GRAND reconstruction

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(on behalf of the simulation and reco team)

Radio-Workshop @Desy Zeuthen
Aug 18-20 201

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Status simulation chain for reco

https://github.com/grand-mother/radio-simus
→ development/clean-up/merge of common tools (python3)

No complete and fully working code for reconstruction exits for now….

Simulated electric field trace

Antenna Response
Add Noise
Filter
Digitize

↓

Voltage trace → geometry of the shower → arrival direction, ...

Deconvolve antenna response

Upsampling

↓

Reconstructed electric field trace → energy and Xmax reco

Bottle necks:
- frame work for GRAND software
- Deconvolution of antenna response, ….
- **(wo)man power!!!**

→ **Forward folding technique?**

Btw: We do not have data or noise measurements yet!

Arrival direction via wave front reco

→ well below 1° needed!

Set of 10 000 simulations of 10^{10} GeV and 10^9 GeV primary neutrinos

$$f_i^{\mathrm{WS}}(r_i, a, b) = \sqrt{a^2 + b^2 r_i^2} - a$$

Hyperbolic parameters fixed from LOFAR measurements

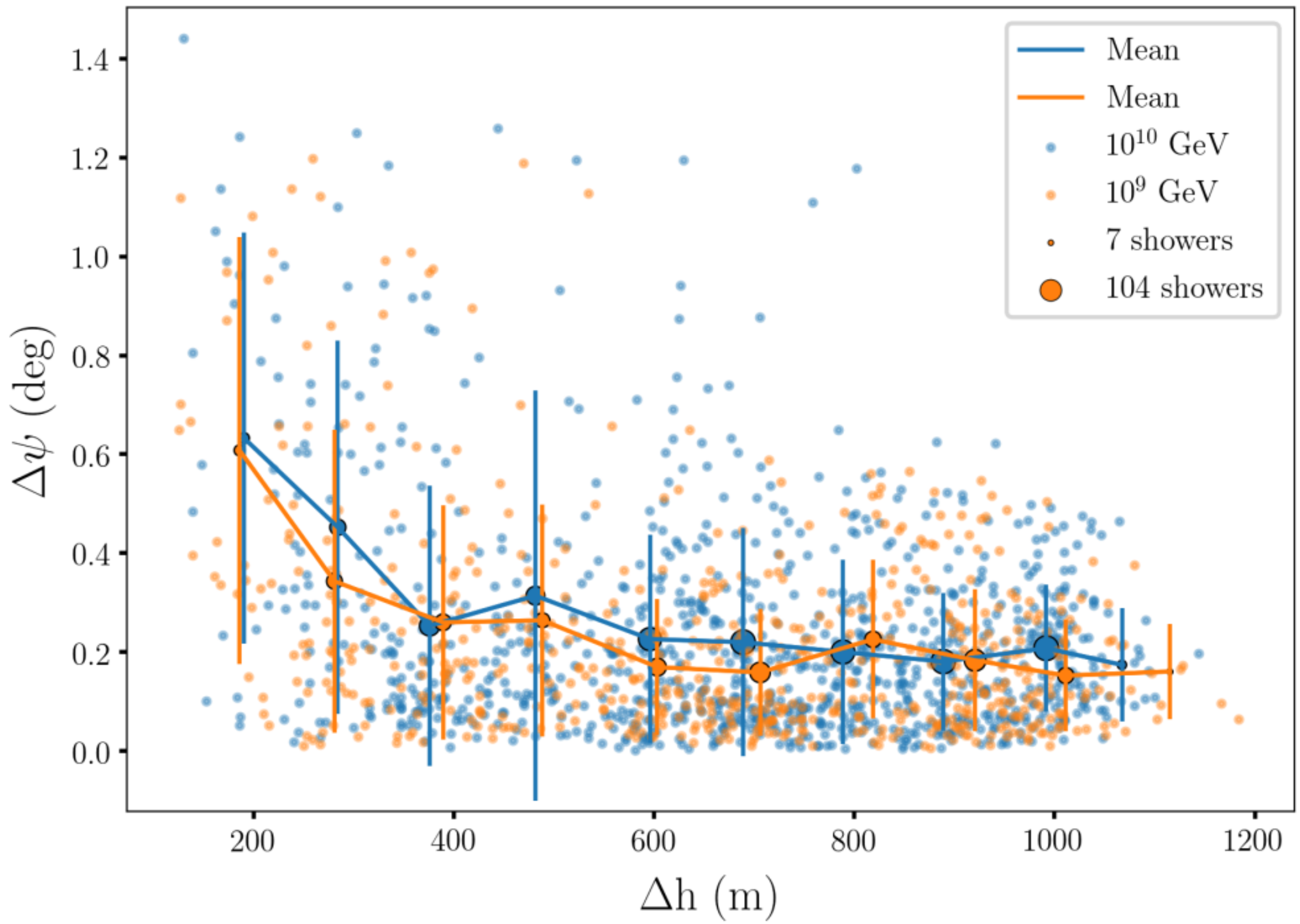
(a, b) = (4.49 m, 0.026)

A. Corstanje et al. 2014

Slow moving source emission
→ hyperbolic wavefront.

Voltage traces
GPS precision = 5ns
No noise
Aggressive trigger conditions
(2x noise level)

Mean angular error ≈ 0.2° reachable

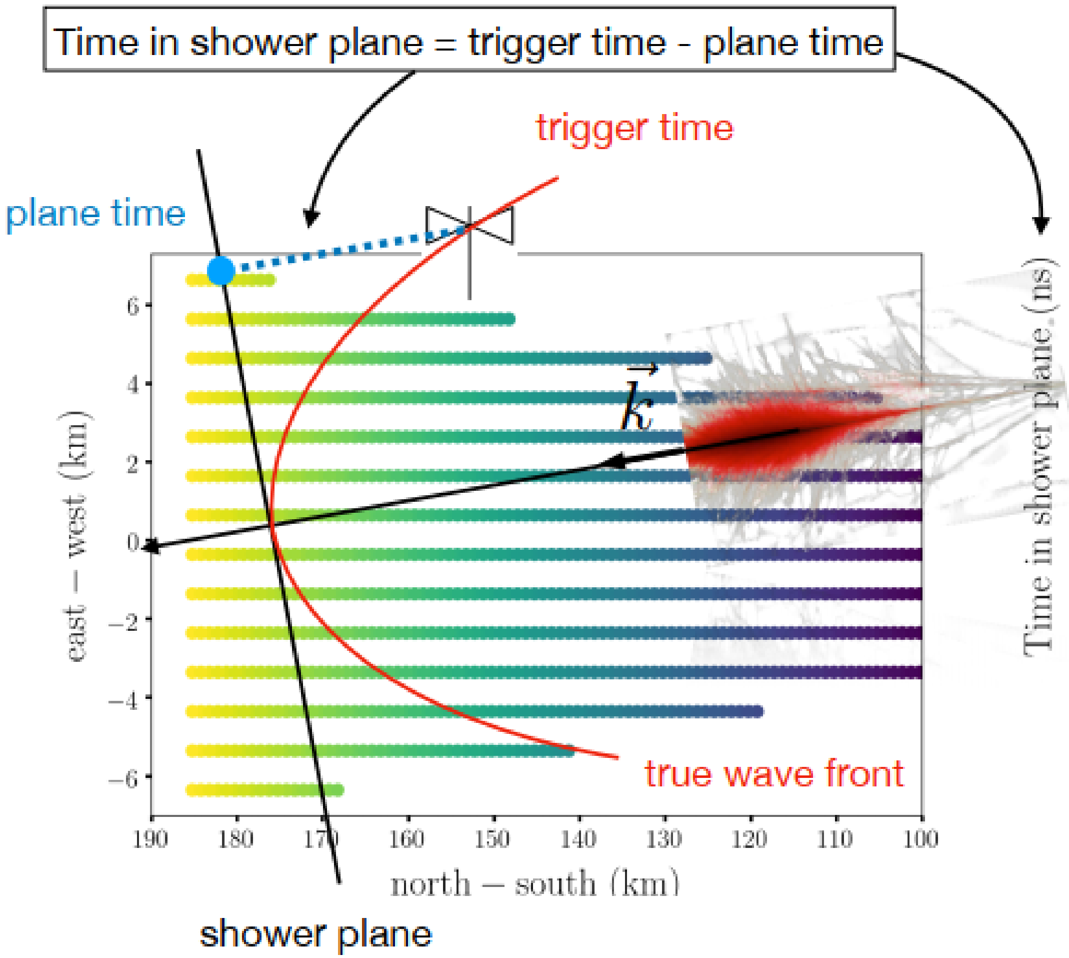


Vertical distance → Lever arm

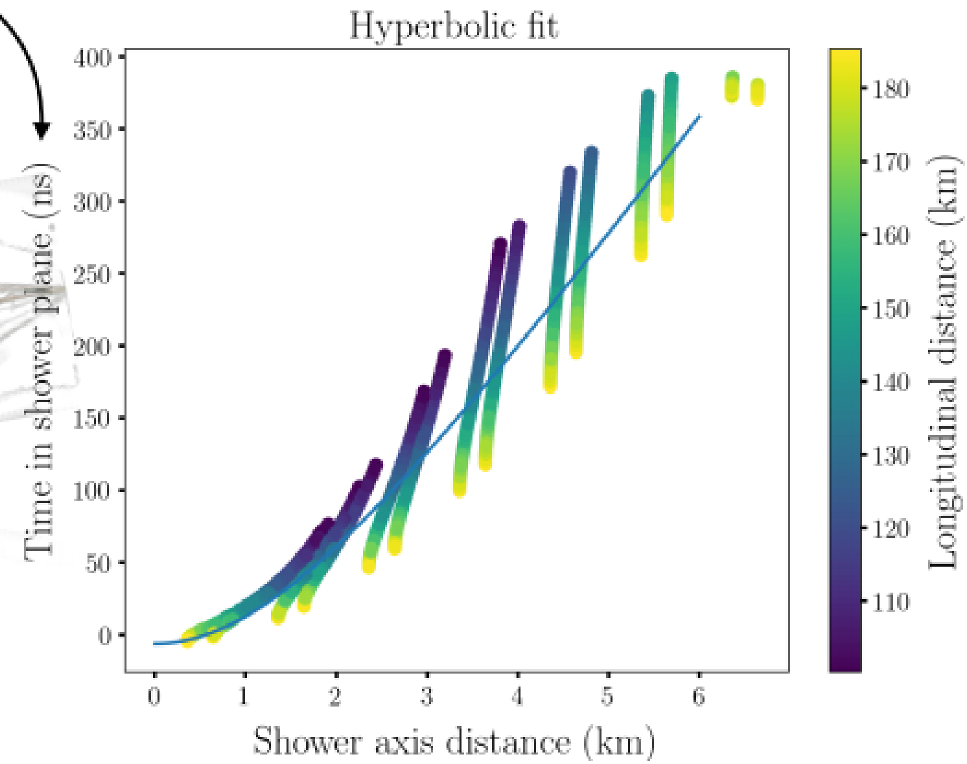
Overall similar results for both energies (slightly better for 10^9 GeV)

(V. Decoene, GRAND collab meeting)

Ageing of the wave front



$$cdt - \vec{k} \cdot d\vec{x} - \sqrt{a^2 + b^2 r^2} + a$$



Toy Model configuration

No noise

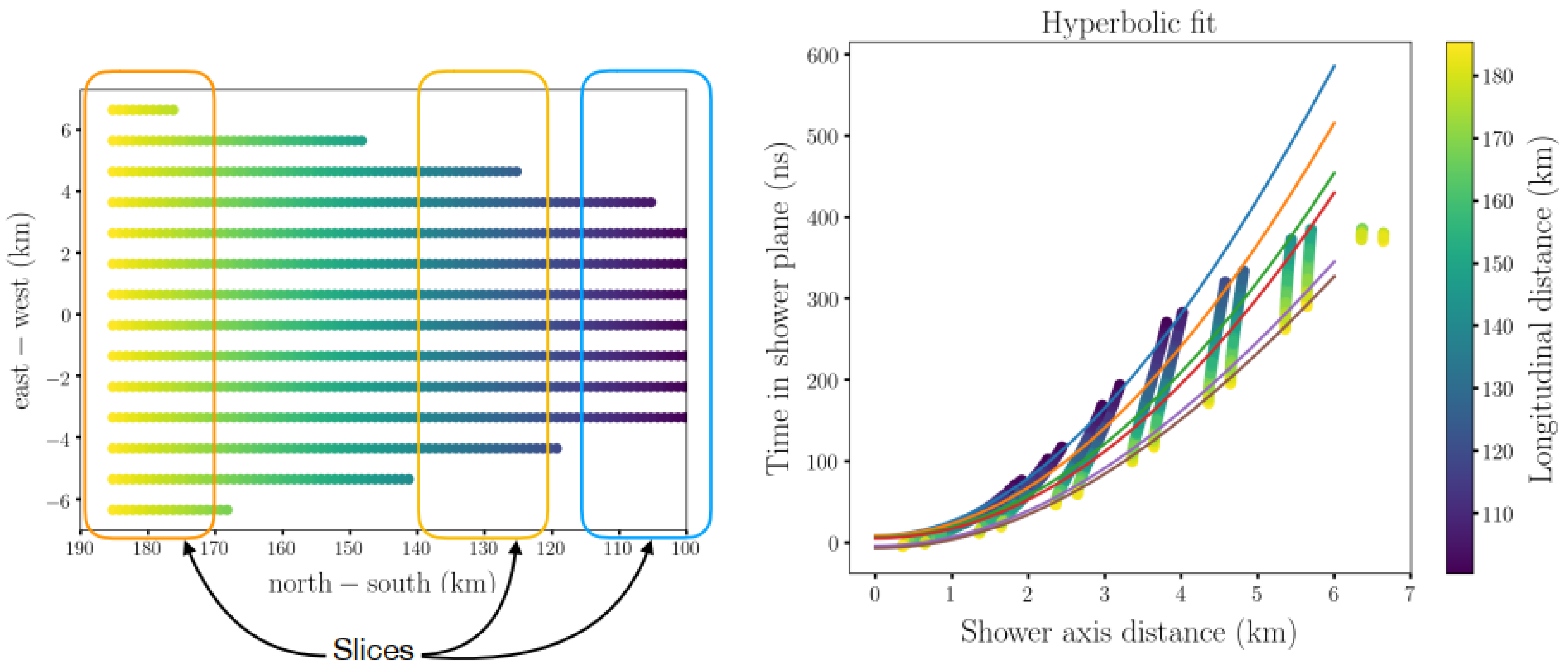
data can't be fitted with one single analytical function because the wave front evolves with time (ageing)

GRAND will observe wave front ageing!

(V. Decoene, GRAND collab meeting)

Ageing of the wave front

To fit different wave front parameters for each propagation distances -> slicing



- **Each slice correspond to a propagation distance -> shower age**
- **For each slice an independent fit is perform (using the correct direction)**

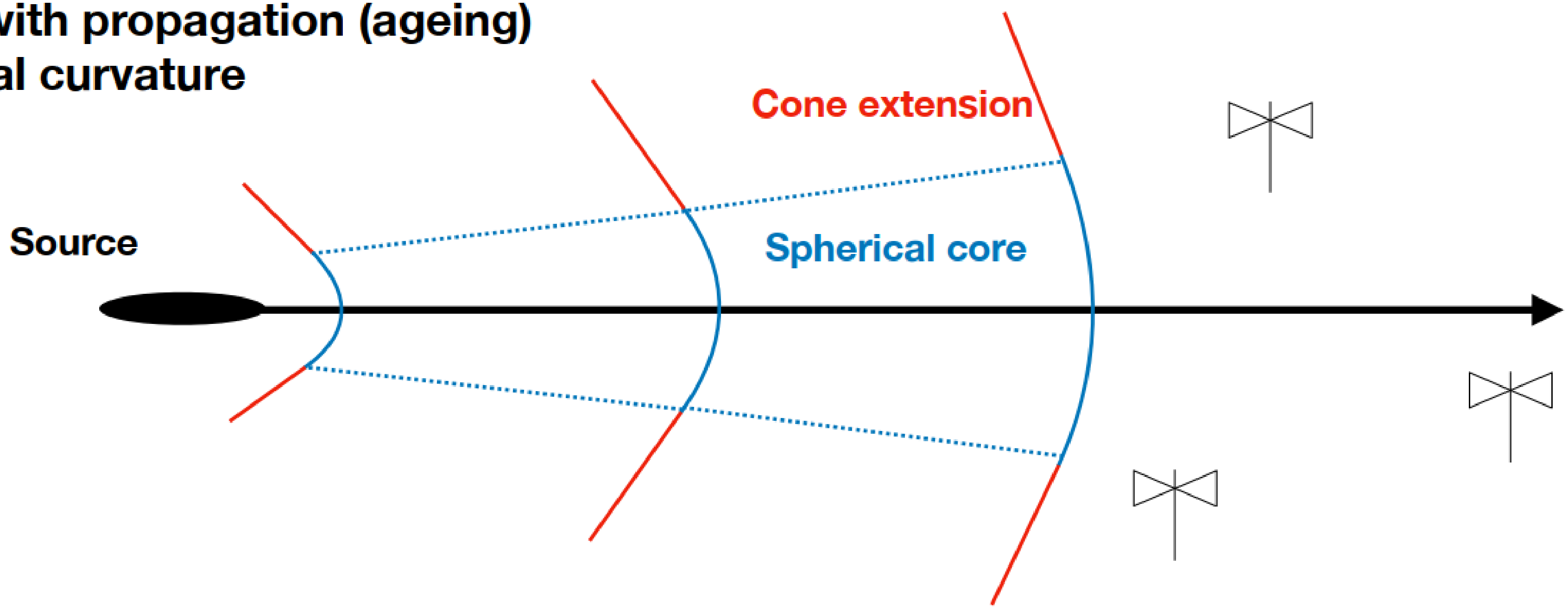
The best parameters (a, b) for each shower age (and each wave front model) are computed

(V. Decoene, GRAND collab meeting)

A new wave front shape picture

Wave front shape :
- **Hyperbolic**
- **Evolve with propagation (ageing)**
- **Spherical curvature**

(V. Decoene, GRAND collab meeting)



But 2 problems :
- **Many parameters to fit and big parameters space (a, b)**
- **Need to compute shower axis distance (r)**

Understand the development of the wavefront
→ parametrize a and b as a function of θ, φ, and n_{ref}

==> Reduce uncertainties in reconstrcution of arrival direction

Reconstruction of event geometry

(V. Decoene, GRAND collab meeting)

Iterative reconstruction:

• Plane wave reconstruction → direction estimate

loop

• Spherical reconstruction → position anchor for the direction
→ Shower axis distances for antennas

• Hyperbolic reconstruction using direction estimate and shower axis distances

↑
Slicing reconstruction
→ Parametrising wavefront at different ages

Hybrid reconstruction:
Mixing timing information with amplitude information
• Amplitude (Cherenkov cone) → shower core
• Polarisation → axis distance

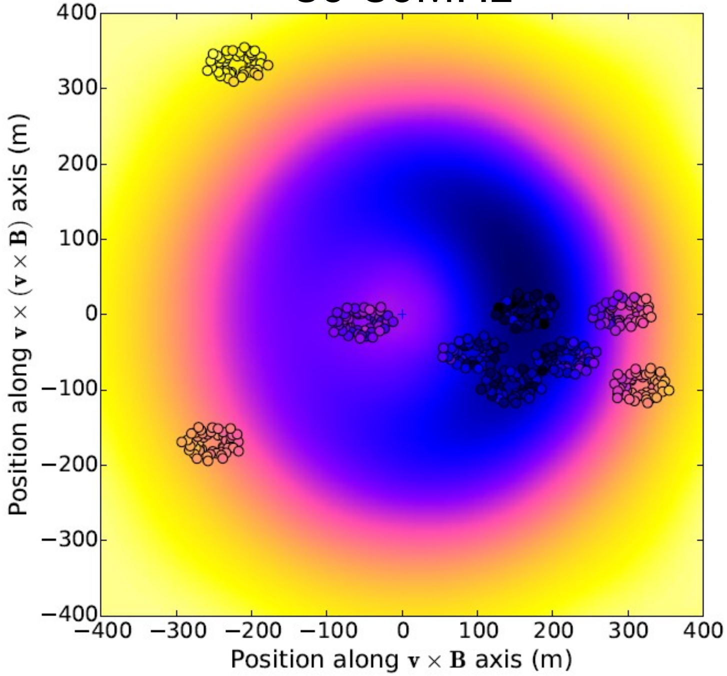
Still ongoing work….

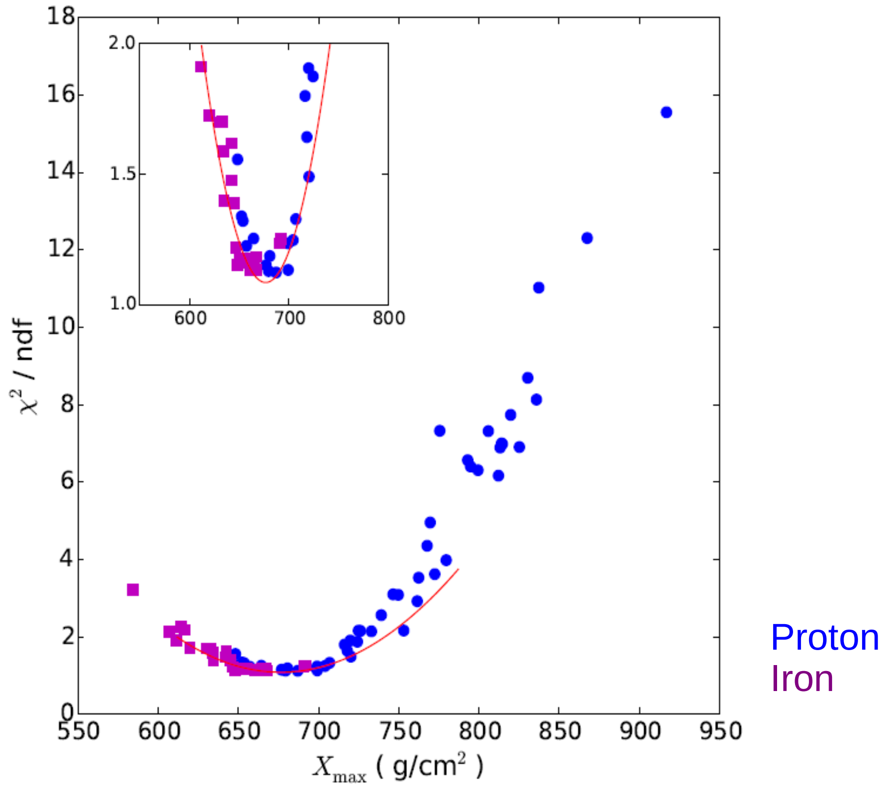
Top-Down in LOFAR - Xmax

Distinguish between CR and neutrinos

Pick the one of <u>many</u> simulations describing data the best

30-80MHz





- **2d LDF fit to radio simulations yields mean X_{max} to ~17 g/cm²**

More: S. Buitink et al., Nature 531, 70 (2016)

- Tunka-Rex achieves 35g/cm² with fitting full pulse shape, not just amplitudes
  P.A. Bezyazeekov+, arXiv:1803.06862

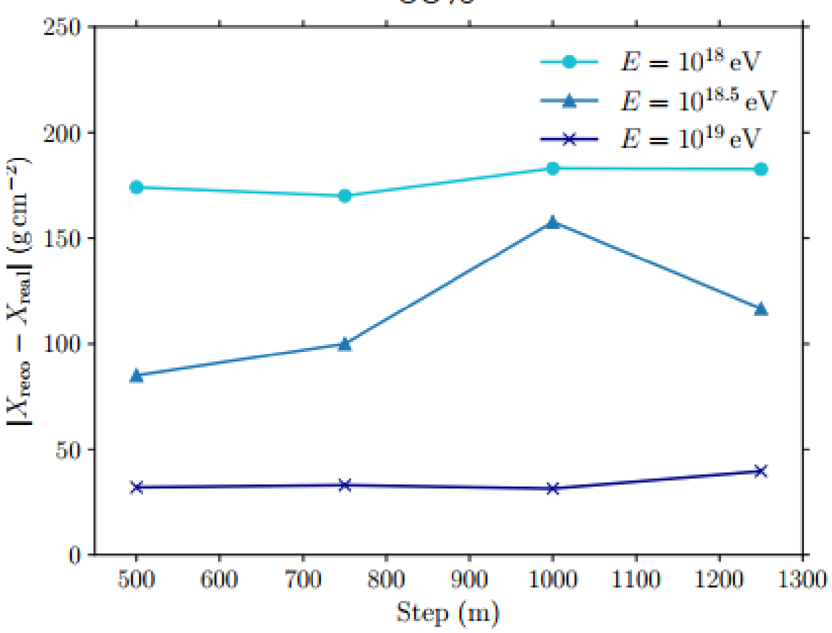
GP300/10k:
Would that be a valuable method for a sparse array? High event rate?
→ **How precisely has the geometry and energy be determined before?** (s. AERA)

Top-Down in GRAND (C. Guepin at WP workshop Aug.2018)

- **Voltage traces used, artificial noise**
- Energy and geomtry perfectly known!

Fixed parameters

- zenith 83°
- azimuth 40°
- mountain slope 10°



LDFs become quite flat for highly-inclined shower → structures not prominent enough?

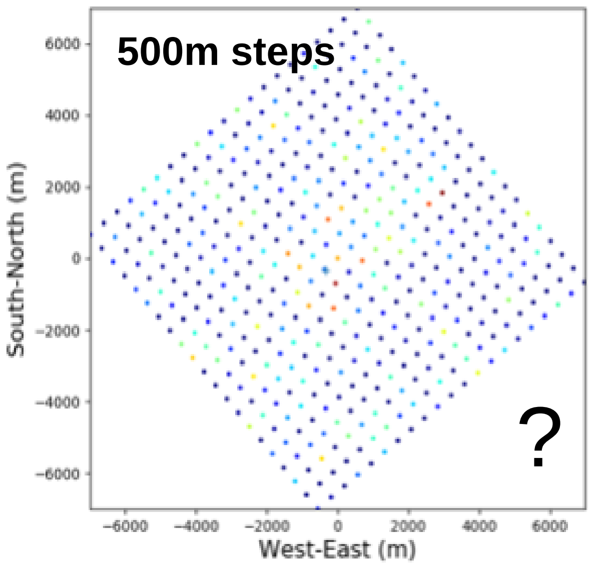
We need to dig deeper into this!

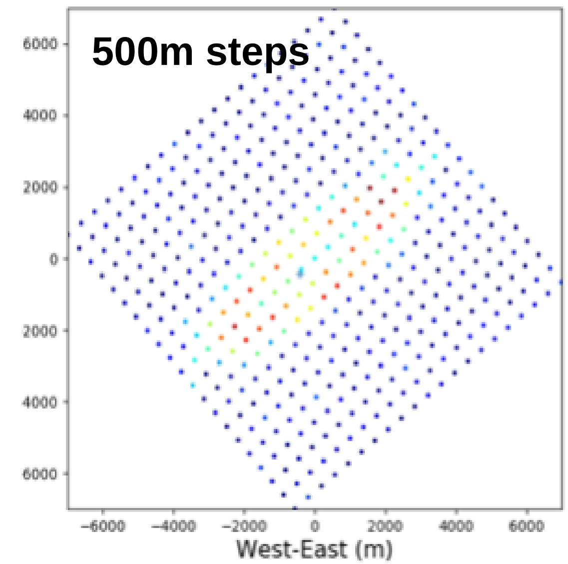
- We should profit from the higher frequencies → more structures to fit (like for SKA-low)
- Denser antenna grid should help to lower the reconstruction uncertainty for lower energies (GP300 okay, but what for 10k?)
- we need <u>enough antennas (?)</u> to perform a meaningful comparison to simulated footprints (+ impact of additional uncertainties)
  → a *methof for ‚high-quality events'?*
  - high number of antennas with trigger, well-reconstructed geometry and energy,….

10^{18} eV

Normalised to max. value

$10^{18.5}$ eV



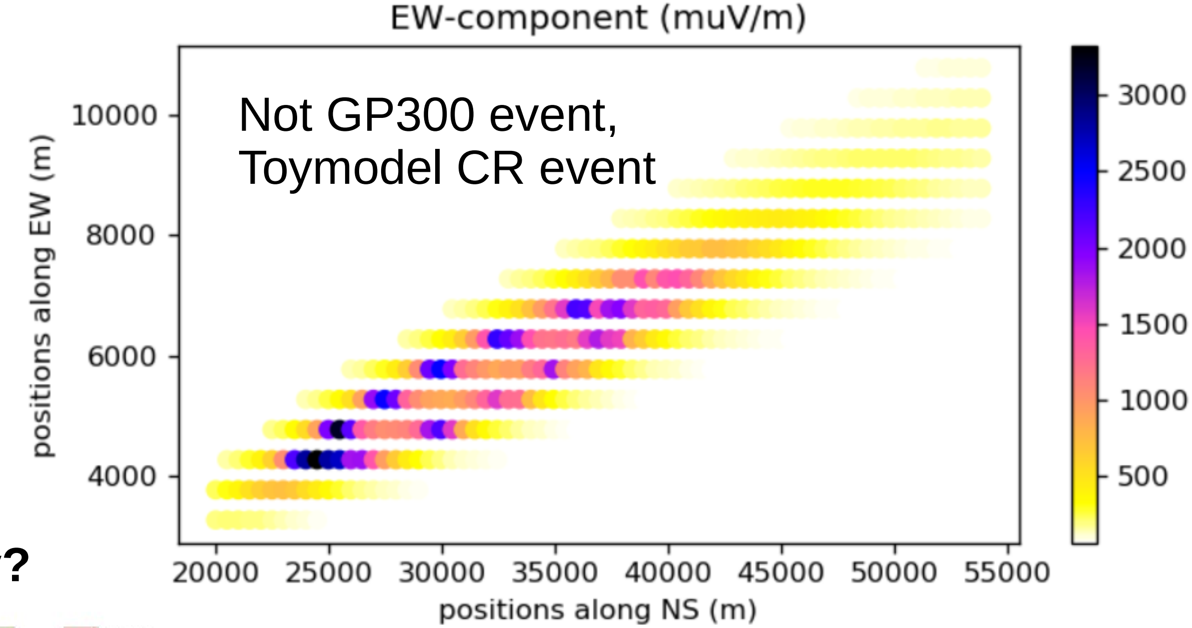


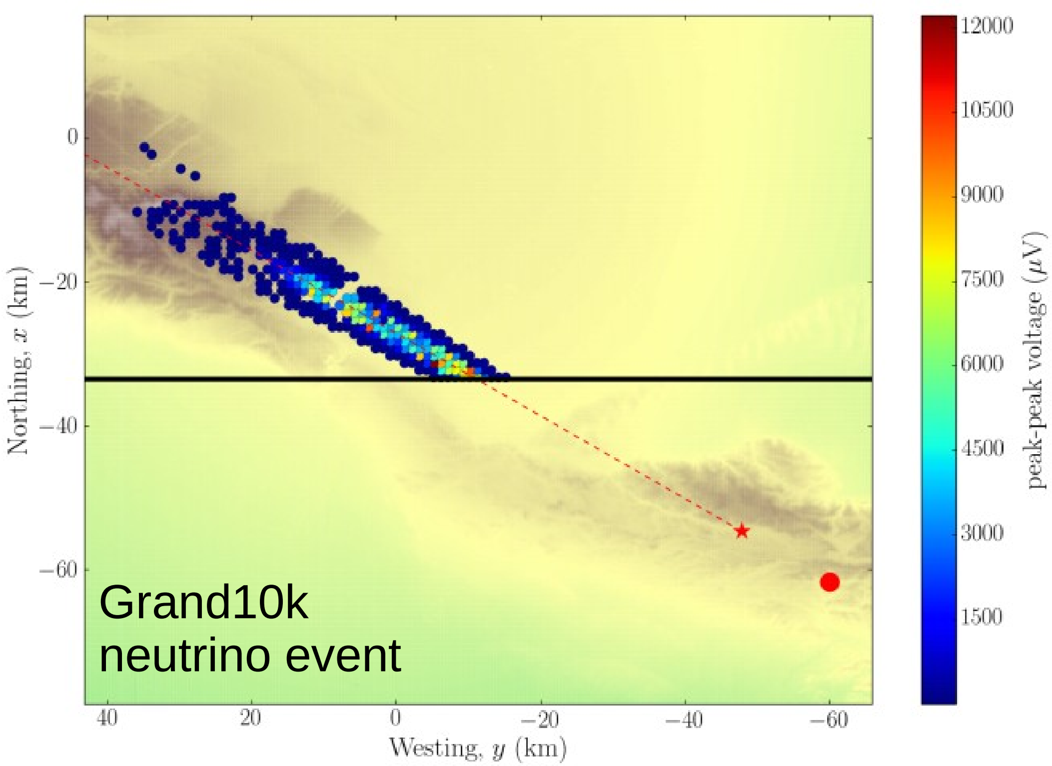
Can we use the Cherenkov ring? - Xmax

Use amplitude distribution
→ visible Cherenkov cone

→ ring radius should help to
determine Xmax by geometry
Krijn+, arXiv:1304.1321
(tested on 3 LOFAR events, Anna+, arXiv:1411.6865)

How well can we sample/identify the position of the ring with a sparse array?





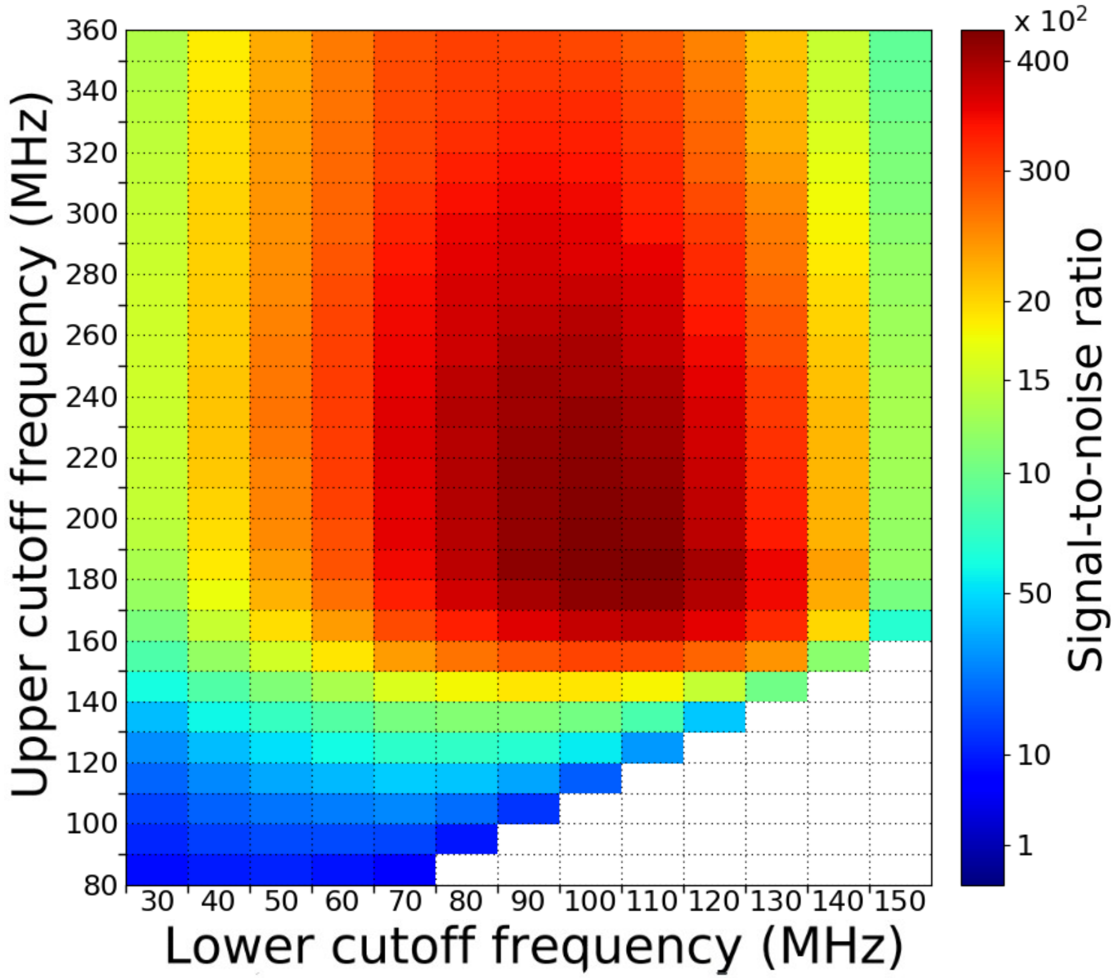
For neutrino events
- Shower passes by the array
  → We will see a conic section in the amplitude distribution
  → **will point back to cone vertex**

How well do we need to know the parameters of the atmosphere (elongated events!)

Optimizing the frequency range

(by Aswathi Balagopal - KIT)

- Same study as performed for IceTop (A. Balagopal+, arXiv:1712.09042)
- Antenna response of a dipole antenna
- ZHAireS simulation with 1ns binning, CRs and neutrinos



antenna@cone
neutrino
5 10^17 eV, zen=87° (GRAND conv)
h=2800m

Best SNR for 100-180MHz band
(same as for IceTop, AERA, TRex)

+ antenna more handable (smaller and not that high pole needed)!

→ GRAND frequencies from **50-200MHz**
(antenna design issue etc)

Do we profit in the reconstrcution if we limit the band to the optimal?

Energy reco

We need at least 5 antennas with a trigger ….

Energy fluence as energy estimator:

Measure radiation energy by integrating over the footprint
Christian+, see 1508.04267, 1606.01641, …
→ how well does it work for highly inclined showers?
→ how precise need the geometry be determined?
→ any experience from AERA and its upgrade

Energy fluence at a single radio station

Christoph+, arXiv:1905.11185
→ antenna inside or outside Cherenkov cone,
→ 80-300MHz

Amplitude at a reference distance (several or single antenna),
position close to Cherenkov cone → 15-20%
Tunka-Rex, JPS Conf. Proc. 9 (2016) 010008

single station approach: spectral slope depends on the distance from the Cherenkov angle
→ enables estimation of the amplitude at the Cherenkov angle → ~30%
ANITA, arXiv:1506.05396

Summary or intro?

Giant Radio Array for Neutrino Detection

Study well-understood standard techniques
But most of the methods:

- are developed for ground-based air-shower radio arrays triggered by particle detectors → need input from the PD.
- are developped for the 30-80MHz frequency range
- are developped for vertical/down-going showers

Some overlap from which we can profit?

check whether they are applicable

- to (highly) inclined/ upgoing showers!
- If the shower core is not contained? → determine geometry
- In our frequency band (50-200MHz or 100-180MHz)

→ Can we achieve the needed resolution on radio data only (w/o PD input)?

Goals of reconstruction:
Lower the energy threshold as much as possible with achieving the best resolution as possible, e.g. by optimising the frequency band
→ enter the interesting energy region, e.g. down to a few PeV for GP300!

Going from GP300 to GRAND10k:
What happens for upward-going shower?

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