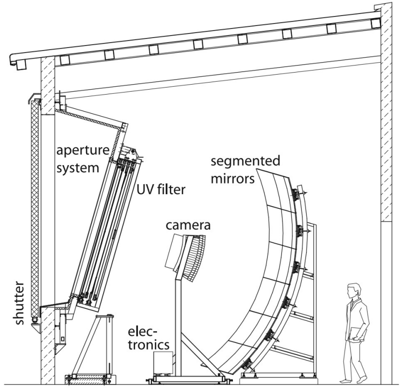
Auger - Roma “Tor Vergata”

V. Verzi	Primo Ricercatore INFN	80%
G. Salina	Dirigente di Ricerca INFN	60%
G. Rodriguez Fernandez	Ricercatore INFN	50%
G. Matthiae	Prof. ordinario	0%

G. Salina leader del *Calibration* task

V. Verzi leader del *Analysis Foundations* task
responsabile *FD camera*



[GAP2018_005](#) **Comparison between the estimations of the invisible energy obtained in vertical and inclined showers**
A. Mariazzi, M. Tueros, G. R. Fernandez, I. Valino and V. Verzi
[GAP2016_079](#) **Estimate of the invisible energy of inclined showers observed with surface detectors of the Pierre Auger Observatory**
G. Mariazzi, M. J. Tueros, G. Rodriguez-Fernandez, V. Verzi
[GAP2012_124](#) **Proposal for an update of the Auger Energy Scale**
B. Dawson, C. Di Giulio, A. G. Mariazzi, R. Pesce, G. Rodriguez Fernandez, G. Salinab, M. Tueros , J. R. Vazquez and V. Verzi
[GAP2010_051](#). **On the angular reconstruction for inclined showers**
G. Rodriguez, A. Parra, R. Pelayo, R. A. Vazquez and E. Zas
[GAP2010_049](#) **Comparison of inclined events reconstruction codes efit-HASOffline**
G. Rodriguez, R. Pelayo, A. Parra, R. A. Vazquez and E. Zas
[GAP2009_152](#) **Effect of no-signal stations in inclined shower reconstruction**
V. M. Olmos-Gilbaja, R. Pelayo, G. Rodriguez, R. A. Vazquez and E. Zas
[GAP2009_049](#) **Simulation of the Surface Detector response for inclined shower reconstruction**
G. Rodriguez, L. Cazon, V. M. Olmos-Gilbaja, R. A. Vazquez and E. Zas
[GAP2009_040](#) **Estimation of the shower energy and Xmax with the spot reconstruction method**
C. Di Giulio, P. Facal San Luis, G. Rodriguez Fernandez and V. Verzi
[GAP2009_038](#) **Update on the method for Tank Signal Response (SdSignalUSC code)**
J. Alvarez-Muniz, G. Rodriguez-Fernandez, I. Valino, E. Zas
[GAP2008_141](#) **Lateral shower light distribution in the spot reconstruction**
C. Di Giulio, P. Facal San Luis, G. Rodríguez, M. Tueros, V. Verzi
[GAP2007_027](#) **Cosmic ray spectrum with inclined showers: November 2006 update**
P. Facal San Luis, V. M. Olmos-Gilbaja, G. Parente, G. Rodríguez-Fernández, I. Valiño, R. A. Vázquez, E. Zas, L. Cazón
[GAP2006_107](#) **Cosmic ray spectrum using inclined showers: Update presented in September 2006**
P. Facal San Luis, V. M. Olmos-Gilbaja, G. Rodríguez-Fernández, I. Valiño, R. A. Vázquez, E. Zas
[GAP2006_029](#) **Reconstruction of the muon production distance**
Lorenzo Cazon, Markus Roth, Ralph Ulrich, Gonzalo Rodriguez, Enrique Zas, Ricardo Vazquez
[GAP2006_025](#) **An estimate of the cosmic ray spectrum using inclined data of the Pierre Auger Observatory**
N. Busca, V.M. Olmos-Gilbaja, P. Privitera, G. Rodriguez, R.A. Vazquez, E. Zas
[GAP2006_024](#) **A guide-line to the Auger-Surface-Detector**
Denis Allard, Maximo Ave, Nicolas Busca$, Aaron Chou, Catherin Newman-Holmes, Paolo Privitera, Gonzalo Rodriguez, Alan Watson, Tokonatsu Yamamoto, Enrique Zas
[GAP2005_054](#) **An Alternative Method for Tank Signal Response and S(1000) Calculation**
J. Alvarez-Muniz, G. Rodriguez-Fernandez, I. Valino, E. Zas
[GAP2004_061](#) **Removing Direct Light From HAS**
López-Agüera, V.M. Olmos-Gilbaja, G. Rodríguez-Fernández
[GAP2004_060](#) **Electronic Off-line Quality Check Noise Control**
A. Lopez-Aguera, G. Rodriguez-Fernandez
[GAP2004_058](#) **Electronic Noise Control Protocole**
Angeles Lopez-Aguera, Gonzalo Rodriguez-Fernandez
[GAP2004_043](#) **A Systematic Comparison of Three Tank Simulators (G4/SDSim/FastSim) in the DPA**
Tohru Ohnuki, Gonzalo Rodriguez-Fernandez, David Barnhill, Arun Tripathi, Tom McCauley, Tom Paul, Katsushi Arisaka
[GAP2004_037](#) **Determination of Absolute Energy & Composition with Minimum Systematic Uncertainties**
Katsushi Arisaka, David Barnhill, Arun Tripathi, Tohru Ohnuki, Joong Lee, William Slater, Aaron Chou, Gonzalo Rodriguez Fernandez
[GAP2004_026](#) **Direct Light Impact parameter dependence in a Cerenkov water tank**
López-Agüera, A.; Olmos-Gilbaja, V.M.; Rodríguez-Fernández, G.
[GAP2003_112](#) **Direct light in inclined showers**
Lopez-Aguera, V. M. Olmos-Gilbaja, G. Rodriguez Fernandez
[GAP2003_038](#) **Signal uncertainty induced by pedestal suppresion procedure**
A. Lopez-Aguera, G Rodriguez Fernandez

UNIVERSIDADE DE SANTIAGO DE COMPOSTELA

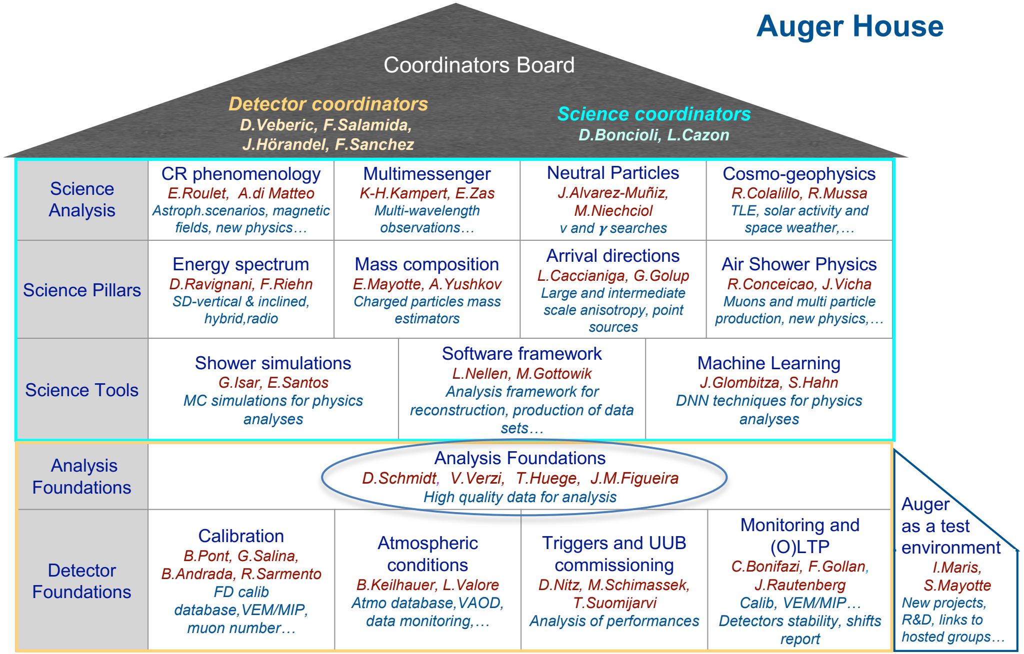
Departamento de Física de Partículas

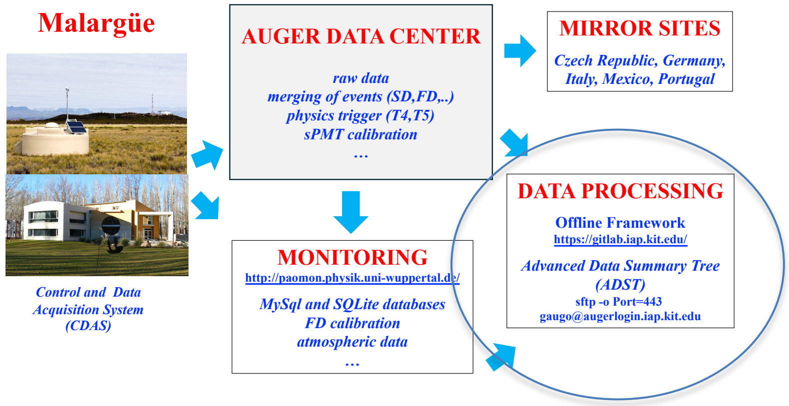
HORIZONTAL AIR SHOWERS AT THE PIERRE AUGER OBSERVATORY

Gonzalo Rodríguez Fernández

Santiago de Compostela, Novembro 2006.

Analysis Foundations task





Reconstruction of events (energy, arrival direction, …)

Advanced Data Summary Tree (ADST)

Analysis Foundations task

Auger House

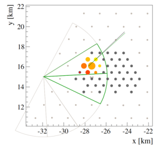
Coordinators Board

Detector coordinators	Science coordinators
D.Veberic, F.Salamida, J.Hörandel, F.Sanchez	D.Boncioli, L.Cazon

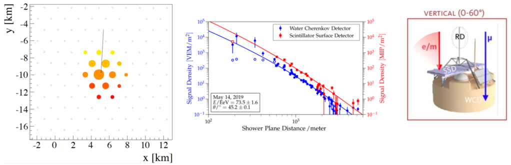
Science Analysis	CR phenomenology *E.Roulet, A.di Matteo* *Astroph.scenarios, magnetic fields, new physics…*	Multimessenger *K-H.Kampert, E.Zas* *Multi-wavelength observations…*	Neutral Particles *J.Alvarez-Muñiz, M.Niechciol* *ν and γ searches*	Cosmo-geophysics *R.Colalillo, R.Mussa* *TLE, solar activity and space weather,…*
Science Pillars	Energy spectrum *D.Ravignani, F.Riehn* *SD-vertical & inclined, hybrid,radio*	Mass composition *E.Mayotte, A.Yushkov* *Charged particles mass estimators*	Arrival directions *L.Caccianiga, G.Golup* *Large and intermediate scale anisotropy, point sources*	Air Shower Physics *R.Conceicao, J.Vicha* *Muons and multi particle production, new physics,…*
Science Tools	Shower simulations *G.Isar, E.Santos* *MC simulations for physics analyses*	Software framework *L.Nellen, M.Gottowik* *Analysis framework for reconstruction, production of data sets…*	Machine Learning *J.Glombitza, S.Hahn* *DNN techniques for physics analyses*	
Analysis Foundations	Analysis Foundations *D.Schmidt, V.Verzi, T.Huege, J.M.Figueira* *High quality data for analysis*			
Detector Foundations	Calibration *B.Pont, G.Salina, B.Andrada, R.Sarmento* *FD calib database,VEM/MIP, muon number…*	Atmospheric conditions *B.Keilhauer, L.Valore* *Atmo database,VAOD, data monitoring,…*	Triggers and UUB commissioning *D.Nitz, M.Schimassek, T.Suomijarvi* *Analysis of performances*	Monitoring and (O)LTP *C.Bonifazi, F.Gollan, J.Rautenberg* *Calib, VEM/MIP… Detectors stability, shifts report*

Auger as a test environment
I.Maris, S.Mayotte
New projects, R&D, links to hosted groups…

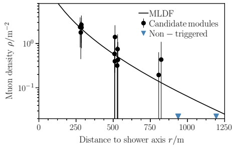
750 m array



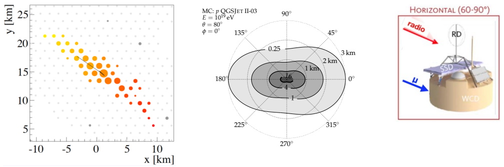
1500 m array vertical (θ < 60⁰)

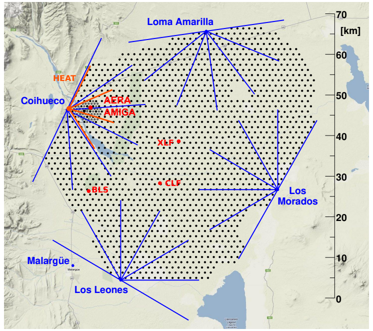


AMIGA (muons)

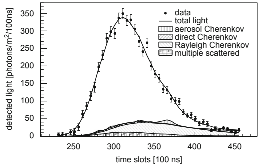


1500 m array inclined (θ > 60⁰)

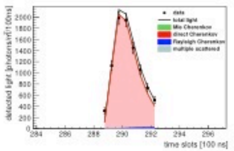




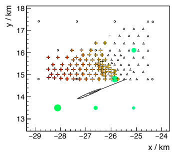
Fluorescence Detector



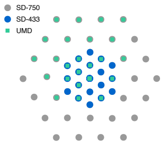
Cherenkov - HEAT



AERA (radio ≈ 100 MHz)



433 m array

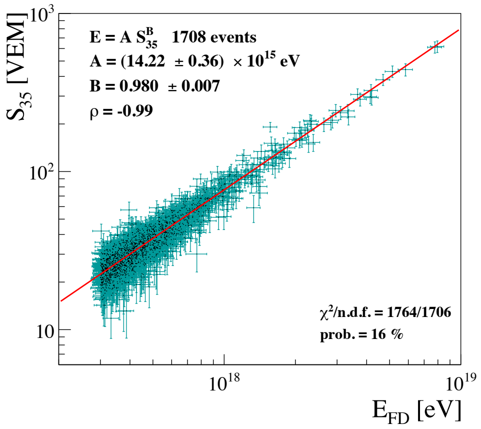


750 m array events: Phase 1 data set

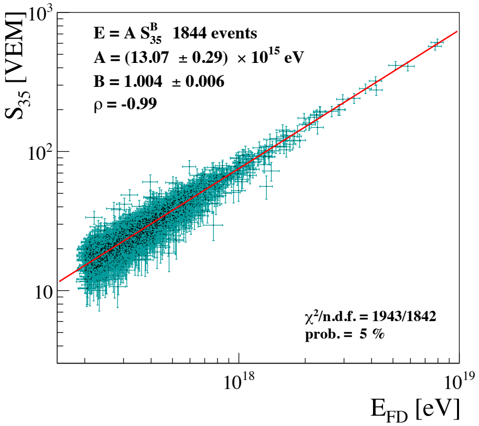
two reconstruction codes for SD events: Herald and Offline

note: only Offline for Phase 2

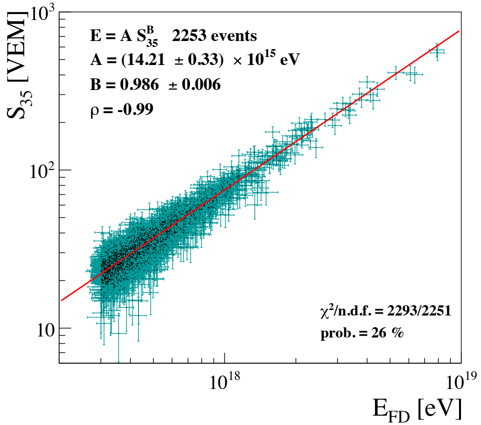
Herald ordinary triggers
FD: EPJC 2021



Herald new triggers ($\theta<55^0$)
FD: EPJC 2021



Offline ordinary triggers
FD: ICRC 2023



reconstr.	triggers	data period	zenith angle range	full trigger efficiency	CIC method	FD data set	purpose
Herald	ordinary	Jan 08 - Dec 22	$\theta < 55^0$	3 x 10^{17} eV	PRD 2020	EPJC 2021	arr. direct.
Herald	new	Jan 14 - Dec 22	$\theta < 55^0$	2 x 10^{17} eV	EPJC 2021	EPJC 2021	arr. direct.
Herald	ordinary	Jan 08 - Dec 22	$\theta < 55^0$	3 x 10^{17} eV	PRD 2020	ICRC 2023	test
Offline	ordinary	Jan 08 - Dec 22	$\theta < 55^0$	3 x 10^{17} eV	JINST 2020	ICRC 2023	radio en. scale

Radio energy scale - AERA

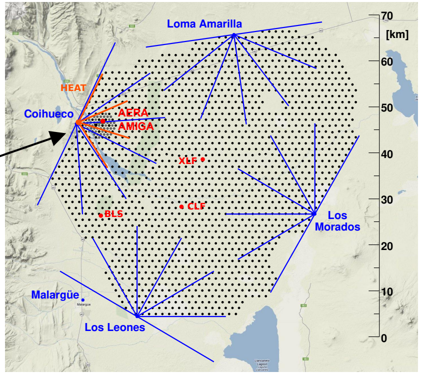
Auger Engineering Radio Array (AERA) precursor of the RD detector of AugerPrime

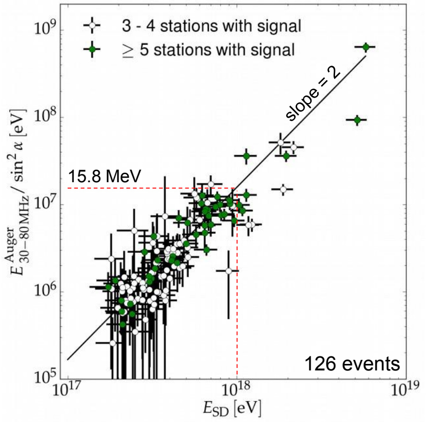
Shower energy from first-principles (QED) but with some caveat:

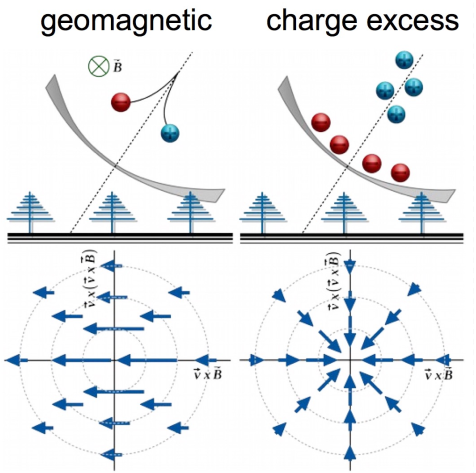
- need an accurate simulation of the shower development
- 100% duty cycle only for inclined events

(no need of atmospheric monitoring)

Comparison with FD energy scale from the analysis of the events detected simultaenously by AERA and 750 m array







- Polarized into direction of Lorentz force
- Radially polarized towards shower axis

Askaryan effect
25% of e^- over e^+

G. Askaryan, Soviet Phys. JETP 14, 441 (1962)

Energy scale from FD (Phase 1)

- paper in preparation → 14% uncertainty
- several issues related to FD rec never published

Absolute fluorescence yield	3.4%
Fluores. spectrum and quenching param.	1.1%
Sub total (Fluorescence Yield)	**3.6%**
Aerosol optical depth	3% ÷ 6%
Aerosol phase function	1%
Wavelength dependence of aerosol scattering	0.5%
Atmospheric density profile	1%
Sub total (Atmosphere)	**3.4% ÷ 6.2%**
Absolute FD calibration	9%
Nightly relative calibration	2%
Optical efficiency	3.5%
Sub total (FD calibration)	**9.9%**
Folding with point spread function	5%
Multiple scattering model	1%
Simulation bias	2%
Constraints in the Gaisser-Hillas fit	3.5% ÷ 1%
Sub total (FD profile rec.)	**6.5% ÷ 5.6%**
Invisible energy	**3% ÷ 1.5%**
Statistical error of the SD calib. fit	**0.7% ÷ 1.8%**
Stability of the energy scale	**5%**
TOTAL	**14%**

Version xx as of July 4, 2024
To be submitted to PRD.
Comment to xxx@xxx.xxx by xxx

The energy scale of the Pierre Auger Observatory

(Dated: July 4, 2024)

The energy scale of the Pierre Auger Observatory is determined with the almost calorimetric measurements of the shower energies provide by the fluorescence detector.

In this paper we present the analysis to estimate the energy scale with a detailed discussion of the systematic uncertainties that in total amount to 14%.

PACS numbers:

I. INTRODUCTION

The Pierre Auger Observatory detects extensive air showers initiated by the highest energy cosmic rays, using an array of 1660 water-Cherenkov detectors spread over an area of 3000 km^2 together with 27 optical telescopes designed to detect the faint nitrogen fluorescence light emitted in the atmosphere. It is these fluorescence observations that set the energy scale of the Observatory, since an air shower induces fluorescence emission in direct proportion to the energy deposited into the atmosphere by the shower particles. The atmosphere thus acts as a giant calorimeter for the measurement of the energy carried by the incoming primary cosmic ray particles. Through coincident measurements of air showers with both the surface and fluorescence detectors, the fluorescence-derived energy scale is transferred to the surface detector analysis, important since the bulk of data collected is from the surface detector alone.

The structure of the paper is as follows. We begin in Sec. II with a description of the Pierre Auger Observatory, including an outline of the techniques used to reconstruct cosmic ray energy with the surface and fluorescence detectors. In the following sections, key quantities and methods are described. The first of these, in Sec. III, is the fluorescence yield (the fraction of deposited air shower energy appearing as light), and we describe laboratory measurements including the pressure, temperature and humidity dependence of the yield. In Sec. IV we discuss aspects of the atmosphere that require careful and regular characterization for good energy measurements, before moving to Sec. V and a discussion of the photometric calibration of the fluorescence detector telescopes and the monitoring of those calibrations over time. In Sec. VI we outline the major uncertainties associated with the fluorescence detector profile reconstruction, the key step in determining energy. The method used to transfer the fluorescence detector energy scale to the surface detector is described in Sec. VII. Finally, we summarize all of the systematic uncertainties in the energy scale already described, before concluding.

II. THE PIERRE AUGER OBSERVATORY

The Pierre Auger Observatory is located in Mendoza Province, western Argentina near the town of Malargüe at a mean altitude of 1400 m above sea level (875 g/cm^2 of atmospheric overburden). It includes as two of its key components a surface detector (SD) and a fluorescence detector. The SD is an array of 1660 water-Cherenkov detectors covering 3000 km^2 on a triangular grid of spacing 1.5 km. A smaller area of 23.5 km^2 contains a denser array of 750 m spacing. Each detector station is a polyethylene tank of area 10 m^2 filled with pure water to a depth of 1.2 m which is viewed with three large photomultiplier tubes. Shower electrons and muons produce Cherenkov light in the water, and even gamma-rays in the shower produce a significant signal via pair production. Photomultiplier signals are digitized with a sampling rate of 40 MHz. Signals are calibrated in terms of that from a vertical, through-going muon (a vertical equivalent muon, or VEM) derived from measurements every minute of signals from unaccompanied cosmic ray muons. An independent reconstruction of a shower direction and energy requires triggers in at least three stations, which corresponds to a threshold energy (100% triggering efficiency) of 3×10^{18} eV for the 1500 m array and 3×10^{17} eV for the 750 m array.

The Fluorescence Detector (FD) is comprised of 27 optical telescopes arranged at four sites around the perimeter of the array. At each site 6 telescopes form an FD station with a total field of view from 2 to 30° in elevation over an azimuth range of 180°. The final three telescopes are situated at the Coihueco site and form the low-energy fluorescence detector HEAT, the High Elevation Auger Telescopes, viewing an elevation range from approx. 30 to 60° over an azimuth range of 90°. The telescopes are of a Schmidt design, with a 1.1 m diameter entrance aperture and a 13 m^2 spherical mirror. Light enters each telescope through the aperture which contains a glass filter with a bandpass of approx. 300 − 400 nm, and an annular ring of lens-segments to partially correct for spherical aberration. Each telescope camera consists of an array of 440 hexagonal photomultiplier pixels, each with a field of view of 1.5° diameter. Pixel signals are digitized with a sampling rate of 10 MHz in the regular telescopes, and 20 MHz in HEAT. The telescopes are

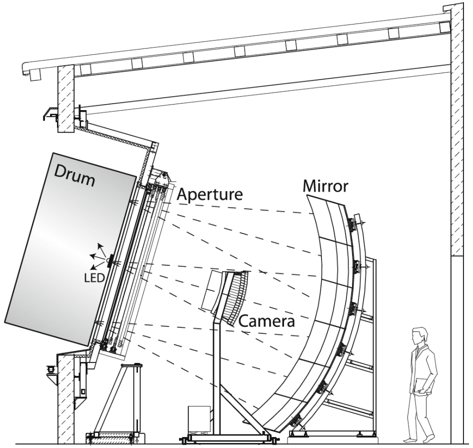
FD Calibration

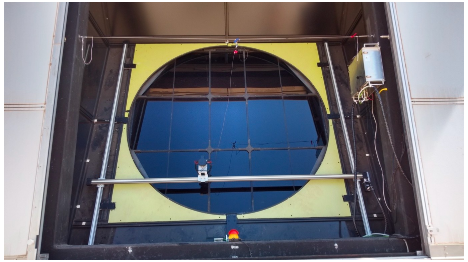
G.Salina

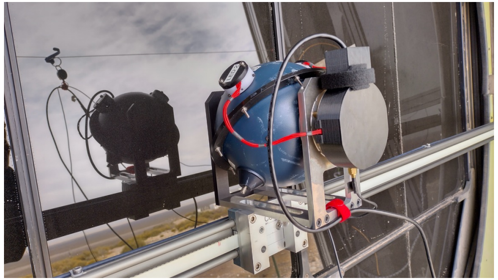
- Calibration database
  - ➢ official release till March 2022
  - ➢ unofficial update till June 2024
    (→ multi-hybrids AugerPrime events)

- analysis of the Night Sky Background data to improve the inter calibration among HEAT and CO telescopes

- implementation of the absolute calibration provided by the X-Y scanner in the calibration db
  → first test on showers
  (last drum calibration in 2013)





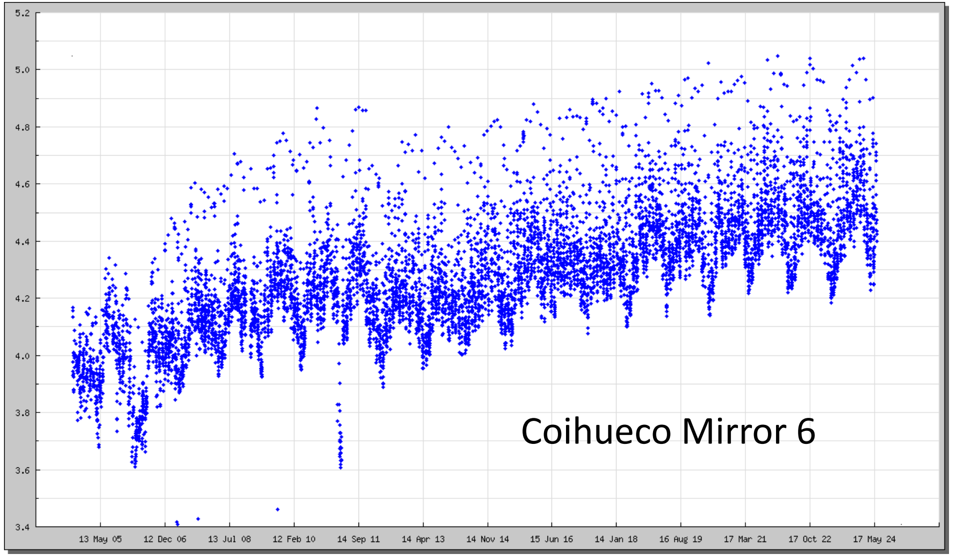


Richieste finanziarie

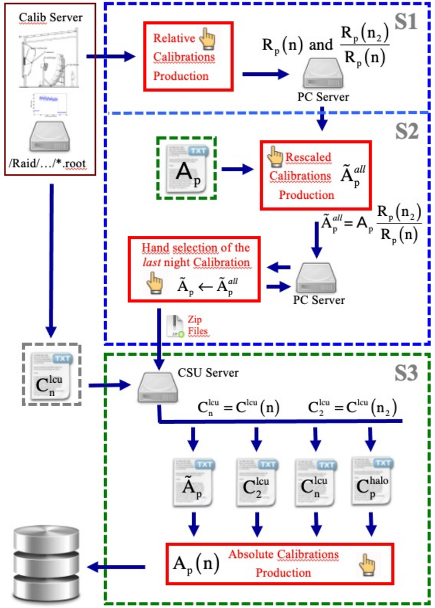
Capitolo	Descrizione	Parziali (k€)		Rimuovi	Modifica	Totale (k€)	
		Richieste	SJ			Richieste	SJ
missioni	Incontri istituzionali e con referee responsabile nazionale	2.00	0.00			22	0
	Partecipazione al meeting di Collaborazione a Novembre (2 persone x 3 keuro = 6 keuro)	6.00	0.00				
	Turno di presa dati FD a Malargue (1 persona x 4 keuro)	4.00	0.00				
	Turno di maintenance camere telescopi a fluorescenza (1 persona x 3 keuro)	3.00	0.00				
	Partecipazione al meeting di Collaborazione a Marzo (1 persona x 3 keuro)	3.00	0.00				
	Partecipazione al meeting Auger di analisi all''Aquila, Maggio 2025 (2 persone x 1,5 keuro = 3 keuro)	3.00	0.00				
	Missioni al CNAF per trasferimento Data Center	1.00	0.00				
spservizi	Common Fund (dettagli sul Progress Report)	345.00	0.00			345	0
trasporti	Trasporti in situ per 1 turno FD e 2 meeting di Collaborazione	3.00	0.00			3	0
Totale						370	0

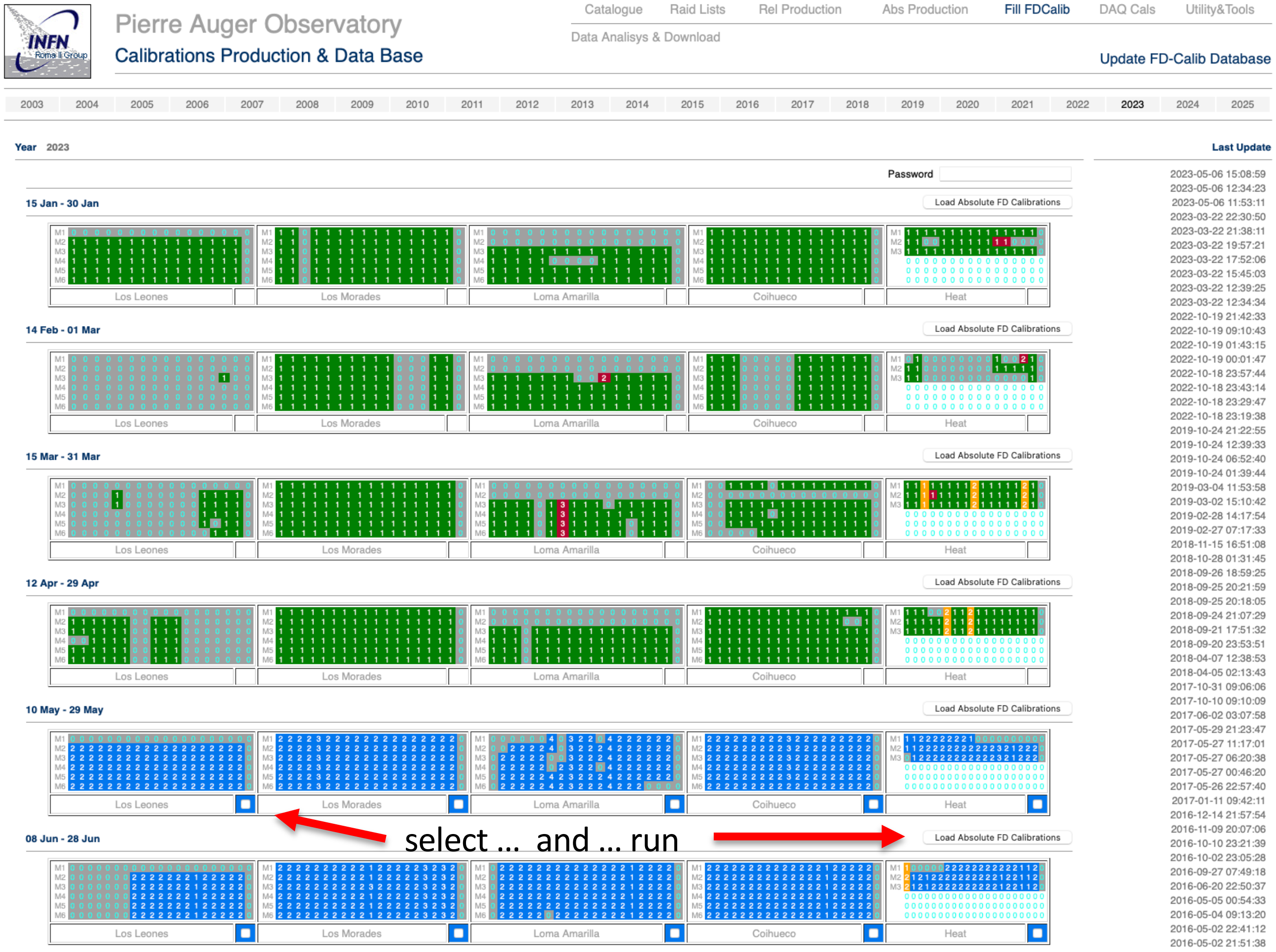
Costanti di Calibrazioni Assolute

- Produzione ed Analisi giornaliera delle Costanti di Calibrazioni Assolute per gli oltre 10000 fototubi del rivelatore.
- Gestione completamente automatizzata, basata su una GUI con tecnologia Apache-MySql-Php/Python
- 20 anni di dati (2005-2024)
- Oltre 180 Mrecords gestiti dal DB

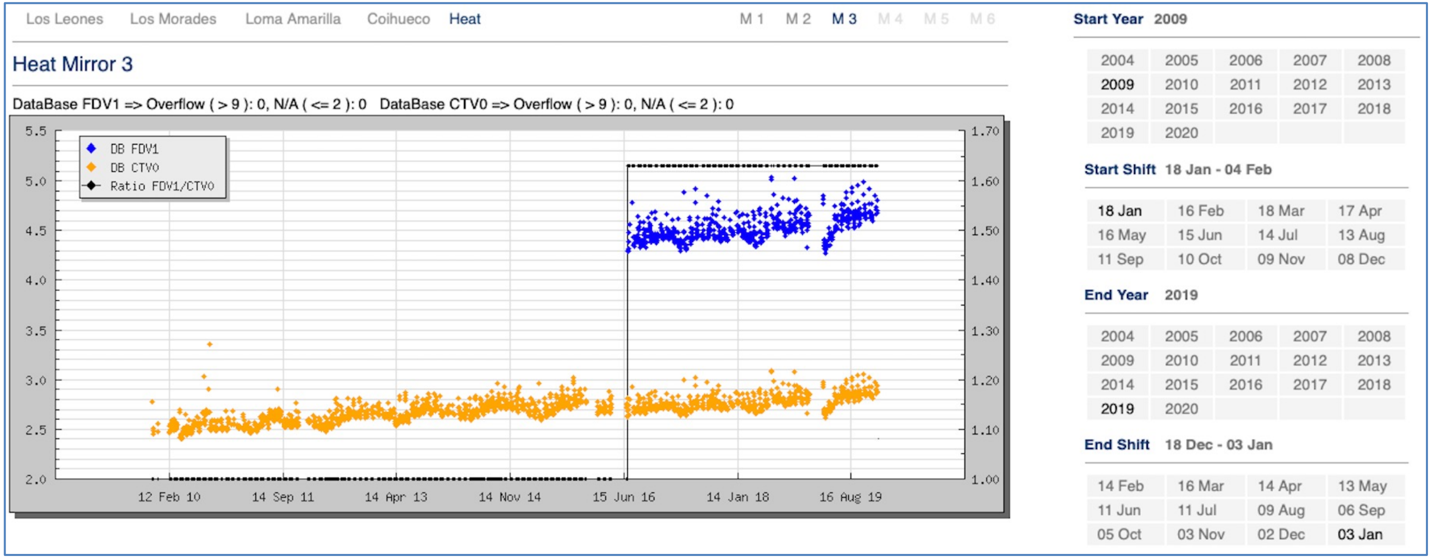


Costanti di Calibrazioni Assolute





Costanti di Calibrazioni Assolute



Produzione ed Analisi giornaliera delle Costanti di Calibrazioni Assolute:
Esempio di correzione delle Calibrazione dovute a malfunzionamenti hardware