Radio Detection of Cosmic Rays with the Auger Engineering Radio Array

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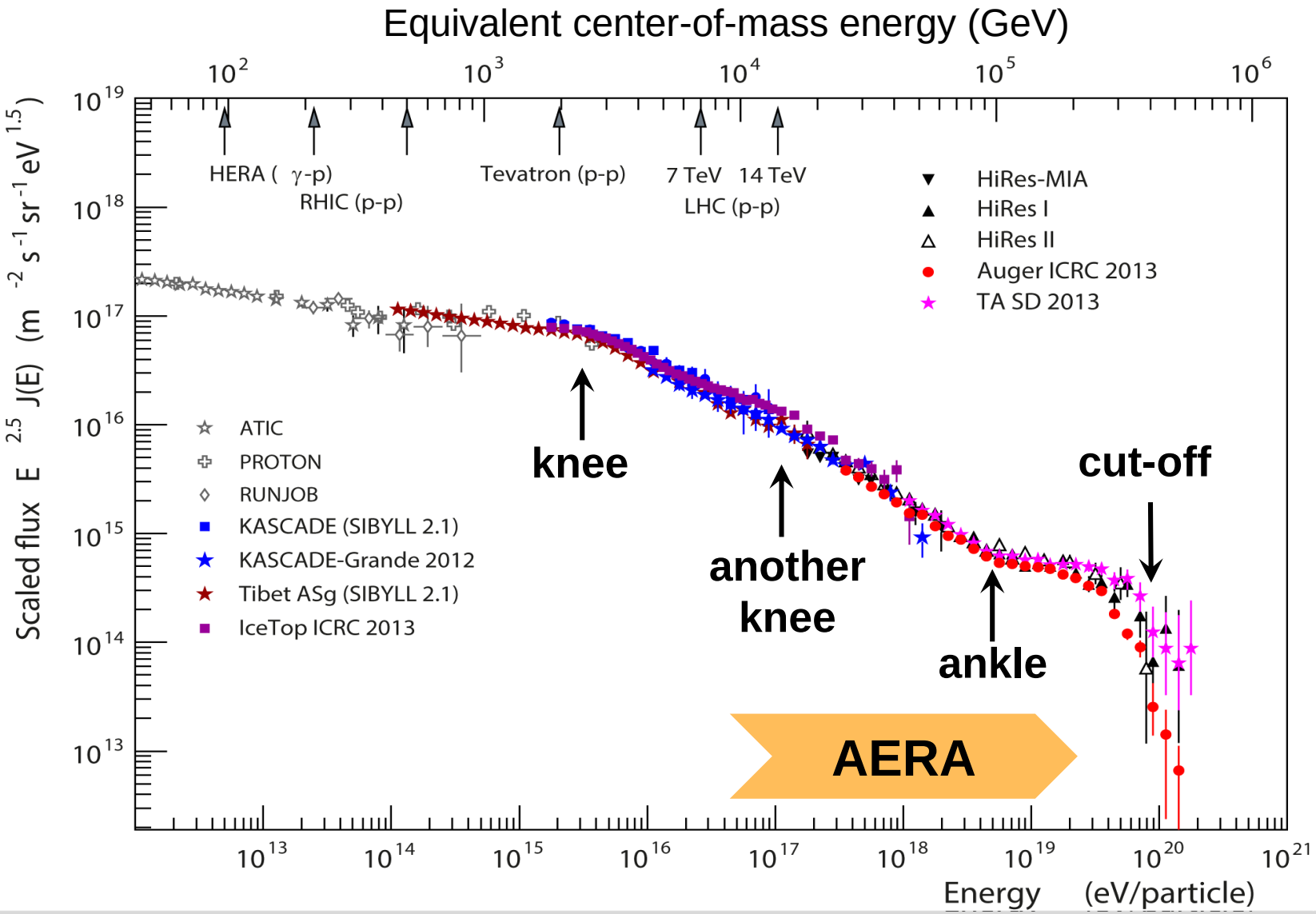
Scaled cosmic-ray energy spectrum



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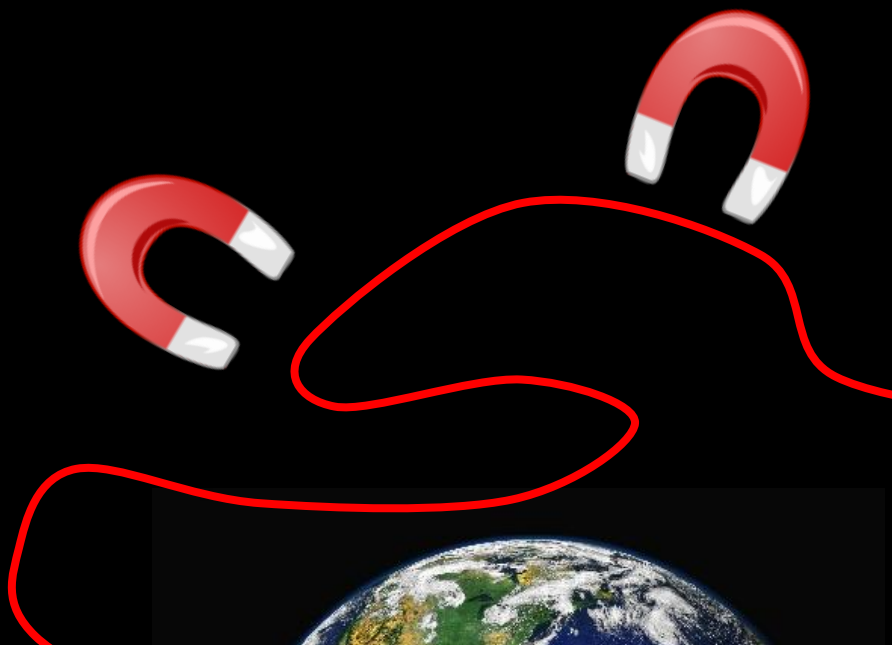
Cosmic Rays

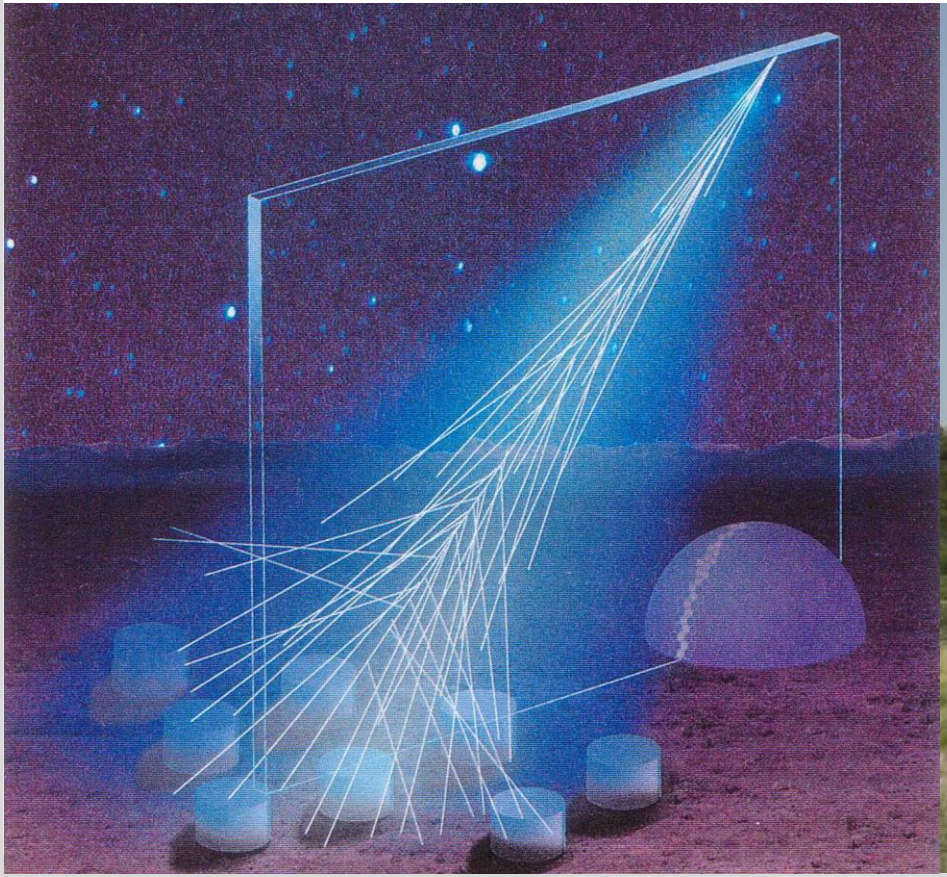


unkown
cosmic-ray
accelerator

interaction with
atmosphere causes
air-shower cascade

Pierre-Auger Observatory

- Hybrid detection of air showers for $E > 10^{18}$ eV



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Pierre Auger Observatory

Location: Argentina, Mendoza, Malargüe

Surface Detectors (SD)

- 1660 Cherenkov tanks
- 100% duty cycle
- High angular resolution

Fluorescence Detector (FD)

- 27 telescopes
- 15% duty cycle
- Composition measurement

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Air Shower Measurements

- Direction
  - triangulation with arrival times
- Energy
  - particles with SD
  - amount of light with FD
- Mass composition
  - e/μ numbers with SD
  - shower depth with FD
- Radio sensitive to all shower parameters:
  - almost 100% duty cycle
  - methods under study

Planned upgrade for better electron / muon separation
→ **poster by M. Kleifges**

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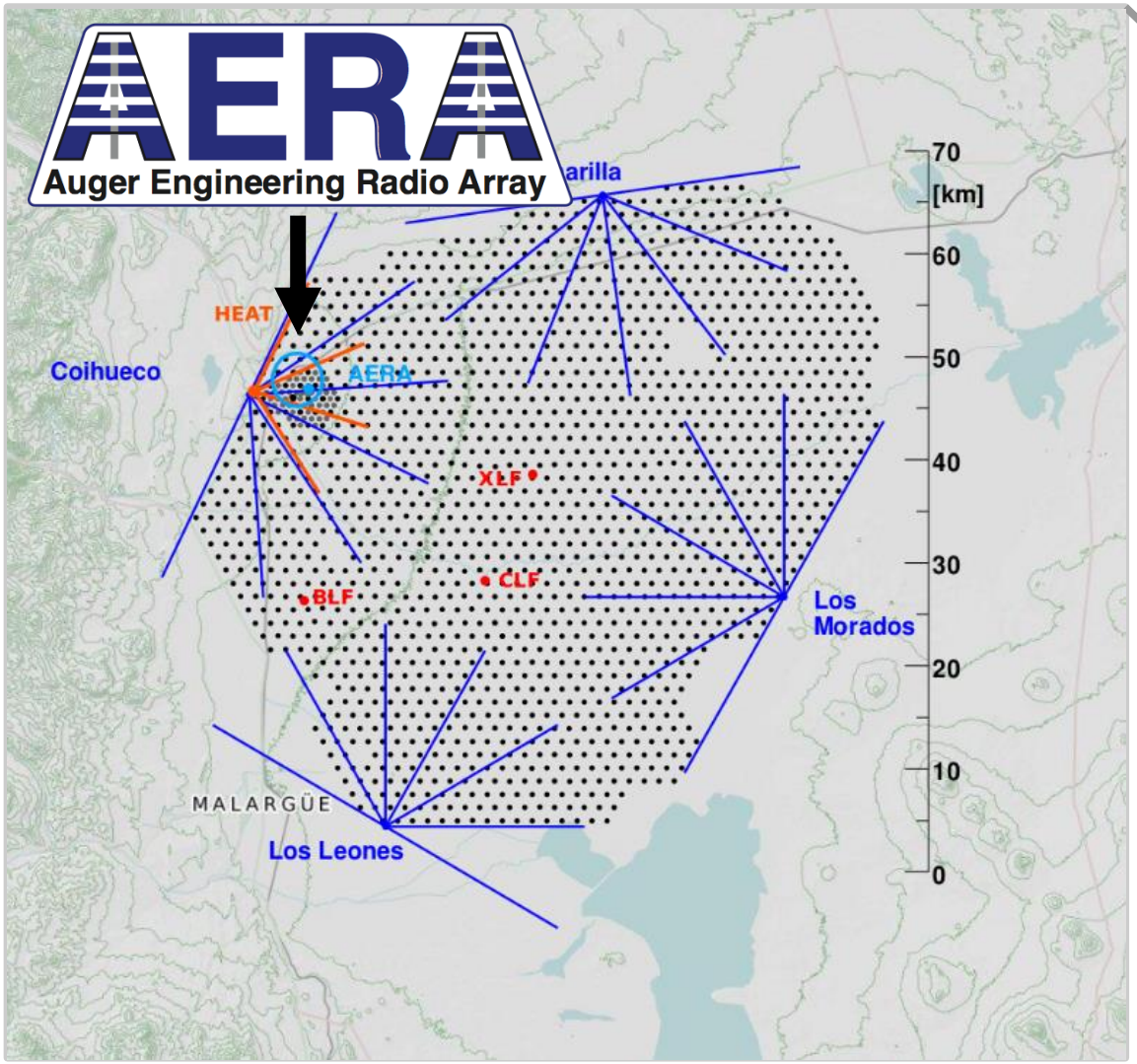
Enhancement area: AMIGA + AERA



Location: Argentina, Mendoza, Malargüe

Muon Detectors (MD)

- underground scintillators
- calibration of upgrade

Radio Detectors (RD)

- AERA
- 30-80 MHz

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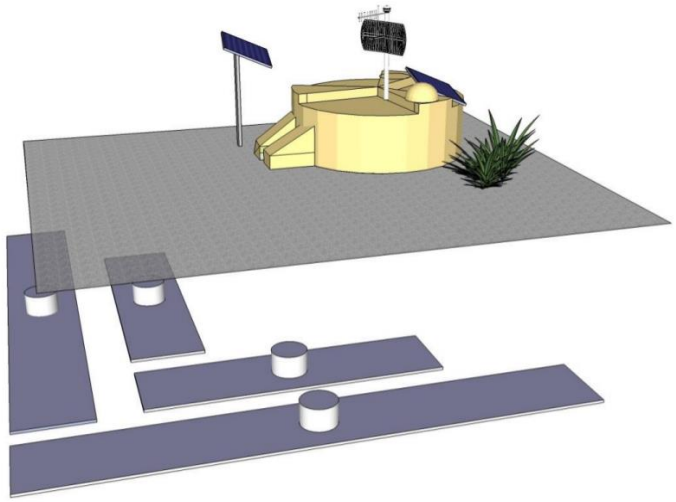
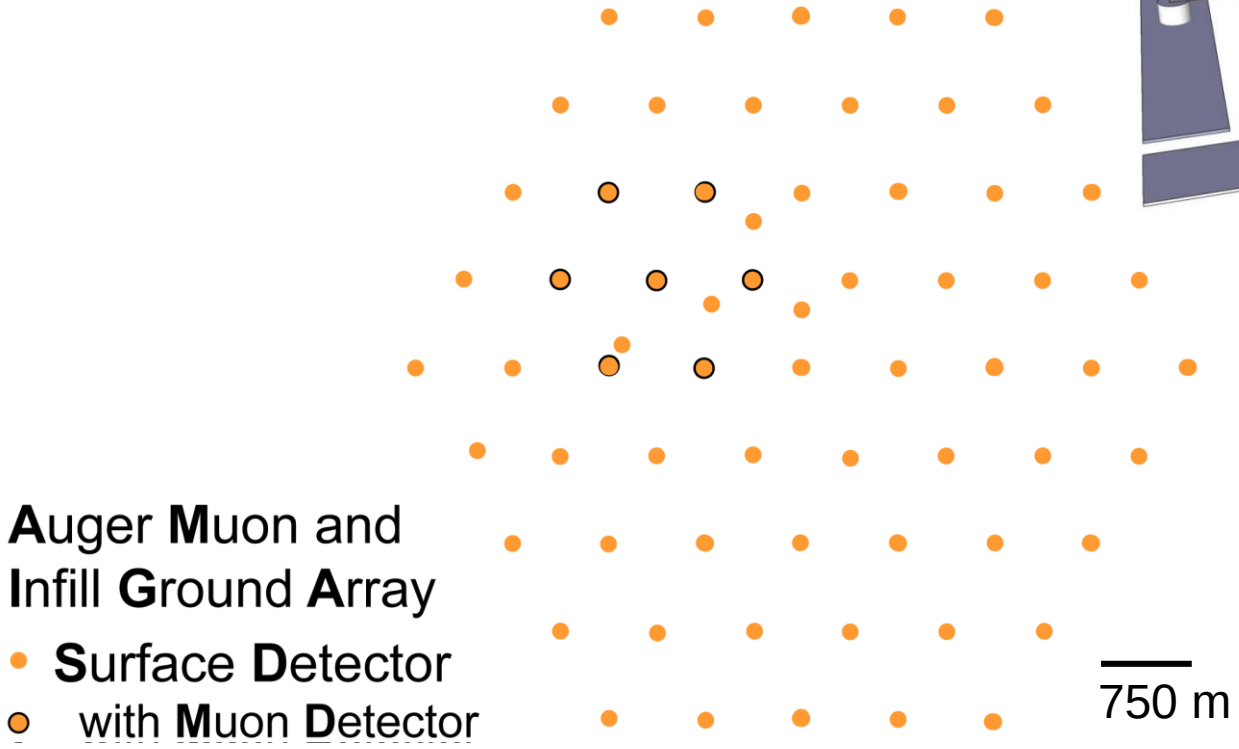
AMIGA and AERA

- 20 km² enhancement area for E > 10^{17} eV
  - closer detector spacing (750 m Infill)
  - buried muon detectors





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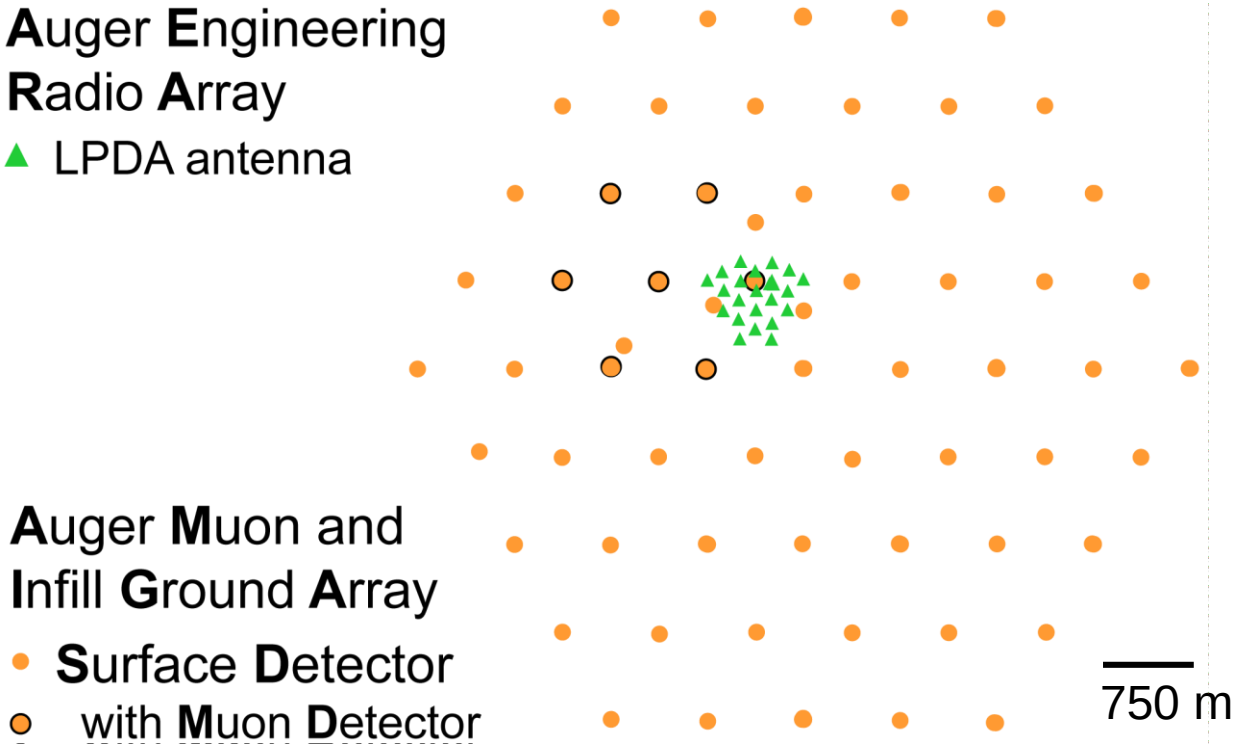
  - 153 autonomous radio detectors

LPDA



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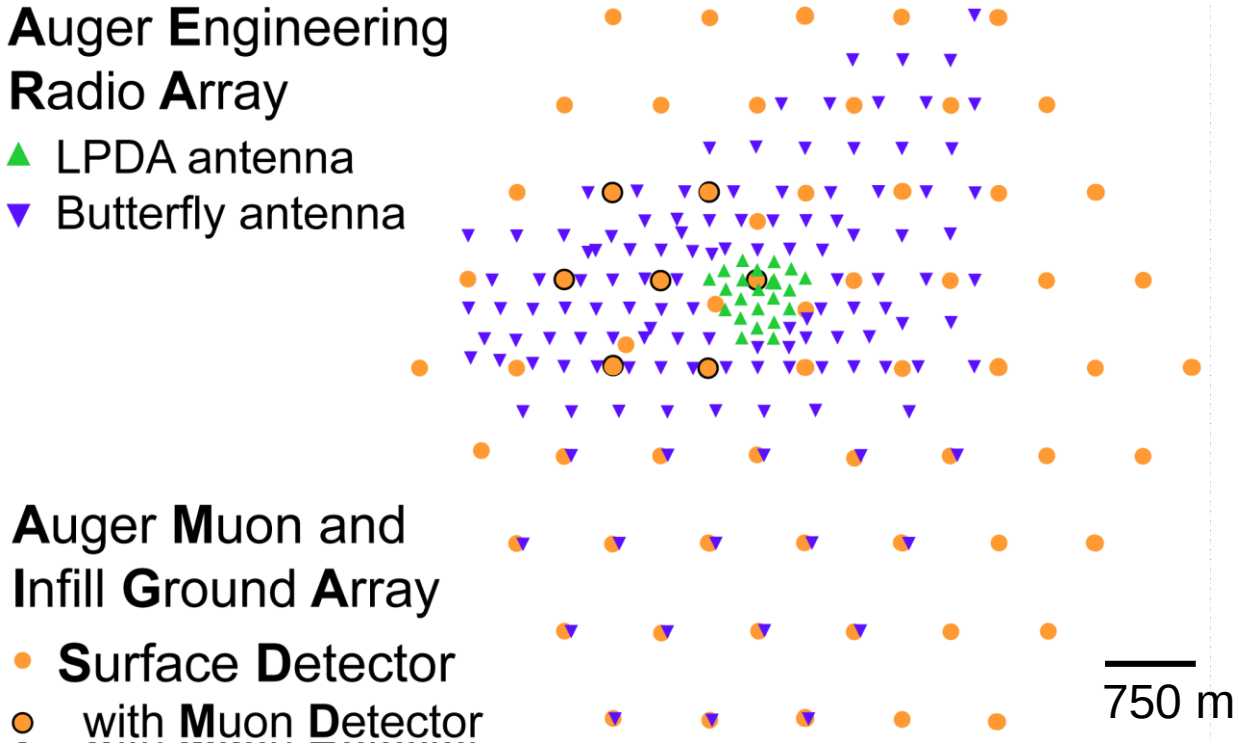

LPDA

Butterfly

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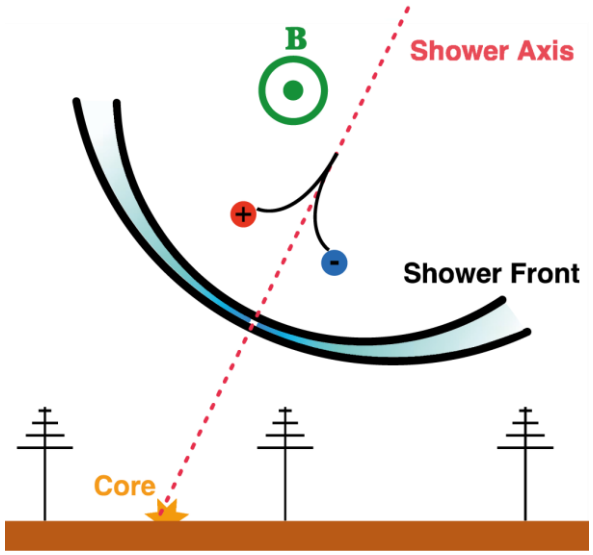
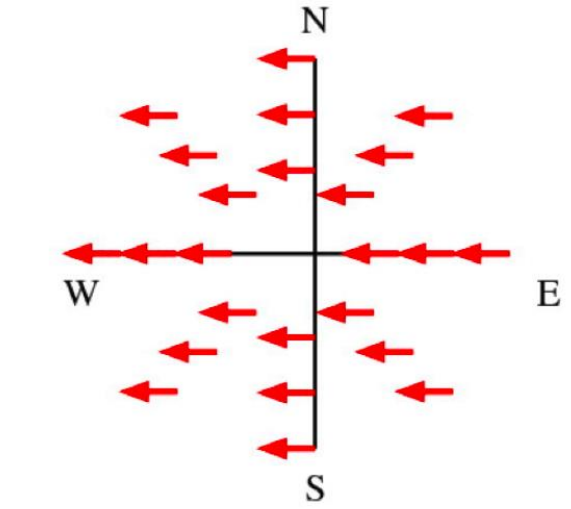
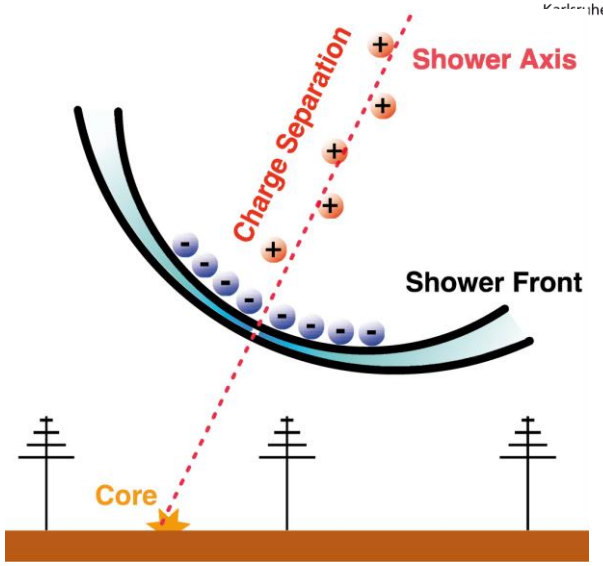
Emission mechanisms: λ ~ few meters

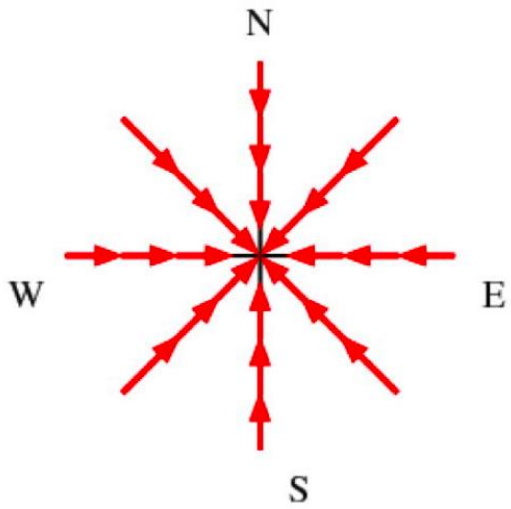
$$\frac{\mathrm{d}I}{\mathrm{d}t}$$





Geomagnetic effect ~ 90%





Askaryan effect ~ 10%

$$\frac{\mathrm{d}Q}{\mathrm{d}t}$$

diagrams by H. Schoorlemmer and K.D. de Vries

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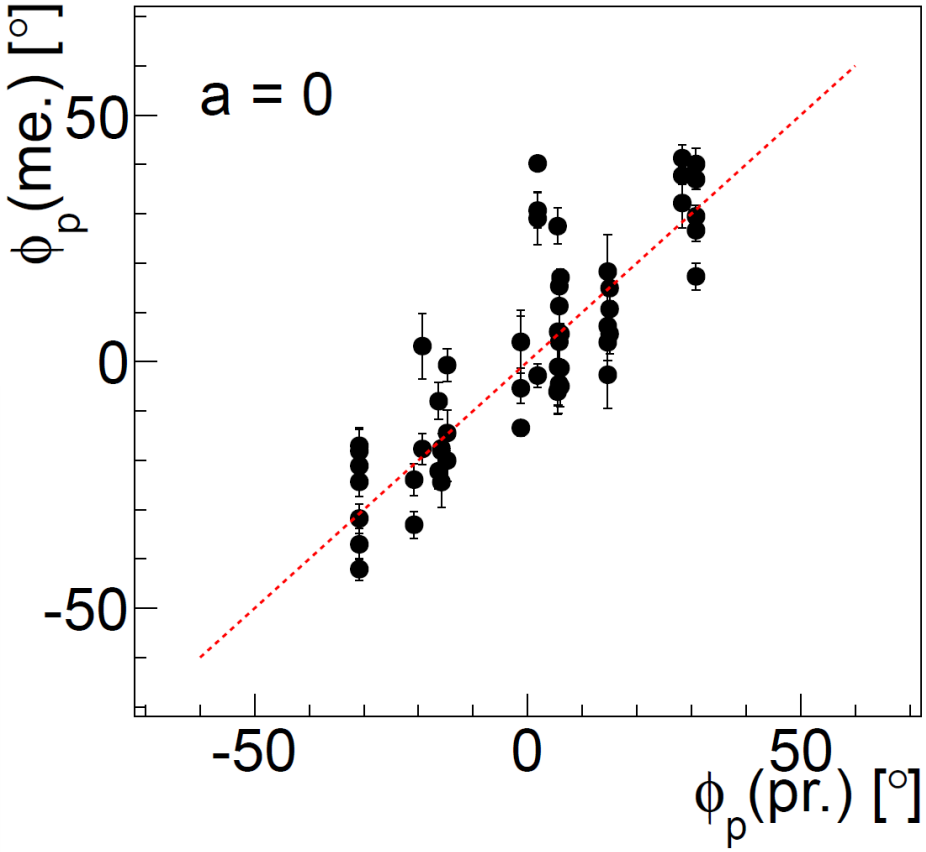
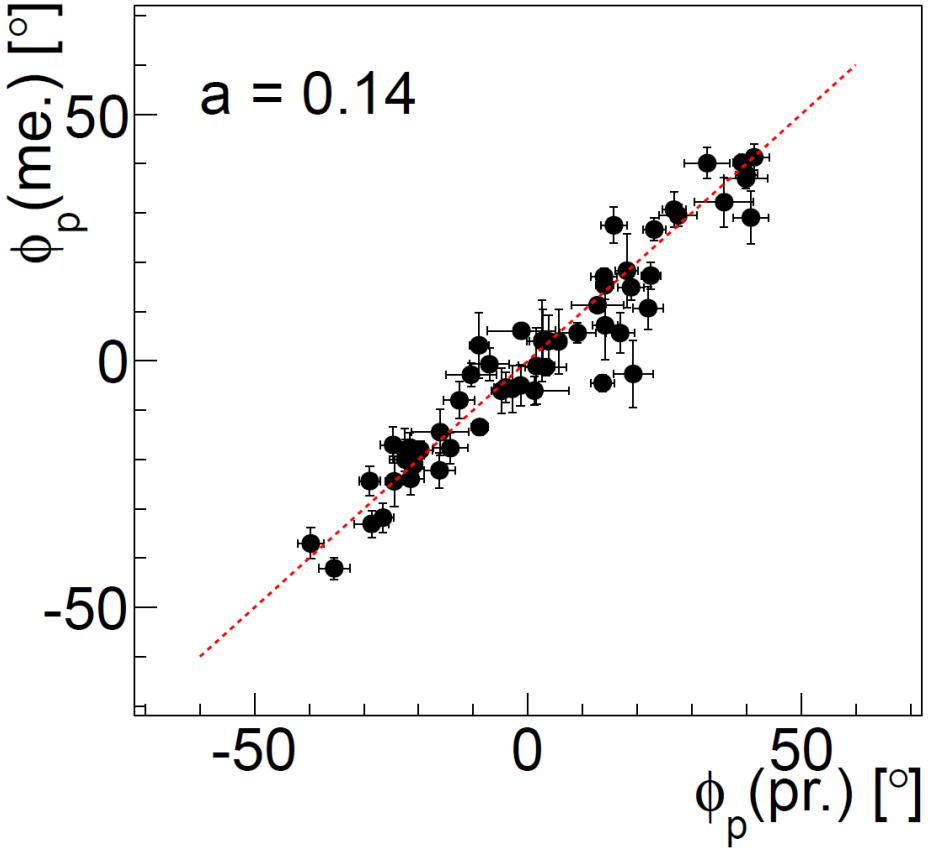
Experimental evidence

- Comparison of measured and predicted polarization angle

only geomagnetic emission



Askaryan + geomagnetic emission



Pierre Auger Collaboration, Phys. Rev. D 89 (2014) 052002

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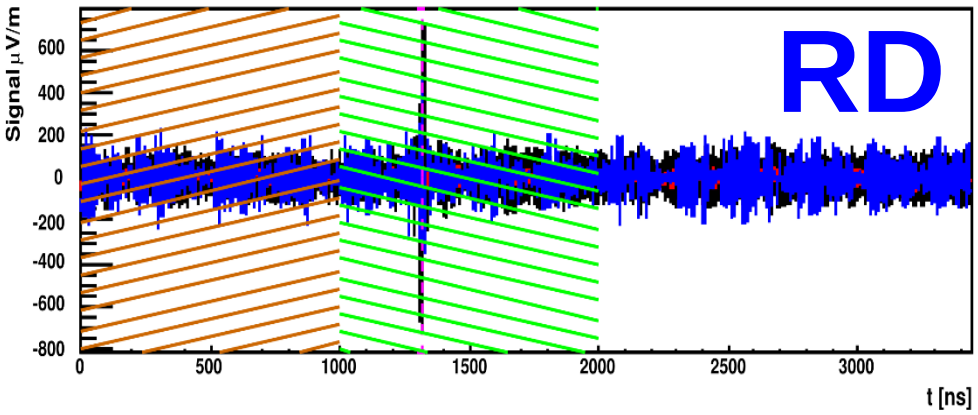
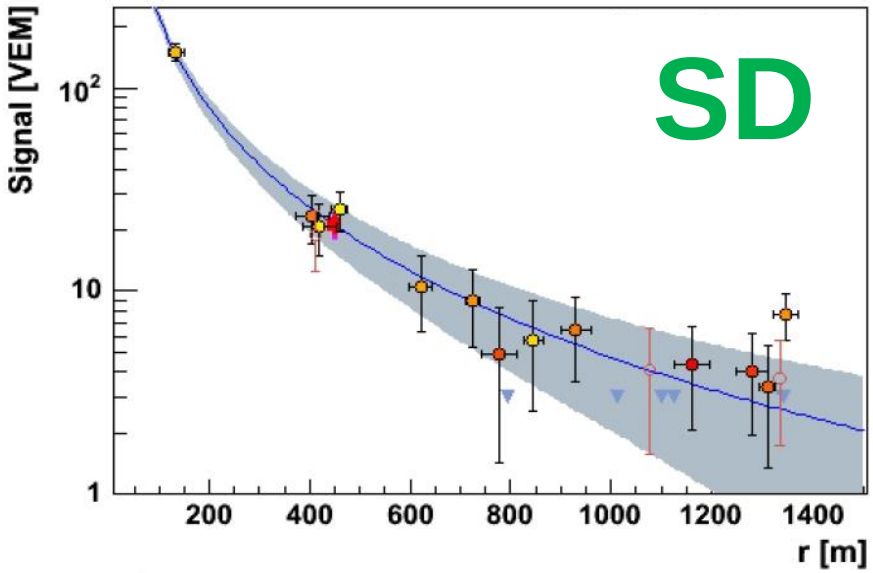
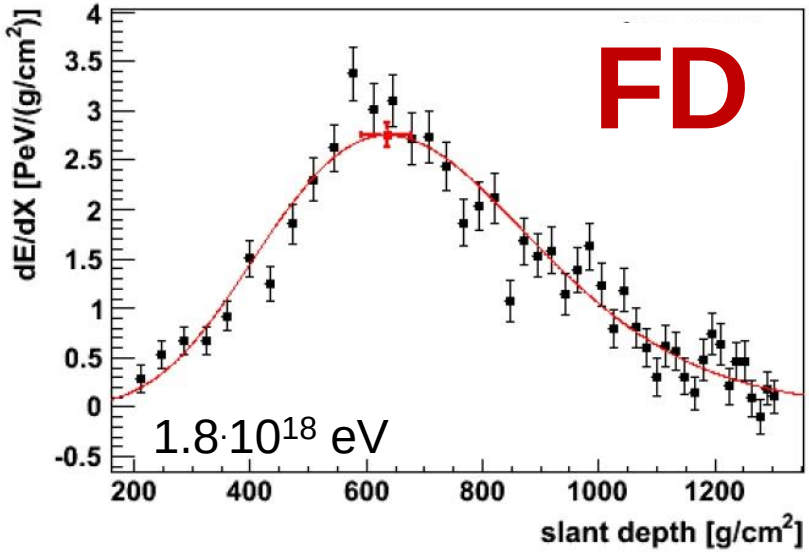
Example event

- Radio measurement
  - hybrid measurements with particles and fluorescence
  - trigger / combined analysis
- Vectorial measurement
  - 2 polarizations
  - both 30-80 MHz







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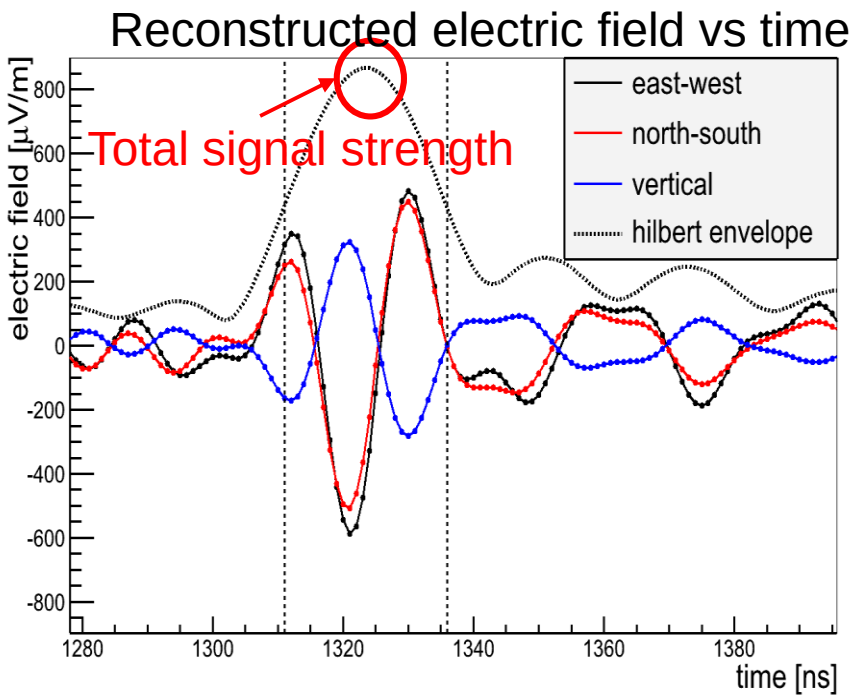
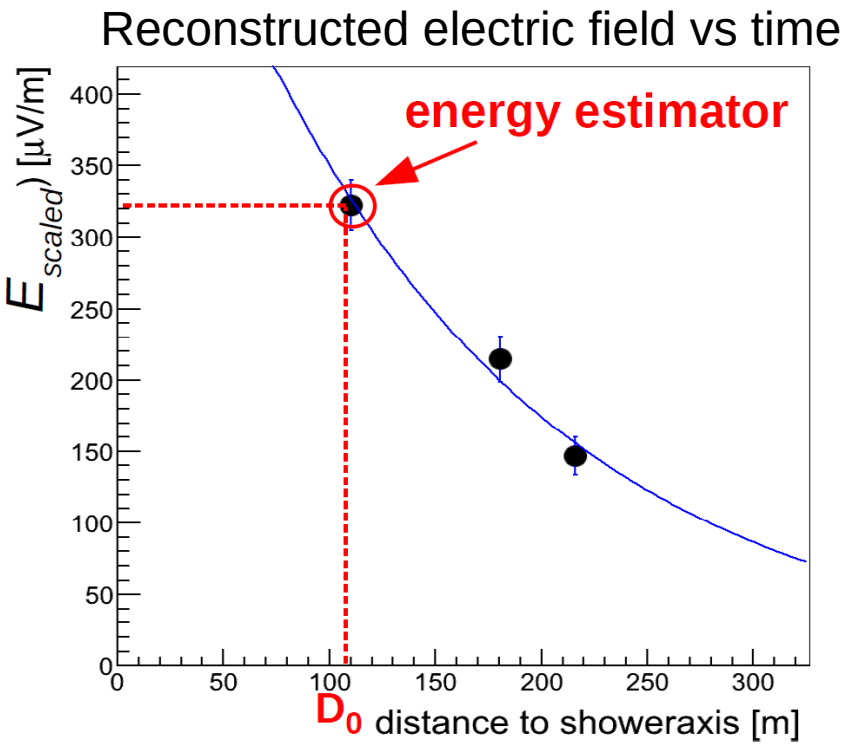
Energy reconstruction with radio

- Radio amplitude proportional to shower energy
  - First approach: Simple 1-D function neglecting asymmetry
  - In preparation: Asymmetric 2-D lateral distribution function





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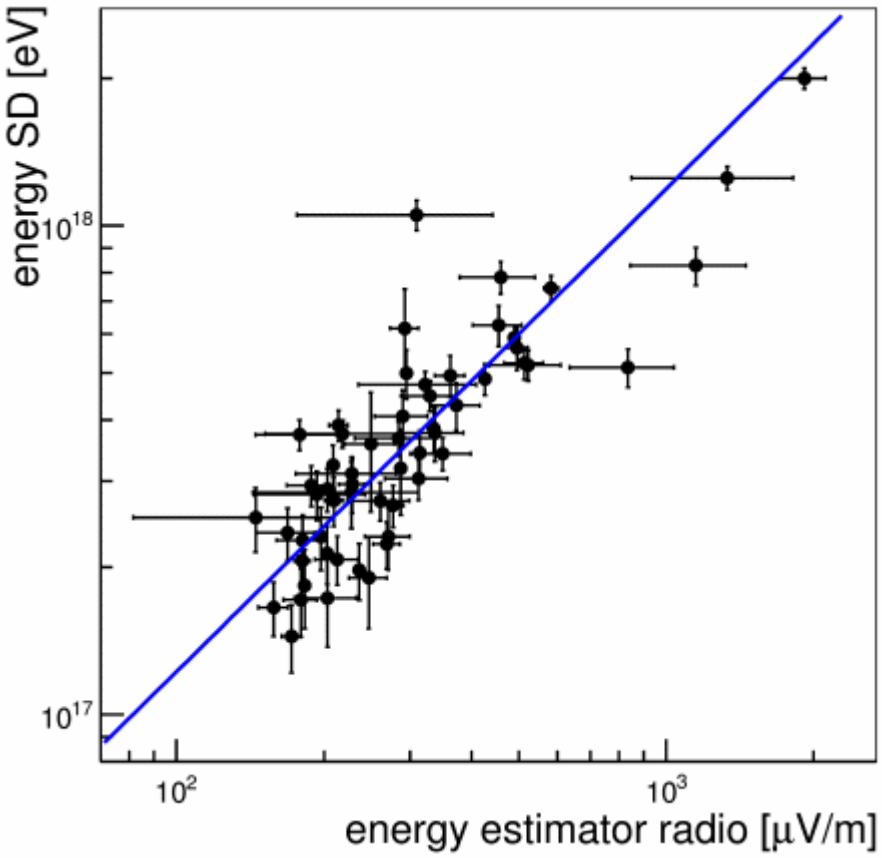
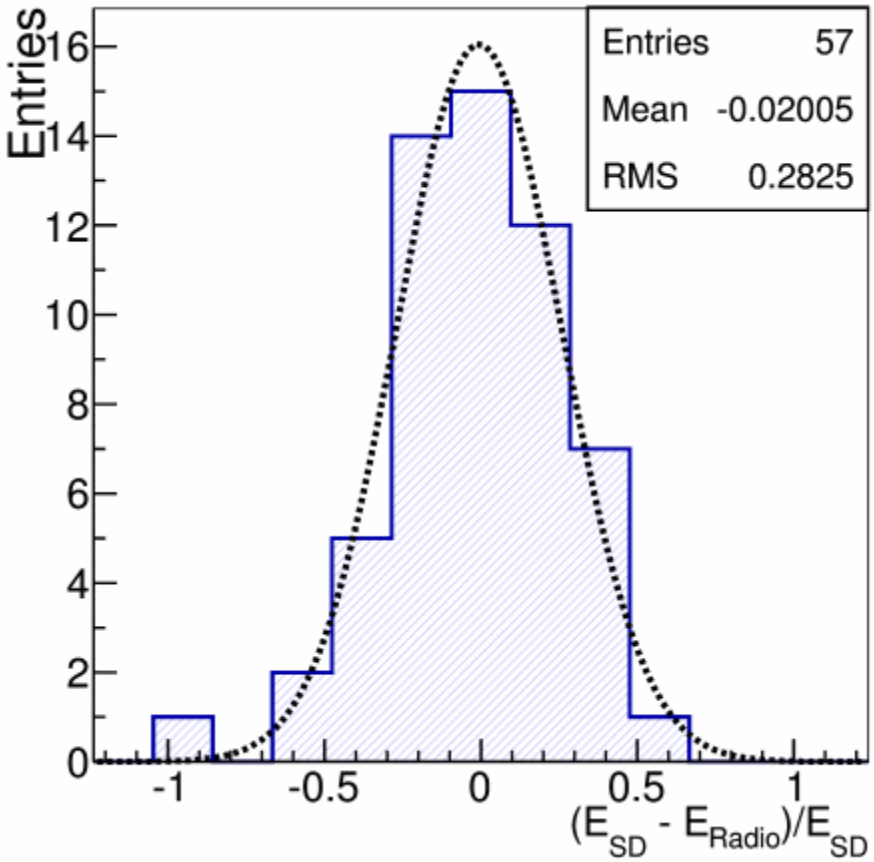
Comparison with surface detectors

- Radio suitable for energy estimation
  - precision seems to be competitive with particle detectors





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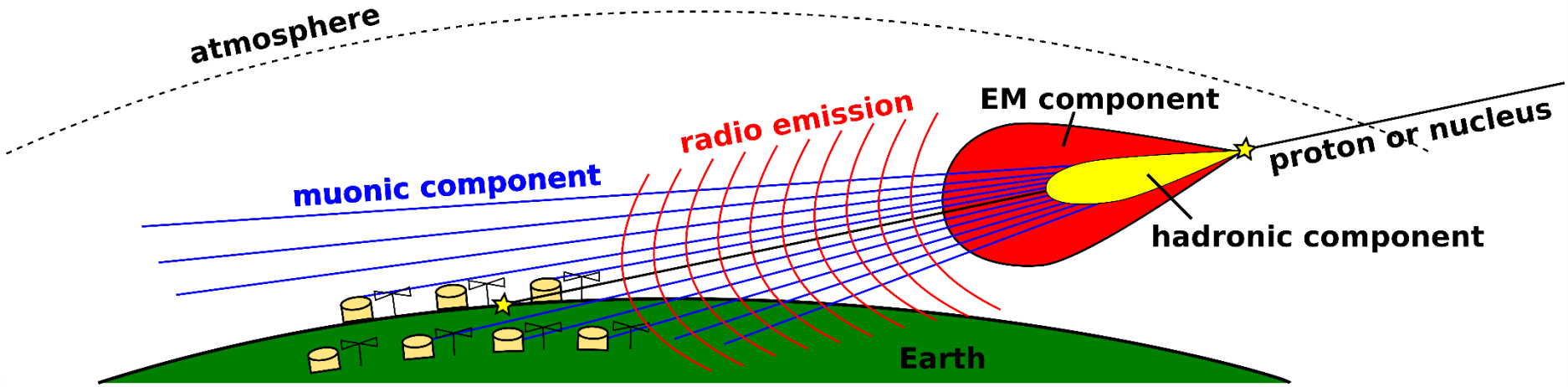
Radio ideal for inclined showers



- Electrons and photons attenuate in atmosphere
- Only muons and radio emission survives
  - Complementary information on shower → primary particle type

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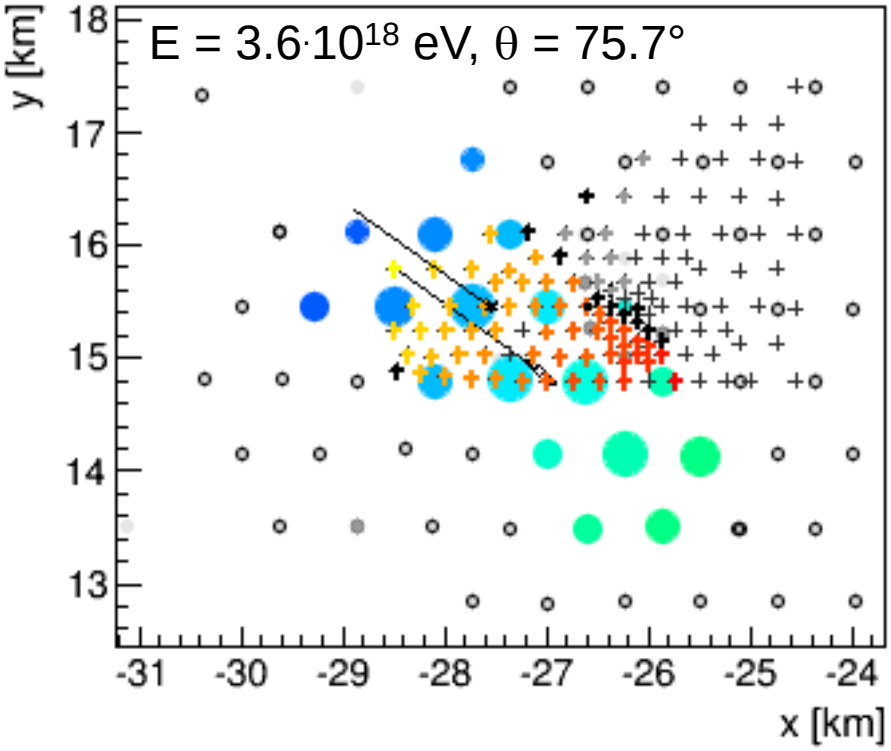
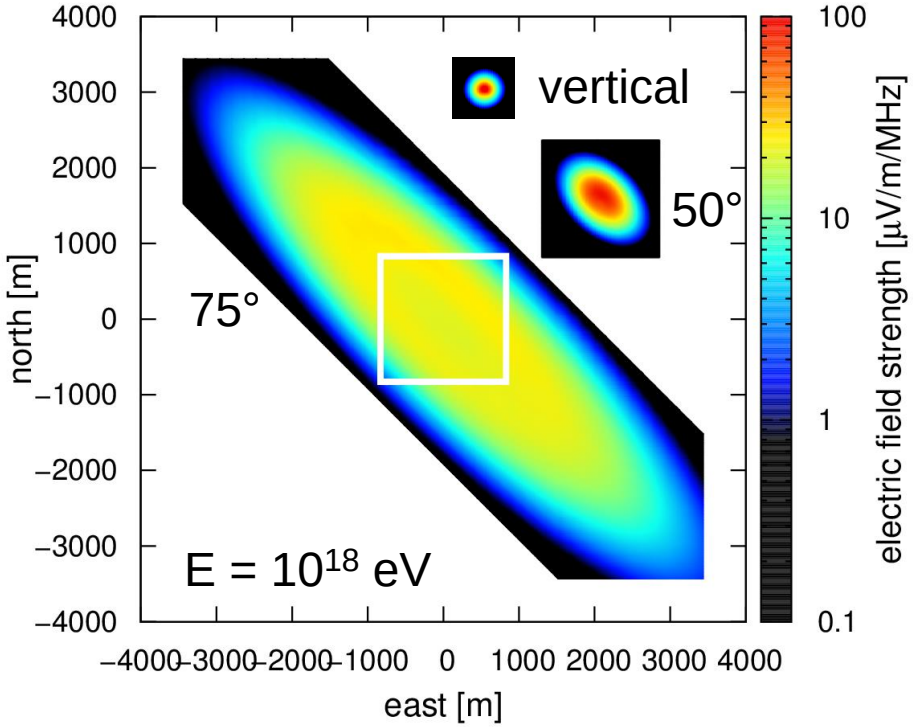
Huge footprint for inclined showers

- Sparse antenna spacing feasible for inclined showers
  - Radio becomes applicable to largest scales for reasonable cost

AERA measurement



CoREAS simulation



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Conclusion

- Radio detection → additional method for air-showers
  - complementary information to particle detectors
  - almost 100 % duty cycle
  - highly efficient for inclined showers
- Auger Engineering Radio Array (AERA)
  - enhancement of the Pierre Auger Observatory
  - physics in the energy range from 10^{17} to 10^{19} eV
  - demonstrator for large scale applicability of radio technique
- Competitive precision for air-shower properties
  - energy shown with AERA, composition under study
  - results of other experiments look promising

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Backup

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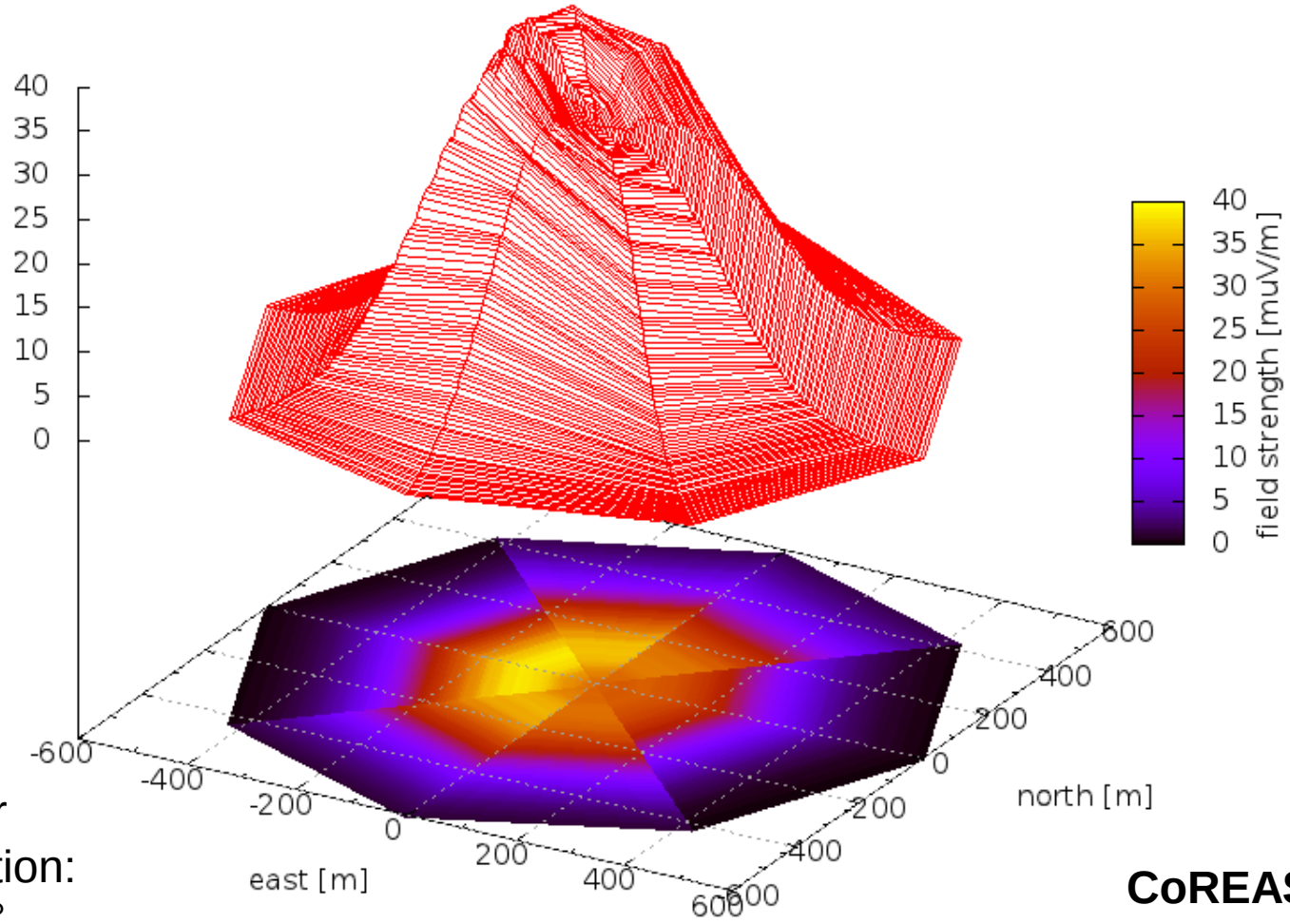
Asymmetric lateral distribution



shower inclination:
$\theta = 45°$

CoREAS simulation for LOPES experiment: 43-74 MHz

T.Huege et al., ARENA2012

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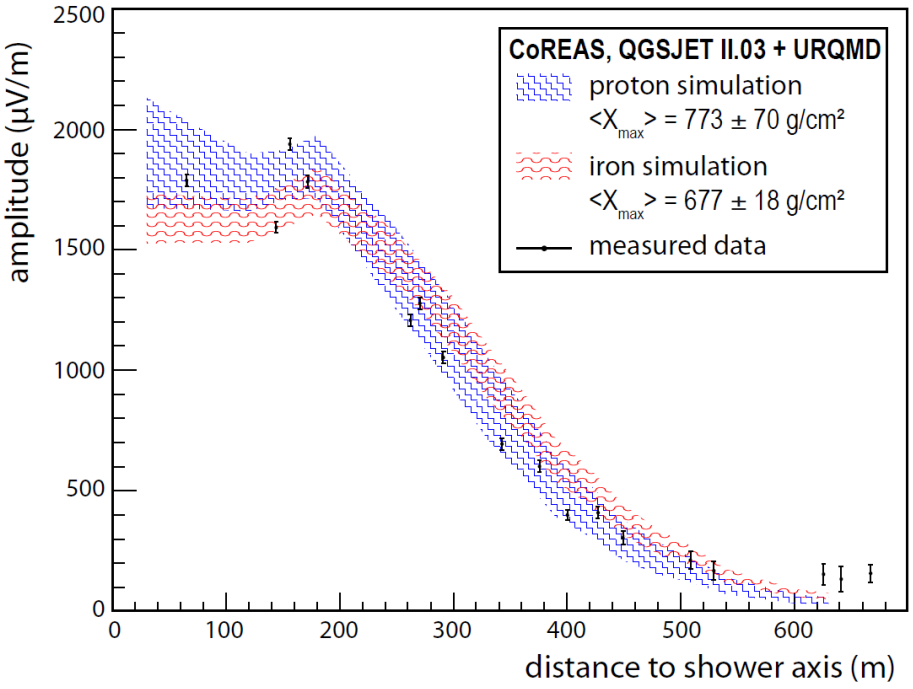
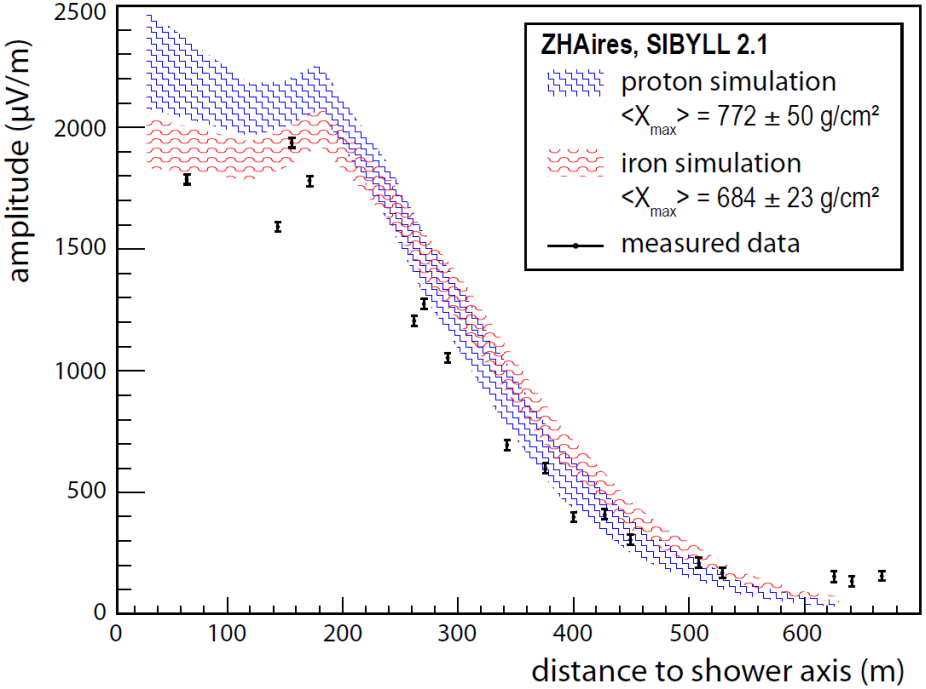
Comparing simulations with AERA event





- CoREAS and ZHAires simulations reproduce shape
  - slight differences in amplitude scale
- General features of radio emission are understood

Pierre Auger Collaboration, ICRC2013, id #899

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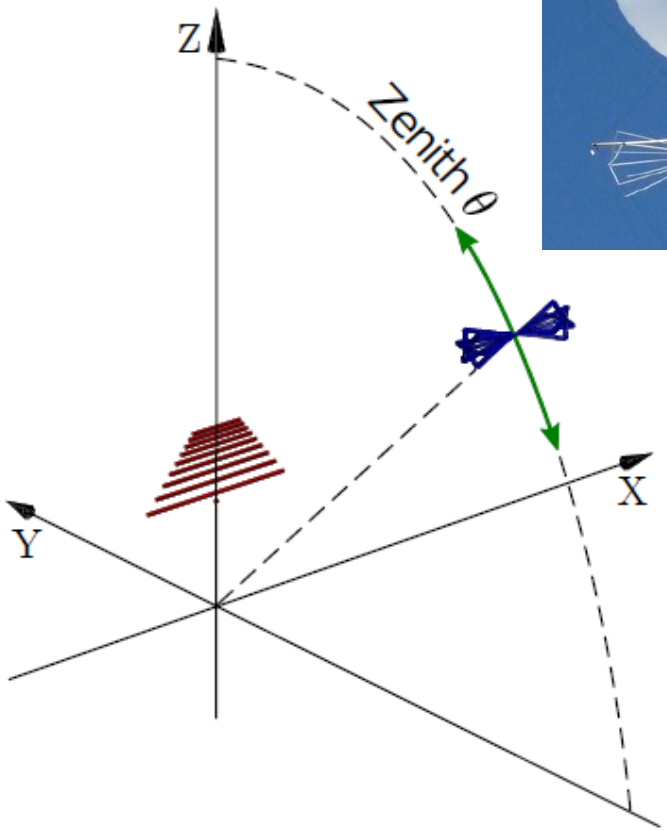
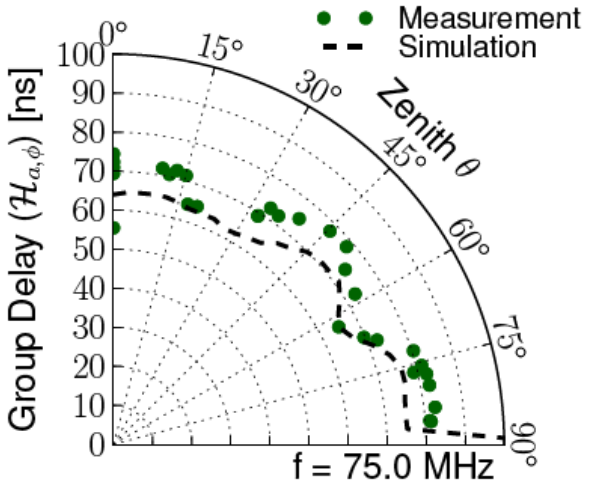
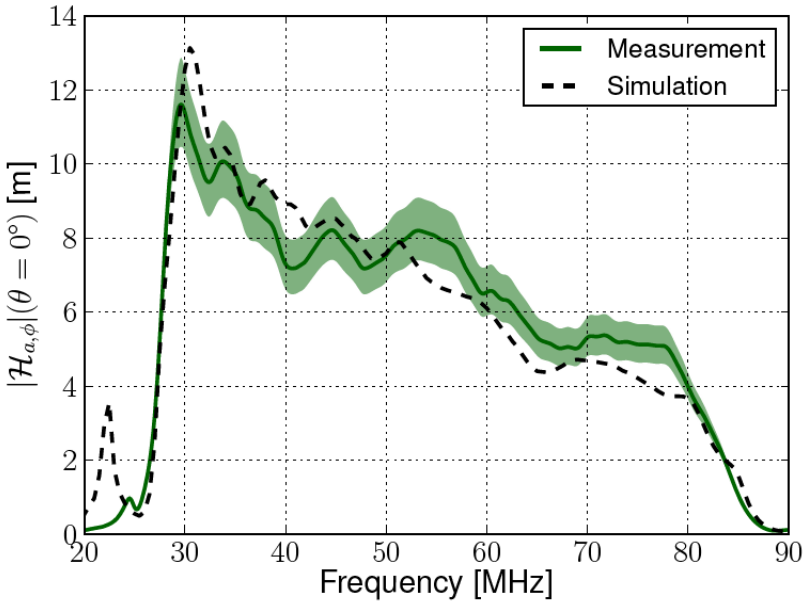
Antenna calibration







Pierre Auger Coll., JINST 7 (2012) P10011

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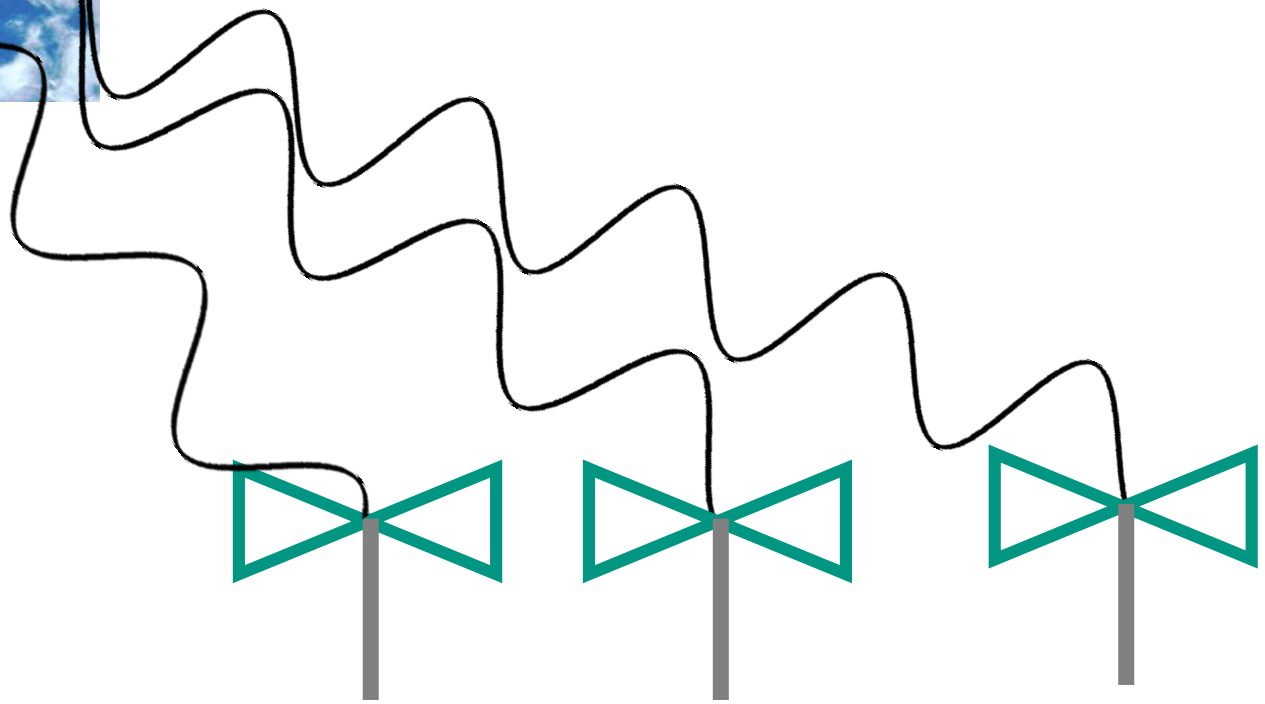
AERA Beacon

- Phasing of sine waves provides nanosecond relative timing precision

Beacon:
continuous wave emitter, 3 km west of AERA



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