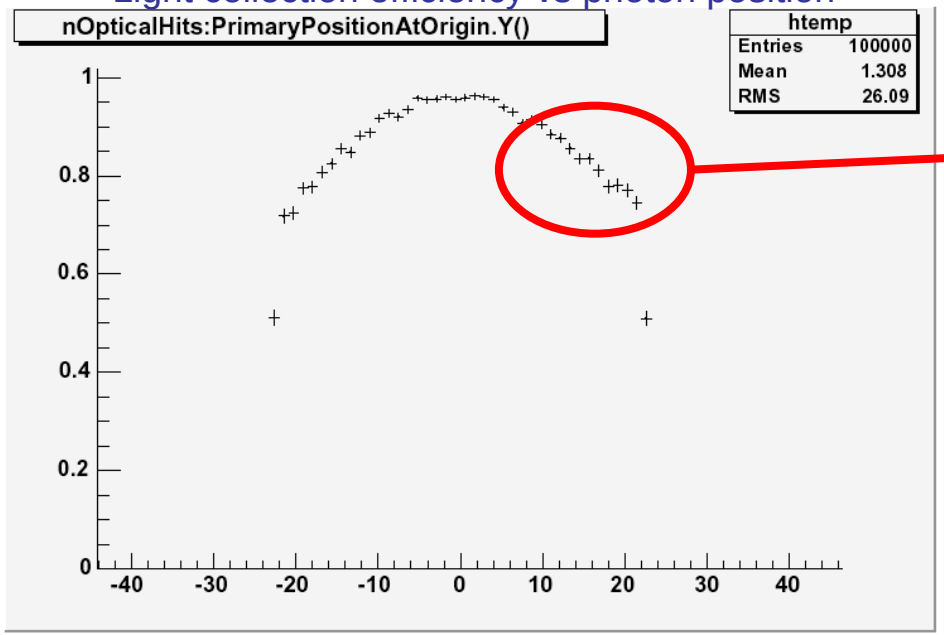


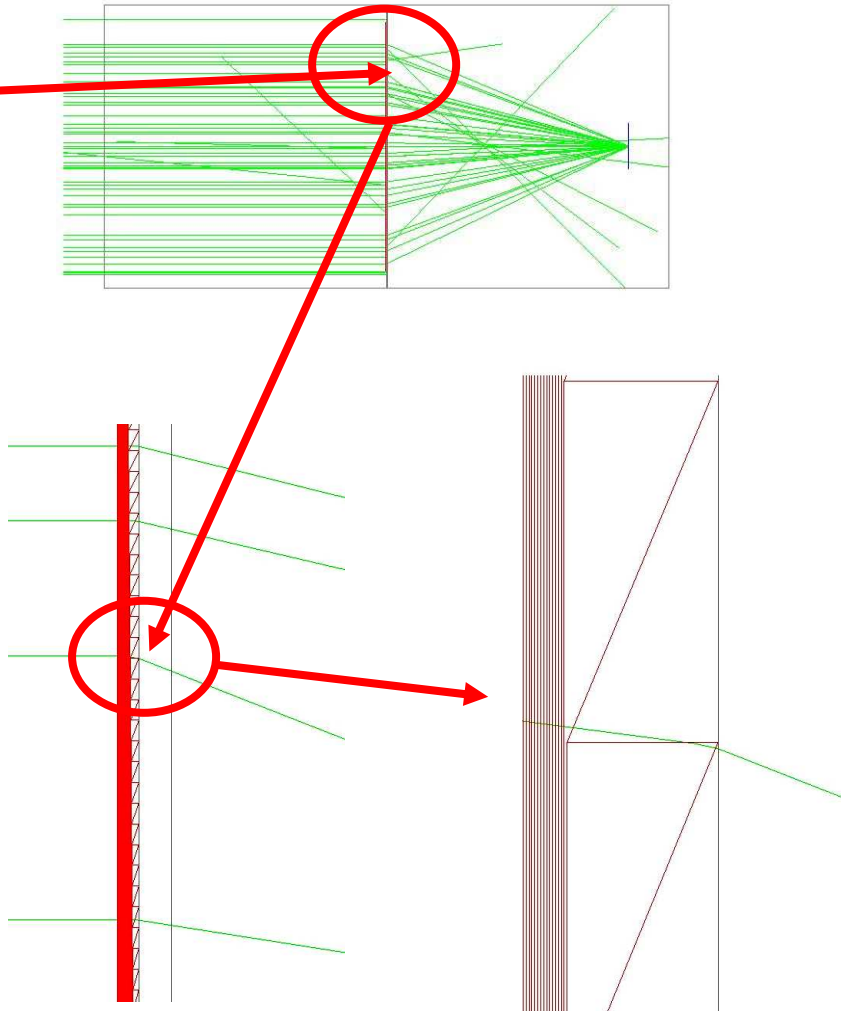
Photon´s spectrum = Cherenkov x Quantum efficiency.

Studies of Fresnel optics performance

Light collection efficiency

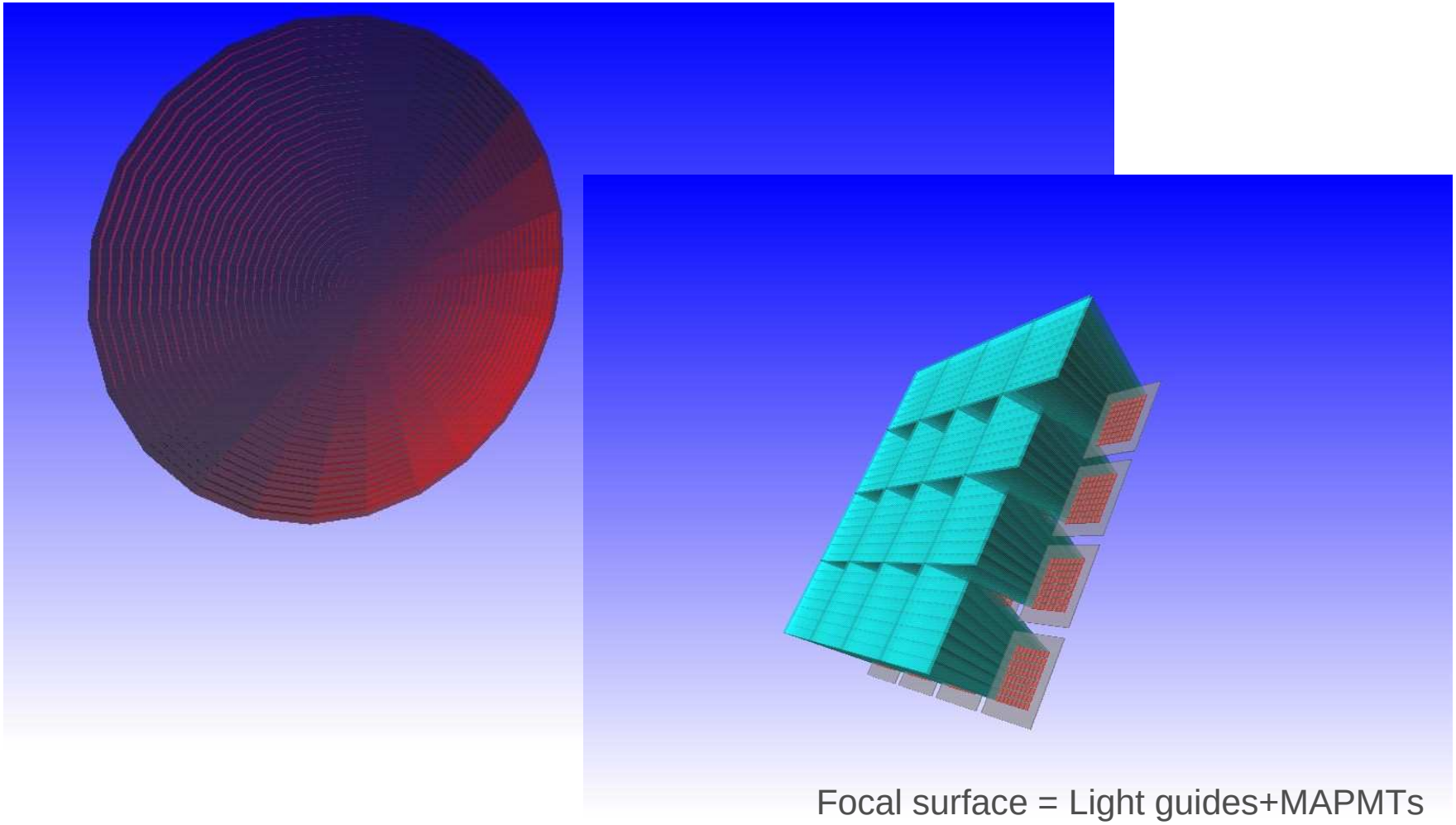
Light collection efficiency vs photon position





IACT simulation (under development...)

Lens + Focal surface simulation



Focal surface = Light guides+MAPMTs

Summary

- Geant4 potential explored in detailed studies of Fresnel lens performance.

- Complete simulation of a IACT using Fresnel optics is being set.

- Geant4 advanced example using a Fresnel lens is available.