Measurement of the UHECR energy spectrum from hybrid data of the Pierre Auger Observatory

The Pierre Auger Collaboration

Presenter: Lorenzo Perrone

Università del Salento and INFN Lecce – Italy
- The Pierre Auger Observatory and the hybrid concept

“In order to make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side.”

V.H.Hess, Nobel Lecture, December 1936
Outline

- The Pierre Auger Observatory and the hybrid concept

“In order to make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side.”

_V.H.Hess, Nobel Lecture, December 1936_

- Hybrid trigger efficiency and time dependent simulation
Outline

- The Pierre Auger Observatory and the hybrid concept

“In order to make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side.”

_V.H.Hess, Nobel Lecture, December 1936_

- Hybrid trigger efficiency and time dependent simulation

- Data selection, uptime and exposure
Outline

- The Pierre Auger Observatory and the hybrid concept

“In order to make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side.”

V.H.Hess, Nobel Lecture, December 1936

- Hybrid trigger efficiency and time dependent simulation

- Data selection, uptime and exposure

- Energy spectrum from hybrid data
Outline

- The Pierre Auger Observatory and the hybrid concept

“In order to make further progress, particularly in the field of cosmic rays, it will be necessary to apply all our resources and apparatus simultaneously and side-by-side.”

V.H.Hess, Nobel Lecture, December 1936

- Hybrid trigger efficiency and time dependent simulation

- Data selection, uptime and exposure

- Energy spectrum from hybrid data

- Systematic uncertainties
The Hybrid Concept

*The Auger Observatory combines independent measurement techniques*

**Surface Detector Array (SD)**

**Air Fluorescence Detectors (FD)**

- reliable geometry and energy measurement
- mass composition studies in a complementary way

*Hybrid data set used for this analysis:*

fluorescence events in coincidence with at least one SD station

Event id: 2276329
Hybrid reconstruction

\[ t_i - t_0 = \frac{R_p}{c} \tan \left( \frac{\pi - \chi_0 - \chi_i}{2} \right) \]

- Azimuth (deg)
  - 60
  - 70
  - 80
  - 90
  - 100
  - 110
  - 120
  - 130
  - 140
  - 150

- Elevation (deg)
  - 0
  - 5
  - 10
  - 15
  - 20
  - 25
  - 30

- Angle (deg) \( \chi \)
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5

- Time (100 ns)
  - 200
  - 300
  - 400
  - 500
  - 600
  - 700
  - 800

- Slant depth (g cm\(^{-2}\))
  - 400
  - 600
  - 800
  - 1000
  - 1200
  - 1400

- \( \frac{dE}{dX} \) (PeV/g cm\(^{-2}\))
  - 0
  - 5
  - 10
  - 15
  - 20
  - 25
  - 30
  - 35
  - 40
Hybrid Trigger Efficiency

**CORSIKA showers**

FD and SD response fully and simultaneously simulated

\( E > 10^{18} \text{ eV}: \)
- Full efficiency
- No dependence on mass composition
Hybrid Exposure: strategy and simulation flow

- Complete and **time dependent** simulation of FD response

- Simulation of SD timing with a realistic and **time dependent** array layout

For each active tank within a given radius, the single tank trigger probability is calculated as a function of core distance to shower axis based on parametrised functions [Lateral Trigger Probability Functions(*)]

The study with full (and simultaneous) simulations of FD and SD detector response with Corsika Showers has validated the used parameterisation for $E > 10^{18}$ eV

(*) D. Allard for the The Pierre Auger Coll. ICRC 2005 (Pune), India
Simulation compared to data

Time dependent simulation agrees fairly good with data
(tightest selection level)
Data selection

**Geometry quality cuts**
- zenith angle $< 60^\circ$
- core distance to tank $< 750$ m
- shower long. profile within the geometrical f.o.v [1]
- core distance to FD telescope within a given fiducial volume [2]
- measurement of atmospheric parameters available

**Profile quality cuts**
- $X_{\text{max}}$ observed
- energy reconstruction uncertainties $< 20\%$
- relative amount of Cherenkov light $< 50\%$
- a successful Gaisser-Hillas fit $\chi^2/\text{n dof} < 2.5$

[1] M. Unger for the The Pierre Auger Collaboration, at this Conference
Hybrid Exposure: Uptime

- **DAQ** – Data acquisition on/off
- **SLC** – Slow control (shutters status)
- Lidar activity veto
- High rate veto

**LL**: Los Leones
**LM**: Los Morados
**LA**: Loma Amarilla
**CO**: Coihueco

*Hybrid detector uptime after different sources of detector inefficiency*
Hybrid Exposure at the tightest selection level
Only statistical uncertainties given
Hybrid vs SD Spectrum

Good agreement found within the systematic uncertainties
Hybrid Spectrum (II)

Good agreement among individual measurements by different eyes
Systematics uncertainties

Overall and individual uncertainties (added in quadrature)

- **Uptime (τ)** 4% from a cross-check with CLF lasers
- **Atmospheric conditions (atm.)** 16% due to cloud coverage
- **Event Selection (sel.)** 15% \((E=10^{18} \text{ eV})\)

**SD uncorrelated uncertainties**

- **SD correlated uncertainty** 22% uncertainty on the energy scale (*)

(*B. Dawson for the The Pierre Auger Collaboration, at this Conference*)
Conclusions

- A measurement of the UHECR energy spectrum from hybrid data of the Pierre Auger Observatory presented \((E > 10^{18} \text{ eV})\). Data sample extend over a time of more than two years in which FD and SD have grown significantly.

- A realistic and time dependent simulation performed in order to evaluate in detail the exposure of the hybrid detector.

- Good agreement with the SD spectrum found within the expected systematic uncertainties.