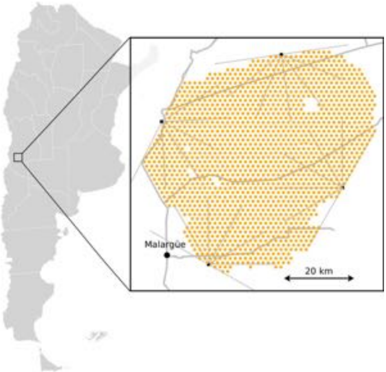
AugerPrime
The Upgrade of the Pierre Auger Observatory

X. Bertou
for the Pierre Auger Collaboration

CNEA/CONICET
Centro Atómico Bariloche

TAUP 2015

The Pierre Auger Observatory



- In Malargüe (Argentina) 69.3^{o} W, 35.3^{o} S
- 1400 m a.s.l. ($870\,\mathrm{g\,cm^{-2}}$)

- UHECR study ($E \geq 10^{18}$ eV)
- Data taking 2004 -
- Construction over in 2008

UHECR hybrid detection

- Ground detectors (SD): 1660 Water Cherenkov Detectors covering $3000\,\mathrm{km}^2$ on a 1500 m triangular grid (+ infill dense region and buried muon detectors)
- Fluorescence detectors (FD): 27 fluorescence telescopes in 4 sites observing over the SD area

The Pierre Auger Observatory
Top results
2004-2015

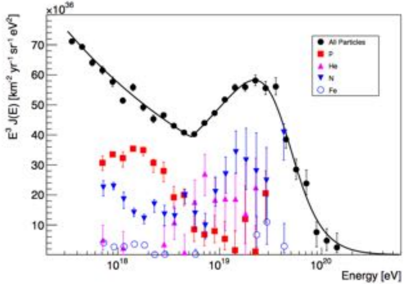
Bottom-Up acceleration of UHECR

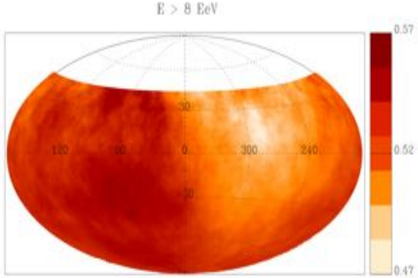
- Auger discarded top-down mechanisms as UHECR main producers
  - Photon limits
    - *Astropart. Phys. 29 (2008) 243-256 - arXiv:0712.1147*
  - Neutrino limits
    - *Physical Review D 91, 092008 (2015) - arXiv:1504.05397*
  - Heavy composition
    - *Physical Review D D 90, 122006 (2014) - arXiv:1409.5083*

→ Search for the astrophysical sources of UHECR

Spectrum, composition and anisotropies

- Flux suppression at the highest energies
- Mixed composition *(see M. Settimo's talk, tomorrow)*
- No strong small scale anisotropy
- Significant large scale dipole above 8 EeV





Remaining questions

- Flux suppression: GZK or end of acceleration power?
- Source identification and acceleration mechanisms
- Are there protons at UHE (CR astronomy)?
- High energy interaction models, muon deficit

▷ Need composition measurements at UHE

▷ Need complementary techniques for composition measurements

▷ Need composition measurements event by event

→ Towards a global picture of HECR and UHECR

The Upgrade of the Pierre Auger Observatory 2016-2025

FD exposure increase

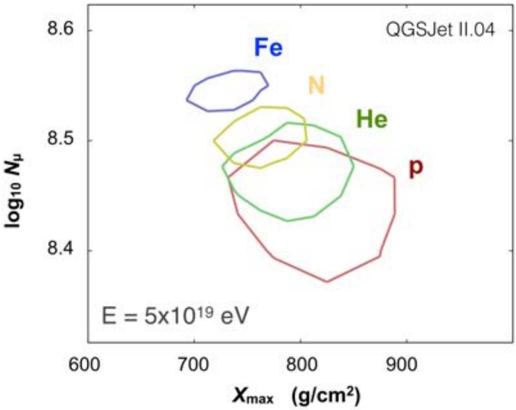
- Operation with moon fraction below 90%
  (instead of 70% and 3 moonless hour current limit)
- Lowering PMT gain by a factor of 10
  $G = 5 \times 10^4 \rightarrow 5 \times 10^3$

$\rightarrow$ Duty cycle goes from 19% to 29%

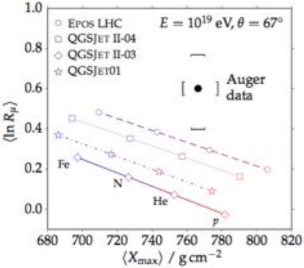
- Ageing tests ongoing
- No systematic on energy and X_{max} determination
  (below 2% and $5\,g/cm^2$)

$\rightarrow$ At UHE, energy and X_{max} resolution worse by only 3% and $5\,g/cm^2$ to below 10% and $20\,g/cm^2$, 50% increase of hybrid events rate

Muons as composition indicators



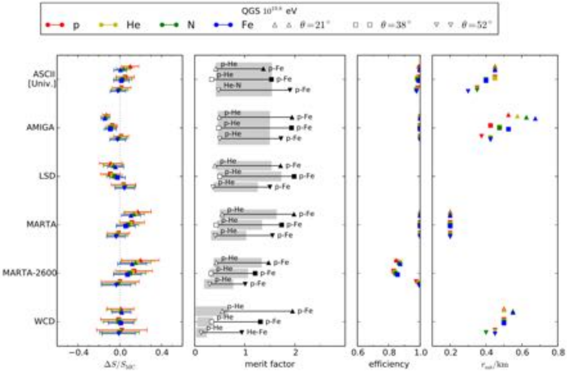
- Muon number scales linearly with energy
- No model predicts current muon measurements



▷ Measure muon component for composition

Five detector options studied for the upgrade

- AMIGA Grande
  buried scintillator
- ASCII
  scintillator on top WCD
- LSD
  double layer WCD
- MARTA
  RPC under WCD
- TOSCA
  scintillator under WCD

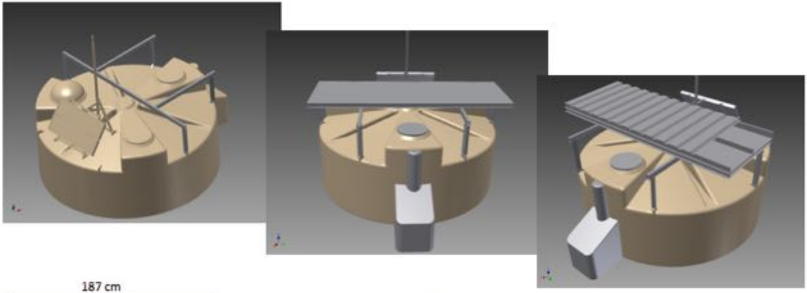


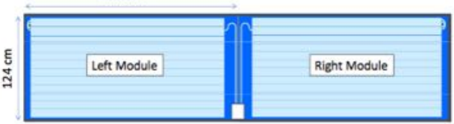
Decision taken in November 2014 after 2 years of comparative studies

Upgrade detector design: the Scintillator Surface Detector (SSD)

- ASCII based design: scintillator on top of the WCD
- size of $\approx 4\,\mathrm{m}^2 \rightarrow S_{SSD}(MIP) \approx S_{WCD}(VEM)$
- scintillator bars with holes, light collection with WLS fibre
- only one readout PMT, with large dynamic range (Hamamatsu R9420), external HV supply (CAEN)
- simple fixed support on top of the WCD
- double roof for thermal control
- no significant extra power needed, behaves as a normal WCD PMT (control voltage, signals...) $\rightarrow$ straightforward integration

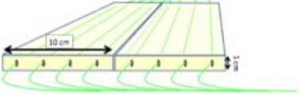
SSD design





Two modules in one box per station, readout by one PMT, area ~4 m²

Read-out of scintillators with WLS fibers

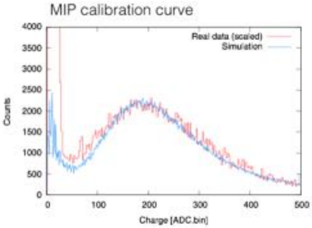


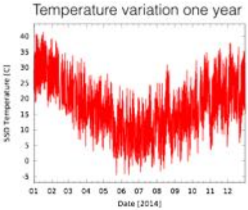
Prototype detectors

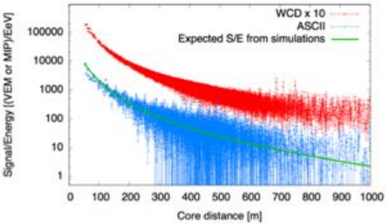
7 detector planes ($2\,m^2$) in operation since April 2014 (5+1 double)

Prototype data

- Clear MIP (WCD triggered)
- Controlled temperature (double roof)
- First signals observed compatibles with expectation
- Now used for testing (SiPM)







Rescaled lateral distribution

Electronics upgrade

- Auger electronics based on a 15 years old design
- New channels needed for SSD
- Upgraded board with more processing power (especially for triggers, more memory against data losses)
- Higher speed FADC sampling (120 MHz from 40 MHz), for SSD and for peak detection in muon counting techniques
- Better timing from upgraded GPS
- New small PMT to increase the WCD dynamic range
- Can be swapped in place with old design (same power, communications, hardware interfaces...)

Data analysis upgrade

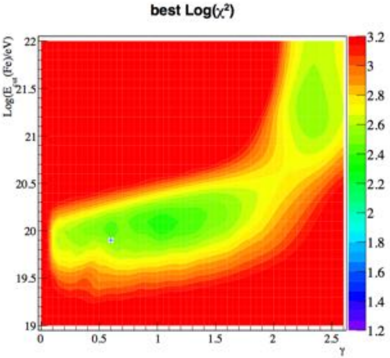
- Multi-component EAS description (Universality)
- Detector expected signals (amplitude and time structure) obtained as model independent functions of EAS macro-parameters: X_{max}, N_{μ}, X^{μ}_{max}, geometry, Energy...
- Model dependence is in the relationship among macro-parameters and between macro-parameters and composition

→ Very well suited for multi detector analysis (no extra parameters)

→ Model and composition constraints arise from multiple detector hybrid events

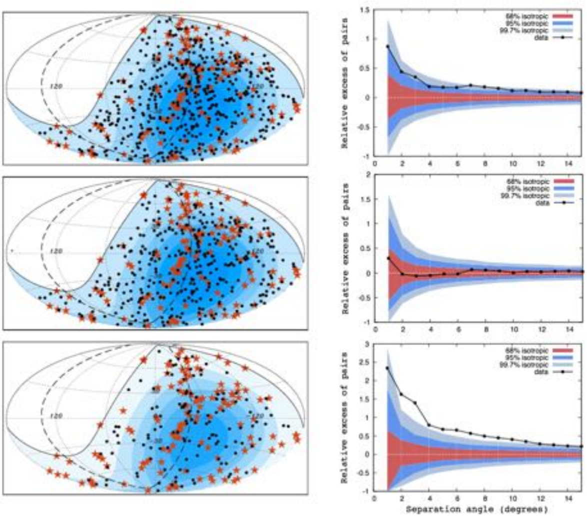
→ First analysis with WCD+FD promising, need SSD to fix the energy scale and calibrate at UHE

Science impact of upgrade (statistics)



Example of likelihood contour maps for fitting spectrum and composition, propagating an extragalactic component, without SSD (left), and adding SSD (right)

Science impact of upgrade (event by event)



all 454 events

proton depleted data set (326)

proton enhanced data set (128)

Conclusions and prospects

- Auger solved the post-AGASA dilemma of top-down vs bottom-up
- To get a complete picture, large statistics of event by event composition is needed at UHE

→ Auger will address the main questions:
  - Nature of the UHE flux suppression
  - Presence or not of a proton flux at UHE
  - Study of EAS physics and fundamental particle physics at UHE

  with a \$15M upgrade based on adding a $\approx 4\,\mathrm{m}^2$ scintillator detector on top of each WCD

- PDR ready since April 2015
- EA planned for March 2016
- Data taking 2018-2024 ($40\,000\,\mathrm{km}^2\,\mathrm{sr}\,\mathrm{yr}$)