

# *Polarization Measurements of the Radio Emission of Cosmic Ray Air Showers with LOPES*



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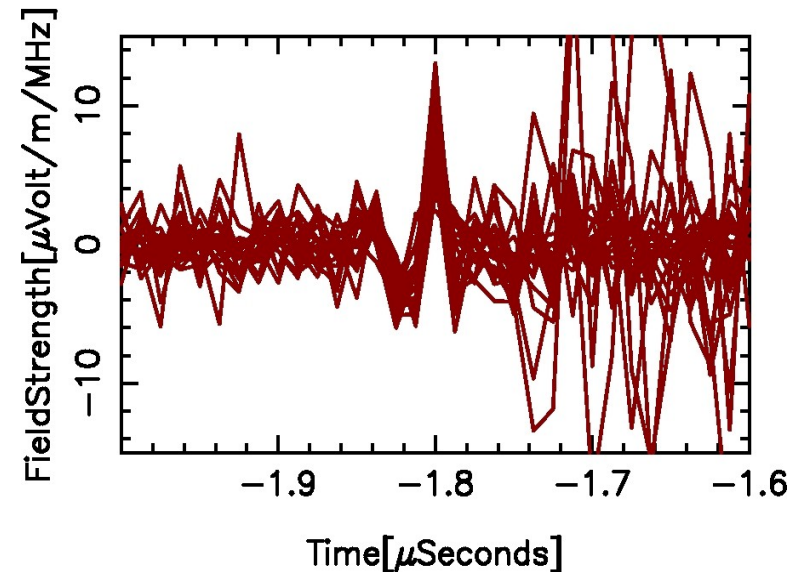
ARENA 2008, Roma, Italy

# Polarization Measurements

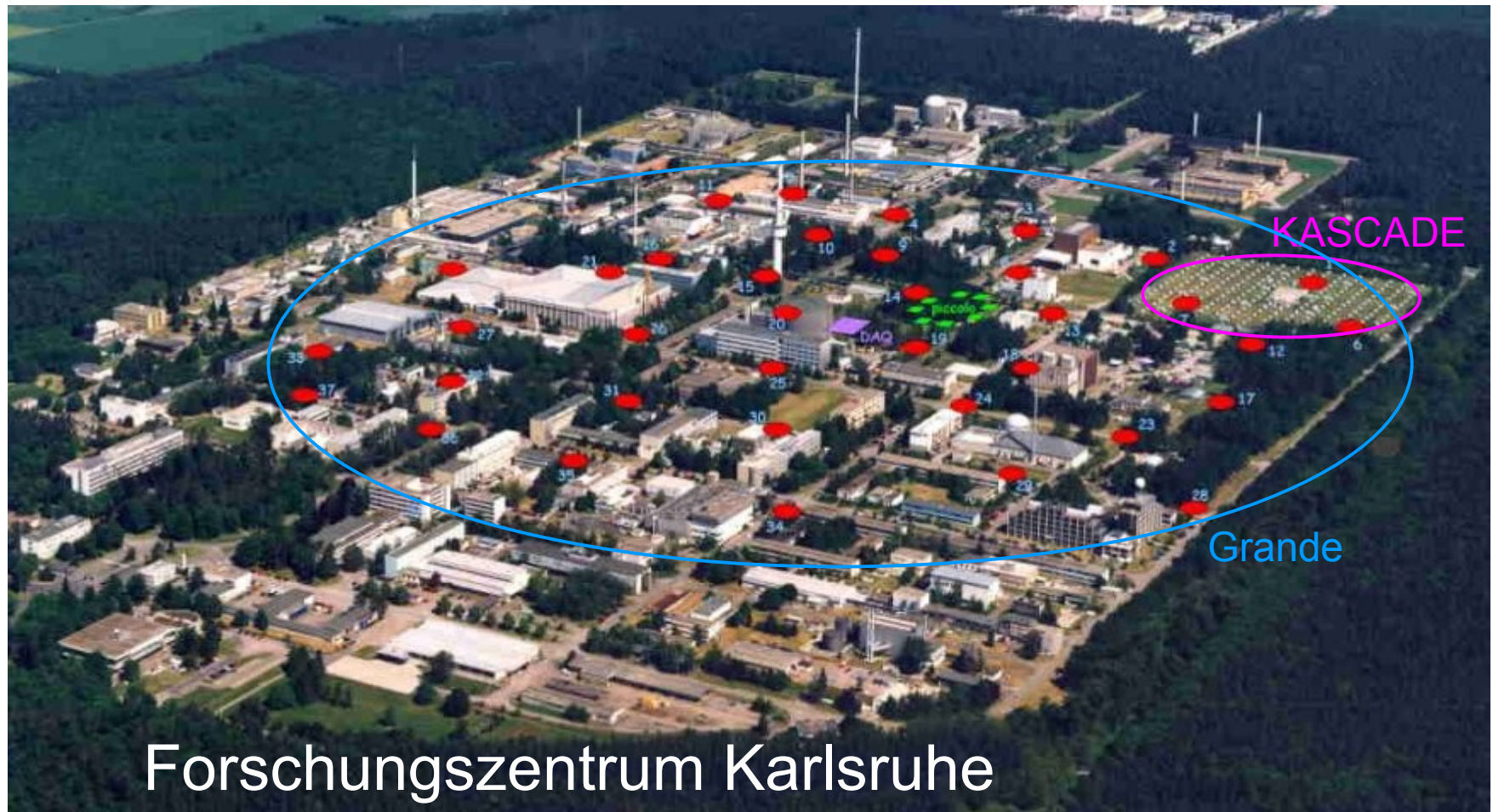
## Motivation:

- Initially, all 30 antennas of the LOPES experiment were aligned to measure the East-West polarization direction of the air shower radio emission only.
- End of 2006, for recording the full radio signal, LOPES30 has been reconfigured to perform polarization measurements.
- Polarization measurements provide the 'tool' that can verify the geosynchrotron mechanism of the radio emission in air showers.

Isar et al., ARENA'06:  
First measurements with LOPES30



# LOPES at the KASCADE-Grande Array



# Polarization Configuration

**Location:** most antennas inside the original KASCADE array

**Configuration:**

5 EW+NS oriented antennas

[28+27, 21+29, 22+30, 5+6, 19+20]

10 NS oriented antennas

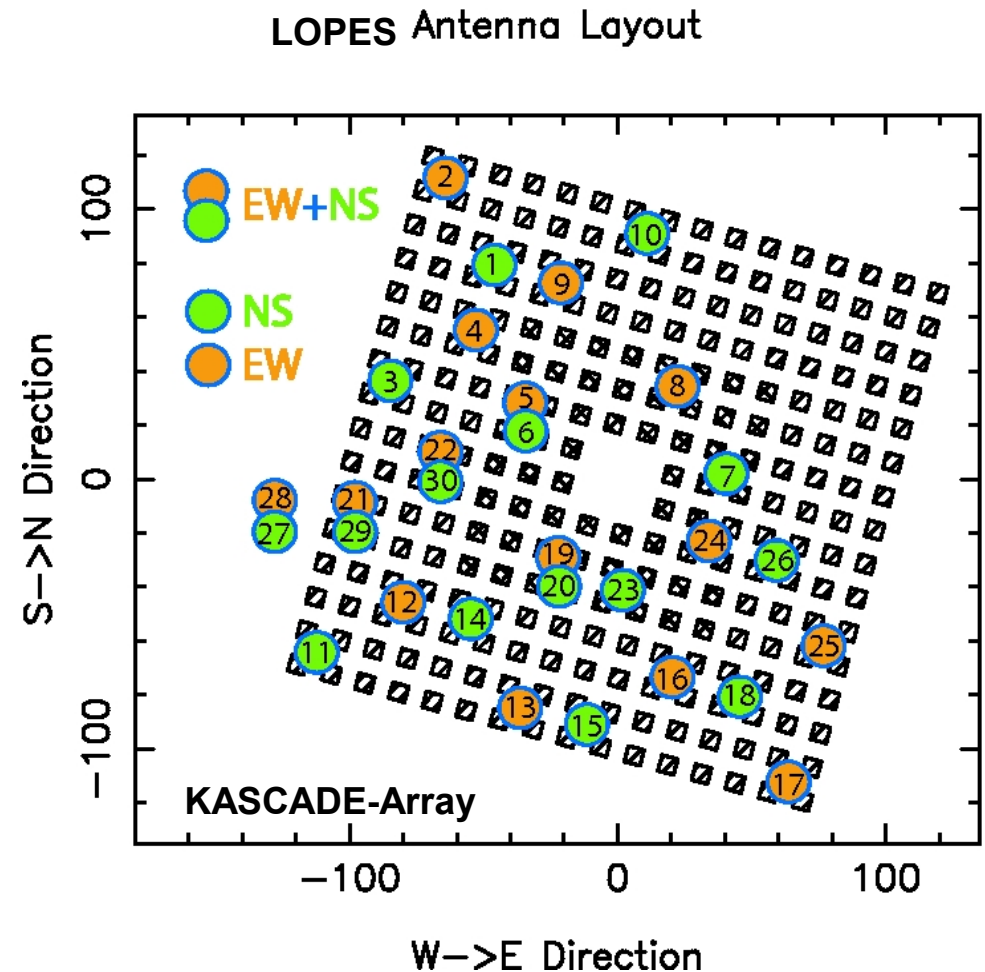
[1, 3, 7, 10, 11, 14, 15, 18, 23, 26]

10 EW oriented antennas

[2, 4, 8, 9, 12, 13, 16, 17, 24, 25]

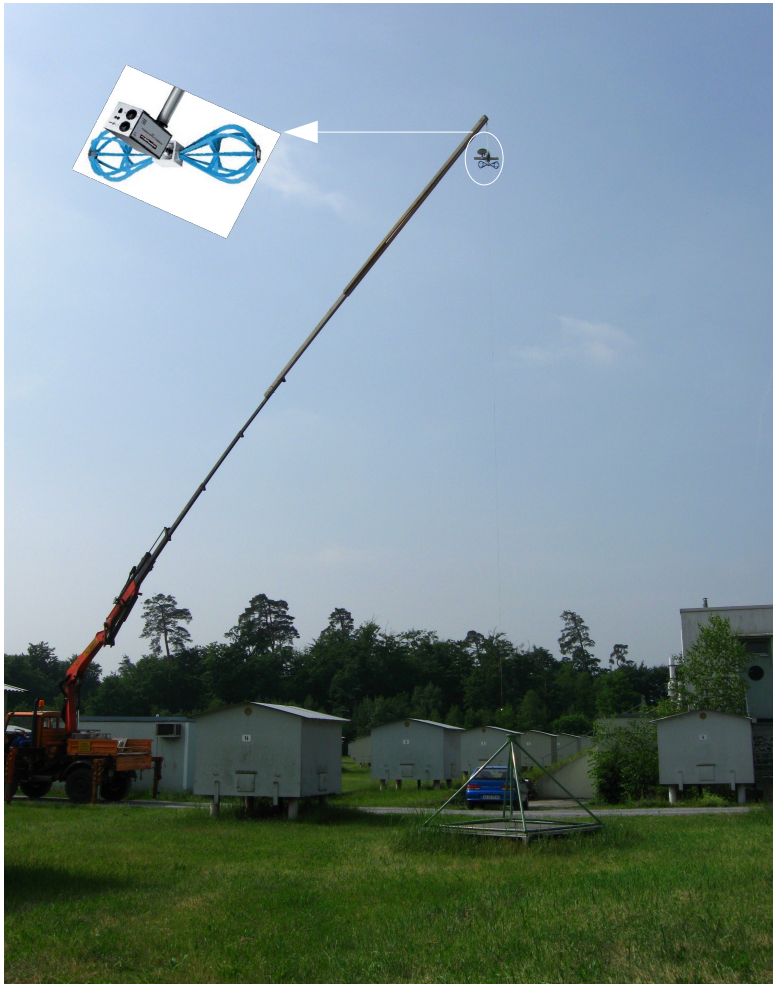
**Trigger sources:**

KASCADE and KASCADE-Grande

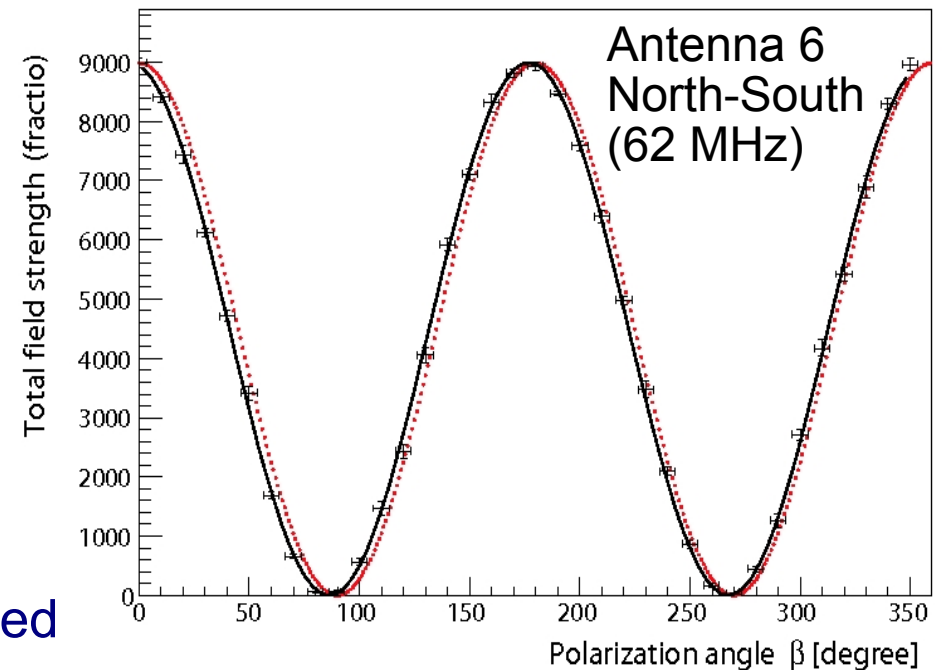
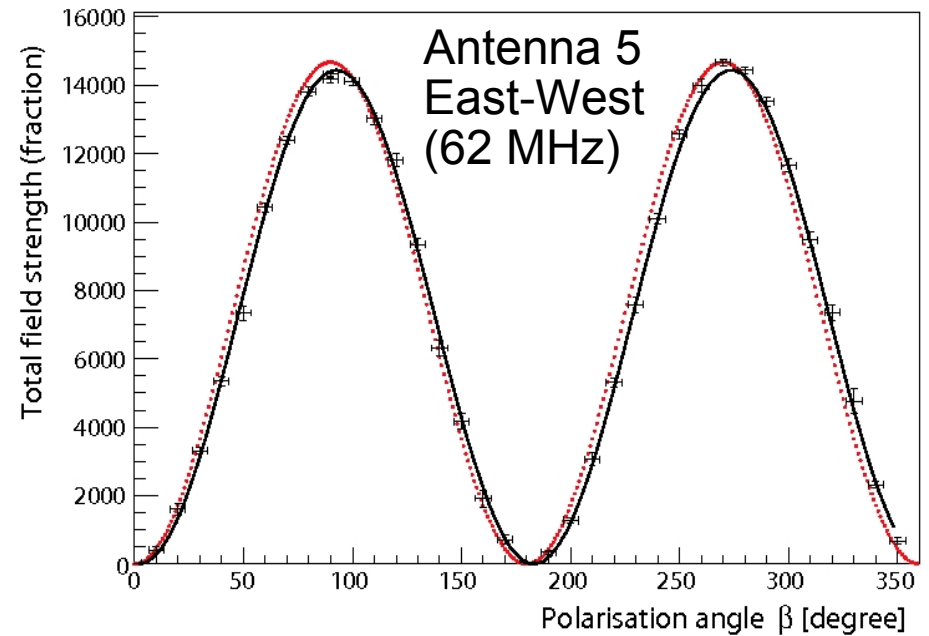




# Amplitude Calibration



- > LOPES antennas are sensitive to the polarization direction where they are oriented
- > no cross-talk between channels

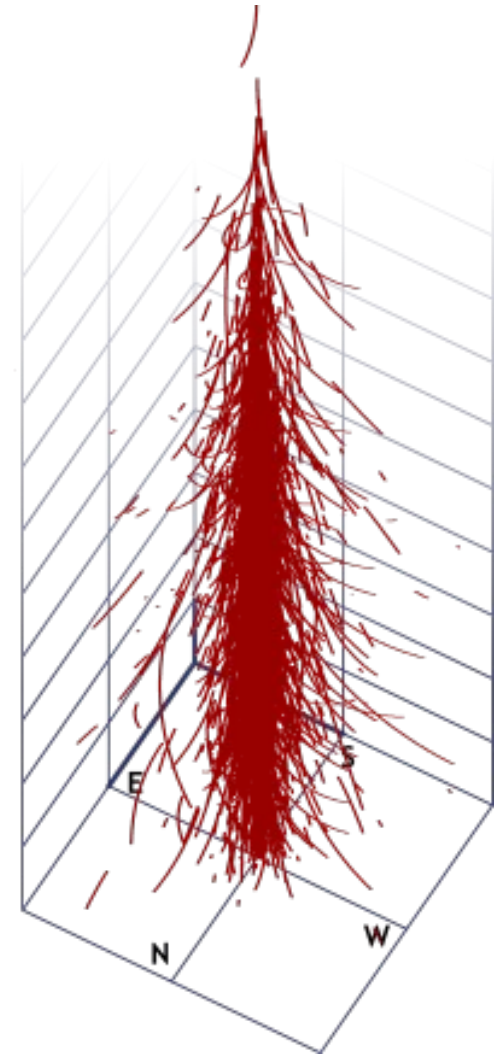


# Theoretical Predictions

What simulations tell us:

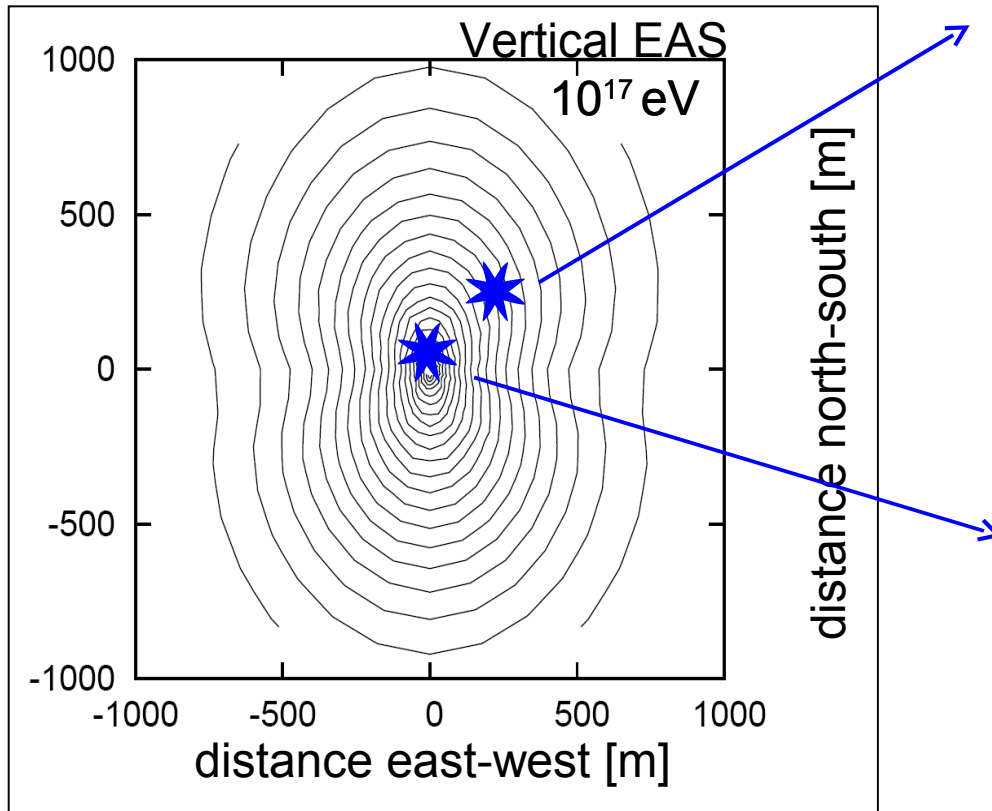
[by T. Huege et al]

- highly linearly polarized radio emission
- signal usually present in both polarization components: East-West and North-South
- polarization directly related with the shower azimuth for a given zenith angle (see actual analysis)
- dependence of the signal on the position of the observer relative to the incoming shower (see next for illustration)

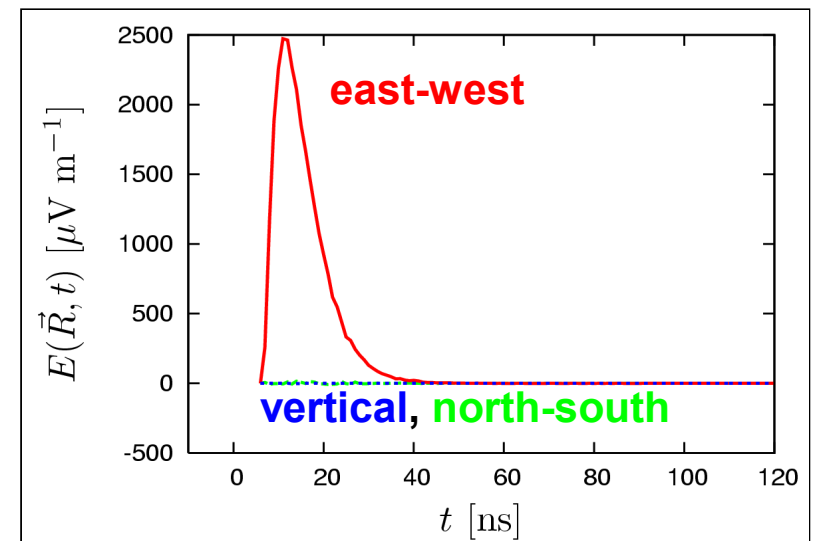
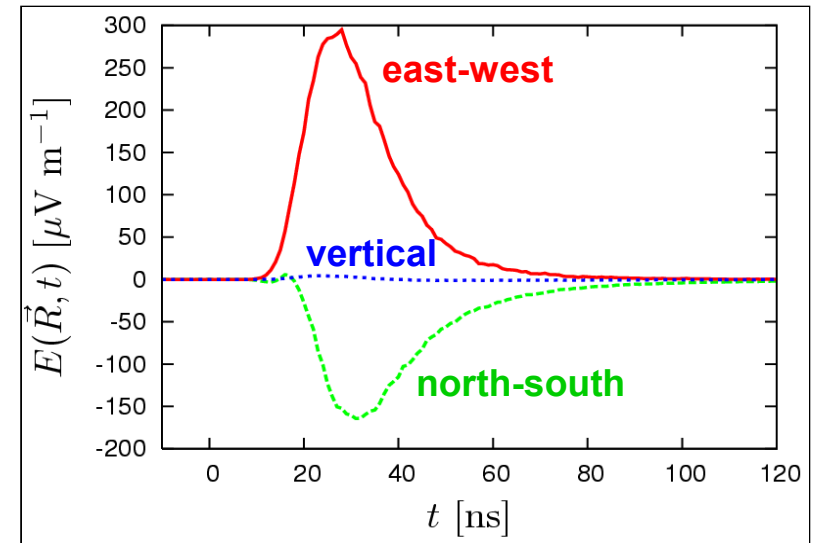


# Simulated Pulse Example

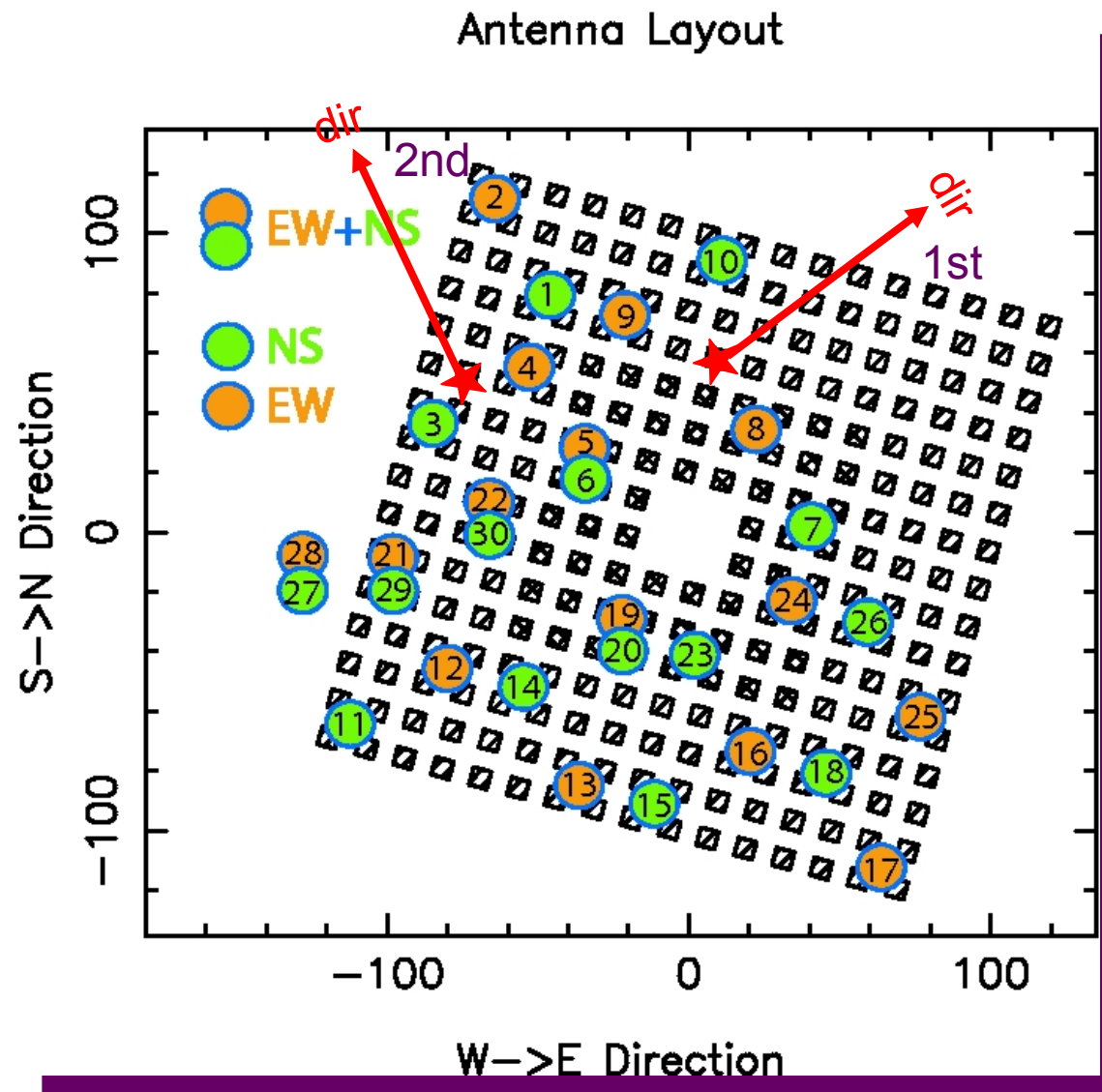
45° inclined air shower, total field strength at 10MHz



Huege & Falcke, AstropPhys 24 (2005)  
116-136



# Measured Event Examples

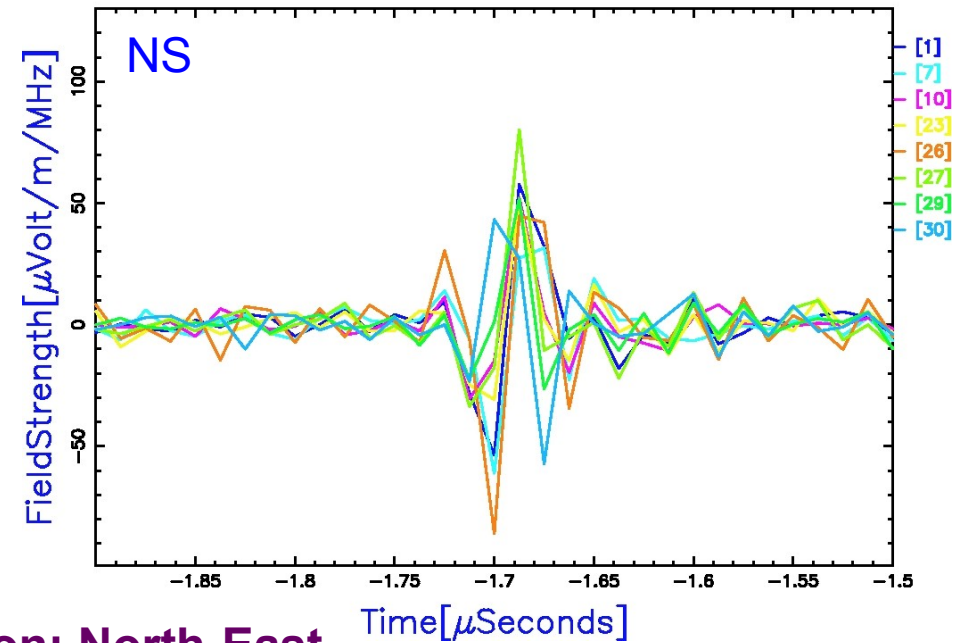
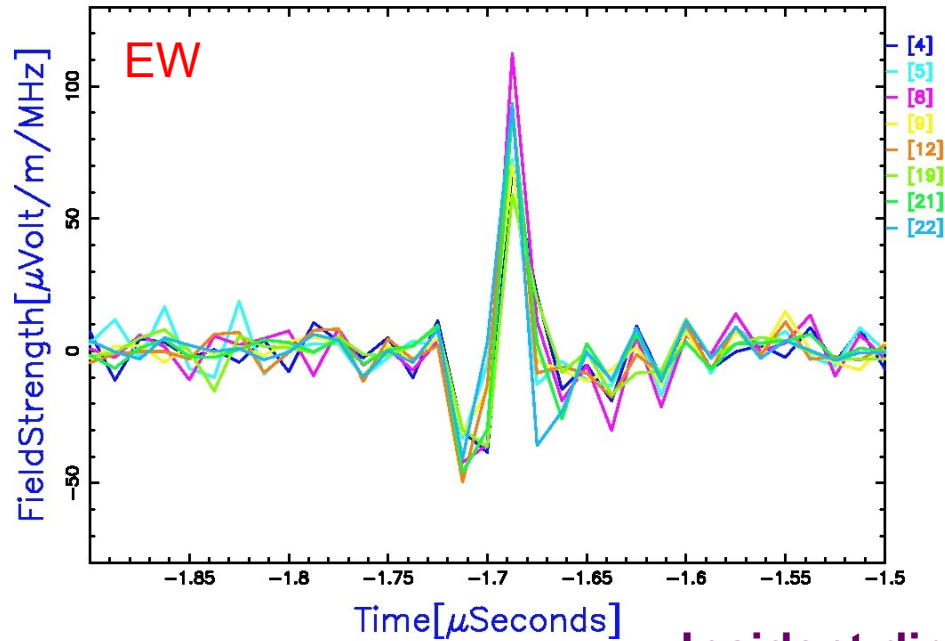




$\phi=51.18^\circ$ ,  $\theta=66.44^\circ$ , Geo-Angle:  $83^\circ$ ,  $\log(N_e)=5.3$ ,  $\log(N_\mu)=5.4$ ,  $E_p(\text{estimate})=1.8 \times 10^{18}$  eV

[4]Event1166245311-10202

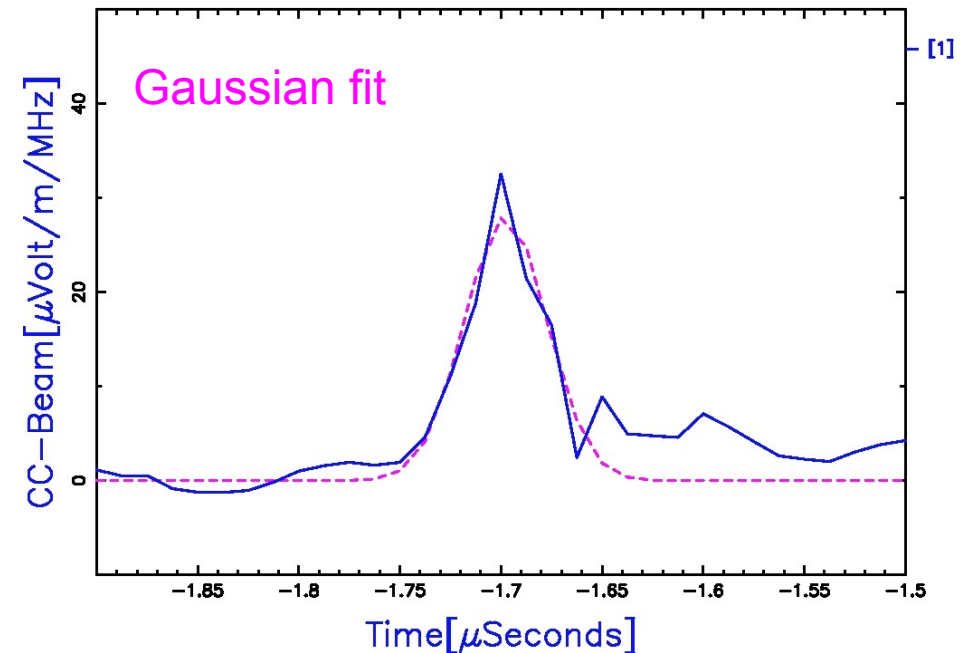
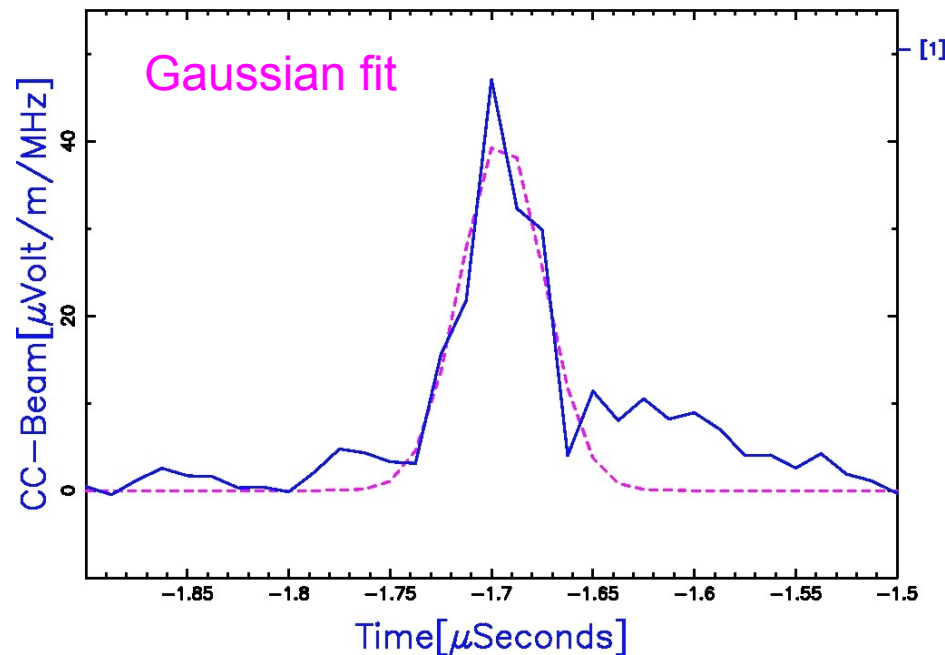
[1]Event1166245311-10101



**Incident direction: North-East**

[1]Event1166245311-10101

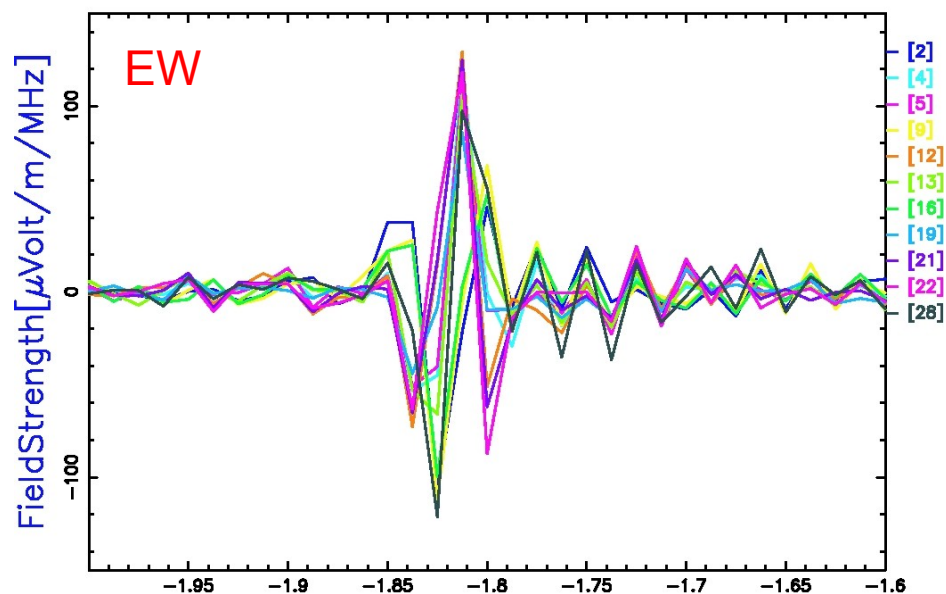
[1]Event1166245311-10101



Ref: Isar et al, ICRC'07

$\phi=332.7^\circ$ ,  $\theta=54.2^\circ$ , Geo-Angle:  $77^\circ$ ,  $\log(N_e)=5.8$ ,  $\log(N_\mu)=5.4$ ,  $E_p(\text{estimate})=2.9 \times 10^{17}$  eV

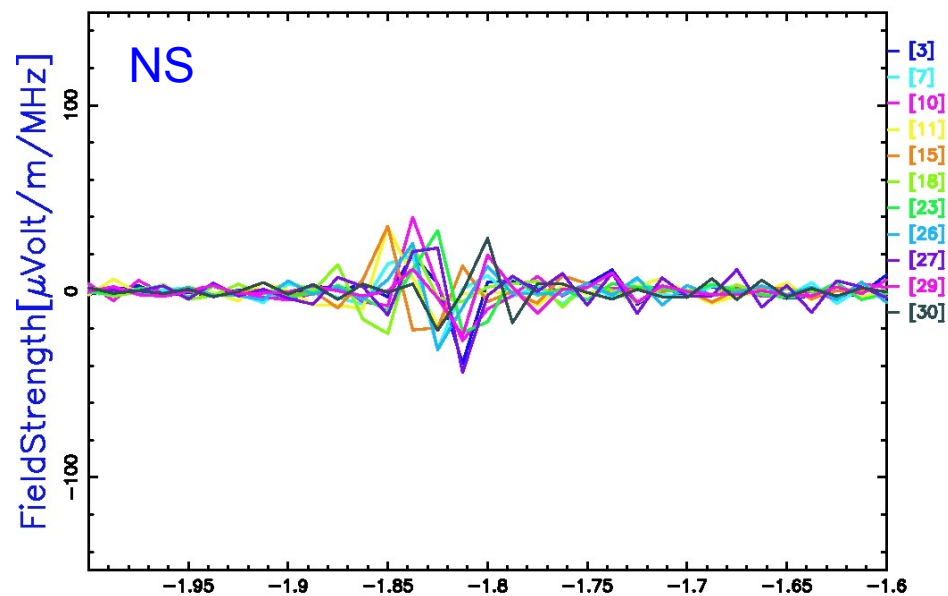
[2]Event1166725345-10102



Time[ $\mu\text{Seconds}$ ]

[1]Event1166725345-10101

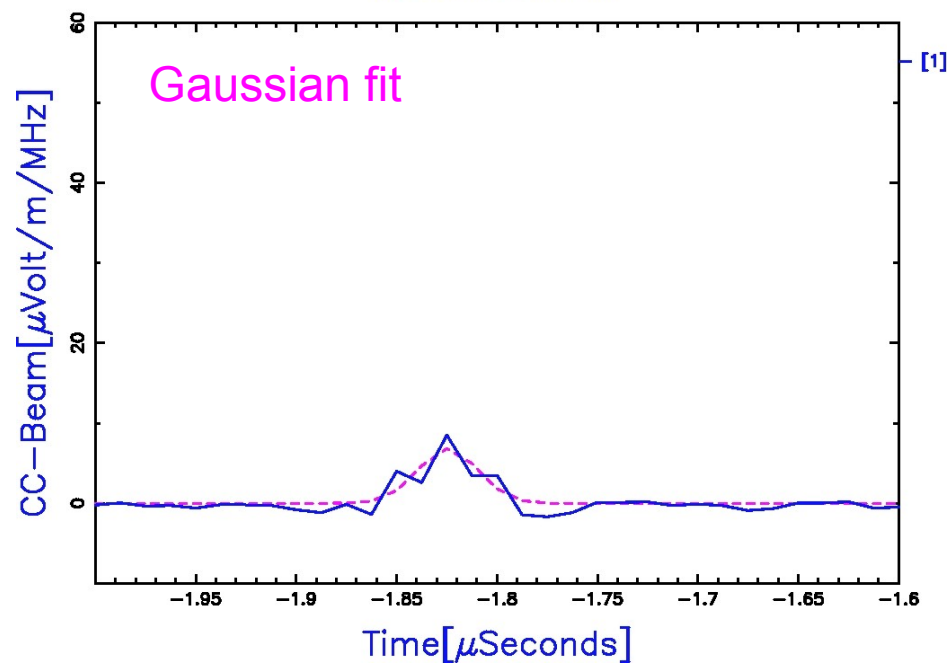
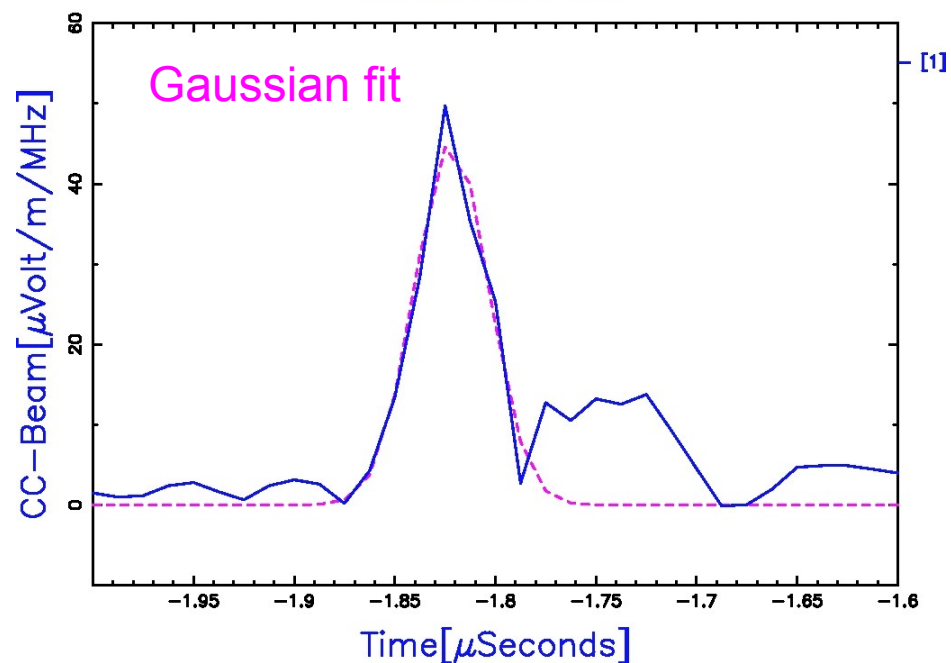
[3]Event1166725345-10201



Time[ $\mu\text{Seconds}$ ]

[1]Event1166725345-10101

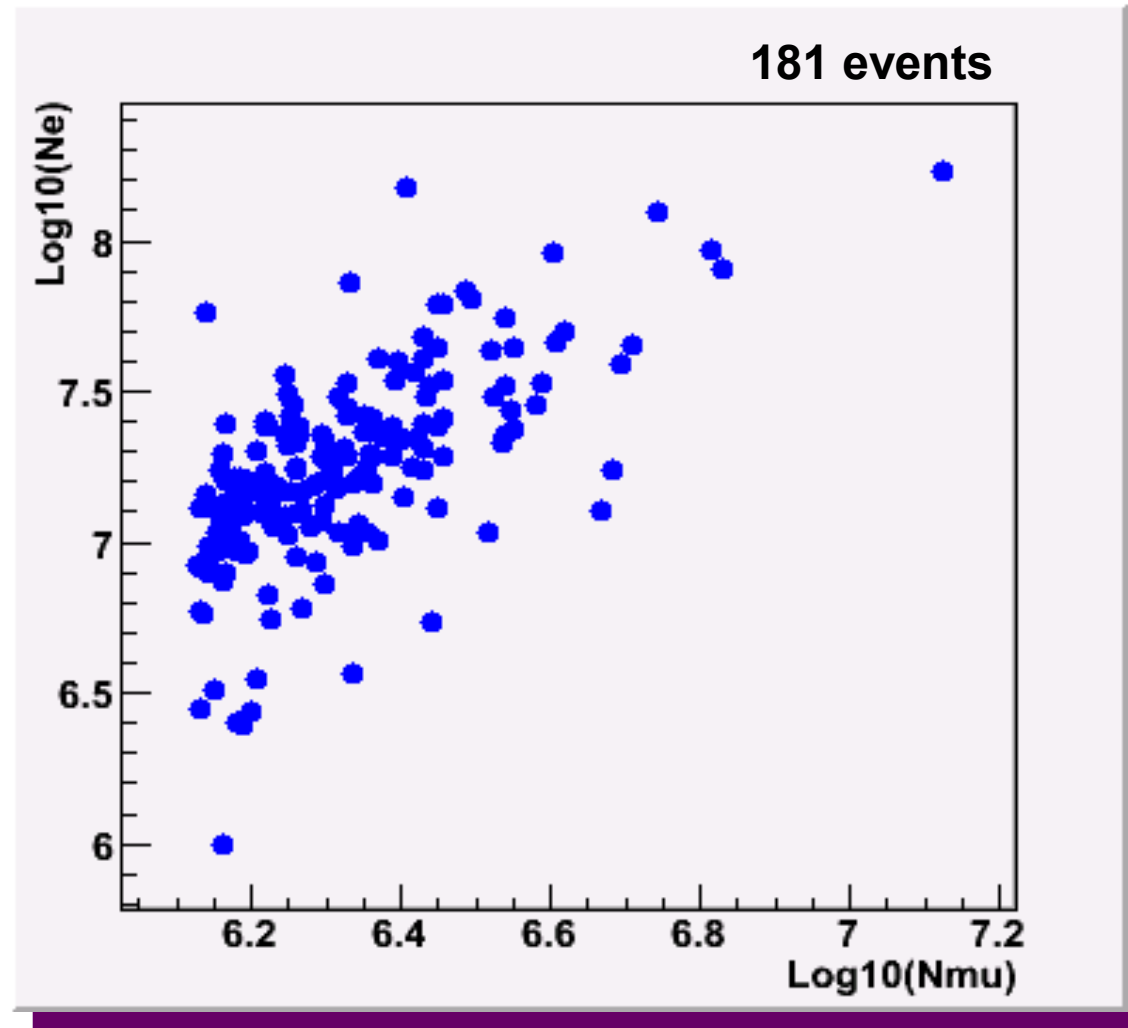
Incident direction: North



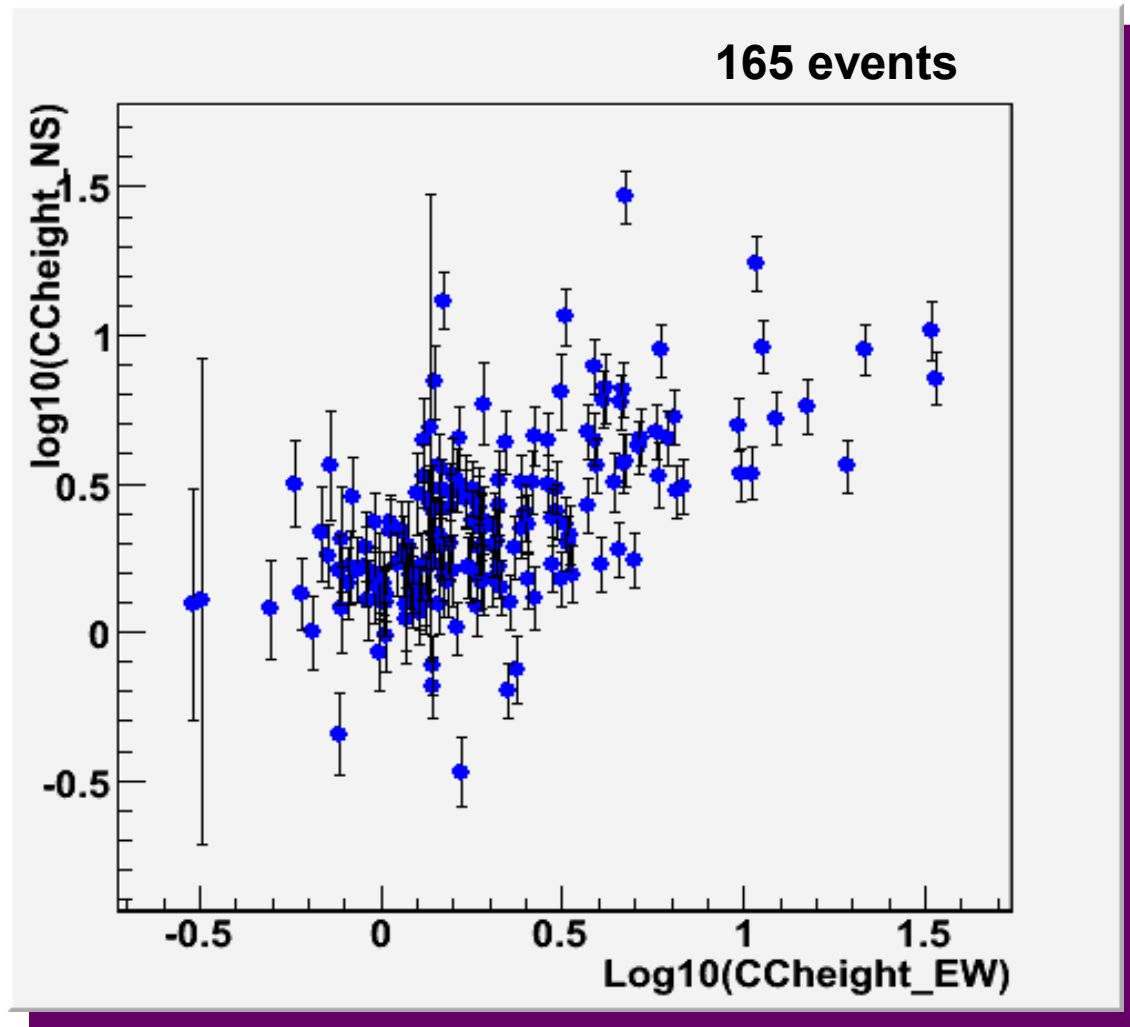
Ref: Isar et al, ICRC'07

# Analysis

- 1) analysed events so far: Dec. 2006 – Aug. 2007
- 2) selection: well-reconstructed by KASCADE - Grande:  $\theta < 50^\circ$ ,  $\log(N_\mu) > 6.1$

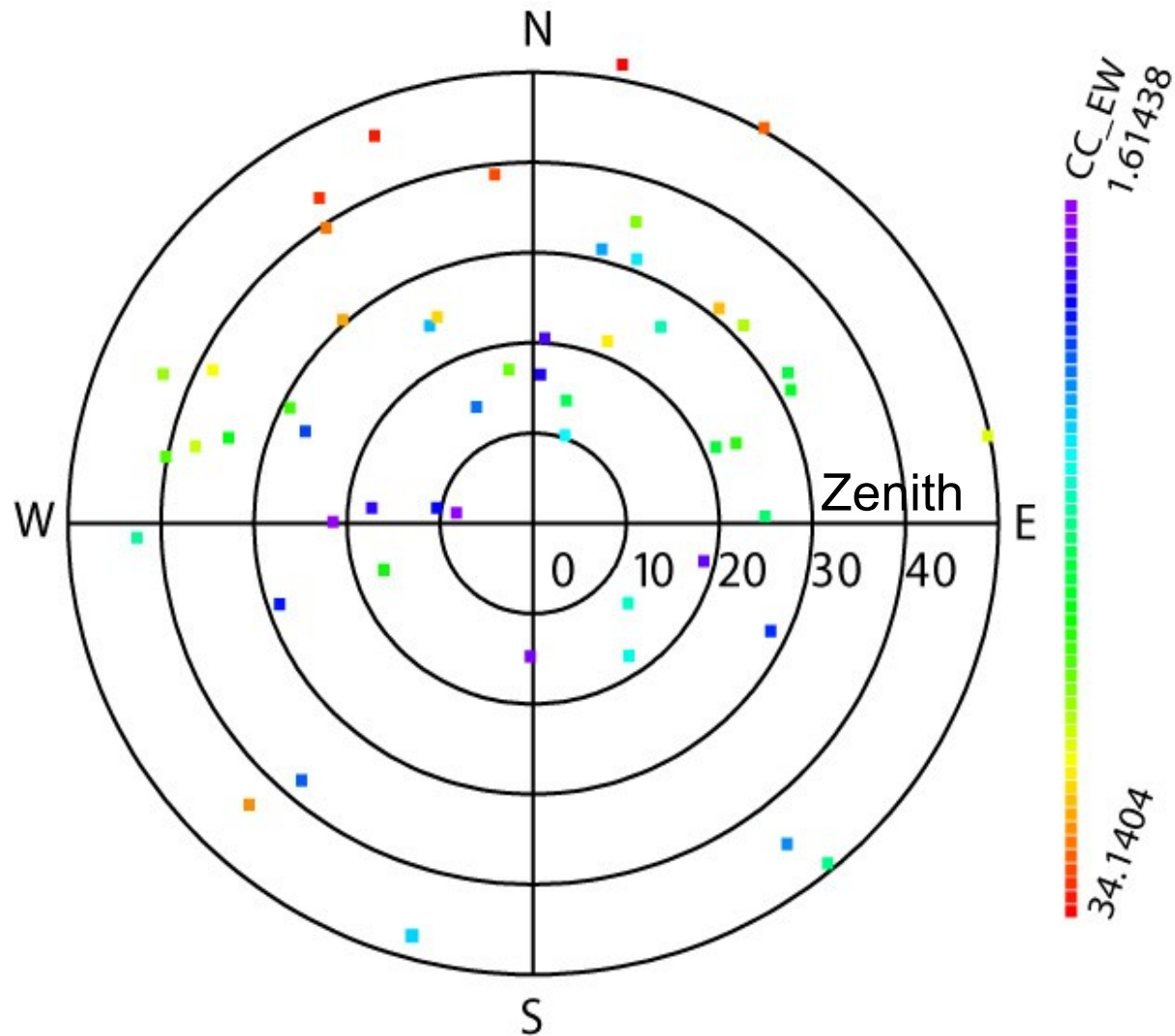


- 3) complete pipeline applied for each EW and NS channel, to calculate the CC-beam in EW and NS polarization components independently



#### 4) Detection

- I. East-West polarization: 52 events  
(CC\_EW-beam>1.5, good\_EW coherence)

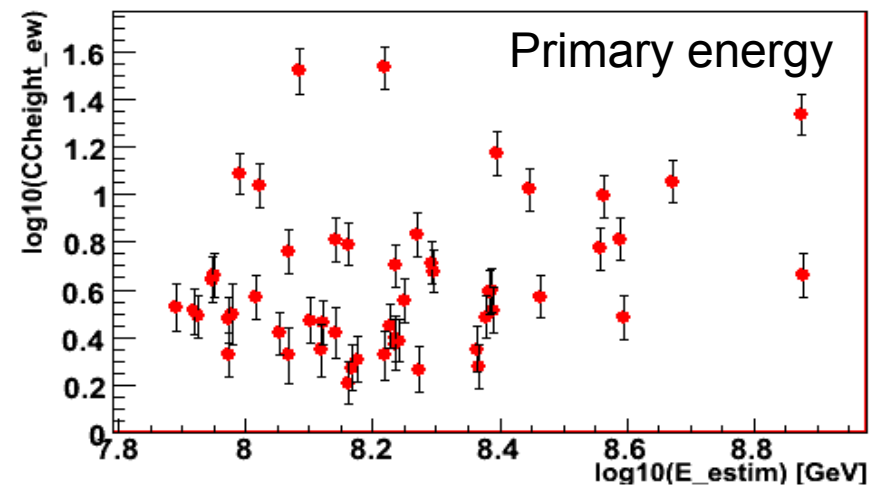
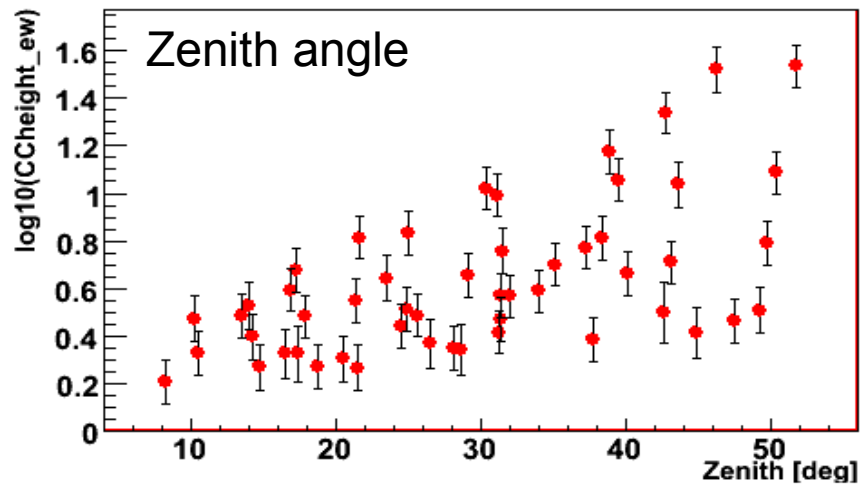
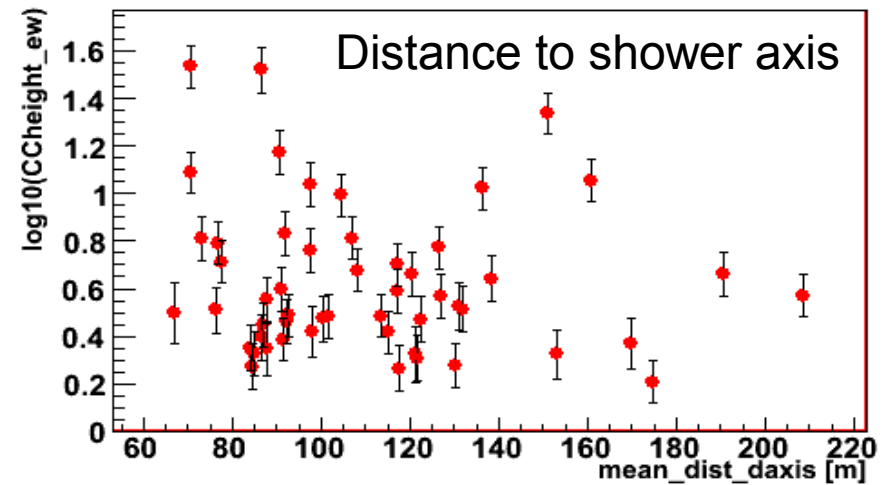
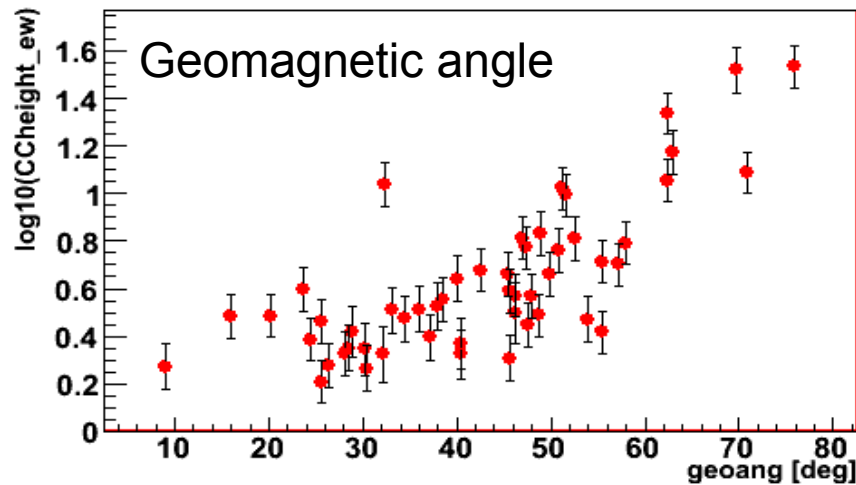


Largest E-W polarized signals detected for showers coming from North



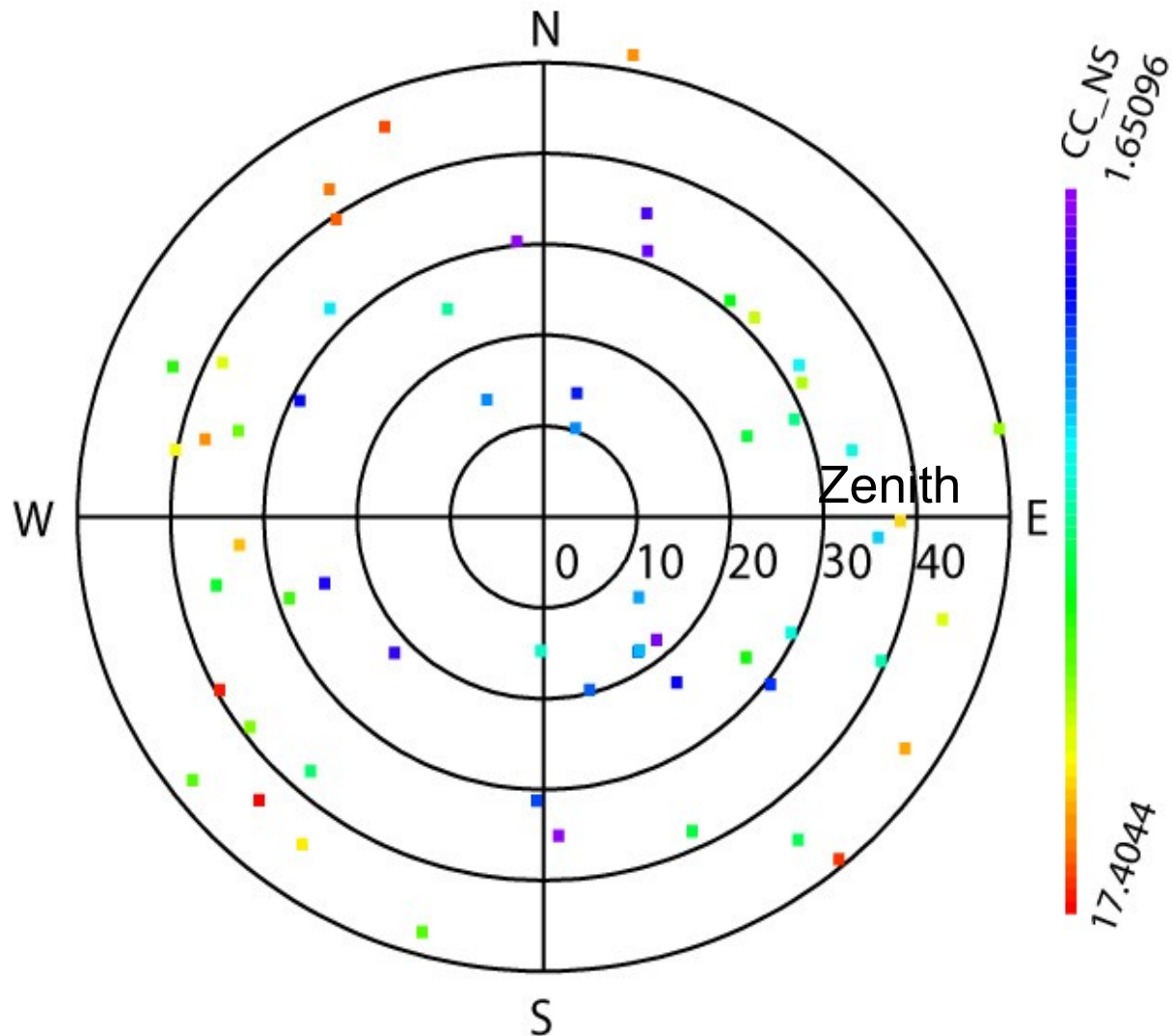
## 5) (unmodified) pulse height correlations with air shower parameters

### I. East-West polarization component



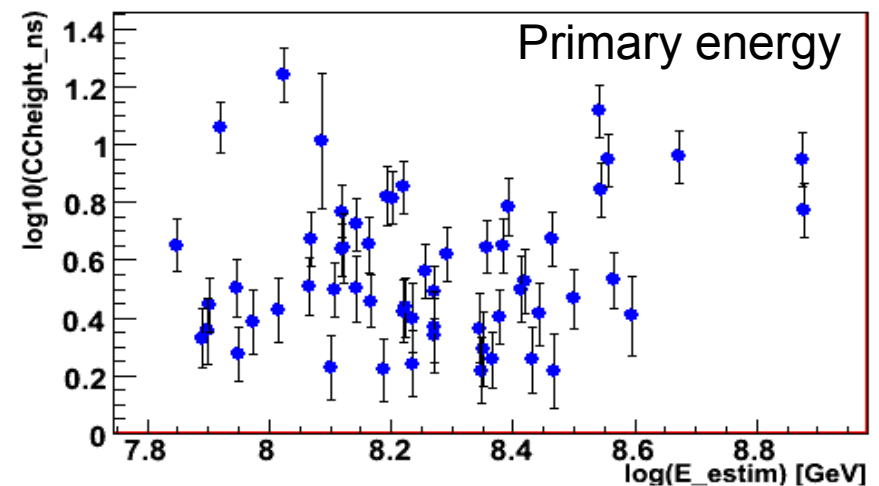
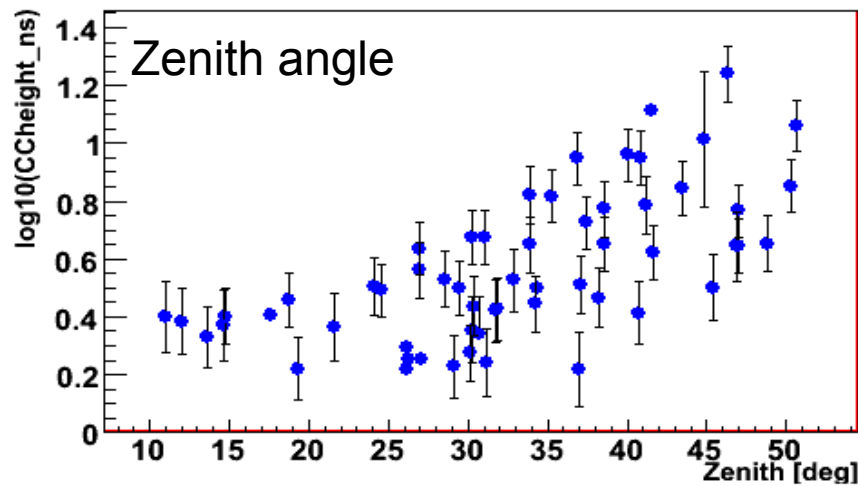
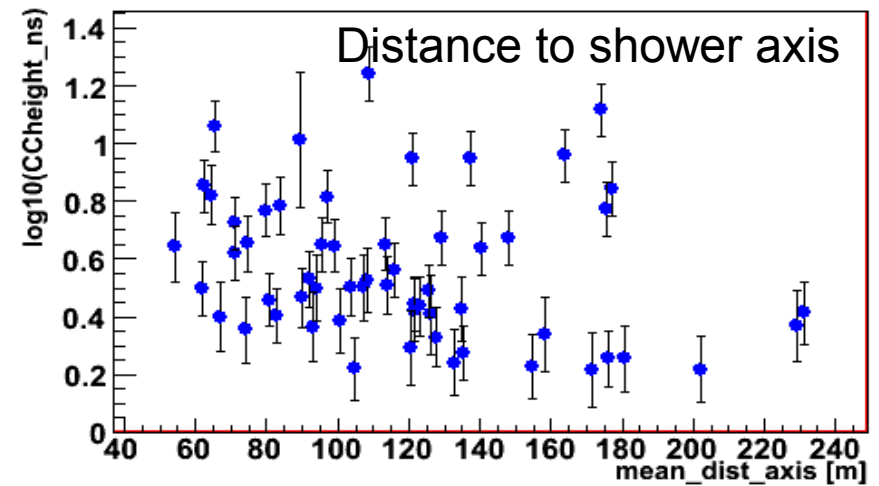
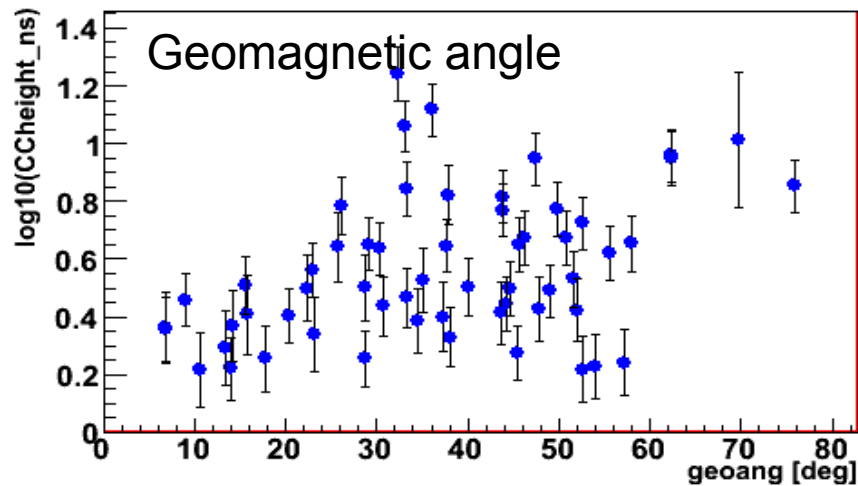
Normal LOPES events

II. North-South polarization: 58 events  
(CC\_NS-beam>1.5, good\_NS coherence)



Largest N-S polarized signals detected for showers coming from West or East

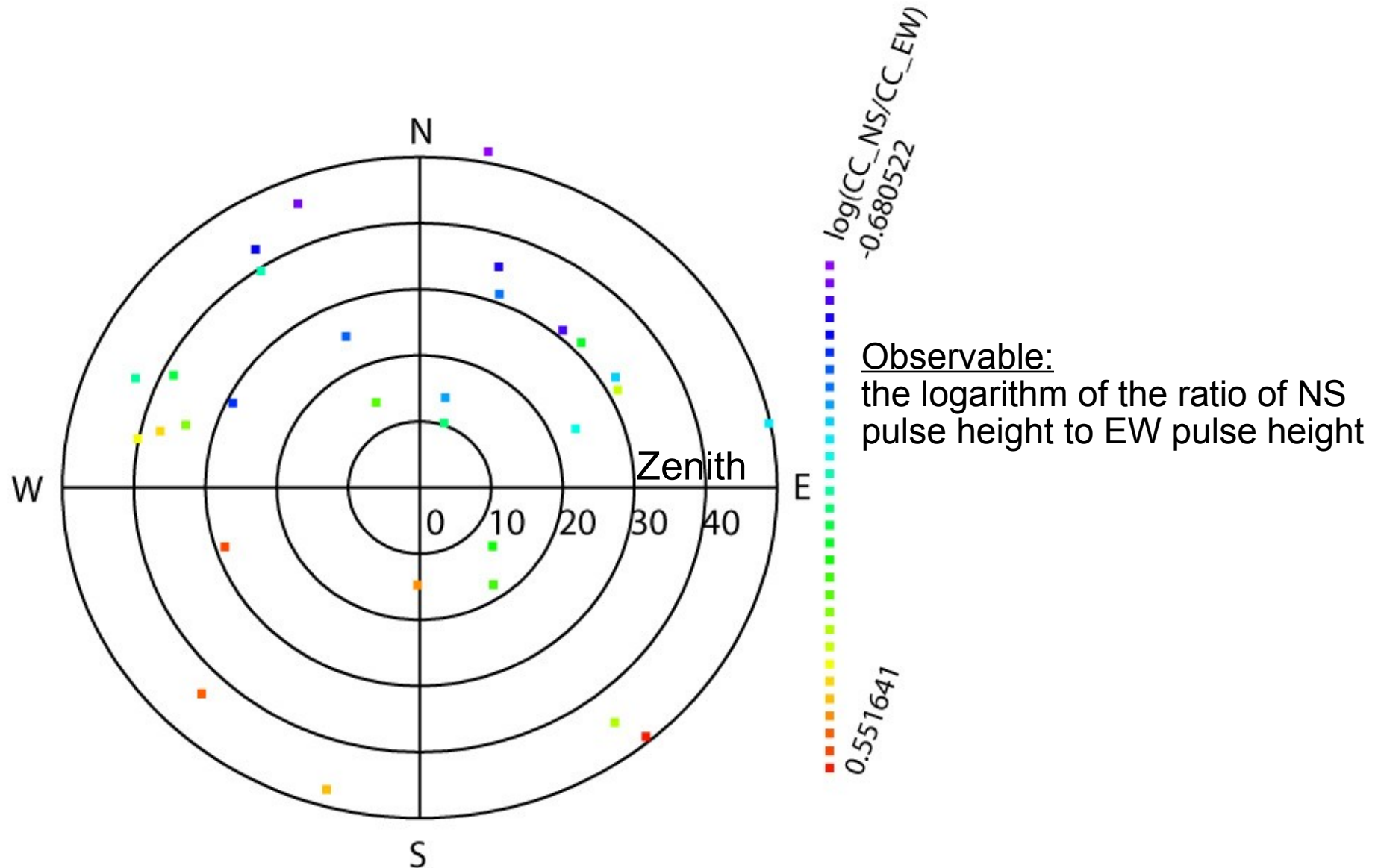
## II. North-South polarization component



Normal correlations with air shower parameters

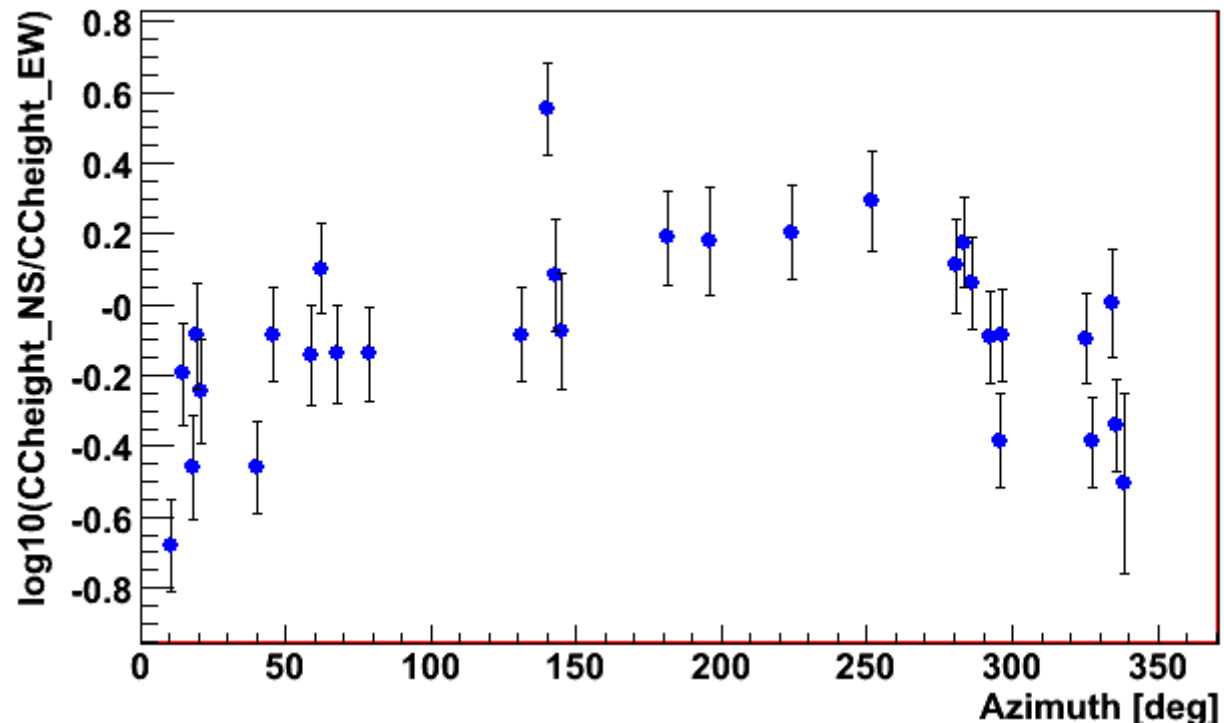
### III. Dual-Polarization: 30 events

CC\_EW-beam>1.5, CC\_NS-beam>1.5, good EW and NS coherence



red: N-S component dominant; blue: E-W component dominant

### III. Dual-Polarization



-> Azimuth dependence of the pulse height ratio!

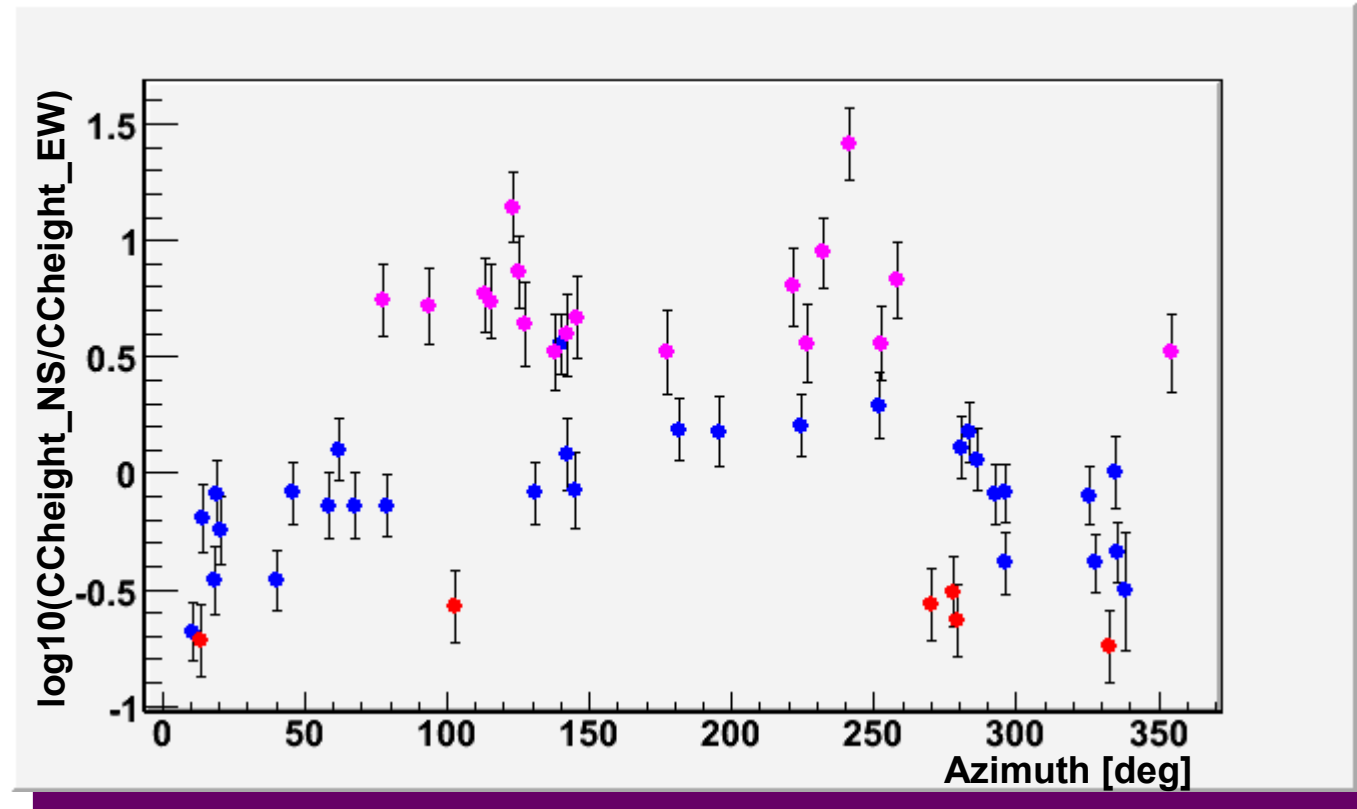
> 0: N-S component dominant

< 0: E-W component dominant



**Pink:**  $CC\_NS > 1.5$ ; good  $NS$  coherence;  $CC\_EW < 1.5$ ;  
value of the  $CC\_EW$  set to 0.5 as upper limit

**Red:**  $CC\_EW > 1.5$ ; good  $EW$  coherence;  $CC\_NS < 1.5$ ;  
value of the  $CC\_NS$  set to 0.5 as upper limit



- > N-S polarization component dominant for showers coming from East and West
- > E-W polarization component dominant for showers coming from North

# Outlook:

- LOPES is performing polarization measurements and allows a much more detailed analysis of the radio events than with measuring the East-West polarization component only.
- The array is absolute amplitude calibrated in order to estimate the electric field strength of the short radio pulse generated in air showers.
- It follows:
  - > analysis of the signal for individual antennas
  - > normalization of the pulse heights to primary energy, distance to shower core, etc.
  - > estimate of the polarization vector of the radio emission in air showers
  - > detailed comparisons with simulations

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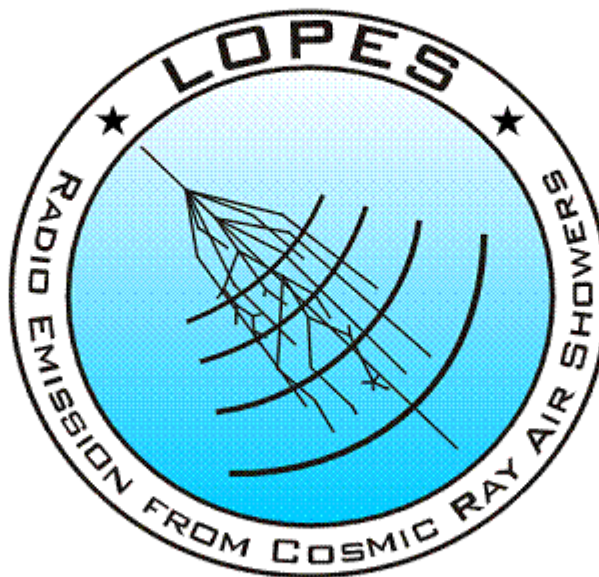
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