NUTRIG

Results of the Second-Level Trigger Study with NUTRIG

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GRAND collaboration meeting 2025

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Event Level Trigger Algorithm

event probability gives likelihood for CR

$$p_{Event} = p^{a}_{1:timing} \cdot p^{b}_{2:signal-strength} \cdot p^{c}_{3:polarization} \cdot p^{d}_{4:polarity}$$

→ **methods 1-3 are mostly defined** ✅

weights a, b, c, d TBD

method 4 *is being developed with the help of intern* ***Alexandra Célaudoux***

→ **needed info from antenna level also defined** ✅

for each antenna:

- antenna ID / position (x,y,z)
- time stamp
- trace amplitude for each channel (incl. sign)

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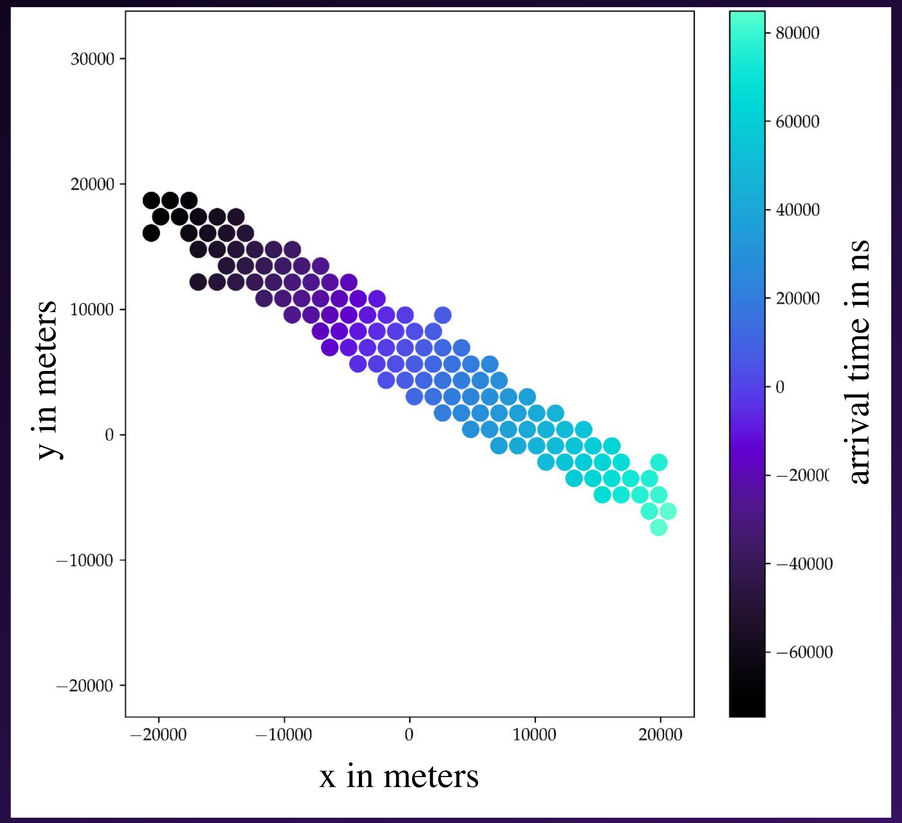
Method 1: Timing

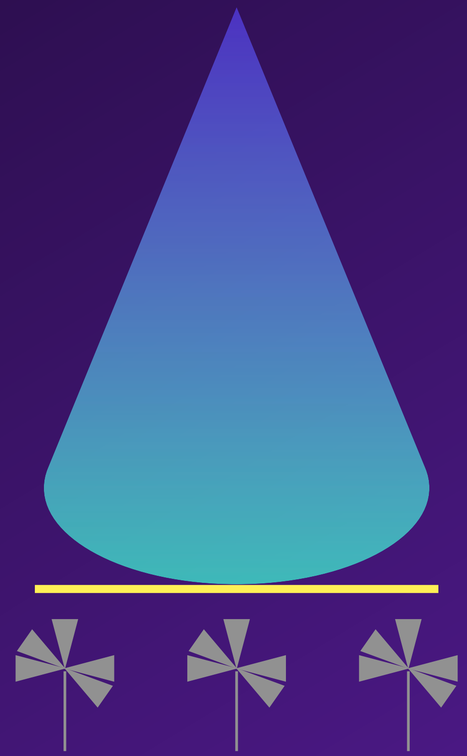
Reconstruction of Trigger Parameters with timing

★ signal arrival times → **Arsène's Plane Wave Fit** → θ_{reco} , φ_{reco}



★ **approximates** curved wavefront with a **flat plane**

★ **orientation of best-fit plane** determines **zenith** and **azimuth**



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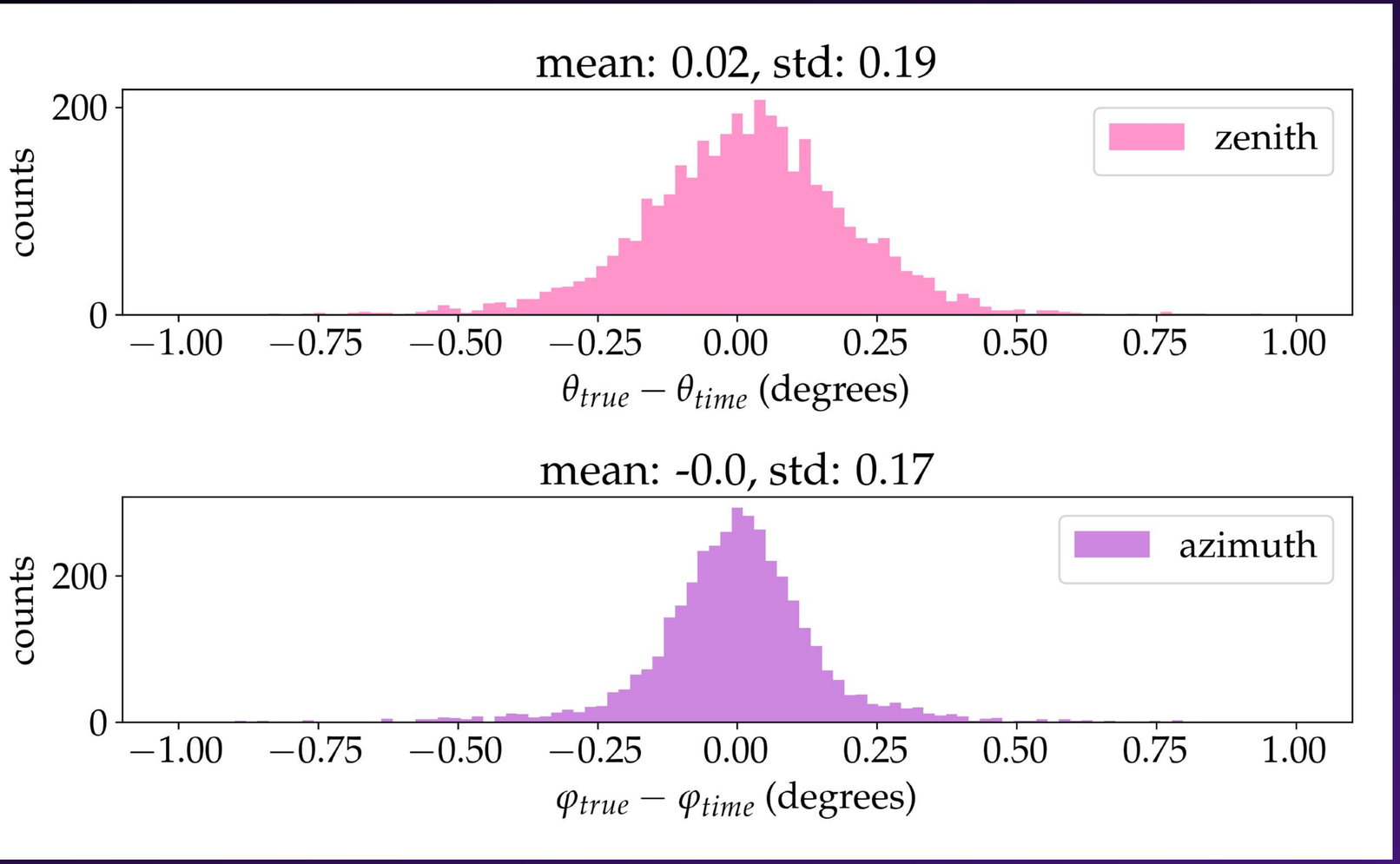
GRAND simulation

Method 1: Timing

~7k events



- ⋆ Plane Wave Fit
  - ⋆ sophisticated analytical method including errors
- ⋆ **sub degree resolution***

GRAND simulation

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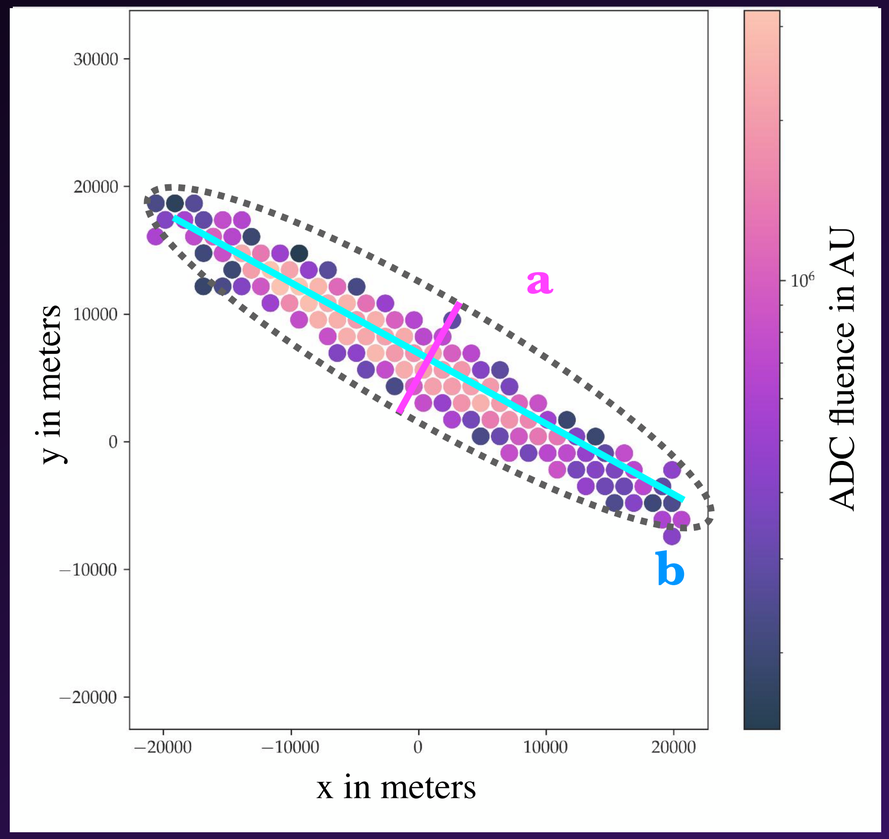
Method 2: Signal Strength

Reconstruction of Trigger Parameters with signal strength

★ measured signal strength → a & b → θ_{fit} , φ_{fit}



★ θ_{fit} : from **eccentricity** of ellipse

→ *based on conic section model of air shower*

★ φ_{fit} : from **orientation** of ellipse

→ *introduces 180° ambiguity (see backup)*

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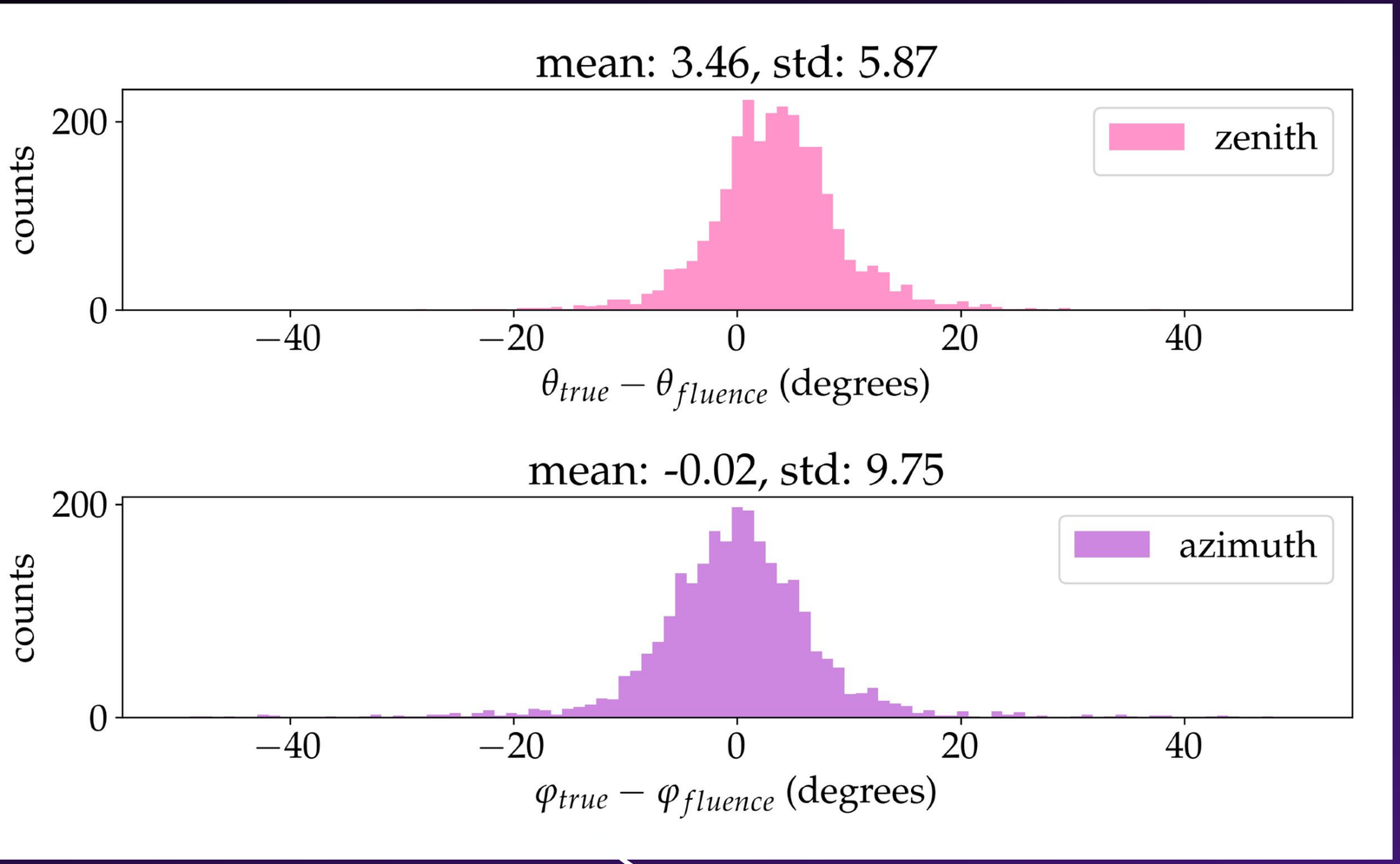
signal strength

Method 2: Signal Strength

~7k events



biased towards larger angles

→ mostly due to border effects

180° ambiguity excluded

polarization

Method 3: Polarization

according to Simon Chiche's work (efield)

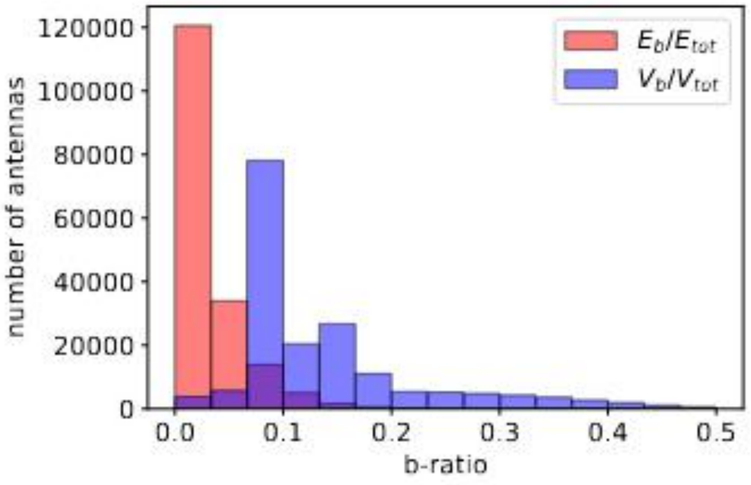


Figure 16: Comparison between of the "b-ratio" for the electric field: E_b/E_{tot} and for the voltage: V_b/V_{tot}.

https://arxiv.org/pdf/2202.06846

$$\text{b-ratio} = E_b/E_{\text{tot}}$$

$$E_b = |\vec{E}_{\text{tot}} \cdot \vec{u}_b|$$

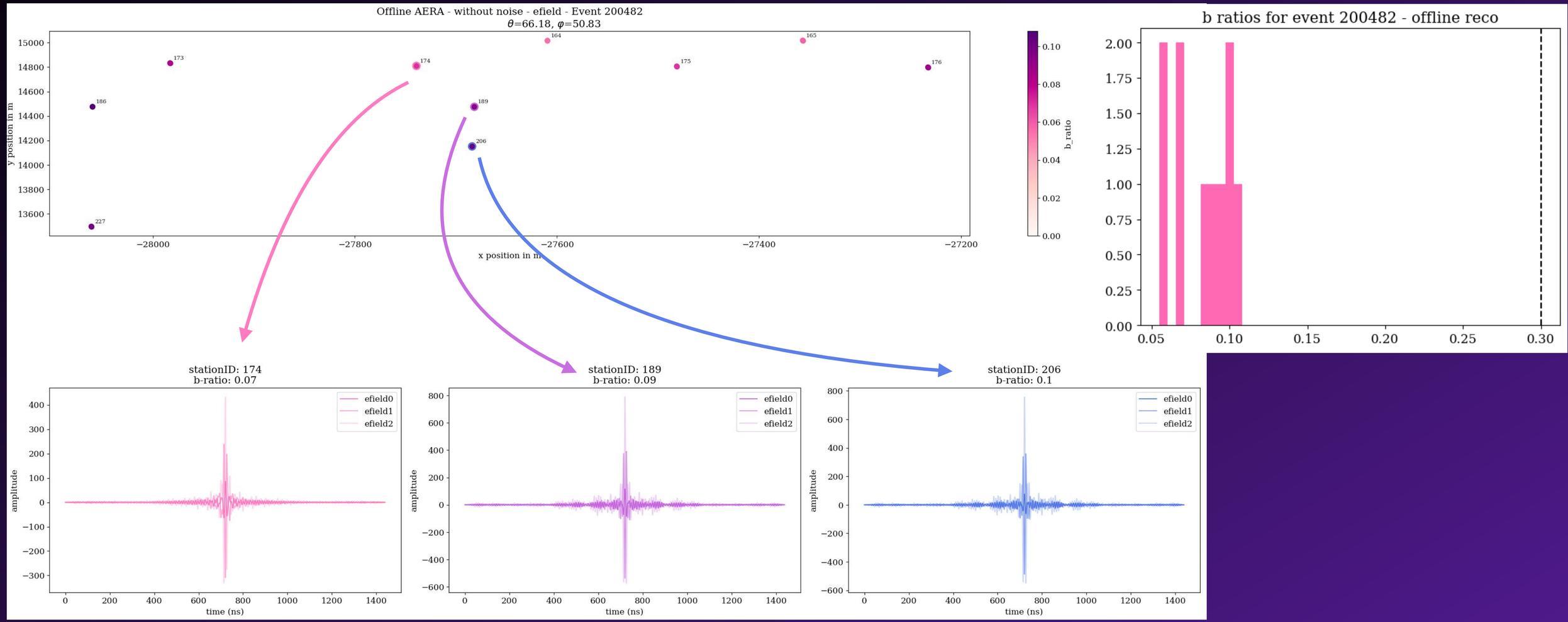
$$E_{\text{tot}} = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

$\vec{u}_b$ - magnetic field vector

polarization

Method 3: Polarization

from Offline - without noise



polarization

Method 3: Polarization

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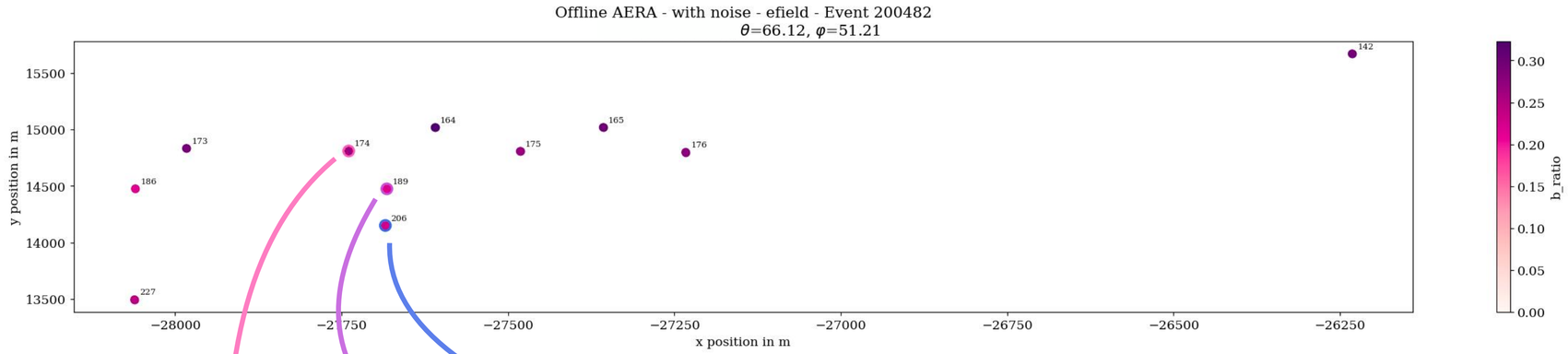
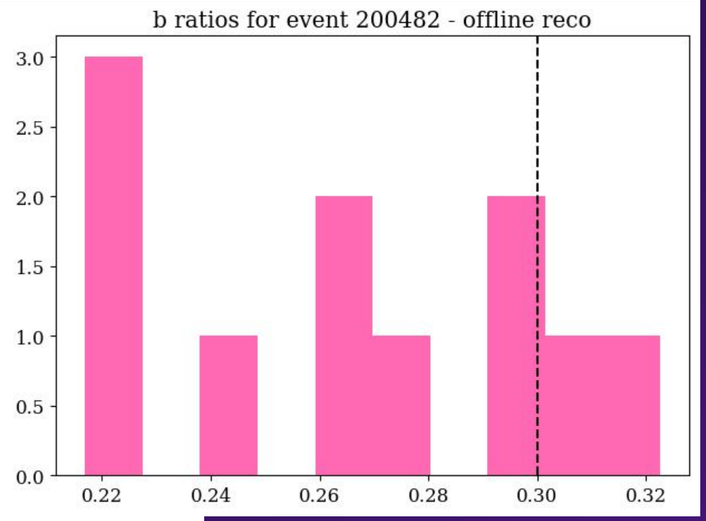
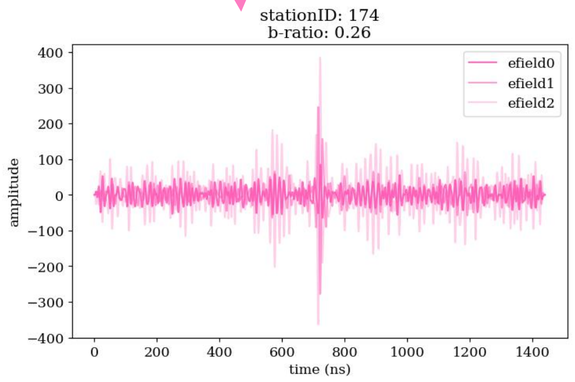
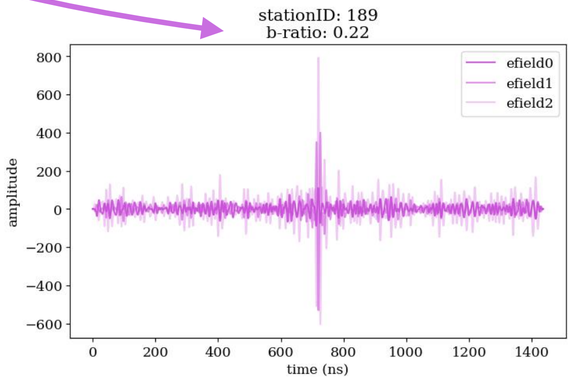
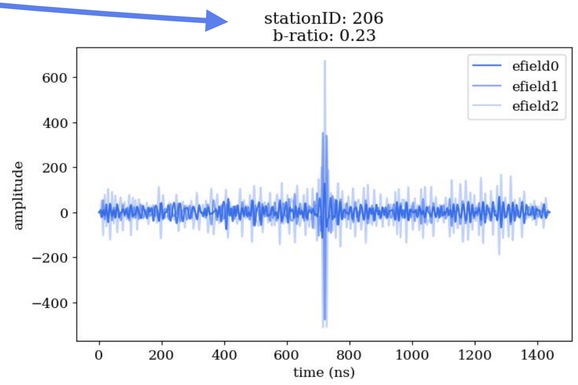








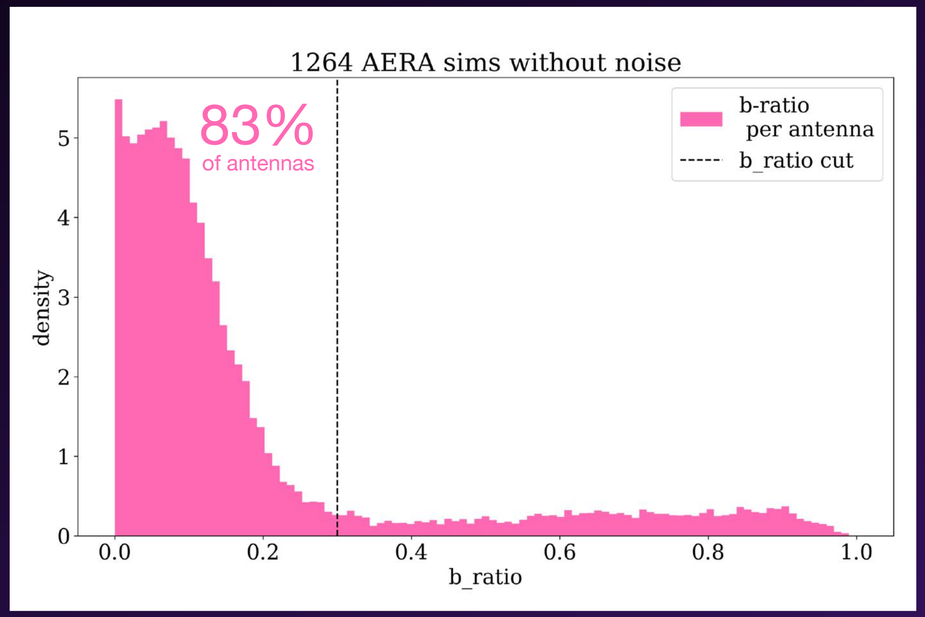


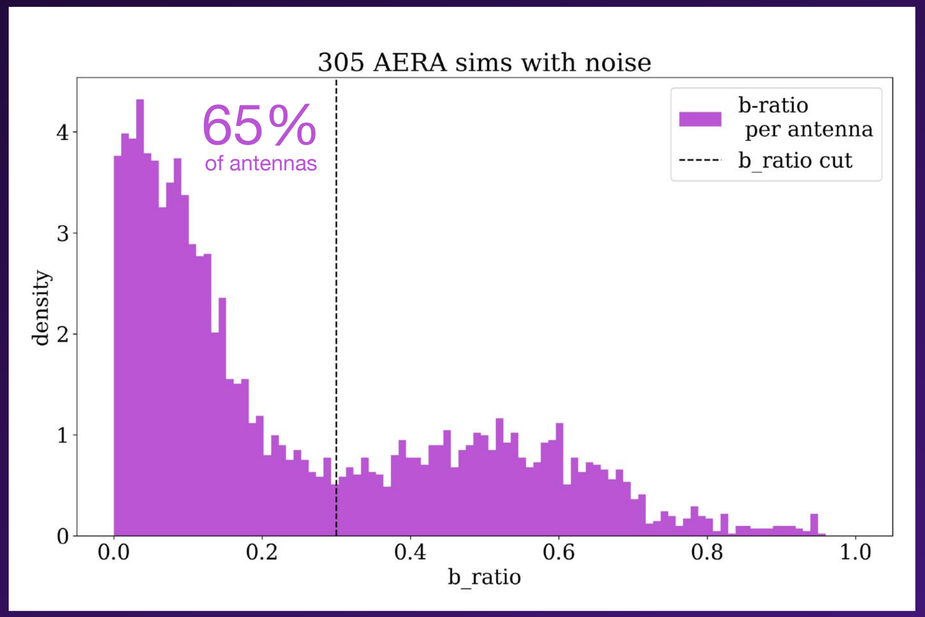
polarization

Conclusion on Polarization Test

for AERA sims SNR > 10

- ★ **The method works out of the box for efield sims** (3 channels)





- ★ Problem:
  - ★ AERA **measurements** have **2 channels + only voltage traces**

polarization

Method 3: Polarization

according to Simon Chiche's work

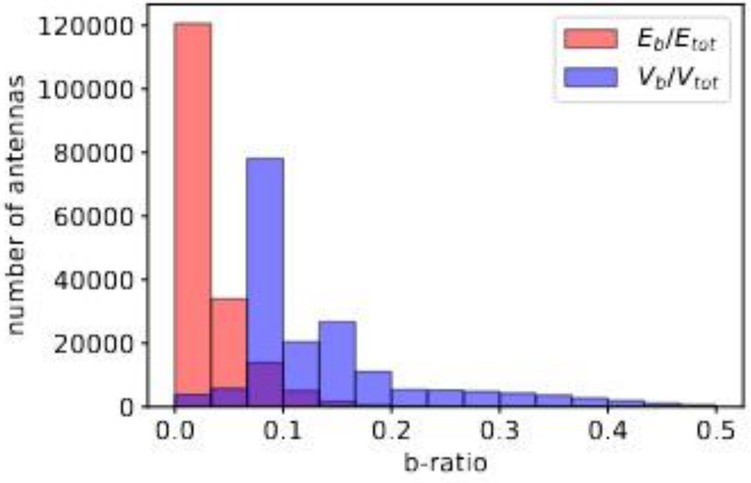


Figure 16: Comparison between of the "b-ratio" for the electric field: E_b/E_{tot} and for the voltage: V_b/V_{tot}.

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$$\text{b-ratio} = V_b/V_{\mathrm{tot}}$$

$$V_b = |\vec{V}_{\mathrm{tot}} \cdot \vec{u}_b|$$

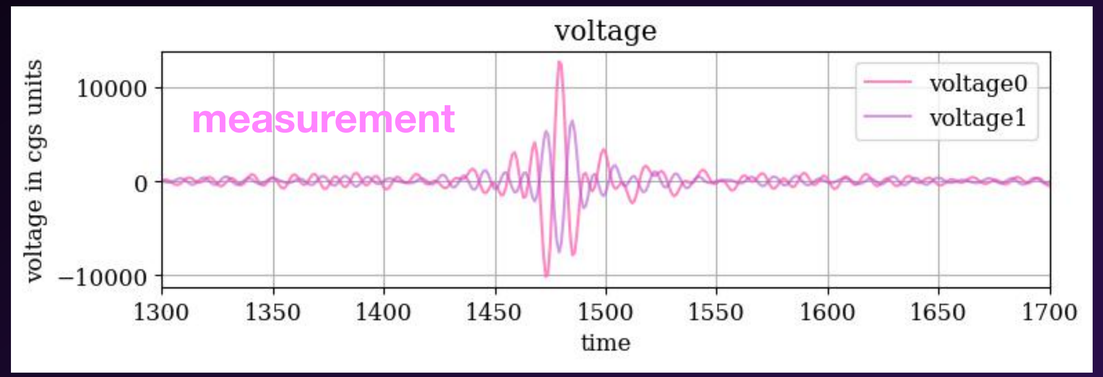
$$V_{\mathrm{tot}} = \sqrt{V_x^2 + V_y^2 + V_z^2}$$

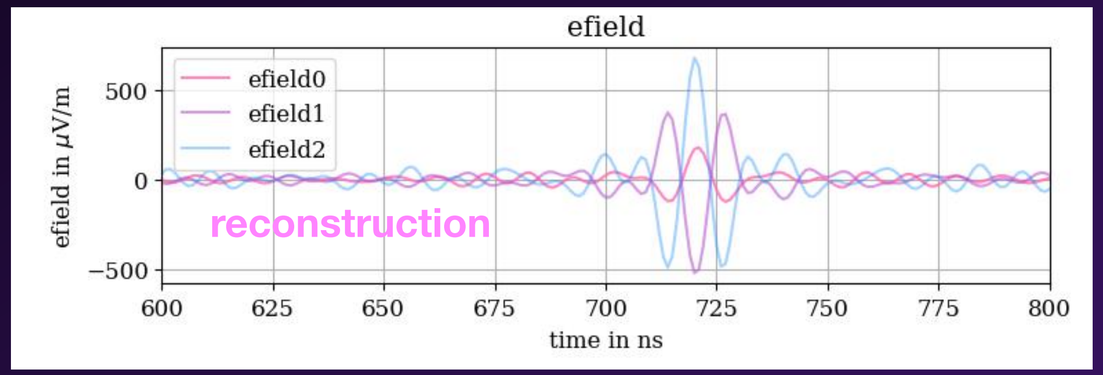
$$\vec{u}_{b,\mathrm{Auger}} = (\cos(-34^\circ), 0, -\sin(-34^\circ))$$

assumes that x,y,z are "equal", but that's not the case on voltage level !

Method 3: Polarization

according to Simon Chiche's work





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$\vec{u}_b$ - magnetic field vector

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Simple Efield Reconstruction

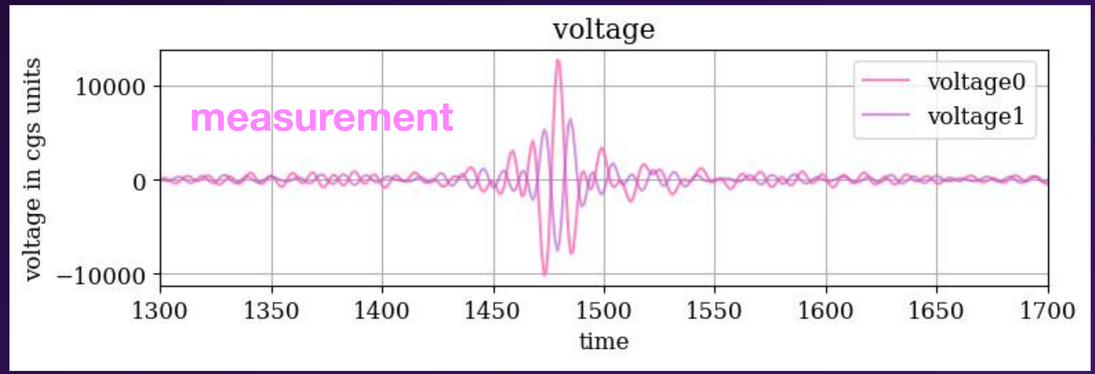
1. Transform voltages to efield using antenna response

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} R_{1\theta} & R_{1\varphi} \\ R_{2\theta} & R_{2\varphi} \end{pmatrix} \begin{pmatrix} E_\theta \\ E_\varphi \end{pmatrix}$$

R_{1i} - response along arm 1

R_{2i} - response along arm 2

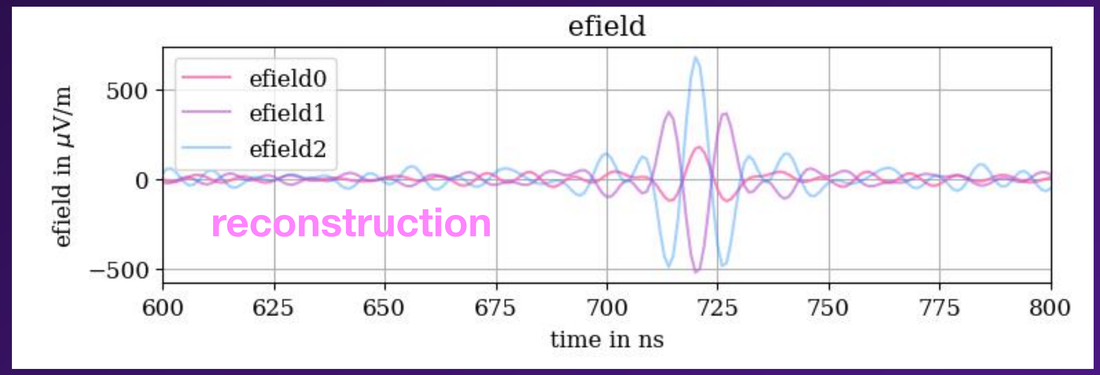
$$\Rightarrow E_\theta = \frac{V_1 - R_{1\varphi} \cdot E_\varphi}{R_{1\varphi}}, E_\varphi = \frac{V_2 \cdot R_{1\varphi} - V_1 \cdot R_{2\varphi}}{R_{1\theta} \cdot R_{2\varphi} - R_{2\theta} \cdot R_{1\varphi}}$$



2. Transform to cartesian coordinates

$$\vec{E} = E_r \hat{r} + E_\theta \hat{\theta} + E_\varphi \hat{\varphi}, \text{ here } E_r = 0$$

$$\Rightarrow \boxed{\begin{aligned} E_x &= E_\theta \cos\theta \cos\varphi - E_\varphi \sin\varphi \\ E_y &= E_r \sin\varphi \cos\theta + E_\varphi \cos\varphi \\ E_z &= -E_\theta \sin\theta \end{aligned}}$$



Polarization Method with Antenna Response

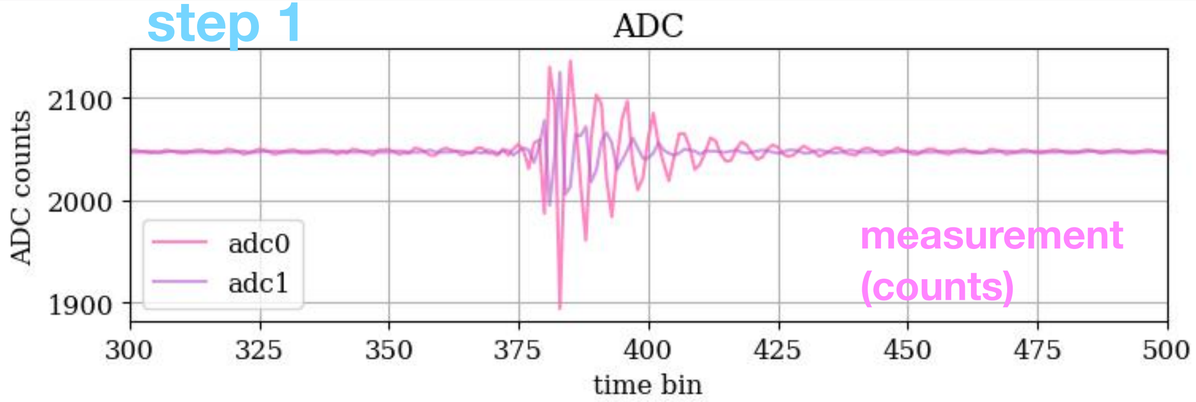
Application of Efield Reco for the Event Level Trigger

- **simplifications for a possible online reco:**
  - **single frequency** $30 - 80$ MHz $\rightarrow$ 55 MHz (Auger)
  - **only transform the amplitudes**
    $\rightarrow$ whole trace will not be available on SLT level
  - **FFT** yes or no?
    $\rightarrow$ not feasible for online triggering

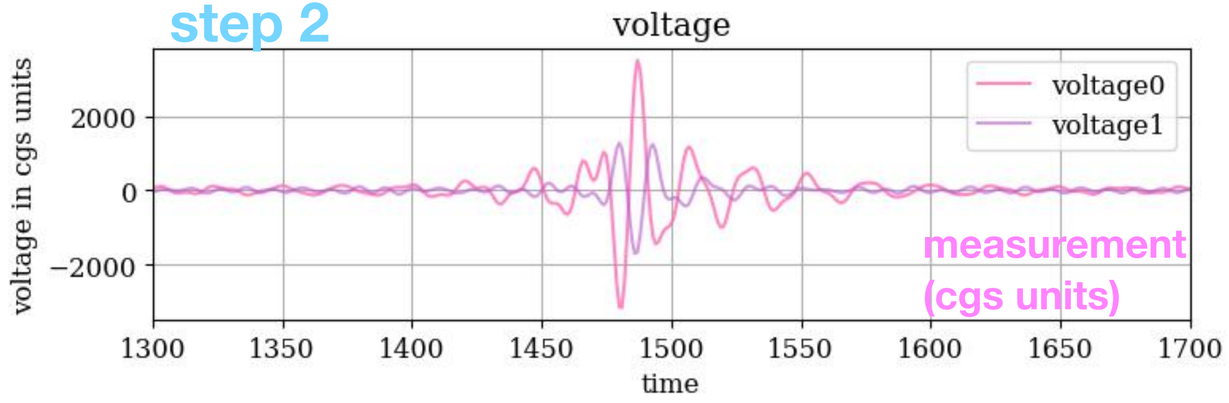
Efield Reconstruction - First Results

Example of one Antenna's Traces

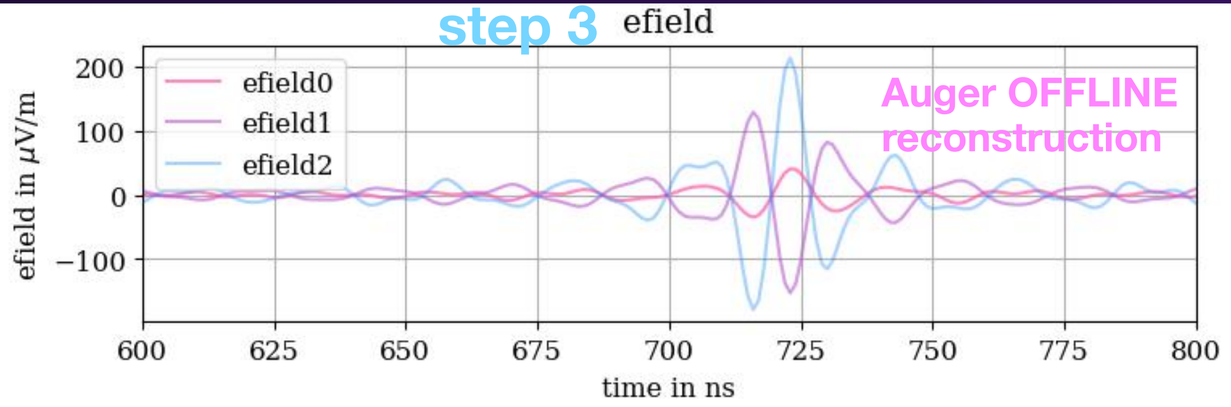
step 1



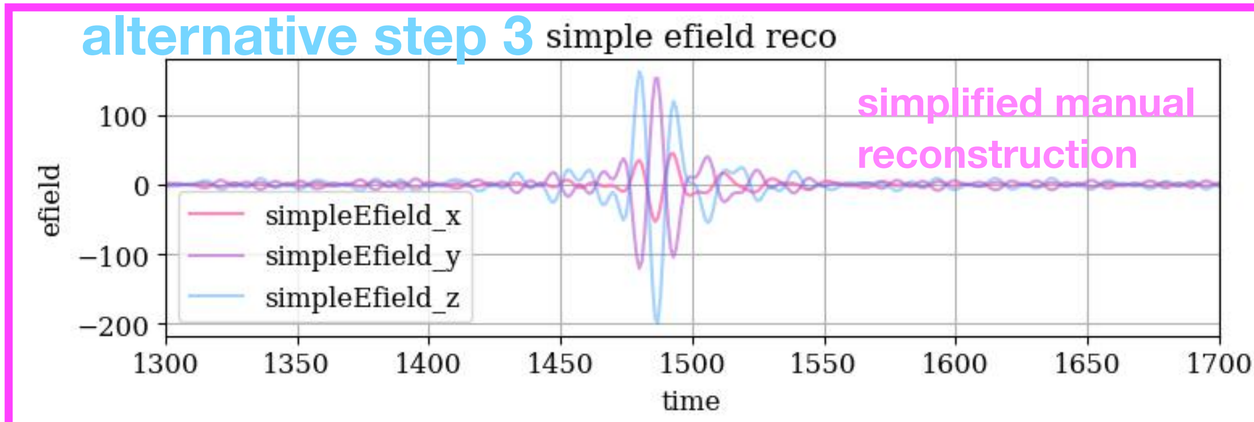
step 2



step 3



alternative step 3



→ first test with FFT and full trace

Polarization For Reconstructed Efields

for selected AERA sims

- **Offline Efield**
  reconstructed using Auger's reconstruction software OFFLINE
  - 80/80 antennas with b < 0.3
- **Simple Efield**
  reconstructed manually from Offline ADC traces
  - 76/80 antennas with b < 0.3

eventID	zenith in °	azimuth in °
201710	50	20
201250	90	124
201838	63	262
200482	67	50
200489	78	237
201003	85	234

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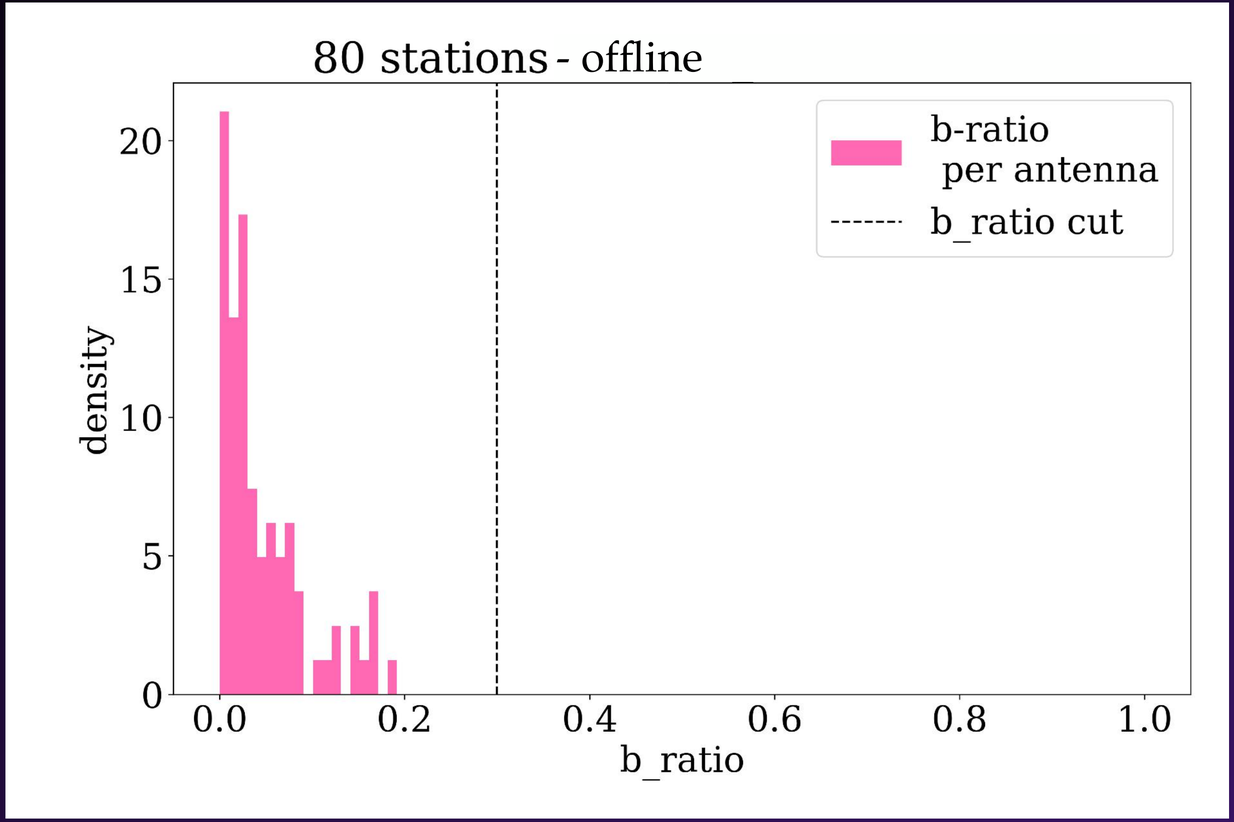
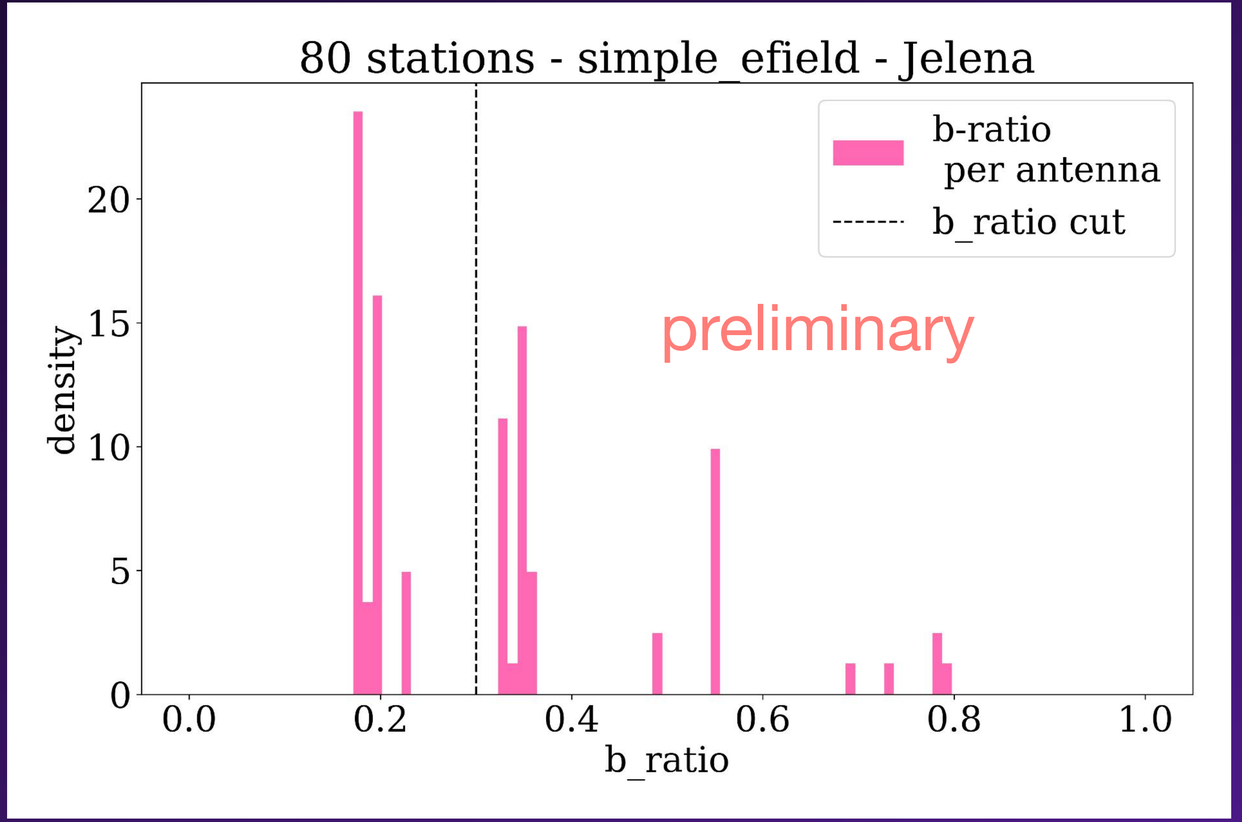
AERA simulation

polarization

Polarization For Reconstructed Efields

for selected AERA sims



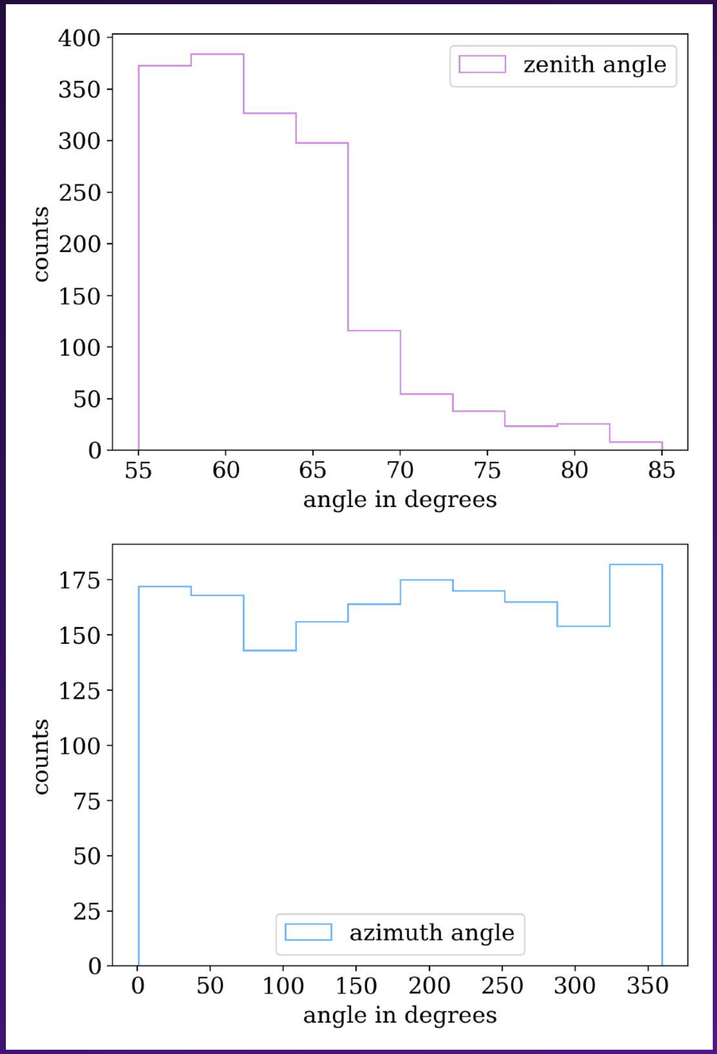


polarization

Polarization For Reconstructed Efields

for AERA sims

- ~ 2k air showers simulated with CoREAS for AERA (before cuts)
- energies $\log(E) \in (2.5,4.5)$ GeV
- zenith $\theta \in [55,85]^\circ$
- azimuth $\varphi \in [0,360]^\circ$
- processed with Auger's reconstruction software OffLine
  - cuts on SNR > 10
  - applies antenna response, measured noise
  - provides traces: efield, voltage, ADC, shower plane

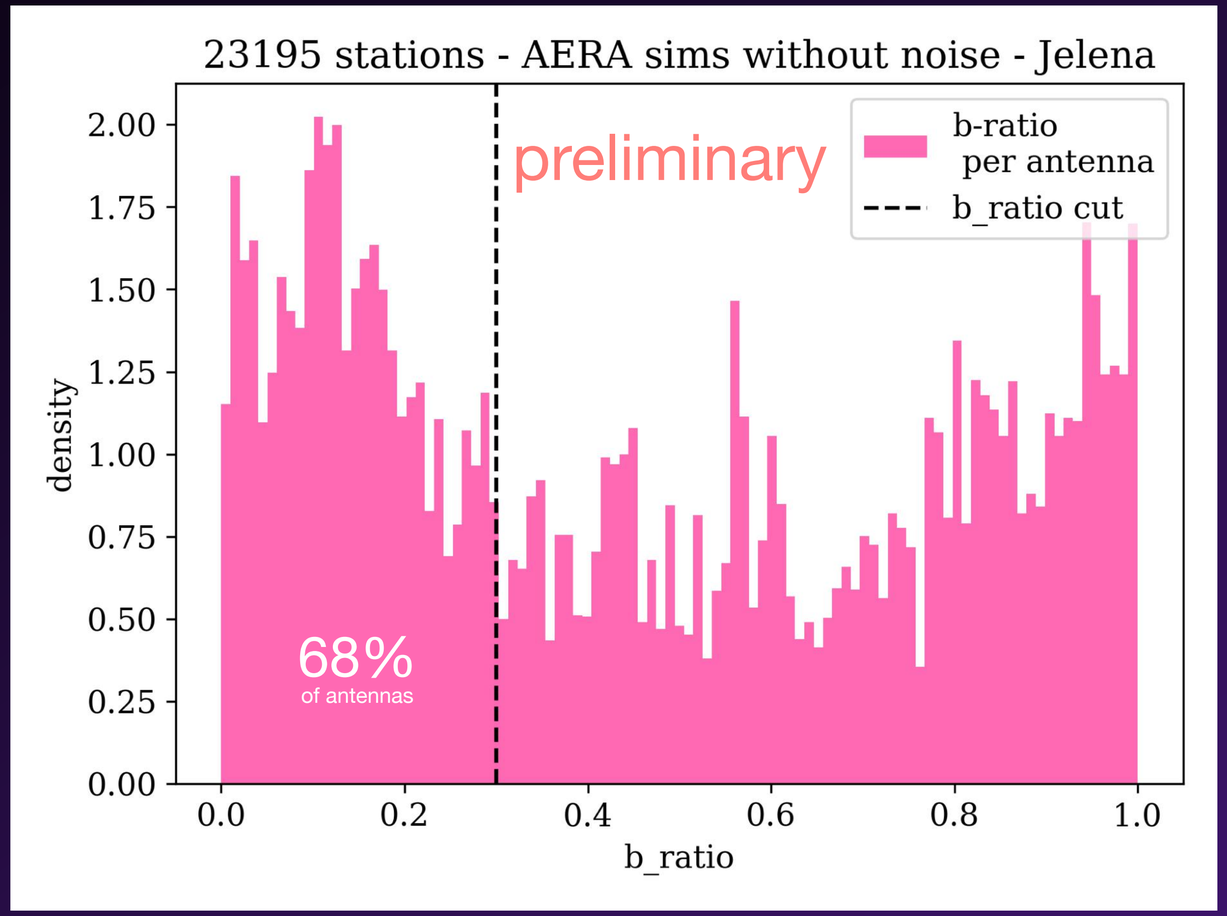


AERA simulation

polarization

Polarization For Reconstructed Efields

for AERA sims SNR > 10



- ⋆ **voltage amplitudes** V_x, V_y, V_z
- ⋆ antenna response for **55 MHz**

→ **work in progress!**

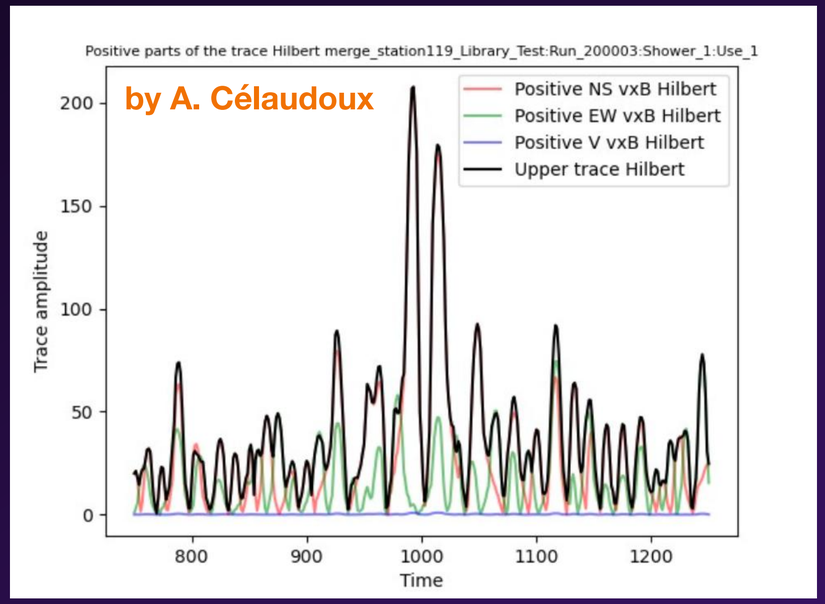
need to **optimize simplified efield reco further** for this application

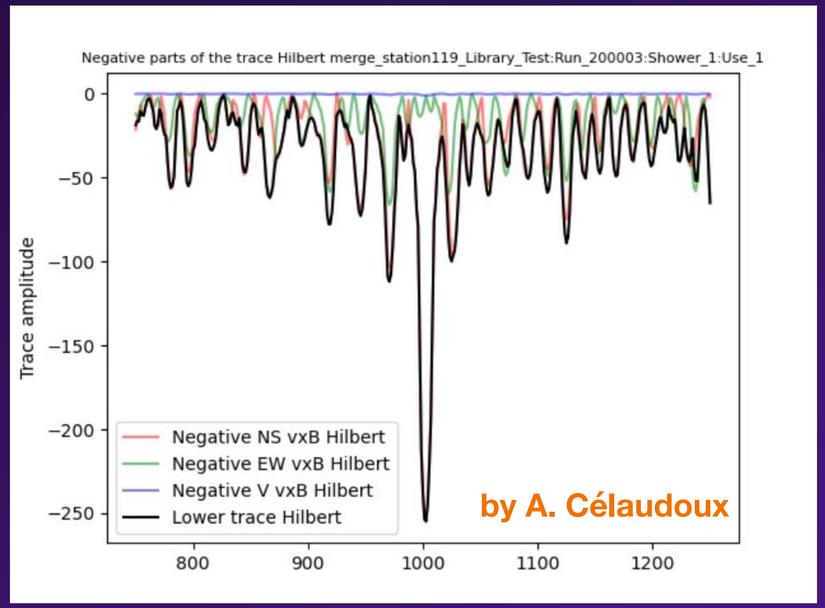
Method 4: Polarity

work in progress

- main idea:
  - determine polarity by **comparing min and max**

- use Hilbert envelopes to **combine all traces into one**





Summary

$$p_{Event} = p^{a}_{1:timing} \cdot p^{b}_{2:signal-strength} \cdot p^{c}_{3:polarization} \cdot p^{d}_{4:polarity}$$

- ⋆ methods 1-3 are **mostly defined**
- ⋆ method 4 **in progress**

Outlook

- ⋆ Efield reconstruction needs to be **further optimized for this purpose**
- ⋆ look into **polarity at GRAND** (different frequency band + 3 channels)
- ⋆ cross-checks with **noise sets**
- ⋆ **definition of weights** for trigger parameters

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Backup

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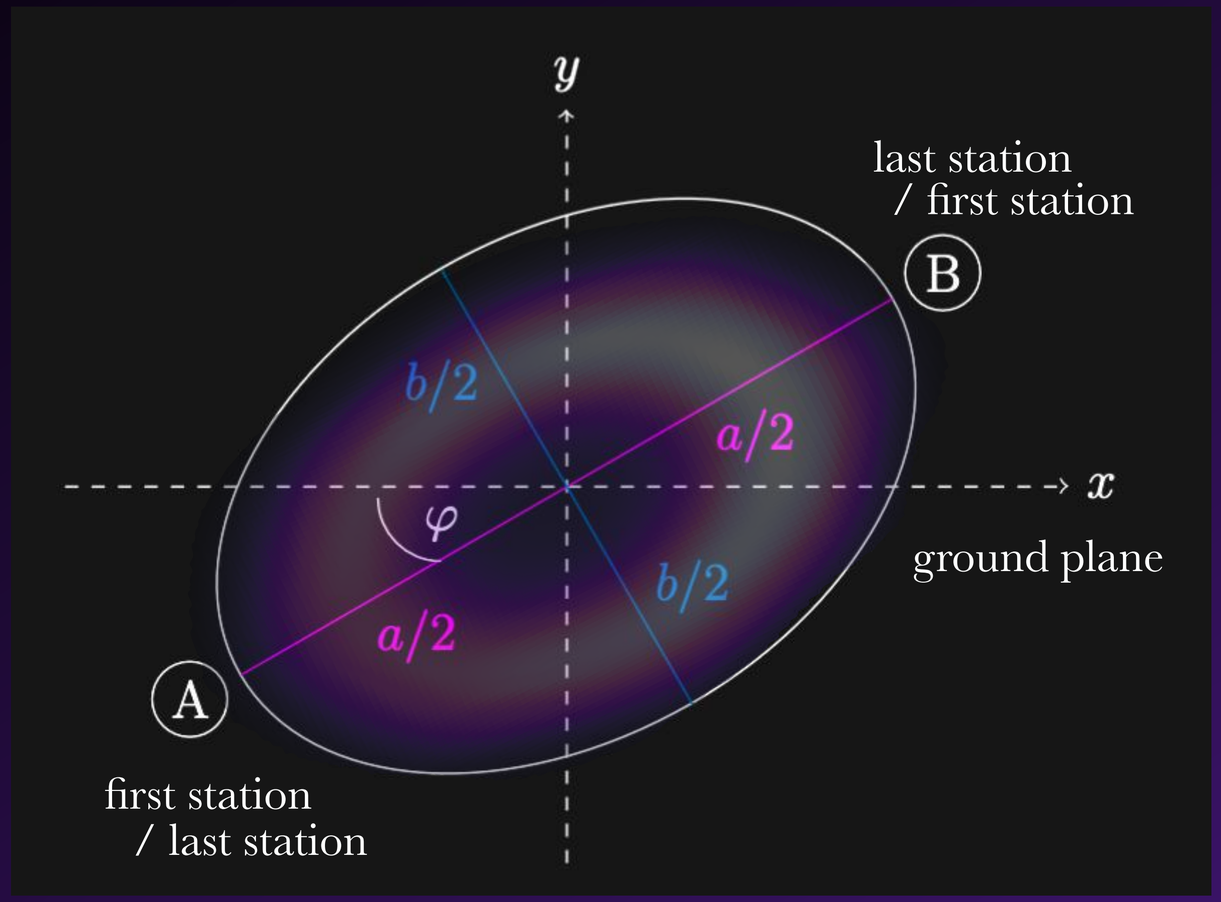
signal strength

Azimuth Reconstruction

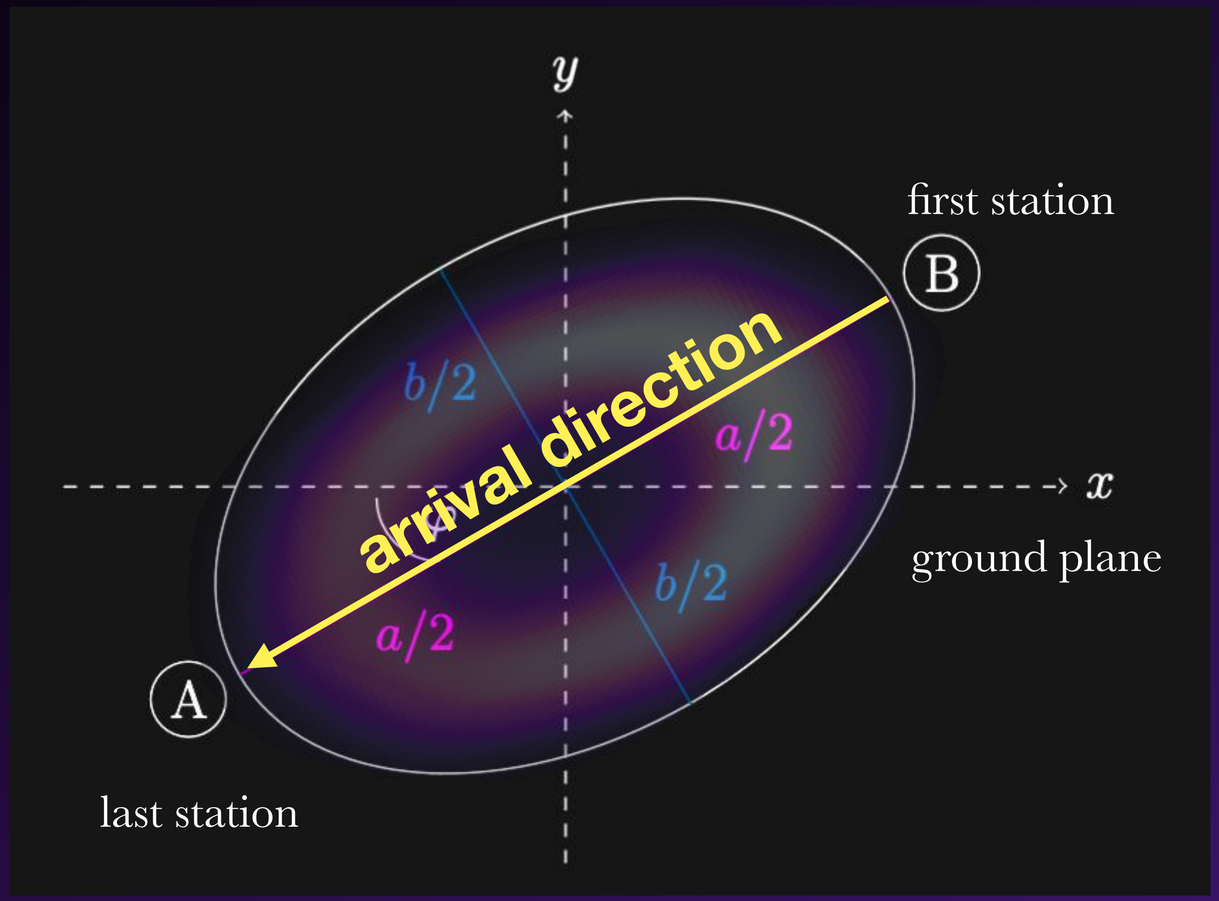


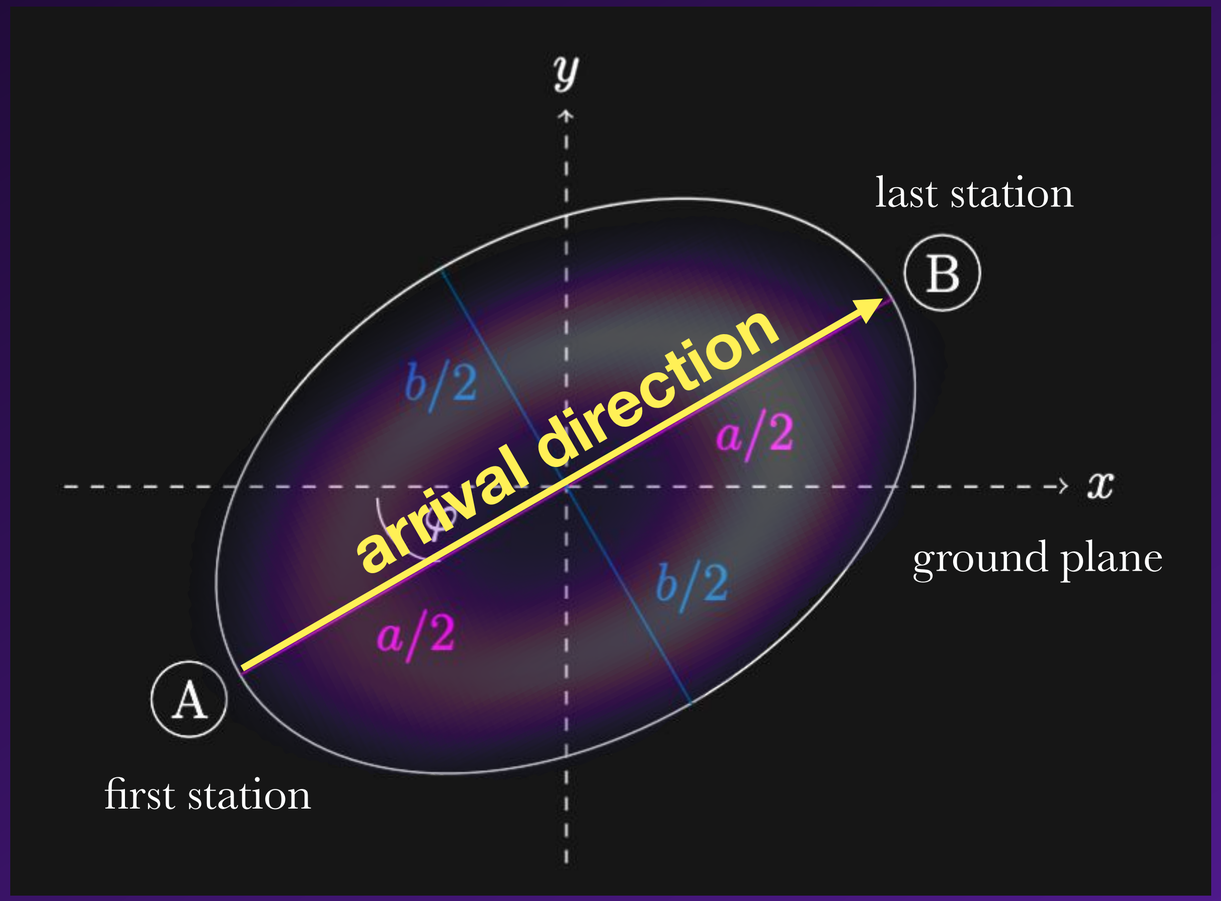
$$\tan\varphi = \frac{dy}{dx}$$

signal strength

Azimuth Reconstruction

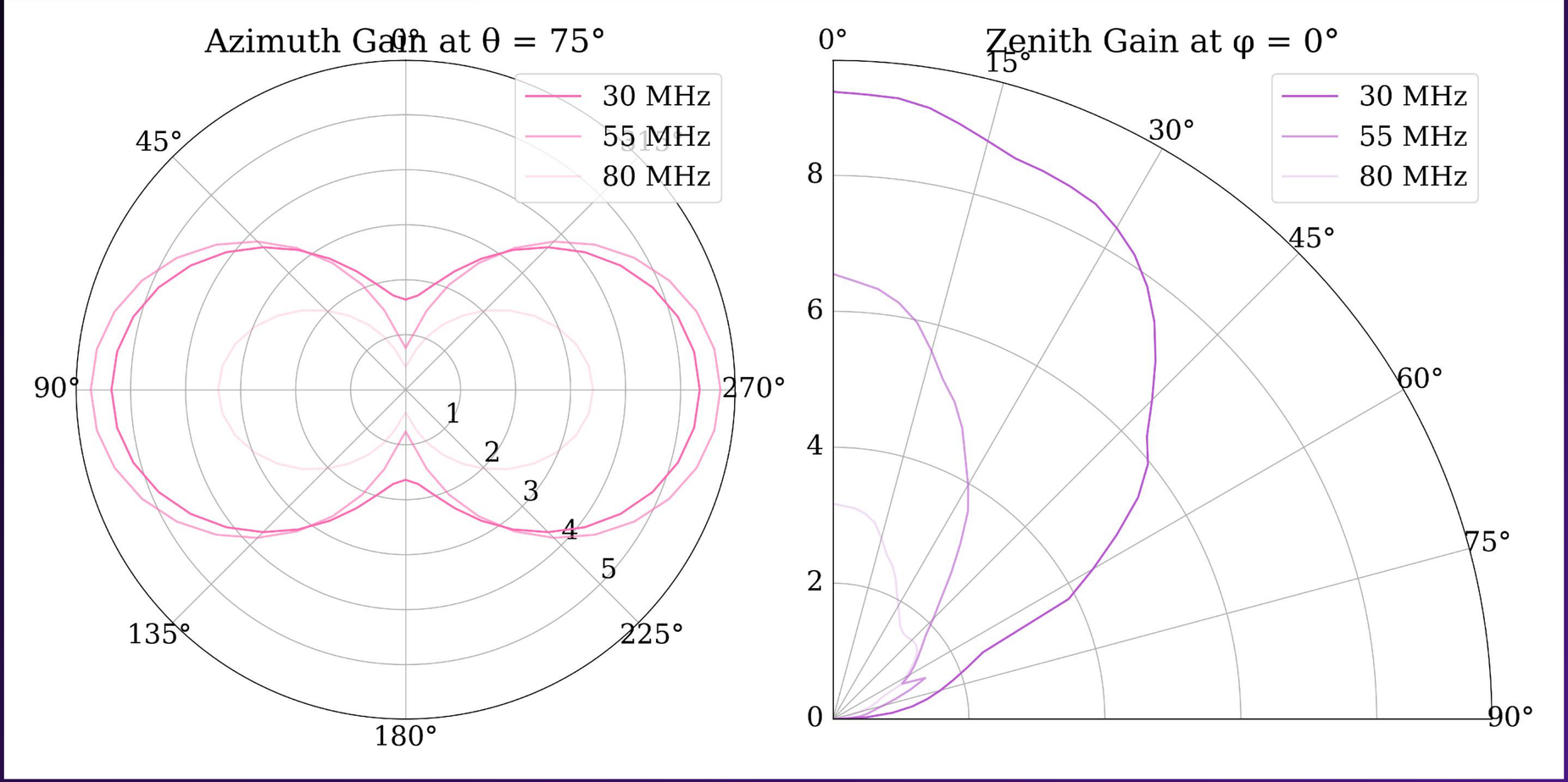
→ 180° ambiguity





Efield Reconstruction

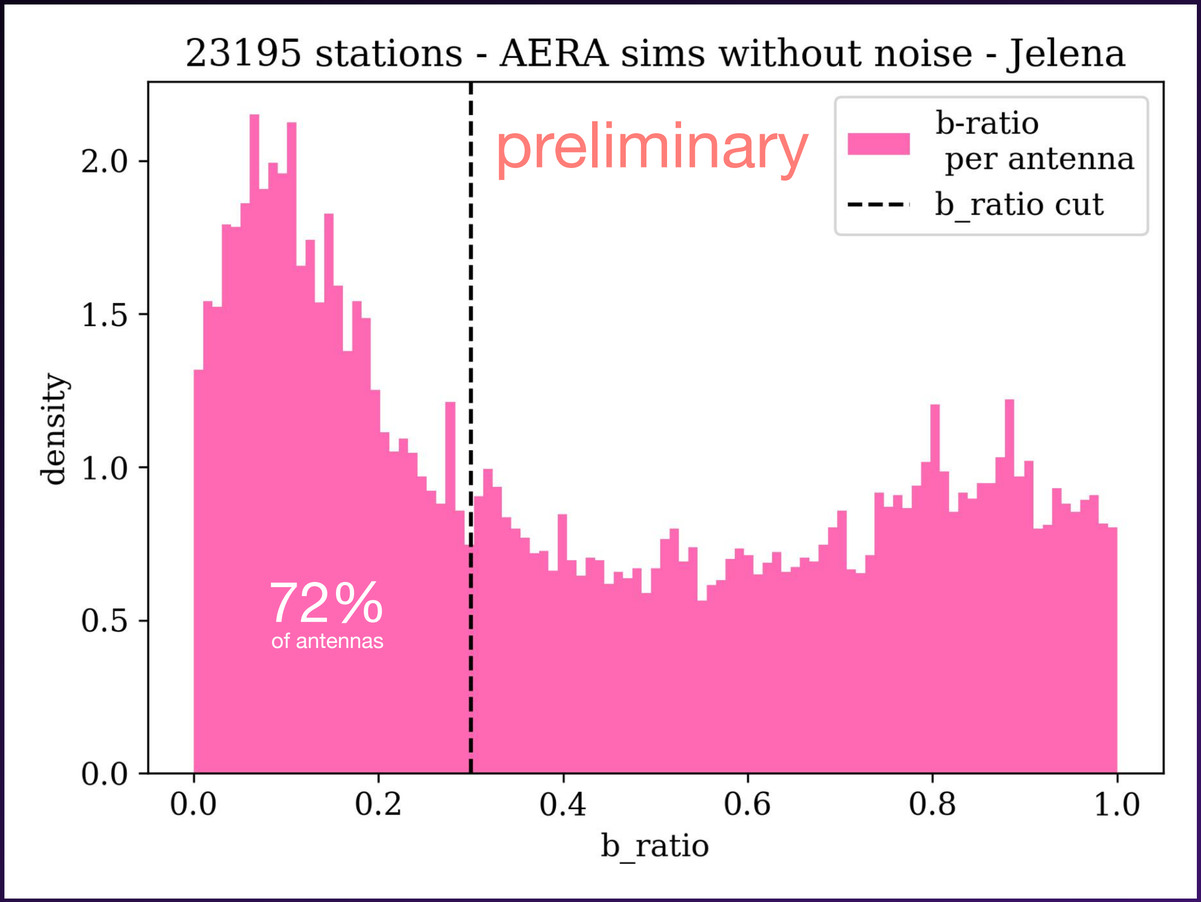
Antenna Patterns - LPDA antenna



polarization

Polarization For Reconstructed Efields

for AERA sims SNR > 10



- ⋆ amplitudes V_x, V_y, V_z of **FFT voltages**
- ⋆ antenna response for **55 MHz**

→ **interesting to see, but FFT not feasible for online triggering**

→ **work in progress!**