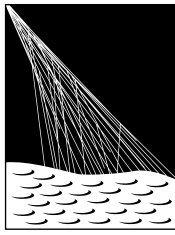


Triggering the PAO science



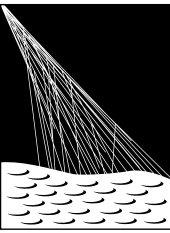
PIERRE
AUGER
OBSERVATORY



Petr Tobiška
for the Pierre Auger
Observatory

Triggering Discoveries
in High Energy Physics
III

Outline

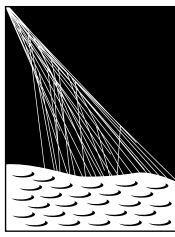
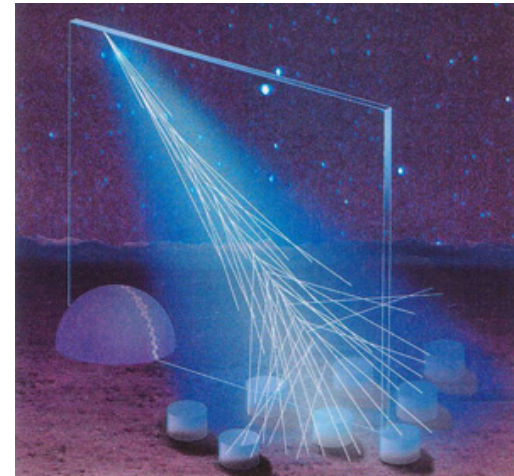


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- Observatory overview
 - Fluorescence detector
 - Surface detector
 - Observatory upgrade: AugerPrime
- DAQ and triggers
 - Fluorescence detector
 - Surface detector
 - Radio detector
 - Elves

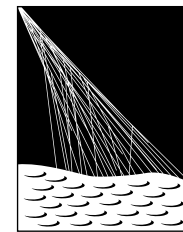
Pierre Auger Observatory

- detection of ultra high-energy cosmic rays via extensive air shower
- hybrid concept
 - array of 1660 Water Cherenkov Detectors
 - 27 Fluorescence telescopes at 4 sites
- located at Argentina, province Mendoza, city Malargüe (observatory campus)
- operated from 2004 – Phase I, Phase II from 2024

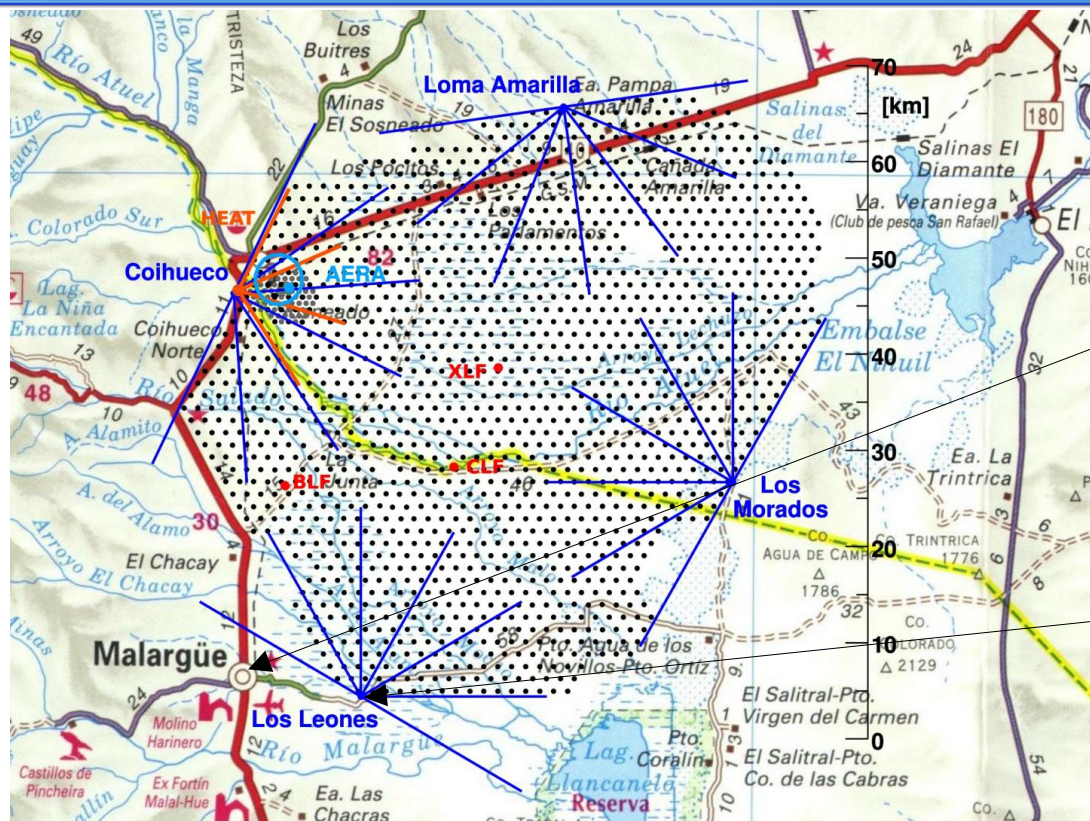


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Pierre Auger Observatory



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- large exposure
- 3000km²
- Central Data Acquisition system (CDAS) Malargüe



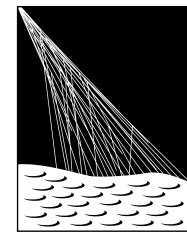
Dec 11th, 2024



Institute of Physics
of the Czech
Academy of Sciences

Petr Tobiška for the Pierre Auger Collaboration

Fluorescence detector

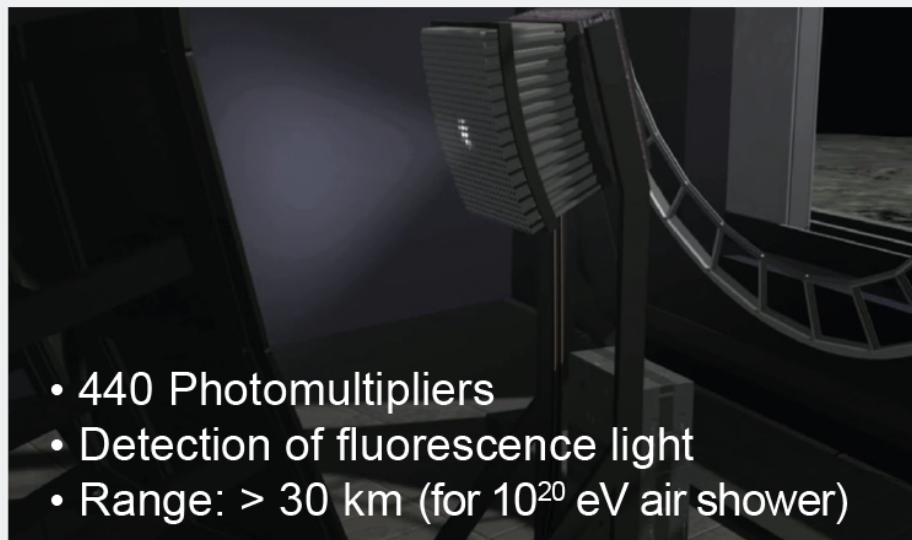
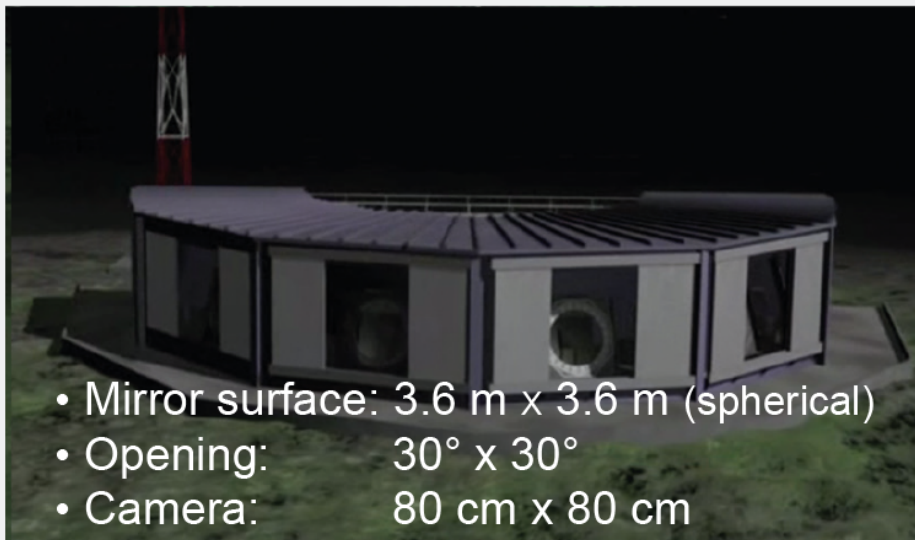


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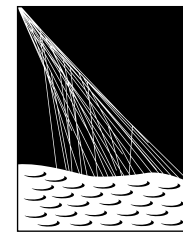
Fluorescence Detector

27 fluorescence telescopes

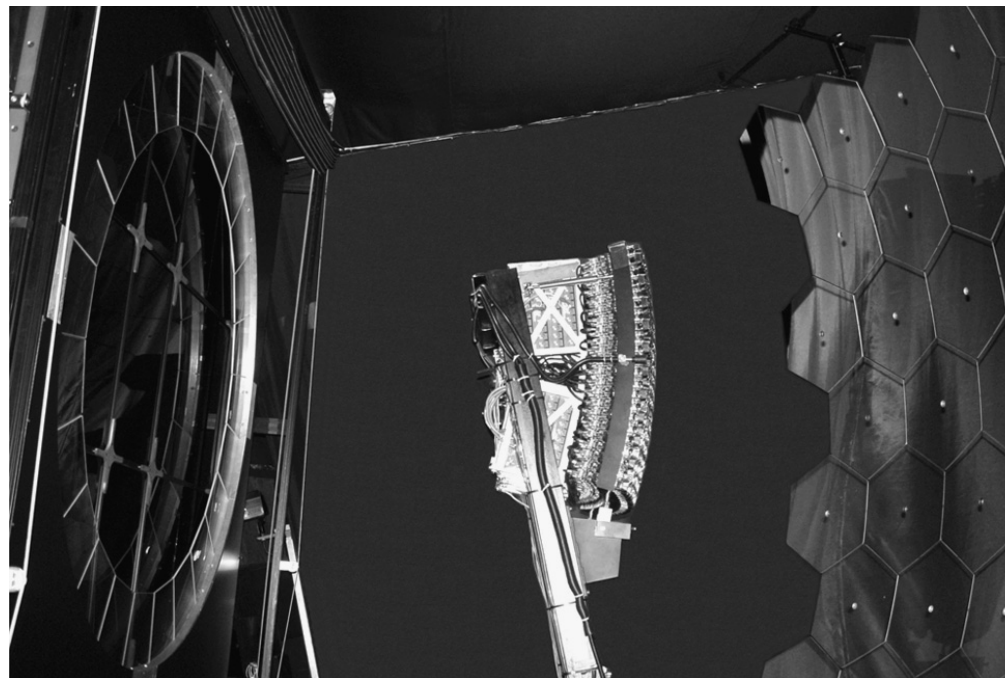
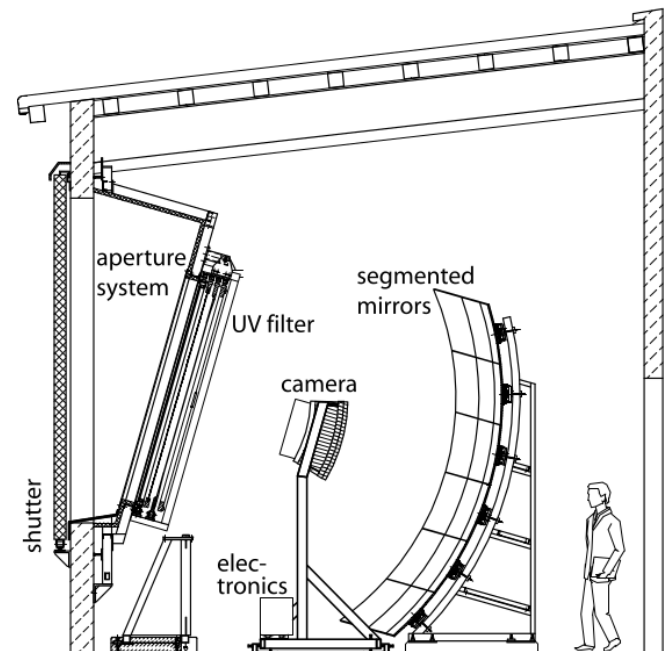
(in 4 different places)



Fluorescence telescope



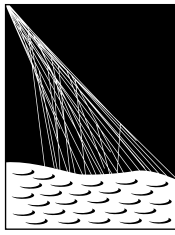
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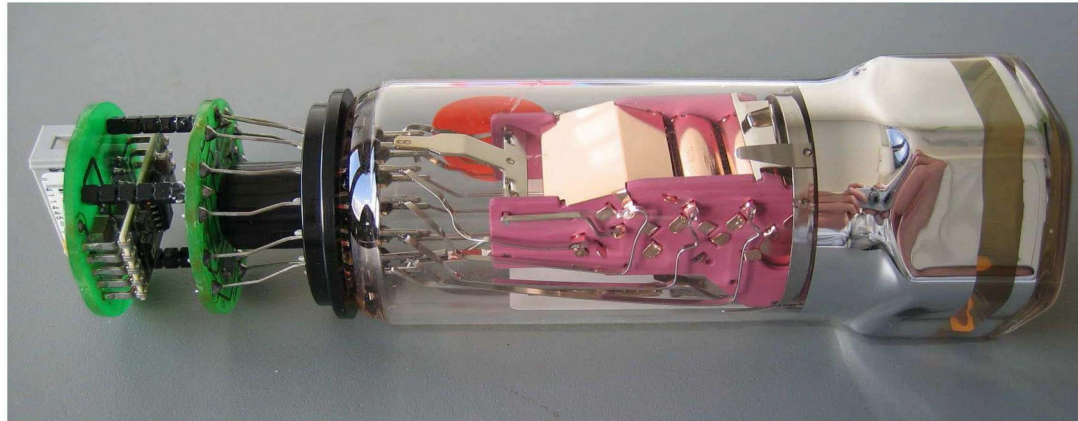
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FD camera

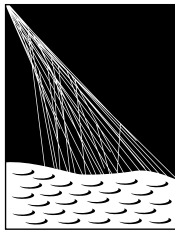
- FD camera: 22 rows x 20 cols, hexagonal arrangement
- PMT + HeadElectronics



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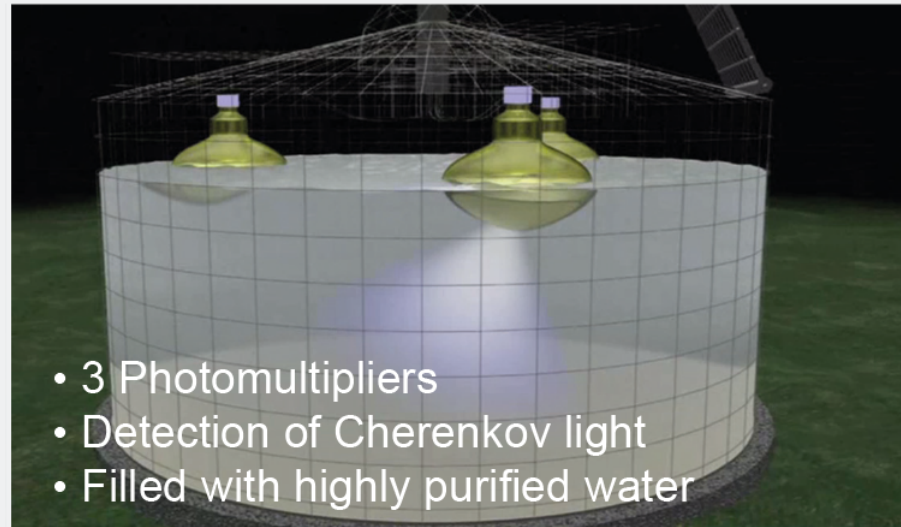
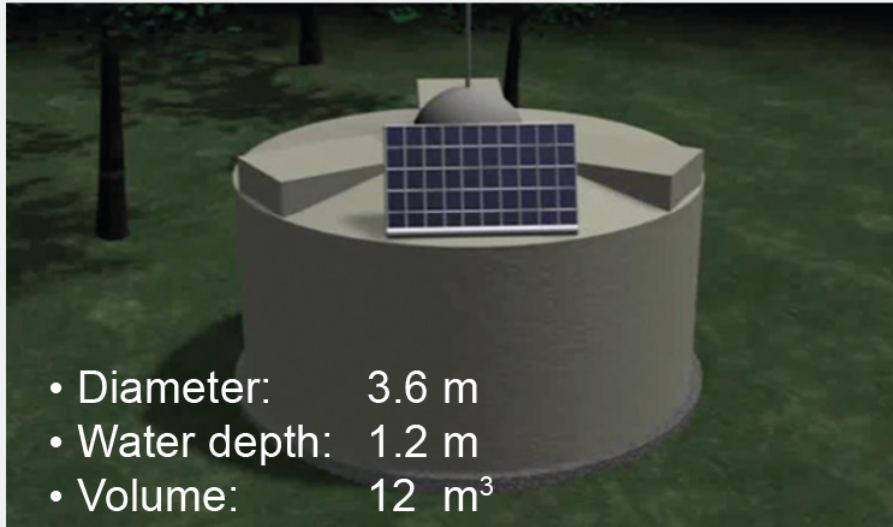
Surface detector



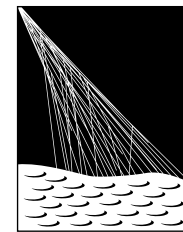
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Surface Detector

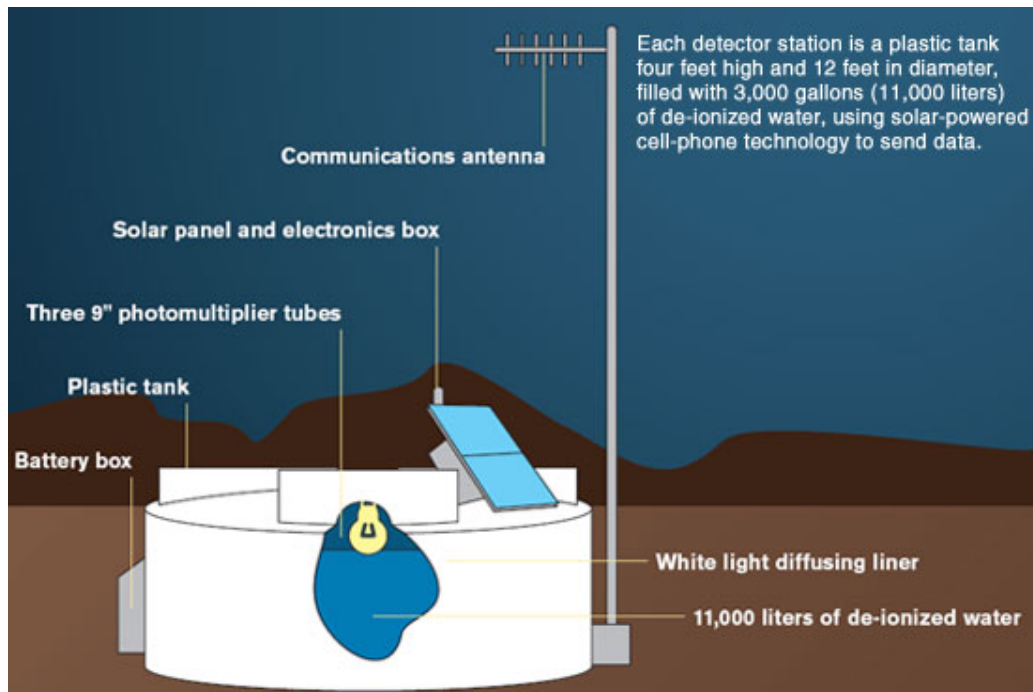
1,660 surface detector stations
(1,500 m apart from each other)



Surface detector - station

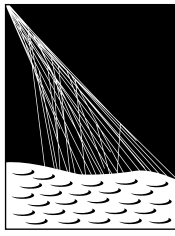


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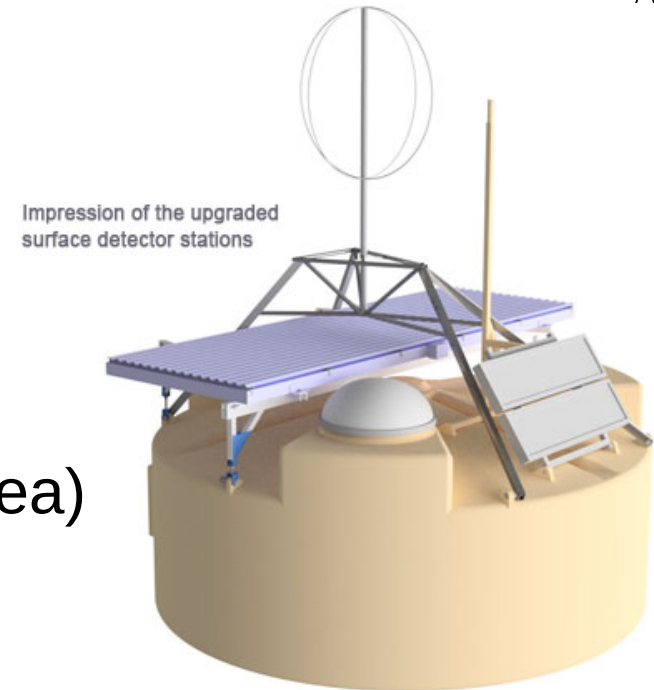
AugerPrime – upgrade of the Observatory



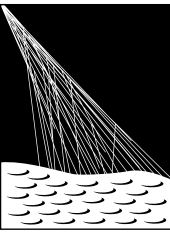
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- scintillator detector (SSD)
- upgraded electronics UB → UUB
- small PMT (extend dyn. range by ~32)
- radio detector (RD)
- underground scintillator muon detector
- 61 AMIGA stations at 750m grid (infill area)
- buried 2.3m, 3x10m² modules

arXiv:1604.03637

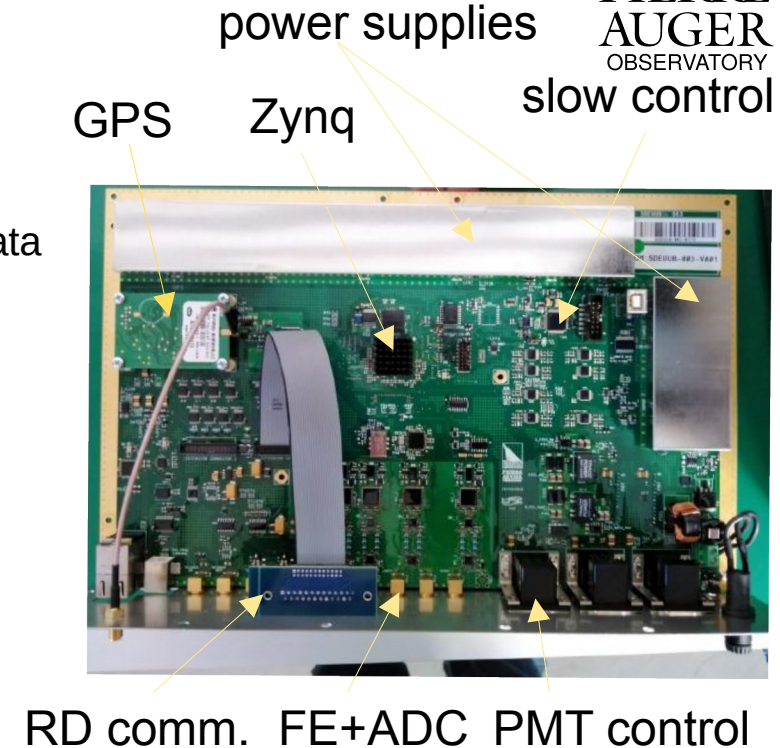


(Upgraded) Unified Board

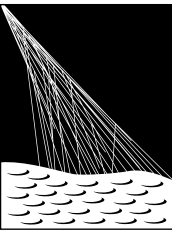


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- electronics of WCD station
- Unified Board (UB)
 - power supply/station management
 - analog frontend + 2x3 channels ADC (10bit @40MHz) + data processing (FPGA) + radio communication with CDAS
 - time synchronization by GPS module
- Upgraded Unified Board (UUB)
 - more powerful, 10 channels ADC (12bit @120MHz)
 - PMT signal electronically divided by 32 – low & high gain
 - Zynq Z7020 (Artix-7 FPGA + 2 ARM cores)
 - interface to Amiga and RD



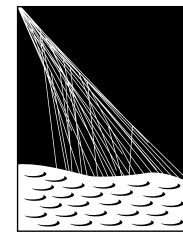
Comparison of detectors at Pierre Auger Observatory



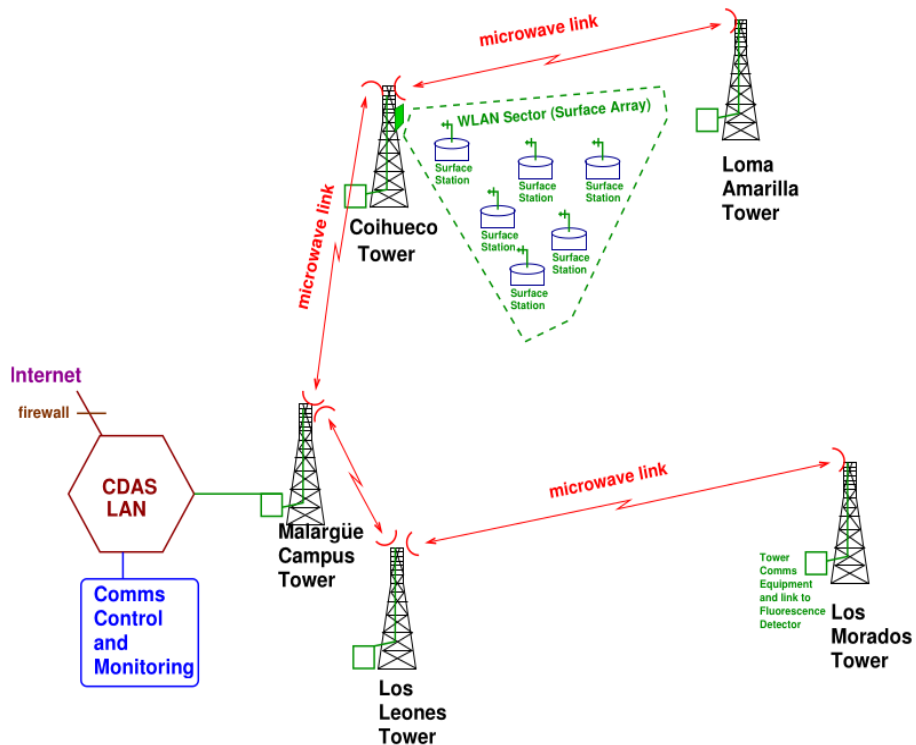
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- FD – direct observation of shower longitudinal profile, low duty-cycle (~13%)
- SD – shower footprint on earth, full-time operation
- Amiga – direct observation of muons, only small area
- SSD – discriminate muon components partially, whole array, thin scintillator → vertical showers
- RD – inclined showers, electromagnetic component of the shower

Comms at PAO

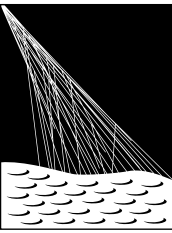


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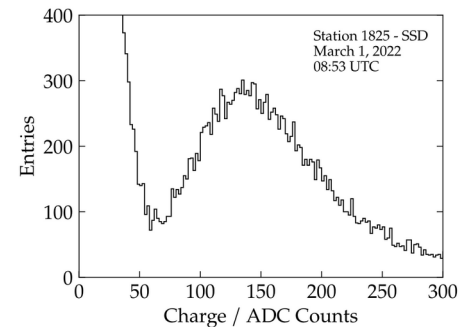
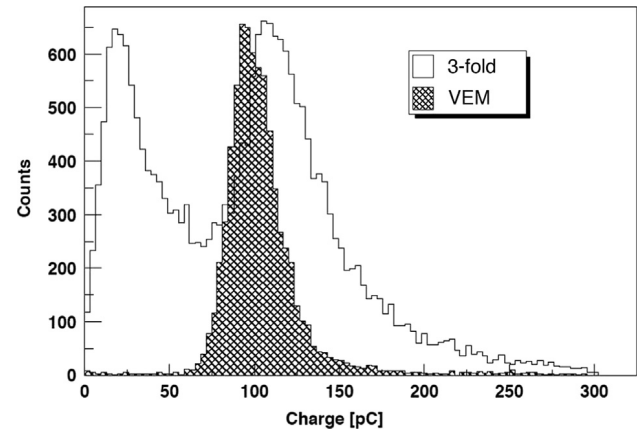
- Wireless LAN:
 - ISM 902-928 MHz, 500kHz channel spacing, TDMA, coherent QPSK
 - 28 sectors of upto 68 WCD
 - over-air-rate 200kbps
 - eff. uplink payload 1200bps/st.
- microwave backbone 7GHz
 - data rate 24Mbps
- CDAS: central data acquisition system

Relation between physical and electronics quantities

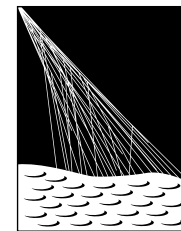


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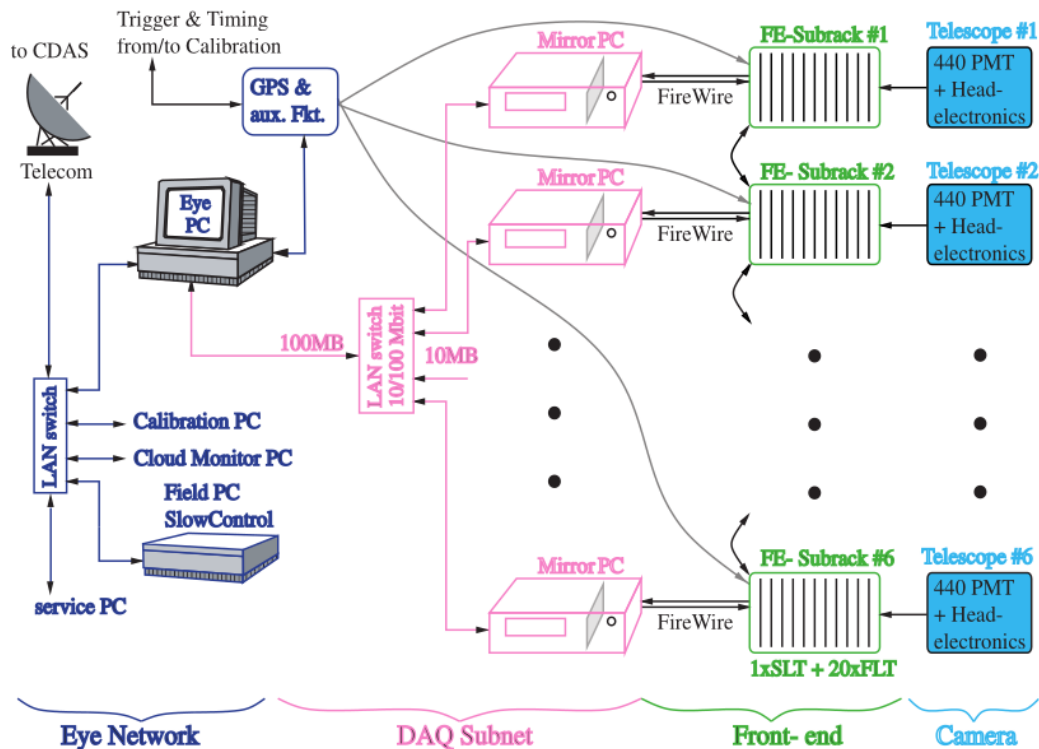
- Vertical Equivalent Muon – VEM
 - response to muon vertically passing WCD
 - peak current I_{VEM} / collected charge Q_{VEM}
- Minimum ionizing particle – MIP
 - response to muon/electron passing scintillator



Readout scheme of an FD site

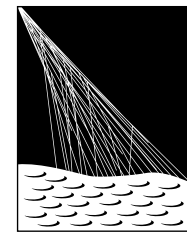


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Dec 11th, 2024

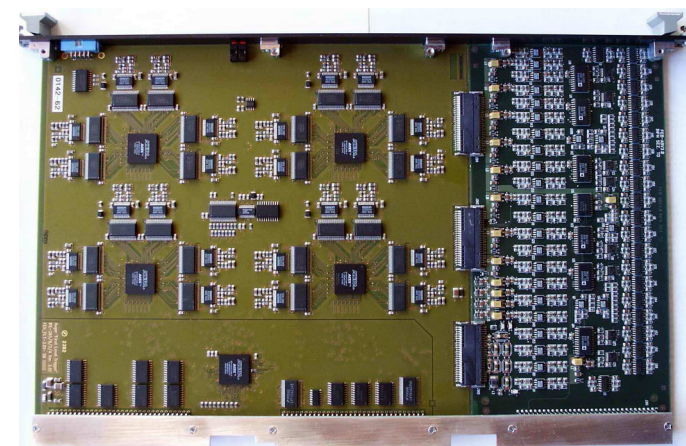
FLT + Analog board



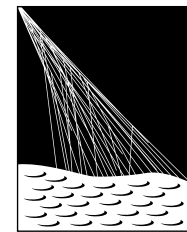
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- AB
 - adjust channel gain
 - anti-aliasing filter (4th order Bessel, 3.4MHz)
 - adapts 15bit range to 12bit ADC (virtual channels, 20:1 HG/LG)
- FLT (FPGA): data from 22-channel column
 - continuously digitized signal from AB @10MHz
 - generate pixel trigger (moving sum) for each channel, measure the hit rate for each channel
 - compensate background, maintain pixel trigger rate at 100Hz (adjust threshold)
 -

FLT : AB



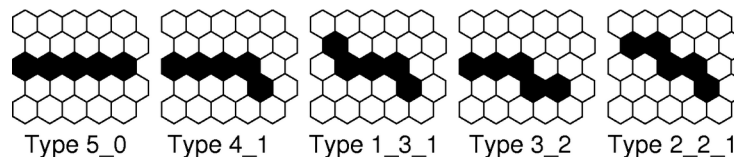
SLT + MirrorPC + EyePC



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- SLT

- read pixel triggers from 20 FLT
- search for straight tracks
- generates trigger if pattern found



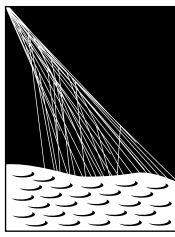
- MirrorPC

- readout from SLT
- filter lightning using multiplicity from FLT → generate TLT

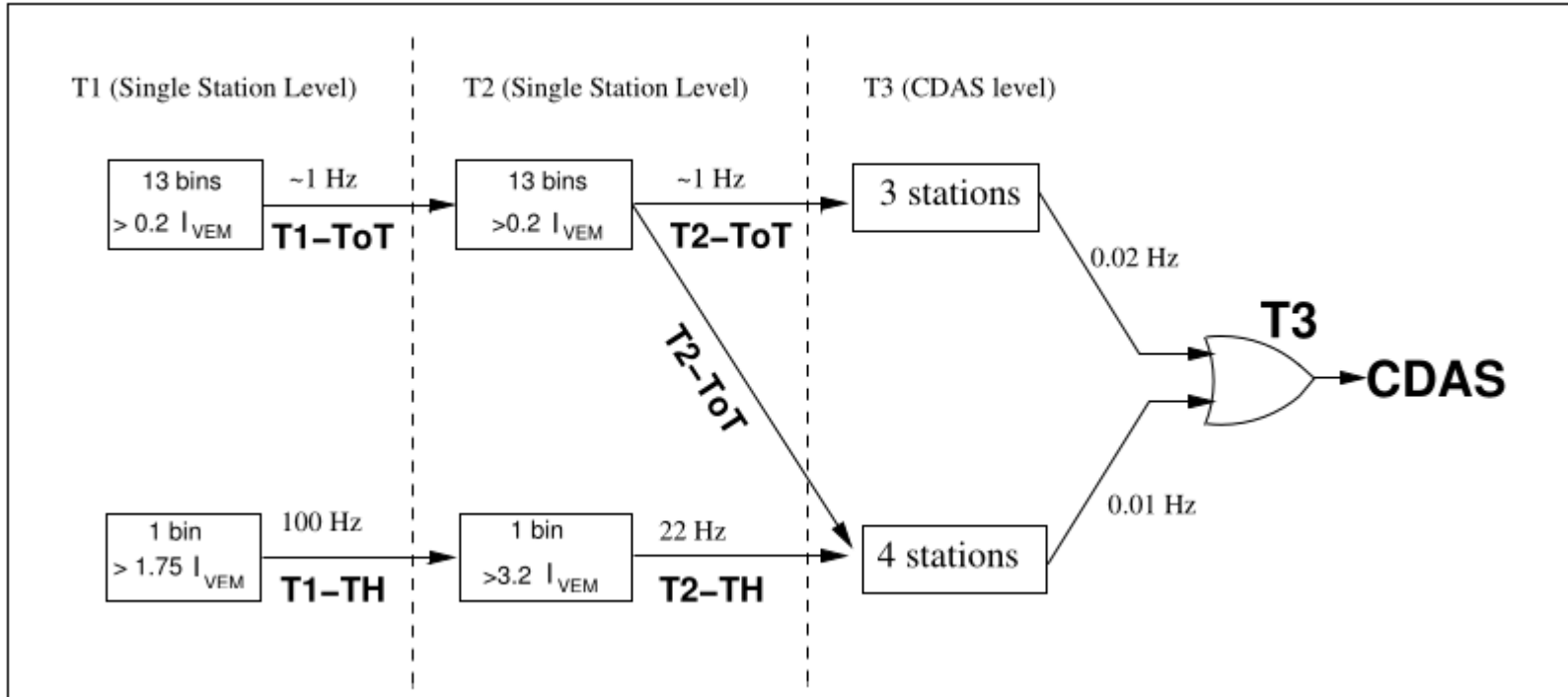
- EyePC

- merge coincident events, generate hybrid T3 event → CDAS

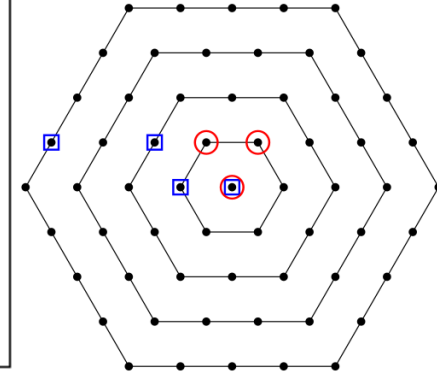
Triggers in SD



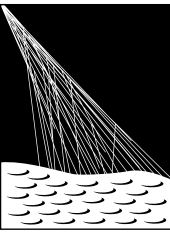
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- atmospheric muon rate: 2500 Hz



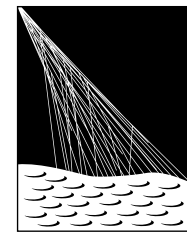
CDAS triggering role



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- local stations retain T1 triggered traces for 8s, apply T2 and sent list of T2 timestamps to CDAS
- CDAS collects T2 from SD array as well as FD telescopes and generates T3 trigger eventually (time/space correlation)
- CDAS receives traces from local stations and FD sites and build the event

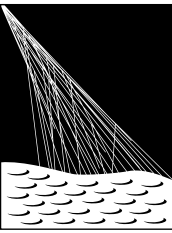
Local triggers



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- Compatibility Single Bin
 - signal over threshold in 1 bin
- Compatibility Multiplicity of Positive Steps (MOPS)
 - aggregate positive steps, min/max height constrained, count in $3\mu\text{s}$ sliding window
- Time-over-threshold trigger (ToT)
 - low threshold, count bins over threshold in $3\mu\text{s}$ sliding window
- Time-over-threshold trigger deconvolved (ToTD)
 - first deconvolve exponential light decay in a water reservoir
- configurable PMT multiplicity

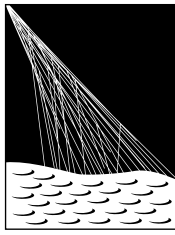
New WCD/SSD triggers



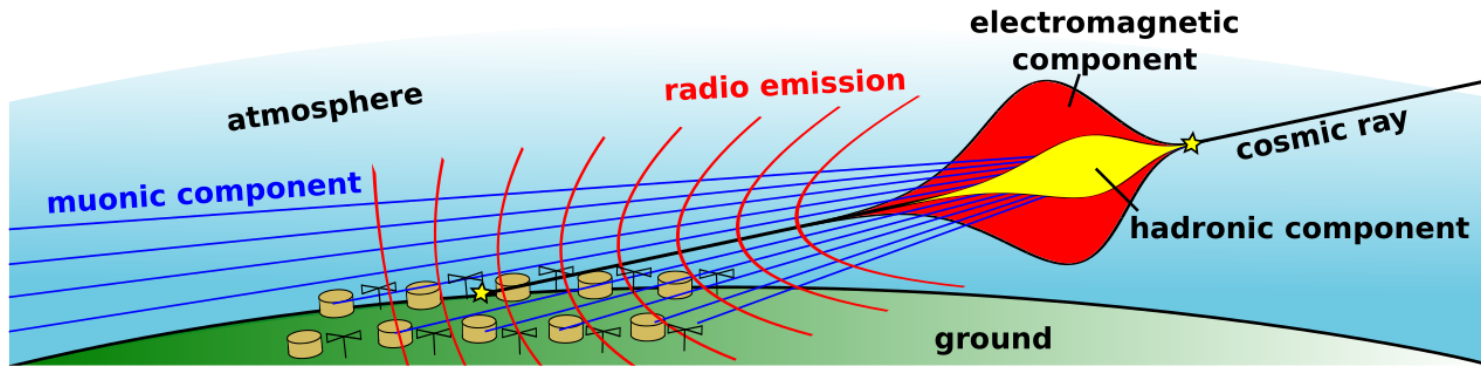
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- Be more efficient for neutrino and photon primaries & horizontal showers
- Direct Light trigger
 - characteristic narrow spike generated when Cherenkov photons hit the PMT directly (without a diffuse wall reflection)
- Electromagnetic trigger
 - signal spread in time (similar to ToT)
- Electromagnetic Integral trigger
 - This trigger compares the integral of the WCD signal with the SSD signal
 - Selects cases where SSD/WCD is larger than typical

Radio Detector at Pierre Auger Observatory



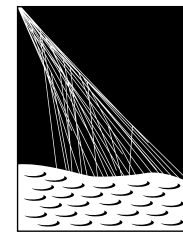
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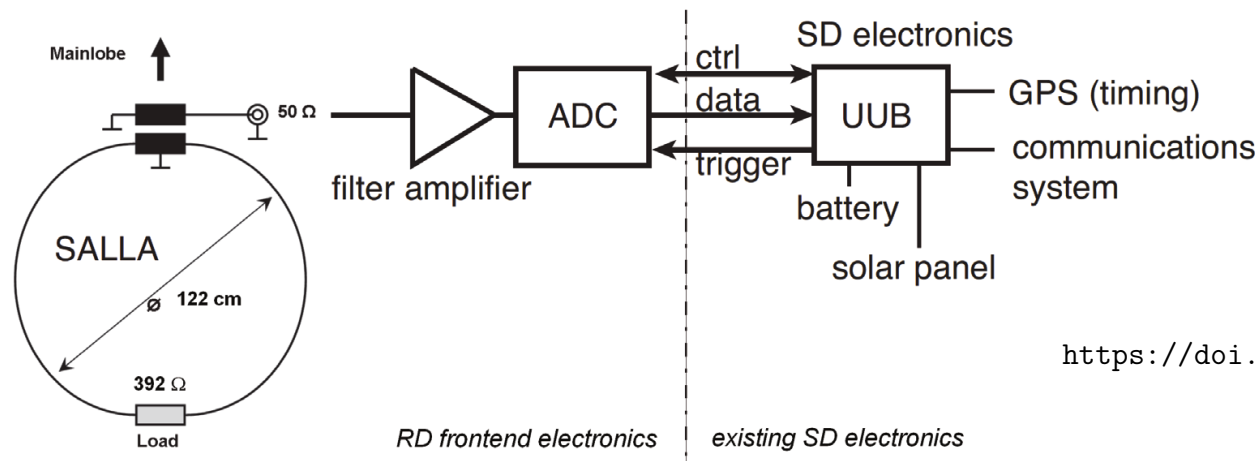
- RD – part of AugerPrime
- sensitive to inclined shower
- <https://doi.org/10.1051/epjconf/201921006005>

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RD data acquisition



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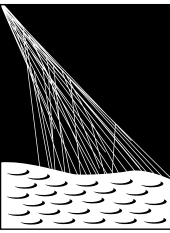


<https://doi.org/10.1051/epjconf/202328306002>

- Small Aperiodic Loaded Loop Antenna, 2 loops for NS/EW polarisation
- sampled @ 250MHz/12 bit

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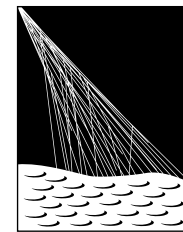
RD trigger



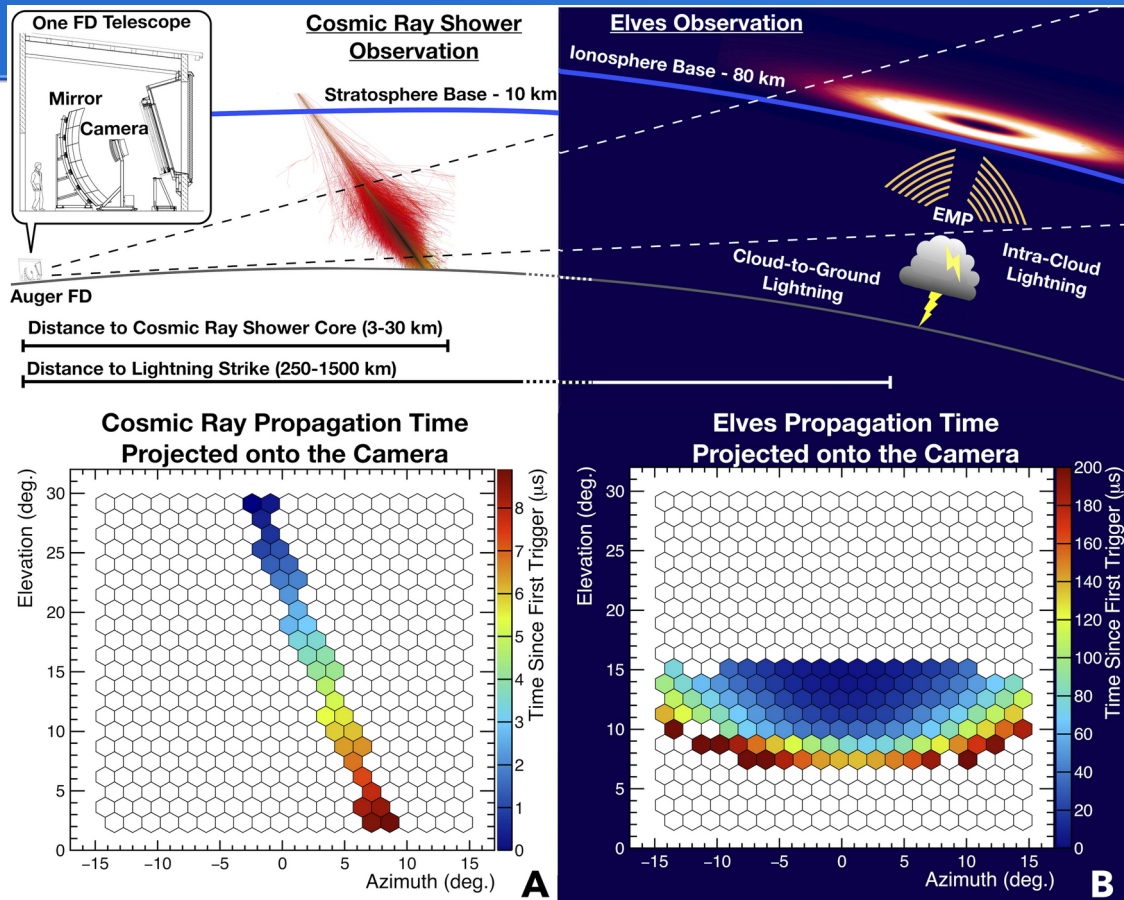
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- currently slave mode of UUB
- RD T1/T2 trigger under development
 - to be triggered only by WCD may miss inclined showers
- concept:
 - increase of photon detection rate
 - compatibility with the limited bandwidth
 - trigger purity

Elves



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- Elves:
- transient luminous events
- radial extent > 250 km
- lower ionosphere above strong electrical storms
- FD: TLT for lightning noise
 - radially expanding light front
- <https://doi.org/10.1029/2019EA000582>

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