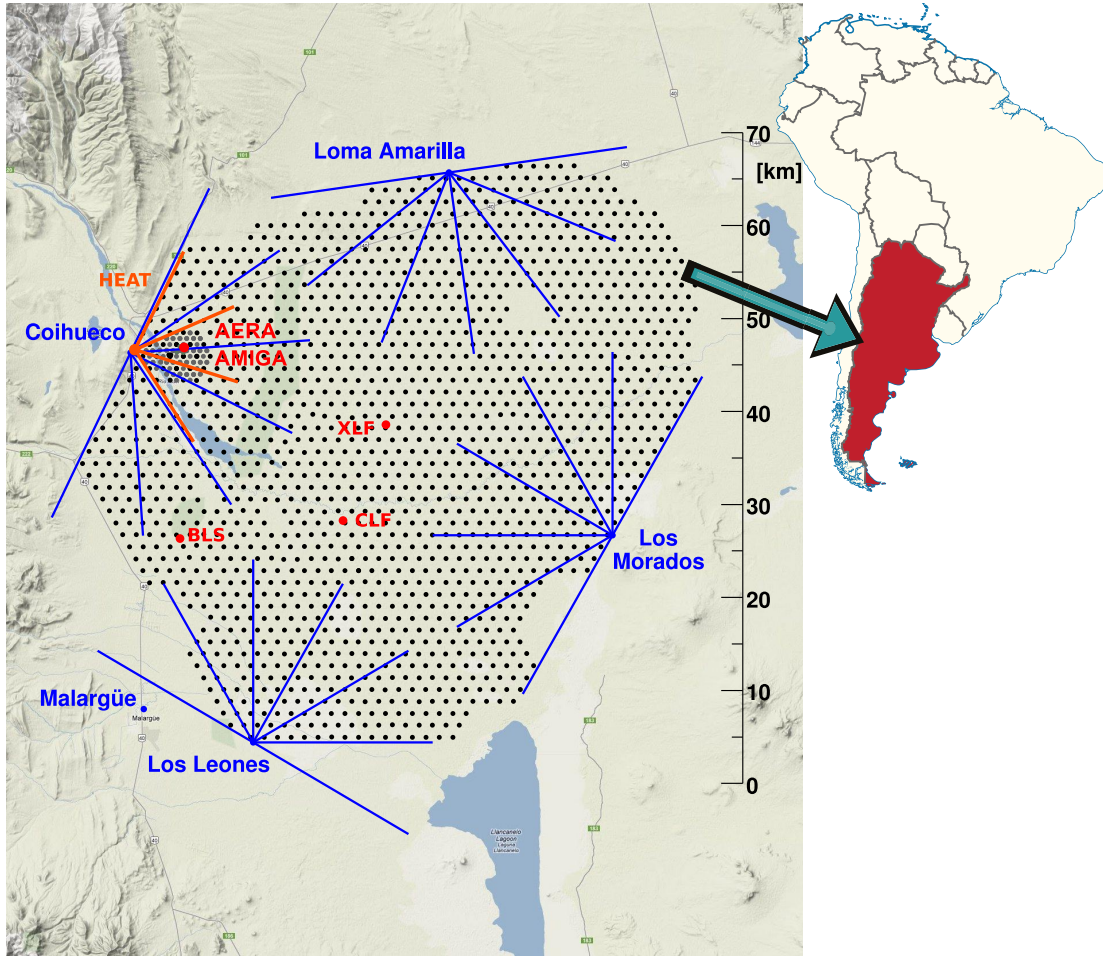
Time calibration of AERA using Airplanes

Andreas Lang for the Pierre-Auger-Collaboration | 13th October 2014

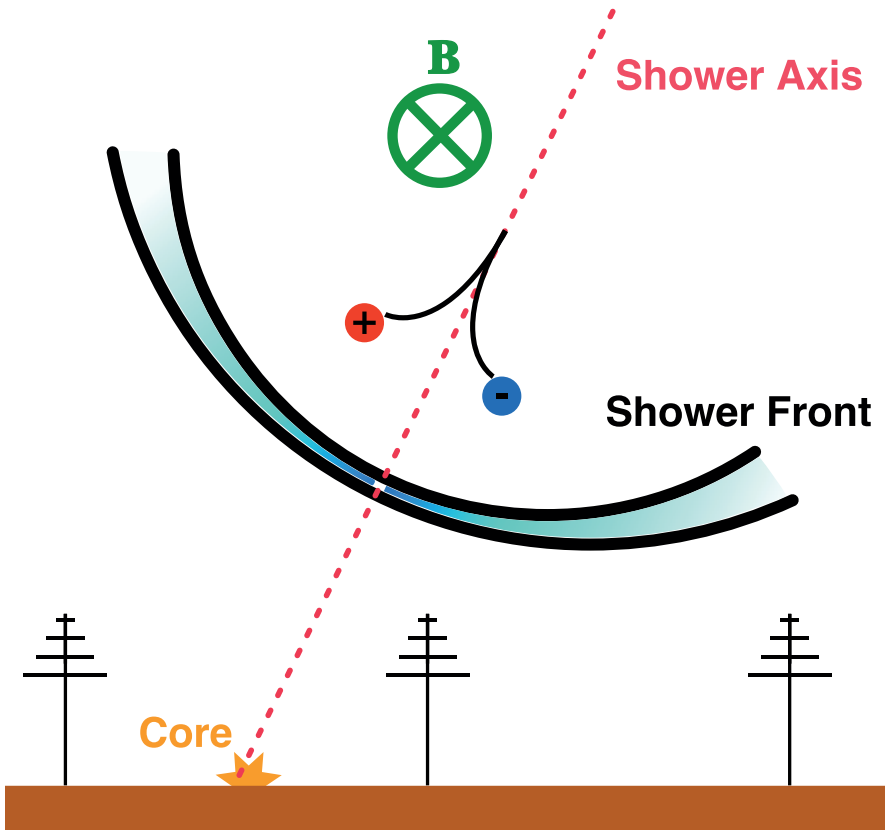
Karlsruhe Institut of Technology (KIT), Institut für Kernphysik, Karlsruhe, Germany

The Pierre Auger Observatory

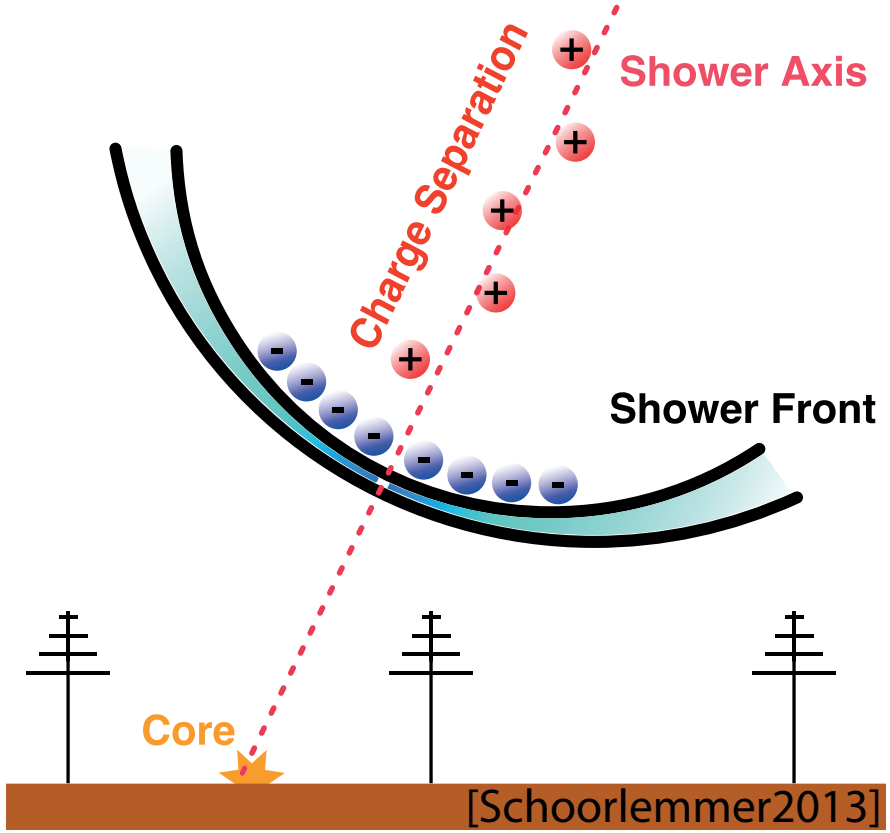
- Area ca. 3000 km^2
- 1660 water Cherenkov tanks
- 5 fluorescence detectors
- World's largest detector for cosmic rays



Radio Emission of Cosmic Rays



Geomagnetic effect



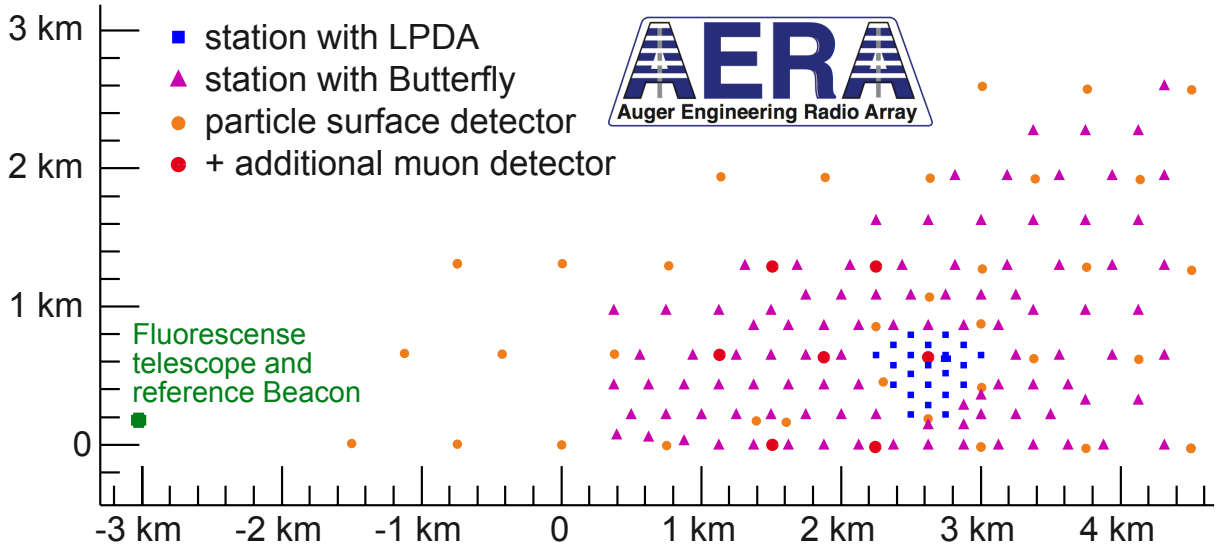
Askaryan effect

AERA – Auger Engineering Radio Array

- 124 autonomous radio stations
- Area $\sim$ 6 km^2
- Band width: 30–80 MHz
- World's largest radio field for air showers

Motivation for time calibration:

- Accurate analysis of:
  - Arrival direction (with triangulation)
  - Mass composition (X_{max})
  - Interferometry



Time calibration

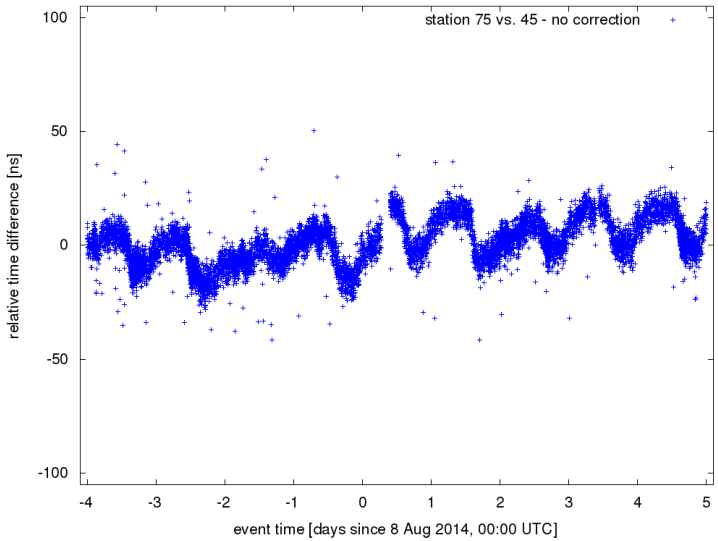
Challenges

- relative time offset between the stations $\approx$ 1 ns
- GPS clocks precise in a range of 20 ns (expected $\sim$ 5 ns)
- For time calibration needed: transmitter with known position
- One method: calibration with beacon

Beacon

- Sine wave at 4 frequencies
- Some kilometers distance to AERA
- Beats between the 4 frequencies
- Arrival time in every stations compared to one reference station
  $\Longrightarrow$ Time difference between expected and measured time of several 10 ns
- Verification with different method:

$\Longrightarrow$ airplanes

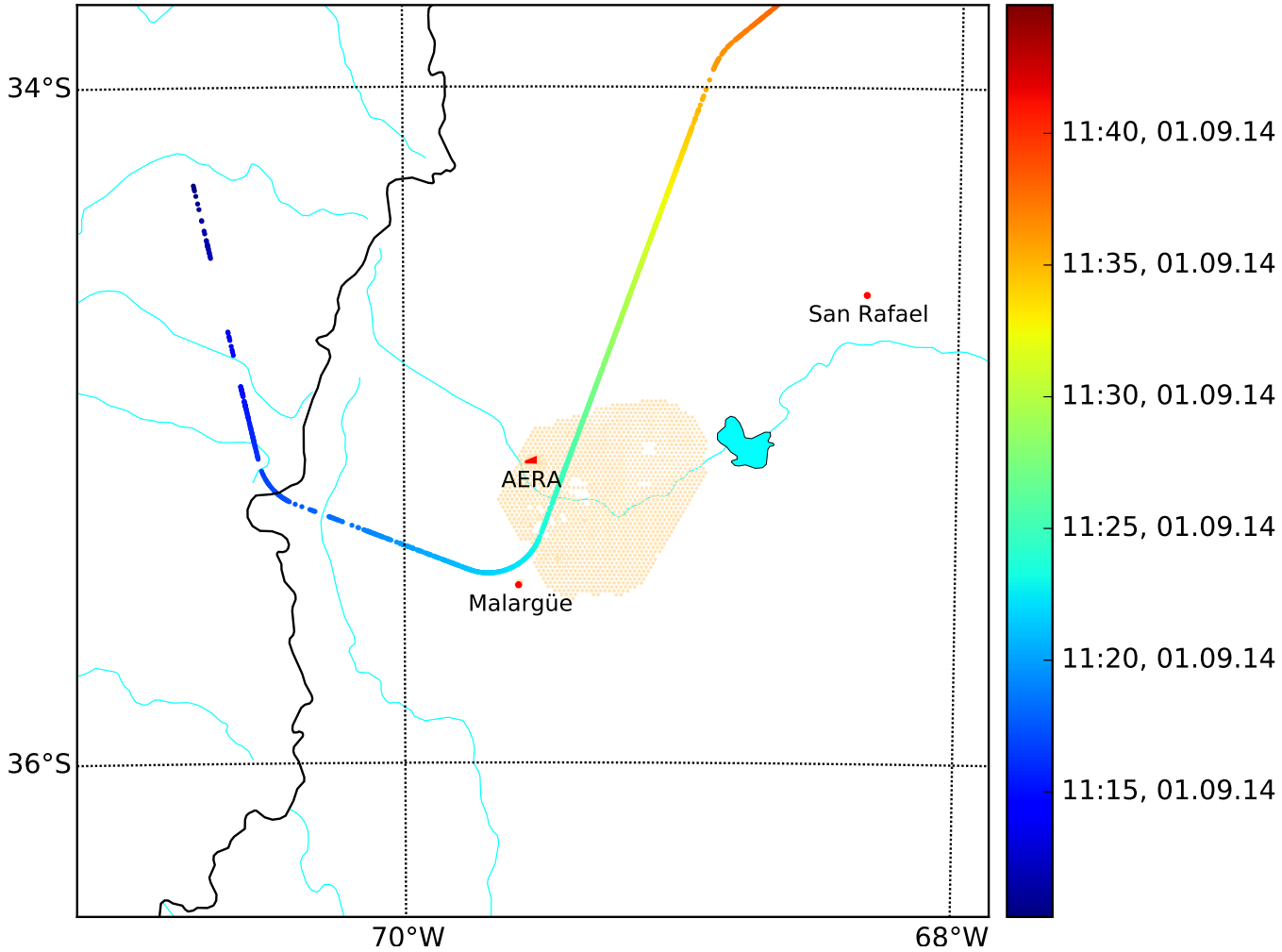


Determination of airplane position

- Airplane position as ADS-B (Automatic Dependent Surveillance - Broadcast) message at 1090 MHz
- DVB-T USB dongle as receiver
- Open source software to decode the ADS-B messages
- Information of latitude, longitude, altitude, heading and speed
- Range more than 400 km

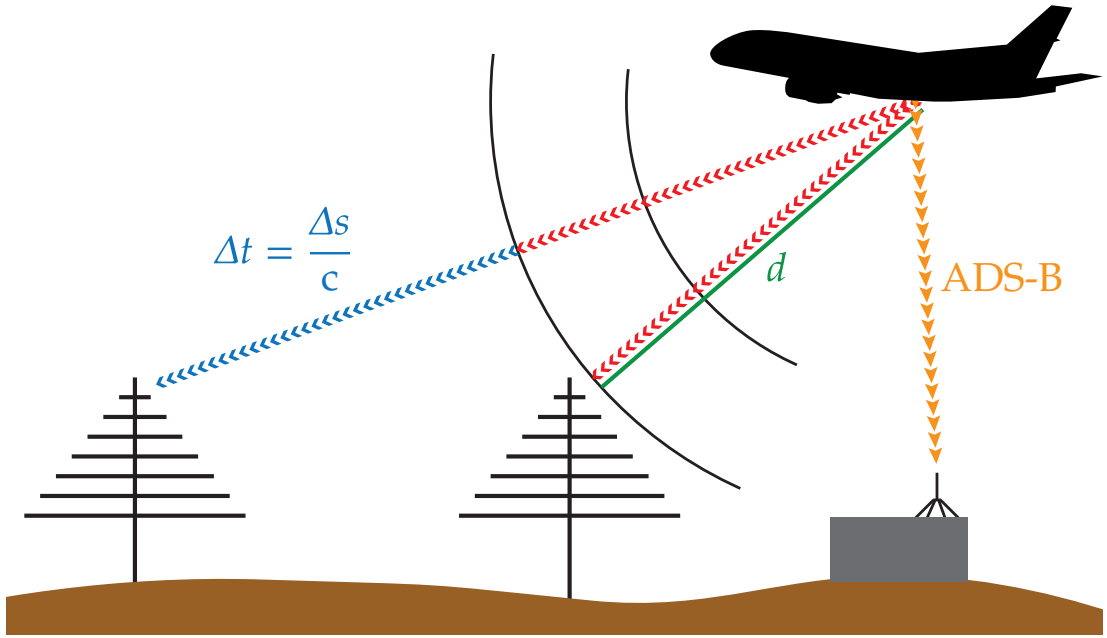
Airplane trajectory out of ADS-B data

Boeing 737-8EH flying from Santiago de Chile to São Paulo



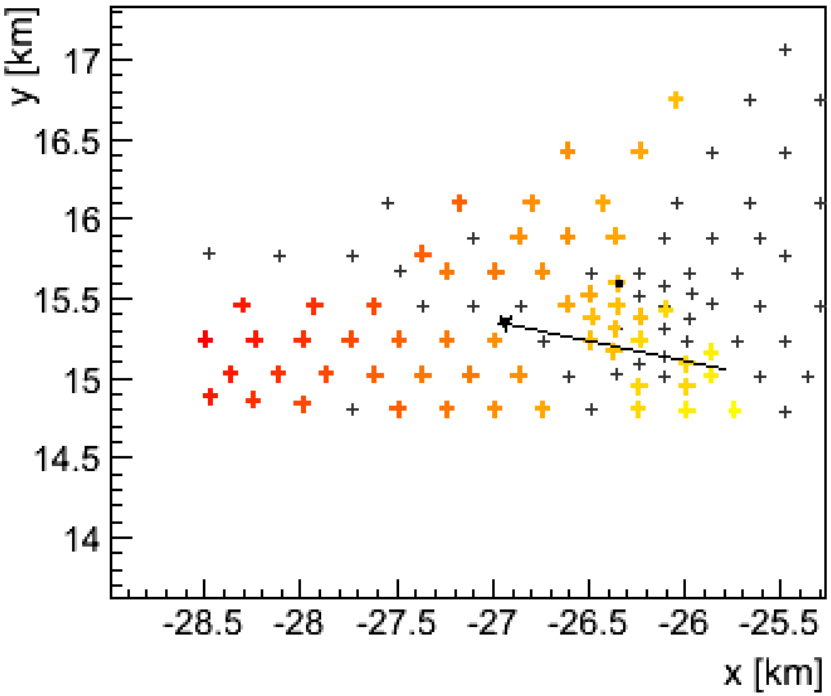
Calibration procedure

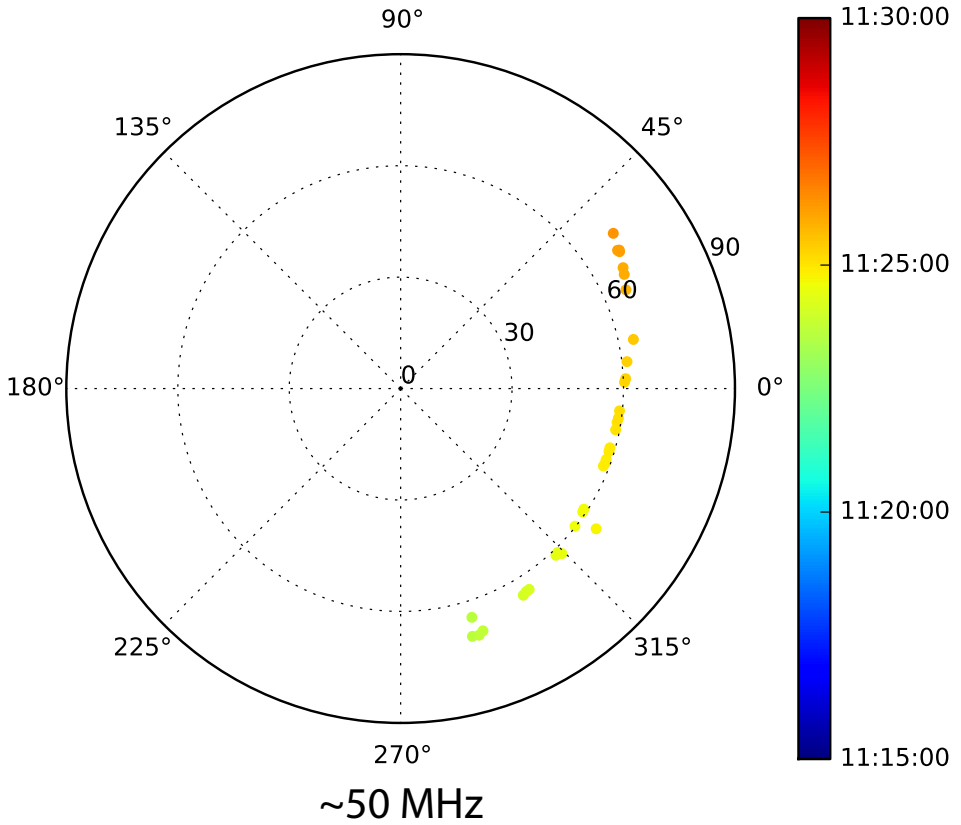
- Calculation of distance between airplane position and every AERA station
- Calculation of pulse arrival time relative to one reference station
- Measurement of the actual arriving time
- Time delay between the stations out of the difference



Airplane pulses in AERA

MHz pulses of airplanes seen in AERA

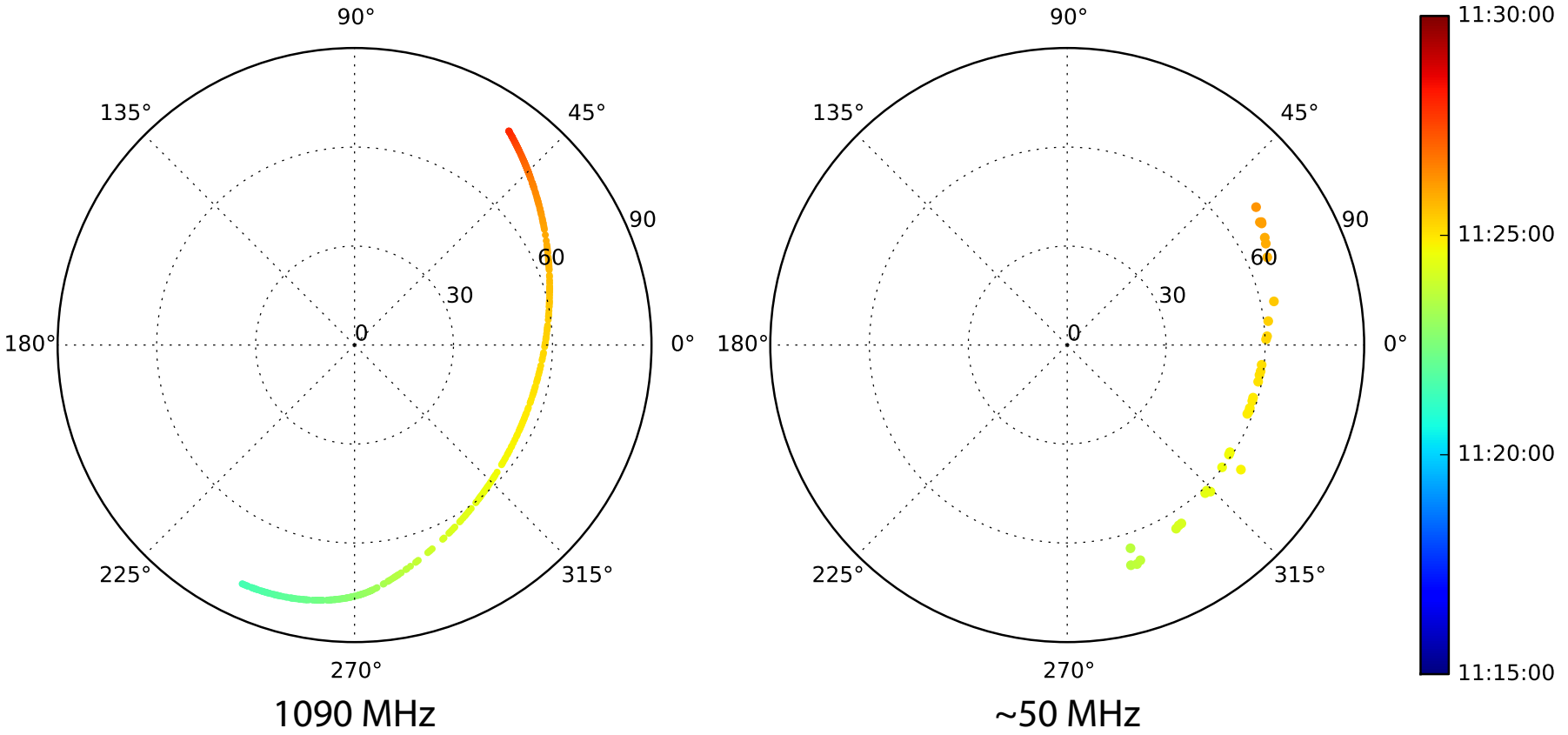




~50 MHz

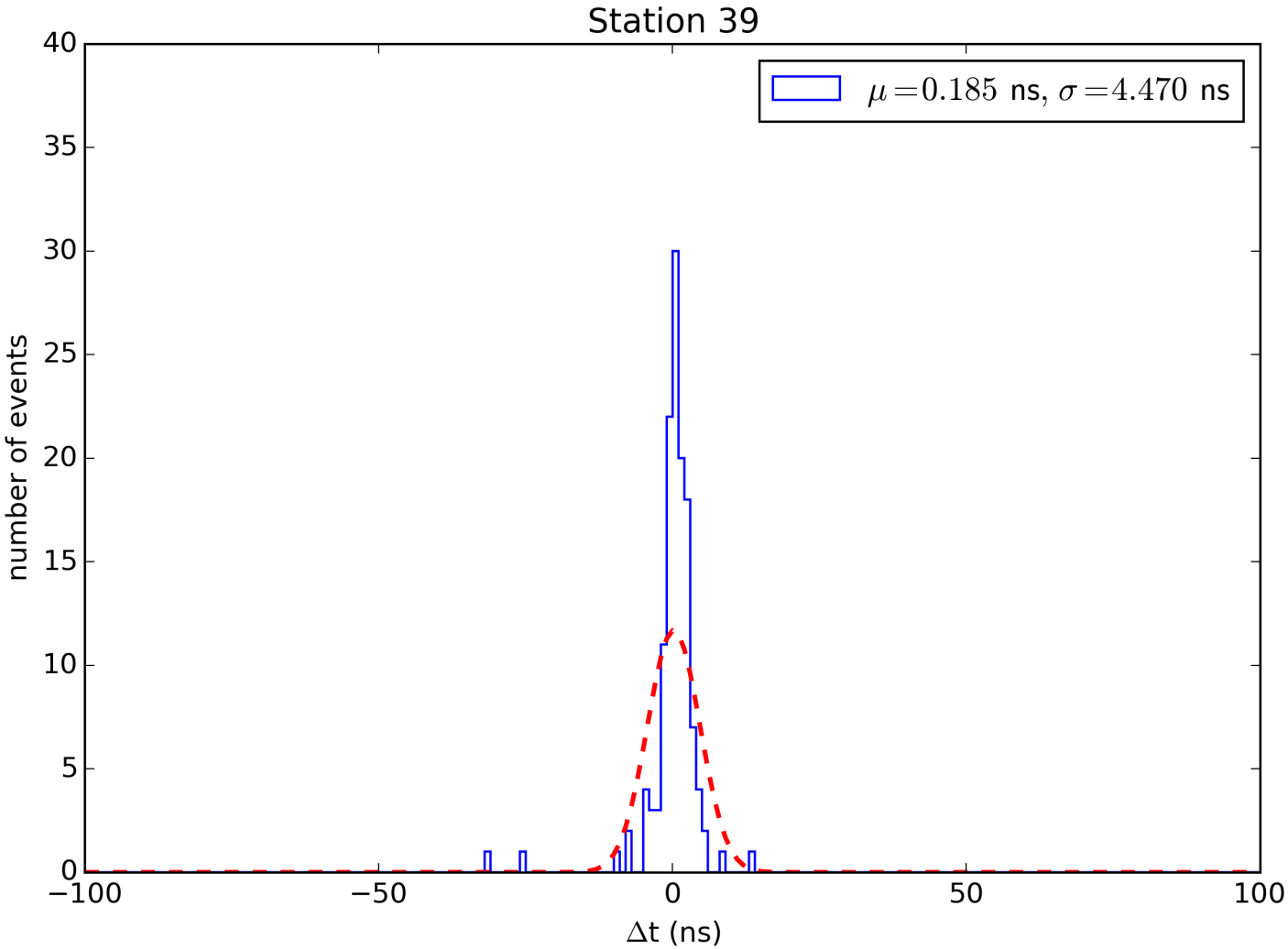
Analysis with one airplane

Airplane position out of ADS-B data and 34 events of the same airplane in AERA



Combination of AERA and ADS-B data

Time difference between station 39 and station 40

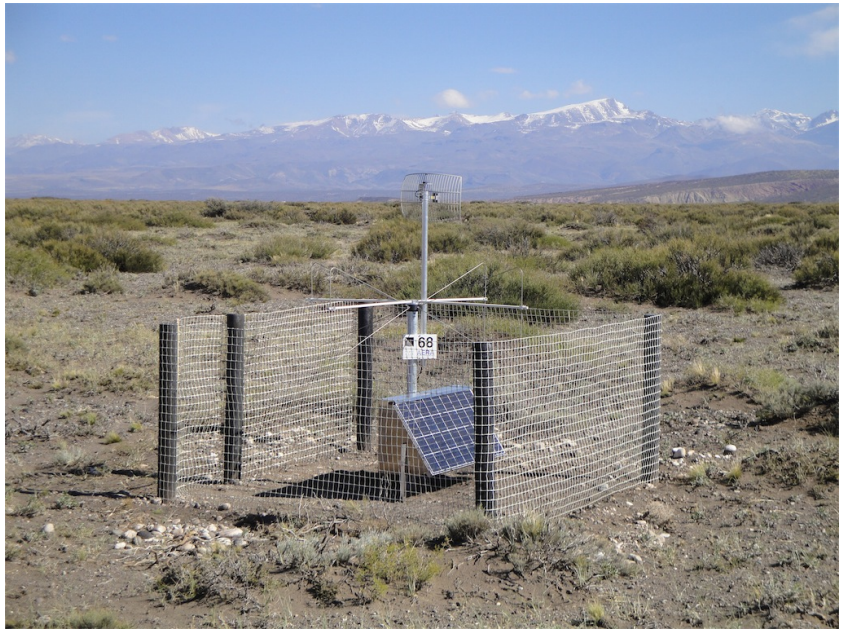


Conclusion

- possible to get airplane positions (ADS-B) and events (AERA)
- beacon can be checked
- airplane method precise in a range of ns
- possible errors:
  - correct airplane position?
  - time delay between receiving position and broadcasting ADS-B ($v \approx$ 200-250 m/s)
  - dimension of airplane
- only 2-3 aiplanes a month with data in AERA

Different Antennas

log-periodic dipole antenna



Butterfly antenna

Combination of AERA and ADS-B data

Time difference between station 53 and station 40