

# The Pierre Auger Fluorescence Detector

Paul Filip

## Outline

- Hardware
- Physics
- Energy calibration
- Access to data
- FD Shifts

# Hardware

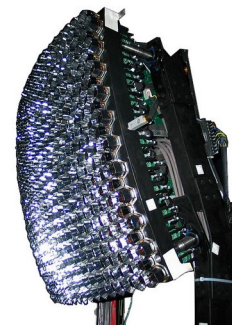
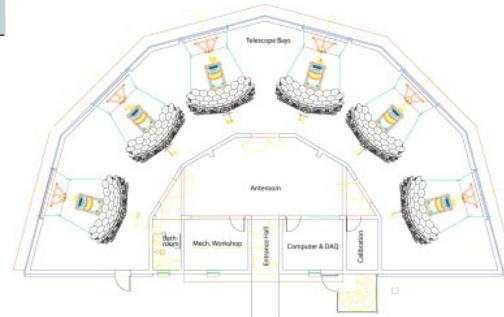
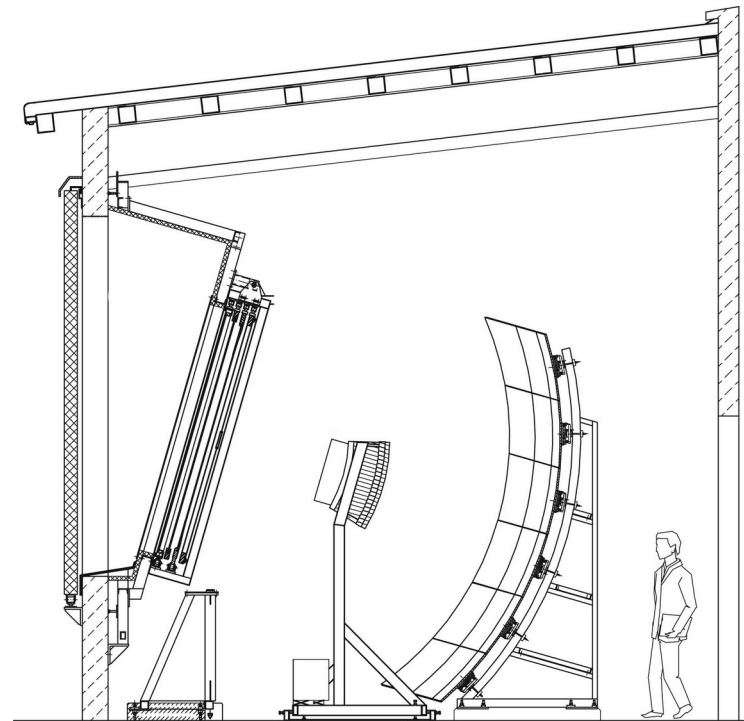
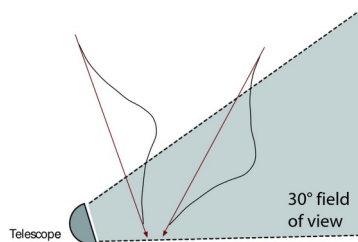
- **5 sites, 27 telescopes**
  - 6 telescopes/bays per building (HEAT: 3)
  - Wide angle  $30^\circ \times 30^\circ$  FOV per bay
  - Camera consists of 440 PMTs
  - 10 MHz sampling rate (HEAT: 20 MHz)

- **HEAT**

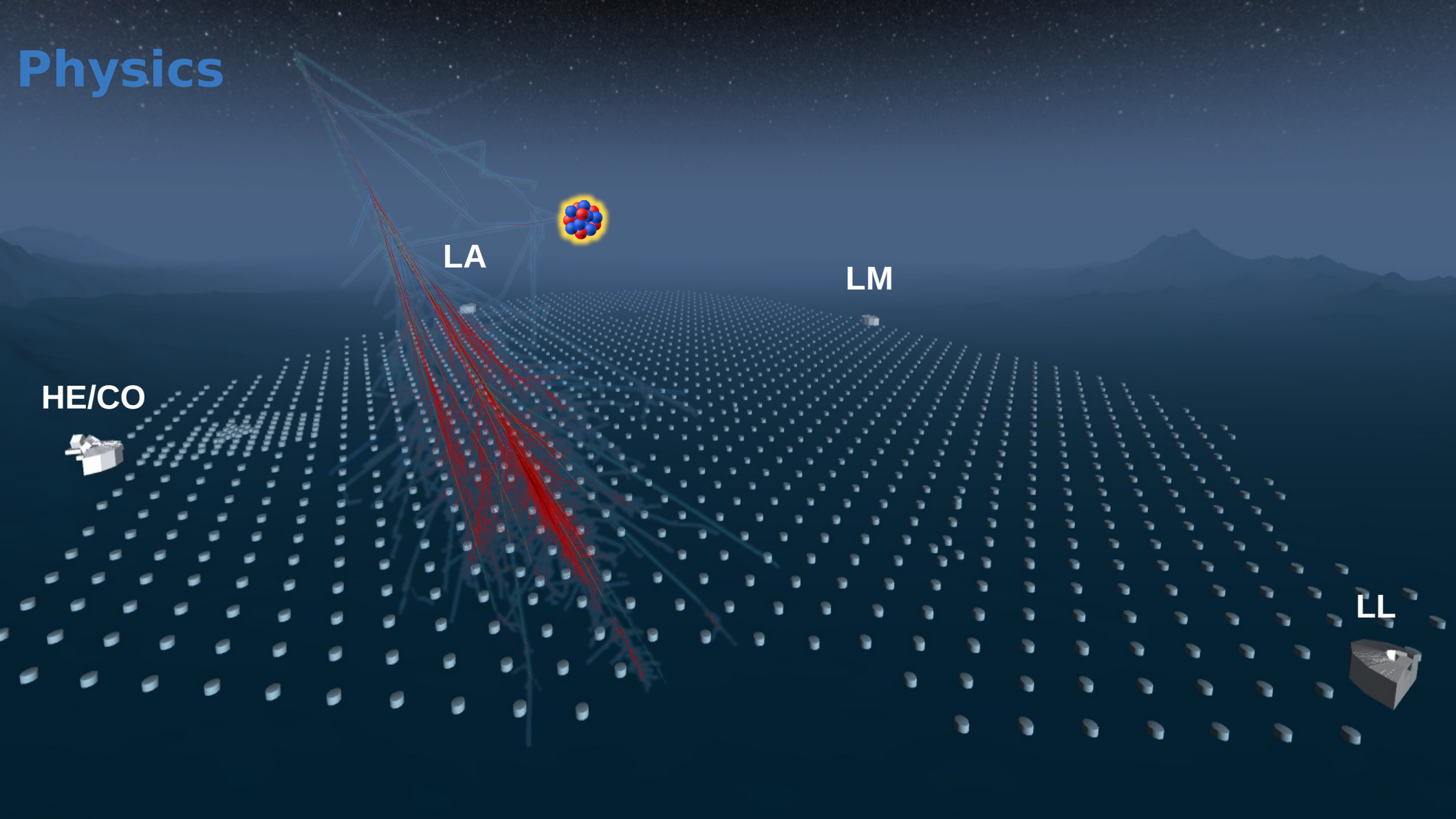
- High-elevation extension of FD
- See higher showers / lower  $E$

- **See also (e.g. for thesis)**

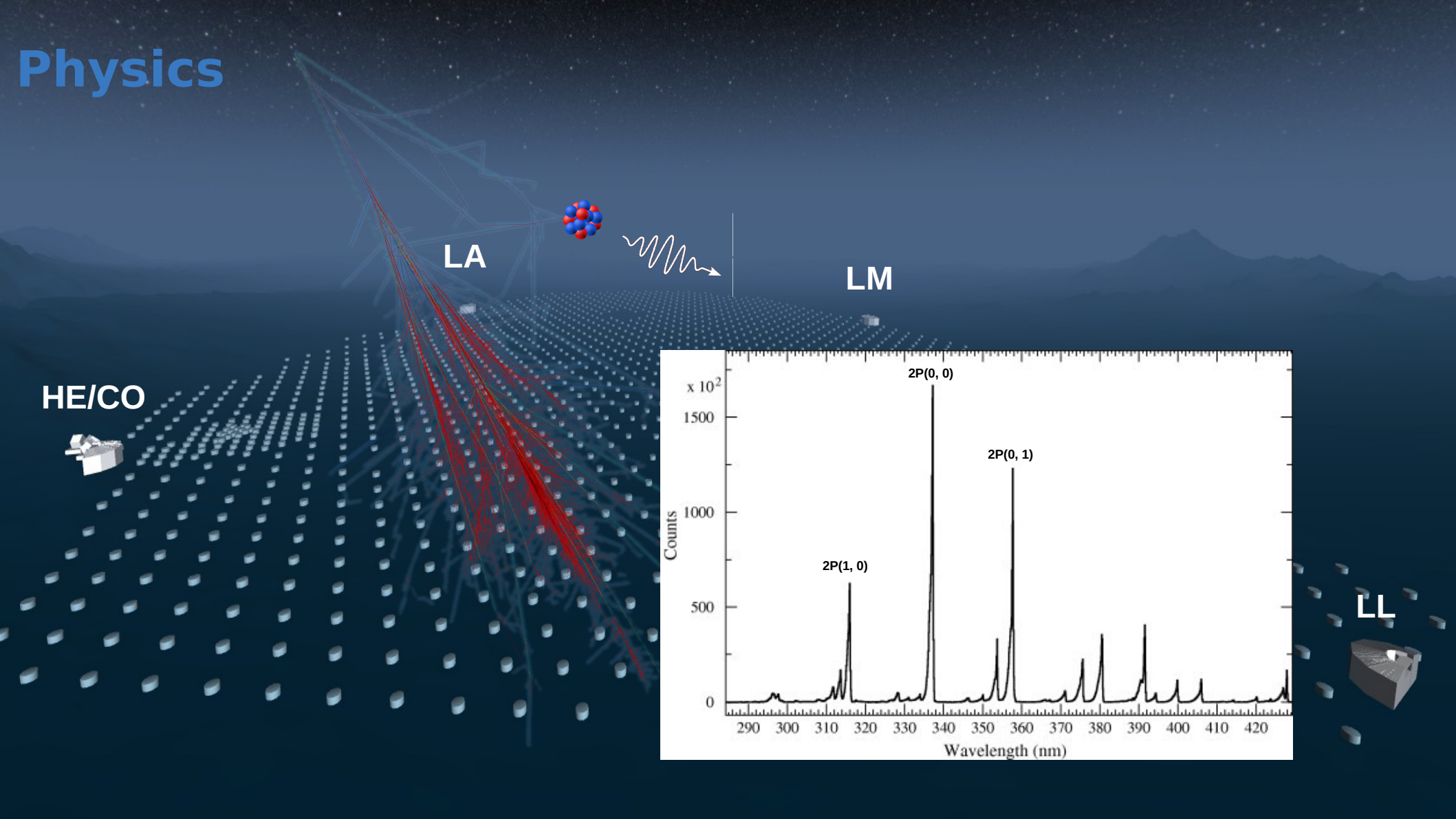
- [J. Abraham et al, NIMA-A 620 \(2010\) 227-251](#)
- [M. Kleifges et al, ICRC31 \(2009\) 10-13](#)



# Physics



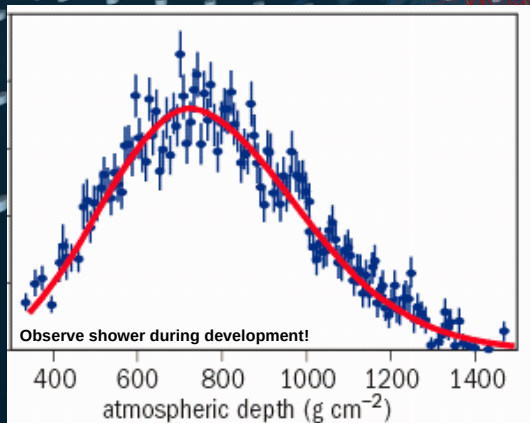
# Physics





# Physics

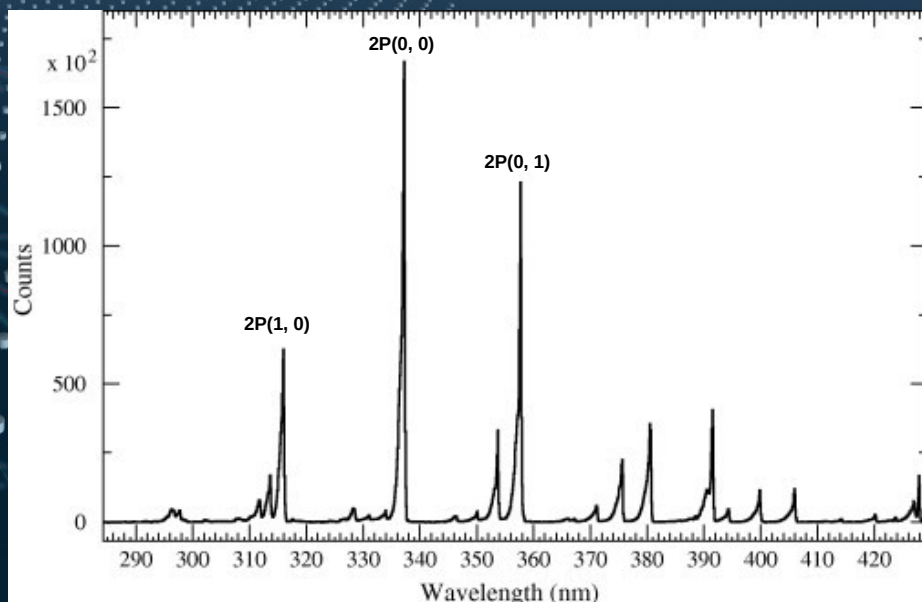
HE/CO



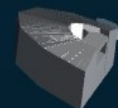
LA



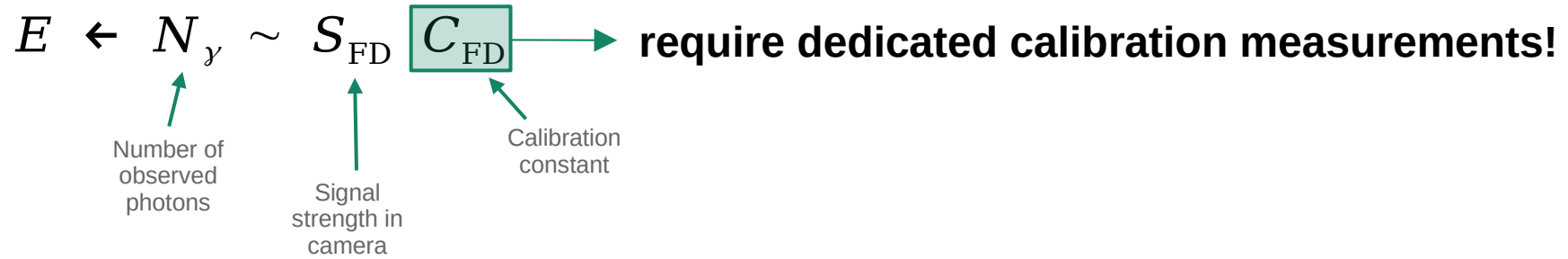
LM



LL

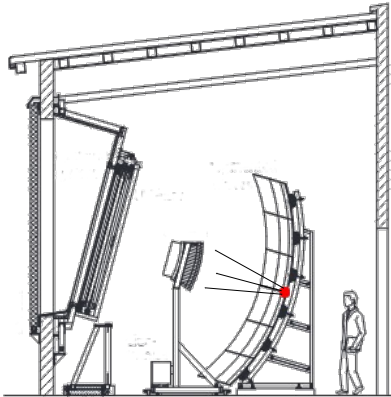


# (Energy) calibration

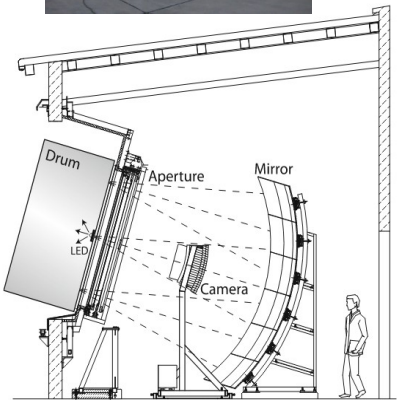


# (Energy) calibration

$E \leftarrow N_\gamma \sim S_{\text{FD}} C_{\text{FD}}$  → require dedicated calibration measurements!

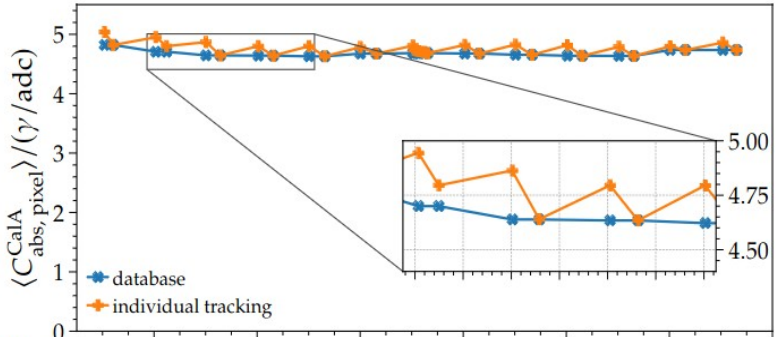


- Track relative drift by exposing **camera** to known light source
- **Blind to changes in mirror/filter!**
- Combined calibration error of **~9%**
- Biggest contribution to  $E$  error



Expose **telescope** to lightsource and measure response from known signal

2013



Mean pixel calibration constant for 2-week period in november 2022, from Calibration A

# (Energy) calibration

$$E \leftarrow N_y \sim S_{\text{FD}} \boxed{C_{\text{FD}}} \longrightarrow \text{require dedicated calibration measurements!}$$

Towards a new end-to-end calibration of FD  
using a light source on a x-y scanner

N. Barenthien, K. Daumiller, J. Debatin, R. Engel, M. Kleifges,  
H.-J. Mathes, A. Menshikov, M. Roth, R. Šmida, R. Ulrich, M. Unger  
(Karlsruhe Institute of Technology; KIT)

P. Horváth, S. Michal, M. Palatka, M. Pech, J. Šupík  
(Palacký University Olomouc)

K.-H. Becker, K.-H. Kampert, E. Mayotte, J. Rautenberg  
(Bergische Universität Wuppertal)

First idea discussed at collaboration meeting in 2017

2017

- Replace large drum with light source on XY stage
- Easy transport of light source (fits in carry-on luggage)
- Reduce workforce/time



transport



2024



- ← Scanner control
- ← Light source
- ← X stage
- ← Y stage(s)



# Access to data

- Auger Open Data (jupyter notebooks for various analysis)
  - The depth of the shower maximum
  - The energy calibration
  - The energy spectrum

## The depth of the shower maximum

The estimation of the atmospheric depth, at which the longitudinal development of a cosmic-ray shower reaches its maximum,  $X_{\text{max}}$ , relies on the reconstruction of the longitudinal profile of events measured by the Pierre Auger Fluorescence Detector (FD), and at least one coincident Surface Detector (SD) station (so-called hybrid events). By building the  $X_{\text{max}}$  distributions in differential energy bins above  $10^{18}$  eV, the energy dependence of their mean and standard deviation is derived and compared to those obtained from simulations of showers produced by proton and iron primaries. Details are given in [Physical Review D 90 \(2014\) 122005 \(arxiv\)](#).

 You can [run it in your browser](#) or [download it](#) together with the necessary [summary file](#) and [auxiliary files](#) to run it locally.

proton-air cross section

2 Copy & Edit 87

Notebook Input Output Logs Comments (3)



Measurement of the tail of the  $X_{\text{max}}$  distribution, and the proton-air cross section

Notebook released together with the Pierre Auger Observatory Open Data release (DOI 10.5281/zenodo.10488964). More information at the [Auger open data website](#).

This notebook illustrates the analysis as published in [Measurement of the proton-air cross-section at  \$\sqrt{s} = 3.6\$  TeV with the Pierre Auger Observatory, Phys.Rev.Lett. 109 \(2012\) 062002 \(arXiv\)](#). However, the procedure has been a bit simplified here with respect to the original paper:

- The same event selection is used as for the measurement of  $\langle X_{\text{max}} \rangle$  and  $\sigma(X_{\text{max}})$ .
- The limiting acceptance of the telescope field of view towards very high values of  $X_{\text{max}}$  is explicitly considered in the fit model. This procedure is introduced and explained in [Appendix A.2 of Phys. Rev. D 90, 122005 \(2014\) \(arXiv\)](#).

The foundation of this analysis is the fact, that the attenuation length of primary cosmic ray (CR) protons in the atmosphere is reflected in the exponential tail of the  $X_{\text{max}}$  distribution at very high values of  $X_{\text{max}}$ . Thus, measuring the exponential shape of the tail of the  $X_{\text{max}}$  distribution can be exploited to determine the proton-air cross section.

The  $X_{\text{max}}$  distribution at very high values of  $X_{\text{max}}$  (thus, the tail of the  $X_{\text{max}}$  distribution) follows an exponential distribution, which is for  $X_{\text{max}} > X_{\text{dec}}$  further modified by the limited field-of-view of the telescopes, where  $X_{\text{dec}}$  is the start of the fit range. Introducing  $z = X_{\text{max}} - X_{\text{dec}}$  and  $z_{\text{dec}} = X_{\text{dec}} - X_{\text{dec}}$ , this can be written as

$$f(z) = \frac{1}{A_0} \exp\left(-\frac{z}{\Lambda_0}\right) \begin{cases} 1; & z < z_{\text{dec}} \\ \exp\left(-\frac{z - z_{\text{dec}}}{\lambda_{\text{dec}}}\right); & \text{otherwise,} \end{cases} \quad (1)$$

where  $A_0$  is the slope of the exponential distribution of  $X_{\text{max}}$  and  $\lambda_{\text{dec}}$  is the additional exponential damping of the limited field-of-view for  $z > z_{\text{dec}}$ .

The normalization is given by integration from  $X_{\text{dec}}$  to infinity:

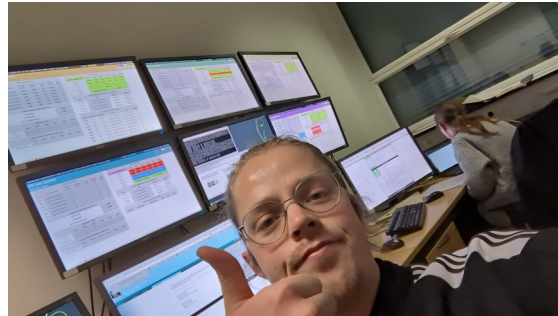
# Access to data

- iRODS @ Lyon (subject to change...)
  - All data Auger data (FD, SD, etc.) available
  - Account @ CCIN2P3, or local iRODS installation

```
#####  
cca011:/pbs/home/p/pafilip(0)>module load irods  
cca011:/pbs/home/p/pafilip(0)>iinit  
Enter your current iRODS password:  
cca011:/pbs/home/p/pafilip(0)>ils /pauger/Malargue/Raid/data/Fd/  
/pauger/Malargue/Raid/data/Fd:  
  FD-minbias.log  
  FD-minbias.sum  
  ListToDelete_20150325_135210.txt  
C- /pauger/Malargue/Raid/data/Fd/FD-Coihueco  
C- /pauger/Malargue/Raid/data/Fd/FD-Heat  
C- /pauger/Malargue/Raid/data/Fd/FD-LomaAmarilla  
C- /pauger/Malargue/Raid/data/Fd/FD-LosLeones  
C- /pauger/Malargue/Raid/data/Fd/FD-LosMorados  
C- /pauger/Malargue/Raid/data/Fd/RAuger  
cca011:/pbs/home/p/pafilip(0)>
```

# Hands on session

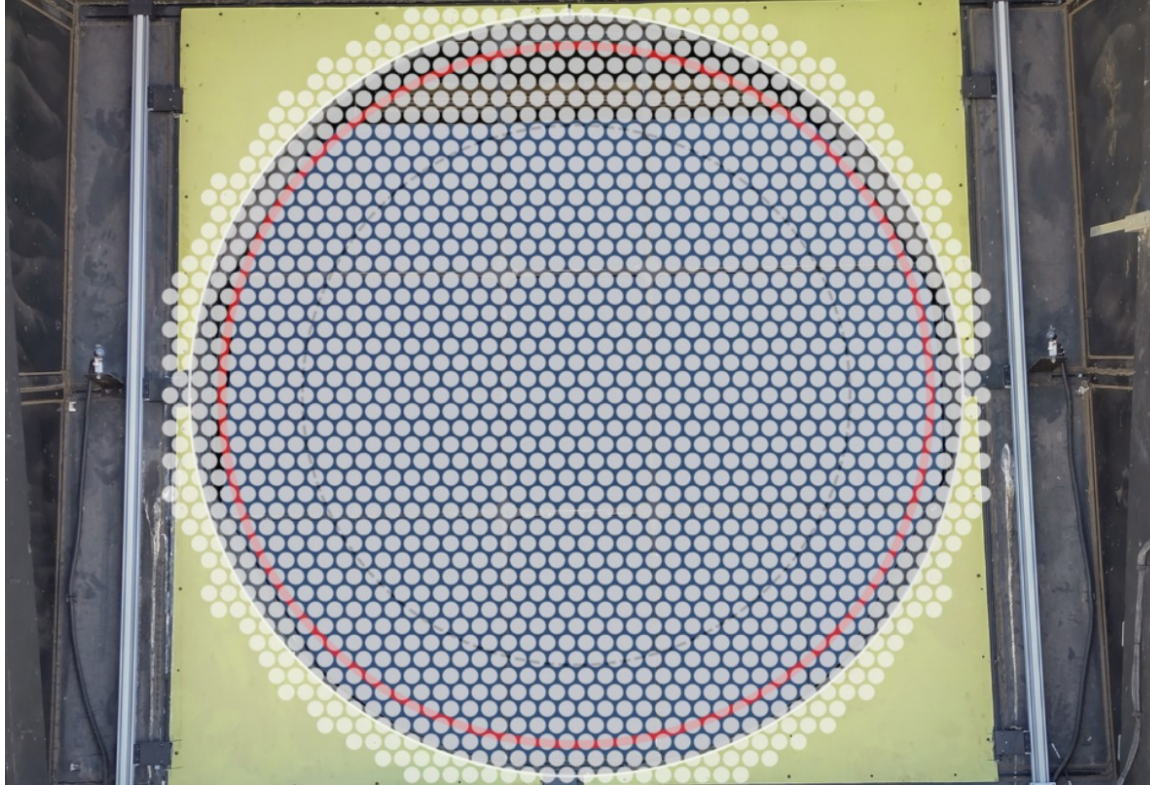
- Go to [https://www.auger.org.ar/FD/shift\\_form/Form.php](https://www.auger.org.ar/FD/shift_form/Form.php)
  - Manual data taking during night operation
  - Enlist for FD shift, help Auger run the FD
  - 2 open spots for Dec 22nd - Jan 08th
  - (typically) 7 nights of intermittent work
  - Can use the rest of the time to work
- CU in the control room! ;)



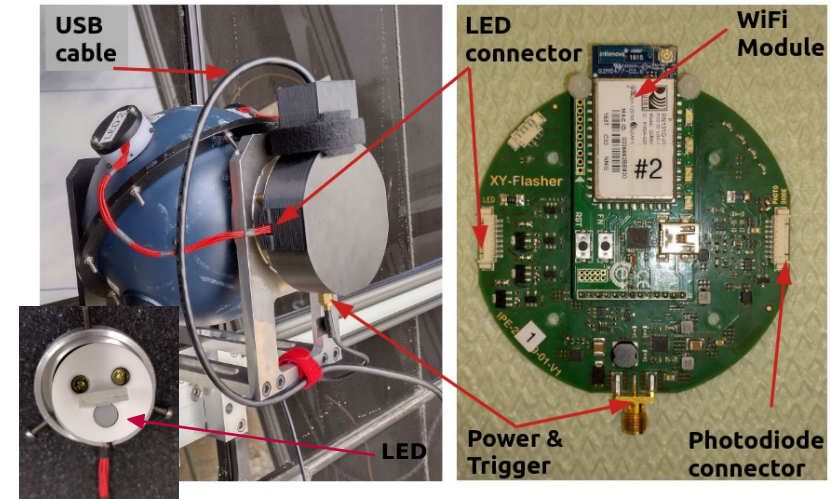
# Backup



# The XY Scanner – size matters



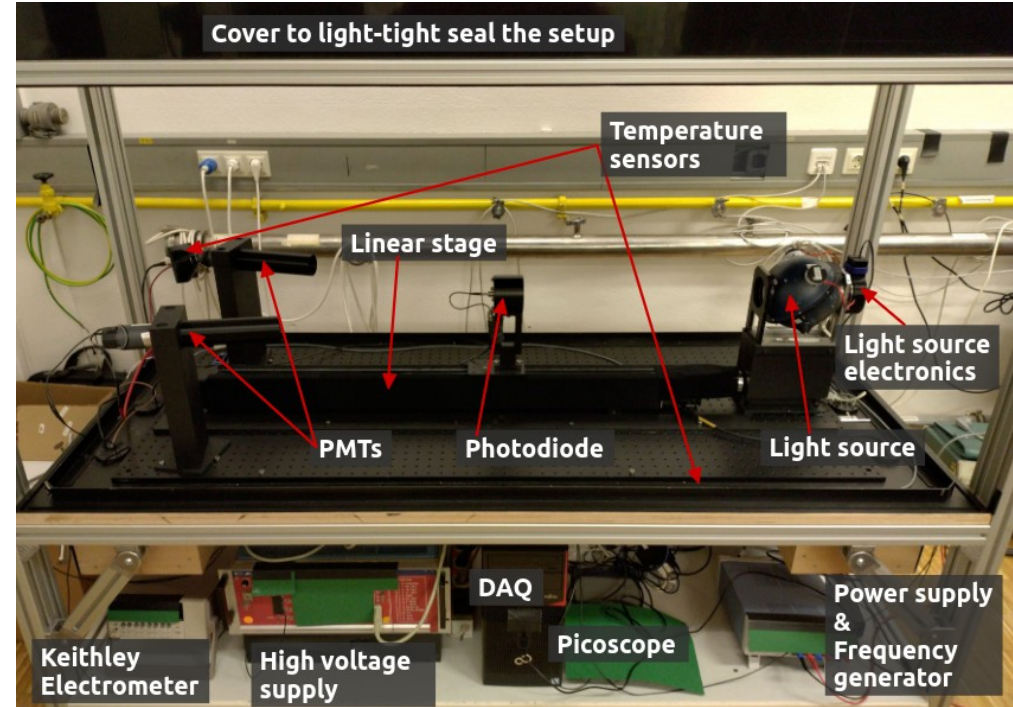
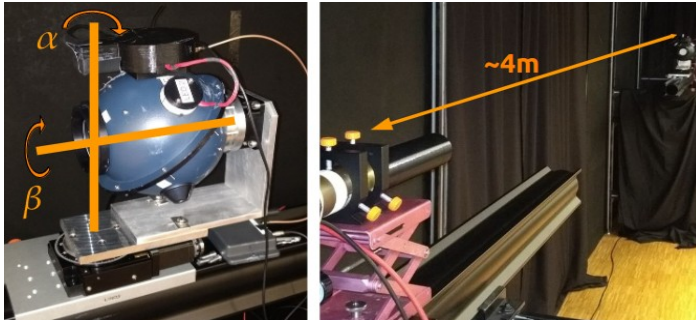
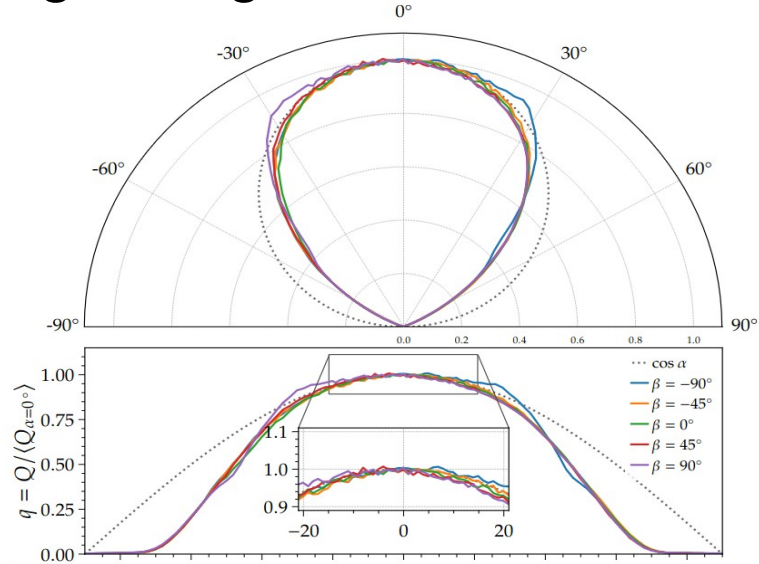
- Sum of many measurements at different positions mimic the drum
- Portable light source
- Absolute calibration is possible on- and off-site





# Probing the light source

## Determine emission characteristics



## Determine photon flux of photodiode