Karlsruhe Institute of Technology

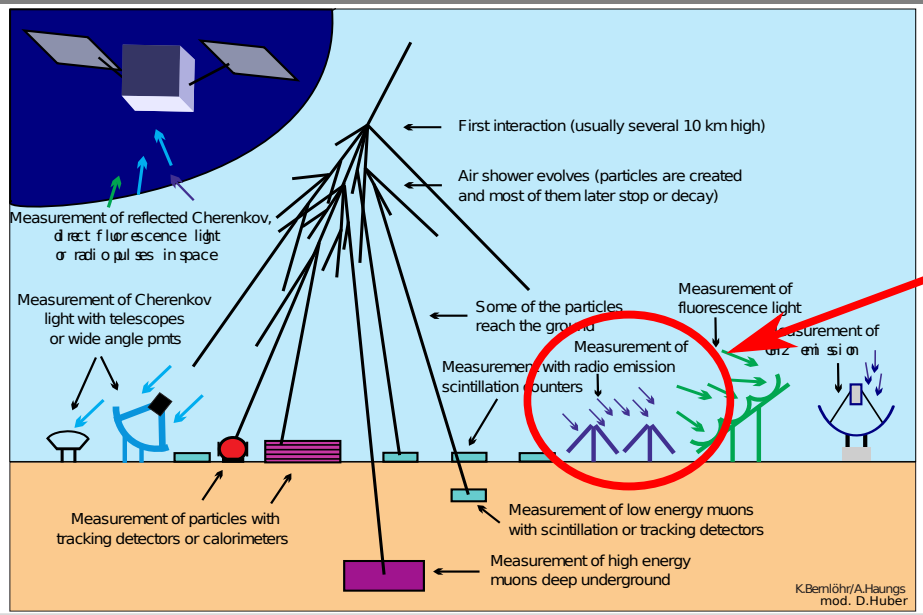
KSETA Doctoral Fellow

Studies of Radio Emission from Particle Showers

3rd KSETA Plenary Workshop 2016

Olga Kambeitz | 24.02.2016

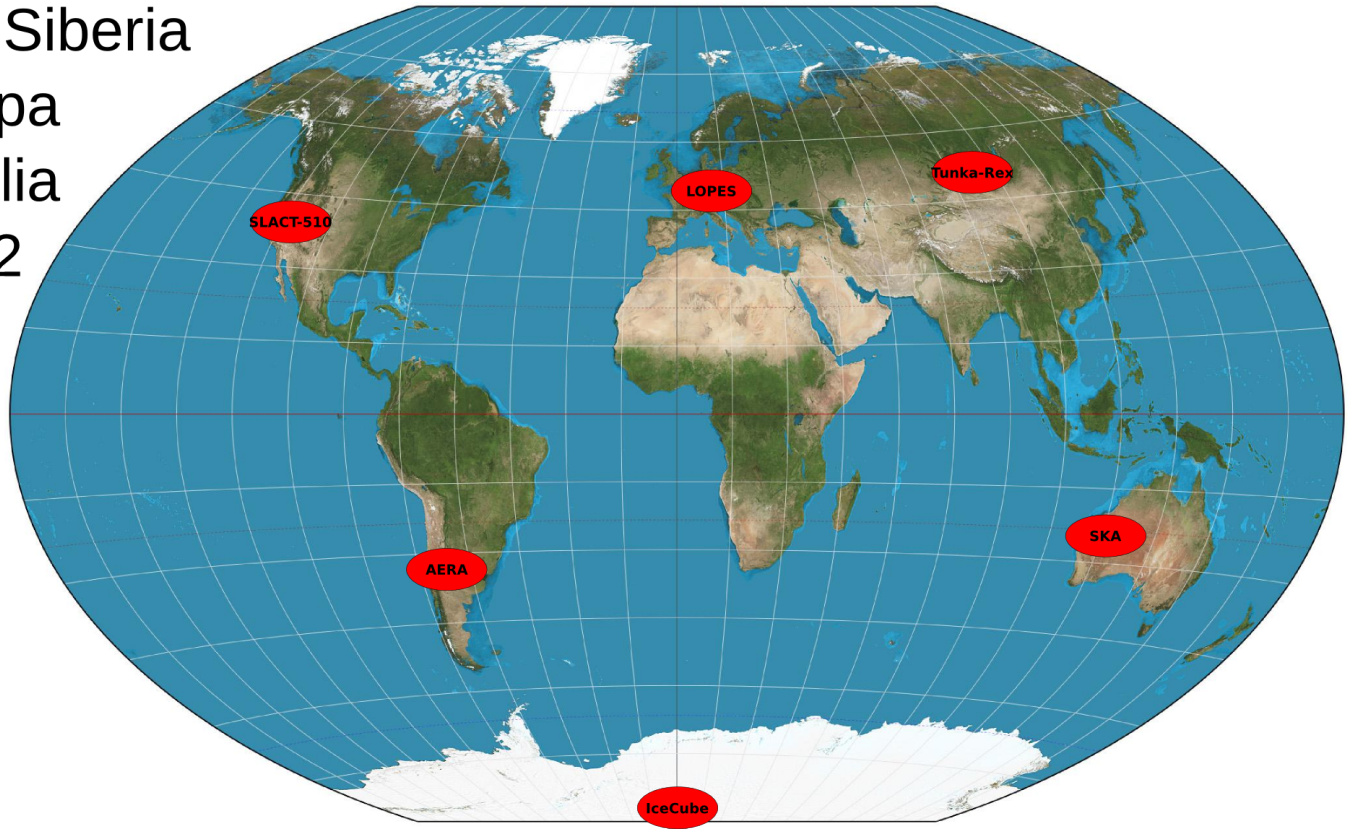
KARLSRUHE INSTITUTE OF TECHNOLOGY (KIT)



This talk

Overview

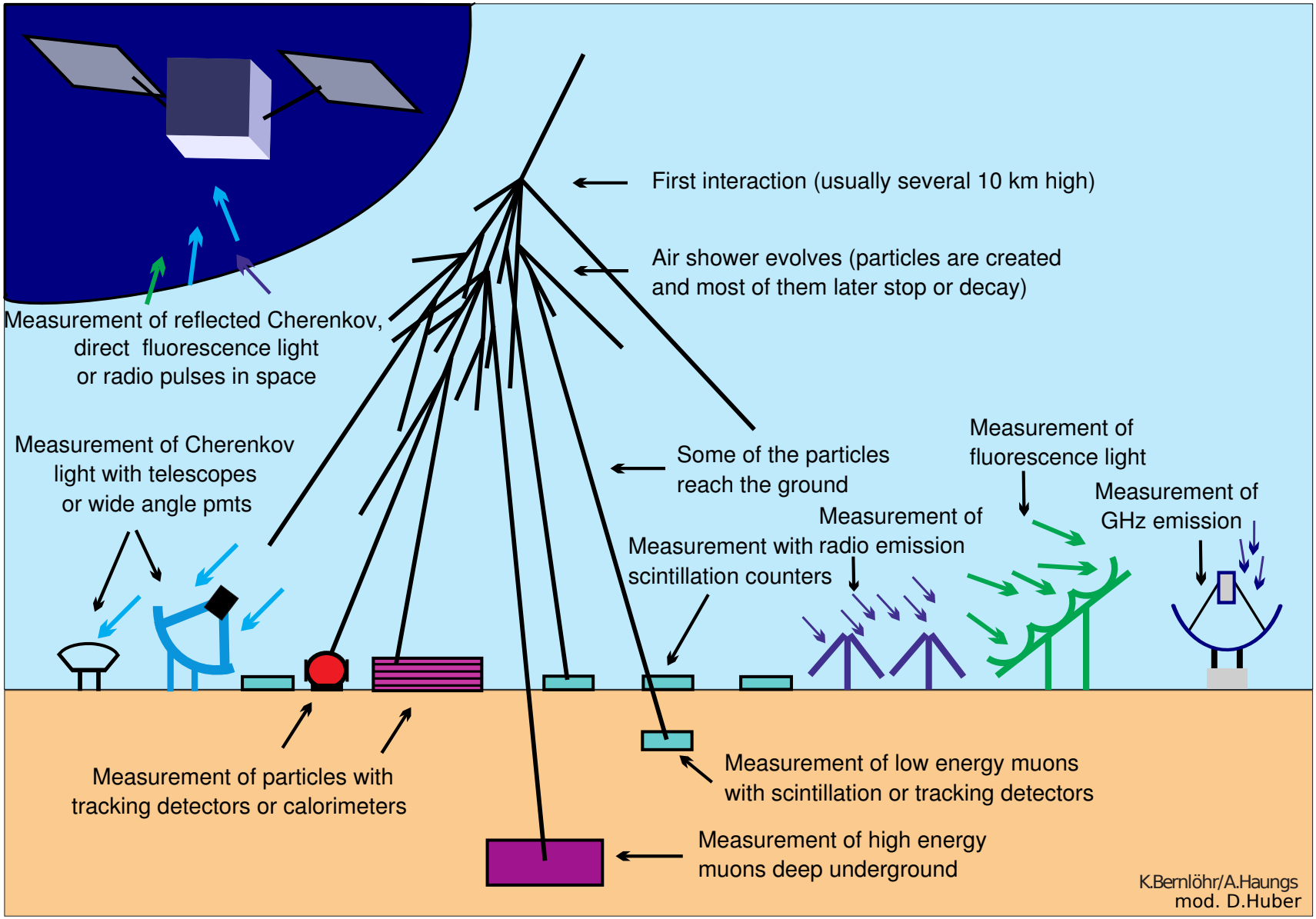
- Cosmic Rays
- Radio Emission
- Radio Detection Technology
  - SLAC T-510 in California
  - LOPES at Campus North
  - Tunka-Rex in Siberia
  - AERA in Pampa
  - SKA in Australia
  - IceCube-Gen2 at South Pole
- Conclusion



Cosmic Rays


Direction?
Energy?
Mass?
Photon
Neutrino
Charged cosmic ray
(ex.: Proton)
Cosmic
Riddle

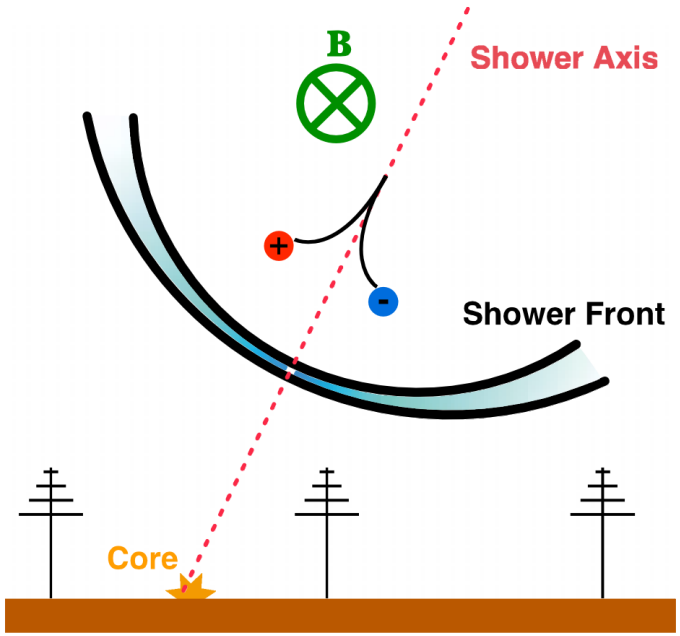
Detection Principles



Radio Emission from Air Showers

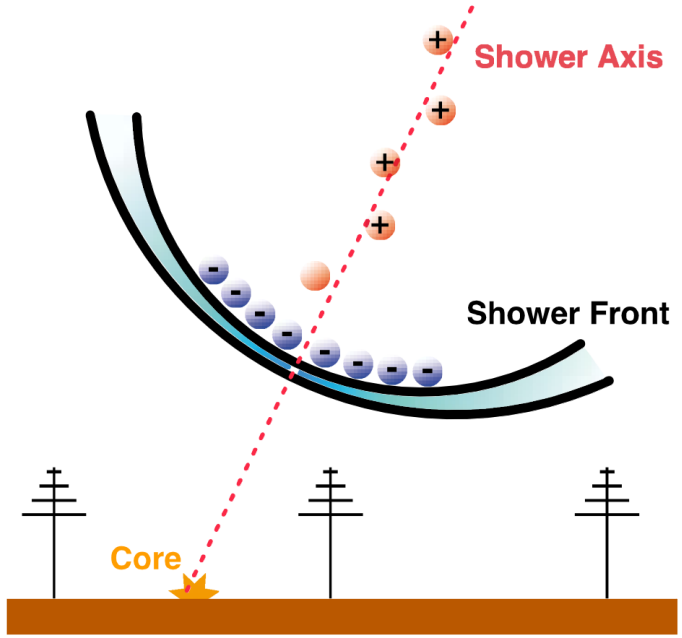
- Coherent emission at MHz frequencies
- Two relevant emission mechanisms:

Geomagnetic Effect



- Induction of time-varying current
- Dominant process

Askaryan Effect

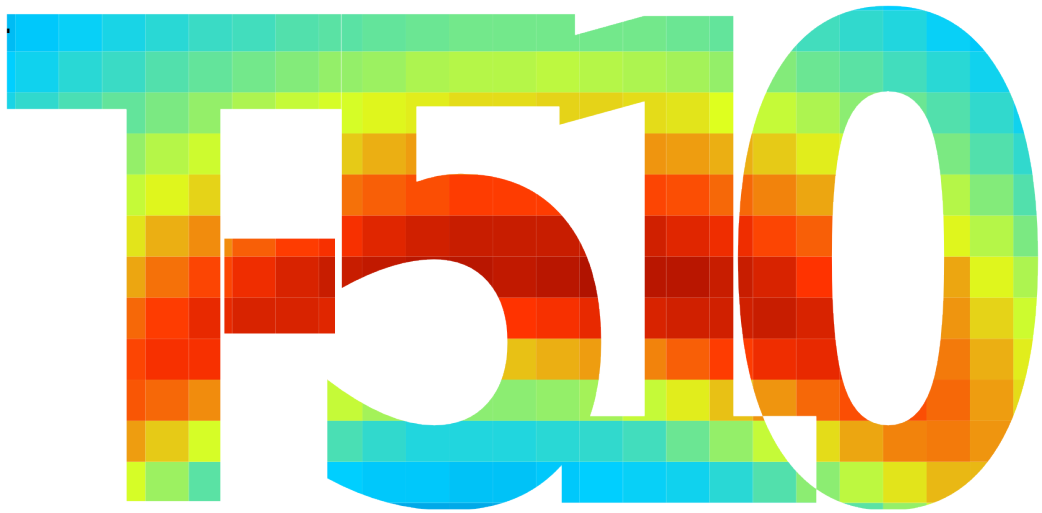


- Time-varying net charge of shower
- Second order effect

Motivation

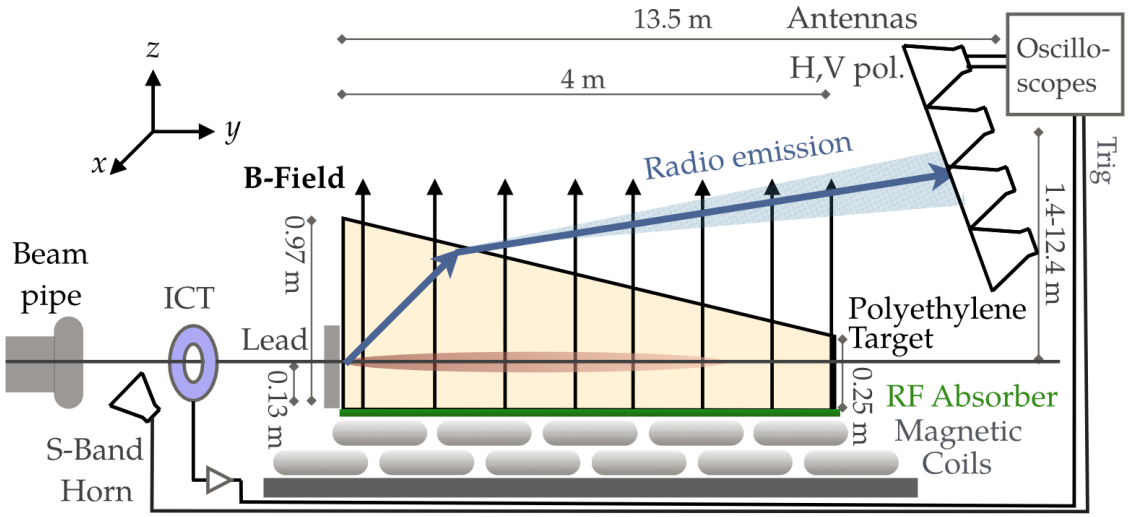
- General mission:
  - understanding radio emission
  - establishing radio detection technique
  - contributing to physics: energy,
    mass composition,
    horizontal air showers
- ideal in hybrid detection mode
- scalable detectors
- duty cycle of almost 100%
- high angular resolution (< 0.5°)
- calorimetric energy measurement of electromagnetic component

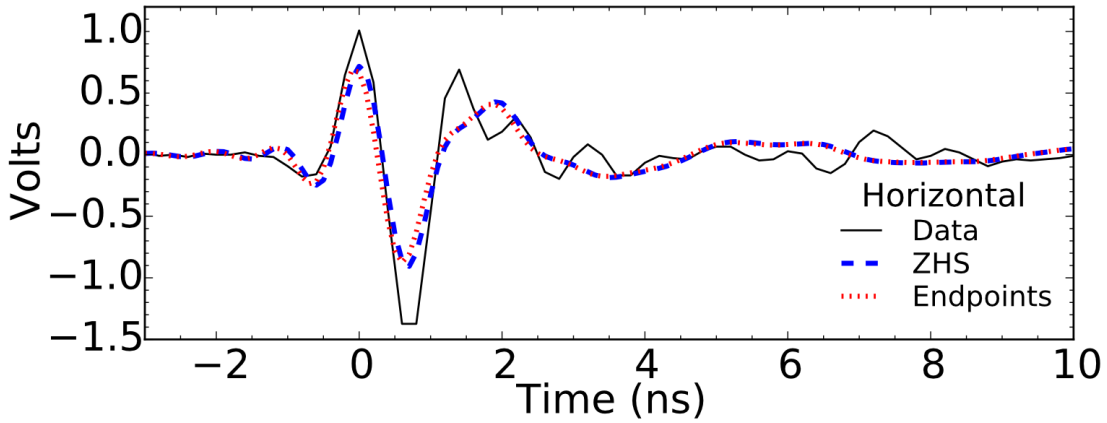
Understanding Radio Emission



- laboratory measurement of radio frequency emission from cascades of secondary particles
- first measurements that validate electrodynamic simulations

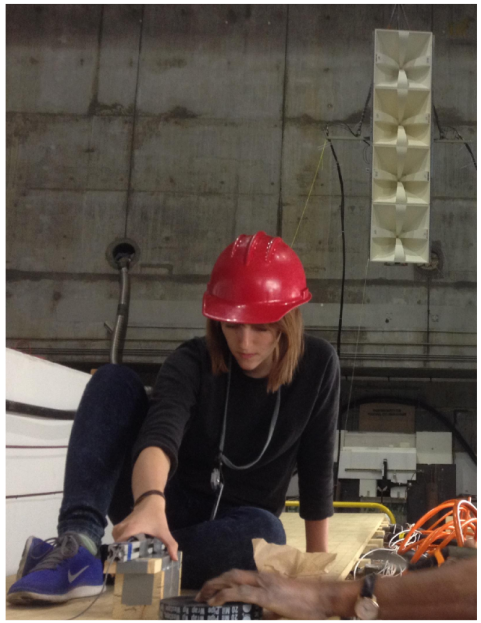
SLAC T-510





Accelerator experiment:

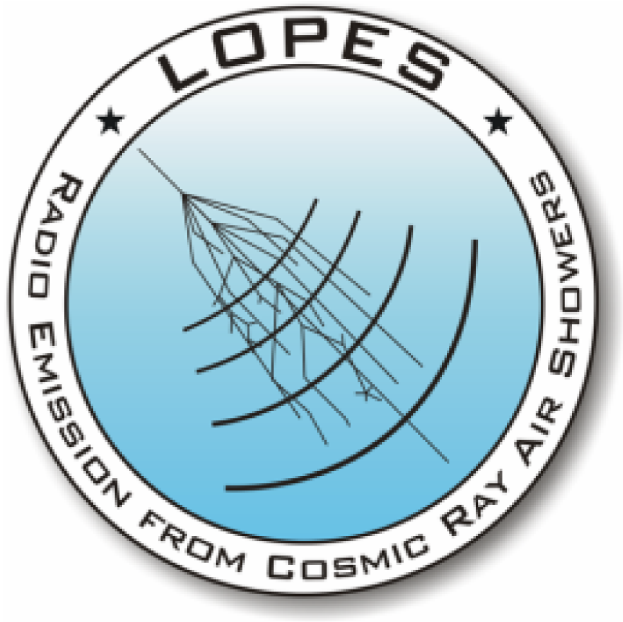
- 5 GeV electron beam
- high-density polyethylene target
- 1000G magnetic field
- 4 ANITA horn antennas



Result:

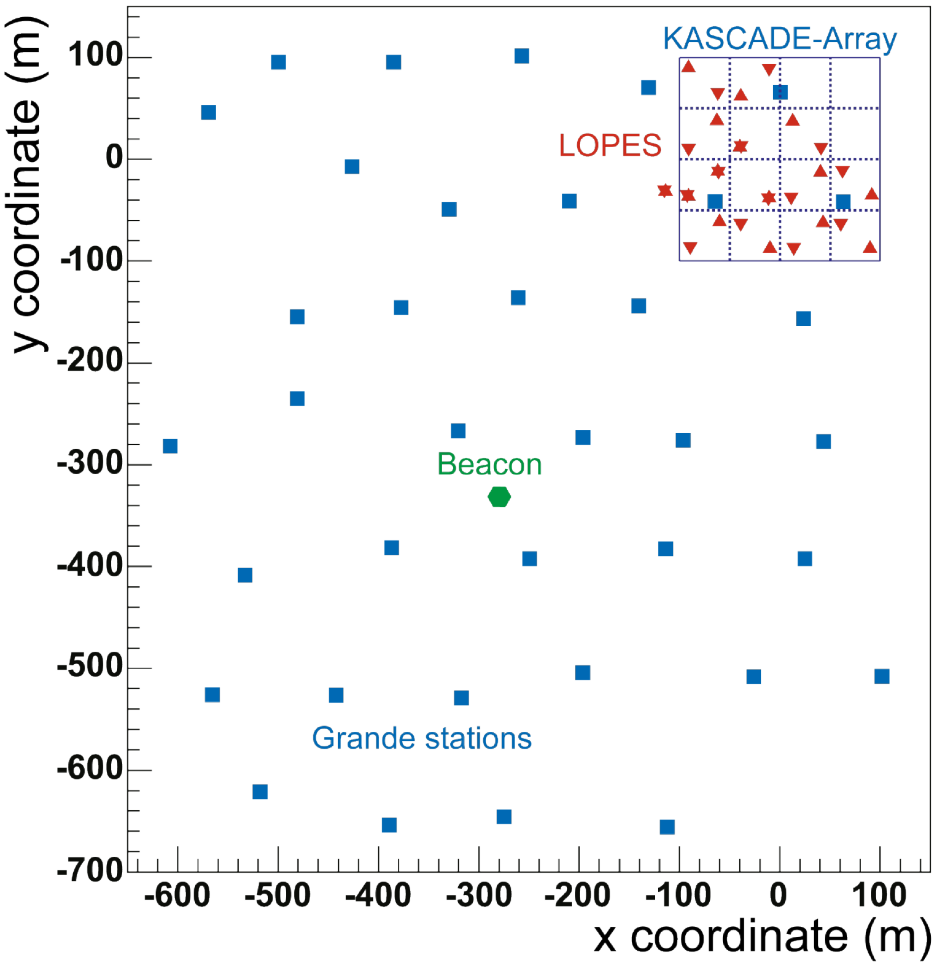
- ZHS and Endpoint describe the measured data

Proof of Principle



- Interferometric visualization of radio pulses
- Sensitivity to longitudinal shower development
- Shower maximum via wavefront

LOPES

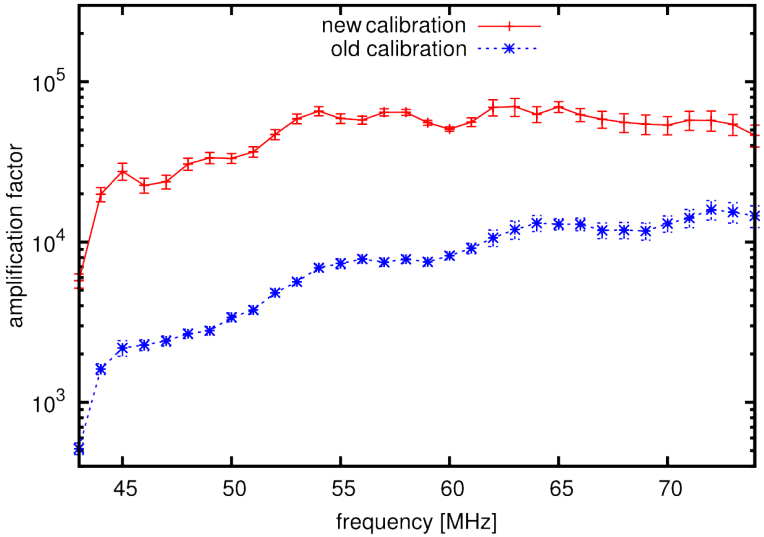


- 30 dipole antennas up to 2010

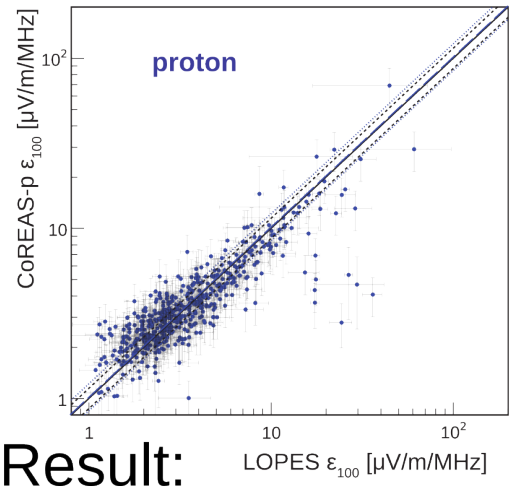
- 10 tripole antennas up to 2013

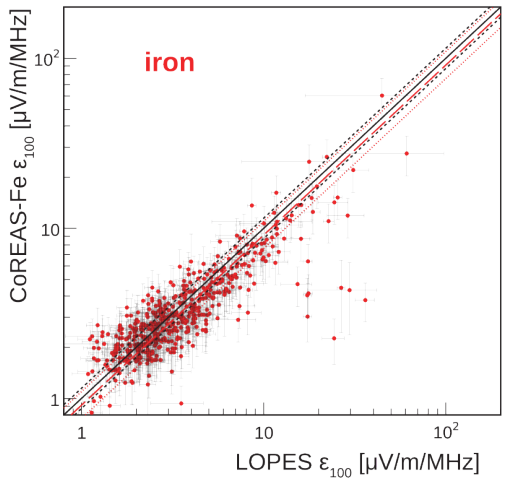
- triggered by KASCADE

LOPES



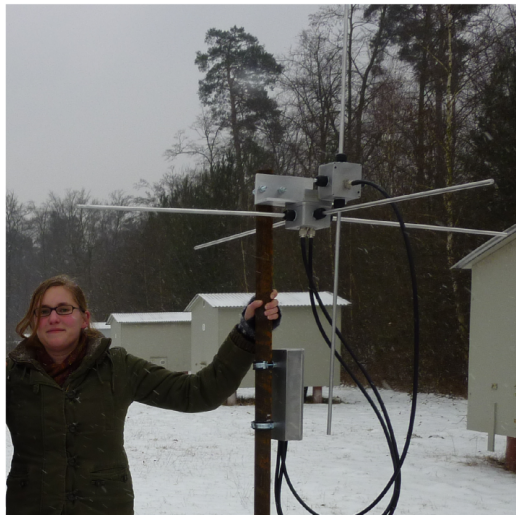
- Comparison of LOPES data with CoREAS simulations using full detector simulation
- Revised absolute amplitude calibration of LOPES





Result:

- The updated calibration leads to a better agreement with CoREAS simulations



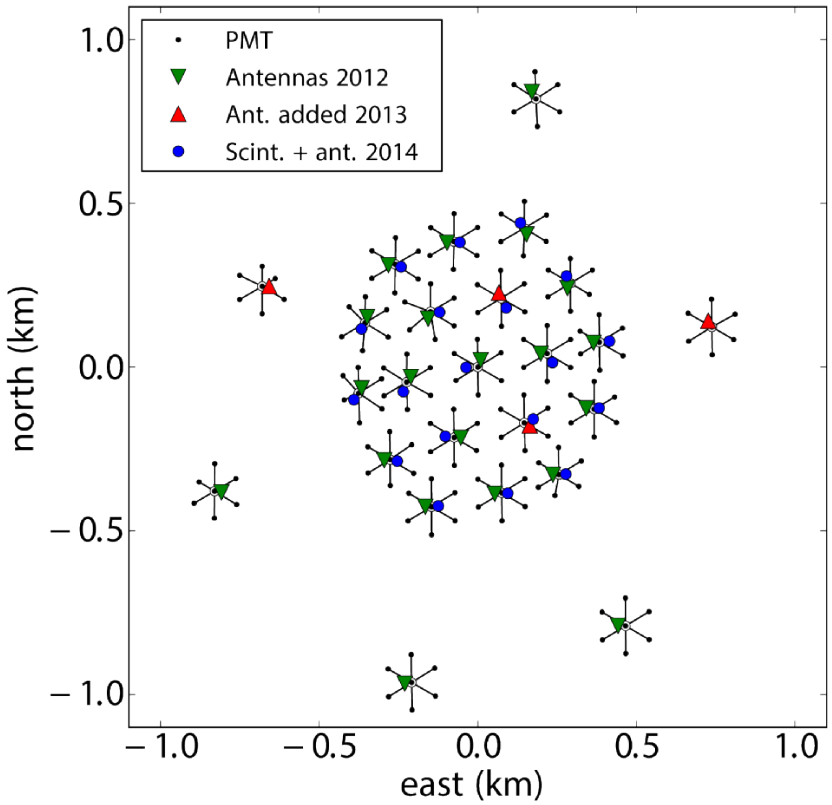
Proof of Feasibility

- Absolute amplitude calibration
- Determination of Xmax and radio energy
- Correction of lateral distribution function for asymmetry

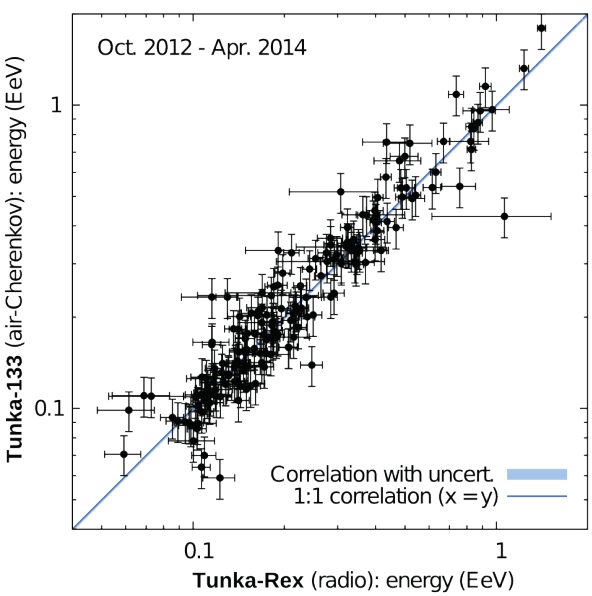
Tunka-Rex

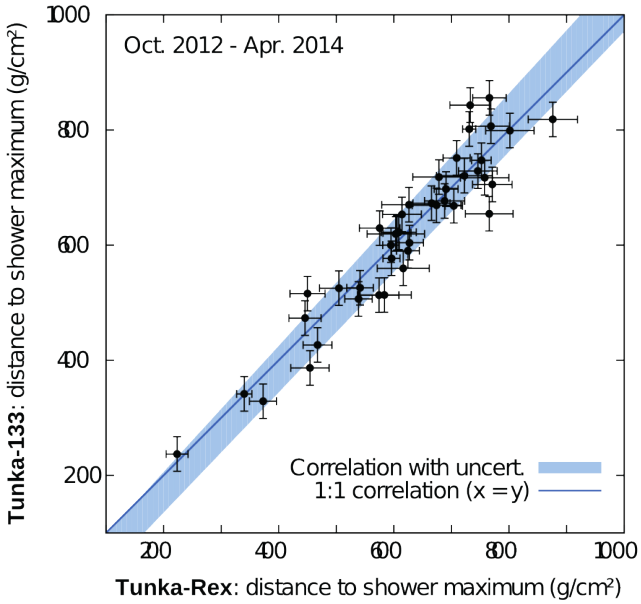
44 SALLA antennas:

- 25 triggered by Tunka-133 photo-multipliers
- 19 triggered by Tunka-Grande scintillators



Tunka-Rex

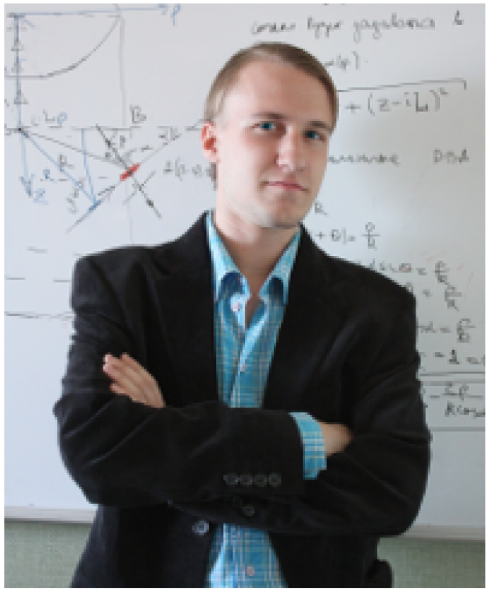




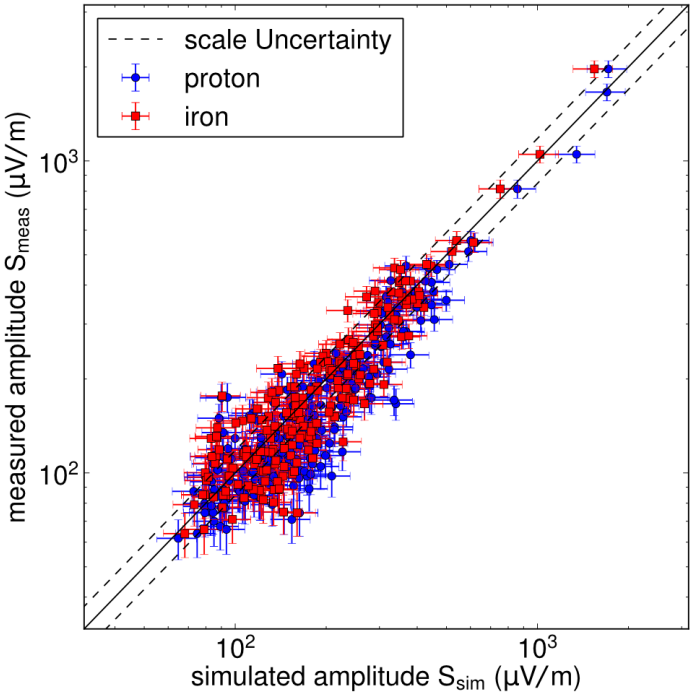
- Determination of radio energy and Xmax
- Reconstruction of air shower parameters

Result:

- Precision in radio energy of 20 % due to the absolute scale uncertainty
- Radio Xmax resolution of 40 g/cm^2



Tunka-Rex

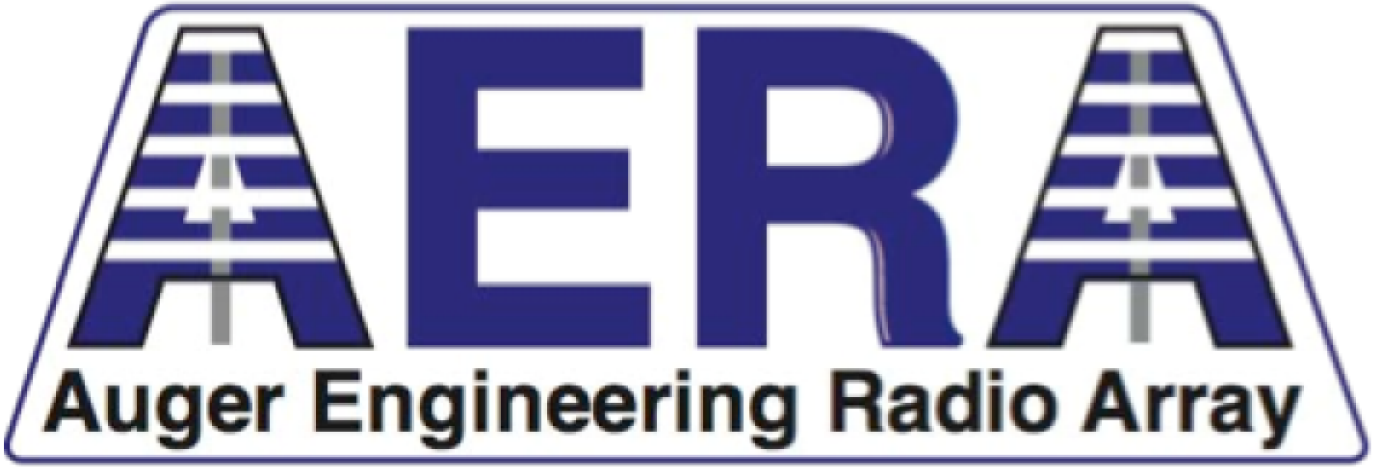


- Absolut calibration of antenna (also for other experiments)
- Measured amplitude and simulation comparison

Result:

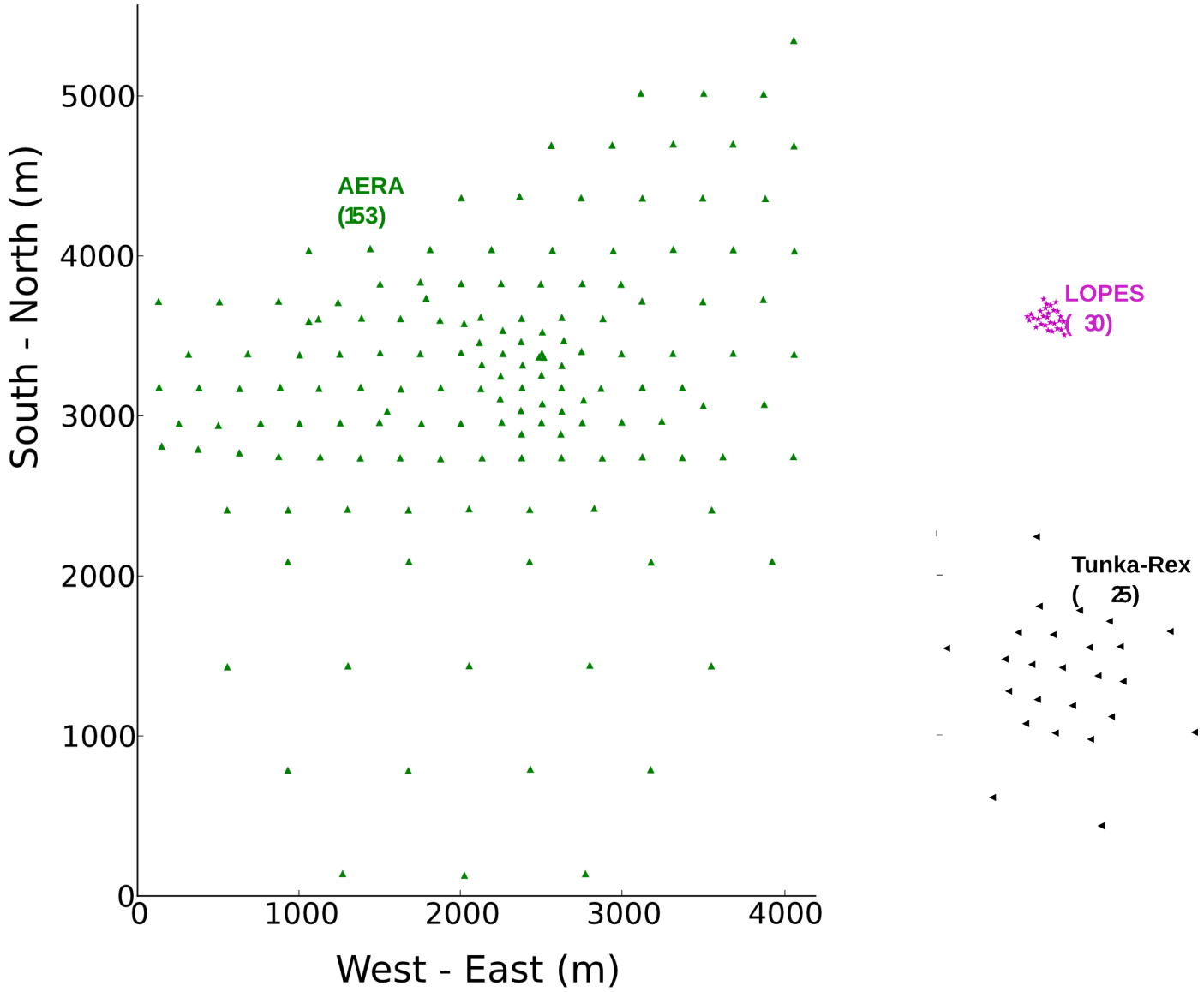
- LOPES got a new calibration and the factor 2 discrepancy of simulation and measured data could be solved
- Radio amplitude precision of 20%

Larger Dimension



- Polarisation measurement
- Nanosecond-level time synchronization
- Energy estimation of cosmic rays
- Different concepts of Xmax determination

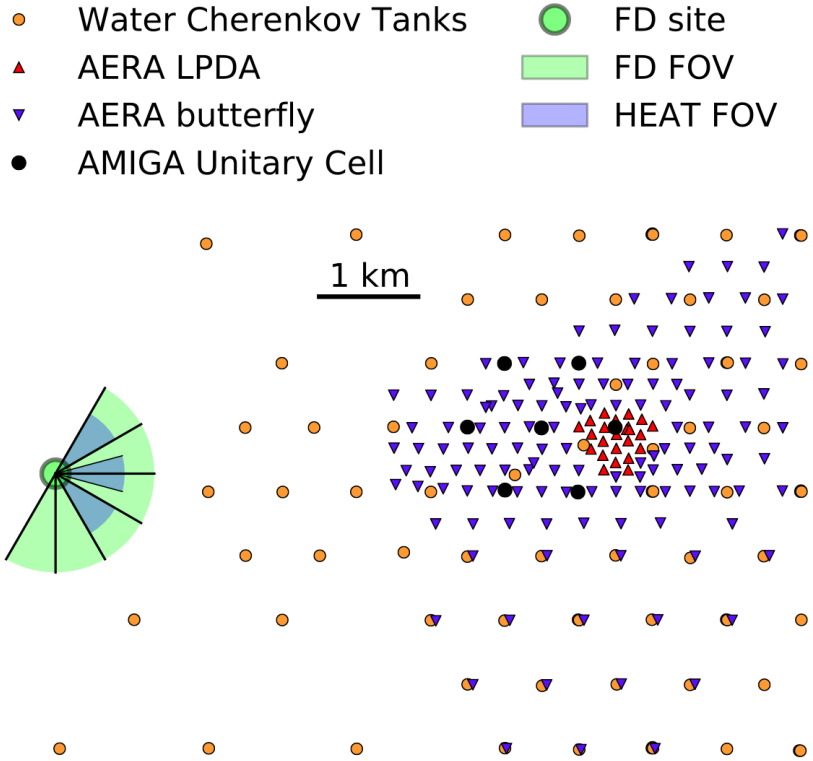
AERA


AERA
(153)
LOPES
(30)
Tunka-Rex
(25)
South - North (m)
West - East (m)
0
1000
2000
3000
4000
5000

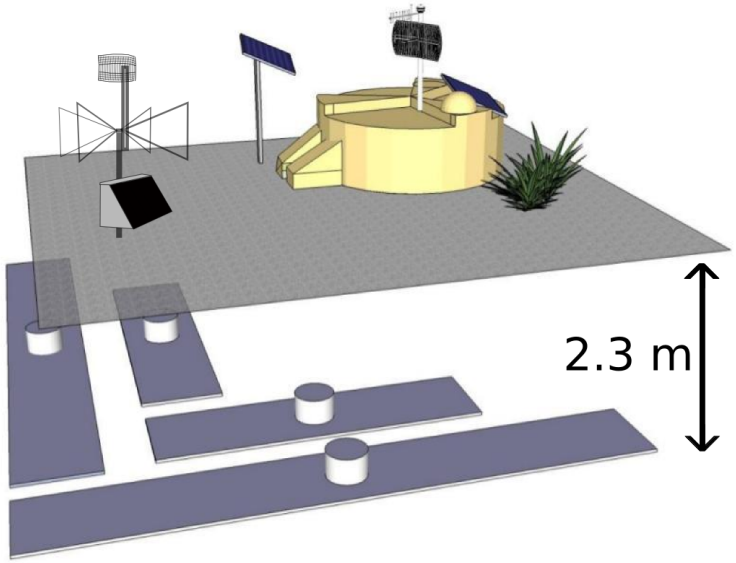
AERA

153 antenna stations:

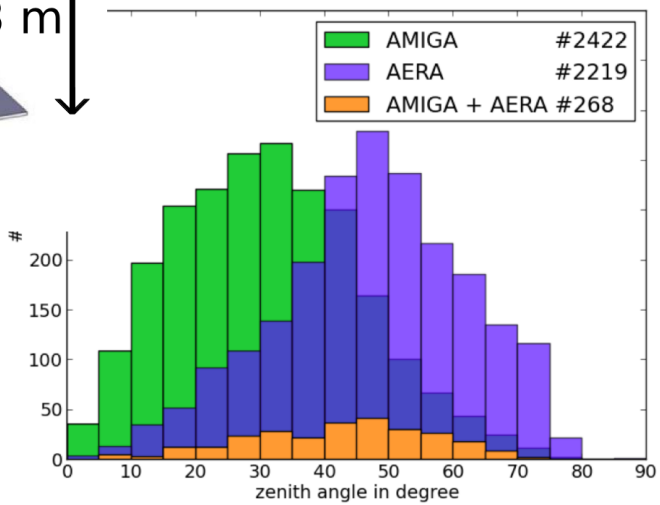
- 24 LPDA antennas since 2011
- 125 Butterfly antennas since 2014
- 4 tripole antennas since 2013
- triggered by Auger (SD and FD)



AERA



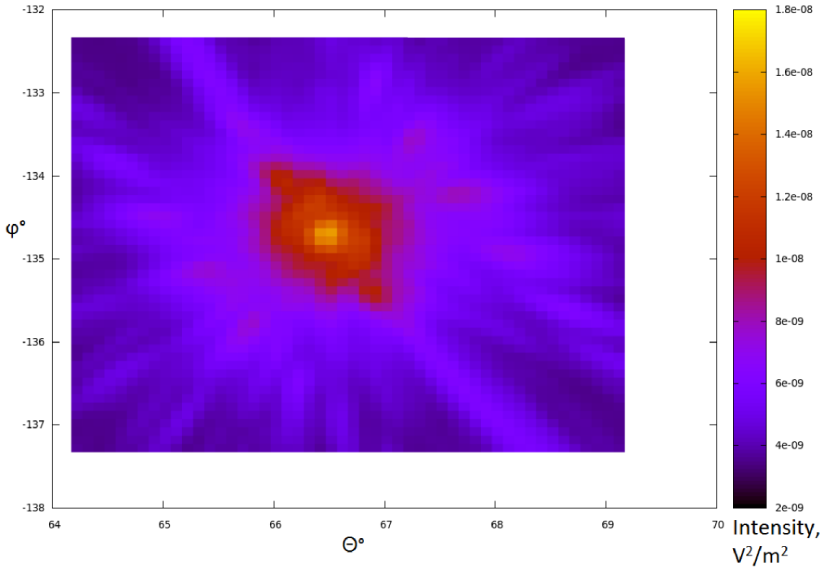
- combined analysis of AERA and AMIGA data
- composition determination



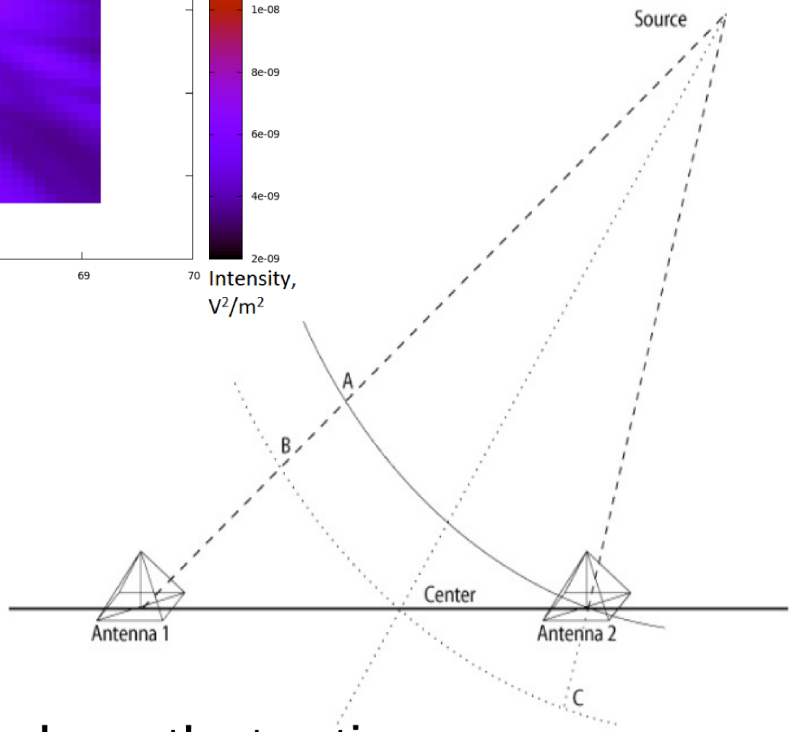
Result:

- Super-hybrid events (AERA, AMIGA, surface detector, fluoreszence detector)
- Muon number (AMIGA) and electron number (AERA) will determine mass composition

AERA



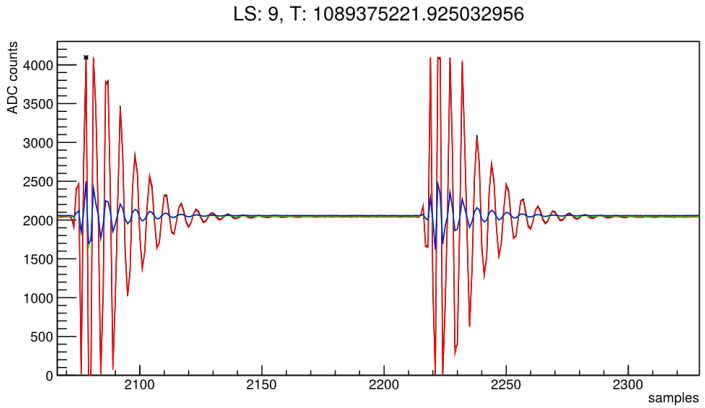
- Interferometry with AERA



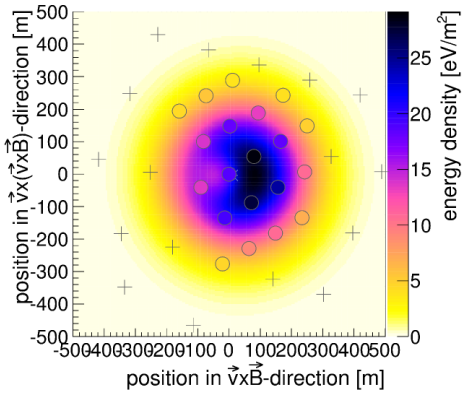
Result:

- Simulation studies show that a time synchronisation of 1 ns is needed for interferometry

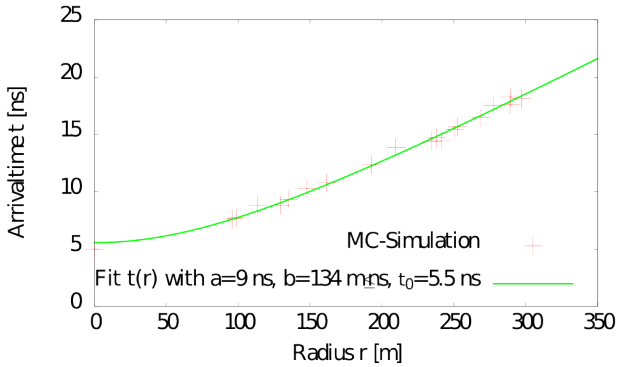
AERA



- changes in electronics software
- "global fit" approach



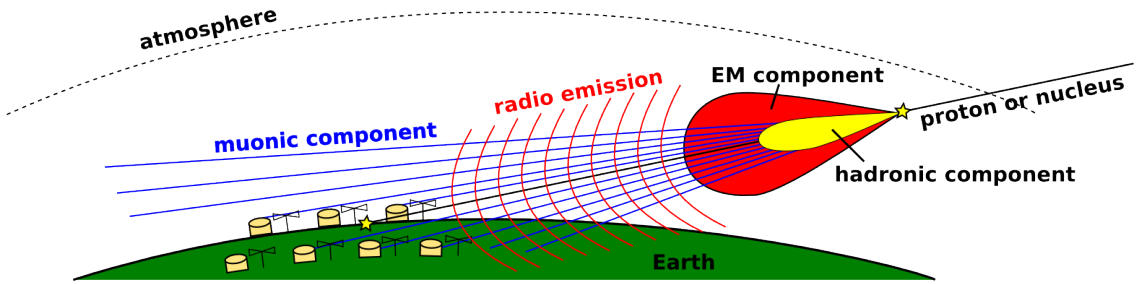
+



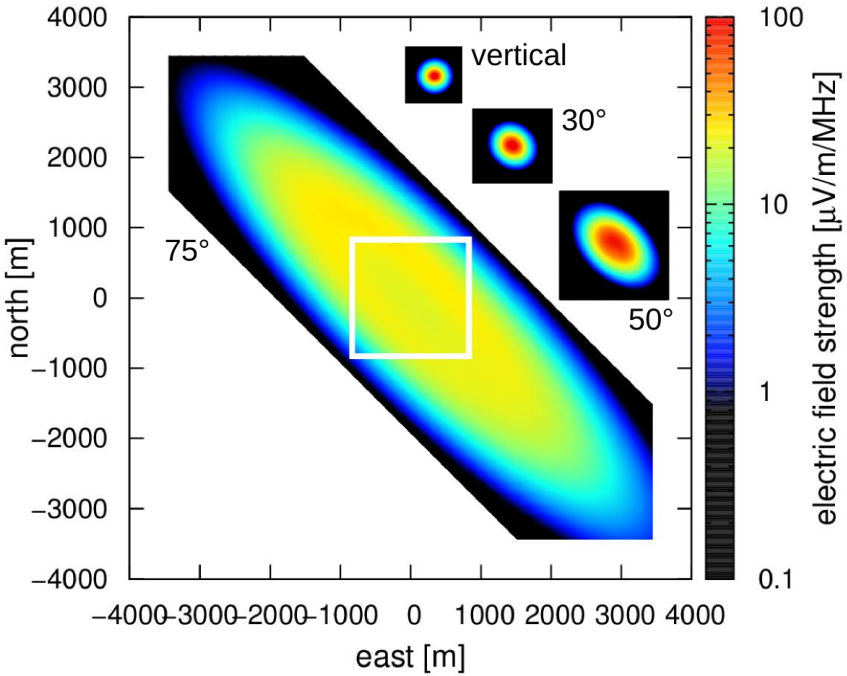
Result:

- Read-out of 4 channels (instead of 2)
- First combination of reconstruction modules for AERA

AERA

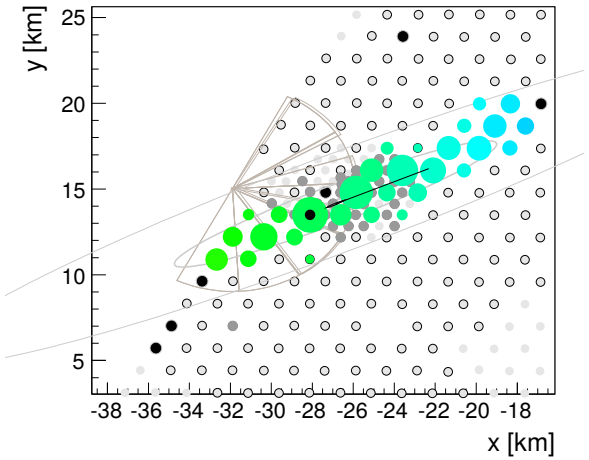


- Radio detection of horizontal air showers
- Lateral distribution function studies
- Energy of horizontal air showers



AERA

SdHAS

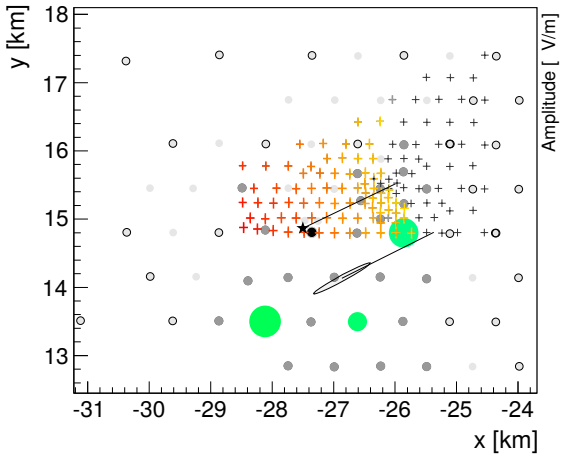


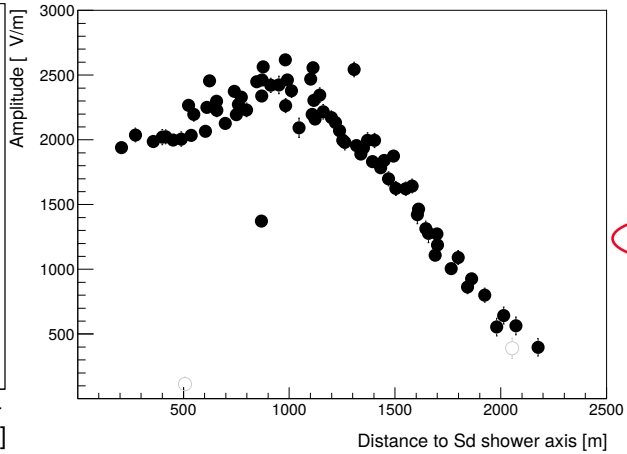
Event 24667045 :-)
Time (UTC): 2013/12/18 12:40:29
Time (GPS): 1071405645 s 189283000 ns
Trigger: 4C1; no T5
Stations: 35 (Acc: 11, Bad: 82)

Global reconstruction (LDF + axis) (5)
E = (1.64 ± 0.16) 10^{19} eV
(θ, ϕ) = (82.8 ± 0.1, 24.3 ± 0.1) deg
(x,y) = (-26.87 ± 0.31, 14.13 ±0.15) km
N19 = 3.4 ± 0.3
radius = 88.86 ± 0.34 km

Monitoring
average stations age: 14.0 yr

AERA



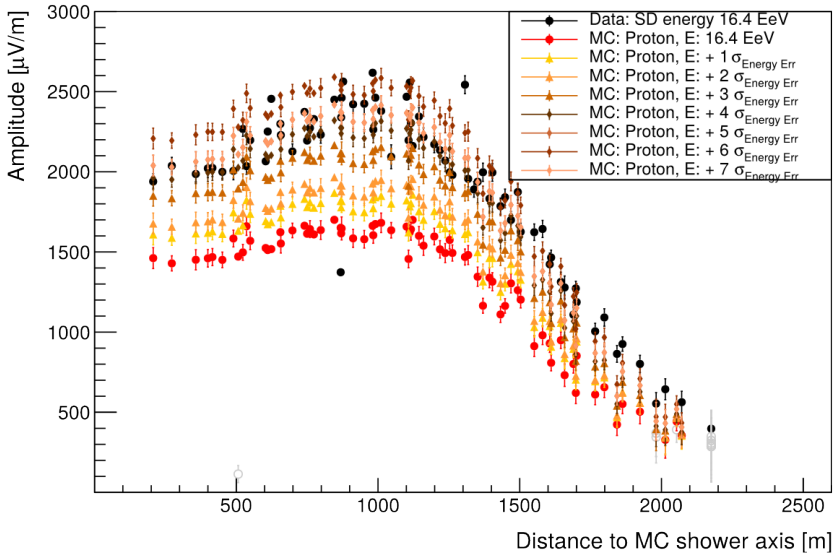


Run 100785 Event 137009
GPS Time 1071405645 s 189270974 ns
UTC Date: 2013/12/18 12:40:29
RecStage = LDFFit2dWithCore
θ = 82.73 deg ϕ= 23. 45
Radio energy: 2.04e+09 +/- 8.27e+07 eV
Stations: 75
radius = 1 ±nan m
FitStatus = successful
Chi2/NDF = 49.3 / 72
x = -27.5 km, y = 14.87 km
α = 65°

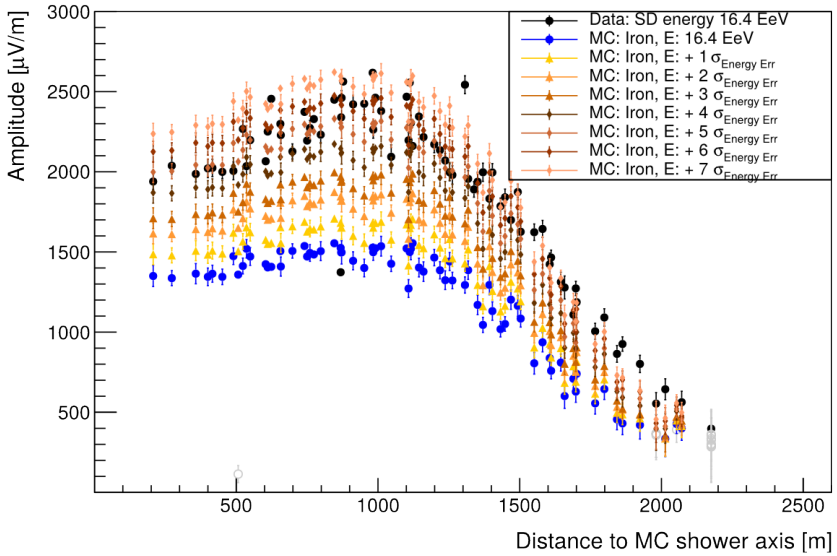
AERA

- Understanding lateral distribution functions of horizontal air showers is essential for radio energy determination

Protons

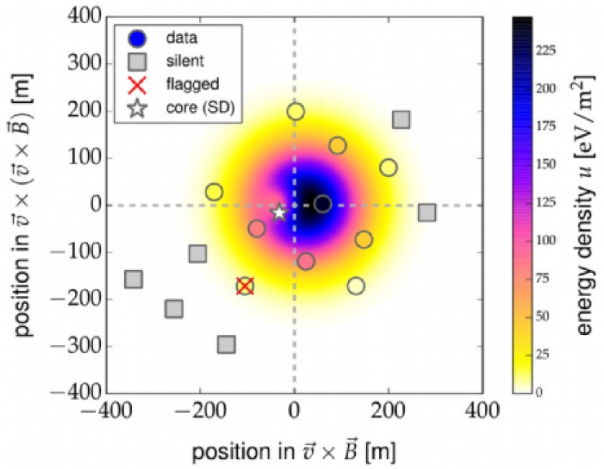


Iron



- Variation in core and energy are performed

AERA

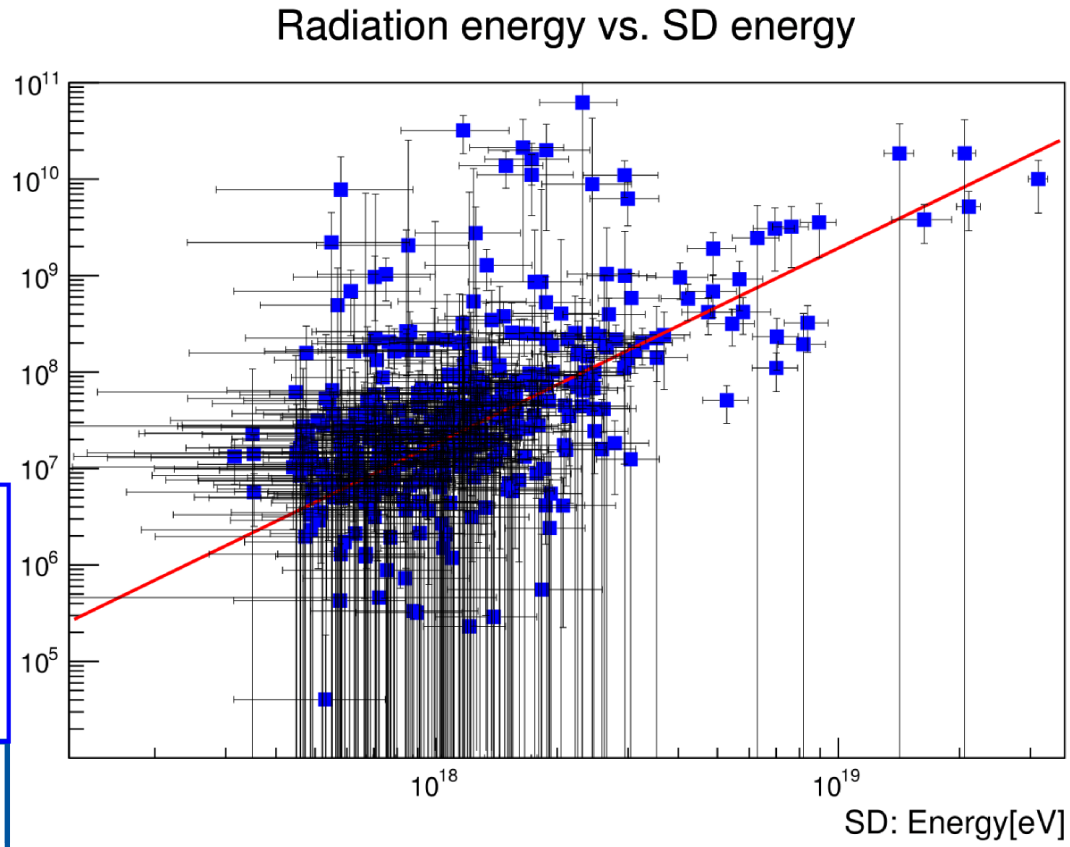


2D fit function:

$$u(\vec{r}) = A\left[\exp\left(\frac{-(\vec{r} + C_1\,\vec{e}_{\vec{v}\times\vec{B}} - \vec{r}_{\text{core}})^2}{\sigma^2}\right) - C_0\exp\left(\frac{-(\vec{r} + C_2\,\vec{e}_{\vec{v}\times\vec{B}} - \vec{r}_{\text{core}})^2}{(C_5 e^{C_3+C_4 v})^2}\right)\right]$$

$$E_{\text{radiation}} = \int u(\vec{r})\,d\vec{r}$$

Energy in MHz radiation [eV]



Result:

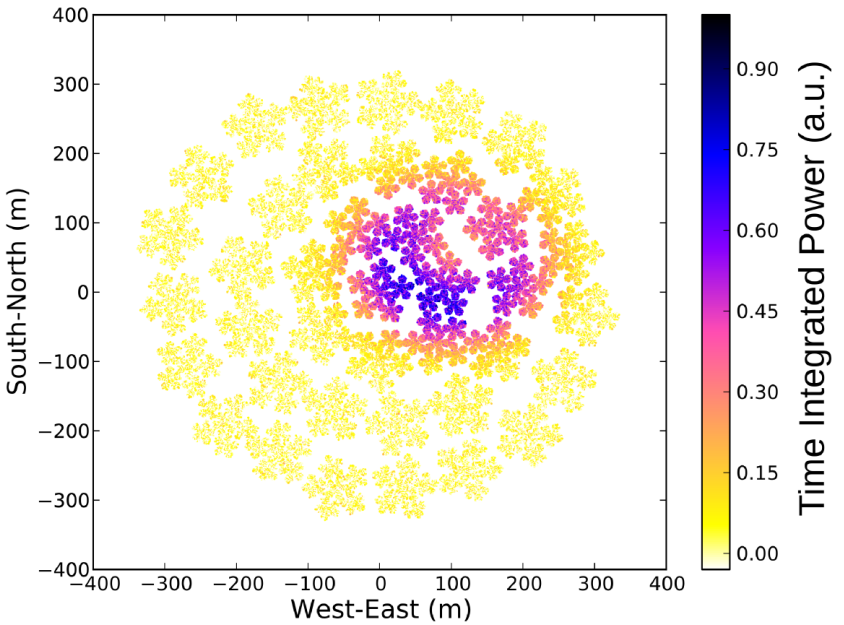
- First determination of energy estimator for horizontal air showers
- Needs some improvements in 2D lateral distribution fit

Experiment of the Future

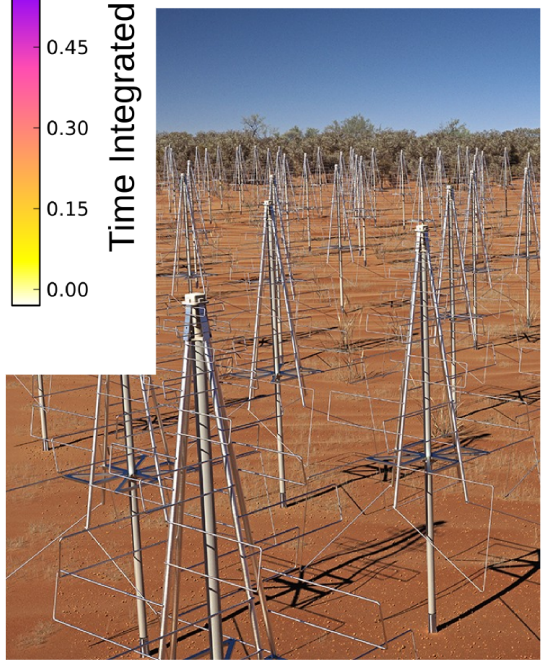
High Energy Cosmic Particles Focus Group

- Exploring the Universe with the world's largest radio telescope
- Topography of radio emission with additional particle detectors

SKA



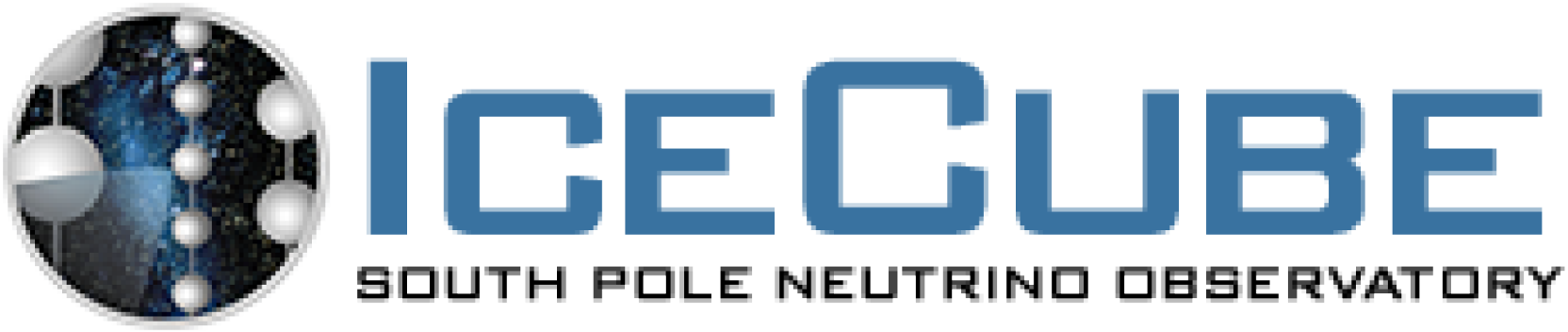
- 60,000 dipole antennas planned
- Particle detectors for triggering



Result:

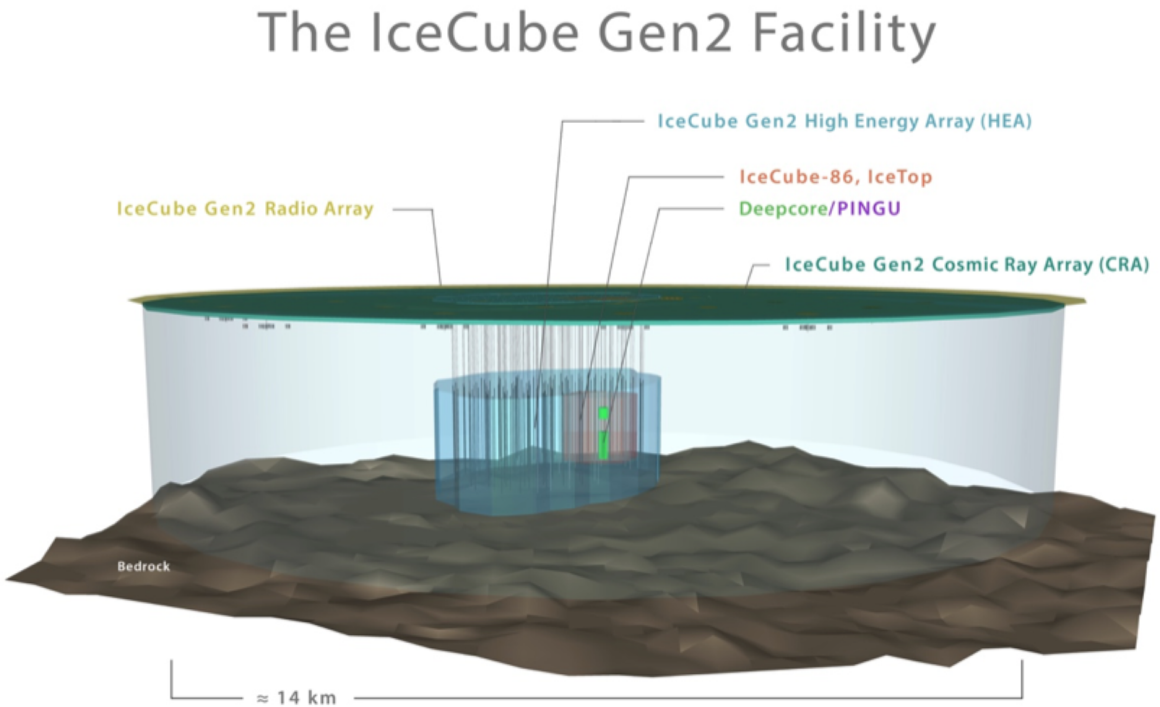
- Simulation studies of feasibility and science potential ongoing

Beyond IceCube



- Upgrade of IceCube from 1 km^3 to 10 km^3 detector volume
- IceCube-Gen2 cosmic ray array on surface (veto)
- IceCube-Gen2 radio array?

IceCube-Gen2



- Upgrade of the surface/veto array
- Studying the radio extension

Result:

- Simulation studies whether primary gammas from the galactic center can be detected

Conclusion

- General mission:
  - understanding radio emission: done
  - establishing radio detection technique: done
  - contributing to physics: energy, mass composition, horizontal air showers: ongoing
- Radio Detection Technology:
  - alternative approach for E $> 10^{17}$ eV
  - similar precision possible as for established techniques
  - ideal for combinations in hybrid detectors
  - high efficiency for inclined showers
- Experiments:
  - SLAC T-510
    accelerator test measurement to validate simulation codes
  - LOPES
    proof of principle of radio technique
  - Tunka-Rex
    proof of feasibility of radio technique
  - AERA
    world-largest radio engineering array
  - SKA
    future radio experiment for topography of radio emission
  - IceCube-Gen2
    study of radio extension