Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

Jörg R. Hörandel on behalf of the Pierre Auger Collaboration

Radboud University Nijmegen, Nikhef, Vrije Universiteit Brussel

http://particle.astro.ru.nl

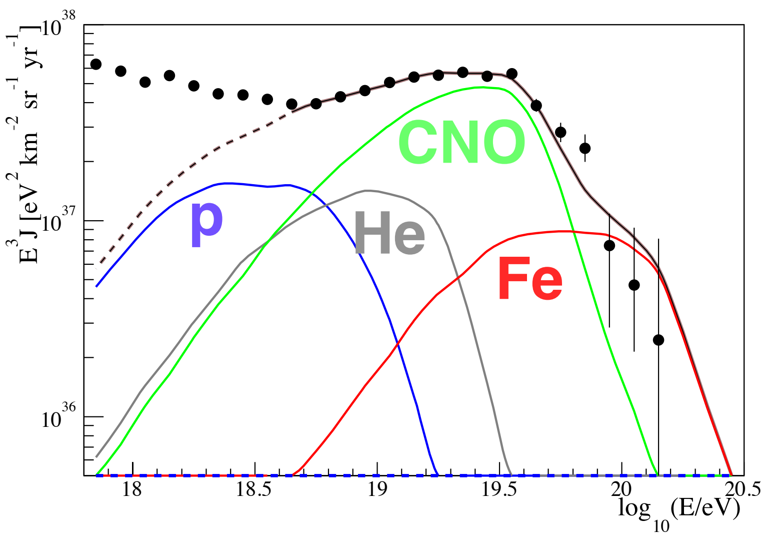
Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

Key science questions

- What are the sources and acceleration mechanisms of ultra-high-energy cosmic rays (UHECRs)?

- Do we understand particle acceleration and physics at energies well beyond the LHC (Large Hadron Collider) scale?

- What is the fraction of protons, photons, and neutrinos in cosmic rays at the highest energies?



maximum rigidity

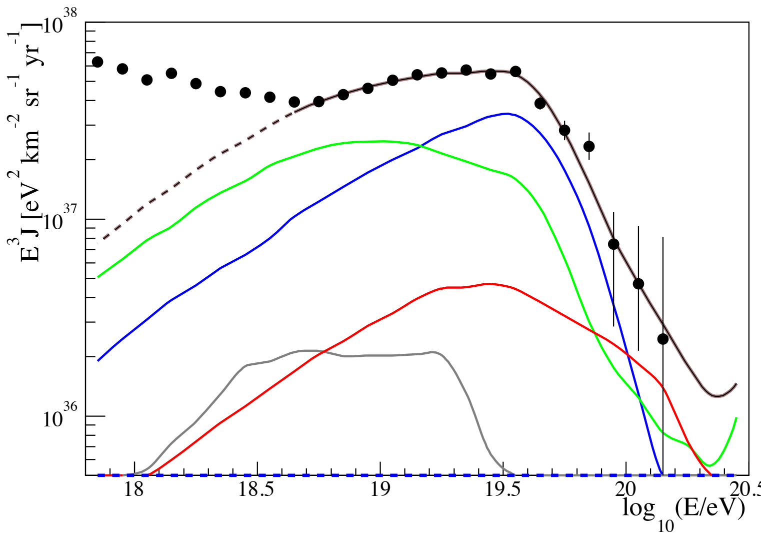


photo disintegration

Jörg R. Hörandel on behalf of the Pierre Auger Collaboration

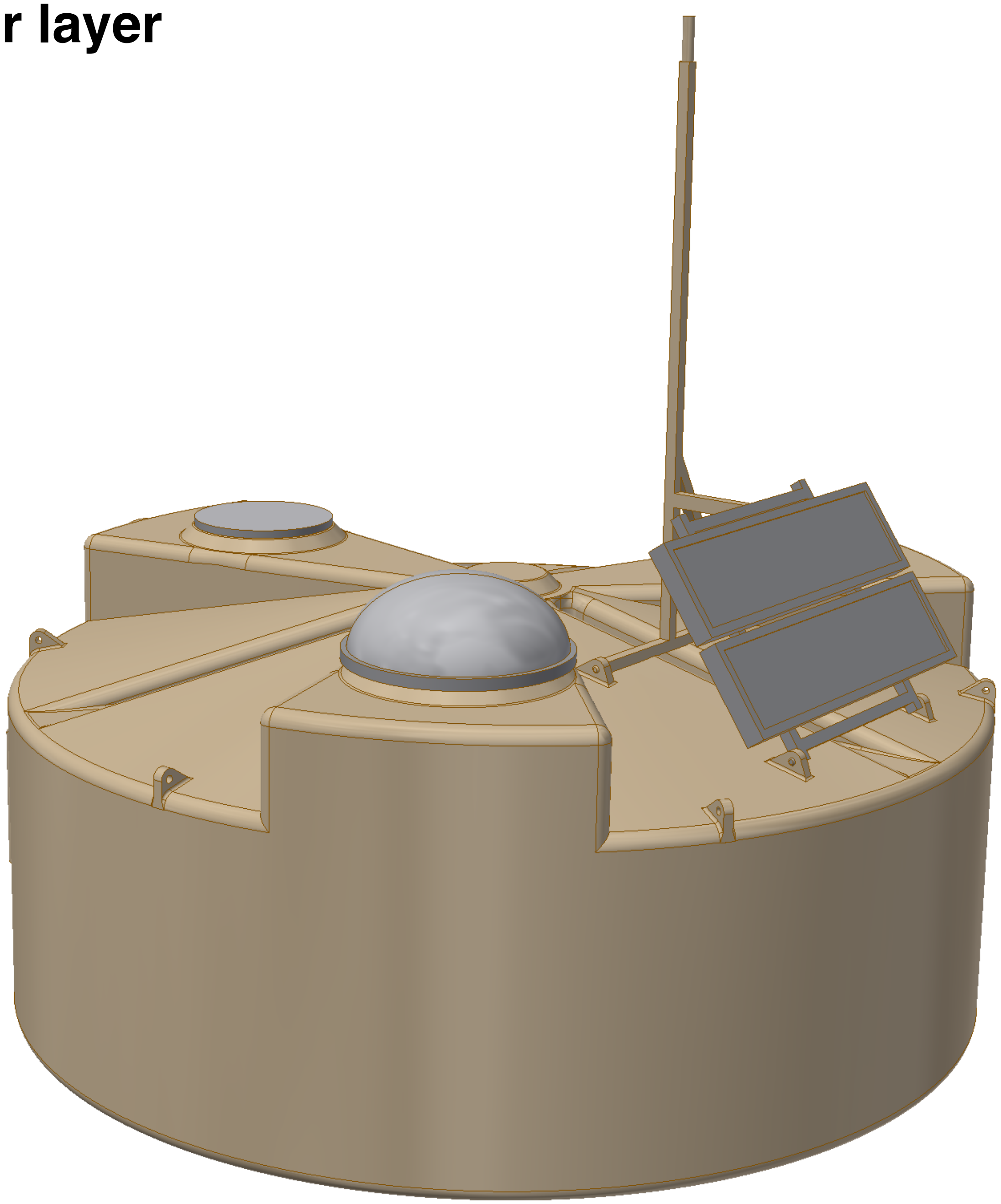
Radboud University Nijmegen, Nikhef, Vrije Universiteit Brussel

http://particle.astro.ru.nl

Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

upgrade PAO

- electronics
- scintillator layer



Key science questions

- What are the sources and acceleration mechanisms of ultra-high-energy cosmic rays (UHECRs)?
- Do we understand particle acceleration and physics at energies well beyond the LHC (Large Hadron Collider) scale?
- What is the fraction of protons, photons, and neutrinos in cosmic rays at the highest energies?

PIERRE AUGER OBSERVATORY

Jörg R. Hörandel on behalf of the Pierre Auger Collaboration

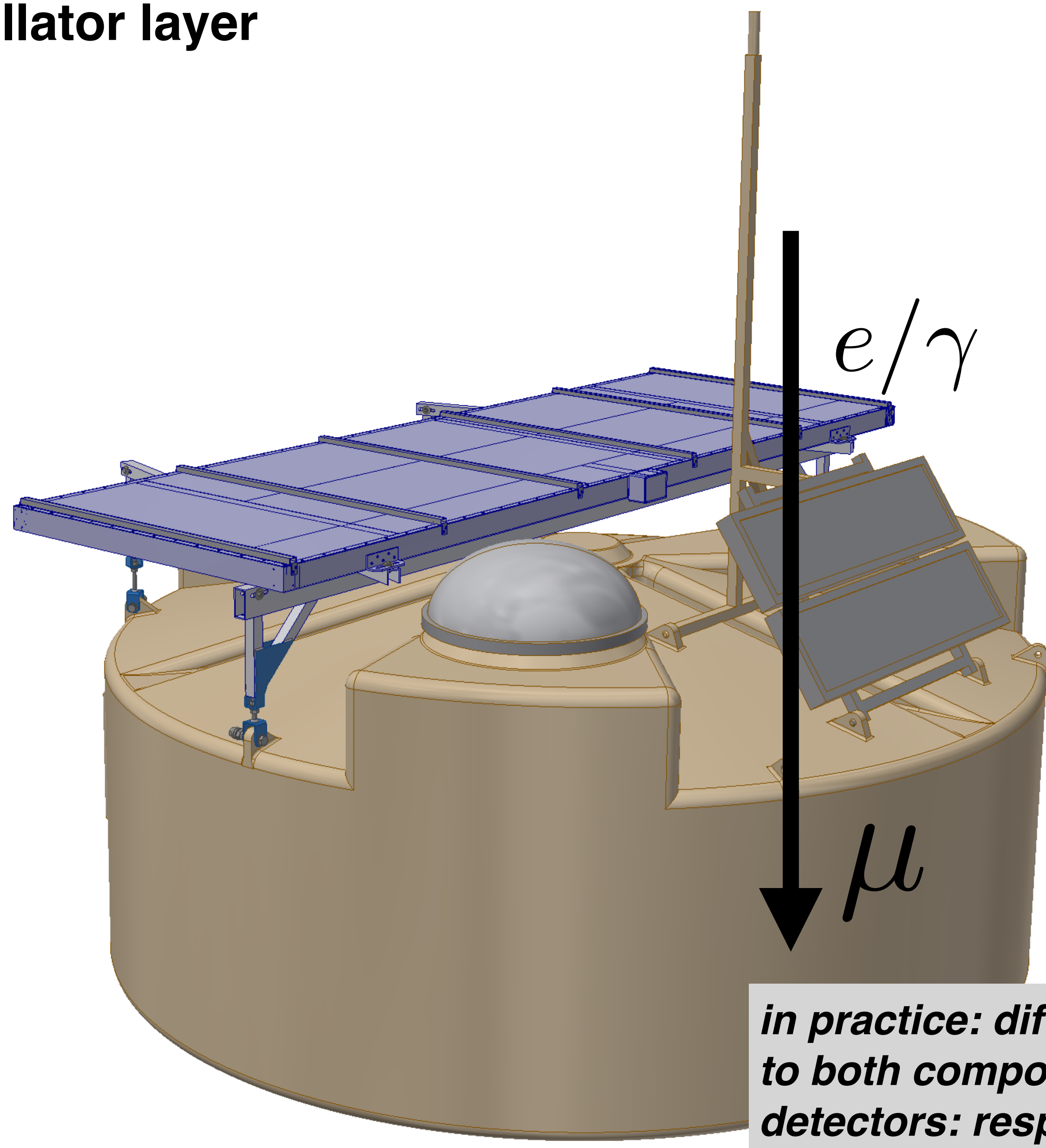
Radboud University Nijmegen, Nikhef, Vrije Universiteit Brussel

http://particle.astro.ru.nl

Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

upgrade PAO

- electronics
- scintillator layer



in practice: different response to both components in both detectors: response matrix

Key science questions

- What are the sources and acceleration mechanisms of ultra-high-energy cosmic rays (UHECRs)?
- Do we understand particle acceleration and physics at energies well beyond the LHC (Large Hadron Collider) scale?
- What is the fraction of protons, photons, and neutrinos in cosmic rays at the highest energies?

PIERRE AUGER OBSERVATORY

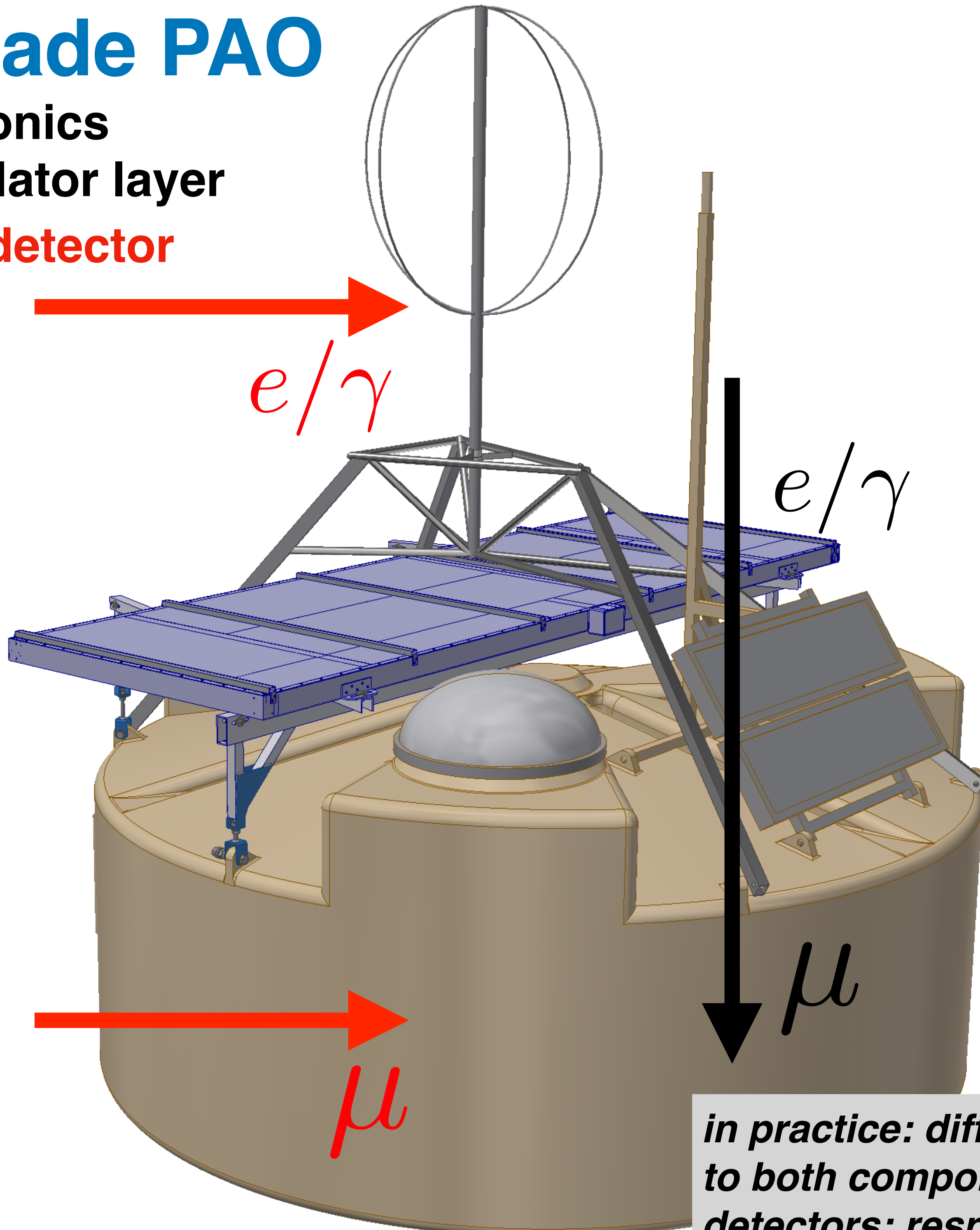
Jörg R. Hörandel on behalf of the Pierre Auger Collaboration

Radboud University Nijmegen, Nikhef, Vrije Universiteit Brussel

Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

upgrade PAO

- electronics
- scintillator layer
- radio detector



in practice: different response to both components in both detectors: response matrix

Key science questions

- What are the sources and acceleration mechanisms of ultra-high-energy cosmic rays (UHECRs)?
- Do we understand particle acceleration and physics at energies well beyond the LHC (Large Hadron Collider) scale?
- What is the fraction of protons, photons, and neutrinos in cosmic rays at the highest energies?

PIERRE AUGER OBSERVATORY

Jörg R. Hörandel on behalf of the Pierre Auger Collaboration

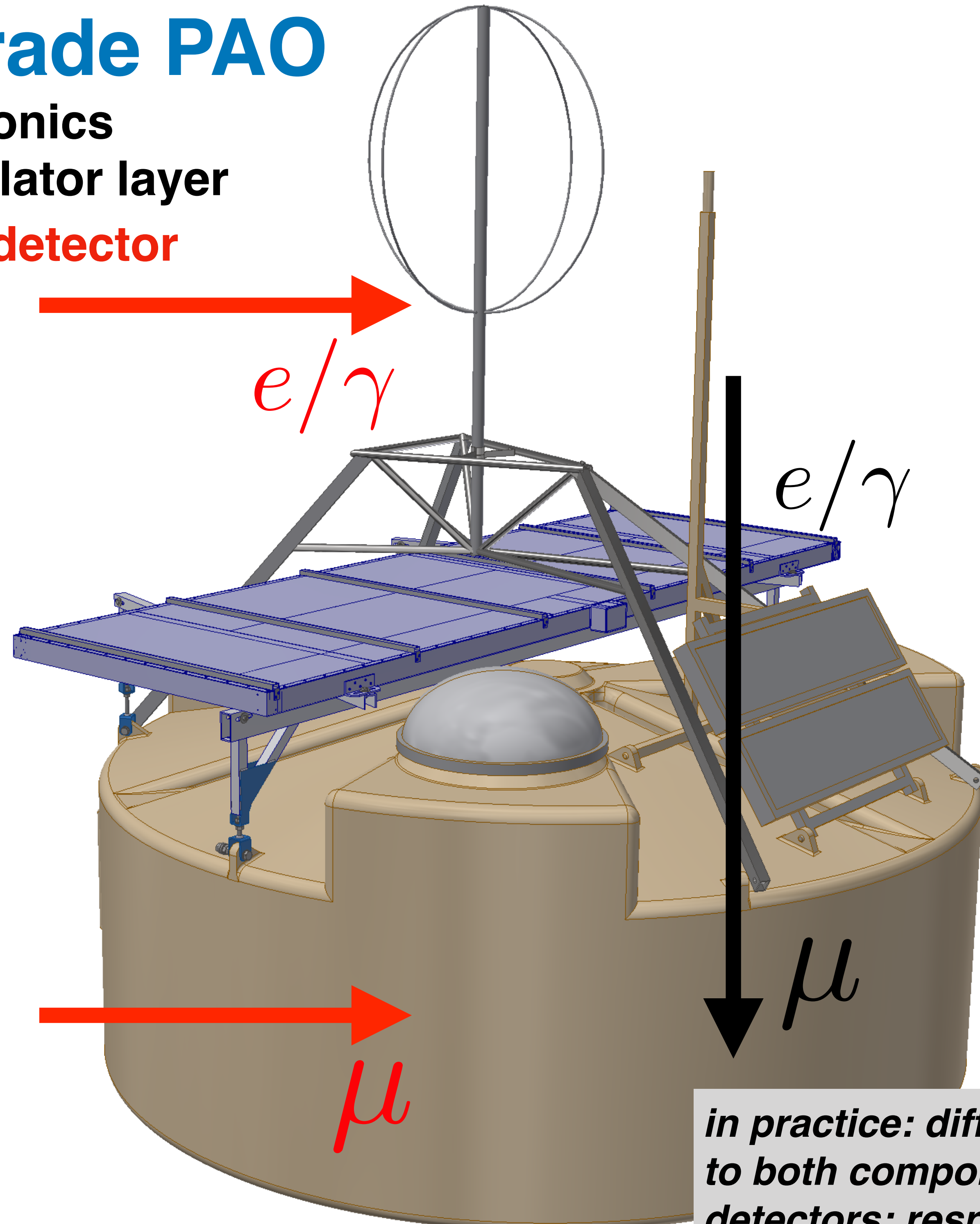
Radboud University Nijmegen, Nikhef, Vrije Universiteit Brussel

http://particle.astro.ru.nl

Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

upgrade PAO

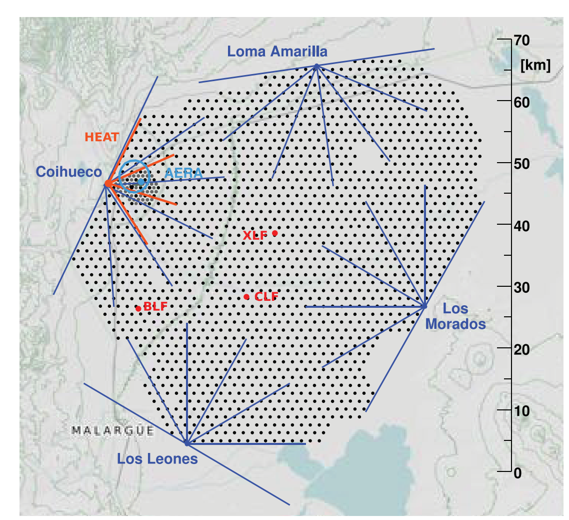
- electronics
- scintillator layer
- radio detector



in practice: different response to both components in both detectors: response matrix

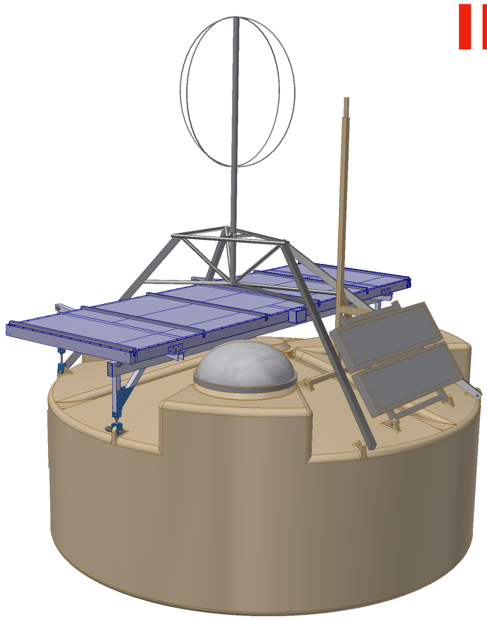
objective

- origin of cosmic rays
- type of particle up to highest energies
- isolate protons, photons, neutrinos
- extend e/m-muon separation to high zenith angles
  --> horizontal air showers
  (i.e. increase exposure of SSD analyses)
- increase the sky coverage/overlap with TA
- absolute energy calibration from 1st principles
- independent mass scale
- clean e/m measurement
  --> shower physics



PIERRE AUGER OBSERVATORY

Precision shower physics (for vertical showers)
in dense region of Pierre Auger observatory



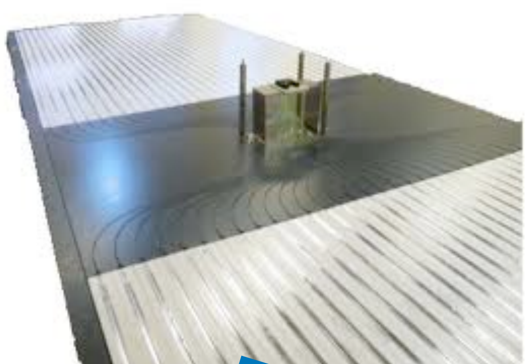
clean separation of shower components

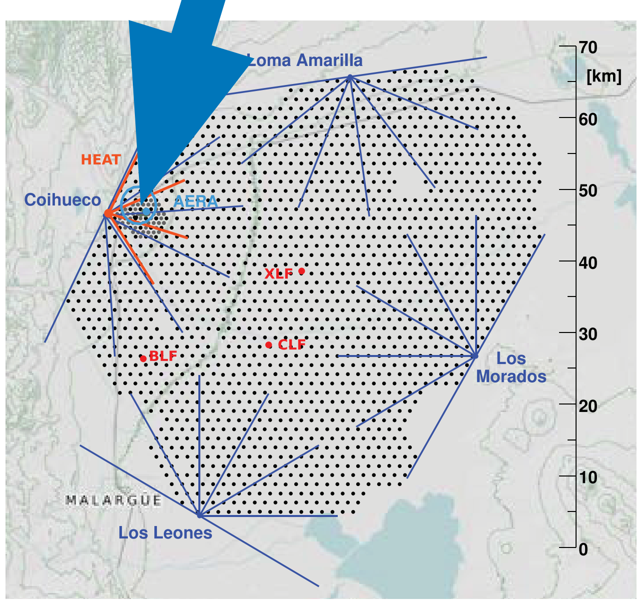
radio detector —> e/m

scintillator (SSD) —> e/m + muons

water Cherenkov detector —> e/m + muons

underground muon detector (AMIGA) —> muons



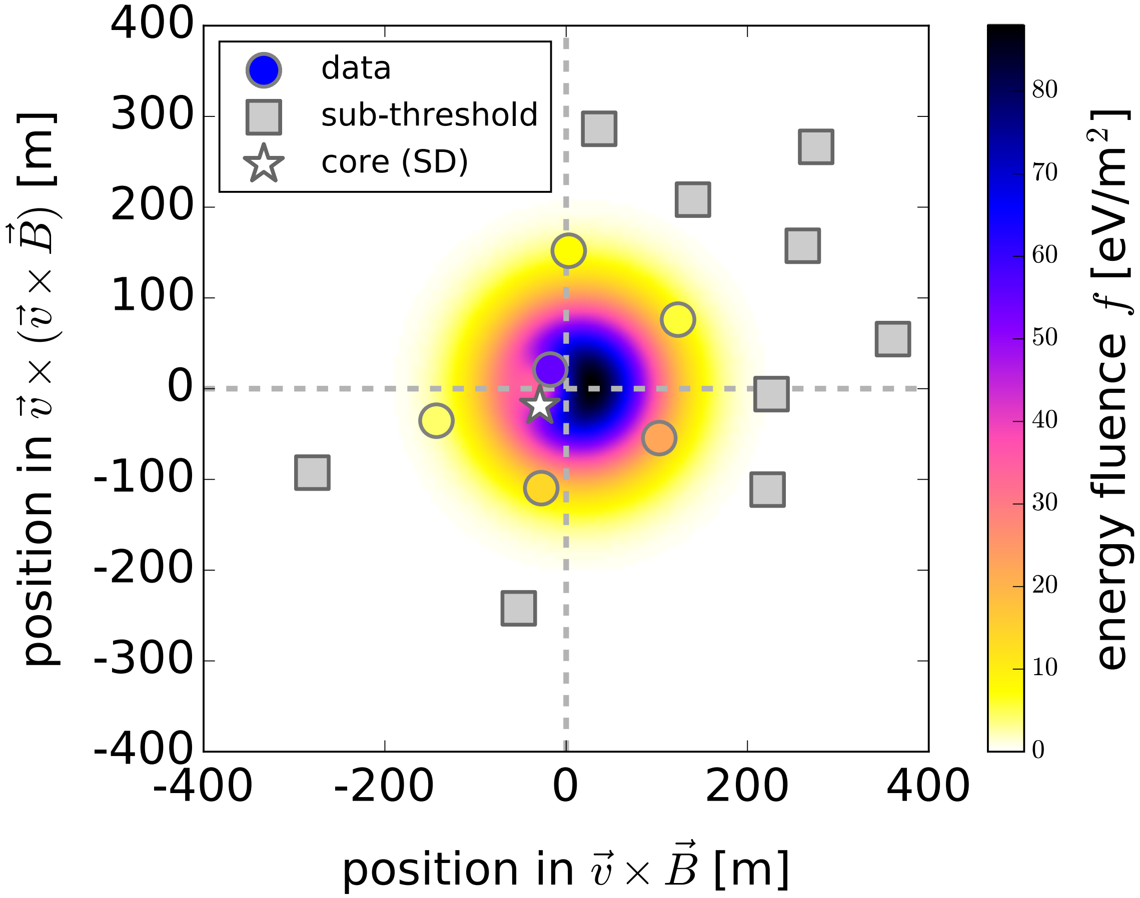


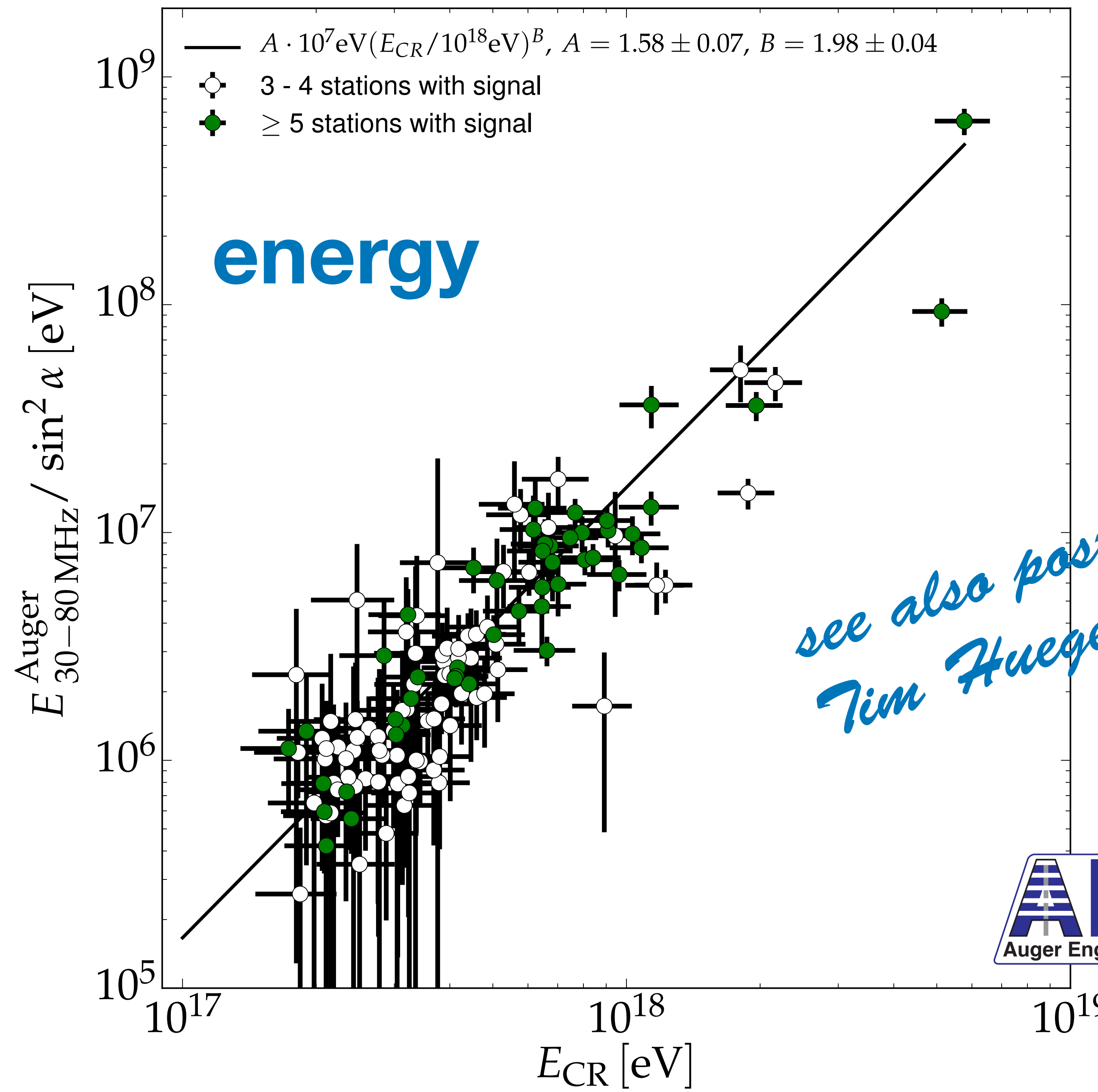
direct verification of deconvolution matrices (SSD/WCD) with measured showers

study hadronic interactions

PIERRE AUGER OBSERVATORY

Radio emission is established as tool to determine properties of cosmic rays





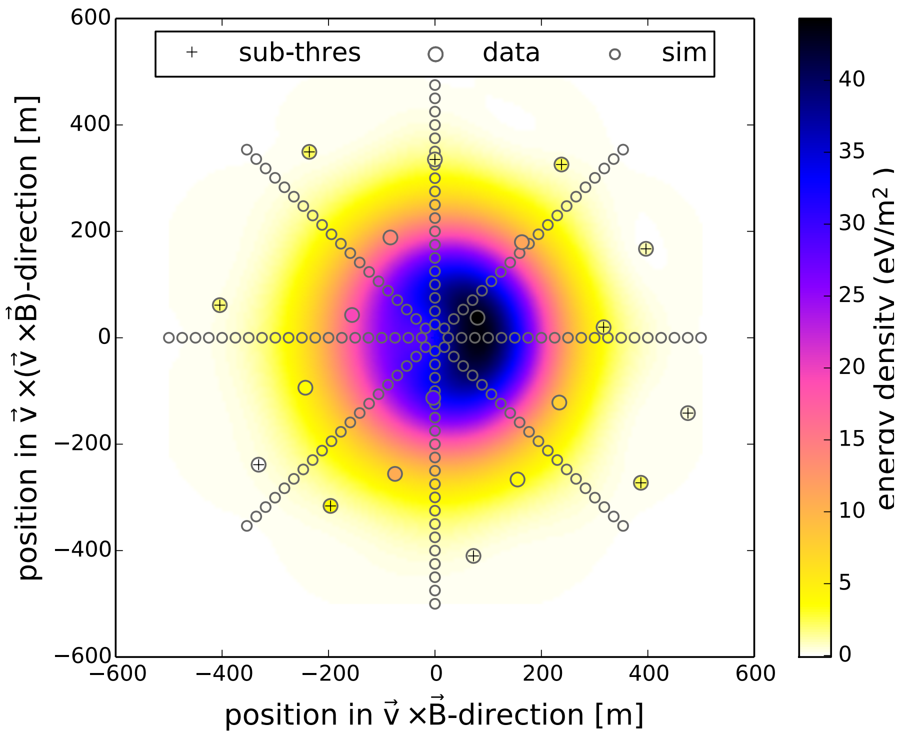
see also poster by Tim Huege et al.

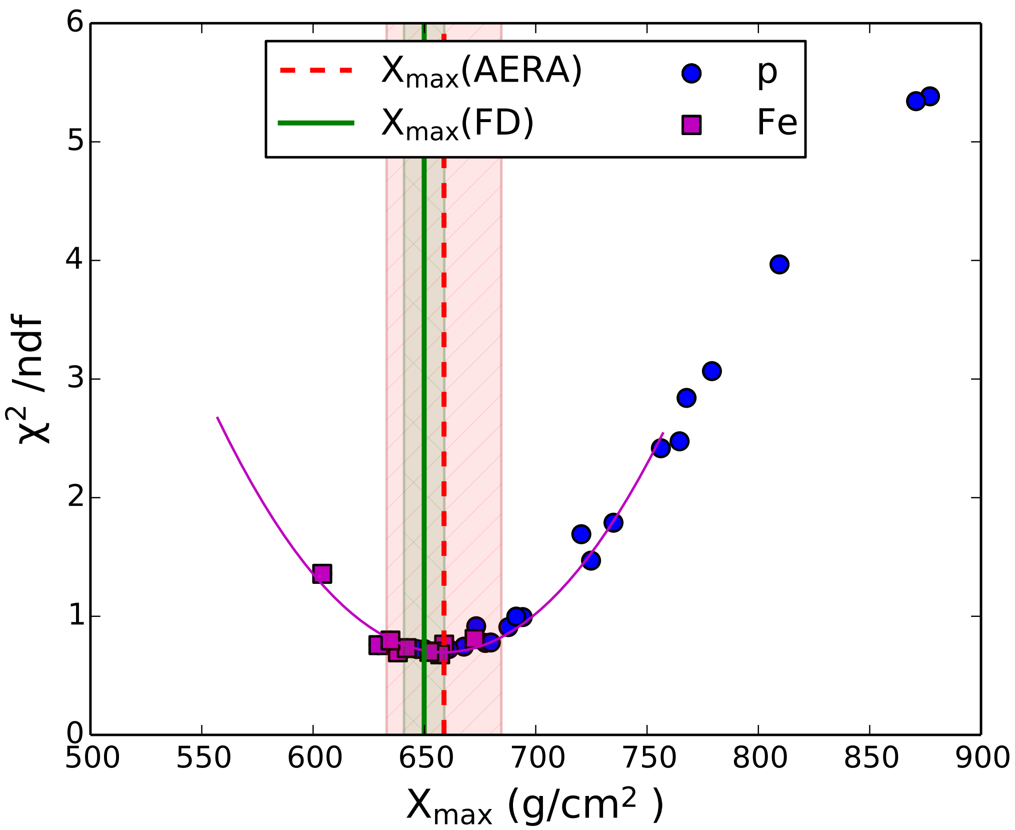
$E_{30\text{-}80}$ MHz = 15.8 MeV @ 10^{18} eV

$$E_{30\text{-}80\ \mathrm{MHz}} = (15.8 \pm 0.7(\mathrm{stat}) \pm 6.7(\mathrm{syst})\ \mathrm{MeV}) \times \left(\sin\alpha \frac{E_{CR}}{10^{18}\ \mathrm{eV}} \frac{B_{Earth}}{0.24\ \mathrm{G}}\right)^2$$

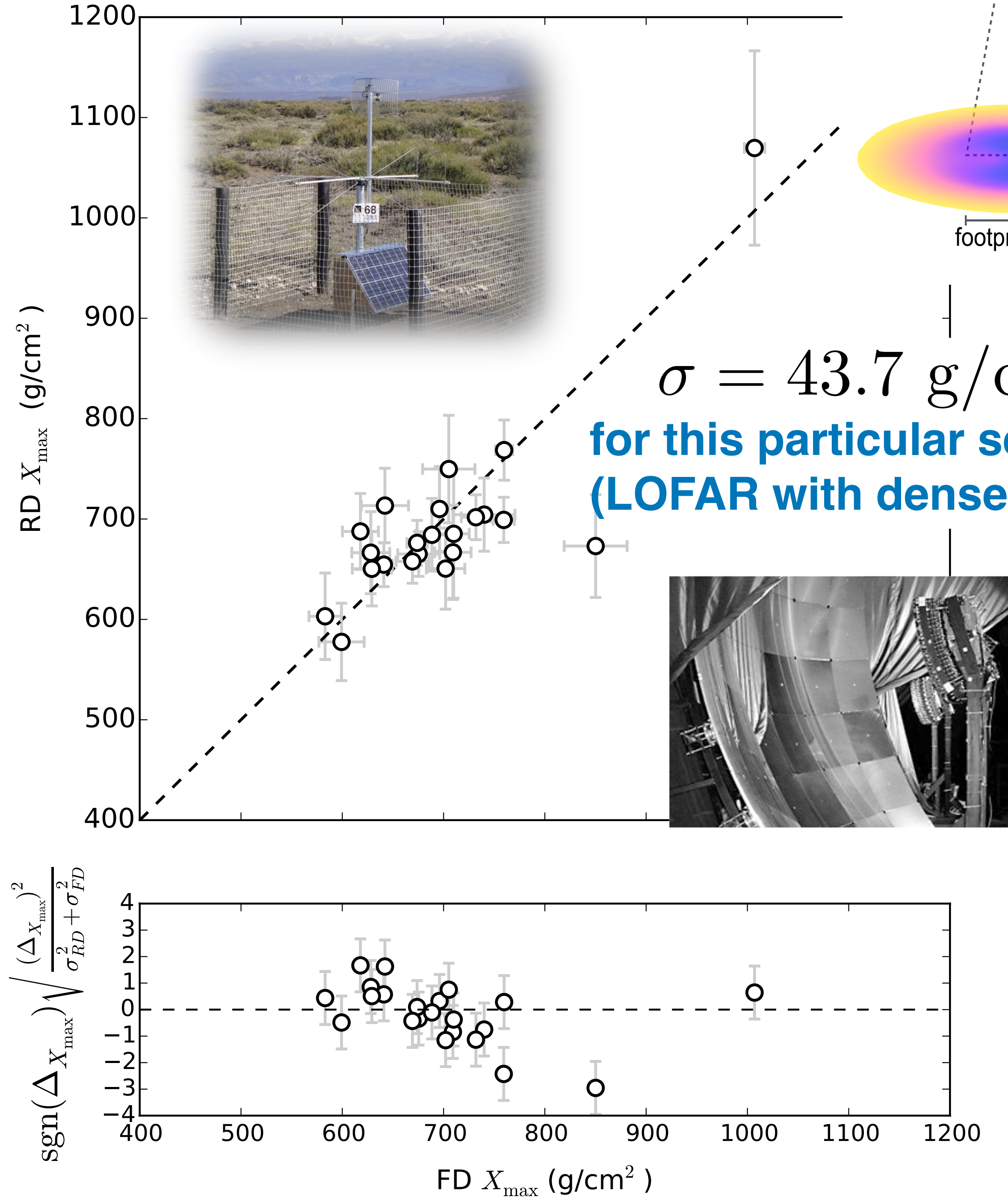
A. Aab et al., PRL 116 (2016) no.24, 241101 A. Aab et al., PRD 93 (2016) no.12, 122005

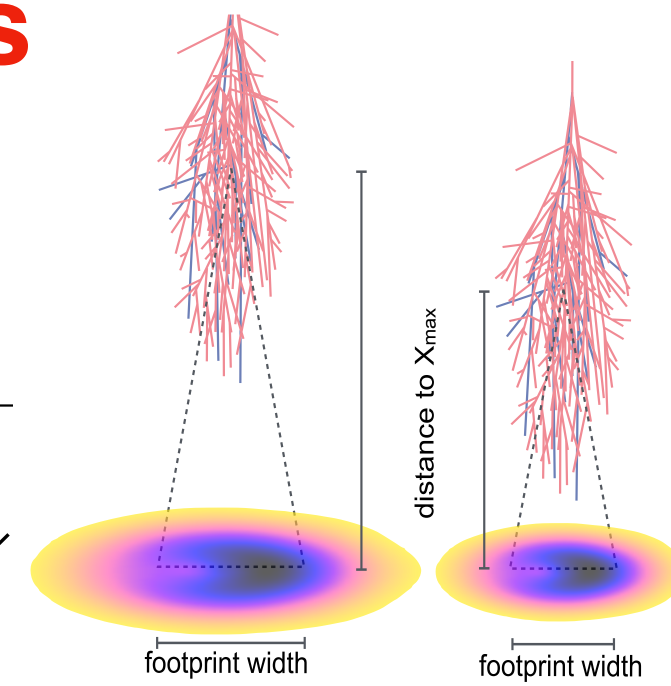
Radio emission is established as tool to determine properties of cosmic rays





particle type





$$\sigma = 43.7\ \mathrm{g/cm^2}$$

for this particular selection of showers
(LOFAR with dense array ~20 g/cm²)

AERA Auger Engineering Radio Array

PIERRE AUGER OBSERVATORY

J. Schulz, PhD thesis RU Nijmegen (2016)

Measurement of particle type

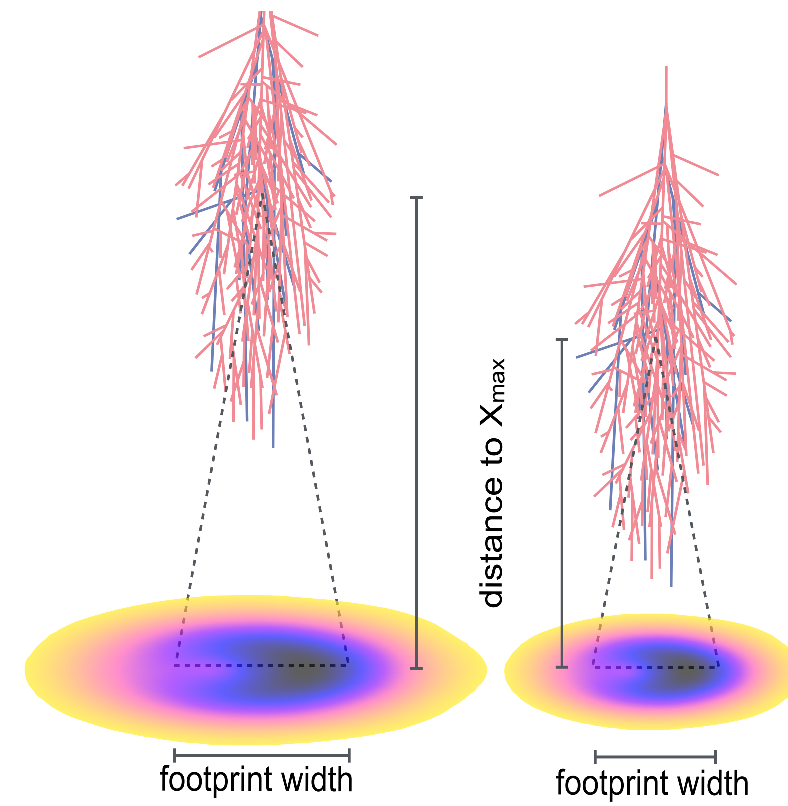
attention:

type of particle determined

for vertical showers:

size of footprint

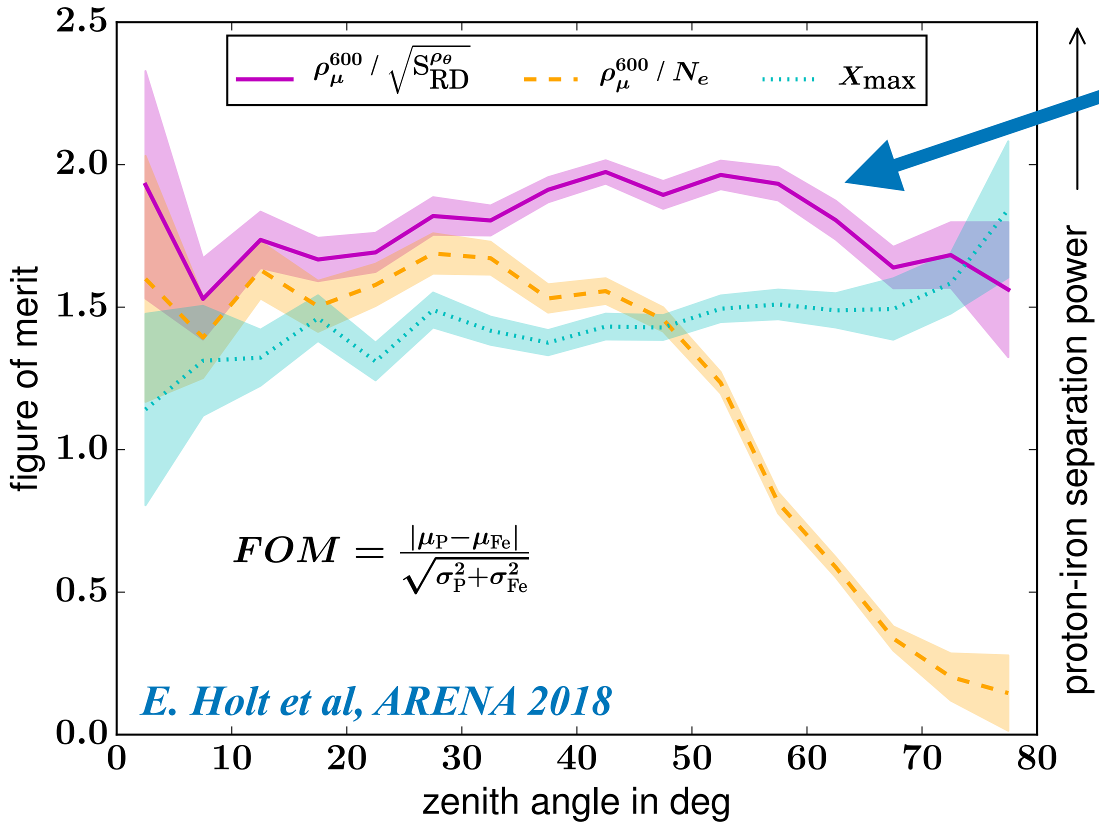
geometrical measurement



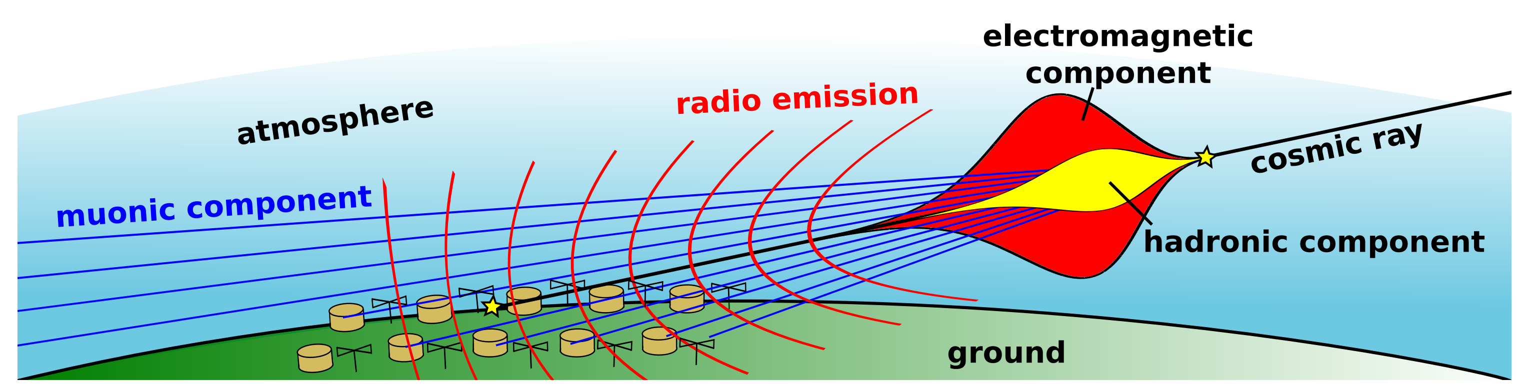
for horizontal showers:

electron/muon ratio

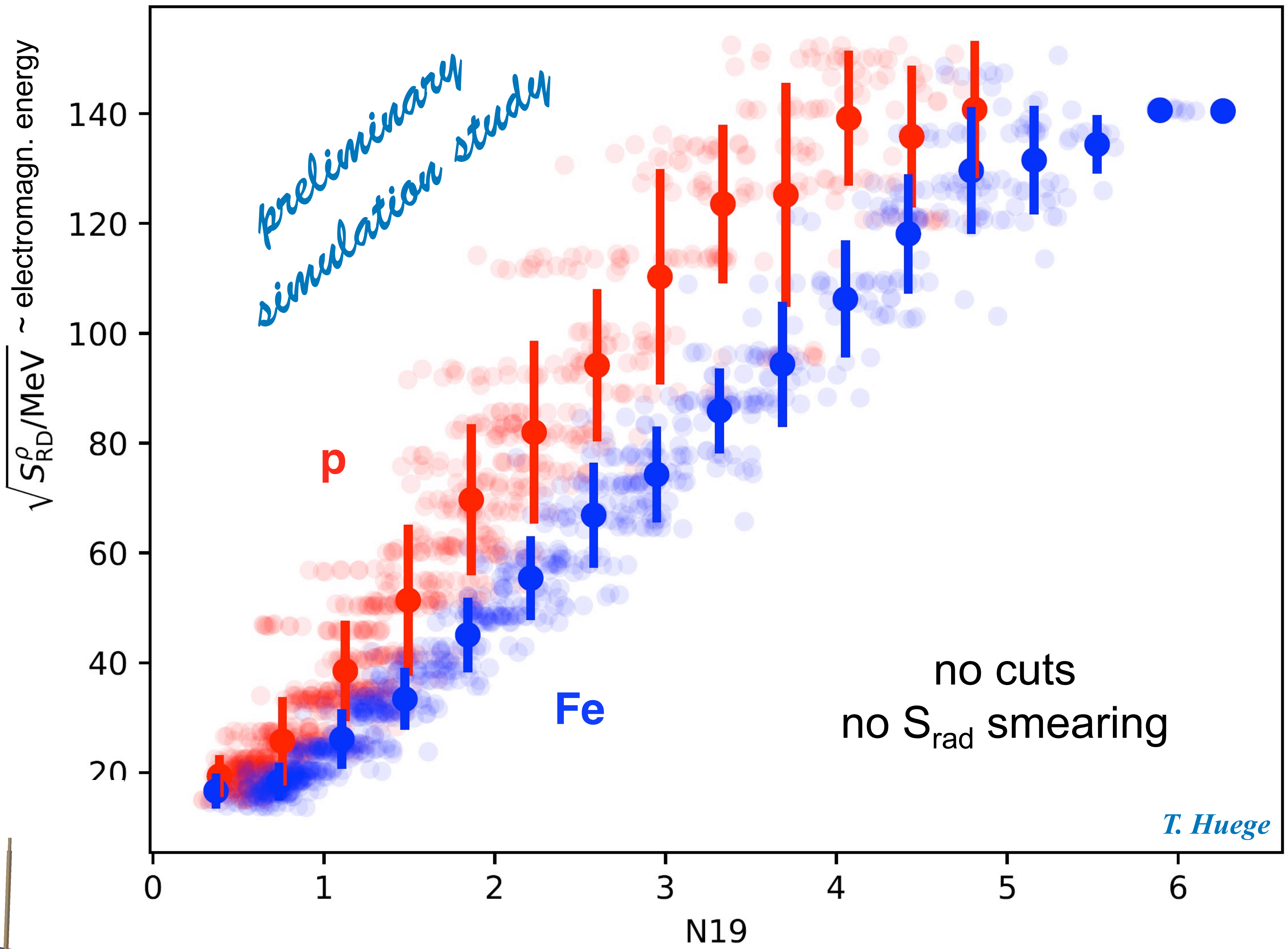
important: radio emission not absorbed in atmosphere



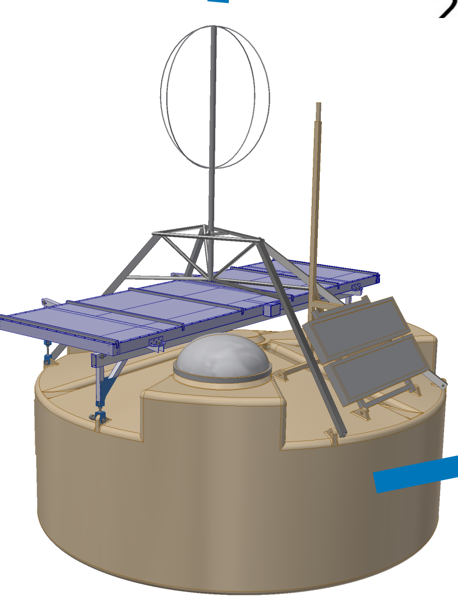
good separation power up to high zenith angles



Radio-WCD provides good mass separation



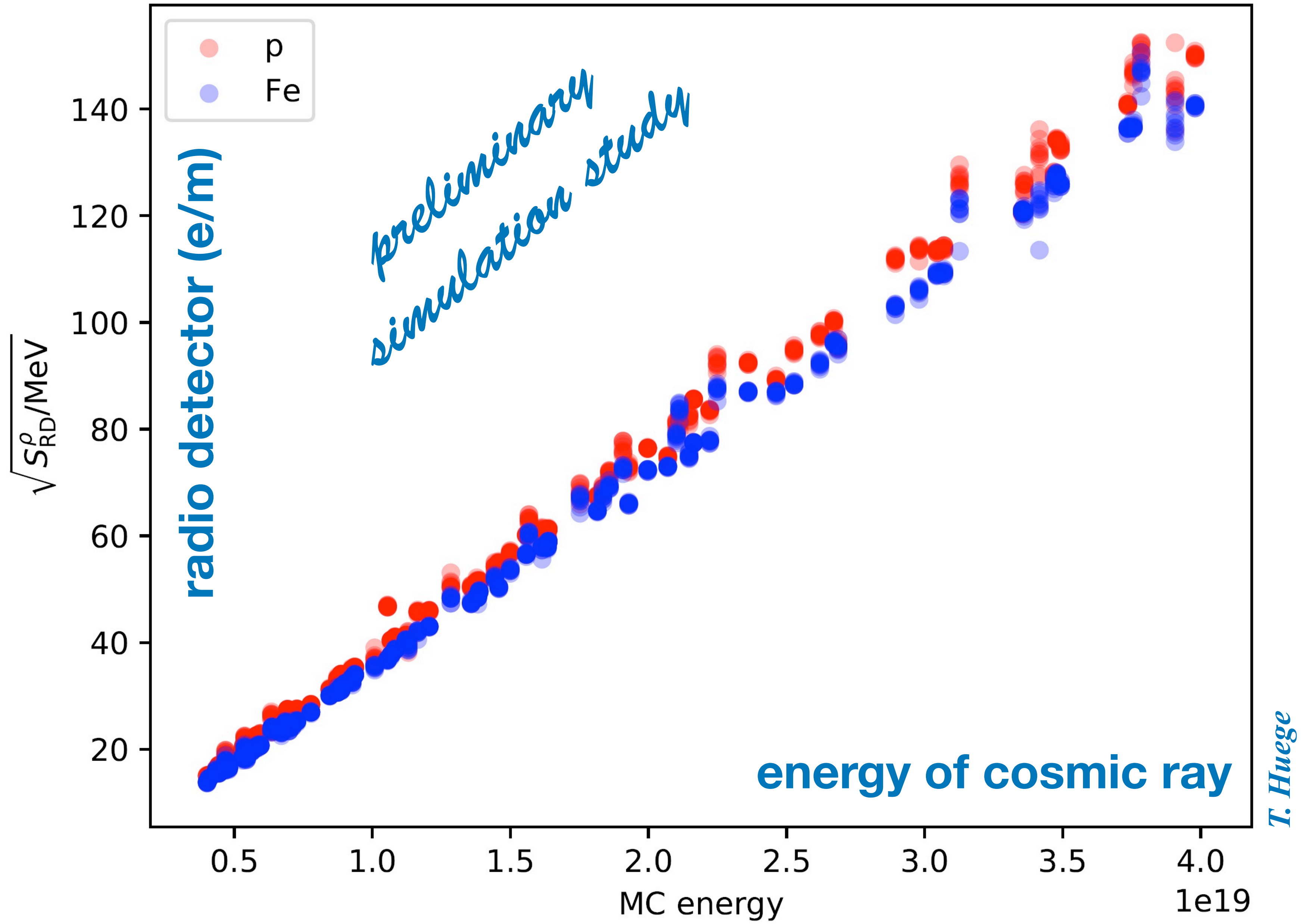
radio detector (e/m)



water Cherenkov detector (μ)

- can separate species with S_{rad} and N_{19}
- separation increases with energy
- saturation at highest energies is an artifact of the maximum simulated energy

Radio detector provides good measurement of e/m energy



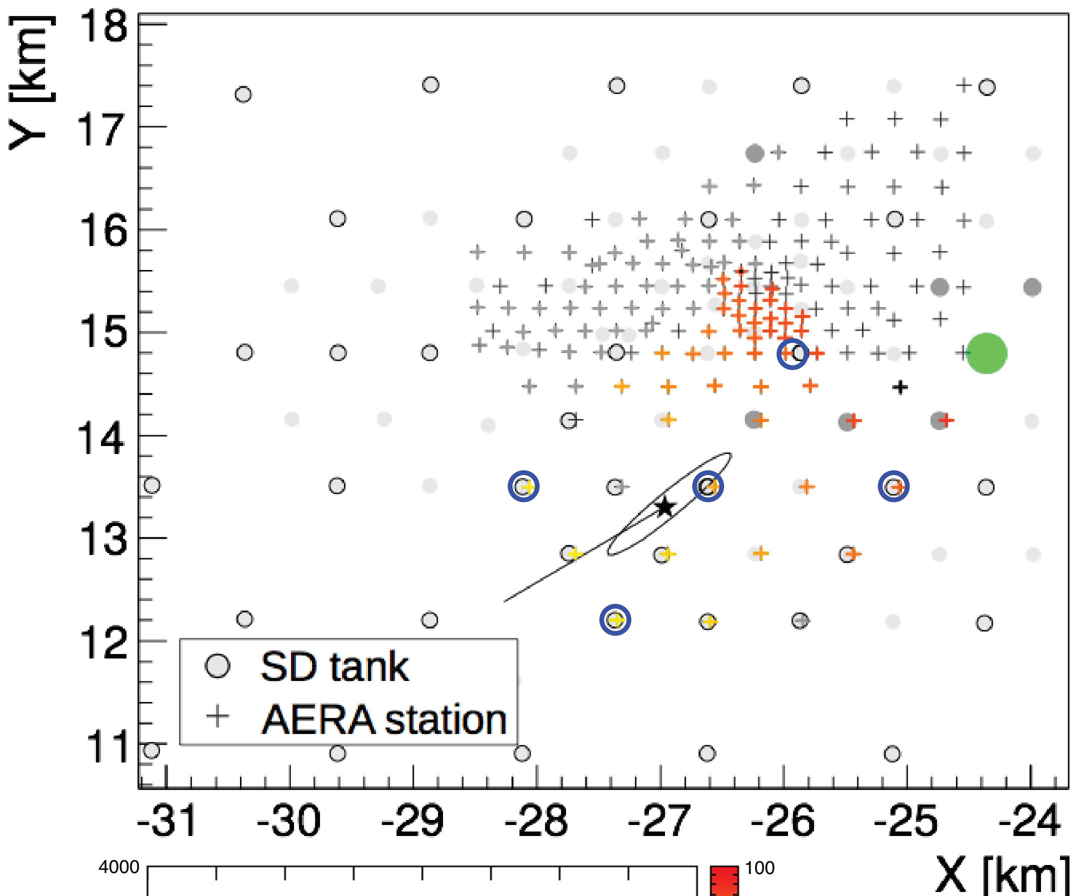
- good correlation
- scatter bigger for showers near magfield axis (we use reconstructed SD direction)
- as expected, p only very slightly above Fe
- caveat: uses MC Xmax info, using mean Xmax will degrade this slightly

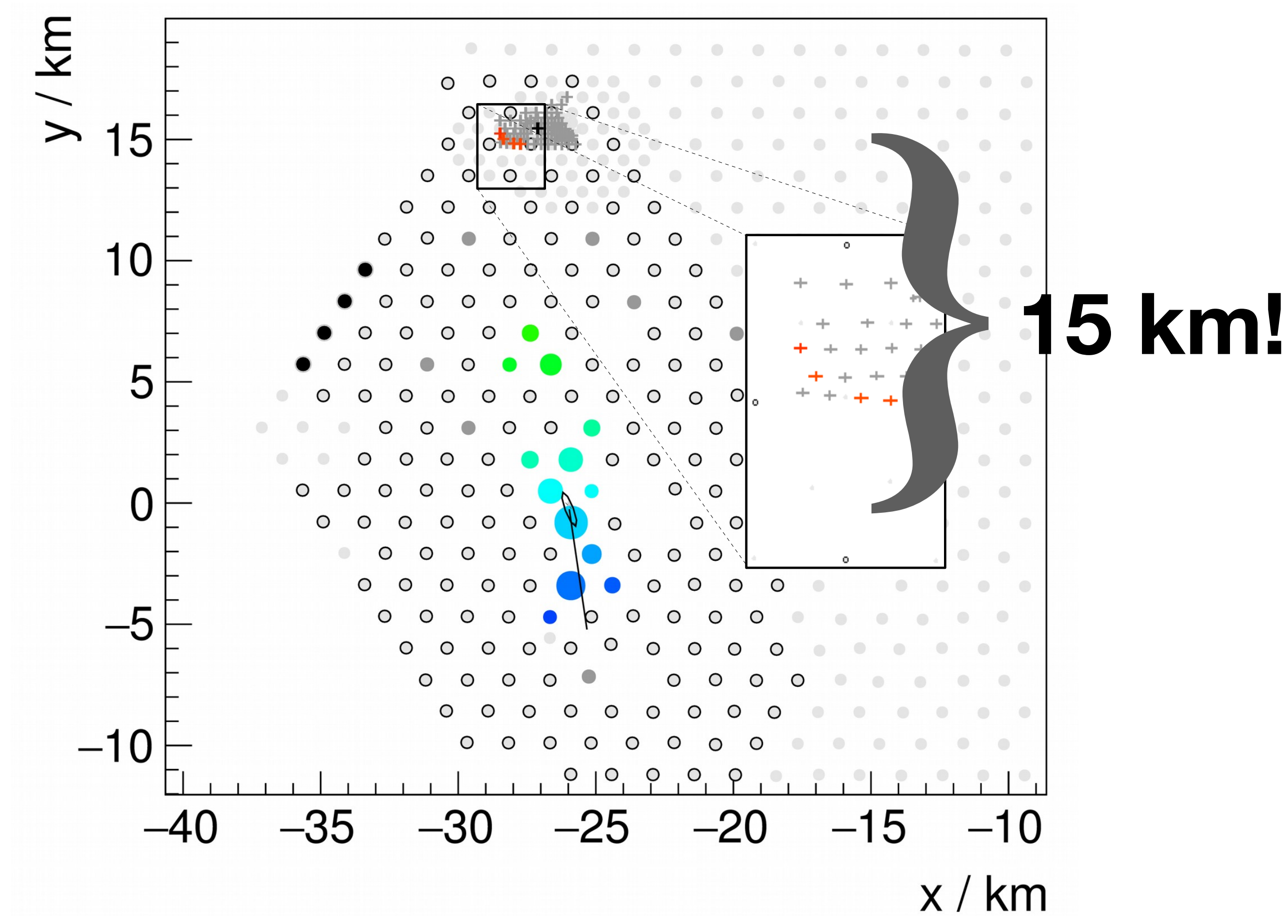
radiation energy can be used to determine energy scale from first-principle calculations for vertical and horizontal showers

see also M. Gottowik et al., Astrop. Phys. 103 (2018) 87
C. Glaser, et al., Journal of Cosmology and Astroparticle Physics 1609 (2016) 024

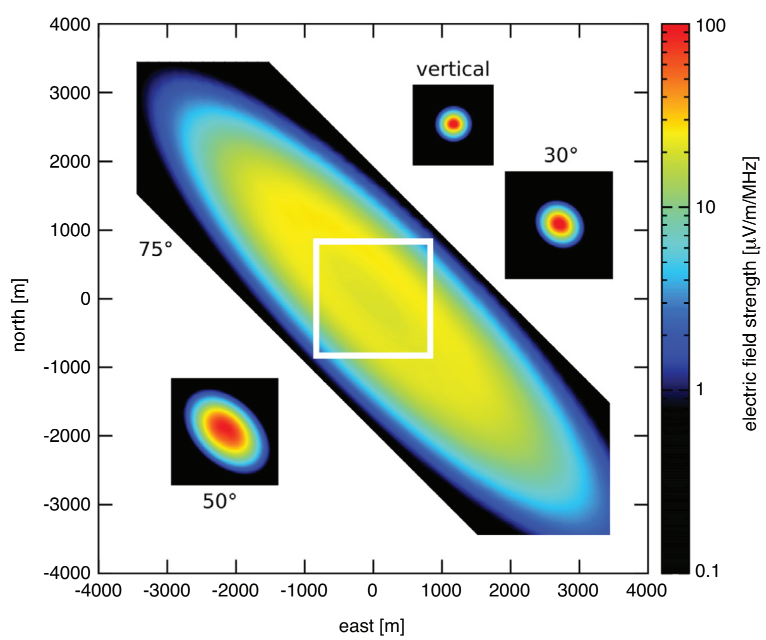
Horizontal air showers have large footprints in radio emission

horizontal air showers registered and reconstructed with existing AERA





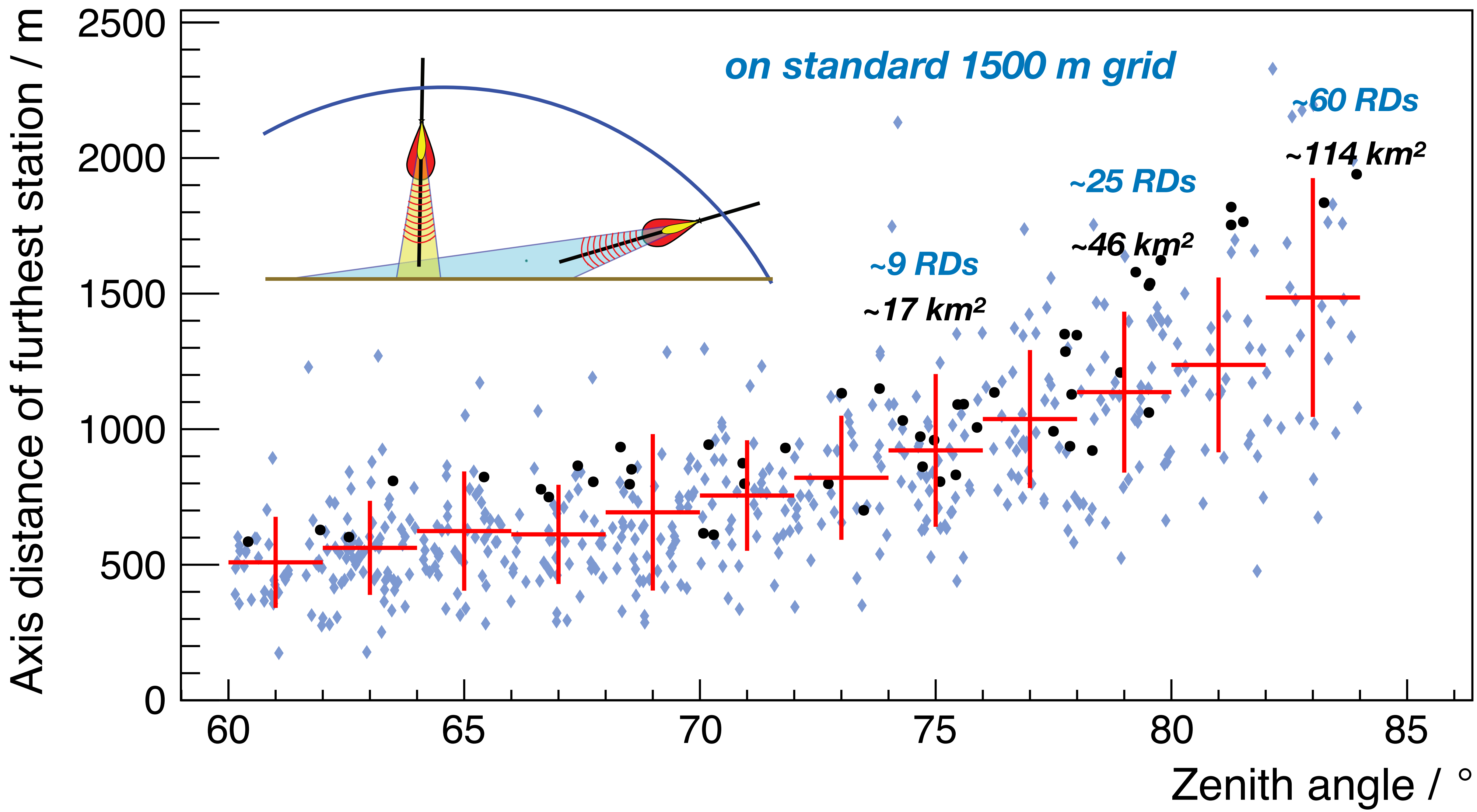
A. Aab et al., JCAP in press (2018) arXiv: 1806.05386



expect large radio footprint from simulations

see e.g. T. Huege, Phys. Rep. 620 (2016) 1

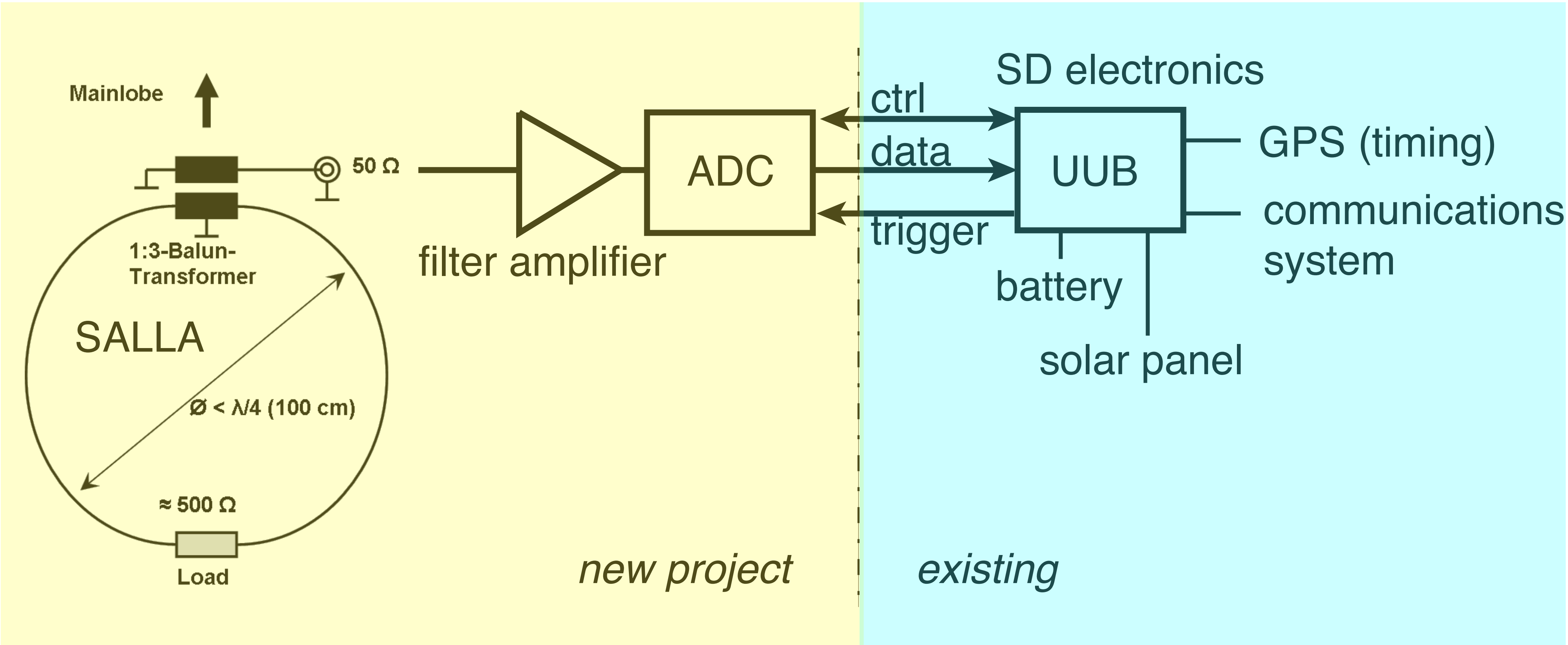
Horizontal air showers have large footprints in radio emission

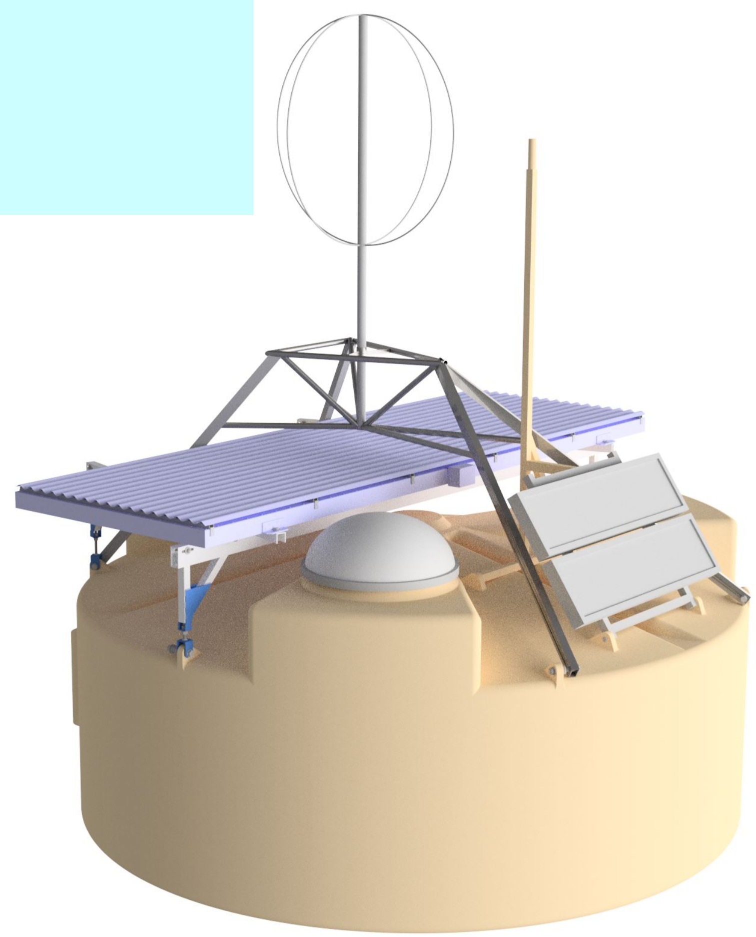


this is MEASURED with the *small* 17km² AERA

A. Aab et al., JCAP in press (2018) arXiv: 1806.05386

Integration of radio upgrade (RD), scintillator upgrade (SSD), and water Cherenkov detector in *ONE* unit



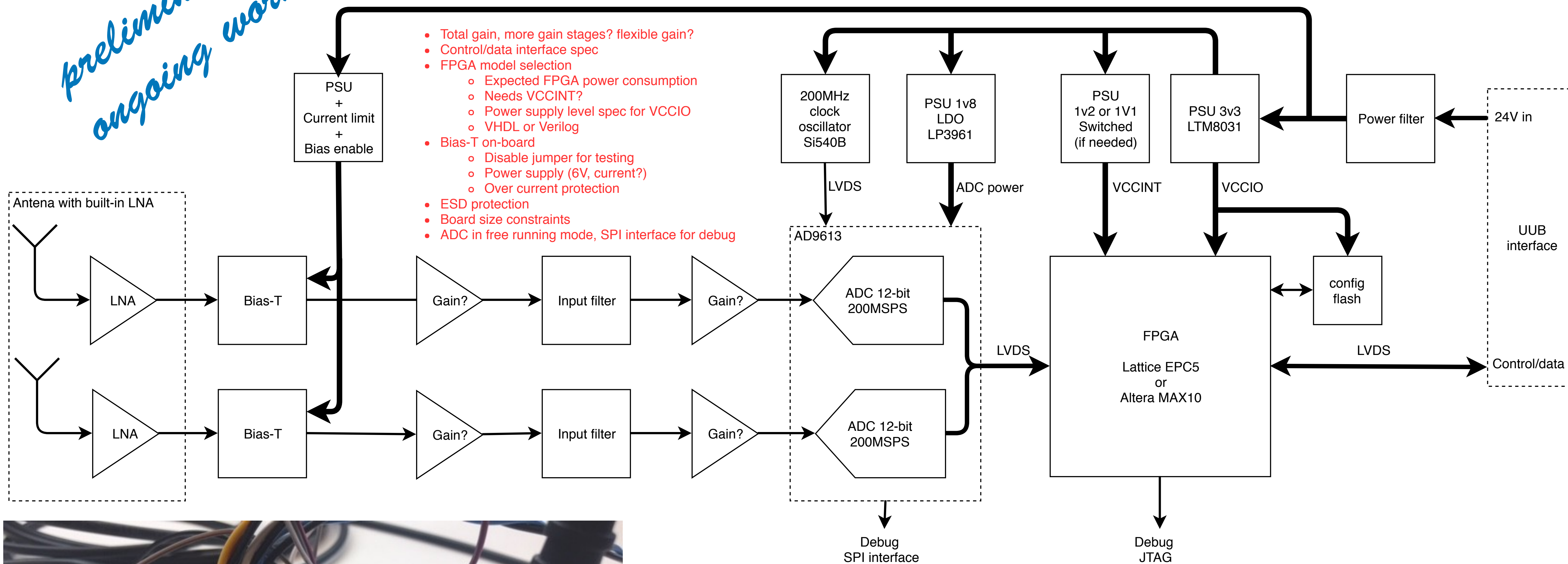


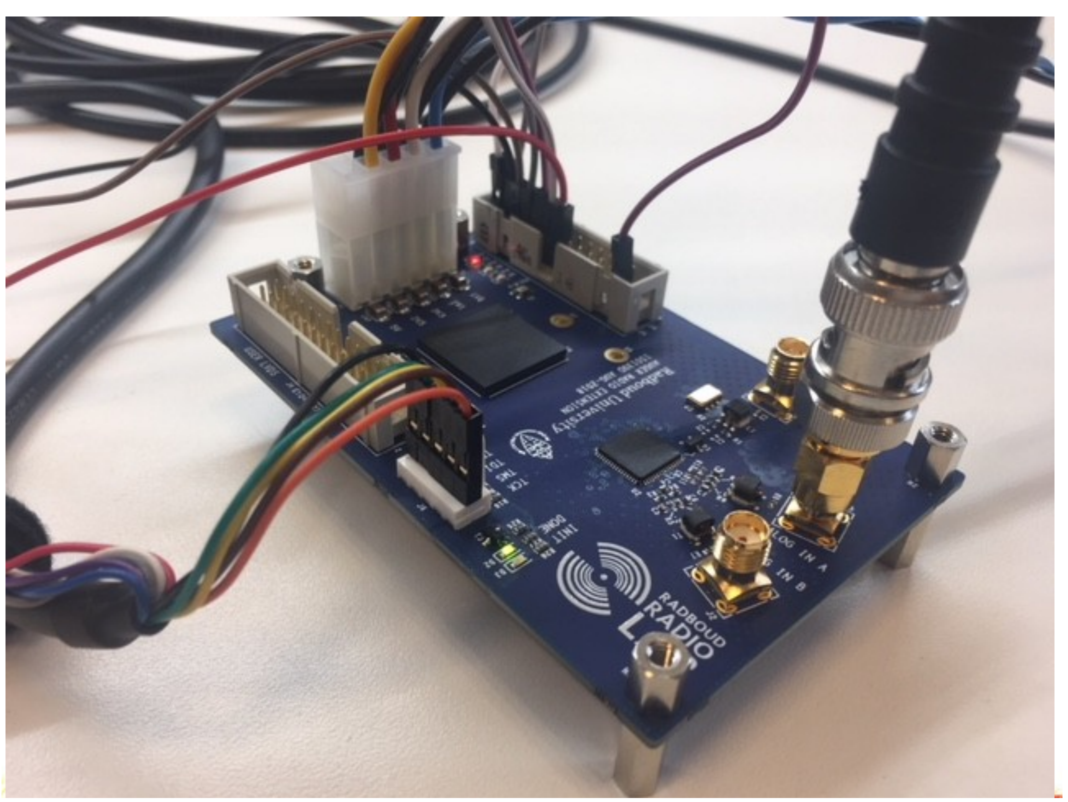
Shared infrastructure (solar power, battery, GPS timing, communications system) and integrated data acquisition

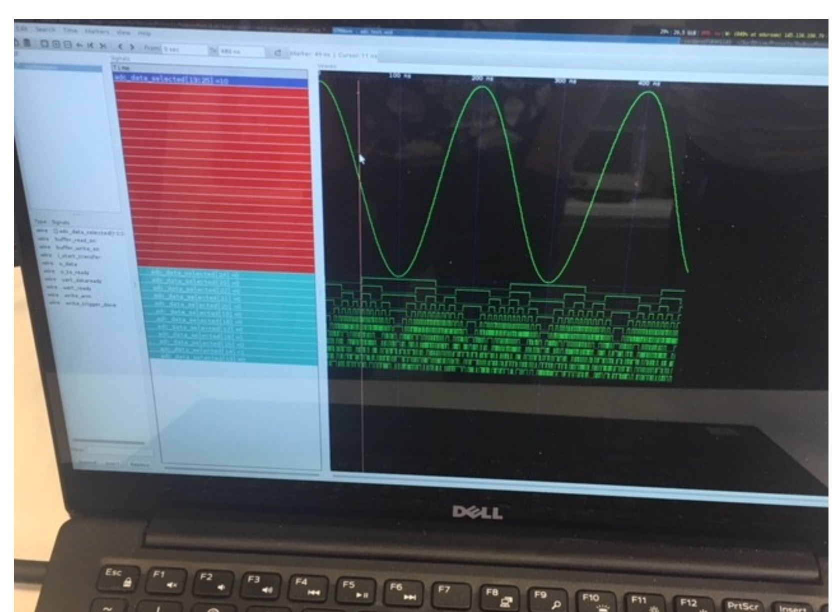
RD front end board

preliminary!
ongoing work

- Total gain, more gain stages? flexible gain?
- Control/data interface spec
- FPGA model selection
  - Expected FPGA power consumption
  - Needs VCCINT?
  - Power supply level spec for VCCIO
  - VHDL or Verilog
- Bias-T on-board
  - Disable jumper for testing
  - Power supply (6V, current?)
  - Over current protection
- ESD protection
- Board size constraints
- ADC in free running mode, SPI interface for debug



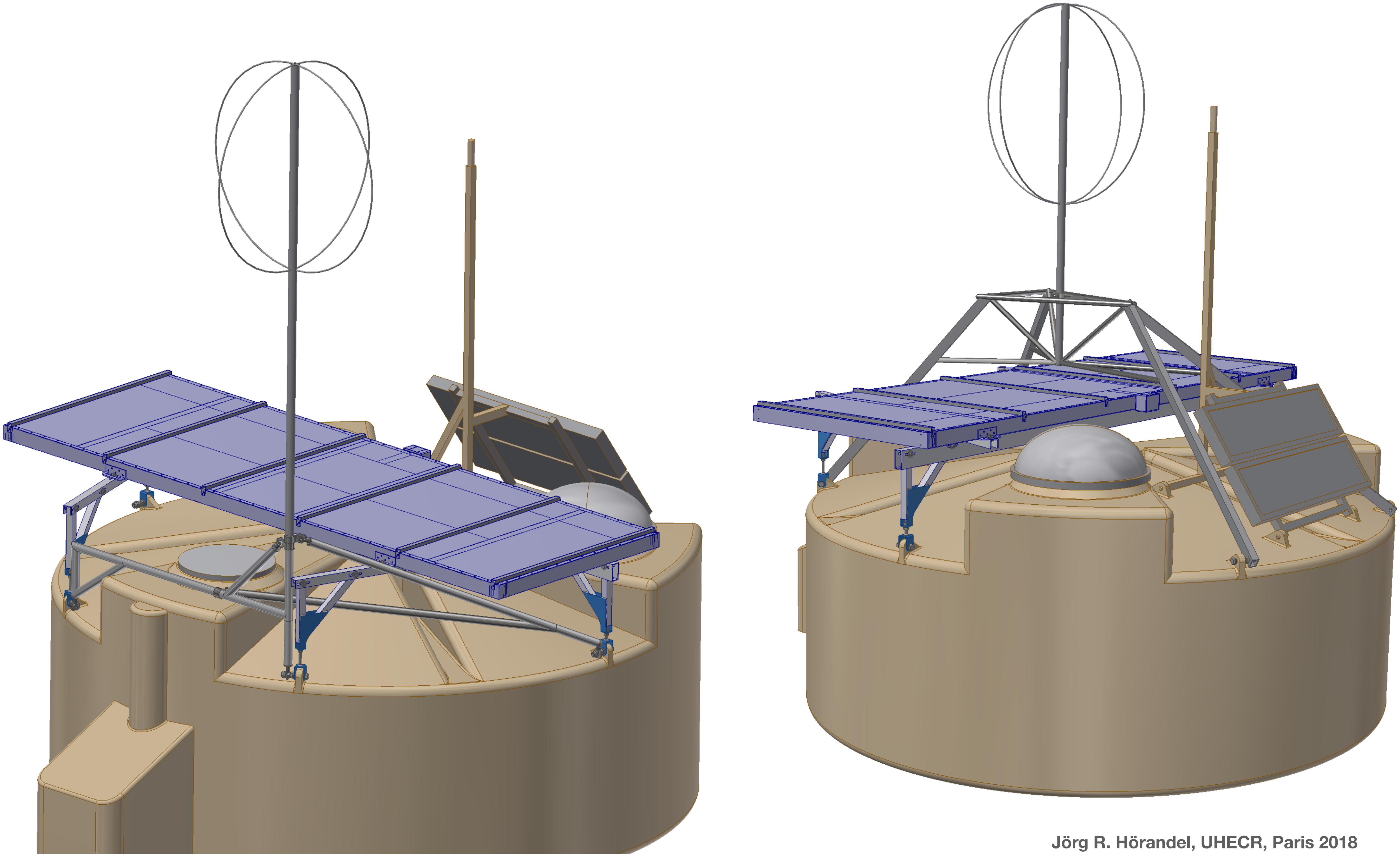




1st prototype existing and under evaluation

Antenna mounting

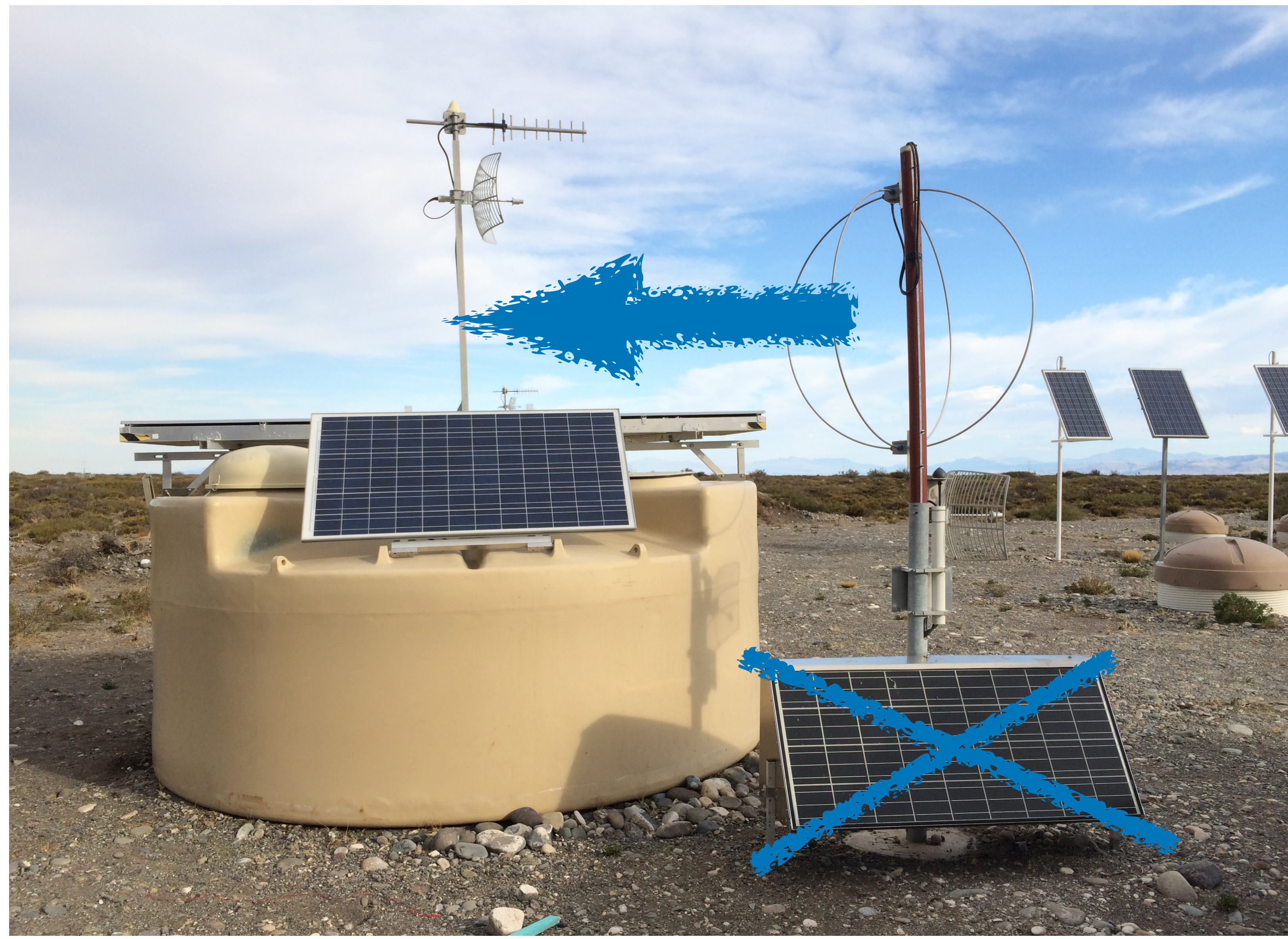
currently studying different scenarios for mechanical mounting



Prototypes at PAO

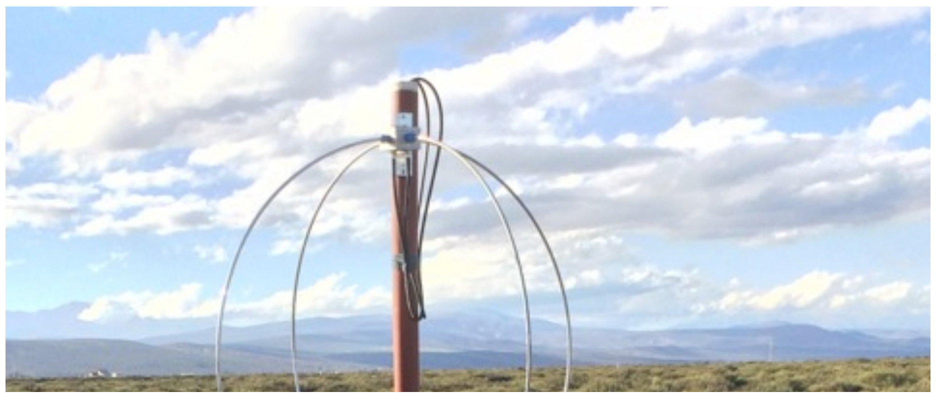
since March 2017
R&D stations

prototype since November 2017

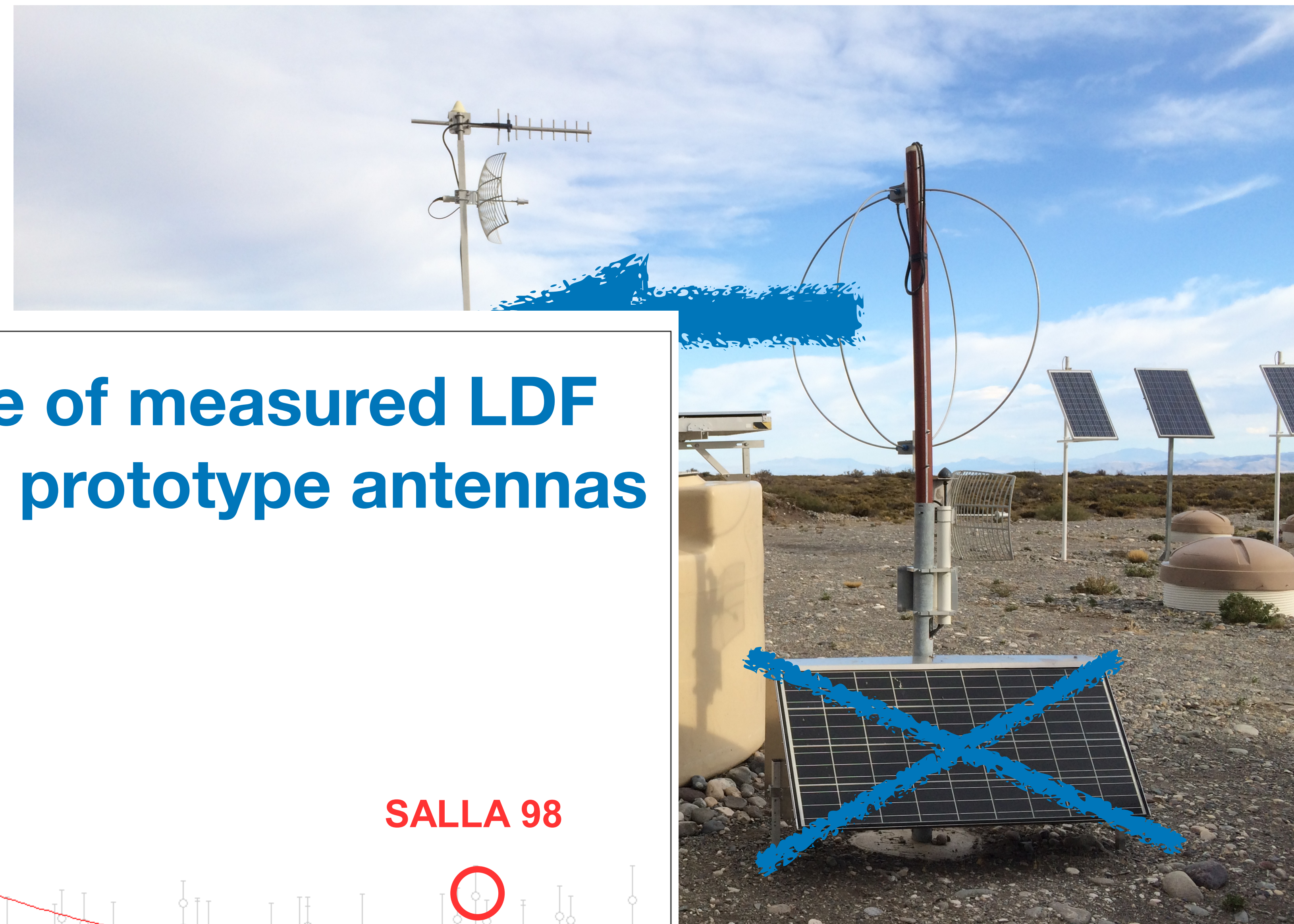


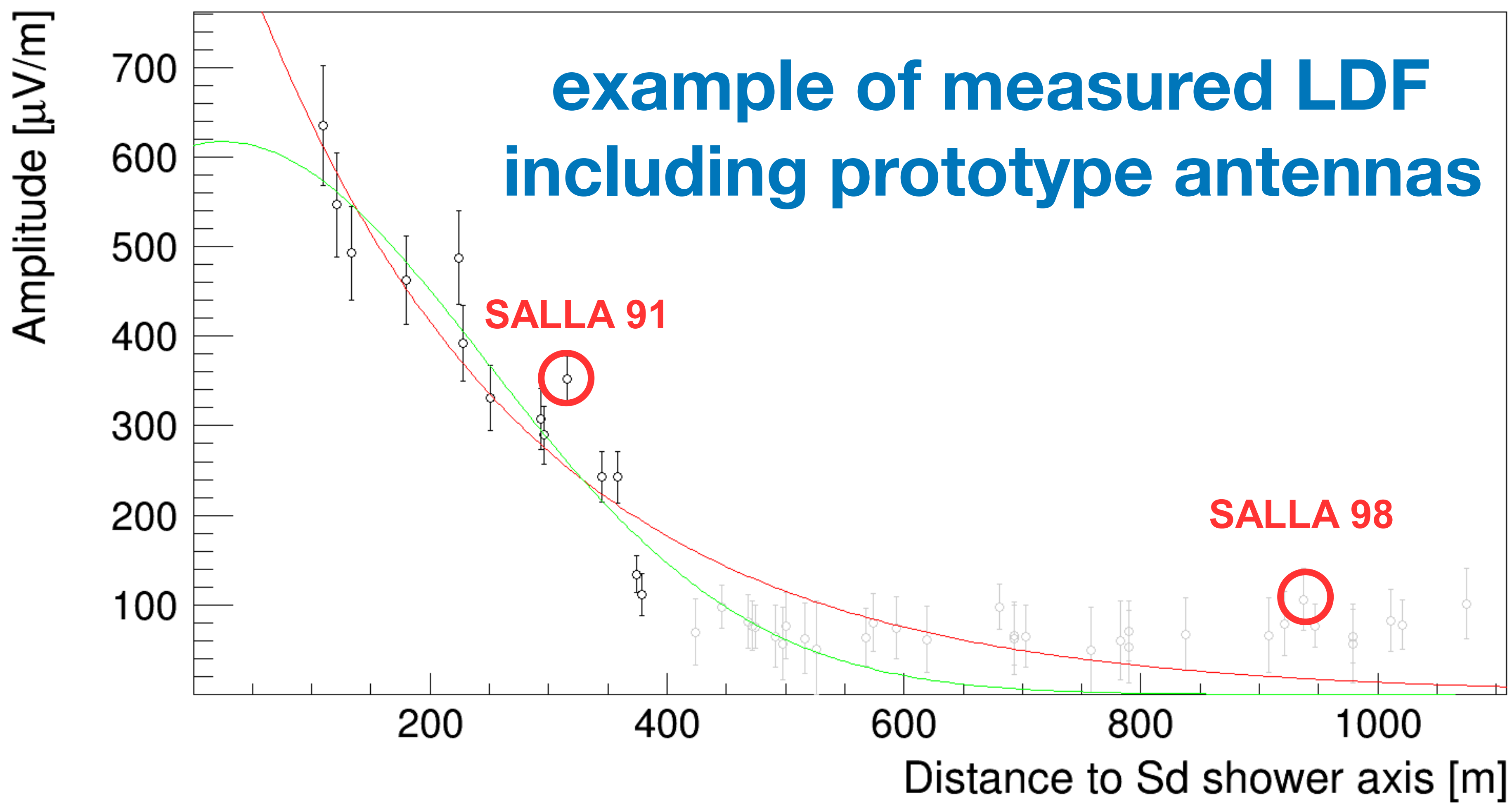
Prototypes at PAO

since March 2017
R&D stations



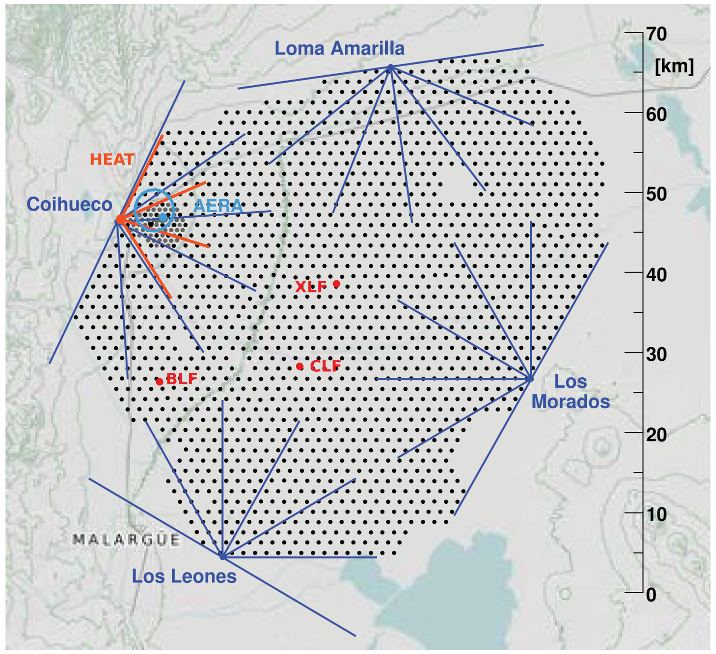
prototype since November 2017

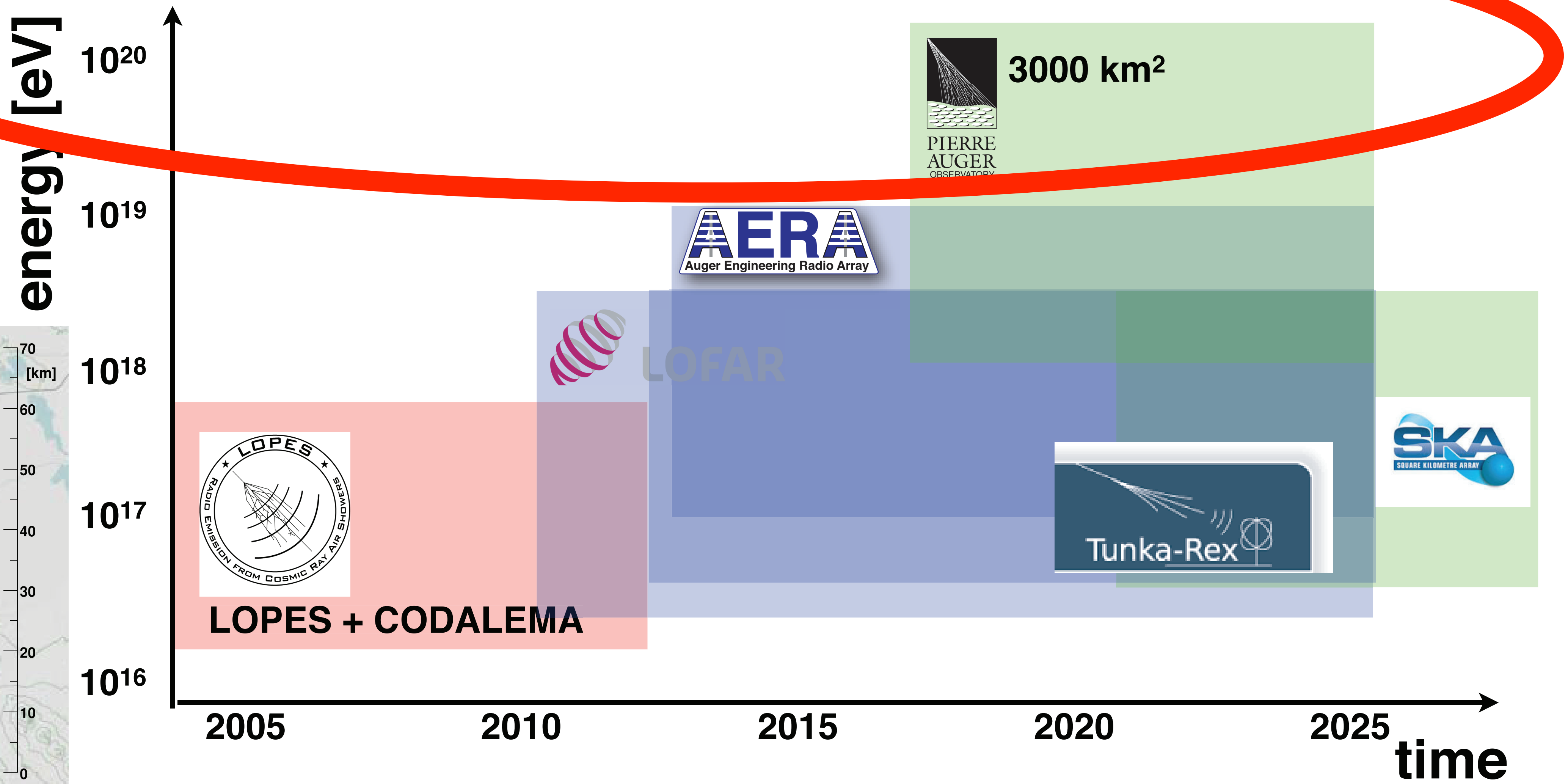




Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory

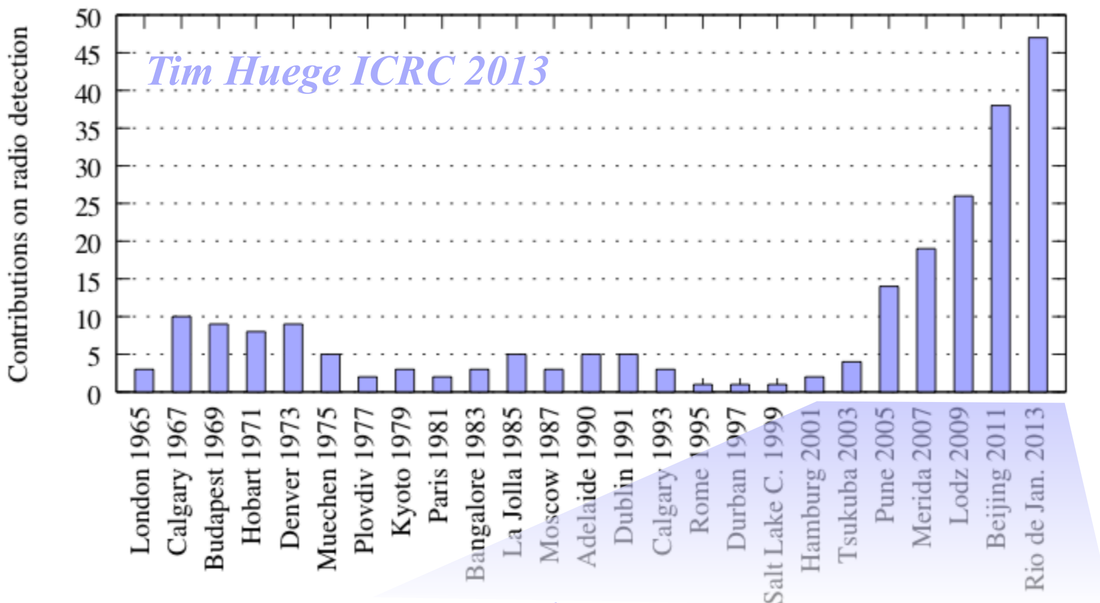
AERA 17 km²
--> 3000 km²

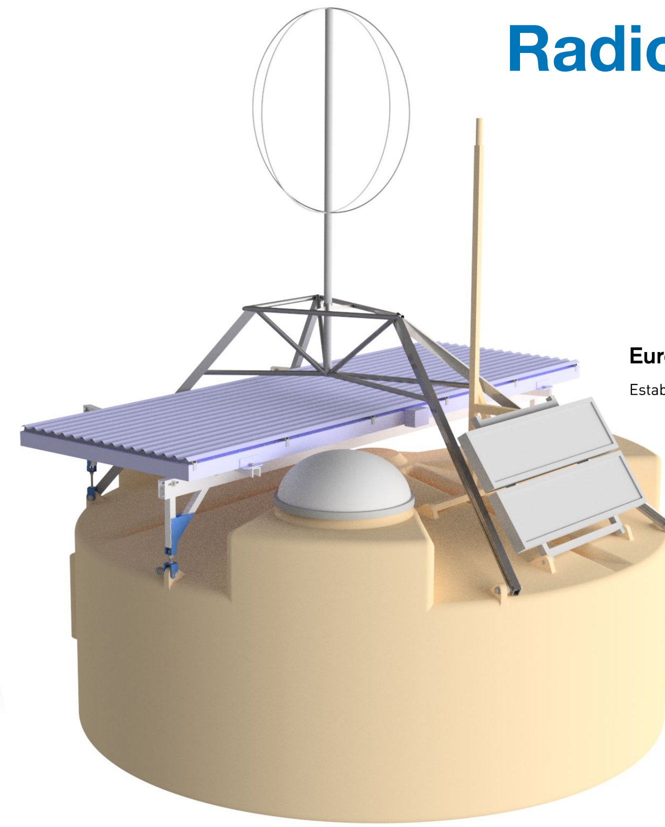




reaching to the highest energies with radio technique

Precision measurements of cosmic rays up to the highest energies with a large radio array at the Pierre Auger Observatory





Radio upgrade is funded through

European Research Council
Established by the European Commission

ERC Advanced Grant Hörandel

Netherlands Organisation for Scientific Research

Bundesministerium für Bildung und Forschung

R&D funds

Project implementation currently ongoing

huge progress in last decade

***2018*: beyond capabilities of standard installations**

***2016*: properties of cosmic rays**

***2014*: understanding the emission processes**

2013: CoREAS radio simulation in CORSIKA

2011: endpoint formalism

2005: understanding the radio signal

PIERRE AUGER OBSERVATORY

Jörg R. Hörandel on behalf of the Pierre Auger Collaboration
Radboud University Nijmegen, Nikhef, Vrije Universiteit Brussel

http://particle.astro.ru.nl