Engineering LiDAR Systems Using Physics-Based Optical Simulations

Introduction

LiDAR (Light Detection And Ranging) is a remote sensing technology that uses laser pulses to measure and generate high-resolution 3D maps of environments. It is a critical enabler for:

- Autonomous driving
- Robotics and drones
- Smart cities and infrastructure
- Industrial automation

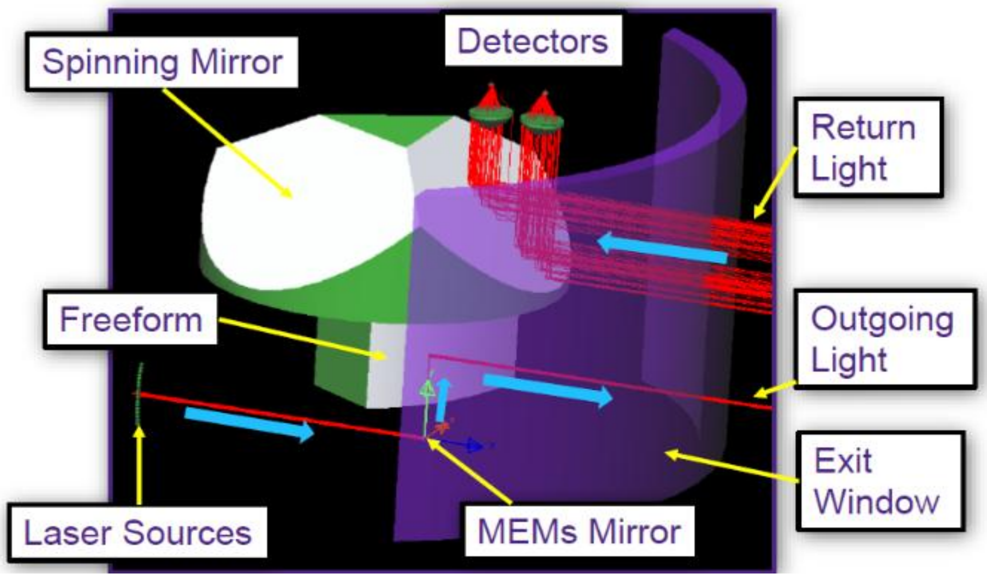
LiDAR works by emitting laser pulses and measuring the **Time-of-Flight (ToF)** of reflected signals to reconstruct spatial information.

LiDAR System Architecture

A complete LiDAR system includes:

- Transmitter- Laser source, beam shaping optics
- Propagation medium – atmospheric effects (fog, dust, rain), scattering and absorption
- Target Interaction – reflectivity, surface properties
- Receiver – collection optics, photodetectors
- Processing – signal extraction, 3D points cloud generation

Simulation Workflow Using CodeV an LightTools- Application Example



In this case study we will consider a fixed-body LiDAR system with a large FOV.

Specifications

- Vertical Field of View: +/-6deg
- Horizontal Field of View: +/- 50deg

The **vertical field of view** is accomplished using an array of17 fiber laser aimed at a MEMs mirror.

– Vertical laser separation = 0.75deg

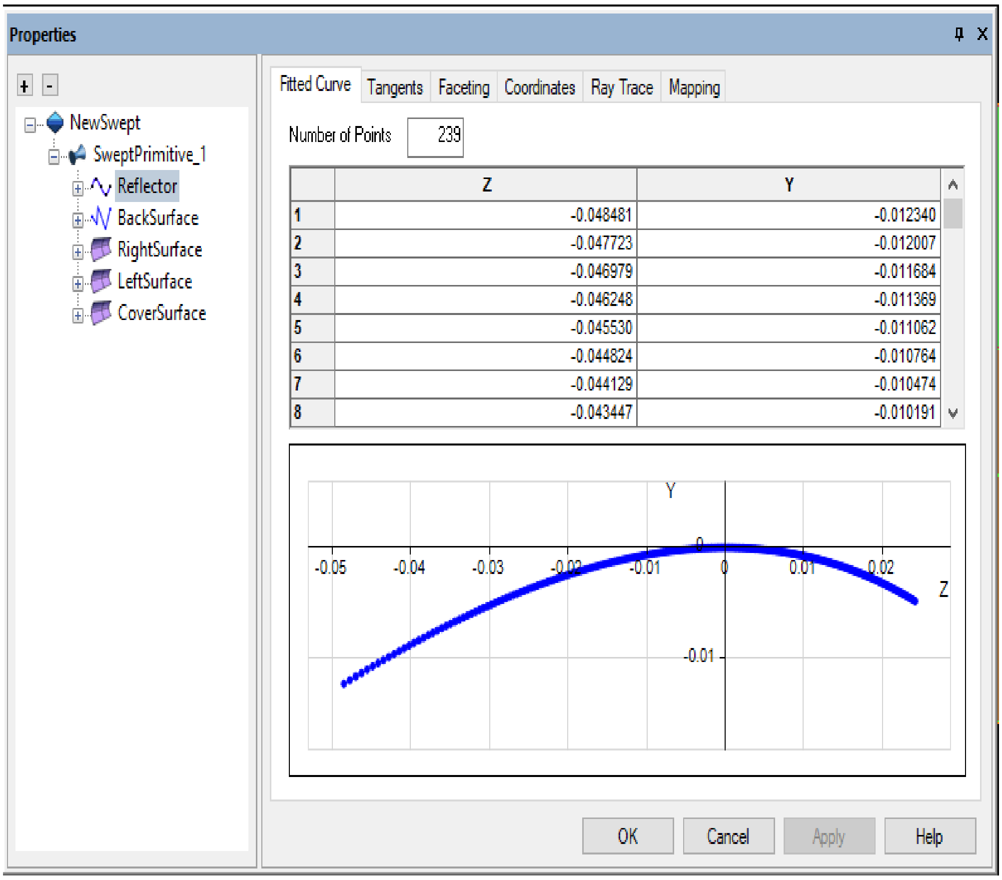
– Mirror travel range = +/-5deg

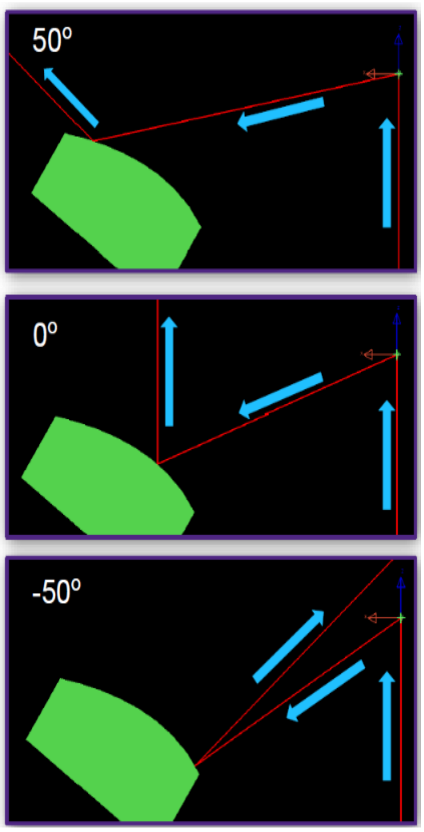
The **horizontal field of view** is accomplished by scanning a MEMs mirror that reflects light onto a freeform that amplifies the scan angle.

Return light is gathered **by two fast photomultiplier devices paired with a spinning mirror** that is synchronized with the MEMs mirror.

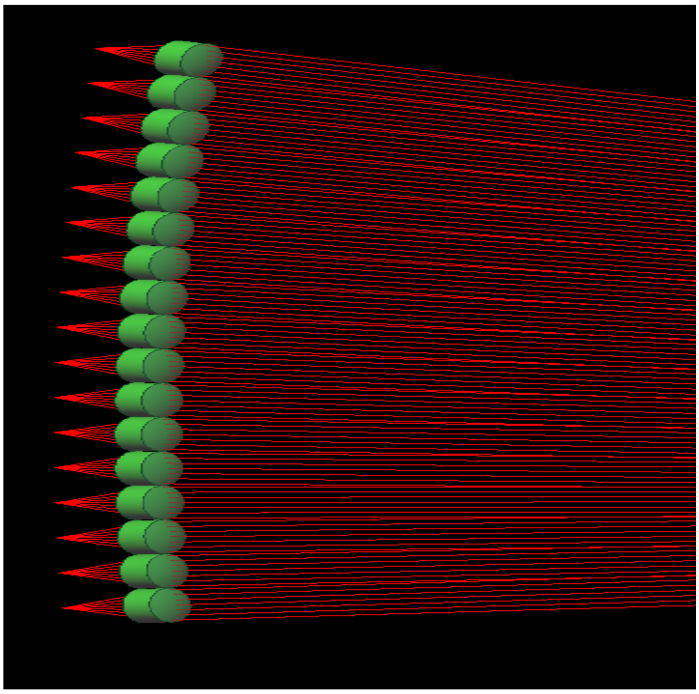
Modelling

➢ **Freeform Mirror -**modelled using LightTools swept primitive



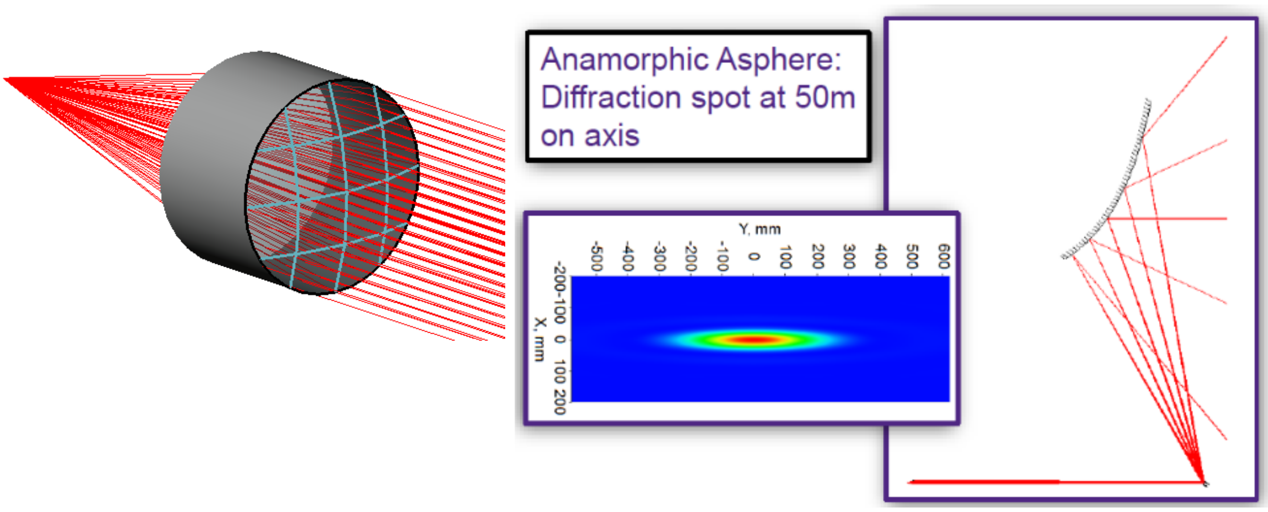


➢ Launch Optics



- Source @ 1550nm
- To stack 17sources in vertical direction, a fiber laser with NA=0.22 from output is designed
- An anamorphic aspheric optics used to collimate beam emerging from fiber.

CodeV used to design and optimize collimating lens.



CODE V's **Beam Synthesis Propagation (BSP)** algorithm to model the propagation of source through model target

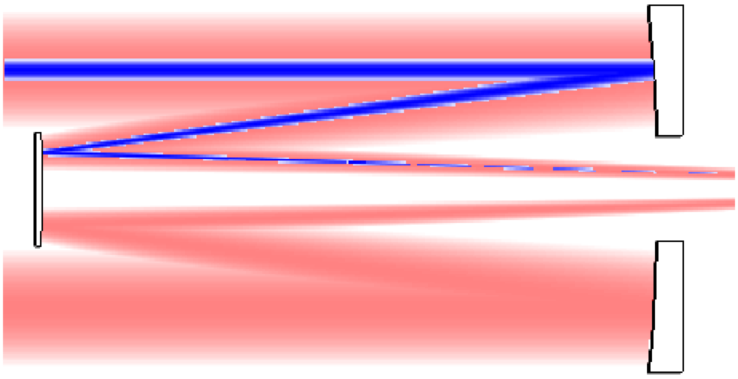


Fig: Light beam (red) modelled as a coherent sum of beamlets. Single beamlet shown in blue.

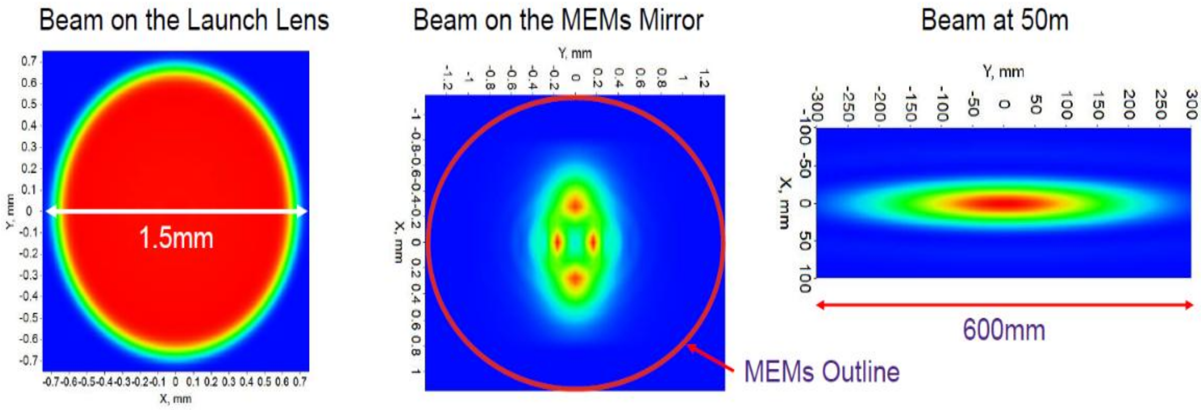


Fig: BSP results

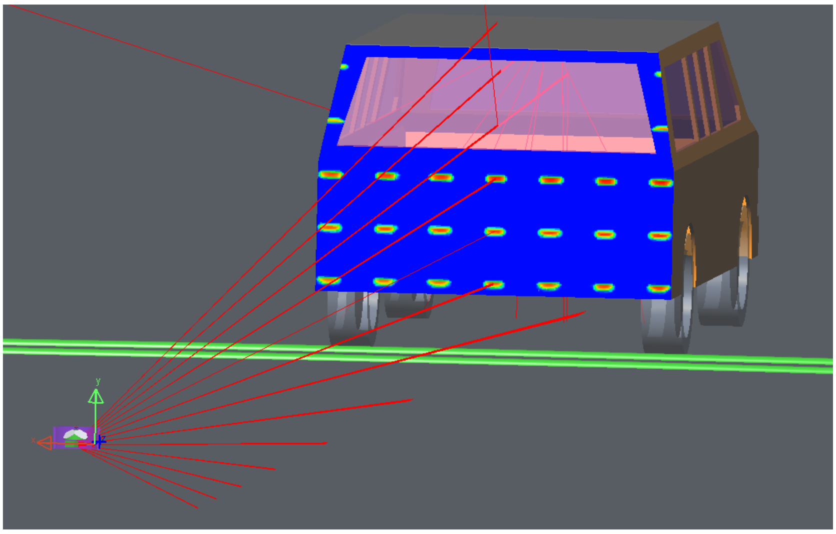
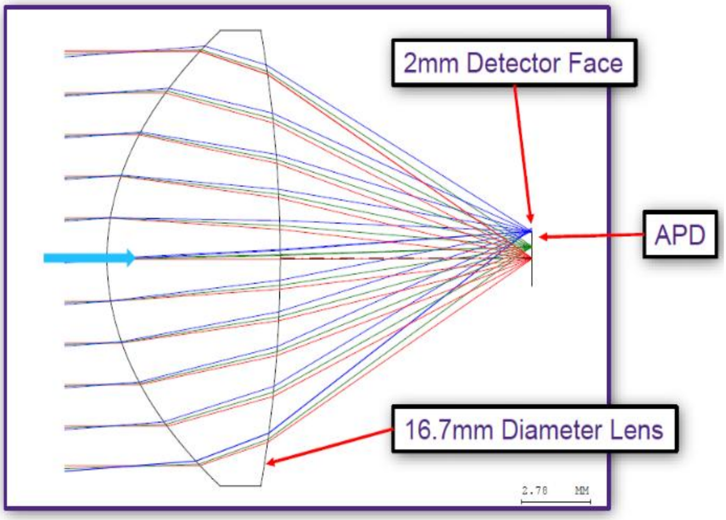


Fig: Propagation to Van target with 50% reflective Lambertian surface

➢ CodeV Detector Lens Design

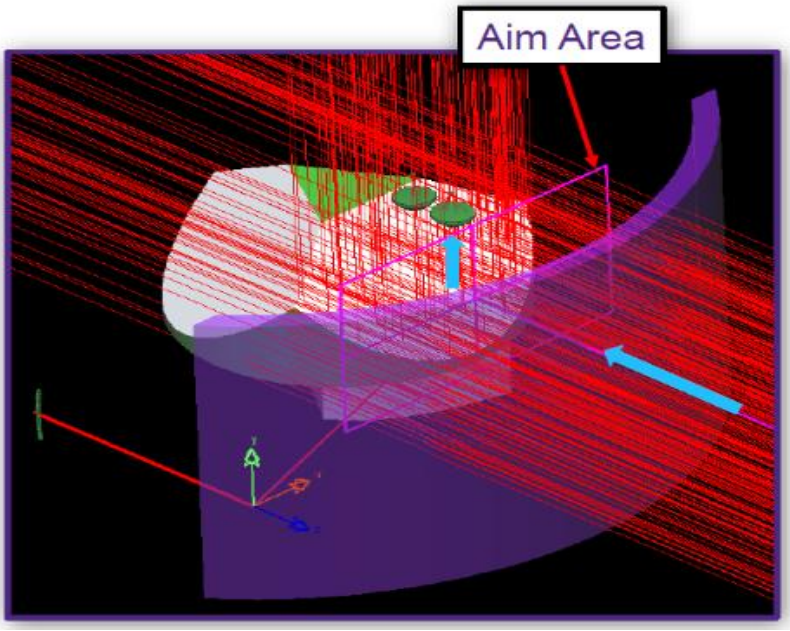
The lens was designed as a singlet with an asphere on the front and a spherical surface on the back.



Each detector covers roughly an 8deg field of view. Two detectors are needed to cover the full 12deg vertical field of view.

➢ Setting up Scattering surface Aim Area

To increase the ray trace efficiency, an aim area was used on the van and road surfaces to direct light back to detector assembly.



For **LightTools Simulation –** forward ray tracing was used.

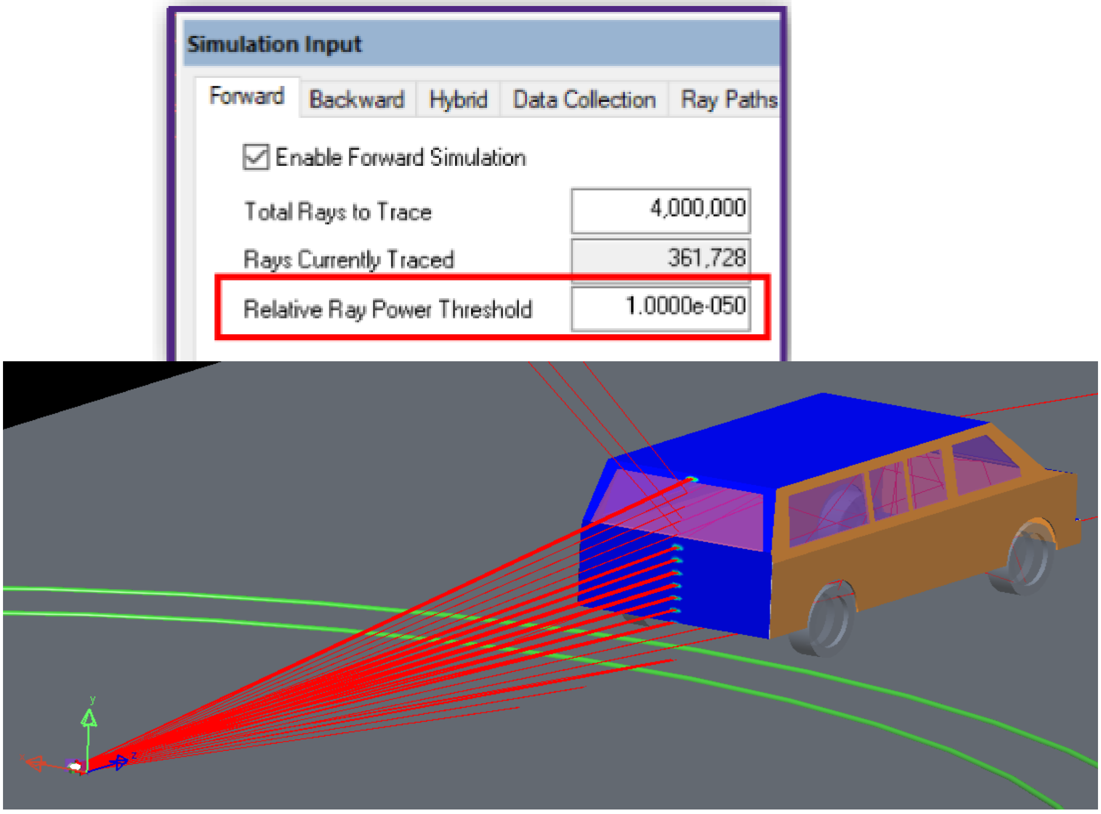
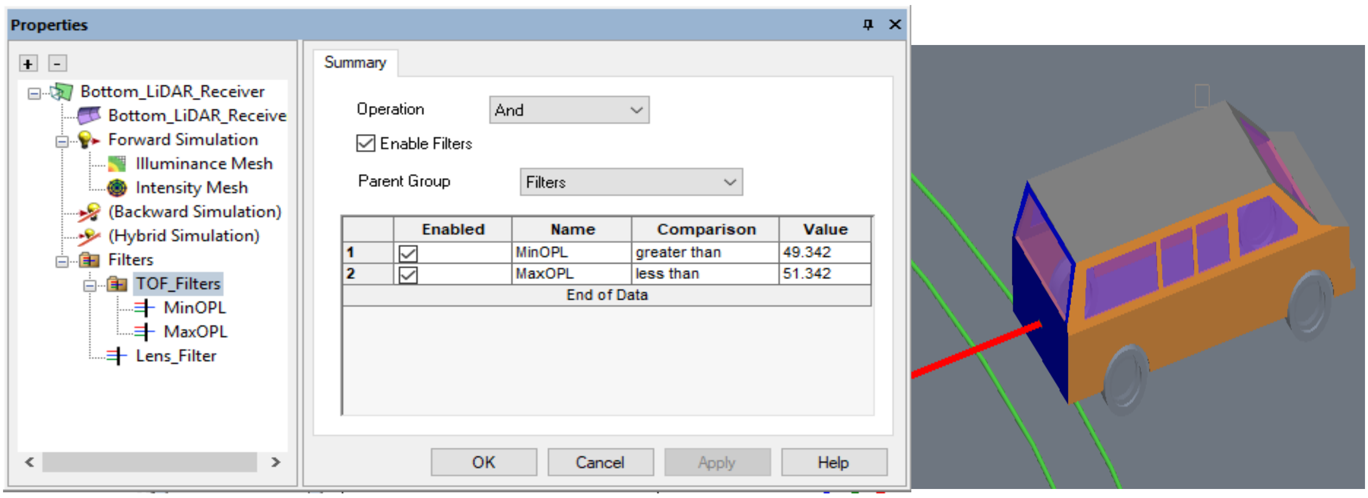


Fig: Full System

➢ Modelling Time-of-Flight in LightTools

To explore the signal-to-noise performance in various atmospheric conditions, it is important to be able to filter out the return signal by the time of flight of the rays.
- detector will find the range to the target.

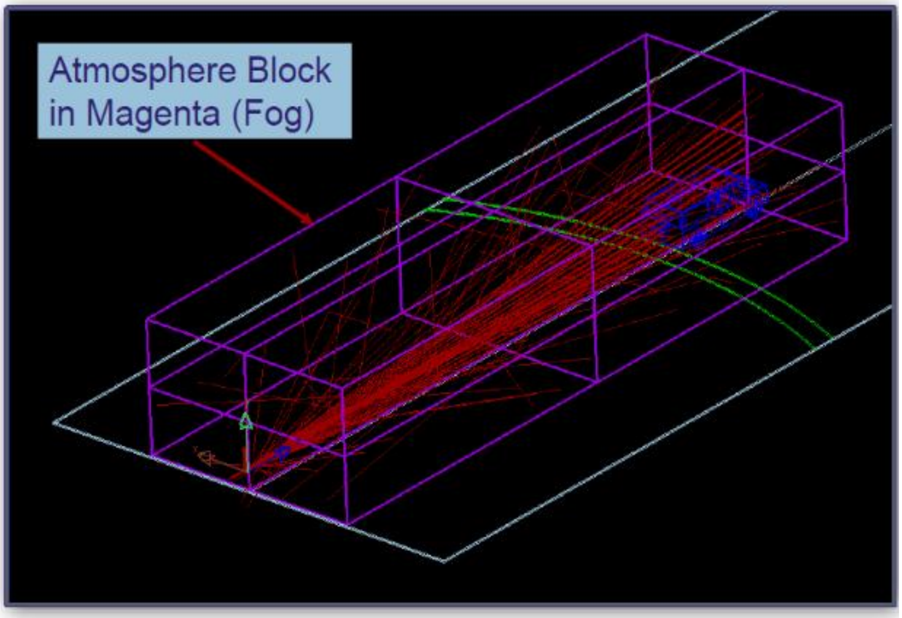
Two **Optical Path Length filters** to set the minimum and maximum length travelled



Modelling Environmental and SNR Effects

To model rain and fog effect, **LightTools volume scattering feature** is used.

- The atmosphere is set up as an air-filled block containing randomly distributed scattering particles
    - The process is handled statistically; particles are not physically present in the model
    - Absorbing sides are used on the atmosphere block to enhance ray trace efficiency
- The density and size of the precipitation droplets can be freely adjusted.



- Raindrops take radius values from 0.5mm to 4mm
    - Raindrop velocity increases with size, ranging from 2m/s for 0.5mm drops to 8.8m/s for 4mm drops
    - Fog droplets are approximately 5.5µm in diameter
- Rain accumulation categorized as light, medium, or heavy
    - Light rain: 1mm/hour
    - Medium rain: 6.35mm/hour
    - Heavy rain: 25.4mm/hour

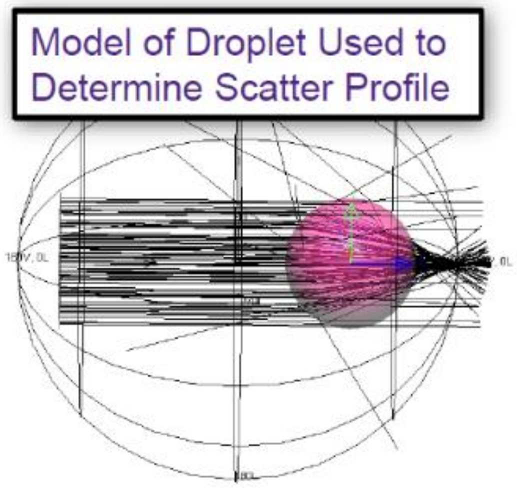
$$Density\left(\frac{drops}{mm^3}\right) = \frac{Accumulation\left(\frac{mm}{hour}\right)}{Velocity\left(\frac{mm}{s}\right) * \frac{4}{3} * \pi * r^3 * 3600\left(\frac{s}{hour}\right)}$$

Setting Up Rain in LightTools

To create rain and fog, a user-defined material with a user-defined volume scattering particle added

- The base material is Air
- Added a user-defined particle
- Particle material is IR Water

To determine the scattering profile, a simple model with a disk source, a water sphere, and a far field receiver is setup as below



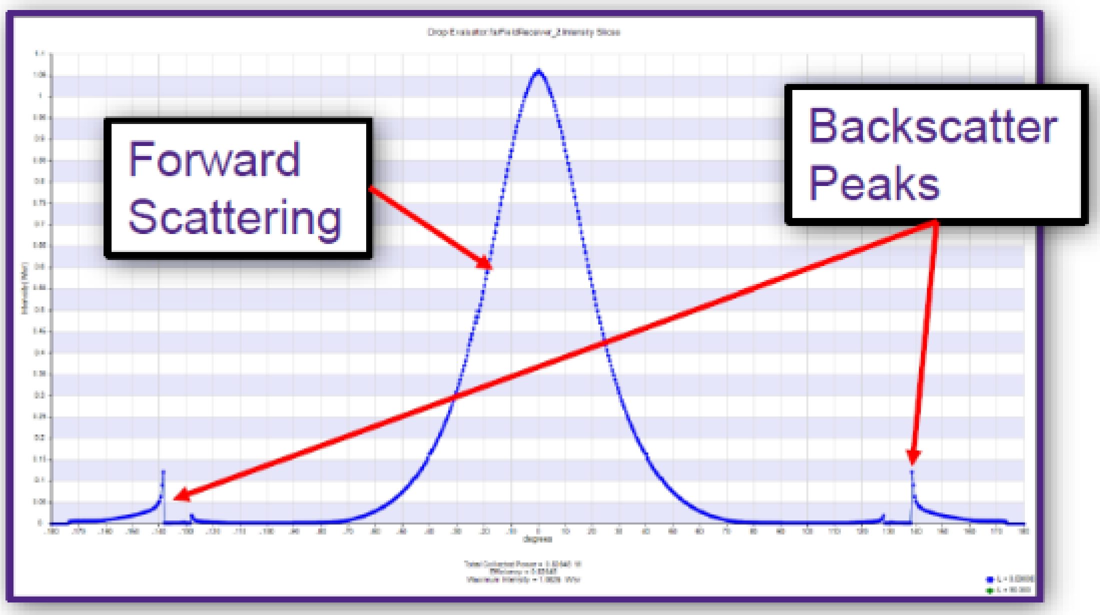
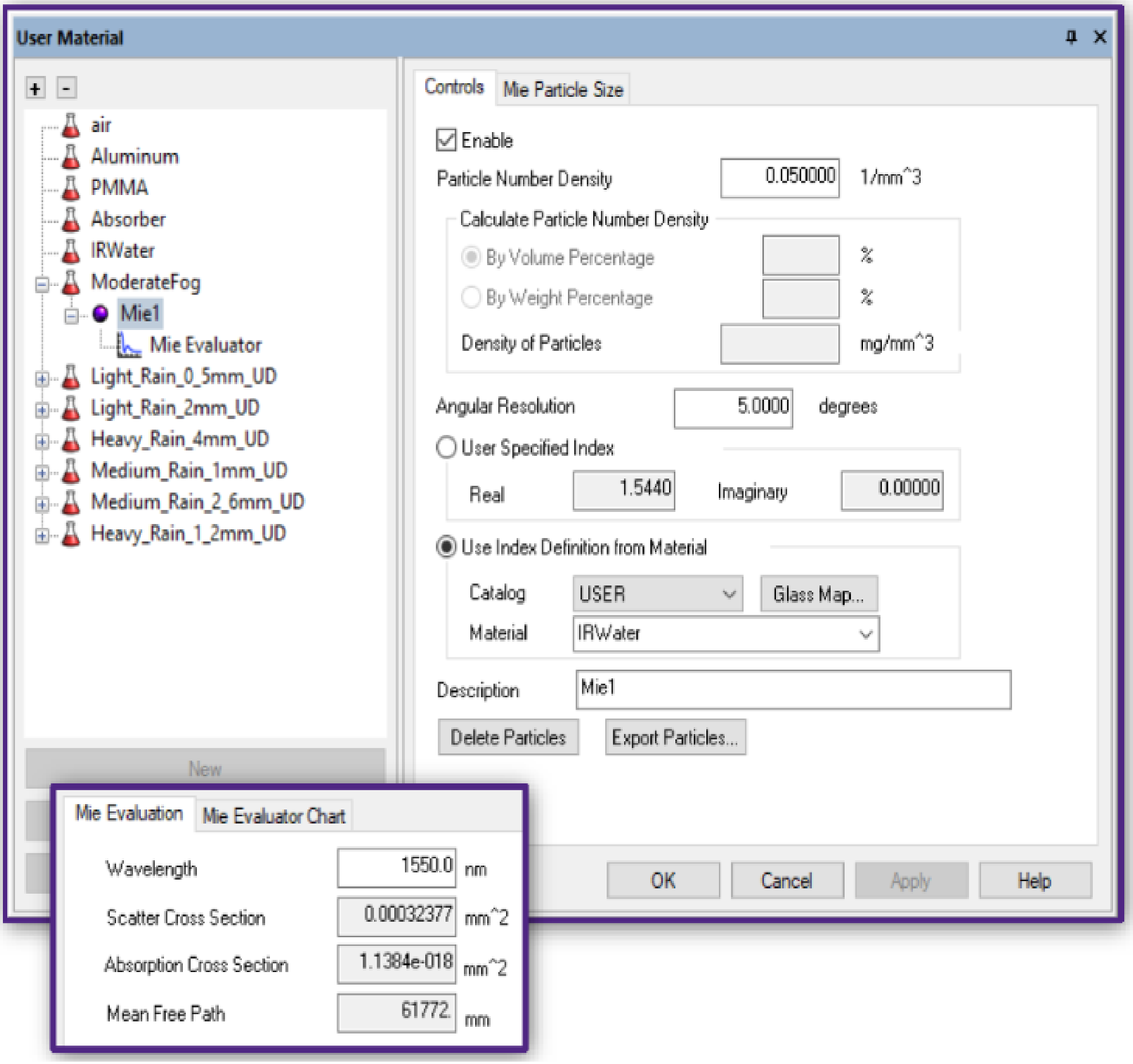


Fig: Slice Data

Setting Up Fog in LightTools

To create the fog atmosphere, a Mie scattering particle with a Particle Number Density of 0.05 particles/mm3 is used.



- **LiDAR Performance comparison under different conditions:**

Precipitation Condition	Drop Radius (mm)	Terminal Velocity (m/s)	Drop Density (m^-3)	Mean Free Path (mm)
Light Rain (1mm/hour)	0.5	0.52	257.5	$2.47\text{x}10^6$
Medium Rain (6.35mm/hour)	1	4.19	104.5	$1.52\text{x}10^6$
Heavy Rain (25.4mm/hour)	1.2	7.24	210.1	$5.26\text{x}10^5$
Moderate Fog	0.007	-	$5\text{x}10^7$	$6.18\text{x}10^4$

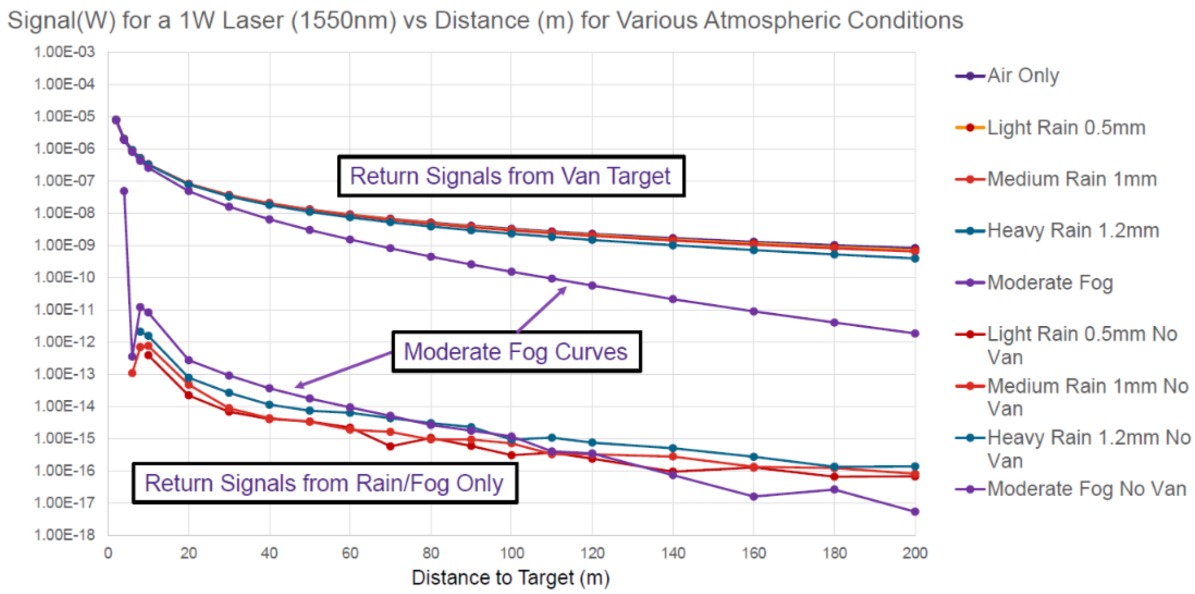


Fig: Return value for various atmospheric conditions

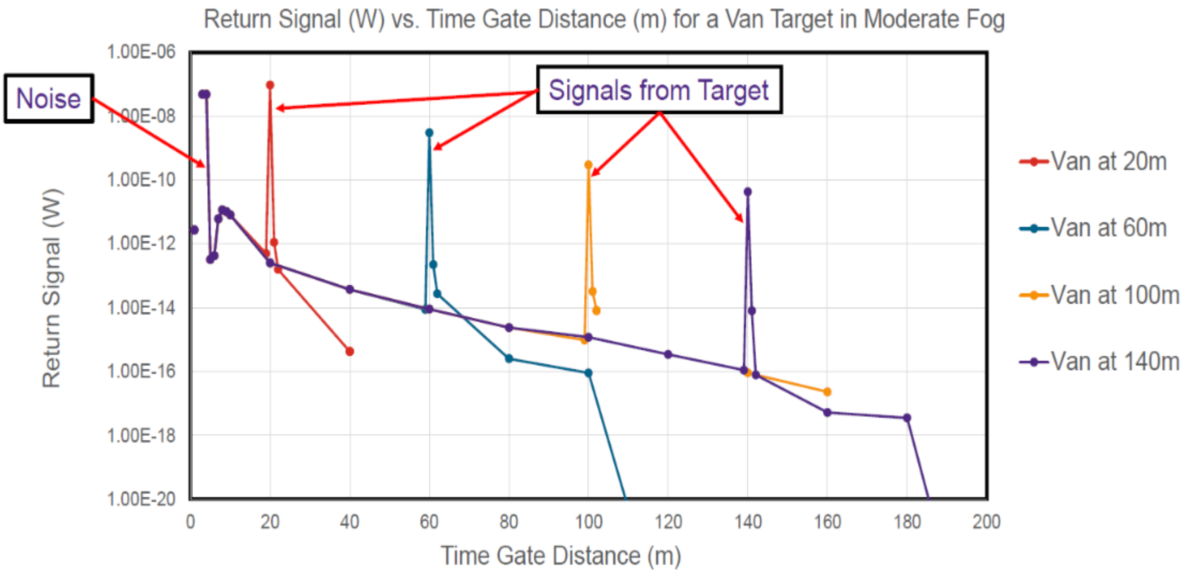


Fig: Signal profile for target in moderate fog at different distances

If you are working on LiDAR or ADAS systems and want to know more about the features contact us at info@fosoptonics.com!