AugerPrime
The Pierre Auger Observatory Upgrade

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INFN, Torino

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The AugerPrime science case

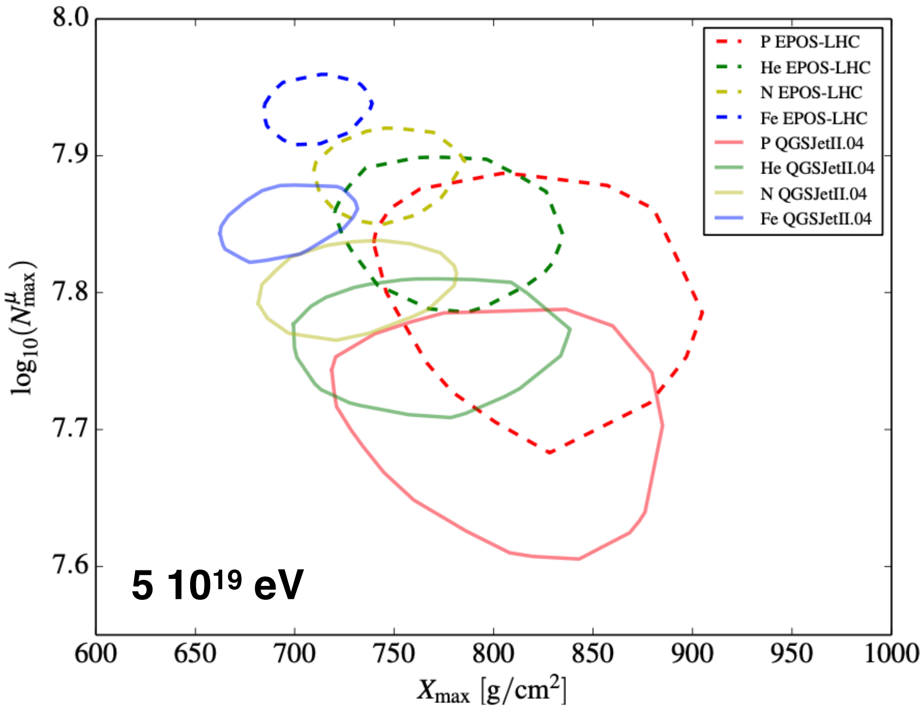
- *study the origin of the suppression*
  - ➡ fundamental constraints to the characteristics of the sources of UHECRs
- *evaluate the existence of a fraction of protons at the highest energies*
  - ➡ feasibility of charged particle astronomy
- *provide better estimates of the neutrino and γ flux*
  - ➡ potential of future CR experiments
- *study the hadronic interactions at UHE and look for non standard physics*
  - ➡ exploration of different interaction phase space

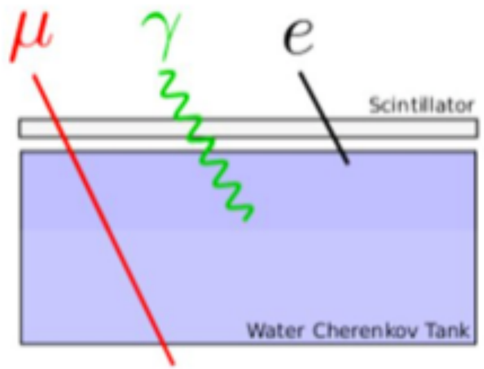
Extend operations to 2025, increasing the statistics

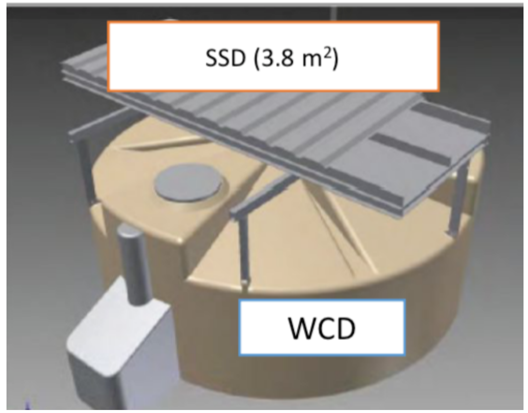
Improve the sensitivity to the composition at UHE :
disentagle the electromagnetic and muonic components

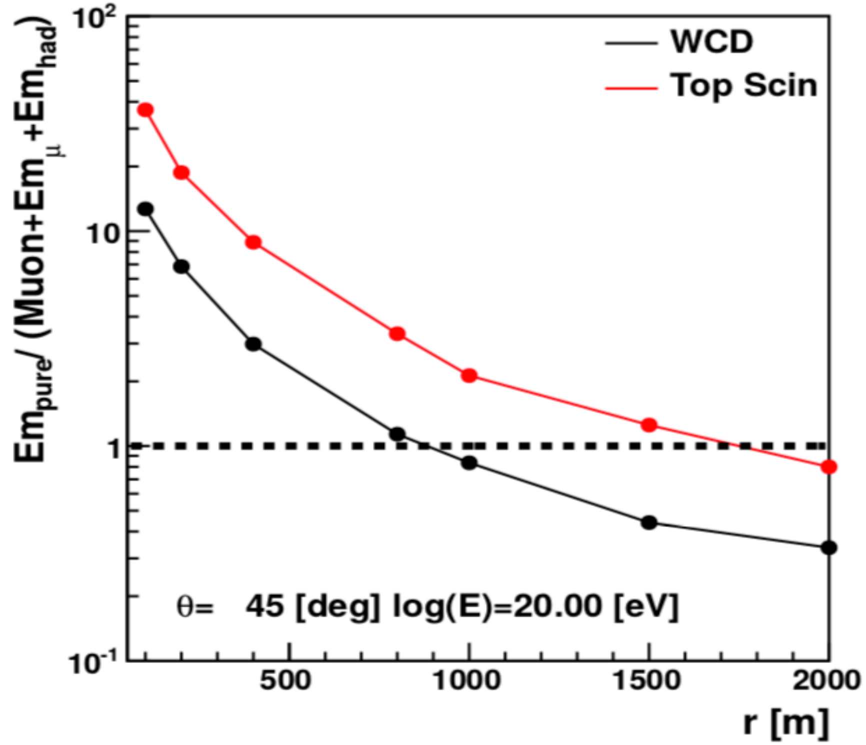
[AugerPrime Design Report, arXiv:1604.03637
EPJ Web of Conf.210 (2019) 06002]

Composition sensitivity





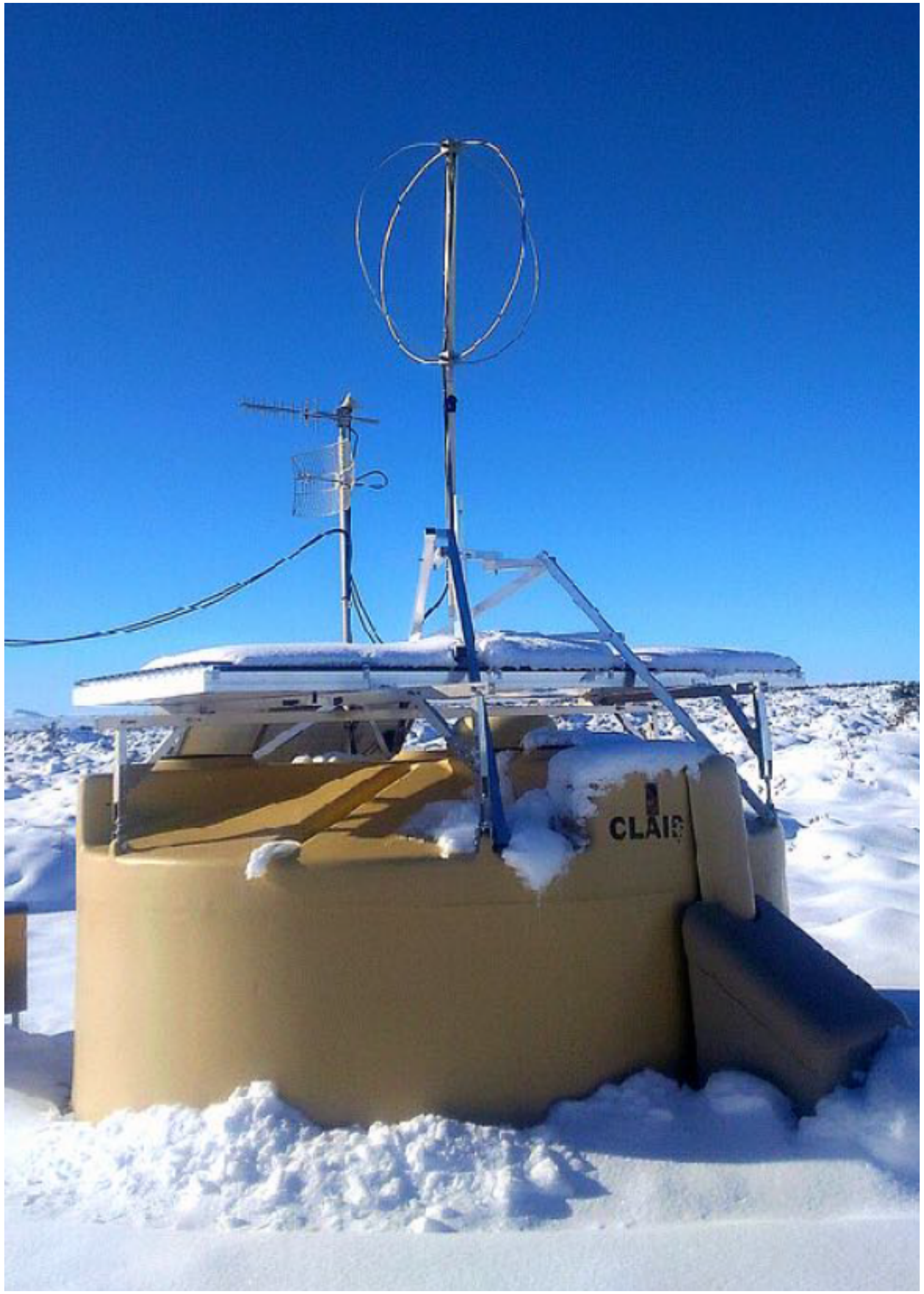




100% duty cycle of the SD
15% duty cycle of the FD

exploit the complementarity of response to particles to discriminate the muonic and electromagnetic components of extensive air showers

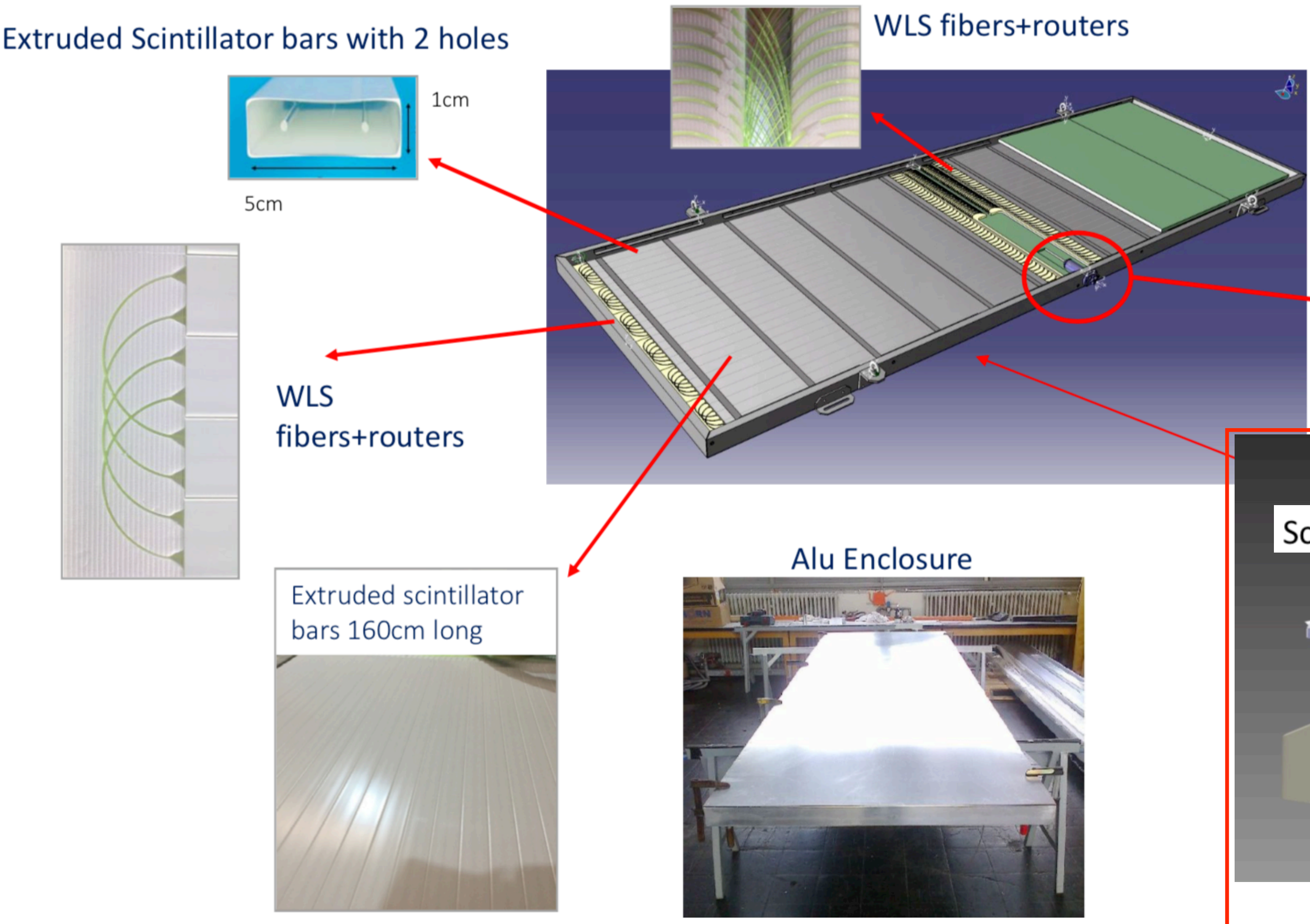
Elements of AugerPrime

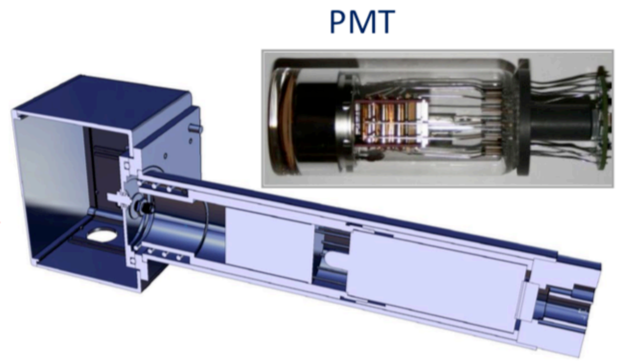


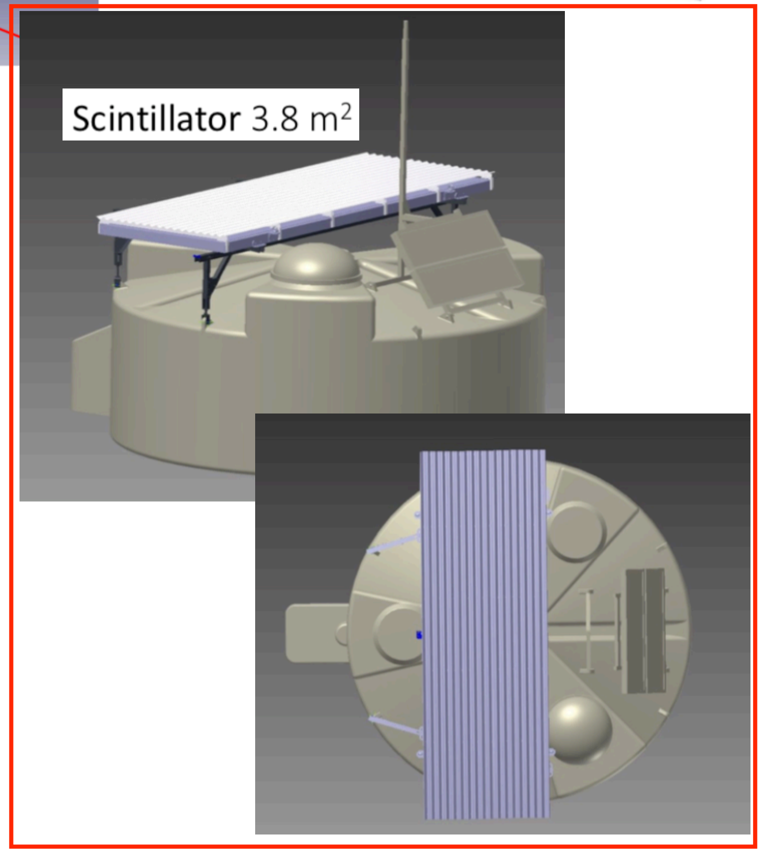
- **Surface Scintillator Detector (SSD)** to measure the mass composition in combination with the Water Cherenkov Detectors (WCD).
- **Upgraded Surface Detector Electronics** to improve the performance of the WCD
- **small PMT** to increase the dynamic range of the WCD.
- **radio antenna** to measure the radio emission of showers in atmosphere (30-80 MHz)
- **Underground Muon Detector (AMIGA)** to have a direct muon measurement and cross-check the SSD-WCD combined analysis (infill area, 61positions)

[Auger Preliminary Design Report, arXiv:1604.03637]
[EPJ Web of Conf.210 (2019) 06002]

The Surface Scintillator Detector







A scintillator plane on top each WCD station

- robust and well understood
- complementary to the WCD in the measurement of the shower components

The SD Upgraded Electronics

Increase the performances of existing detectors + allows the addition of the new ones

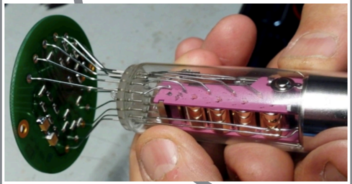
- 12 bit FADC with faster sampling : 40 ⟶ 120 MHz
- better timing accuracy
- increased dynamic range

Faster data processing and enhanced local triggers

- more powerful processor and FPGA

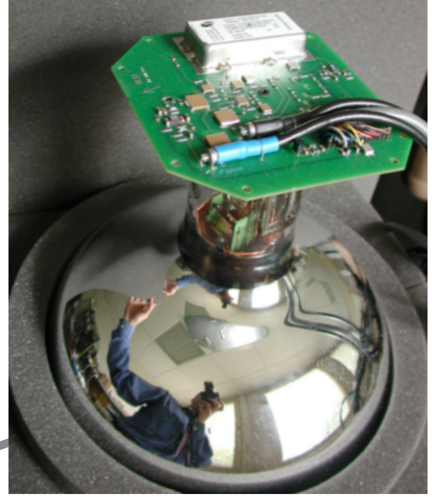
Improved calibration and monitoring capabilities

- >90 monitoring variables managed by slow-control
- low gain to high gain calibration purely electronic (both for WCD and SSD)



Hamamatsu R8619, 1" ⌀

XP1805 Photonis, 9" ⌀

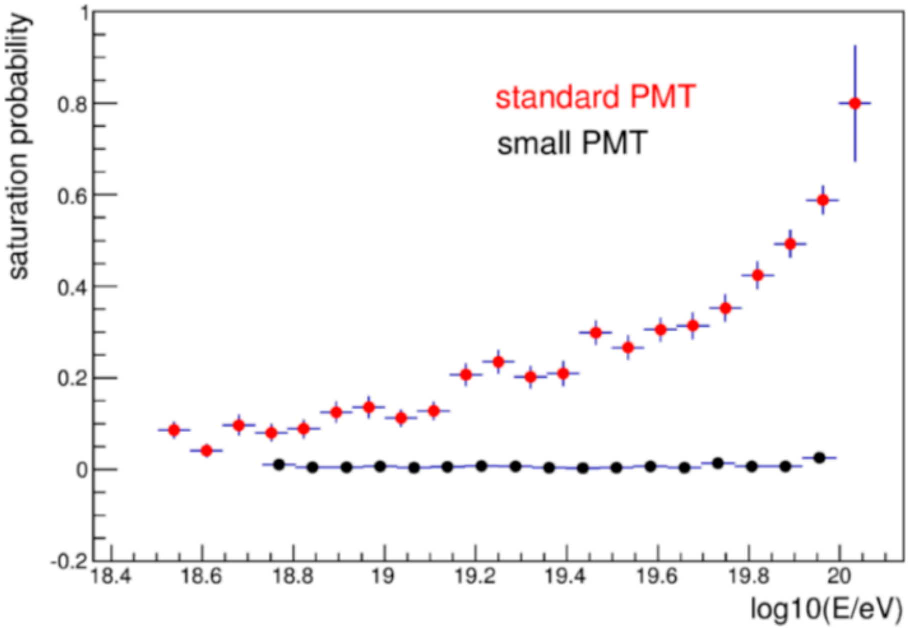


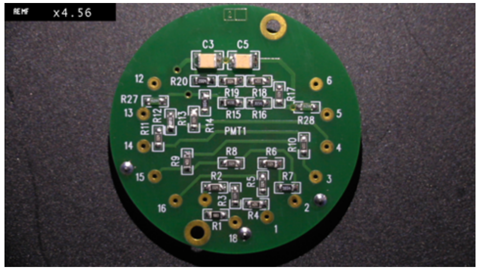
Hamamatsu R9420, 1.5" ⌀

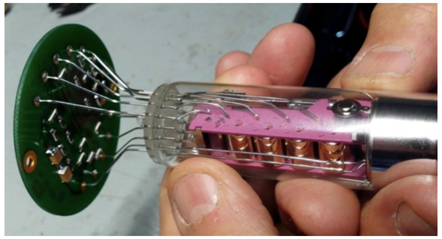
Extending the dynamic range

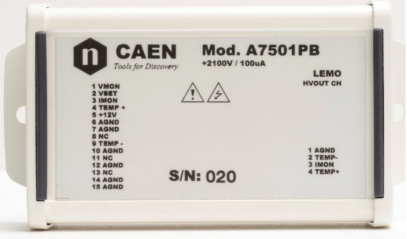
Extra small PMT in the WCD (1″ ∅)

- x32 dynamic range : ~20000 VEM
- P(≥1 saturated SD) ~0 at all energies
- signals measured as close as 250 m from the core
- easy installation (no mechanical modification of SD tanks)
- dedicated input in the UUB
- comparable dynamic range in WCD and in SSD



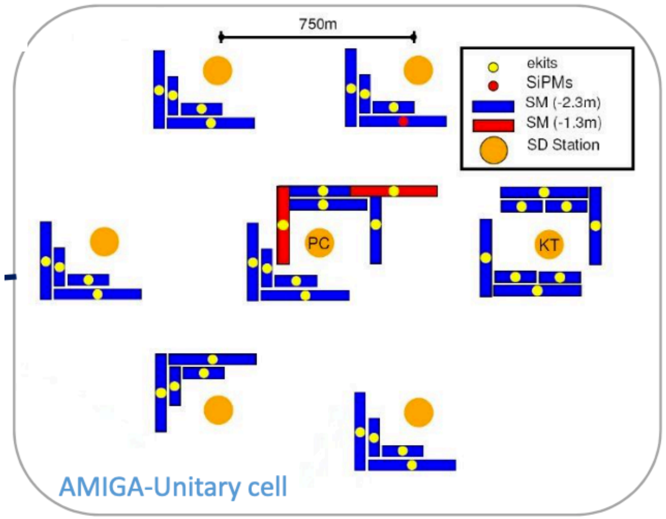


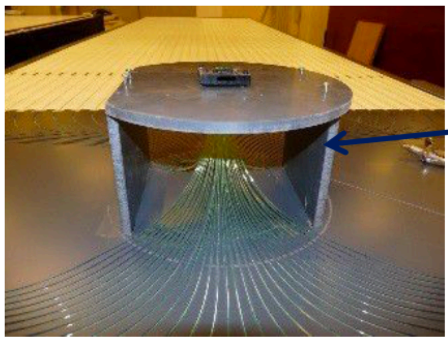




Underground Muon Detector

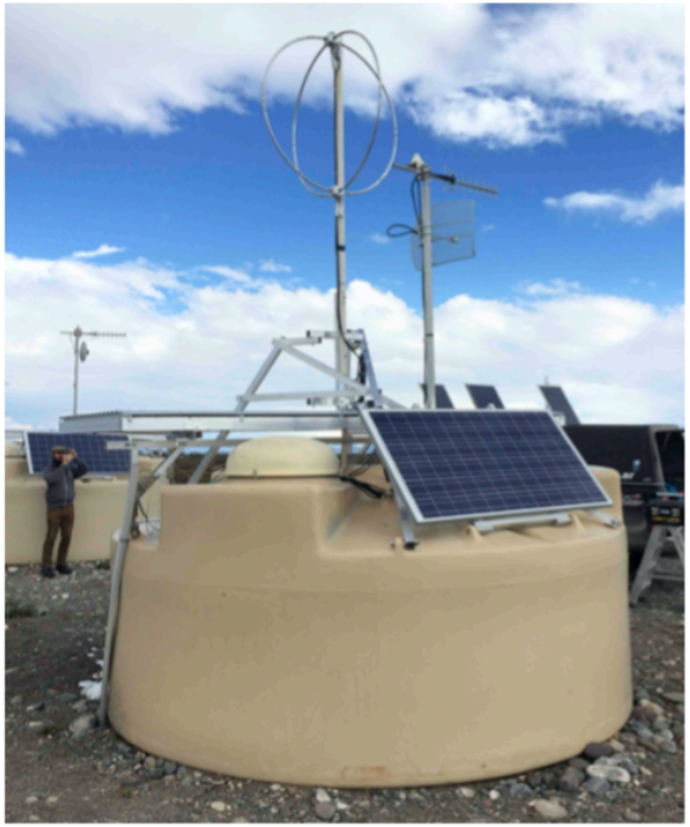
- 61 detectors in the Infill area (23.5 km^2 in a 750 m grid)
- 3 modules/WCD (~30 m^2), 2.3 m underground, triggered by the surface detectors
- muon energy threshold ~600 MeV/cosϑ_μ
- **direct measurement of the muon content and its time structure in showers with $E \gtrsim 10^{17.5}$ eV**
- **verify and fine-tune the methods used to separate the muon component with SSD**





Radio detector

FIRST FULLY UPGRADED PROTOTYPE STATION



ANTENNA DESIGN

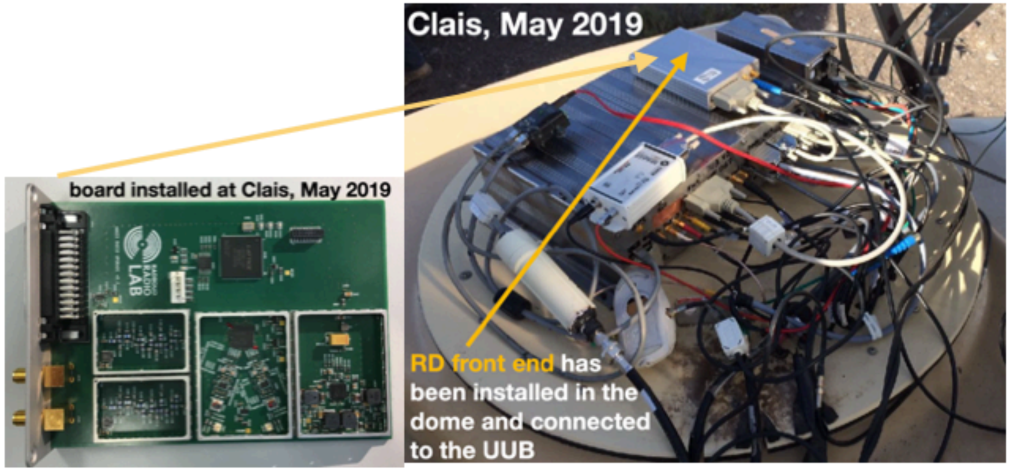
- Designed for: **low cost & low maintenance**
- 1660 radio antenna stations on 1.5 km triangular grid.

- Measuring at 30-80 MHz frequencies.
- Short Aperiodic Loaded Loop Antenna (SALLA).
- **Two polarisation** directions (2 dipoles of ø 1.2 m).
- Digitization of signal at **200 Msps.**
- Sensitivity is flat in frequency.

HARDWARE INTEGRATION

- Shares power, communication, GPS timing, and DAQ with existing infrastructure (*PoS(ICRC2019)370*).
- Triggered by Water Cherenkov Detector signal

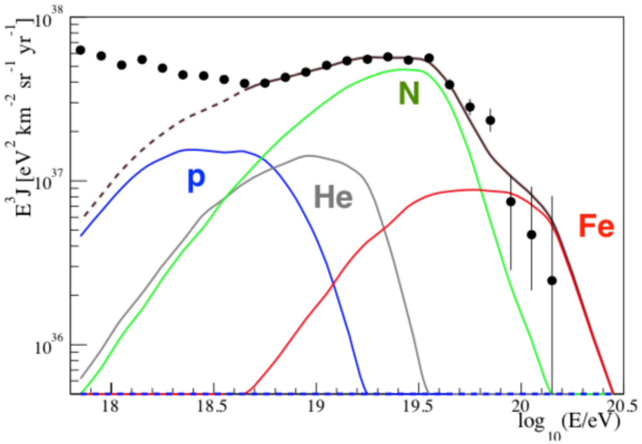
Full working prototype at Clais since May 2019



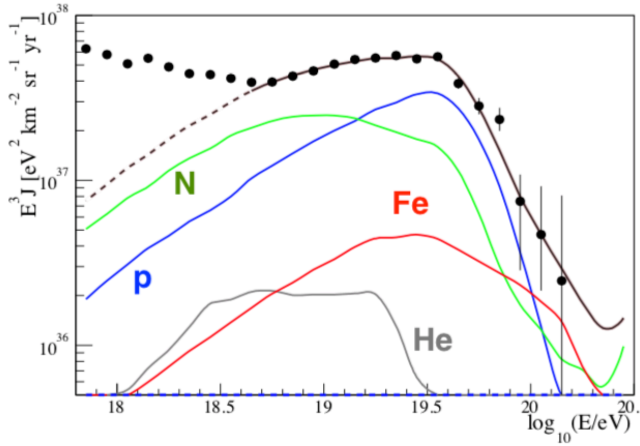
Interpreting the flux suppression

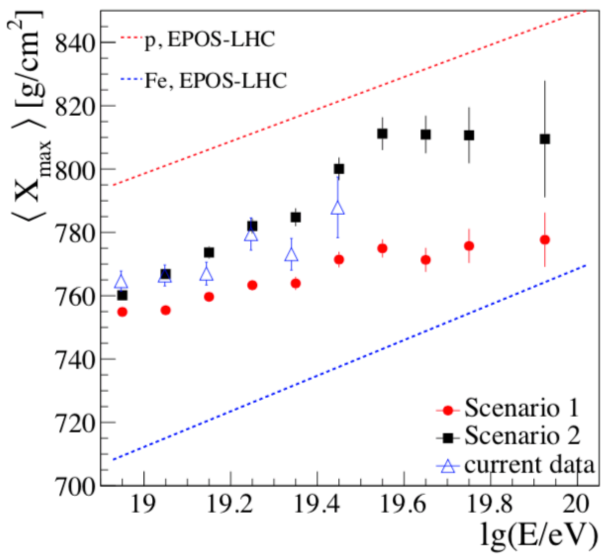
Simplified benchmark scenarios :

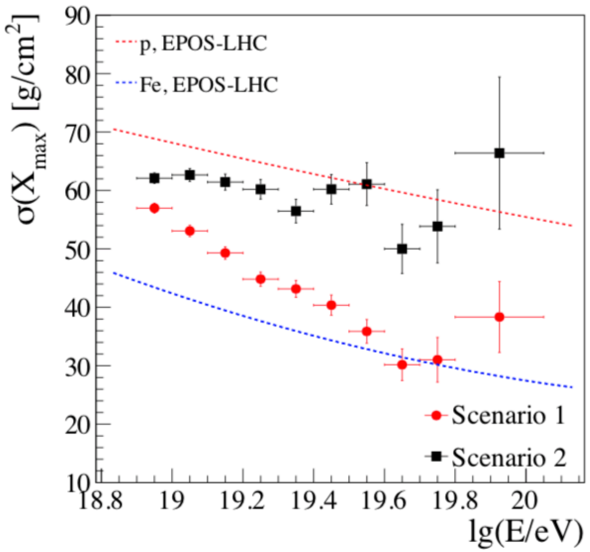
Scenario 1: maximum rigidity model

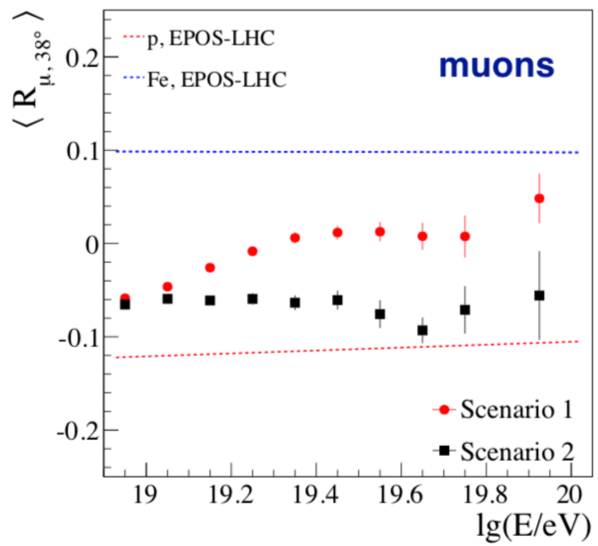


Scenario 2: photo-disintegration model

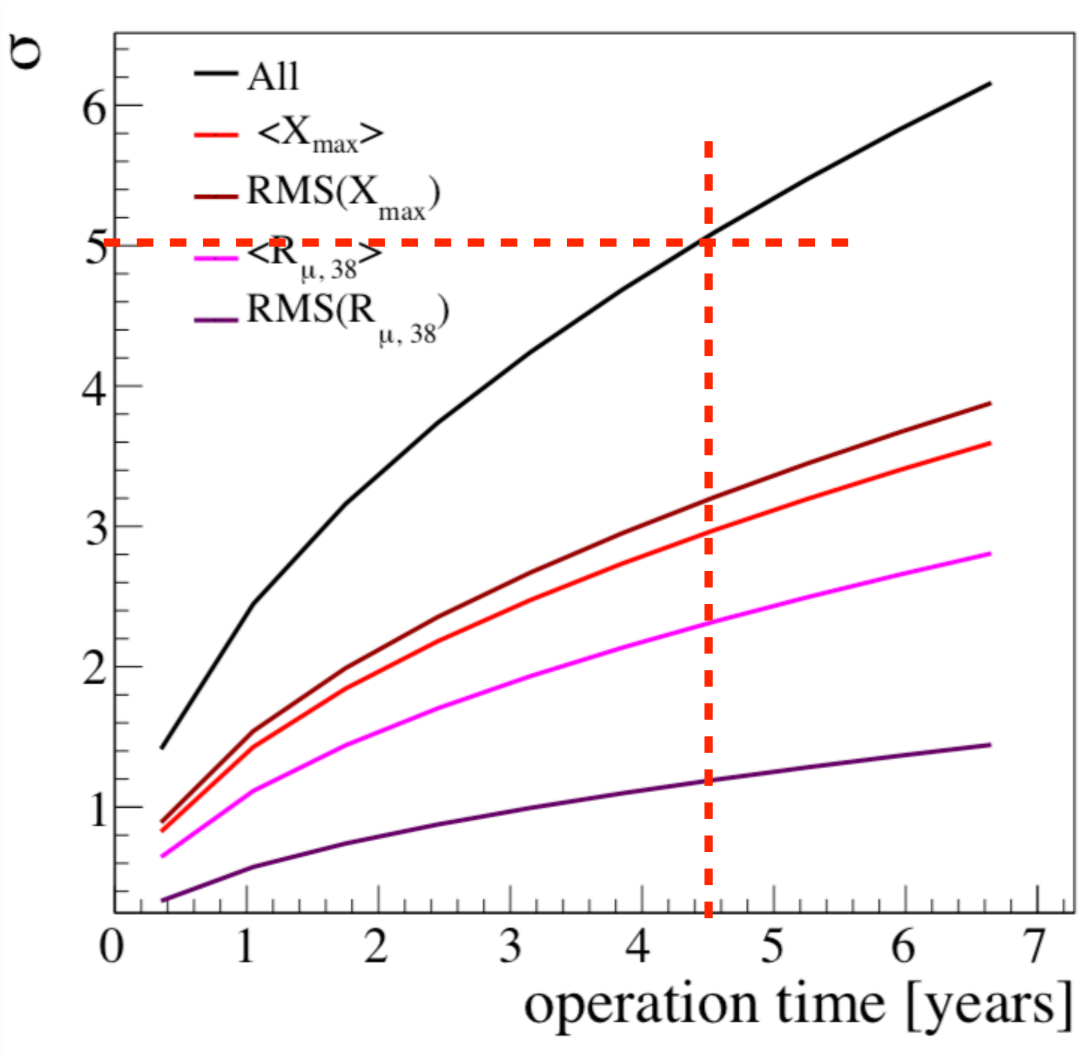








Is there a proton fraction at UHE?



Significance of distinguishing two different realisations of Scenario 1 (maximum rigidity model) :

- as it predicts, i.e. no protons at UHE
- adding 10% protons

For the combined significance

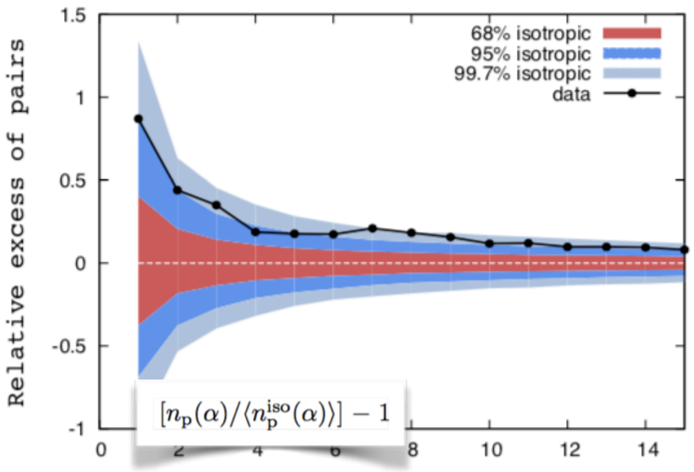
$$\sigma^2 = \sigma^2(\langle X_{\max}\rangle) + \sigma^2(RMS(X_{\max})) + \sigma^2(\langle R_{\mu,38}\rangle) + \sigma^2(RMS(R_{\mu,38}))$$

>5σ in 5 years of operations

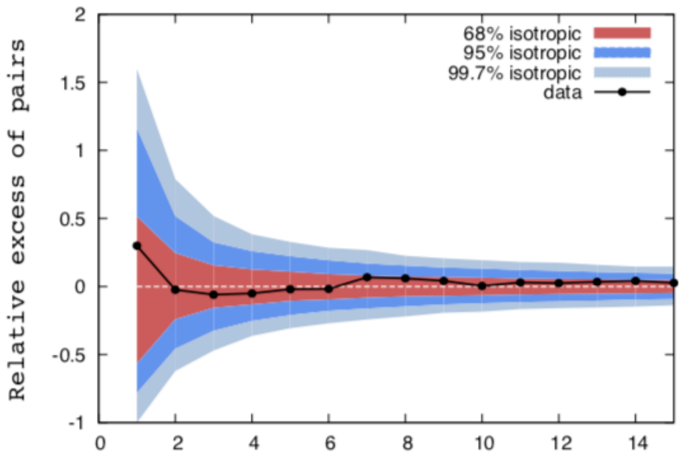
Composition-driven anisotropy search

454 events with E>4 10^{19} eV, ϑ<60^0

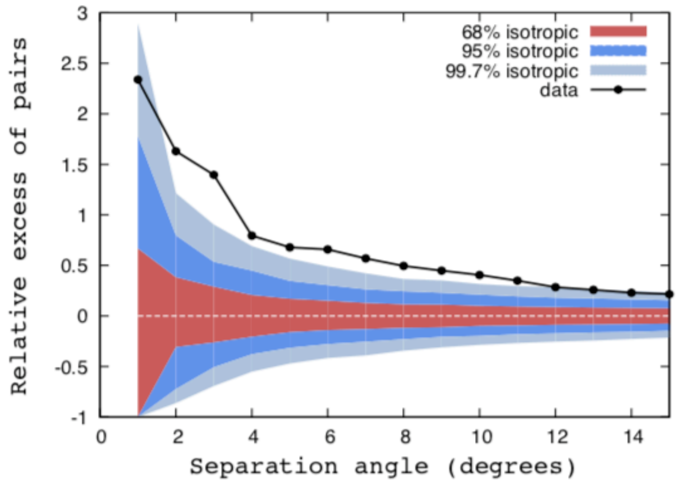
- keep ϑ, assign random X_{max} according to scenario 1, proton-like for 10% of them
- correlate 50% of the protons within 30 to one AGN of the Swift-BAT catalog <100 Mpc



all 454 events



no p-like events



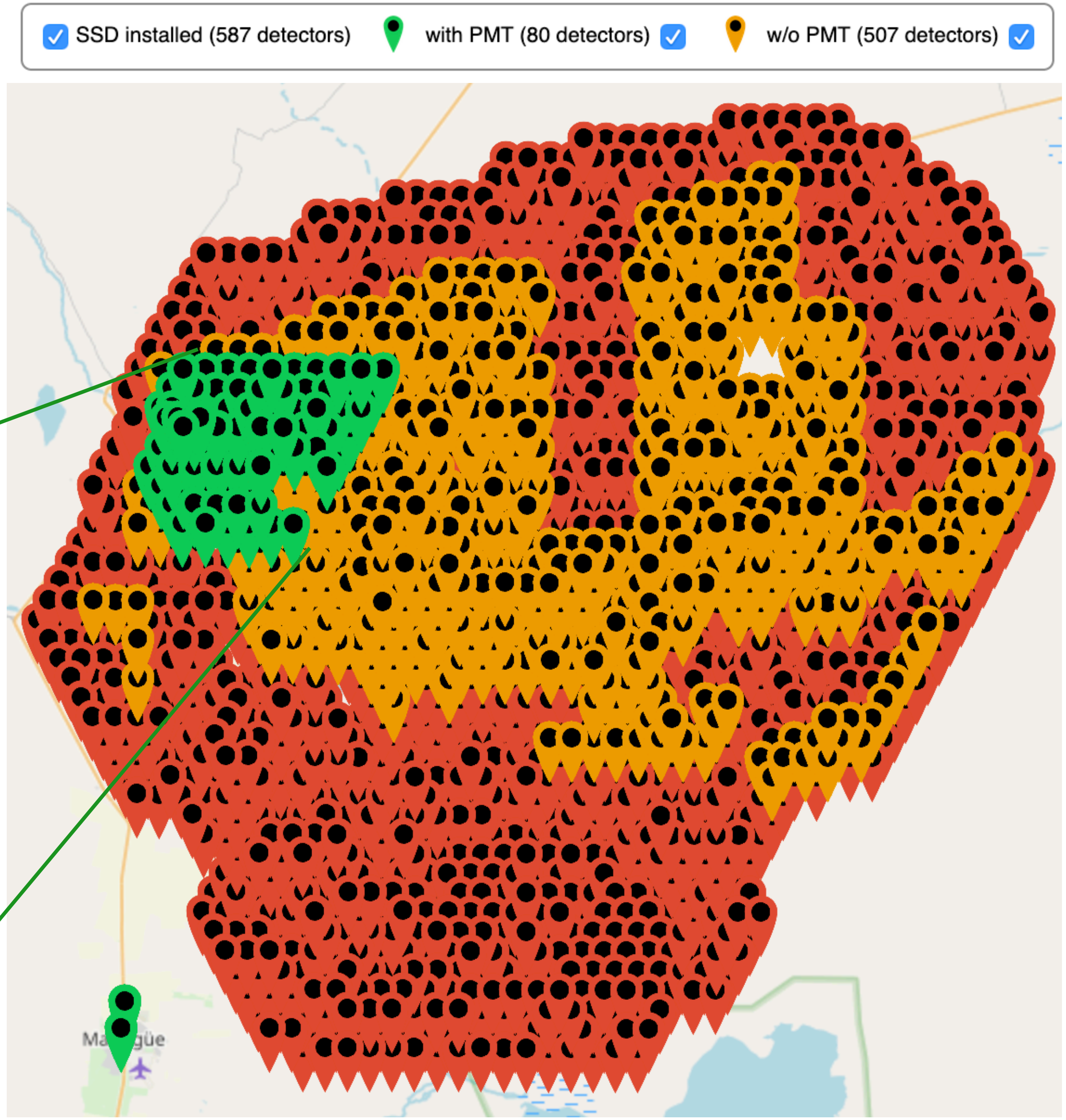
p-like events

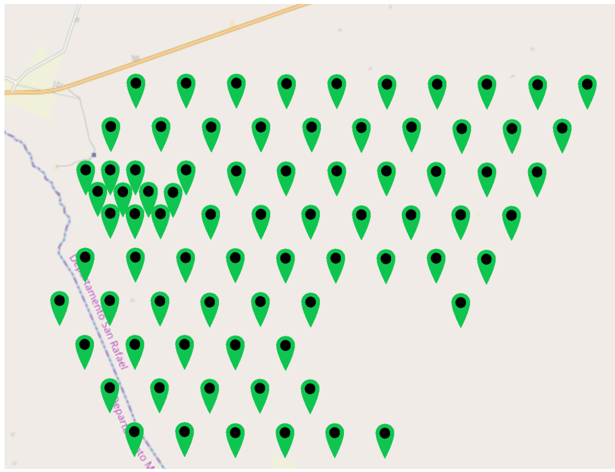
Correlation at 3σ is visible for the proton enriched sample

Deployment

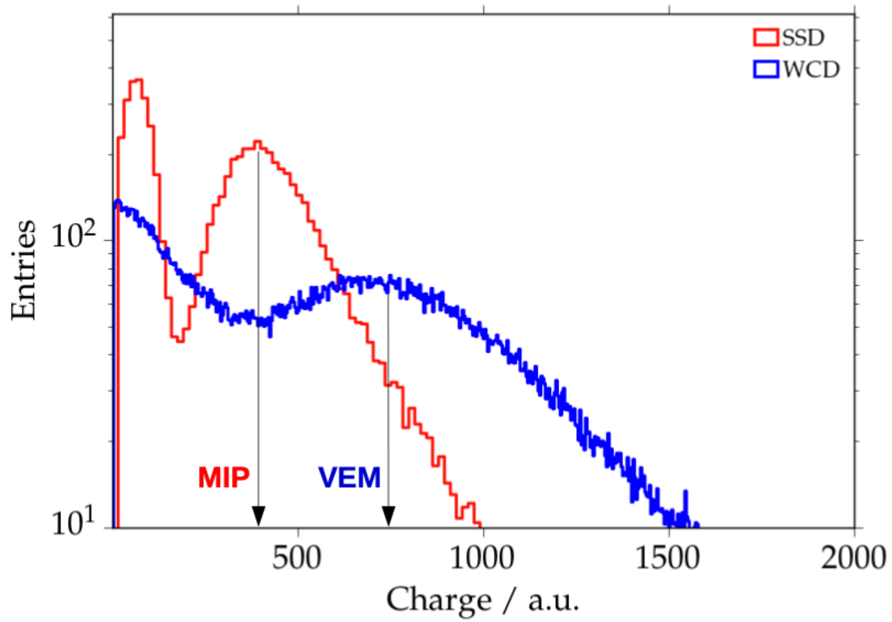
- ***587 SSD deployed in the field w/o PMT (08.11.2019)***

- ***pre-production array of 77 SSD with PMT exploiting the old UB***
  - total area 120 km^2
  - it allows us to test of performances of the SSD



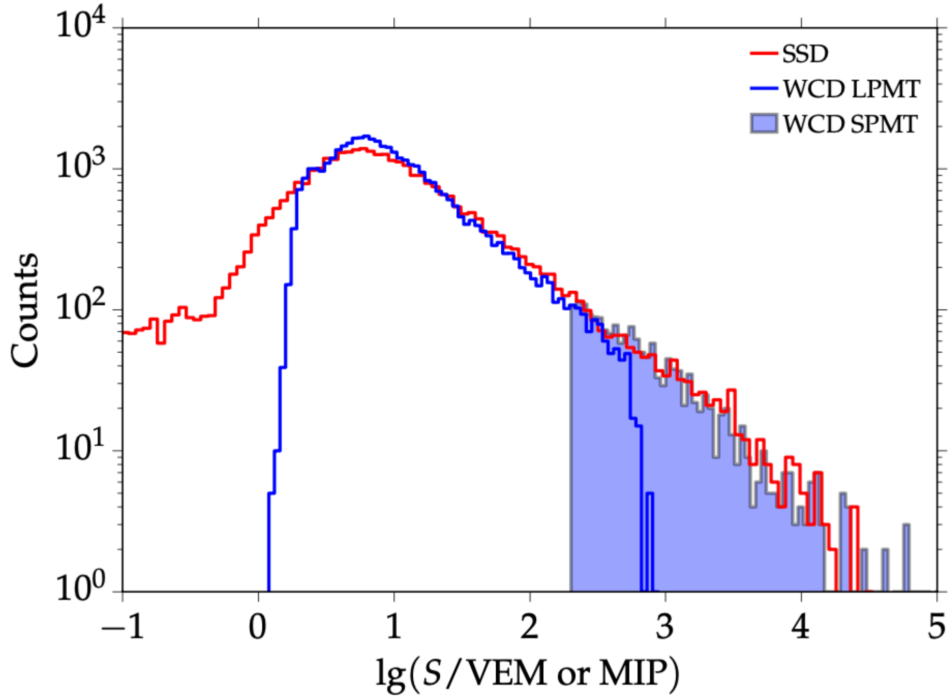


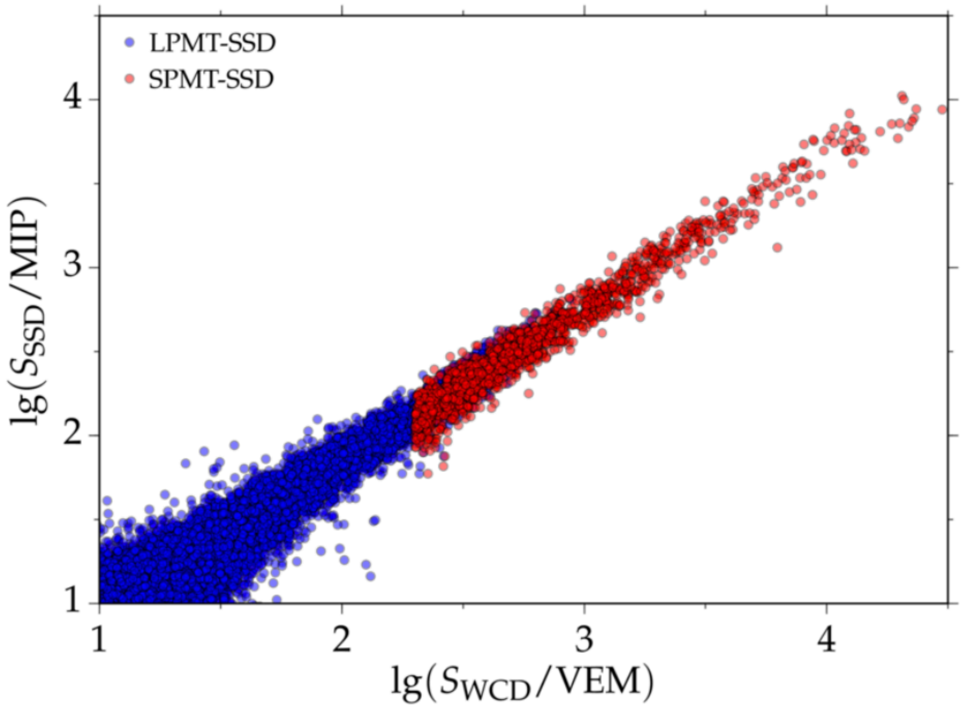
Pre-production array data



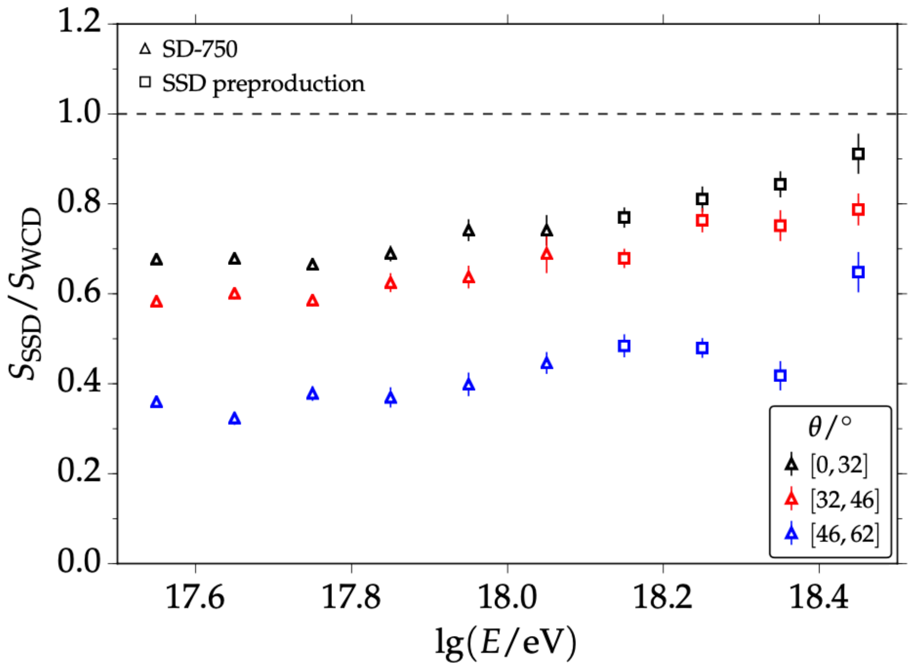
Calibration

- VEM$_{WCD}$: from calibration with atm.muons, ~95 PE/VEM
- VEM$_{SPMT}$: selection of small showers to cross-calibrate with calibrated LPMT signal
- MIP: single of MIP crossing the detector. ~40% of calib trigger of the WCD produce a MIP in the SSD



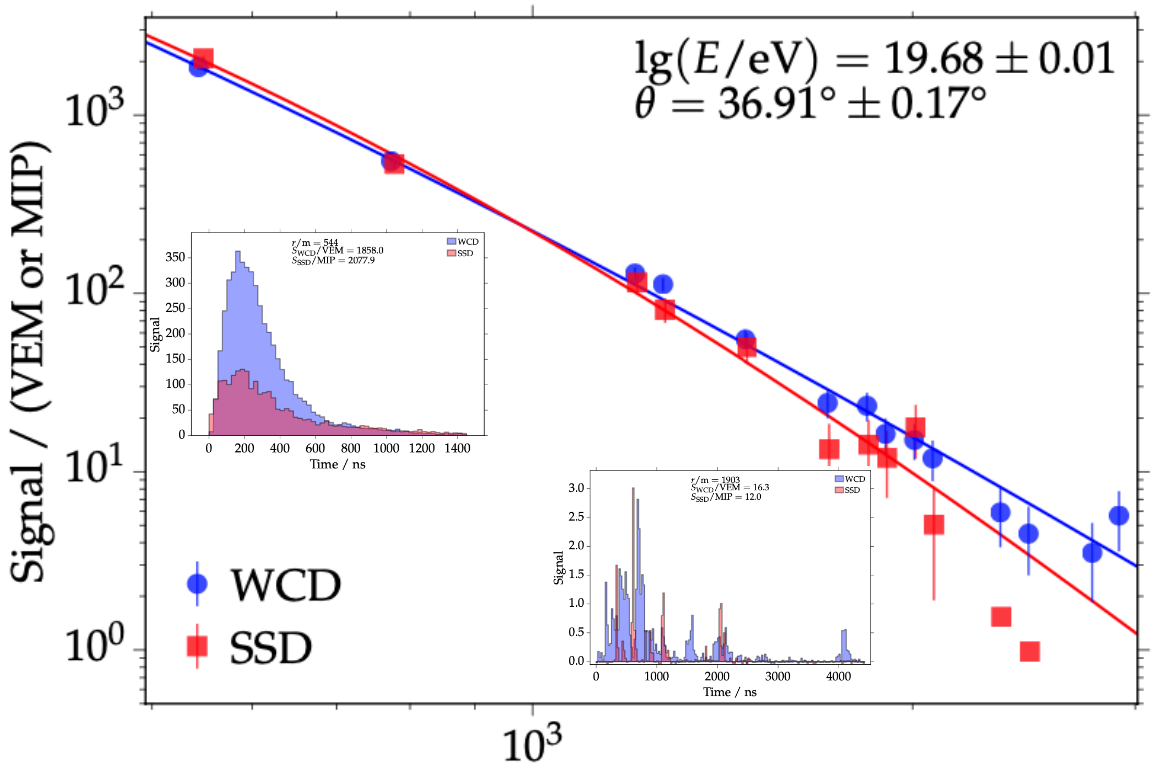


Pre-production array data

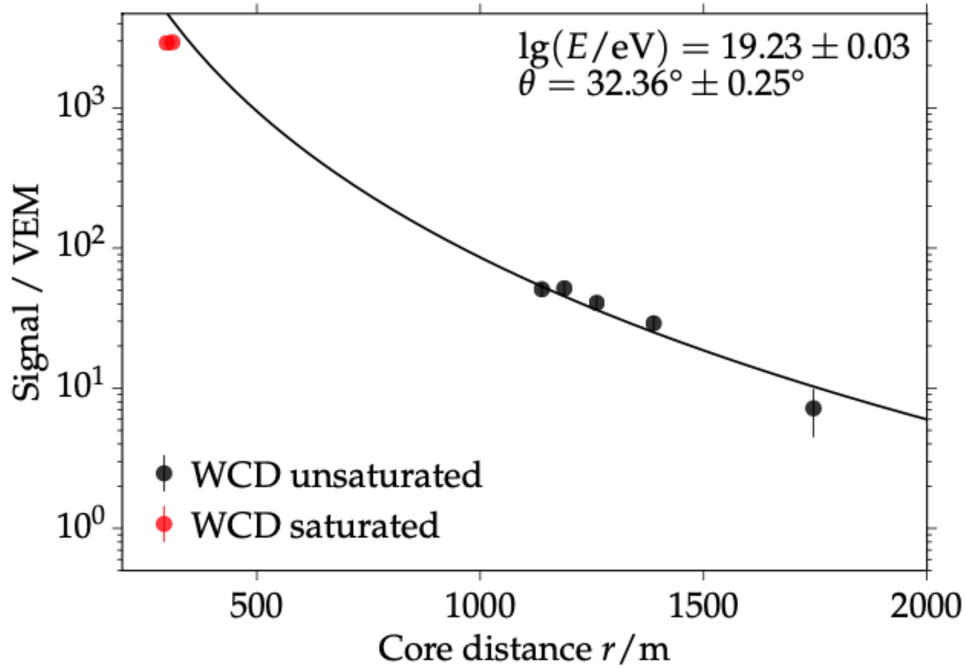


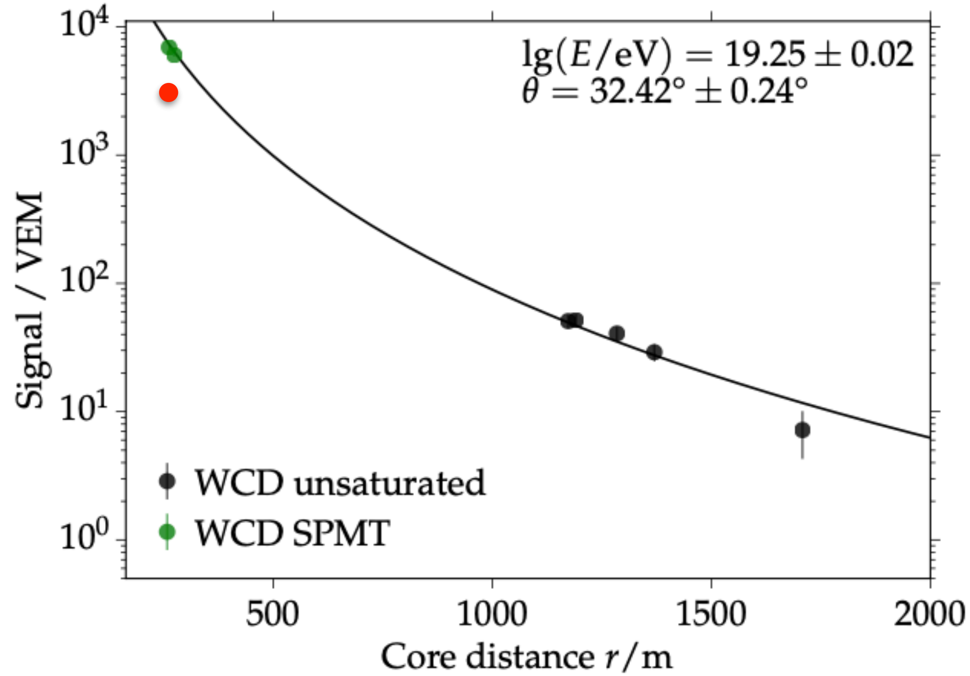
SSD signal becomes more dominant with increasing energy as EM component grows faster than muons.

- Geometry and energy of the shower estimated from WCD LDF.
- This information is used for the fit of the SSD LDF.
- Different time distributions in SSD and WCD traces.



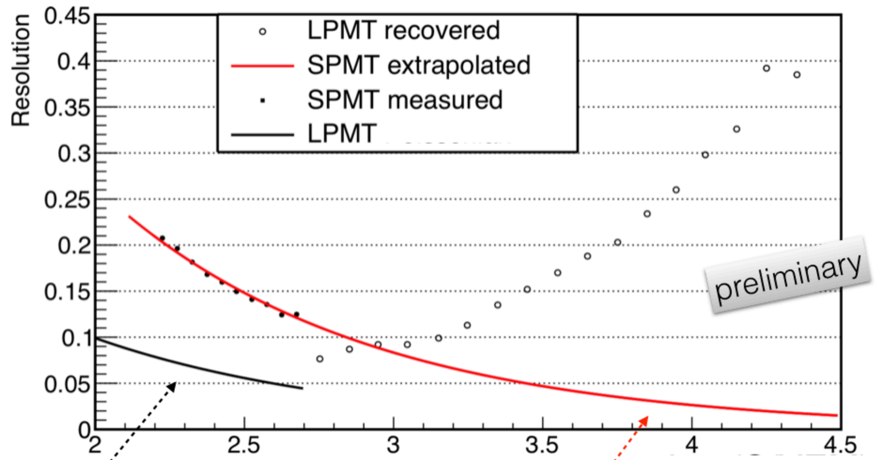
Pre-production array data





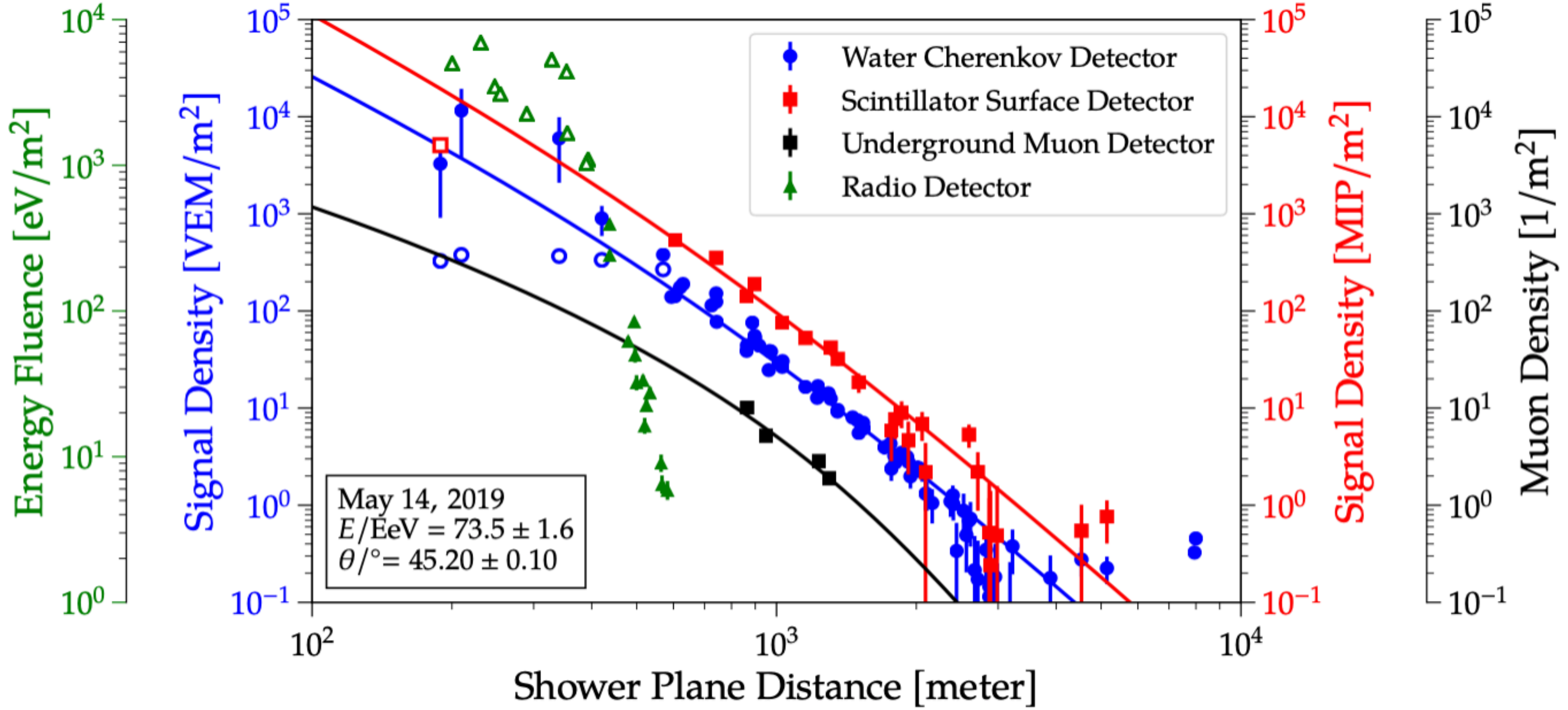
The SPMT allows us to extend the unsaturated measure of the signal very close to the core

Large improvement in reconstruction resolution



$$\sigma(S_{VEM}) = (0.99 \pm 0.02) \times \sqrt{S_{VEM}}$$

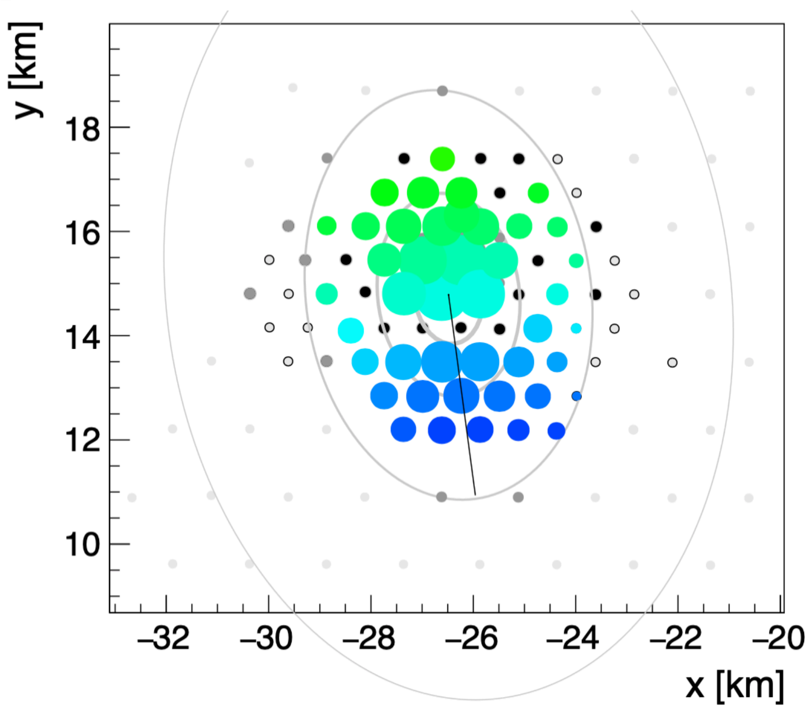
$$\sigma(S_{VEM}) = (2.63 \pm 0.02) \times \sqrt{S_{VEM}}$$



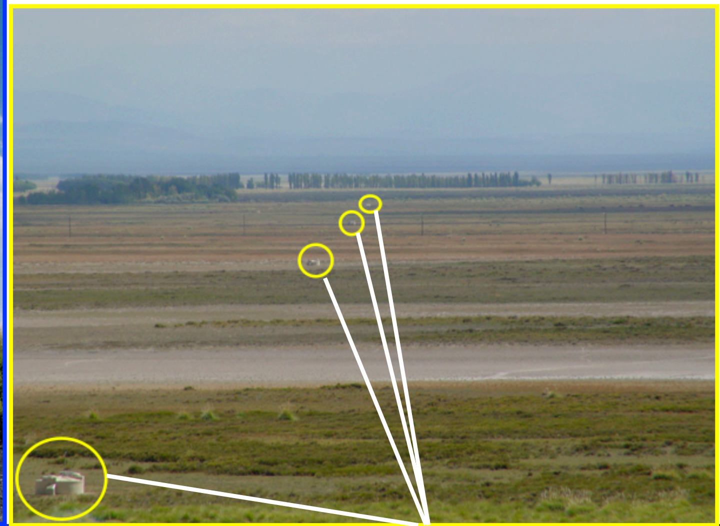
The highest energy event so far from the pre-production array

E = 73.5 EeV

$\vartheta = 45^0$



Going for the tour….




OBSERVATORIO
PIERRE AUGER
Buses waiting for us at the
main building, hurry up !