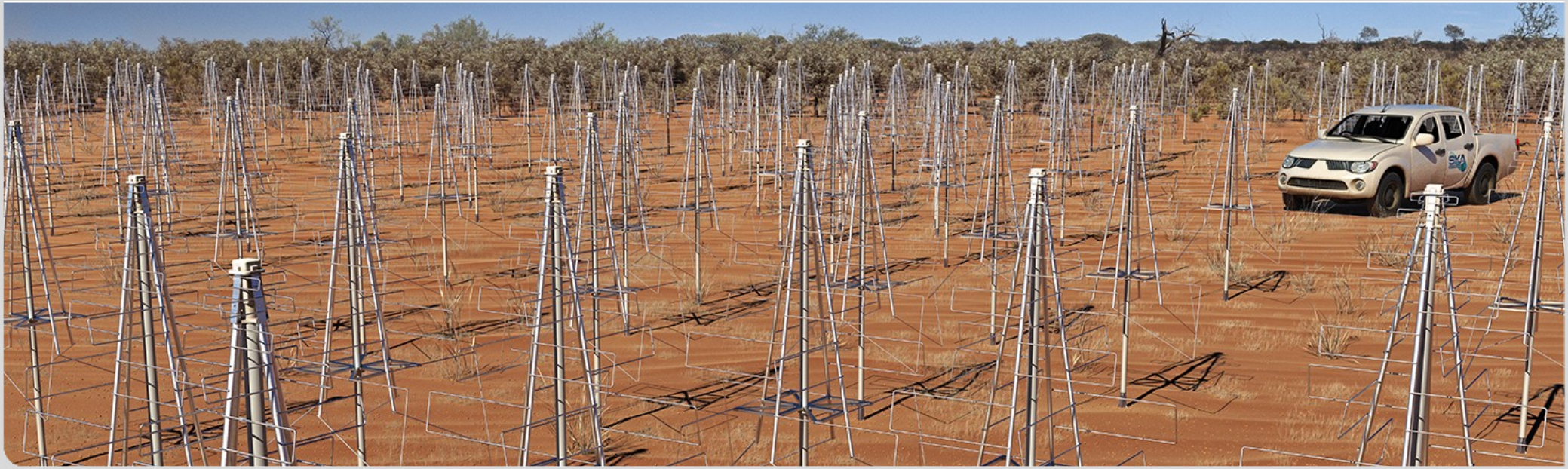
Karlsruhe Institute of Technology

Preliminary

Simulation study on high-precision radio measurements of the depth of shower maximum with SKA1-low

Anne Zilles (KIT- IEKP)
ARENA 2016, Groningen, The Netherlands

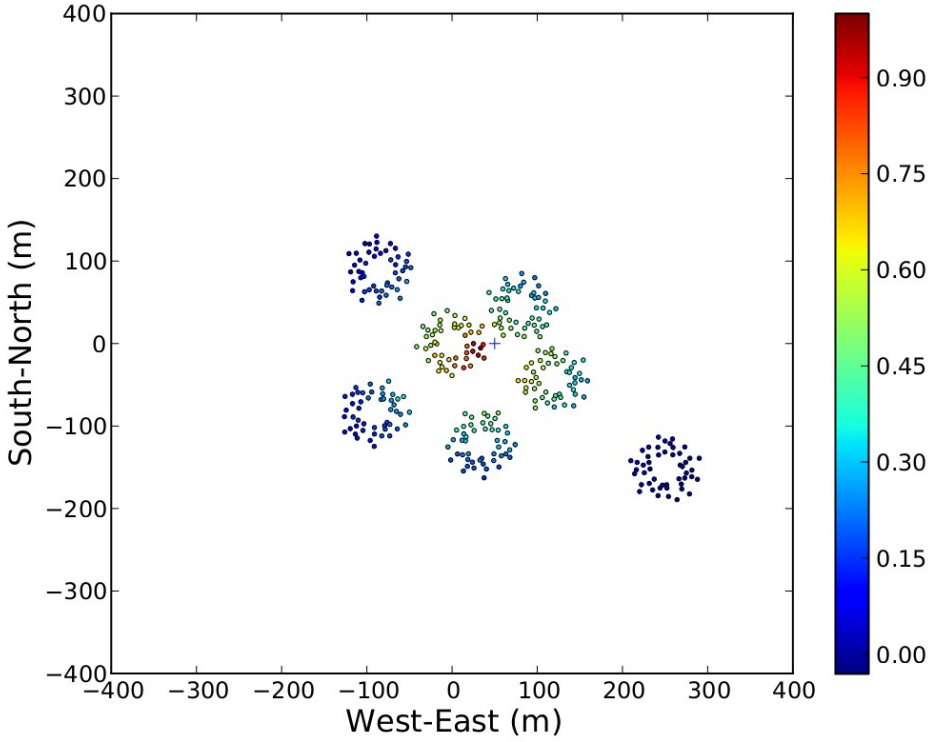


SKA will provide detailed radio footprint

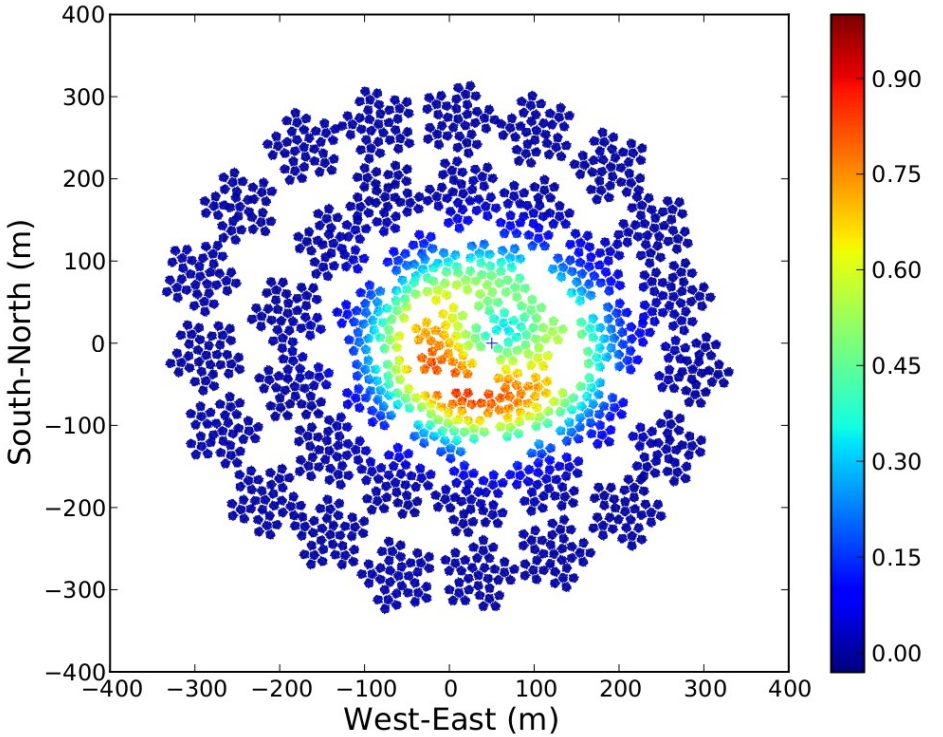
Much better sampling of the footprint!

Proton, 10^{18}eV, zenith = 30°

LOFAR



SKA-low

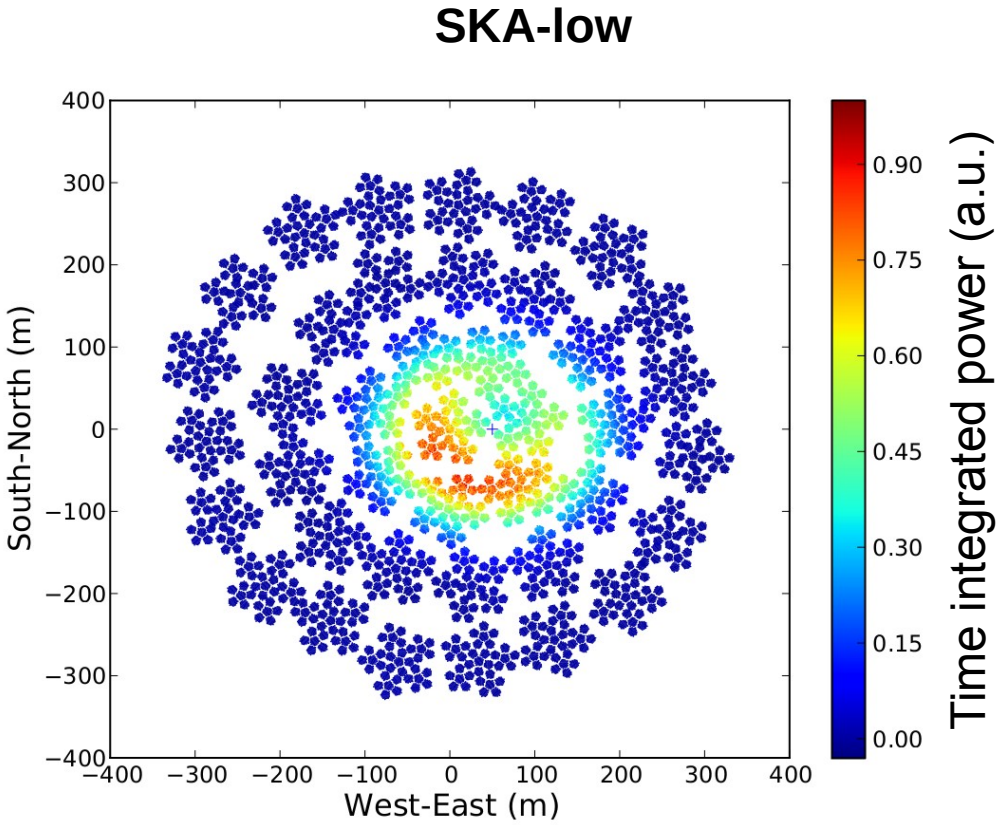


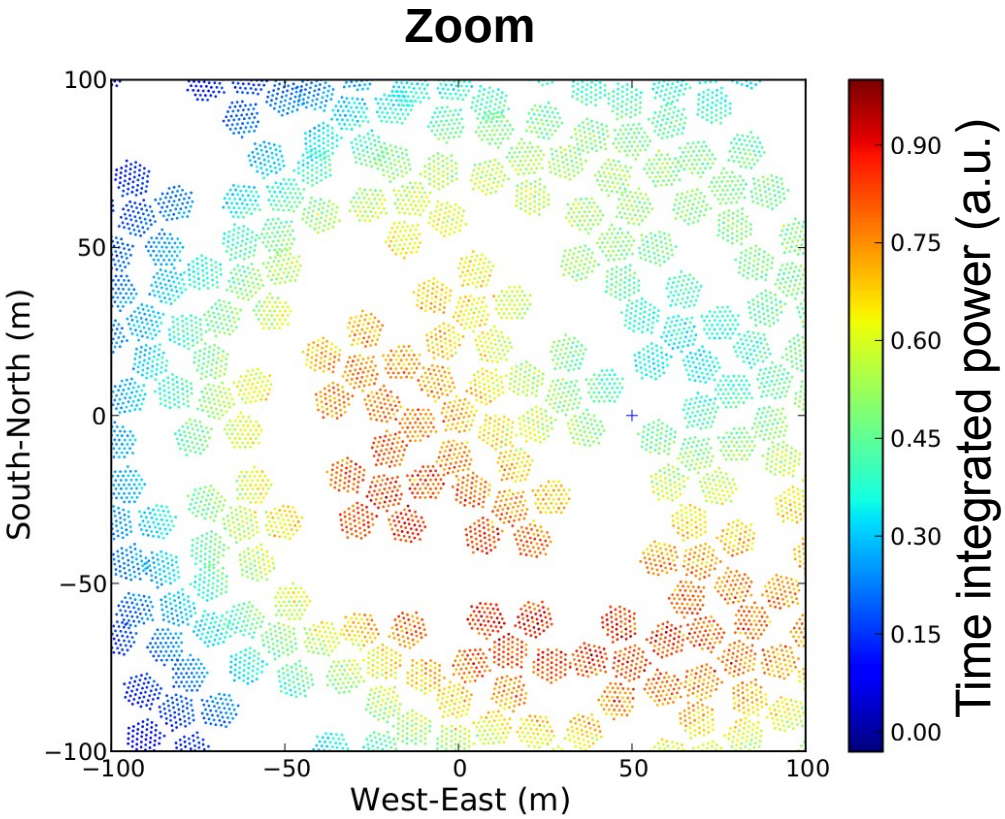
Frequency range:	**30 – 80 MHz**	**50 – 350 MHz**
Bandwidth:	**50 MHz**	**300 MHz**

Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

SKA will provide detailed radio footprint

SKA1-low can measure individual air showers with ***extreme*** precision





→ **Xmax determination with <= 10 g/cm² resolution seems feasible!**

Fluorescence detection technique: ~ 20 g/cm²

Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

How to get a radio footprint for SKA

Simulate the radio signal for 160 antenna positions which forms a star shape in vxB - vxvxB

↓

Get east-west and north-south component
→ Bandpass filter for 50-350MHz, no antenna model included so far

↓

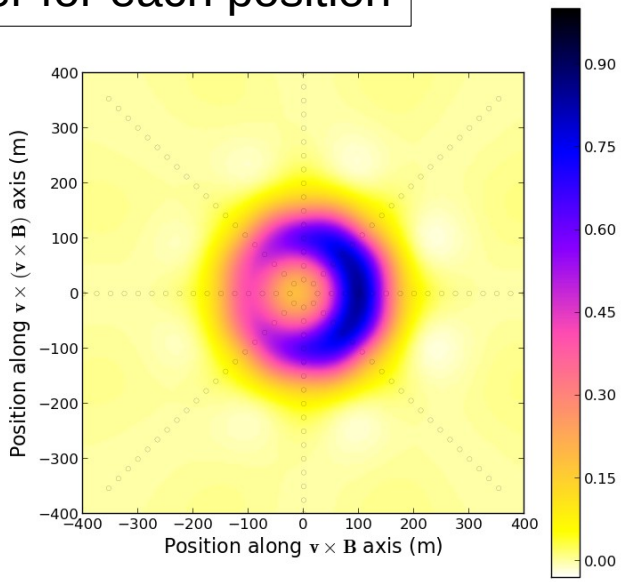
Get the total integrated power for each simulated antenna position

↓

Interpolate the power in vxB – vxvxB
→ rotate SKA positions in shower coordinates and choose power for each position

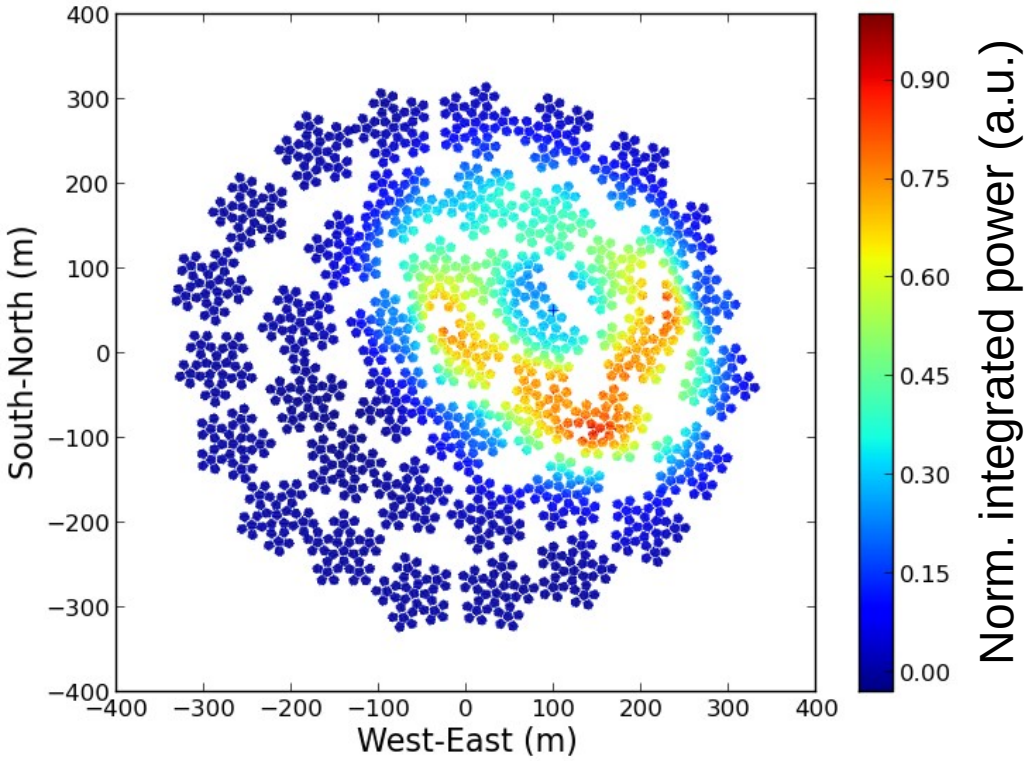
↓

If fake data: Add noise to the “data”



Reconstruction method of shower depth

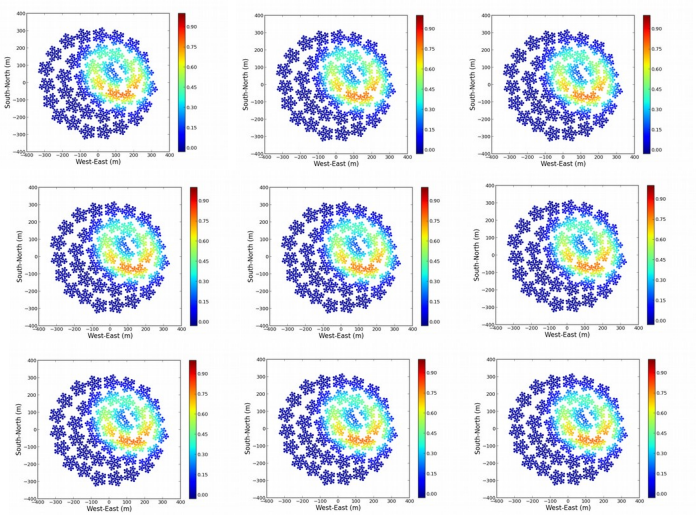
1 simulation =“Fake Data” with known depth



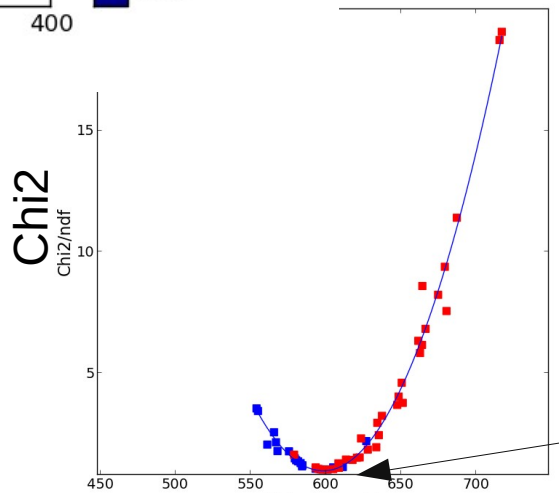
comparison

Get Chi2

Simulation set of same energy and zenith and known shower depth



1 event



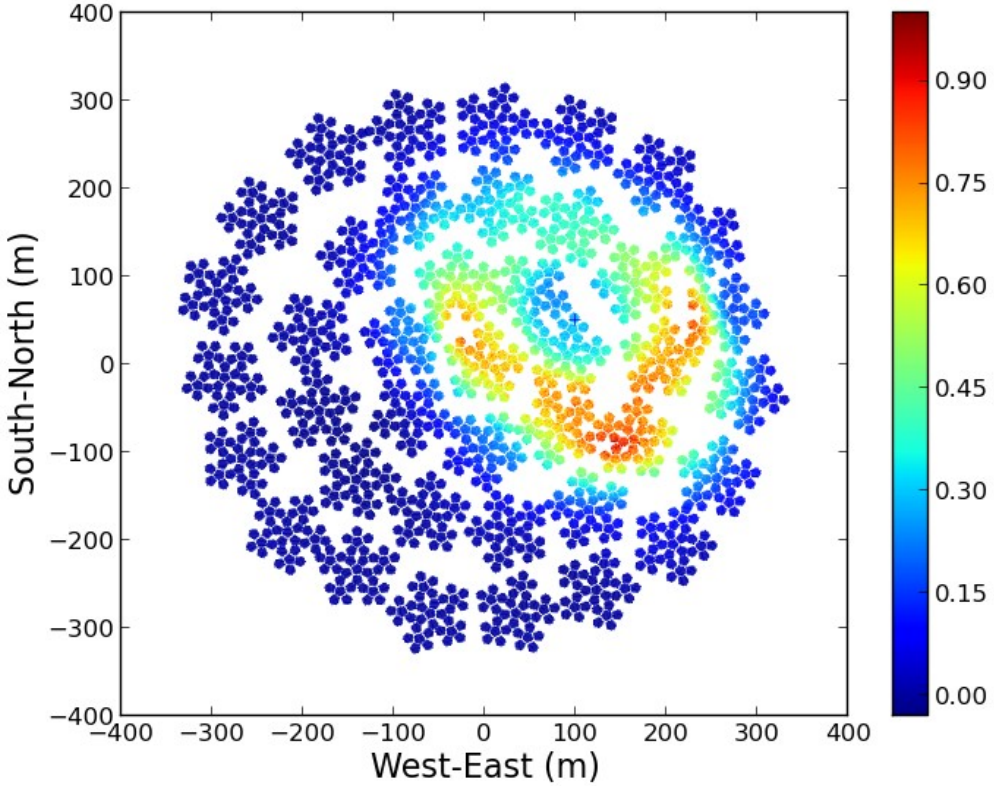
Minimum of parabola fit
= reconstructed shower depth

= comparing structures in the radio footprint

Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

Reconstruction method of shower depth

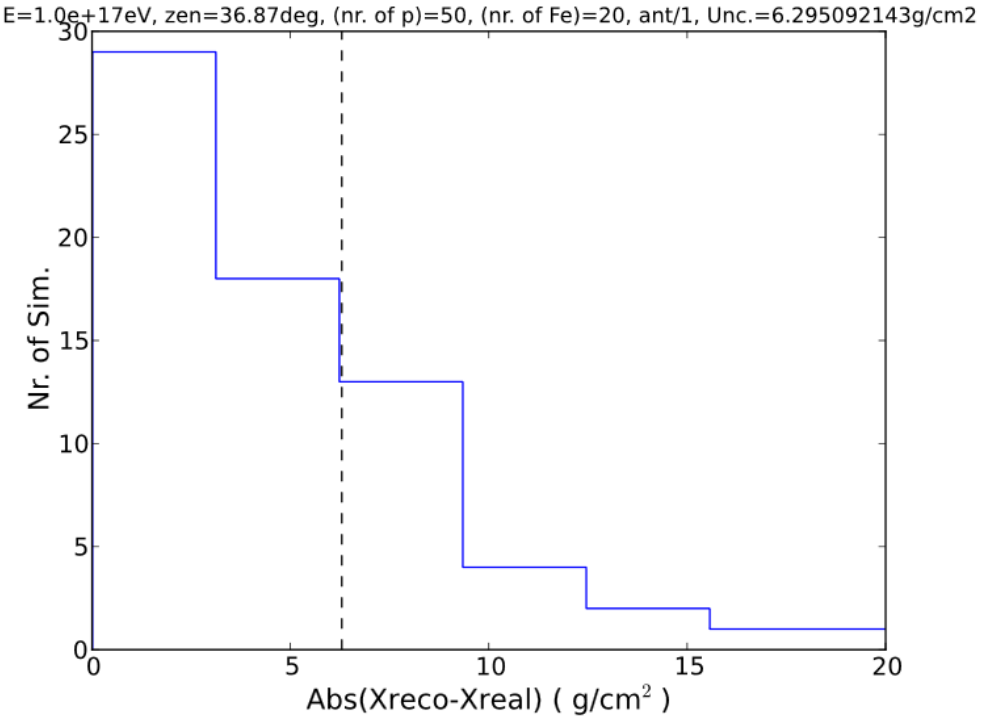
Proton, 10^{17}eV, zen=36.26°



Many simulation sets

many events

68% confidence level (just statistic)
→ reconstruction uncertainty: **6.29 g/cm²**



Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

On what parameters do the uncertainty depend?

What could influence the value of the mean reconstruction uncertainty?

→ **primary energy**
→ arrival direction **(here focusing on zenith)**
→ **noise distribution**
→ **number of antennas “read out”**
→ refractive index
→ magnetic field
→ ….

→method:
- interpolation method
- **number of simulated antennas**
- **frequency band**
- ...

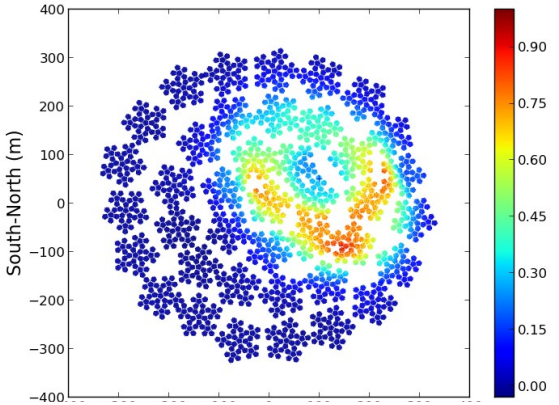
Preliminary results!
→ simulation sets of 50p+25Fe not yet completed
→ **just giving hints how precise the measurements can become!**

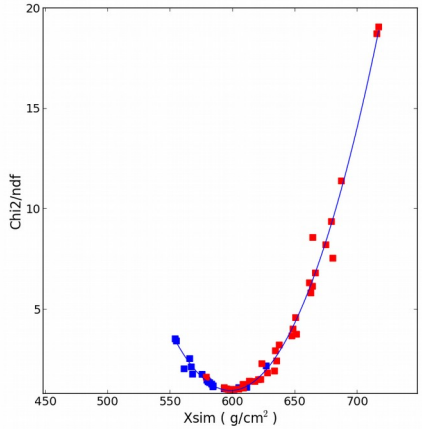
Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

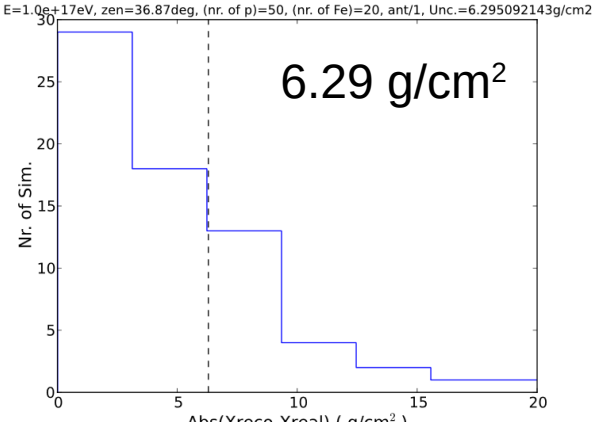
Zenith angle

(fixed primary energy: 10^{17} eV)

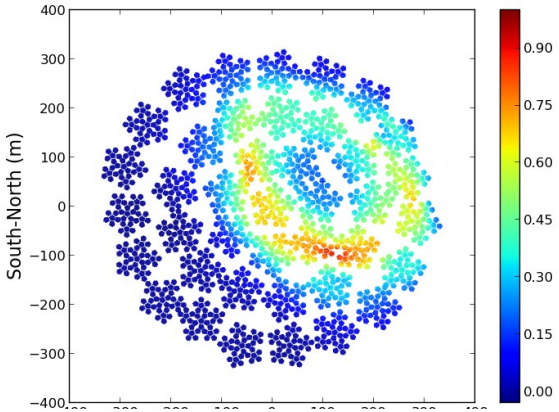
Zen= 36.87°

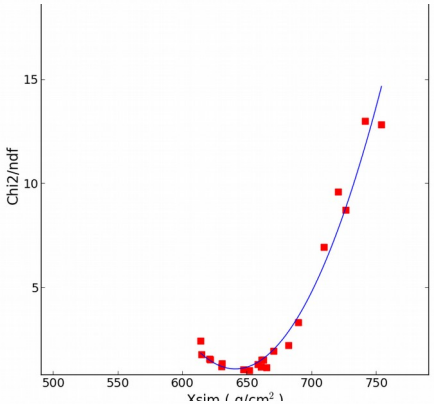


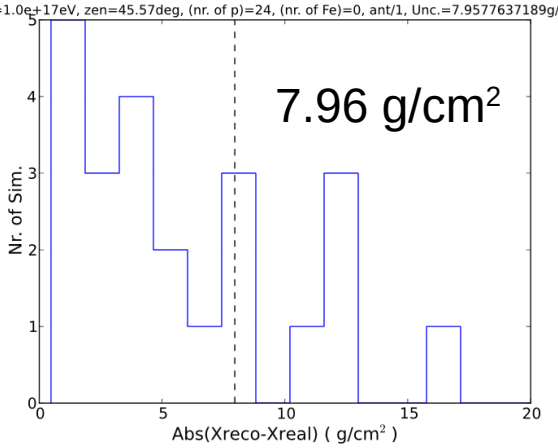




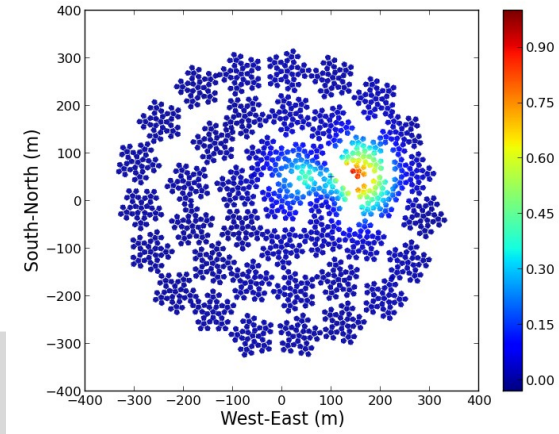
Zen= 45.57°

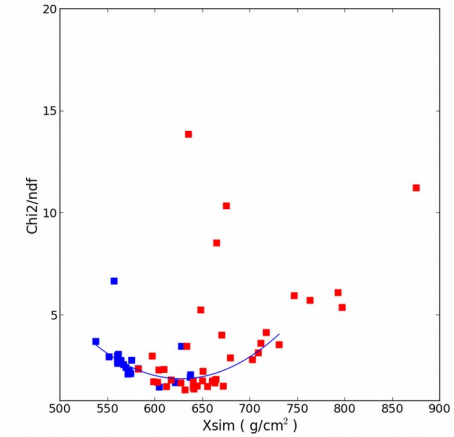


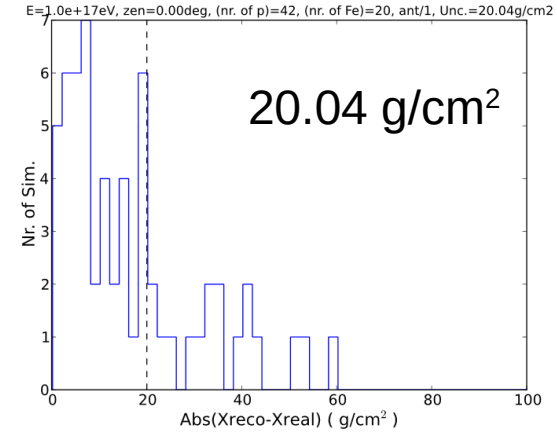




Zen= 0.0°



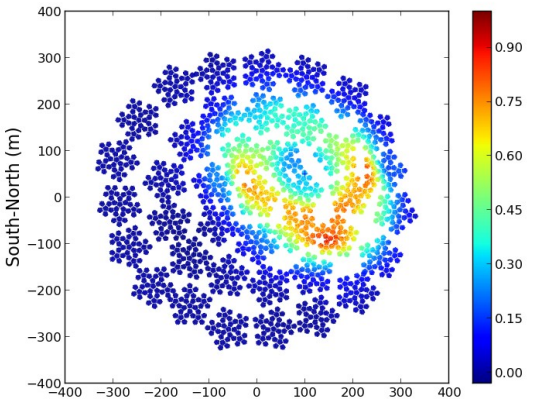


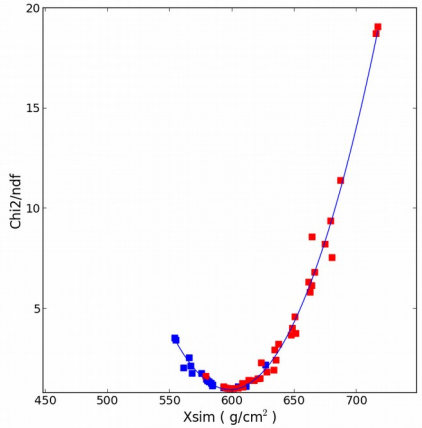


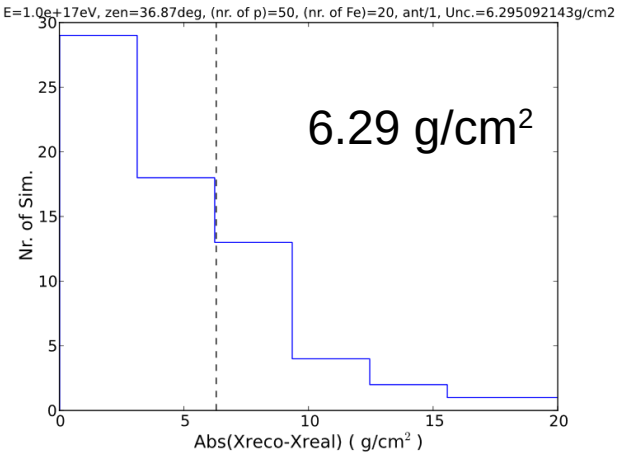
Primary energy

(fixed zenith: 36.87°)

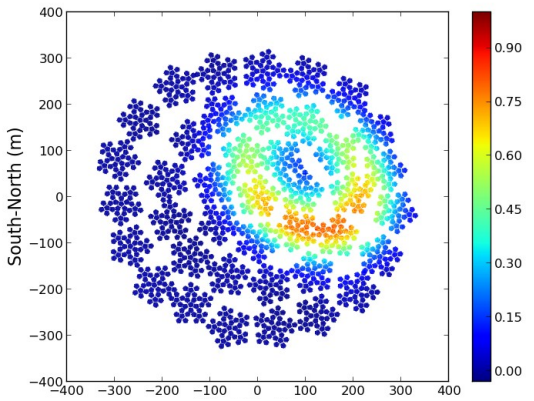
E=10^{17}eV

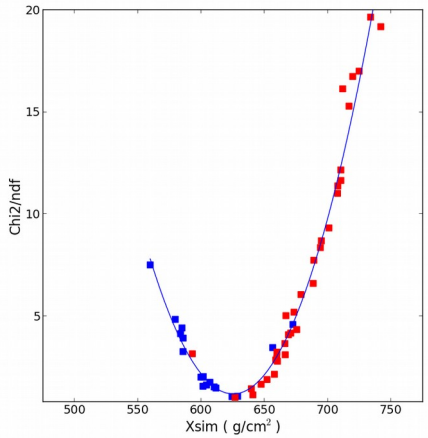


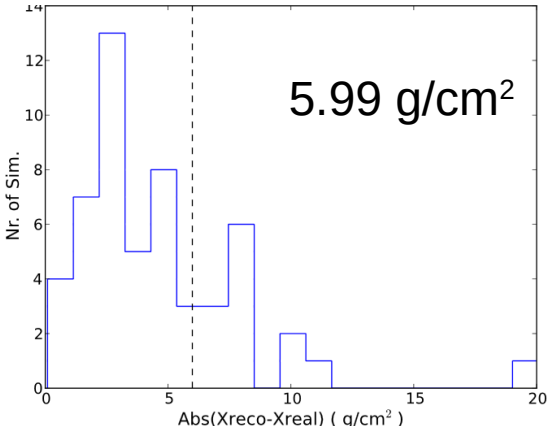




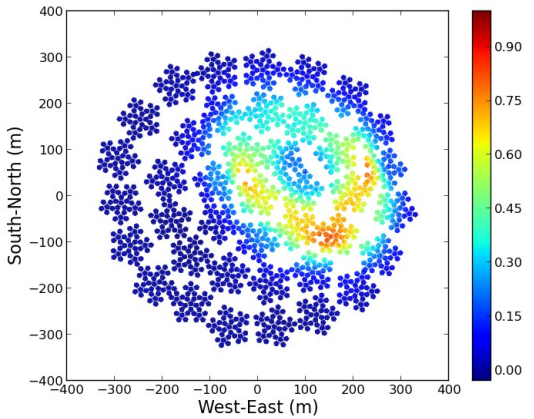
E=$10^{17.5}$eV

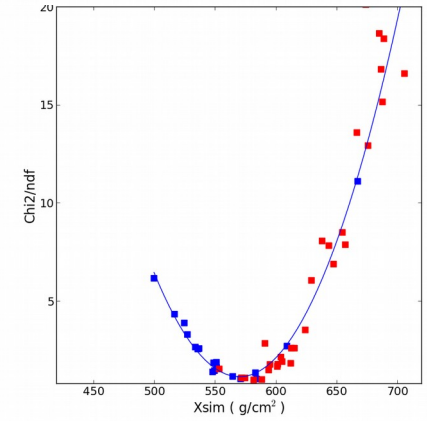


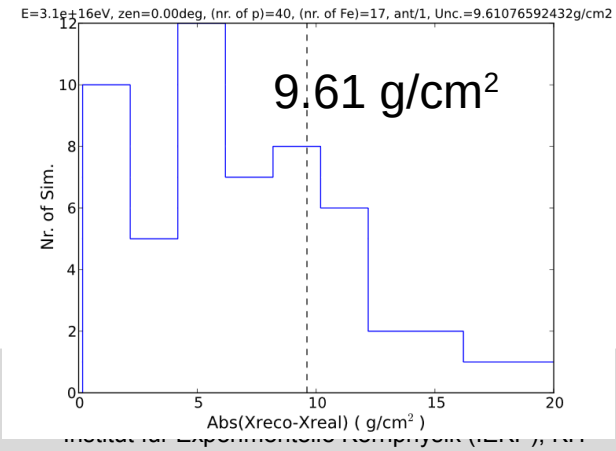




E=$10^{16.5}$eV



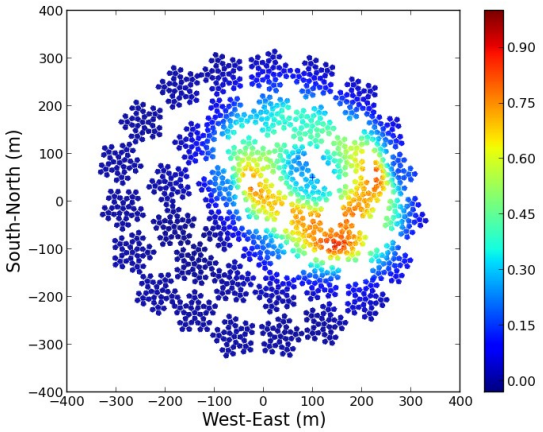


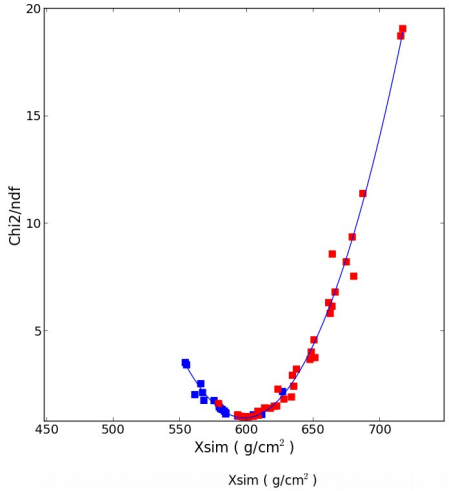


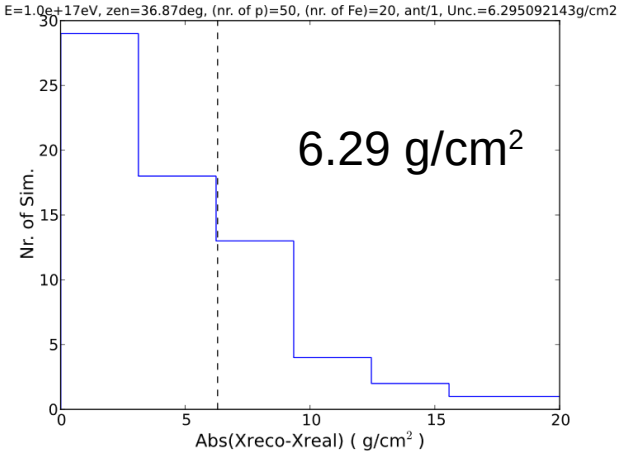
Noise

(fixed zenith: 36.87°, fixed energy: 10^{17}eV, Full SKA)

- Max. 5% of antenna peak power as random noise for mimic uncertainty in antenna calibration
- Add.: 1% of the maximal power of whole antenna array to mimic galactic noise (**not a realistic model, not frequency and energy dependent)**





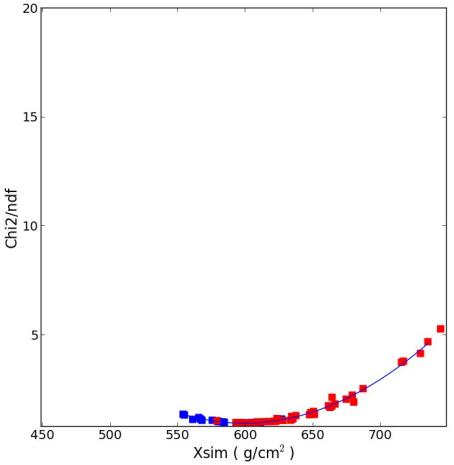


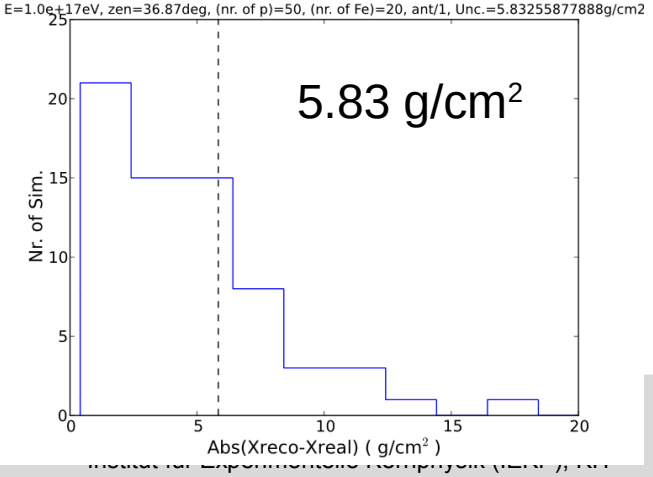
- raise value to 5% of the maximal power of whole antenna

→ distribution gets flatter since error larger

→ still finding a minimum possible (fit uncertainty gets larger)

→ mean reconstruction uncertainties consistent



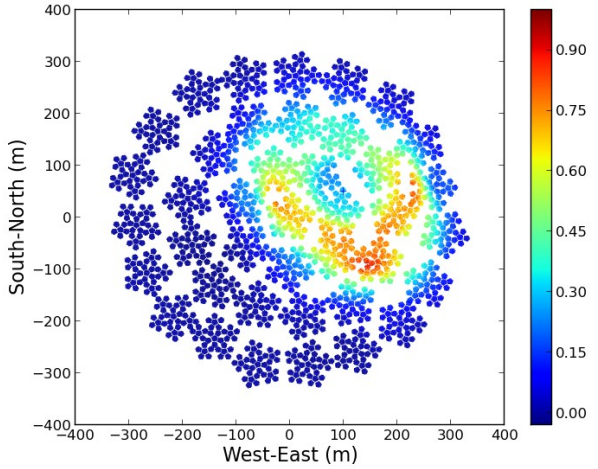


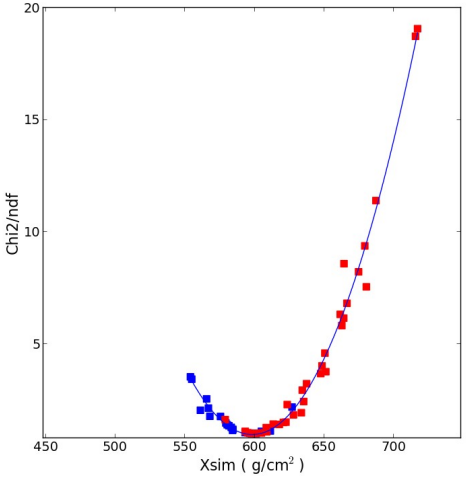
Frequency band

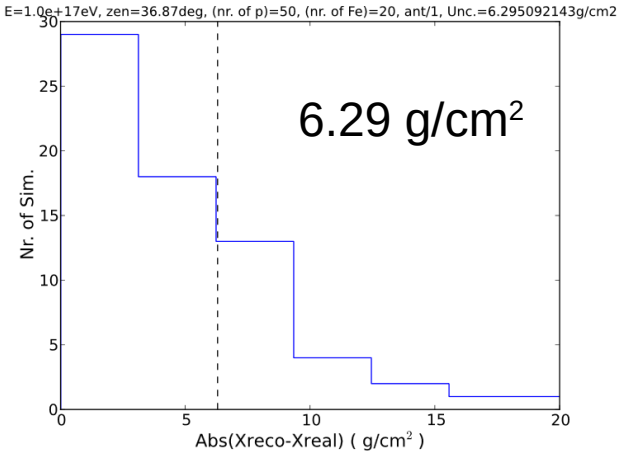
(fixed zenith: 36.87°, fixed energy: 10^{17}eV, Full SKA)

50 - 350 MHz

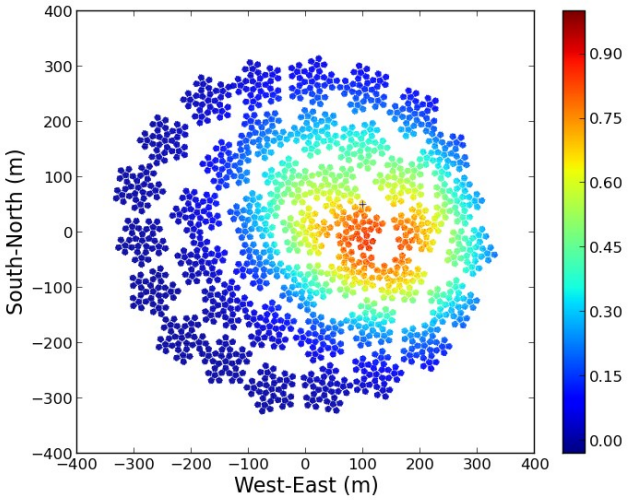
→ gain from larger frequency band since more complex structure to fit

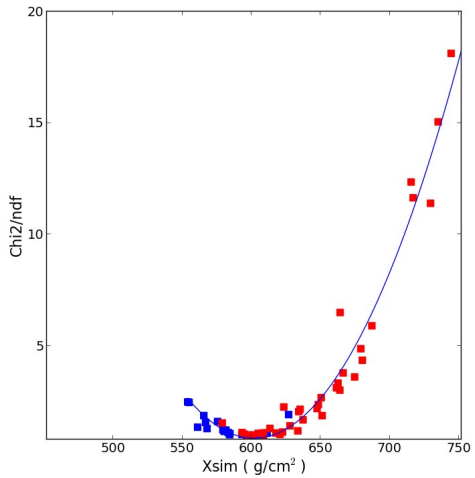


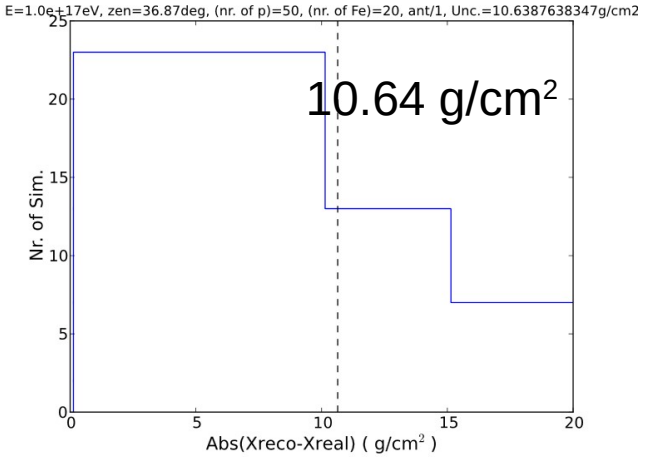




30 - 80 MHz





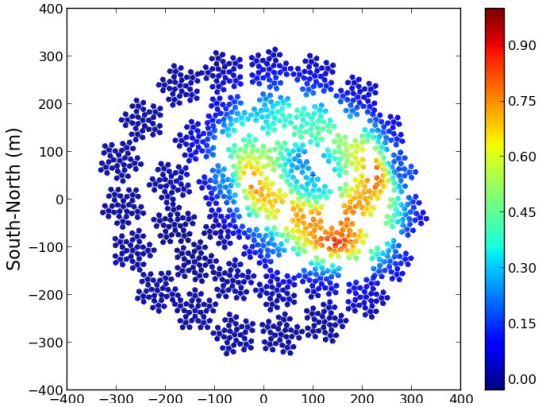


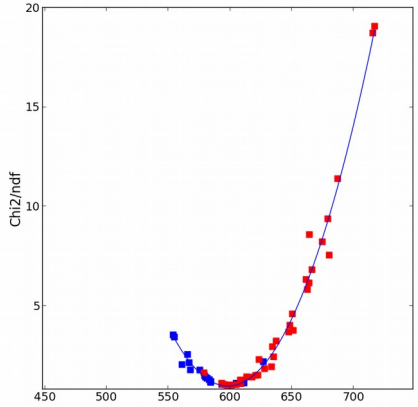
Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

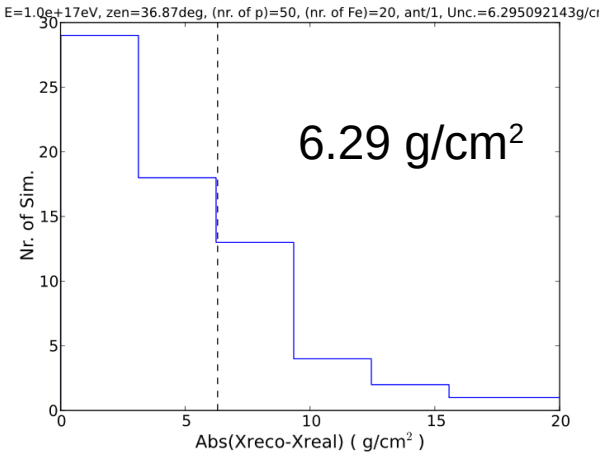
Numbers of antennas read out

(fixed zenith: 36.87°, fixed energy: 10^{17}eV)

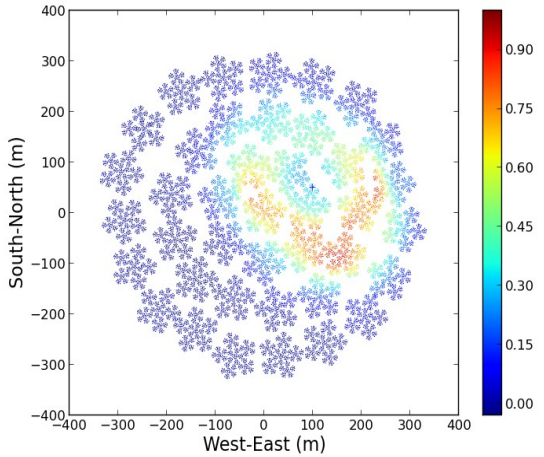
Full SKA

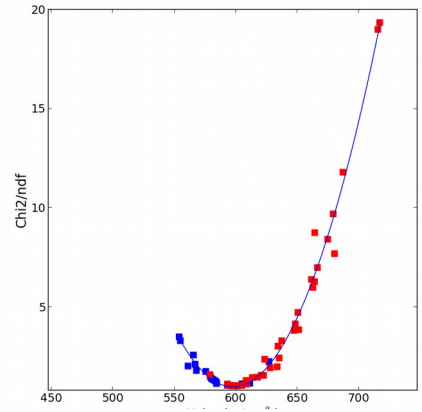


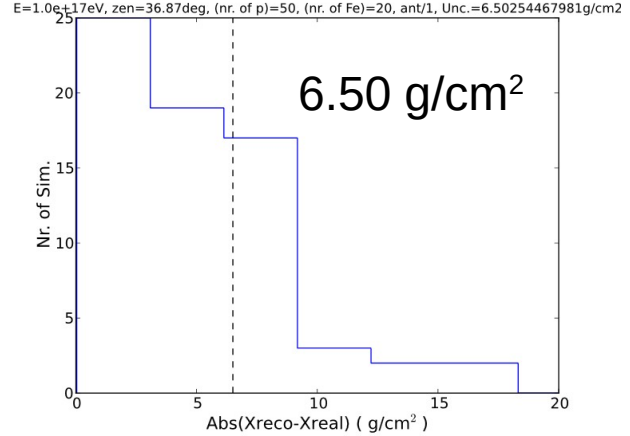




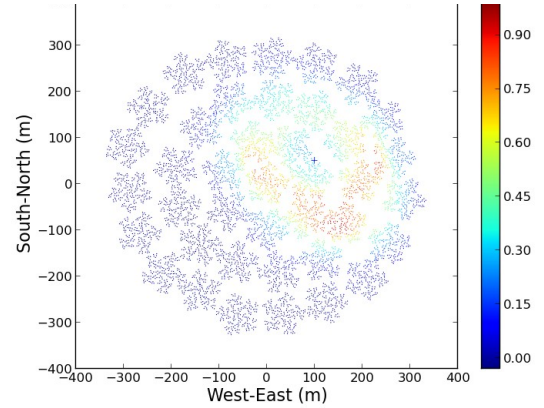
Every fourth

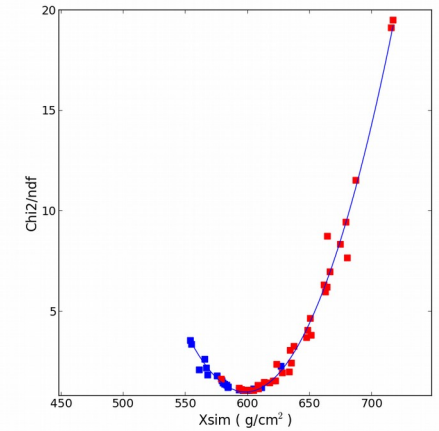


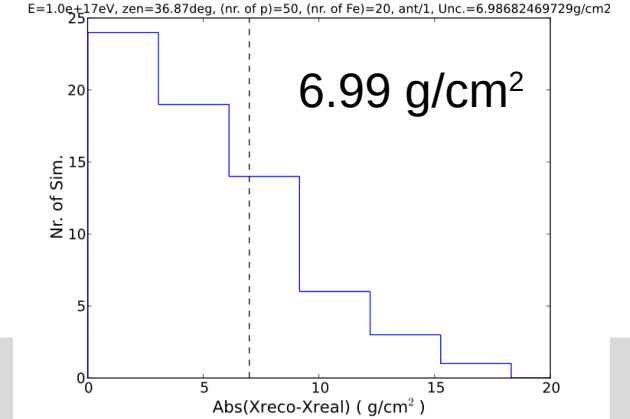




Every tenth



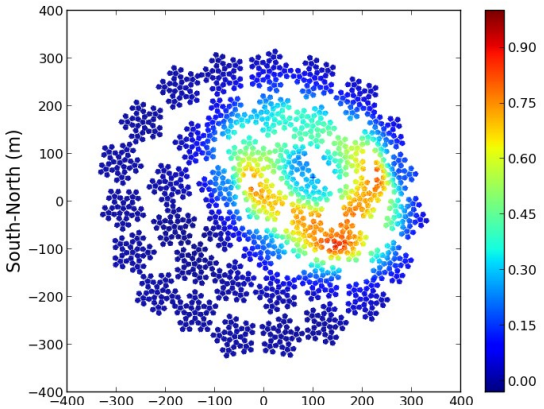


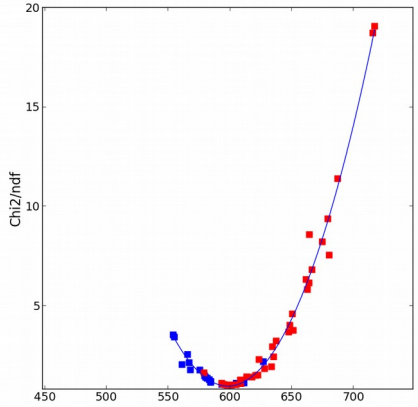


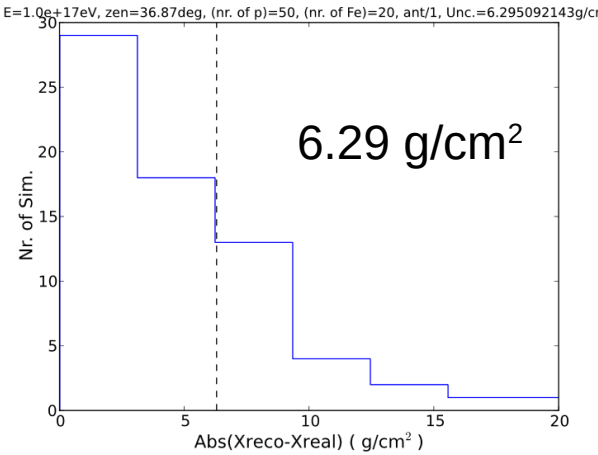
Numbers of antennas read out

(fixed zenith: 36.87°, fixed energy: 10^{17}eV)

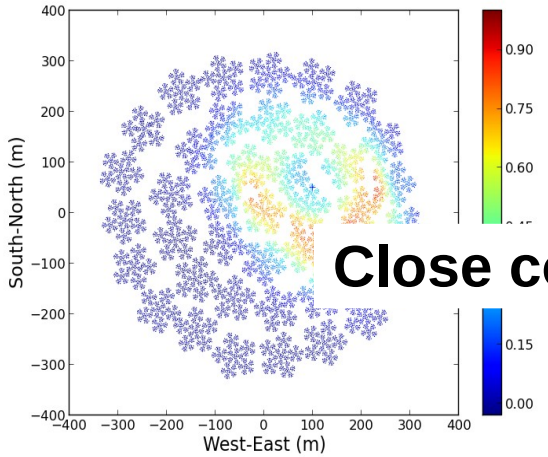
Full SKA

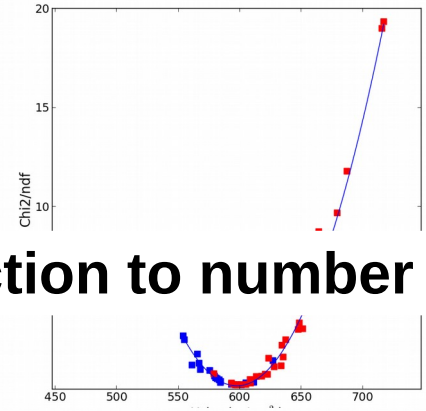


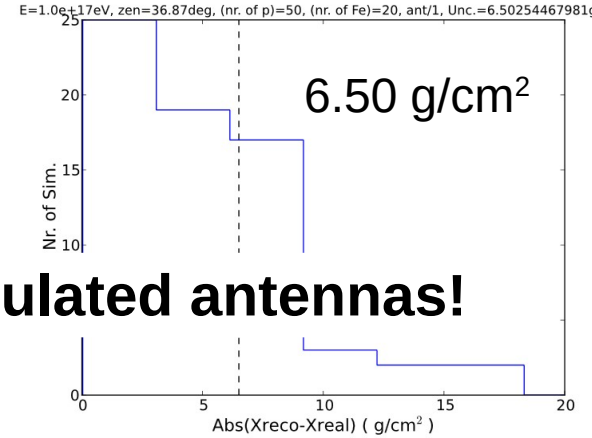




Every fourth

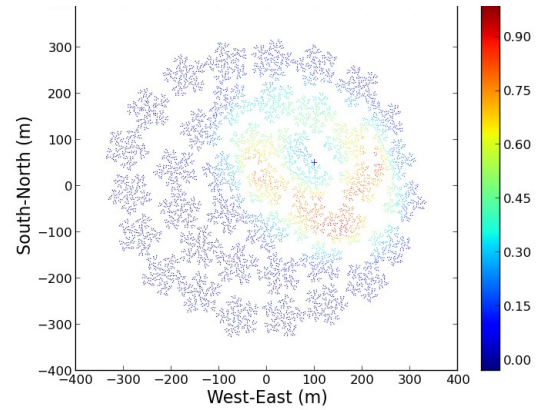


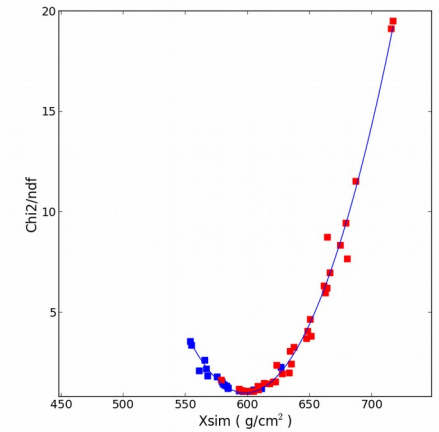


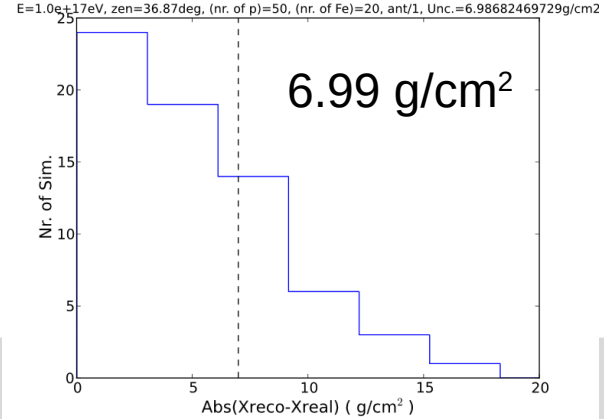


Close connection to number of simulated antennas!

Every tenth







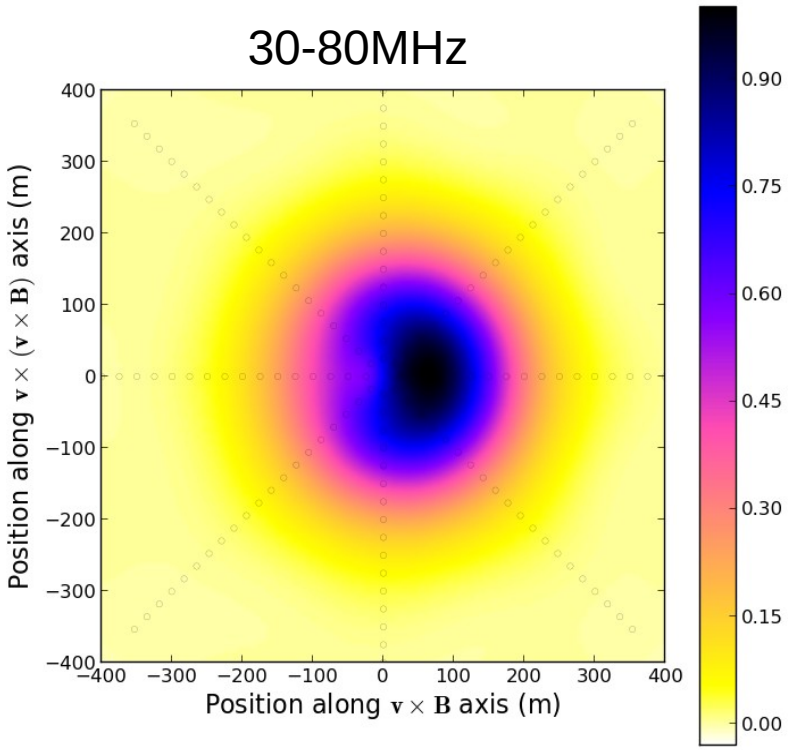
Limitations on Xmax reconstruction by method

Or: Can we simply adapt the LOFAR scripts?

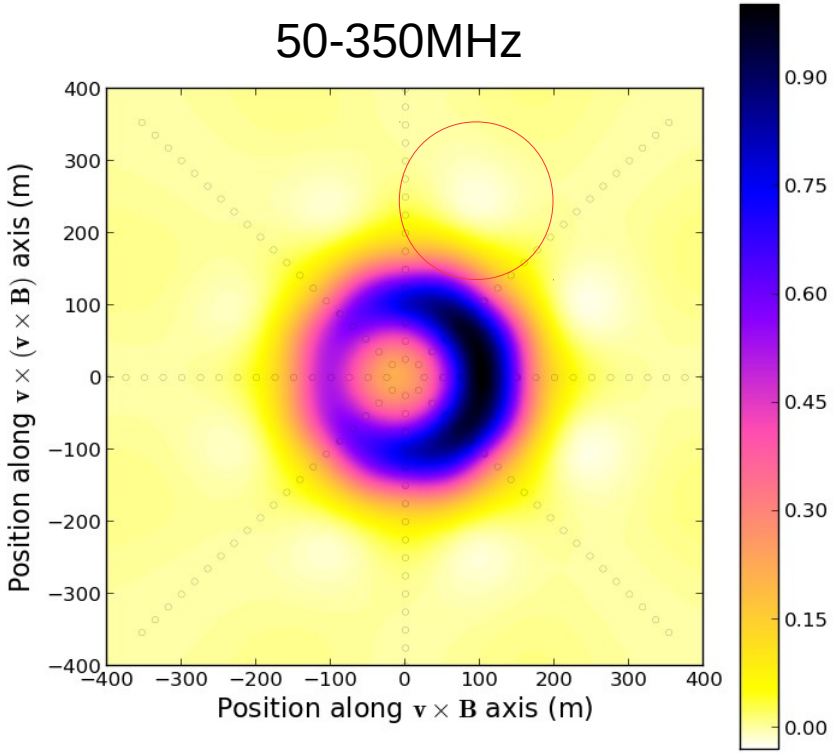
(fixed zenith: 36.87°, fixed energy: 10^{17}eV)

→ Cherenkov cone gets prominent

30-80MHz



50-350MHz



Additional structures appearing

→ **Interference effects get visible for larger frequency band?**

→ Splitting up the frequency band in sub-bands for interpolation needed?

→ Can we gain extra information out of the large frequency band?

→ **Interpolation method?!**

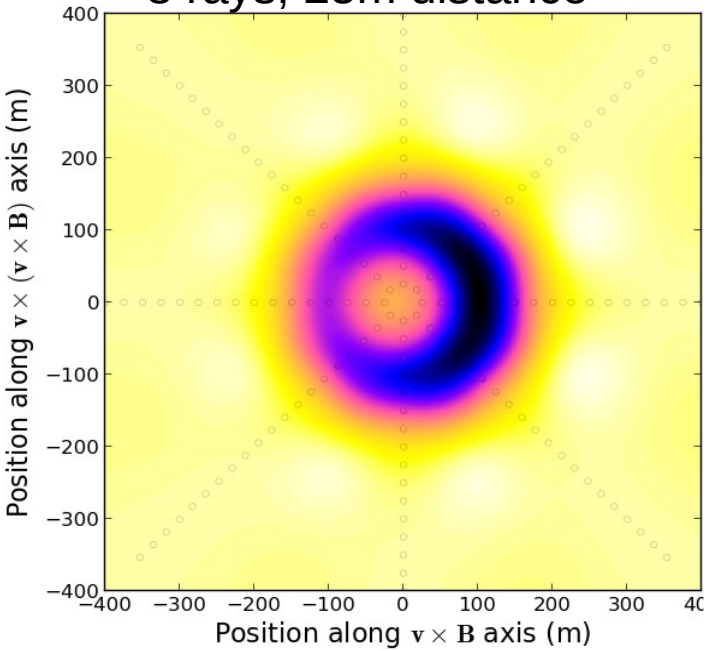
Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

Limitations on Xmax reconstruction by method

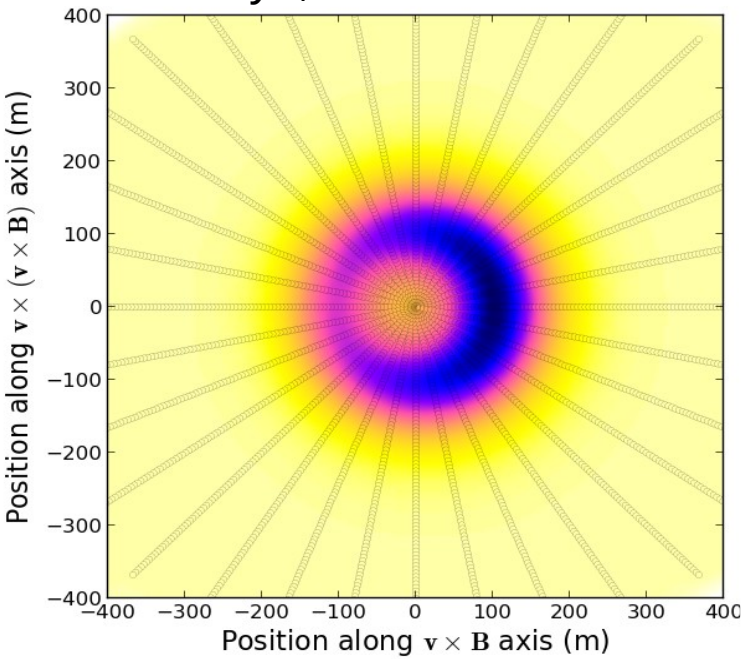
(fixed zenith: 36.87°, fixed energy: 10^{17}eV, Full SKA, 50 - 350 MHz)

→ **structures seem to vanish**

Simulate 160 antennas:
8 rays, 25m distance



Simulate 3328 antennas:
32 rays, 5m distance



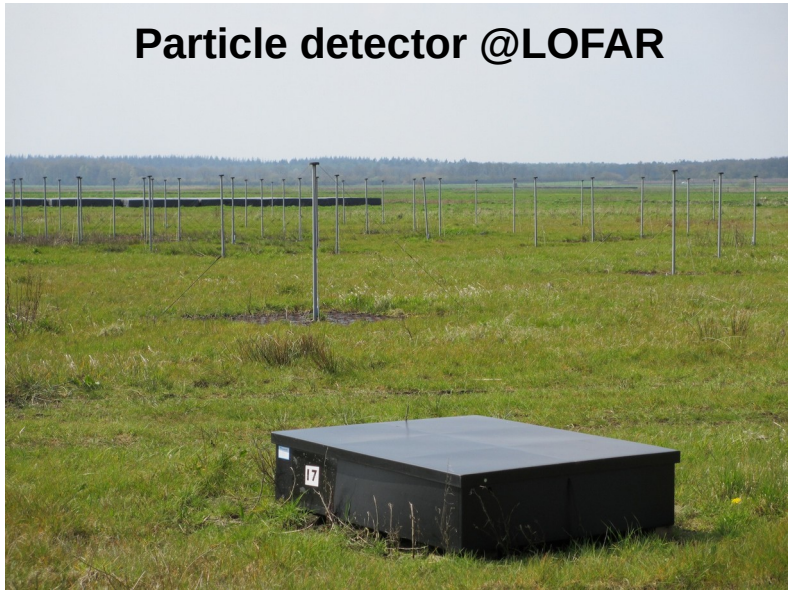
→ **How many antennas have to be simulated to have no limitations on the Xmax reconstruction by the interpolation/number of simulated antenna?**

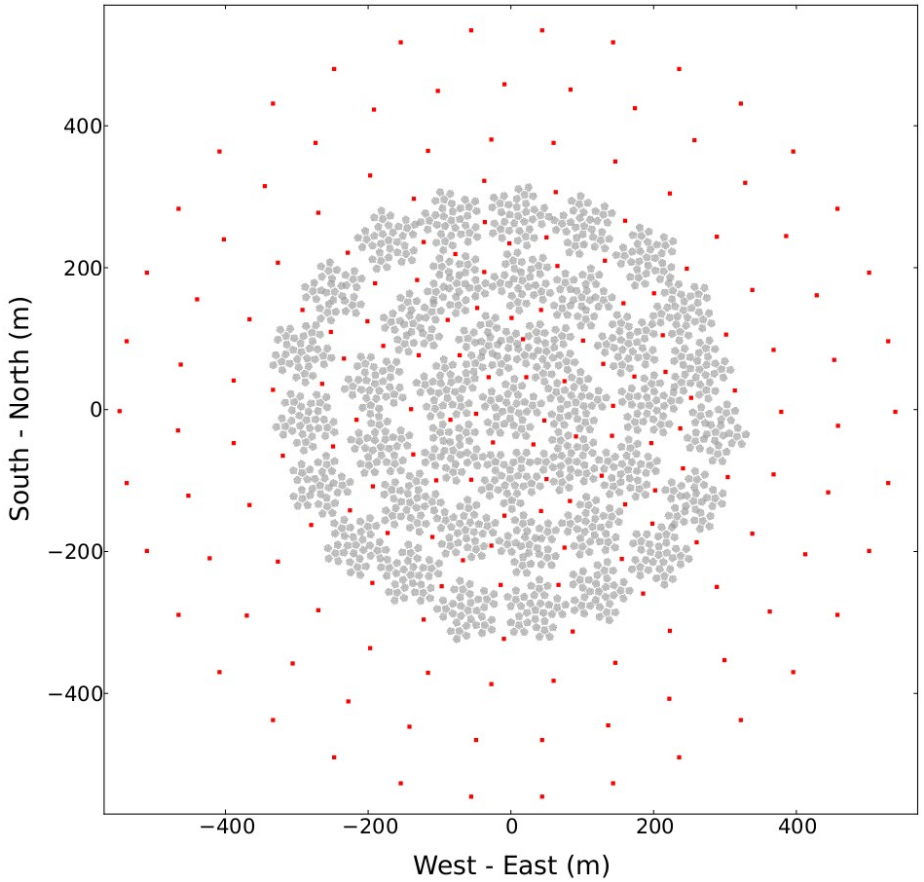
→ Ultimate check: Run one simulation including all SKA antenna positions (CORSIKA+CoREAS parallel)

Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

Particle detector input

180 KASCADE scintillators
as pure and efficient trigger for E > 10^{16}eV





Red: PD

Can we profit from additional informations from the particle detector?
→ Fit to 2D particle LDF and calculate the combined Chi2 of radio and particle footprint

Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT

Outlook & Summary

→ A **LOFAR-like approach for Xmax reconstruction** is also possible for SKA, leading to a **mean uncertainty of less than 10 g/cm², ** as long fit works

→ seperating p and He seems to be feasible

→ sensible at the level of systematics from hadronic interaction models, refrative index,...

→ There are possible impacts which can limit the reconstruction uncertainty, just by the method itself (interpolation,…)

→ **still a lot to do and to study**

- Completion of the simulation set! Conclusion limited by statistics!
- Gaining additional information from the large frequency band?
- Gaining from the information of the particle detectors?

….

- SKA1-low if upgraded for cosmic ray detection
  → a unique radio detector, allowing ultimate detail in measurements of the radio footprint on ground

Thank you for your attention!

Anne.Zilles@kit.edu
Institut für Experimentelle Kernphysik (IEKP), KIT