Absolute energy calibration of the Fluorescence Telescopes at the Pierre Auger Observatory with a roving laser system

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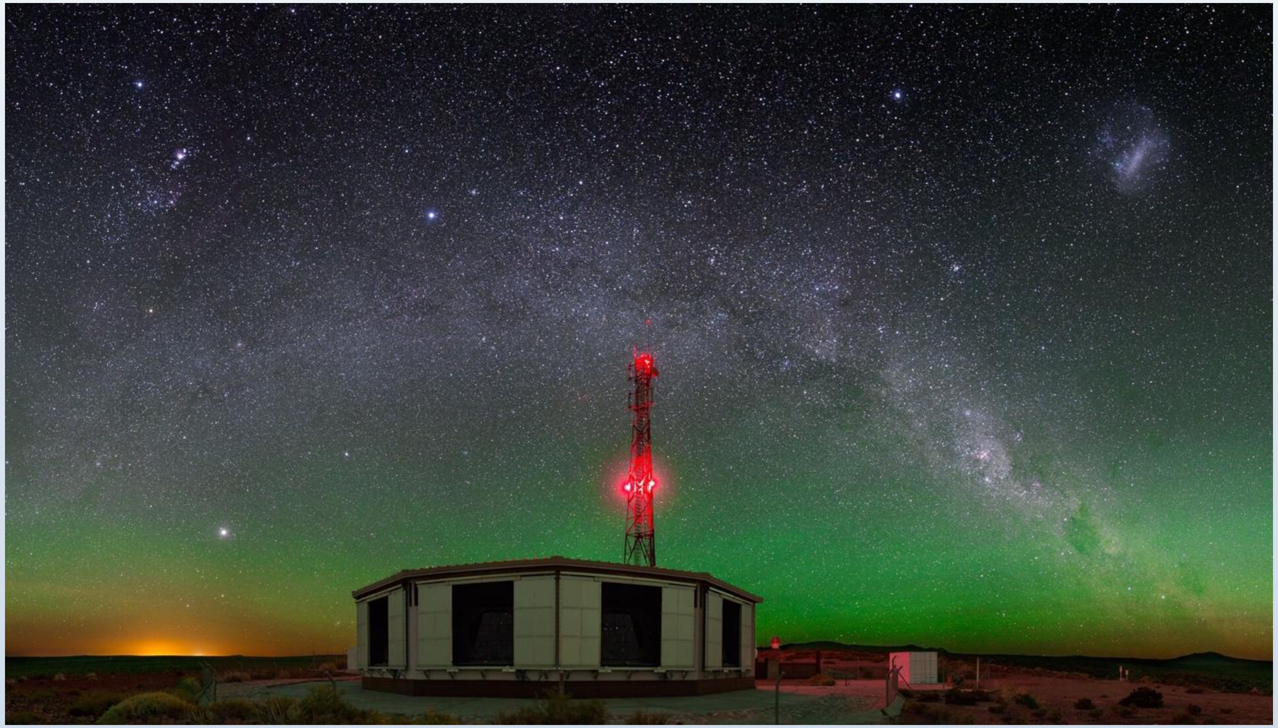
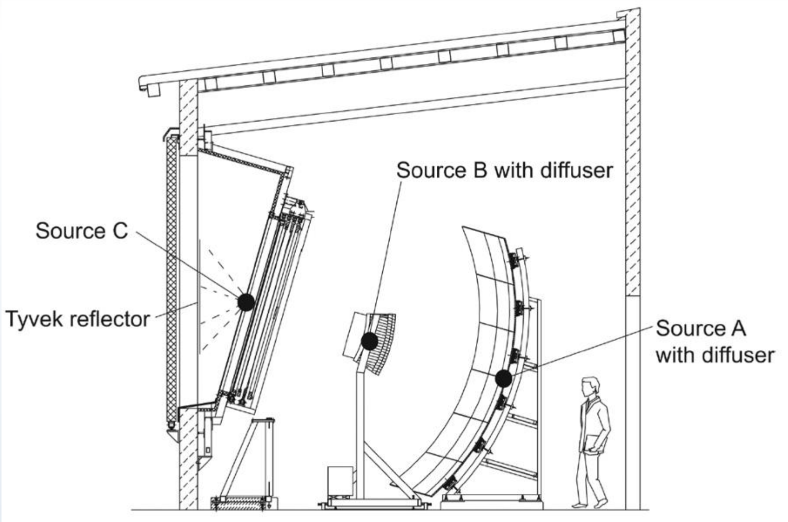
Introduction

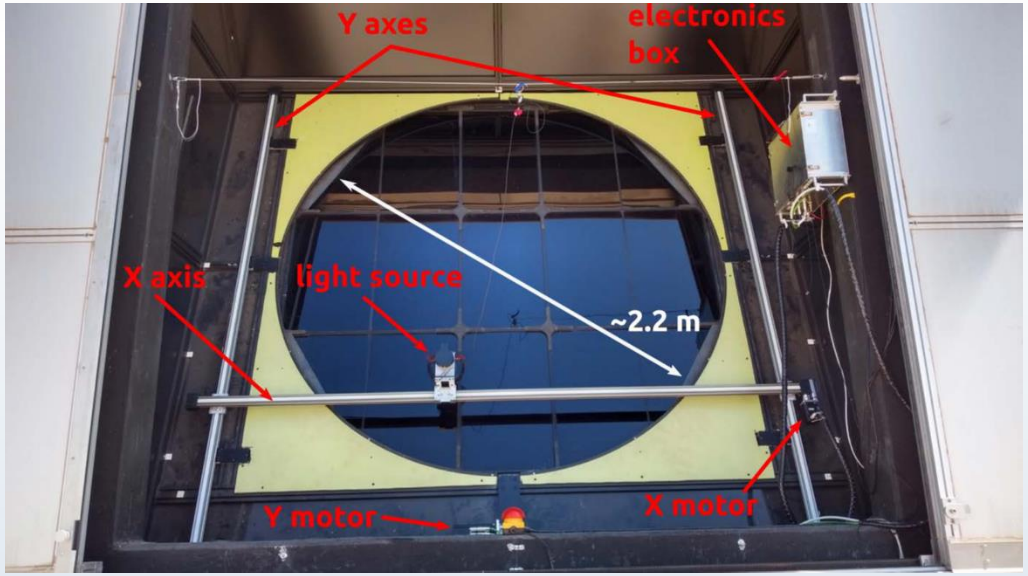
- The data of the Fluorescence Detector (FD) allows for the reconstruction of longitudinal profiles and determination of total energy of extensive air shower
- The FD sets the energy scale for the entire observatory
- Calibration is crucial as it directly affects the accuracy of the detector's measurements.

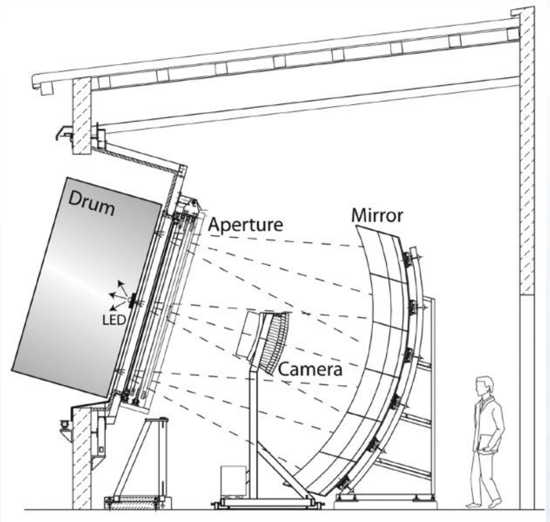


FD Calibration Methods



(b) relative calibration





(a) "drum" calibration

Relative Calibration:

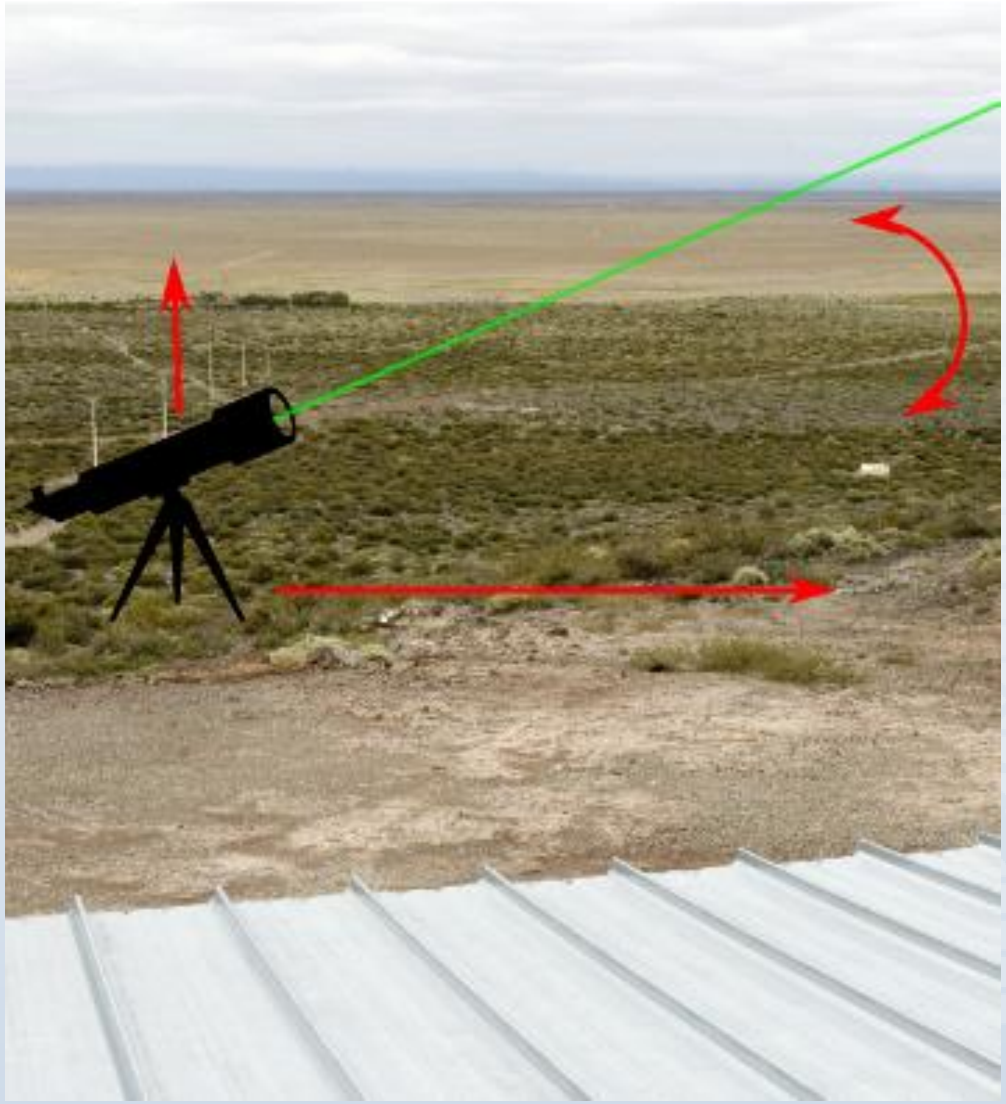
- Monitors changes in the detector response over time or across different wavelengths, without providing a direct absolute sensitivity measure.
- Examples:
  - PMT, mirror, and UV filter calibration
  - Multi-Wavelength Calibration

Absolute Calibration:

- Determines the overall detector response to a known light source, providing a direct measure of the detector's sensitivity.
- Examples:
  - Drum
  - XY-Scanner
  - Roving Laser System

Roving Laser System

- **Approach:**
  - Use a thoroughly tested laser in the lab
  - Perform laser shots in the atmosphere to simulate fluorescence light from extensive air showers
- **Measurement Process:**
  - Position the laser in front of the FD
  - Fire laser shots and measure the scattered light using the FD telescope
  - Predict the number of photons reaching the FD by applying Rayleigh and aerosol scattering models
- **Validation:**
  - Cross-check results with other calibration methods
  - Analyze atmospheric effects like Rayleigh and aerosol scattering

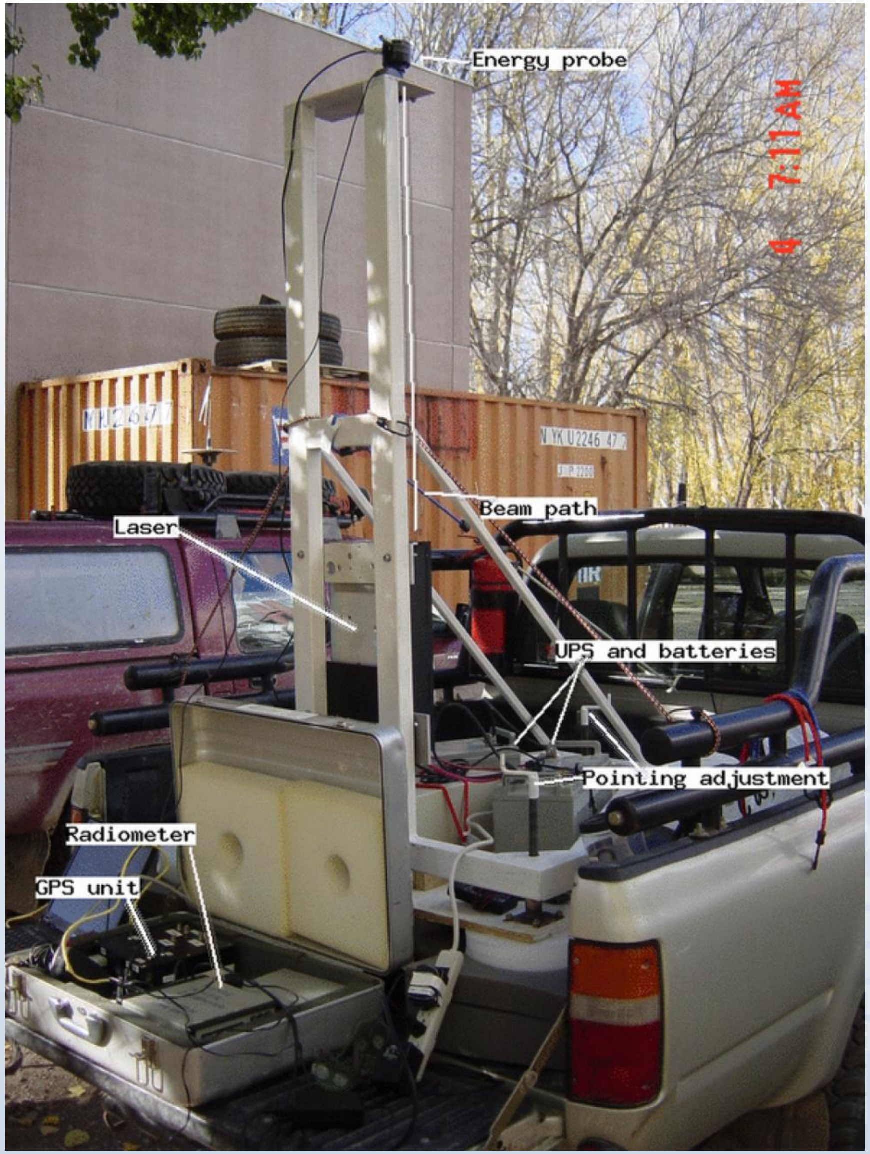


Previous Campaigns

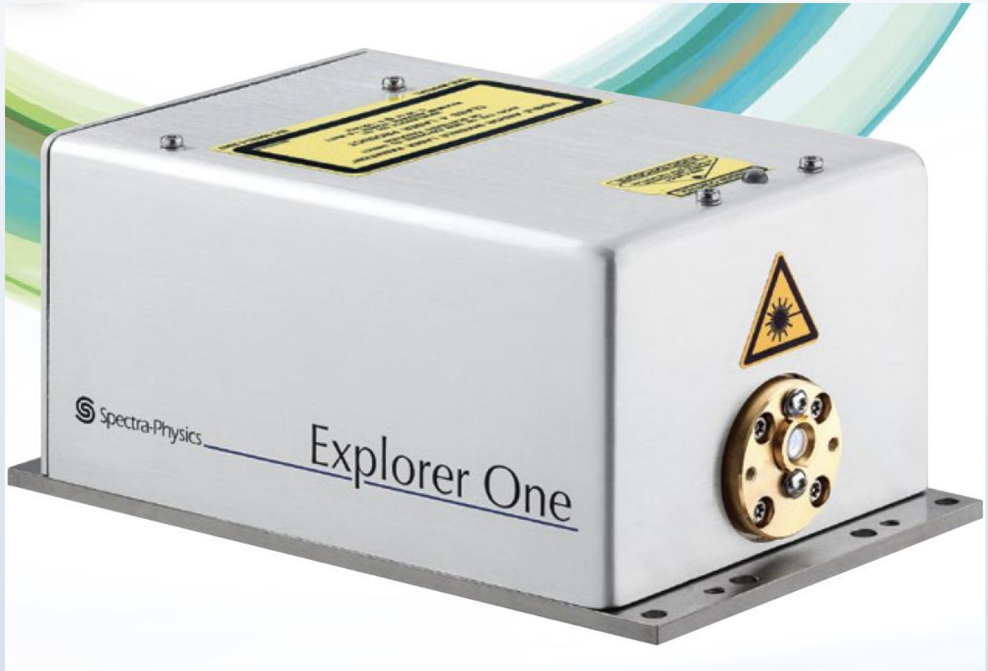
- **Calibrated Telescopes from Previous Campaigns:**

October 2001:	LL4
March 2002:	LL4
May 2005:	LL3/4/6, CO2/3
August 2006:	LL3/4/6, CO3
July 2010:	LL, CO
Feb-Jun 2011:	LL, LA, CO

- **Problems Encountered:**
  - Imprecise energy measurements (E-Probe)
  - Low statistics
  - Residual polarization
  - Contamination with green light
  - Even getting lost in the dark
- **Optimizations to Consider:**
  - Avoid previous issues
  - Calibrate other telescopes
  - Vary distances and angles

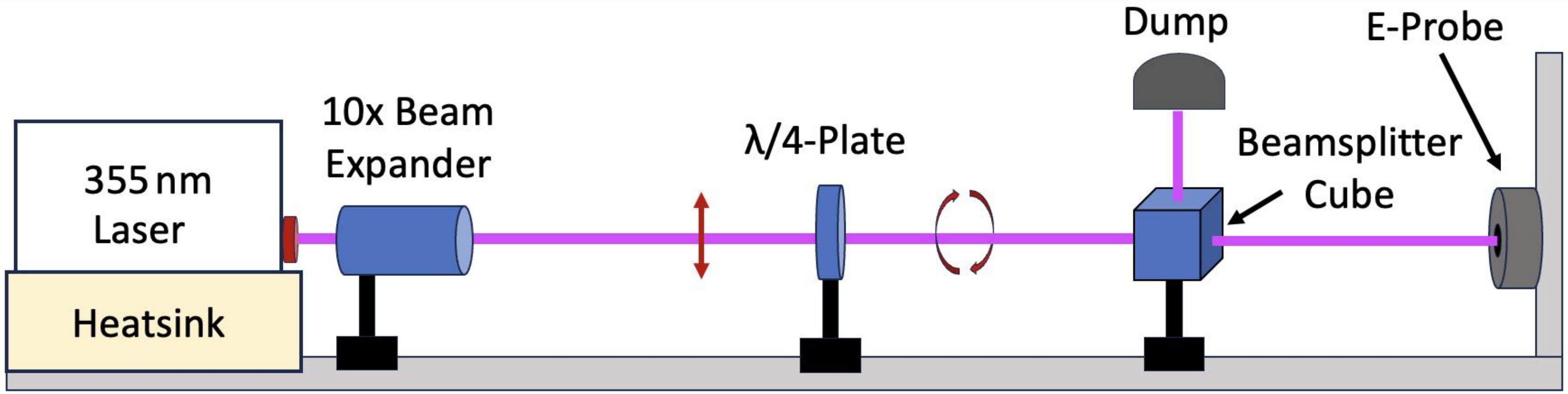


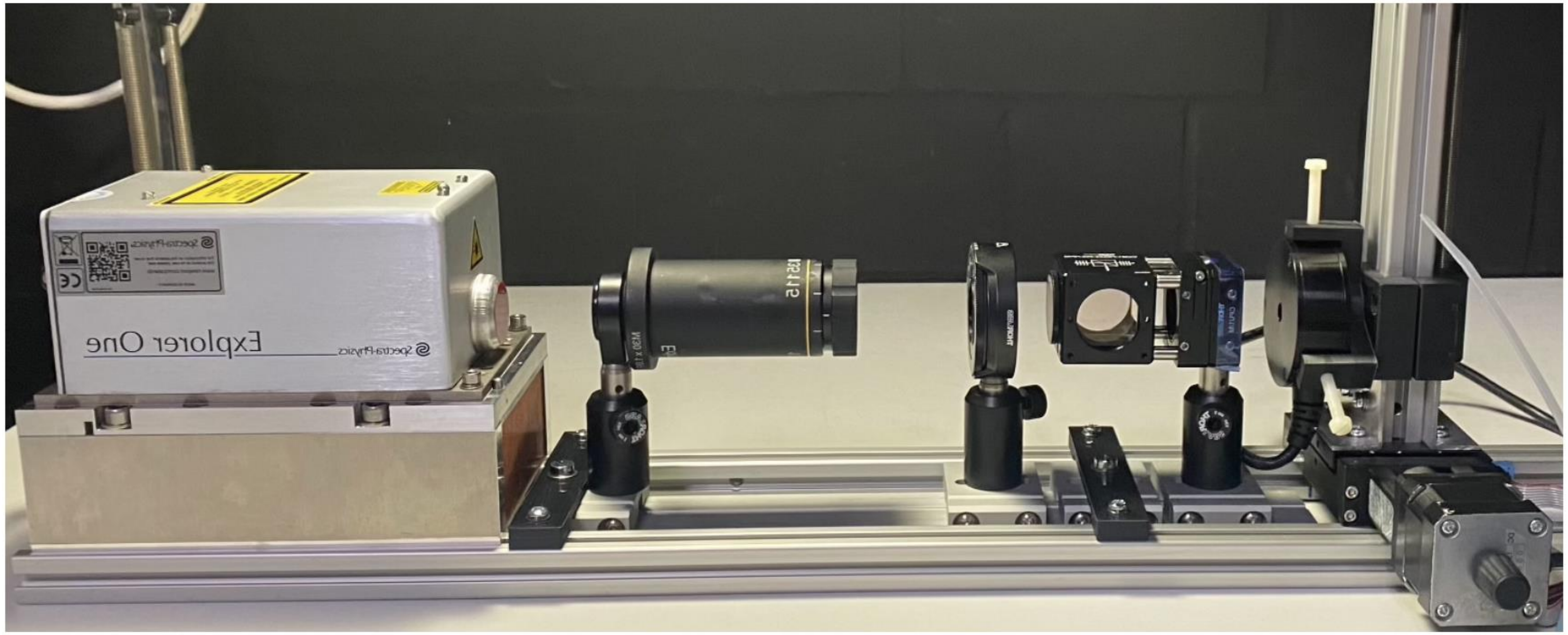
Technical Specifications of the Laser



- Pulsed laser
  - Adjustable pulse repetition rate: 0-60 kHz
  - Adjustable pulse energy up to 150 µJ (dependent on adjustable diode laser current)
- Wavelength: 355 nm (UV)
  - Comparable to fluorescence light
- Leakage wavelengths due to the optical design at maximum power:
  - Diode laser emission: 808 nm < 1%
  - Fundamental beam: 1064 nm < 1%
  - Second harmonic: 532 nm < 1%

Experimental Setup in the Lab

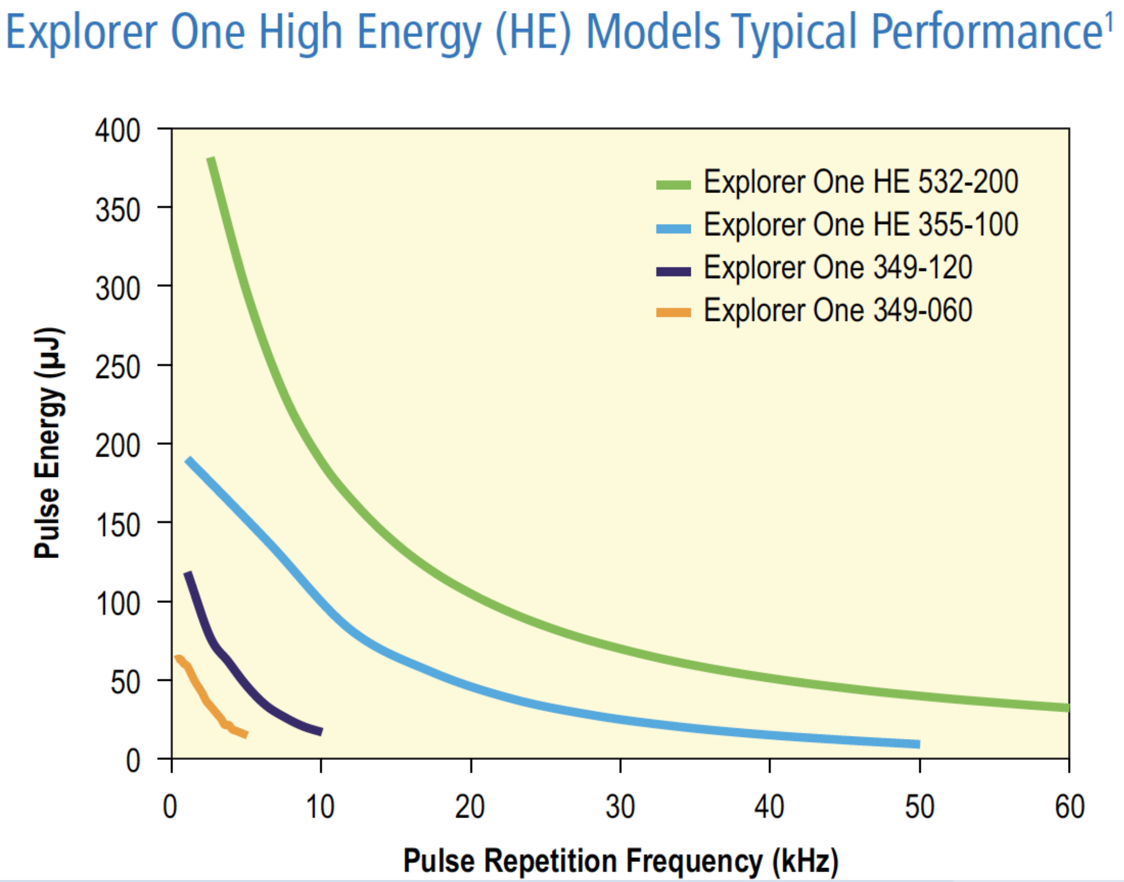




Lab Measurements

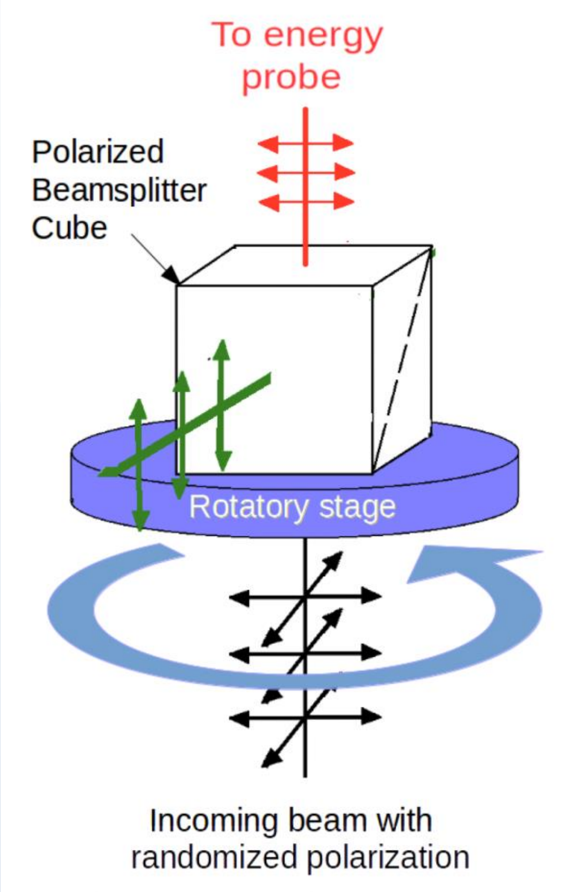
Planned Measurements:

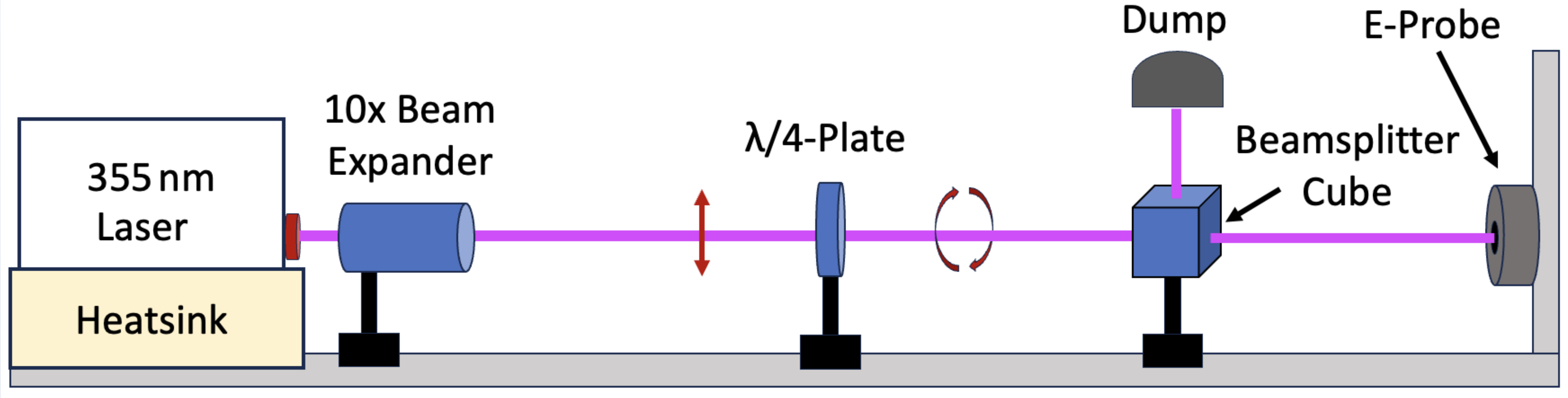
- Determination of the relationship between diode current and laser output energy
- Verification of the laser’s internal energy at different pulse repetition frequencies using an external energy probe
- Achieve maximum circular polarization of the beam using a $\lambda/4$-plate
- Check the fraction of leakage wavelengths at different energy levels (?)



Polarization Measurement

- Problem: Polarized laser light affects the phase function of Rayleigh scattering
- Goal: Minimize the residual degree of polarization
- Measuring procedure to determine the optimal angle of the $\lambda/4$-plate:
  - Set a fixed angle for the $\lambda/4$-plate.
  - Rotate the beamsplitter in defined steps (e.g., 45 degrees)
  - Measure the transmitted energy for each angle
  - Ideal case: With no residual polarization, the measured energy remains constant for each angle



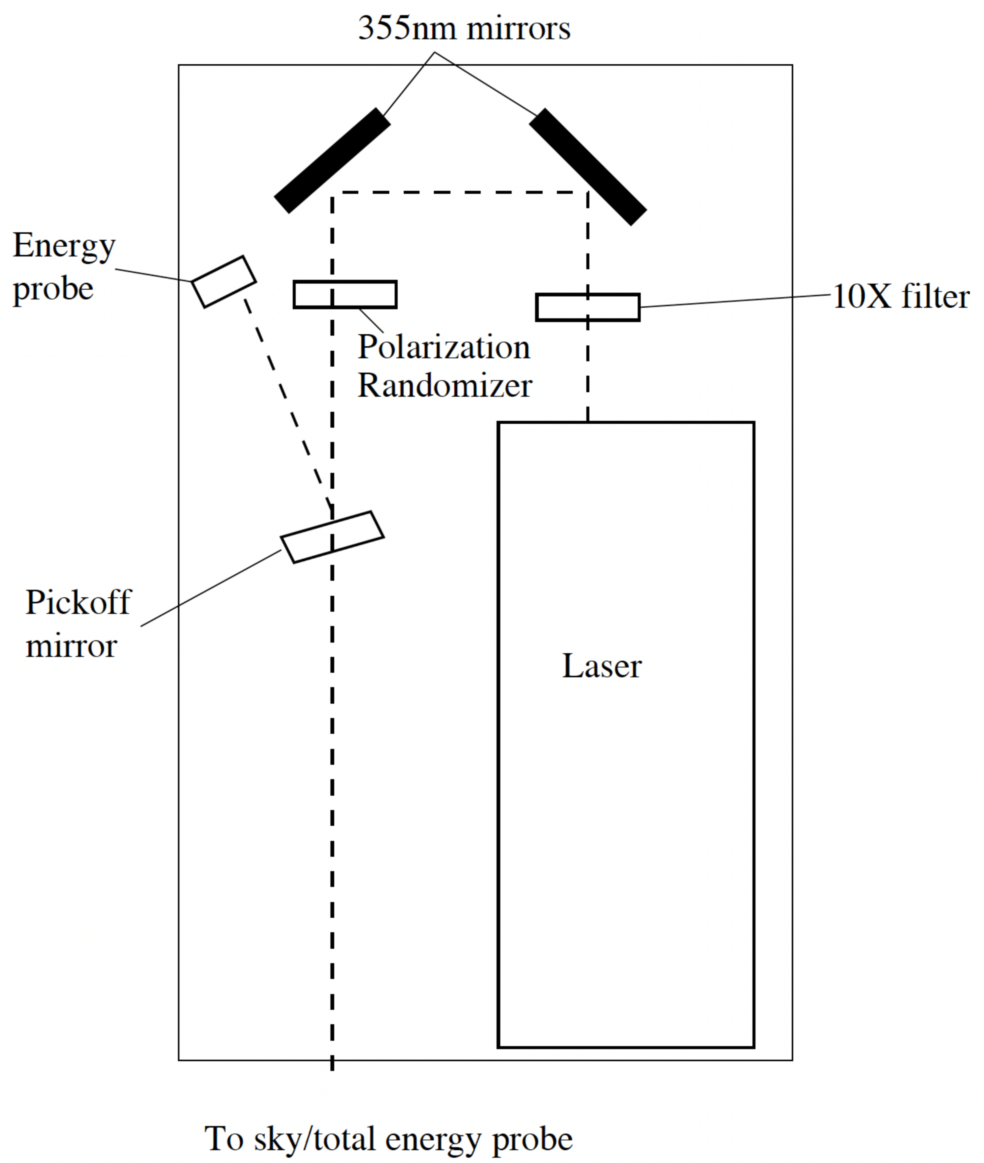


Measurement of Leakage Wavelengths

- Problem: Rayleigh scattering Cross-Section:

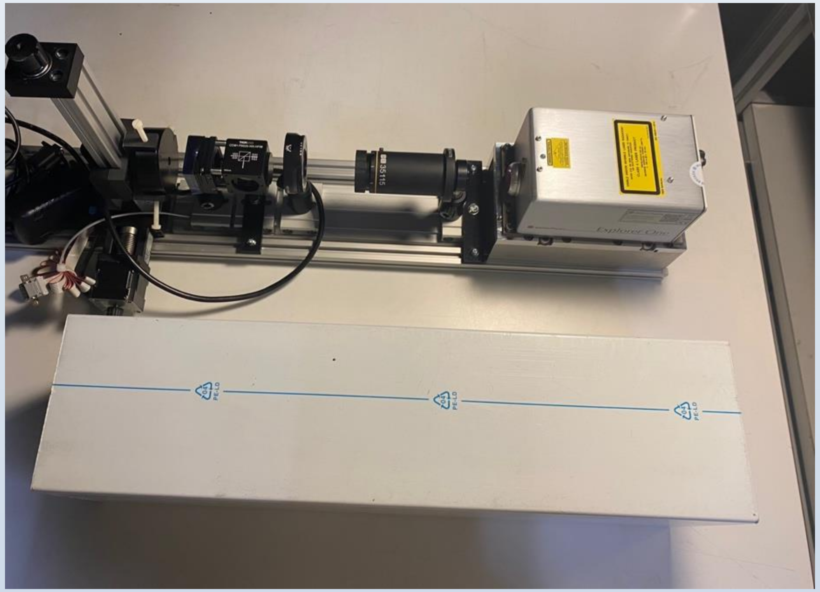
$$\sigma \propto \frac{1}{\lambda^4}$$

- Impact: Leakage wavelengths can affect calibration uncertainty
- Goal: Determine if lab measurements are necessary
- Procedure:
  - Run offline simulations
  - Based on simulation results, decide if additional lab measurements are needed
- Consider beam filtering with mirrors that only reflect 355 nm, as done in 2002
- Note: Measurements will be conducted only in the laboratory to ensure handy setup conditions in the field



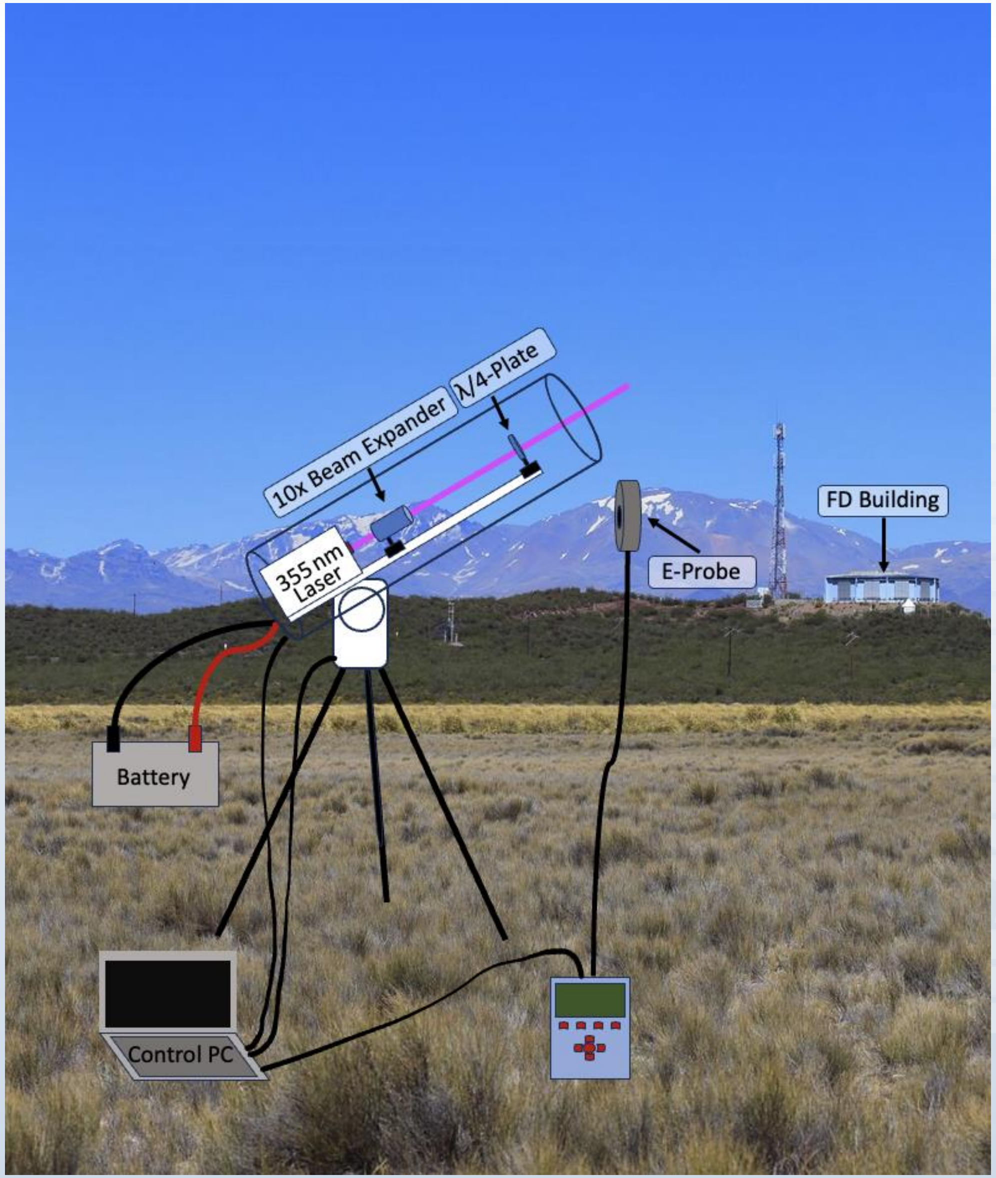
Experimental setup for the field

- Laser system placed inside a metal box
- Box fixed on a telescope mount
- Box prevents reflected light from escaping in other directions
- Handy features of new design:
  - High energy and angular accuracy
  - Mobility
  - Logistical independence
  - Automation capacity



Field Measurements

- Place the laser at a 4 km distance in front of one telescope
- Vertical alignment of the laser system
- Laser parameters:
  - Pulse frequency: 1 Hz
  - Pulse energy: 100 - 200 µJ
- Measuring procedure:
  - 50 shots with an energy probe
  - 200 shots directed towards the sky
  - 50 shots with an energy probe
- Rotate the laser 360° around the zenith
  - Repeat the measurement procedure
- Measurements for different distances and zenith angles

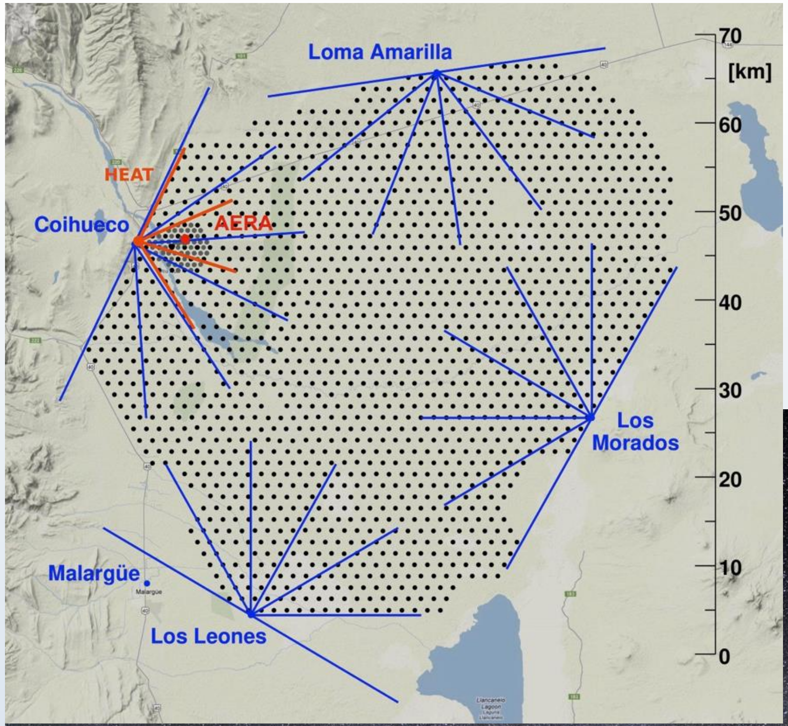


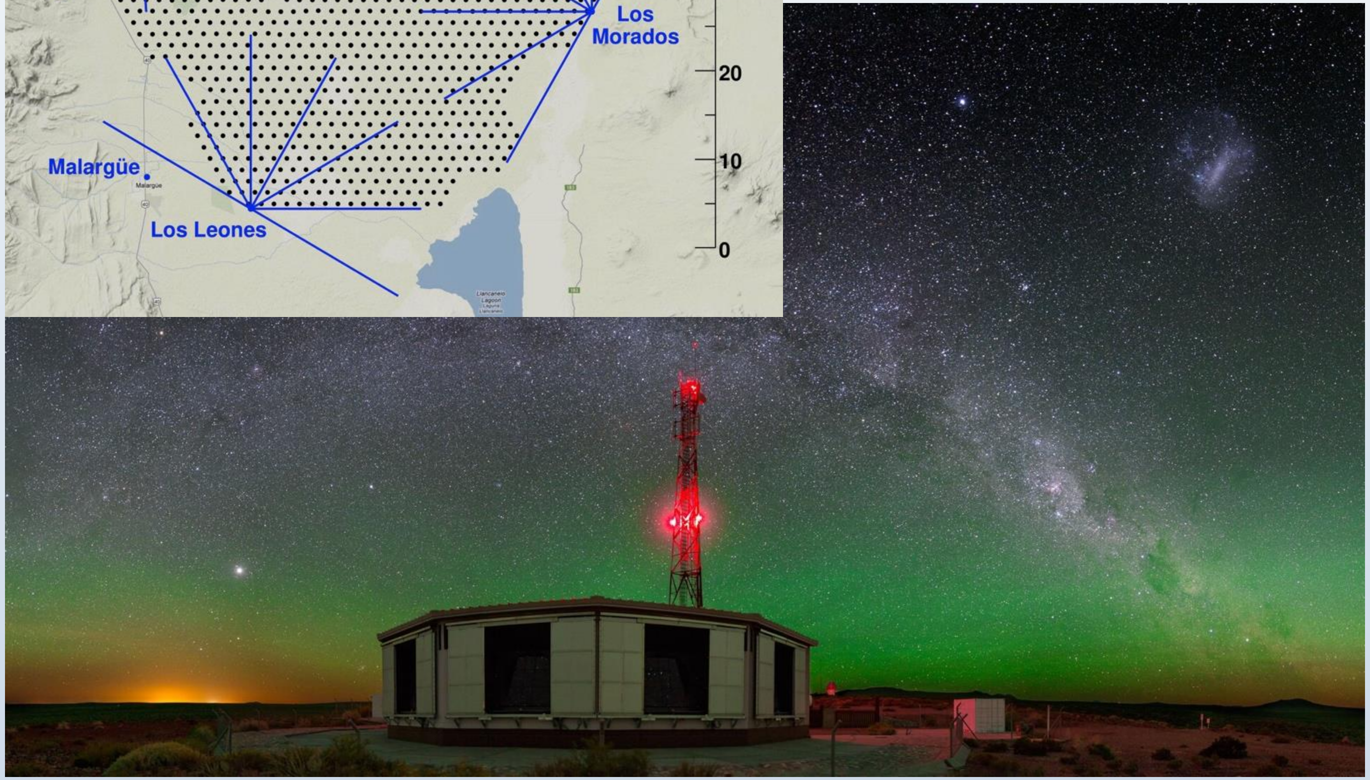
Next Steps

- **Turn on laser..**

Backup

The Fluorescence Detector

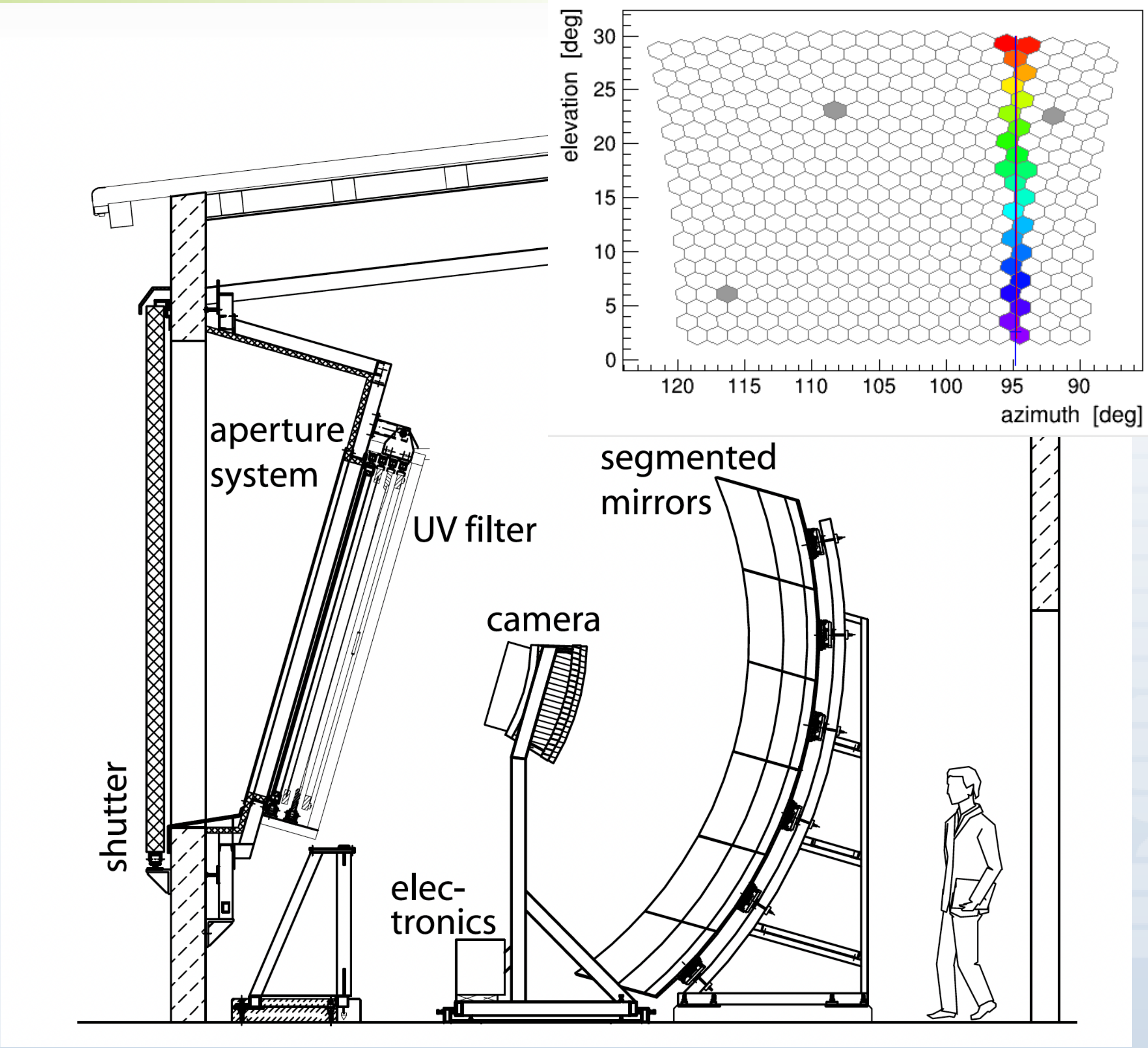




- The FD comprises four observation sites
- Loma Amarilla, Los Morados, Los Leones, Coihueco
  - 6 telescopes per building
  - Field of view per telescope: $30° \times 30°$ in azimuth and elevation
- 3 additional High Elevation Auger Telescopes (HEAT)
  - Extend the field of view of the Coihueco telescopes by in $30°$ elevation

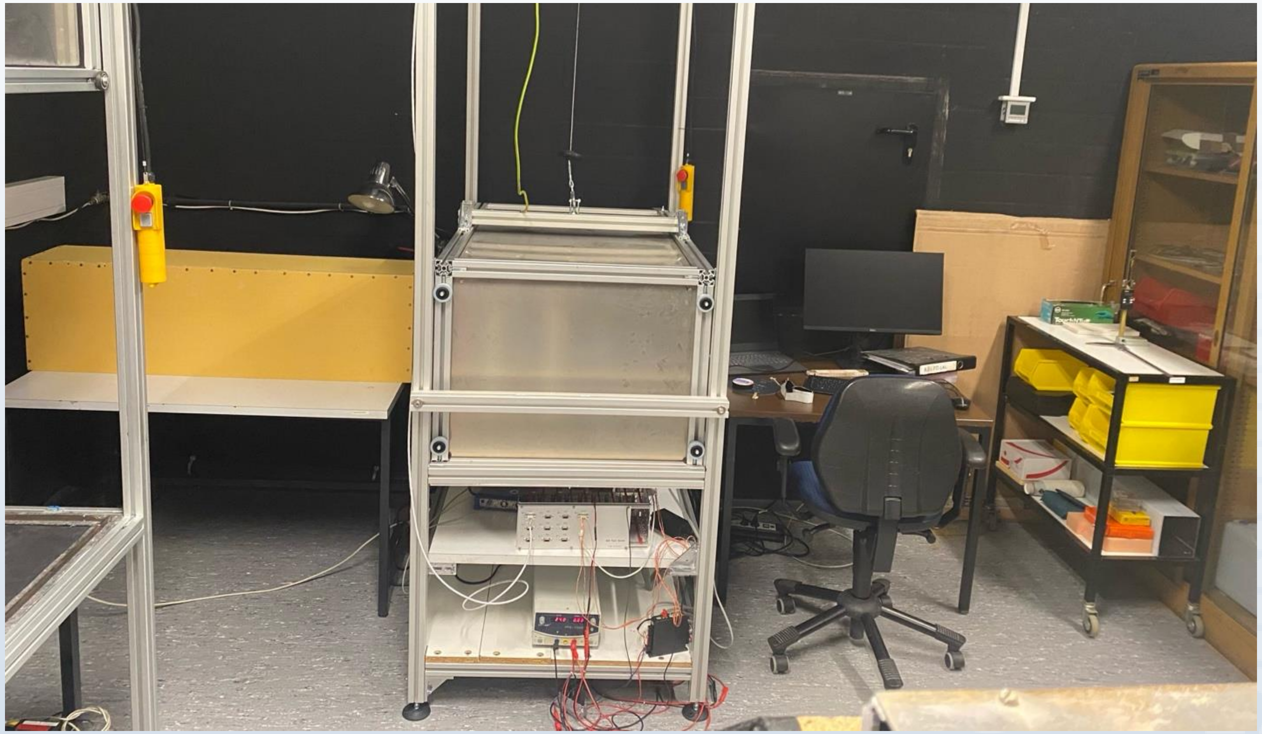
Telescope of the Fluorescence Detector

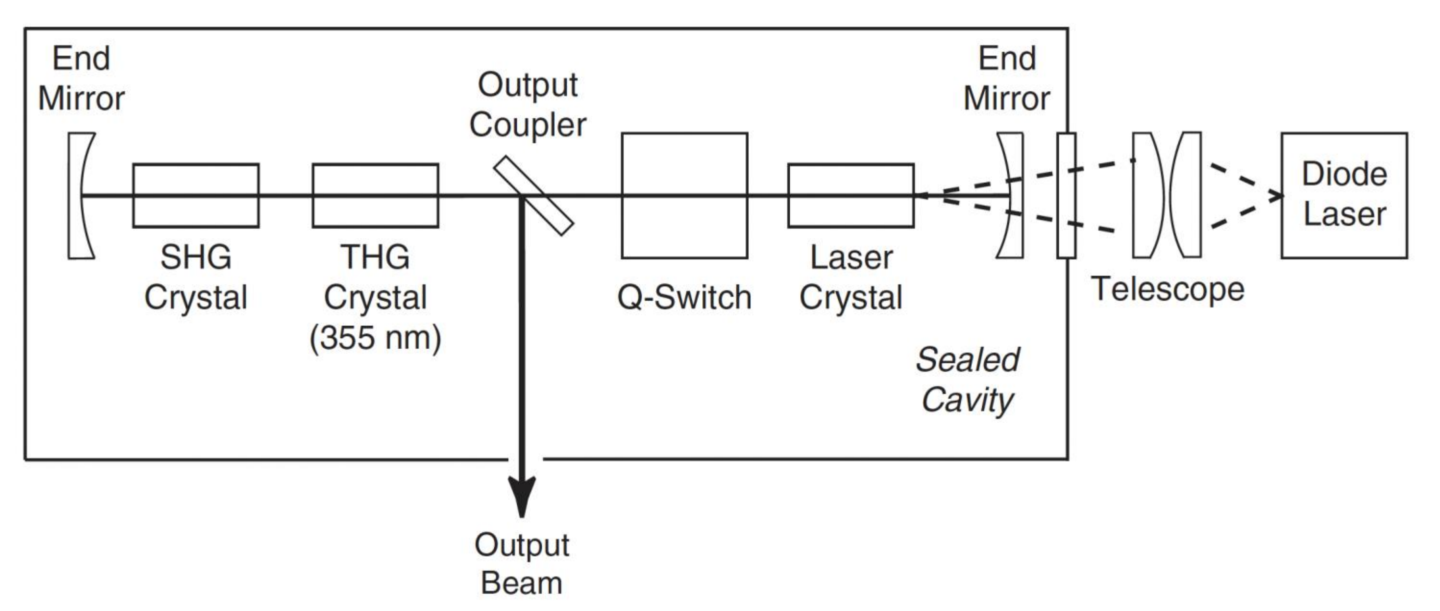
- Shutter and a curtain to protect the camera from unexpected direct light
- Fluorescence light enters through an aperture system with a UV-transparent filter to reduce background light
- Light then strikes a 13 m² segmented spherical mirror
- The mirror's curvature focuses the light onto a camera with 440 pixels equipped with PMTs
- Light pulses in the pixels are digitized every 100 ns



Operating a Class 4 Laser: Safety and Setup

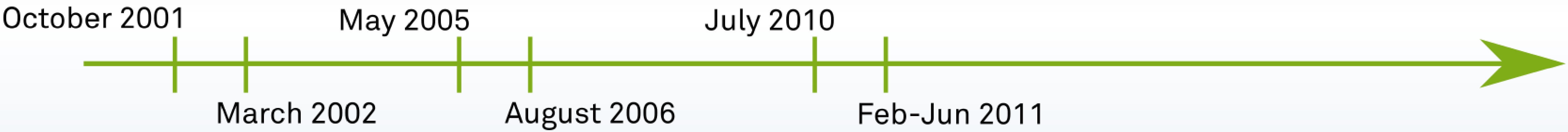
- Four Different Laser Classes
  - Higher laser class → Greater danger
- Explorer One Laser: Class 4
- Paperwork:
  - Registration of the laser with the relevant authority
  - Appointment of a Laser Safety Officer
  - Documentation of the hazard assessment
- Setup Efforts:
  - Covering the laser to prevent UV light from escaping into the lab
  - Box lined with black cardboard to absorb stray light
  - Signage with warning signs
  - Warning lamp outside the door when the laser is turned on
  - Interlock system ensures the laser is turned off when the door is opened





- Diode Laser Emission:
  - 808 nm: Emitted by the diode laser, serves as the pump light for the Nd:YAG crystal.
- Fundamental Beam:
  - 1064 nm: Fundamental emission wavelength of the excited Nd:YAG laser.
- Second Harmonic:
  - 532 nm: Produced through second harmonic generation (SHG) by doubling the 1064 nm wavelength in the crystal.

Previous Campaigns



2001	LL4	low statistics, light pollution, residual polarization
2002	LL4	12% uncertainty, residual polarization
2005	LL3/4/6, CO2/3	7% uncertainty, unpolarized 337 nm laser
2006	LL3/4/6, CO3	~10% difference to drum cal, total uncertain corrected to 12% (energy measurement)
2010	LL, CO	routine operation
2011	LL, LA, CO	business as usual