Hybrid Detection of UHECR with the Pierre Auger Observatory

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Outline



Motivation

- The UHECR puzzle
- Previous Work
- 2 The Hybrid detection concept
 - The Pierre Auger Observatory
 - The Hybrid Features
- Our Results/Contribution
 - Main Results
 - Ideas for Implementation

The UHECR puzzle Previous Work Open questions

The Origin of Cosmic Rays



 10⁹ eV: galactic, strong solar modulation

- 10⁹ eV to 10¹⁵ eV: galactic, probably from SNR
- 10¹⁵ eV to 10¹⁹ eV some hints of:
 - galactic anisotropy at 10¹⁸ eV
 - composition from heavy to light

• Above 10¹⁹ eV: UHECR

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terra incognita



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The UHECR puzzle

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The puzzle of Ultra High Energy Cosmic Rays



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An Extensive Air Shower



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The UHECR puzzle Previous Work Open questions

The Highest Energy Cosmic Rays



UHECRs: a reality!

Over the last 40 years \sim 20 events above $\sim 10^{20}~\text{eV}$

- 1991 Fly's eye detector in Utah $3.2 \times 10^{20} \text{ eV}$
- 1993 AGASA detector in Japan 2×10^{20} eV

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 2003 AGASA has 11 events above 10²⁰ eV



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Some Open Questions

Theory

- Origin of CRs
- Shock acceleration or decay?
- Local or cosmologically distributed?

Experiment

- Spectrum shape
- Up to what energy?

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- Composition
- Anisotropies

UHECRs

- A challenge because of very small fluxes
- Carry more info about origin than lower energy CRs

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The Pierre Auger Observatory Description of a Hybrid Event The Hybrid Features Status of the Southern Observatory

The Pierre Auger Observatory The Southern Site





The Pierre Auger Observatory Description of a Hybrid Event The Hybrid Features Status of the Southern Observatory

Description of the Observatory Layout





The Pierre Auger Observatory Description of a Hybrid Event The Hybrid Features Status of the Southern Observator

definition

Hybrid Event: Simultaneous detection in the sky and at ground

Golden Events: independent triggers

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definition

Hybrid Event: Simultaneous detection in the sky and at ground

Golden Events: independent triggers

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Golden Events: independent triggers

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Sub-Threshold Events: FD-promoted trigger

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Main Features

hybrid capability

Combine longitudinal and lateral measurements



More accurate geometry

- Independent measurements
- Reach to lower energies



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Motivation The Hybrid detection concept Our Results/Contribution The Hybrid Features

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Hybrid Event-Rate

From turn-on to present



2002 - 2004

Engineering Array test events



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2002 - 2004

Engineering Array test events



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The Pierre Auger Observatory Description of a Hybrid Event The Hybrid Features Status of the Southern Observatory

Hybrid Event-Rate

From turn-on to present



2002 - 2004

Engineering Array test events


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From turn-on to present



Beginning 2004

First production hybrids! \sim 20 events

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From turn-on to present



Mid 2004

First STEREO events! \sim 1500 events

UNIVERSITY

(신문) 신문 (문) 문) 문

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UNIVERSITY

Miguel

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End 2004

First STEREO hybrids! \sim 5500 events



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UNIVERSITY

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From turn-on to present



March 2005

Waiting for TRIPLE-Stereo... $\sim \! 10000 \text{ events}$

(신문) 신문 (문) 문) 문

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End 2005

First Tri-ocular event! \sim 30000 events



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End 2005

First Tri-ocular event! ~30000 events



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Miguel Hybrid detection in Auger

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May 2006

Taking data right now \sim 40000 events

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Main Results Ideas for Implementation

Hybrid Products



ICRC 2005 Paper :

Angular resolution of the Pierre Auger Observatory



Main Results Ideas for Implementation

Hybrid Products

 Angular resolution Improved geometry Anisotropy studies eg., point sources • γ fraction New methods • FD-SD synchronization ICRC 2005 Paper & Journal paper coming soon!: Anisotropy studies around the galactic centre at EeV energies with Auger data



Main Results Ideas for Implementation

Hybrid Products



Main Results Ideas for Implementation

Hybrid Products

 $\begin{array}{c} \text{Improved geometry} \\ \downarrow \\ \\ \text{High quality events} \\ \downarrow \\ \\ \text{Combined measurements} \end{array} \stackrel{\circ}{\Rightarrow} \begin{array}{c} \text{Angular resolution} \\ \text{Anisotropy studies} \\ eg., point sources \\ \\ \text{o} \gamma \text{ fraction} \\ \text{o} \text{ New methods} \\ eg., Cherenkov subtraction} \\ \\ \text{o} \text{ Energy conversion} \\ \\ \text{o} \text{ FD-SD synchronization} \end{array}$

ICRC 2005 Paper :

Impact of a new Cherenkov light parameterisation on the reconstruction of shower profiles from Auger hybrid data



Main Results Ideas for Implementation

Hybrid Products

 Angular resolution Improved geometry Anisotropy studies eg., point sources ∜ • γ fraction High quality events New methods eq., Cherenkov subtraction ∜ Energy conversion Combined measurements ICRC 2005 Paper : First estimate of the primary cosmic ray energy spectrum above 3 EeV from the Pierre Auger Observatory

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Main Results Ideas for Implementation

Hybrid Products

 Angular resolution Improved geometry Anisotropy studies eg., point sources ∜ • γ fraction High quality events New methods eq., Cherenkov subtraction ∜ Energy conversion Combined measurements FD-SD synchronization ICRC 2005 Paper :

Timing calibration and synchronization of surface and fluorescence detectors of the Pierre Auger Observatory



Main Results Ideas for Implementation

Hybrid Ideas



Anisotropy studies eg., point sources

 Ground parameters from data Lateral Distribution Function Extended Energy conversion

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Combined measurements

eg., composition

Main Results Ideas for Implementation

Hybrid Ideas



Main Results Ideas for Implementation

Hybrid Ideas



Main Results Ideas for Implementation

Hybrid Ideas



Summary

Conclusions

- Greater angular accuracy
- Extended energy range
- The combination of SD and FD measurements gives rich possibilities

Outlook

- Finish construction in Malargüe + upgrades
- Get Auger North started in 2008



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For Further Reading I



🍉 M. Mostafá

The Hybrid Performance of the Pierre Auger Observatory Proceedings of the 29th ICRC, 2005

- The Pierre Auger Collaboration Anisotropy studies around the Galactic Center at EeV energies with the Auger Observatory Journal to be submited soon, 2006
- The Pierre Auger Collaboration

An upper limit to the fraction of photons in primary cosmic rays above 10¹⁹ eV as determined using the Pierre Auger Observatory

Journal to be submited soon. 2006

