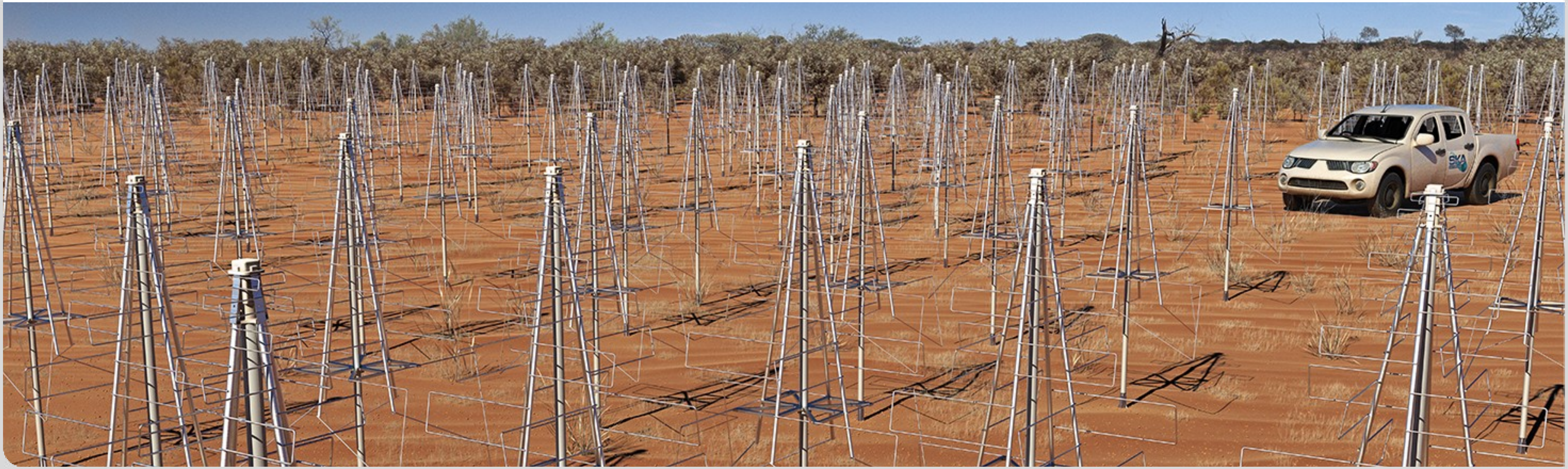
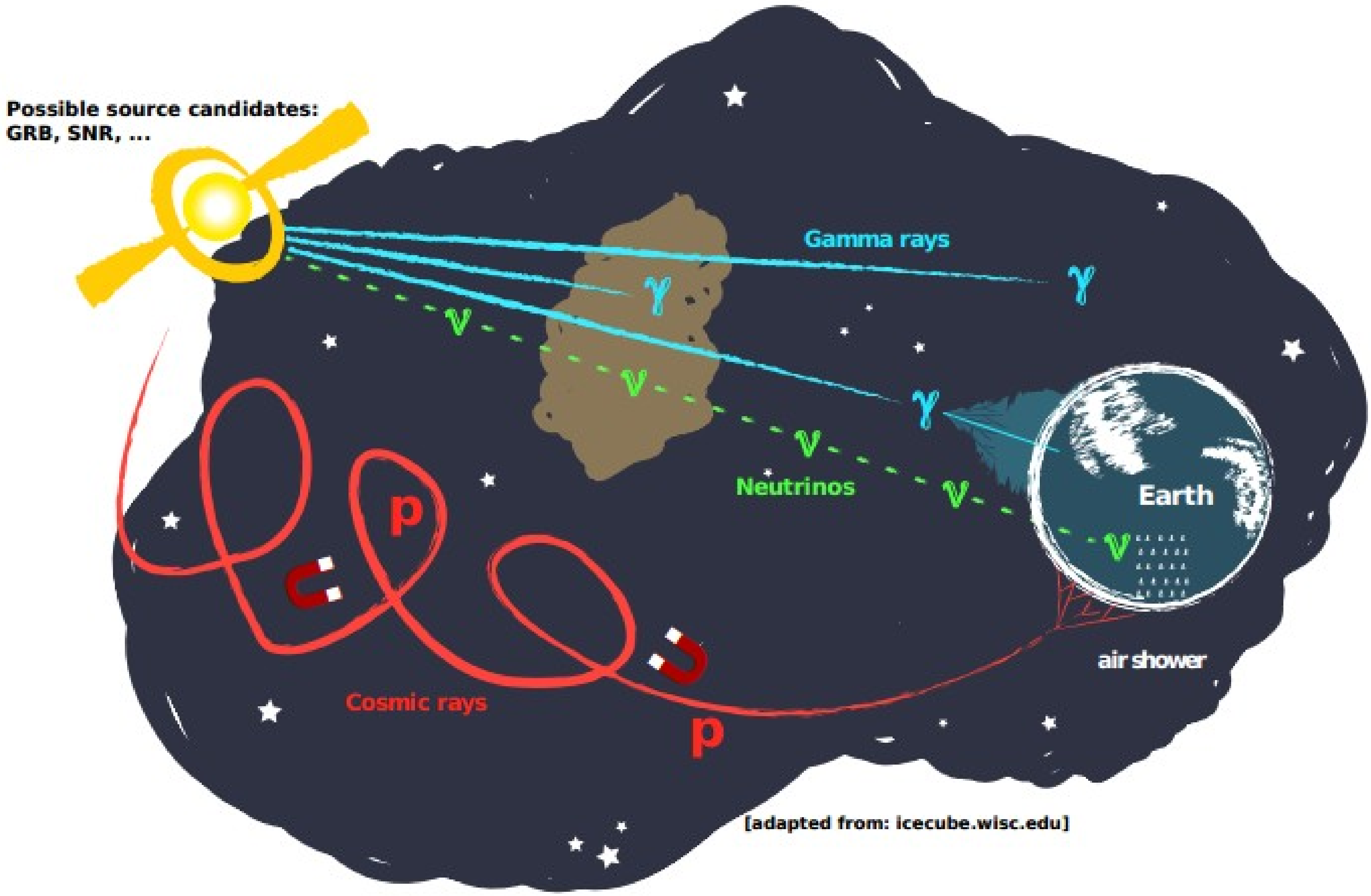
Potential of Cosmic Ray measurements with the SKA

Anne Zilles (KIT) for the SKA focus group on High-Energy Cosmic Particles



Where do cosmic rays come from?



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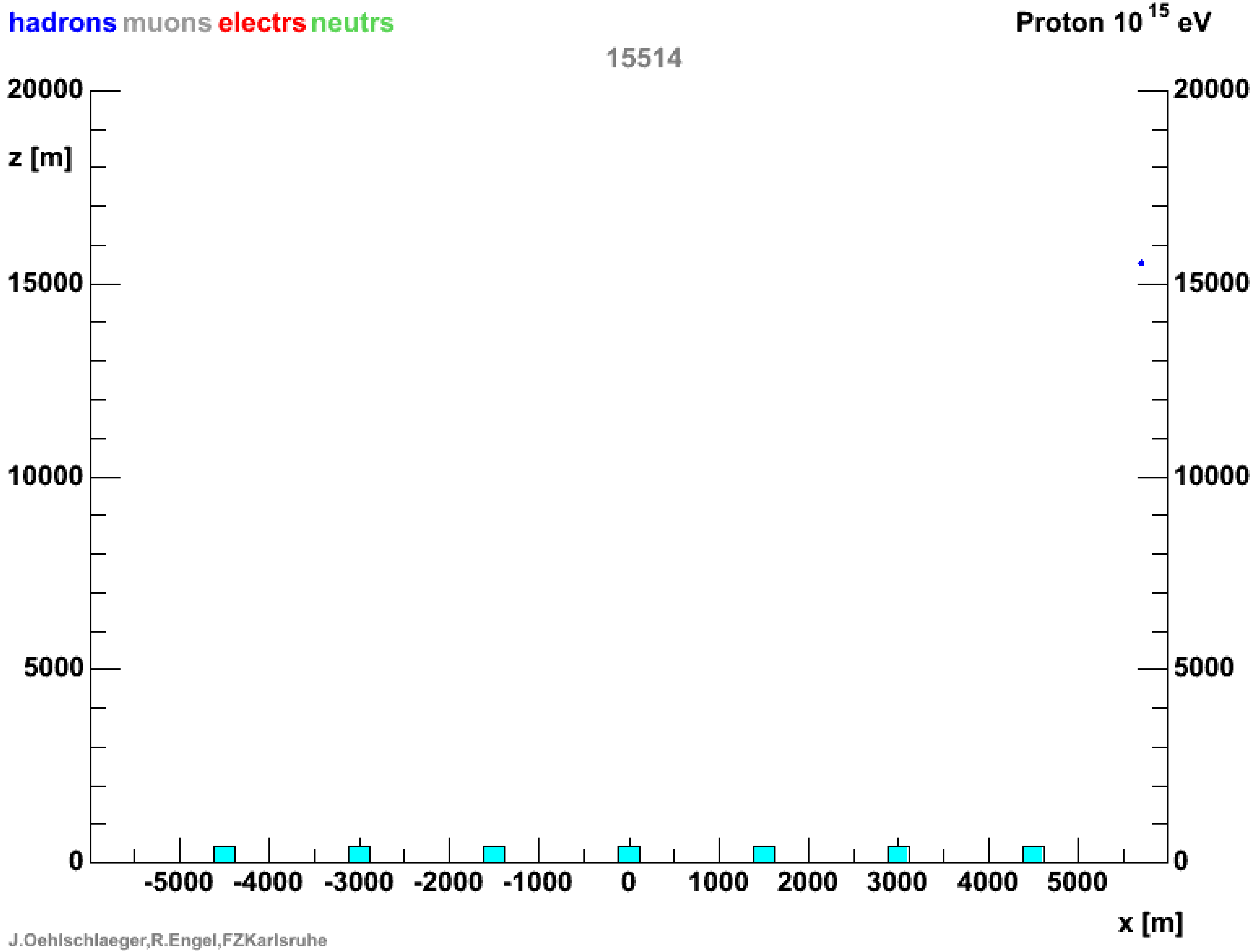
Air shower: Earth´s atmosphere as target



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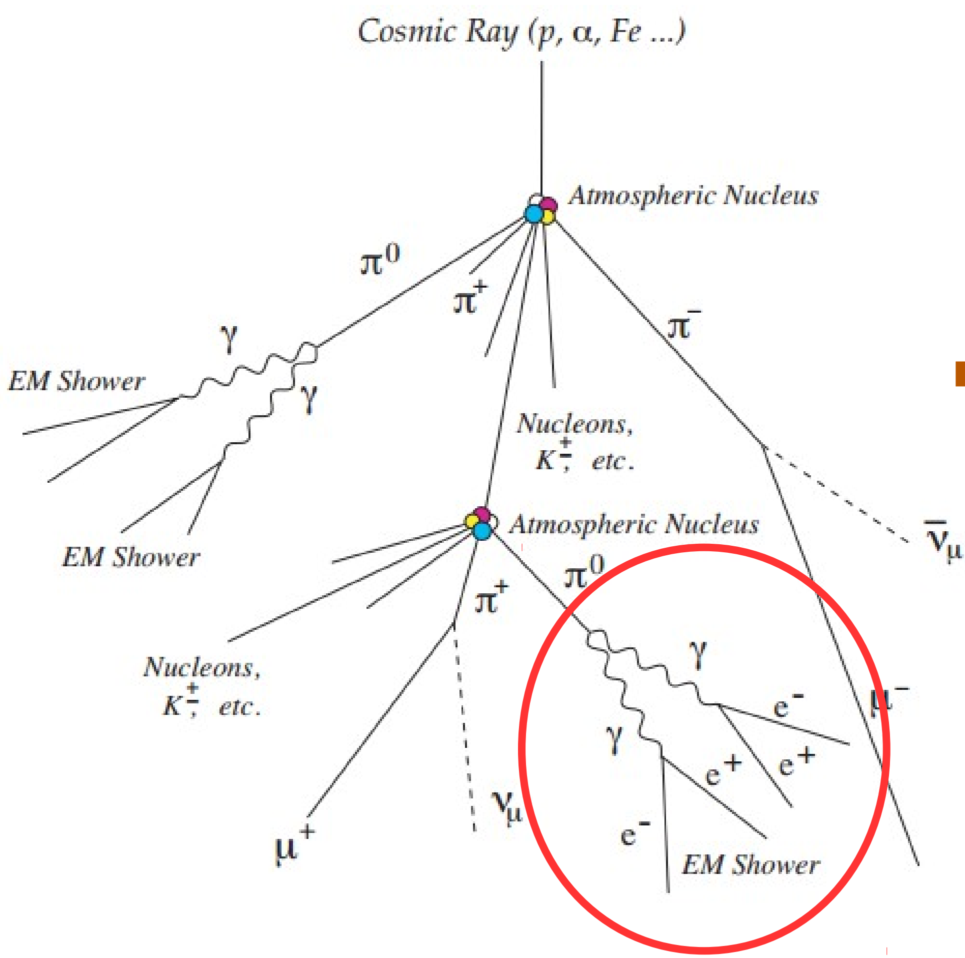
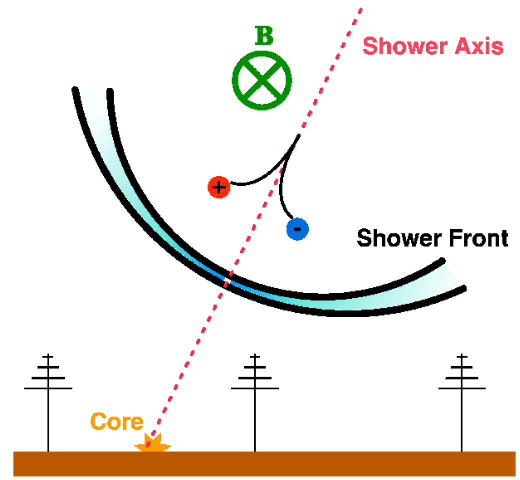
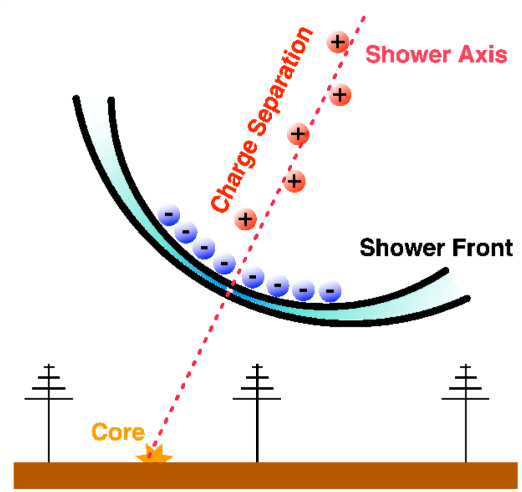
Air shower and emission of radio signal





Geomagnetic effect:
Deflection of e^- and e^+ in Earth´s magnetic field
→ **time dependent transverse current**



Askaryan effect

→ **Time variation of net charge excess**

[adapted from: Auger internal note GAP-2008-160, 2008]

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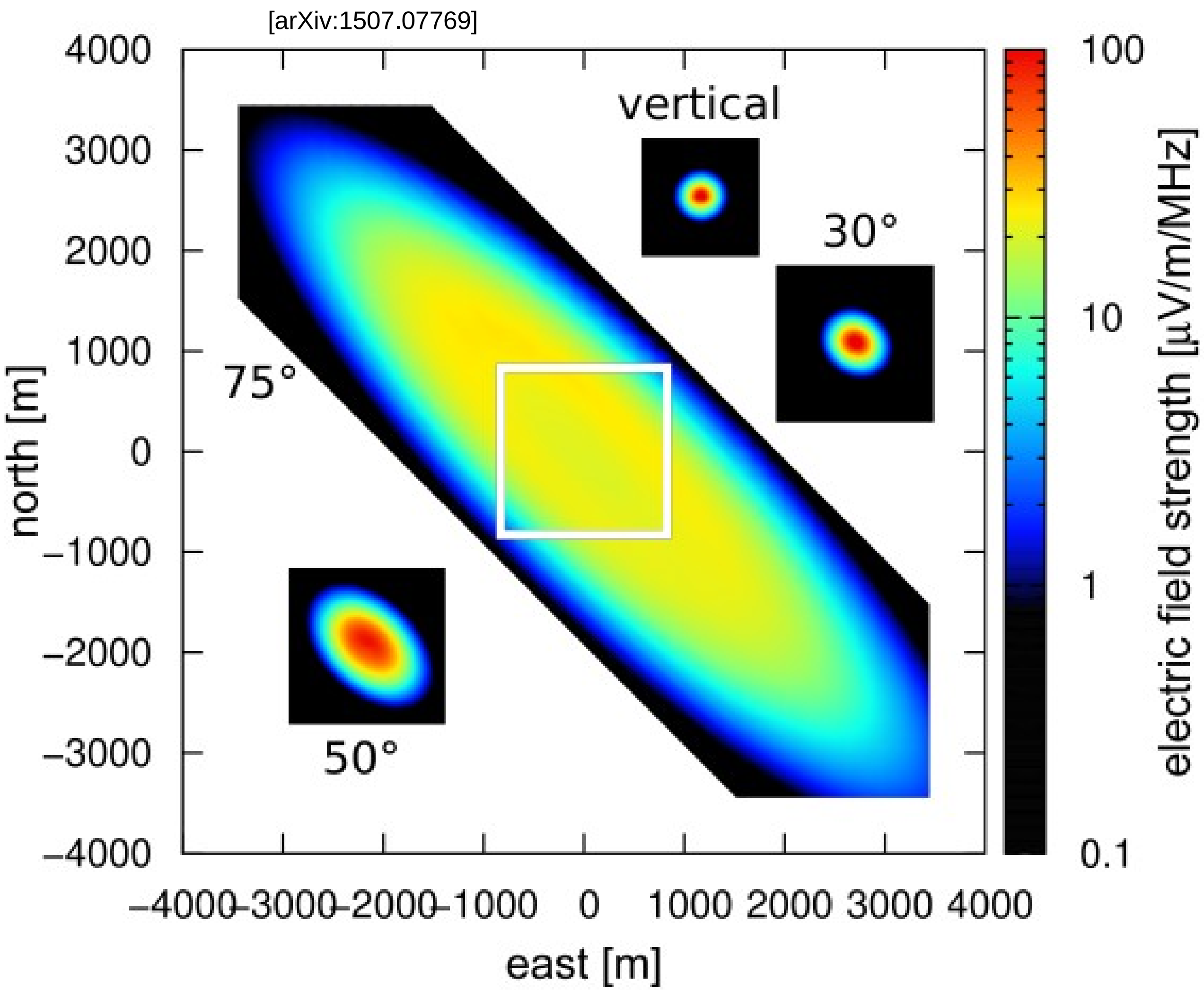
Radio footprint on ground



Analysis based on simulations
Leading simulation program:
CORSIKA + CoREAS

- Simulated footprints of the radio emission of extensive air showers with an energy of 5×10^{18} eV
- Typical 30-80 MHz freq. band
- detection threshold: by Galactic noise ≈ 1-2 µV/m/MHz

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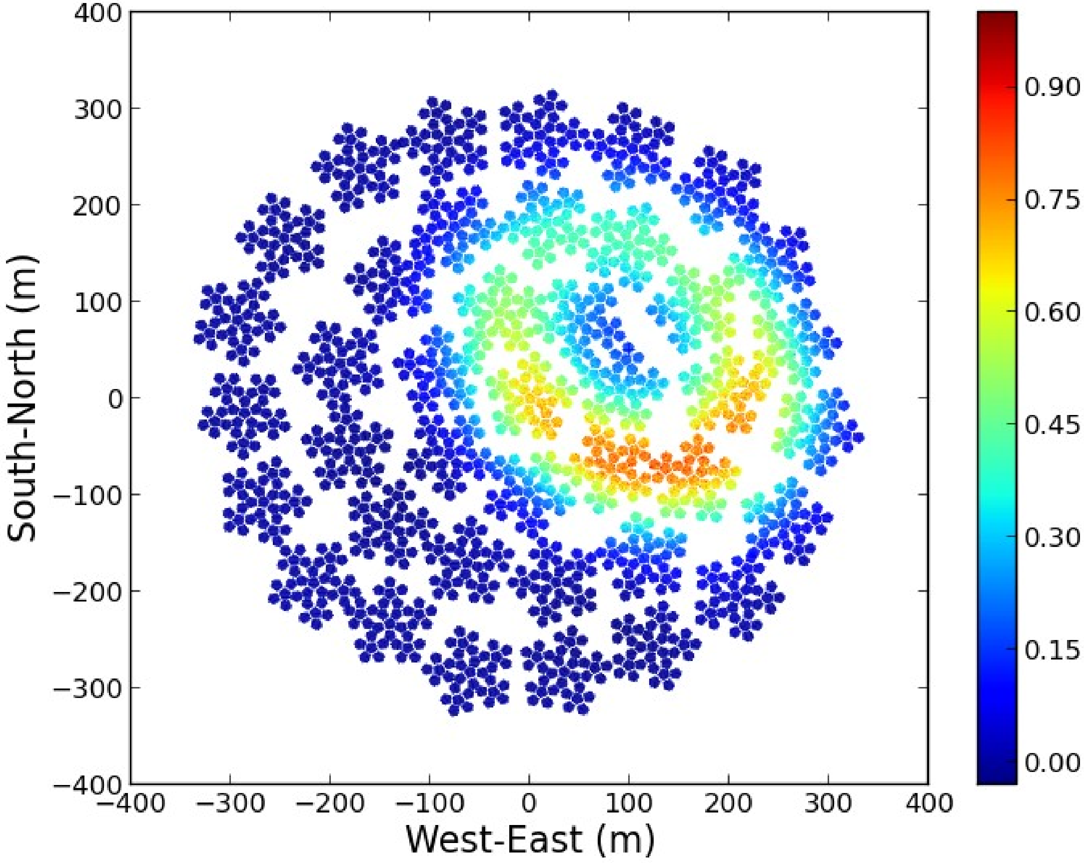
SKA1-low - low frequency array stations

Proton, $10^{17.5}$ev,
36.26°



- phase 1 construction 2018-2023
- first science 2020
- **~70,000 dipole antennas in a circle of 750 metre diameter**
- **bandwidth 50-350 MHz** (different part of radio signal)
- can be used for air shower detection with minor additions

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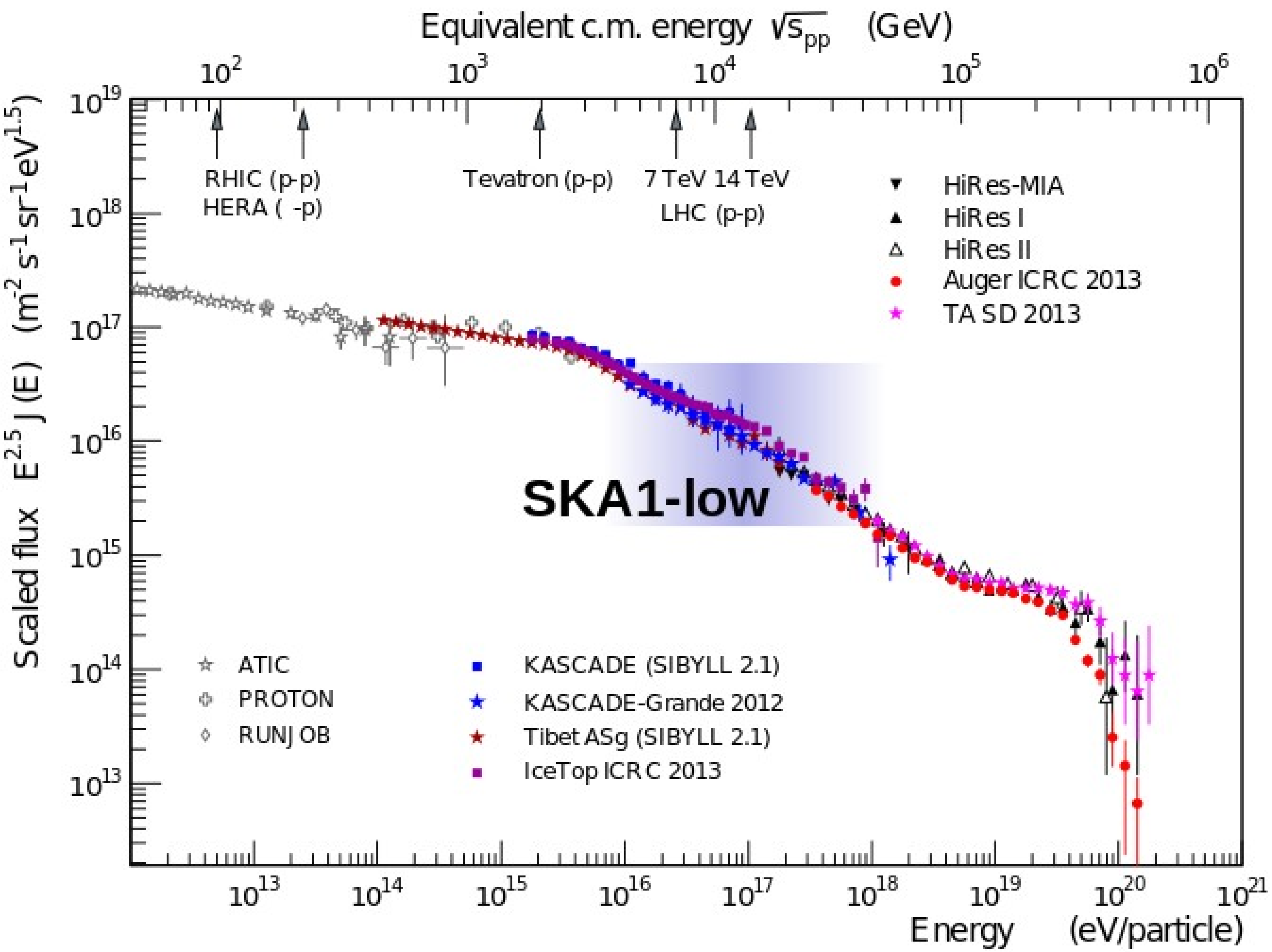
Transition from galactic to extra-galactic

Number of measured primaries in dependence of their energy:



= sum of spectra of individual elements

Origin of structures?

@ SKA energies: Transition from galactic to extragalactic origin

adapted from R.Engel et al., updated by T.Huege/AZ

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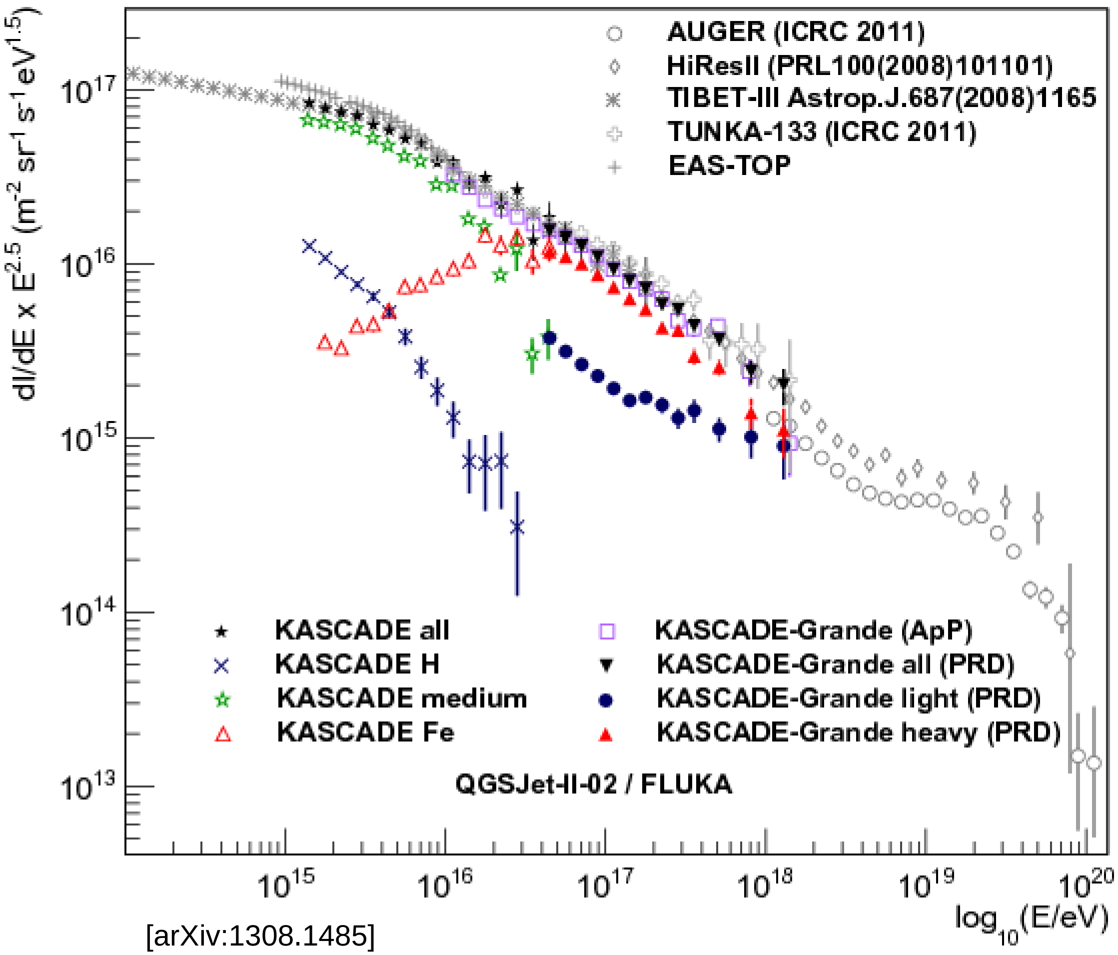
Transition from galactic to extra-galactic

Number of measured primaries in dependence of their energy:



[arXiv:1308.1485]

Already roughly measured
→ need higher resolution

High-precision composition measurements in transition region with SKA
→ possibly decompose
in individual elements
(p, He,…., Fe)

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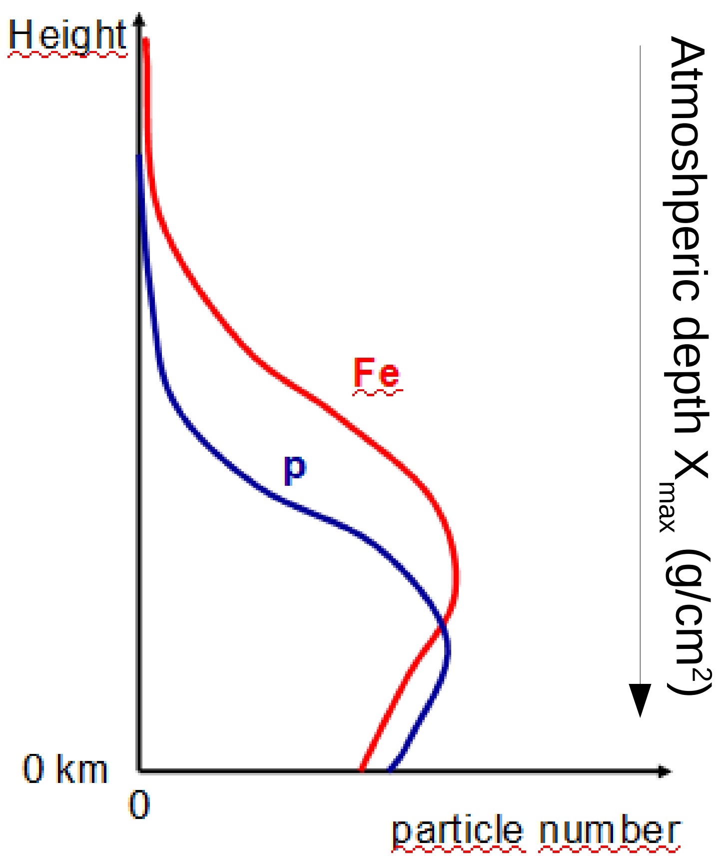
Identifying primary particle: Separation of mass of CR by atmospheric depth

→ **Methods based on statistics!**



[adapted from F.G. Schröder]

Development of a heavy ion induced shower starts earlier

→ reaches the maximum number of particles earlier (low atmosheric depth)

than is the case for proton induced showers of the same energy (high atmosheric depth)

Typically: $(X_{max,p} – X_{max,Fe}) \approx 100$ g/cm^2

Best reconstruction uncertainty by Fluorescence detection technique: ~ 20 g/cm^2

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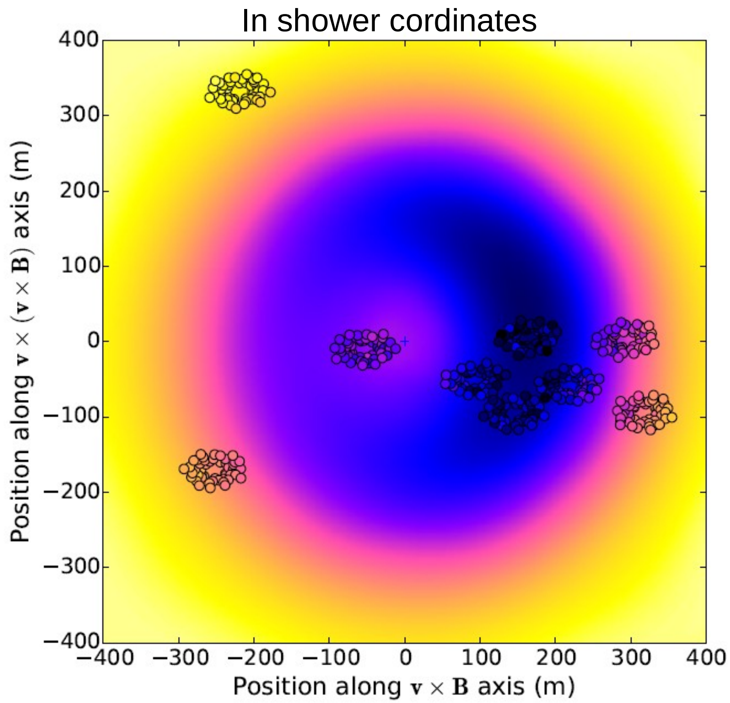
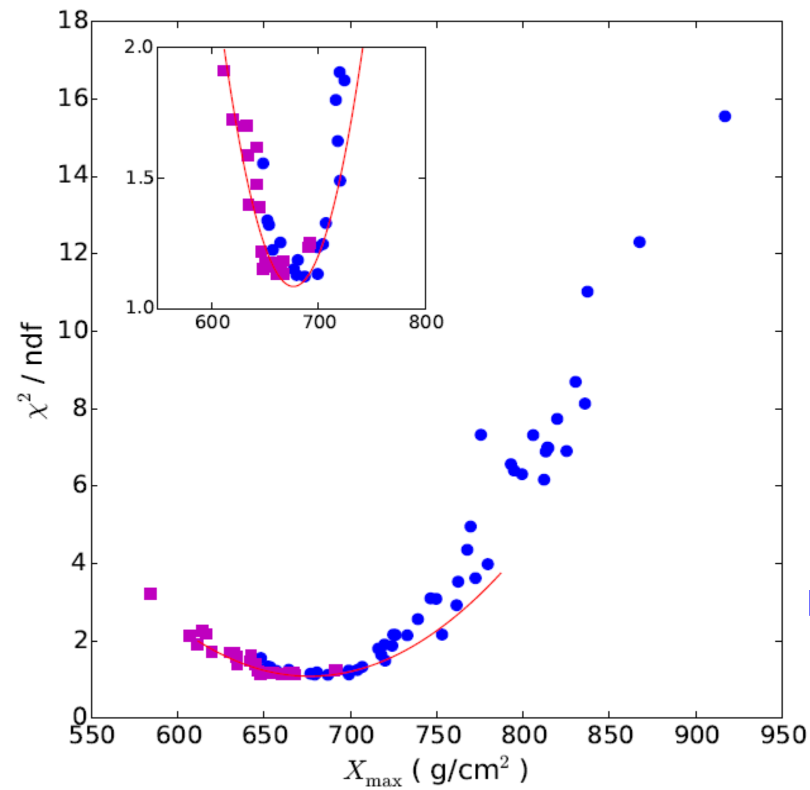
Shower depth reconstruction from radio footprint on ground - LOFAR

S. Buitink et al., Phys Rev D (2014), arXiv:1408.7001

First successful application of a radio telescope as cosmic ray detector





Proton
Iron

Measured footprint compared to many simulations yields mean Xmax uncertainty to ~17 g/cm^2

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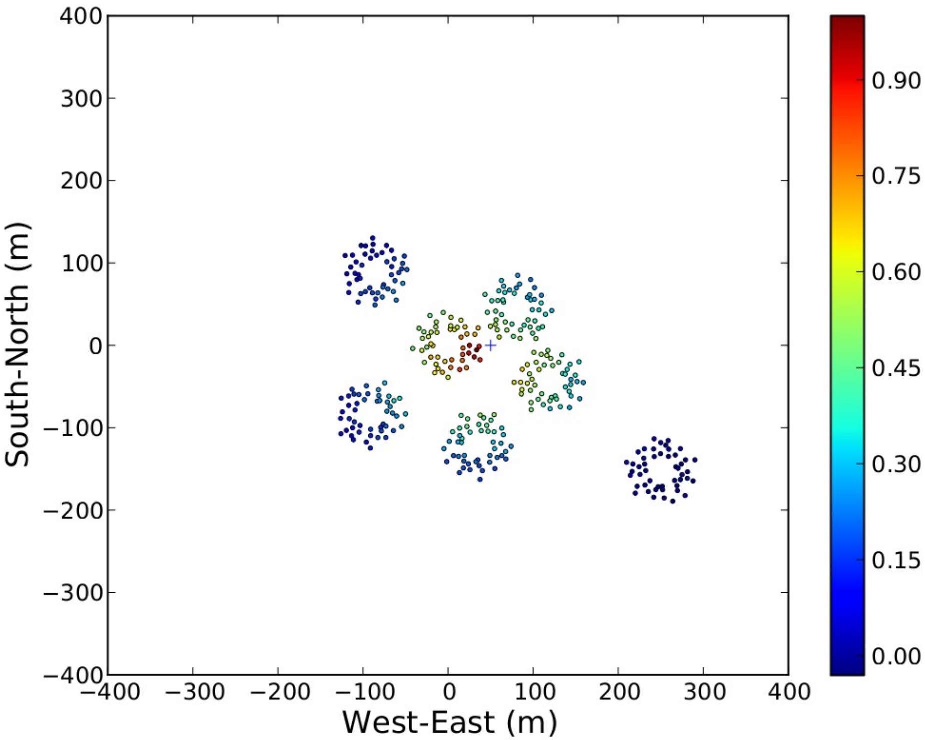
SKA will provide detailed radio footprint

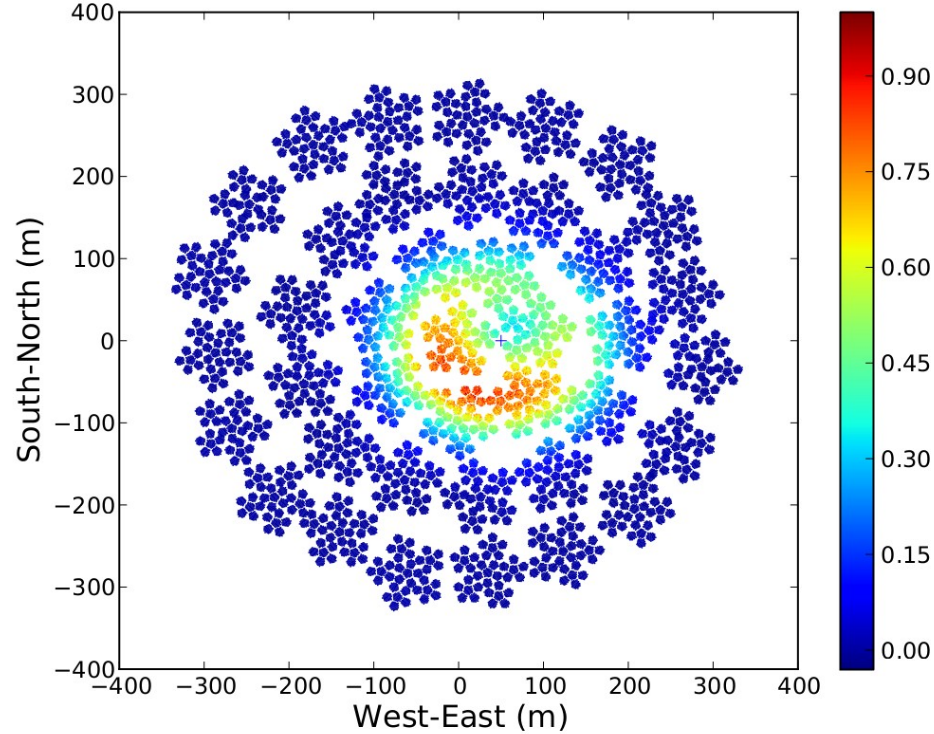
Much better sampling of the footprint!

Proton, 10^{18}eV, zenith = 30°

LOFAR



SKA-low



	LOFAR	SKA-low
Frequency range:	**30 – 80 MHz**	**50 – 350 MHz**
Bandwidth:	**50 MHz**	**300 MHz**

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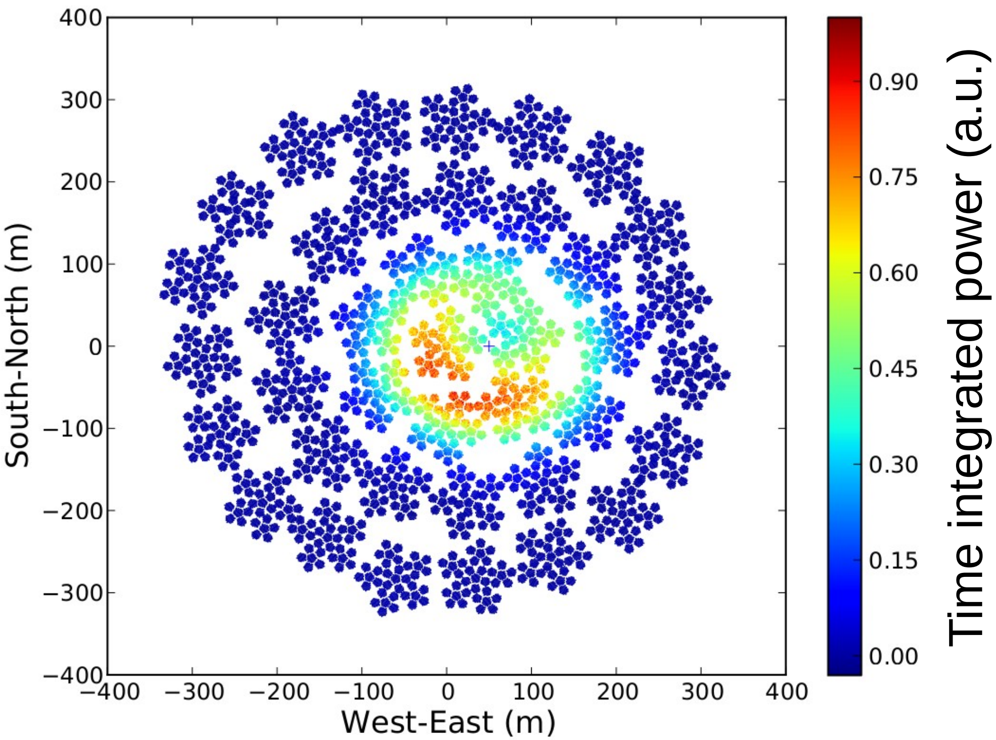
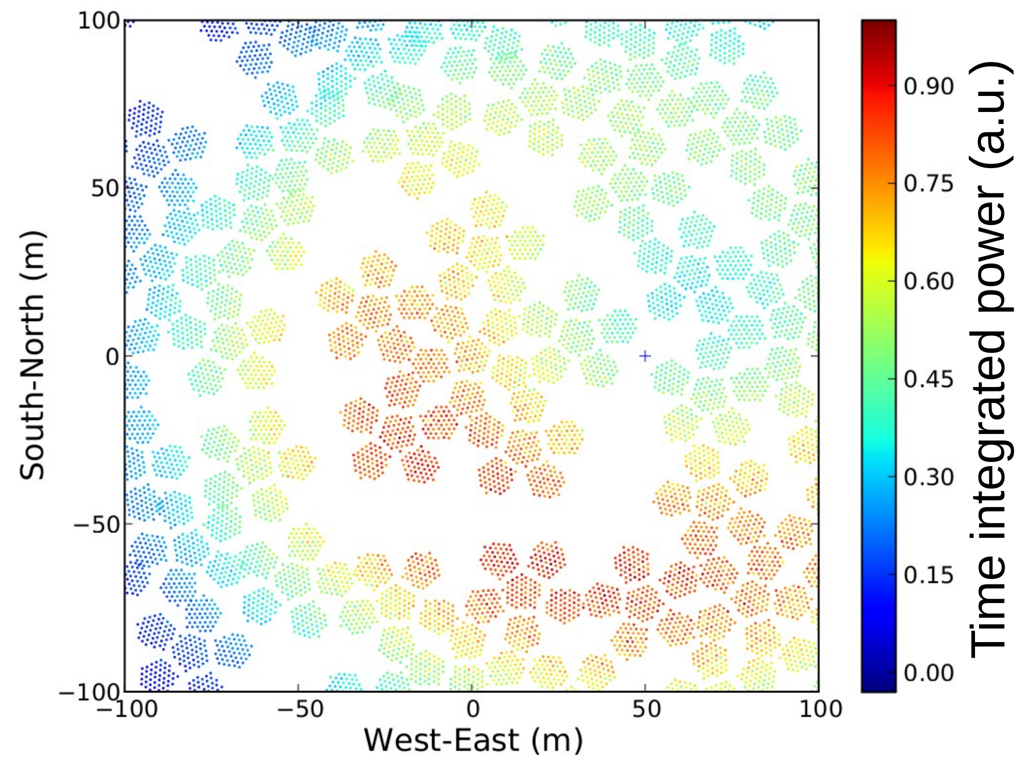
SKA will provide detailed radio footprint

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

SKA-low



Zoom



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

Fluorescence detection technique: ~ 20 g/cm²

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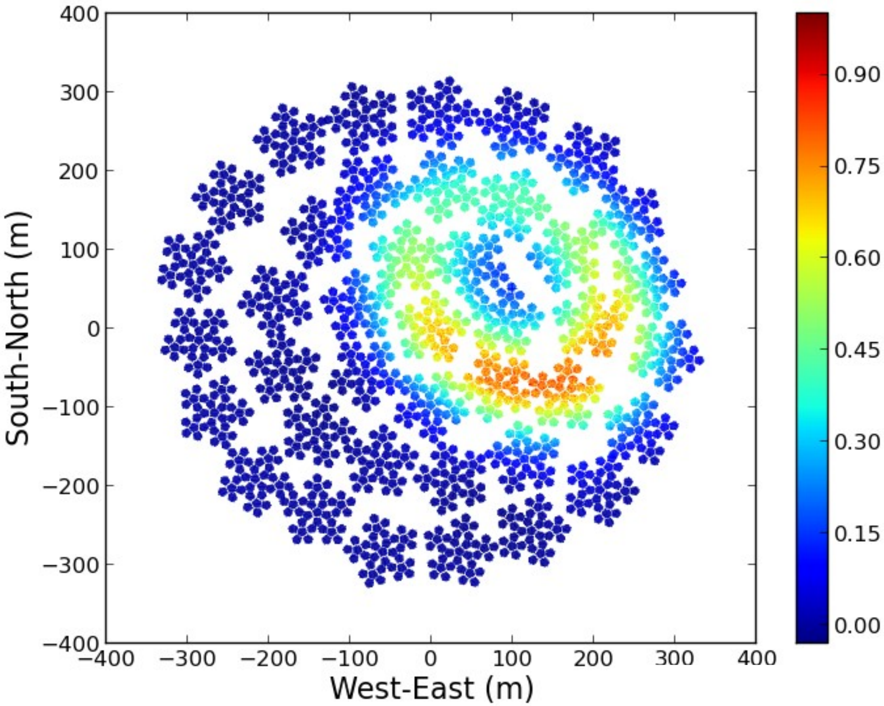
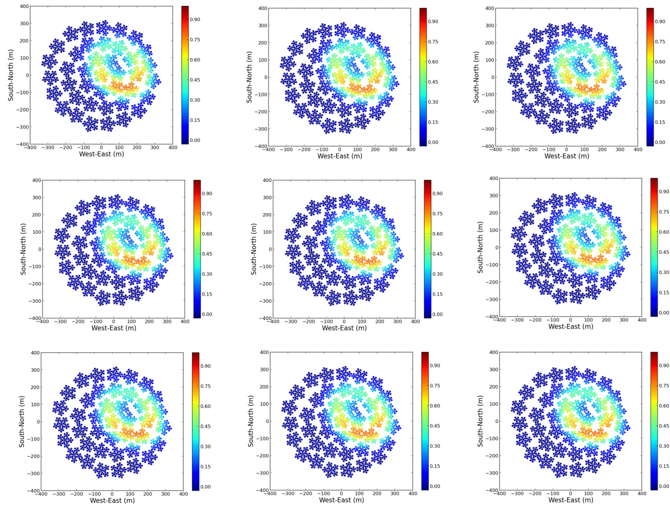
Reconstruction method of shower depth

1 simulation ="Fake Data" with known depth

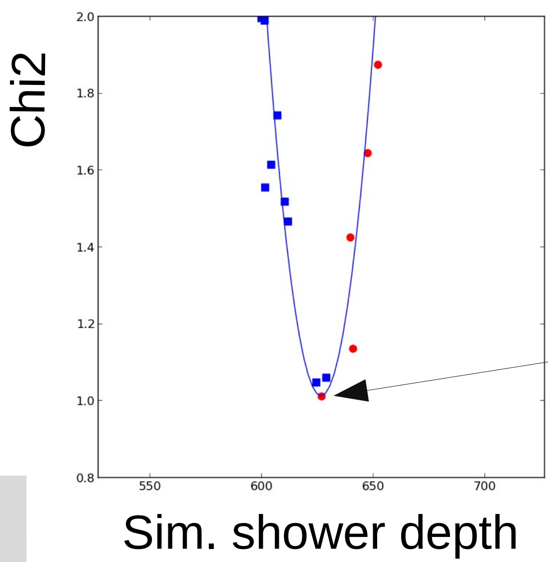


Simulation set of same energy and zenith and known shower depth



comparison

Get Chi2



1 event

Minimum of parabola fit
= reconstructed shower depth

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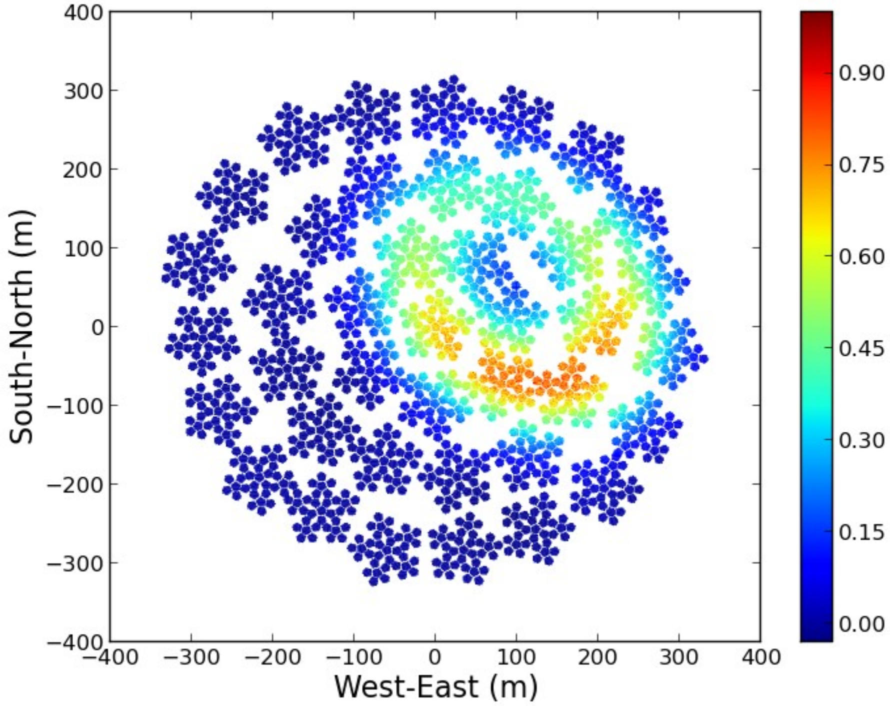
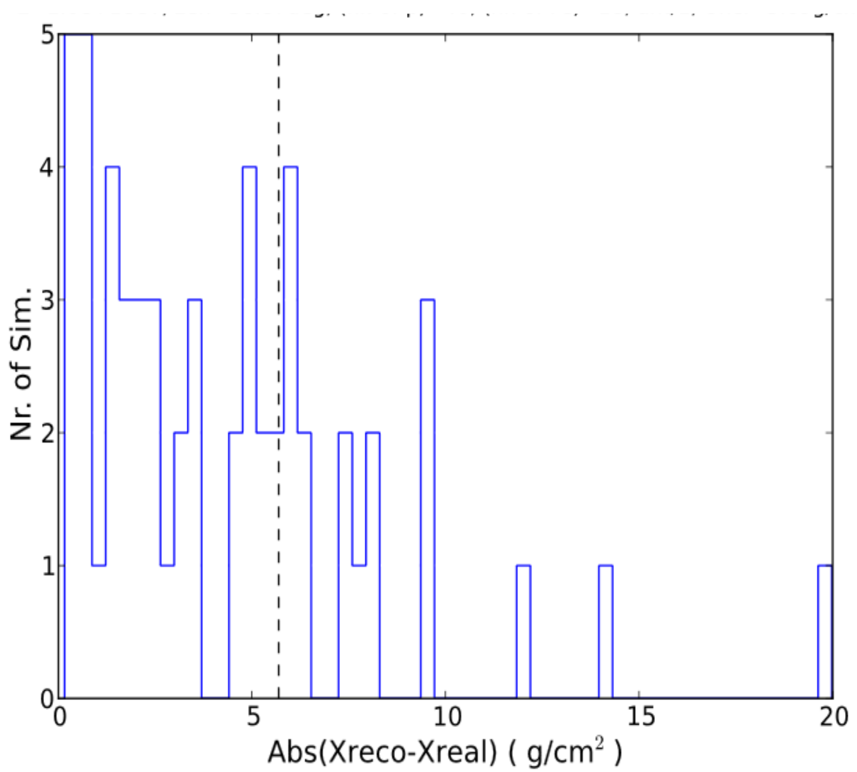
Reconstruction method of shower depth

Proton, $10^{17.5}$ev, 36.26°



many events

68% confidence level (just statistic)
→ reconstruction uncertainty: 5.69 g/cm²



Many simulation sets

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Science potential of SKA-EAS

- precision study of transition from galactic to extragalactic cosmic rays → Xmax determination with ~ **10 g/cm²** resolution

- precision study of interaction and air shower physics beyond LHC energies
  - proton-air cross section, ...

- precision studies of radio emission from EAS
  - „tomography“ of EAS using near-field interferometry

- study of thunderstorm physics and possible connections with EAS

See: T.Huege et al. (ICRC2015)

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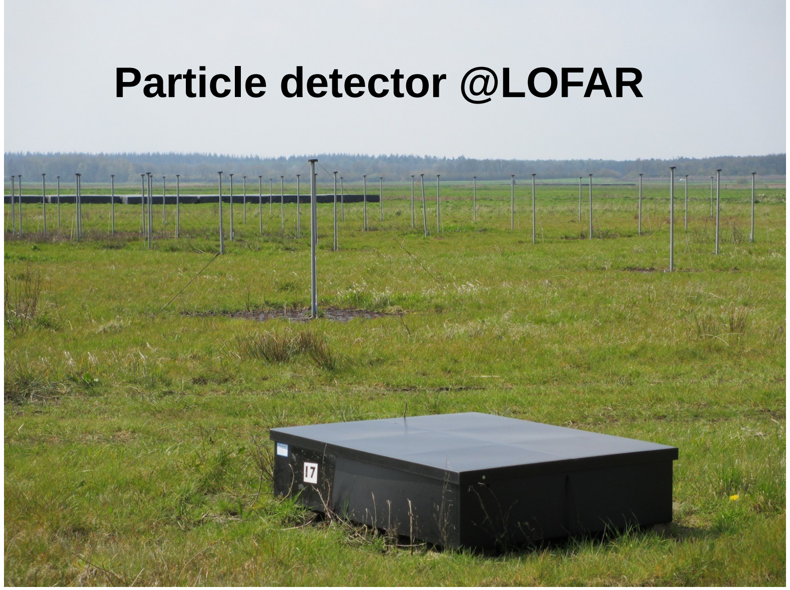
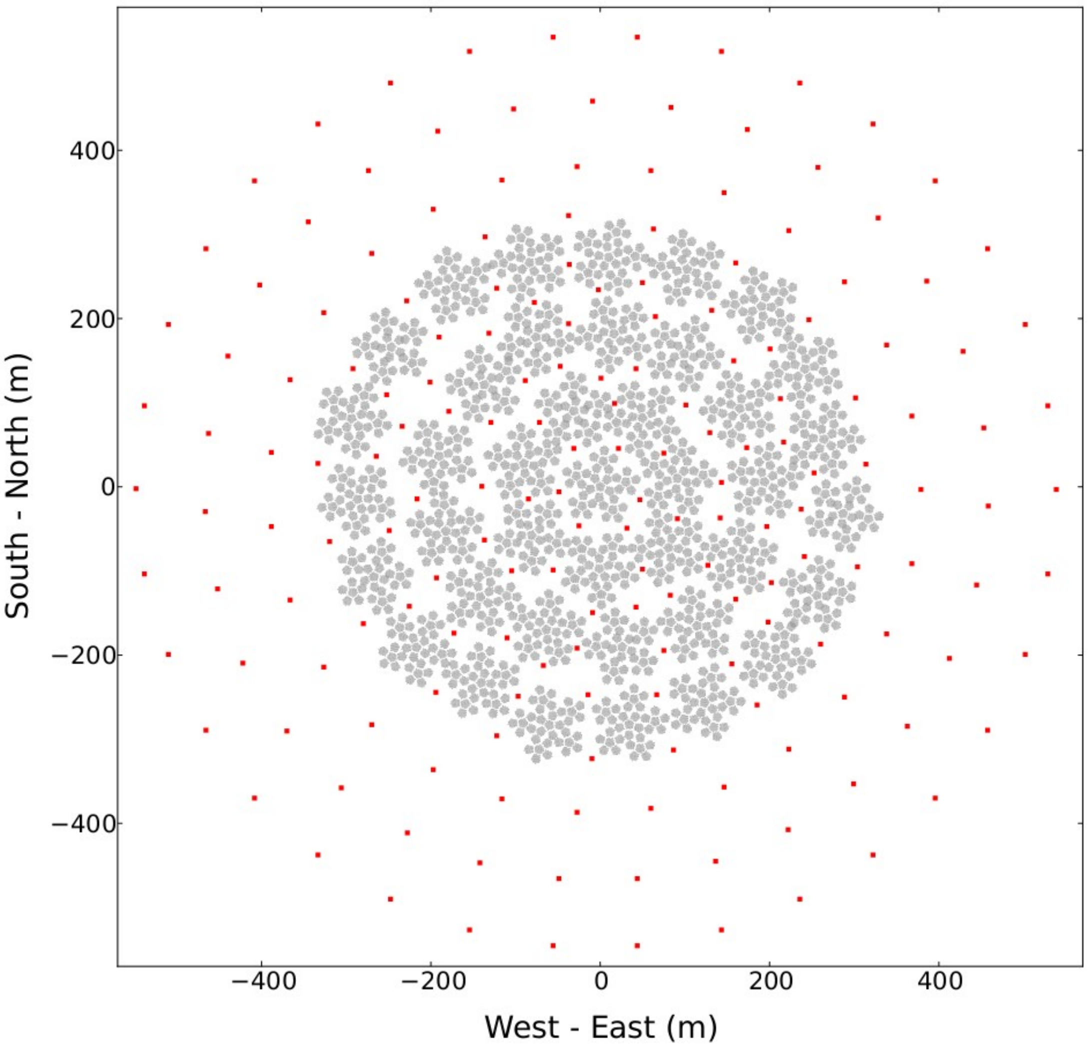
Engineering change: e.g. triggering array

- particle detector array for efficient and pure trigger (also done by LOFAR)

- extend fiducial area outside the SKA1-low core to area ~1 km²:
  eg. 180 scintillators



Red: Particle detectors



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SKA
SQUARE KILOMETRE ARRAY

SCIENCE WEBSITE

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Exploring the Universe with the world's largest radio telescope

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Home » Home » Focus Groups » High Energy Cosmic Particles

High Energy Cosmic Particles

Focus group dedicated to cosmic ray science, details coming soon...

High Energy Cosmic Particles Focus Group Membership

Name	Institution	Country	Membership Type
Anne Zilles	Karlsruhe Institute of Technology	Germany	
Benoit Revenu	Nantes University	France	
Clancy James	ECAP	Germany	
Frank Schroeder	Karlsruhe Institute of Technology	Germany	
Heino Falcke	RU Nijmegan	Netherlands	
Jaime Alvarez-Muniz	Santiago Compostela	Spain	
Justin Bray	University of Manchester	UK	
Ken Gayley	University of Iowa	USA	
Lilian Martin	Nantes University	France	
Maaijke Mevius	ASTRON	Netherlands	
Olaf Sholten	University of Groningen	Netherlands	
Ralph Spencer	University of Manchester	UK	
Richard Dallier	Nantes University	France	
Robert Mutel	University of Iowa	USA	
Ron Ekers	CSIRO	Australia	
Rustam Dagkesamanskii	Pushchino Observatory	Russia	
Sander ter Veen	RU Nijmegan	Netherlands	
Stijn Buitink	Vrije Universiteit Brussel	Belgium	
Tim Huege	Karlsruhe Institute of Technology	Germany	
Torsten Ensslin	MPA Garching	Germany	
Katherine Mack	University of Melbourne	Australia	
Julian Rautenberg	University of Melbourne	Australia	
Nadir Hashim	Kenyatta University	Kenya	
Steven Tingay	ICRAR, Curtin	Australia	
Evan Keane	SKA Organisation	UK	Office Contact

KIT
Karlsruhe Institute of Technology

State of the project

- we have become a „SKA focus group“ since May 2015
- we have submitted a detailed „Engineering Change Proposal“ and entered phase 4 out of 6
- there is still a lot to be done before first data in 2020

http://astronomers.skatelescope.org/home/focus-groups/

SUMMARY

- SKA1-low can be easily upgraded for cosmic ray detection
- extreme precision measurements → unique radio detector for cosmic rays
- the science potential lies in precision measurements
  - Transition galactic to extragalactic cosmic rays
  - Particle interactions and air shower physics beyond LHC energies
  - Understanding lightnings and thunderstorms
- an engineering change proposal is under consideration

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