Overview

- the science potential of SKA air shower detection
- the engineering changes needed in the SKA

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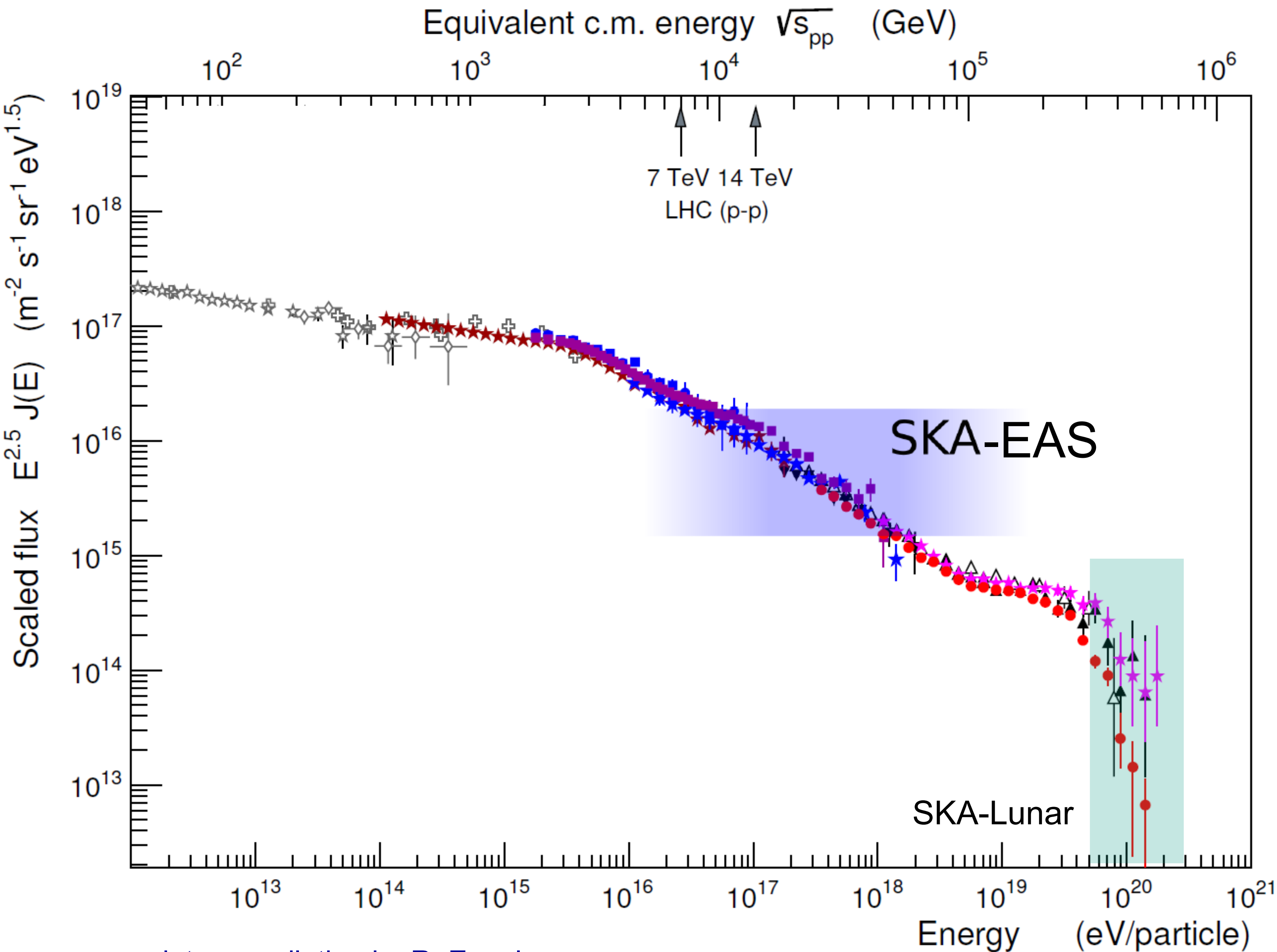
SKA-EAS science



data compilation by R. Engel

Extensive air showers (EAS) and their detection

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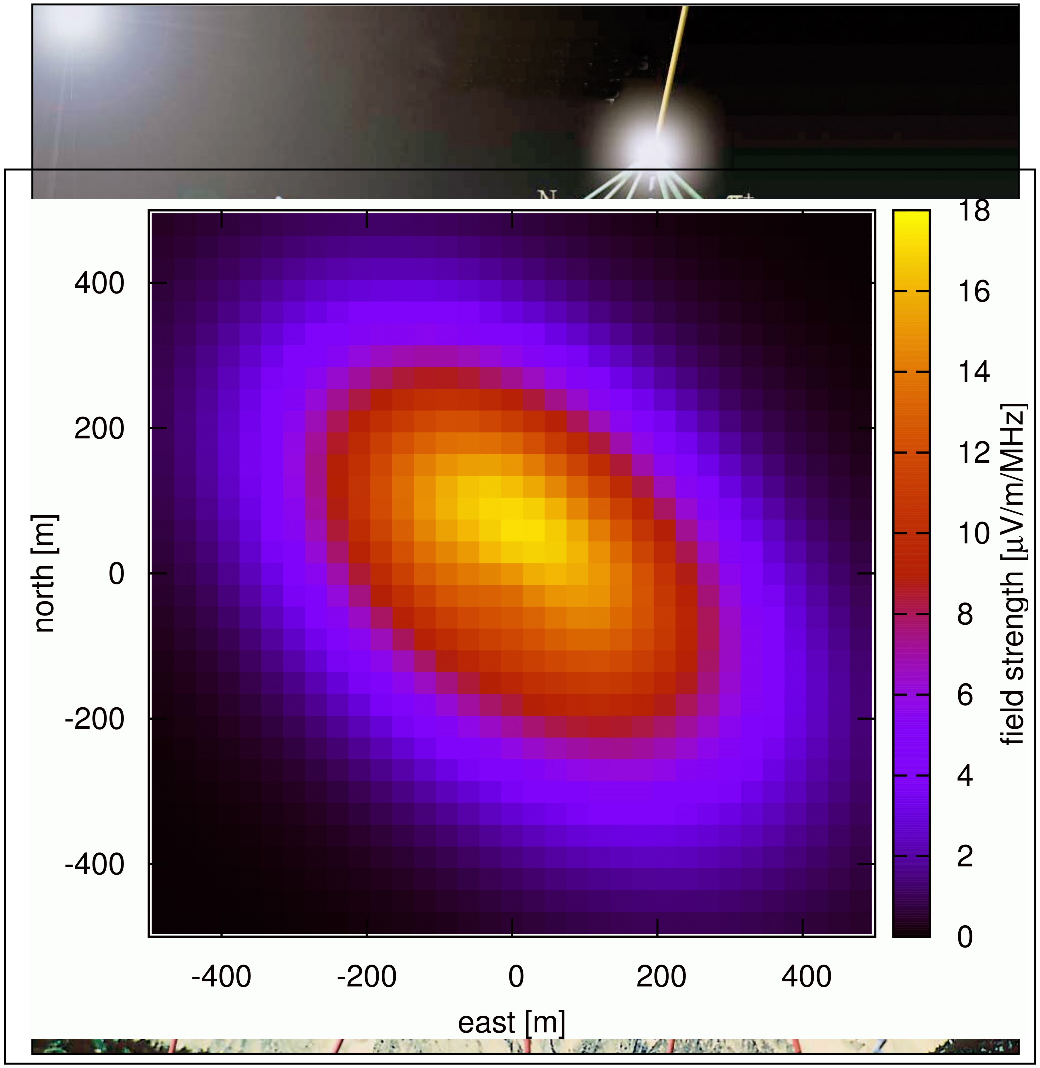
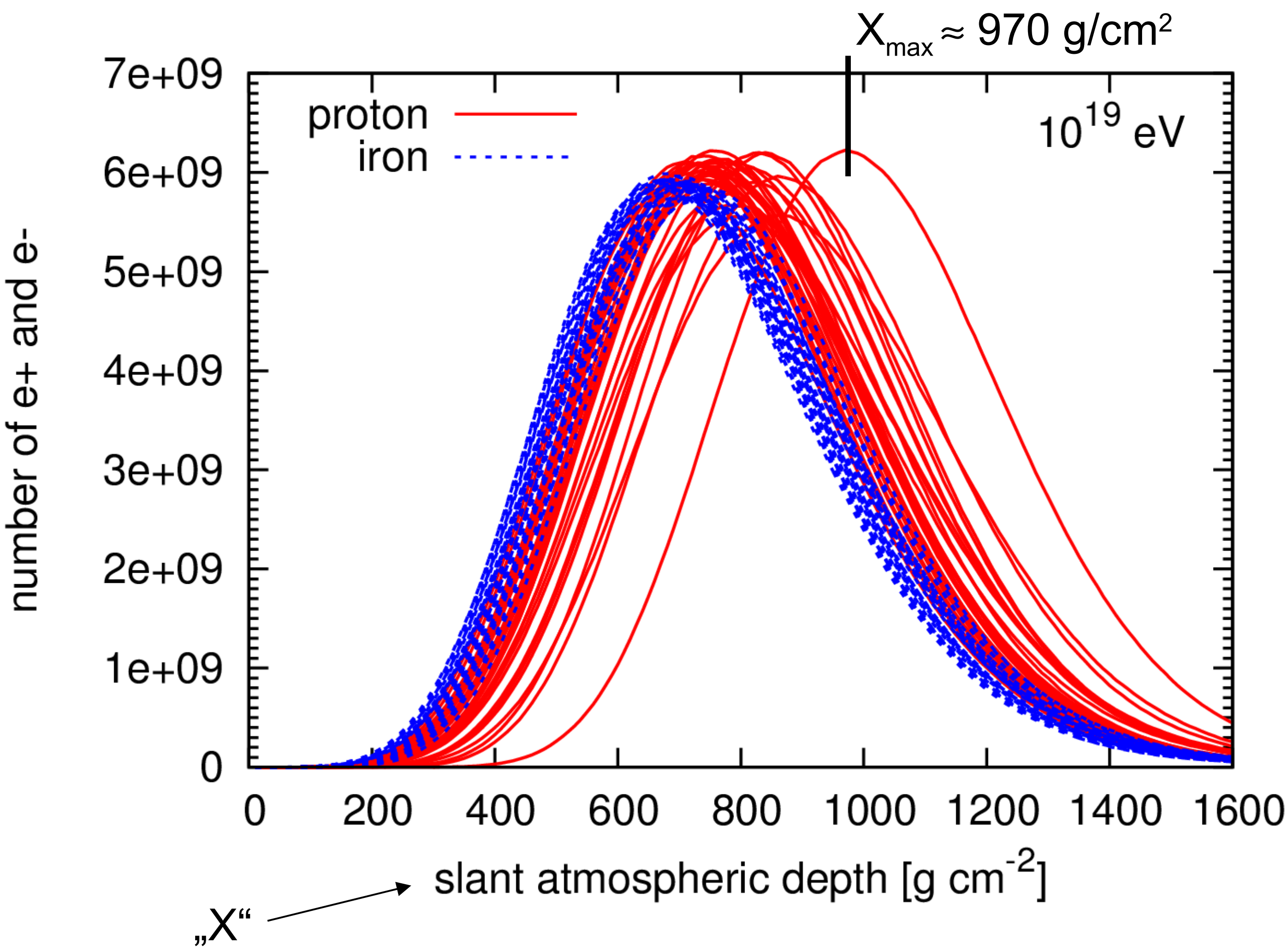
- cosmic ray interacts with nucleus in atmosphere
- cascade of secondary particles evolves
  - particle detectors register particles at ground
  - optical telescopes measure energy deposit via N_2 fluorescence
  - radio detectors measure short (~100 ns) coherent radio pulses in a limited area



Depth of shower maximum (Xmax) and mass

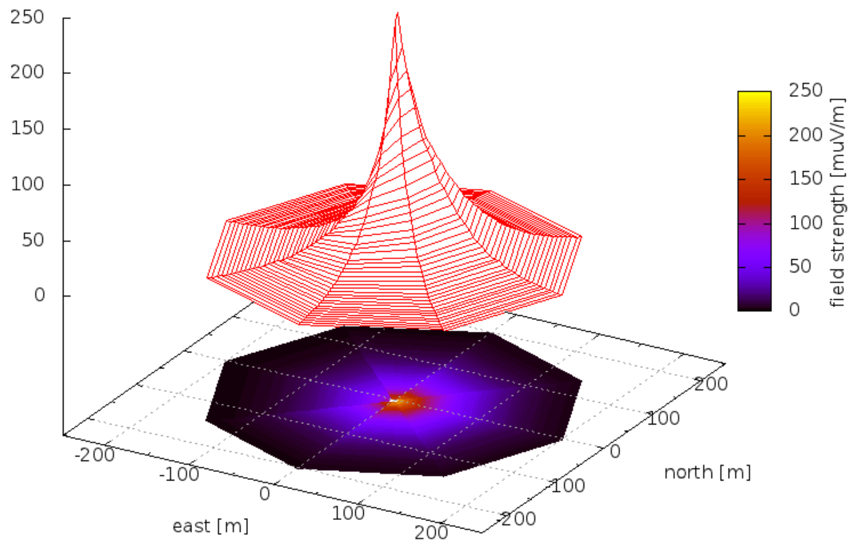


- X_{max} and RMS(X_{max}) provide information about cosmic ray mass
- directly measured by fluorescence detectors, resolution $\approx$20 g/cm^2

Mass composition in the EAS radio signal

- systematic differences in the radio footprints of light and heavy particles

TH et al., ARENA2012



vertical proton shower
at LOPES frequencies
simulated with CoREAS

vertical iron shower
at LOPES frequencies
simulated with CoREAS

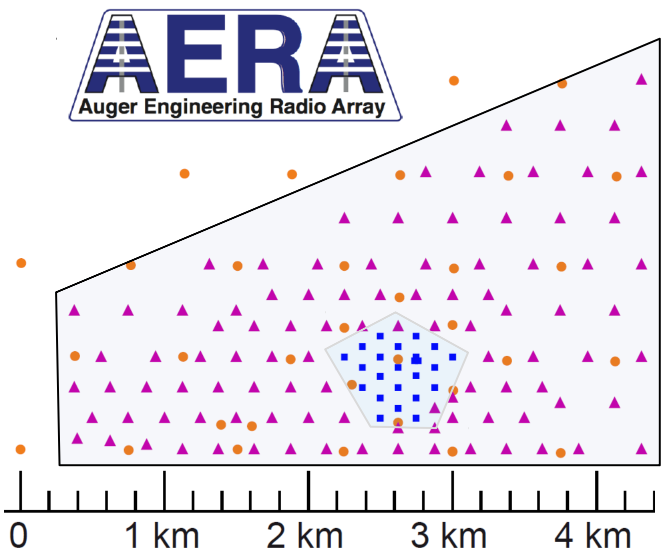
- plus wavefront timing, plus polarization, plus pulse-shape

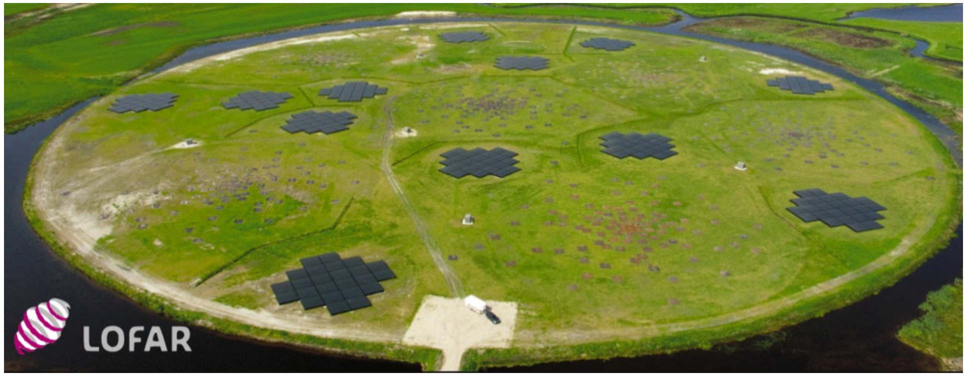
Radio detection of cosmic ray air showers

- prototyping phase is over (LOPES, CODALEMA, …)
- we clearly understand the radio emission
- different paths can now be followed

cover large areas (>10 km²), sparse antenna arrays

measure individual air showers very precisely with dense antenna arrays





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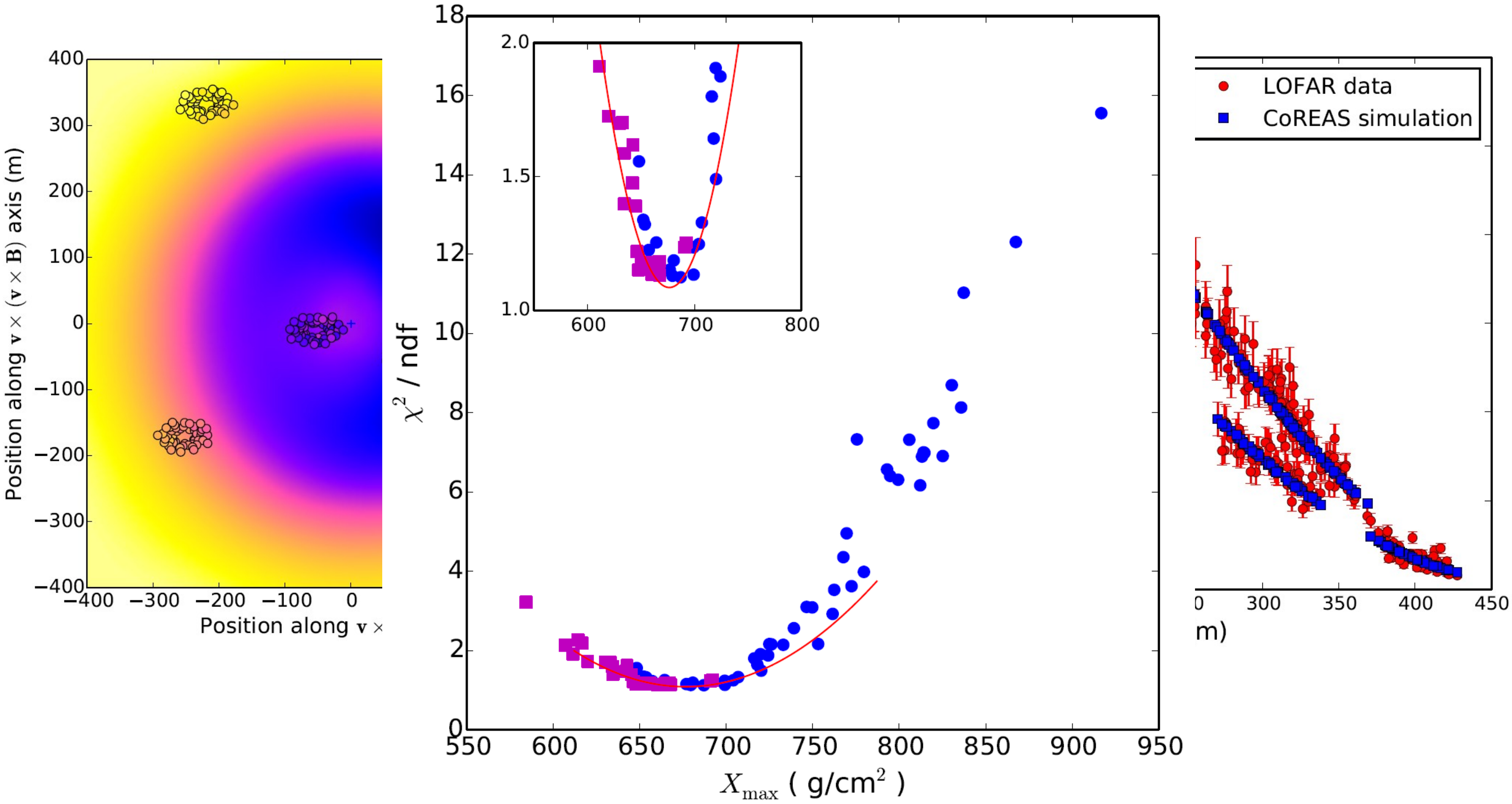
Detailed studies – LOFAR dense core

- O(800) antennas in 400 m diameter circle, ~0.1 km^2
  - *either* 30 – 80 MHz *or* 120 – 240 MHz
- small particle detector array (trigger & event information)
- allows extremely detailed studies of individual cosmic rays

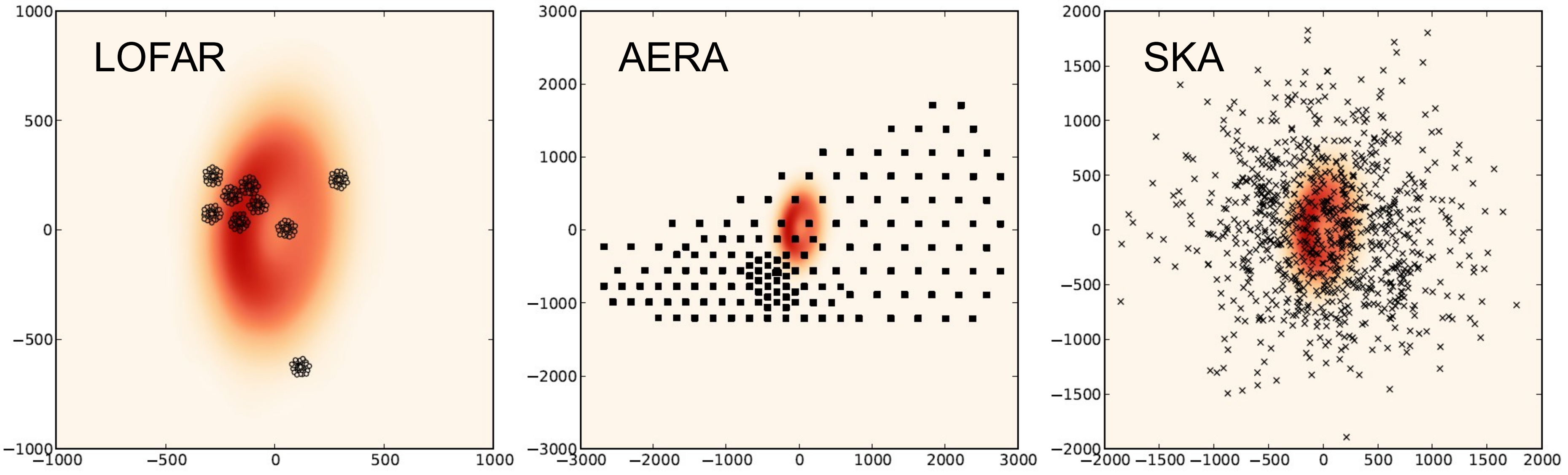
Xmax reconstruction with LOFAR from LDF



- 2d LDF fit to CoREAS simulations yields Xmax to ~20 g/cm²

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

The SKA will be a *precision* EAS detector



- *dense* core with very *homogeneous* instantaneous u-v coverage
- observing frequencies 50 – 350 MHz (now typically 30-80 MHz)

- **Xmax determination with ~10 g/cm² resolution seems feasible!**

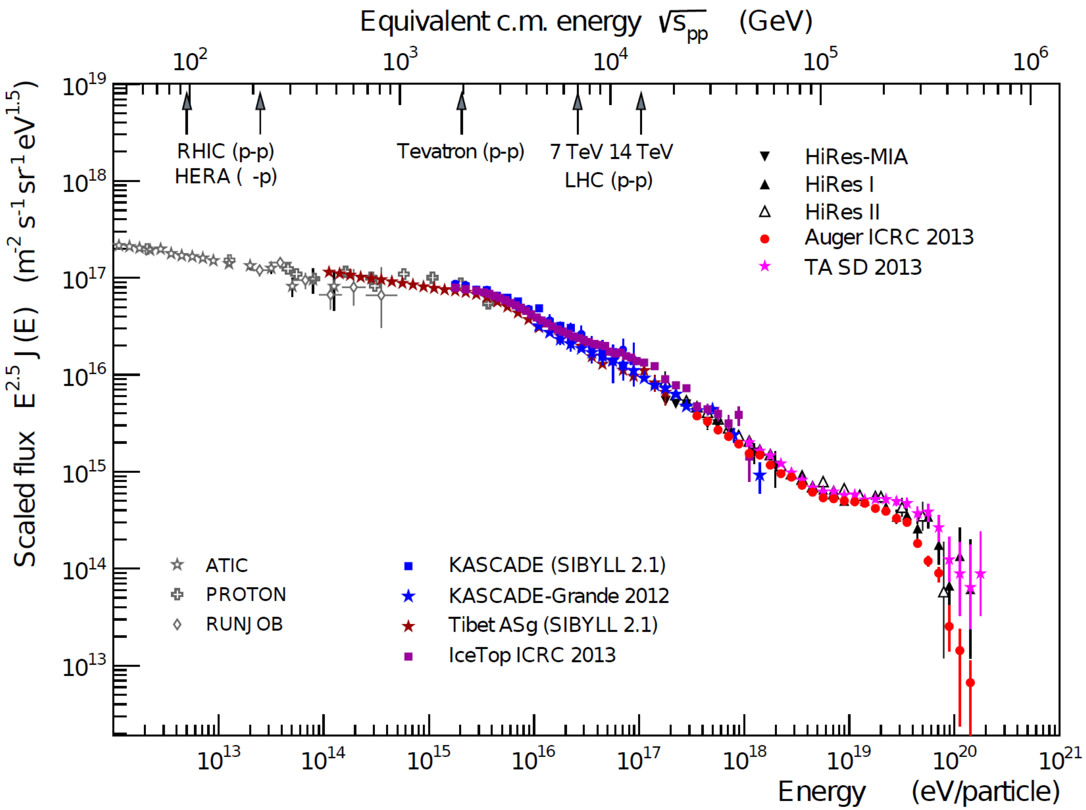
Science goals for SKA-EAS, arXiv:1408.5288

- precision study of transition from Galactic to extragalactic cosmic rays
- precision study of interaction physics beyond LHC energies
- study physics of thunderstorms and possible connections with EAS
- wide-band studies of radio emission from EAS

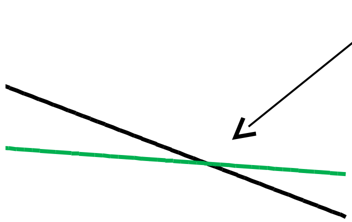
- we need to quantify the potential of these with simulation studies!

Transition from Galactic to extragalactic CRs

- needs precise mass composition studies from 10^{17} to 10^{19} eV
- SKA will be able to measure Xmax with unprecedented precision



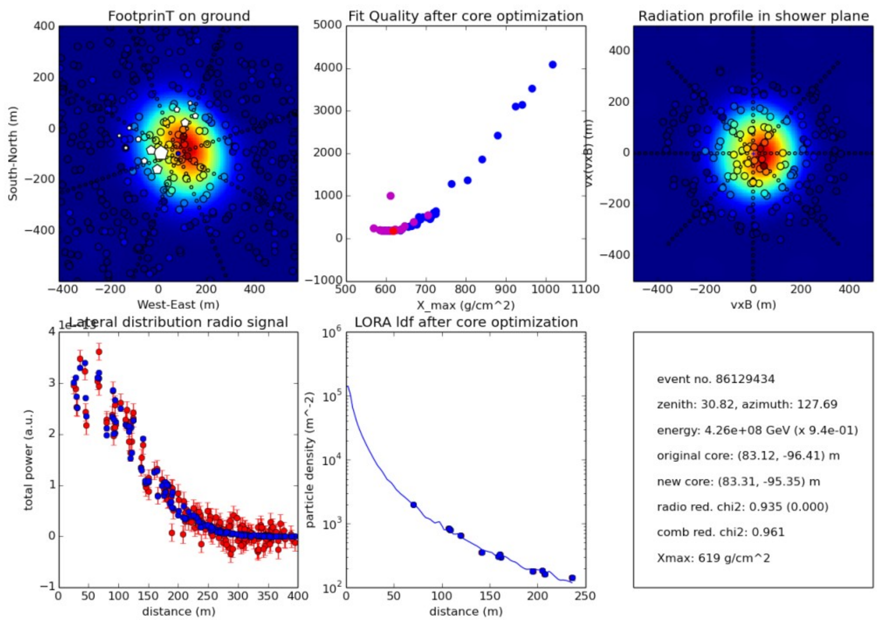
„Ankle“ at 3 10^{18} eV
transition from galactic heavy particles to extragalactic protons?



KASCADE-Grande Collaboration, Phys. Rev. D 87 (2013) 081101(R)

Transition from Galactic to extragalactic CRs

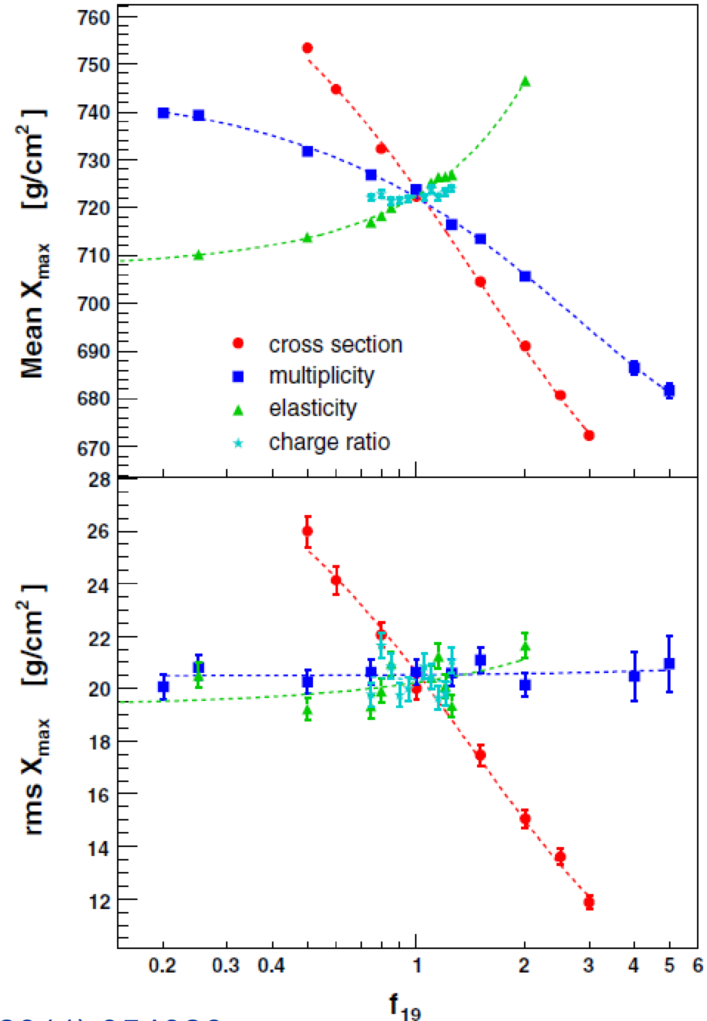
- superior Xmax determination in the 10^{17} to 10^{19} eV range
  - how good will the Xmax determination be?



  - how useful is a 10 g/cm^2 resolution for mass separation when the intrinsic widths of the distributions for individual particles are much wider?
  - can we identify individual elements, or groups of elements?

Particle physics beyond-LHC energies

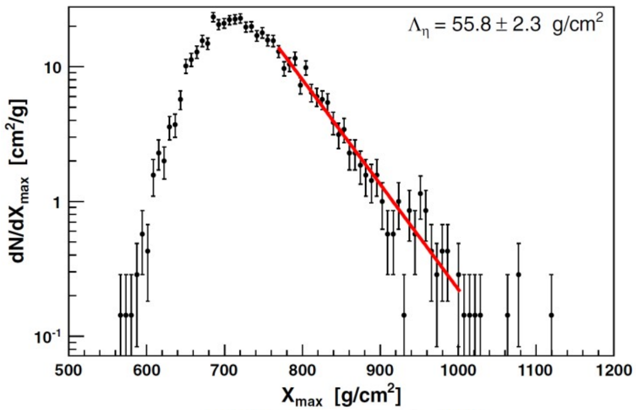
- study precise Xmax distributions to probe hadronic interactions
  - hadronic particle pro-duction cross sections
  - multiplicity of secondary particles in interactions
  - elasticity (E_leading/E_tot)
  - pion charge ratio
- how useful will Xmax resolution of 10 g/cm2 be?
- what is the energy reach (event statistics)?

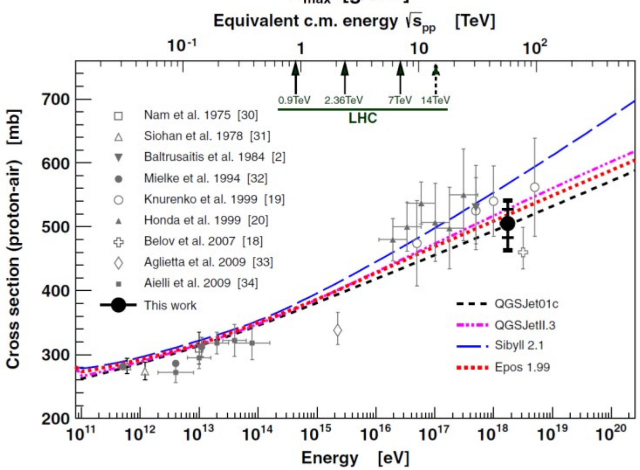


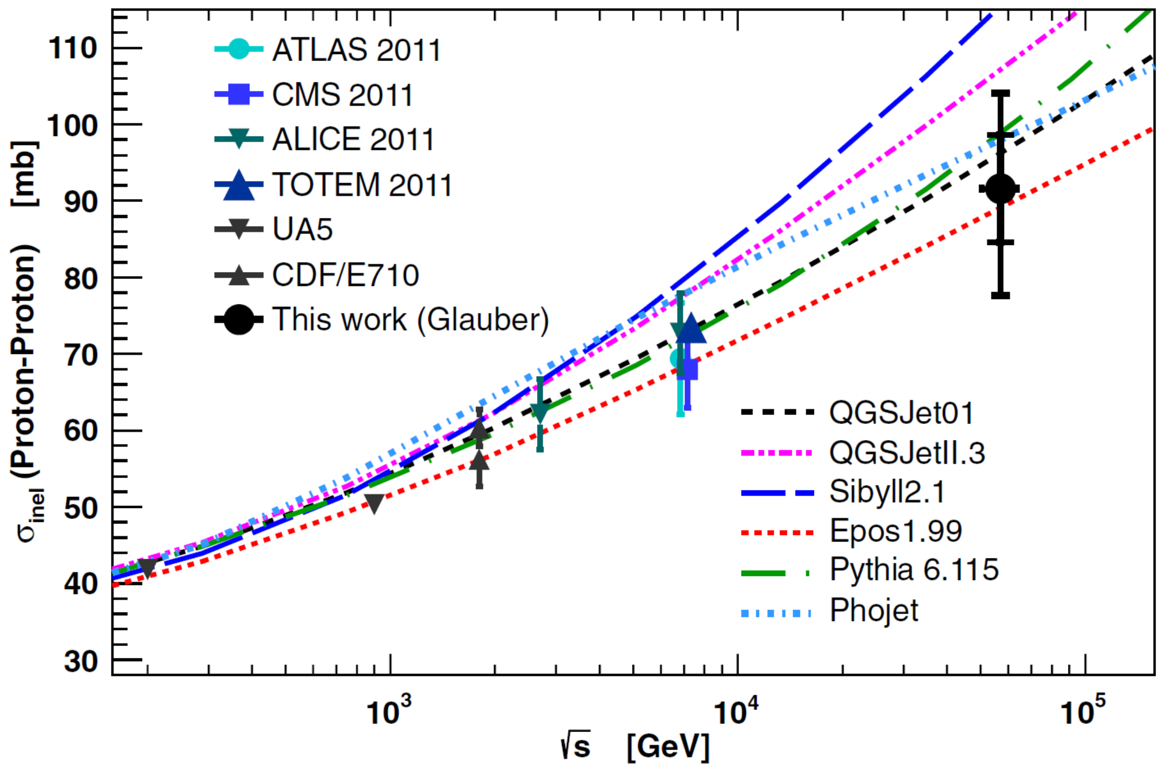
Ulrich, Engel, Unger, PRD 83 (2011) 054026

Particle physics beyond-LHC energies

- air shower measurements can be used to study particle interactions
- Auger uses tail of Xmax distributions
- near-field interferometry could do much better!



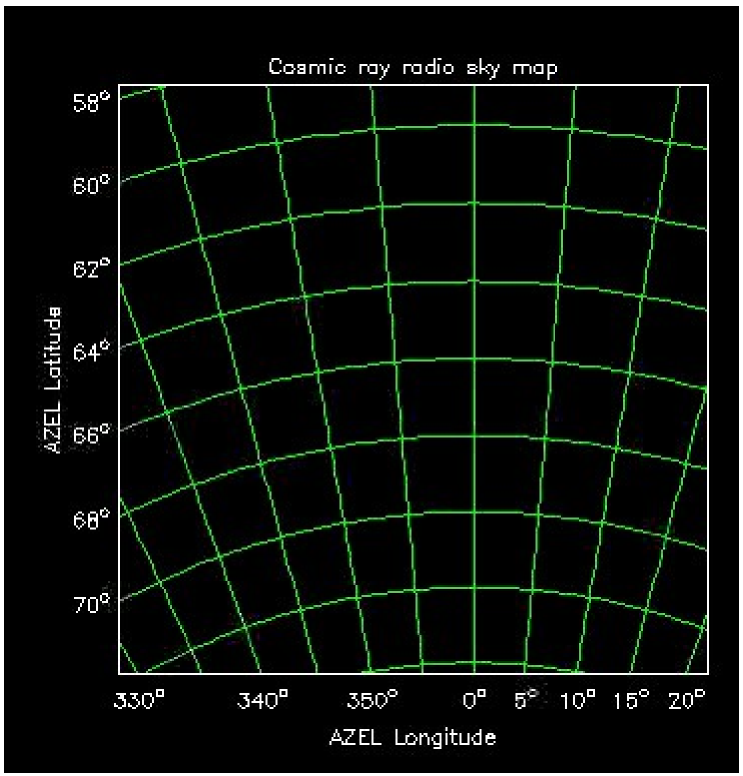




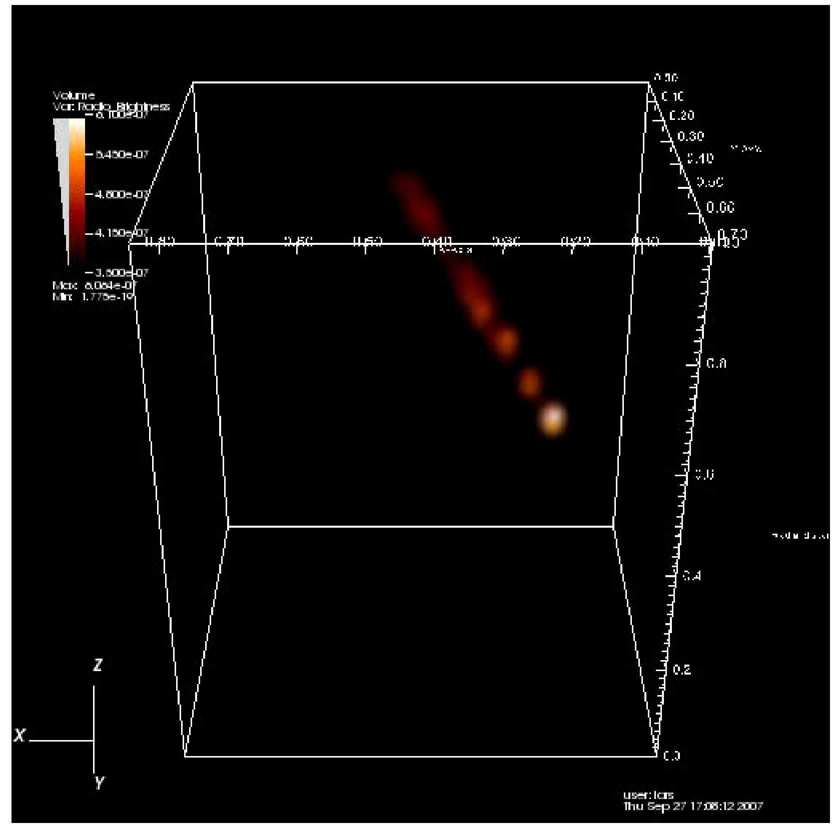
Pierre Auger Collaboration, PRL 109 (2012) 062002

Particle physics beyond-LHC energies

- near-field interferometry will yield unprecedented level of detail
  - 4-dimensional „tomography“ of e^+ and e^- in air showers, study shower physics
  - how to do it? apply „information field theory“ techniques?



LOPES, „far-field interferometry“



tomography with „near-field interferometry“

Particle physics beyond-LHC energies

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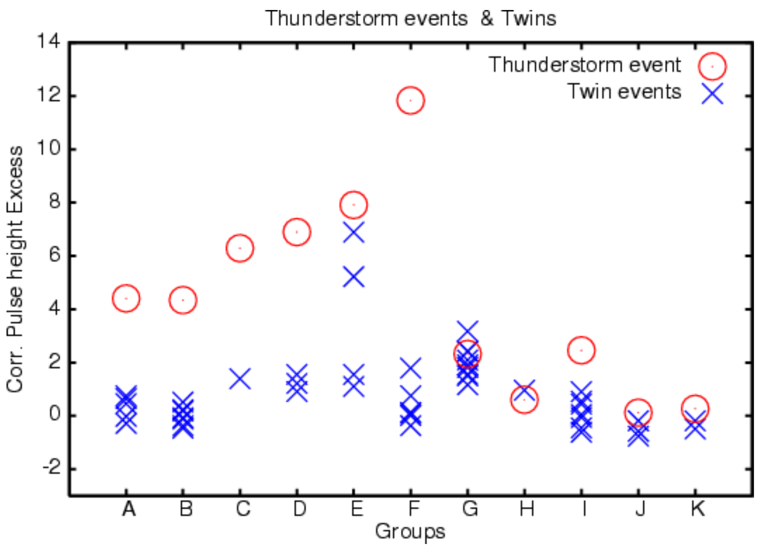
- combine radio measurements with sophisticated muon detector?
  - do we want a simple scintillator array for triggering only?
  - or do we want electron-myon separation? what is the cost?
  - we need to study possible particle detector designs, also for the ECP

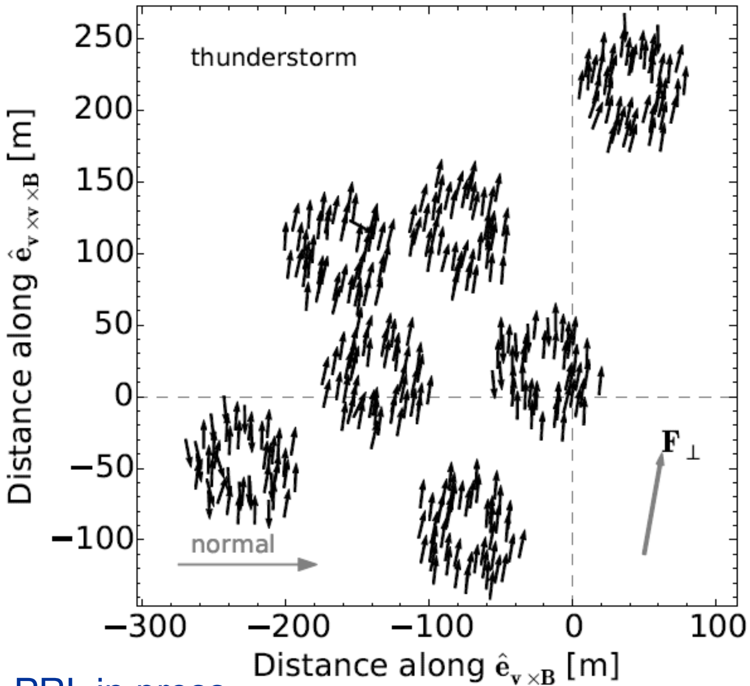
Physics of thunderstorms and connections to EAS

- atmospheric electric fields influence EAS radio emission
- boosting of emitted radio pulses seen with LOPES



Buitink et al. (LOPES Coll.), A&A 467 (2007) 385

- LOFAR compared measured data with detailed CoREAS simulations including E-fields and constrained atmospheric E-field strength and structure



Schellart et al. (LOFAR Coll.), PRL in press

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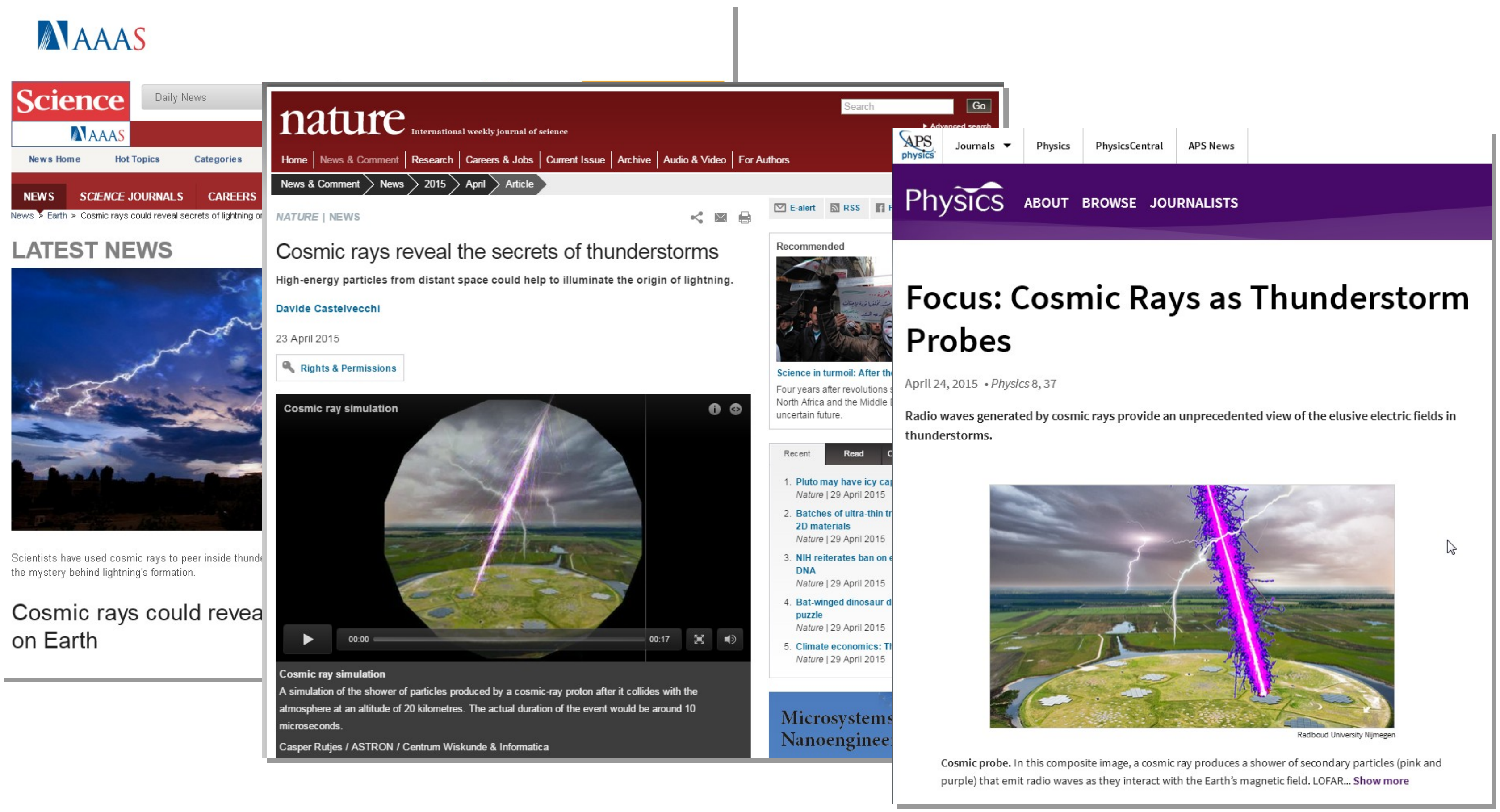
Physics of thunderstorms and connections to EAS

- quite some media echo to the LOFAR thunderstorm results



Where to go from here …

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- precision study of transition from Galactic to extragalactic cosmic rays
- precision study of interaction physics beyond LHC energies
- study physics of thunderstorms and possible connections with EAS
- wide-band studies of radio emission from EAS

- we need to flesh out these ideas
  - do simulation studies, quantify the potential
  - develop analysis strategies
  - publish papers
- what have we forgotten?

SKA-EAS engineering

Engineering Change Proposal 140034

SQUARE KILOMETRE ARRAY

SKA PHASE 1 TRANSIENT CAPTURE ECP 140026, ECP140034 & ECP 140035 ANALYSIS DOCUMENT

Document number: SKA-TEL-SKO-0000XX
Context: Architecture
Revision: C
Author: W.Turner
Date: 2014-10-13
Document Classification: UNRESTRICTED
Status: Draft

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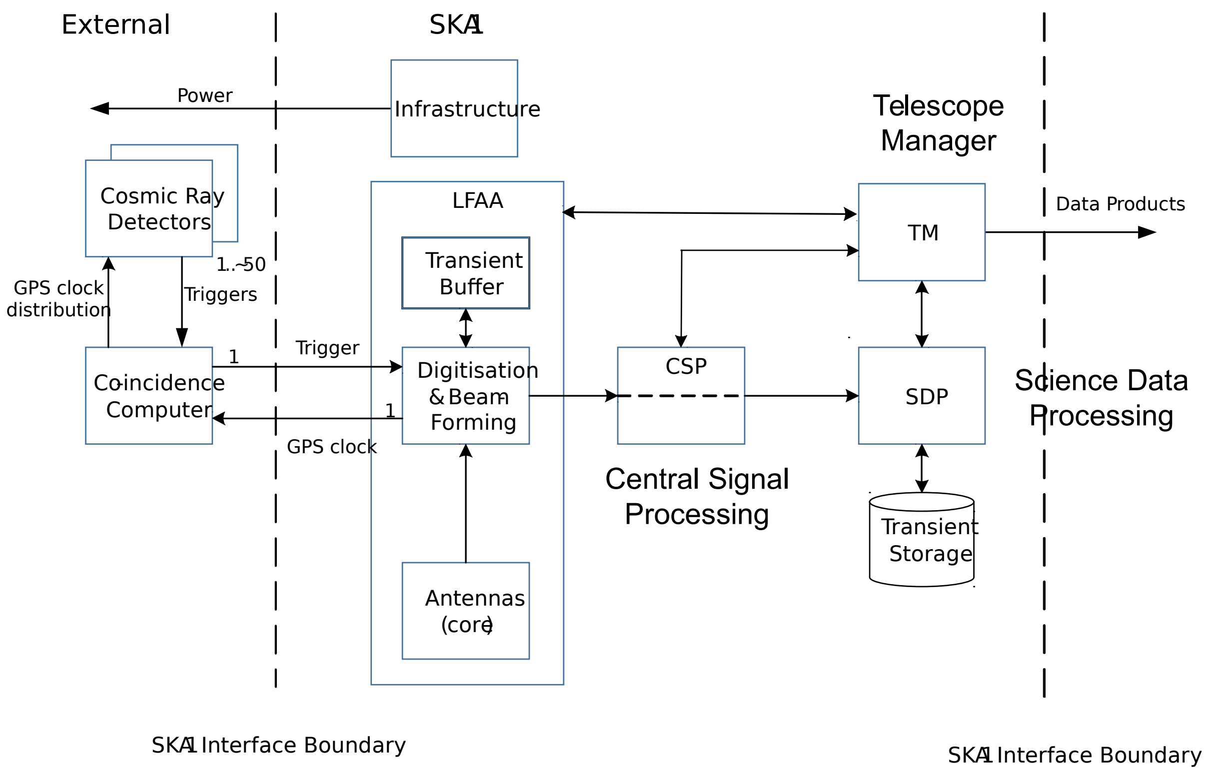
			Date:	2014-10-13

- we filed an ECP in March 2014
- several teleconference calls followed to clarify the proposal
- this led to a joint „analysis document“ on ECPs 140026 (Transients), 140034 (SKA-EAS) and 140035 (SKA-Lunar)

Requested Engineering Changes for SKA-EAS



- sample and buffer at individual antennas
- trigger by particle detector array
- read out buffers and store data
- remote access to coincidence computer

ECP 140034 analysis document

Sample and buffer at individual antennas

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- digitize with at least 8 „effective bits“ above the noise, i.e. 12+ bits
- relative timing calibration of 1 ns or better
- sample with at least 700 MSPS (50-350 MHz frequency window)
- continuously buffer raw waveform signal of individual antennas
- 10 ms buffer depth (latency of particle array trigger)
- 50 μs readout window (capture diameter up to 10 km) [10 ms during thunderstorms?]
- only buffer antennas on a grid of ~10-20 meters, not all antennas
- also buffer antennas outside the 1km diameter core as long as the spacing between antennas is not more than ~100 meters (or more?)

Trigger by particle detector array

- particle detectors ensure low rate of false positives, low detection threshold, little computing power needed
- need ~50-100 scintillator detectors per km^2
  (document: „50 to 100 across the 1 km diameter core“)
- one coincidence computer – or hierarchical trigger topology?
- power consumption (solar power disfavoured, batteries age fast)
- coincidence computer which also stores particle array data
- time synchronization with SKA/sampling clock (document: „GPS clock“)
- needs to be radio-quiet

- we need a design study, including cost estimation (this will not be paid for by the SKA)

Read out buffers and store data

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- assume average trigger rate of one every 6 minutes per km^2
- buffer size of 10 ms at 12 bits requires 12 MB/antenna (with 2 polns.)
- buffer for at all antennas in the core would require 2.9 TB of RAM
- read-out of 50 μs every 6 minutes for every 4th antenna in the core produces a data rate of only 11 MB/s

The verdict on our ECP

- ECP140034 – Low-level access to SKA-Low antenna signals to allow cosmic array detection. Despite the recommendation to accept, the CCB rejected the ECP based on “the amount of work currently needed to establish the cost and interface with SKA. The ECP can be considered at a later time without much impact. With the next submission of this ECP a detailed proposal plan needs to accompany it, as the Atmospheric Particle Detection Group propose they supply the hardware. The SKA requirements need to be clearly stated.”

- We need to come up with a concrete design for the particle detector array, at least regarding requirements from the SKA. Until when?

Conclusion

- we have a promising science case, but we need to flesh it out
- the requested engineering changes are viable, but we need to become more precise in our requirements, in particular for the trigger array
- we need to prepare a revised ECP – until when?
- *more people need to get involved* in doing the work
- we need to acquire funding for people and the trigger array