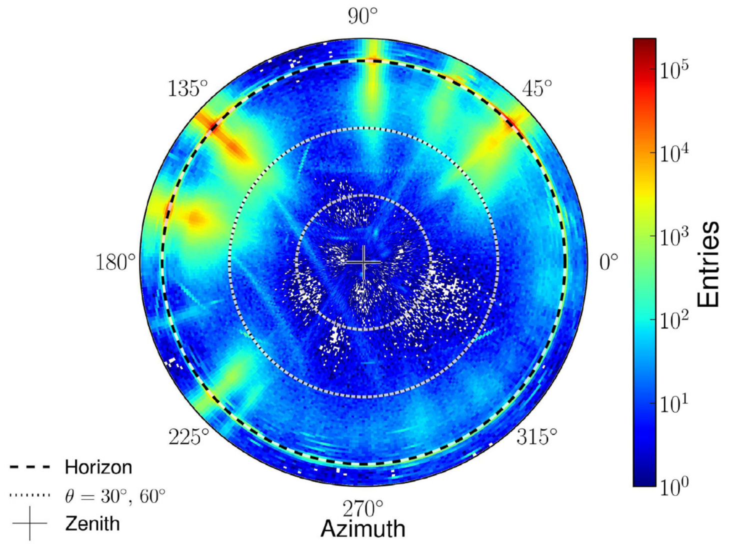
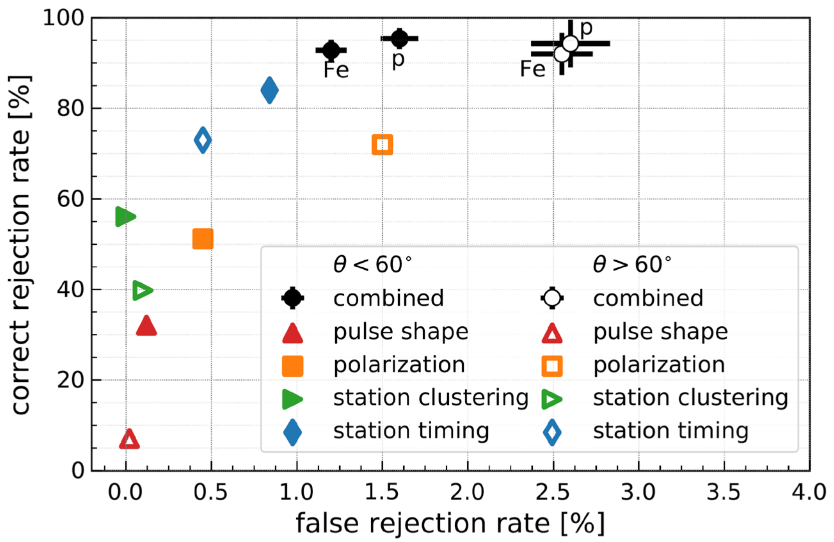
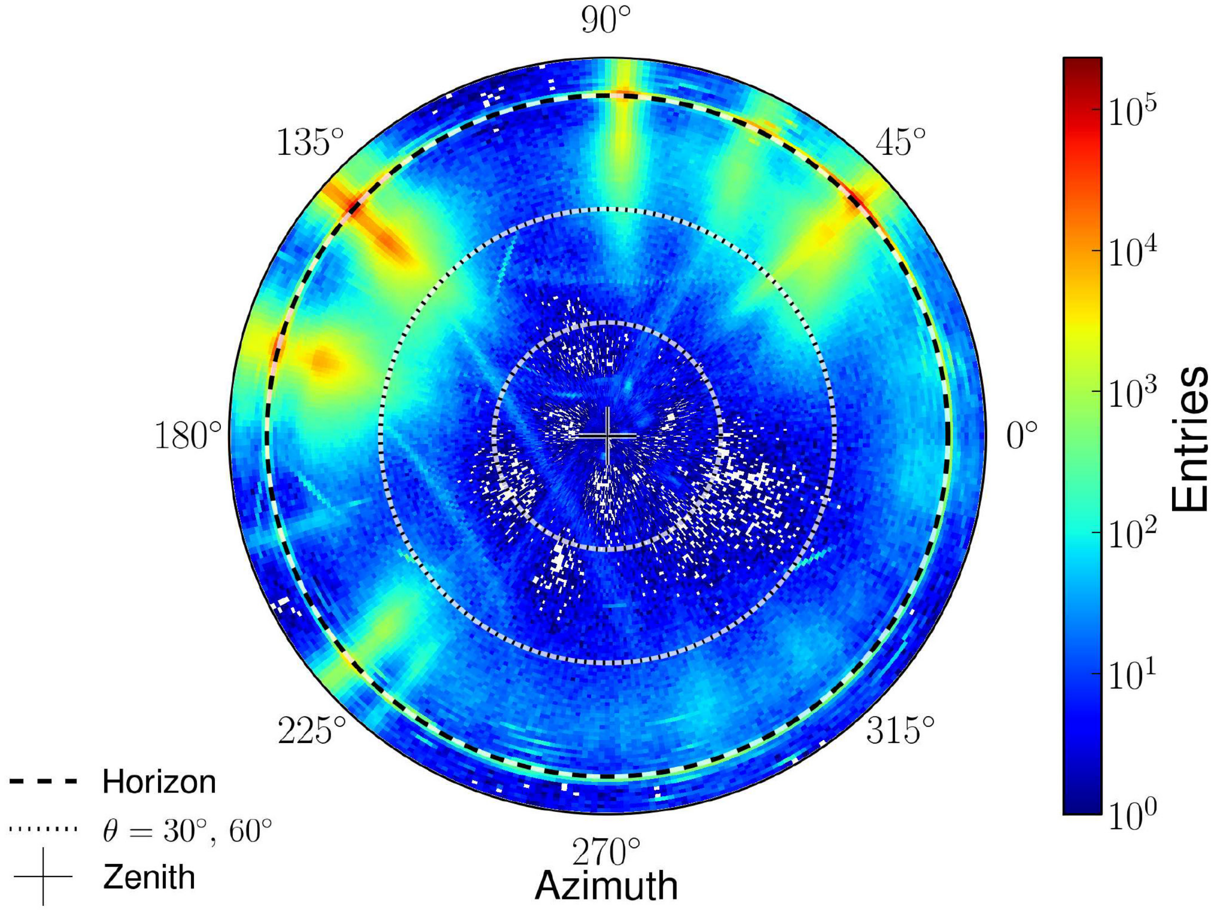
Reconstruction of air-shower measurements with AERA in the presence of pulsed radio-frequency interference

Tim Huege for the Pierre Auger Collaboration



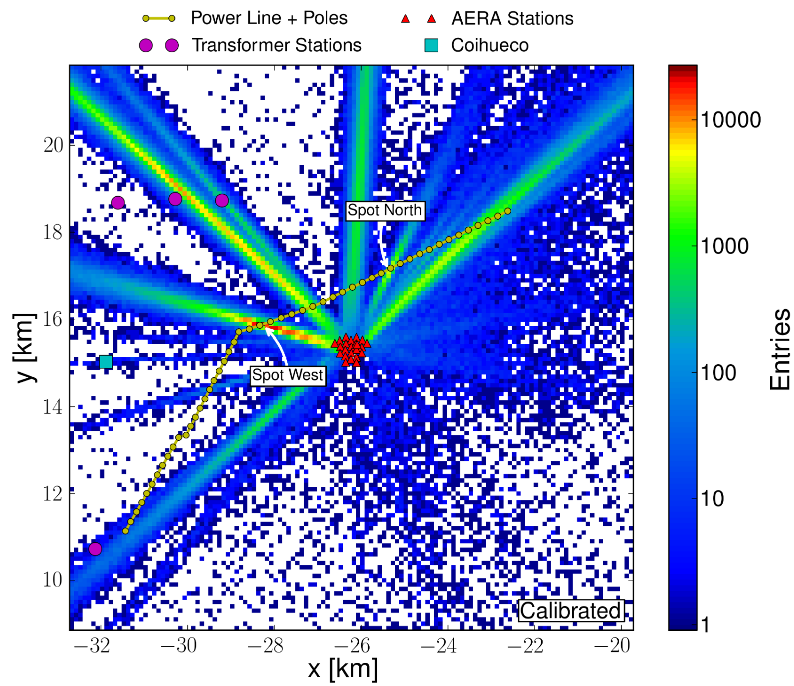


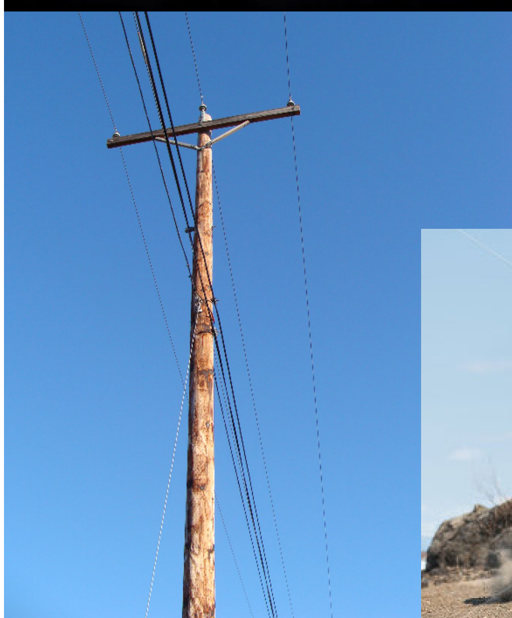
Transient RFI at the site of AERA



- (even) the Pampa Amarilla is bursting with transient RFI
- we have 15 kHz of transient RFI
- most from horizon, but misrecon-structions
- very challenging for self-trigger

RFI comes from a multitude of sources



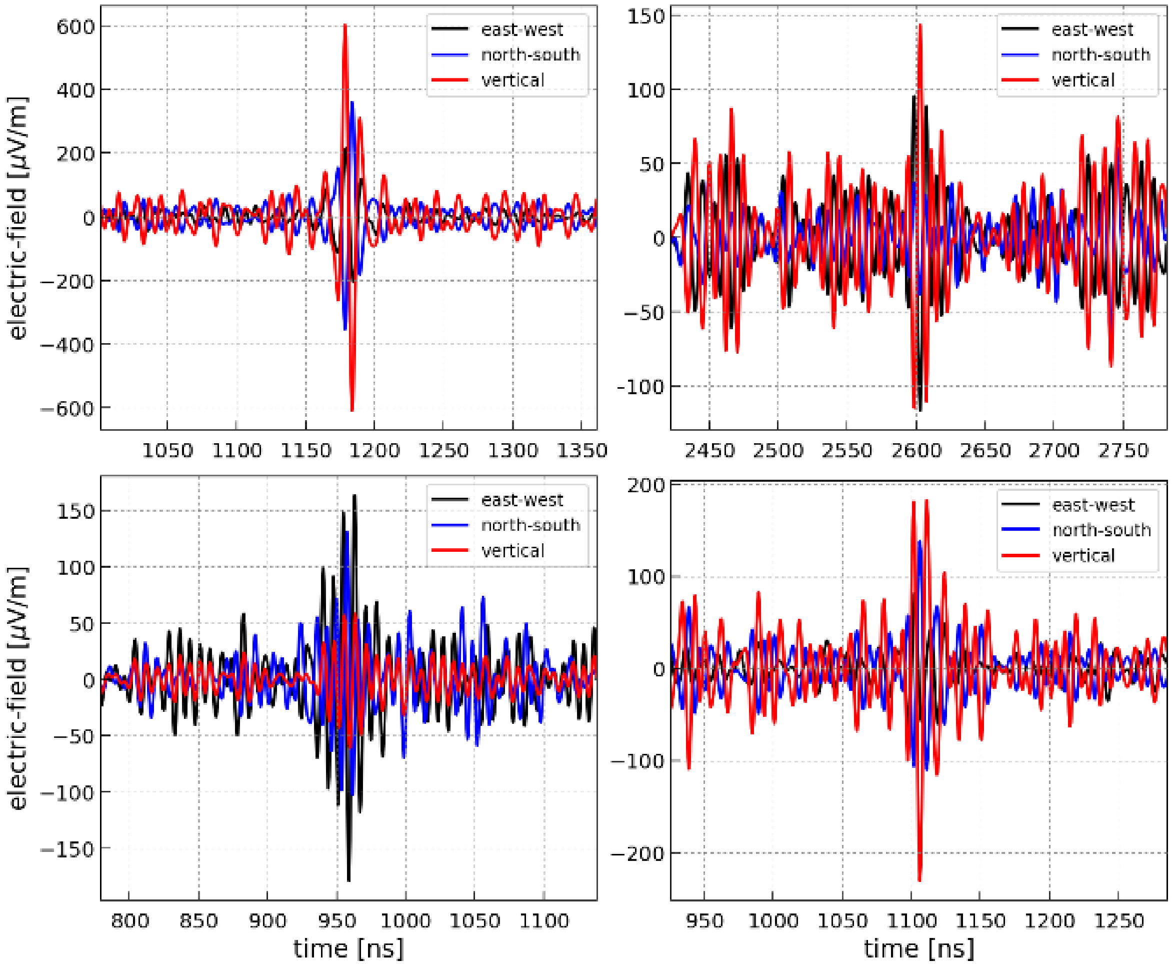


How we measure in this environment

1. we make use of external triggers
   - a buffer of 7 s allows us to wait for triggers from the surface and fluorescence detectors of the Pierre Auger Observatory
2. we use information from particle detectors in a „hybrid reconstruction“
   - we know the event-geometry before starting the radio reconstruction
   - on this basis, we set narrow „signal search windows“
   - even so, there is a high change probability for RFI pulses in the window: 1000 ns window x 15 kHz RFI = 1.5% RFI pulse probability per station, and we read out up to 150 stations per event
3. we apply several strategies to discern CR pulses from RFI
   - pulse length
   - signal polarization
   - signal clustering
   - consistency of signal arrival times

Cosmic-ray and noise pulses are very similar

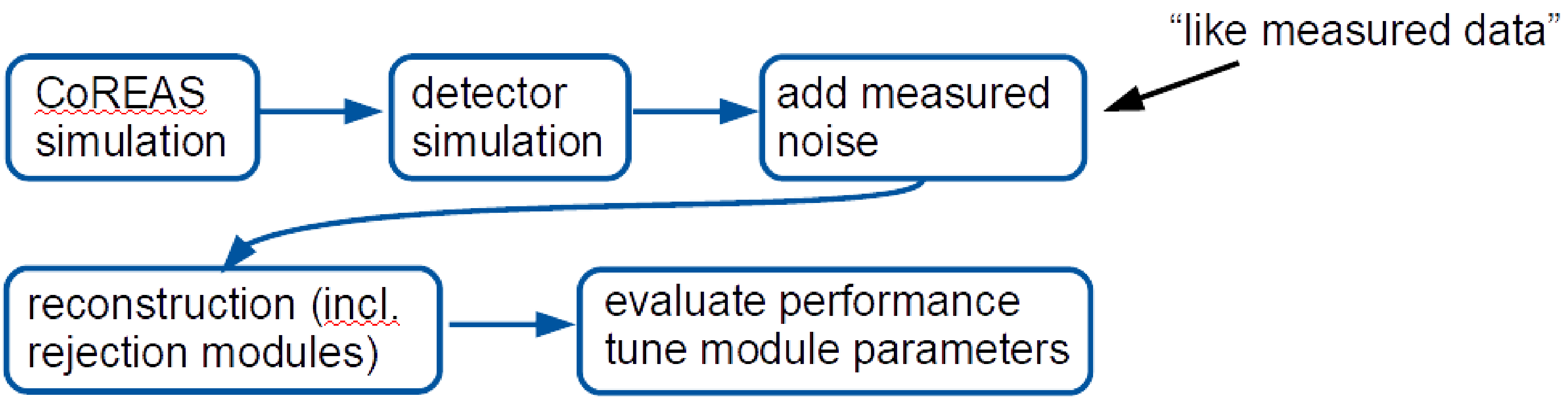
Which one is a cosmic-ray pulse?



- we have to develop multiple criteria to discern RFI from cosmic-ray signals
- future: deep neural networks? even usable for on-line self-triggering?

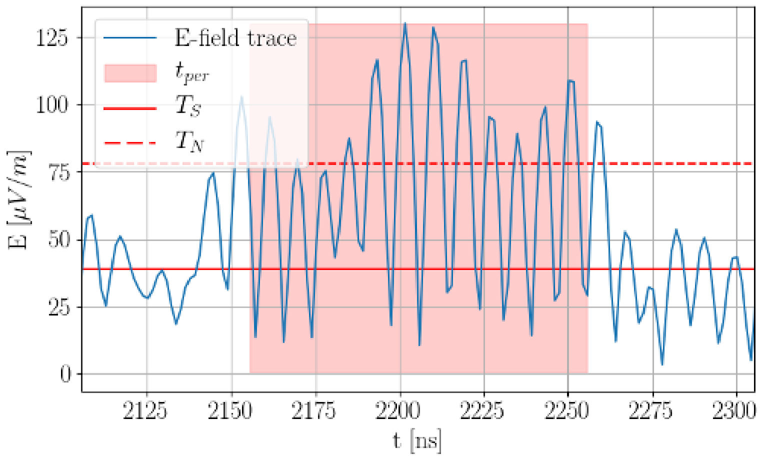
Methodology and definitions

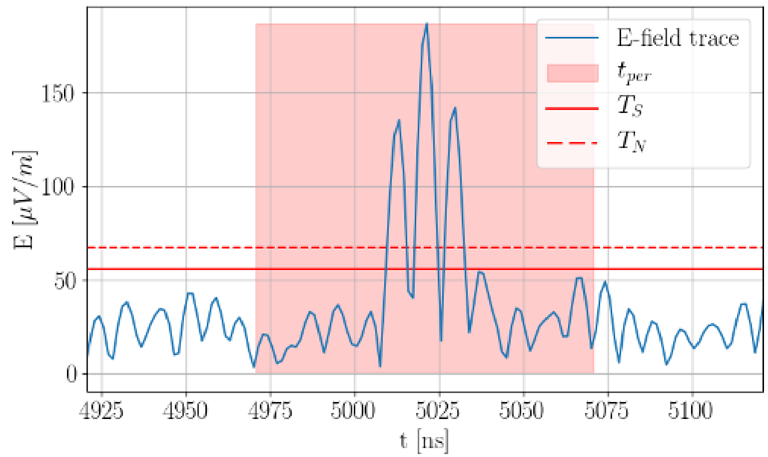
- we define:
  - a ***correct rejection*** as a rejection of an RFI pulse by our algorithms
  - a ***false rejection*** as a rejection of a CR pulse by our algorithms
- we evaluate and optimize our algorithms on the basis of simulations superposed with actual, measured AERA noise



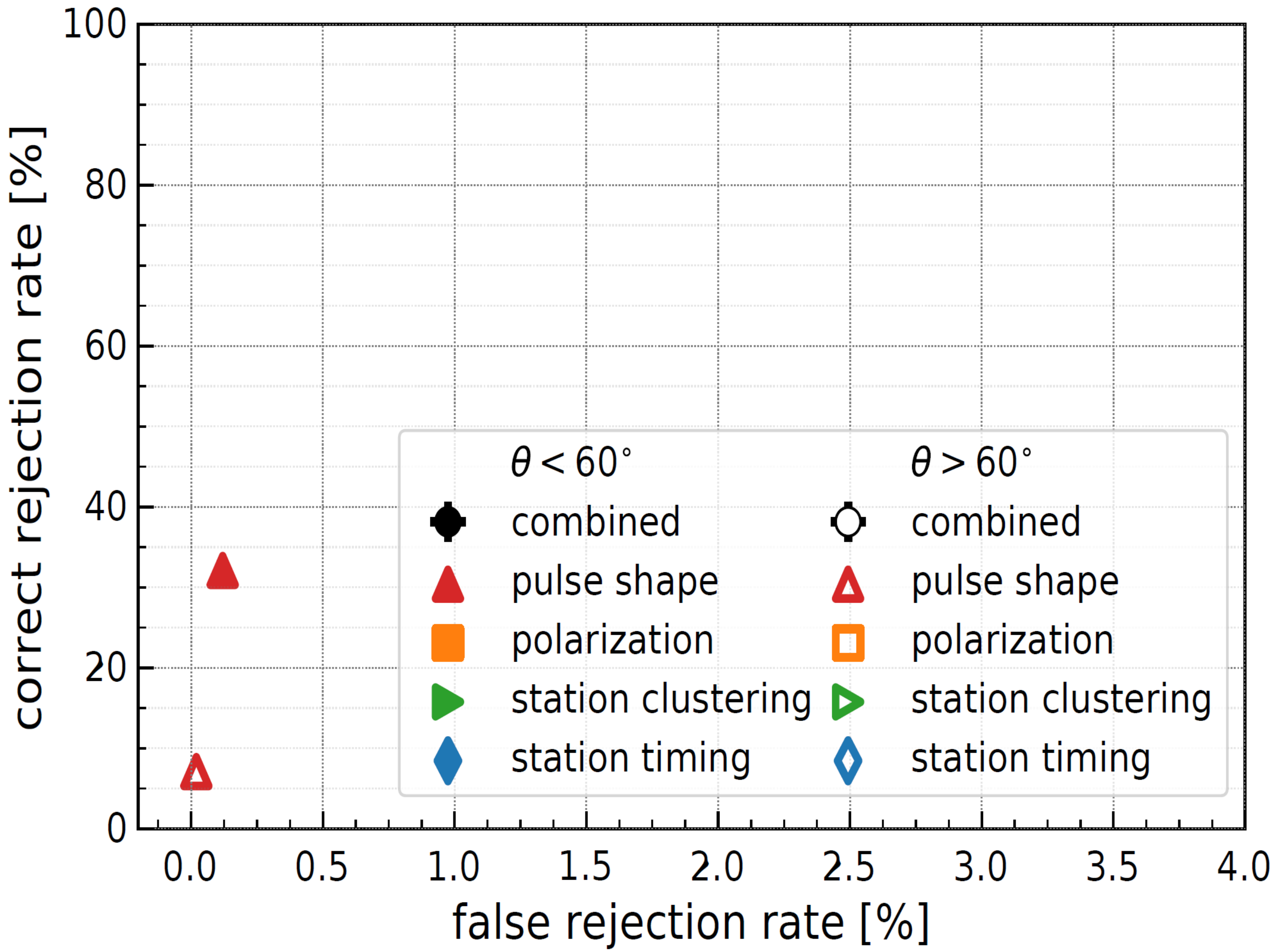
Algorithm 1: Pulse-length rejection

- CR pulses are bandwidth-limited, short pulses
- define two electric-field thresholds
  - fraction of peak amplitude $T_S = a\, E_{max}$
  - multiple of noise RMS $T_N = b\, E_{RMS}$
- count # of upward crossings of the thresholds in time window t_{per}
  - pulses with too many crossings are too long to be CR pulses





Performance of Pulse-length rejection

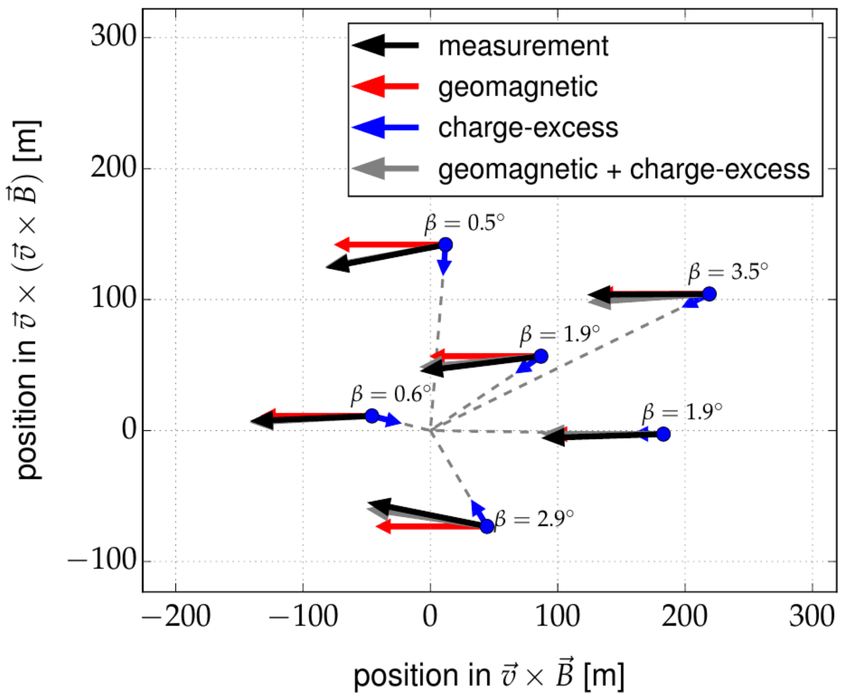


Algorithm 2: Polarization rejection

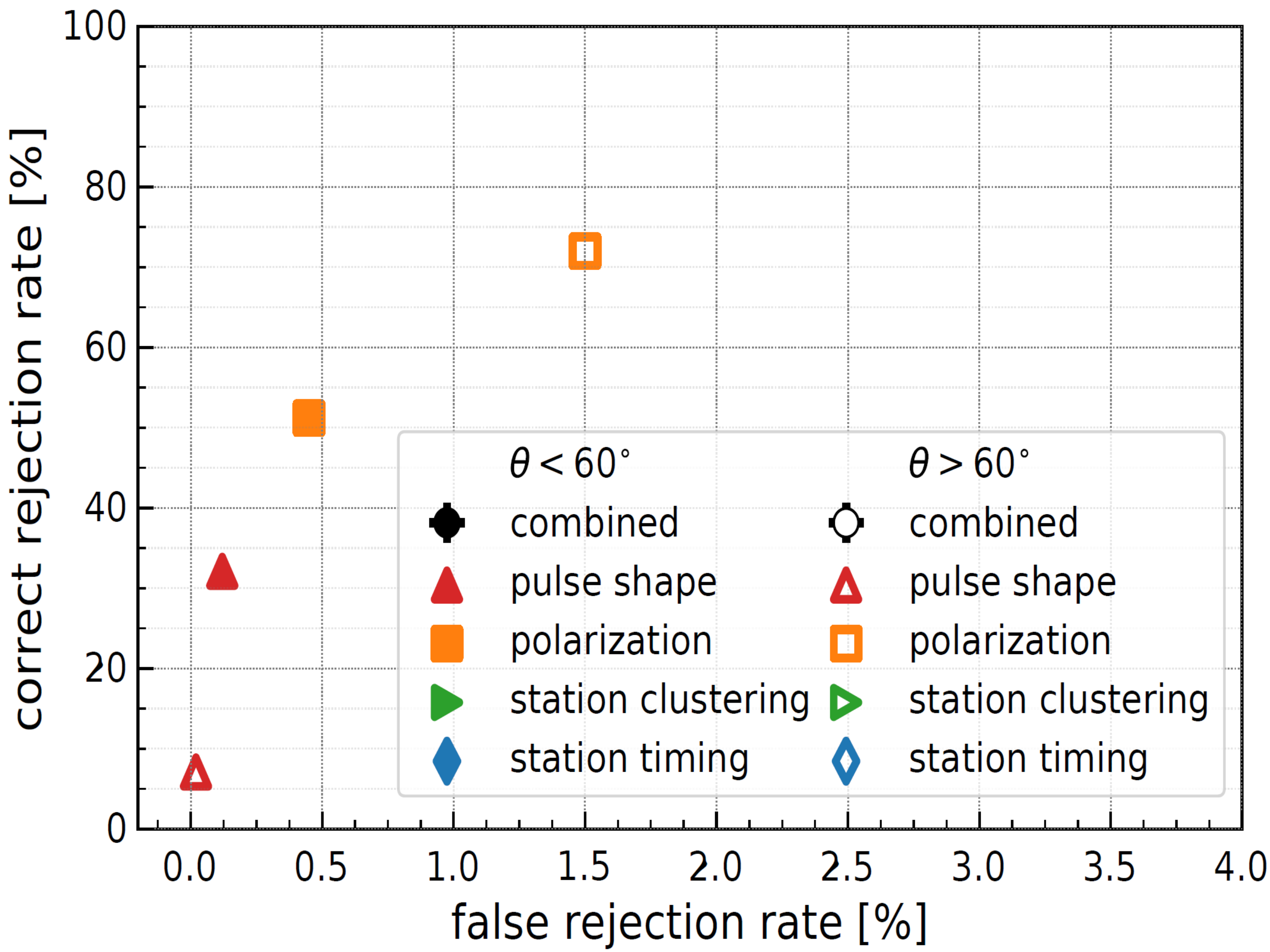
- given the core position (here from the surface detector reconstruction) and a simulations-derived model for the charge excess fraction a, the expected polarization and its uncertainty at each antenna is estimated

$$\vec{E}_{\mathrm{exp}} \propto \sin\alpha\,\vec{e}_{\mathrm{geo}} + a\,\vec{e}_{\mathrm{CE}}$$

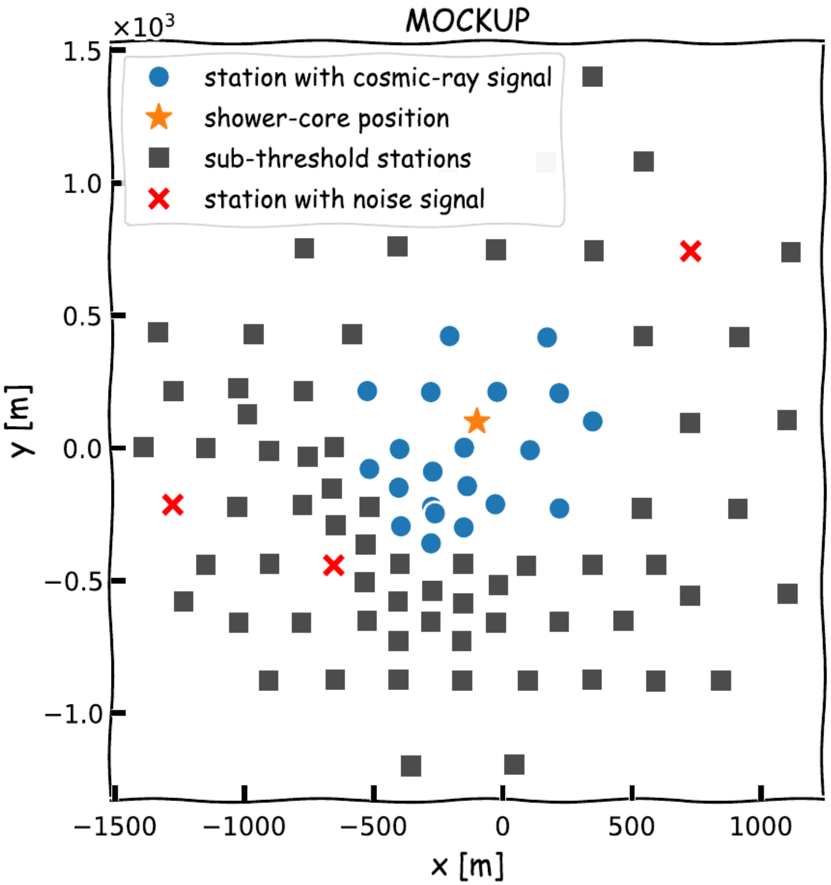
- if polarization angle is well outside expected range, the signal is rejected as a non-CR pulse



Performance of Polarization Rejection

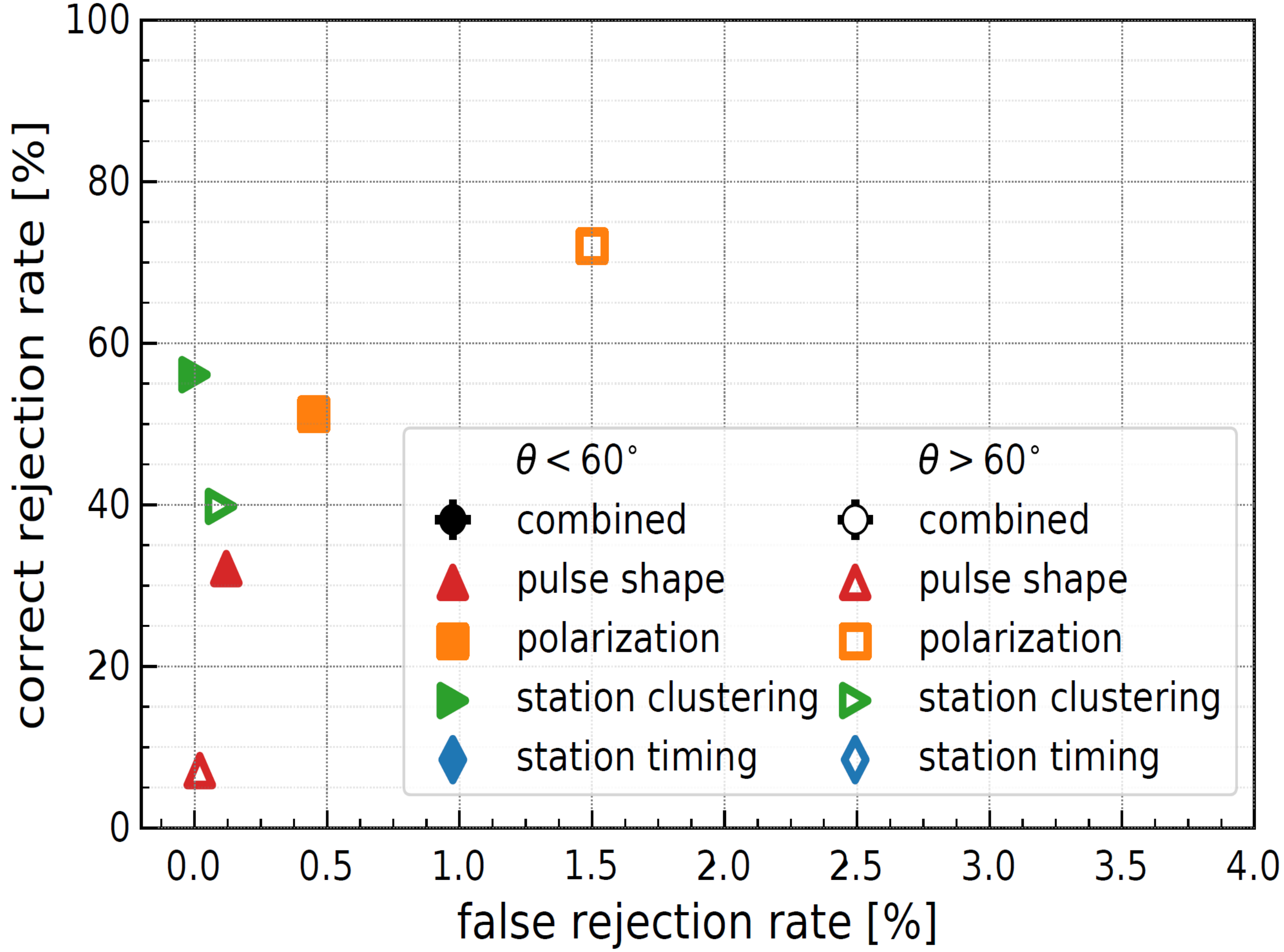


Algorithm 3: Station clustering



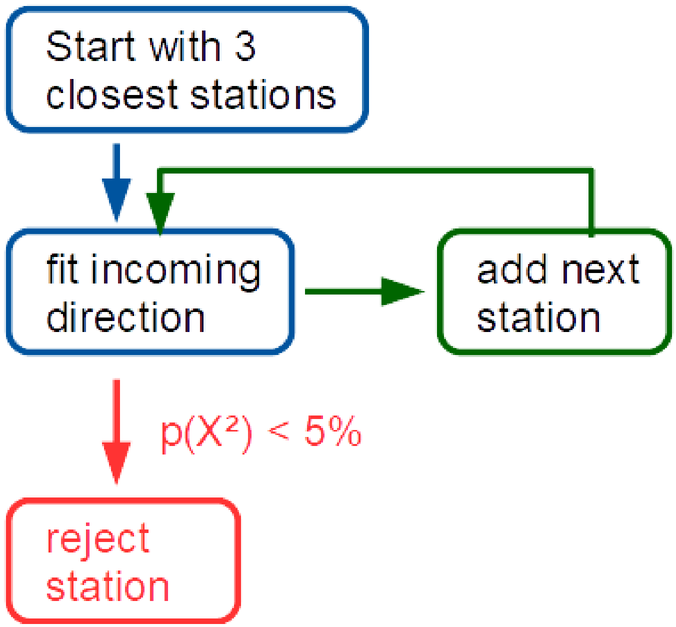
- the radio-emission footprint illuminates a contiguous area
- isolated antennas with radio pulses likely record RFI
- caveat: variable grid of antenna stations complicates matters

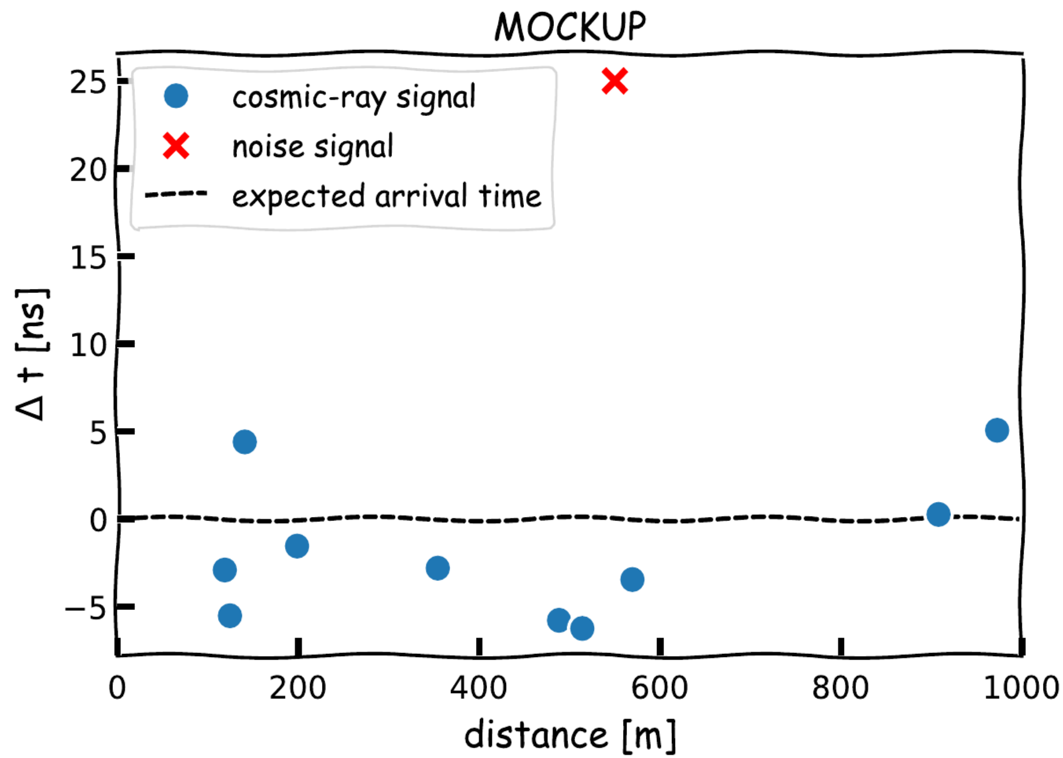
Performance of clustering rejection



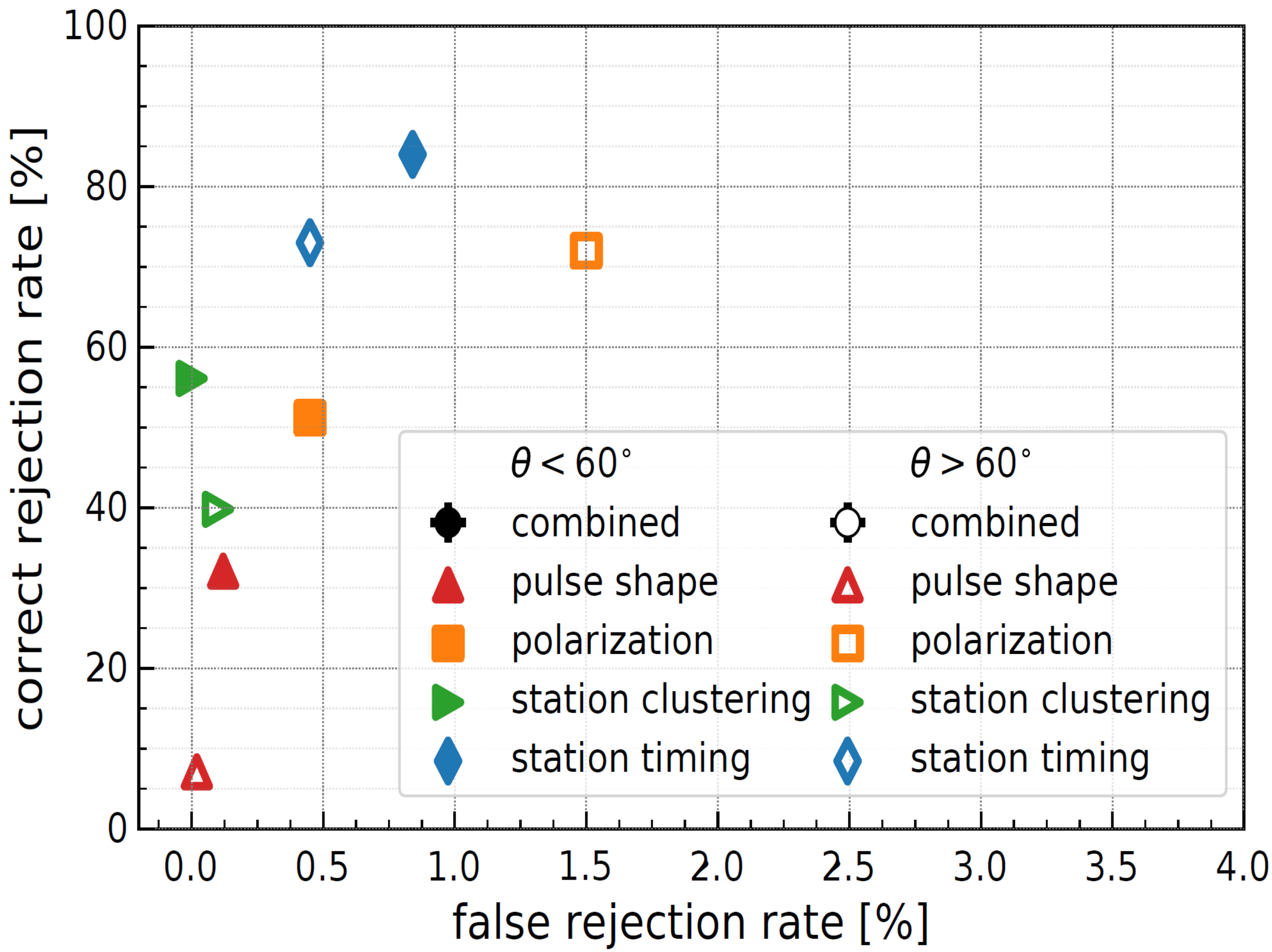
Algorithm 4: Consistency of signal arrival times

- the arrival times should form a hyperbolical (approximately conical) front
- we identify stations with non-fitting pulse arrival times in an iterative way

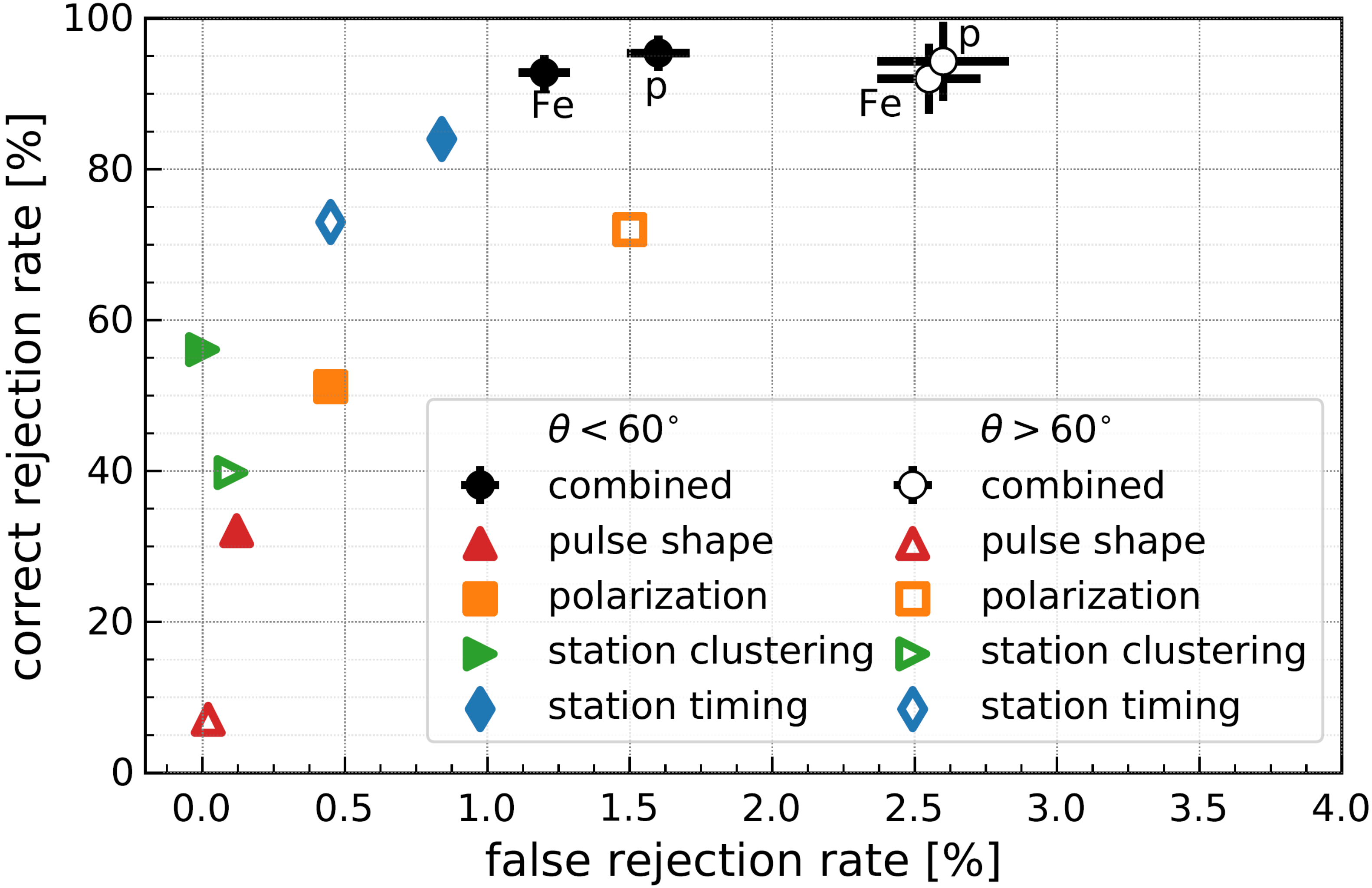




Performance of arrival time rejection

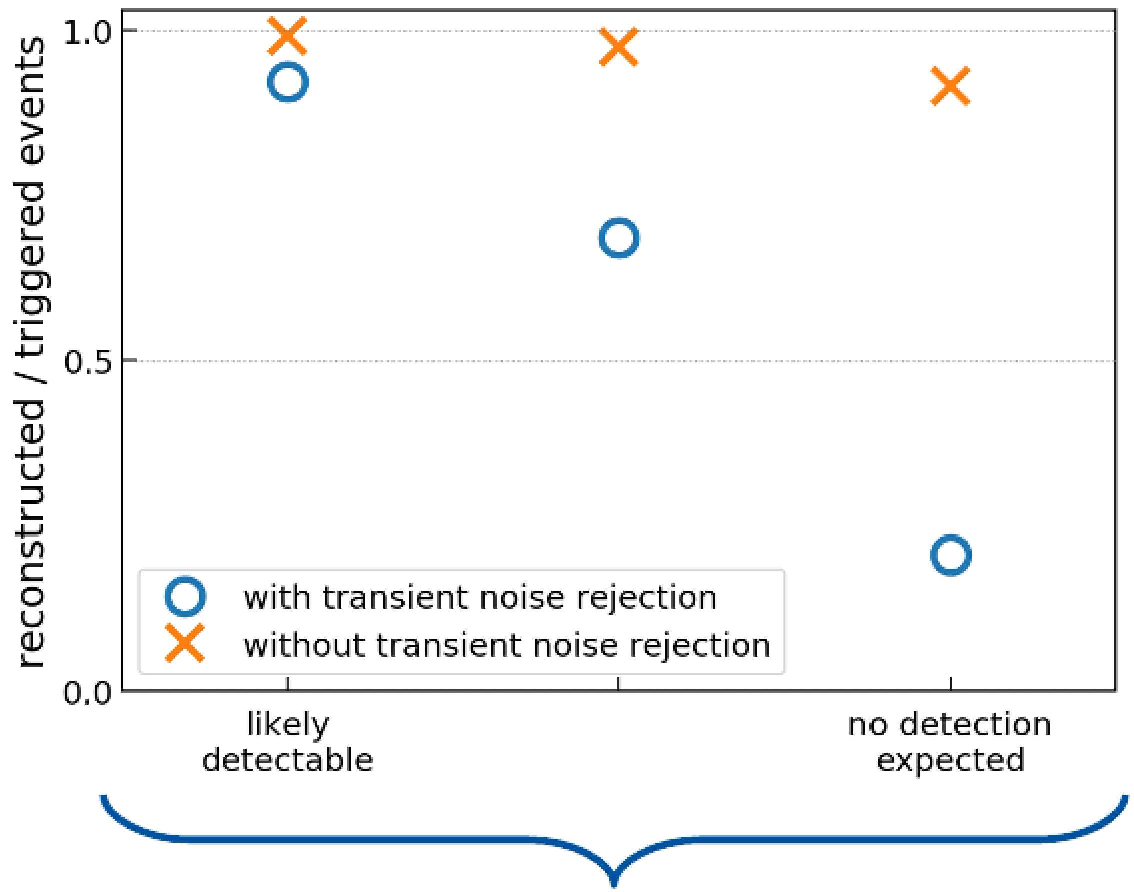


Combined performance of the algorithms



Performance when applied to data

- study performance on externally triggered events taken in 2015
- require three radio stations with signal
- evaluate fraction of successfully reconstructed events for different classes of events
- significant reduction of false-positive events



calculated from air shower parameters (SD) and model of radio signal (2D LDF)

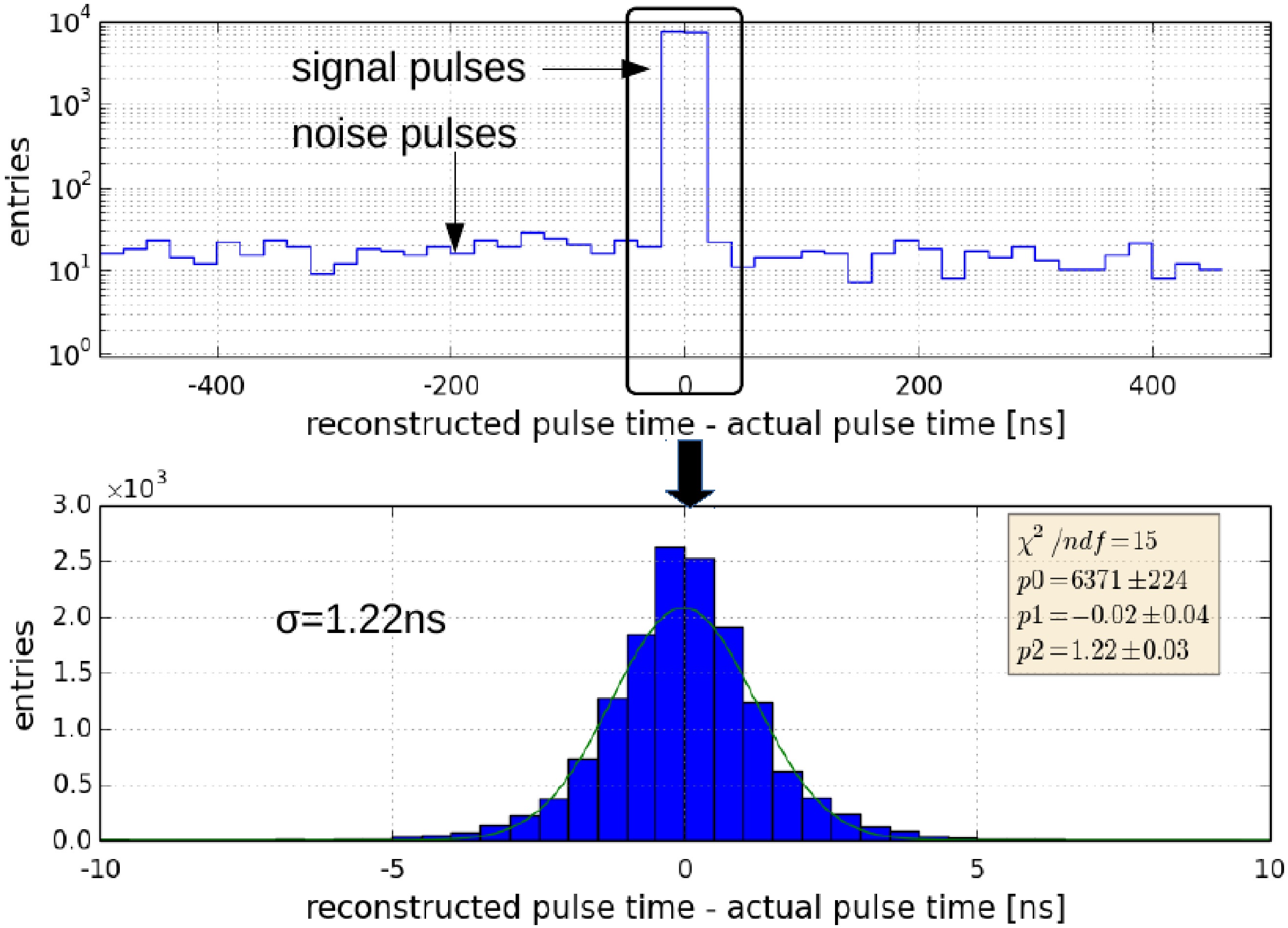
Conclusions

- for AERA, not only triggering, but also reconstruction is challenging due to 15 kHz of transient RFI
- we exploit external triggers and hybrid reconstruction to mitigate the adverse effects of RFI pulses
- even so, significant numbers of RFI pulses contaminate our signal search windows during reconstruction
- we combine 4 algorithms to discern CR and RFI pulses during reconstruction
  - pulse-length rejection
  - polarization rejection
  - signal clustering rejection
  - signal timing rejection
- the application of these algorithms yields high correct and low false rejection rates, no biases, and improves reconstruction efficiency
- these strategies could be very useful for other experiments

Backup

Signal and Noise Pulses

- **Signal Pulse:** A radio pulse that is actually caused by the air shower
- **Noise Pulse:** A radio pulse that is caused by noise
- Identification: $\Delta T < 4\sigma = 5$ns



Performance of consecutive application