

# AugerPrime

## The Upgrade of the Pierre Auger Observatory



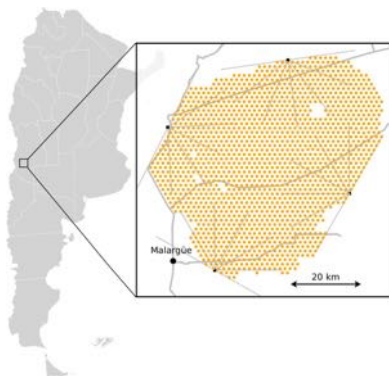
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for the Pierre Auger Collaboration

CNEA/CONICET  
Centro Atómico Bariloche

TAUP 2015



# The Pierre Auger Observatory



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

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

## UHECR hybrid detection

- Ground detectors (SD): 1660 Water Cherenkov Detectors covering  $3000 \text{ km}^2$  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

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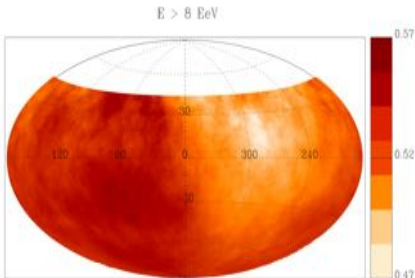
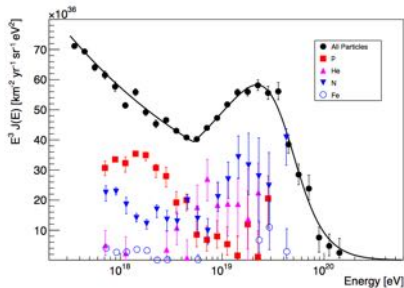
- Auger discarded top-down mechanisms as UHECR main producers
  - Photon limits
    - ▷ *Astropart. Phys.* 29 (2008) 243-256 - *arXiv:0712.1147*
  - Neutrino limits
    - ▷ *Physical Review D* 91, 092008 (2015) - *arXiv:1504.05397*
  - Heavy composition
    - ▷ *Physical Review D* 90, 122006 (2014) -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

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- 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
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- ▷ Need composition measurements at UHE
  - ▷ Need complementary techniques for composition measurements
  - ▷ Need composition measurements event by event
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- Towards a global picture of HECR and UHECR

# The Upgrade of the Pierre Auger Observatory 2016-2025

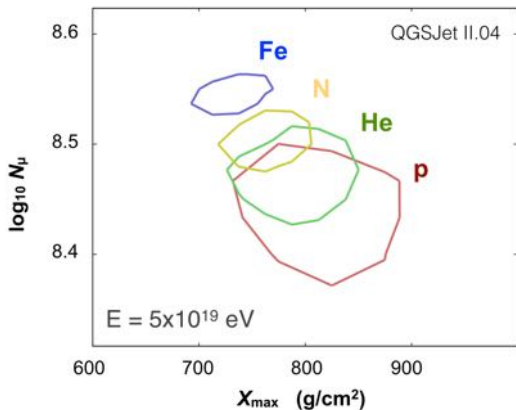
## FD exposure increase

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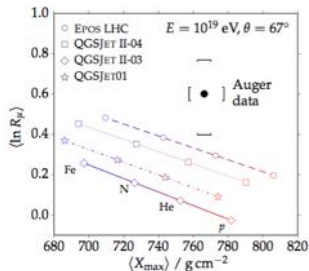
- Operation with moon fraction below 90%  
(instead of 70% and 3 moonless hour current limit)
  - Lowering PMT gain by a factor of 10  
 $G = 5 \times 10^4 \rightarrow 5 \times 10^3$
- Duty cycle goes from 19% to 29%
- Ageing tests ongoing
  - No systematic on energy and  $X_{max}$  determination  
(below 2% and 5 g/cm<sup>2</sup>)
- At UHE, energy and  $X_{max}$  resolution worse by only 3% and 5 g/cm<sup>2</sup> to below 10% and 20 g/cm<sup>2</sup>, 50% increase of hybrid events rate



# Muons as composition indicators



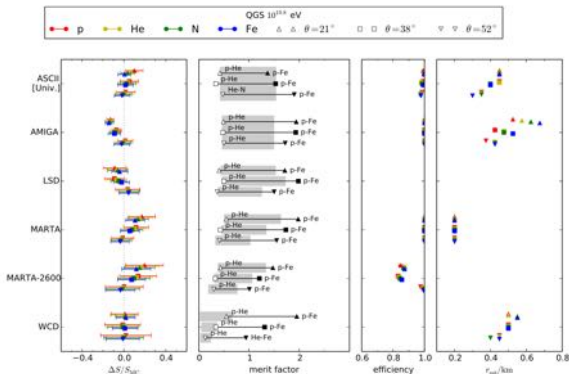
- Muon number scales linearly with energy
- No model predicts current muon measurements



▷ 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*
- MARTA-2600
- WCD
- TOSCA  
*scintillator under WCD*



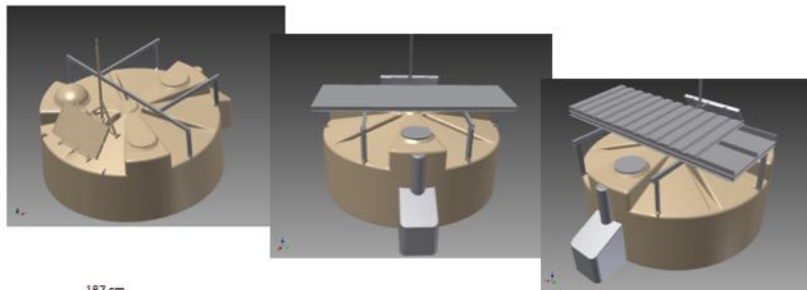
Decision taken in November 2014 after 2 years of comparative studies

## Upgrade detector design: the Scintillator Surface Detector (SSD)

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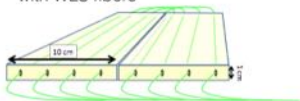
- ASCII based design: scintillator on top of the WCD
- size of  $\approx 4 \text{ m}^2 \rightarrow S_{SSD}(MIP) \approx S_{WCD}(VEM)$
- scintillator bars with holes, light collection with WLS fibre
- only one readout PMT, with large dynamic range (Hamamatsu R9420), external HV supply (CAEN)
- simple 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  $\sim 4 \text{ m}^2$

Read-out of scintillators  
with WLS fibers



## Prototype detectors

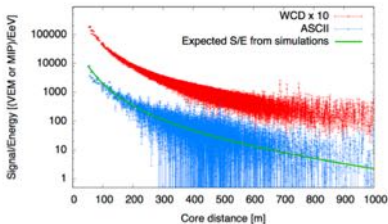
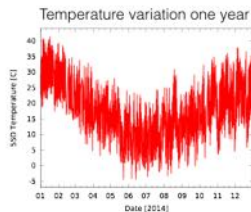
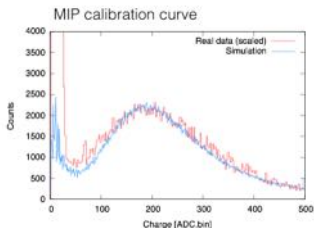
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7 detector planes ( $2\text{ m}^2$ ) in operation since April 2014 (5+1 double)

# 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

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- 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

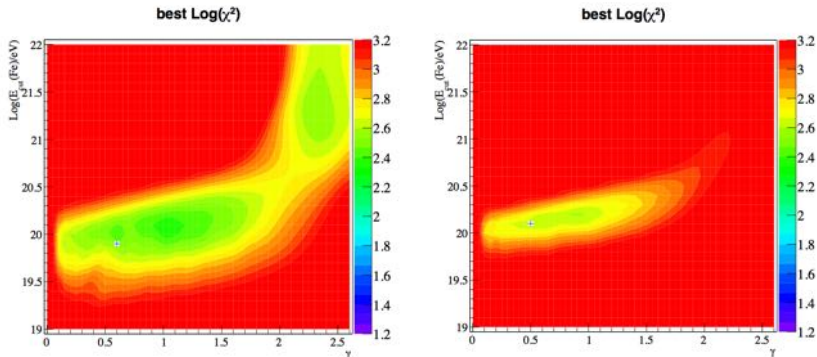
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- Multi-component EAS description (Universality)
  - Detector expected signals (amplitude and time structure) obtained as model independent functions of EAS macro-parameters:  
 $X_{max}$ ,  $N_{\mu}$ ,  $X_{max}^{\mu}$ , geometry, Energy...
  - Model 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



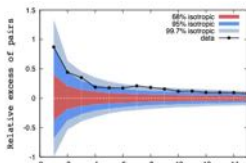
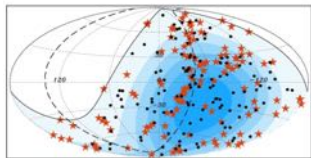
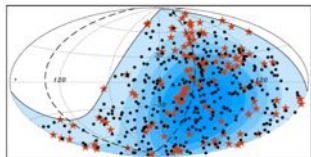
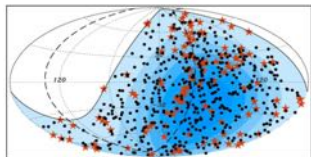


## Science impact of upgrade (statistics)

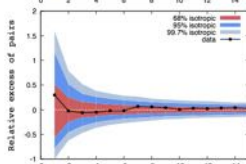


Example of likelihood contour maps for fitting spectrum and composition, propagating an extragalactic component, without SSD (left), and adding SSD (right)

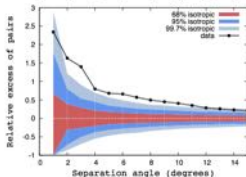
# Science impact of upgrade (event by event)



*all 454 events*



*proton depleted  
data set (326)*



*proton enhanced  
data set (128)*

## Conclusions and prospects

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- 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  $\approx 4 \text{ m}^2$  scintillator detector on top of each WCD
- PDR ready since April 2015
  - EA planned for March 2016
  - Data taking 2018-2024 (40 000  $\text{km}^2 \text{ sr yr}$ )

