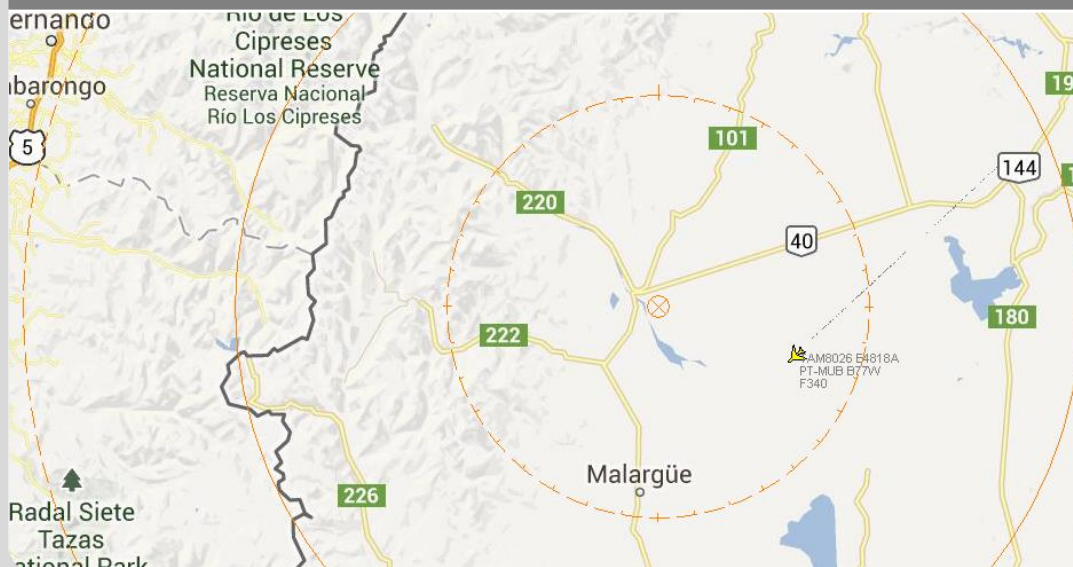


Nanosecond-level time synchronization of AERA using a beacon reference transmitter and commercial airplanes

Tim Huege for the Pierre Auger Collaboration



Time synchronization

- several analyses need nanosecond-level time synchronization
 - wavefront reconstruction, e.g. for measurement of X_{\max}
 - interferometric event reconstruction
- for cabled setups, solutions exist: in particular „WhiteRabbit“
- autonomous detectors typically rely on GPS
 - manufacturers state ~5 ns time resolution, but really achieved?

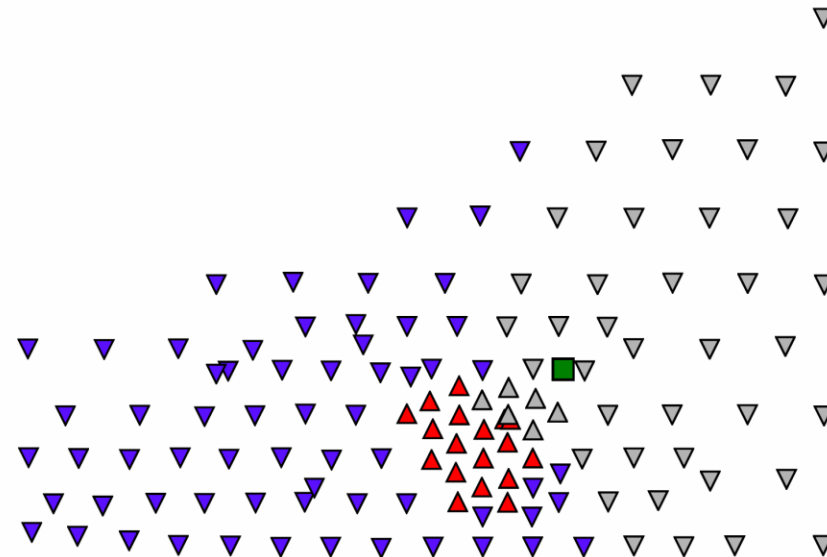
AERA – a distributed detector

▲ AERA LPDA
▼ AERA butterfly

■ CRS
⬡ beacon



1 km



■ fully autonomous detector stations, GPS timing

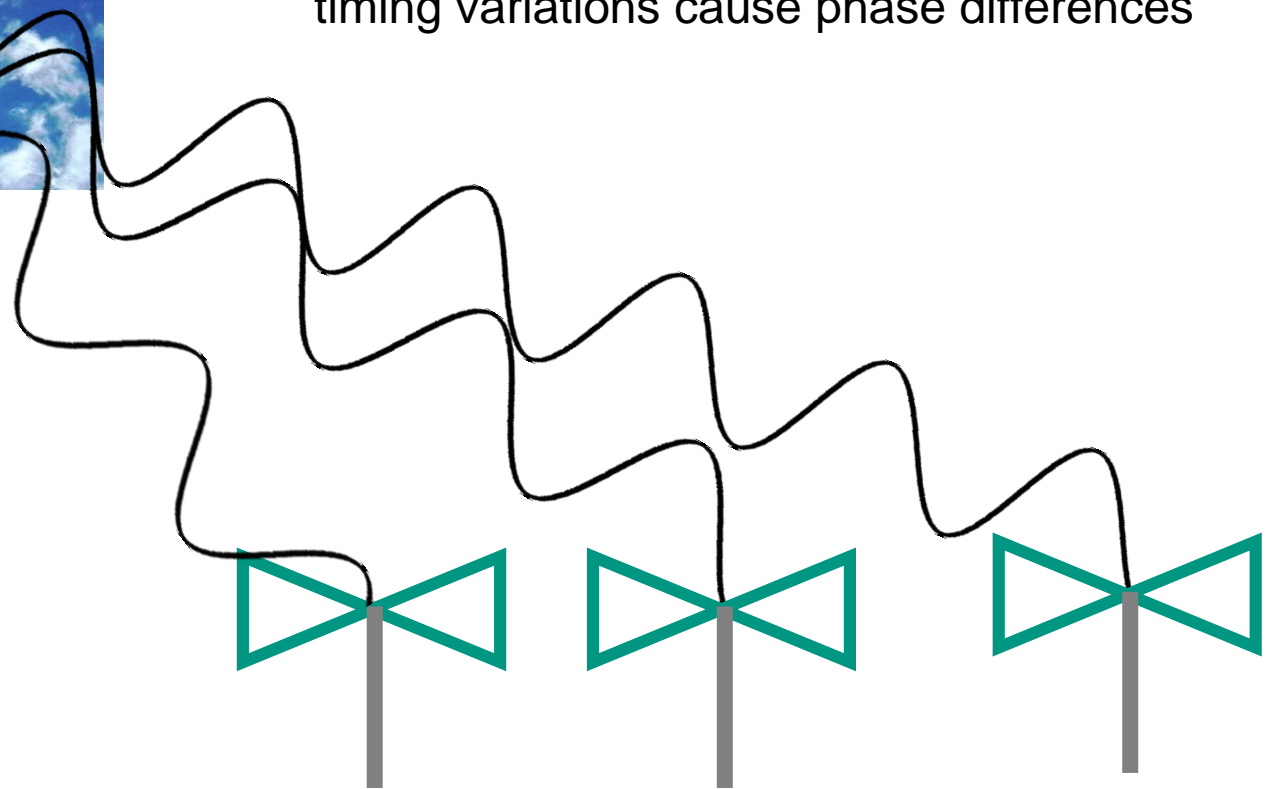
■ here, data from externally triggered stations of AERA-124 are used

The AERA Beacon

- a reference transmitter emitting sine-waves
 - signals recorded in AERA data stream
 - absolute phase not meaningful, but timing variations cause phase differences



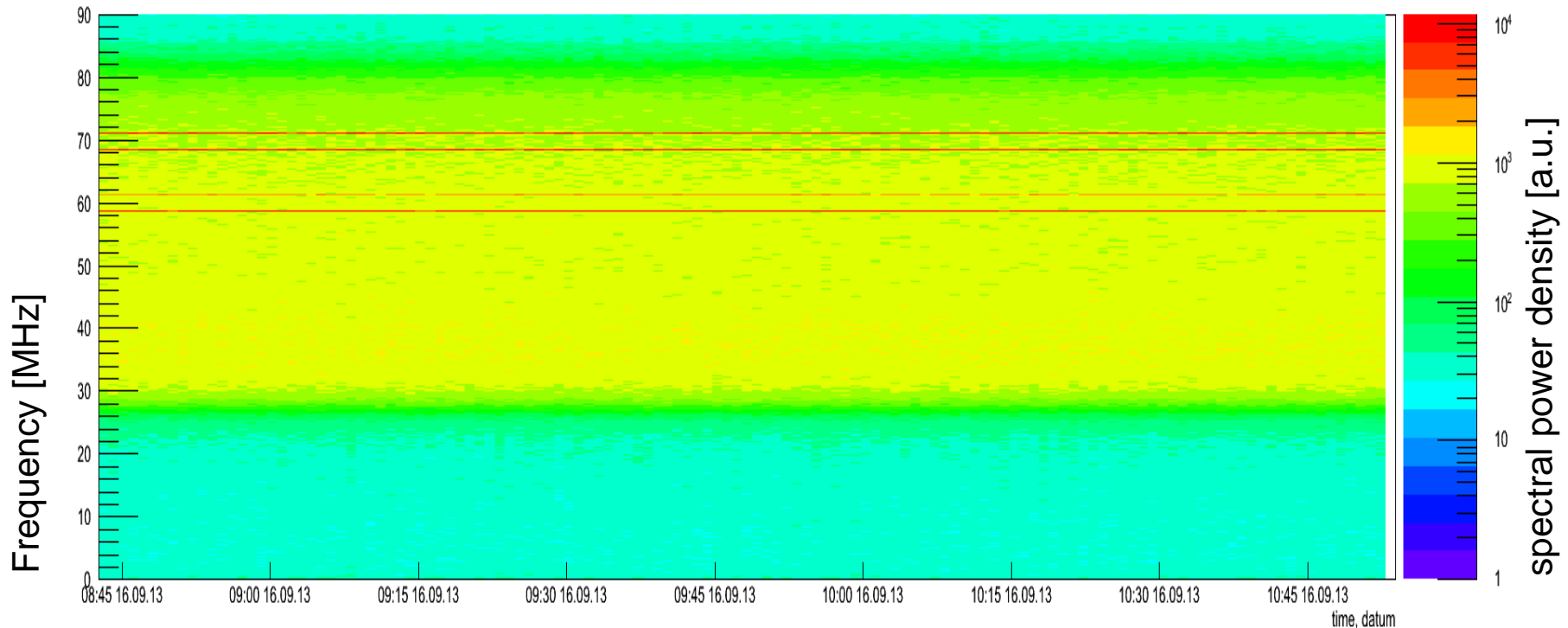
Beacon: folded dipole
at communication
tower of Coihueco



originally developed within LOPES
NIM A 615 (2010) 277-284

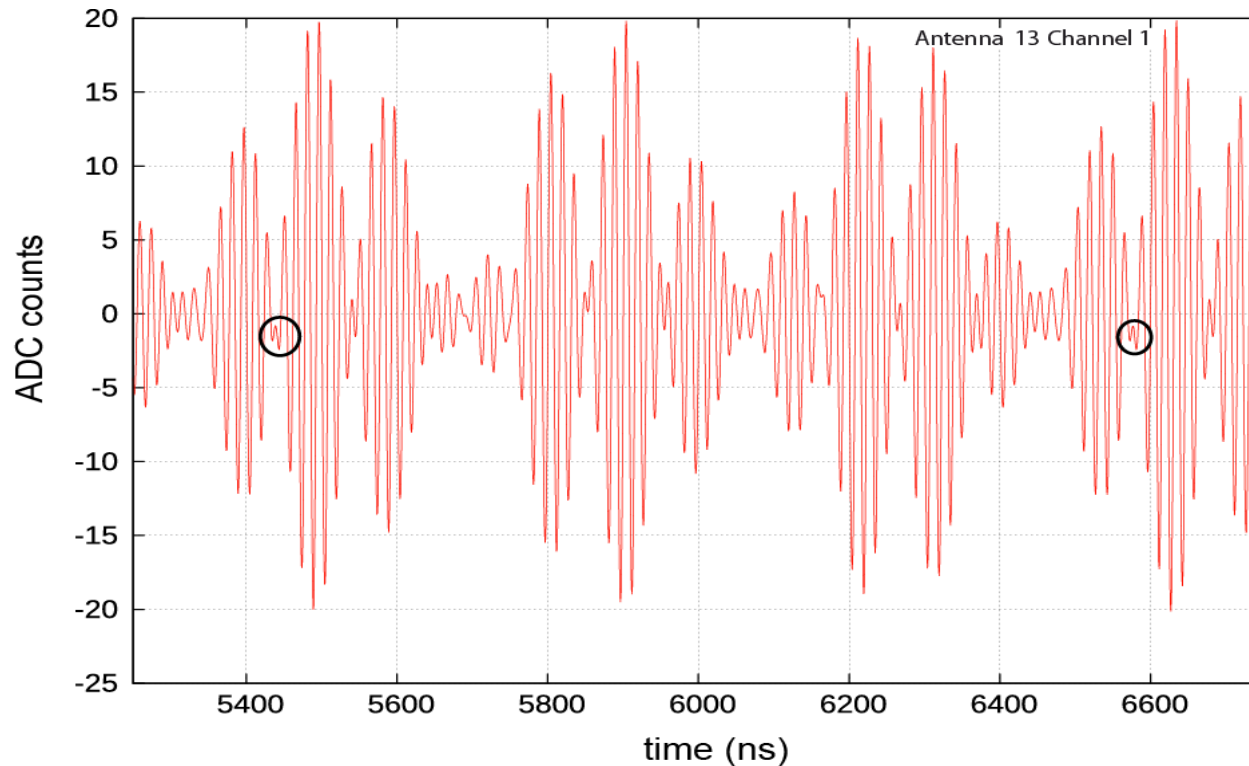
Beacon lines in dynamic spectrum

- four frequencies
 - 58.887 MHz, 61.523 MHz, 68.555 MHz, 71.191 MHz
 - matching frequency bins for traces of $n \times 2048$ samples
 - can thus be digitally filtered with minimal loss of data



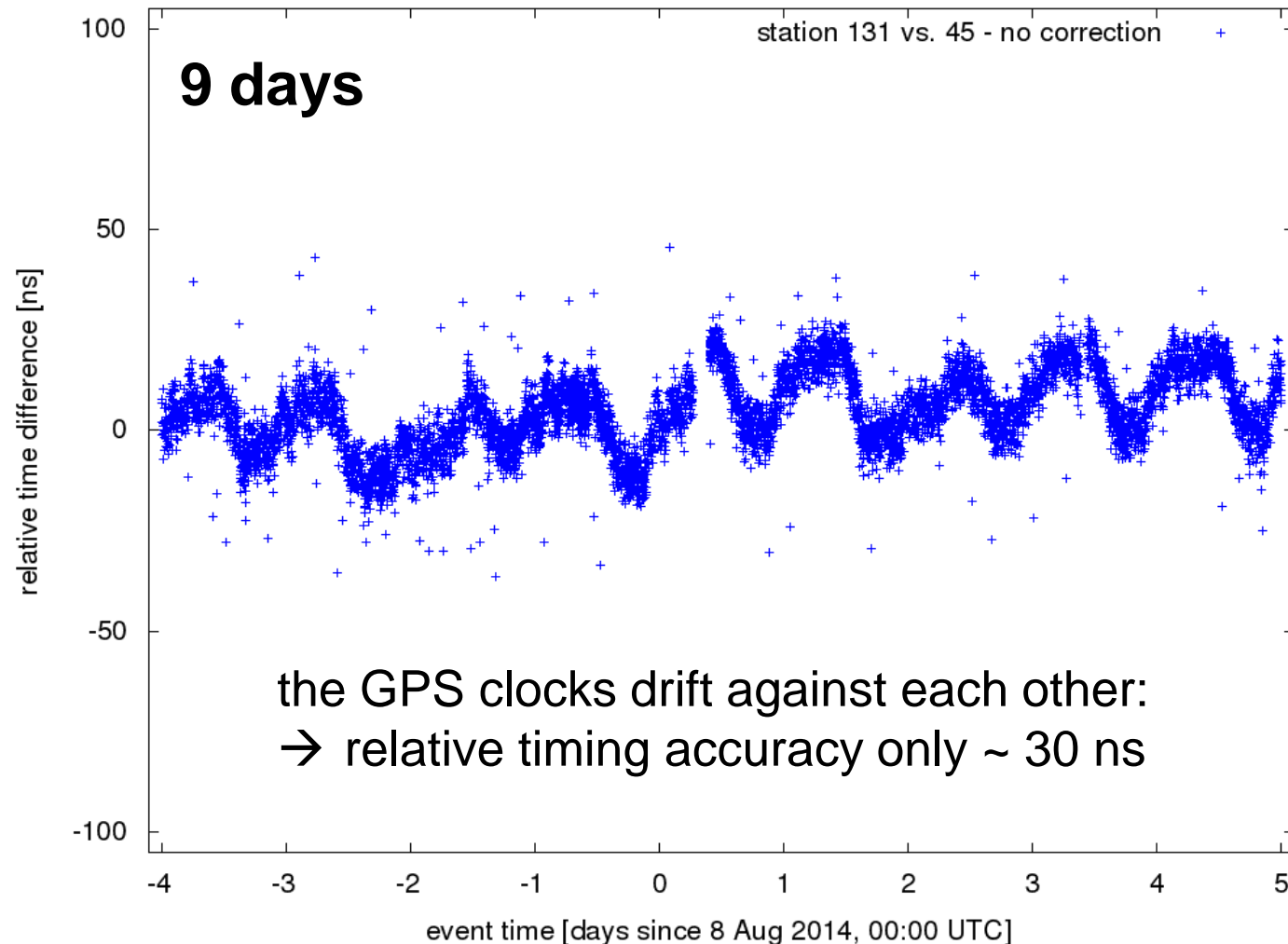
Determine station timing from Beacon signals

- overlapping sine waves lead to a “beat”
- the “beat” repeats every $1.1 \mu\text{s}$
 - compare arrival time of beat with expected propagation time
 - same information is contained in phases of beacon signals

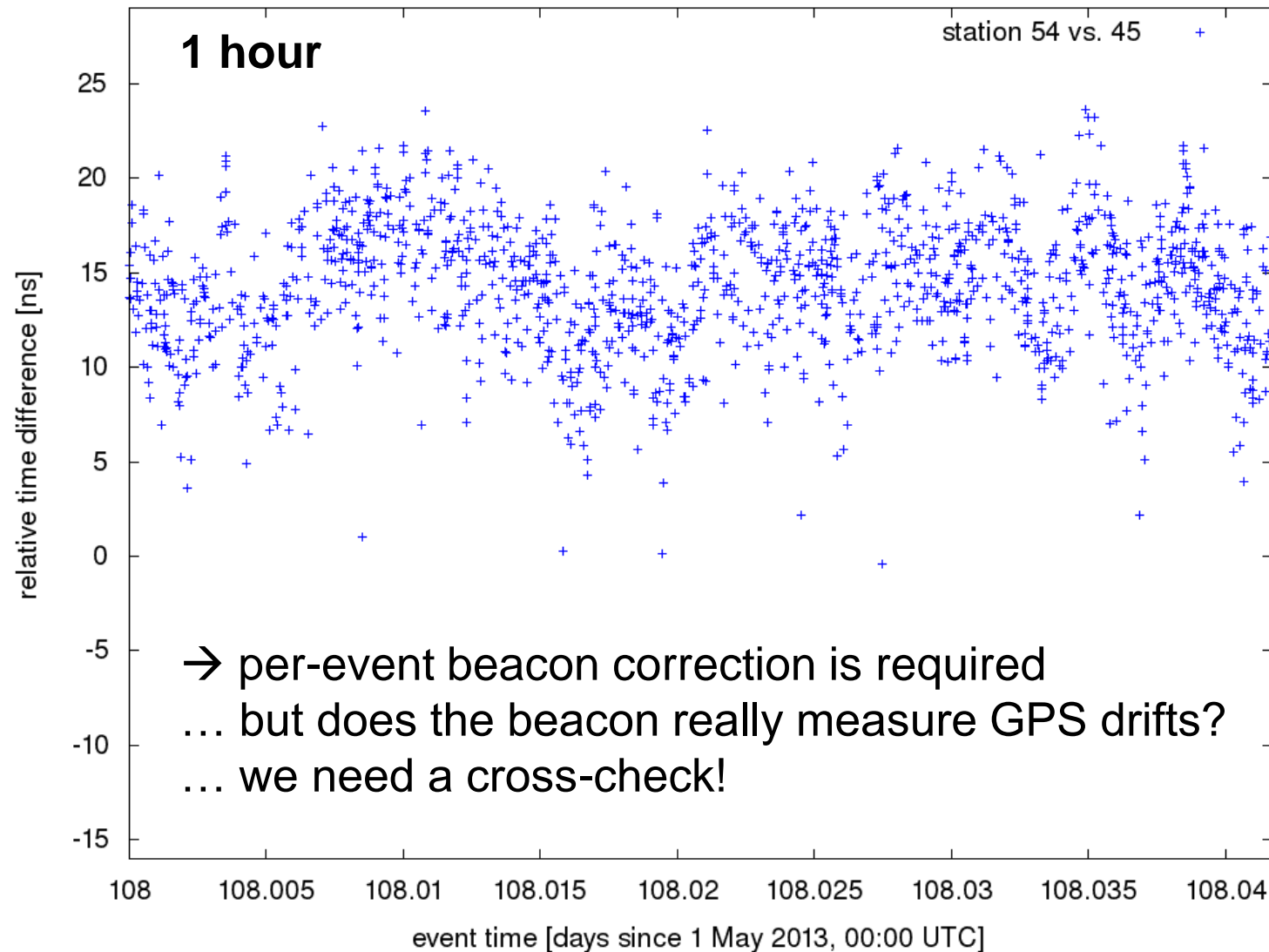


Relative clock drifts revealed by the beacon

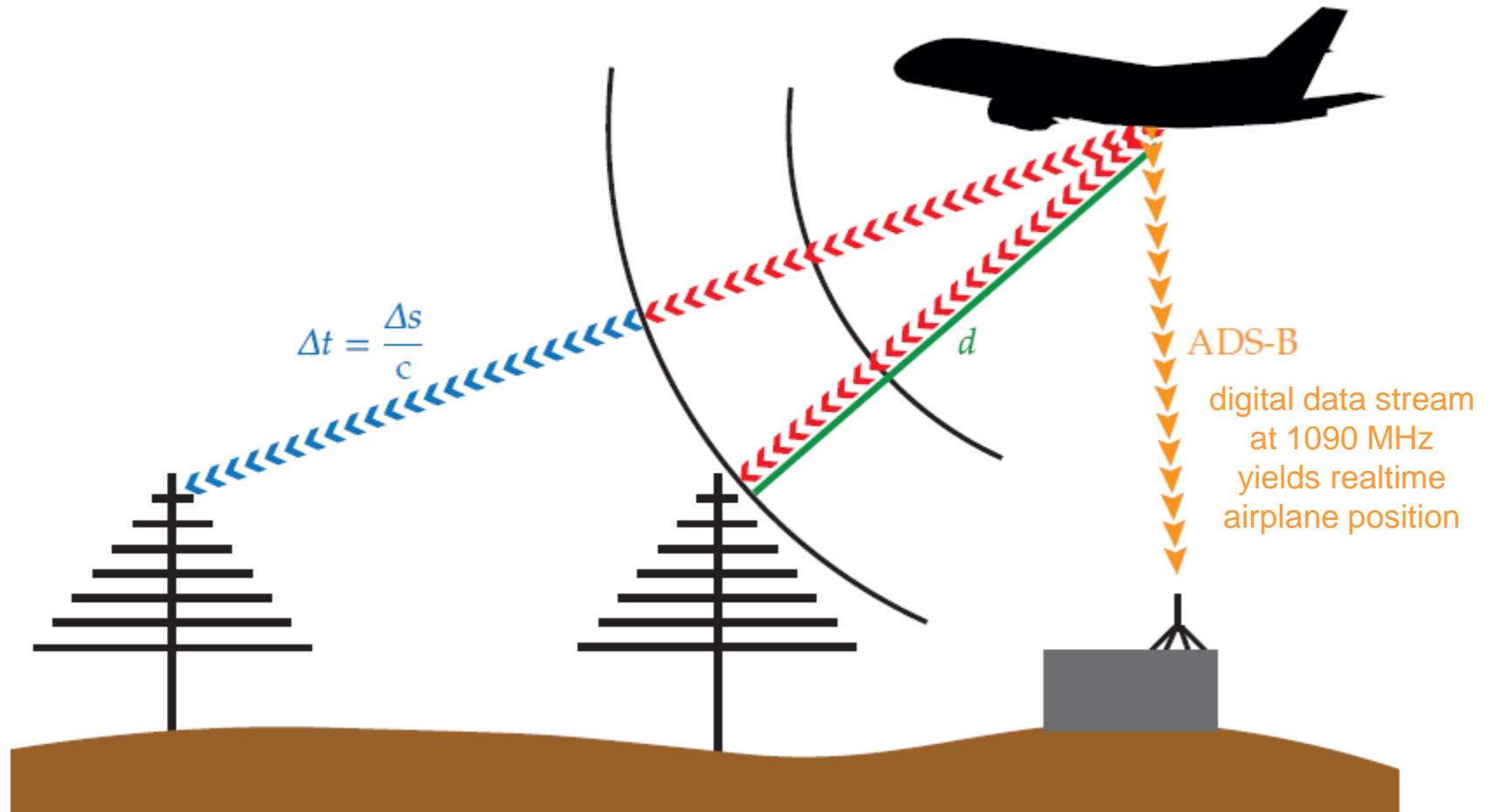
- each point = timing difference between two stations for one event



Smallest scale of drifts: a few minutes



Principle of airplane timing calibration



How to receive ADS-B data stream?

Terratec NOXON DAB+ Digitalradio für PC

Artikel-Nr.: R12818
 Hersteller-Nr.: 10774
 17,95 €
 inkl. MwSt. zzgl. Versand

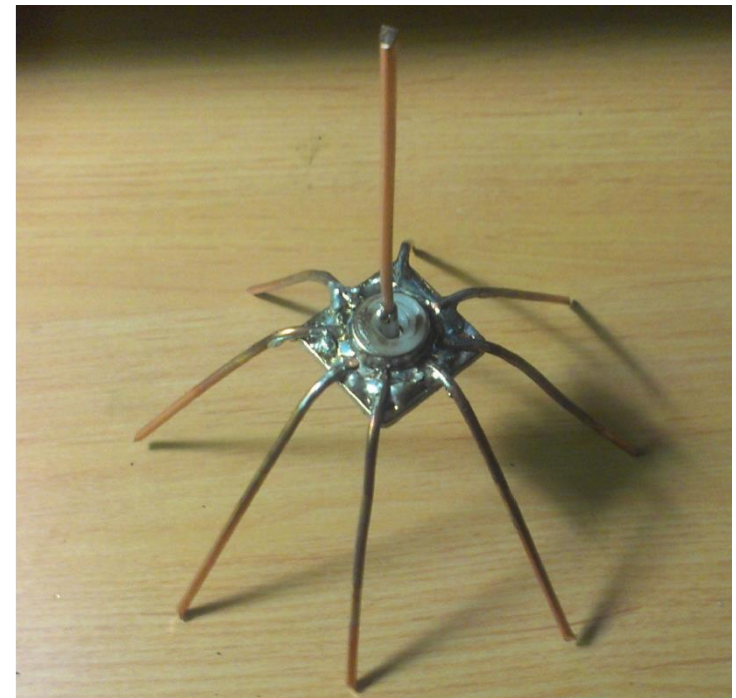
★★★★☆ [3]

TERRATEC

1 Stück [In den Warenkorb](#)

Verfügbarkeit	sofort lieferbar
Versandkosten in Deutschland	4,95 €
Versandkosten in EU-Länder	9,95 €
24h Lieferung	mit 4,00 € Aufschlag möglich
Lieferung an Packstation	möglich
Anschluss-Garantie	nicht möglich

Drucken Produktvergleich Merken Produkt empfehlen



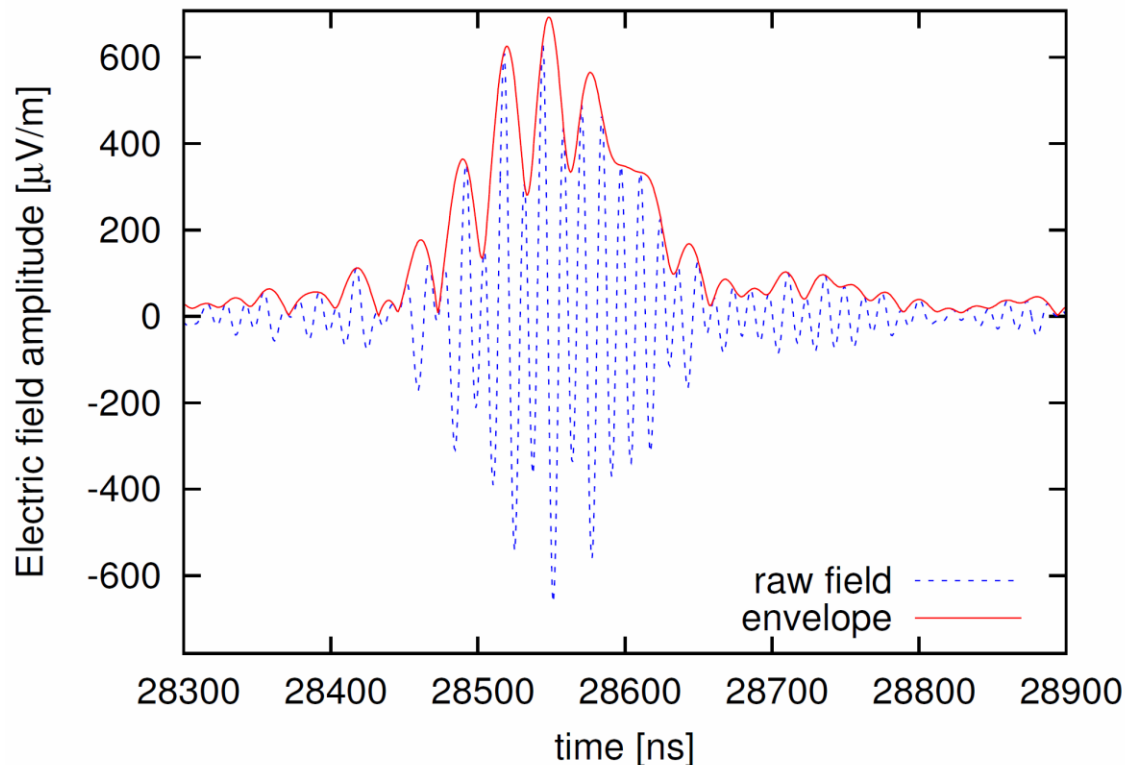
Produktdaten **Zubehör (5)** häufig auch bestellt (12)

Überblick
 Digitalradioempfang (DAB/DAB+) am PC oder Notebook
 Zusatzinformationen und Nachrichtenservice (Journaline)

Technische Daten
 Abm.: (B x H x T) 25 x 9 x 53 mm
 Marke: TERRATEC

- hardware: DVB-T receiver and custom-made antenna
- software: software-defined radio for decoding of ADS-B packets and notification of the DAQ to let events pass

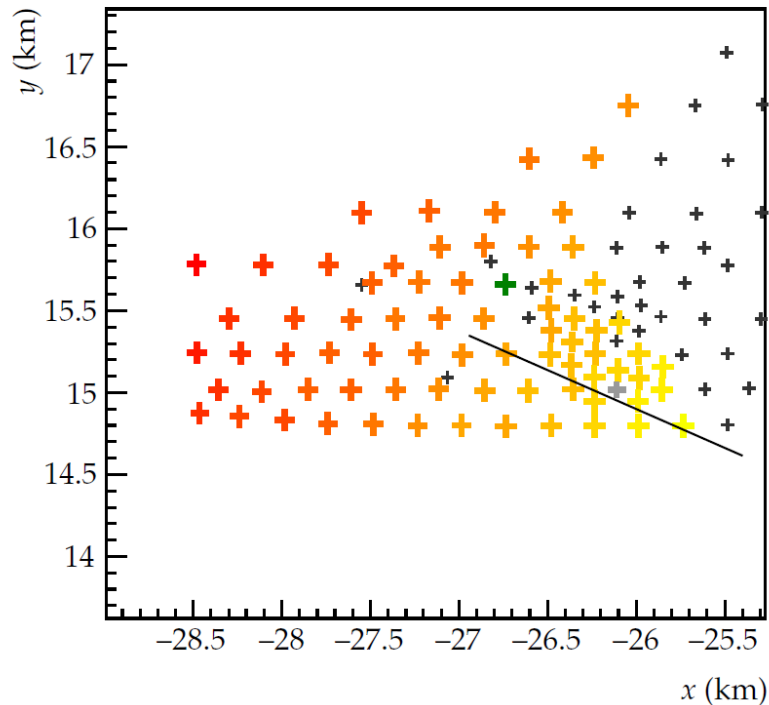
Radio pulses from airplanes detected by AERA



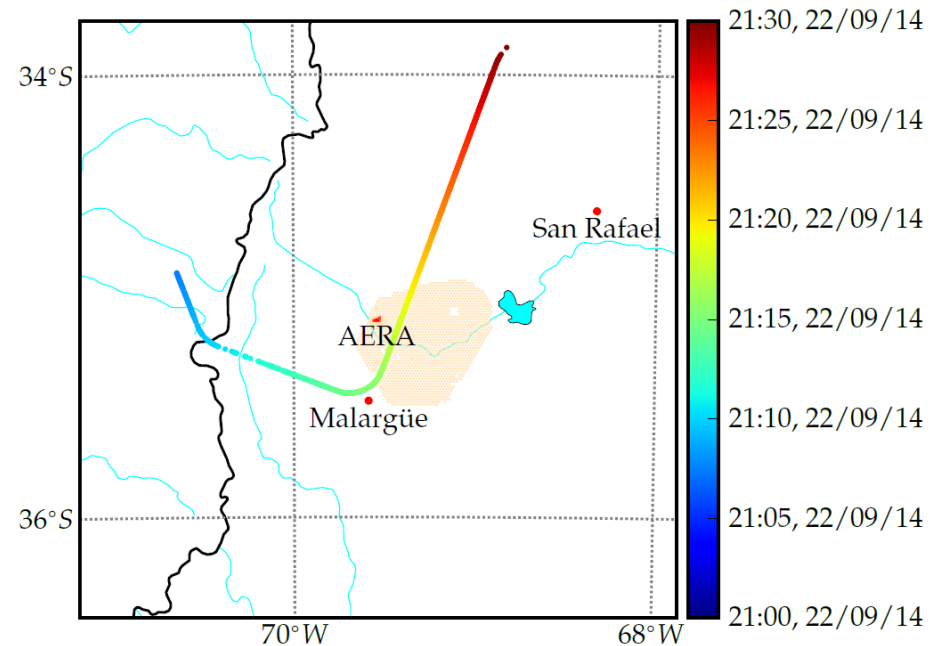
- (some) airplanes emit radio pulses triggerable in AERA band
- the exact pulse origin is unclear, possibly some unintended byproduct
- pulse arrival times can be extracted from enveloped traces

Airplane observed in ADS-B and AERA

AERA data

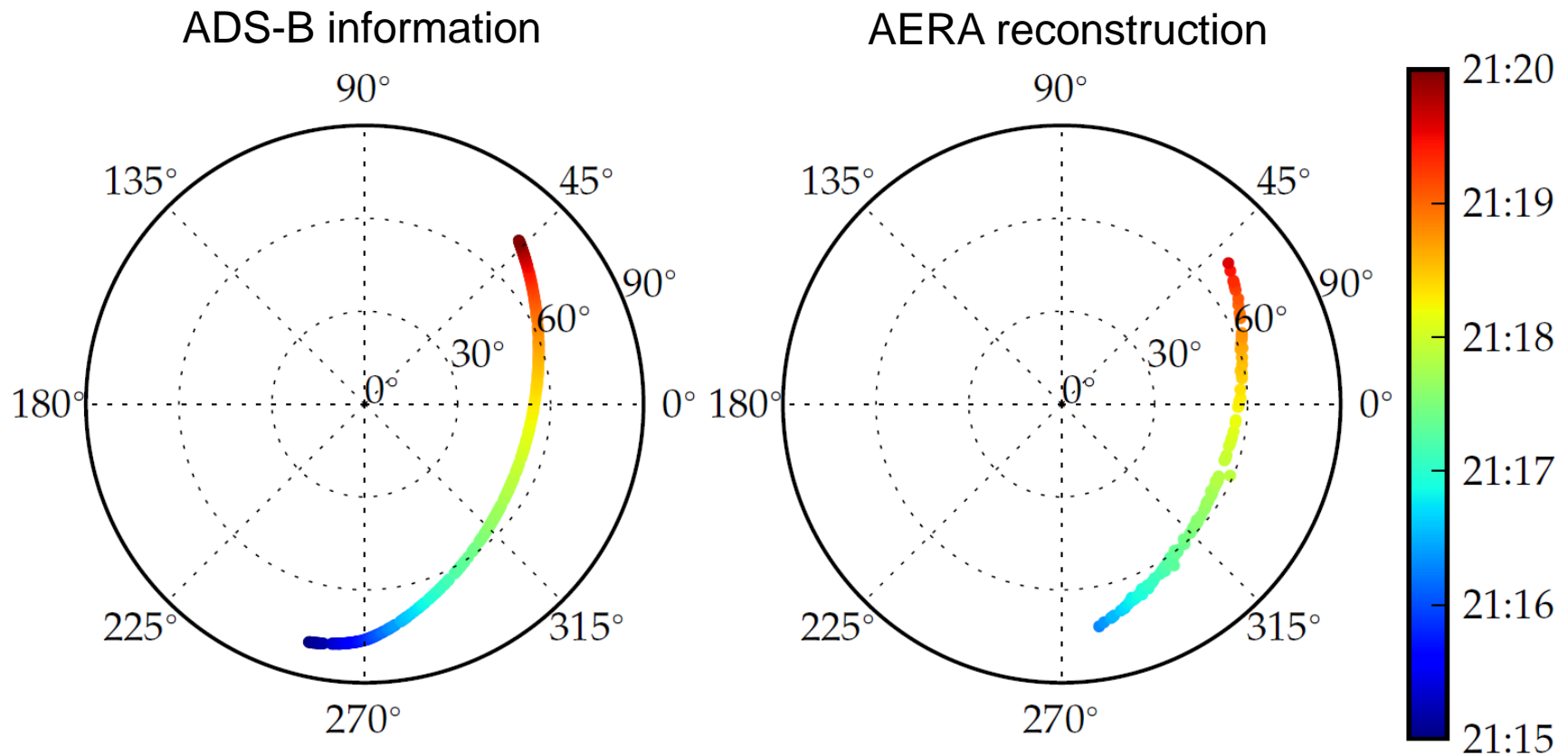


ADS-B data



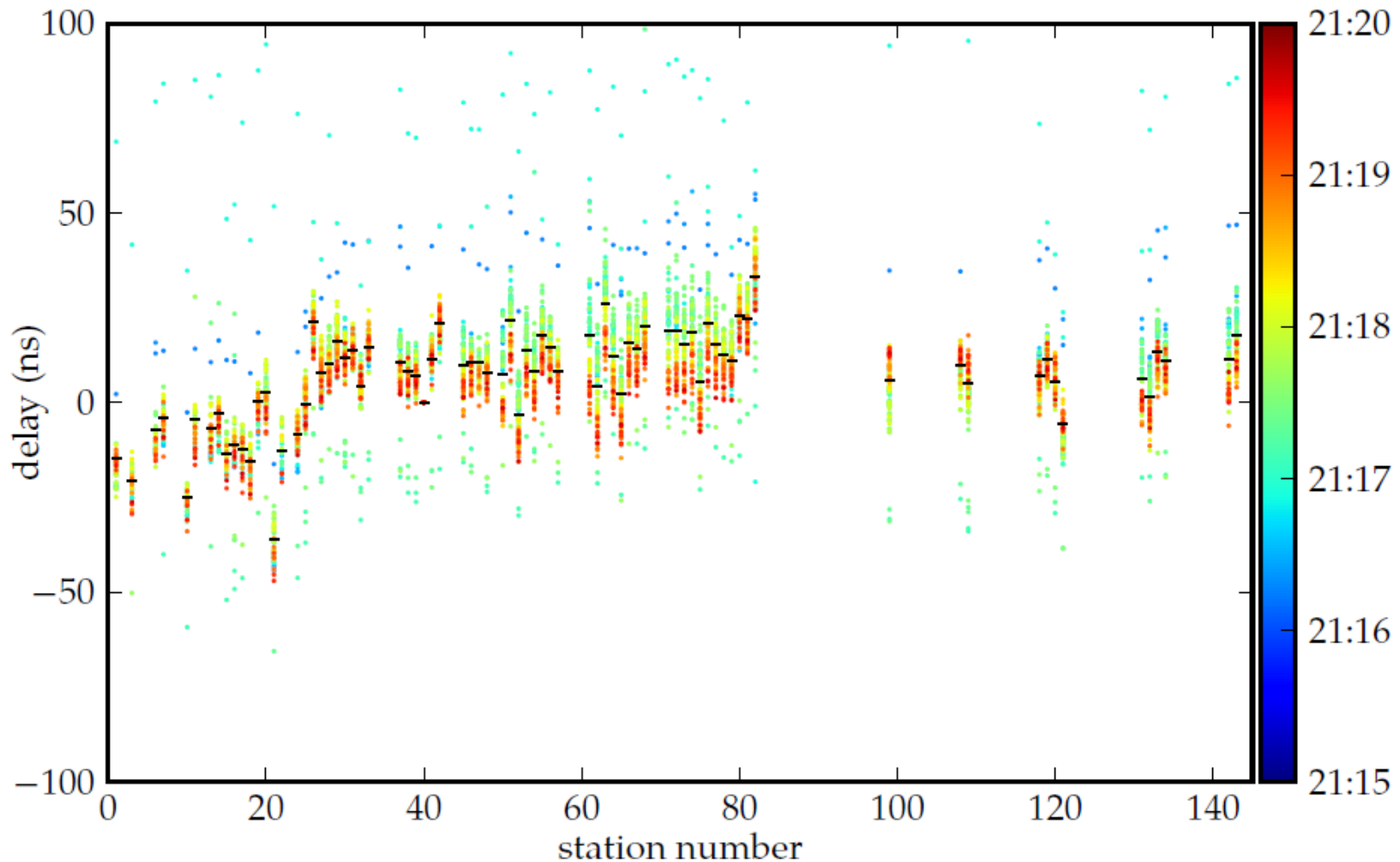
- we see clear radio pulses in AERA antennas over the whole array

Comparison between ADS-B and AERA



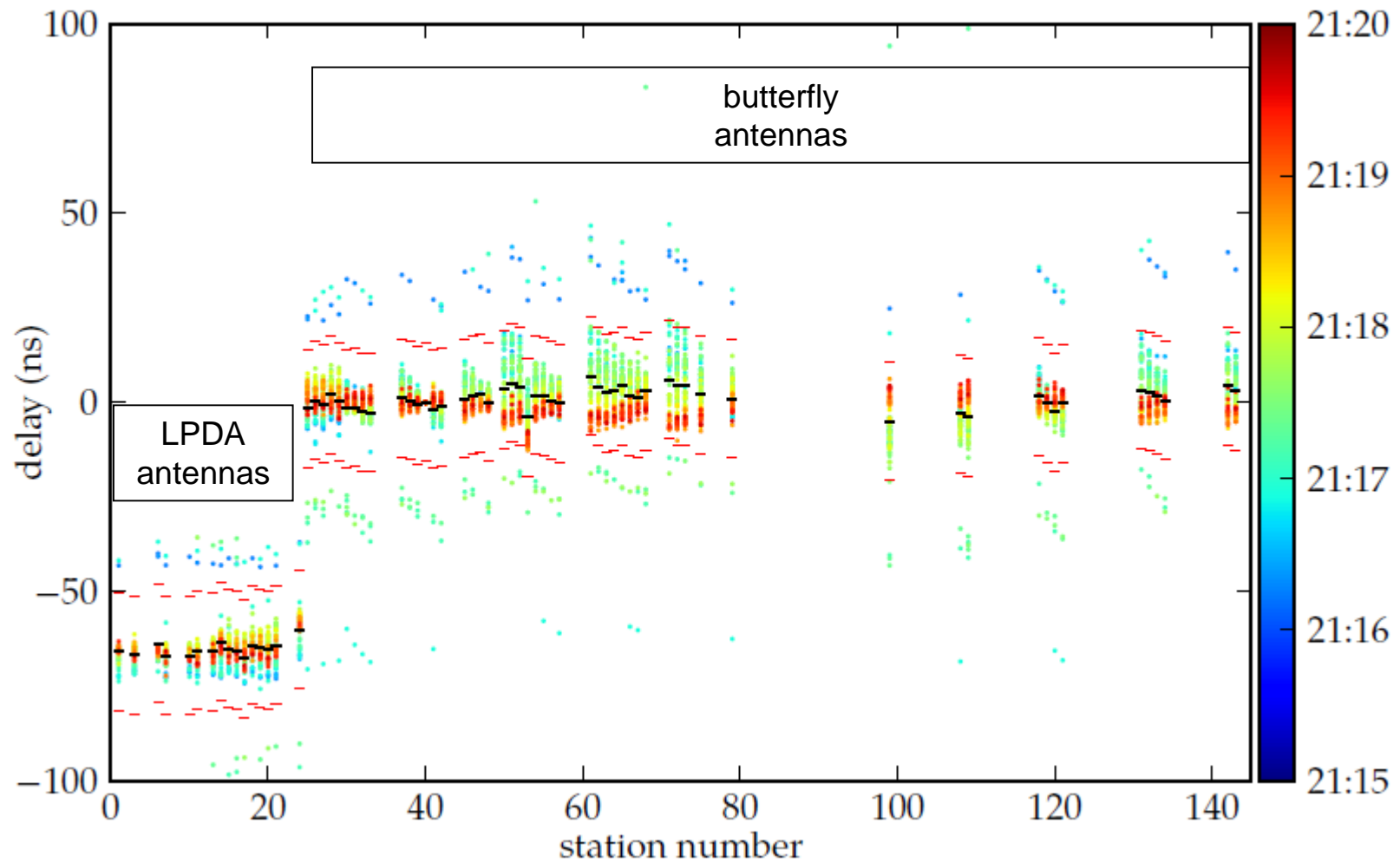
- we can clearly reconstruct the airplane trajectory from AERA data
 - direction and even source distance match nicely

Timing offsets determined from single airplane



■ the mean time offset scatters around, also quite some outliers

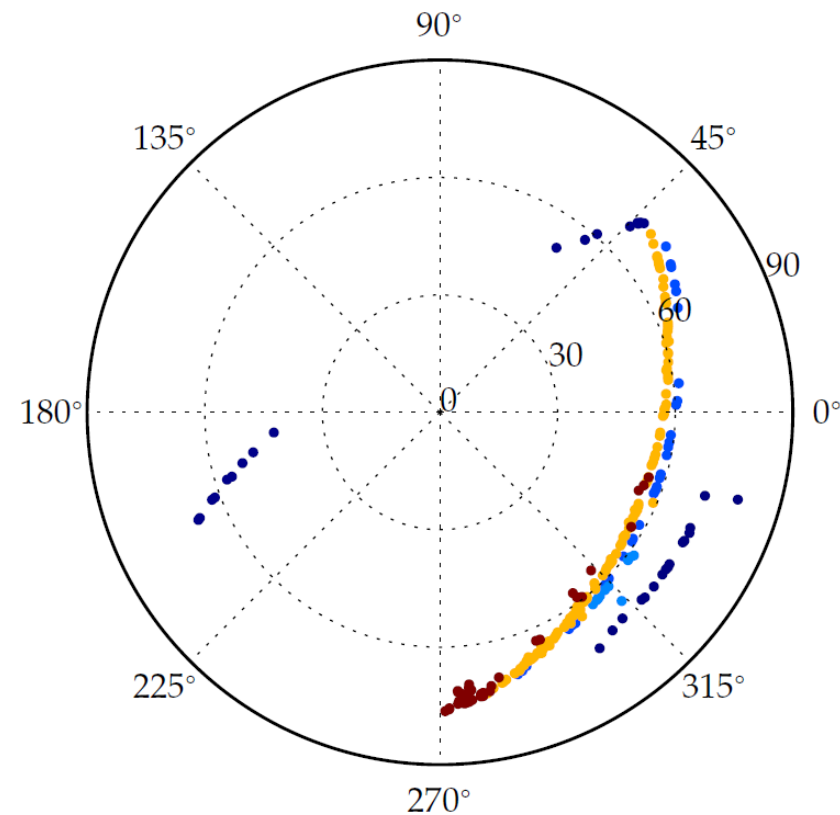
Apply beacon correction for single airplane



■ mean timing offsets now consistent, but offset between antenna types

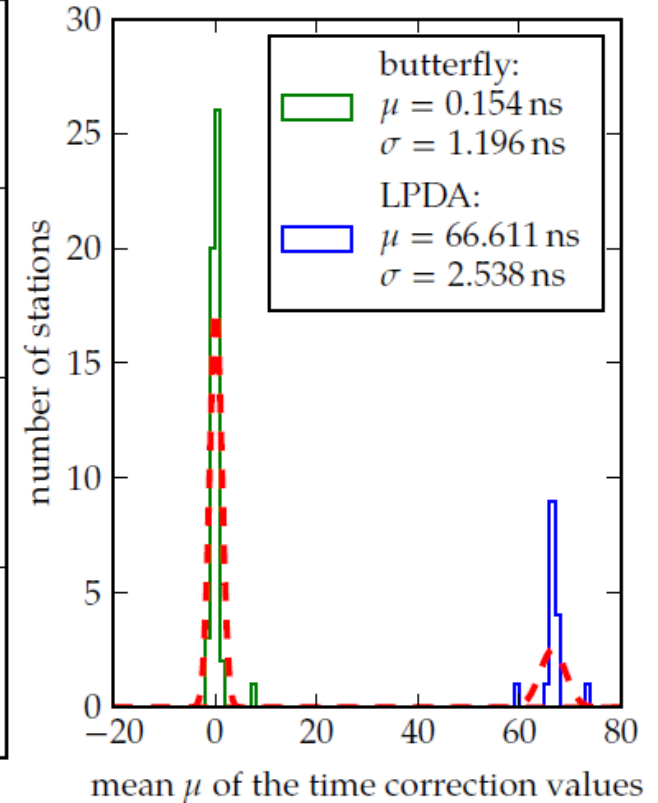
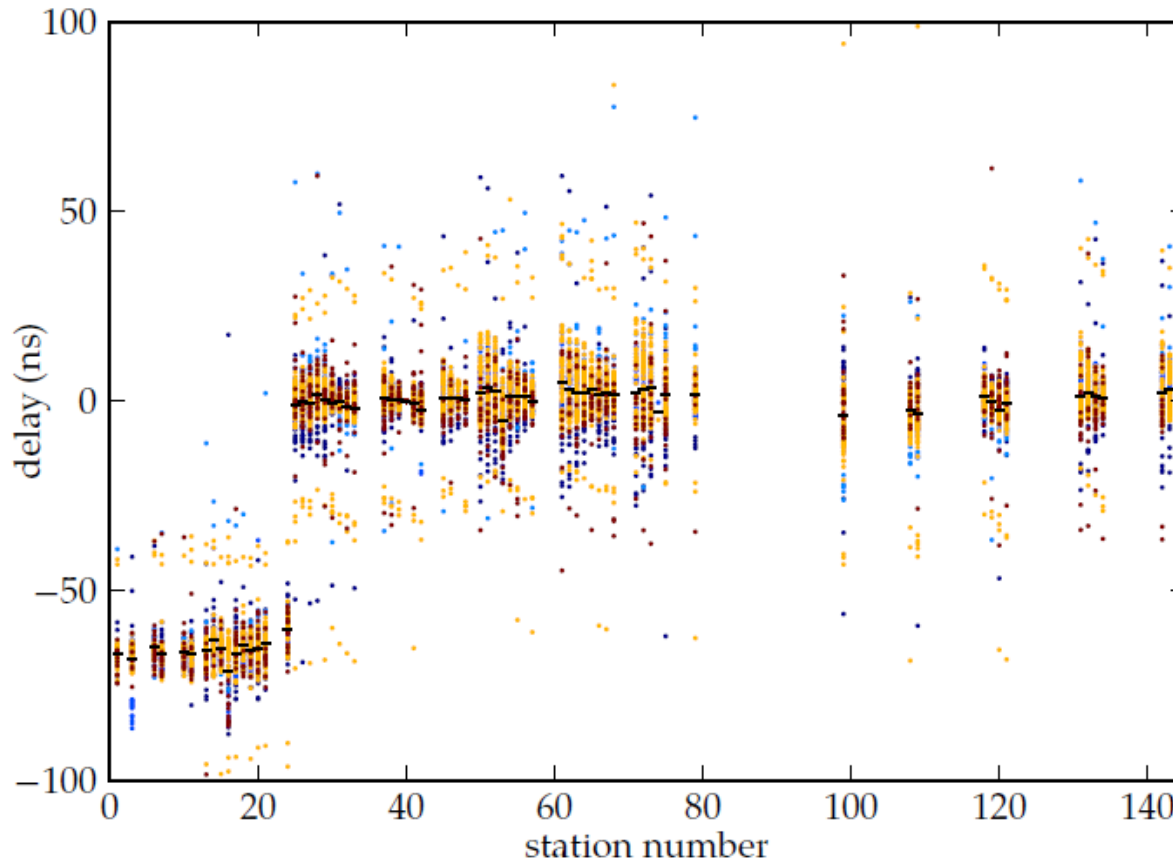
Statistics of airplanes seen in AERA and ADS-B

UTC date	events	Mode S	airplane type	airline
20/06/14, 16:26	3	C05843	Boeing 767-35H	Air Canada
22/07/14, 03:26	1	E48987	Boeing 737-8EH	GOL Transportes
22/07/14, 03:34	6	E47FE0	Airbus A320-232	TAM Linhas Aereas
28/07/14, 15:43	1	E06541	Boeing 737-81D	Aerolineas Argentinas
31/07/14, 06:29	1	E80320	Airbus A319-111	Sky Airline
31/07/14, 11:28	4	E48C03	Boeing 737-8HX	GOL Transportes
31/07/14, 18:20	1	E48987	Boeing 737-8EH	GOL Transportes
03/08/14, 11:27	1	E48986	Boeing 737-8EH	GOL Transportes
24/08/14, 03:36	16	E48854	Boeing 737-8EH	GOL Transportes
24/08/14, 11:30	17	E48854	Boeing 737-8EH	GOL Transportes
01/09/14, 11:23	32	E48854	Boeing 737-8EH	GOL Transportes
03/09/14, 21:21	11	E48C04	Boeing 737-8HX	GOL Transportes
08/09/14, 21:33	9	E48C03	Boeing 737-8HX	GOL Transportes
08/09/14, 22:07	4	E80411	Airbus A320-233	LAN Airlines
10/09/14, 01:58	1	E80413	Airbus A320-233	LAN Airlines
13/09/14, 13:02	3	E80414	Airbus A320-233	LAN Airlines
22/09/14, 21:16	115	E48854	Boeing 737-8EH	GOL Transportes
28/09/14, 21:27	1	E48C04	Boeing 737-8HX	GOL Transportes
02/10/14, 14:27	1	0C208E	Boeing 737-8V3	Copa Airlines
04/10/14, 11:28	14	E48985	Boeing 737-8EH	GOL Transportes
04/10/14, 17:13	33	E48853	Boeing 737-8EH	GOL Transportes



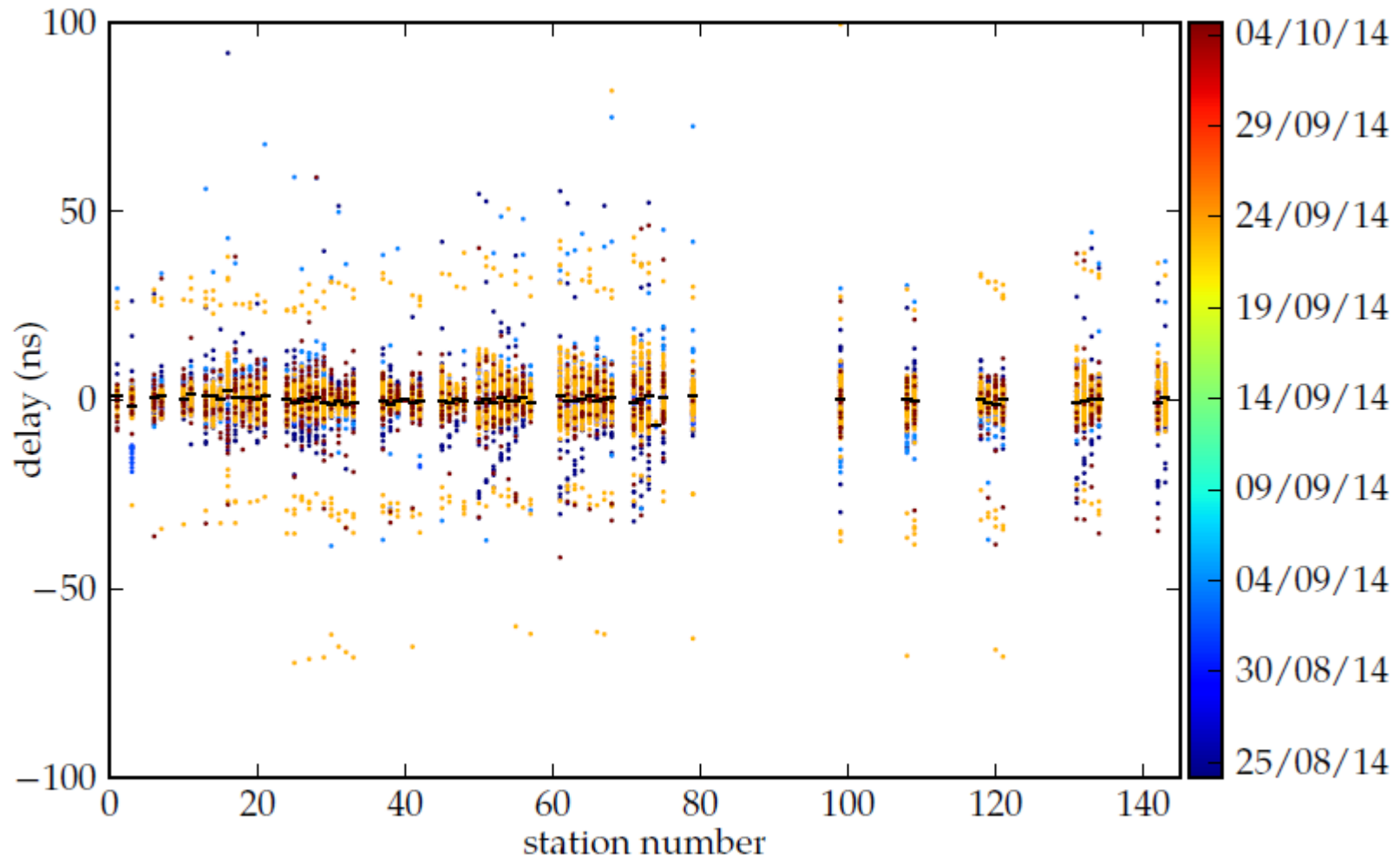
■ usable airplane „every few weeks“

Analysis of many airplanes



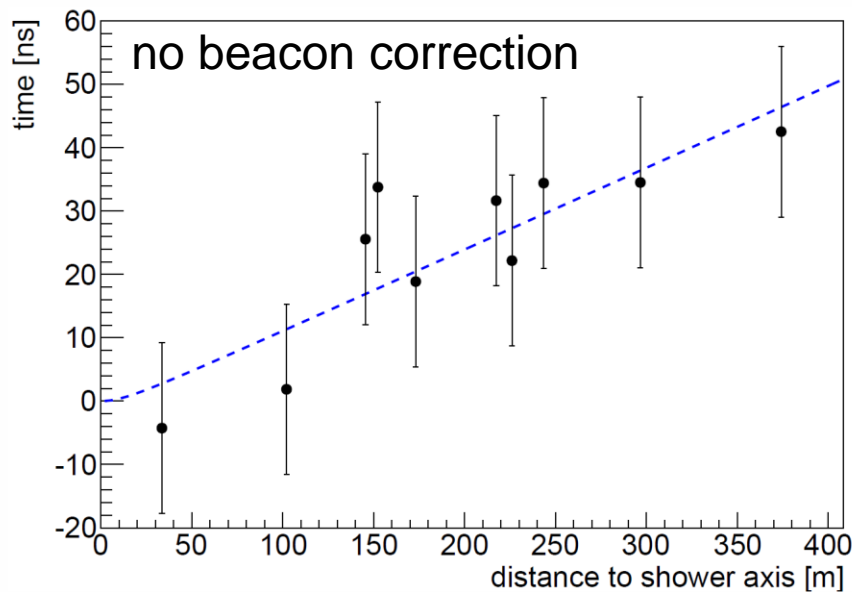
- consistent results from airplanes measured in different months
- after cutting away clear outliers (mean ± 4 MAD), sigma ~ 2 ns

Cross-check after offset correction

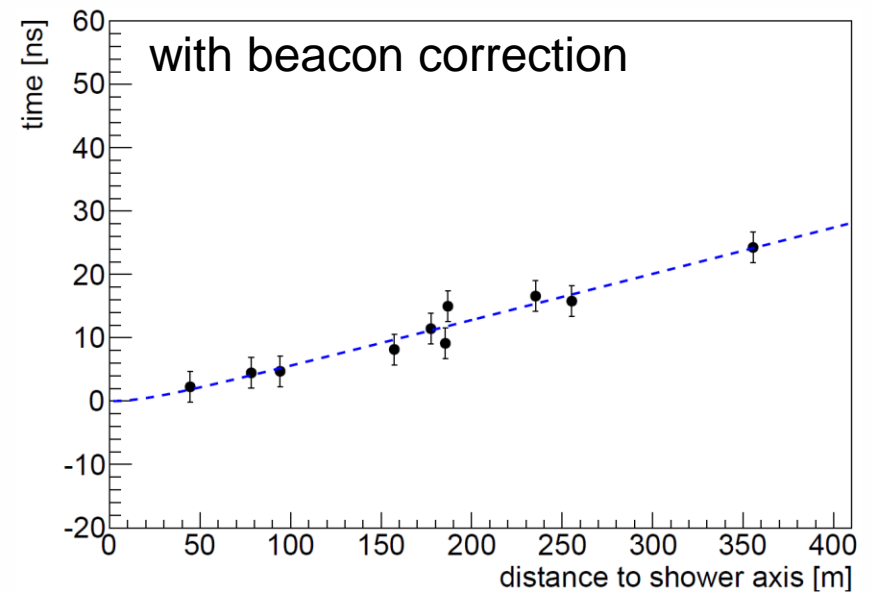


Improvement in wavefront reconstruction

- reconstruction of the hyperbolic wavefront of an example event



- reconstructed core position incompatible with surface detector reconstruction



- reconstructed core position consistent with surface detector reconstruction

Conclusion

- using a „beacon“ transmitter, we observe timing drifts in AERA stations
- exploiting radio pulses emitted by airplanes and real-time position information from ADS-B, we confirm that these are GPS clock drifts
- a systematic timing offset between antenna types was also discovered
- the combined accuracy of the two methods is ~ 2 ns
- the beacon method can be used alone and might well achieve the desired 1 ns resolution
- published in JINST 11 (2016) P01018, arXiv:1512.02216