Performance of PMTs during high night sky brightness

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Using improved measurement technique w/ already installed technology

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The Pierre Auger Observatory

The primary goal is a study of the most energetic cosmic rays (above 10^{19} eV)

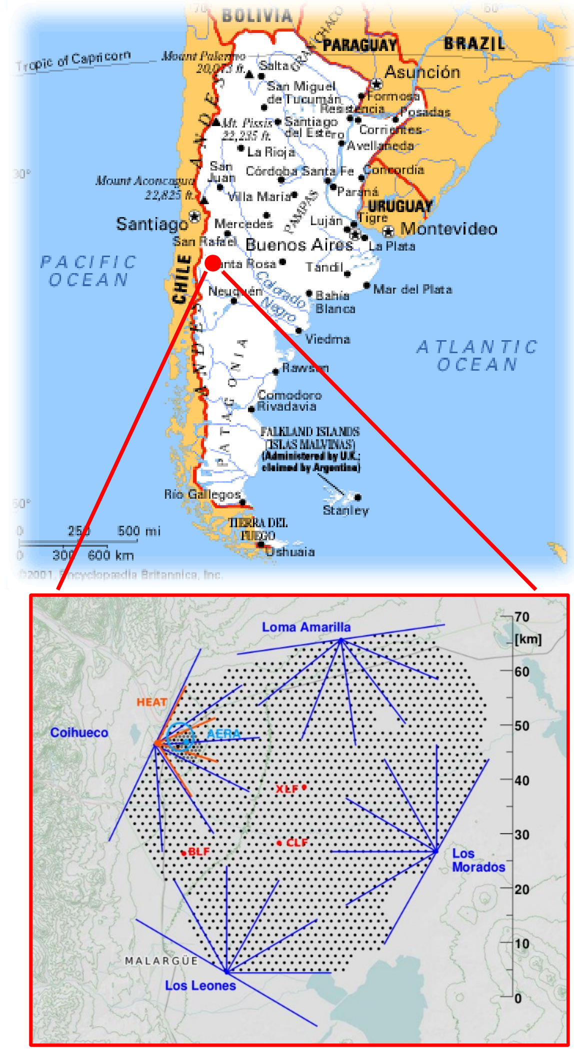
Located in the southern hemisphere in province Mendoza (Argentina) next to the Andes mountain in a semi-desert area (1300 – 1500 m a.s.l.)

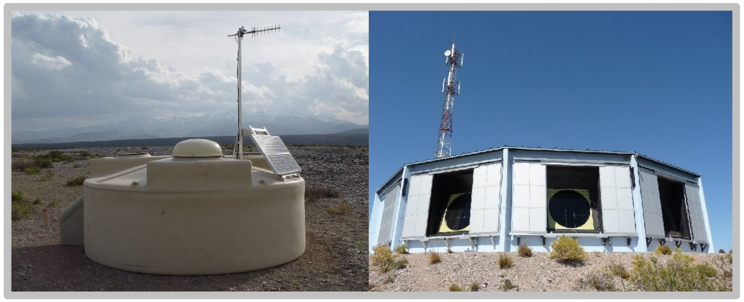
The observatory covers a flat semi-desert area of 3000 km^2 because the cosmic-ray flux is extremely low (about 1 CR / km^2 sr century at 10^{19} eV)

Construction started in 2004 and was finished in 2008

The Auger observatory consists of

- Surface detector (SD): 1660 stations
- Fluorescence detector (FD): 24 telescopes
- High Elevated Auger Telescopes (HEAT)
- Underground muon detector (AMIGA)
- R&D activities (radio – AERA, GHz, etc.)





Pierre Auger Coll., NIMA 798 (2015)

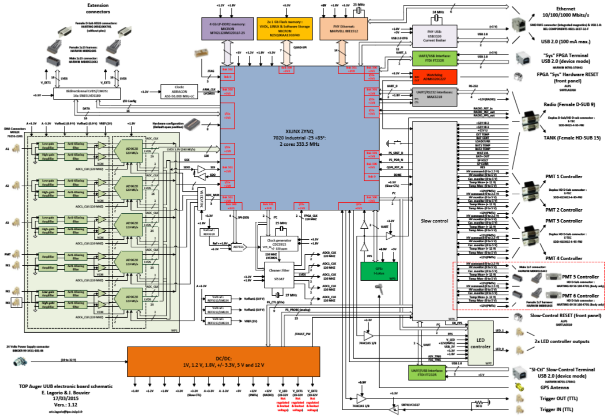
AugerPrime

Preliminary Design Report,
arXiv:1509.03732

AugerPrime: the upgrade of the Auger observatory and operation for next 10 years

Goal: Mass composition measurement above 4 x 10^{19} eV

The Auger detectors have been designed 15 yrs ago



Proposed upgrades:

1) New surface detector electronics

2) Scintillator SD

3) Finishing AMIGA

4) Possible extension of the FD duty cycle

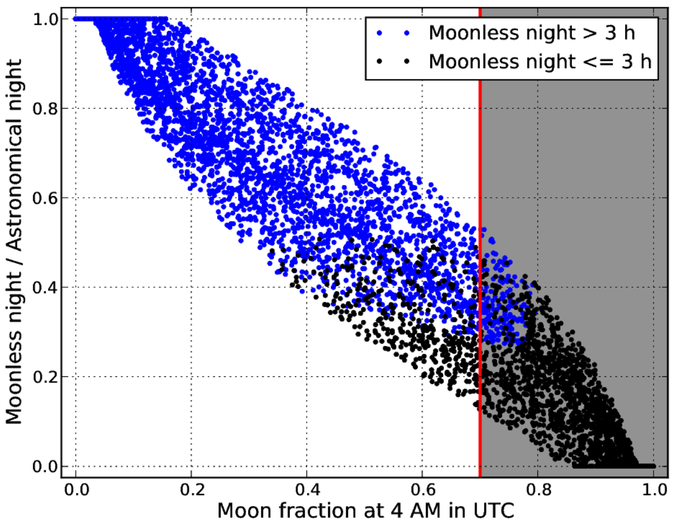
Extension of the FD duty cycle

Idea: increase the FD exposure for the most energetic events (above 10^{19} eV) by *extending the measurement to periods w/ high night sky brightness* (NSB)

Reasons: FD provides exceptional information about extensive air showers (e.g. model-independent energy reconstruction and mass composition measurement). The main limitation of the FD is its duty cycle (about 15%).

The current criteria for FD measurement:

1. The sun more than 18 deg below the horizon
2. The moon remains below horizon for longer than 3 hours
3. The illuminated fraction of the moon must be below 70%



These criteria:

Define measurement periods (about 17 days long), limits the PMT illumination (i.e. no significant aging) and the PMT response stays linear.

By relaxing criteria #2 and #3 the FD duty cycle <u>can be increased by 50%</u>, while keeping very high selection efficiency and reconstruction.

Expected FD measurement

Clear sky, no moonlight | *40 times higher NSB (90% moon)*

$7x10^{19}$ eV

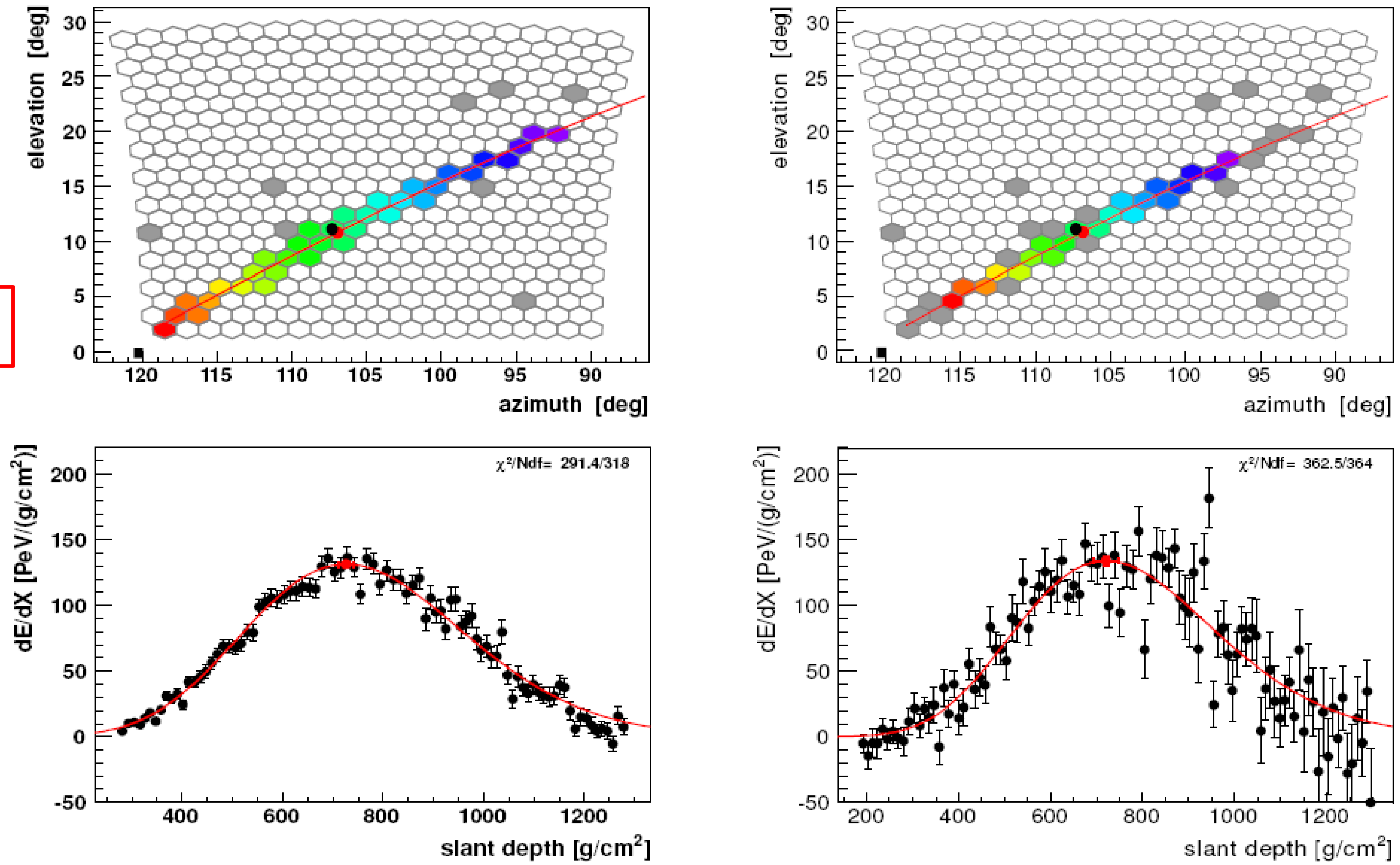
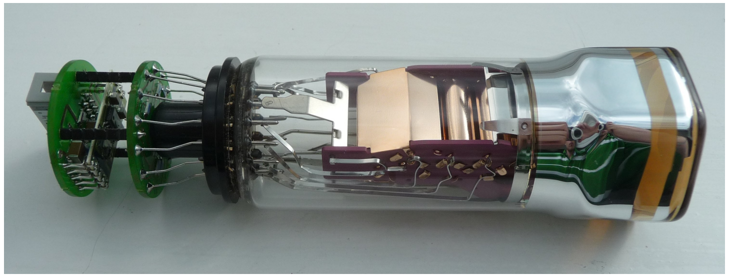


Figure 6.3: A real FD event with reconstructed energy 7×10^{19} eV. In the left panel are measured data (clear sky and no scattered moonlight, a baseline variance of 25 (ADC counts)^2) and in the right panel the same data after adding random noise corresponding to a 40 times higher NSB.

Test of PMT's performance

Photonis XP 3062: 8-stage, bialkali (QE_peak = 27%)

Auger: the nominal gain is 5×10^4 (and HV between 850 to 1050 V),
with an active voltage divider,
AC-coupled => the DC light level is obtained from the variances of the signal.



Pierre Auger Coll., NIMA 620 (2010),
Photonis datasheet

To reduce the PMT illumination and keep the anode current below 10 μA (as has been recommended by Photonis) the PMT gain must be reduced by reducing applied HV

→ *It is possible with the HV power supply already used in the FD!*

Necessary tests in a laboratory:

a) Can be the PMT operated below 800 V?

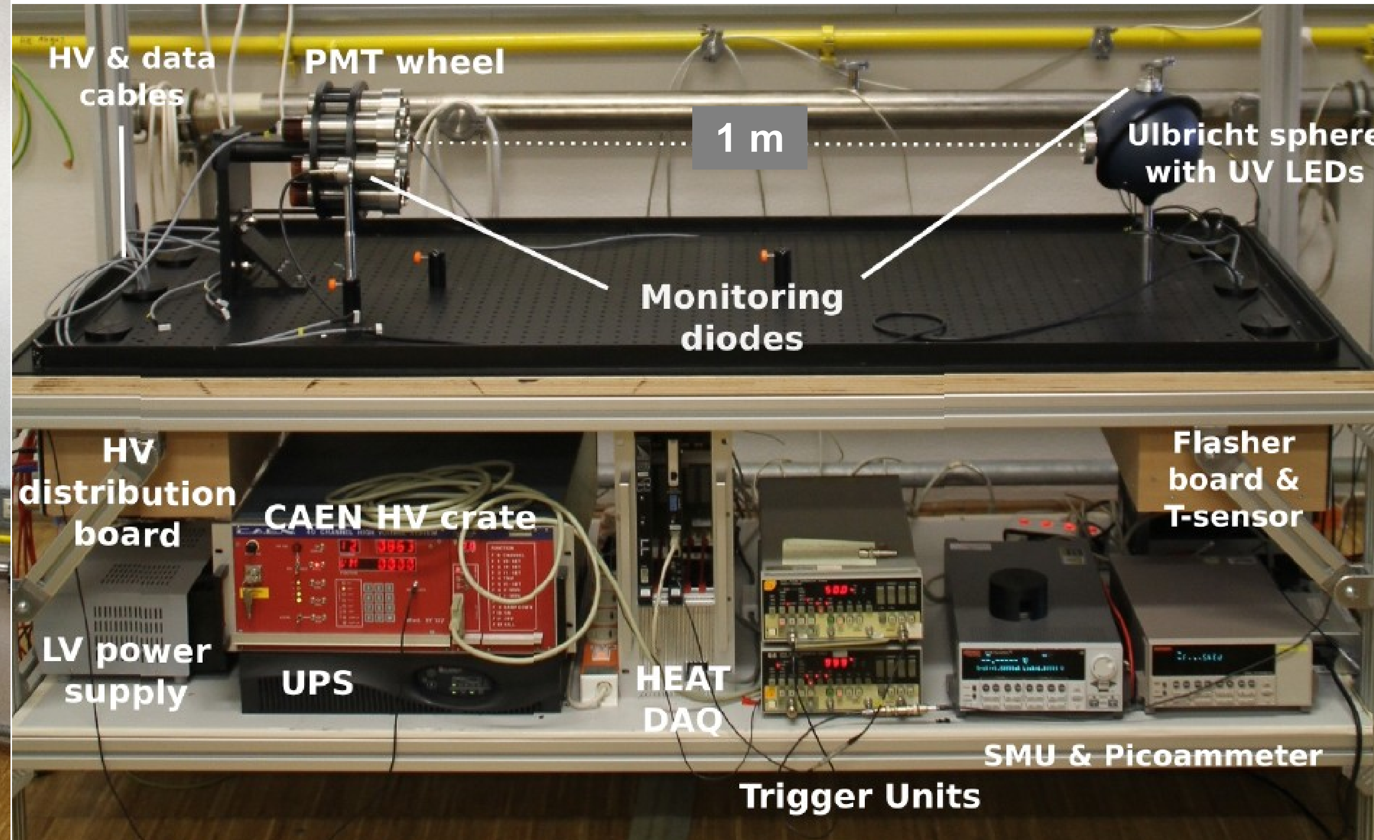
b) The PMT performance at reduced HV

c) Aging of the PMT at the nominal and lower gain

d) Sensitivity to changes of the NSB level

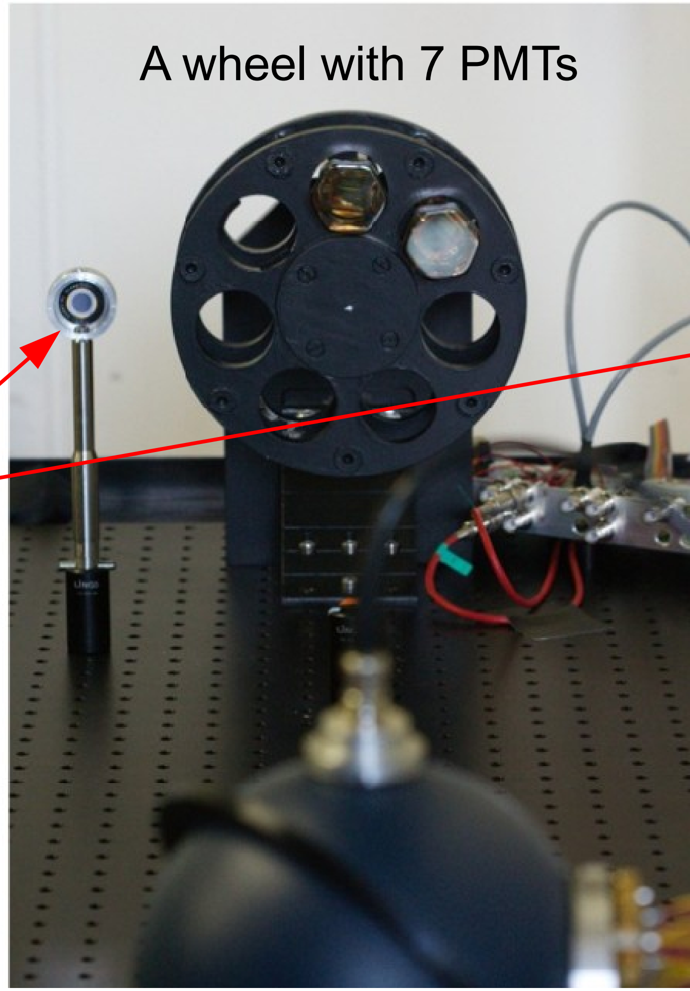
The PMT test stand at KIT

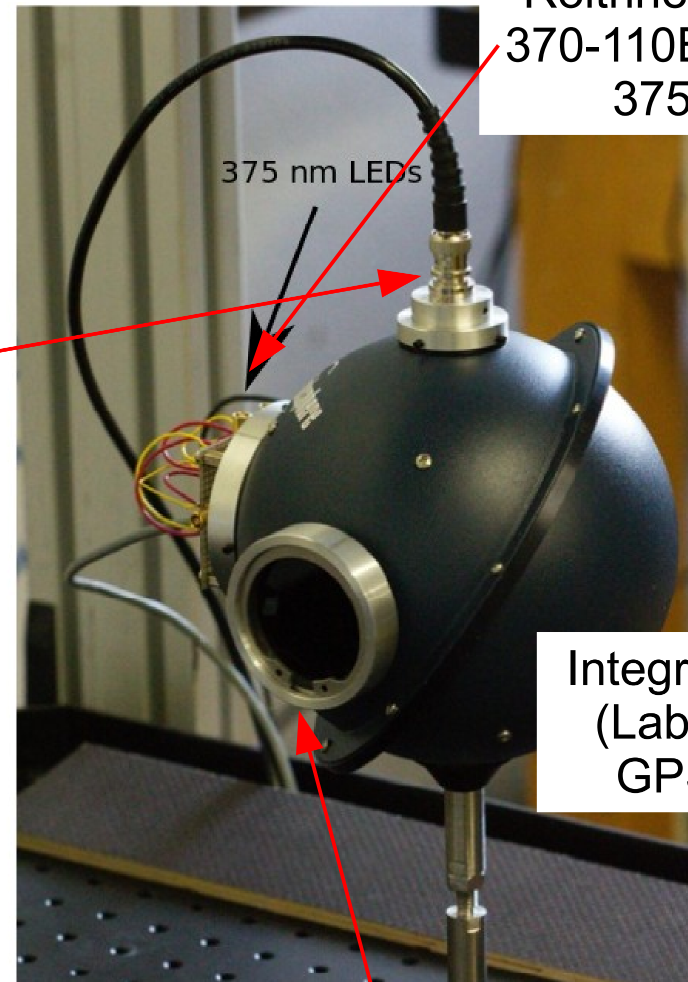
J. Zorn, master thesis (2015)



A uniform UV light source, which can be simultaneously operated in the DC and pulsed mode, illuminates FD PMTs. The FD electronics (20 MHz) is used to read-out measured signals.

The light source and sensors





Photodiodes (Hamamatsu S2281-01)

Roithner UVLED 370-110E (max. at 375 nm)

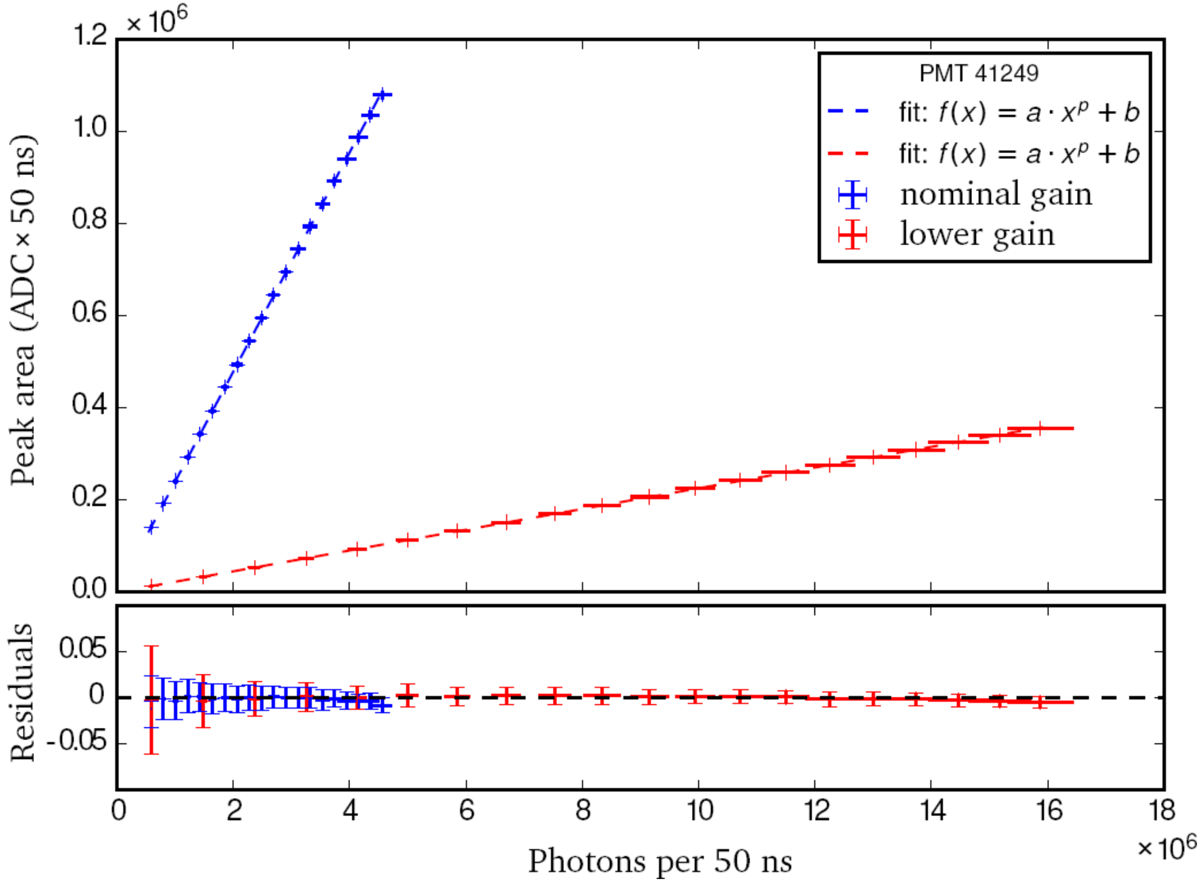
Integrating sphere (Labsphere 3P-GPS-053-SL)

And temperature sensors

UV filter (MUG-6)
A light reducer

The linearity

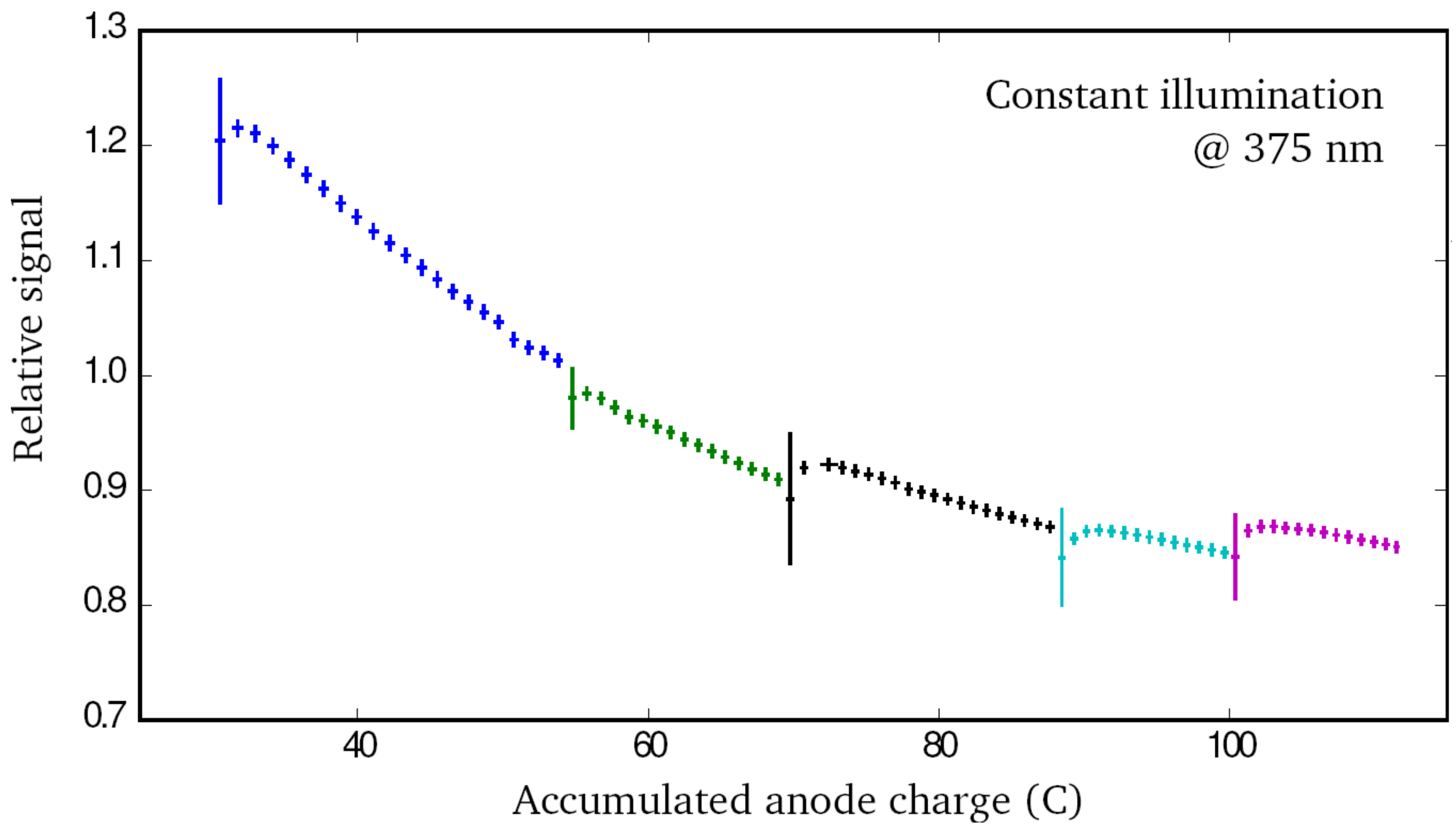
The PMTs were tested at HV as low as 400 V and their gain changes were measured as a function of HV over the whole studied range of HV.



The PMT response to photon flux up to the saturation level measured at the nominal (blue) and reduced (red) gain. The exponent p is 1.0 for both gains.

The aging

The PMT aging (i.e. loss of sensitivity) was studied at the gain of 5×10^3 (HV of 644 V).



The PMT response as a function of the accumulated anode charge is shown above. After the initial aging phase the PMT response changes very slowly as has also been measured for PMTs operated at the nominal gain.
Jumps correspond to a recovery phase after breaks in our measurement.

Conclusions of the laboratory measurement

- PMTs perform (surprisingly) well even at 10x lower gain than the nominal one.
- No accelerated aging.
- The PMT response can be measured with a calibration pulse.
- No problem during a continuous change of the background light level.
- Even at low gain the PMT provides information on the DC light level.
- The PMT gain can be automatically changed according to the measured light flux.

No show-stopper for tests with a real FD telescope.

Test with a fluorescence telescope

The moon and Jupiter above Los Leones in the morning on 4 Mar, 2015.

The illuminated fraction of the moon was 98%.

Relative calibration A and B

The PMT response is monitored with relative calibration light sources.

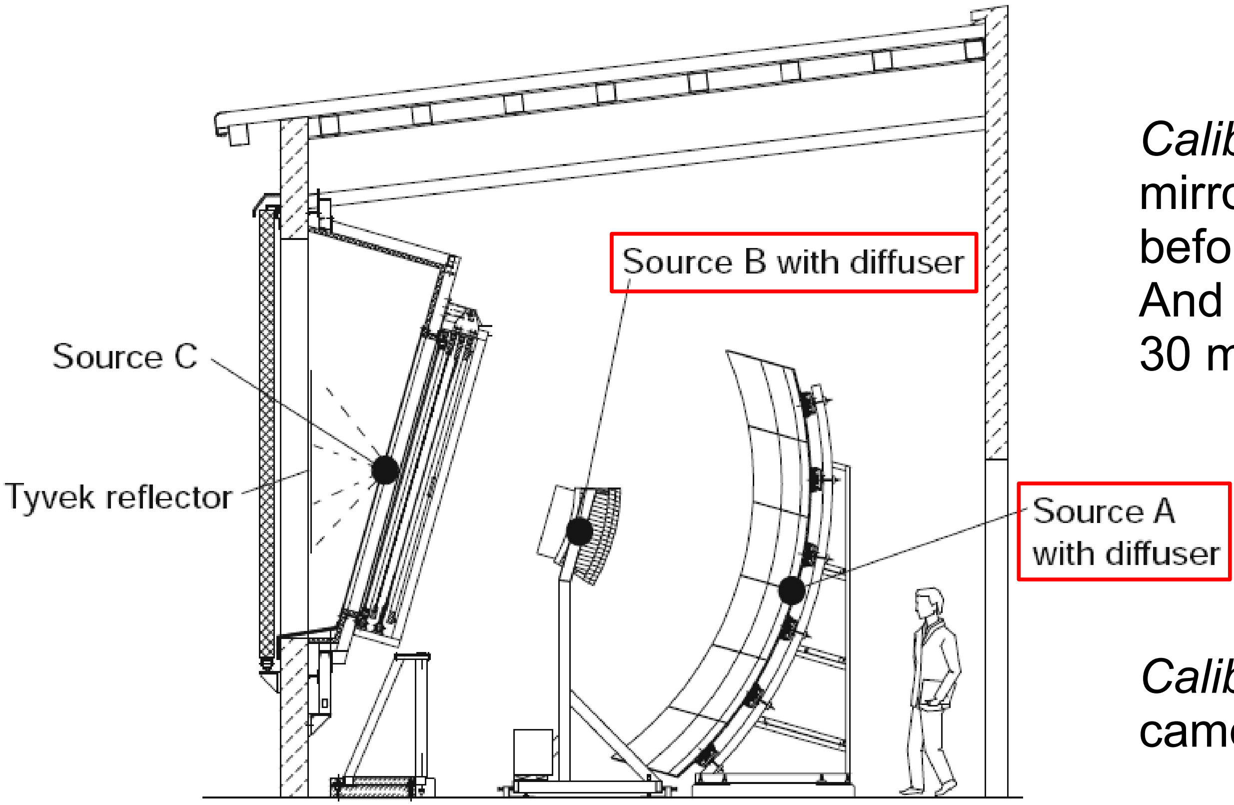


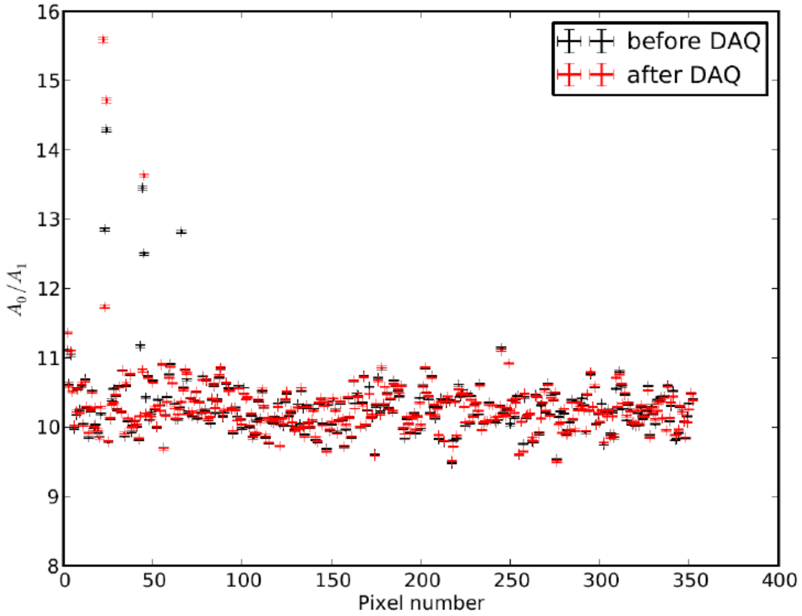
Fig. 28. A schematic showing positions of light sources for three different relative calibrations of the telescope.

Calibration A (in the center of a mirror) monitors the PMT response before and after each run
And in addition it is performed every 30 minutes during the data taking.

Calibration B (on both sides of a camera body) has 5 light intensities.

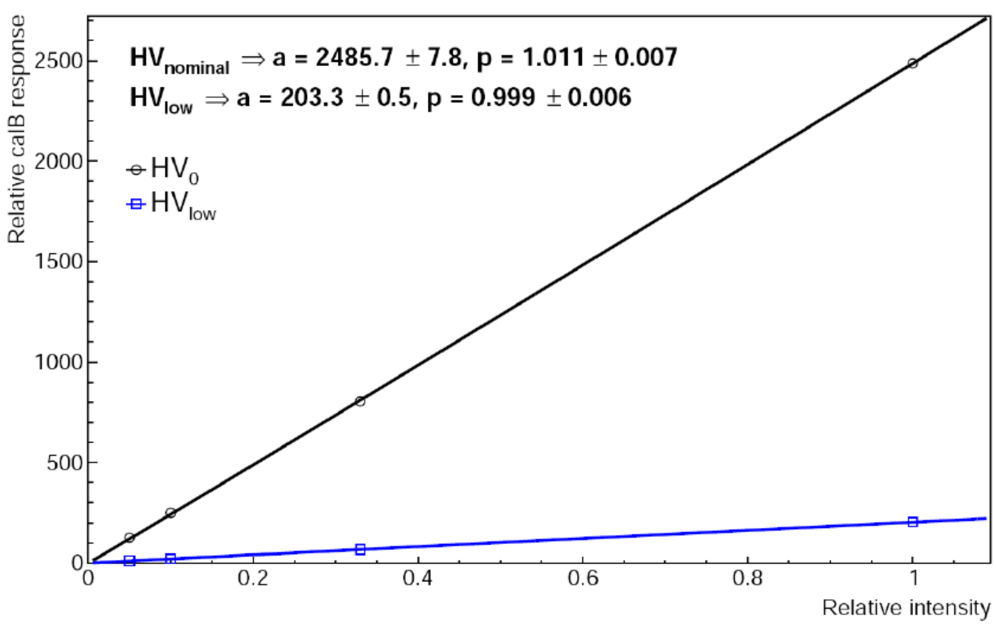
Pierre Auger Coll., NIMA 620 (2010)

Response of PMTs before and after DAQ



The ratio of calib. measurement A at the nominal ($5x10^4$) and reduced gain ($5x10^3$) before (black) and after (red) data taking.

The ratio equals 10 as expected.



The camera averaged response to calib. B as a function of calib. B intensity for nominal HV (black circles) and reduced HV (blue squares).

Results of both HV settings are fitted with a power law and in both cases the exponent *p* is compatible with 1 (i.e. a linear fit).

Response of PMTs during a DAQ run

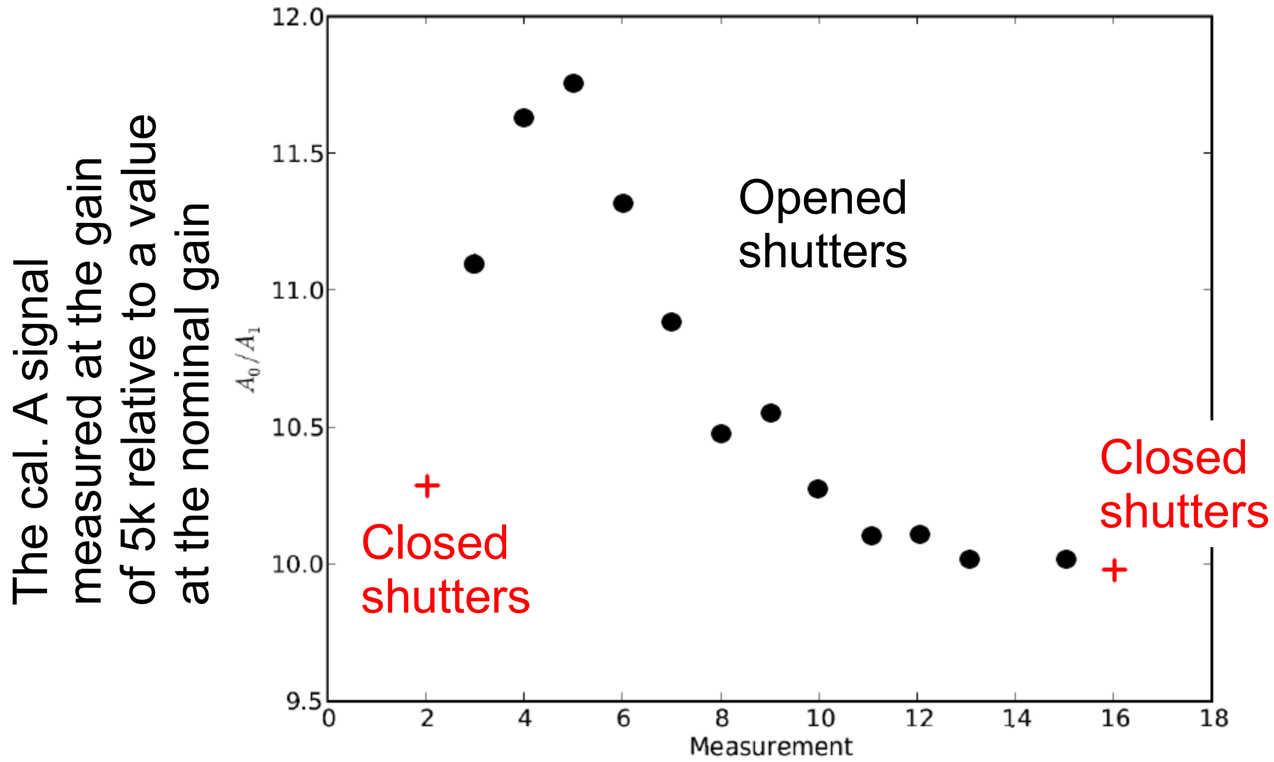
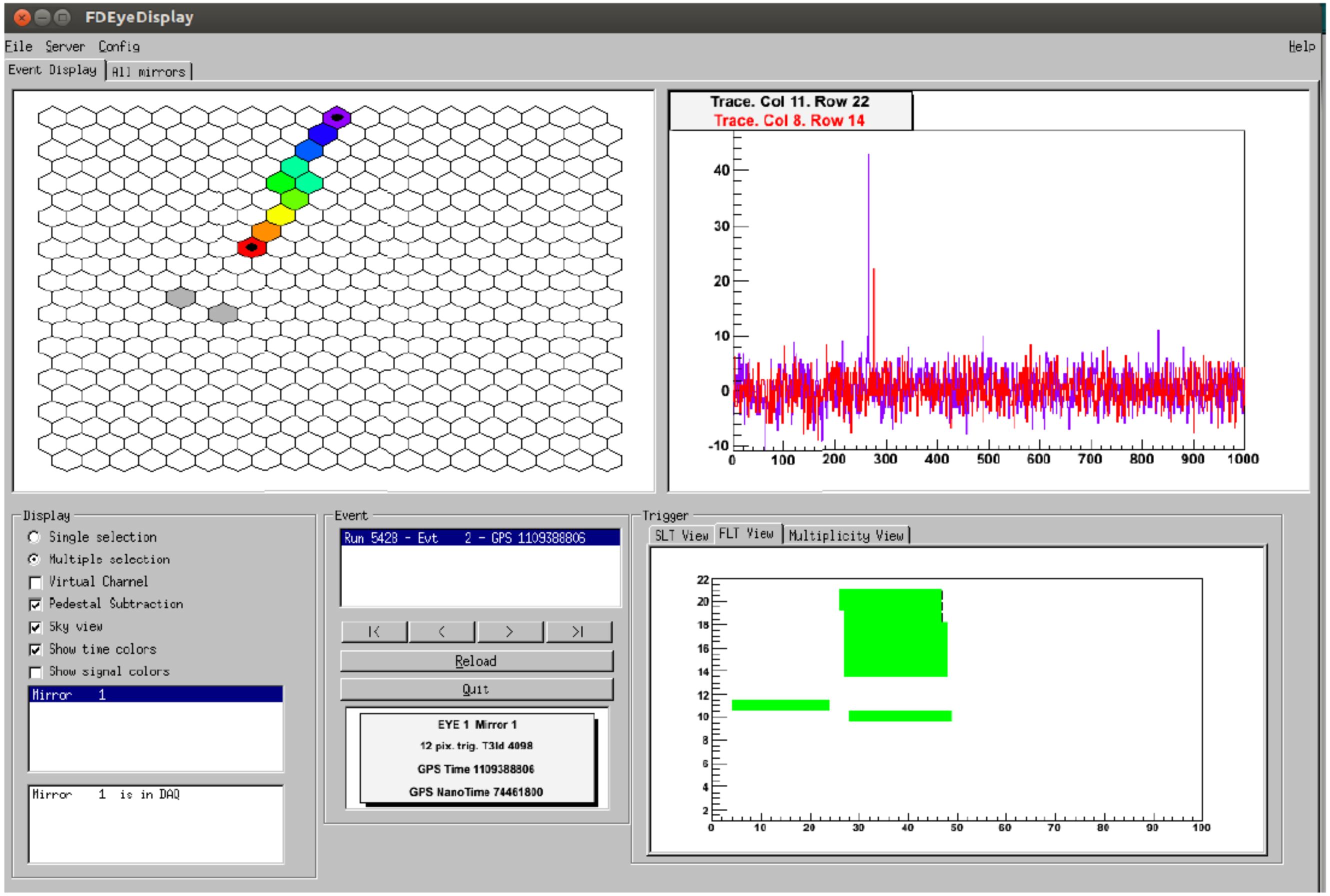


Figure 6: The relative response of the PMTs measured at the reduced gain during data taking. Crosses and stars indicate closed and open shutters, respectively.

The response of PMTs at reduced HV behave the same way as at the nominal HV.
(The change of the signal is caused by an exposure to the NSB.)

A cosmic-ray event measured at reduced gain



The FD DAQ system has performed in standard way, w/o any problems.

The FD telescope has triggered cosmic-ray events, a trigger rate was lower due to high NSB.

Conclusions and outlook

The FD duty cycle can be increased by 50% by switching between two HV levels depending on the night sky brightness.

We have demonstrated that this is possible with the current FD setup of the Auger observatory.

No additional funding is required for application.

It is an example of using improved measurement technique with already installed technology.

Further testing are planned soon

Remote operation of the FD will be needed

Dedicated rooms are available in Aachen and Wuppertal, other places soon.