Towards the all-particle energy spectrum of cosmic rays measured with LORA — an air shower array for LOFAR

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http://particle.astro.ru.nl
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The 456 scintillators cover a description of the system can be found in CORSIKA/CRES simulations.

Streamer tube pads, corrected for non-muon hits according to tracked by the MWPC, filled symbols represent hits in the reconstruction of arrival time distributions.

4.3. Trigger layer

Investigation.

The largest muon numbers are currently under detection. The discrepancies at high densities for 0-3\,\text{MeV} and efficiently shields the scintillators against

4.3. Trigger layer

The layer of scintillation detectors in the third gap is used for fast trigger purposes and for effective shielding.
LOFAR Radboud Air Shower Array
Measured signals in single detector

ADC trace

energy deposition in single detector

read-out window 10 µs
start 2 µs before trigger
12-bit ADC (2.5 ns sampling rate)

fit of Landau distribution to data calibration: „single-muon“ peak
A measured air shower

arrival time

energy depositions

reconstruct for each shower:
• position & direction of shower axis
• lateral distribution
• number of (charged) particles
• energy estimator
Fit of NKG function to data

\[ \rho(r, s, N_e) = \frac{N_e}{r^2_M} \frac{\Gamma(4.5 - s)}{2\pi \Gamma(s) \Gamma(4.5 - 2s)} \times \left( \frac{r}{r_M} \right)^{s-2} \left( 1 + \frac{r}{r_M} \right)^{s-4.5} \]

single air shower
Reconstruction accuracies (from data) using chess-board method (1/2 array vs. 1/2 array)

position of shower axis

< 5 m
Reconstruction accuracies (from data) using chess-board method (1/2 array vs. 1/2 array)

- Position of shower axis: $< 5 \text{ m}$
- Direction of shower axis: $< 0.75^\circ$
Reconstruction accuracies (from data) using chess-board method (1/2 array vs. 1/2 array)

position of shower axis

- < 5 m

direction of shower axis

- < 0.75°

number of (charged) particles

- < 25%
Average lateral distributions

\[ \rho(r, s, N_e) = \frac{N_e}{r_M^2} \frac{\Gamma(4.5 - s)}{2\pi \Gamma(s) \Gamma(4.5 - 2s)} \times \left( \frac{r}{r_M} \right)^{s-2} \left( 1 + \frac{r}{r_M} \right)^{s-4.5} \]

\[ s = 1.5 \text{ (fixed)} \]
\[ r_M \sim 50 \text{ m} \]
Average lateral distributions

comparison to KASCADE data

The measured shower size spectrum, obtained by determining the arrival directions of cosmic rays. Approximately 33 days, 40,000 showers, 4 detector coincidence trigger. 

\[ \Theta < 45^\circ \]

The measured shower size spectrum can be described by the NKG function:

\[
\rho(r, s, N_e) = \frac{N_e}{r_M^2} \frac{\Gamma(4.5 - s)}{2\pi \Gamma(s)\Gamma(4.5 - 2s)} \\
\times \left( \frac{r}{r_M} \right)^{s-2} \left( 1 + \frac{r}{r_M} \right)^{s-4.5}
\]
The measured shower size spectrum can be described by a function

\[ N_e^{2.5} \times \rho(r, s, N_e) \]

\[ \rho(r, s, N_e) = \frac{N_e}{r_M^2} \frac{\Gamma(4.5 - s)}{2\pi \Gamma(s) \Gamma(4.5 - 2s)} \times \left( \frac{r}{r_M} \right)^{s-2} \left( 1 + \frac{r}{r_M} \right)^{s-4.5} \]

where \( N_e \) is the number of electrons (or particles), \( r \) is the distance to the shower axis, \( s \) is the lateral index, and \( r_M \) is the Molière radius.

- ~ 33 days
- ~ 40000 showers
- 4 detector coincidence trigger
- \( \Theta < 45^\circ \)
Reconstructed energy spectrum

Use simple Heitler model to estimate energy spectrum

\[
\frac{E_0}{1 \text{ PeV}} \approx \left( \frac{N_e}{5.95 \cdot 10^5} \right)^{1/1.046} A^{0.046/1.046}
\]

\( \gamma \approx -2.66 \)

A measured air shower

particle detectors & radio antennas

air shower registered by LORA
used to trigger
LOFAR radio antennas

see also: August 17th, 15:36-17:00, Hall 3, J. Kelley: LOFAR: Detecting cosmic rays with a radio telescope

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