# *The experimental future of ultra-high energy cosmic rays: projects and perspectives*

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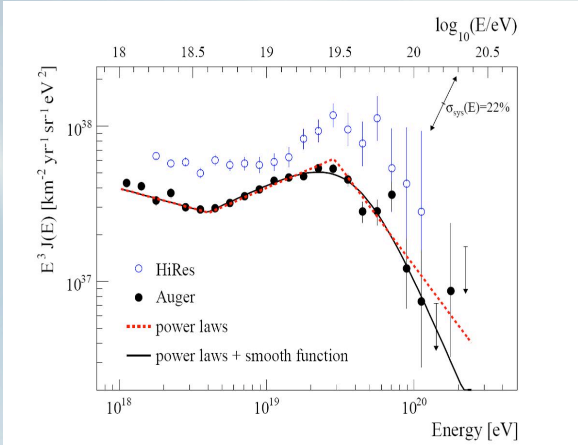
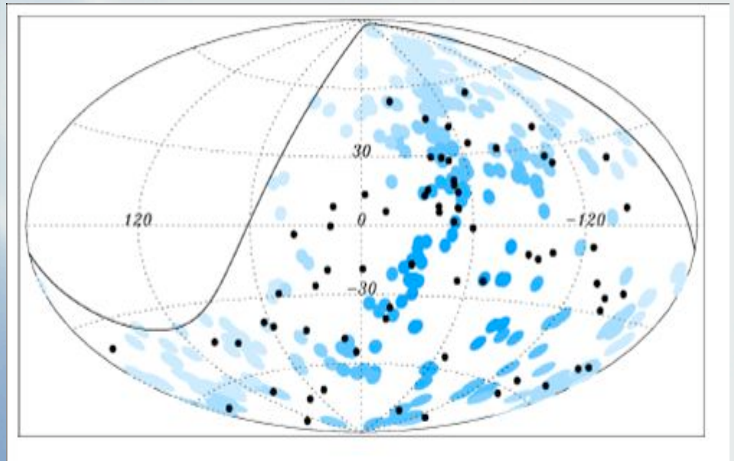
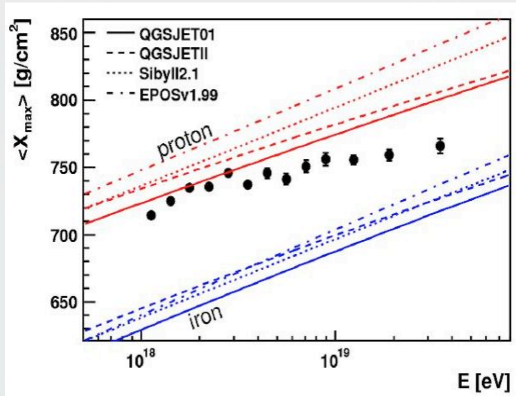
# Results from Pierre Auger Observatory

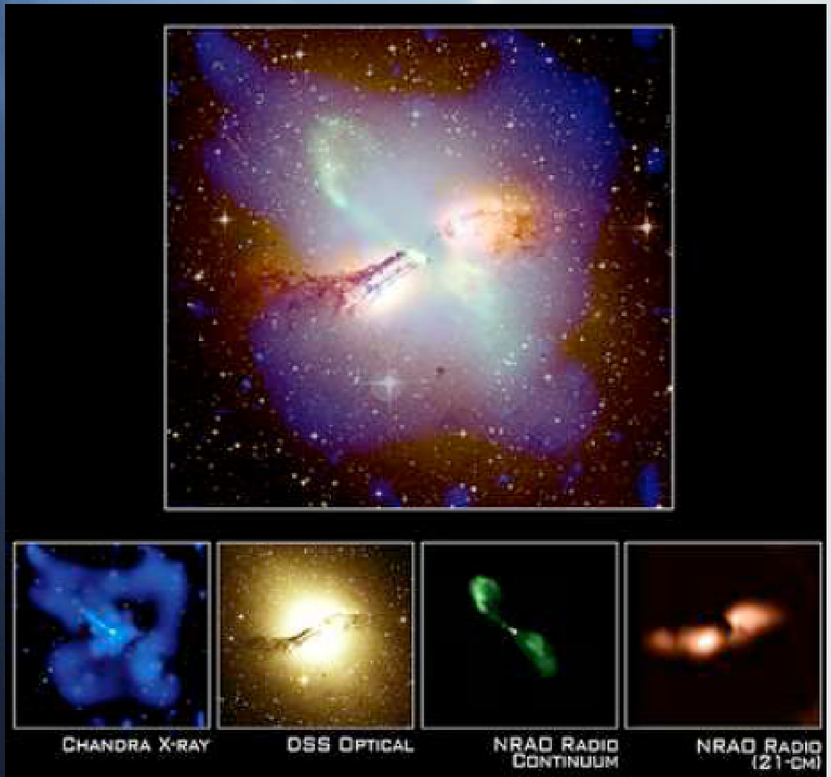



- Flux suppression above 4 $10^{19}$ eV.
- Anisotropy above about 5 $10^{19}$ eV.
- Photon limit.
- Limit for GZK neutrinos.
- Composition (?)



# Science goals for ultra-high energy cosmic rays




Centaurus A

- Identify and study nearby (<100 Mpc) cosmic-ray sources.
- Study composition.
- Particle interactions at high energy.
- Multi-messanger studies: neutrinos, photons.

**Requirements**

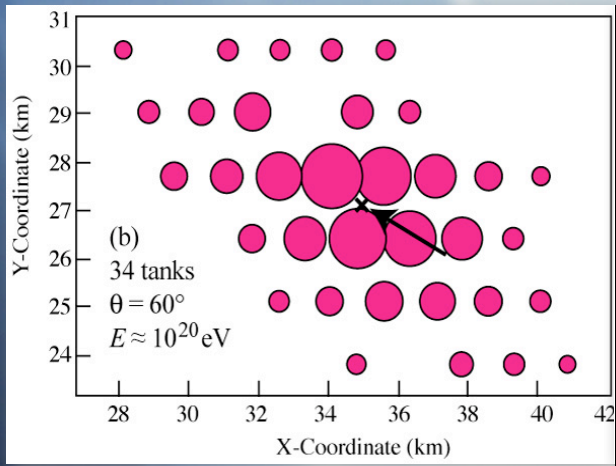
- Increase acceptance
- Good energy and angle resolution
- Primary identification
- Full sky coverage

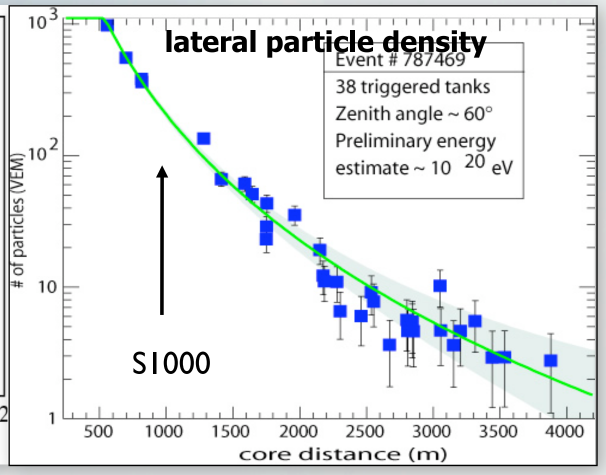
# Experimental strategy

- High precision measurements on the ground with increased acceptance
- Large field of view measurements from space
- Develop new air shower detection techniques

# Currently used techniques

## Auger Surface Detector (SD)

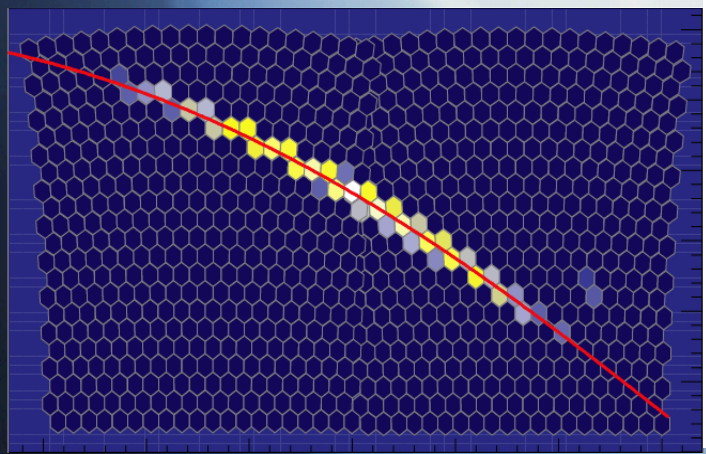


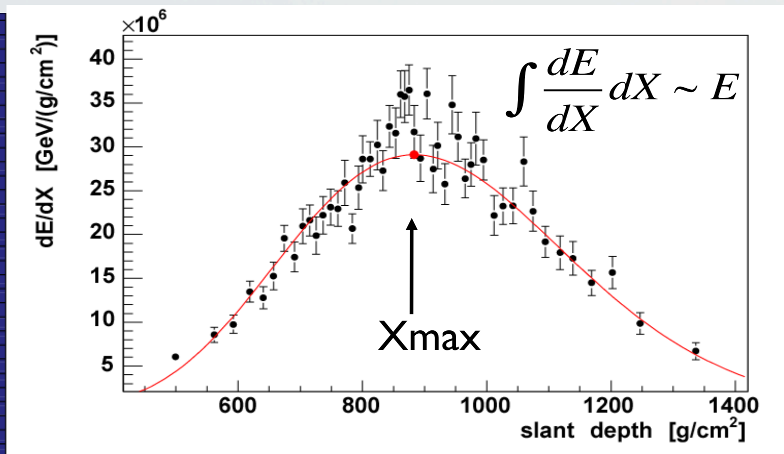




SD:
Angle from arrival times.
Signal density S1000 (in VEM).

FD:
Absolute energy from the integral of the light yield.
Composition from Xmax.

## Auger Fluorescence Detector (FD)



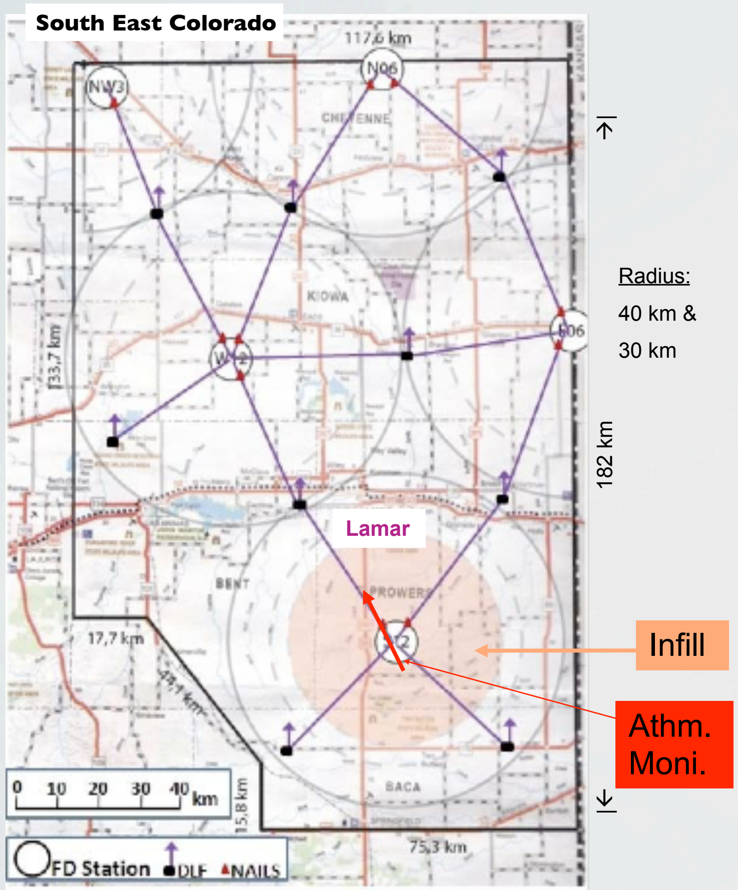


# Outline

- Large acceptance ground detector: Auger North
- Large field of view space detector: JEM-EUSO
- Development of radiodetection techniques

# Auger North Layout


- 4,000 SD stations cover a total area 20,000 $km^2$, rectangular grid with 2.3 km spacing
- Infill of 400 additional SD stations placed with 1.6 km spacing
- 39 FD telescopes with estimated viewing of 40 km placed in 5 buildings



# Differences between Southern vs. Northern site

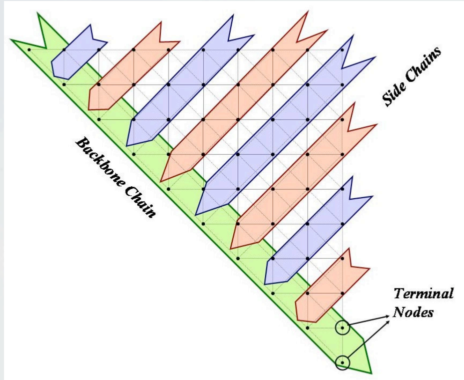
<u>Design changes are driven by</u>

- Physics goals
  - focus on energy > 40 EeV → SD: larger SD spacing, improved dynamic range
- Climate / environmental differences between sites
  - harsh winter at Colorado → isolation of SD tanks required
  - no hills for comms tower → sensor network topology for communication
- Advancement of technology
  - redesign of electronics for SD and FD to state-of-the-art technology
  - use PMT with higher Q.E. (26 % → 35%) → changes in FD camera
- Simplify design for lower cost at similar performance

# Communication network

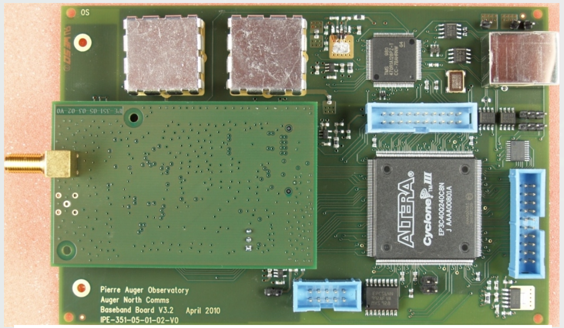
Communications system Architecture:

- Tank-to-tank communication with a Wireless Sensor Nets (WSN)
- Fault-tolerance by second order power chain topology (→ transmit to 2 neighbors)
- Sectors with backbone & side chains
- Terminal nodes and FD data connect to Concentrator stations; finally join the pre-existing fiber network on site



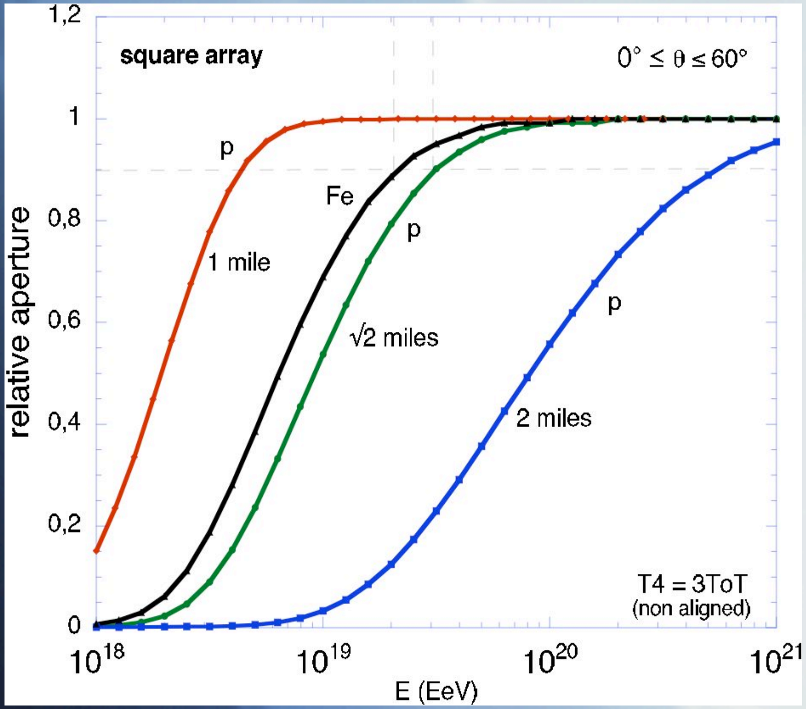

Radio transmitter hardware (=Subscriber)

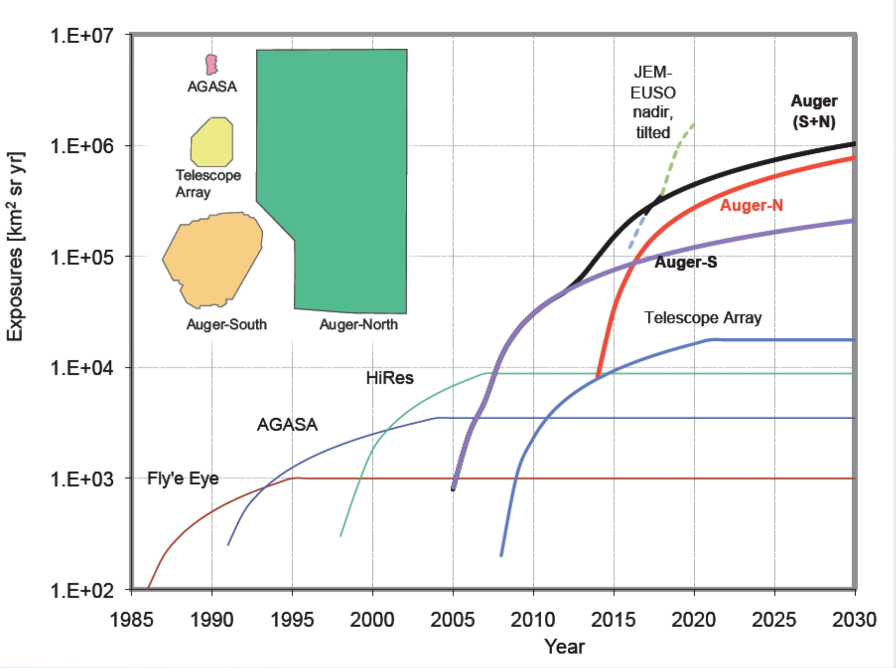
- semi-custom design using commercial radio with Altera Cyclone III
- use of 4.6 GHz license-free band (US)
- antenna height about 6 m



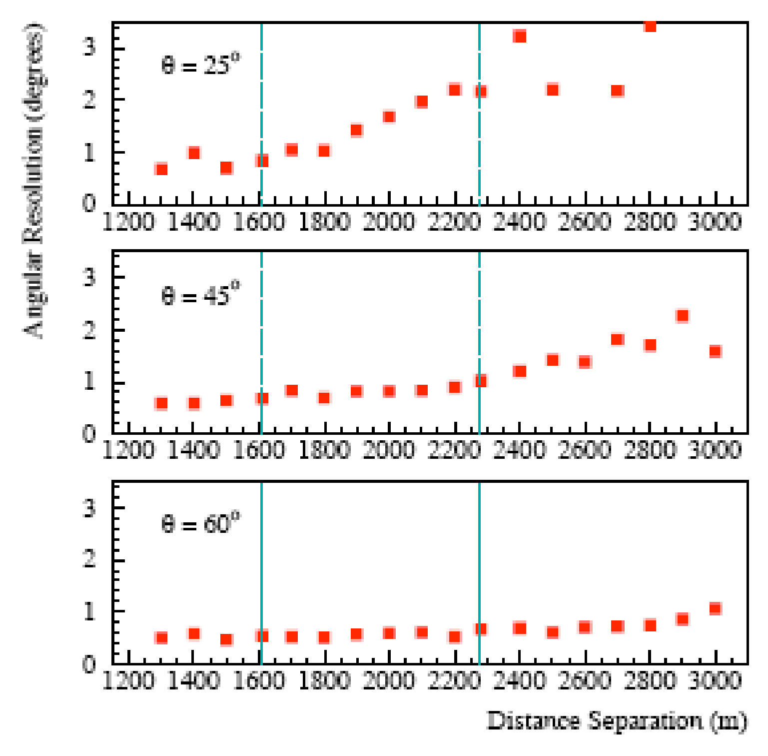

Prototype subscriber: baseband & RF- board

# Aperture and exposure



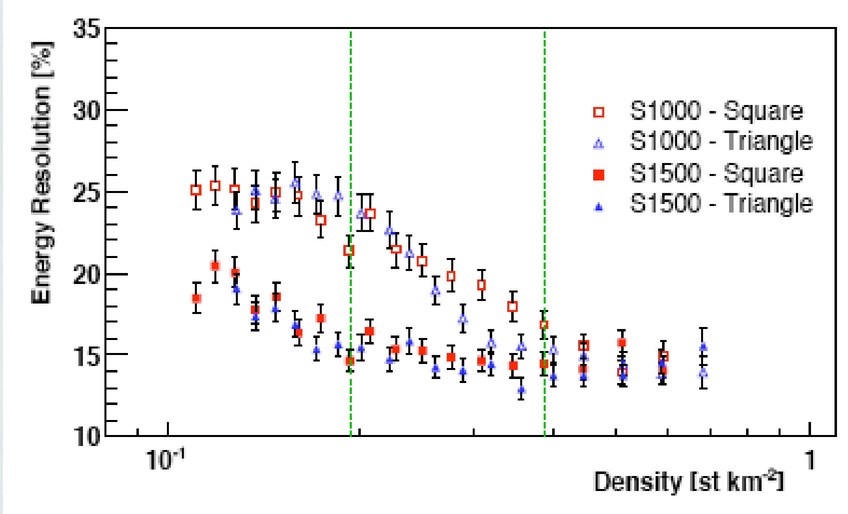
# Expected angular & energy resolutions for SD




Angular resolution (1σ) for events of 50 EeV with 5 or more stations based on Monte Carlo simulation:

depending on zenith angle: 0.7°...2.2°

Energy Resolution vs. Density



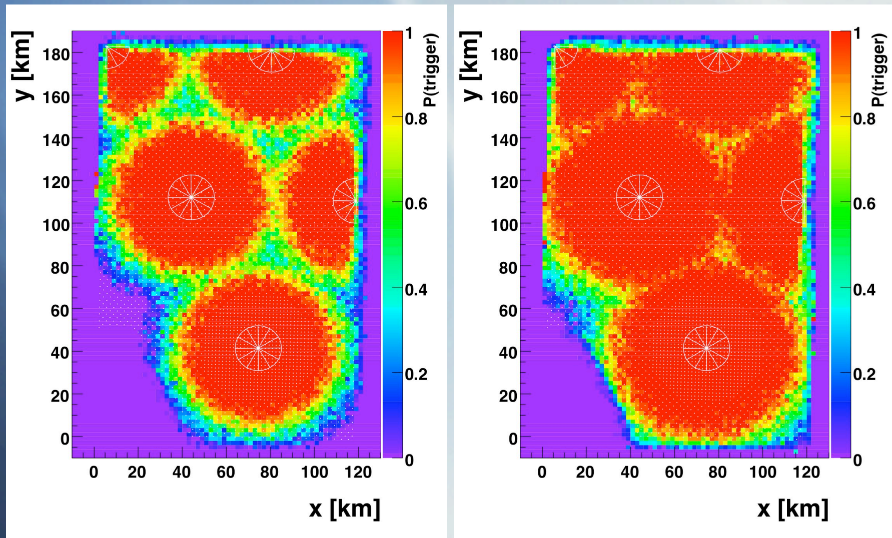

**Energy resolution depends on:**

Choice of energy estimator in LDF fit
AS: S(1000m), AN: S(1500m)

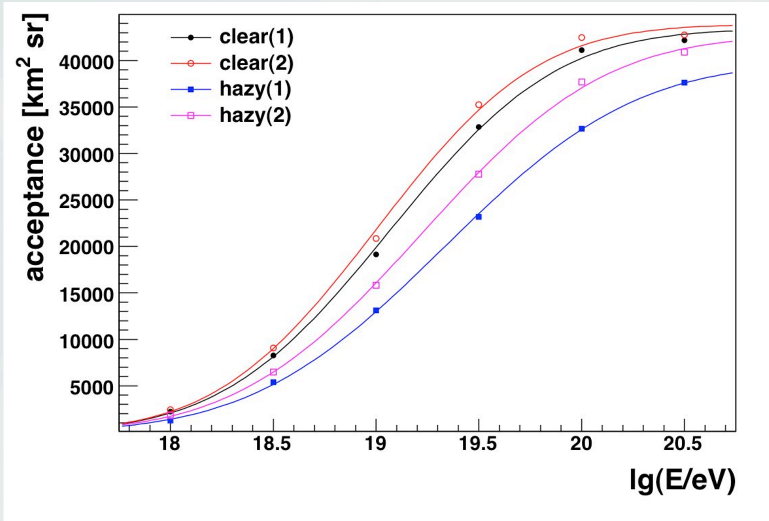
The resolution of the shower core position is less than 150 m.

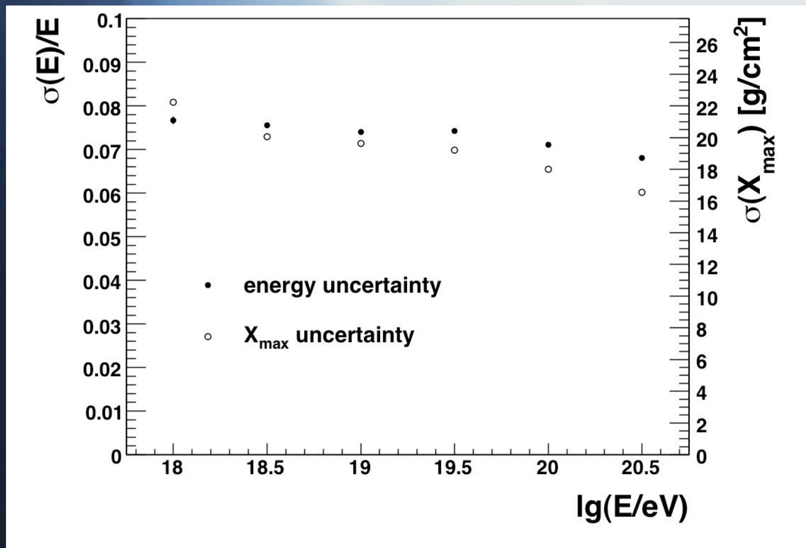
The increased dynamic range will allow to measure up to 100 m from the shower core.

# FD acceptance and resolutions




Trigger efficiency at $10^{19}$ and $10^{20}$ eV.

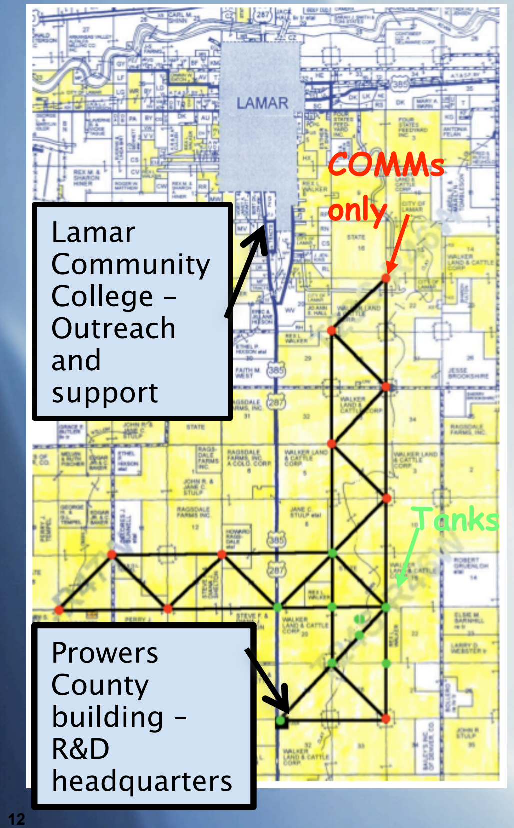


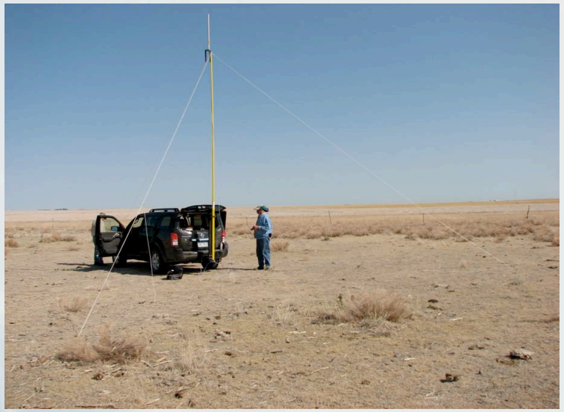

Energy and Xmax resolution after standard quality cuts

- Acceptance depends on atmospheric clarity
- Resolution of energy and Xmax are about the same as in Auger South
- For highest energy uniform trigger efficiency over full array

# Research and Development Array (RDA)




- 10 SD detector stations plus 10 additional COMMS only stations
- used for test of prototypes
  - new SD tanks and electronics
  - new communication system
  - only limited physics data
- Several deployment phases
  1. towers / standalone masts (without comms)
  2. tanks without SD electronics or comms
  3. SD electronics and comms installed in the field → early 2011
- train students and gain local experience



# Status of Auger North

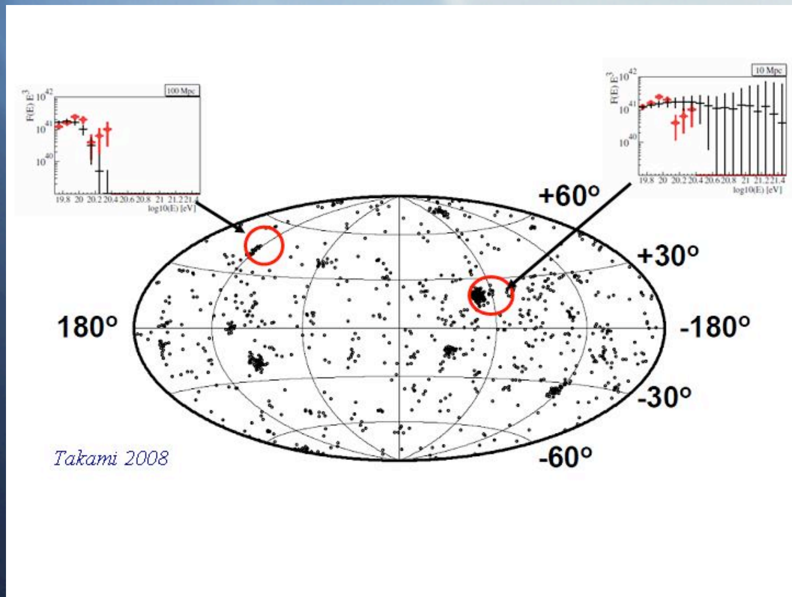
- RDA funded and will be completed early 2011
- Funding problems in US for Auger North
  - Construction in Colorado becomes difficult
  - Open site selection?
  - Revise design for potential new sites?

# JEM-EUSO

- Observe ultra-high energy cosmic rays from the ISS

# Success criteria

*JEM-EUSO sky simulated with 1,000 events*




**<u>Full success</u>：detect more than 1000 events with energy higher than $7\times10^{19}$ eV**

**<u>Minimum success</u>： 500 events**

***(minimum to identify sources)***

- **Analysis of the arrival direction of particles**
  - **Accuracy of the determination of the arrival direction：less than 2.5 °**
- **Analysis of spectrum**
  - **Accuracy of the energy determination： less than 30%**
- **Identification of Hadron/ photon/ neutrino：**
  - **Accuracy of the Xmax determination: <120 g /cm$^2$**

# Detection method

***Large distance > 400 km***

***Large FOV*** $\gamma \pm 30^\circ$

$A^{geo} \approx 6 \times 10^5\ km^2 \times sr$

$\eta_{cycle} \approx 10 \div 25\,\%$

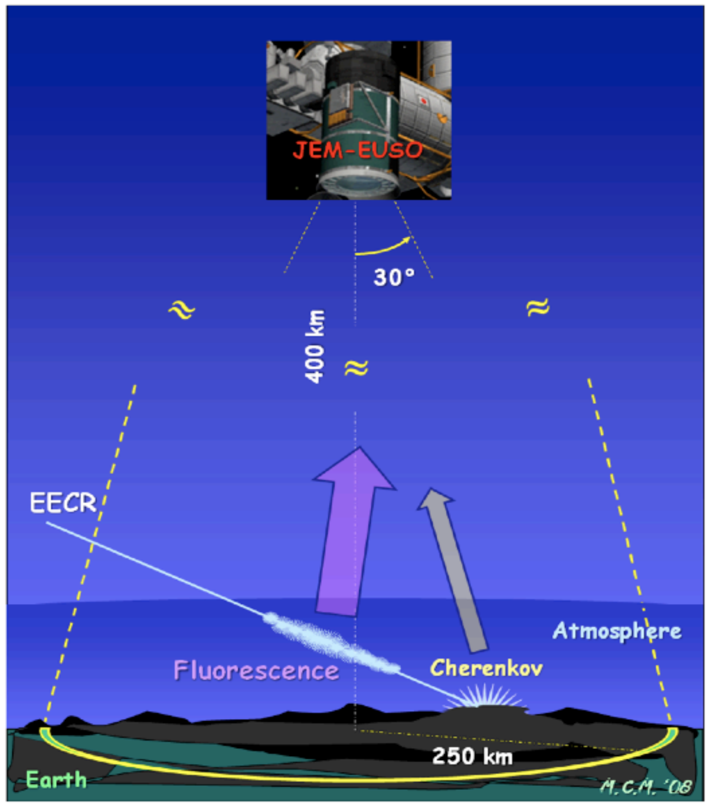
$A_{Euso}^{eff} \approx (6 \div 9) \times 10^4\ km^2 \times sr$

***Large Target Mass of the atmosphere***

$\approx few \times 10^{12}\ tons$

***Full sky coverage looking at both North and South sky***

$4\pi$ ***coverage***

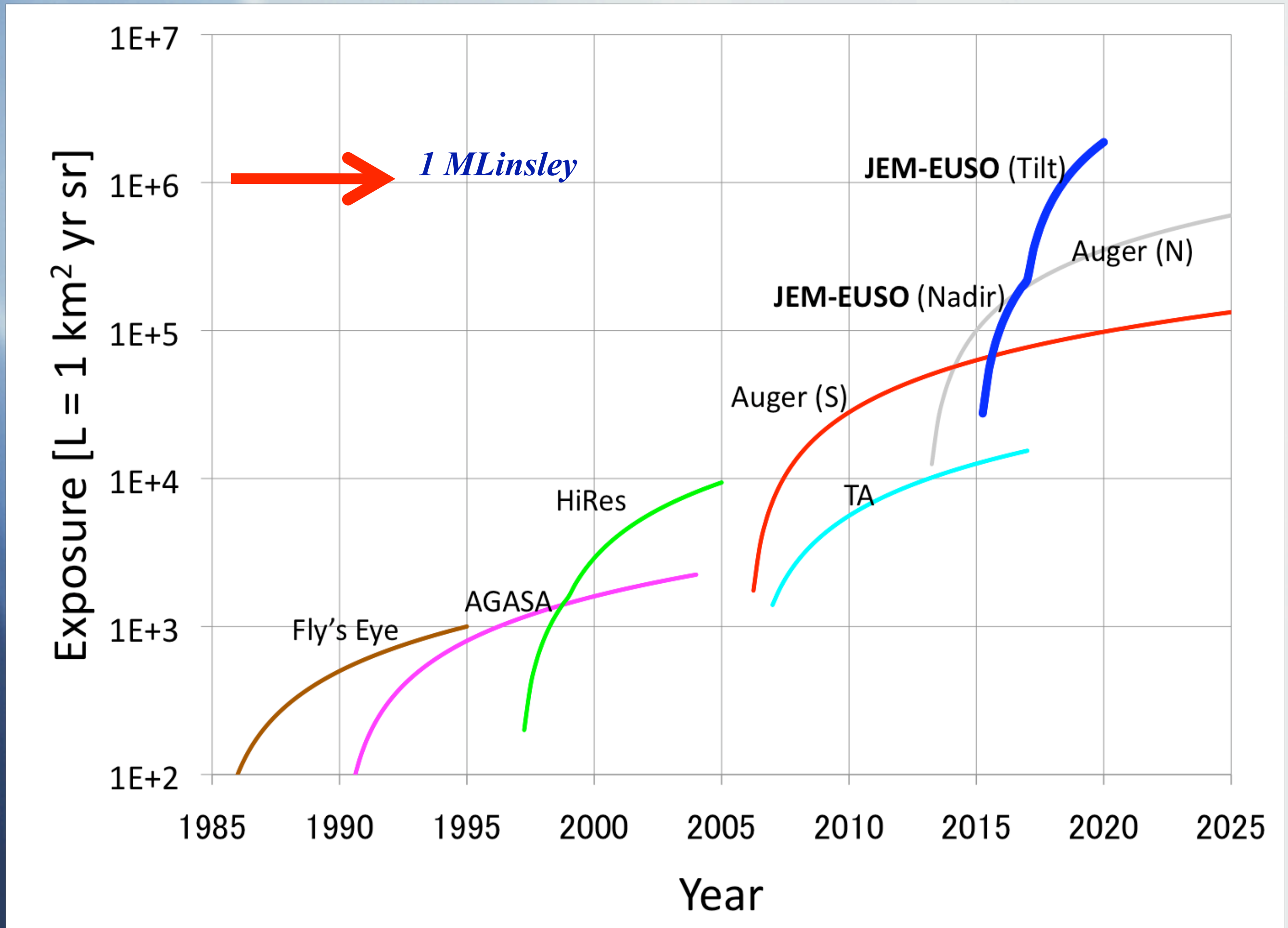


# JEM-EUSO field of view in Nadir and Tilt Mode


- **International Space Station**
  - Orbiting at ~400 km in ±51.6 degrees latitudes
  - Covers both northern and southern hemisphere
  - Flight in varying geomagnetic field (~0.6 gauss) around orbit

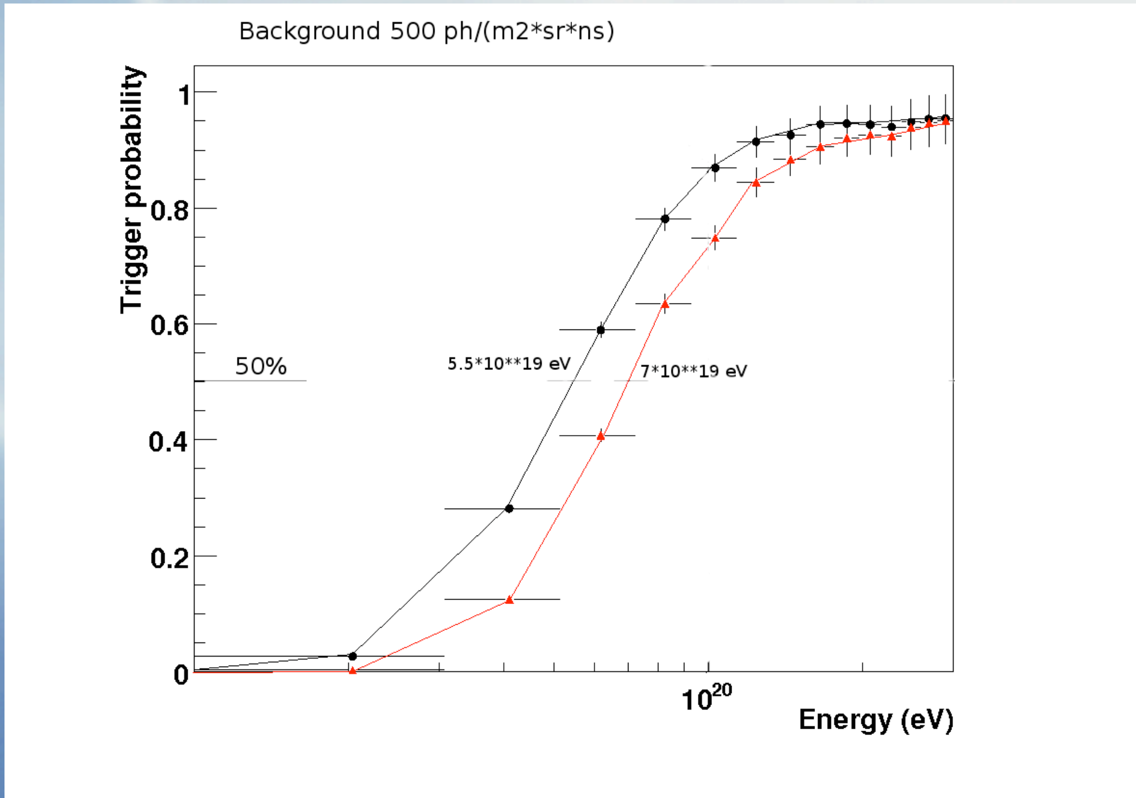
- Viewing night atmosphere in ~500 x 400 km area (nadir mode)
  - Wide FOV allows to measure entire slowly developing showers
  - Target volume exceeding an order of $10^{12}$ tons

# Exposure

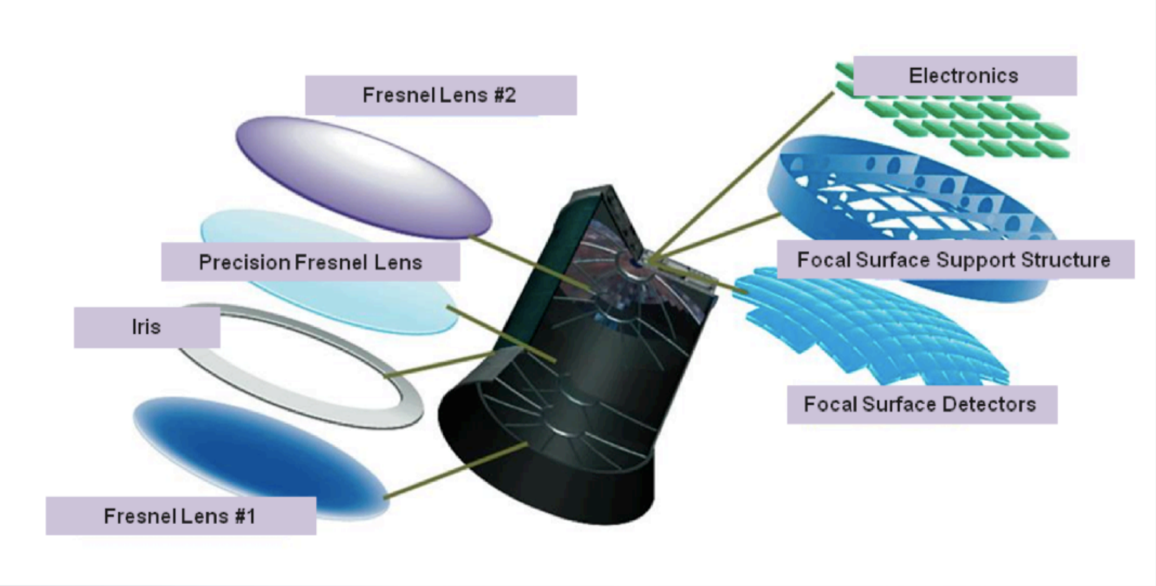


1E+7
1E+6
1E+5
1E+4
1E+3
1E+2
Exposure [L = 1 km² yr sr]
1 MLinsley
JEM-EUSO (Tilt)
Auger (N)
JEM-EUSO (Nadir)
Auger (S)
TA
HiRes
AGASA
Fly's Eye
1985
1990
1995
2000
2005
2010
2015
2020
2025
Year

# Trigger efficiency

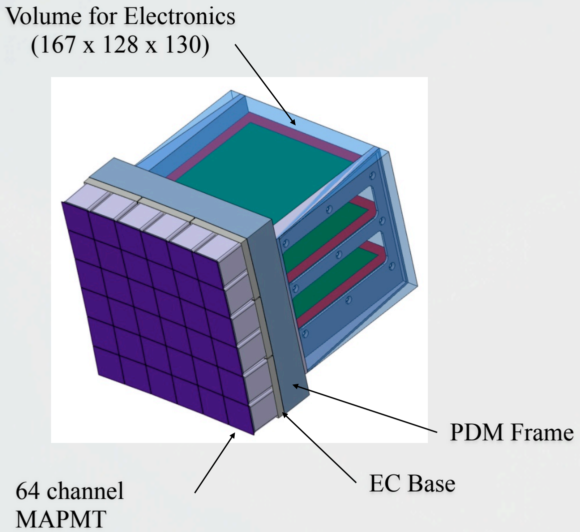


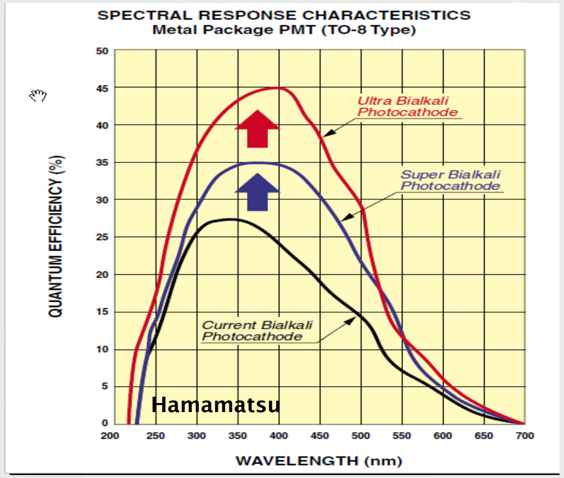
# UV telescope



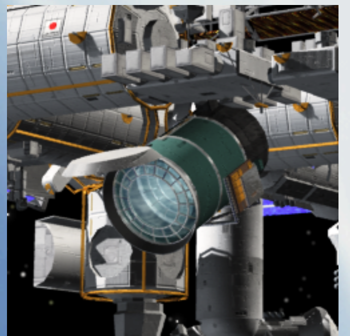

2.65 m diameter Fresnel lens

Photodetector module



# Mission parameters

- Time of launch: year 2015
  - Operation Period: 3 years (+ 2 years)
- Launching Rocket : H2B
- Transportation to ISS: un-pressurized Carrier of H2 Transfer Vehicle (HTV)
- Site to Attach: Japanese Experiment
  Height of the Orbit: ~400km
- Inclination of the Orbit: 51.64°
- Mass: 1983 kg
- Power: 926 W (operative), 352 W (non-operative)
- Data Transfer Rate: 285 kpbs + on-board storage

# Status of JEM-EUSO

JEM-EUSO has completed phase A/B with JAXA. Ready to proceed to phase B/C

Proposal to national funding agencies and institutes have been submitted and accepted or under evaluation

ESA:

- Positive Recommendation in Fundamental Physics Roadmap and Astronomy WG of ESA
- Approved in the research pool of ELIPSE program by Human Spaceflight Div. ESA

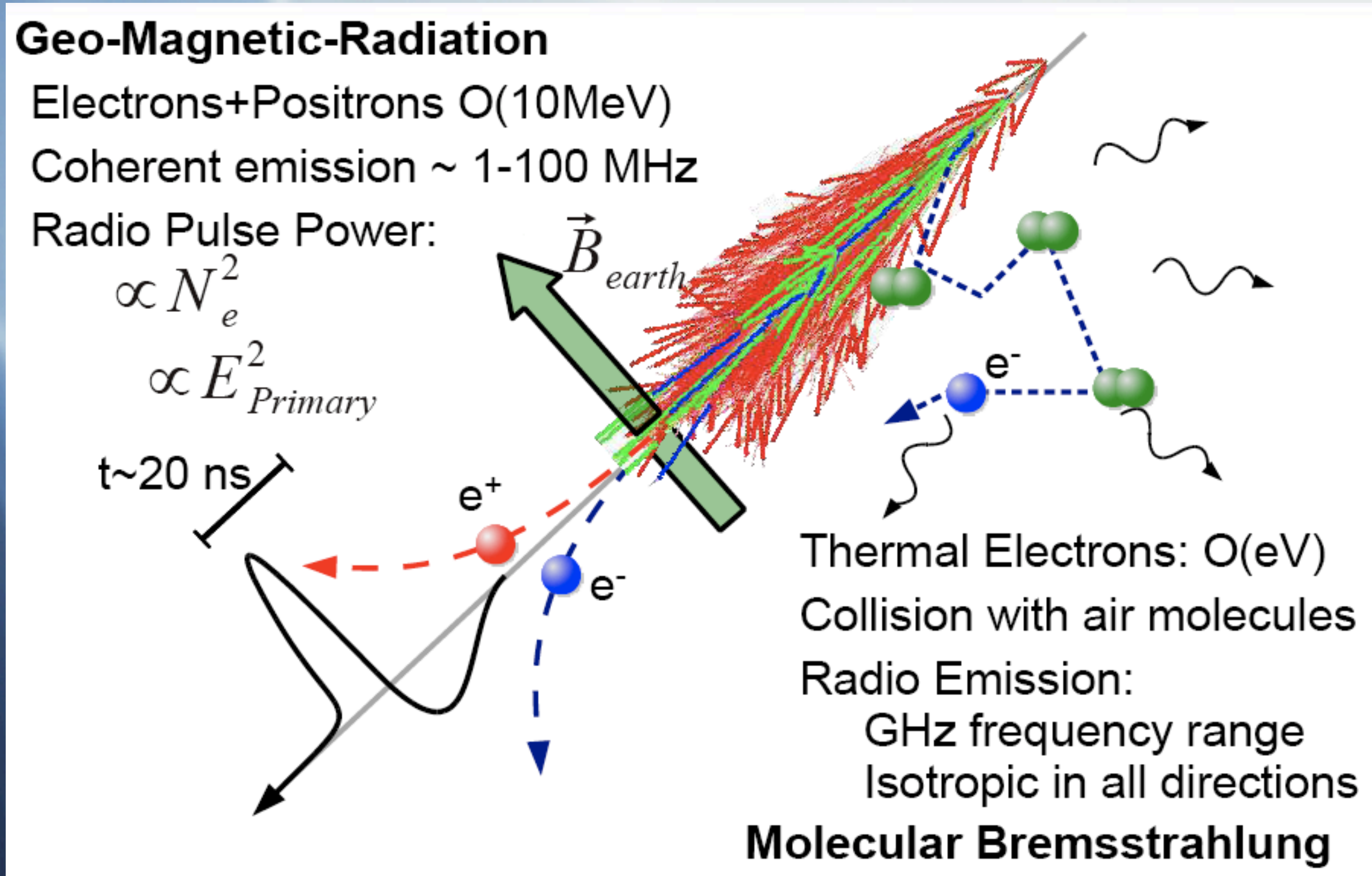
Launch foreseen in 2015

# Radioemission from cosmic showers

First tries in the 60 with fully analogue processing chain
Analogue chain worked, but analysis was difficult.
From this time we have clues
on :

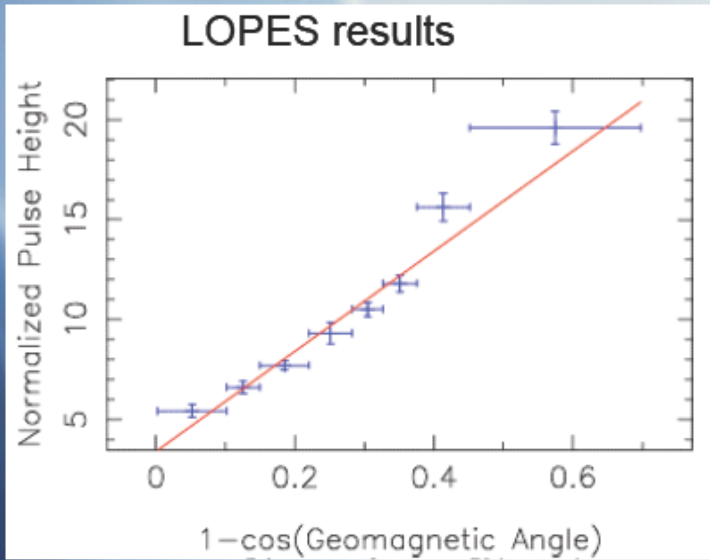
- ✓ Influence of the geomagnetic field
- ✓ Amplitude ~ E
- ✓ Amplitude drops exponentially with core distance

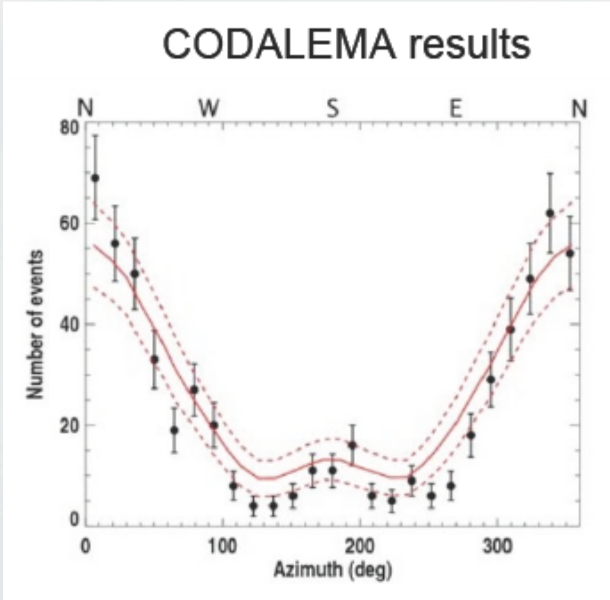
# Radioemission mechanismes




Fluorescence detector like measurement with 100% duty cycle!

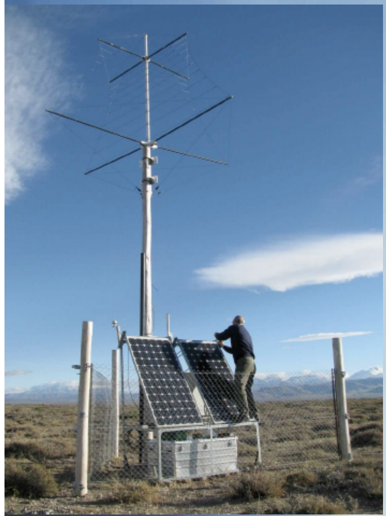
# LOPES and CODALEMA

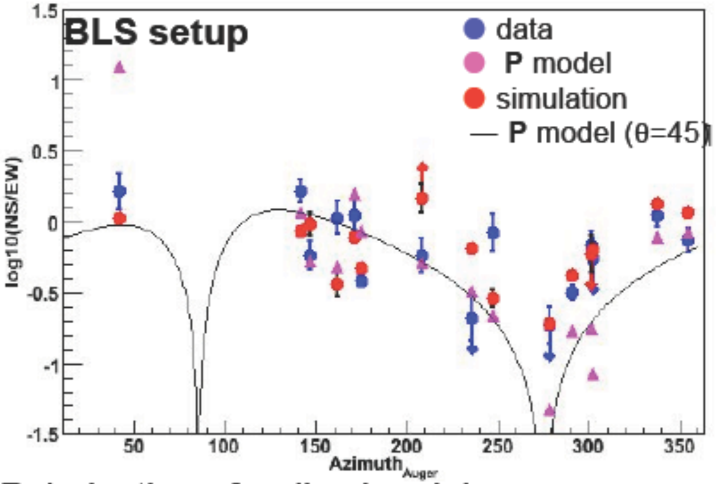



From LOPES and CODALEMA we know :
Radio amplitude drops exponentially with lateral distance.
Radio amplitude scales linearly with particle energy.
Radio amplitude is strongly correlated with “geomagnetic angle”.
Problem : LOPES and CODALEMA are small experiments,
run out of statistics at ~ $10^{18}$ eV

# Test setup in Auger

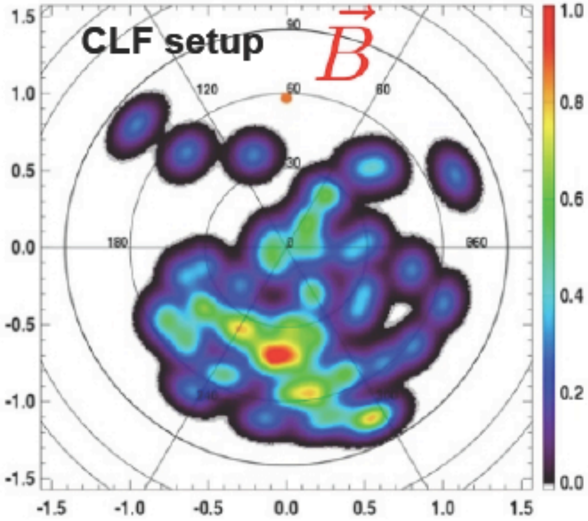





Polarization of radio signal, is consistent with simple geomagnetic model :

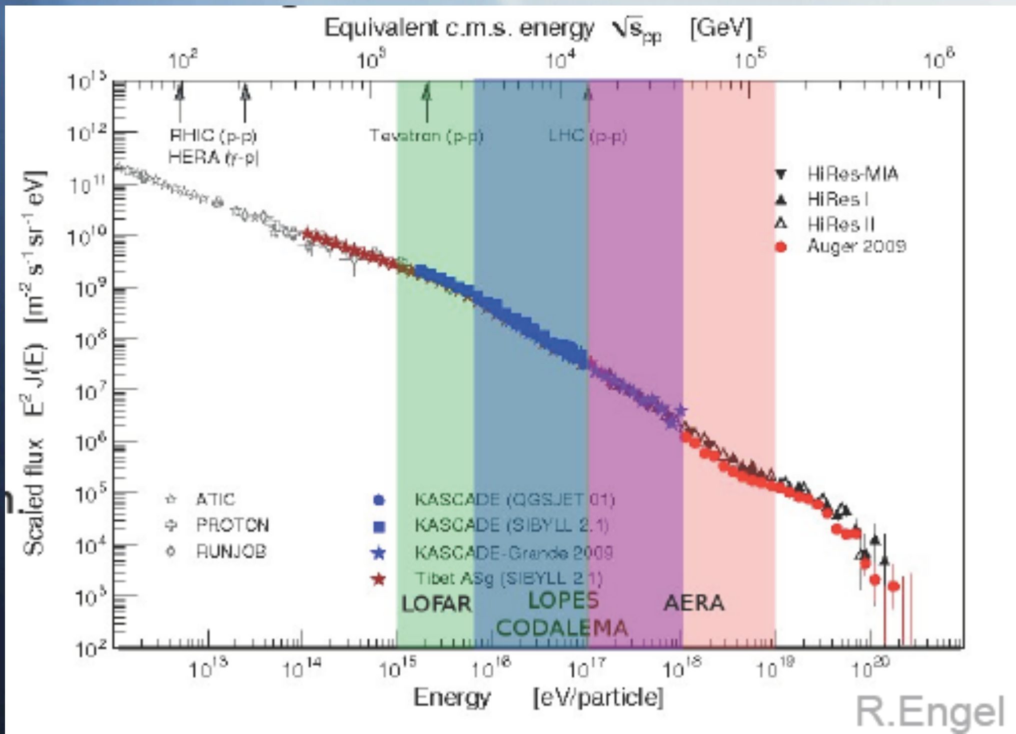
$$\vec{P}_i = \vec{v}_i \wedge \vec{B}$$

In agreement with geomagnetic emission mechanism.




Events come from south.
Agreement with a geomagnetic mechanism.

# AERA Auger Engeneering Radio Array




**Physics goal**

Calibration of the radio emission in air-showers E > $10^{18}$.

Capability of the radio detection method.

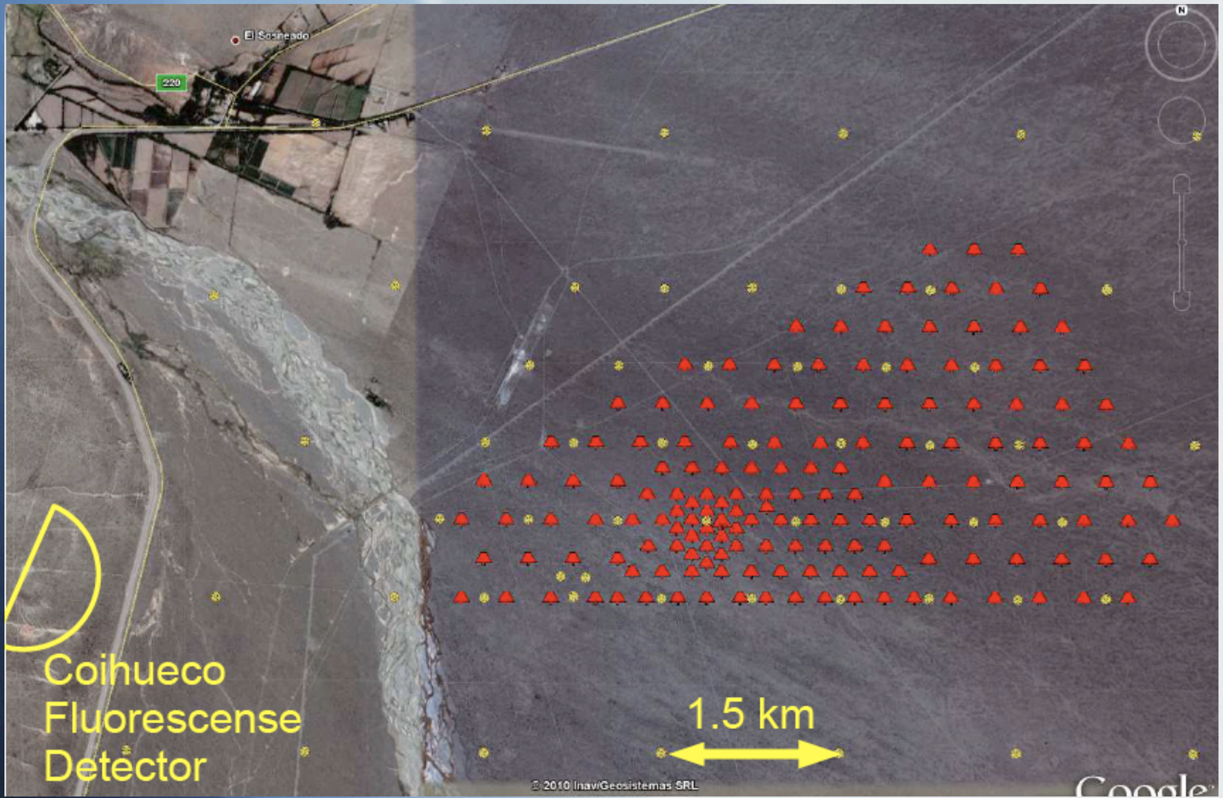
Cosmic ray physics in the transition region.

**Open questions**

Radio-emission mechanism?

Influence of the primary particle?

# AERA site



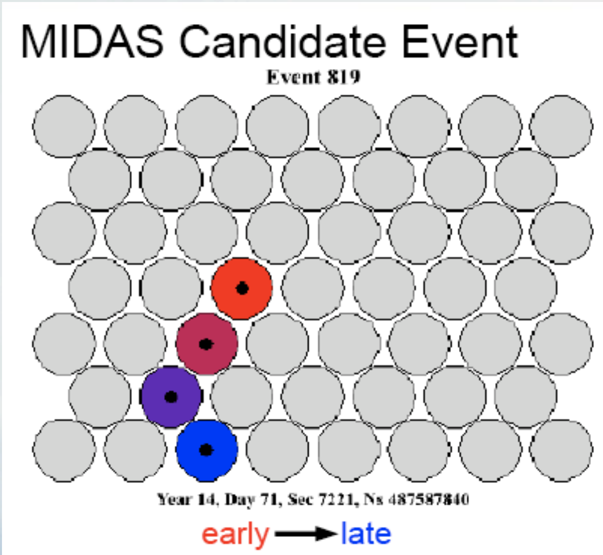

161 radiodetector stations
Dense core: 150m spacing
Medium dense: 250m spacing
Large spacing: 380m

Super-Hybrid: Radio + SD + FD

**AERA status**
First Antennas and central station deployed.
Electronic and data acquisition chain not mounted yet.
Next on-site operation after the (austral) winter.
Central

# Microwave R&D

- AMBER
- MIDAS
- EASIER




Event topology similar to fluorescence events
Trigger concept: external or trigger from Auger

# Conclusions

- Gianni's vision: Large acceptance with high precision is needed!
- Chalenging  goal for the cosmic ray scientists!

Gianni working on Auger site