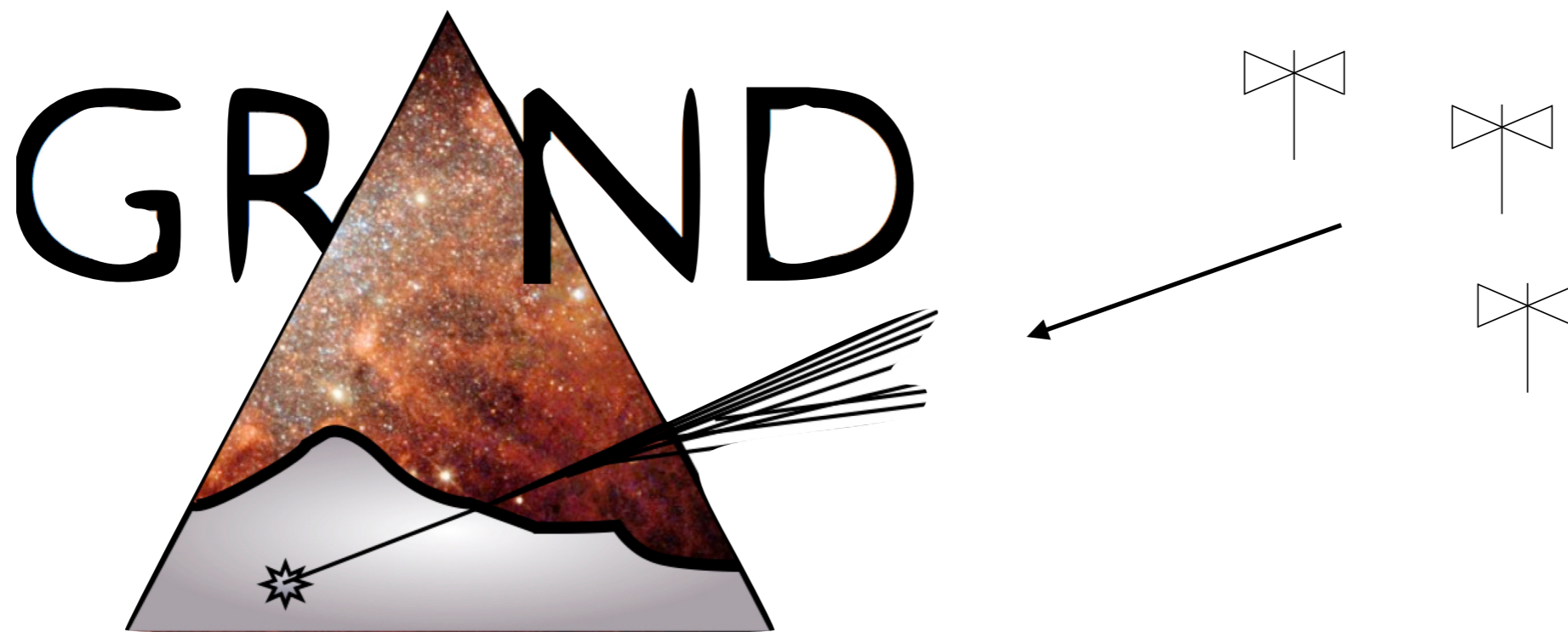


GRAND reconstruction status :
Plane wave reconstruction study of GRAND-like arrays

Valentin Decoene (IAP) & Olivier Martineau (LPNHE)



Time dependant only :

relies on antennas position and triggering times -> no need for the core position

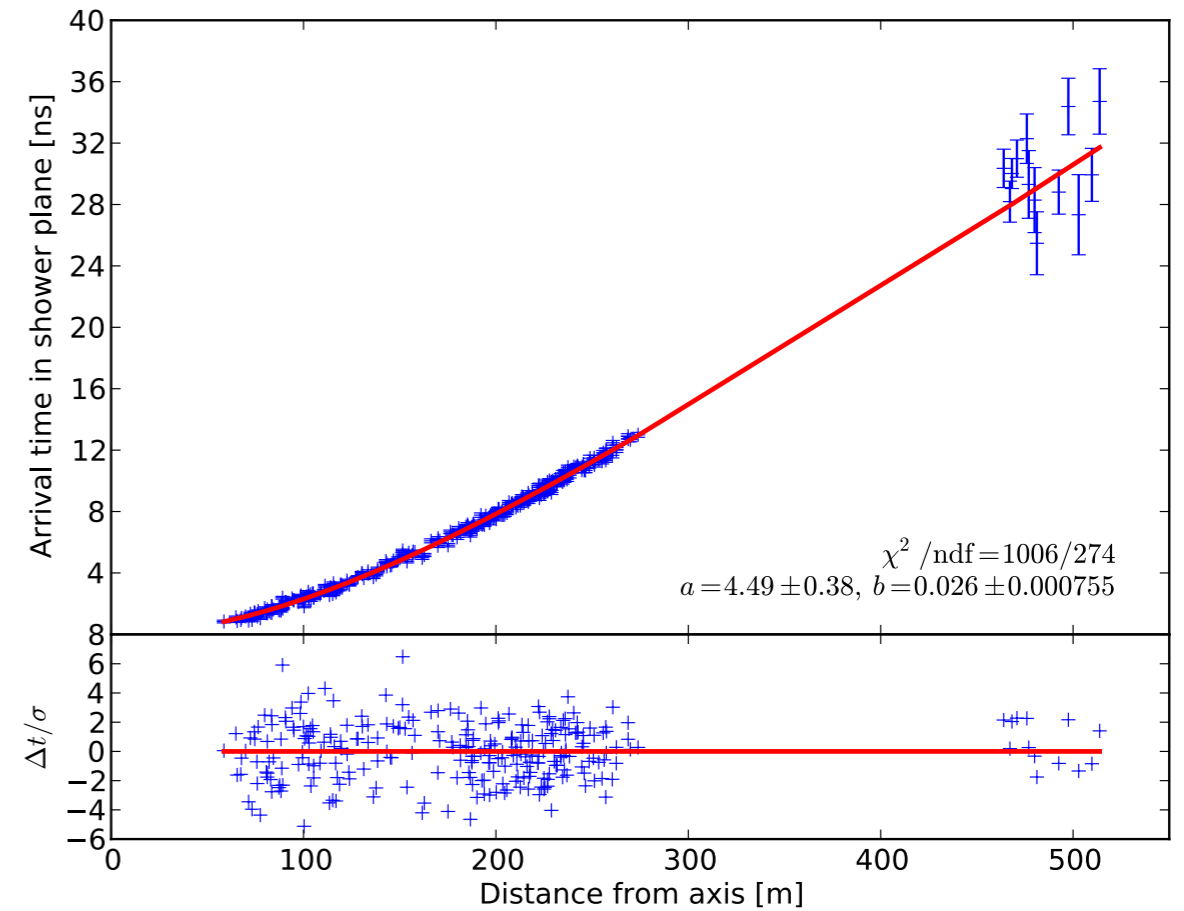
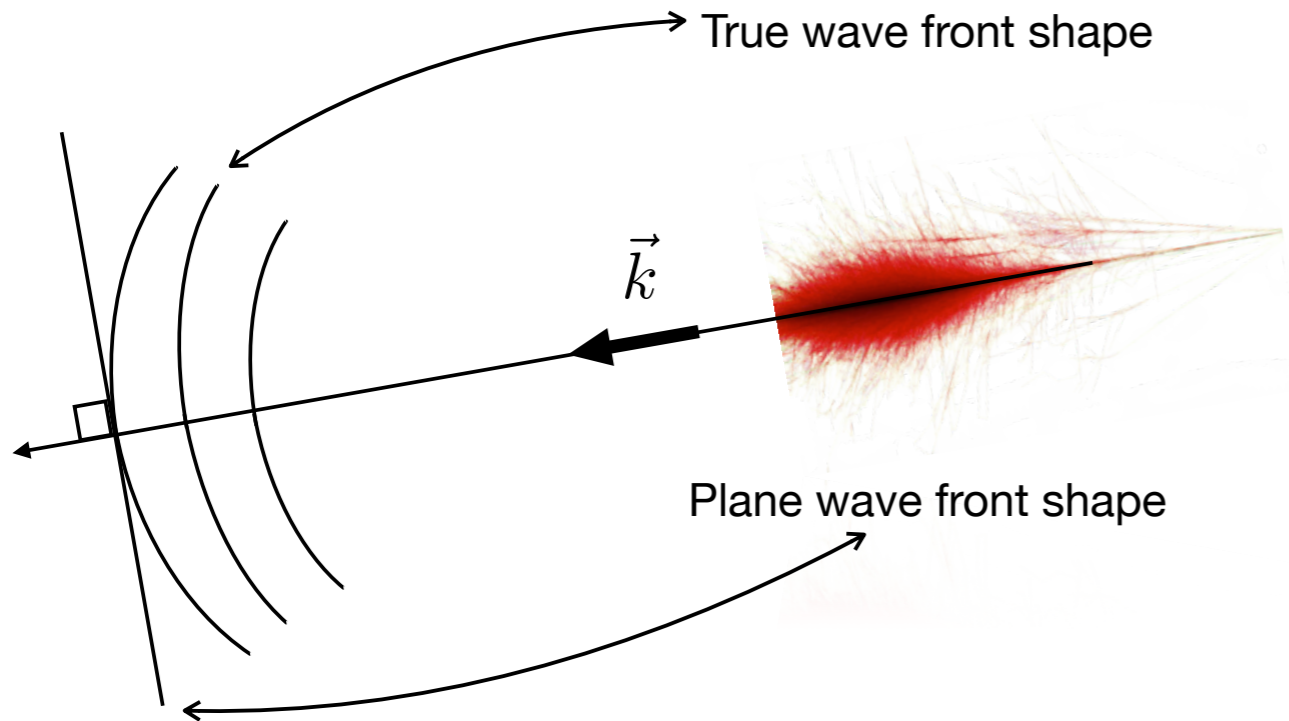
Reconstruction software already existing : TREND

Bad reconstruction accuracy :

Plane fit does not correspond to the actual wavefront shape (hyperbolic)

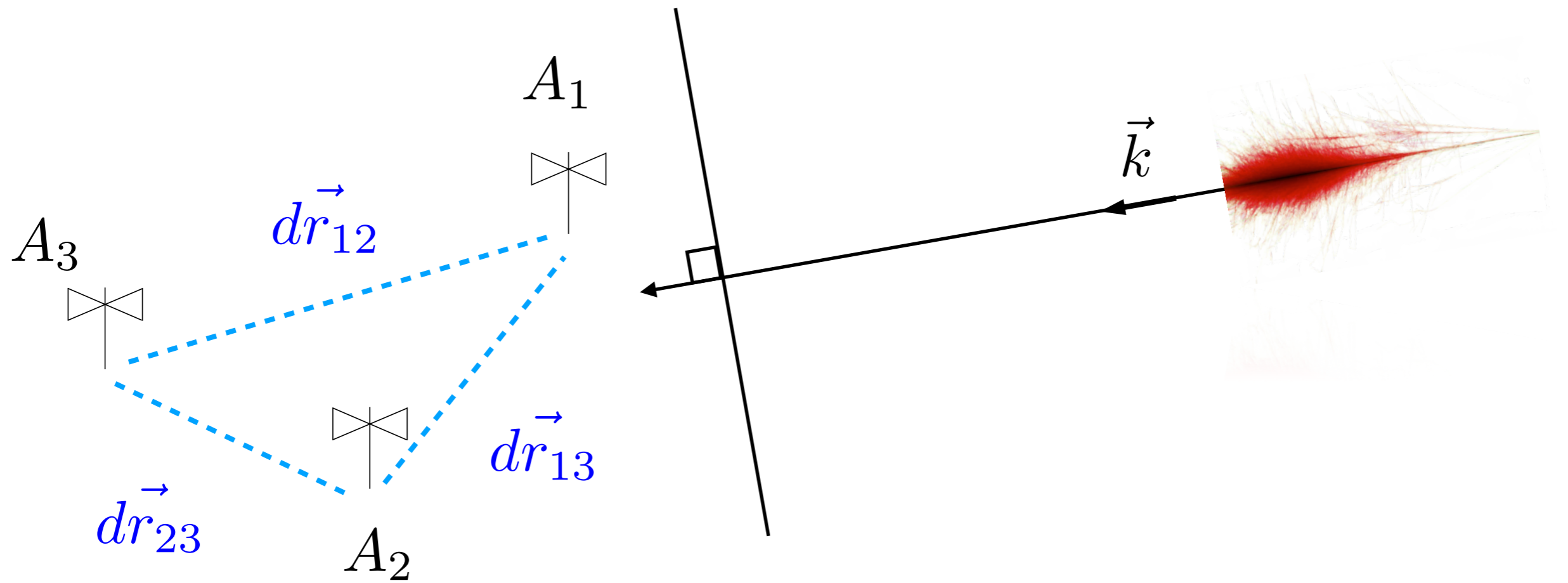
Plane wave reconstruction : Concept

Plane wavefront shape is not realistic

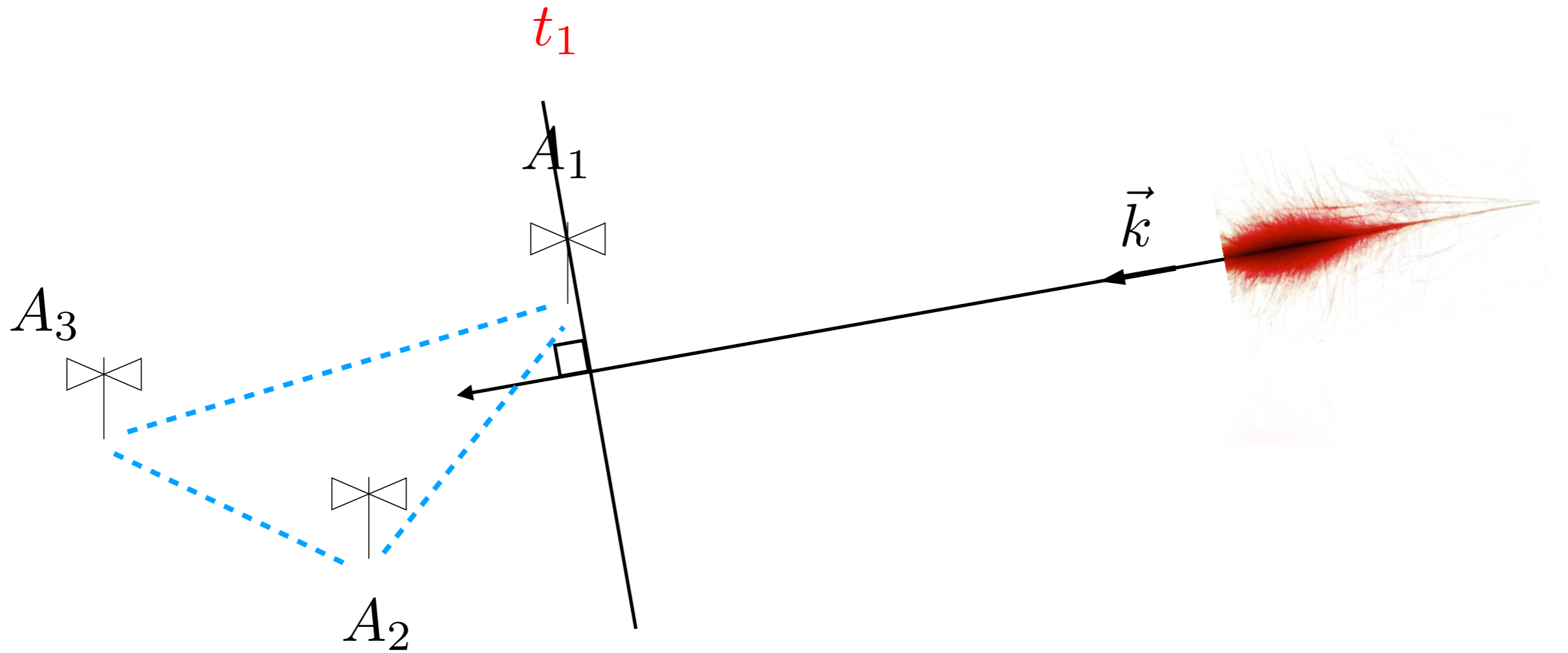


*The shape of the radio wavefront of extensive air showers as measured with LOFAR.
A. Corstanje et al. 2014.*

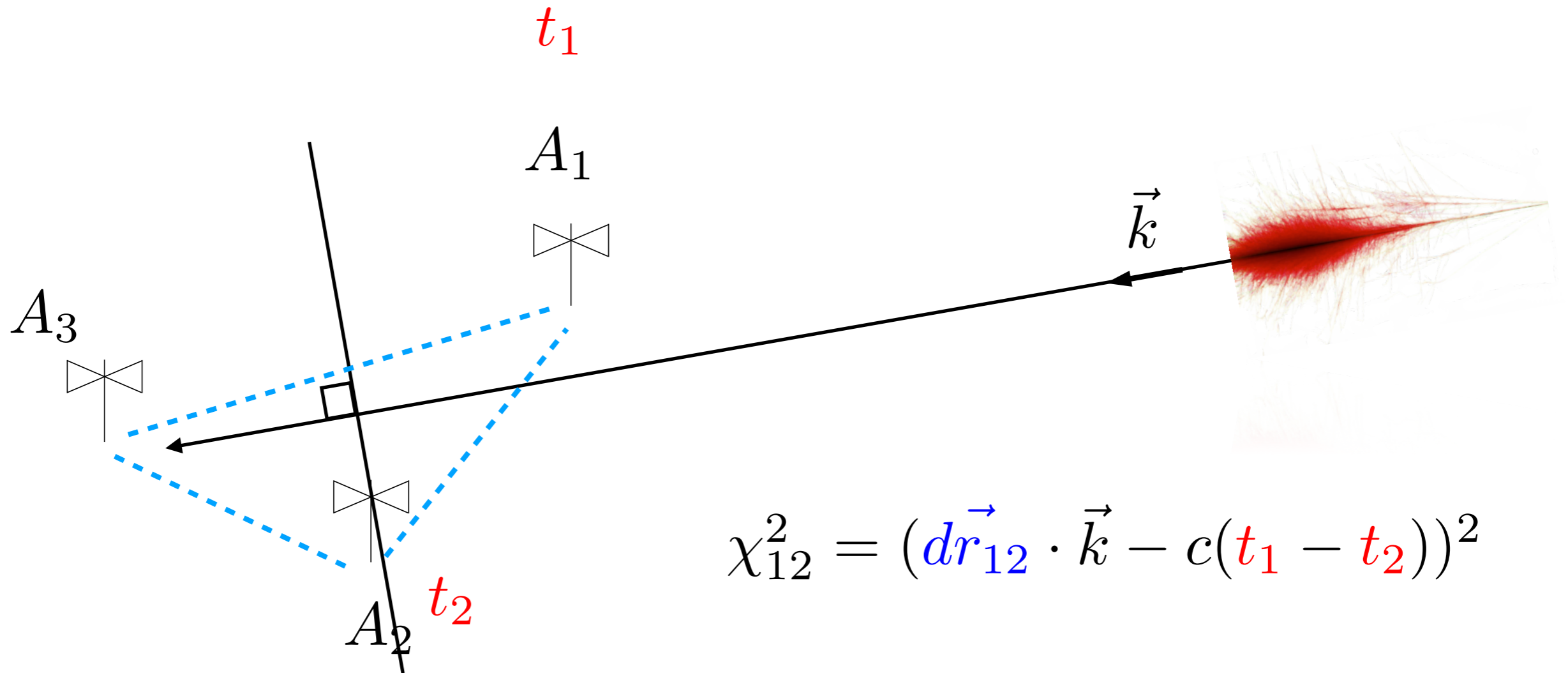
Plane wave reconstruction : Method



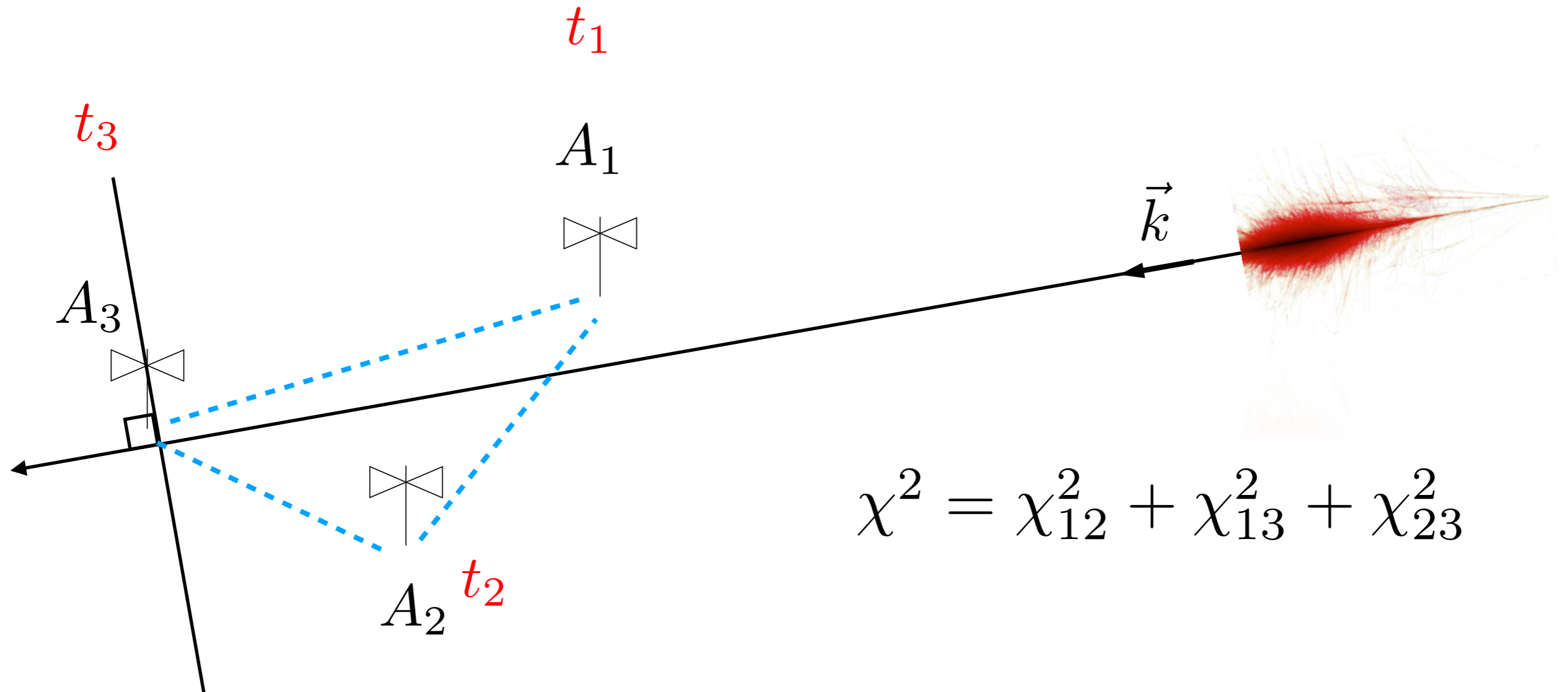
Method



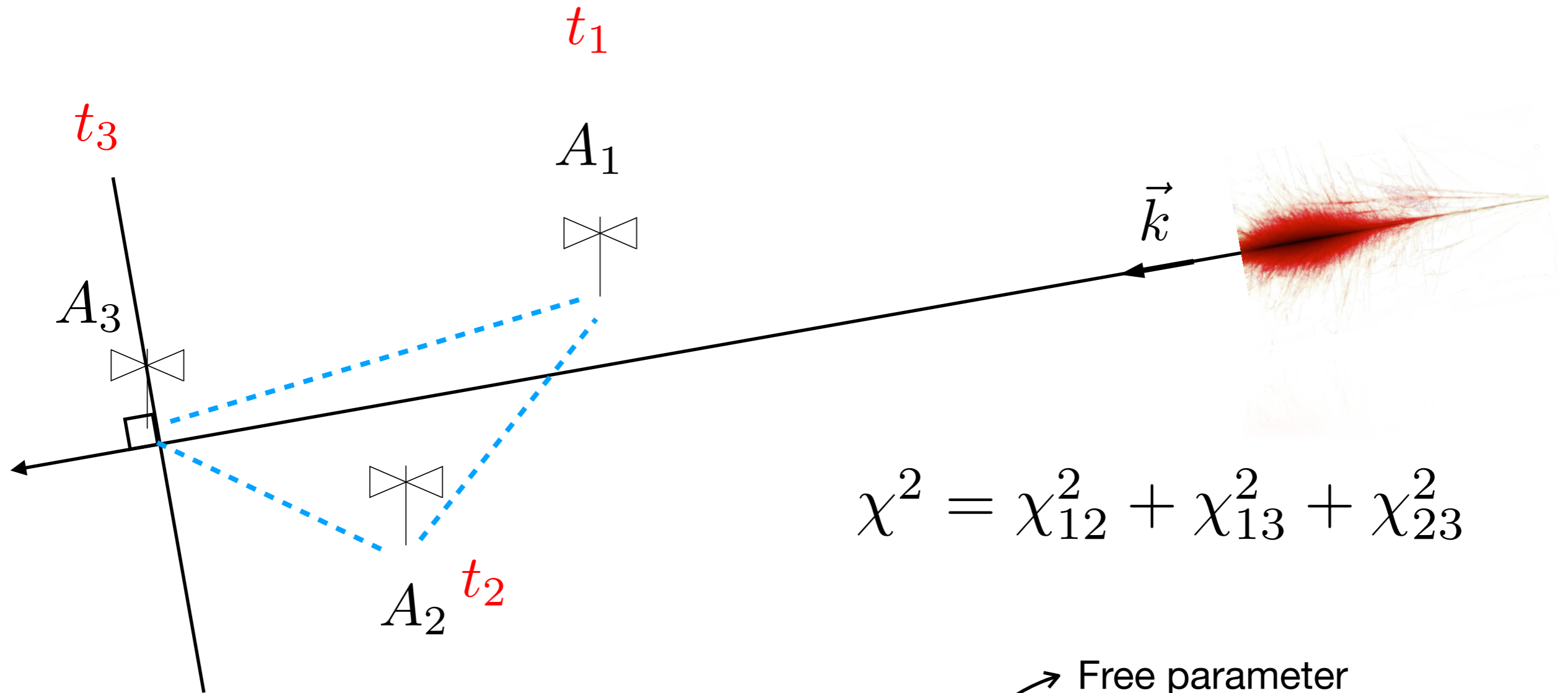
Method



Method



Method



$$\chi^2 = \chi_{12}^2 + \chi_{13}^2 + \chi_{23}^2$$

Free parameter

→
$$\chi^2 = \sum_i \sum_j (d\vec{r}_{ij} \cdot \vec{k} - c(t_i - t_j))^2 \quad \text{minimisation}$$

First attempt of a realistic reconstruction:

- realistic simulated events
- realistic antenna layout (HS1 array for neutrinos, GP300 array for CRs)

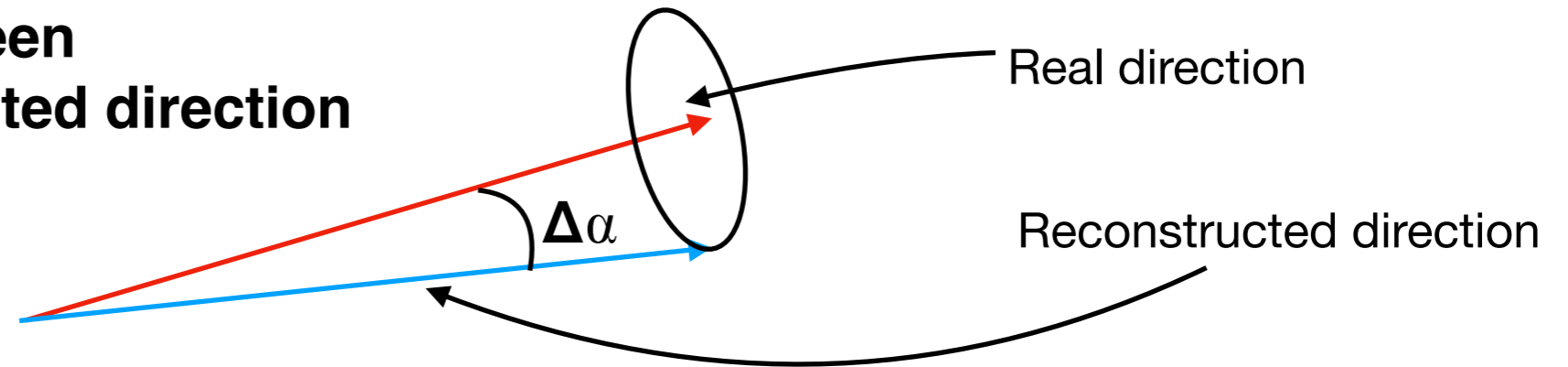
provide a benchmark for reconstruction performances (and estimate how wrong plane reconstruction can be)

Study of the impact of the array characteristics on the reconstruction (antennas number, denivelation, etc...)

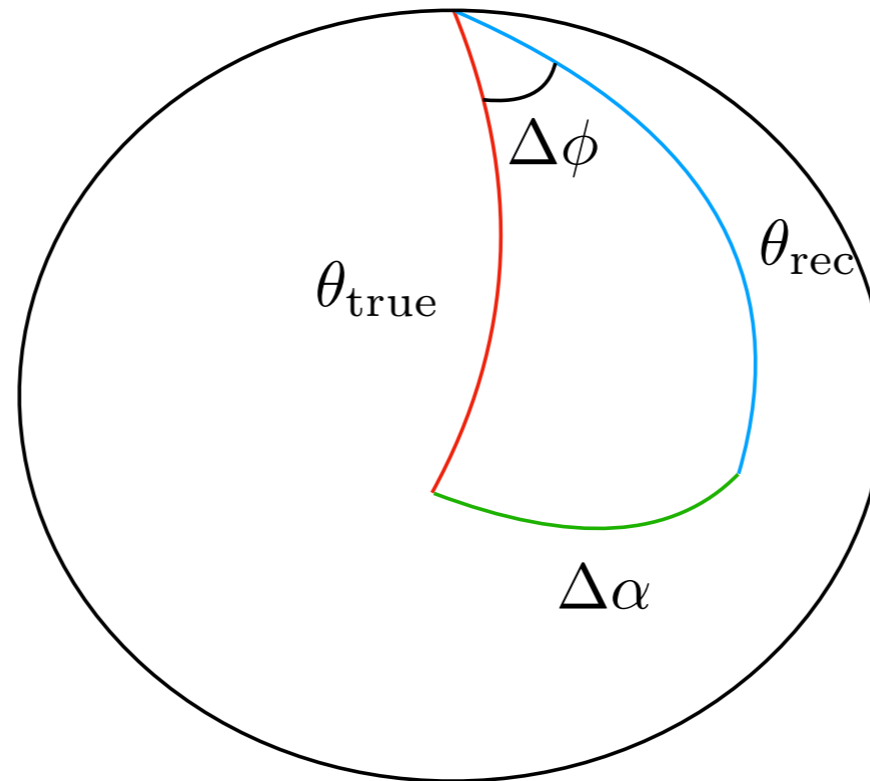
Notation

Angular error : $\Delta\alpha$

distance on the sphere between true direction and reconstructed direction



$$\cos(\Delta\alpha) = \cos(\theta_{\text{rec}}) \cos(\theta_{\text{true}}) + \cos(\phi_{\text{rec}} - \phi_{\text{true}}) \sin(\theta_{\text{true}}) \sin(\theta_{\text{rec}})$$

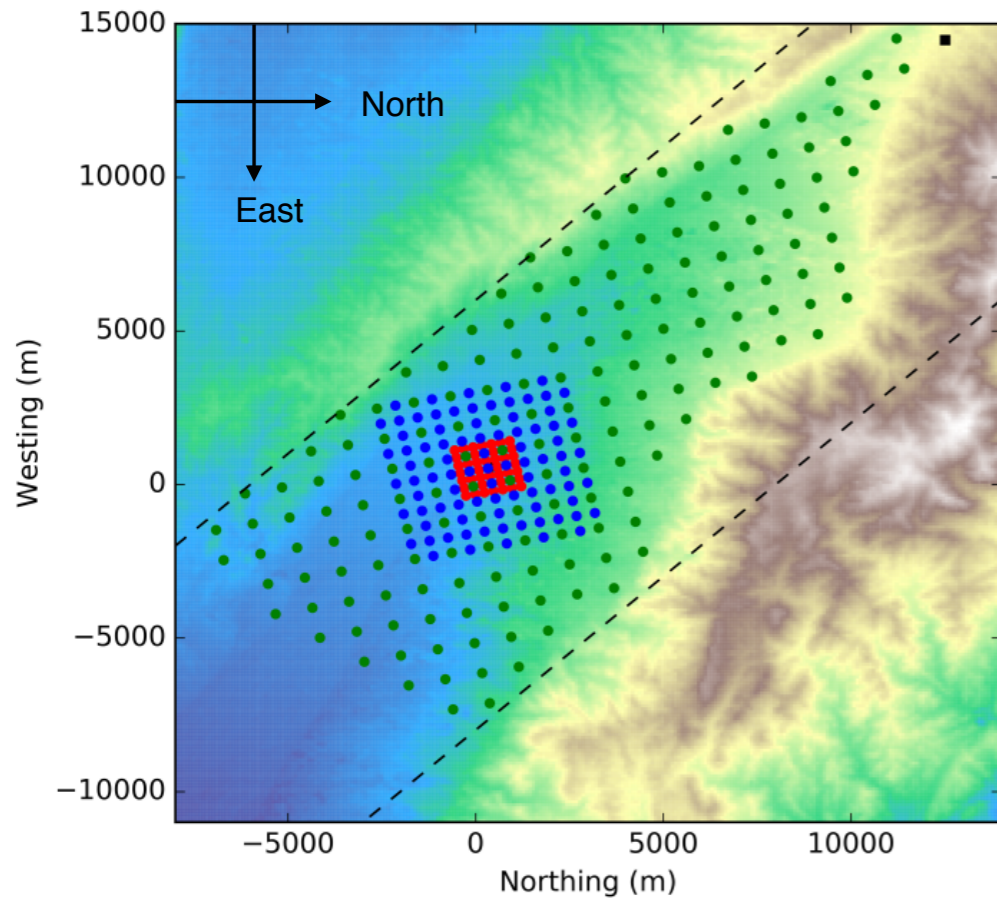


Setups : GRAND Proto 300 site

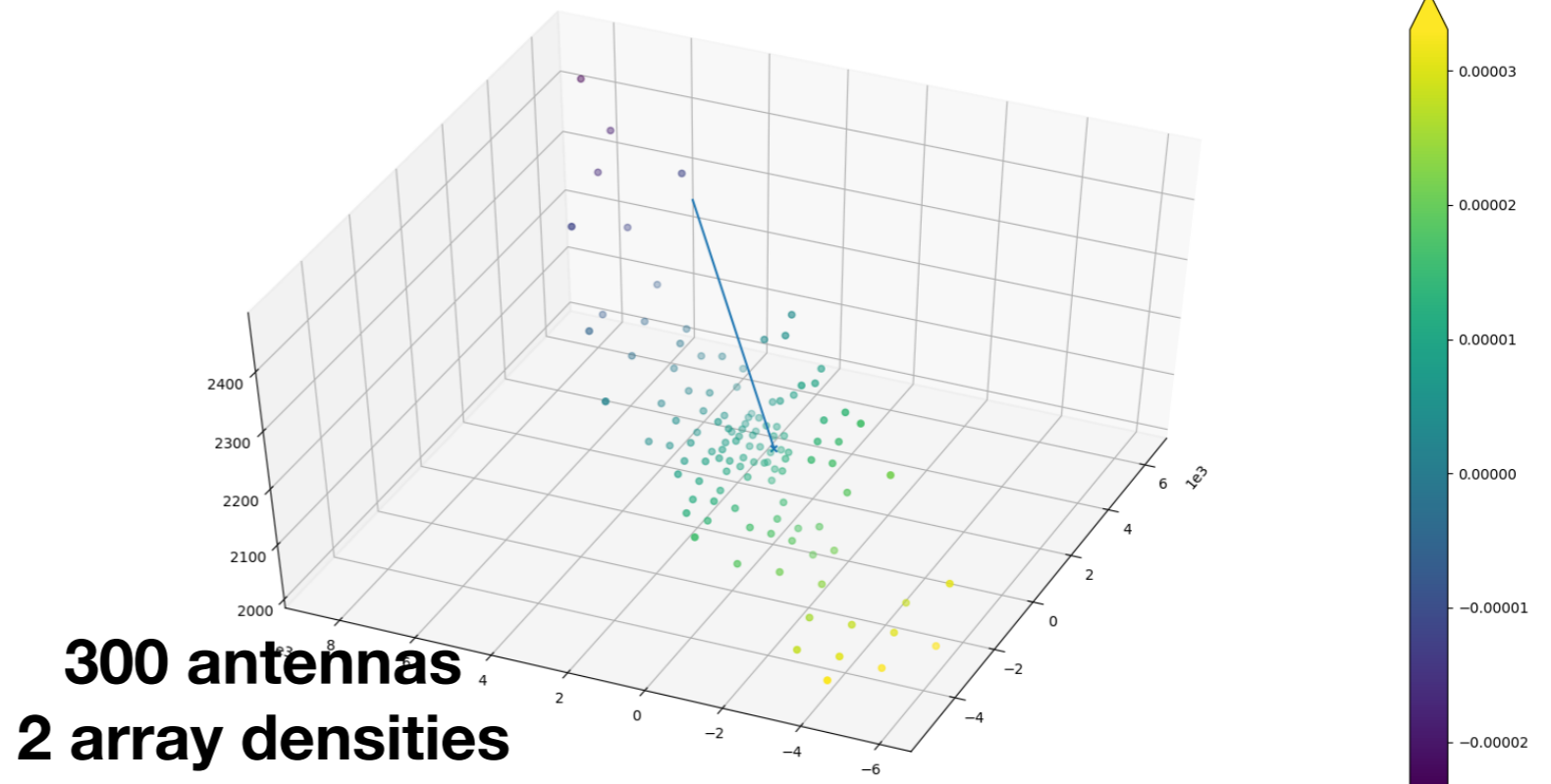
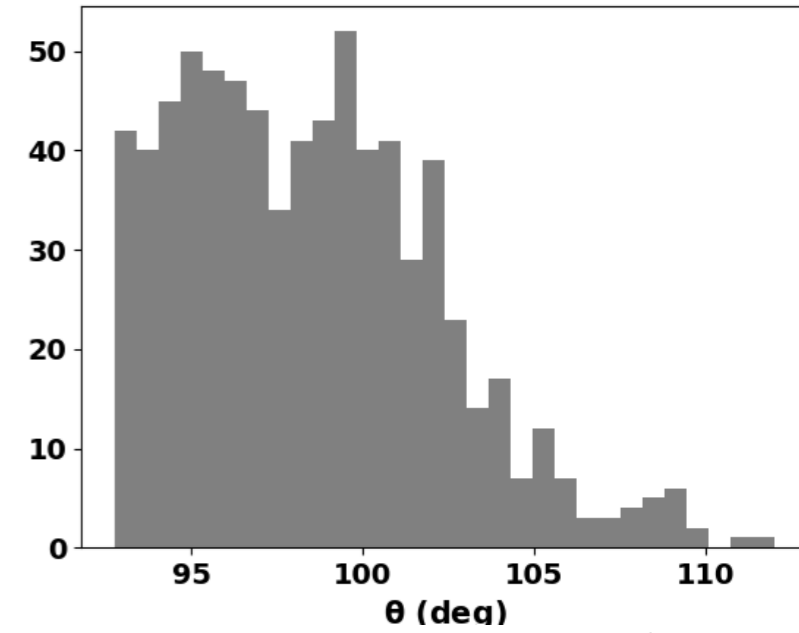
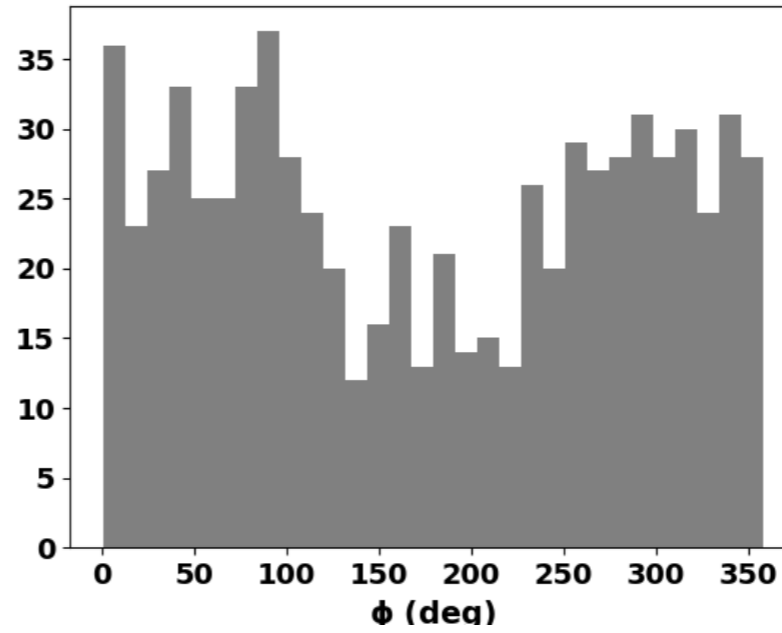
≈ 4 000 CRs events

@Renault Tinacci

Zhaires + Compute_Voltage + Noise + Frequency Filtering + Sampling



Balikun, XinJiang



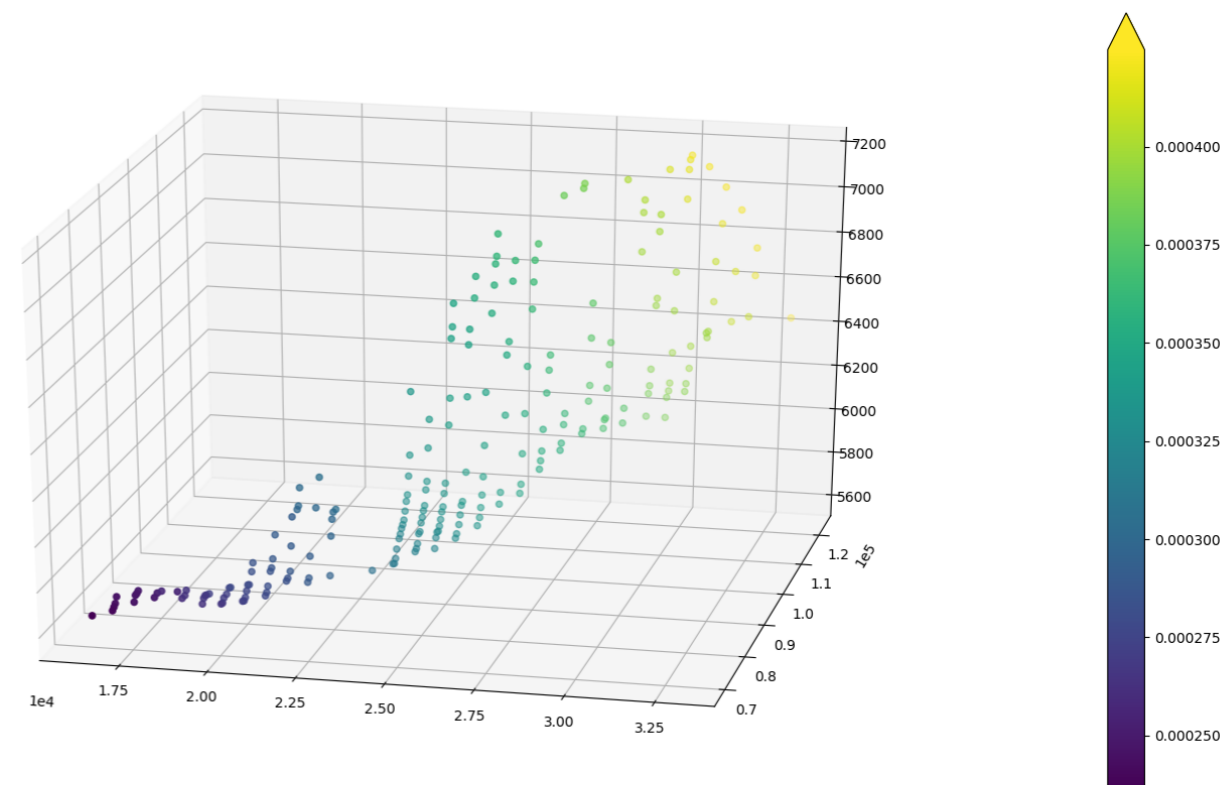
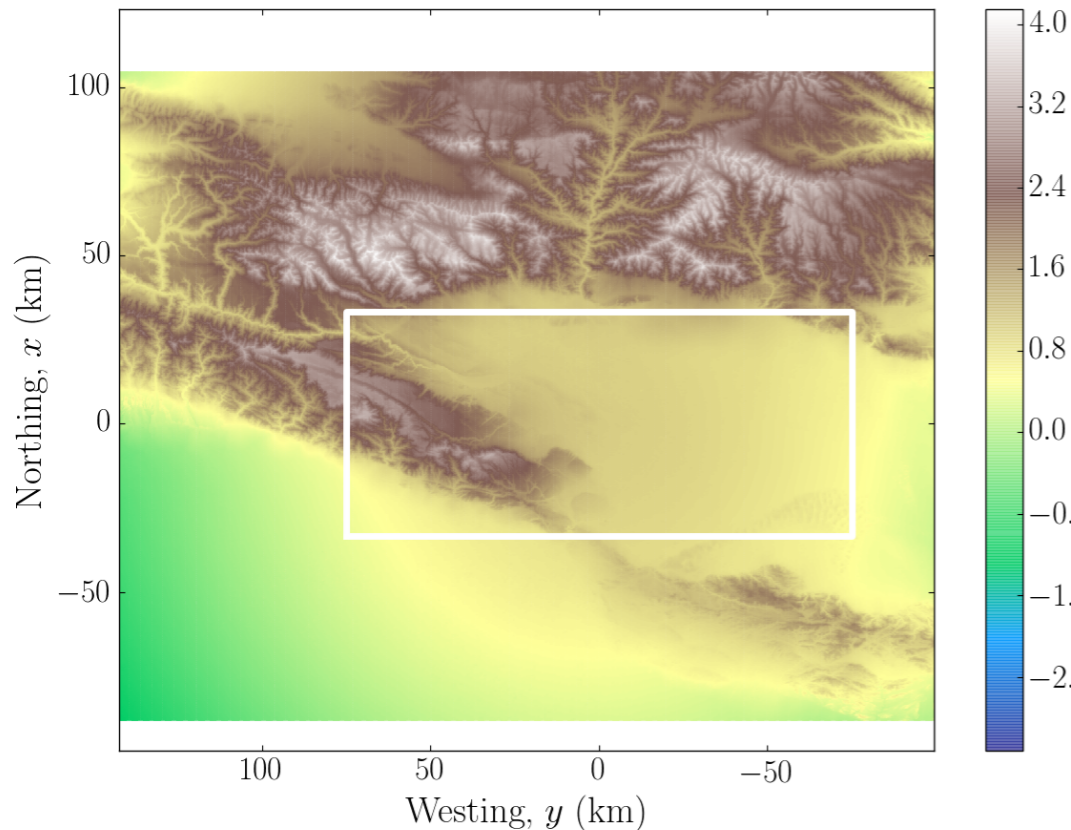
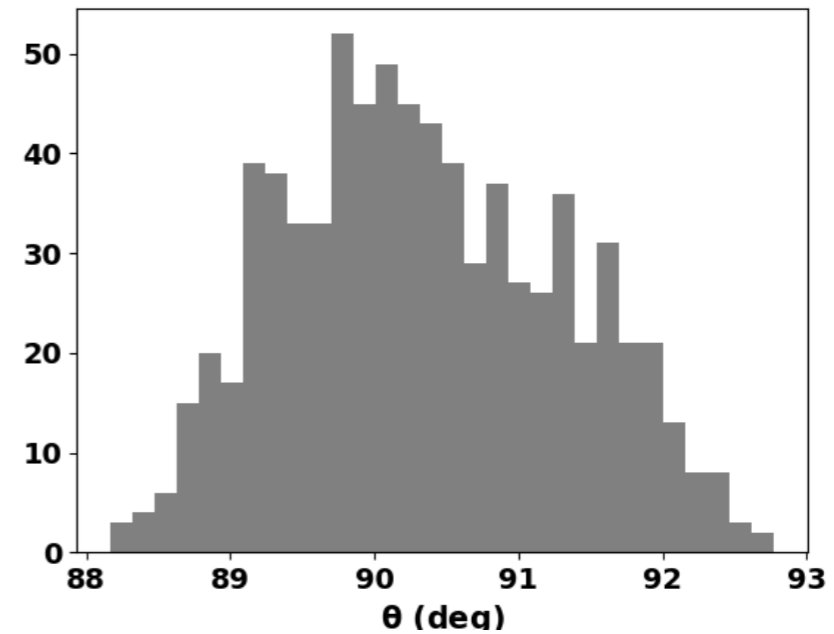
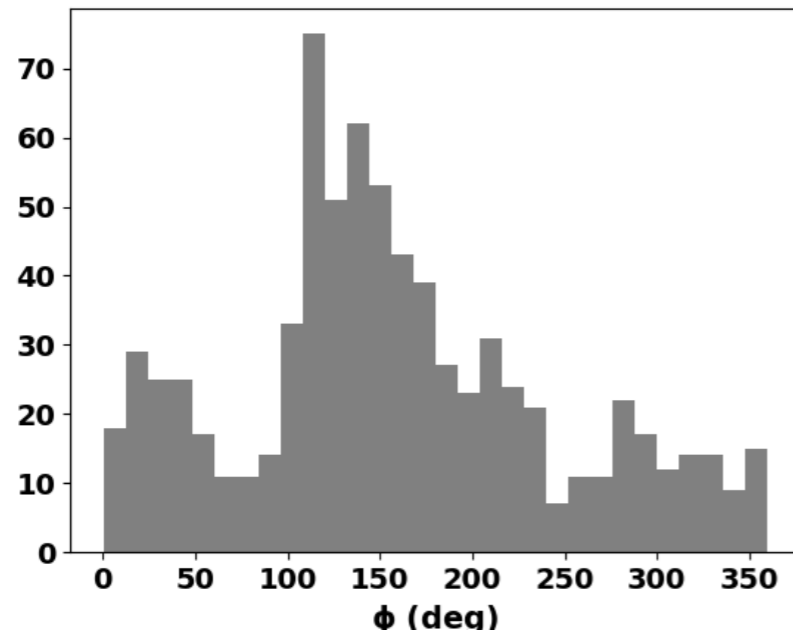
**300 antennas
2 array densities**

Setups : Hot Spot 1 site

≈ 20 000 neutrinos events

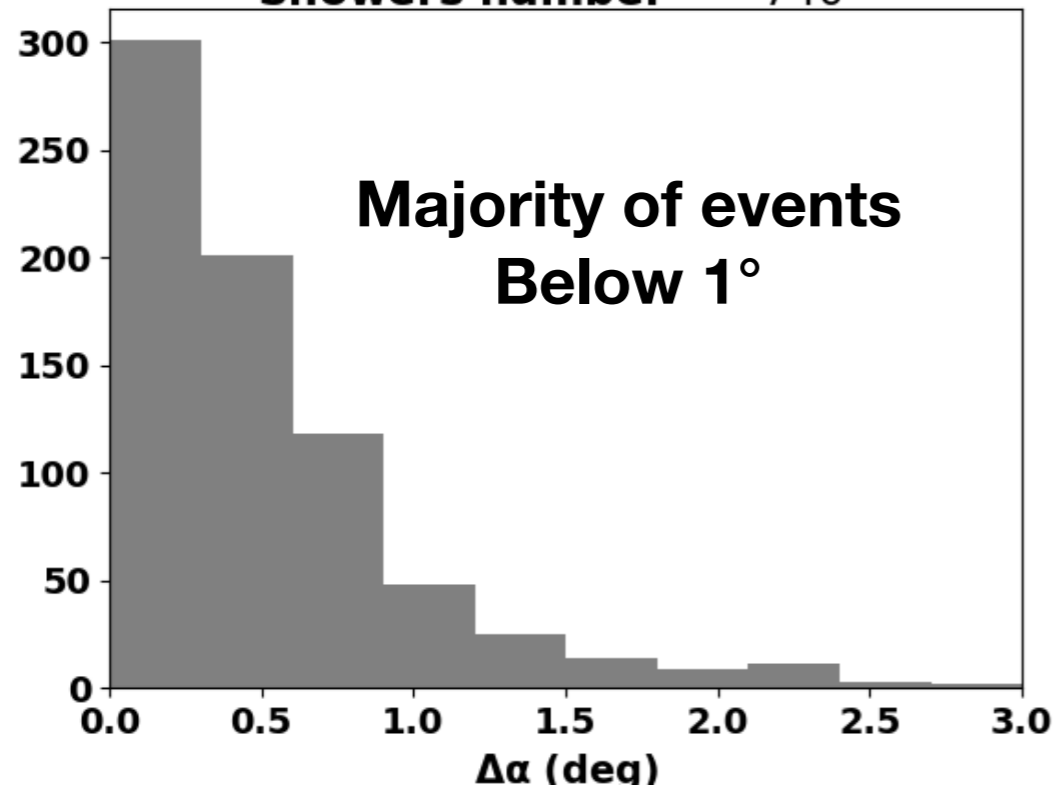
Radio-Morphing preselection (before generic shower fix)

Zhaires + Compute_Voltage + Noise + Frequency Filtering + Sampling



Reconstruction results : GRAND Proto 300

$\langle \Delta\alpha \rangle = 0.574$ $\text{std}(\Delta\alpha) = 0.681$
Showers number = 740

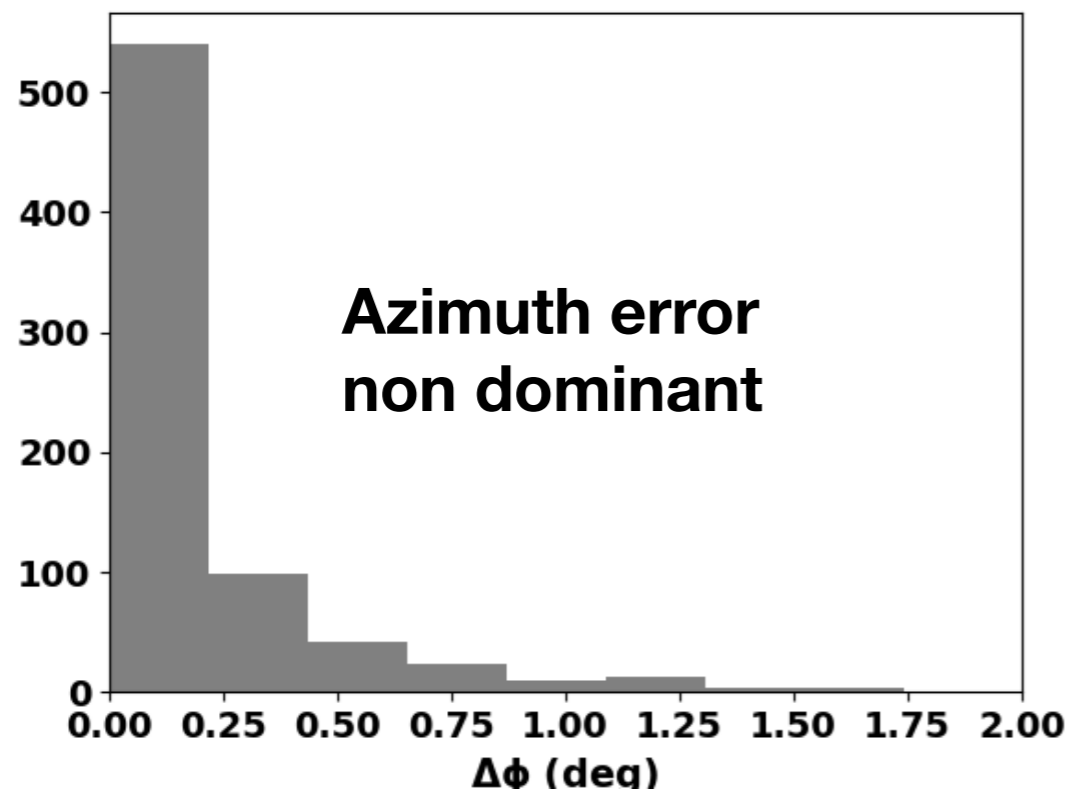


Cuts on reconstruction quality :

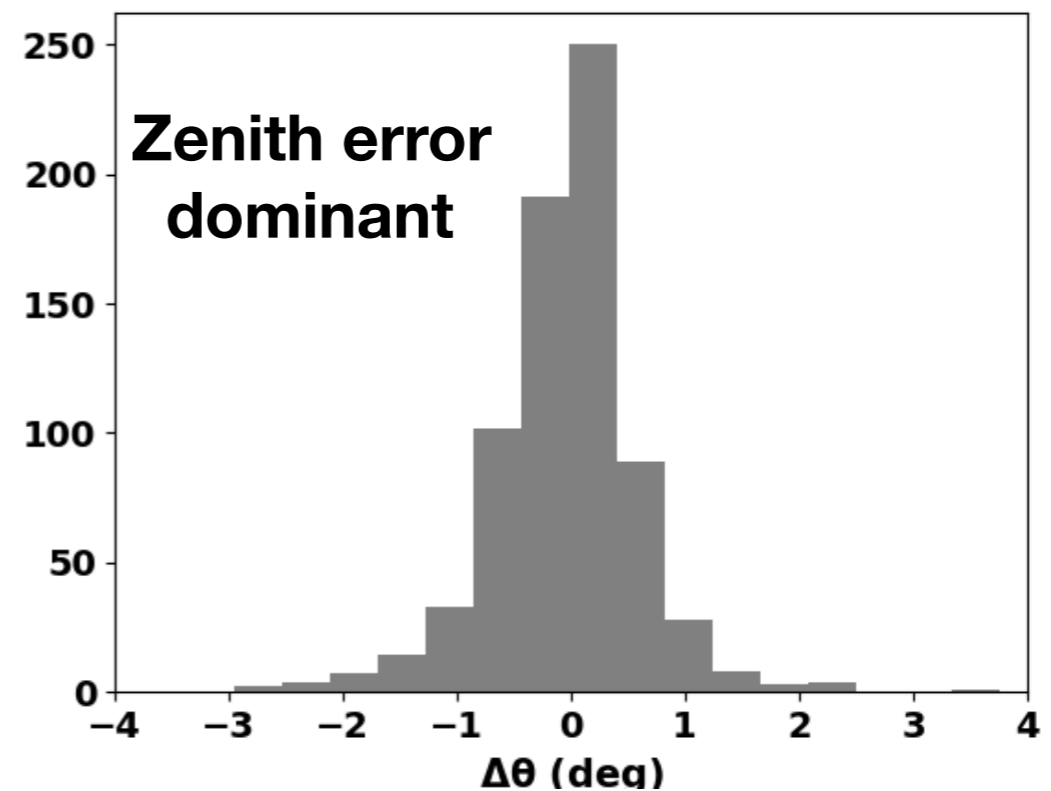
Significance < inf and NaN

Exclude range limits $\theta = 92.0$ & 113.0

$\langle \Delta\phi \rangle = 0.231$ $\text{std}(\Delta\phi) = 0.409$

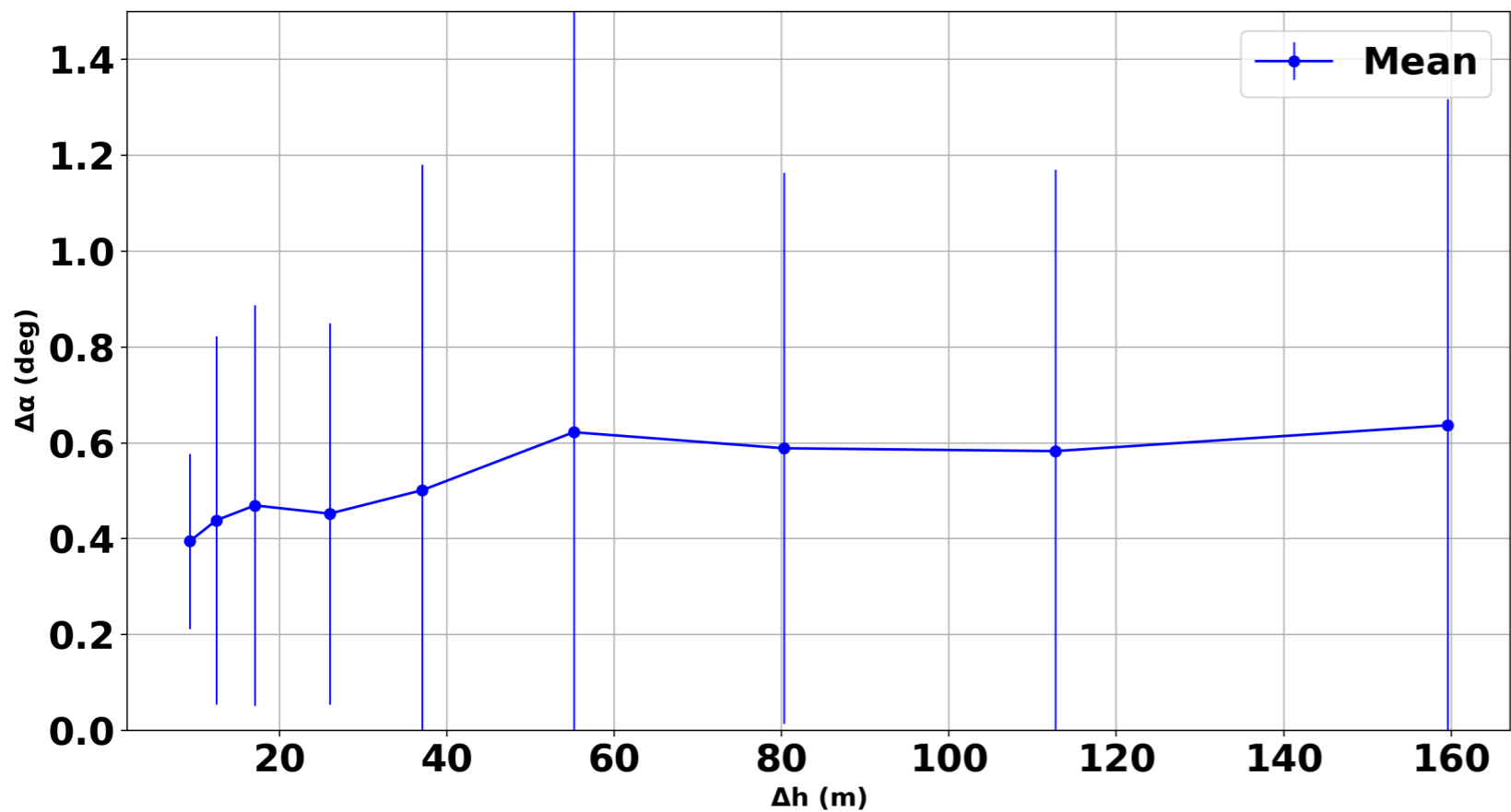
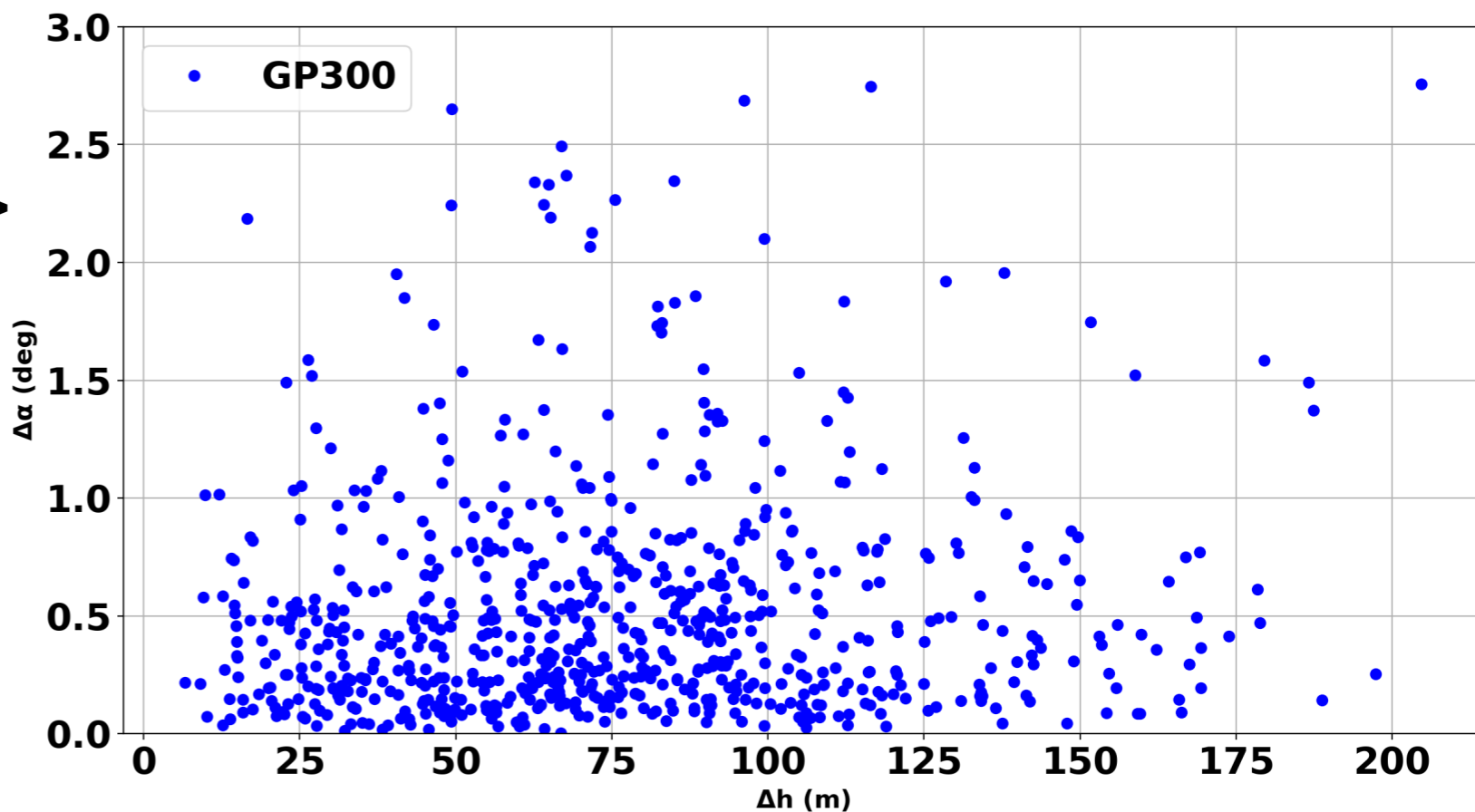


$\langle \Delta\theta \rangle = 0.474$ $\text{std}(\Delta\theta) = 0.594$



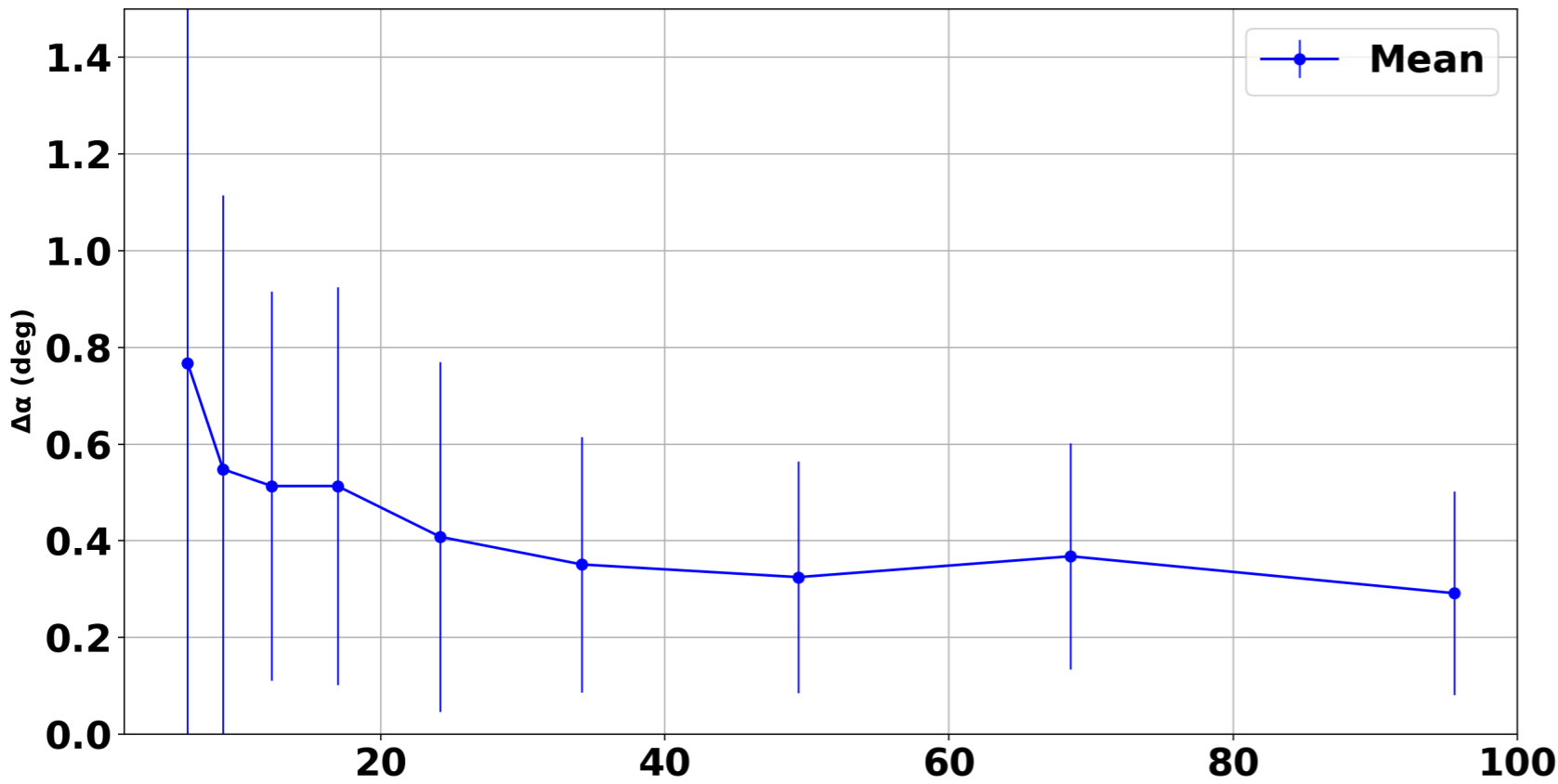
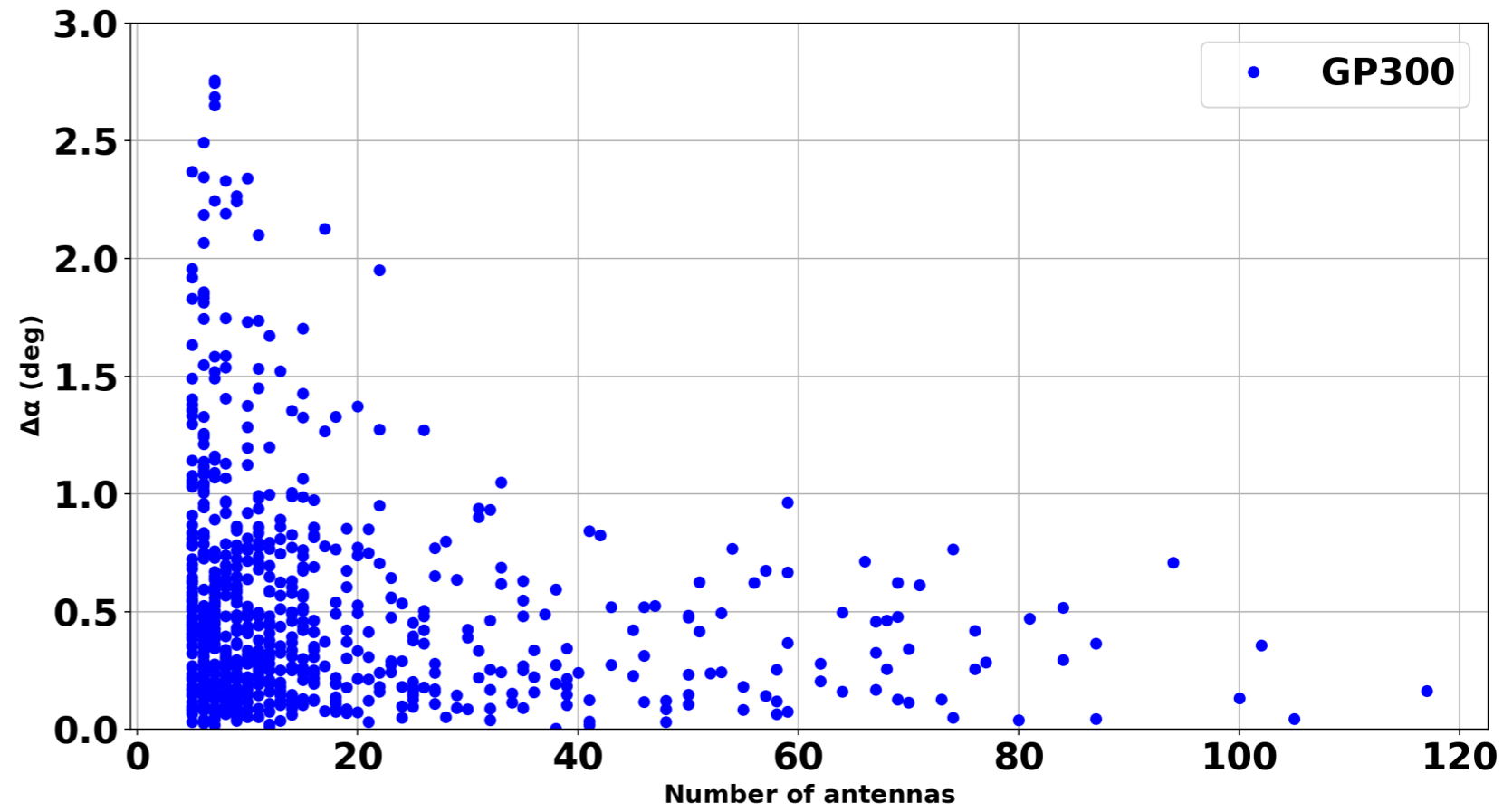
Reconstruction results : GRAND Proto 300

$\Delta h =$
 $\langle \text{antenna pairs altitude difference} \rangle$



**Increase of errors
for small slopes**

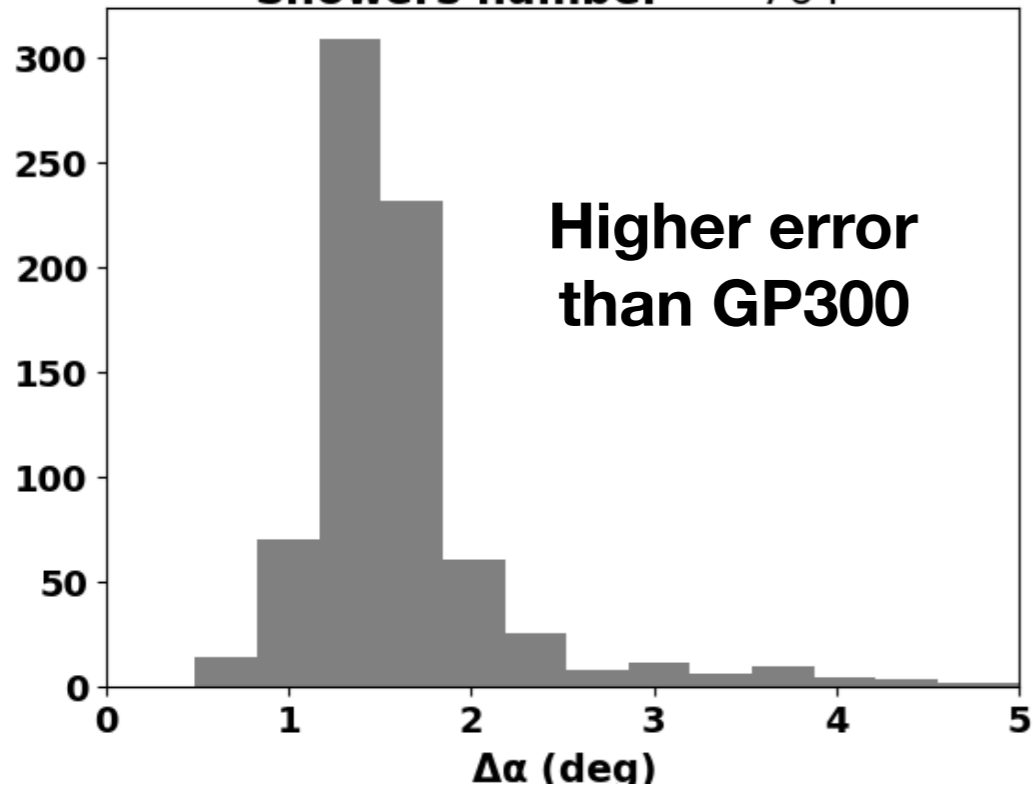
Reconstruction results : GRAND Proto 300



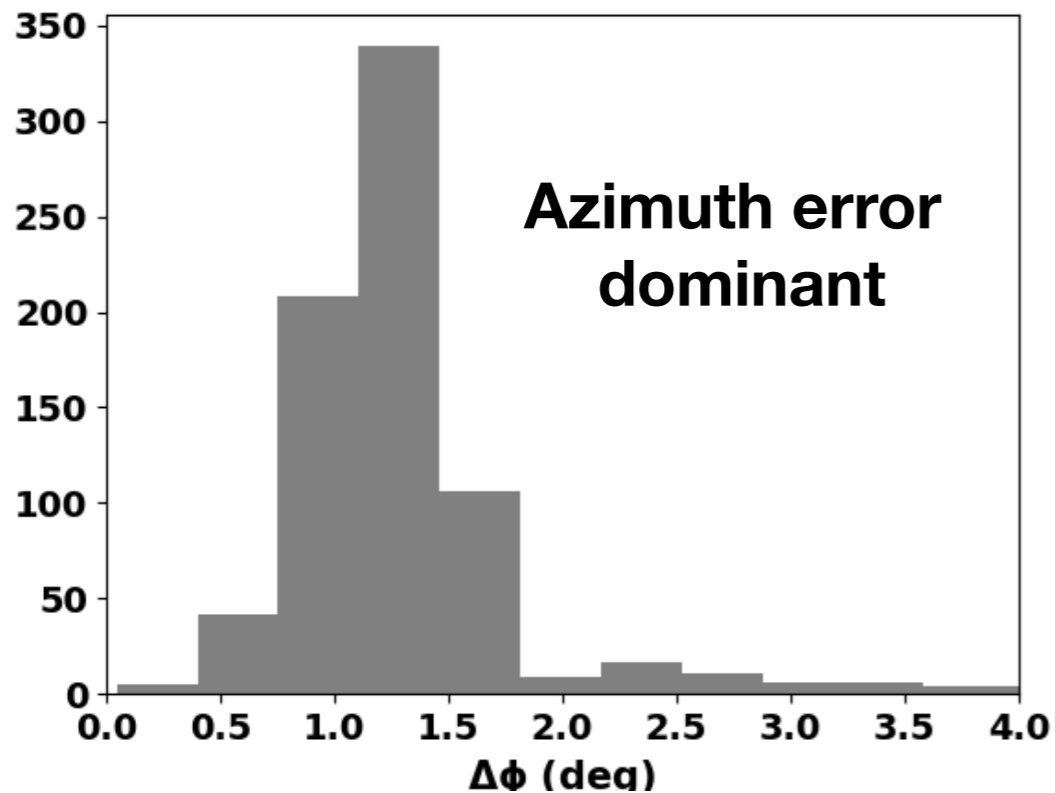
**Reduction of errors
with the number of antennas**

Reconstruction results : Hot Spot 1

$\langle \Delta\alpha \rangle = 1.641$ $\text{std}(\Delta\alpha) = 0.739$
Showers number = 764



$\langle \Delta\phi \rangle = 1.341$ $\text{std}(\Delta\phi) = 0.721$

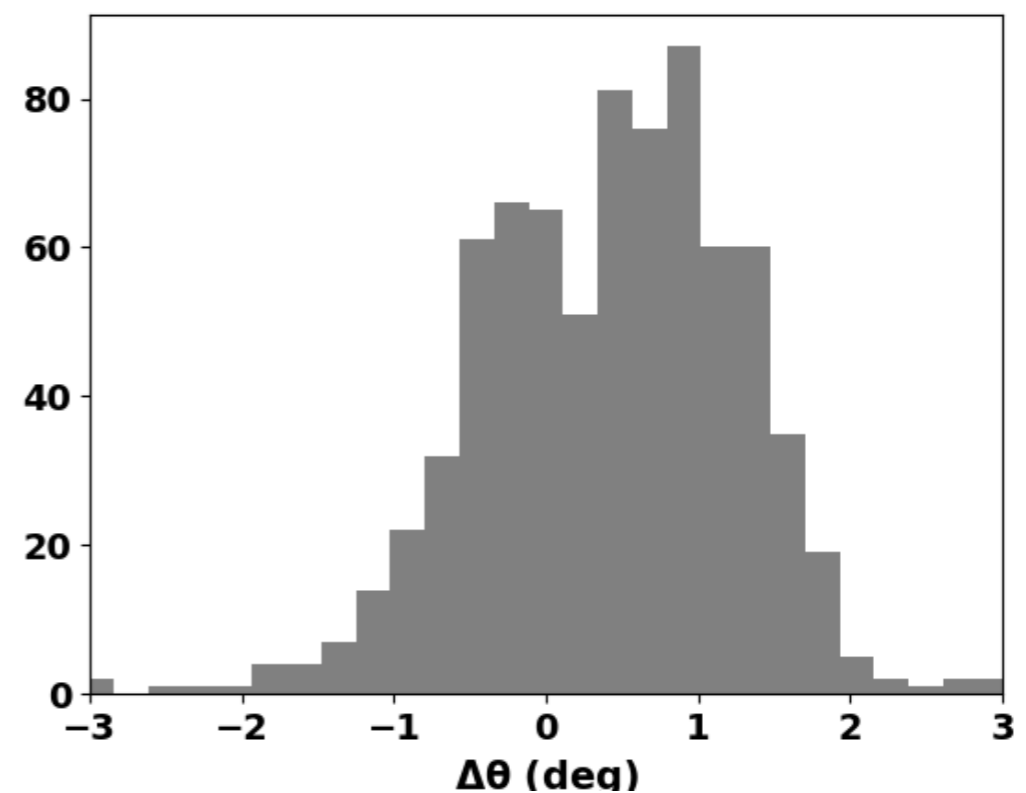


Cuts on reconstruction quality :

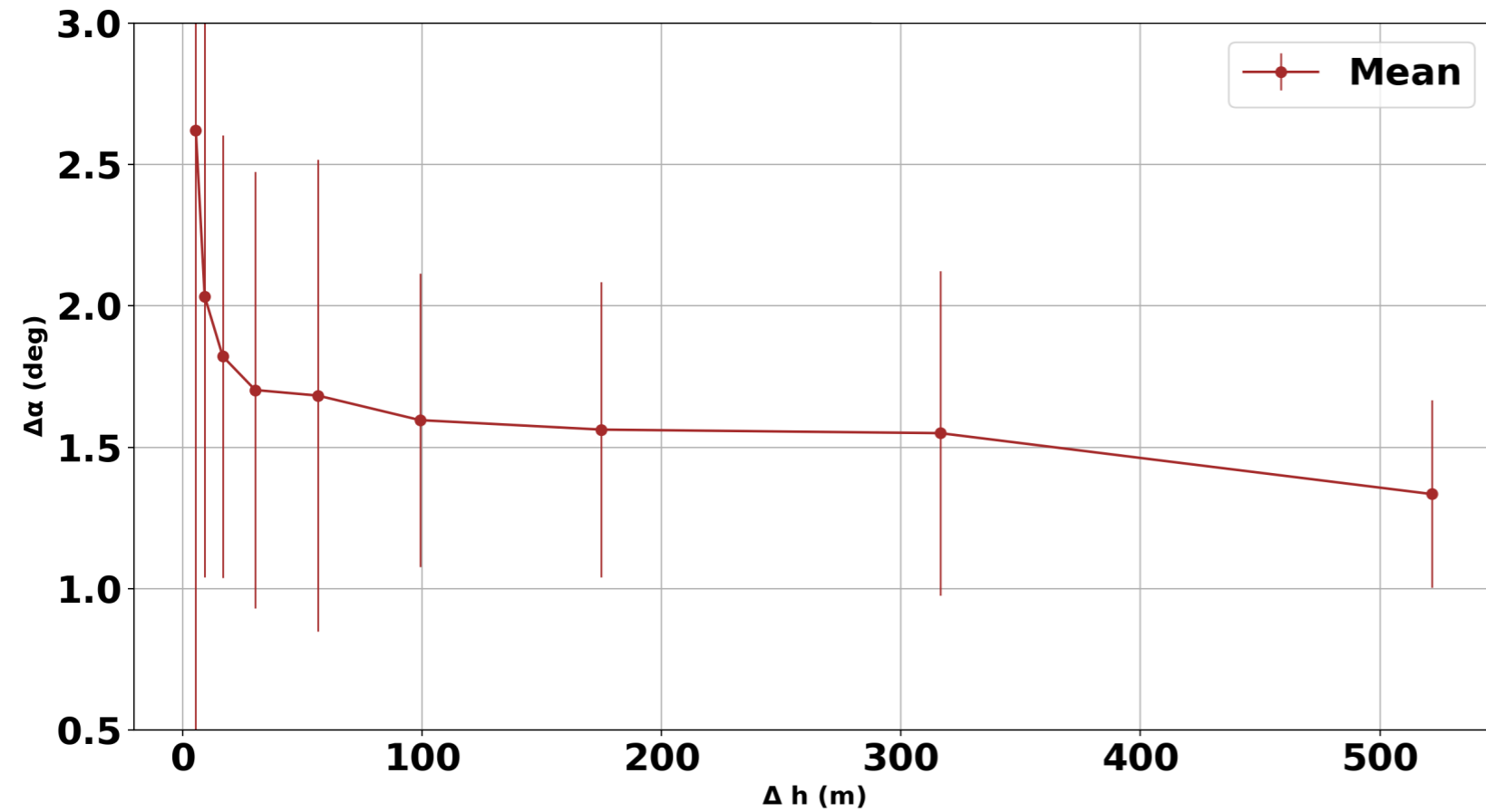
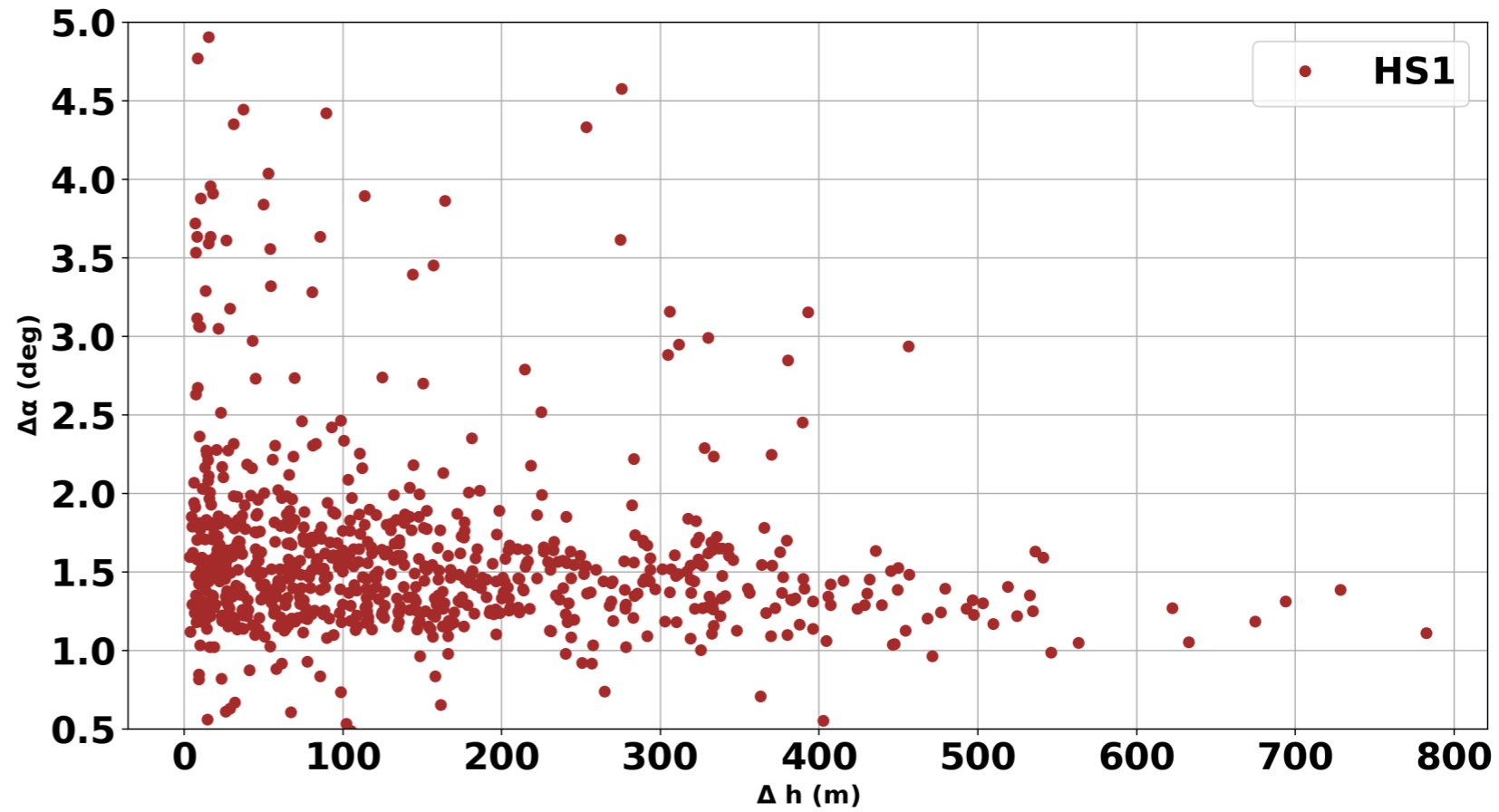
Significance $< \text{inf}$ and NaN

Exclude range limits $\theta = 88.$ & $93.$

$\langle \Delta\theta \rangle = 0.779$ $\text{std}(\Delta\theta) = 0.561$

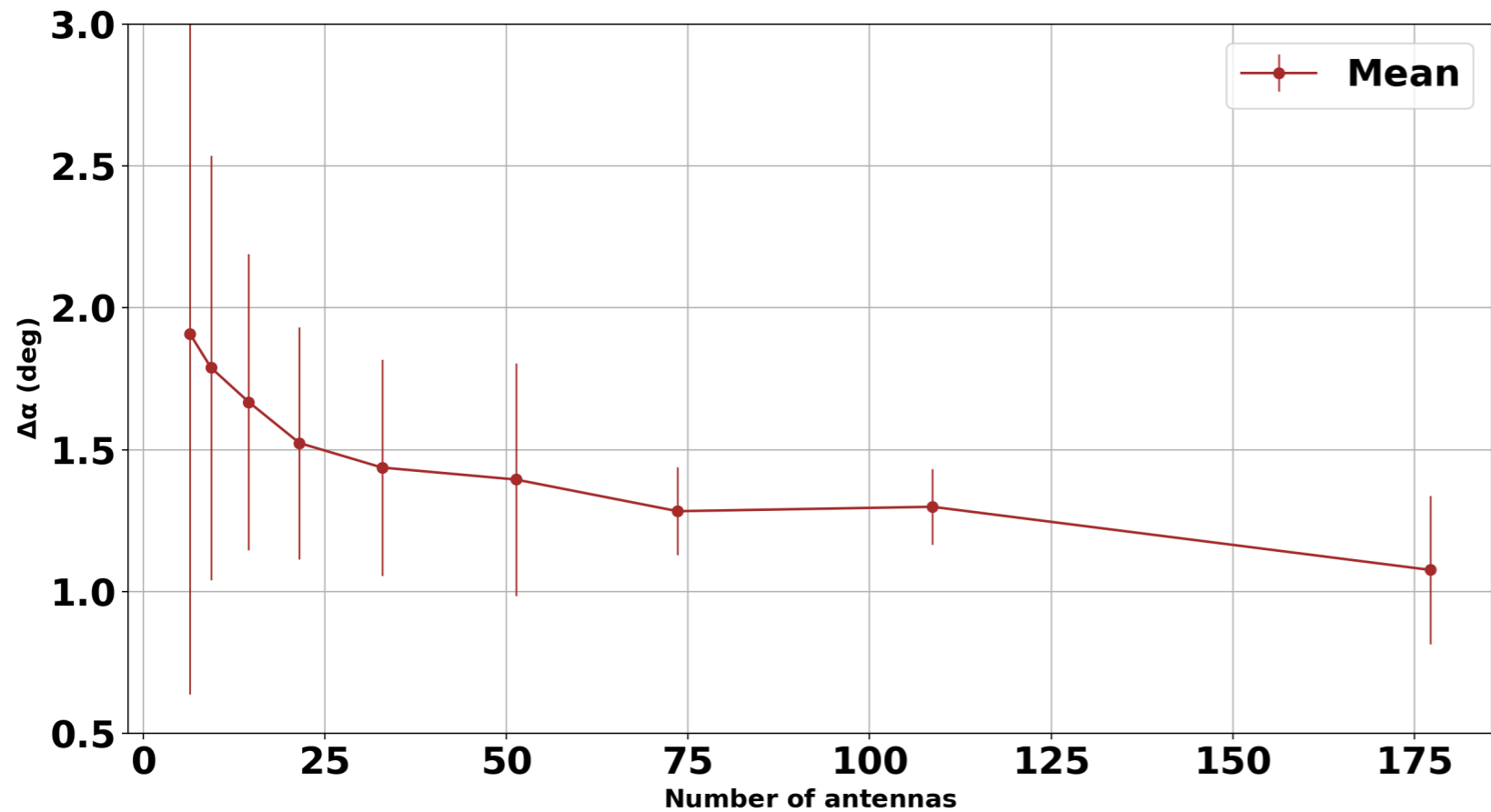
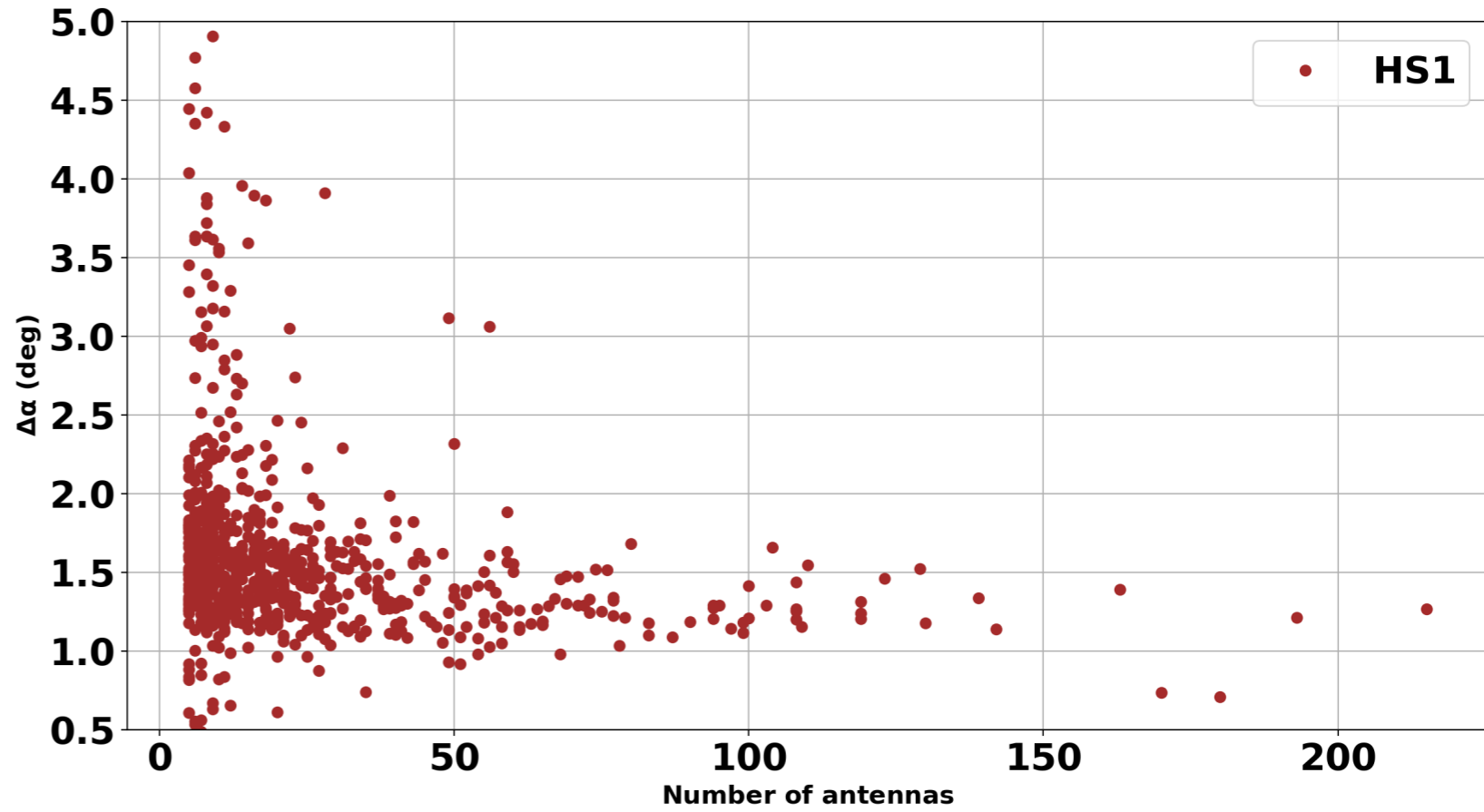


Reconstruction results : Hot Spot 1



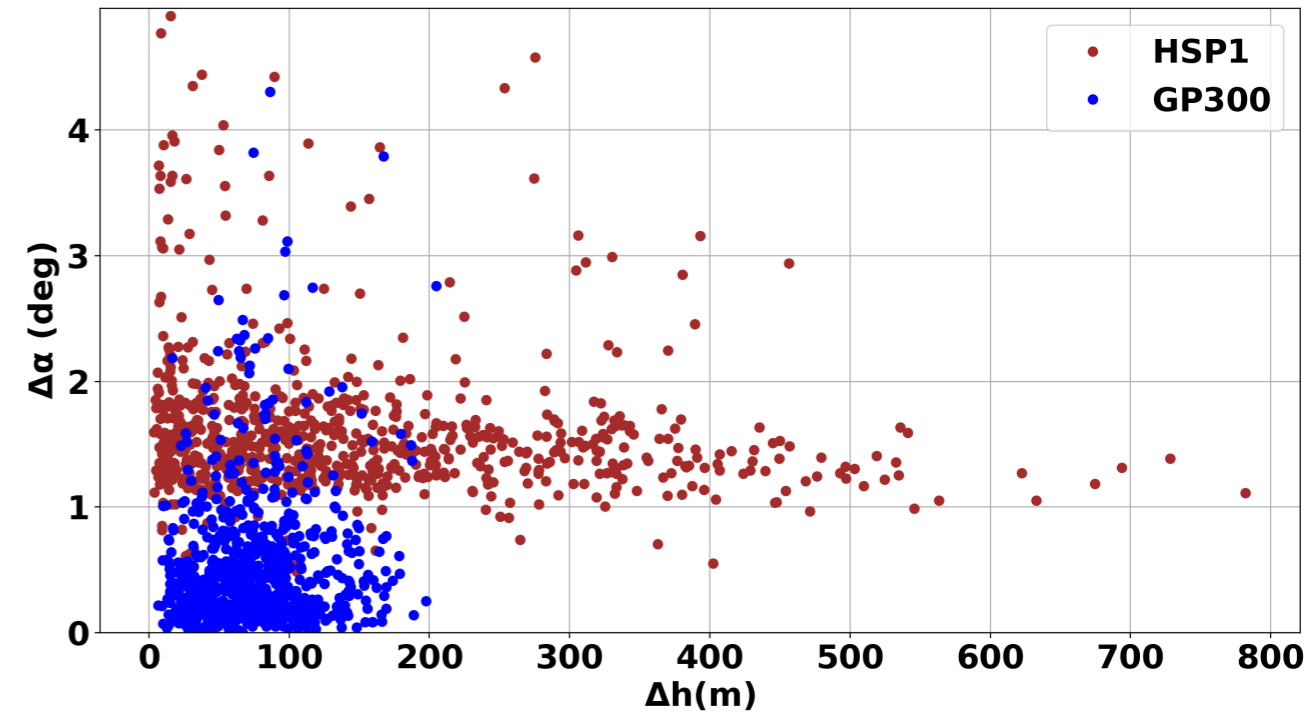
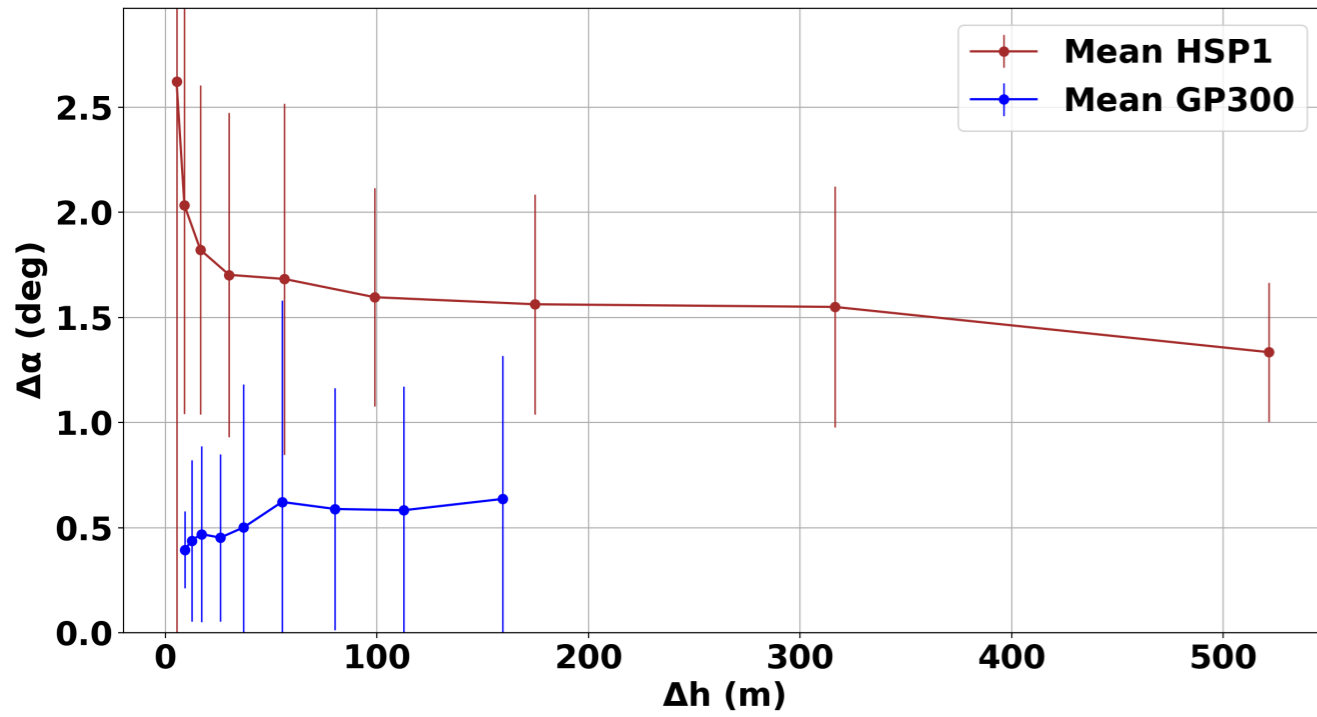
**Reduction of the errors
with the slope**

Reconstruction results : Hot Spot 1

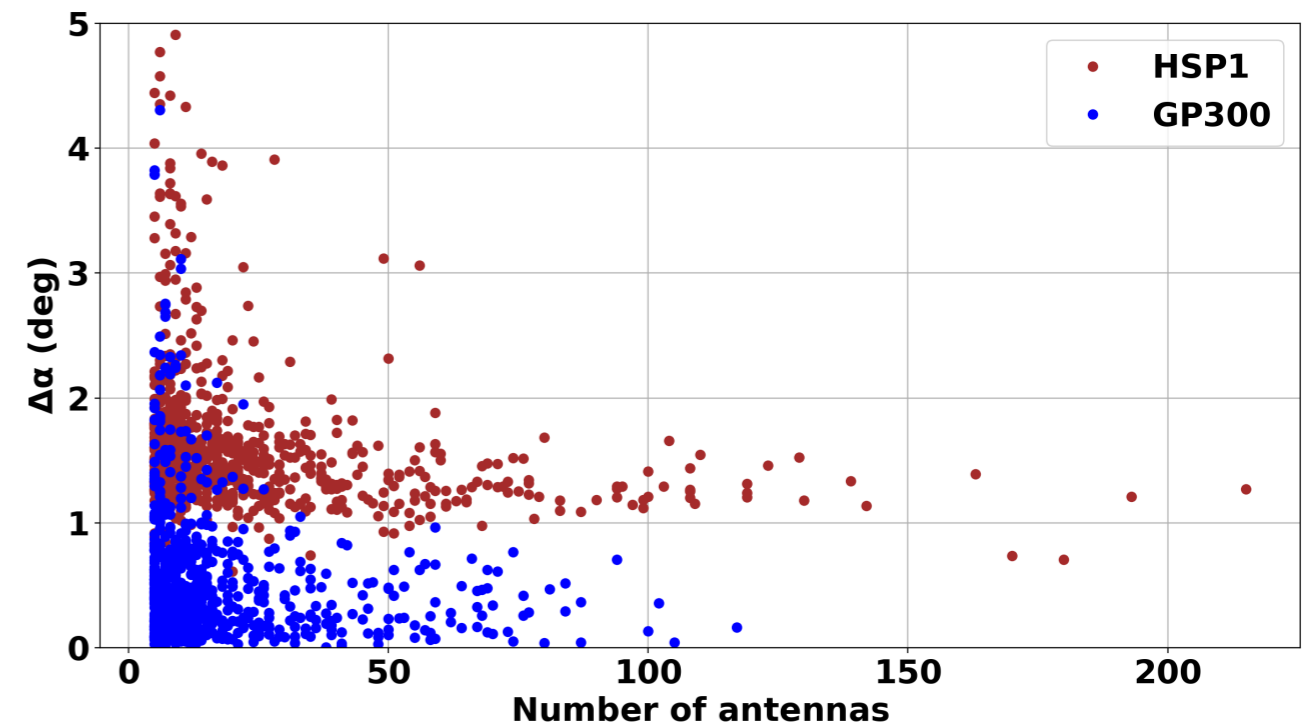
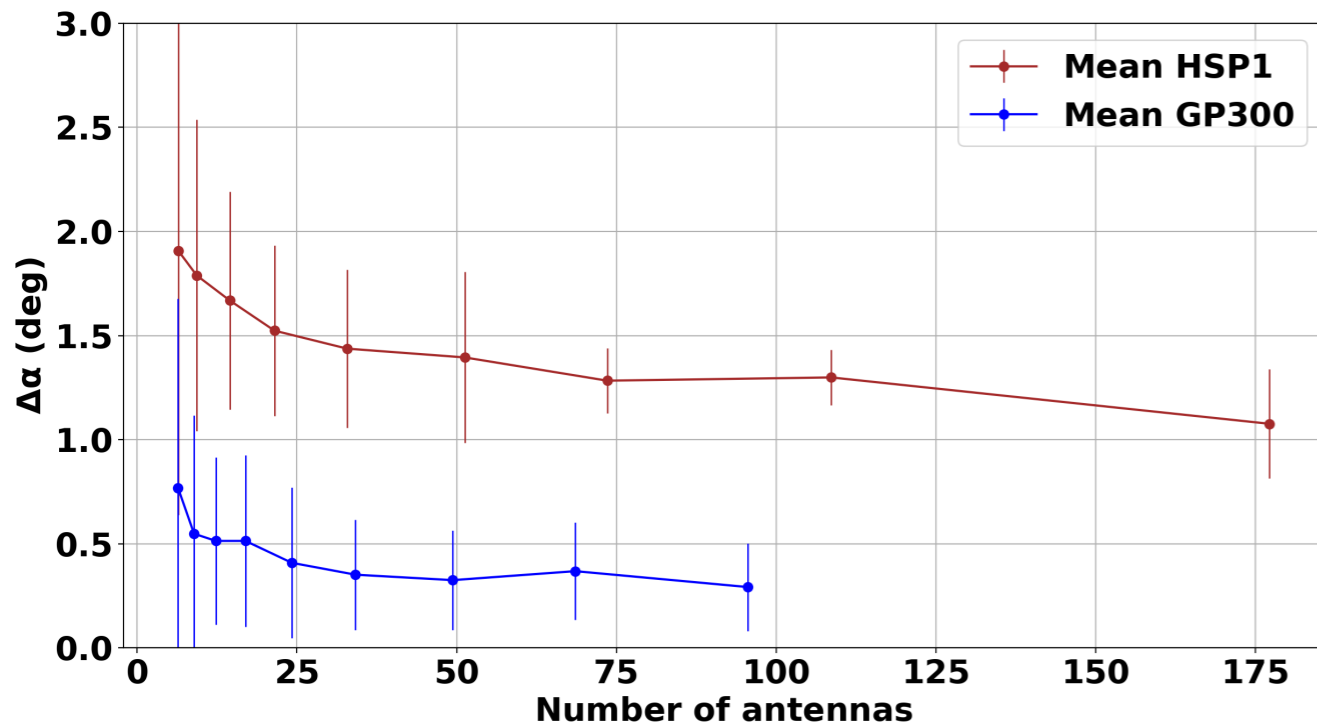


**Reduction of errors
with the number of antennas**

Reconstruction results : GP300 vs HS1

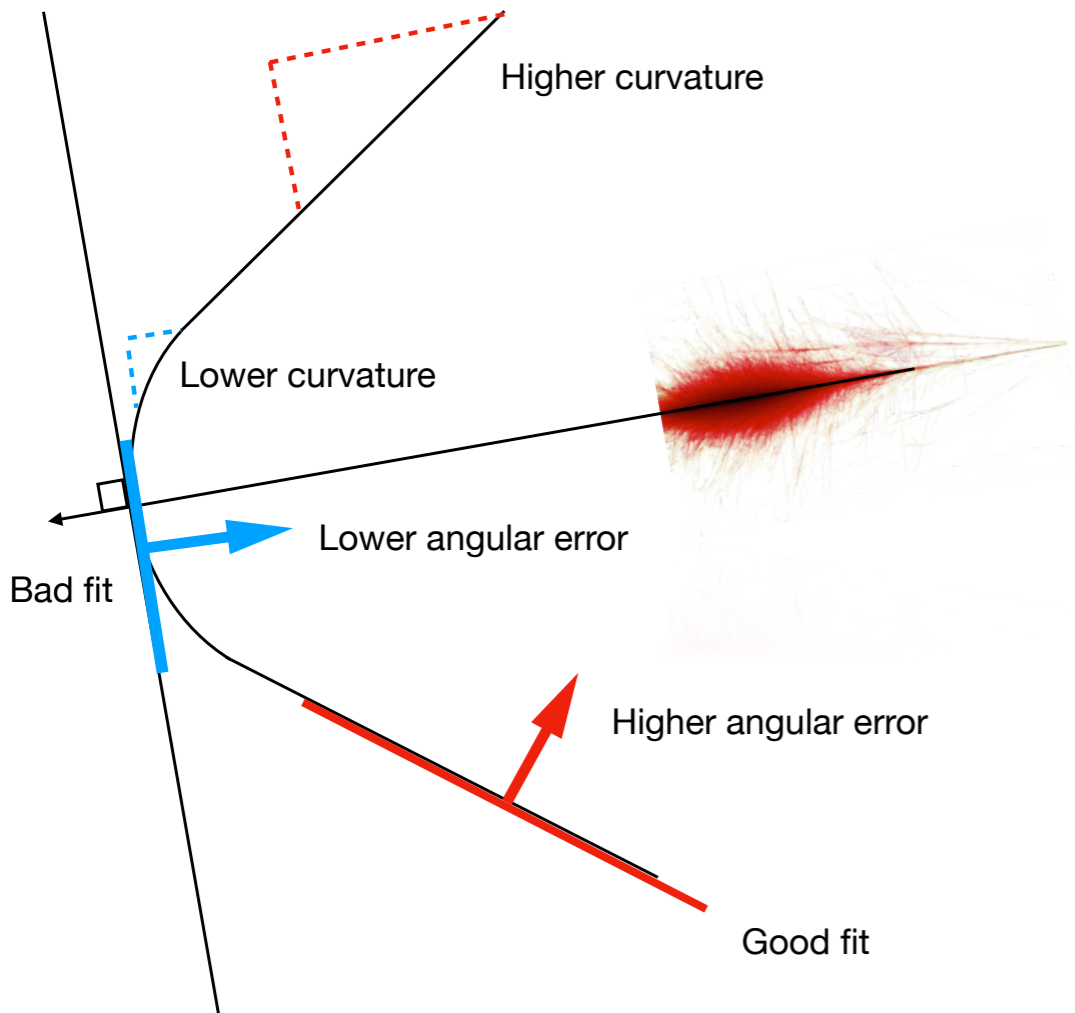


Differences for the same parameters range



Reconstruction results : GP300 vs HS1

χ^2 explanation

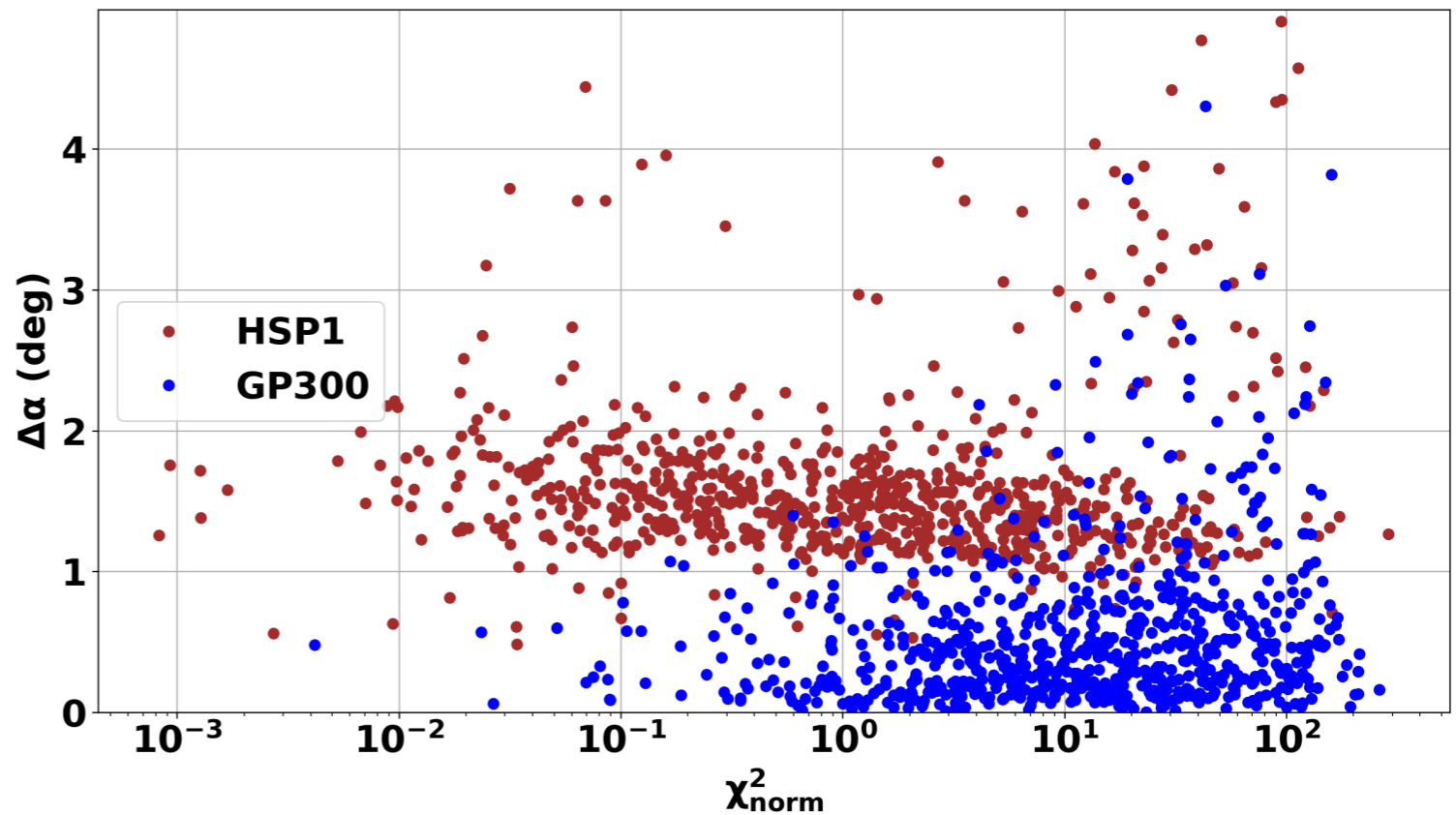
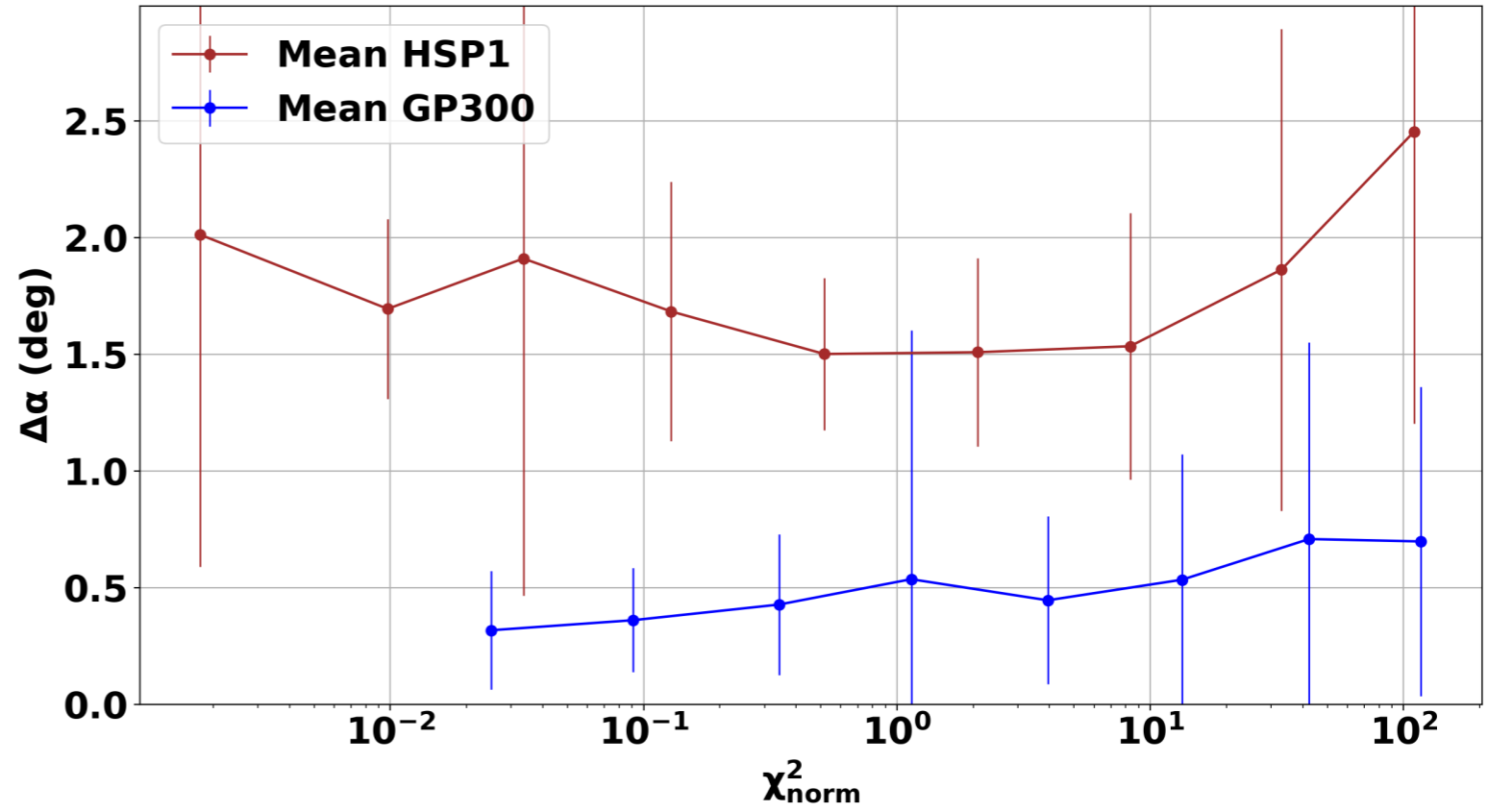


Core positon



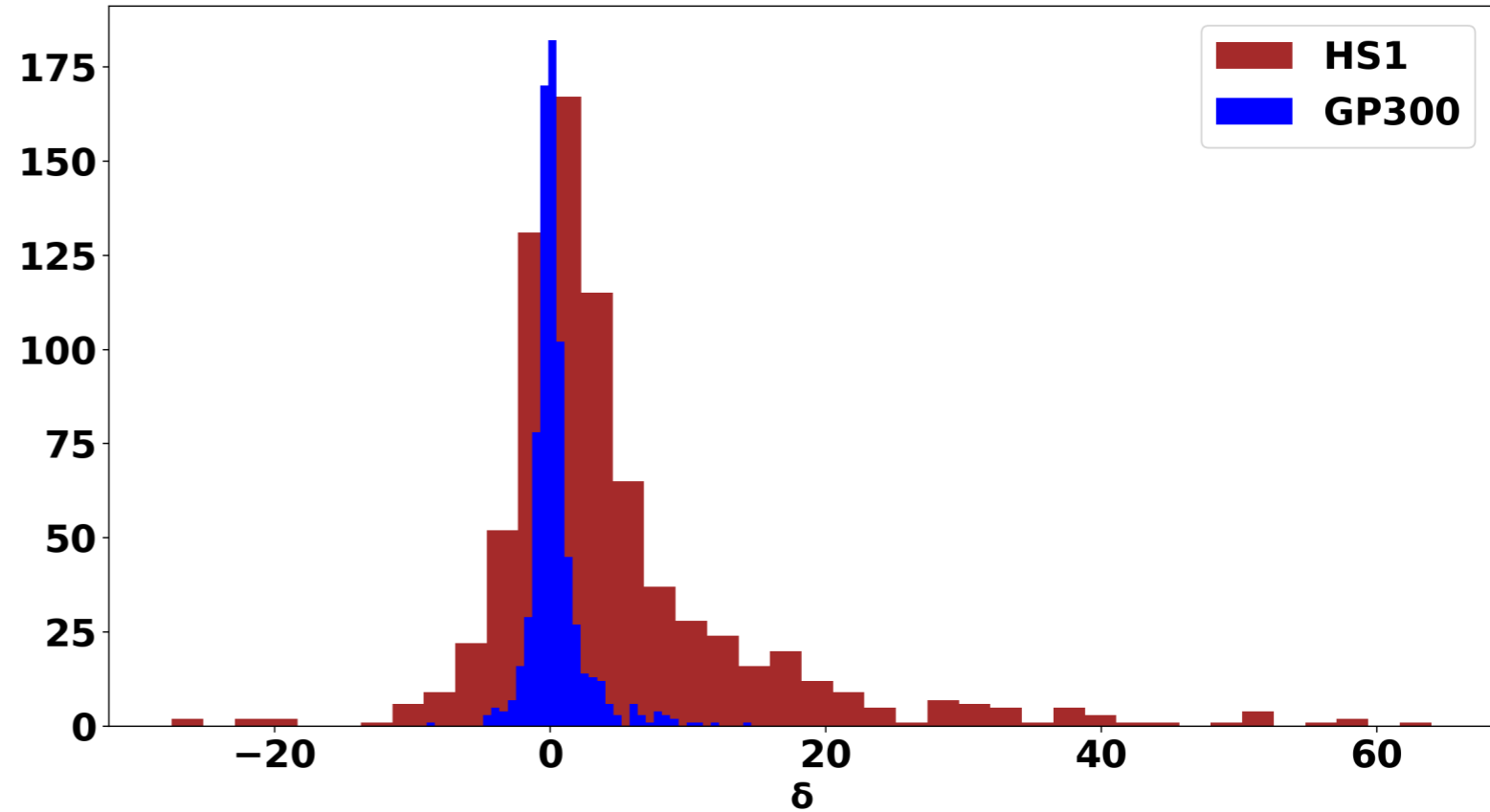
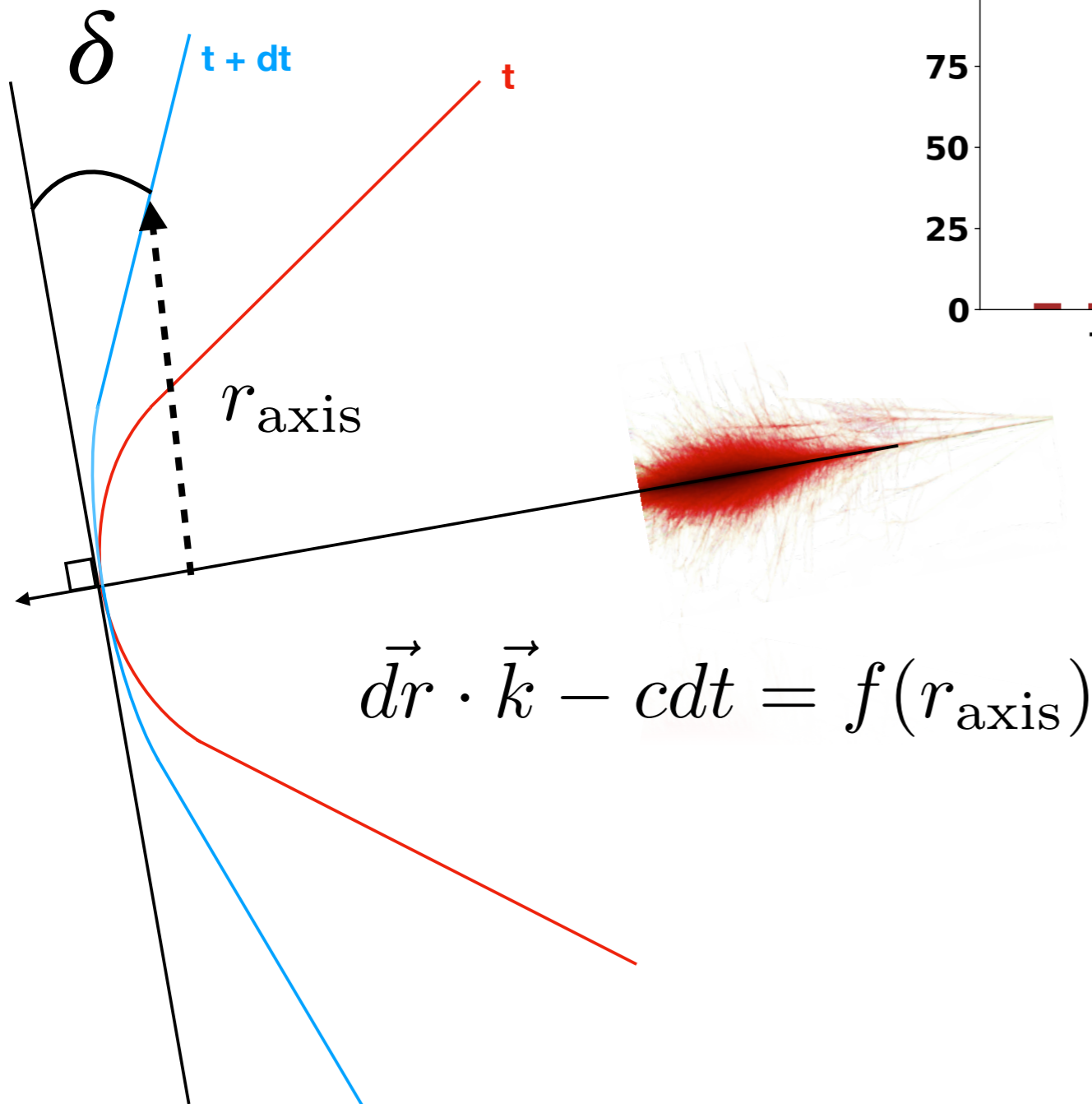
Included events

Array extension



Reconstruction results : GP300 vs HS1

The curvature answer :
slope from the plane



During propagation
the wavefront shape flatten



Distance from max
Array extension

Conclusion

**Upper limit of GRAND reconstruction
with the most basic method used and on real GRAND configurations**

**Better understanding of reconstructions on GRAND-like arrays
Wavefront shapes evolution, impacts of shower configurations and array parameters**



Key parameters identified



**Toward more complex and more sensitive reconstruction methods
Using more realistic wavefront shapes (conic/hyperbolic)
Using the voltage pattern (core reconstruction)**



$$\Delta\alpha < 0.1^\circ$$