Performance and upgrade plans of the Pierre Auger Observatory surface detectors

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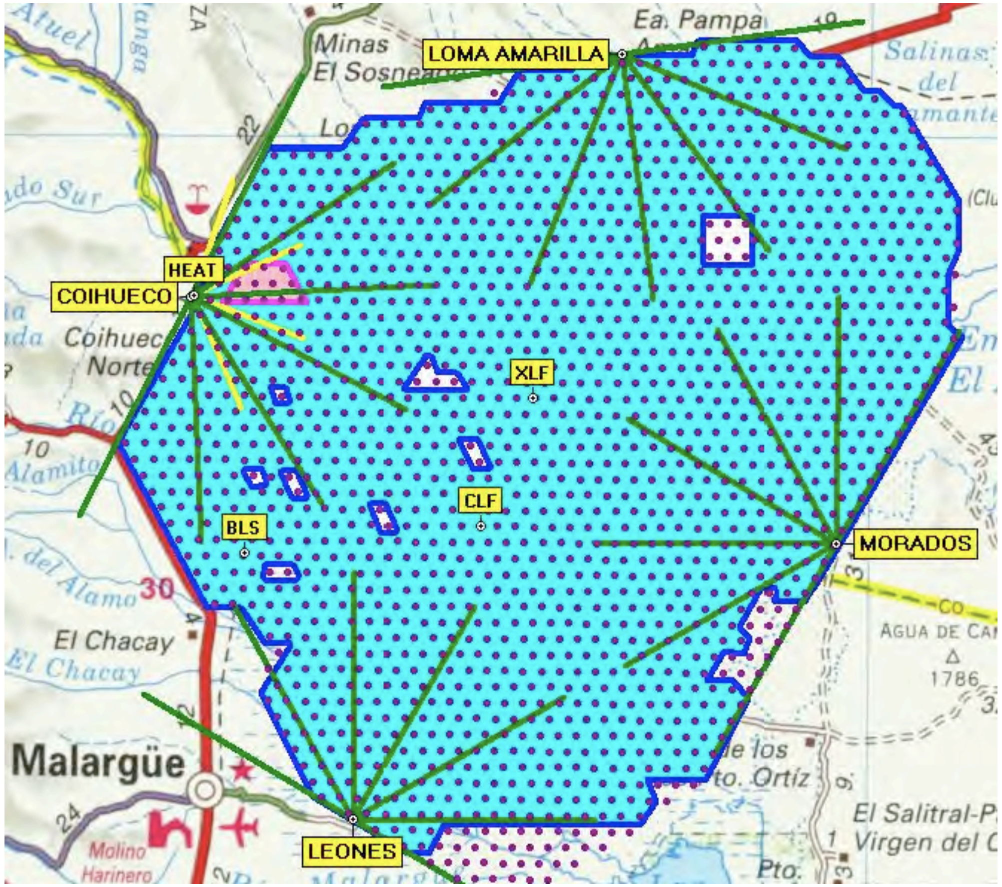
Outline

- Auger Surface Detector
- Calibration and monitoring
- Performance
- Operation and maintenance
- Science case for Surface Detector upgrade
- How to upgrade Surface Detector Electronics
- Conclusions
- The Link

Pierre Auger Observatory



Surface Array

1600 detector stations

1.5 km spacing

3000 km^2

INFILL array:

60 detector stations

750 m and 433 m Spacing

100% duty cycle

Fluorescence Detectors

4 Telescope enclosures

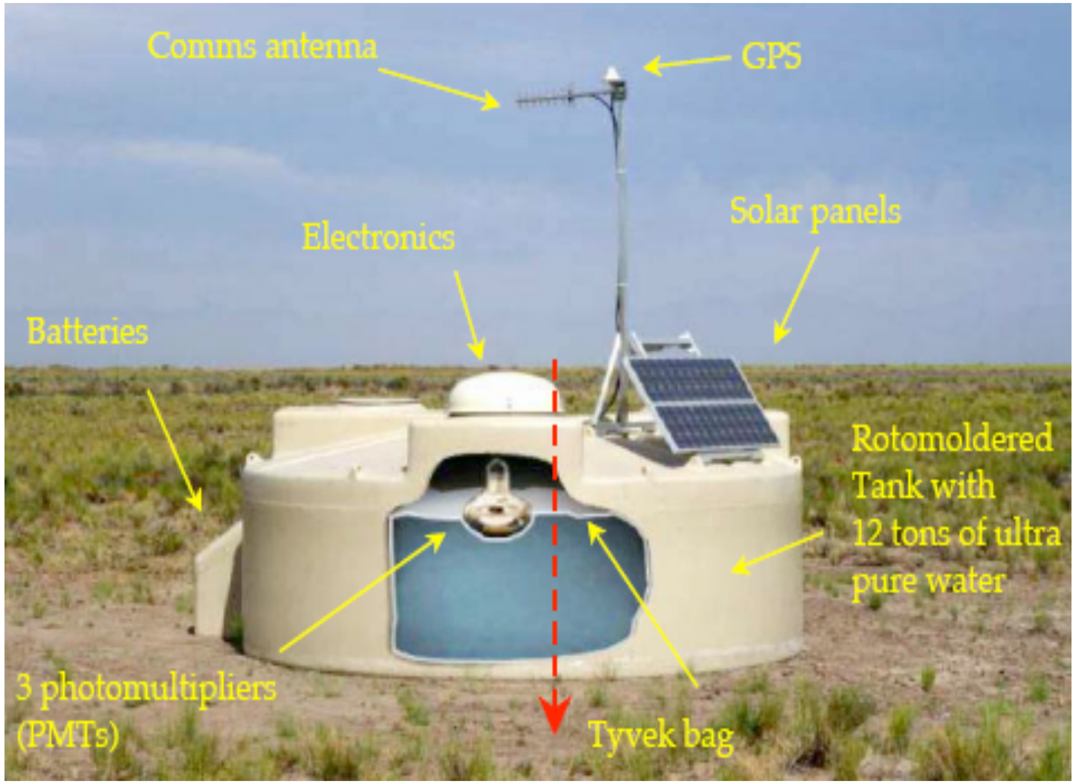
6 Telescopes per enclosure

24 Telescopes total

HEAT: 3 Telescopes

14% duty cycle

Surface Detector



3.6 m diameter water tank containing a sealed liner with a reflective inner surface.
12~000~l of ultra-high purity water. Solar power system providing 10 W.

Three 9 inch PMTs (Photonis XP1805) look downwards through windows of clear polyethylene. Low gain (about 2 10^5) to achieve good linearity up to large anode currents (50 mA at this gain).

Signals from anode and dynode outputs are filtered and sampled with **40 MHz, 10 bit FADC**.
Total dynamic rage: from few to about 10^4 photoelectrons (**15 bits**).

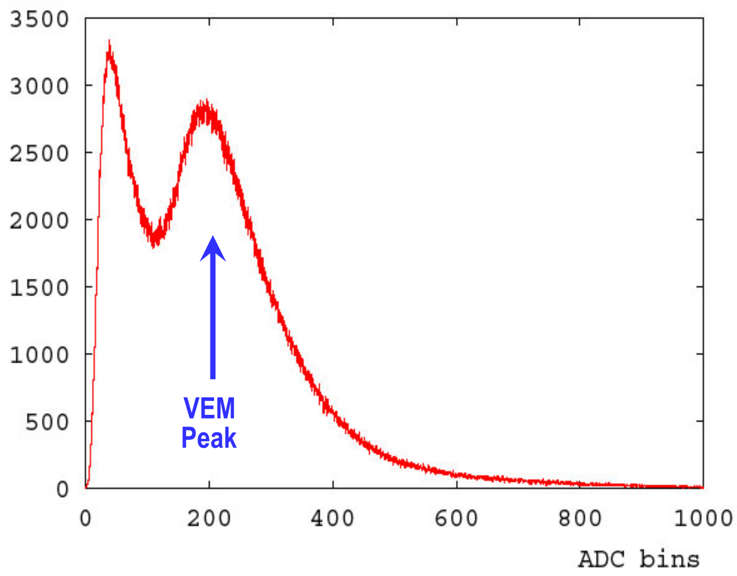
Two shower triggers implemented in **FPGA**:
- Threshold trigger (ThT)
- Time over threshold trigger (ToT)

A common time base is established by using the **GPS system** (Motorola OnCore UT receiver)

Each detector station has **an IBM 403 PowerPC micro-controller** for local data acquisition, software trigger and detector monitoring, and memory for data storage.

The station electronics is implemented on a single board, called the Unified Board.

Calibration and monitoring



Detector calibration with the total charge deposited by the vertical muons crossing the center of the tank: VEM.

Determination of the VEM unit with background muons (Q peak).

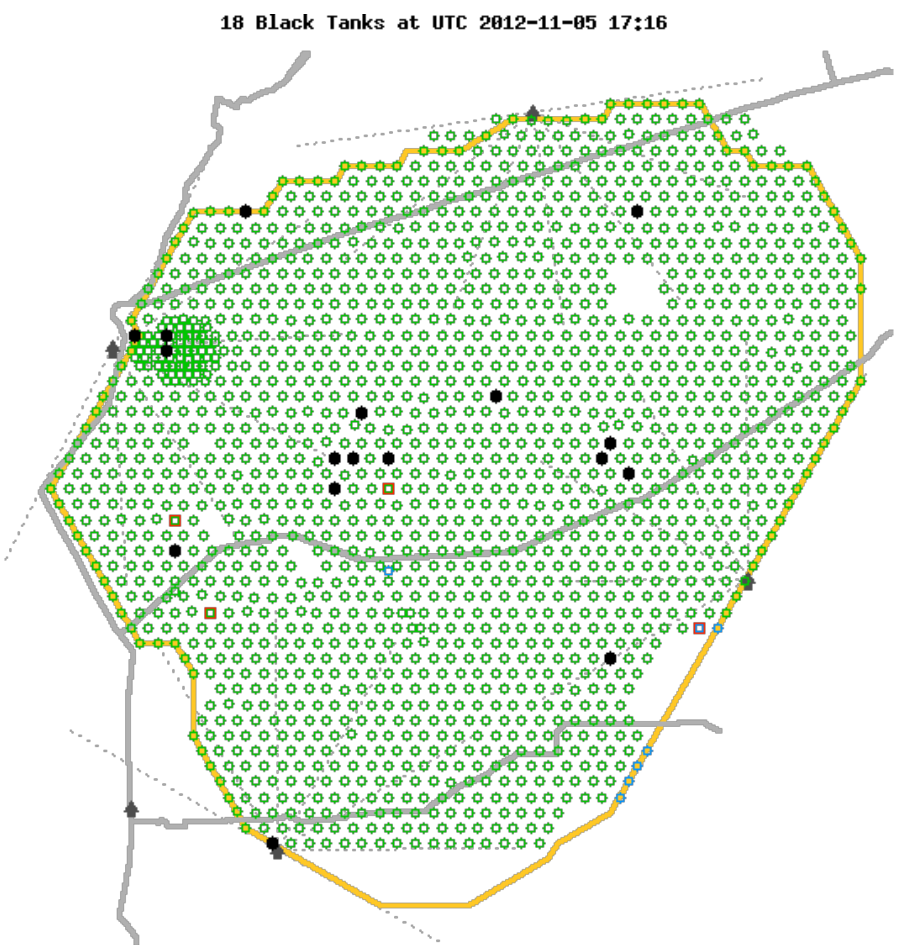
Calibration performed continuously.

The signal decay constant correlates with so called area-to-peak (A/P): $\mathbf{A/P = Q_{VEM}/I_{VEM}}$ where Q_{VEM} is the integrated charge and I_{VEM} the maximum current for the muon signal.

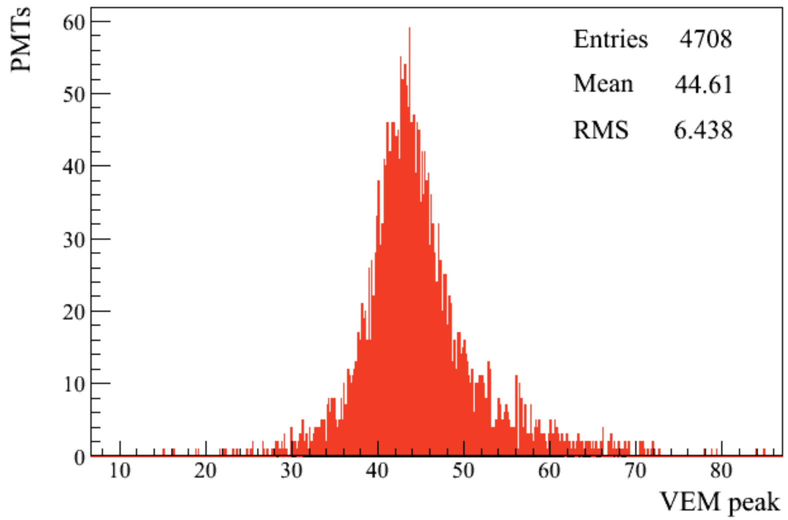
A/P is related to absorption length of the light produced. This depends of various parameters such as Tyvek reflectivity and the purity of the water.

Area-to-peak ratio is a routine monitoring quantity that is directly available from the local station software.

Performance



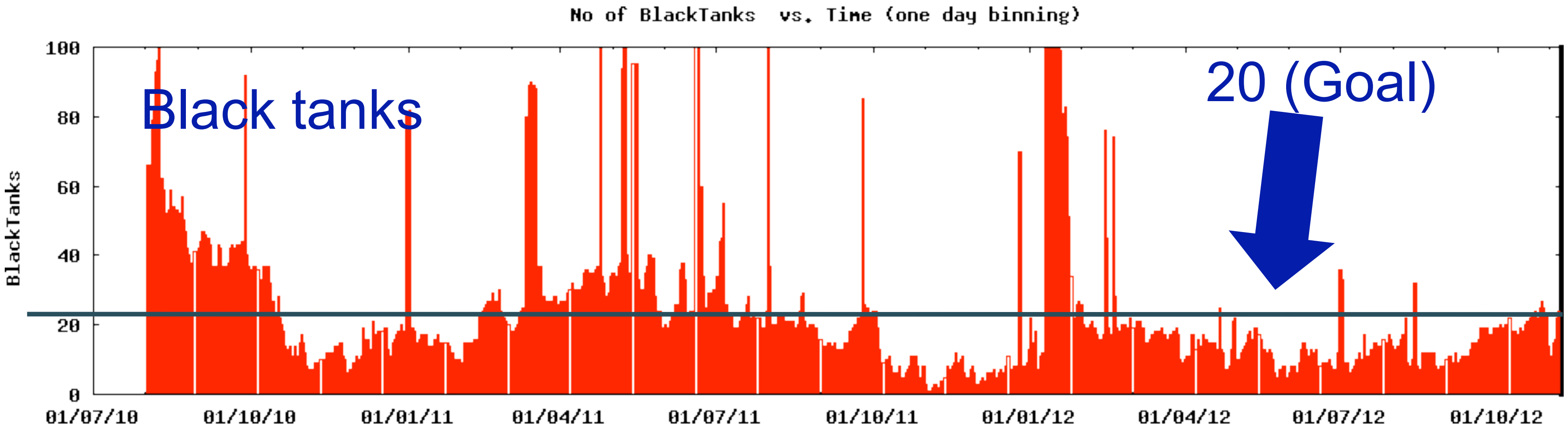
Currently (5 Nov) 18 “black tanks”.

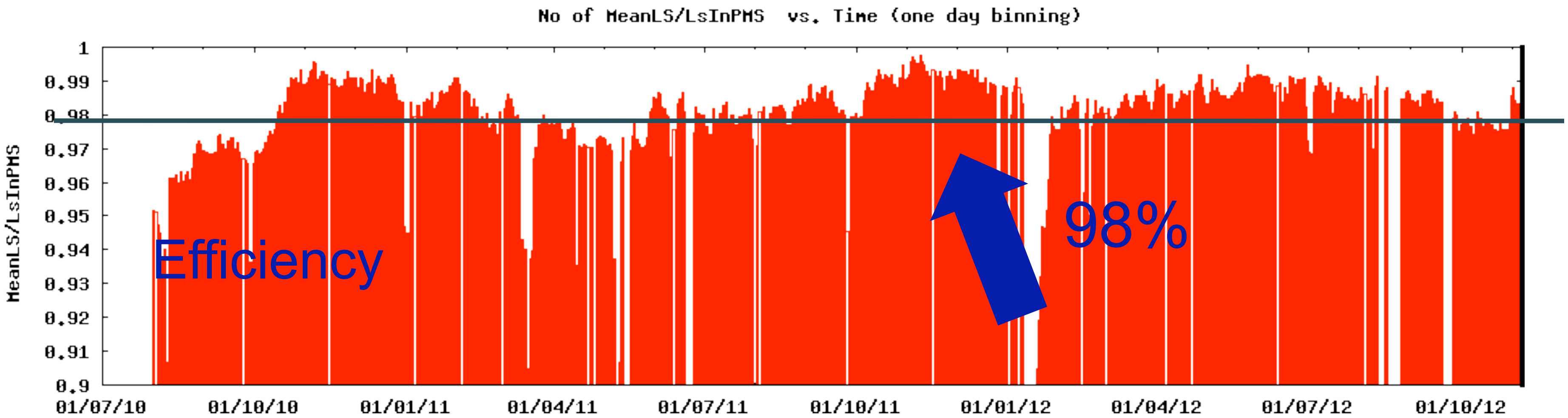


VEM measured for 4708 PMTs.

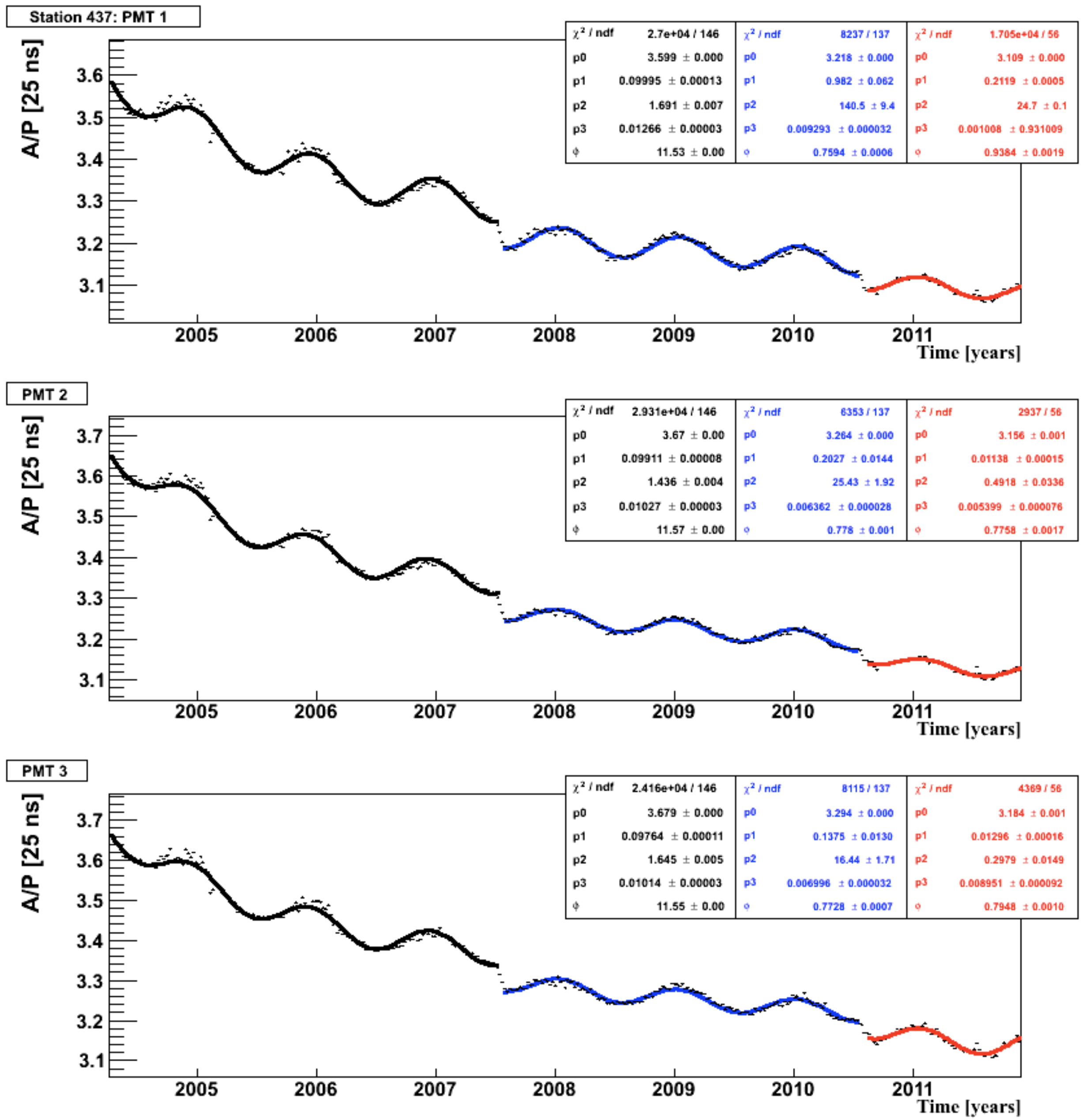
The mean value of the muon peak is at channel 44.6 with an RMS of 6.4 showing **a very good uniformity** of the detector stations.

Performance Metrics





Long term performance



Long term behaviour of the area-to-peak:

- A slight global decrease
- Small seasonal variations

Continuous calibration takes into account signal variations.

The expected fractional signal loss in 10 years is less than 10% which gives confidence in a **very stable long term performance.**

Area-to-peak ratio as a function of time for 3 PMT channels.

Operation and maintenance

The operation of the array is monitored online and alarms are set on various parameters.

Typically more than 98 % of the detector stations are operational at any time.

Failure rates are low: 0.5% per year for PMTs and about 1% for the main electronics parts.

The average battery lifetime is 4-5 years, and batteries are changed during regular maintenance trips.

Most of the failures can be repaired on site. **Enough spares to run >10 more years.**

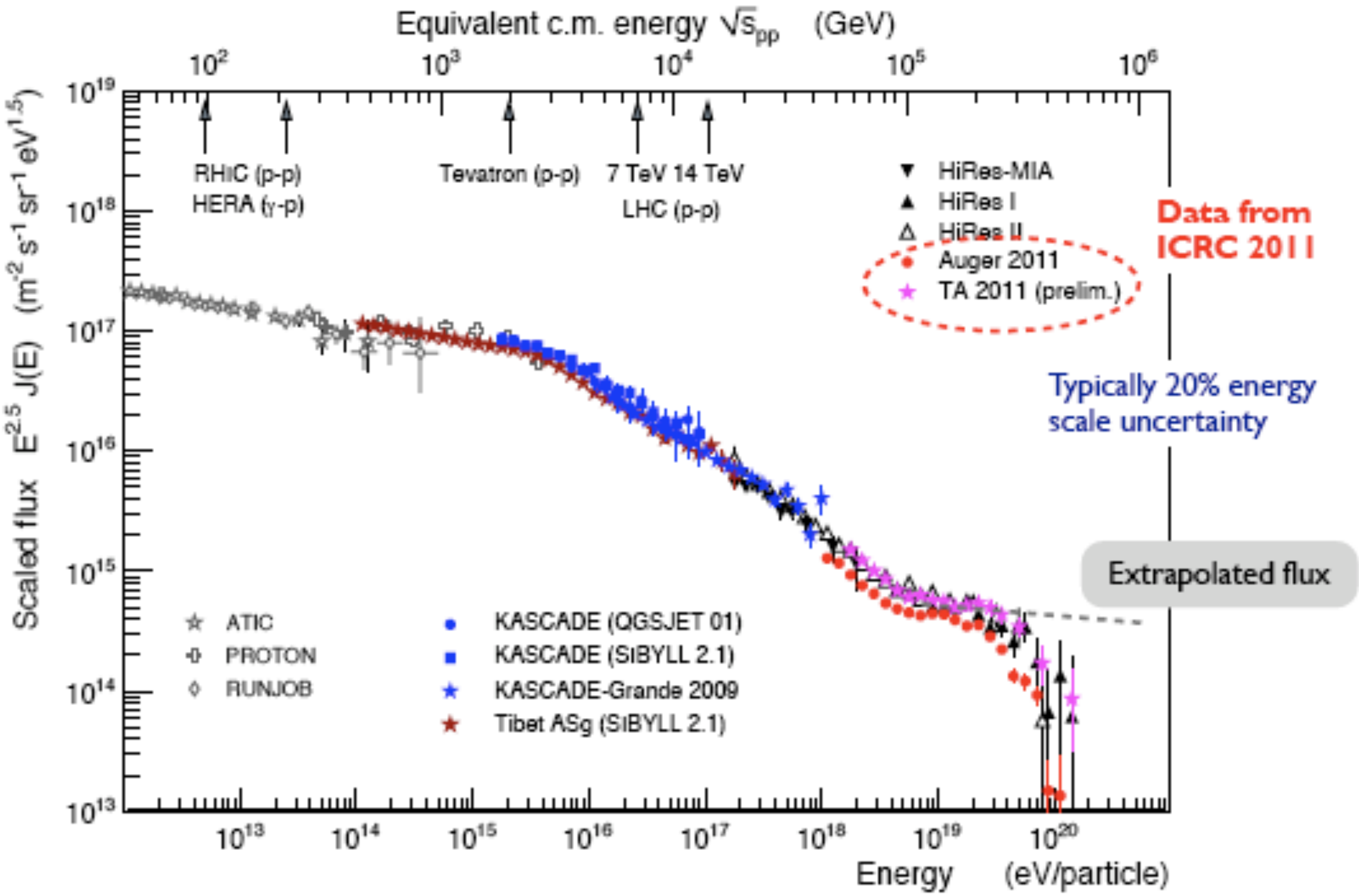
Can we do better?

- Science case has evolved.
- We have better knowledge of detector.
- Technology has advanced.

⇩

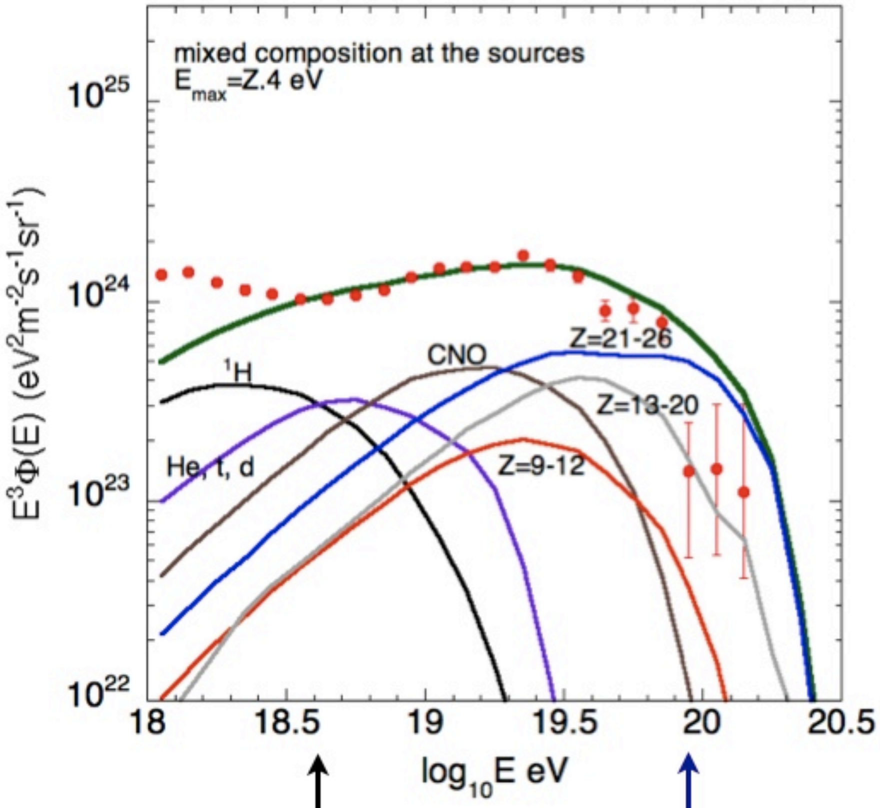
Plan for Surface Detector Electronics upgrade.

Unambiguous detection of flux suppression



Upper end of the source energy?

(Allard, 1111.3290)



Protons
$E_{max,p}$ = 4×10^{18} eV

Iron
$E_{max,\,Fe}$ = 26 $E_{max,p}$
= 10^{20} eV

Rigidity dependent maximum injection energy.

Assume galactic composition.

Natural transition to heavier composition at high energy.

Hard source injection spectrum, difficult for Fermi acceleration.

$$\frac{dN}{dE} \sim E^{-1.6}$$

How to distinguish maximum energy and GZK suppression?

Anisotropy

- Rigidity-dependent scenario: same anisotropy over energy range from 10^{18} eV up to $10^{19.5}$ eV
- Anisotropy only at very highest energies
- Is there a ~10% proton component of different origin (AGN correlation)?

Composition (very important!)

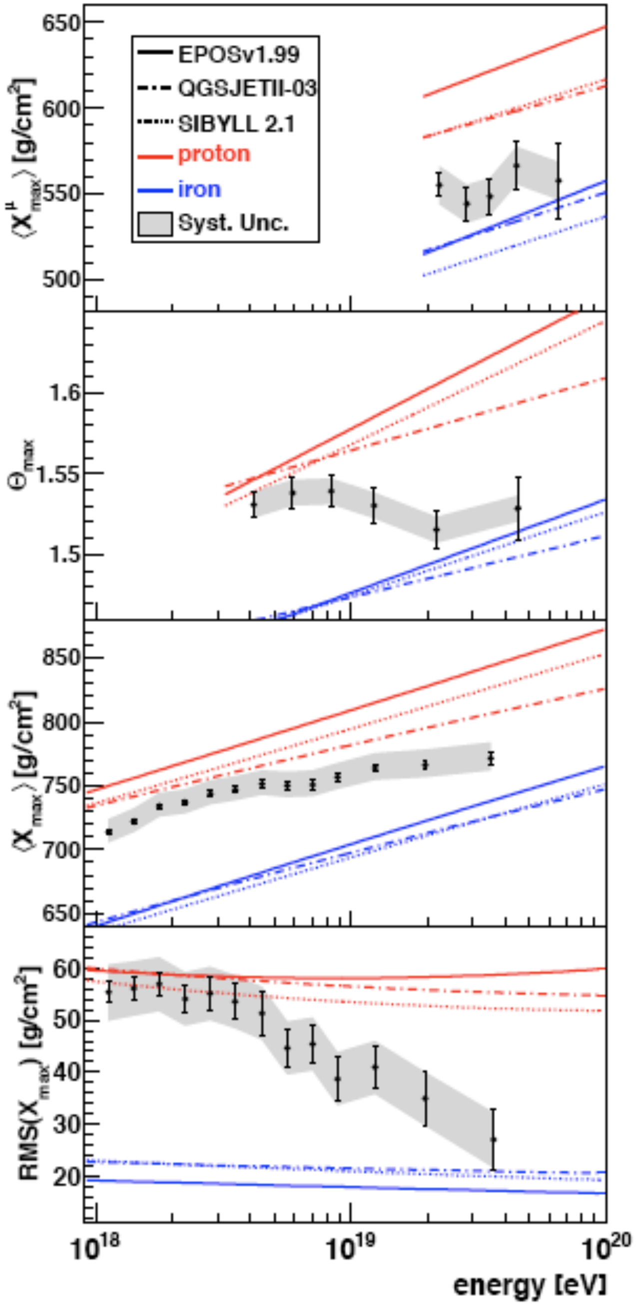
$10^{17.5}$ - $10^{18.5}$ eV: search for the end of the proton spectrum

$10^{19.5}$ - 10^{20} eV: iron-like composition, some protons left?

Secondary particles (promising for significant proton fraction)

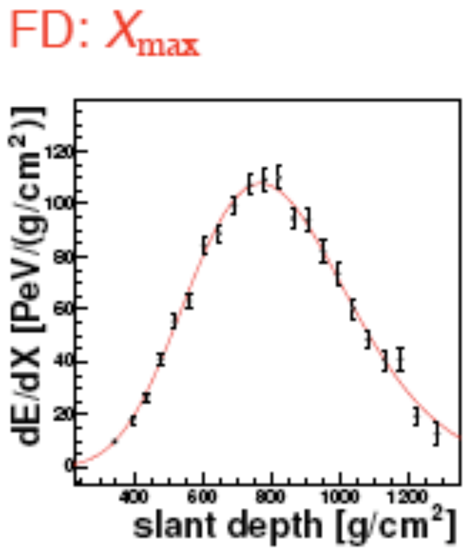
- Neutrinos
- Ultra-high energy photons

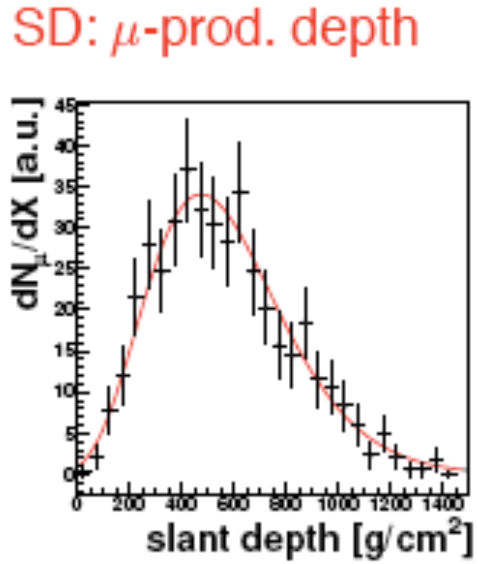
Improve composition sensitivity of SD for E > $10^{19.5}$ eV



Event-by-event analysis at highest energies based on SD-only: exploit FADC traces.

Time difference between shower plane and muons: X^{μ}_{max} (Muon Production Depth)





Pierre Auger Collaboration, ICRC 2011

<u>Other methods:</u>

Azimuthal asymmetry of the signal rise time Q_{max}

Muon counting

Shower curvature

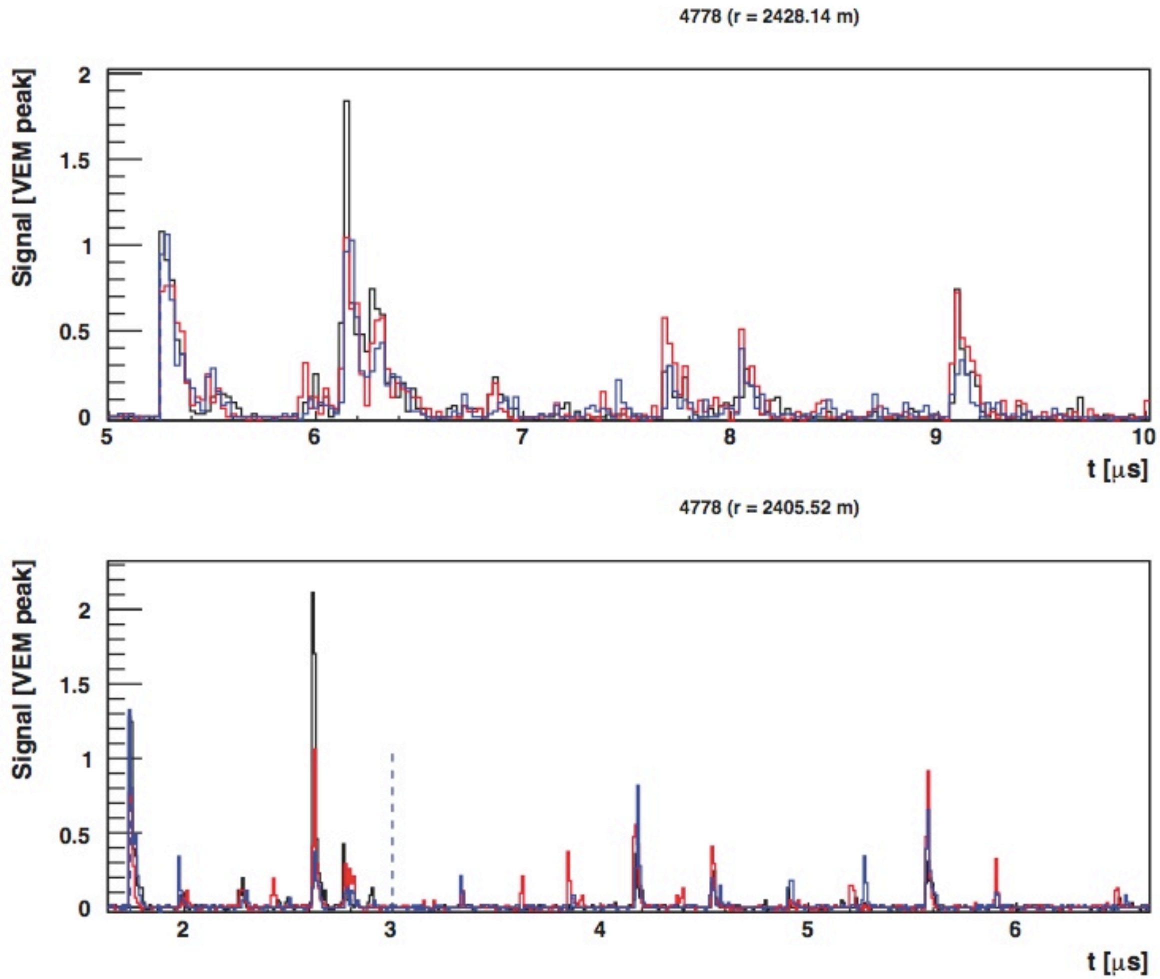
…

Improve SD data quality

- Higher sampling frequency
  - 40 MHz to 120 MHz
- Larger dynamic range
  - From 10 to 12 bits, slow integrating channel?
- Better timing
  - From 8 ns to 4 ns GPS
- Enhanced local processing power under Linux
- FPGA trigger with enhanced capabilities
- Enhanced control and monitoring
- Enhanced calibration capabilities

Example of simulated trace

Proton 40 EeV, 30°



40 MHz sampling

100 MHz sampling

SDE upgrade characteristics

- Improvement in data quality: muon counting, EM/muon, timing, shower front definition, measurements close to the shower core.
- Even better operation and maintenance.
- Provides **backward compatible** operation of the SD!
- Feasible with the current power budget (10 W).
- Deployment in parallel with regular operation and maintenance.
- Low cost.
- Fast schedule: upgraded SDE in operation in 2016.

	2013	2013	2014	2014	2015	2015	2016	2016
Studies and Prototypes	x	x						
Pre production			x	x				
Production					x	x		
Deployment			x			x	x	x
Upgraded SDE in the field				100		600	1300	1600

Preliminary schedule

Conclusions

- Auger Surface Detector has excellent performance and is robust against harsh environment.
- It has controlled and smooth evolution as a function of time.
- SD Electronics upgrade will increase data quality and allow to enhance science capabilities.
- Other upgrades (denser FD array, larger radio array, additional detectors) are also under discussion.

The Link

- Auger has wide expertise in constructing and running large scale infrastructure in Argentina.
- Auger has future plans for upgrades: “We are happy to be here and we plan to stay”.
- CTA could profit from Auger experience.
- Both Auger and CTA could profit from increased exchange of in several domains:
  - Operation, monitoring (also atmospheric), science …