Long distance correlations: analysis proposal

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Long-distance correlations

The existence of time correlations in detectors separated by distances much larger of the extension of the highest energy extensive air shower has been discussed.

Different candidate mechanisms:

1. Gerasimova & Zatsepin
2. Single source emitting correlated particles that produce correlated showers
3. Interaction of the primary particle with intestellar medium

Gerasimova & Zatsepin mechanism

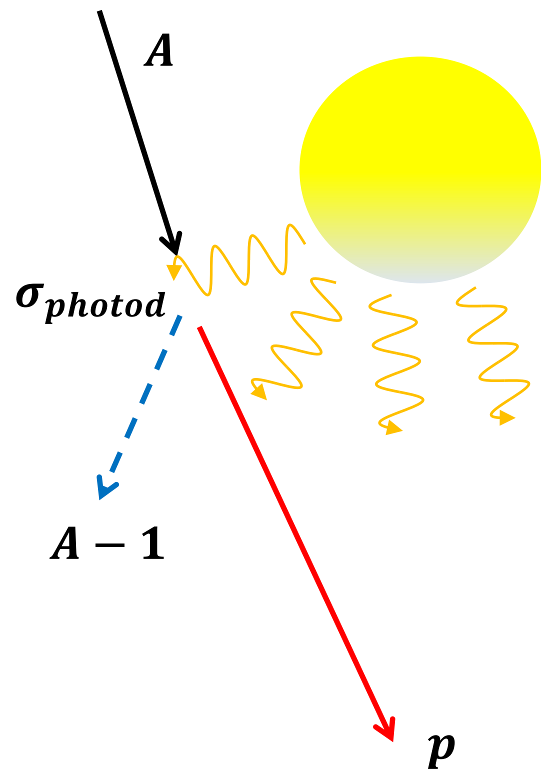
A heavy high energetic cosmic ray nucleus A entering the solar system may interact with a photon from the sun, thereby emitting two fragments:

$$A \rightarrow (A-1) + p$$

by interaction with the solar photons → the relative energy between a high-energy particle and the photons from the sun could correspond to an enhancement of $\sigma_{photodisintegration}$

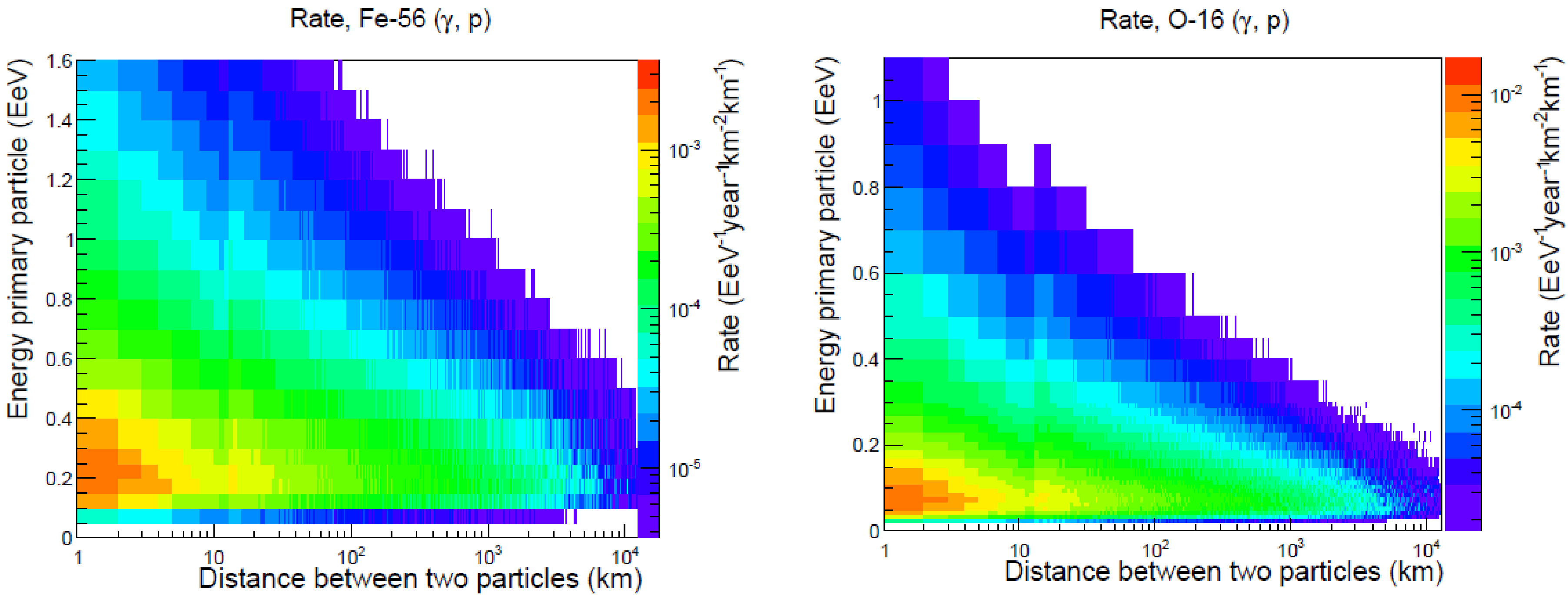
$(A-1), p$ propagate then in the Interplanetary Magnetic Field and arrive on Earth, producing two correlated showers

In principle measurable. **So far no experimental evidence has been reported.**



An example of calculation

"Cosmic ray interactions in the solar system: The Gerasimova-Zatsepin effect"
https://arxiv.org/pdf/1606.07693.pdf



Rate per km^2 as a function of the distance between the two secondaries and the energy of the primary nucleus (iron or oxygen)

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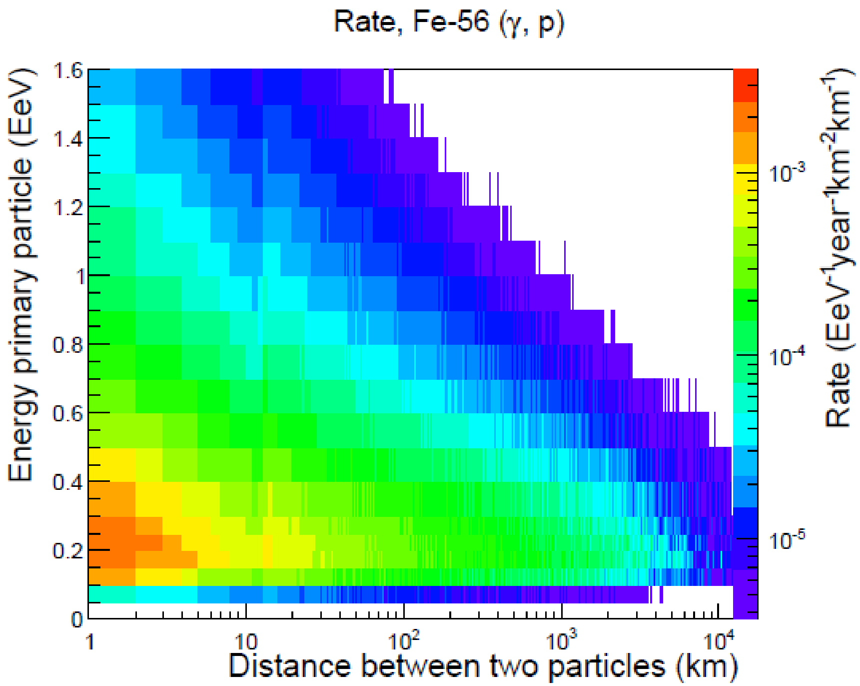
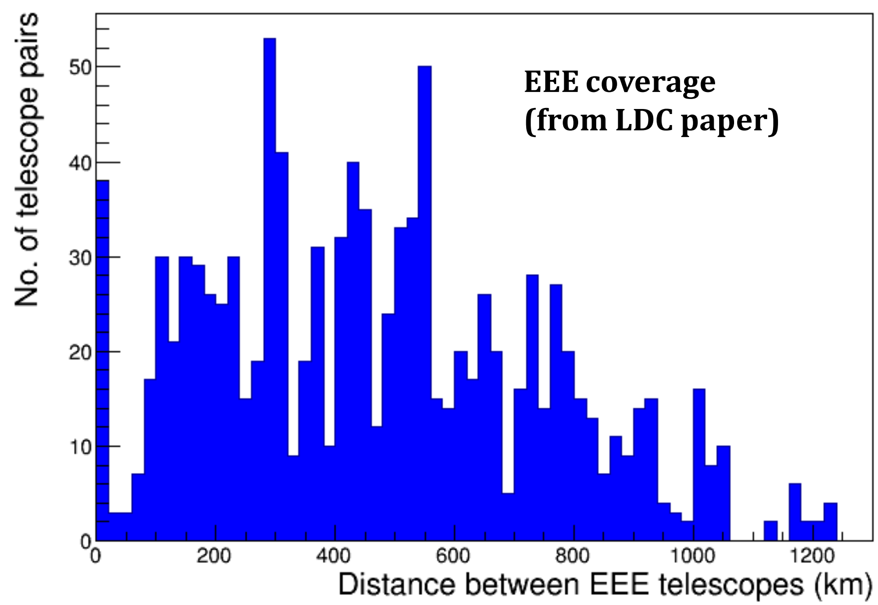




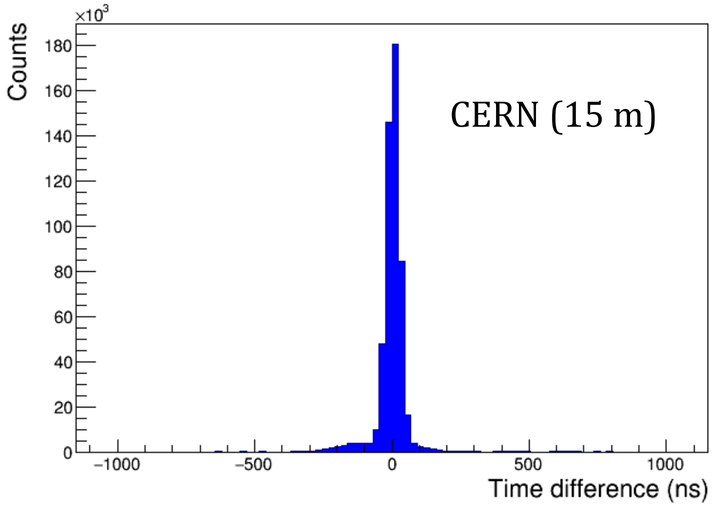
Rate per km^2 as a function of the distance between the two secondaries and the energy of the primary nucleus (iron or oxygen)

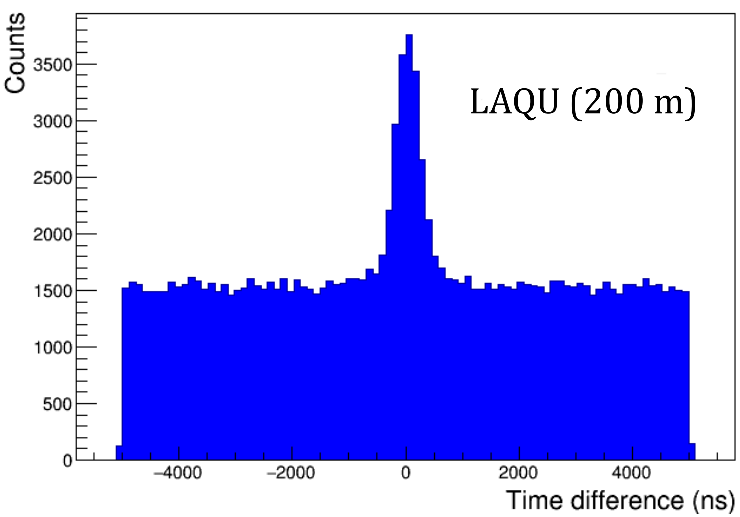
Detecting long distance correlations

Correlations induced by individual estensive air showers detected by a MRPC cluster.

⇒ Strategy (from EEE paper): identify a configuration where the rate of spurious events is acceptable: using pairs of MRPC clusters, for which the rate of spurious event is

$$2 \, x \, 0.04 \, x \, 0.001 \, x \, 10^{-3} = 8 \, x \, 10^{-8} \, Hz$$



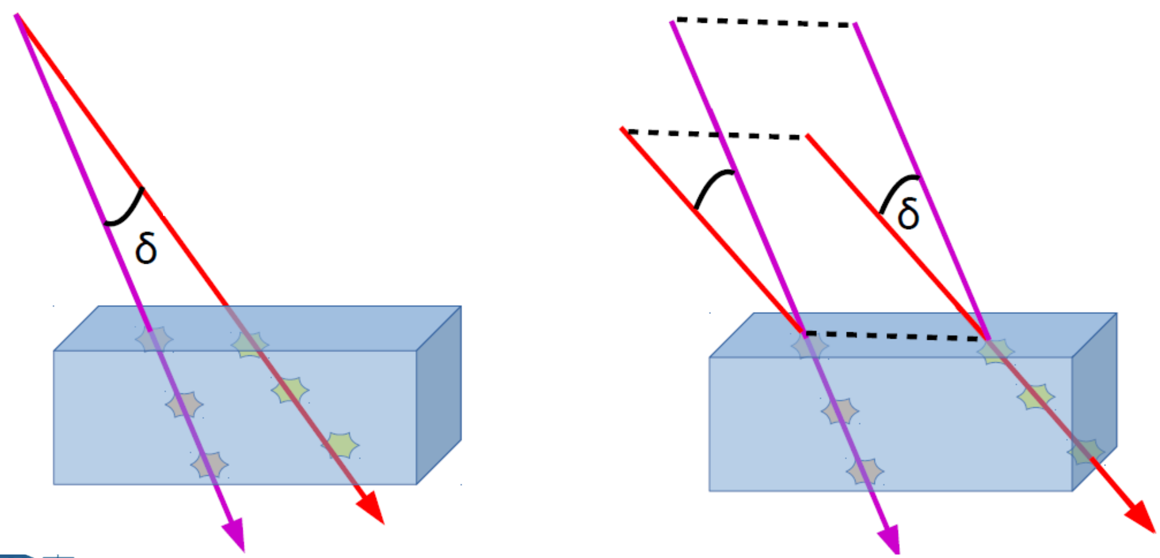


Angular analysis (on a single cluster)

The cut $\vartheta < 40°$ could, in principle, remove good events

- for larger distance angles could be bigger
- latitude effects already included (e.g., CERN-Lampedusa: 11° difference in latitudine)?

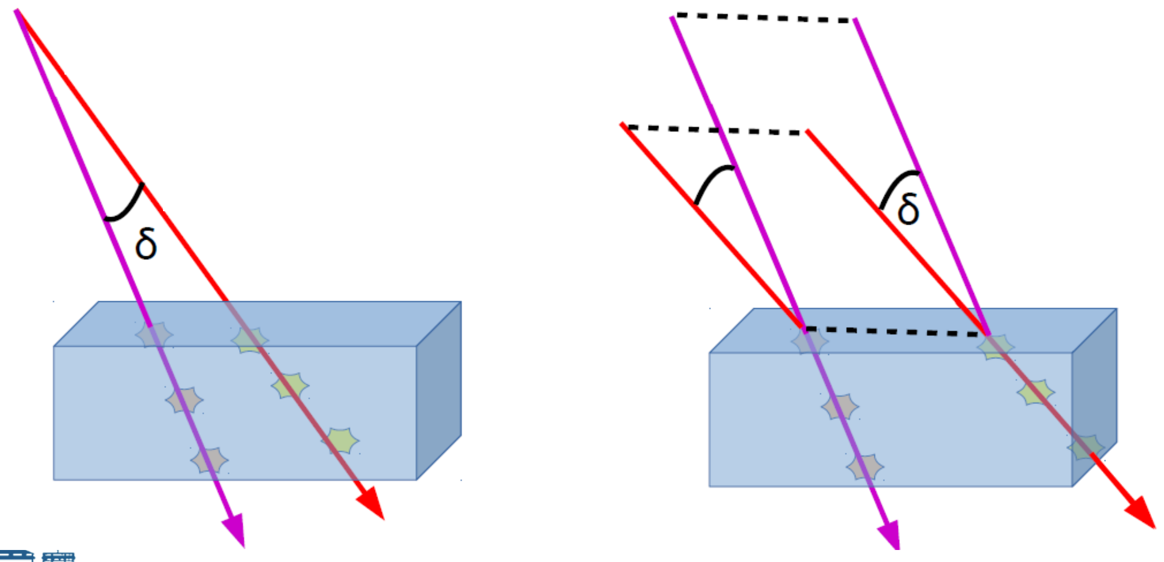
Proposal ⇒ check the convergence among the two tracks



Angular analysis (on a single cluster)

Build an indicator exploiting both the spatial and the time information

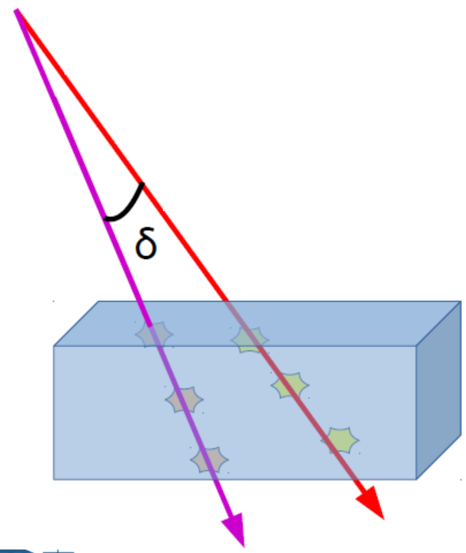
- introducing a «spatial χ^2», large for divergent tracks
- *e.g.*, vertex at 10 km that minimizes angular distance of the two tracks, squared sum of the distances as χ^2
- combine with time information?

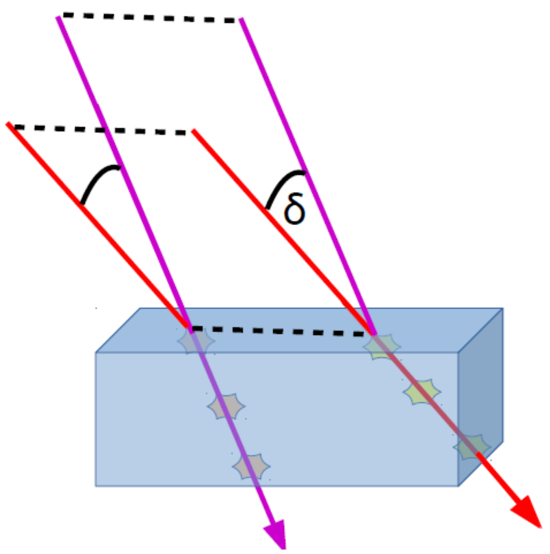


Angular analysis (on a single cluster)

Build an indicator exploiting both the spatial and the time information

- once the vertex is defined, a prediction of the time difference is available
- space and time info are correlated and can be combined
- $3D \rightarrow 4D$ approach: minimization should be globally performed on angles and times





Analysis on cluster pairs

To reduce the rate of combinatorial background, the simultaneous detection of events on two clusters can be exploited → four-fold telescope coincidence

Coincidences can be looked for in all the possible pairs of clusters, exploring a wide distance range

Being the rate very low:

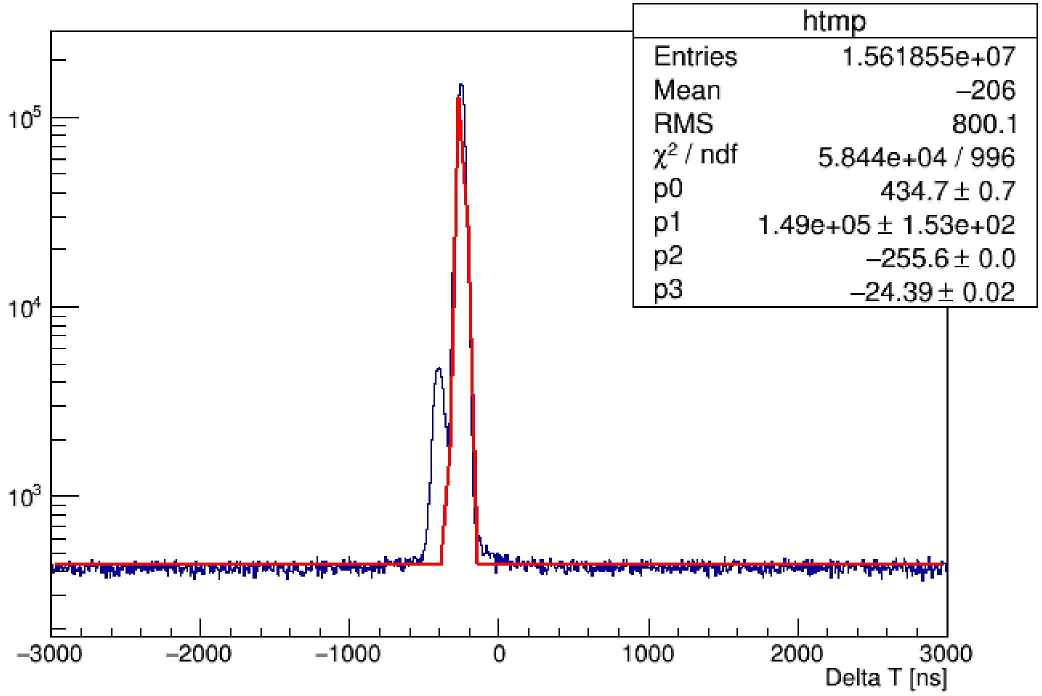
- need to pileup coincidences from different telescope pairs
- explore possible way to improve the time resolution of the coincidence peak to maximize the (time flat) background rejection

⇒ time-peak properties as a function of track-related and external parameters

Properties of observed coincidences

CERN cluster

CERN 1-2

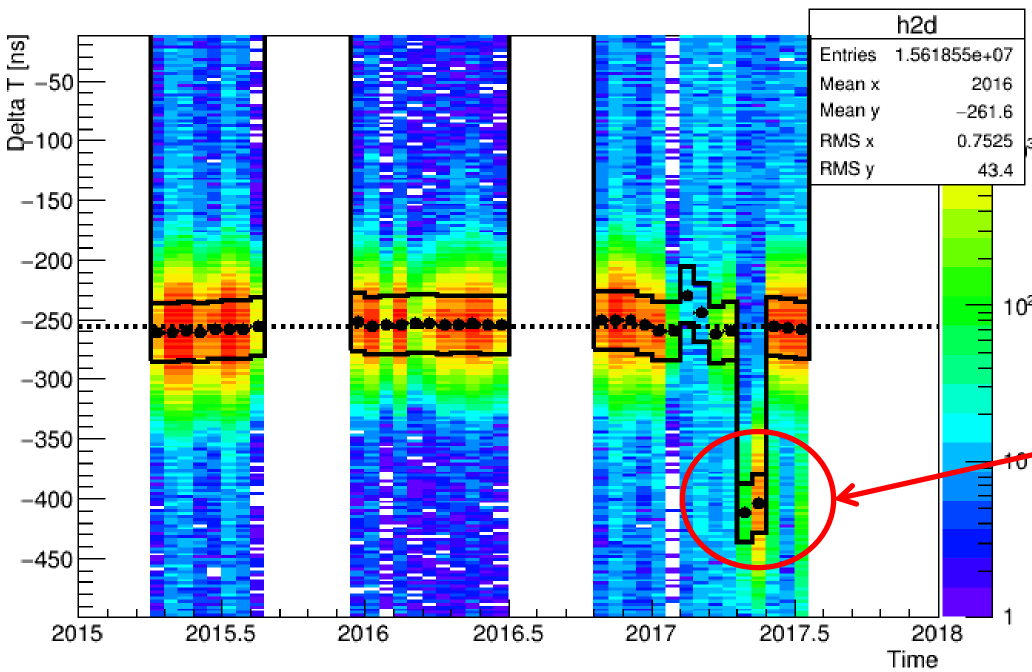


Time shift of 256ns
Much larger than the "natural" width of the peak 24ns (to be improved by correction)

Time-stability of observed coincidences

CERN cluster

CERN 1-2



Time shift of 256ns
Much larger than the "natural" width of the peak 24ns (to be improved by correction)

In April 2017 and within last month the time shift **increases to ~430 ns** (bin 18.25 days)

Beyond the main shifts, the system is stable at level of few ns.

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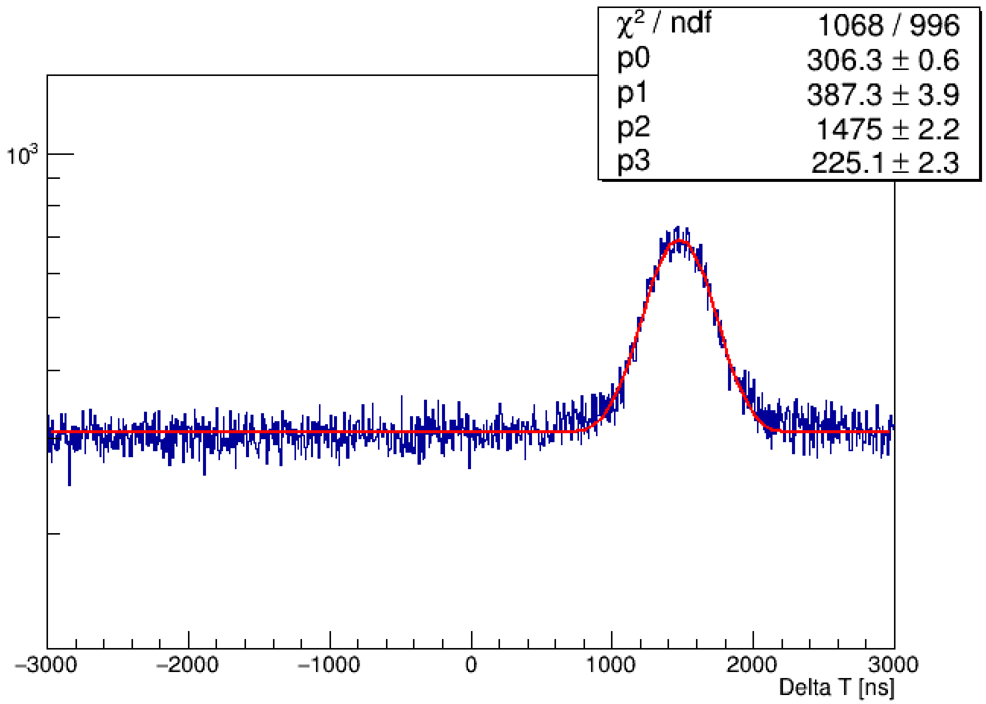
Properties of observed coincidences

BOLO cluster

BOLO 1-4



Time shift of 1475ns
Larger than the “natural” width of the peak of 225ns

How the fitted width depends on the distance?

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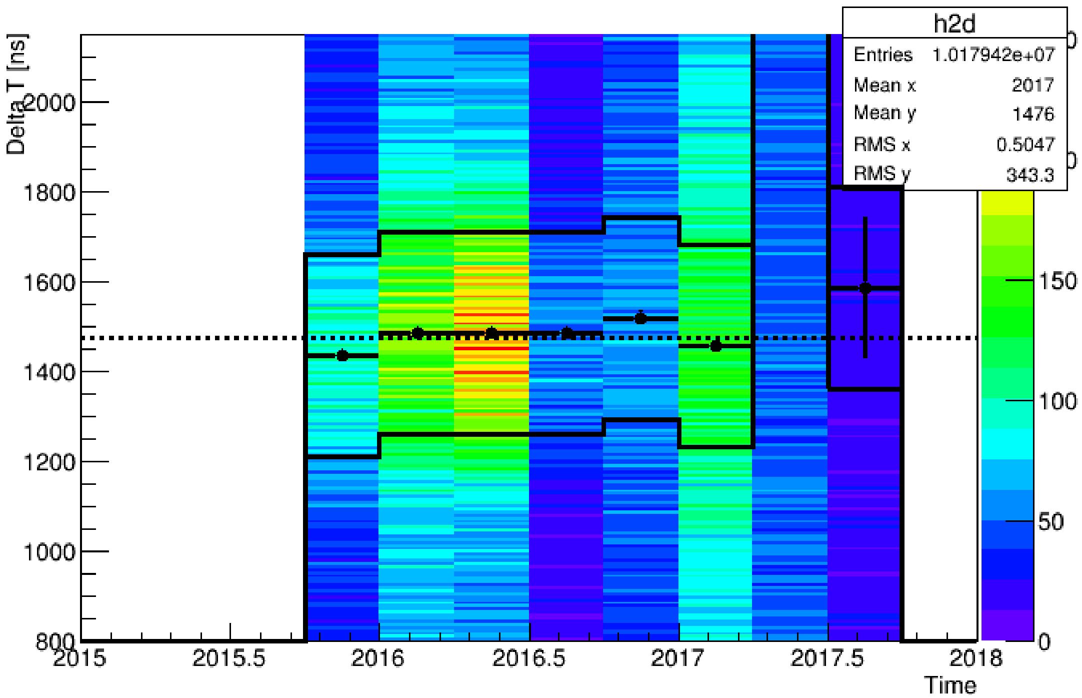
Time-stability of observed coincidences

BOLO cluster

BOLO 1-4



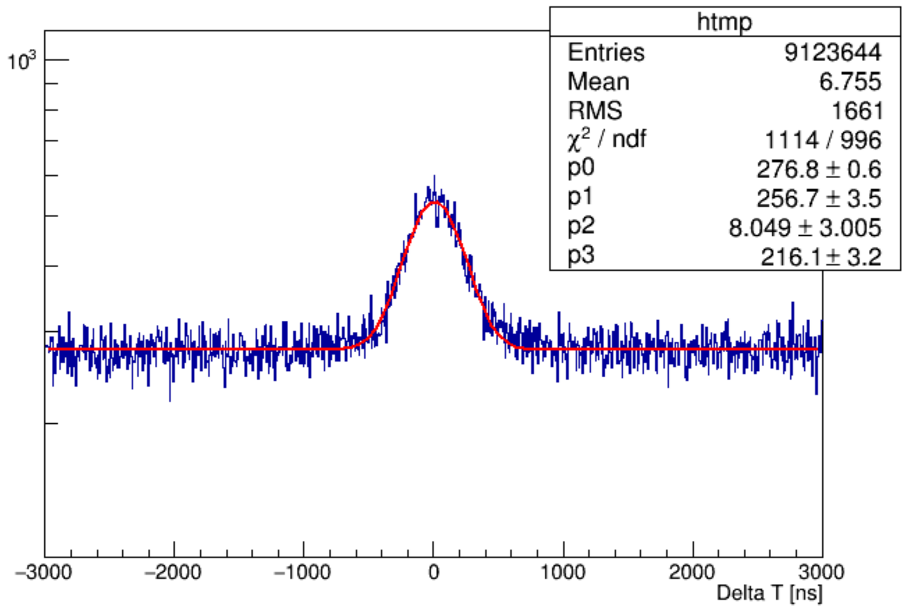
Time shift of 1475ns
Larger than the "natural" width of the peak 225ns

Stable in time within ~50 ns
(3 month bin due to small statistics)

Properties of observed coincidences

LAQU cluster

LAQU 1-2

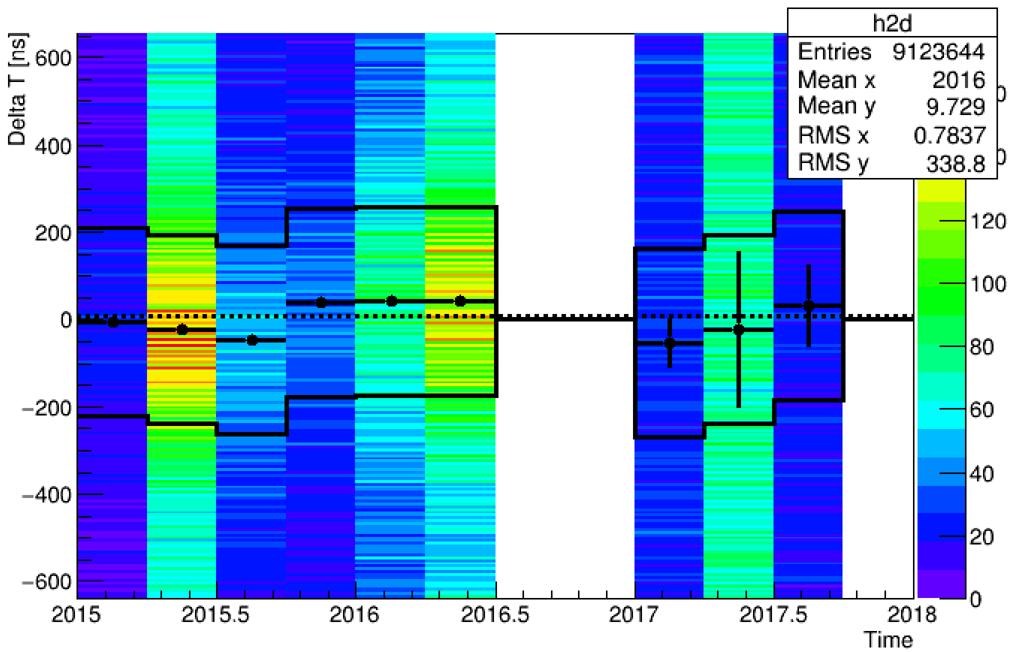


Time shift of 8ns
Smaller than the "natural" width of the peak of 216ns

Time-stability of observed coincidences

LAQU cluster

LAQU 1-2



Time shift of 8ns
Smaller than the "natural" width of the peak of 216ns

Stable in time within ~50 ns
(3 month bin due to small statistics)

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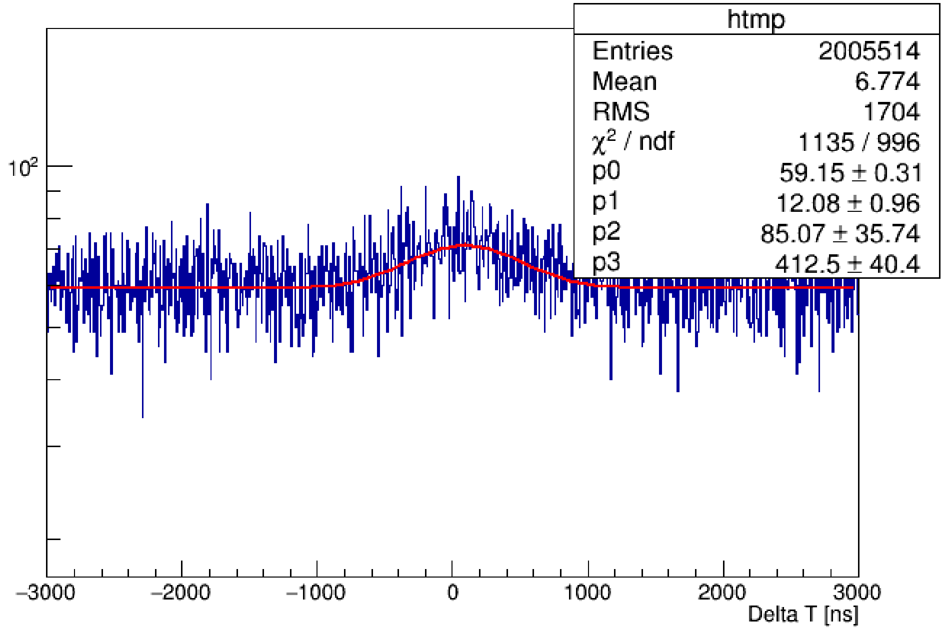
Properties of observed coincidences
GROS cluster

GROS 1-2

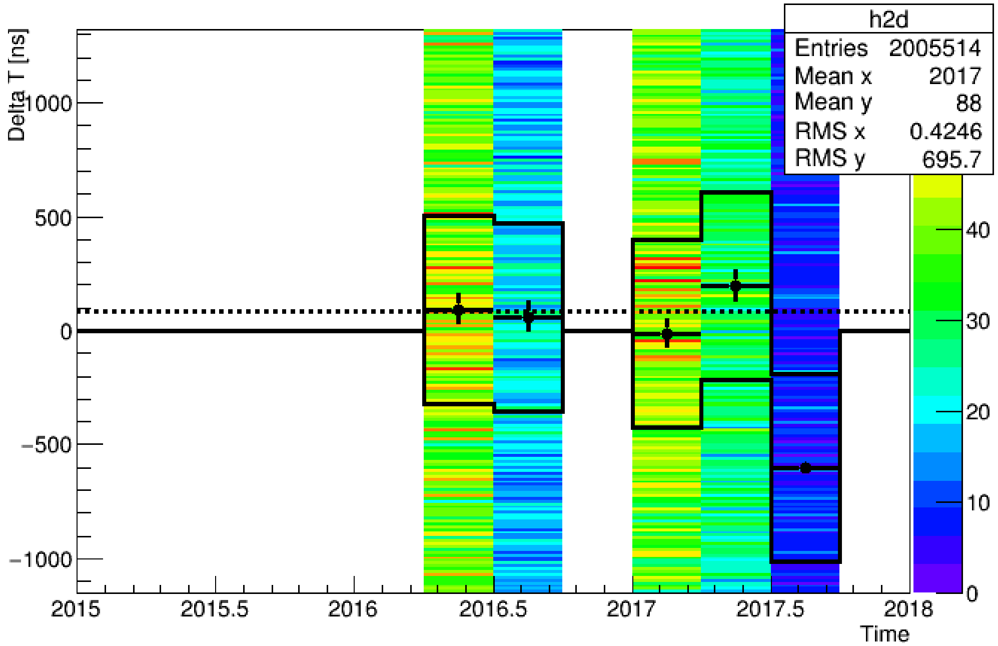


Time shift of 85ns
Smaller than the "natural" width of the peak of 413ns

Time-stability of observed coincidences

GROS cluster

GROS 1-2



Time shift of 85ns
Smaller than the "natural" width of the peak of 413ns

Stable in time within ~50 ns
(3 month bin due to small statistics)

Comments

1. Typical time shifts of few hundreds of ns, not negligible (due to cable length? This should be “fixed” in time)

2. CERN1-2 seems to be stable at level of few ns most of time

3. CERN1-2 found some weeks with further 200ns “jump”

4. BOLO1-4 LAQU1-2 GROS1-2 stability show that shifts are stable within ~50ns (no evidence for “jumps”, but maybe the time bin is too large due to small statistics.)

Time shifts

Reason for the time shifts to be identified

- No clear hypothesis on why they occur
- Are they dependent on the distance of the telescopes?
- If due to the cable length, why not observed between different chambers in a single telescope?

Strategy

1. Study the dependences of the shifts as a function of external parameters (time, temperatures etc)
2. Does it depend on track cuts?
3. It doesn't obviously affect the search (time separation among two clusters is known – e.g., for $1200\text{km} \rightarrow 4ms$)

Comments #2

1. This analysis will strongly benefit from MonteCarlo simulations
2. identify possible configurations that maximize the chance to observe such phenomenon with the EEE network (nuclei, primary energy etc)
3. Dependence on the direction with respect to the sun (different mechanisms could play a role: IMF, primary cosmic ray direction with respect to the solar photons – the latter assumed to be emitted in the radial direction from the sun core) $\Rightarrow$ cfr. LDC paper
4. Is there any simulation tool producing these spectra?
5. Likelihood approach?

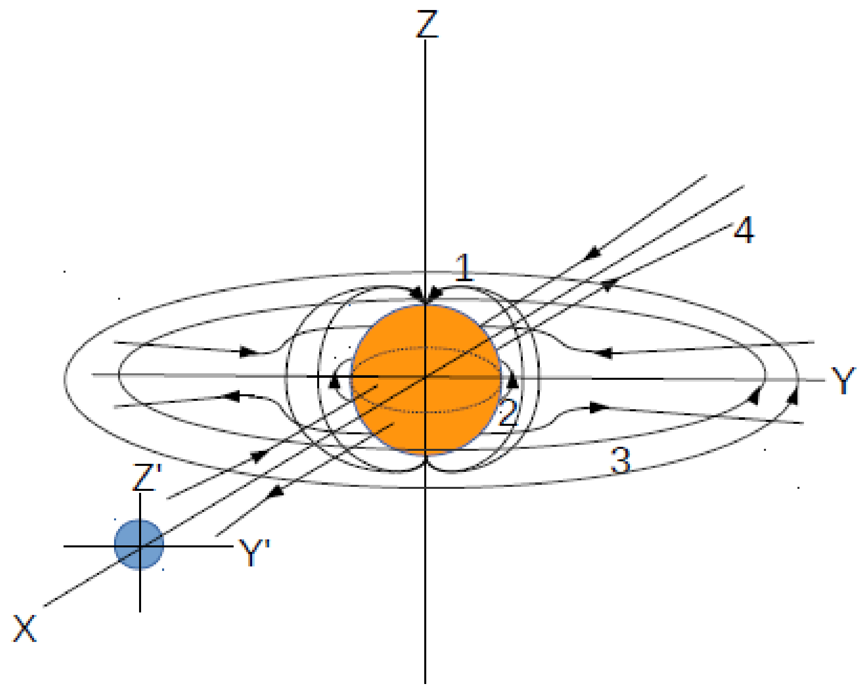
backup

Interplanetary Magnetic Field

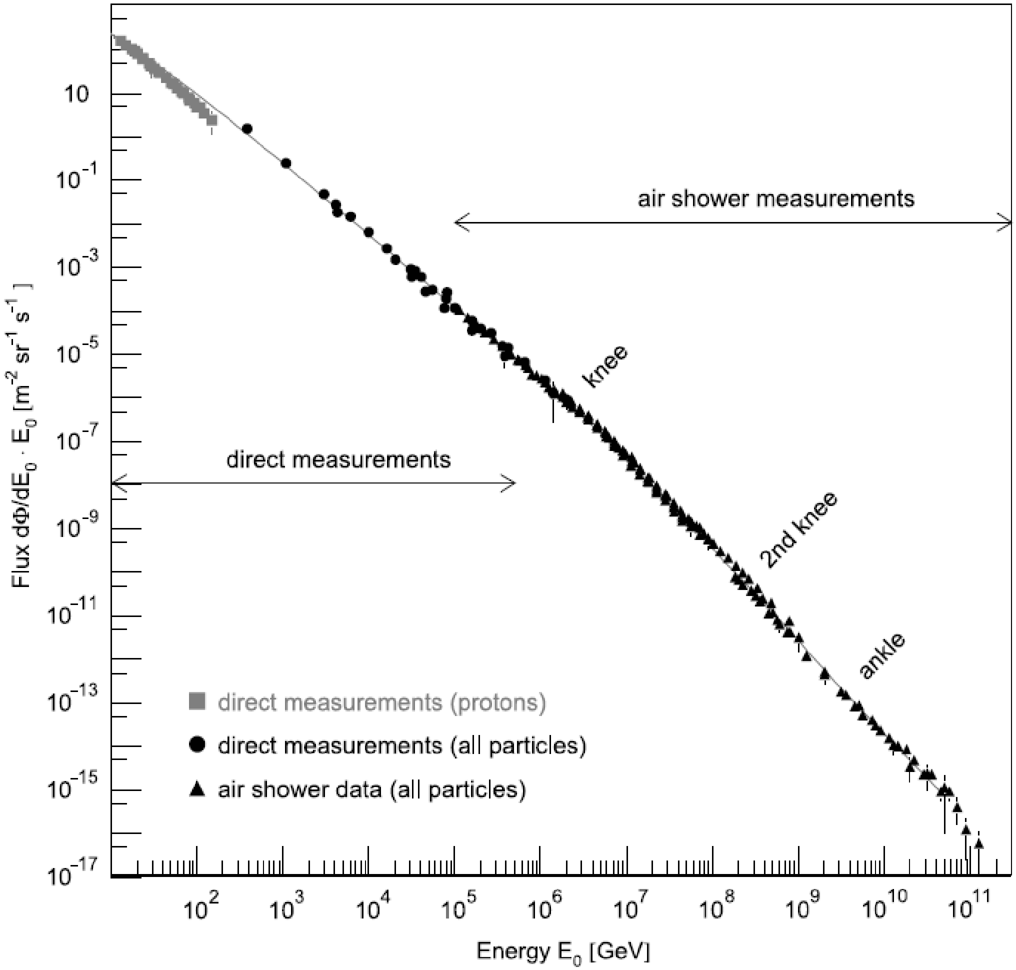
4 main components

1. Dipole
2. Sunspots
3. Dynamo field
4. Ring field

The total field, responbile for deflecting the charged particles, is obtained by adding the different components



Cosmic ray spectrum



Element abundance in cosmic rays

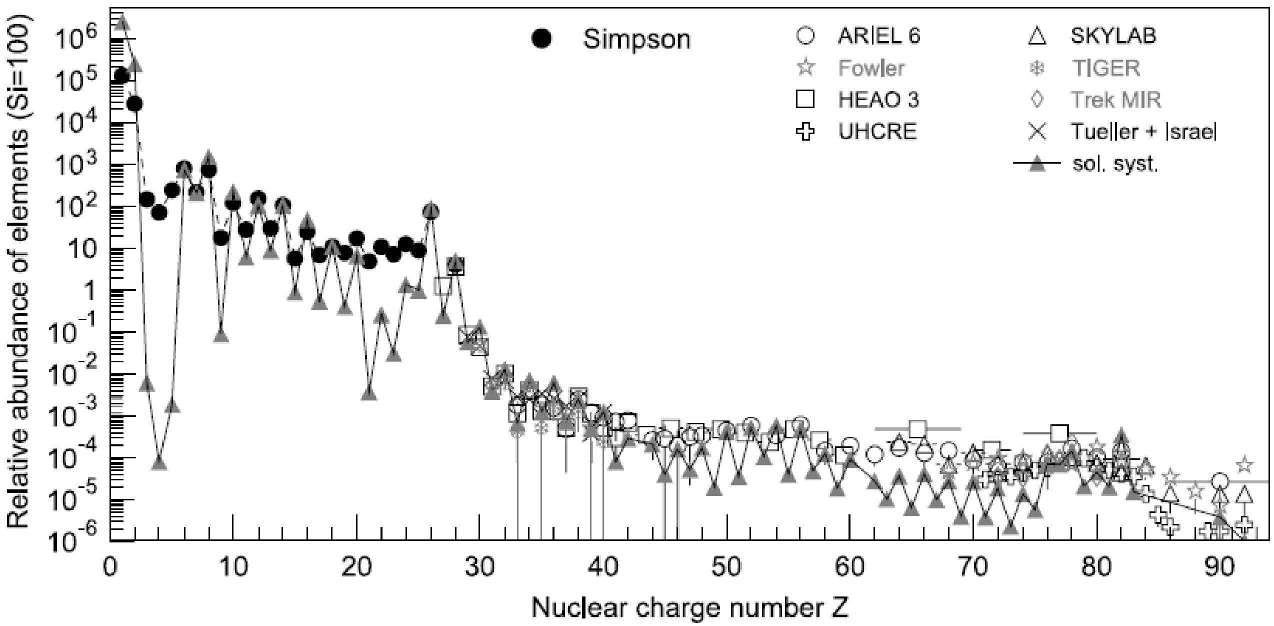
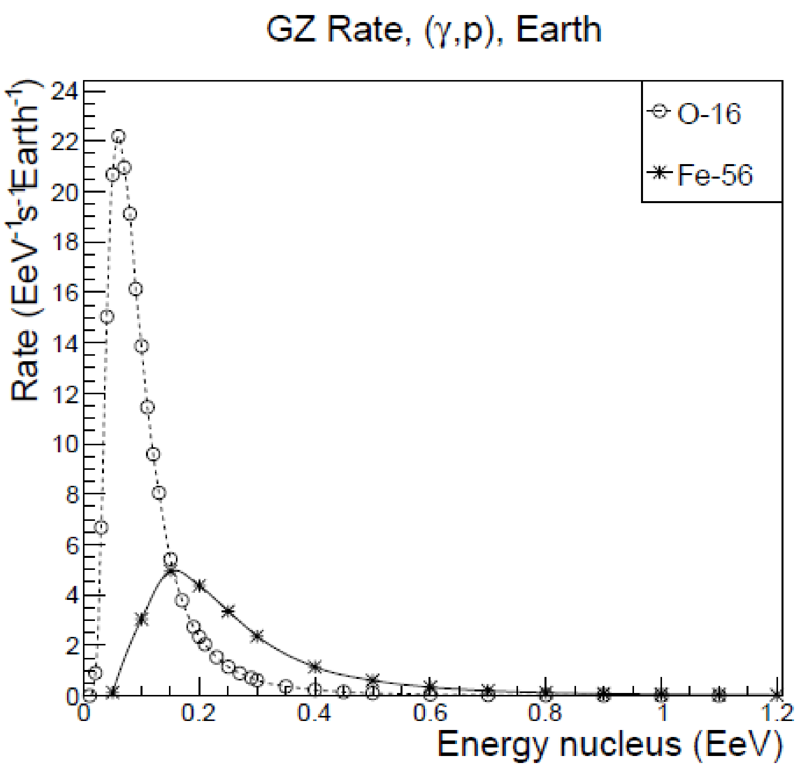
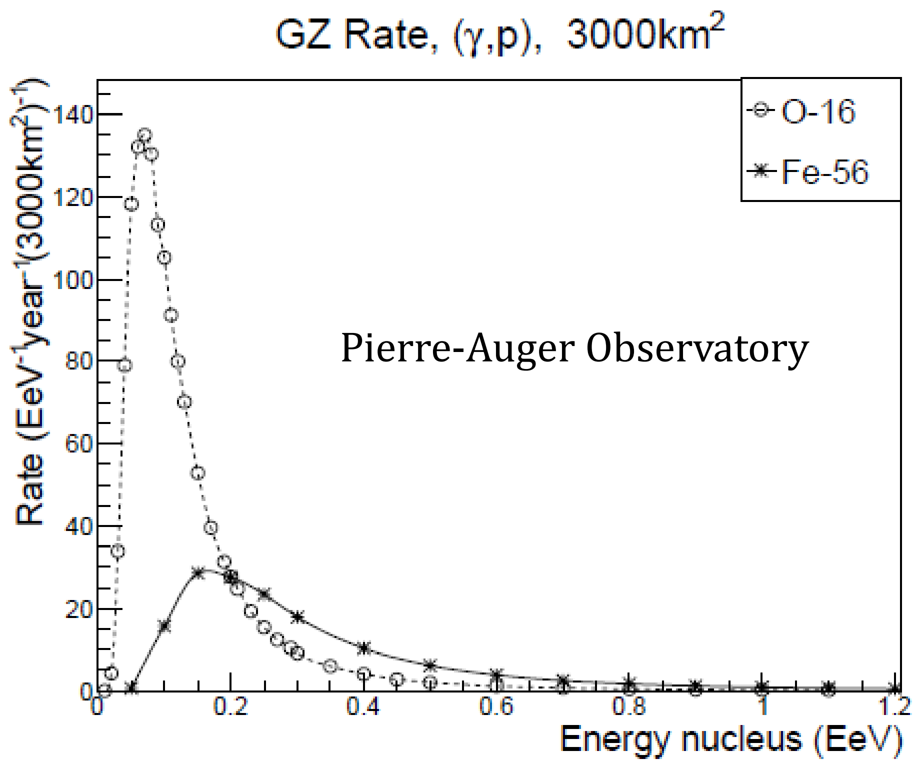


Fig. 2. Abundance of elements in cosmic rays as a function of their nuclear charge number Z at energies around 1 GeV/n, normalized to $Si = 100$ [40]. Abundance for nuclei with $Z \leq 28$ according to [41]. Heavy nuclei as measured by ARIEL 6 [42,43], HEAO 3 [44], SKYLAB [45], TIGER [46], TREK/MIR [47, 48], as well as UHCRE [49]. In addition, the abundance of elements in the solar system is shown according to [50].

Rates for given elements





Possible improvements (time measurement)

1. Upgrade the Cosmic-box with its own GPS
2. Put the box on top of a “standard” telescope for “long” time
3. Check that Cosmic-box time reference is stable (no CERN1-2 like “jumps”, or try to discover why “jump” happens)
4. two “time-tuned” Cosmic-box will help a lot, one on top of CERN1 the other on top of CERN2 to “reproduce” the “jump”
5. Calibrate all EEE telescopes with a “short” time Cosmic-box coincidence run