Results from the Hellenic Open University extensive air shower array

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8th ICNFP 2019, 21-29 August 2019 Kolymbari, Crete, Greece

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On behalf of the ASTRONEU group

- A. Leisos, A.G. Tsirigotis, G. Bourlis: Physics Laboratory, School of Science and Technology, Hellenic Open University.
- K. Papageorgiou, I. Gkialas : School of Engineering, University of the Aegean.
- S.E. Tzamarias, I. Manthos : Department of Physics, Aristotle University of Thessaloniki.

Outline

1. Cosmic Rays - Extensive air Showers (EAS)
2. Radio Emission
3. ASTRONUE Array
4. HDM's Performance
5. Event Selection-RF Analysis
6. Correlation Study and Combined Performance
7. Reconstructing EAS direction using RF signal from one antenna
8. Core-Energy-X_{max}
9. Conclusions and future work

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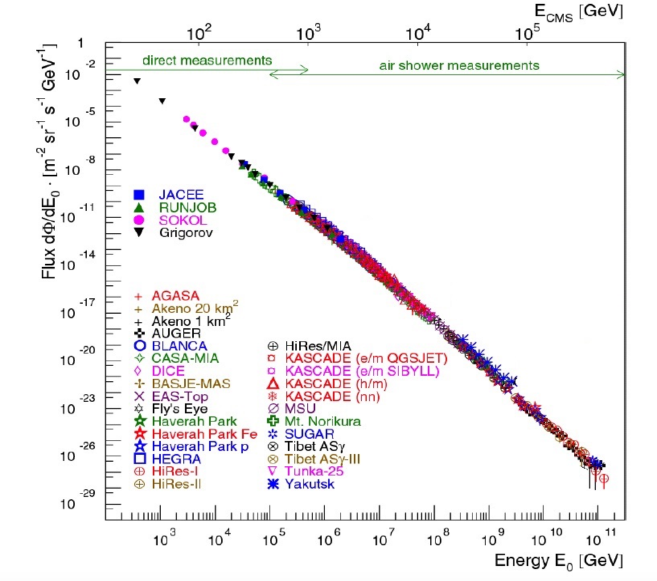
Cosmic Rays Spectrum

- Spectrum power law $dN/dE \sim E^{-3}$



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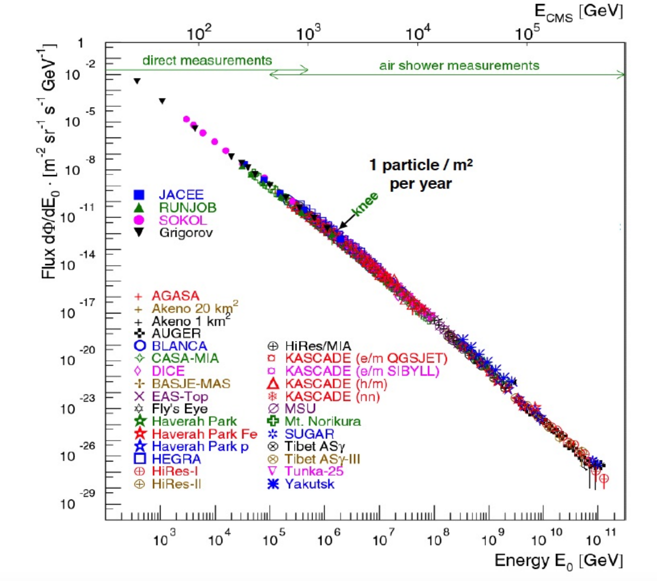

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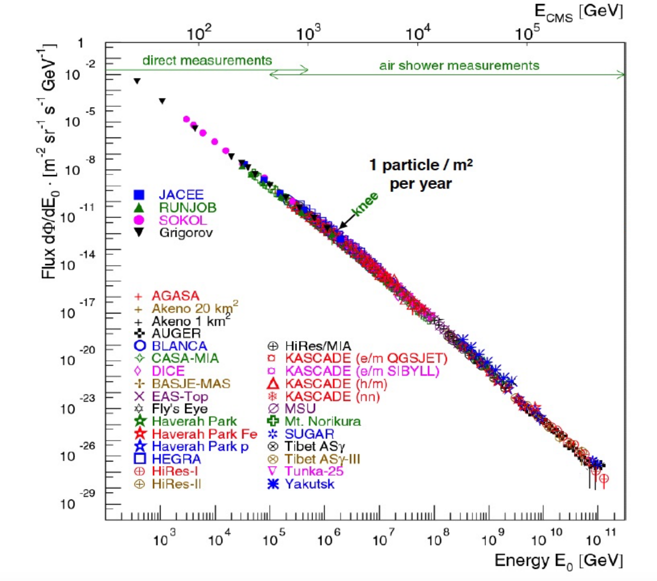

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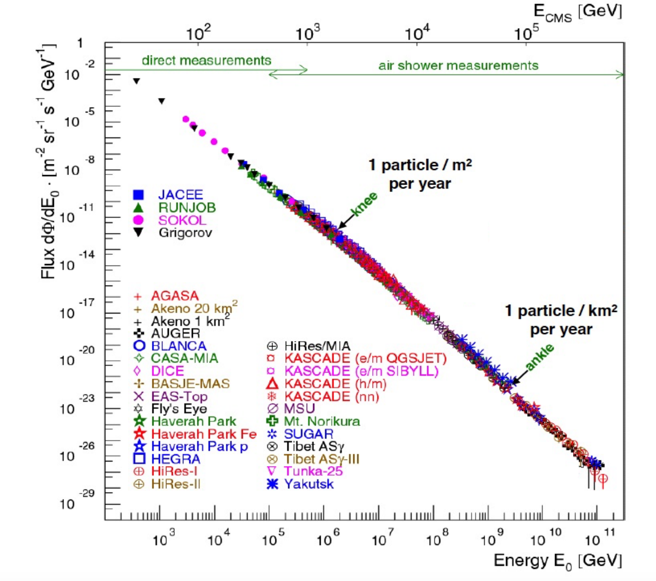

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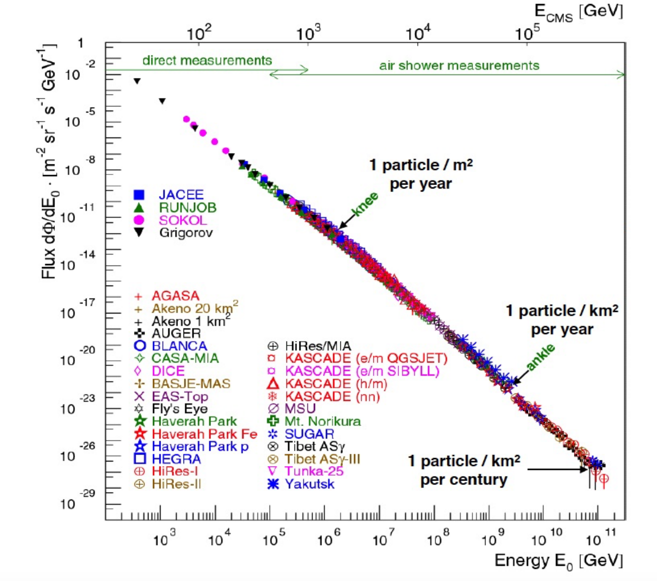

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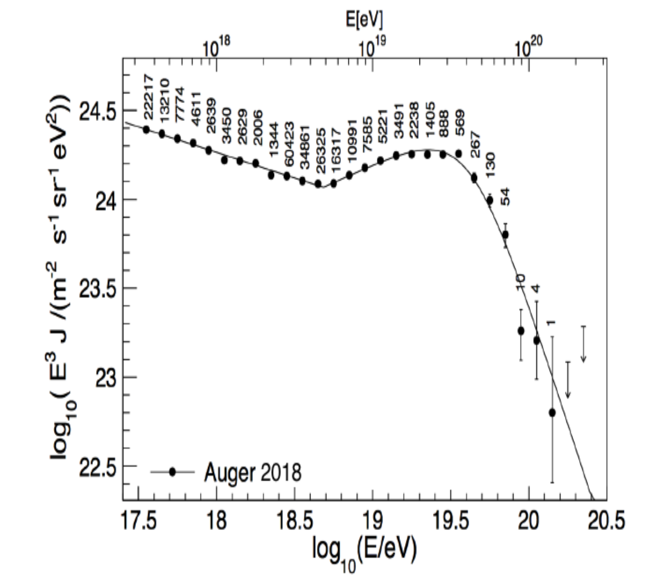

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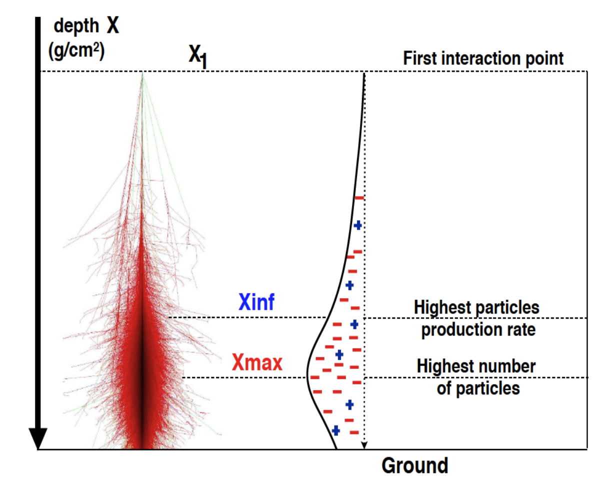
- Why the flux goes down dramatically? (Flux$/\ 10^3$ when energy$\cdot 10$).

Extensive Air Showers (EAS)

- EAS: Cascade of particles.



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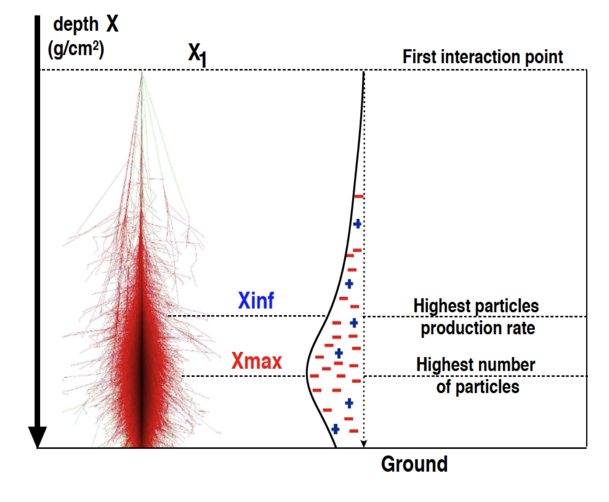

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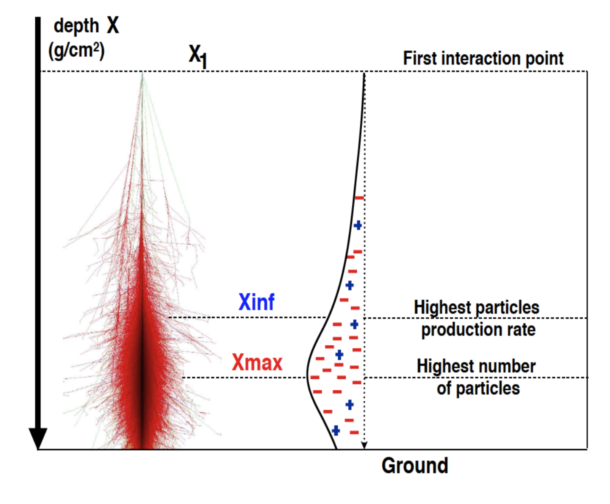

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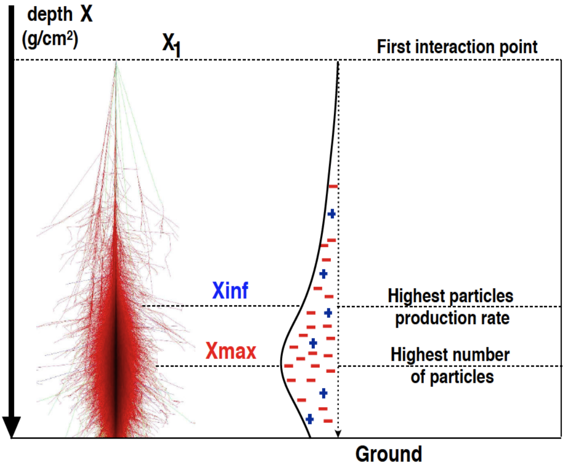

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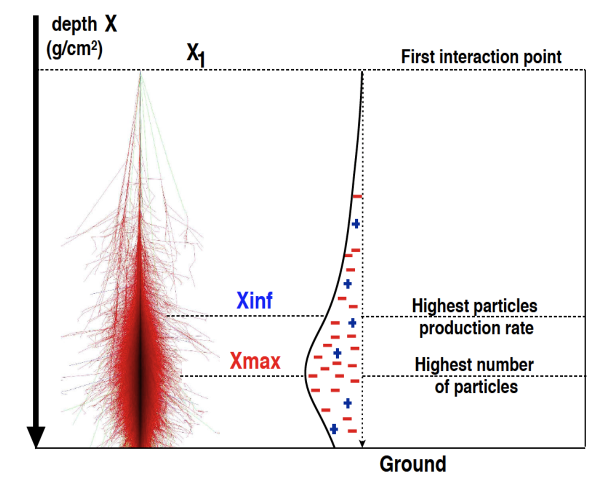

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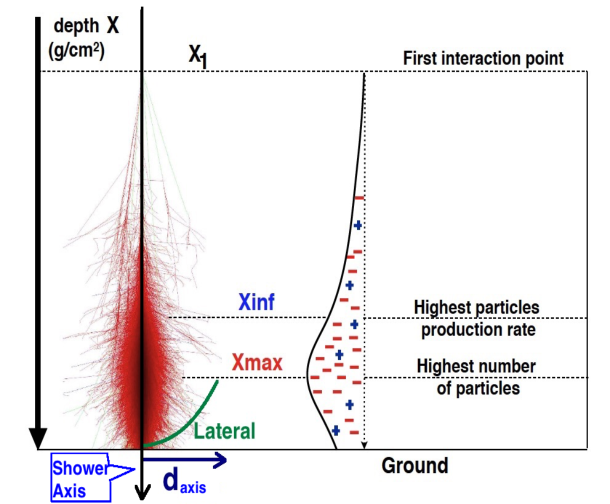

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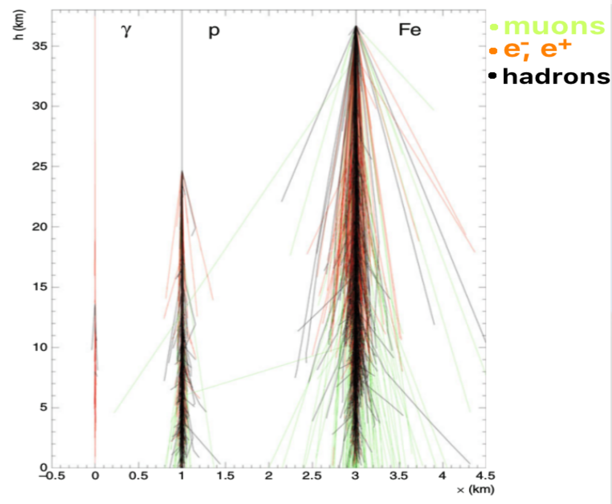

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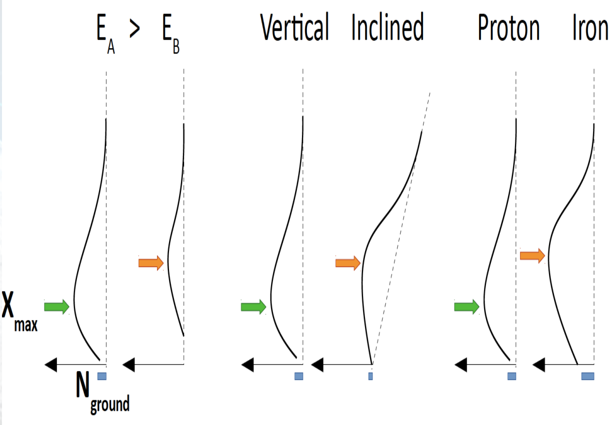
- Both profiles are correlated to **direction, energy, mass**



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- Charges moving in the geomagnetic field.

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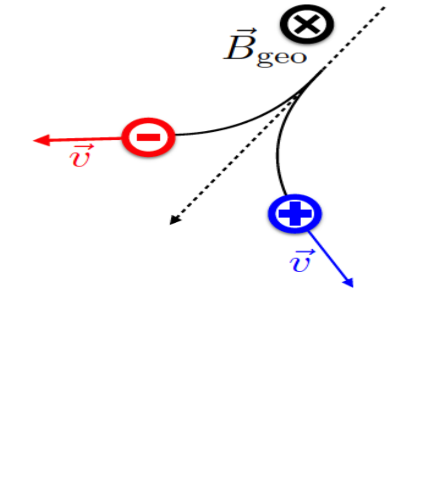

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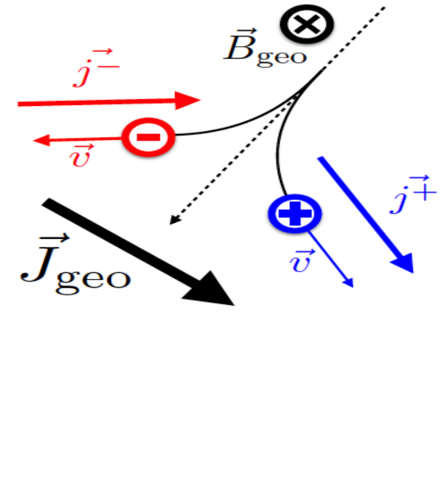

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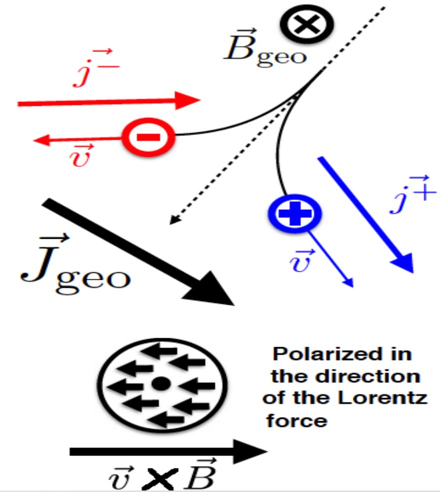

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Charge excess effect

- **During shower development**

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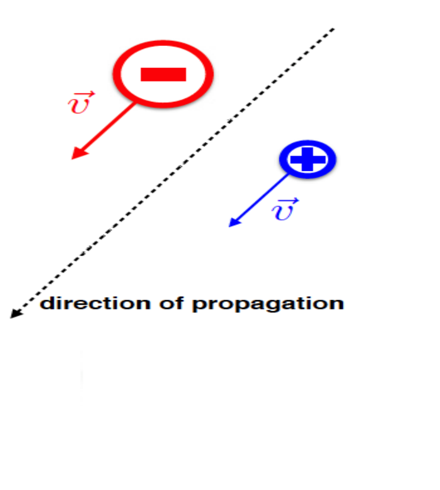

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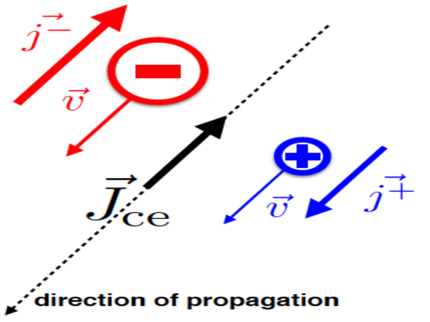

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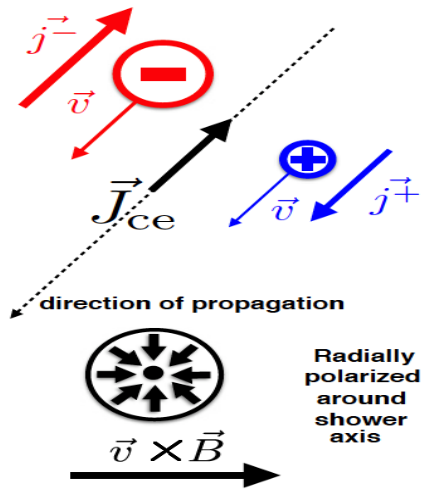

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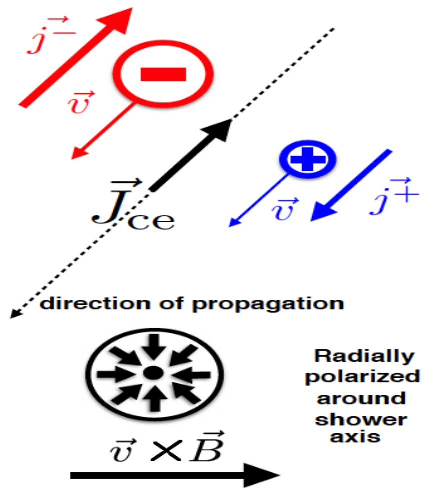
- Electric Field radially polarized around the shower axis.
- The amplitude and the polarization pattern of the 2 contributions depends on the shower direction. The geomagnetic effect usually dominates.



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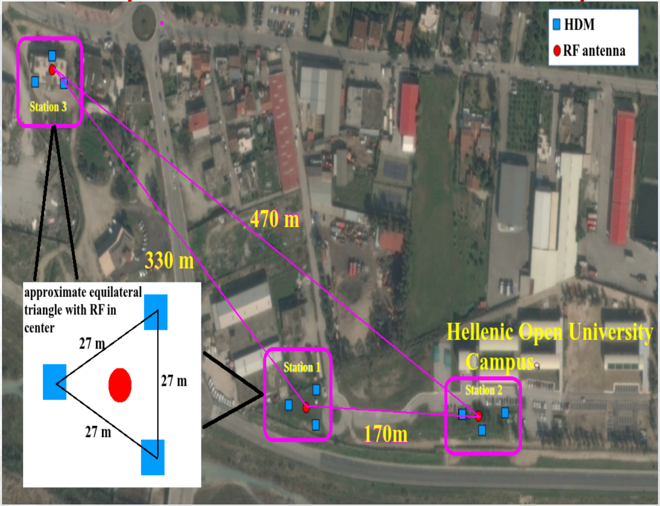
- **ASTRONEU: SD and RF array (3 stations) developed in the campus of the HOU.**



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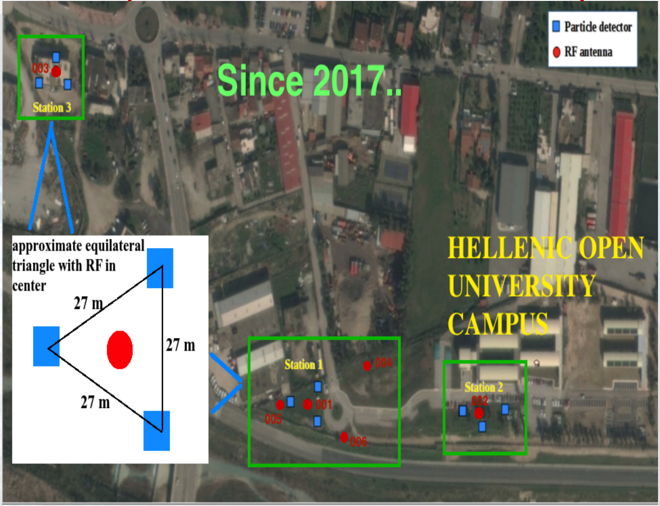

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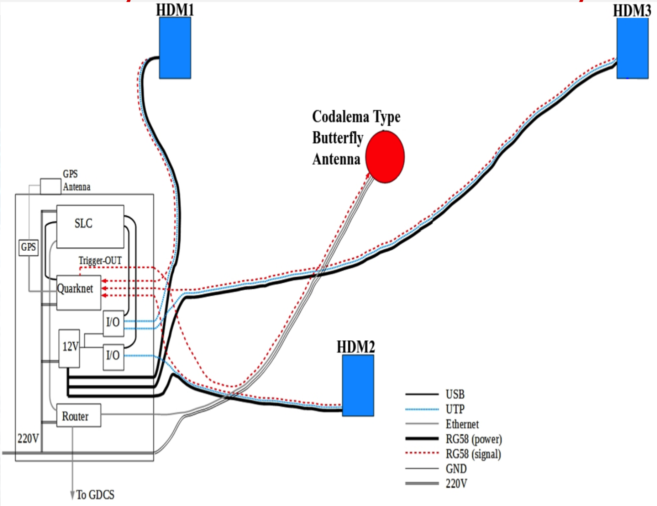

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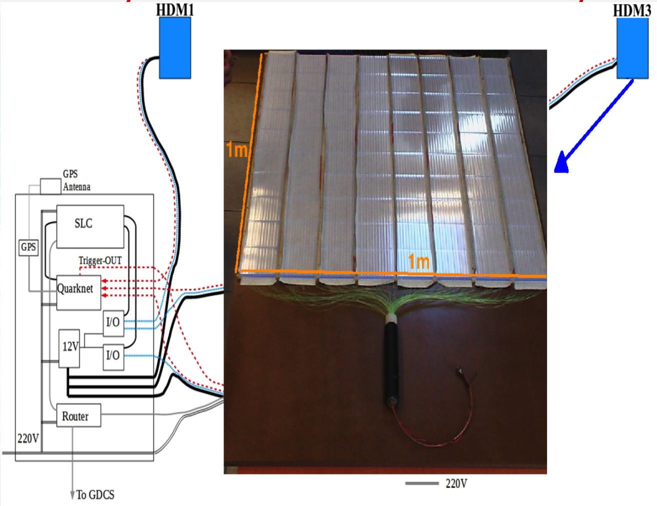

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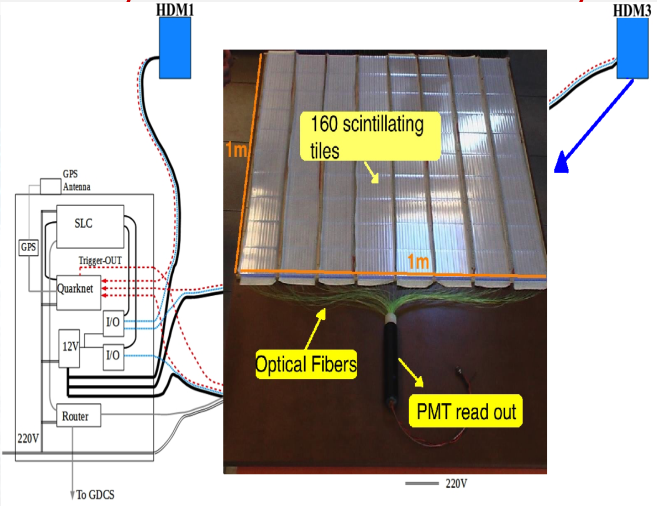

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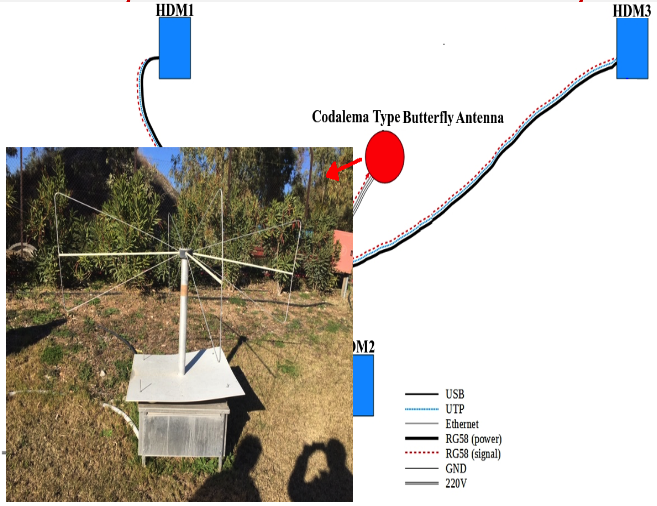

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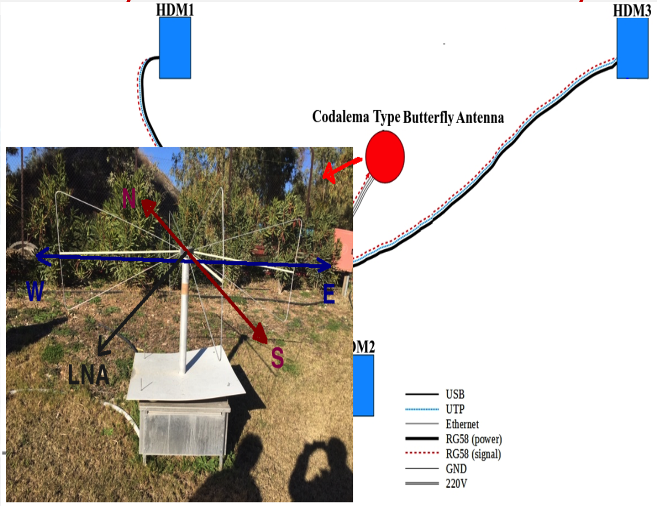

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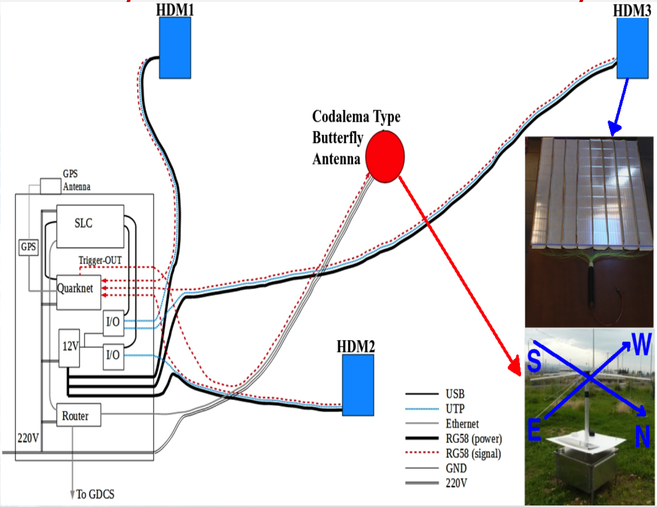

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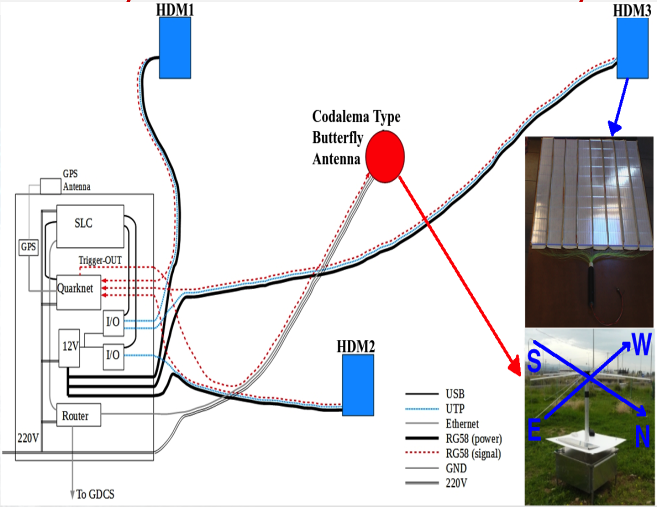
- ASTRONEU CR telescope operates in an urban environment.



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- **Results for the evaluation of the HDM's performance of the 3 stations.** [4]

[4] arXiv:1801.04768 [physics.ins-det]

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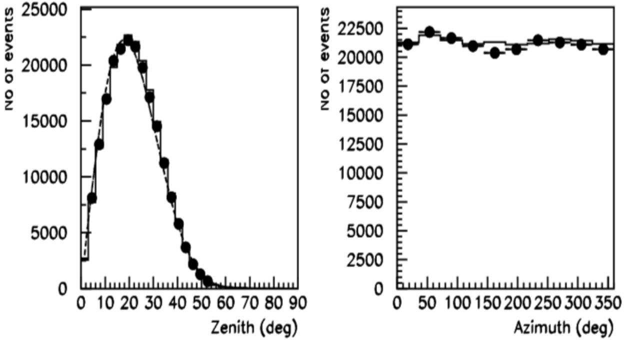

station	Event Rate (hr^{-1})	σ_θ (deg)	σ_ϕ (deg)	ω_{median} (deg)	E_{th} (TeV)
A	17.5	3.3	10.4	3.3	20
B	11.5	6.0	14.8	5.5	30
C	18.9	3.7	11.2	3.6	20

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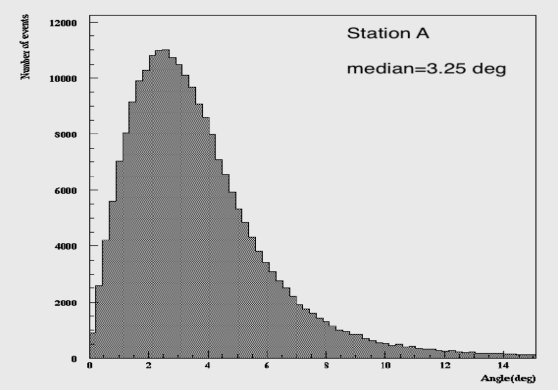

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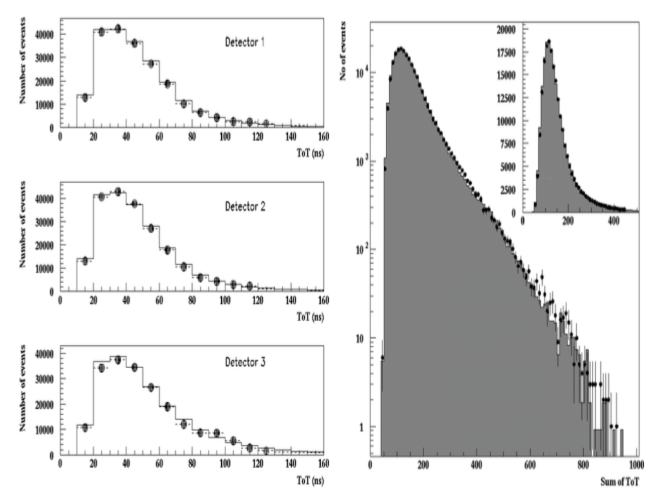

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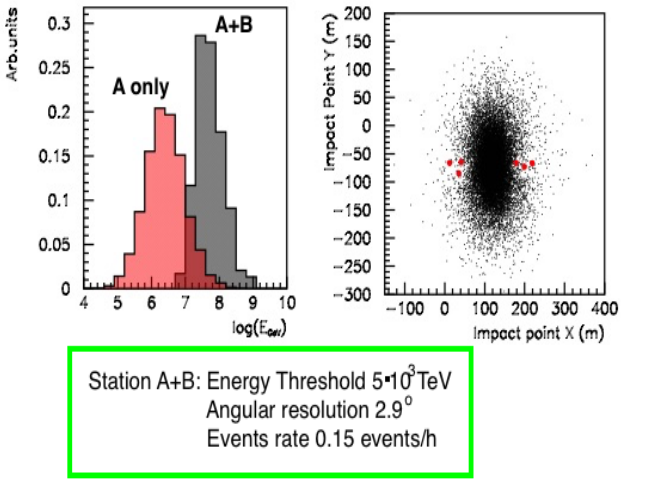
- Energy and shower core distribution for MC events.



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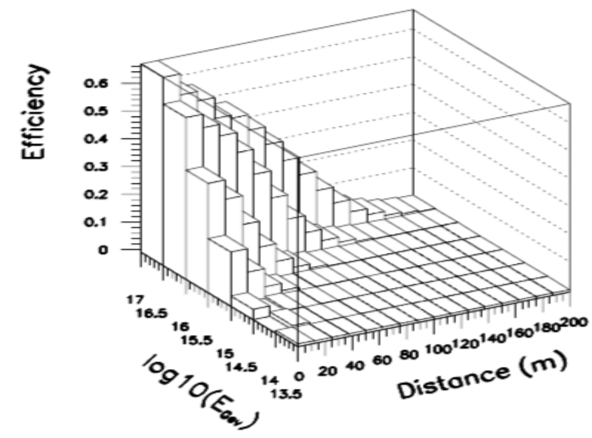
- Efficiency of HDM in detecting showers. Depends on shower core, energy. Max 60% for A.



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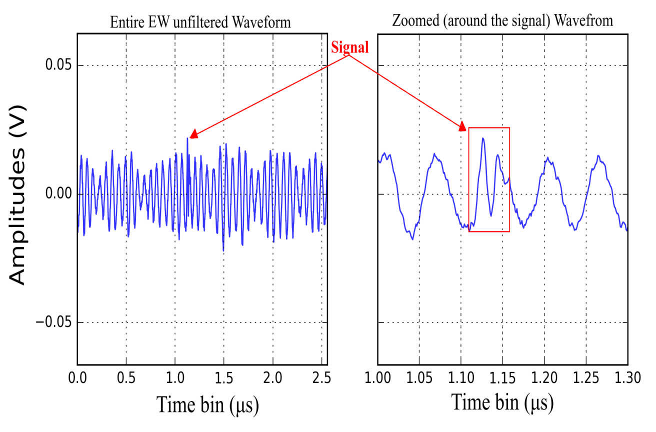
RF signal characteristics[5]

- **Intense peak localized in a time interval of 20-30ns**



5 arXiv:1702.05794 [physics.ins-det]

6 Diego Torres Machado and the CODALEMA Collaboration 2013 J. Phys.: Conf. Ser. 409 012074

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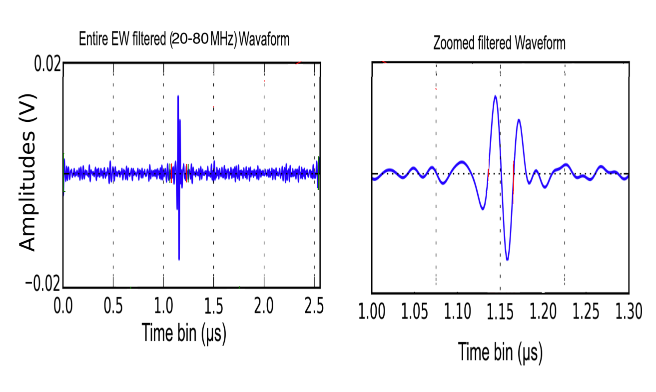

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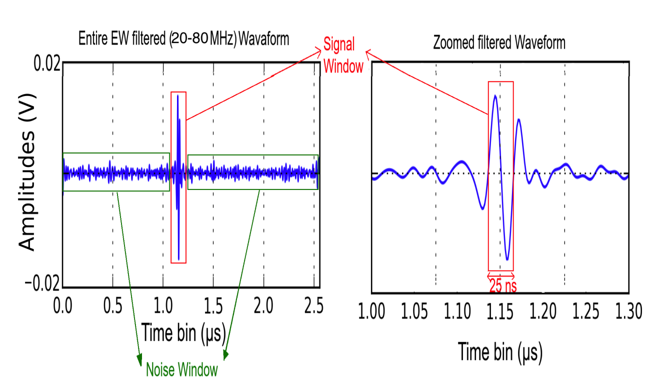

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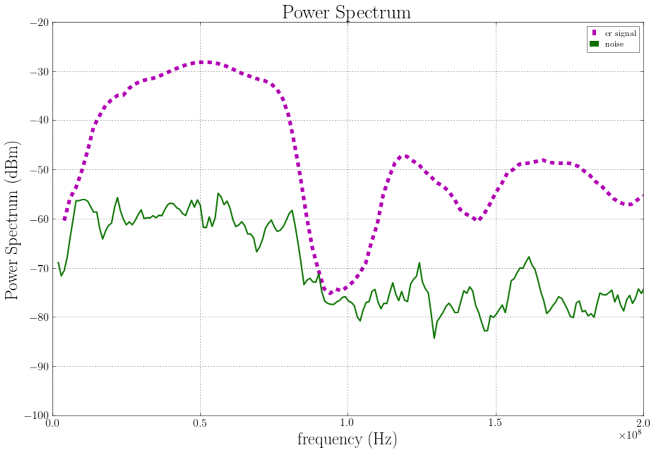

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6 Diego Torres Machado and the CODALEMA Collaboration 2013 J. Phys.: Conf. Ser. 409 012074

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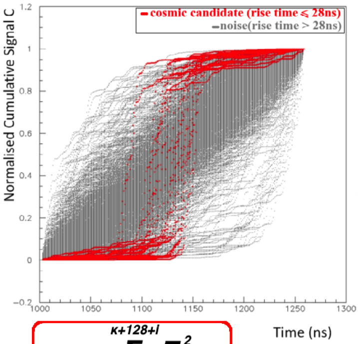

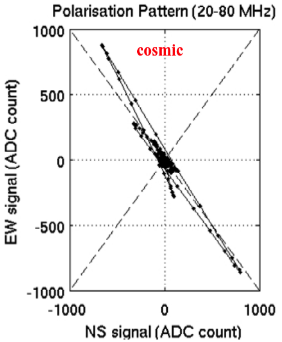

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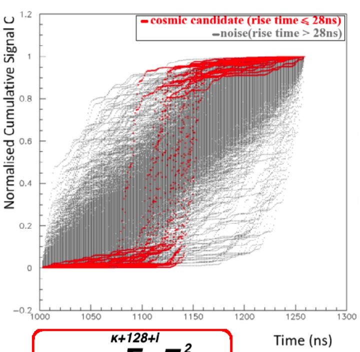

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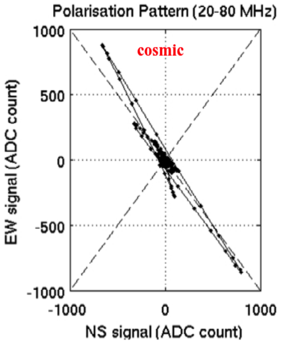

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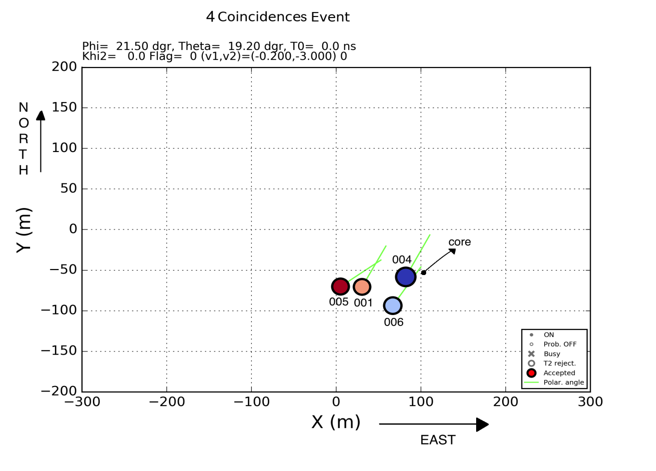

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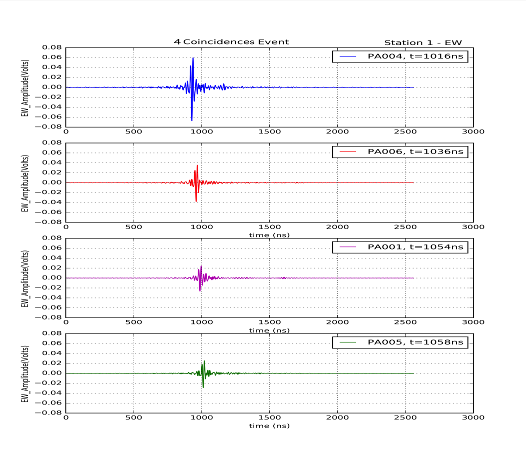

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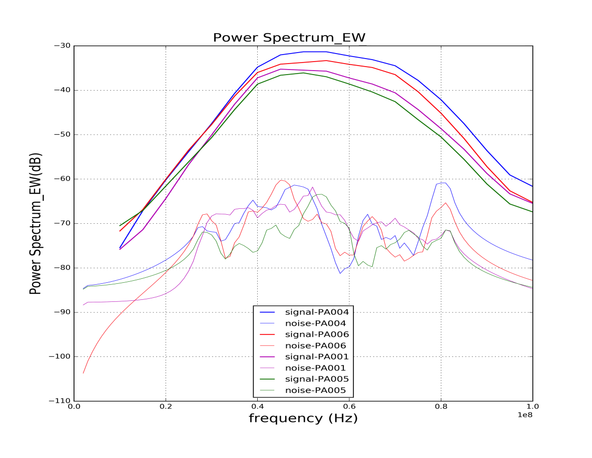

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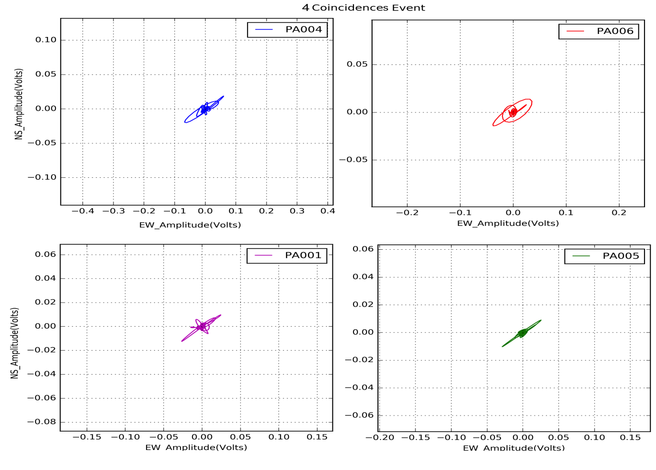

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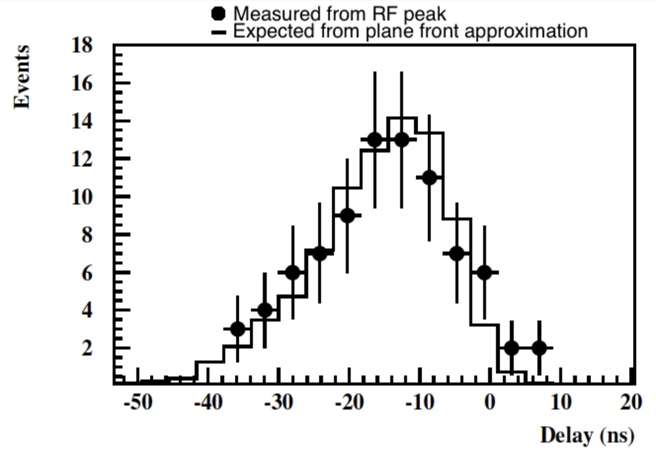

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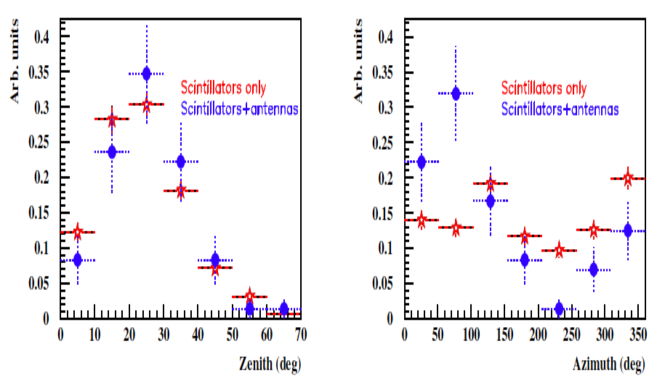

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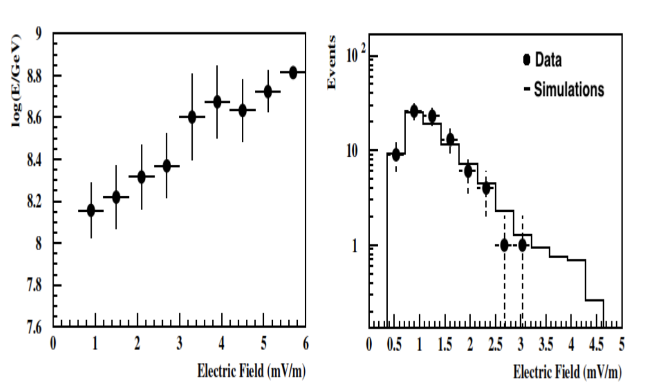

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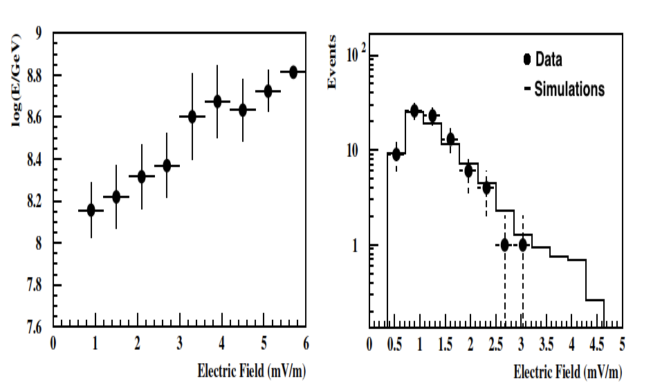

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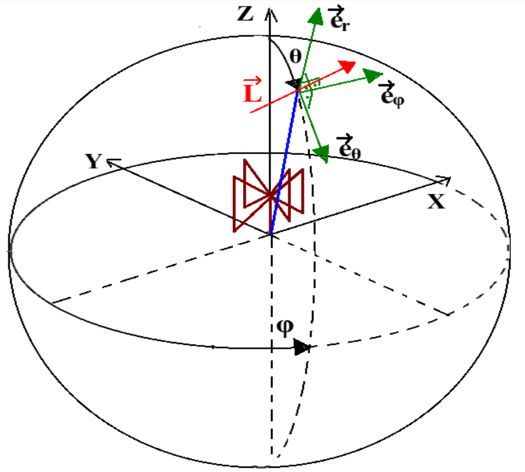
- **Antenna+LNA Vector**

  Effective Length (L):

  $$L = \frac{V_{LNA}}{E_{field}}.$$



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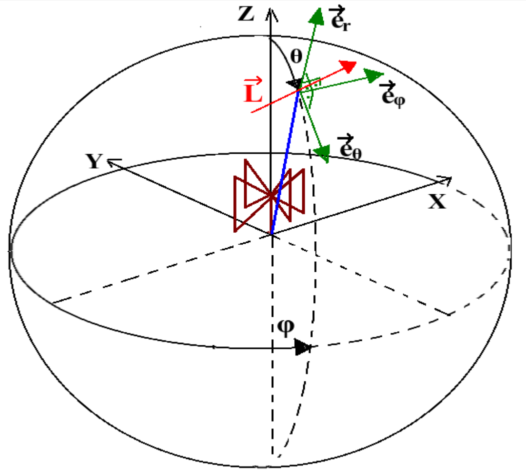

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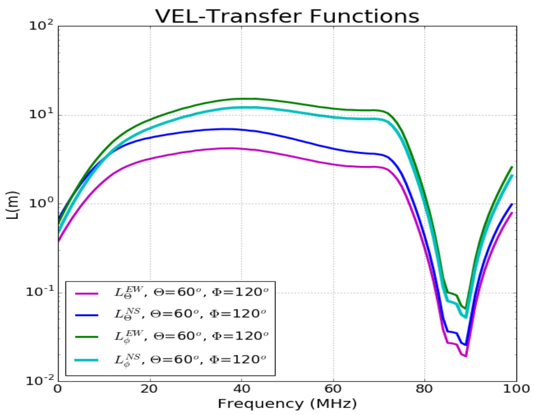

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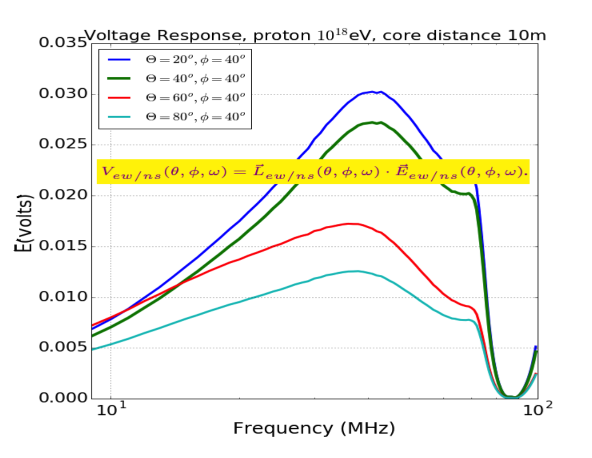

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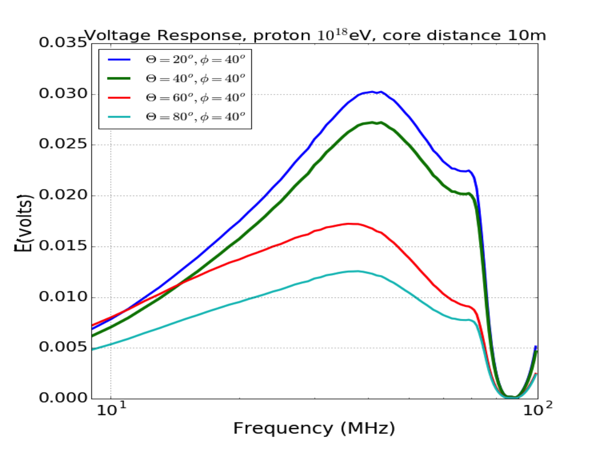

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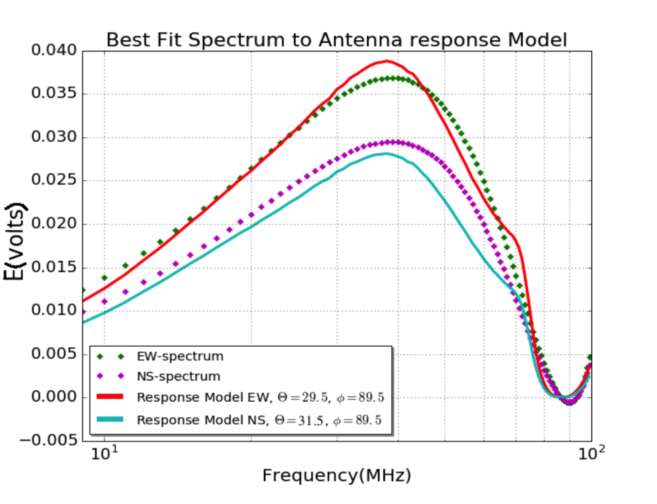

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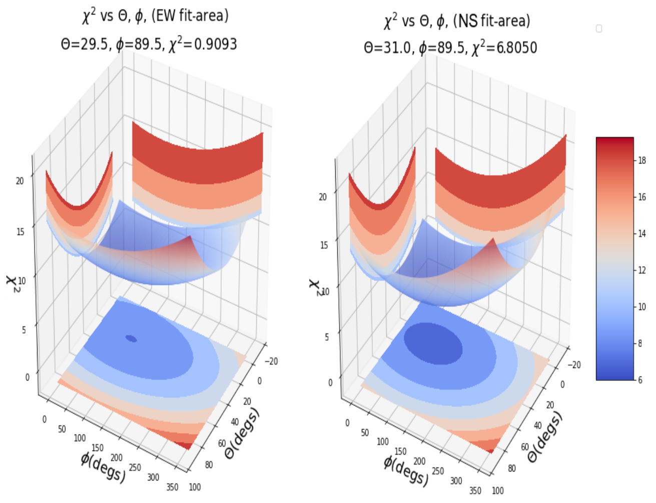

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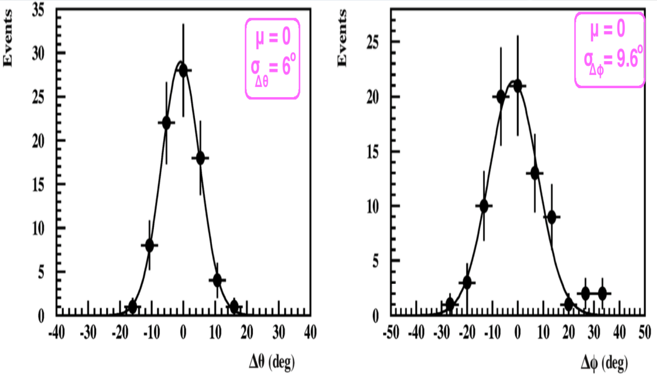

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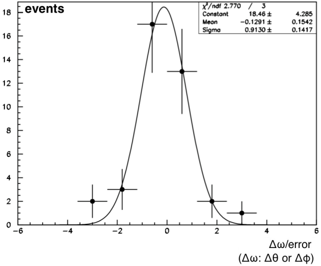

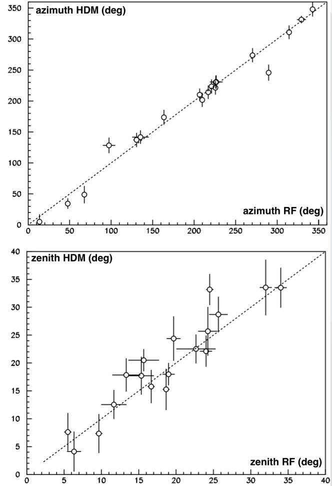

19 events with 2,3 or 4 antenna coincidences compared with HDM's arrival reconstruction

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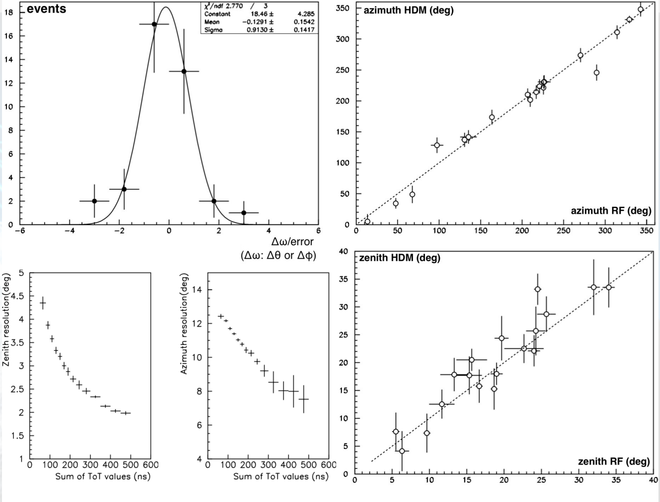

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Reconstruction of main shower parameters - Tools

- **Positions of counters and antennas of station-A.**

Station	HDM position (x,y,z) (m)	RF position (x,y,z) (m)
A	(41.2, -64.4, 0.5) (35.4, -84.7, 0.3) (12.6, -66.2, 0.0)	(30.5, -70.6, 0.4) (82.1, -58.3, 1.1) (5.1, -70.2, 0.5) (66.8, -93.7, 1.0)

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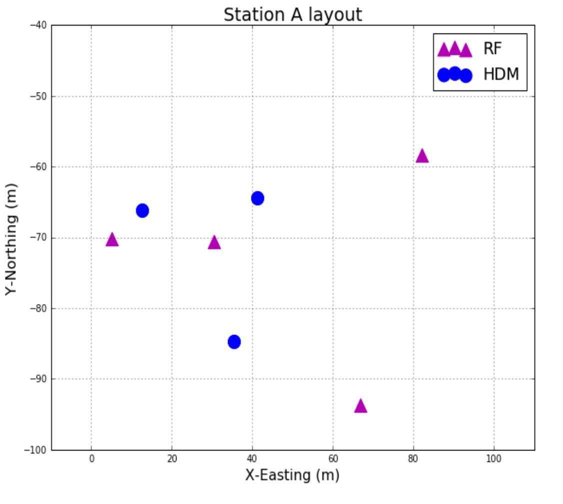

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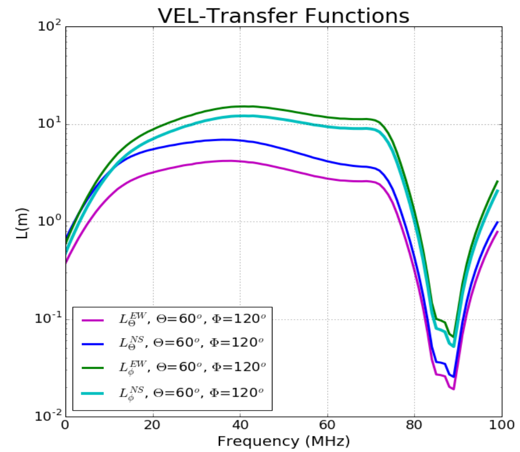

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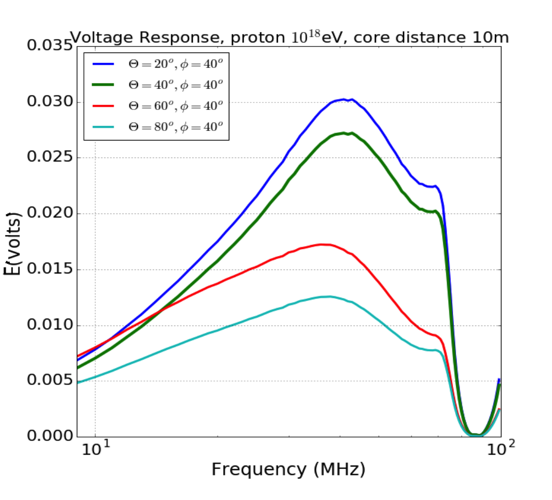

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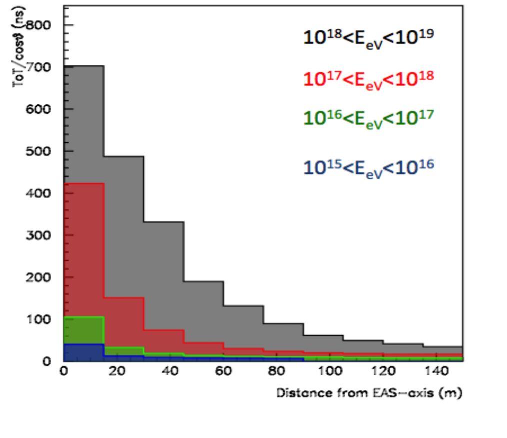

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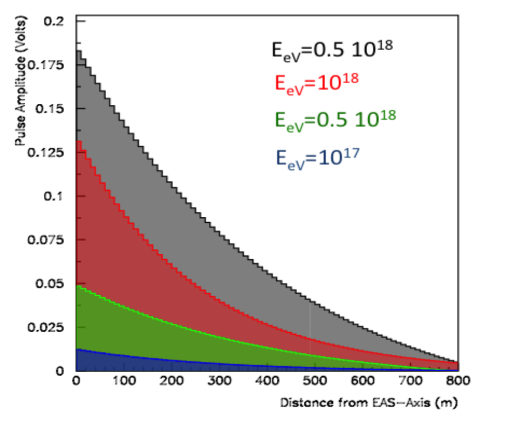

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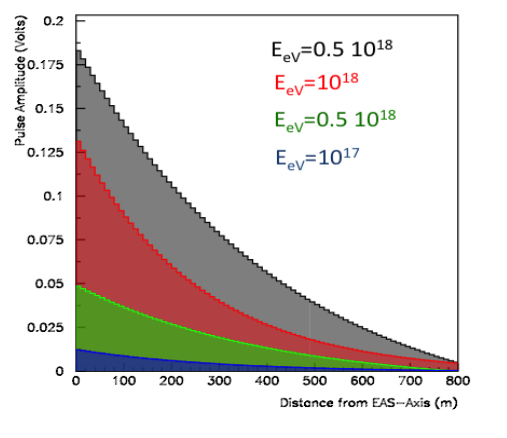

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- **RF data + simulations $\rightarrow$ core, energy, X_{max} with 4 antennas.**

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- **Simulation of 60 showers for the virtual array for realistic X_1, X_{max}**
  - **40 protons + 20 iron nuclei.**
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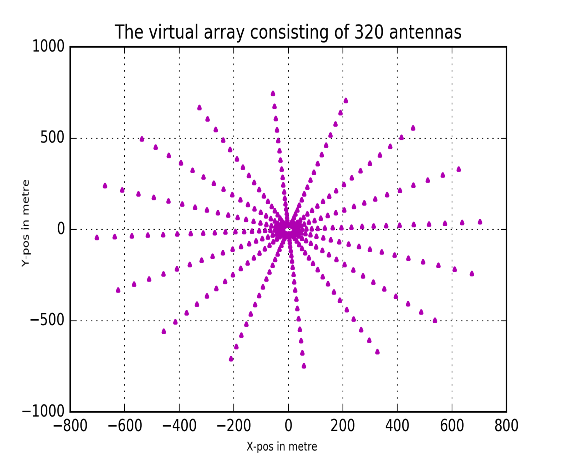
  - **primary energy: 1EeV, fix core (0,0).**



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$$\chi^2(x_c, y_c, E, X_{\max}) = \sum_{k=1}^{4} \left(\frac{V_{\exp}(x_c, y_c, E, X_{\max}) - V_{meas}}{\sigma} \right)^2$$

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- Energy of the shower enters as a scaling parameter α.
- Plot $\chi^2 = f(X_{max})$ for all 60 simulations. The minimum of the plot corresponds to reconstructed X_{max}.

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$$(\chi^2, a, X_{max})_i$$

Test the method with simulated events

- **Simulated event true**

  parameters: $E = 0.8EeV$,

  $\theta = 20^0$, $\phi = 40^0$,

  primary=p**, core**

  $(x_c = 50m, y_c = -120m)$,

  $X_{max} = 720gr/cm^2$

Test the method with simulated events

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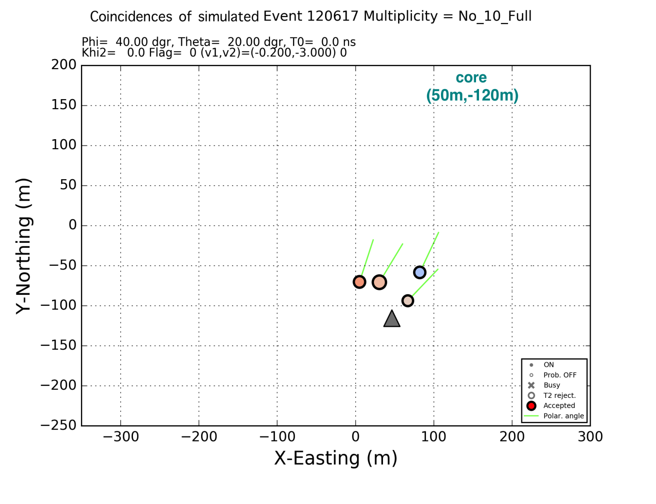

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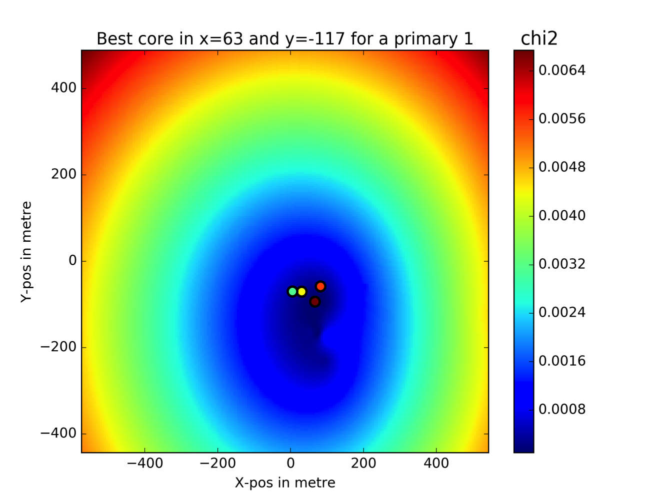

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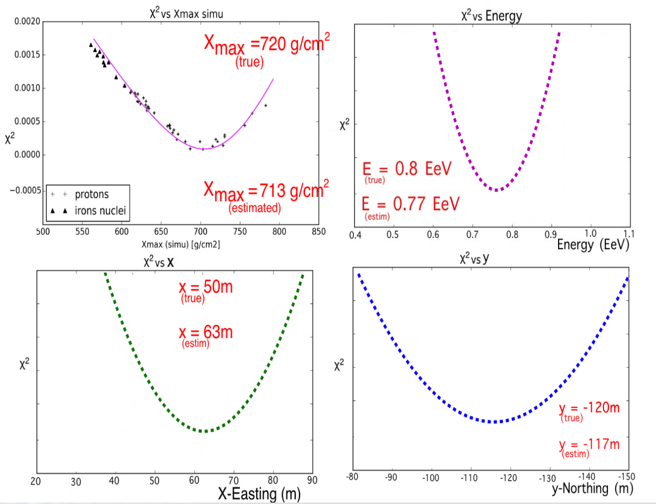

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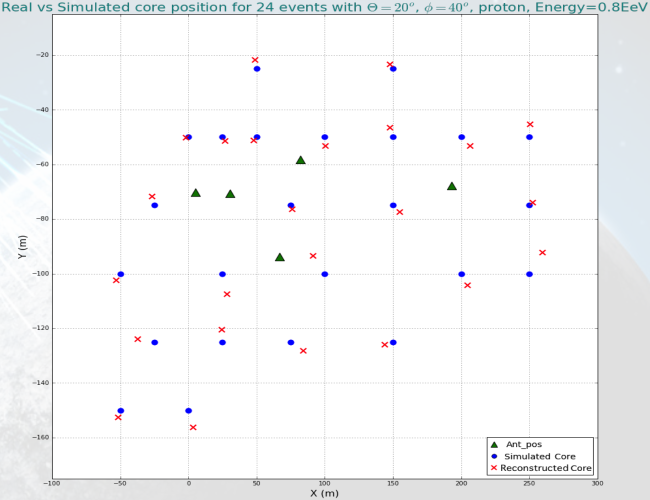

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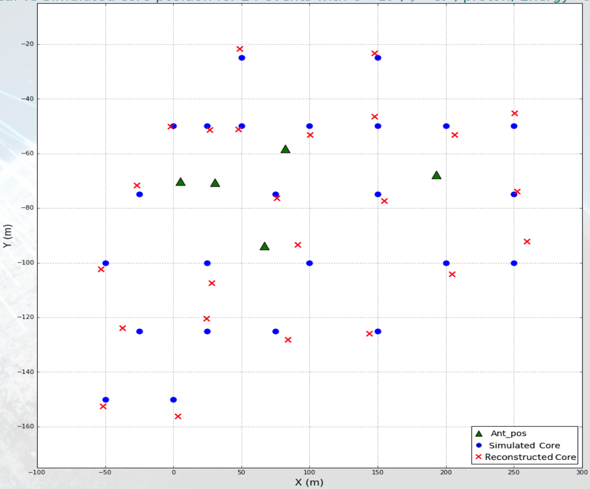
Real vs Simulated core position for 24 events with $\Theta = 20^o$, $\phi = 40^o$, proton, Energy=0.8EeV



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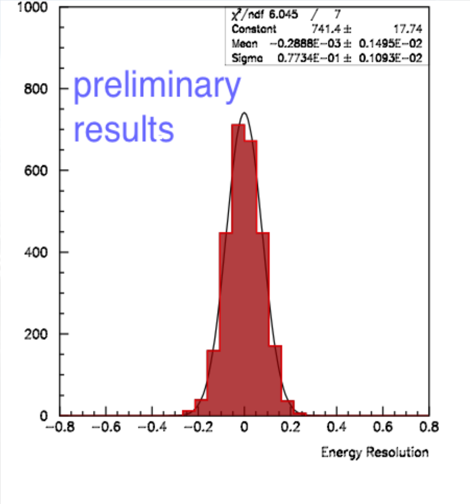

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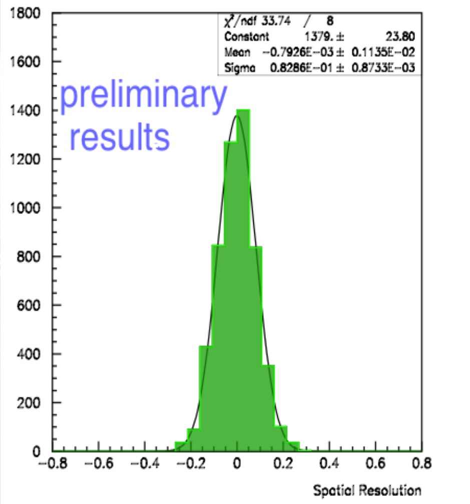

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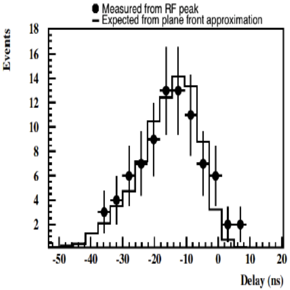

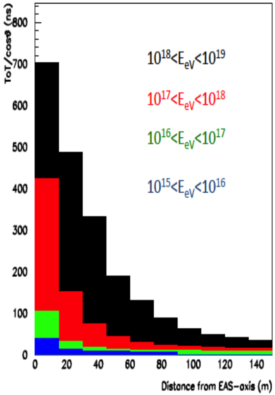

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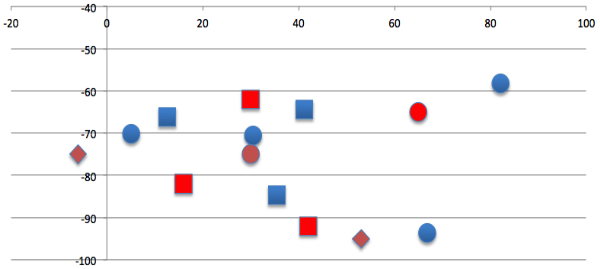
- **The HOU group has designed a low cost station with 3 SDM and 2 RF antennas (3SDM-2RF) station which is under calibration tests. The station is positioned at the same area as station A.**



Outline

1. Cosmic Rays - Extensive air Showers (EAS)
2. Radio Emission
3. ASTRONUE Array
4. HDM's Performance
5. Event Selection-RF Analysis
6. Correlation Study and Combined Performance
7. Reconstructing EAS direction using RF signal from one antenna
8. Core-Energy-X_{max}
9. **Conclusions and future work**

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