Report on the Absolute Calibration of the AirLight Experiment

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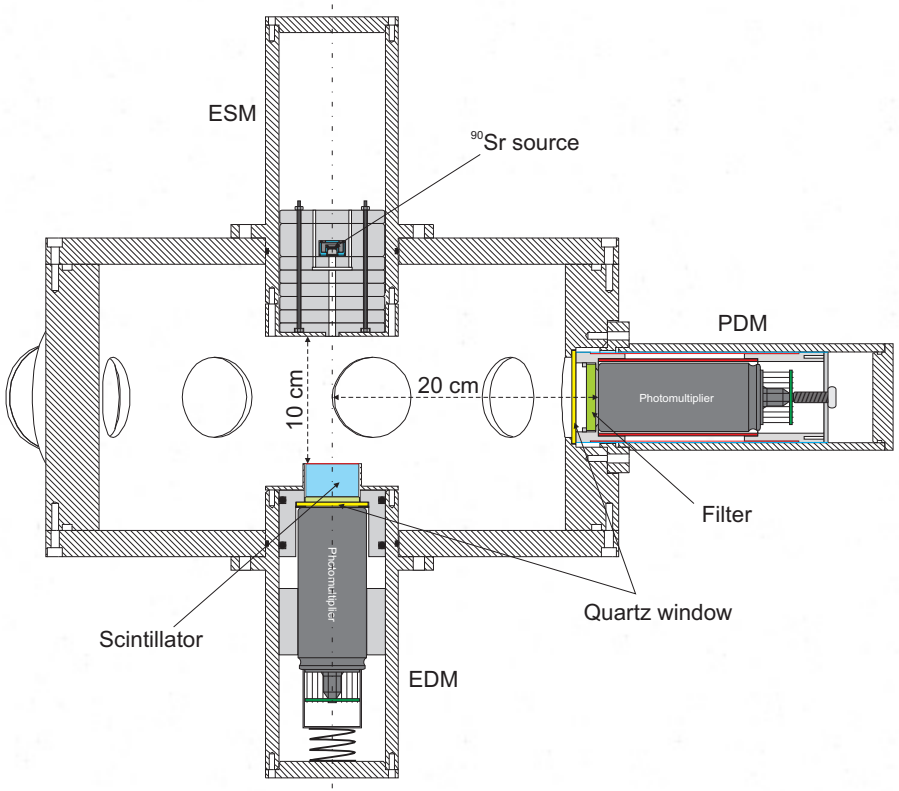
Outline

- AirLight Experiment – Short Review
- Absolute Calibration using the Rayleigh Scattering of a N_2 laser beam
  - System Overview / Components – Short Review
  - Si Photodiode Response vs GaAsP Photodiode
  - Absolute Calibration Setup Improvements
    - Mechanical System Stability
    - Scattering inside the instrument
  - Results with the present setup
  - Pressure scan
  - Rayleigh Calibration
- Outlook

•**Experimental Setup**: Electrons emitted from ^{90}Sr-source produce fluorescence light in gas. This fluorescence is measured by photon detectors around the electron beam [T. Waldenmaier et al. Astropart. Phys. (arXiv:0709.1494)]



AirLight Experimental Setup [T. Waldenmaier]

- ^{90}Sr, 37 MBq
- Energy Range: 250 keV – 2 MeV
- Gas: N_2, Dry Air, N_2:O_2 mixture (90:10)
- Pressure: 2 hPa – 1000 hPa
- Temperature: ~ 20 ^{0}C
- Wavelength Range: 300 – 400 nm
- Detection: 7 PMTs with 5 different narrow-band filters and one broad-band (M-UG6) filter
- Fluorescence Yield was absolutely determined with a precision of 15%

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Absolute Calibration using the Rayleigh Scattering of a N_2 laser beam

Measure the PMT efficiencies by comparison to an energy meter

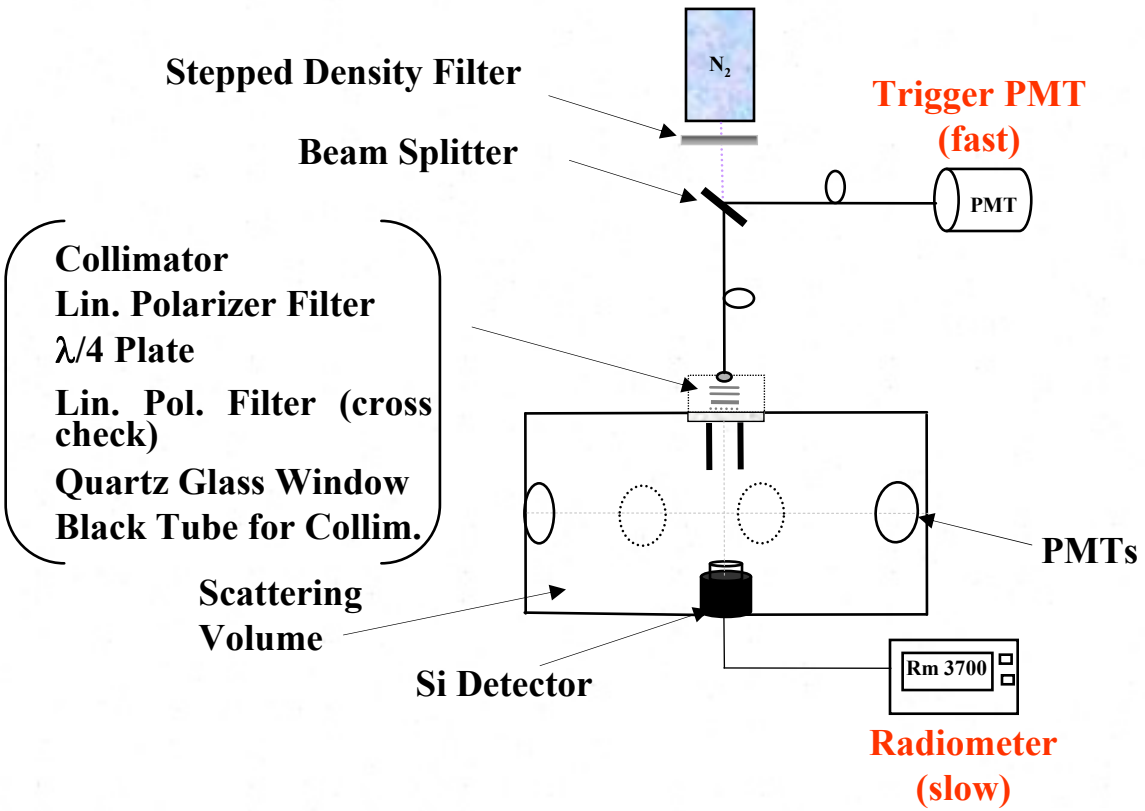
with an accuracy of ±5%

Rayleigh Scattering theory is used to obtain the precise number of Rayleigh scattered photons:

$$N_{Scatt\gamma} = N_L \sigma_{tot}^{Rayl} \cdot N_{mol} \cdot \varepsilon_{\Omega}^{Rayl}$$

$$X = \frac{N_{dtected}^{Scatt\gamma}}{N_{Scatt\gamma}}$$

Absolute Calibration – System Overview / Components

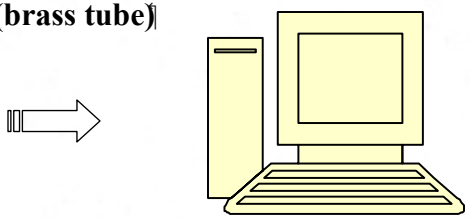


PMT

Photonis XP 2268 and XP2262

Aperture Ring (Ø = 4.0 cm) Limits the Sensitive Area of the Photocathode.

PMTs surrounded by Electrostatic Shield (brass tube)



Windows PC – LabView DAQ

Light Source

N_2 Laser, $\lambda = 337.1$ nm

$E_{max} = 120\ \mu J$

Pulse Width, FWHM = 3ns

Silicon Energy Probe

Laser Probe – RjP-465

($E_{minDet} = 500$ fJ, $E_{maxDet} = 250$ nJ)

Detection Area = 1.0 cm^2

Calibration Accuracy ± 5 %

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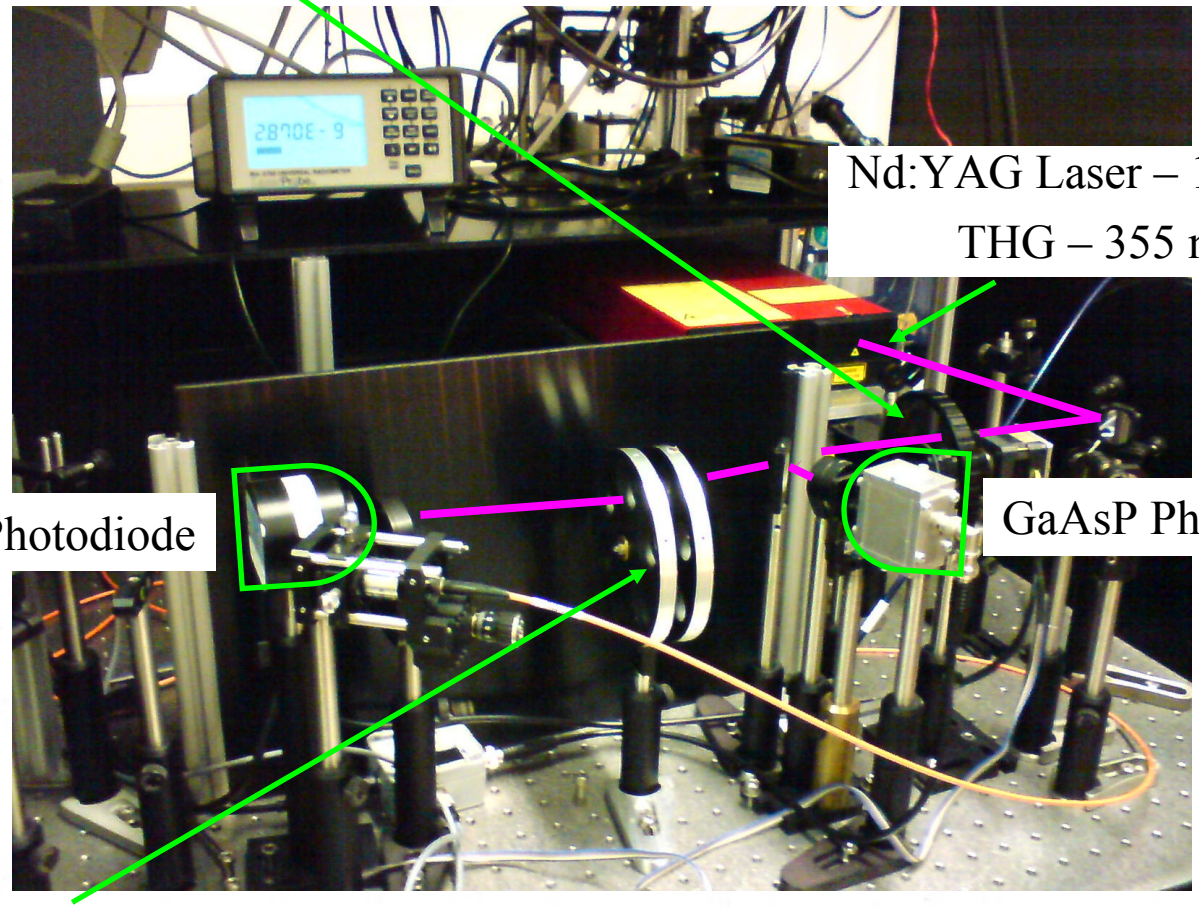
Si vs GaAsP Photodiodes' Energy Response Measurement @355 nm Nd:YAG

Circular Neutral Density Filter



Nd:YAG Laser – 1064 nm

THG – 355 nm

Si Photodiode

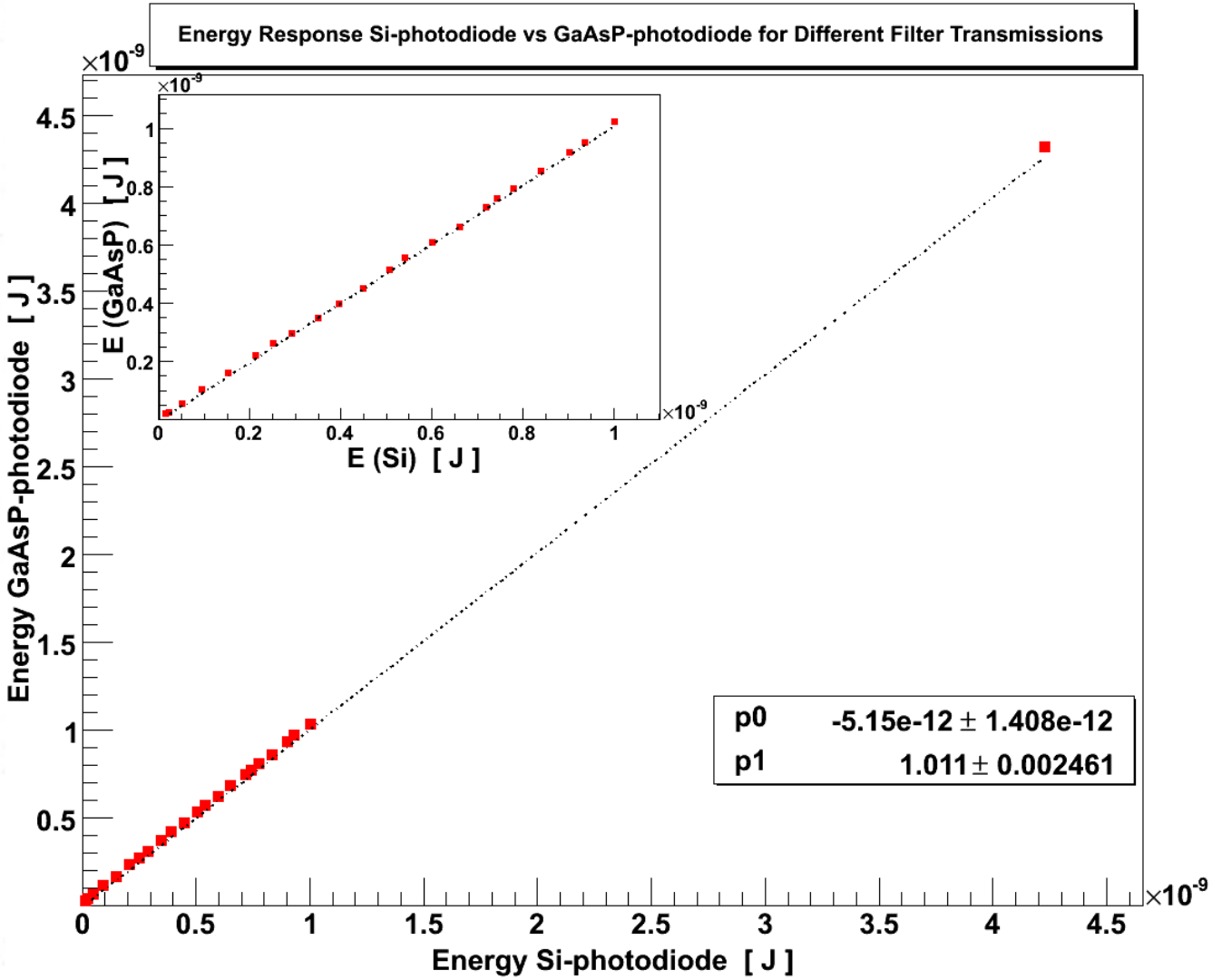
GaAsP Photodiode

Circular Stepped Density Filter

$T_{Filter} = 0.69$

$$E_{Si} = \frac{1}{T_{Filter}} \cdot E_{Si}^{Rm}$$

Si vs GaAsP Photodiodes' Energy Response Measurement



Energy response of the Si and GaAsP photodiodes for different energies (14 pJ – 4.5 nJ). The response remains linear

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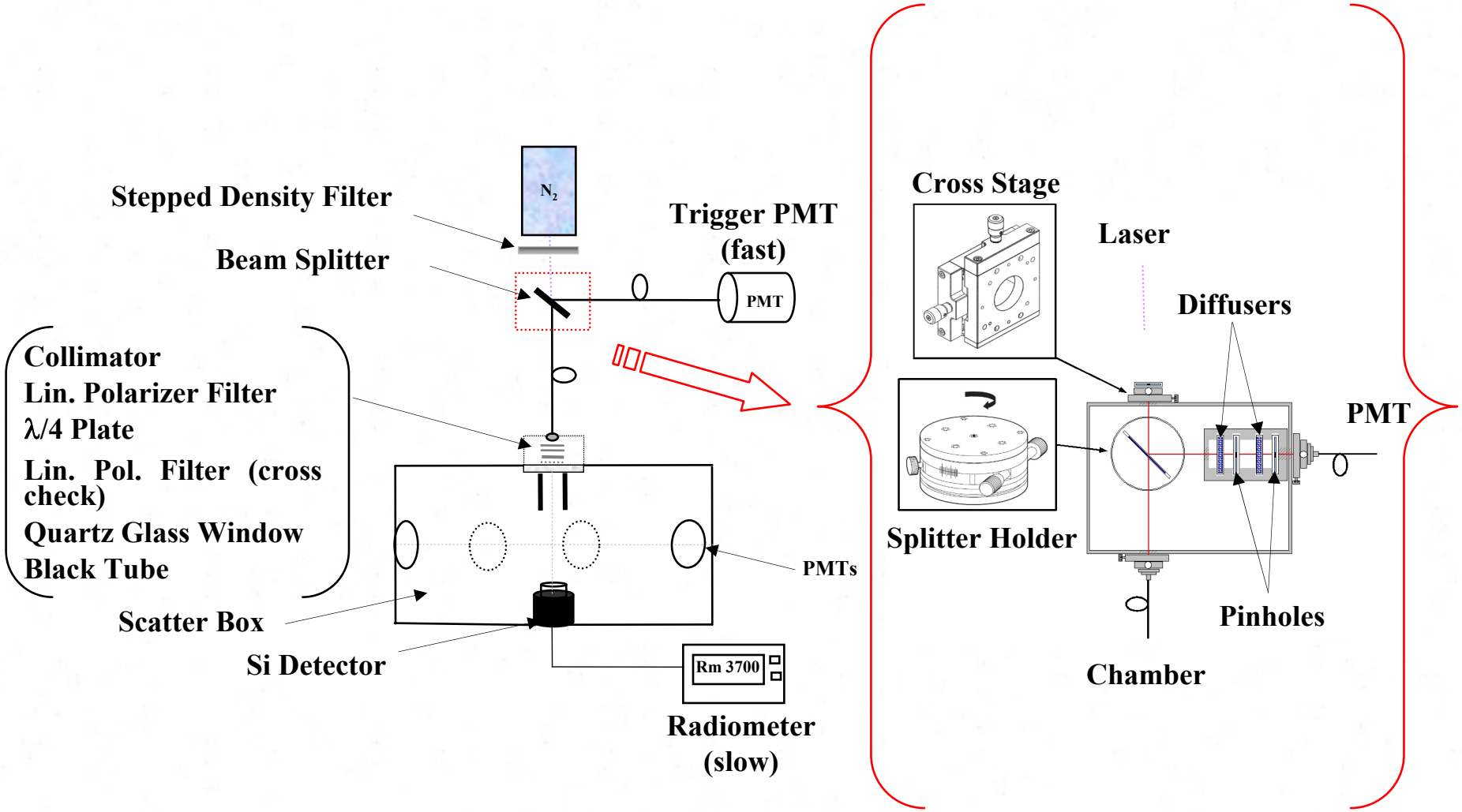
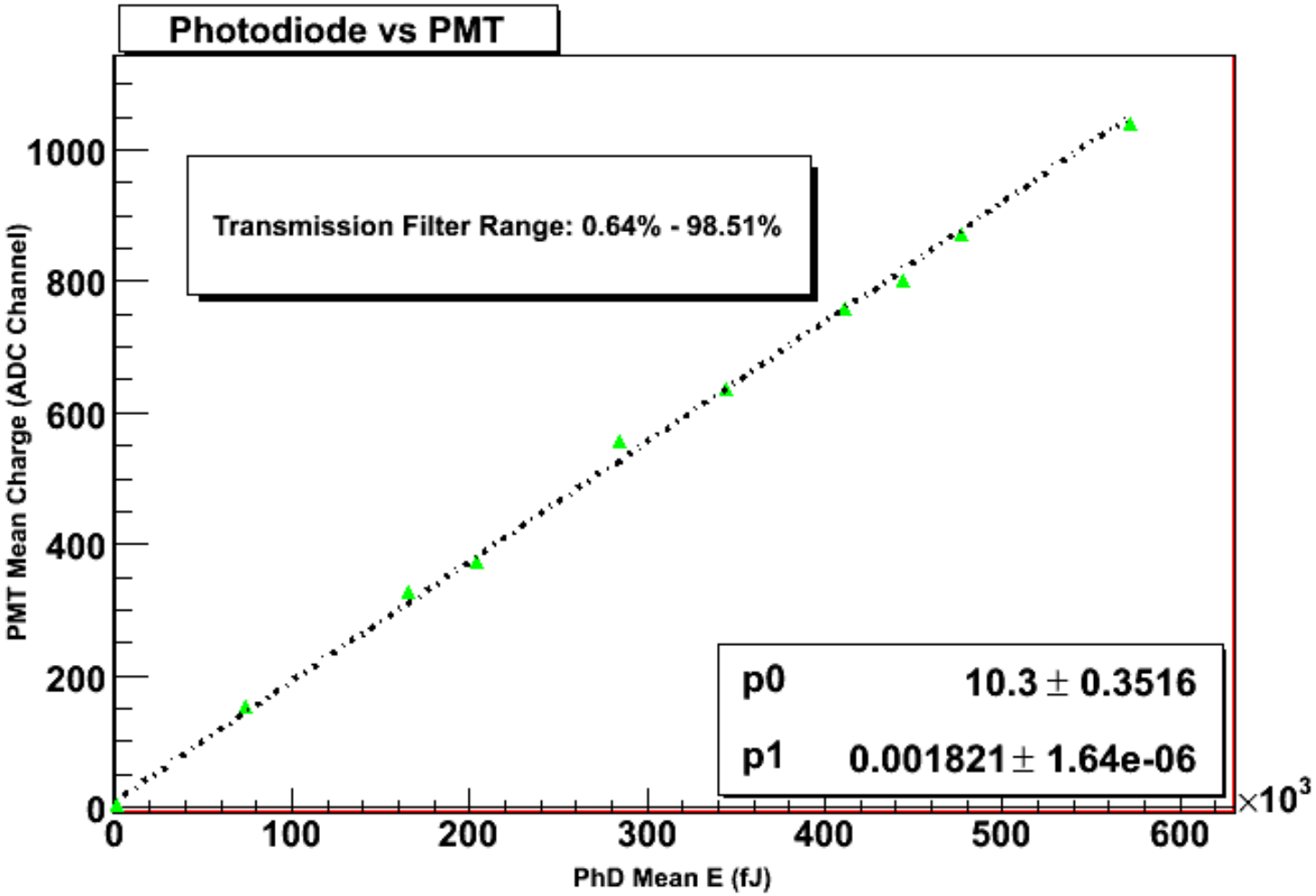
Linear response of the photodiode



Si photodiode vs the trigger PMT responses – Energy Range: 12 fJ up to 0.6 nJ



Comparison of the photodiode vs PMT responses for different intensities, using a 337 nm of the N_2 laser.

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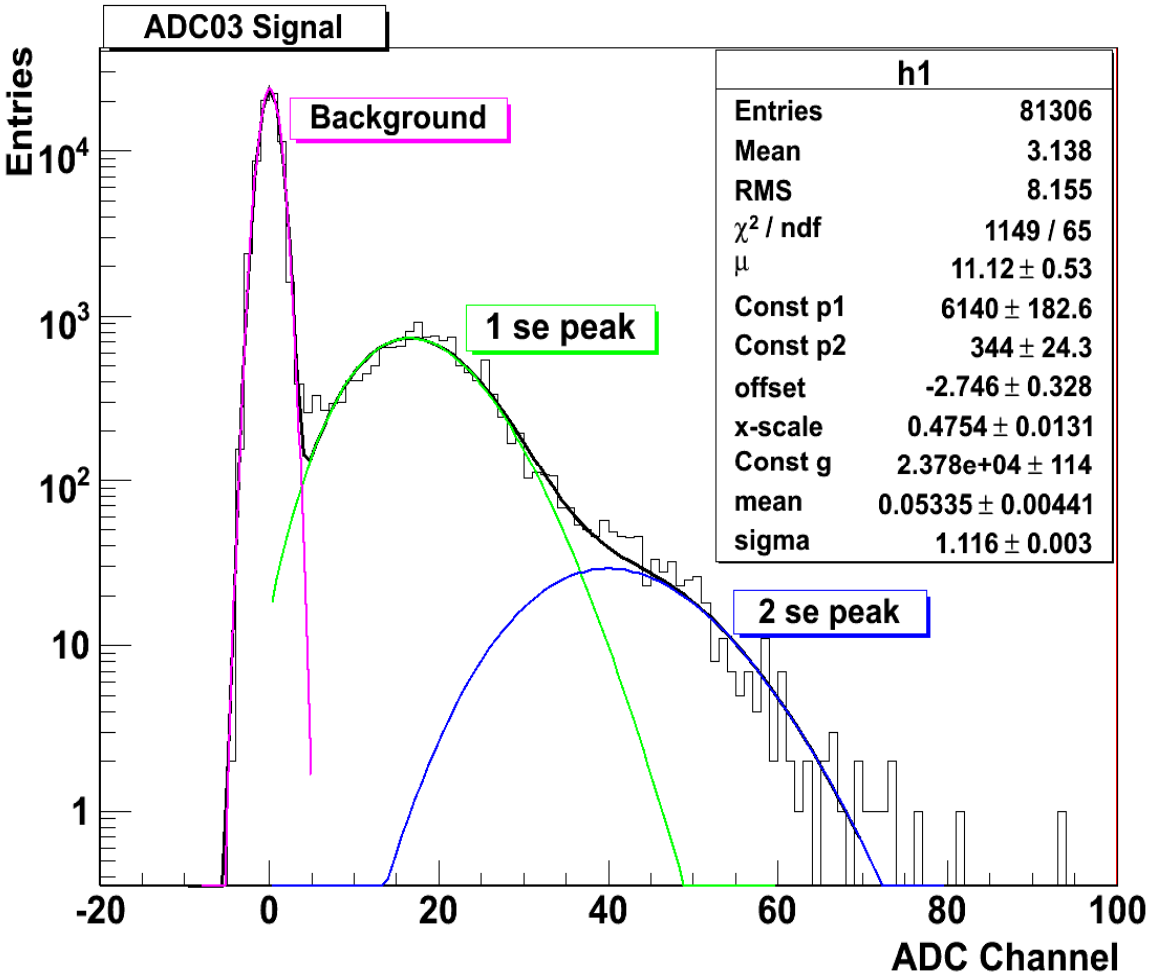
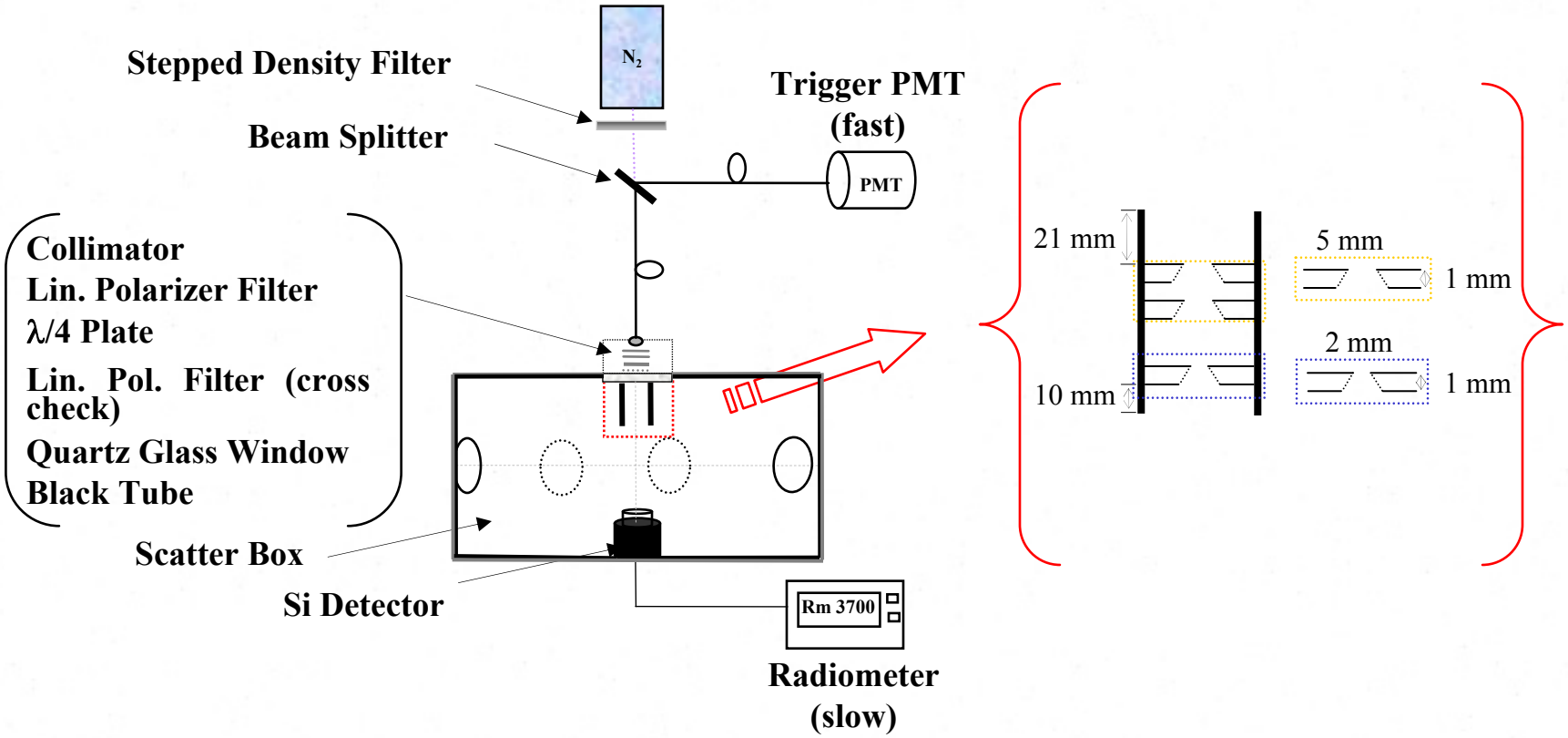
High Scattering inside the instrument



Single photoelectron distribution of one of the PMTs located around the Laser beam (2.5 pJ and 948 hPa of N_2)

Setup Background Improvement

Flock Paper, Mechanical Modifications, Vacuum Improvements: removing the flock paper contribution as a trap to the Nitrogen Molecules between measurement sets… ⟹ Considerable Reduction of the Background Noise



Mechanical setup improvement: Flock Paper, Baffles (Laser shape), Vacuum

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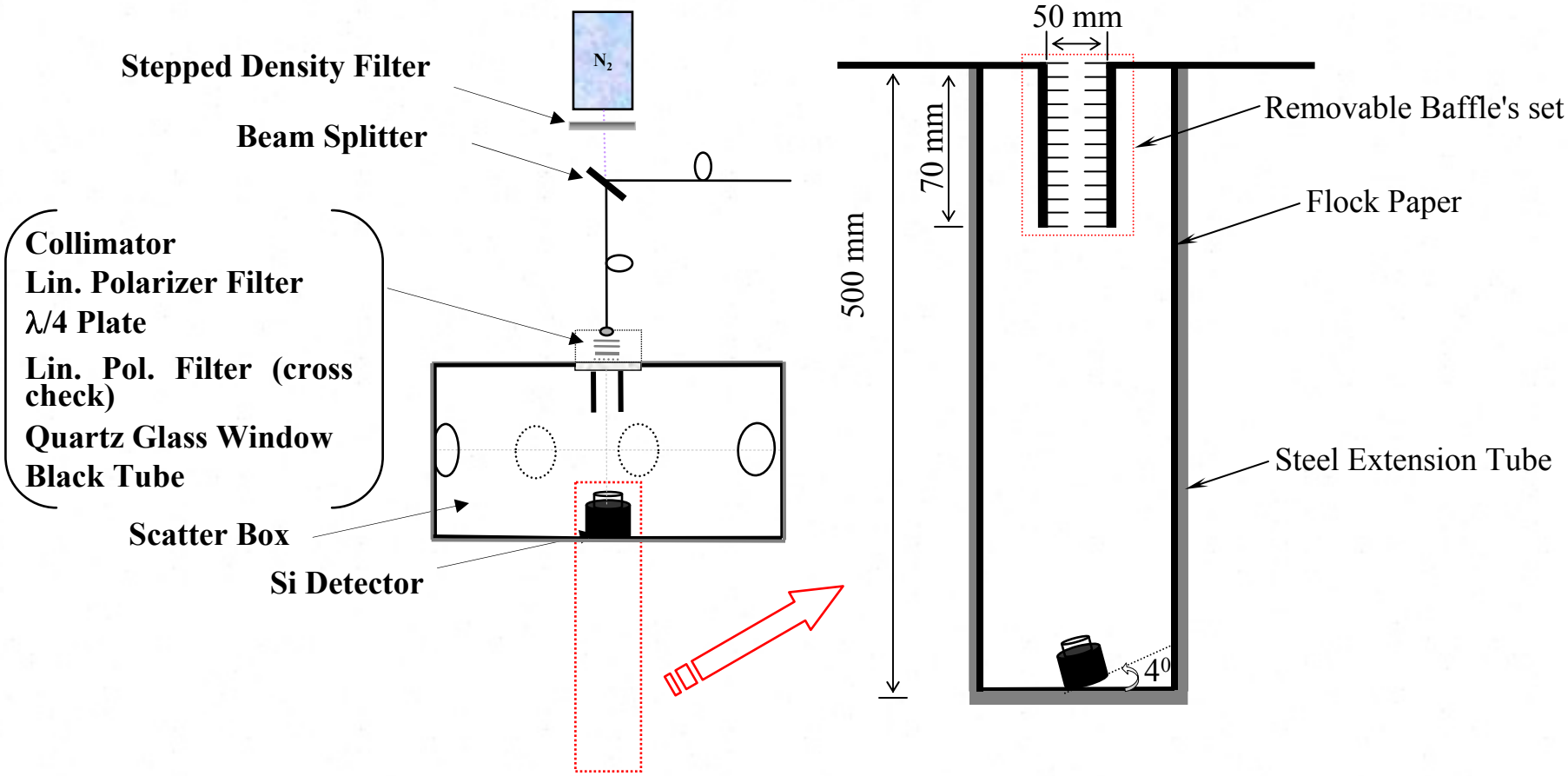

Mechanical setup improvement: Flock Paper (only 1 PMT uncovered), Baffles (backscatter light phd), Tilted phd

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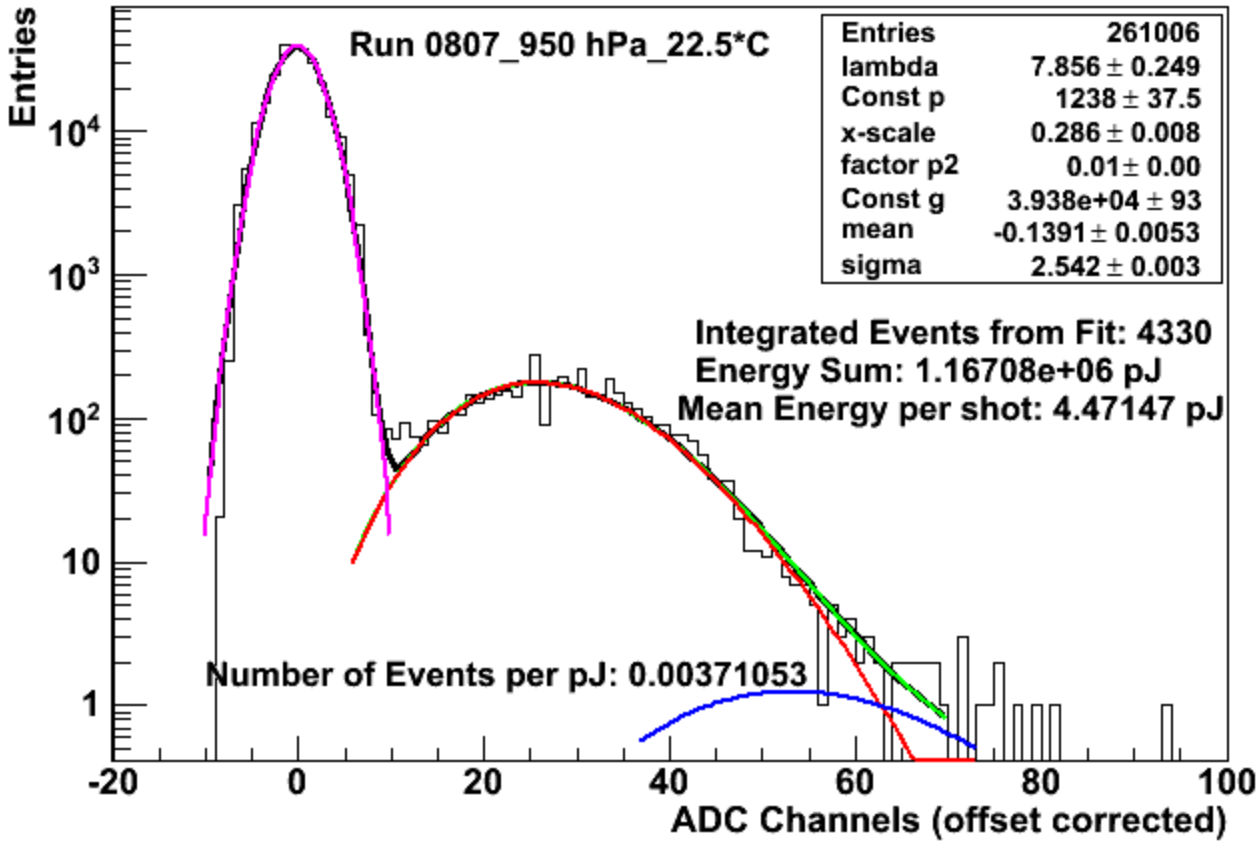

Single photoelectron distribution of one of the PMTs located around the Laser beam

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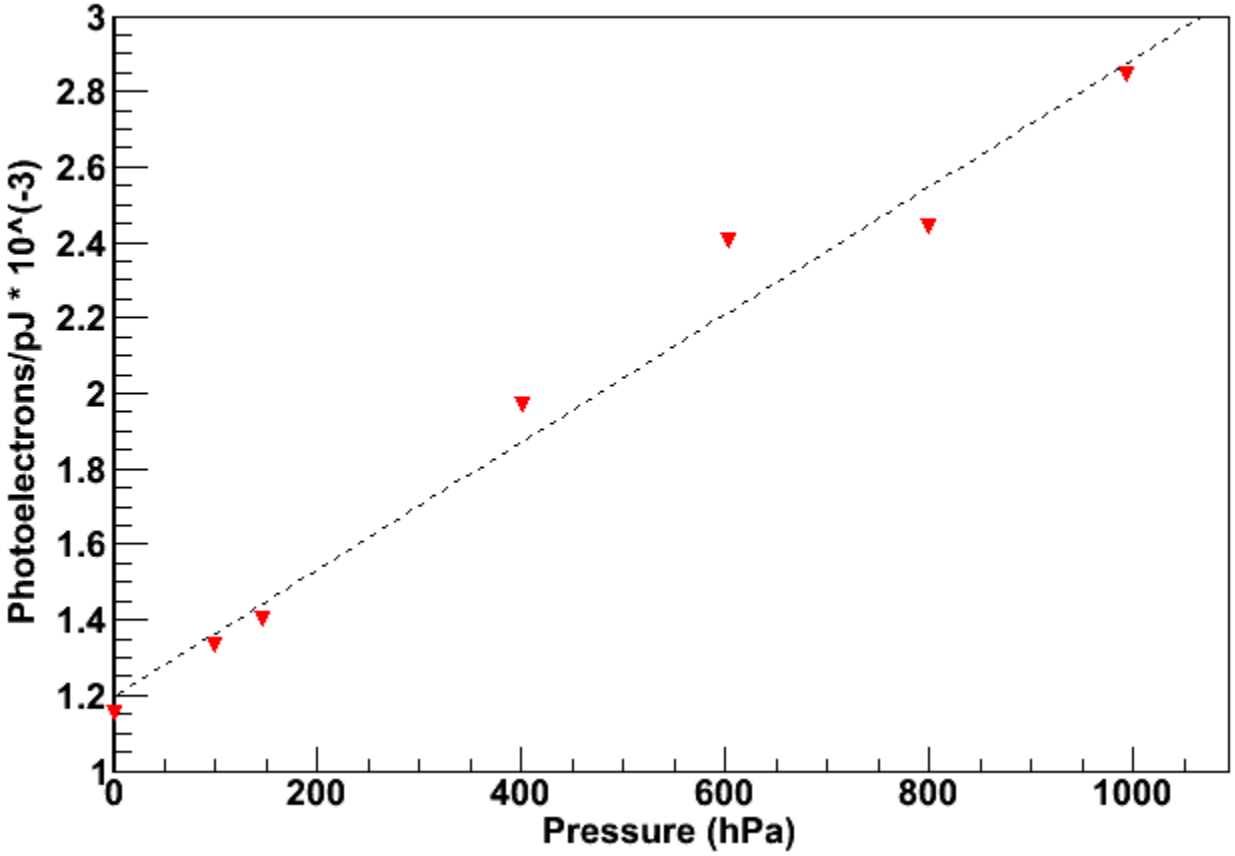
Pressure Scan



Pressure range from 10^{-3} h Pa up to 1000 h Pa of Nitrogen

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Rayleigh Calibration

Fluorescence

simulated

$$N_{\text{det}} = Y(\lambda, p, T) \cdot E_{dep} \cdot \varepsilon_{\Omega}^{fluo} \quad X$$

measured/simulated

measured

Rayleigh

calculated

X

$$N_{\text{det}} = N_{scatt\gamma} \cdot T_{glass} \cdot T_{filter} \cdot \varepsilon_{QE} \cdot \varepsilon_{coll}$$

background corrected

Rayleigh scattering cross section

$$\frac{d\sigma}{d\Omega} = \frac{24\pi^3}{\lambda^4 N_{mol}^2} \cdot \frac{\left(n^2-1\right)^2}{\left(n^2+2\right)^2} \cdot F_k \cdot \frac{3}{16\pi} \cdot \left(1+\cos^2\theta\right)$$

Number scattered photons reaching the PMT's iris

$$N_{scatt\gamma} = N_L \cdot \sigma_{tot}^{Rayl} \cdot N_{mol} \cdot \varepsilon_{\Omega}^{Rayl}$$

Geometrical Acceptance

$$\varepsilon_{\Omega}^{Rayl} = \left(\frac{\#detected \quad photons}{\#generated \quad photons} \right)$$

simulation

Number scattered photons (Si photodiode)

$$N_{Scatt\gamma} = N_L \sigma_{tot}^{Rayl} \cdot N_{mol} \cdot \varepsilon_{\Omega}^{Rayl}$$

$N_L = 1.70 \times 10^6 \,(\text{for } 1\,\text{pJ})$

$N_{mol} = 9.18 \times 10^{18}$

$\sigma_{tot}^{Rayl} = 3.80 \times 10^{-26} cm^{-2}$

$\varepsilon_{\Omega}^{Rayl} = 0.015$

$\Rightarrow \quad N_{Scatt\gamma} = 8.68 \times 10^{-3}$

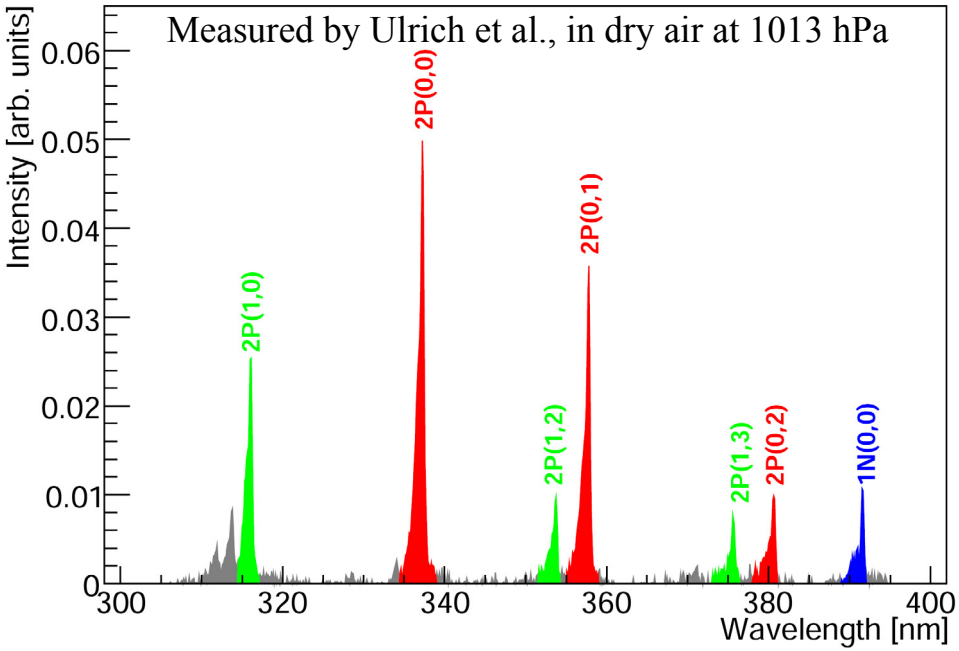
Detected number photons (PMT) background corrected

$$N_{\text{det}} = 1.69 \times 10^{-3} \pm \ldots$$

$$X = \frac{N_{dtected}}{N_{Scatt\gamma}} = 0.19 \quad \Leftrightarrow \quad X = T_{QuartzGlass} \cdot \varepsilon_{QE} \cdot \varepsilon_{coll}$$

Data provided by Photonis: $\varepsilon_{QE} \cdot \varepsilon_{coll} = 0.25$

Error Estimation - Preliminary



Error estimation (preliminary)

Accuracy of energy meter:	5%
Rayleigh cross-section:	3%
Pressure accuracy:	1%
Beam polarization:	0.25%
Acceptance:	2%
Total uncertainty of calib. factor:	6%

Absolute uncertainty of individual N_2 bands: 8% - 11%

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Status / Outlook

✓ http://www.auger.org/admin/GAP_Notes//GAP2009/GAP2009_128.pdf

✓ Background from scattering inside the instrument is understood and considerably reduced

✓ Measurements @ various pressures performed (near vacuum to ambient pressure)

✶ Measurement of PMT with the 337 nm filter for end-to-end calibration

✶ Long tube, vacuum tight and with baffles on top of the chamber, Light trap @ the bottom extension tube, baffles, new phd angle scan… new Laser!

➢ Modify the Simulation code: reflectivity of the PMTs, laser shape, geometry of the experiment…

➢ AirLight absolute calibration using a N_2 Discharge Lamp and a NIST photodiode (collaboration with Andreas Ulrich and Thomas Heindl)

✓ - done ✶ started…working on ➢ - to be done

THANK YOU FOR YOUR ATTENTION!

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