SpecTro

Proof of Concept by photonicEyes

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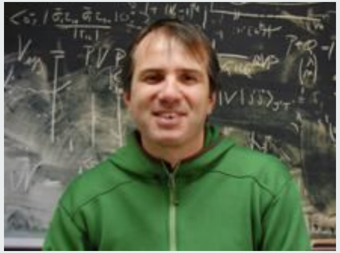


Fabrice Retiere

Research Scientist

Summary

- Many industries need to monitor particulates in the air
- SpecTro is an air particle detector (0.1 - 10 Microns range)
  - High frequency UV LED
  - Scattered light detection using SiPM
  - FPGA to analyze data from SiPM
- Targeting both professional & non-professional market
  - Competitive price

Business Information

Business Case and Costs

- Main reasons for the market growth: air quality degrade, health issues, cheap and counterfeit product
- Competitors are Dylos Corporation, IQAir, Honeywell and etc
- Ideal consumer are institutes that need to monitor and maintain their air space
    - Consumers: Semiconductor, electronics, industrial, and Pharmaceutical manufacturing,
    - Factors: Ambient air monitoring, and Specialty indoor air quality monitoring
- Approximate cost for ENSC 440: CAD $1100 - $3000
- Software/Google cloud computing cost will be ~$100/month
- Sponsored by Senior Scientist Fabrice Retière from TRIUMF

Risk Analysis and Management

- Reliance of simulations to model real physical systems
  - Through experimentations and tests we mitigate this risk
- Will the simulations verify our assumptions for the project and be reliable to the end user ie. size, concentration and shape detection
  - Testing on known sized particles, and verifying correctness
- Requirements being too stringent
  - Simulation software should help
- Reevaluation of the components after manufactured
  - Design must be simulated and confirmed before added
- Product might be more expensive than anticipated
  - After working product need to optimize

Standards Adherence

- ISO 14644-12:2018 - Clean rooms and associated controlled environments, Part 12: Specifications for monitoring air cleanliness by nano-scale particle concentration.
- IEC TR 62471-2:2009: Photobiological safety of lamps and lamp systems - Part 2: Guidance on manufacturing requirements relating to non-laser optical radiation safety
- ISO 14040 and ISO 4044: These ISO standards are guidelines for the life cycle assessment, including a cradle to grave methodology
- ISO 21501-4: “Determination of particle size distribution — Single particle light interaction methods, Part 4: Light scattering airborne particle counter for clean spaces”. Used to set the standard for calibrating SpecTro.

Cradle-to-Cradle

- Recyclable circuit boards and RoHs compliant components
- Using metals which are easily reclaimed
- Using recyclable plastic (ie, PLA or PET)

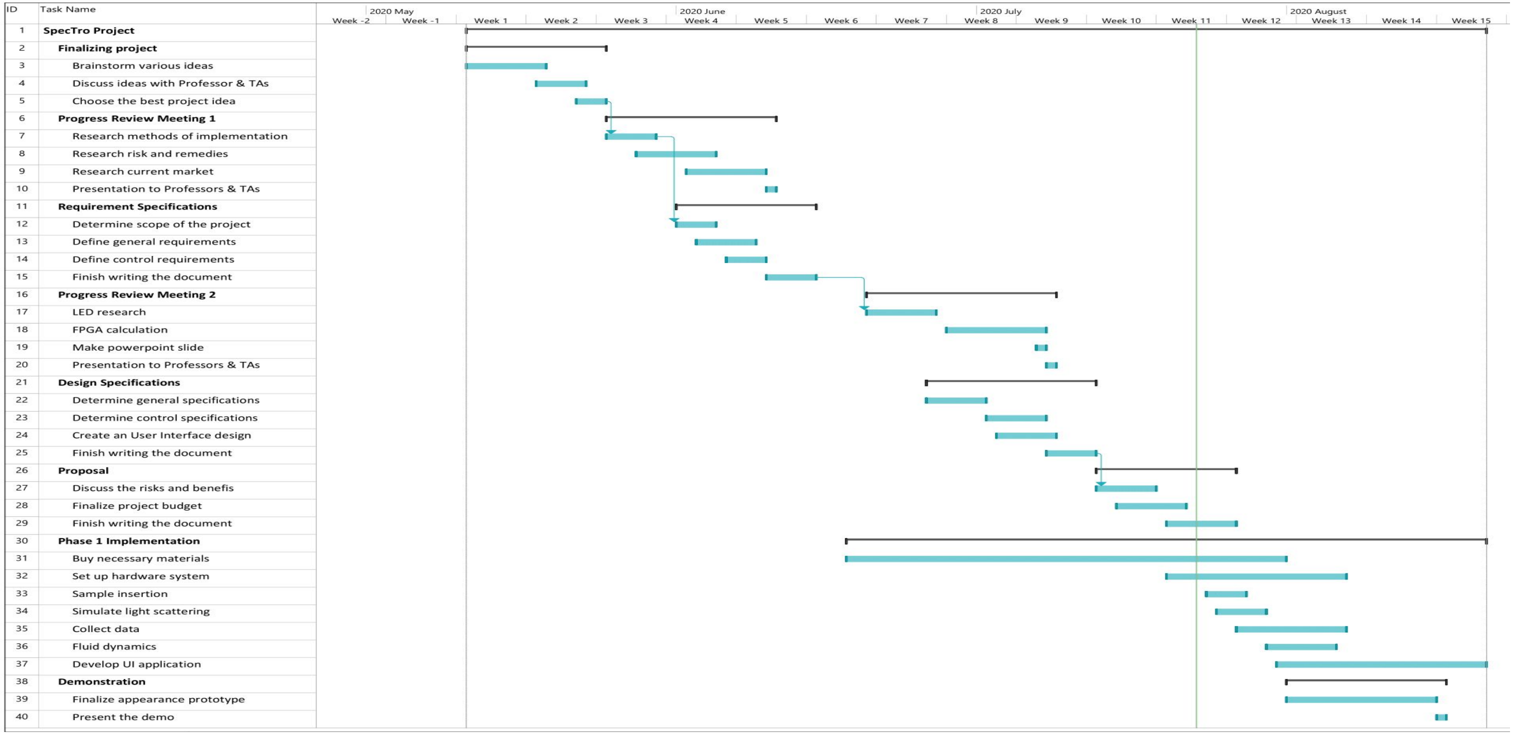
Scope and Major Design changes

- Many aspects of the project appeared on a surface level to be smaller tasks, but instead to be huge tasks which required weeks to accomplish (ie, the optics for the pulse light source).
- Many of the specification requirements and design requirements outlined in the documents are unmet

Self Reflection

- Work in teams rather than individual work. Helpful for gaining insights and diminishing burden.
- Clearly define tasks and apply better deadlines to tasks
- Have designated work periods for teams
- Investigate deadlines of teammates for other courses. So the work can be divided better.
- Anticipate that technical tasks are usually much larger than anticipated, and should be decomposed into smaller tasks
- Have socially distanced meet ups to work

Gantt chart for Semester 1



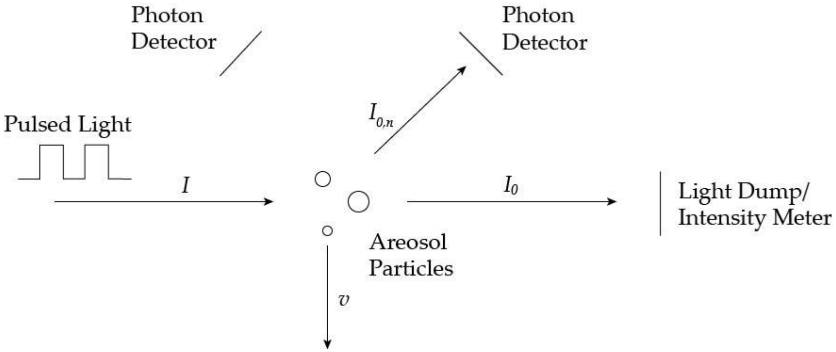
Project schedule

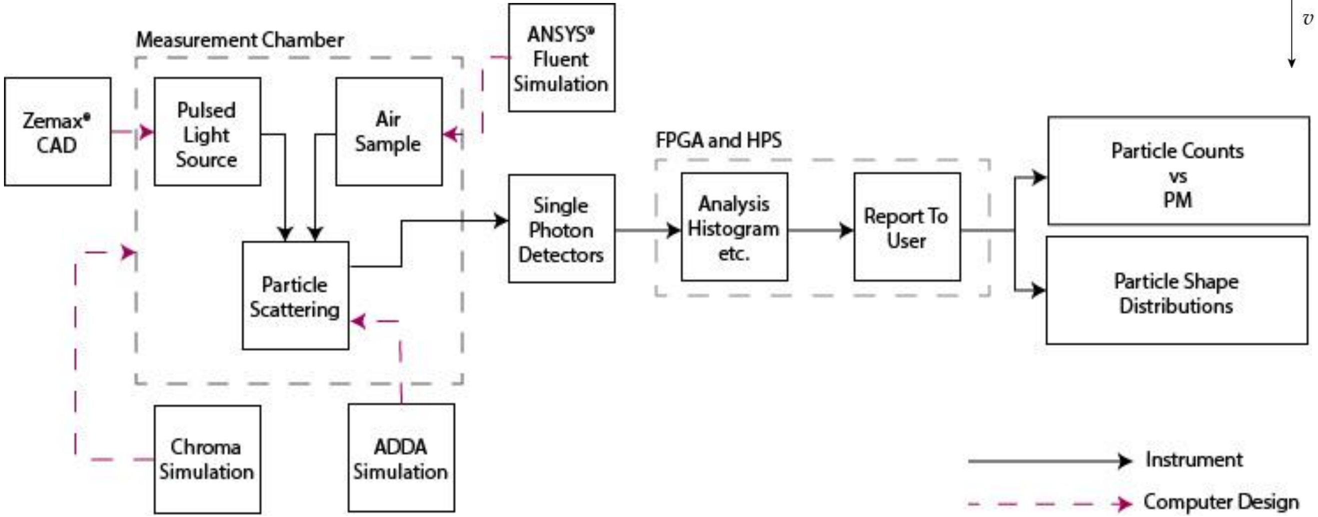
- **Implementation of Phase 1 during 405W:**

  Proof of Concept Prototype (July 20 - August 20, 2020)
  - Setting up Chroma
  - Light scattering simulations
  - Optical system design
  - Solidworks designs for modules
- **Implementation of Phase 2 throughout 440:**
  - Reduction of systematics (stray light, dark noise, etc) over UBC prototype
  - Verification of CAD designs and software simulations by inspecting hardware
  - Other improvements

Demonstration

Instrument Overview



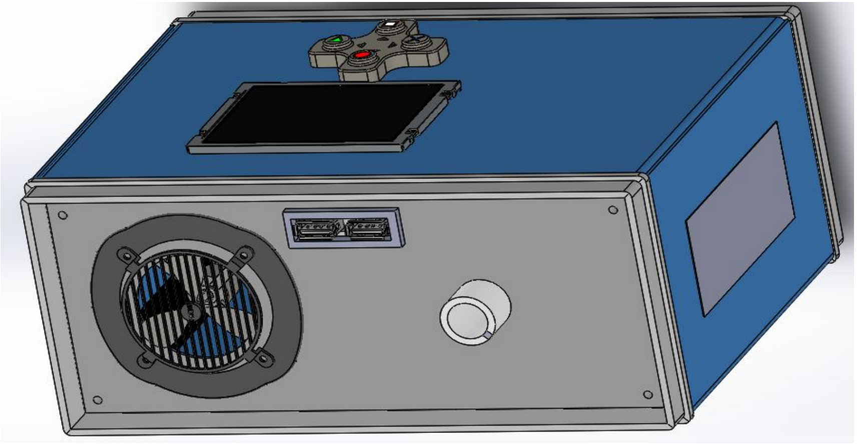


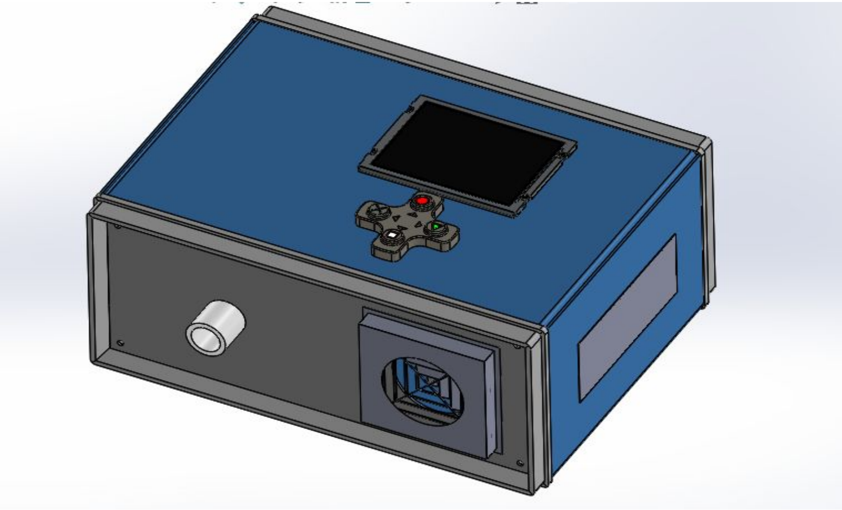
Figures taken from ENSC 440 project proposal

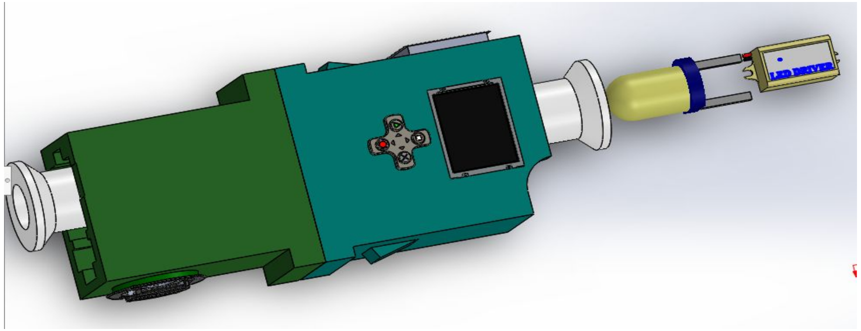
Appearance modelled

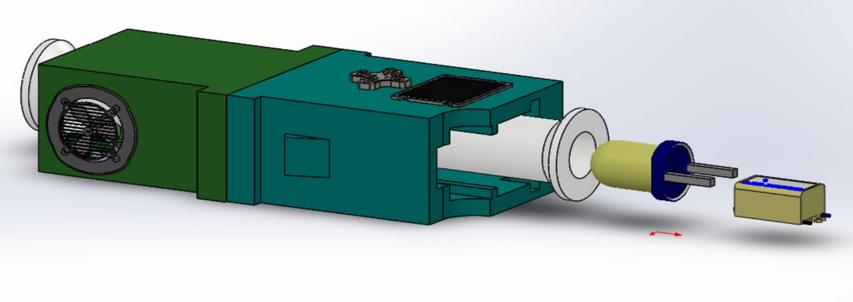
- It was a learning experience for designing
- We have designed a 3d model of the whole appearance through SolidWorks®
- We have designed several parts for the exterior appearance
- We also made two external designs for our prototype model and decided to choose one among them due to the chamber size
- There are more external parts like LCD, buttons, enclosure, usb, led drivers and etc. which are not fully included in the assembled parts.

Assembled: External parts







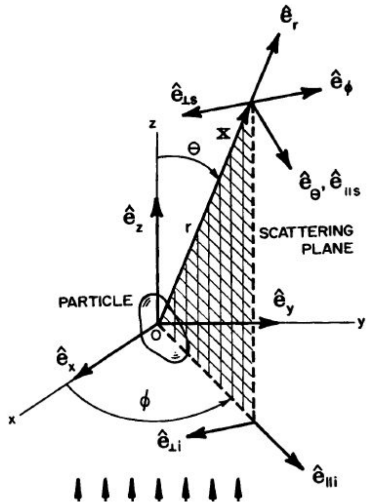


$$\frac{d\sigma}{d\Omega} = |f(\theta)|^2$$

Light Scattering Background

$$\begin{pmatrix} E_{\parallel s} \\ E_{\perp s} \end{pmatrix} = \frac{e^{ik(r-z)}}{-ikr} \begin{pmatrix} S_2 & S_3 \\ S_4 & S_1 \end{pmatrix} \begin{pmatrix} E_{\parallel i} \\ E_{\perp i} \end{pmatrix},$$

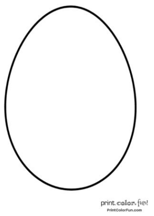
- Incident beam makes contact with particulate and bounces off at different angles.
- Light can be scattered, absorbed and extinguished
- Investigating the far field solution
- Amplitude scattering matrix (ASM) give us information about the Parallel and Perpendicular fields to the scattering plane
- ASM gives the differential scattering cross section which is the angular distribution into a unit solid angle

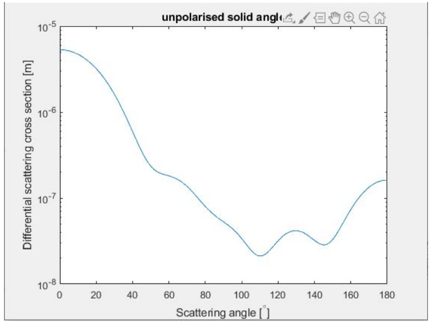


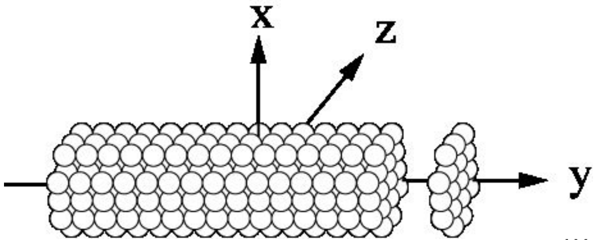
[1],[2], [7]

Discrete Dipole Approximation

- Approximates continuum target by finite array of polarizable points
- ADDA is open source software for DDA approximation
- Shape variants ie. egg
- For future analysis of non spherical shapes



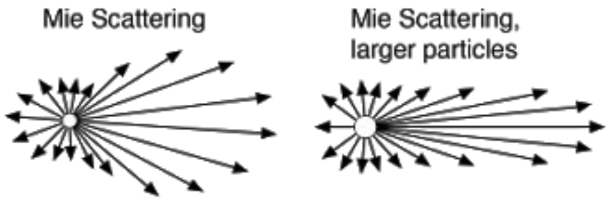




[9]

Mie approximation

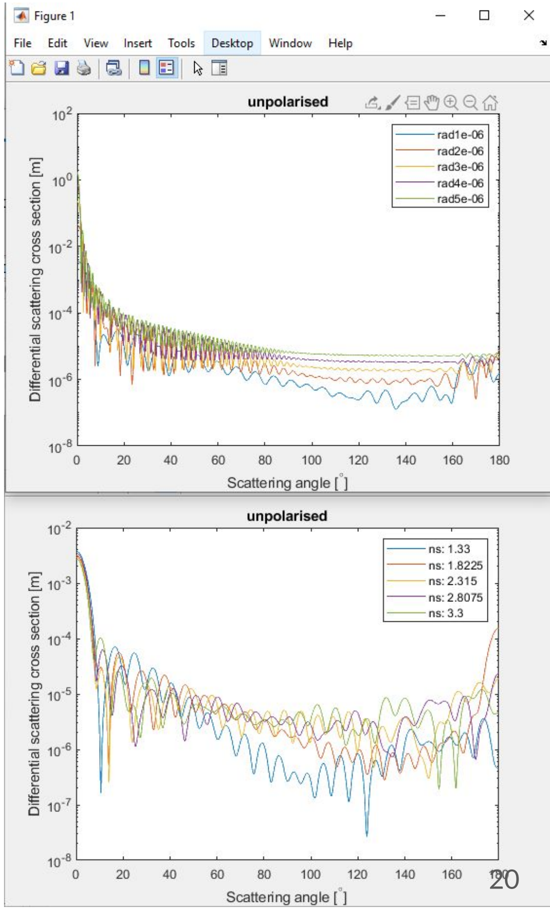
- Solution to Maxwell's equations
- Describes scattering by stratified sphere or infinite cylinders
- Particles with diameter comparable to the wavelength
- More scattering is seen close to 0 degrees.



[5], [6]

Analysis Sphere

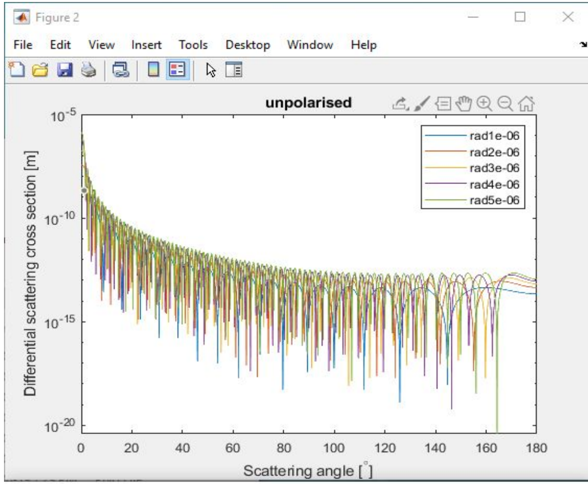
- High angular distribution around 0 - 15 degrees
- Bigger sized particles have higher differential scattering cross section (DSCS) as the scattering angle increases
- DSCS drops faster when changing the refractive index
- Variable refractive index similar trend with variable radius but lower frequency
- Both graphs stabilize between 10^-4 and 10^-6
- Around 50 to 140 degrees higher refractive indices have higher DSCS

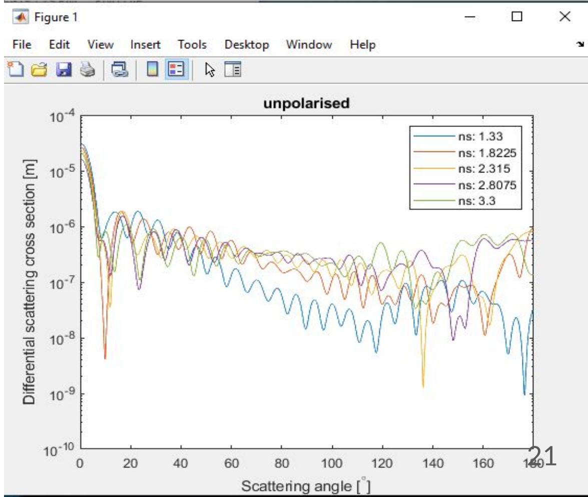


[3], [4]

Analysis Cylinder

- Similar trends compared to spheres
- Higher fall of DSCS in variable radius
- Lower DSCS overall compared to sphere version

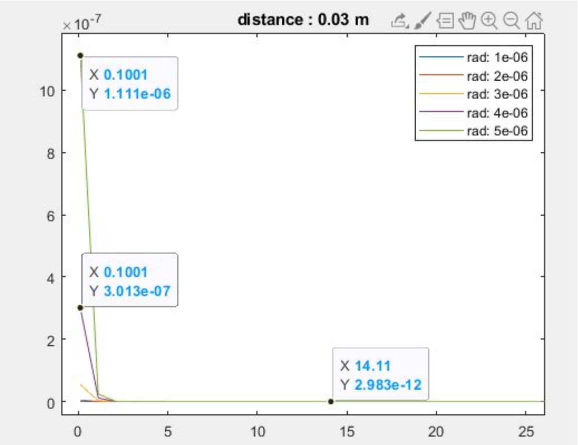




[3], [4]

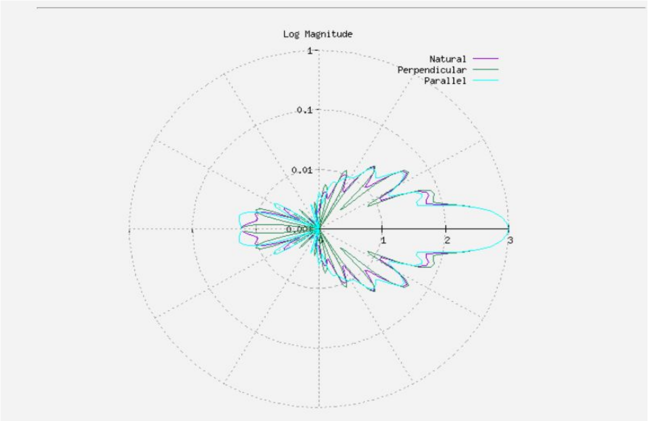
Detector Hit

- Detector probability relies on scattering angle, probability, detector efficiency(20 %), size (3mm^2), distance (30mm) and other parameters
- Higher chance of detector hit close to 0 deg
- Higher chance when bigger particles
- Higher chance when distance from detector to particle decreases ie. Solid angle increasing
- Probability fluctuates between 10^-13 and 10^-15



Proposal of Detector Positions

- Mainly for spherical particle analysis
- Detector positions at 15, 0 , and -15 deg from the center of measurement chamber
- 3 more at 50, 100, and 150 deg
- Because of symmetry add 3 more -50, -100, and -150 deg



Data Acquisition System

- Multi channels and fast calculations needed for analysis therefore Cyclone V SOC FPGA
- Single photon counting
- Hard process system
- Only needed for large amounts of photon detectors. Otherwise COTS hardware.

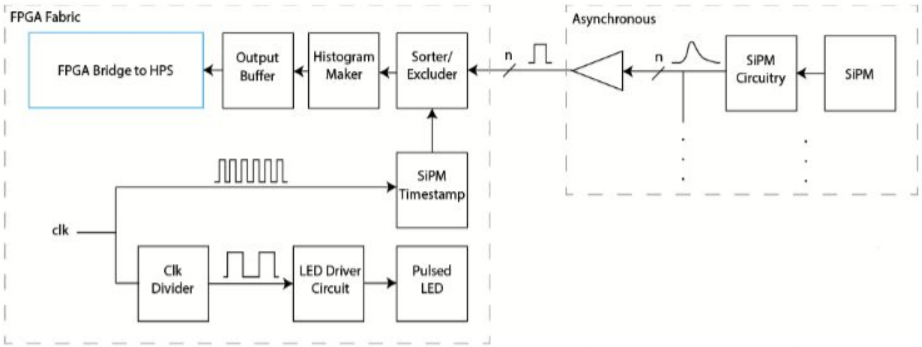
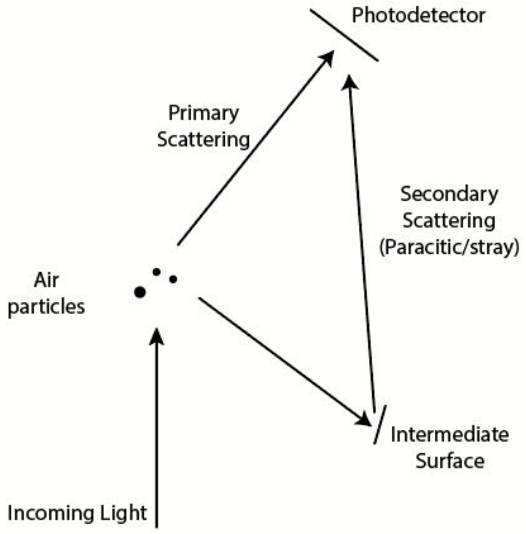


Figure 20: Block diagram visualizing the flow of information from Detector to FPGA bridge

Basics of Stray Light

Main contributors:

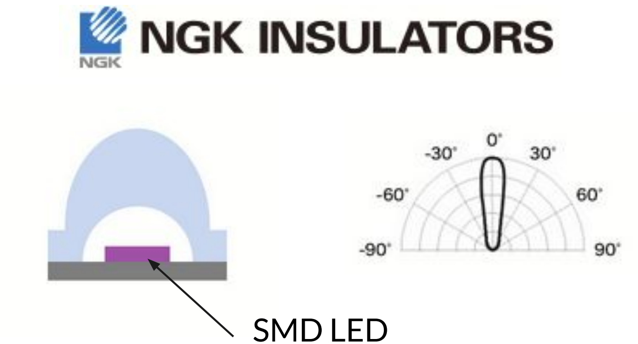
- Ghosting (Reflection off lenses) → Using AR-UV coatings
- Scattering (Unexpected paths) → Black coatings, smooth surfaces
- Straight paths (Improper design) → Baffles, fieldstops, pin-holes/apertures, good design, etc



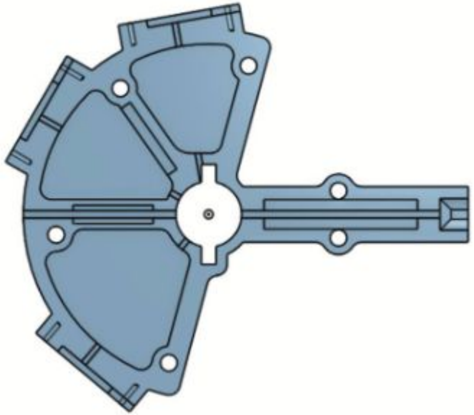
Must be investigated using software, ie. Zemax or Chroma

Revamping Light Source

- Previous prototype used an LED and a long tube to collimate the light source
- New system uses pinholes and baffles to control stray light
- Modeled using Zemax®
- Many iterations!

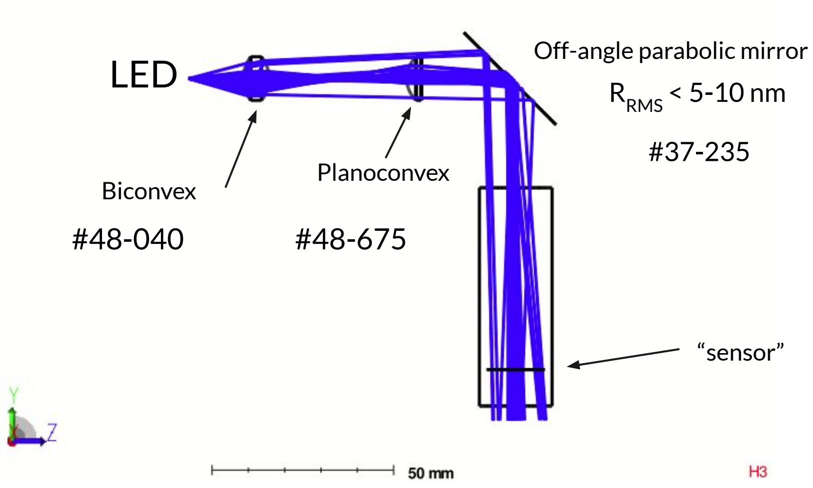


SMD LED

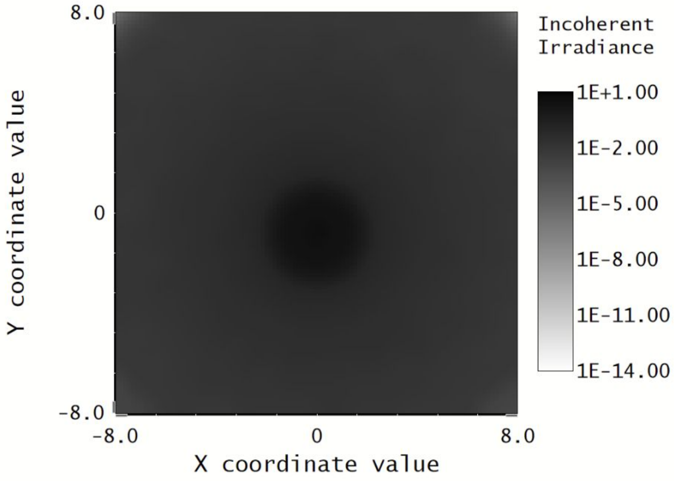


UBC prototype [8]

Commonality: the necessity of baffles



~23% Efficiency



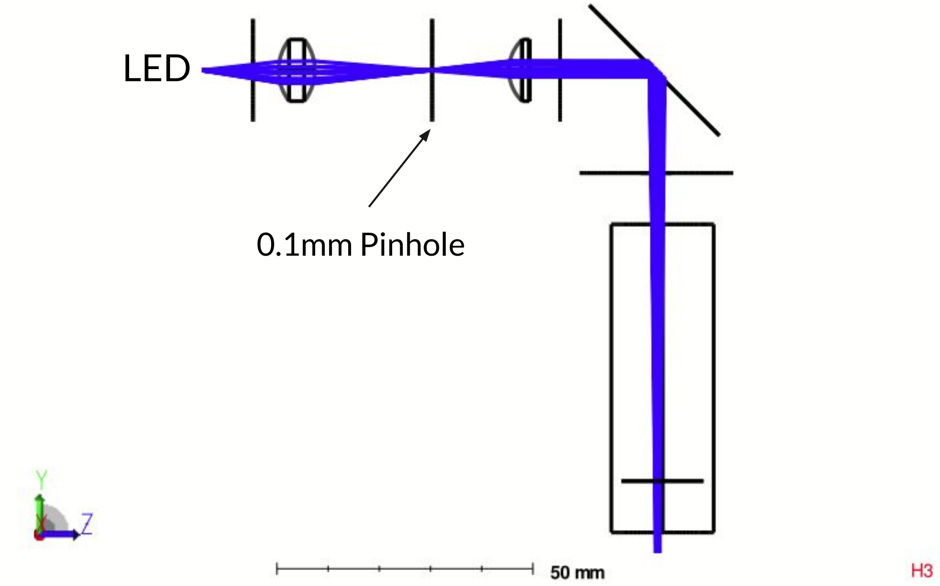
Edmund optics | worldwide

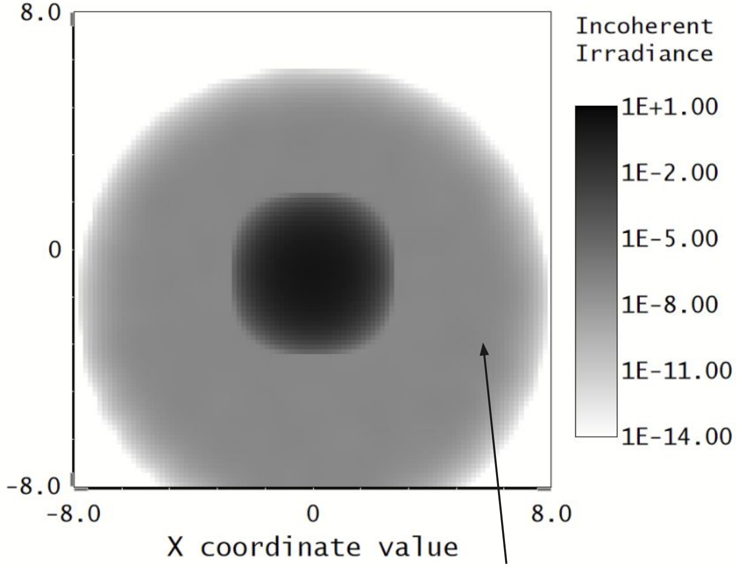
~$450 US

Lots of stray light!

PoC of new light source

~6.2% Efficient



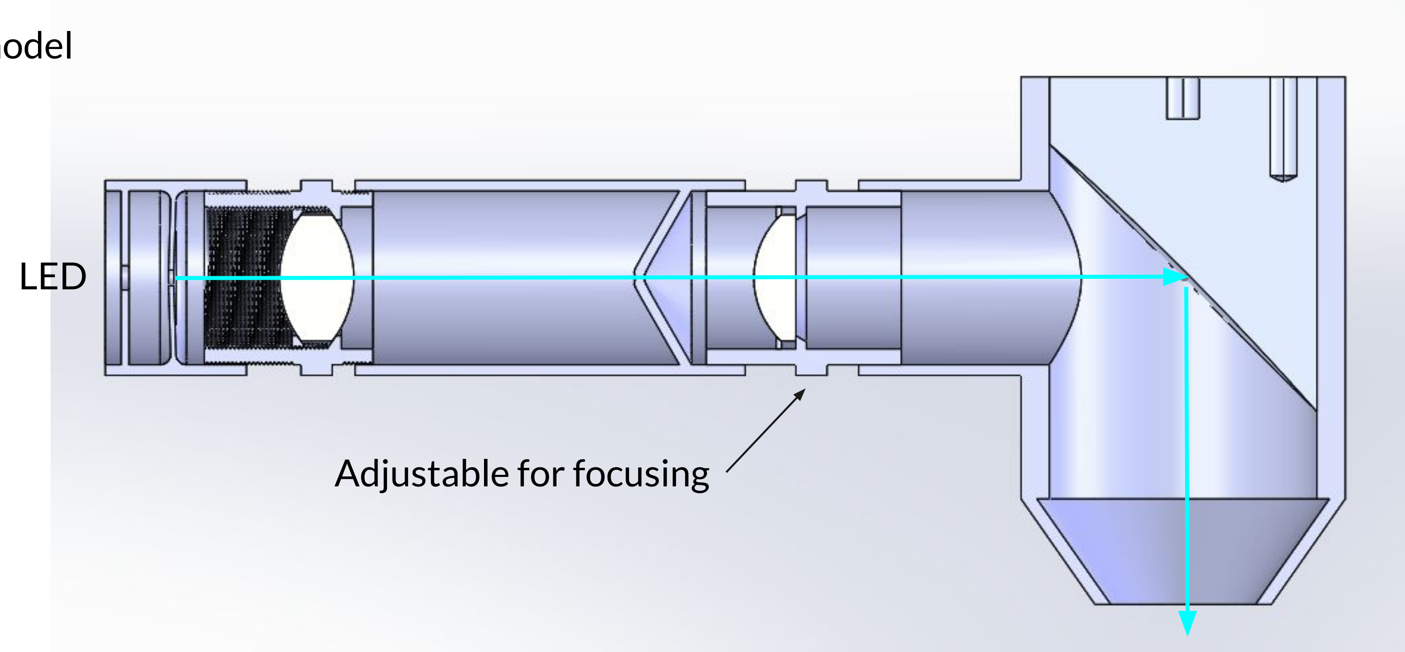


More iteration required to reflect reality

1e-8 W/mm^2
~14 photons/mm^2/ns

3D Printable Enclosure for Lenses and Baffles

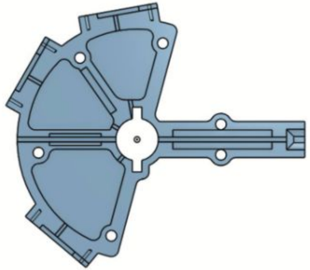
SolidWorks® model



Measurement Chamber Redesign

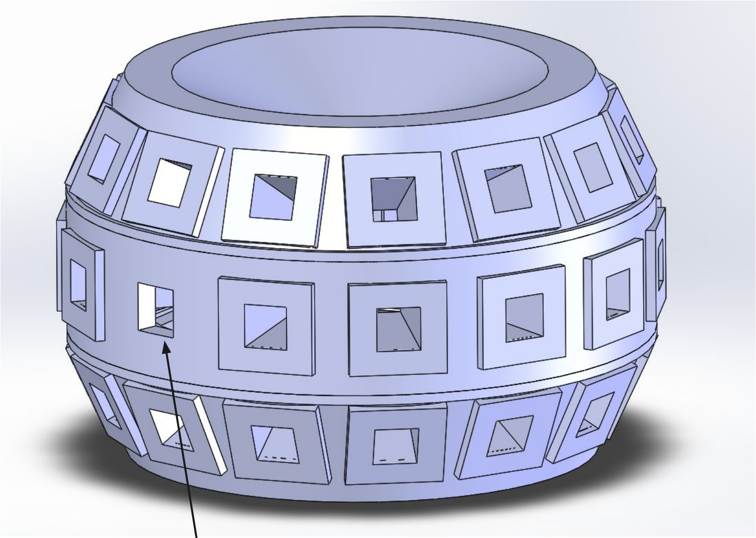
- Previous chamber is static and non-configurable
- It also does not minimize the amount of stray light

⇉ Redesign!



UBC prototype [8]

Measurement Chamber Redesign: CAD Model

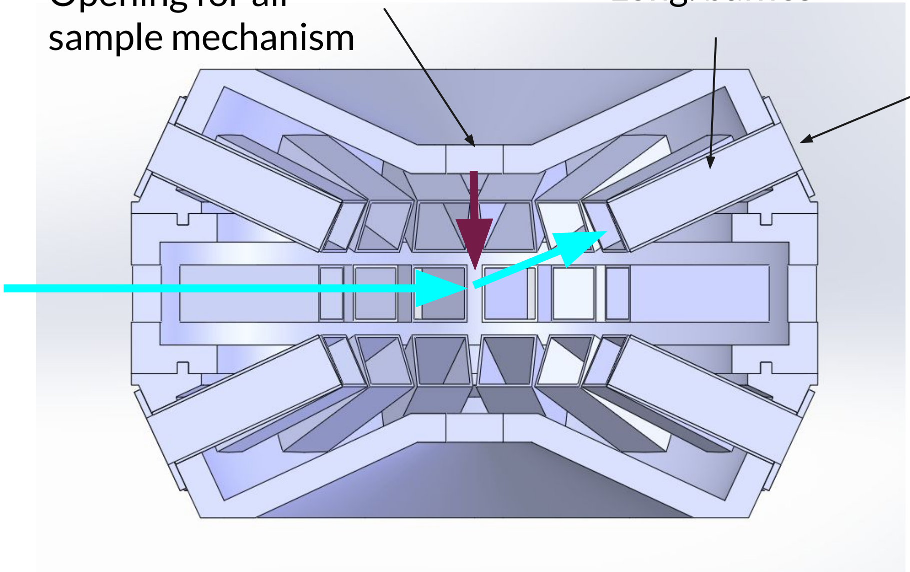


Open spot for light source/dump

Opening for air sample mechanism

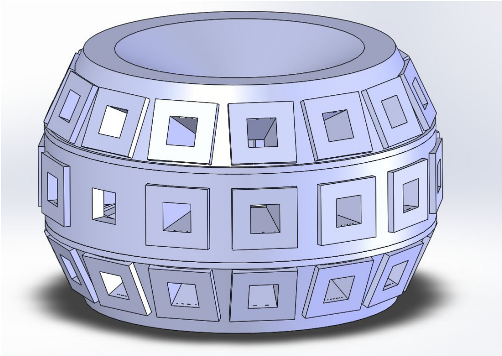
Long. baffles

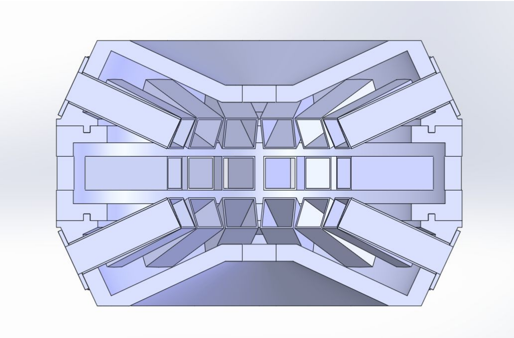
SiPM



Measurement Chamber Redesign: Notes

- Current design is incompatible with previous PCB’s used to hold the SiPMs (1.25”x0.72”)
- Reduction in stray light hasn’t been inspected using Chroma yet.
- Longitudinal baffles need to be worked on to include baffles inside them ⇒ better off angle light rejection
- Central to entire instrument! Important!

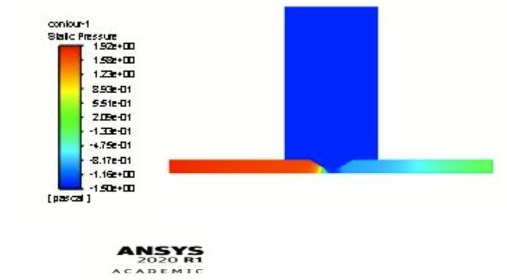




Basics of Chroma

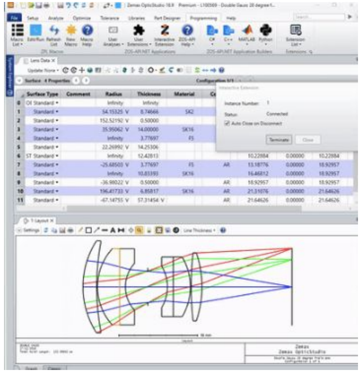
- Fast optical Monte Carlo simulation based on Python with surface-based geometries
- Requirements
  - An x86-64 CPU with at least four cores
  - 8 GB or more of system RAM
  - An NVIDIA GPU
- Build surfaces called “triangle mesh” made up of small triangles representing boundary between “inside” and “outside”
  - Each triangle can be given properties such as index of refraction, transparency, etc
  - Ability to specify different surface properties for different regions of the same object
- Can build detectors, objects, and light sources to simulate photon propagation
- Can be used to simulate light scattering based on surface properties of object as well as wavelength and angle of incident light

Looking ahead to ENSC 440



Air Flow Simulations to develop and “air sheath” using ANSYS® fluent

CHROMA simulations to aid in reducing stray light in measurement chamber

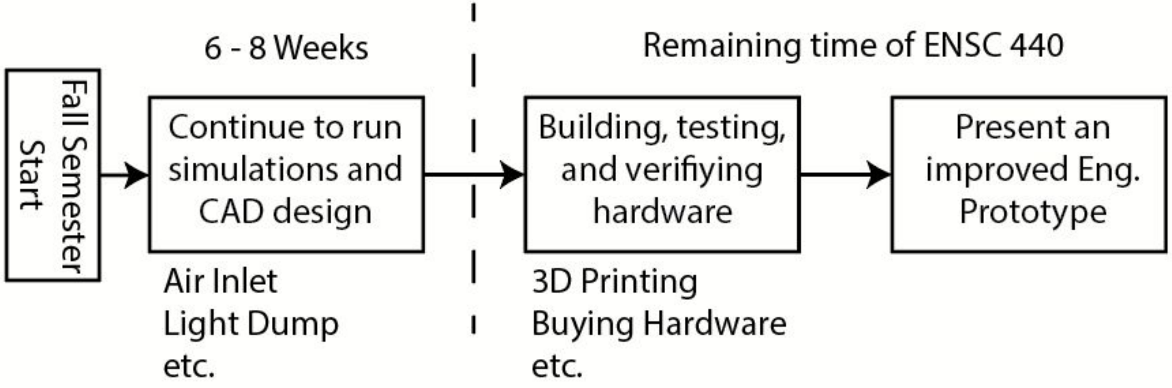


More light source development using OpticStudio

Testing, building, verifying hardware designed in CAD

Looking ahead to ENSC 440

Tentative Schedule:



Conclusions and Acknowledgements

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  - Craig for offering guidance through lectures and one-on-one time
  - Andrew for offering criticism and suggestions
  - Both TA's which provided valuable feedback on the course deliverables and providing open office hours every week
- We would additionally like to thank:
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  - Those who have previously worked on this project
  - And to anyone else who may have contributed, but have been left out of the above.

SFU SIMON FRASER UNIVERSITY

TRIUMF

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[8] “Single Photon Air Quality Analyser” Project report from UBC students, contact for access

[9] “Discrete dipole approximation,” *Wikipedia*, 15-Aug-2020. [Online]. Available: https://en.m.wikipedia.org/wiki/Discrete_dipole_approximation. [Accessed: 21-Aug-2020].

Backup slides