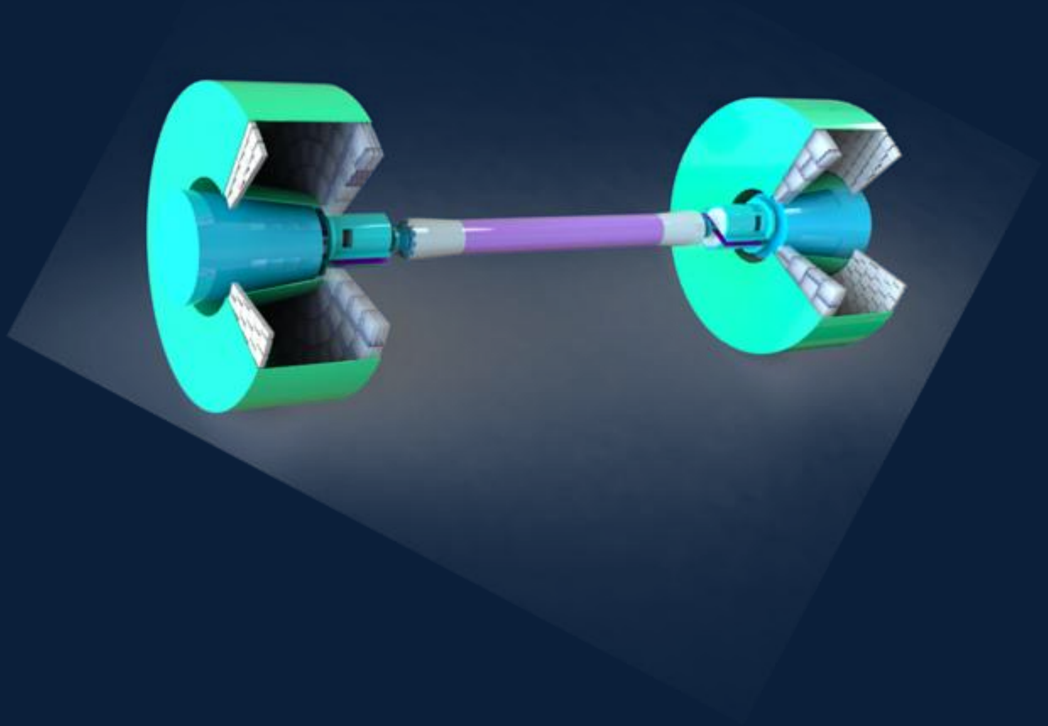
CEPC · Endcap Aerogel RICH

Endcap Aerogel RICH Standalone Optical Simulation Progress

Zemax Ray Tracing × Geant4 Photon Generation



Haojie, Dong / IHEP
Date: 2026-07-20

Agenda

Four parts

1 **Zemax Optical Setup**
Detector size · material / index · mirror on/off

2 **Link to Geant4**
G4 generates photons; handoff & references

3 **G4 Setup & Four Sources**
Simulation setup → four sources in Zemax

4 **Discussion & Next Steps**
Findings · open questions · next steps

PART 1

Zemax Optical Setup

Detector geometry · materials & refractive index · mirror on/off

Ansys Zemax OpticStudio

Subtitle: Optical Design & Ray-Tracing Software · Overview

What it is

A mainstream optical-engineering package for lens design, illumination systems, and detector ray-path modeling & ray-tracing analysis. Now maintained and released by Ansys.

Core capabilities

3D geometry modeling

Quickly build mirrors / cylindrical walls & other structures

Materials & refractive index

Define aerogel n(λ) via the user glass catalog
Supports fixed index or a dispersion formula

Ray tracing

Verify photon paths, refraction & focusing
Detector Viewer for spot/hit distribution

Division of labor with Geant4

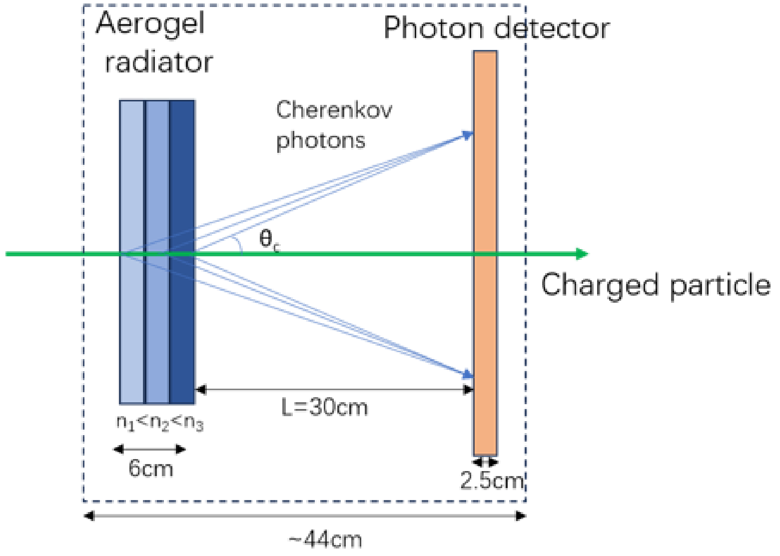
Zemax: fast optical-layout validation
Geant4: full physics & PID performance

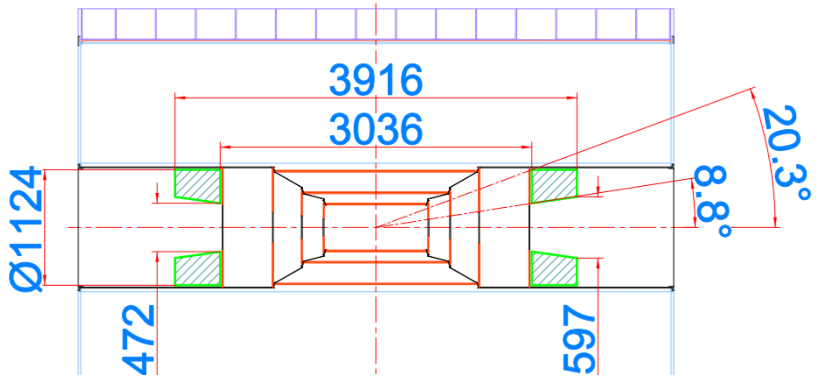
Role in our project

Optical-layout validation for the CEPC endcap aerogel RICH: proximity-focusing gap (300 mm), multi-layer aerogel stack, mirror-shape selection, and whether Cherenkov photons reach the SiPM detector. A low-cost layout screening before the full Geant4 simulation.

Detector Geometry & Structure

Proximity-focusing aerogel RICH (hollow annular frustum)





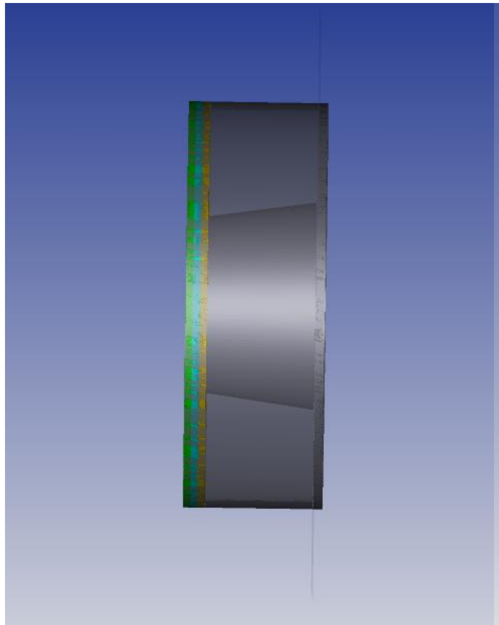
Component / Parameter	Value
Aerogel front-face Z	1518 mm (origin = IP)
Radiator	3 aerogel layers, 20 mm each (60 mm)
Proximity gap	300 mm (air)
Photon detector	SiPM, ~25 mm
Shape	Hollow annular frustum (cone + cylinder)
SiPM annulus	Rin = 287 mm, Rout = 562 mm
Polar-angle range	~8.8° – 20.3° (location 2)
Inner cone / outer cyl.	Reflective coating

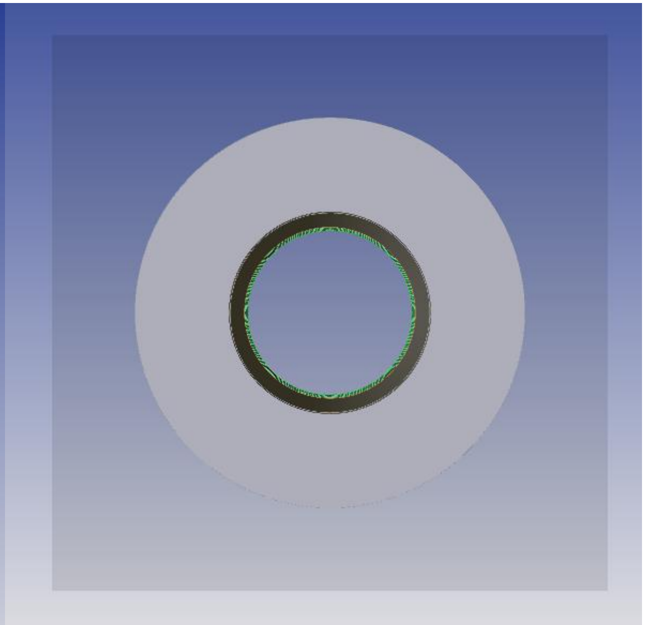
From CAD design file(.stl)

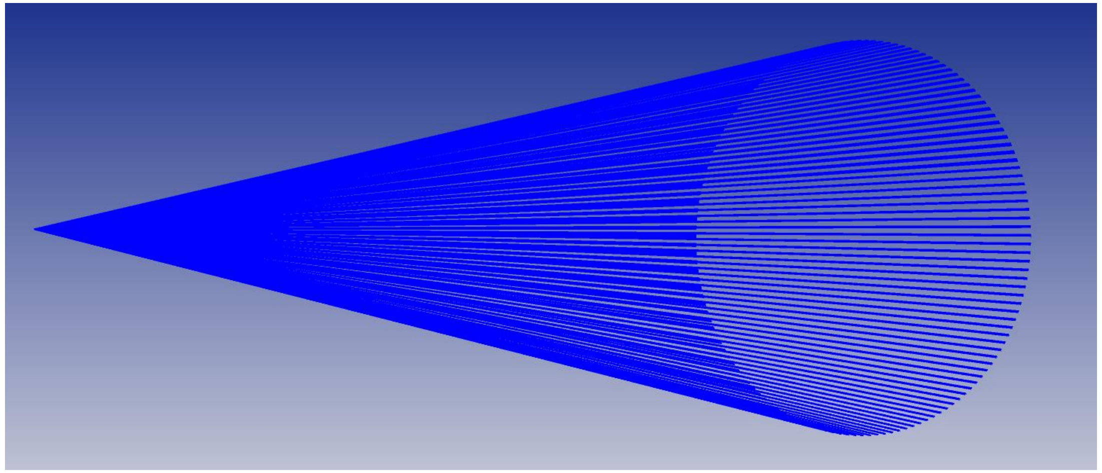
Materials & Refractive Index

User glass catalog USER_AGF · index & dispersion formula

- **Three aerogel layers (USER_AGF.AGF)**
  · AEROGEL1 / 2 / 3: n = 1.008 / 1.009 / 1.010
- **Reflective films**
  · ideal material
  · when Film ON, R=100%; OFF, R=0%(absorbing)
- **Photon detector**
  · SiPM object — **placeholder only** (geometry / visualization, not sensitive)
  · Actual readout: Zemax built-in rectangular detector
  · 800 × 800 mm, pixel size 1 × 1 mm
  · Only hits inside the annulus (Rin–Rout) are analyzed
- **Light source**
  · Conical point source modeling the Cherenkov emission
  · 360 rays; cone half-angle = Cherenkov angle θc ≈ 7.2°
  · Wavelength range 0.3 – 0.7 µm ·
- **Dispersion: disabled for now**
  · No measured aerogel n(λ) yet → constant n
  · Add wavelength dependence after BINP / Fudan tests



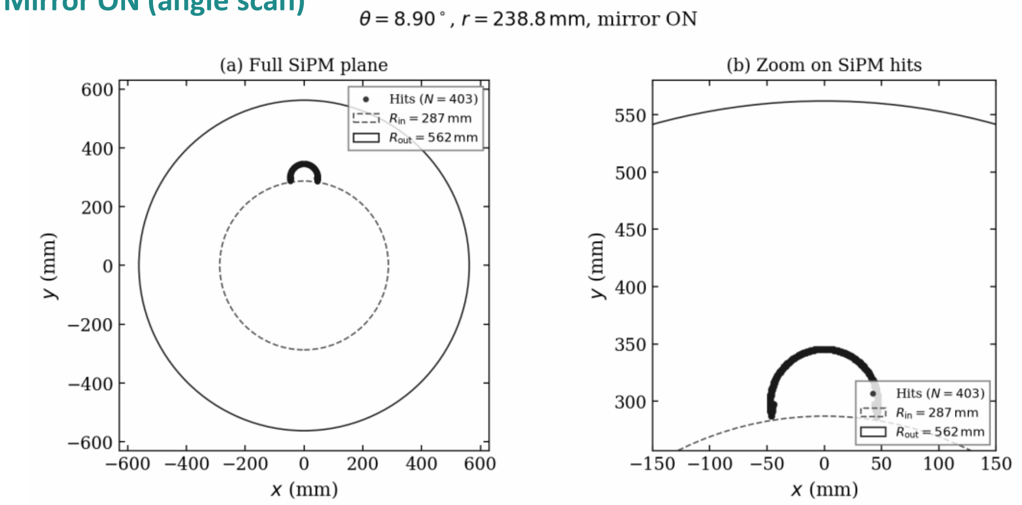




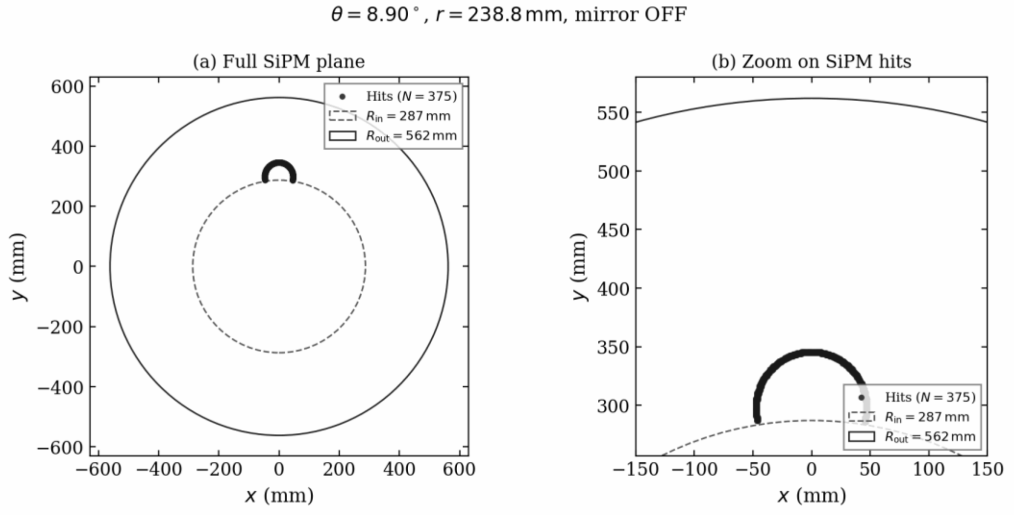
Mirror Configuration & On/Off Comparison

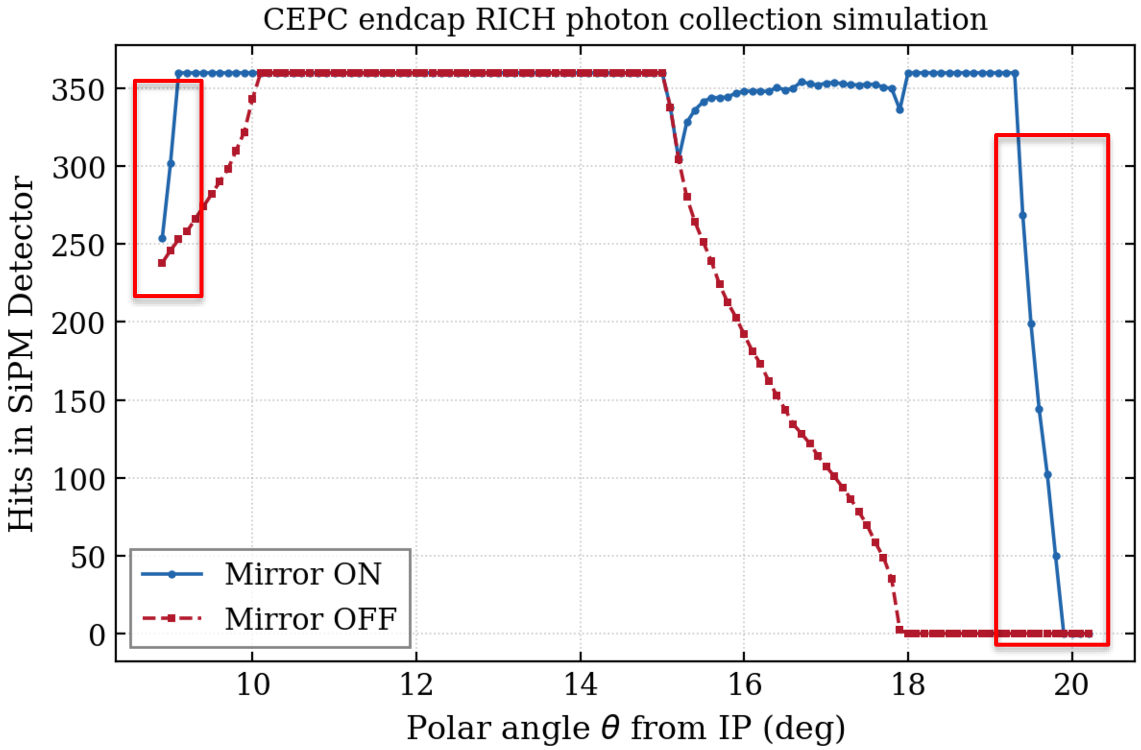
Inner cone + outer cylinder: ideal reflector, R = 100%

Mirror ON (angle scan)



Mirror OFF (angle scan)





- **Mid 10–15°: ON ≈ OFF**
  - · Direct light already sufficient
- **Large >15.5°: outer cyl. recovers**
  - · Direct light exits boundary, reflected back, mirror substantially increase photon collection
- **Small <10°: inner cone helps**
  - · without mirror: half ring only, collection 57-100%

PART 2

Link to Geant4

G4 generates photons, Zemax does the optical tracing

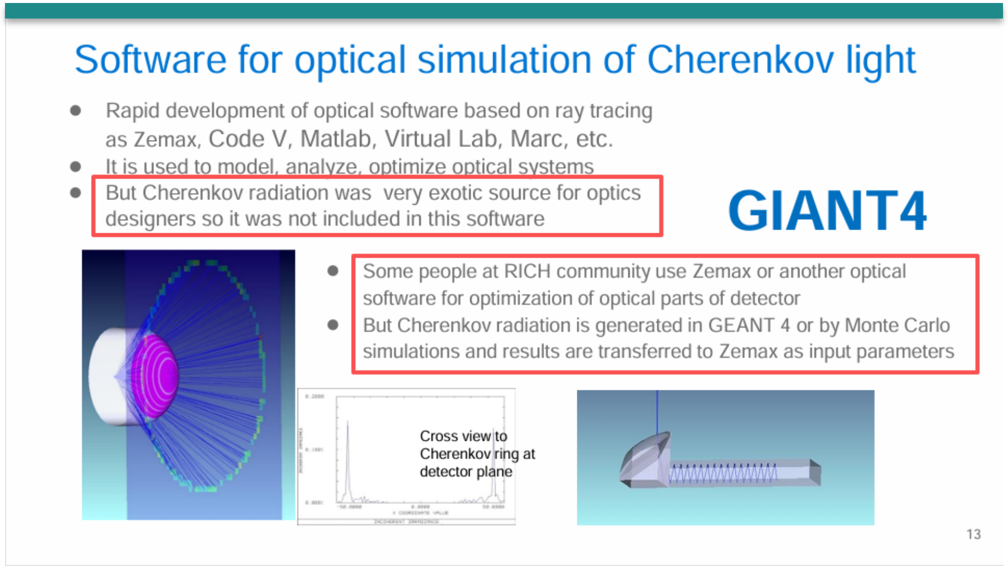
Why Geant4: Photon Generation vs Tracing

OpticStudio cannot self-generate Cherenkov radiation

Charged particle in aerogel → Cherenkov / Rayleigh / absorption / exit refraction → ★ Handoff: generated photons as inputfile → Zemax: mirror + cavity + SiPM(?)

First three steps in Geant4; after exit → Zemax

- **G4 side (physics inside aerogel)**
  - · Cherenkov, Rayleigh scattering, absorption, boundary refraction
- **light source form G4— per exit photon**
  - · position (x,y,z) + direction (ux,uy,uz) + wavelength weight
  - · → export Zemax Source File (global coords baked in)
  - · **source now starts at the aerogel exit face, not inside the bulk**
- **Zemax side (optics after aerogel)**
  - · mirror + cavity + SiPM annulus collection
  - · aerogel scattering / absorption not recomputed



M. Šulc, "Optical components and technologies for RICH application," talk at CERN, Geneva, April 2025.

PART 3

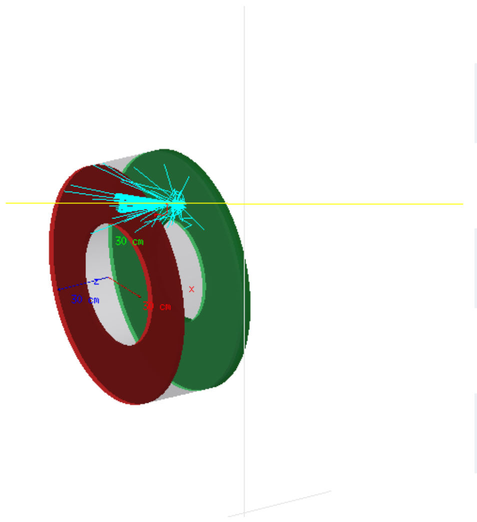
G4 Setup & Four Sources

Simulation setup → four simple sources in Zemax

Geant4 Simulation Setup(very preliminary)

Geometry per spec · full optical processes · θ particle gun

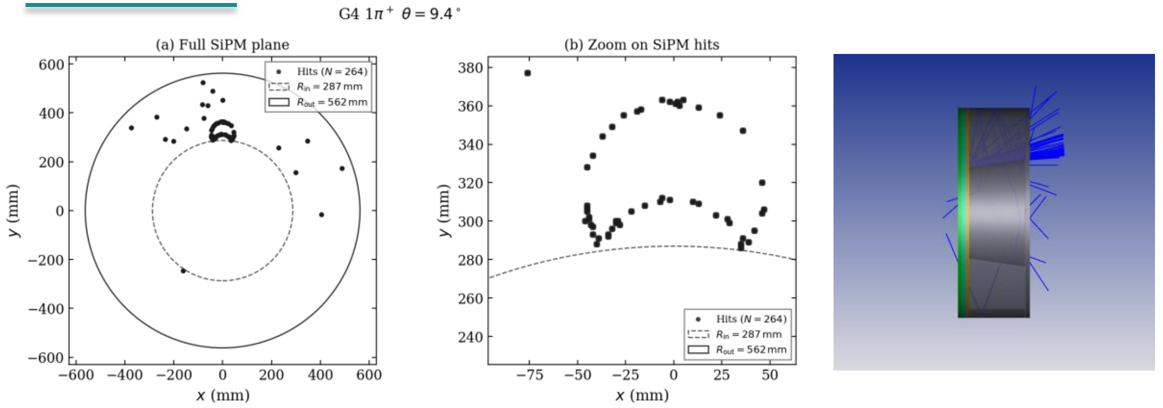
Item	Configuration
Geometry	+Z endcap; 3 aerogel layers + inner cone + outer cyl.; origin=IP; aerogel Z ≈ 1518–1578 mm
Physics list	G4EmStandardPhysics_option4 + G4OpticalPhysics
Optical processes	Cherenkov, Rayleigh scattering, absorption
RINDEX	1.008 / 1.009 / 1.010 (constant, no dispersion)
Rayleigh length	40 mm @ 400 nm ($\propto \lambda^4$)
Absorption length	4 m
Particle gun	π^+, 10 GeV/c, from IP
Scan angles θ	9.4° / 11.5° / 15.4° / 19.5° (aligned with Zemax by_angle)
Record / export	photon entering air → .dat / .csv (Zemax Source File)

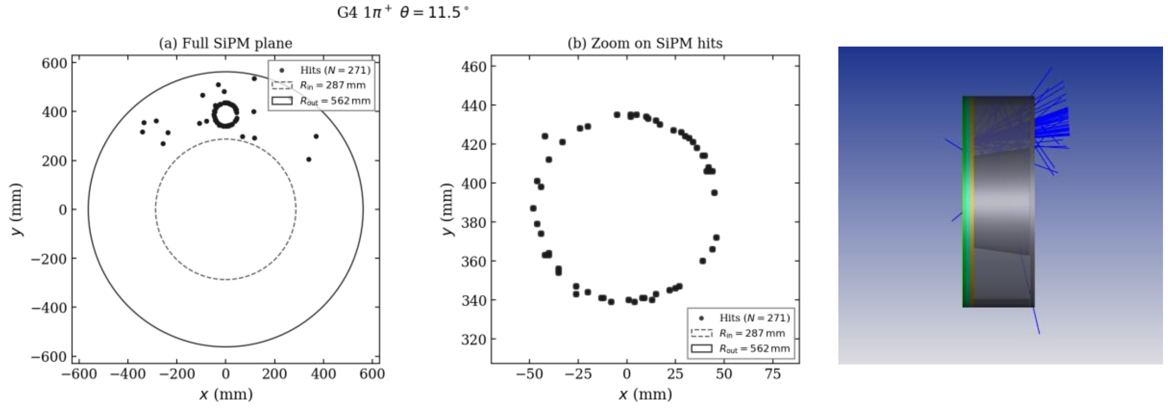


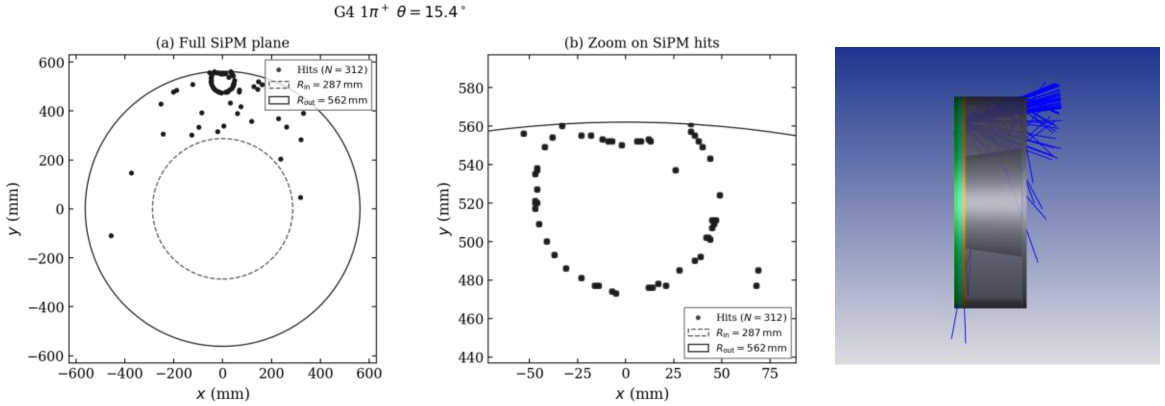
At this stage G4 only generates & exports exit photons; mirror / SiPM collection handled in Zemax

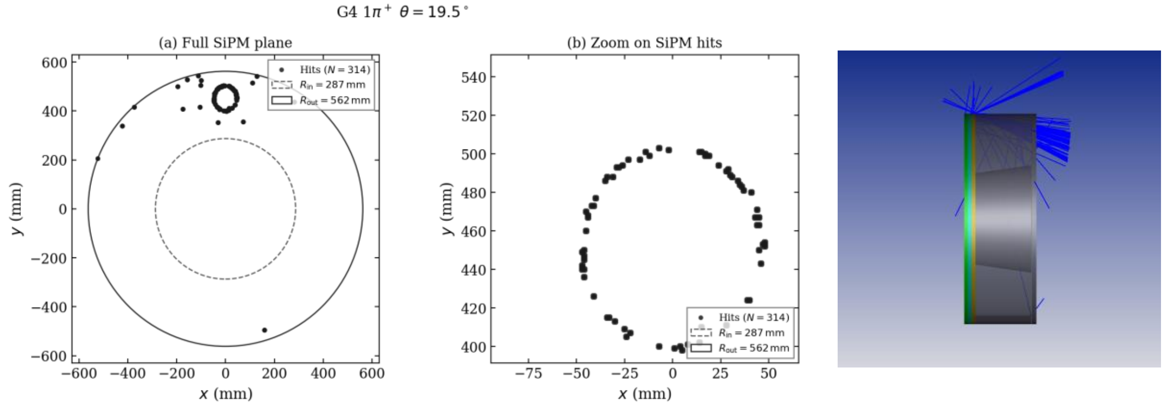
Four Simple Sources in Zemax

G4 photons → Zemax tracing; clear Cherenkov rings on the SiPM plane







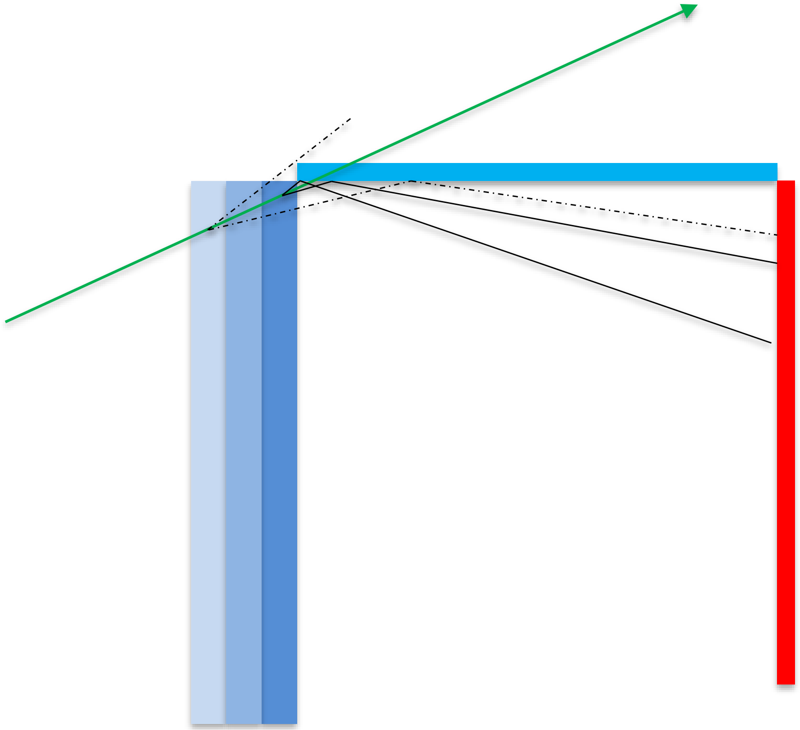


θ	9.4°	11.5°	15.4°	19.5°
Exit photons	78	76	88	117
Annulus collection	91.0%	93.4%	93.0%	74.2%

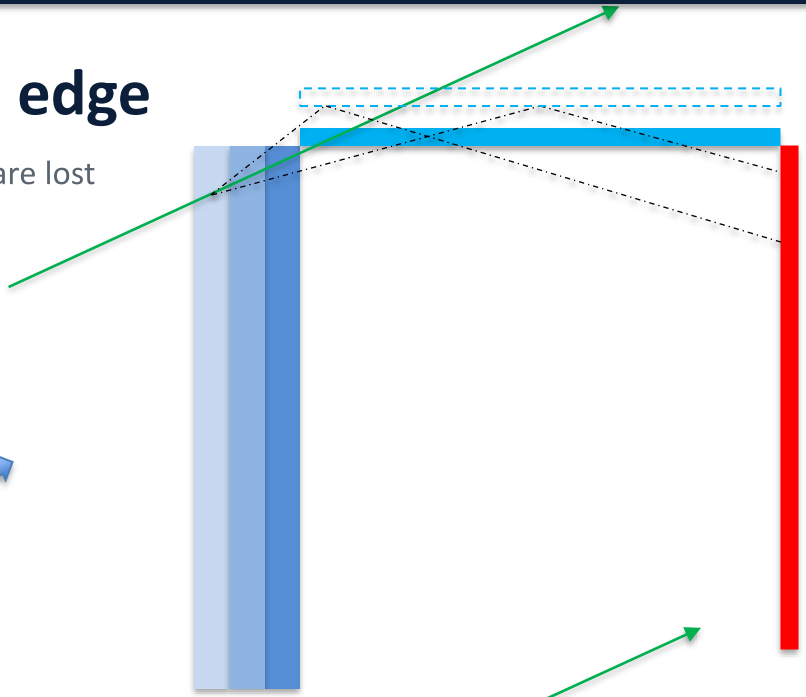
Ring radius grows with θ (r ≈ Z·tanθ); at 15.4° the ring top is slightly clipped by Rout = 562 mm

Large-angle photon loss at the aerogel edge

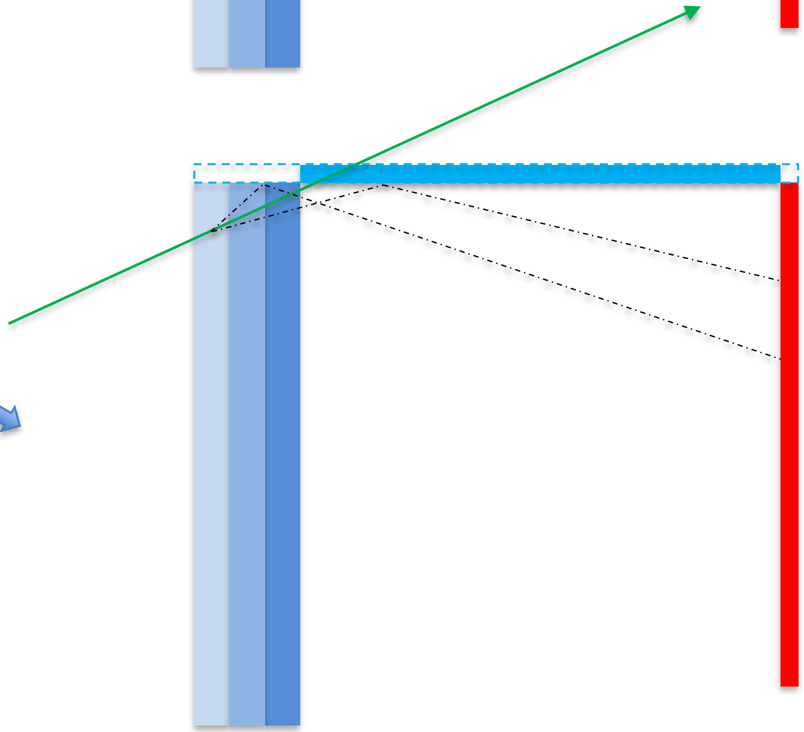
At large θ, part of the Cherenkov photons escape past the outer edge and are lost



Photons generated far from the mirror are missed;
those generated near it are still collected, completing the Cherenkov ring.



recovered by a larger-R (taller) mirror



by extending the mirror to cover the aerogel

PART 4

Discussion & Next Steps

Findings · open questions · next steps

Discussion

What's validated, and what remains

Finished

1. Optical simulation established (mirror on/off compared)

   · with mirror: >90% collection over the full angular range

2. Cherenkov light generated in Geant4

   · four angular sources produced so far

Open Questions & Discussion

1. Both optical and G4 simulations are at a preliminary stage

   · suggestions / questions welcome

2. Photon hits on the detector: which is more appropriate for simulation — G4 or Zemax?

Next Steps

By priority

1. Mirror studies

Optical simulation for different mirror options — coating material & shape

2. Measured aerogel inputs

Update material parameters from testing data: dispersion, index uniformity

3. More realistic modeling

Refine the simulation — current model is too idealized

Thank You

Questions & Discussion