Designing and building the SAEMPL light scattering instrument

Göran Maconi, Ivan Kassamakov, Antti Penttilä, Maria Gritsevich, Petteri Helander, Tuomas Puranen, Ari Salmi, Edward Hæggström, and Karri Muinonen

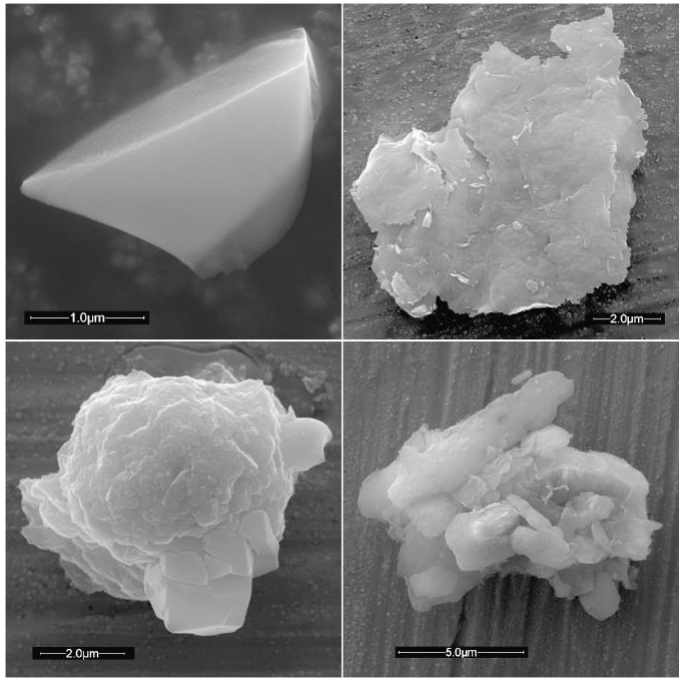
University of Helsinki

Dept. of Physics

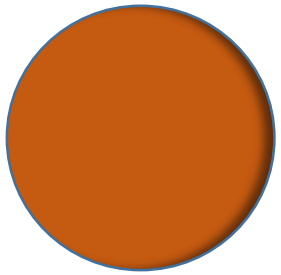
07.11.2018

Light scattering models

- Approximate numerical scattering models are very popular
  - Particles are often assumed to be spherical
- Questions:
  - How well do our approximations work?
  - Can we verify / create better models using empirical data?



=?



Scattering theory

- The ideal Mueller matrices for a linear polarizer $\mathbf{M}_p$ and a quarter wave plate $\mathbf{M}_q$ are:

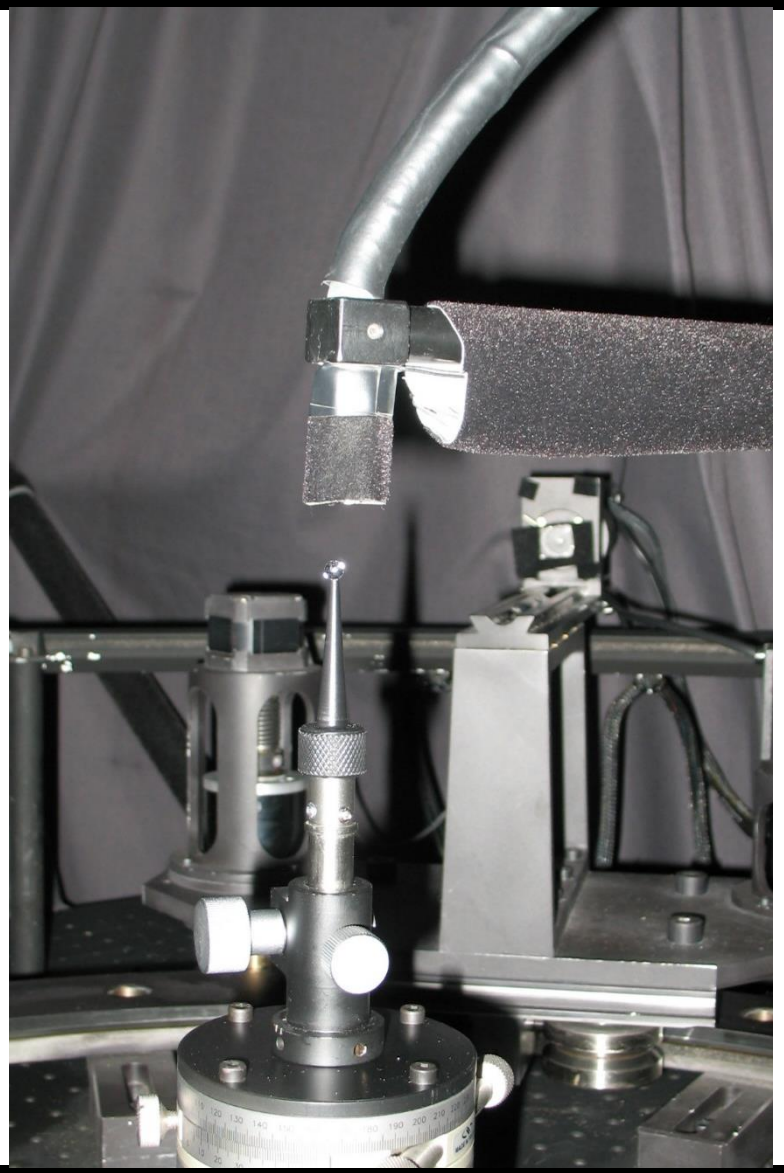
- $$\mathbf{M}_p(\theta) = \frac{1}{2}\begin{pmatrix} 1 & \cos(2\theta) & \sin(2\theta) & 0 \\ \cos(2\theta) & \cos^2(2\theta) & \sin(2\theta)\cos(2\theta) & 0 \\ \sin(2\theta) & \sin(2\theta)\cos(2\theta) & \sin^2(2\theta) & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

- $$\mathbf{M}_q(\theta) = \frac{1}{2}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos^2(2\theta) & \sin(2\theta)\cos(2\theta) & \sin(2\theta) \\ 0 & \sin(2\theta)\cos(2\theta) & \sin^2(2\theta) & -\cos(2\theta) \\ 0 & -\sin(2\theta) & \cos(2\theta) & 0 \end{pmatrix}$$

- $\boldsymbol{I}_s = \mathbf{M}_p(\theta_4)\mathbf{M}_q(\theta_3)\mathbf{M}\,\mathbf{M}_q(\theta_2)\mathbf{M}_p(\theta_1)\boldsymbol{I}_i$
- By choosing suitable values for the four angles, we can isolate individual elements of **M**

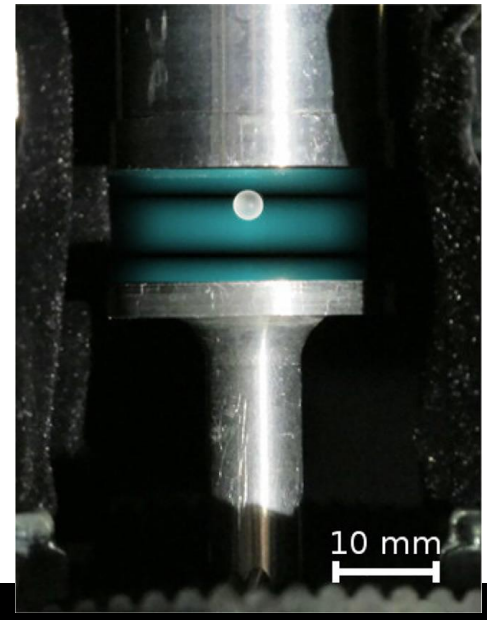
Existing setups

- Arizona(1973)
  - Hg lamp with polarizer, flow of 110 nm latex spheres
- Amsterdam (2001)
  - Mineral aerosol samples, HeNe laser, polarized
- Granada (2010)
  - Further development of Amsterdam setup
  - Tunable Ar-Kr laser, laminar flow, static holders



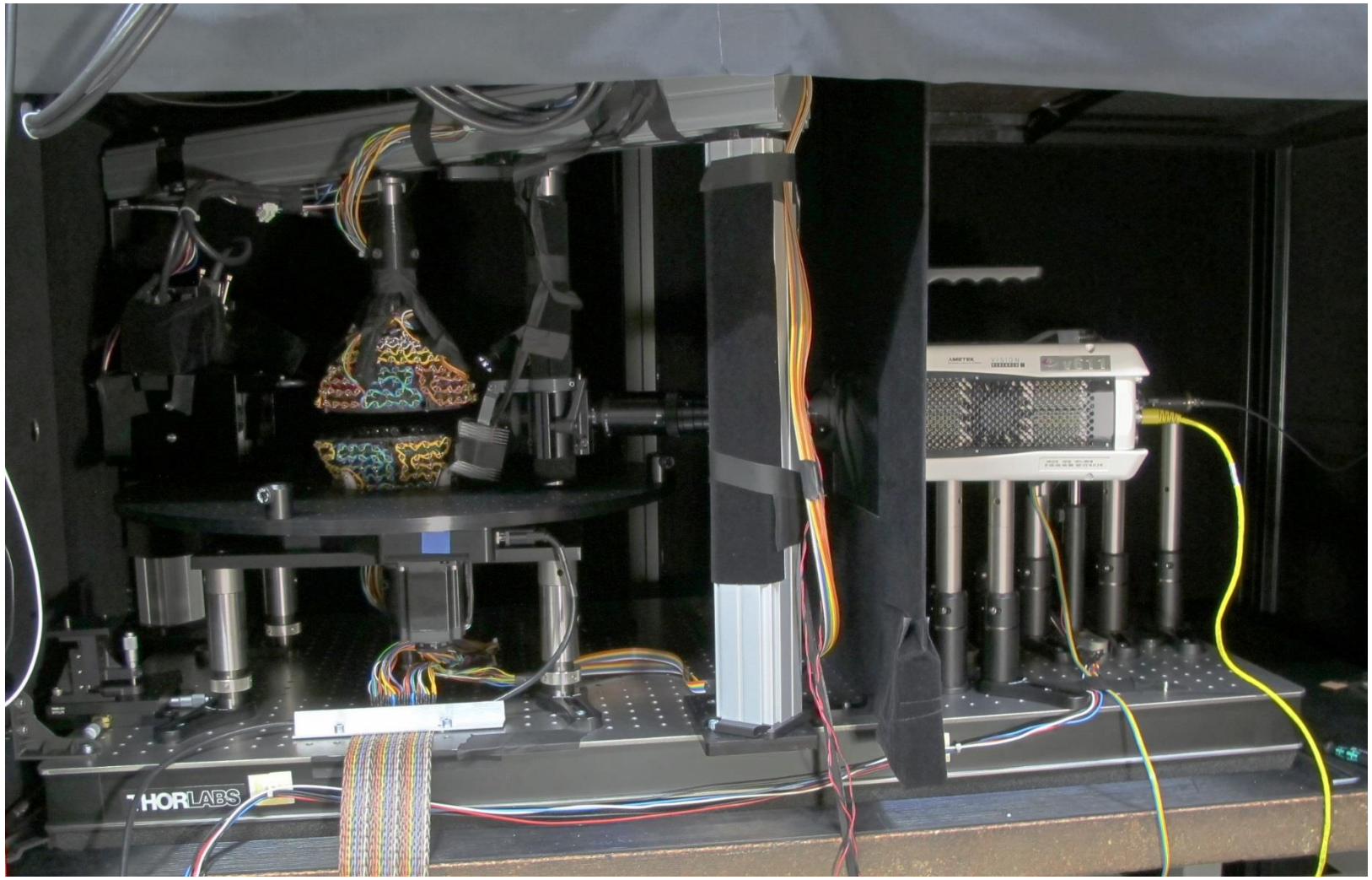
Holding the sample

- Surfaces: Easy ☺
- Aerosols: Laminar flow
  - Provides enough light, gives good average properties
  - No info about the individual particle
- mm-scale samples: Physical holder
  - Holder always contributes to the scattering
- Our approach: Acoustic levitator
  - No contact
  - Suitable for fragile samples



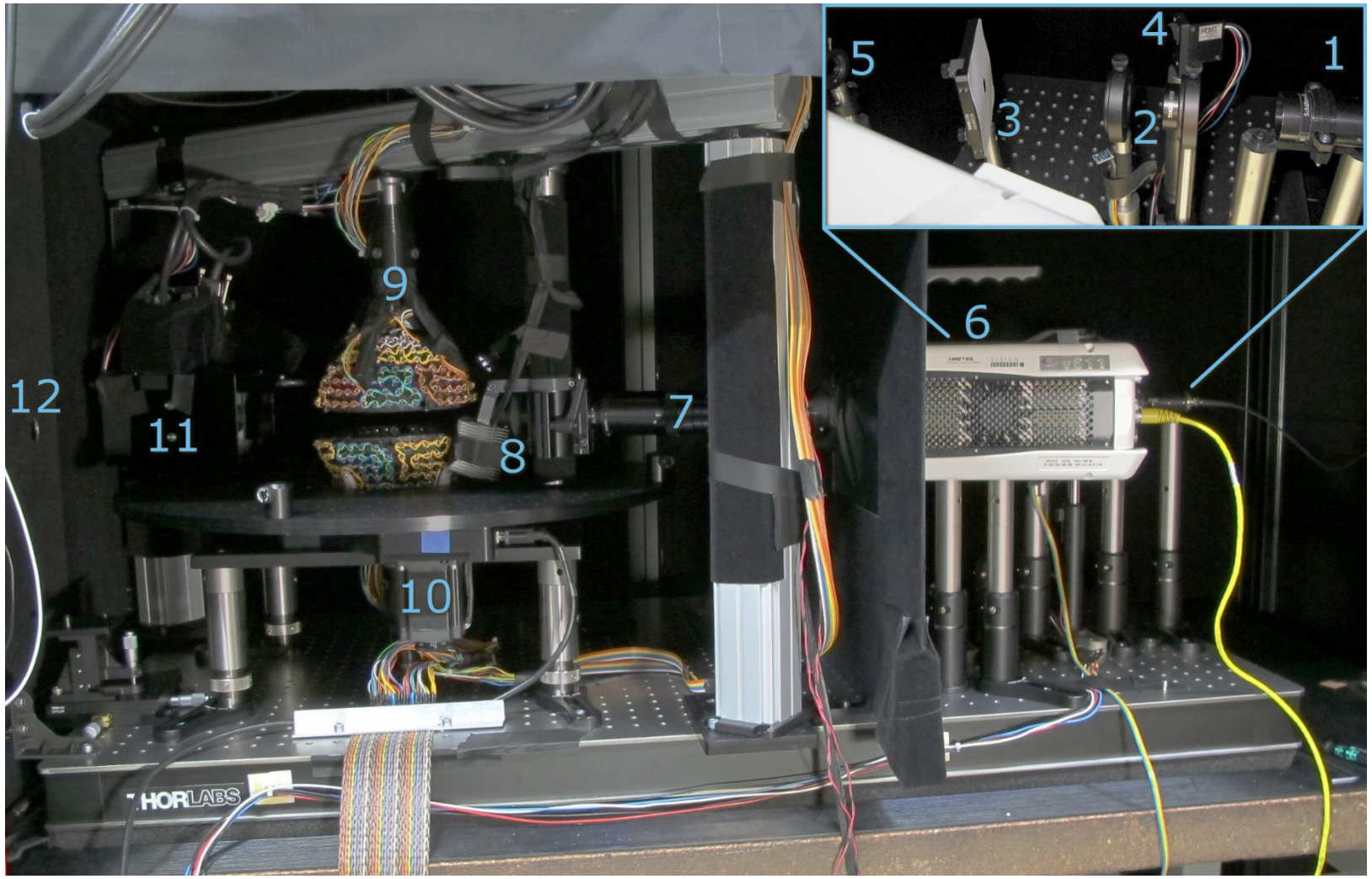
Scatterometer system design

- 4 major parts
  - Light source
  - Sample levitator
  - Analyzer
  - Camera imaging
- Enclosed in black velvet compartments



Scatterometer system design

- 4 major parts
  - Light source (1...5)
  - Sample levitator (9)
  - Analyzer (10, 11)
  - Camera imaging (6,7,8)
- Enclosed in black velvet compartments

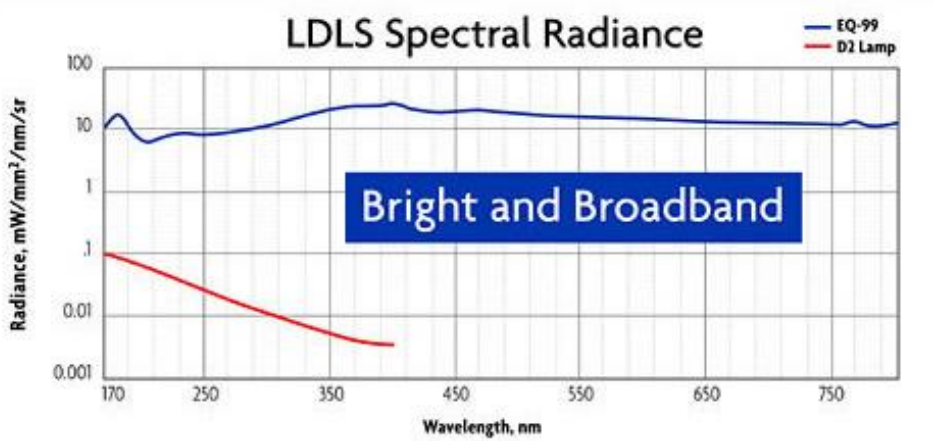


Light source

- Fiber coupled
  - Temperature control
  - Easy to swap out
- Light source 1: Melles Griot Ar-Kr laser
  - Same as in Granada
  - High stability, 14 wavelengths (blue to red)
  - Quarter wave plate, linear polarizer, second quarter wave plate, reference photomultiplier tube (PMT), adjustable aperture

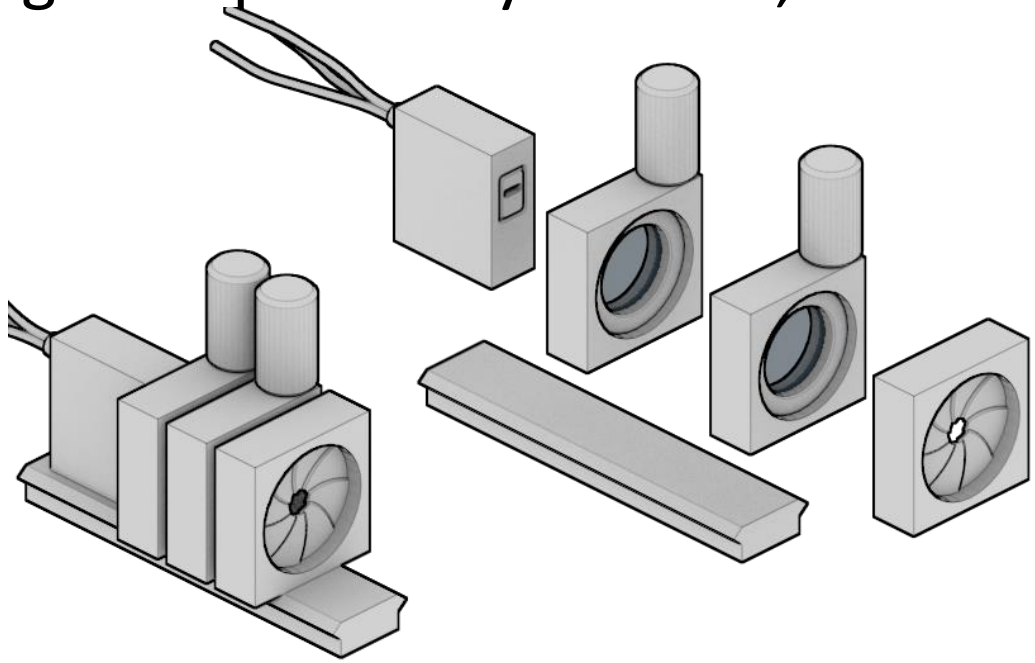
Light source

- Light source 2: Energetiq LDLS
  - Laser Driven Light Source
  - Broadband light source with laser stabilized arc
  - Wavelengths picked out by filters
- Line filter, linear polarizer, quarter wave plate, reference PMT, adjustable aperture



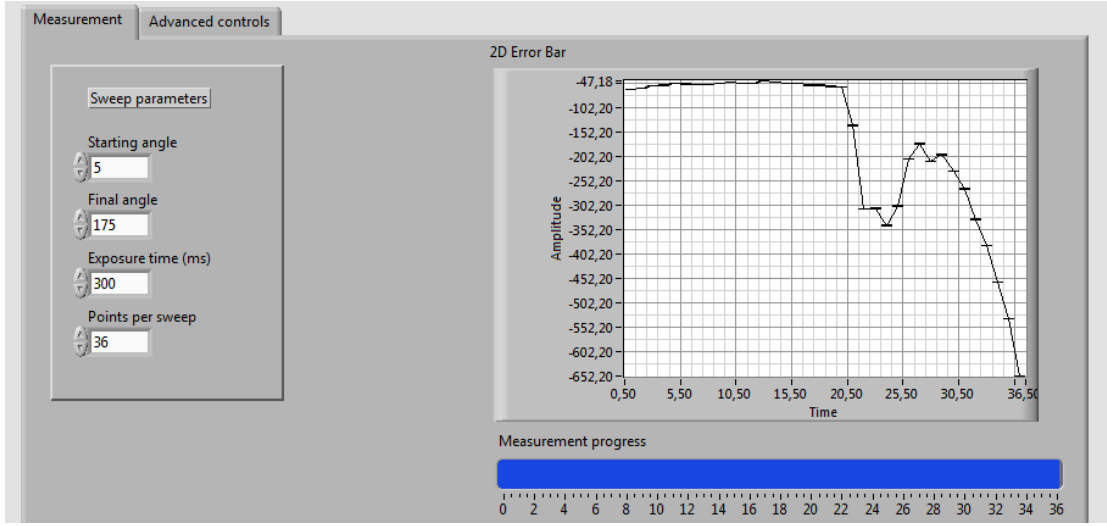
PMT analyzer design

- Analyzer: Hamamatsu microPMT
  - Can see individual photons
  - Integrated high voltage source
- Motorized shutter, quarter wave plate, linear polarizer, PMT
- Signal captured by a 14-bit, 250 MHz 8-channel oscilloscope card

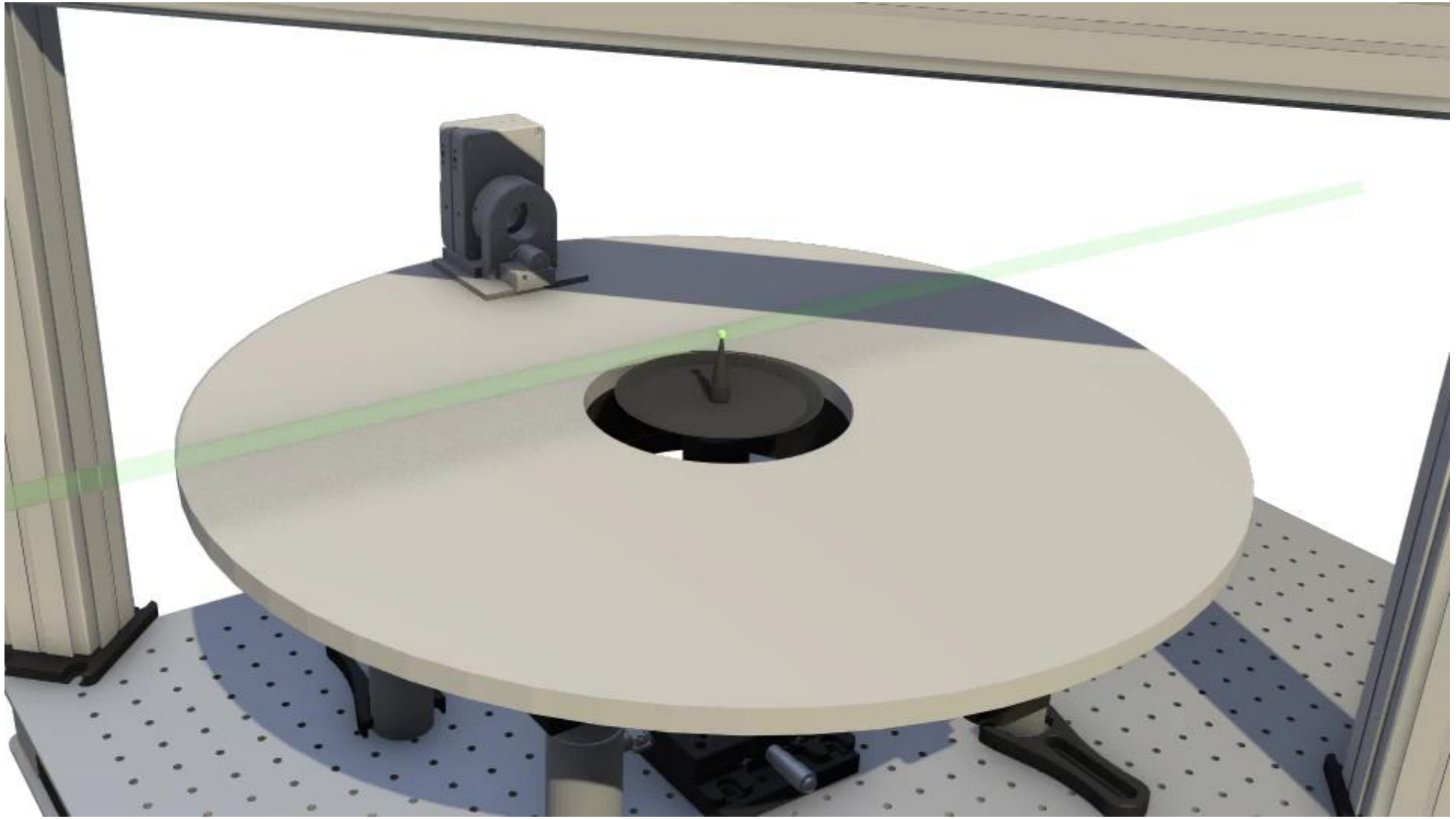


Control software

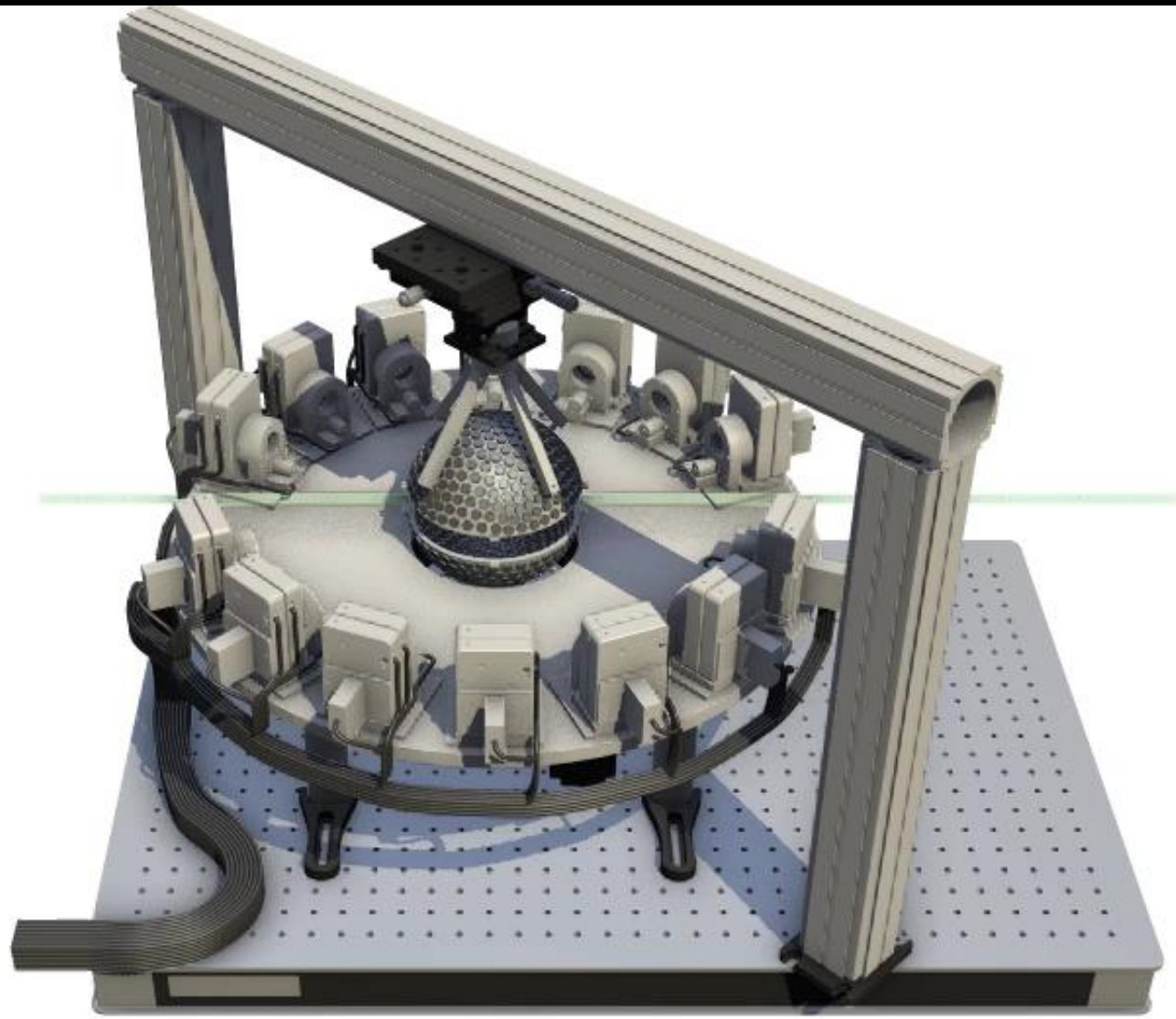
- Data acquisition & system control implemented in NI LabVIEW
- PXIe platform allows n-channel oscilloscope input (max 64)
  - Onboard FPGA:s allow realtime data processing
- Automated sweeps & polarization configurations
- Formats and saves data



PMT sweep



PMT analyzer design



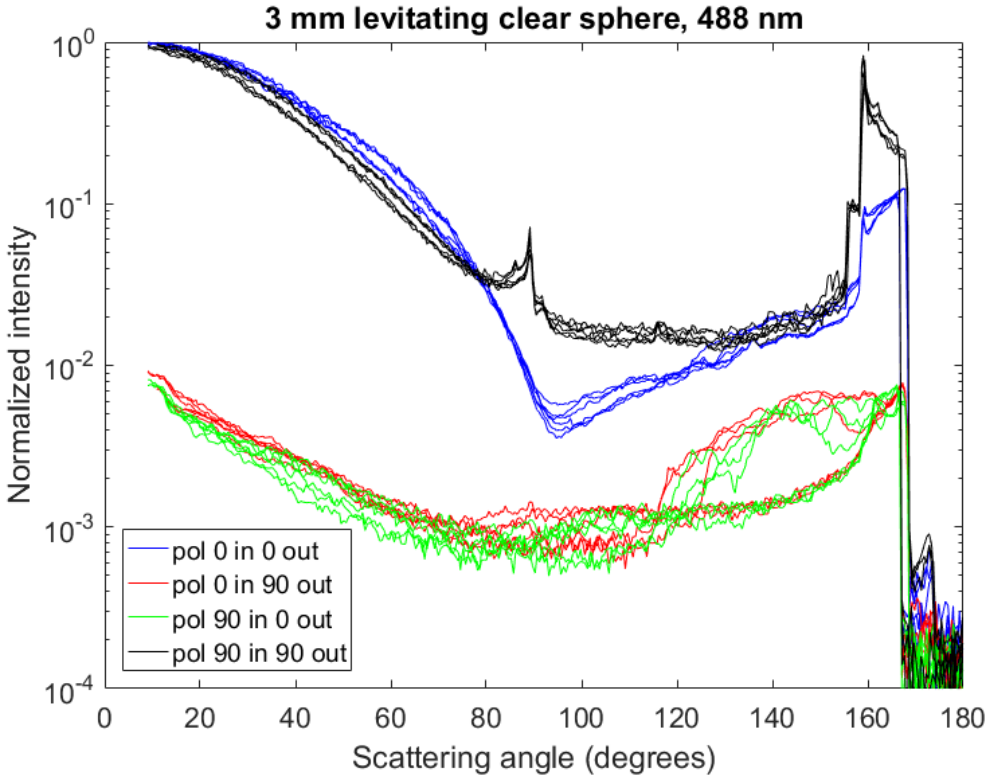
Camera imaging

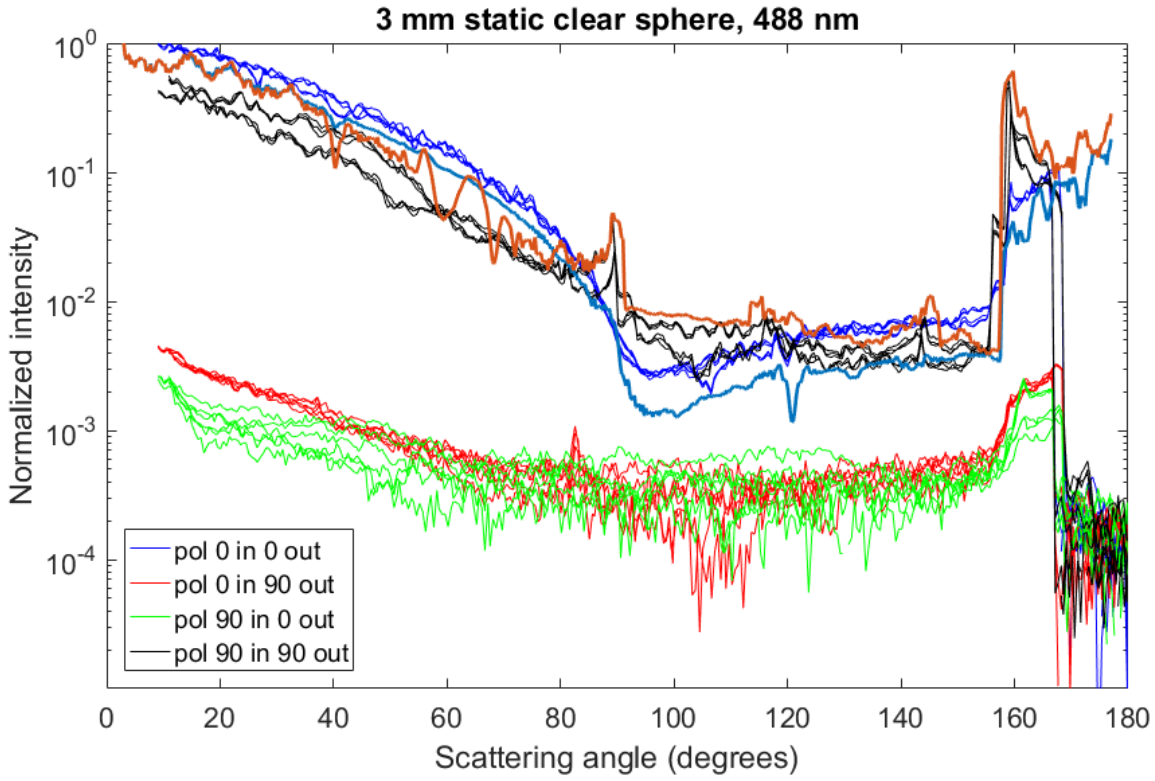
- Camera: Phantom v611
  - 1Mfps – doesn’t miss any movements
  - Large sensor, high sensitivity
- Navitar 12x microscope objective

- Illumination by focused 850 nm near IR LEDs
  - PMTs currently protected by a shortpass filter
  - Planned: Gated PMTs & stroboscopic LED drivers
    - Simultaneous measurement & imaging

Measurements

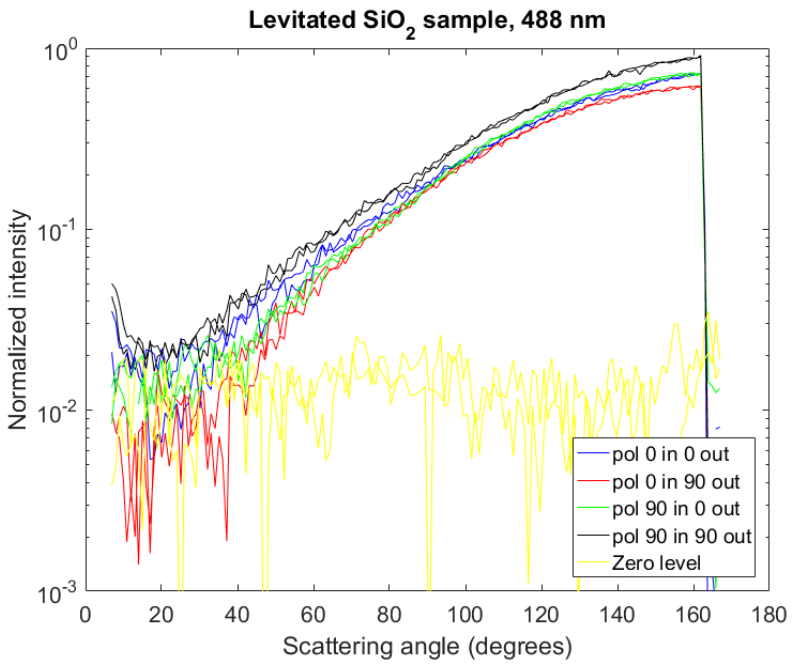
- 3 mm glass spheres
  - Easy to simulate using Mie scattering
  - Allows comparison to other instruments

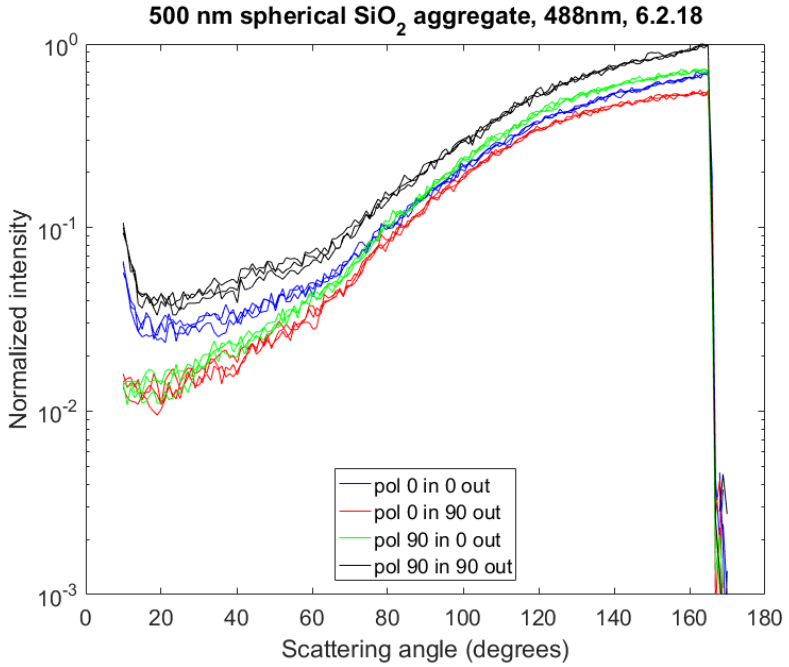


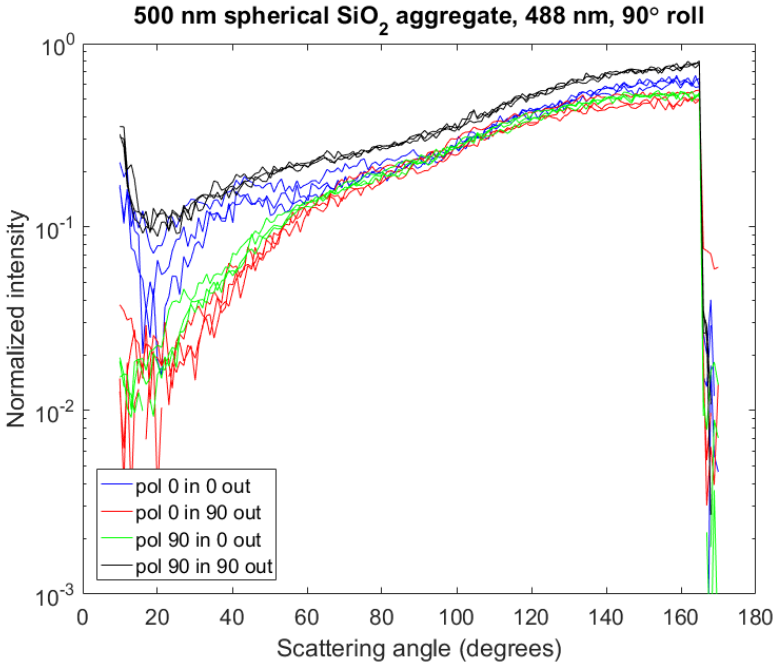


Measurements

- SiO_2 dust agglomerates
  - 0.1-10 µm irregular grains (left graph)
  - 500 nm microspheres (middle & right graph)
  - Natural clumping, 1-3 mm pieces, ~15% packing density







Thank you!

Questions?