Searching for ultra-high-energy cosmic rays and events related to atmospheric electricity at the Pierre Auger Observatory

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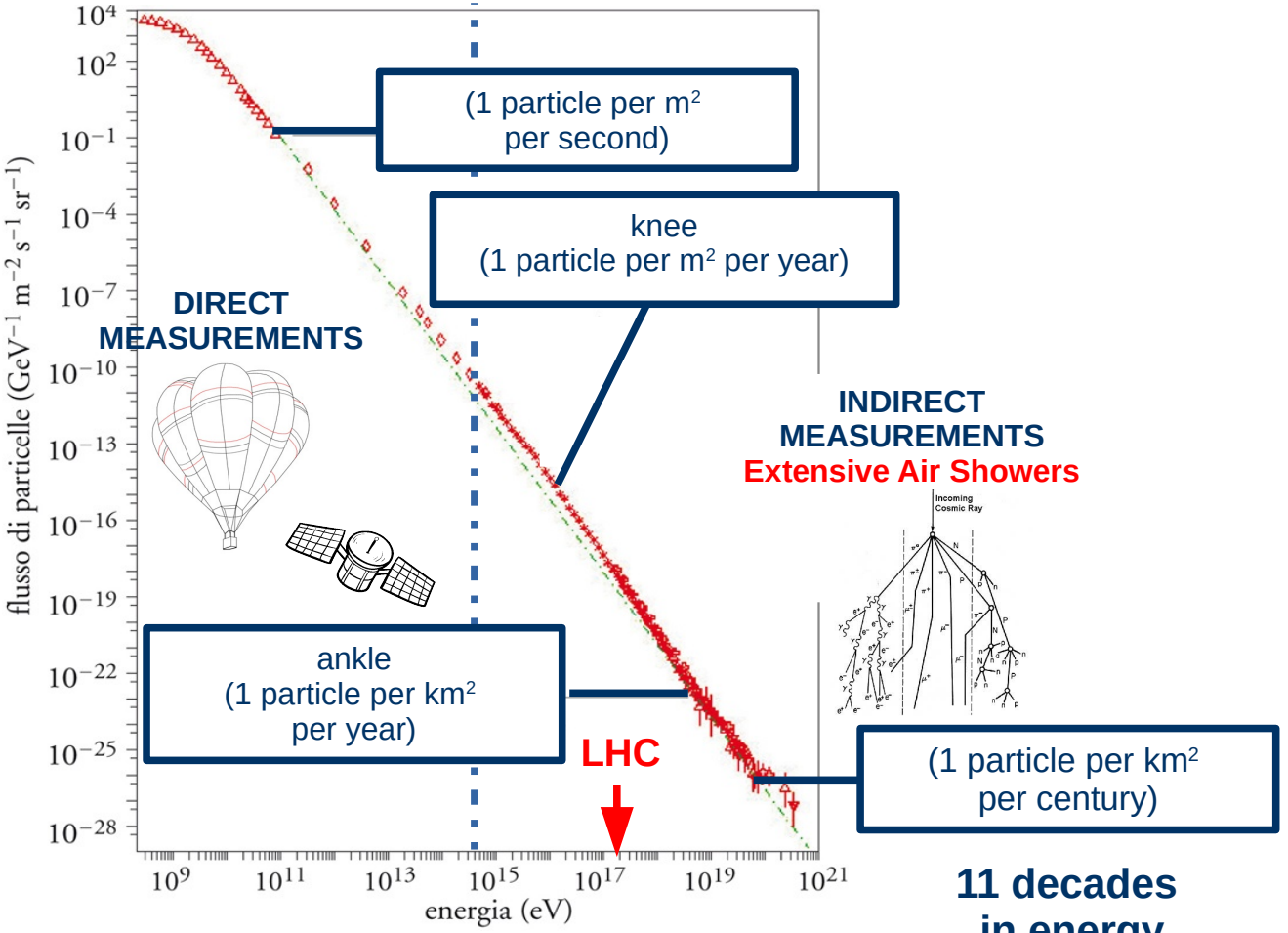
Re[incontri] di Fisica Partenopea, Napoli, December 19, 2023

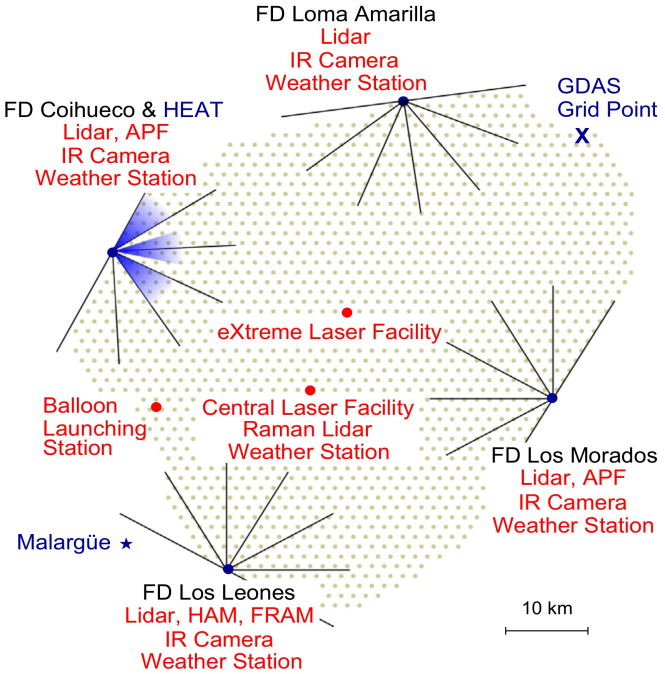
Cosmic Rays

32 decades in intensity



11 decades in energy

The Pierre Auger Observatory



Goals of the Experiment:

- Energy Spectrum
- Mass Composition
- Arrival Directions

Located in the Argentinian pampa (Malargüe), at ~1400 m above sea level.

SD detector:

1660 Water-Cherenkov Detectors (WCD), covering 3000 km^2 and arranged in a triangular grid with 1500 m spacing.

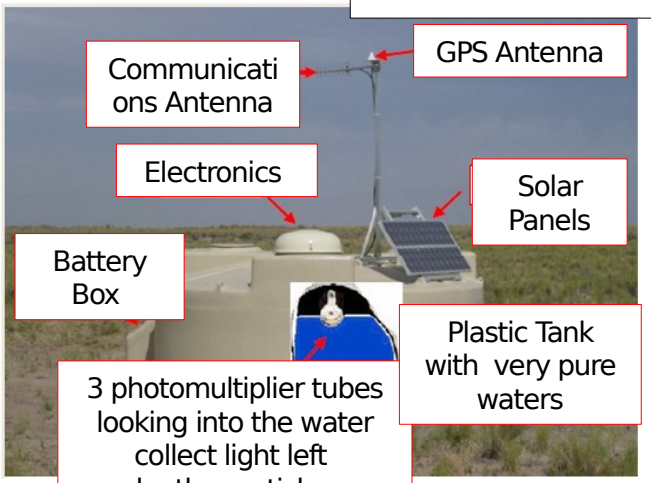
FD detector:

24 telescopes, 6 for each sites, arranged to overlook the area covered by the SD.

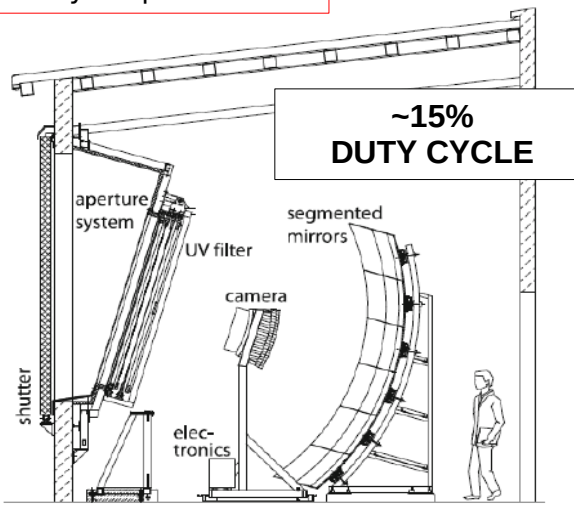
① **Large Aperture**
(about 7000 km^2 sr)

② **Hybrid Technique**

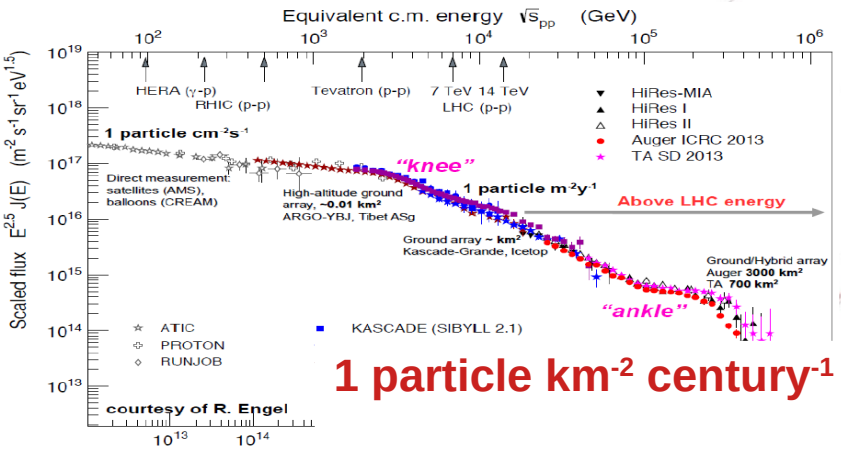
100% DUTY CYCLE



~15% DUTY CYCLE



Indirect cosmic-ray measurements



1 particle km^{-2} century^{-1}

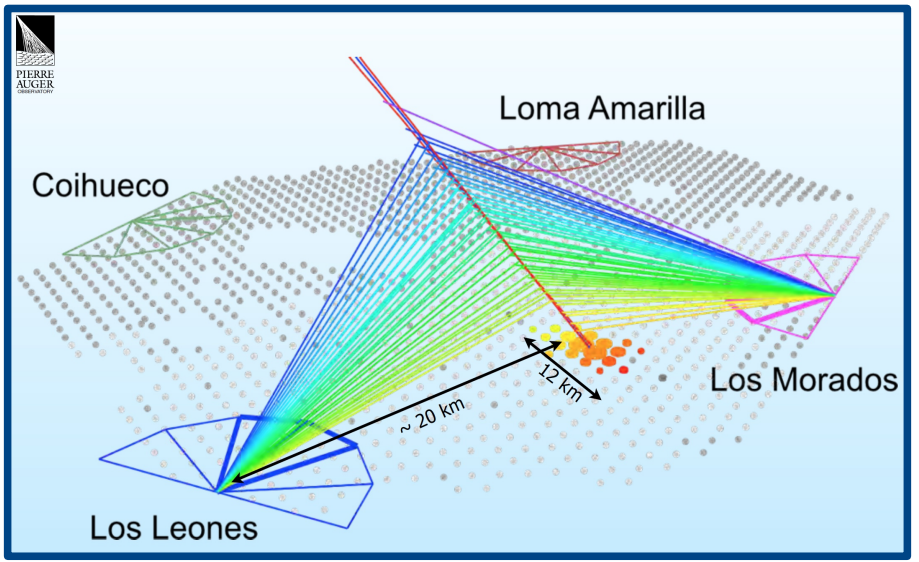
Cosmic ray 1st interaction high in the atmosphere

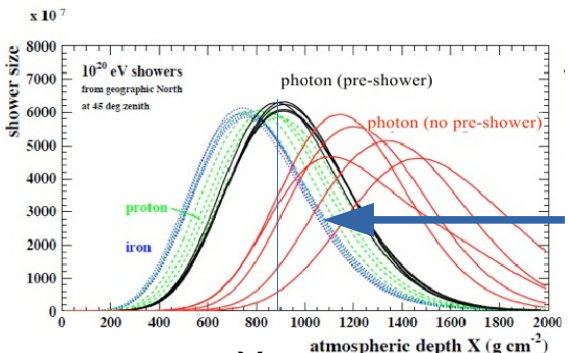
Shower development: electromagnetic and muonic cascades

FD - longitudinal profile

SD - lateral profile

An Auger event



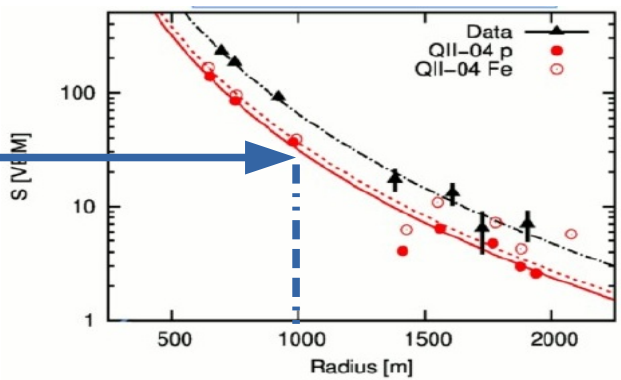


Xmax

$E_{cal} = \int dE/dX \, dX$

S_{1000}

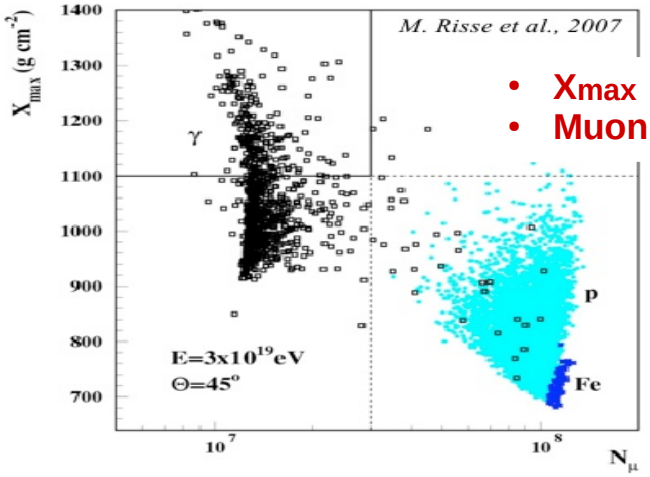
$E_{surface} = f(S_{1000}, \theta)$



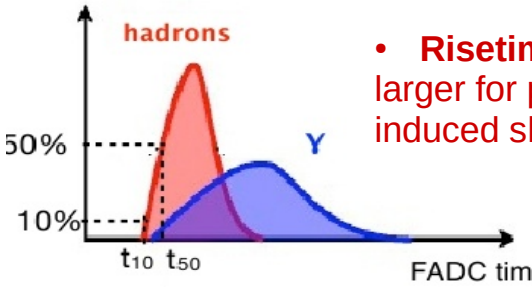
longitudinal profile

lateral profile

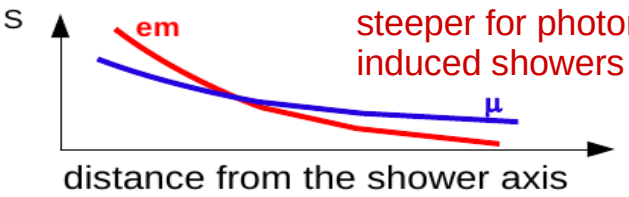
Photon Search



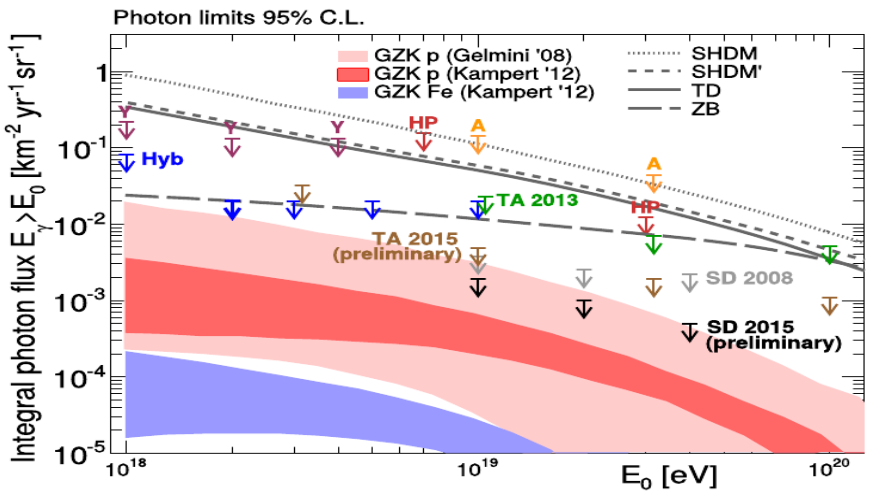
- **Xmax**
- **Muon Content**



- **Risetime:** t50-t10, larger for photon-induced showers



- **LDF of total signal:** steeper for photon-induced showers

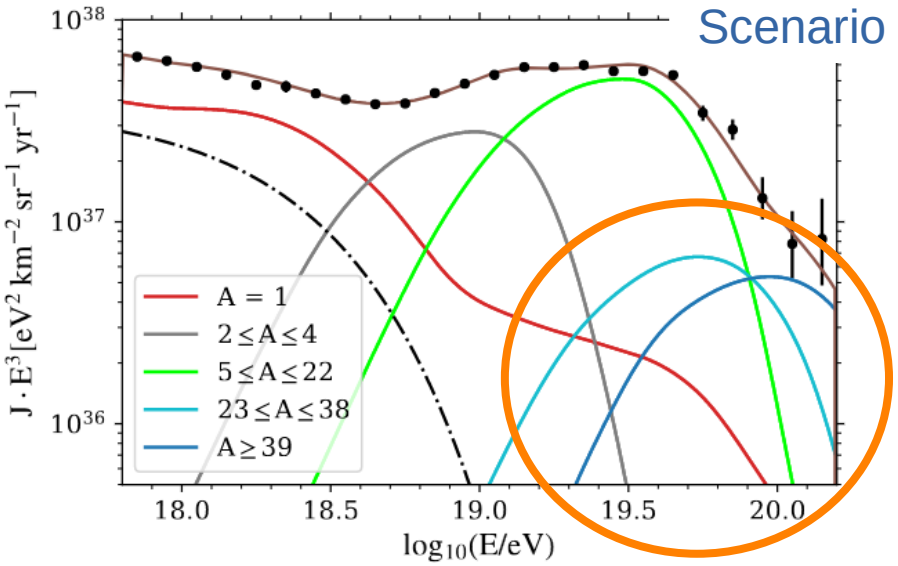


- No photon events observed;
- “Top down” models strongly disfavoured.

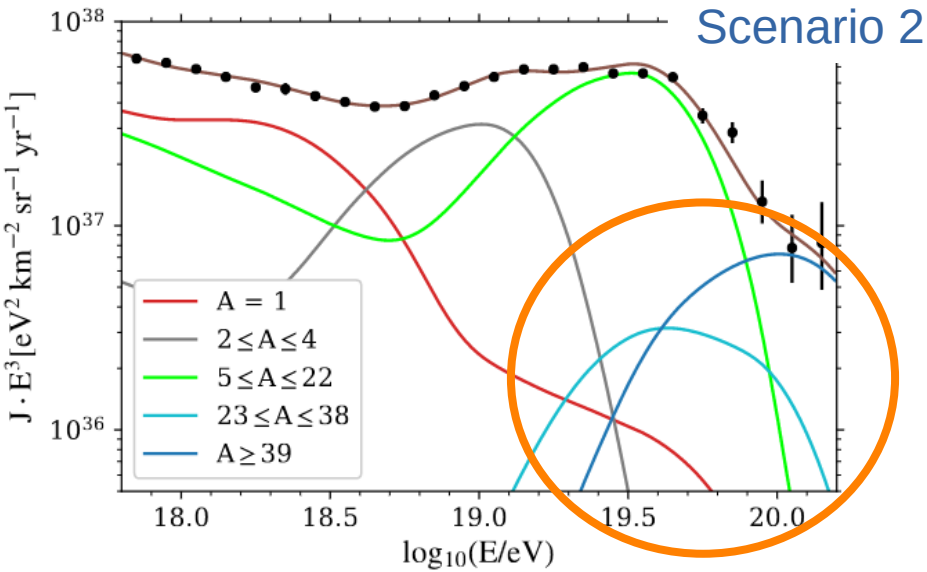
Spectrum and Composition

It is possible to reproduce the Auger energy spectrum using different astrophysical models as input for simulations.

Scenario 1



Scenario 2



The composition can help to distinguish one model from another.
FD provides important information about composition but **at the highest energies, the statics is too low**. We want to use data collected by the SD, which has a 100% duty cycle e we want to measure the **muonic component** of the shower.

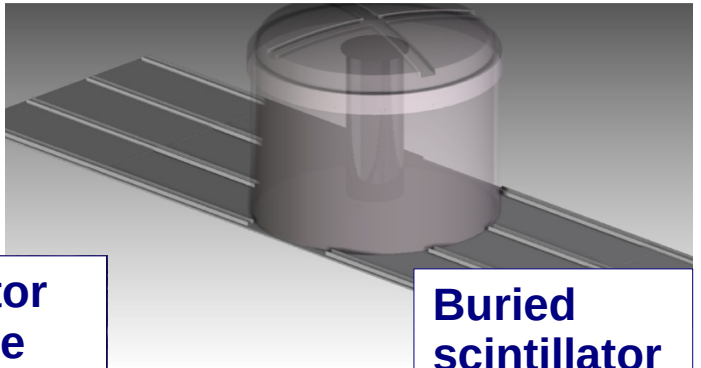
How to measure the muonic component?

LSD (Layered Surface Detector)

dominated by em signal

dominated by muonic signal

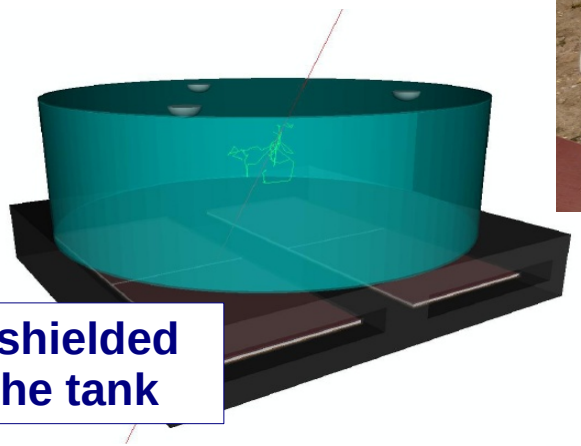
AMIGA (Auger Muons and Infill for the Ground Array) **- Grande**



Buried scintillator

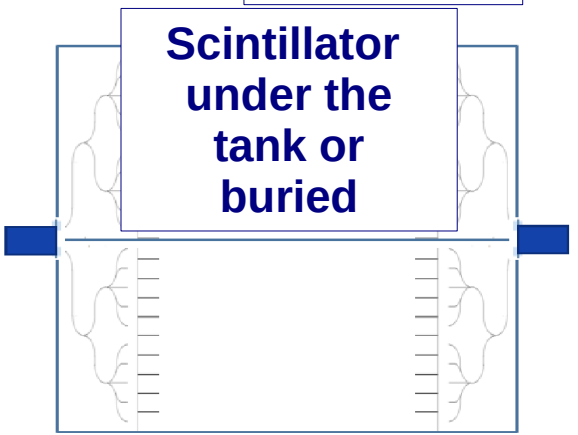
Scintillator above the tank

ASCII (Auger Scintillators for Composition-II)



RPC shielded by the tank

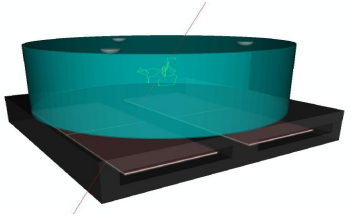
MARTA (Muon Auger RPC for the Tank Array – 8 m^2)

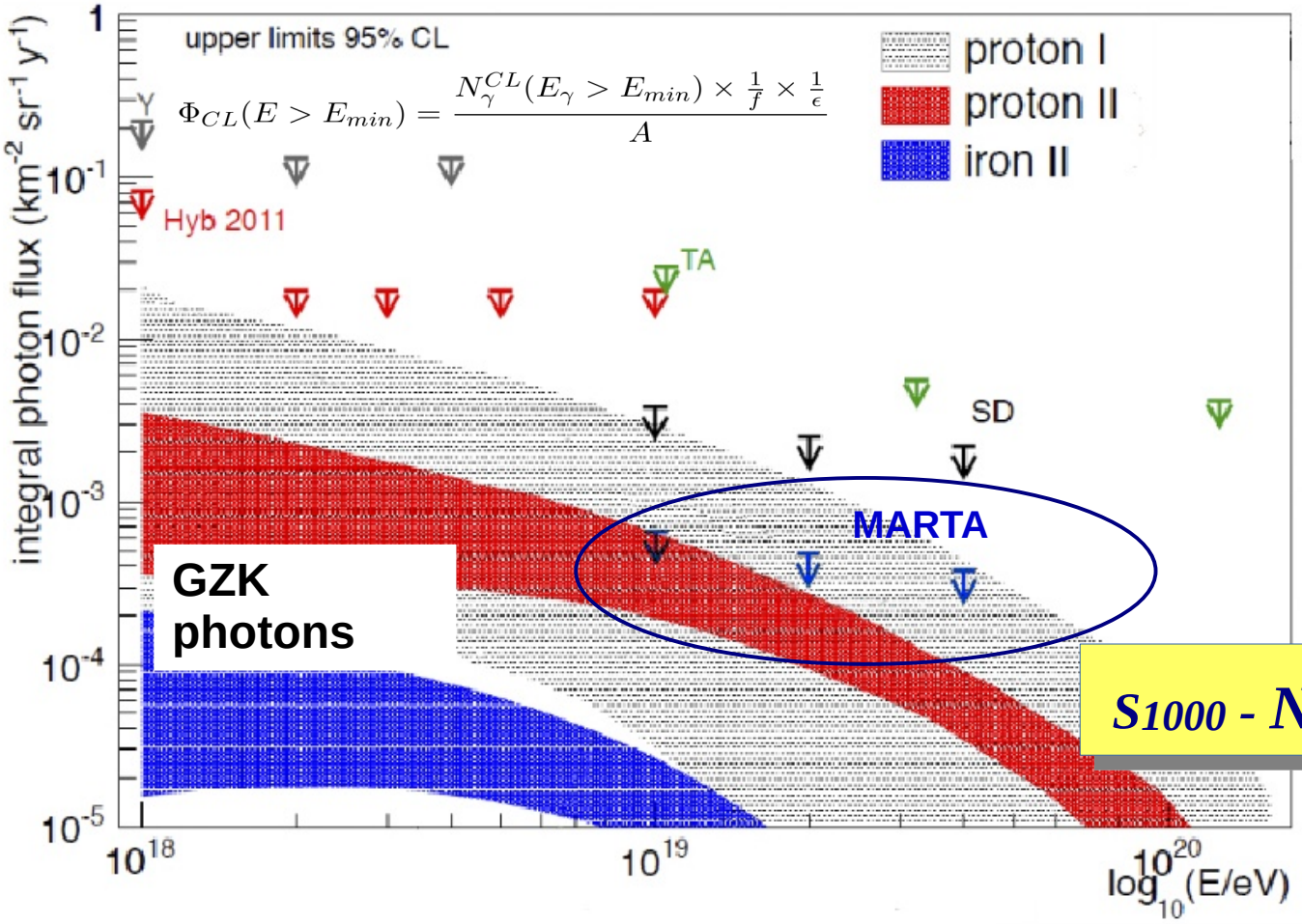


Scintillator under the tank or buried

TOSCA-A or B (4 m^2 – 10 m^2)
(The Observatory Scintillator Array)

Photon Search with MARTA





The MARTA detector could have been used to put a stronger upper limit on the flux of photon, that would probe the GZK photon region

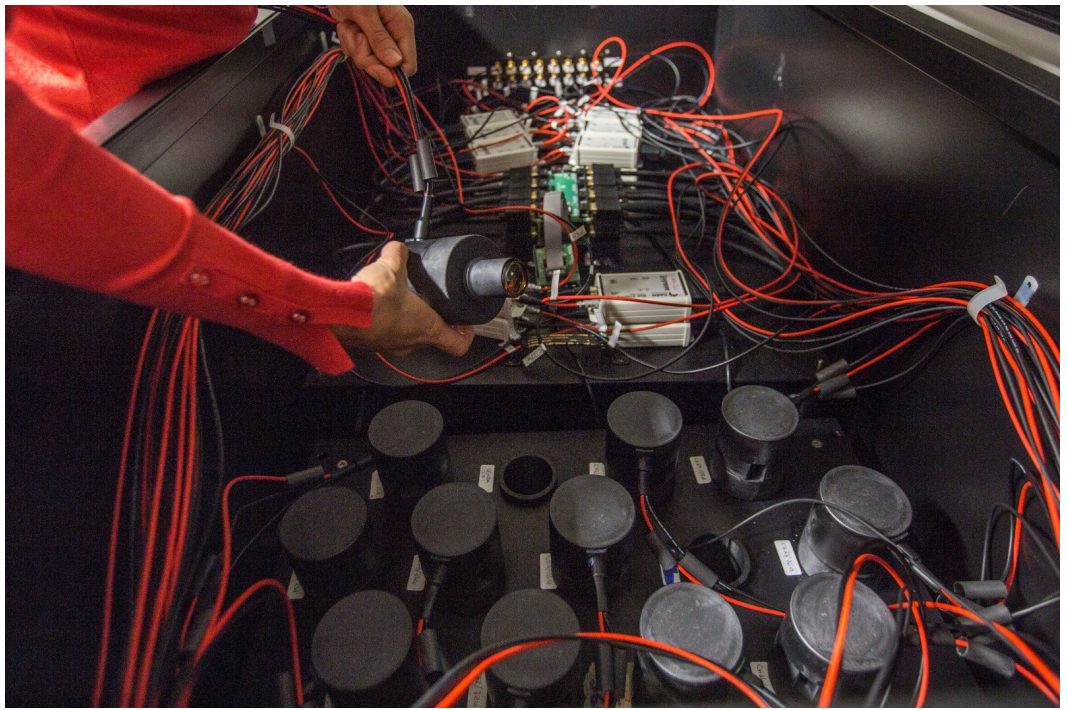
S1000 - Nμ - SR4

AugerPrime: the major upgrade of the Auger SD

- A complementary measurement of the shower particles will be provided by plastic Surface Scintillator Detectors (SSD) placed above the existing 1660 WCDs.
- The SD stations will be upgraded with new electronics that will process both WCD and SSD signals.
- To increase the dynamic range, each WCD will be equipped with an additional smaller low gain photomultiplier tube.

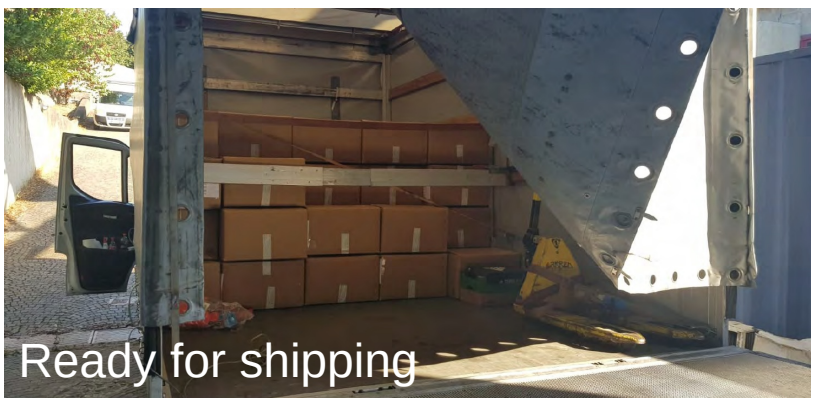
- An Underground Muon Detector (UMD) will provide important direct measurements of the shower muon content.
- Each SD station will be complemented with an antenna for the detection of radio signal produced by cosmic-ray showers.

The Auger Napoli group and the characterization of PMTs for AugerPrime



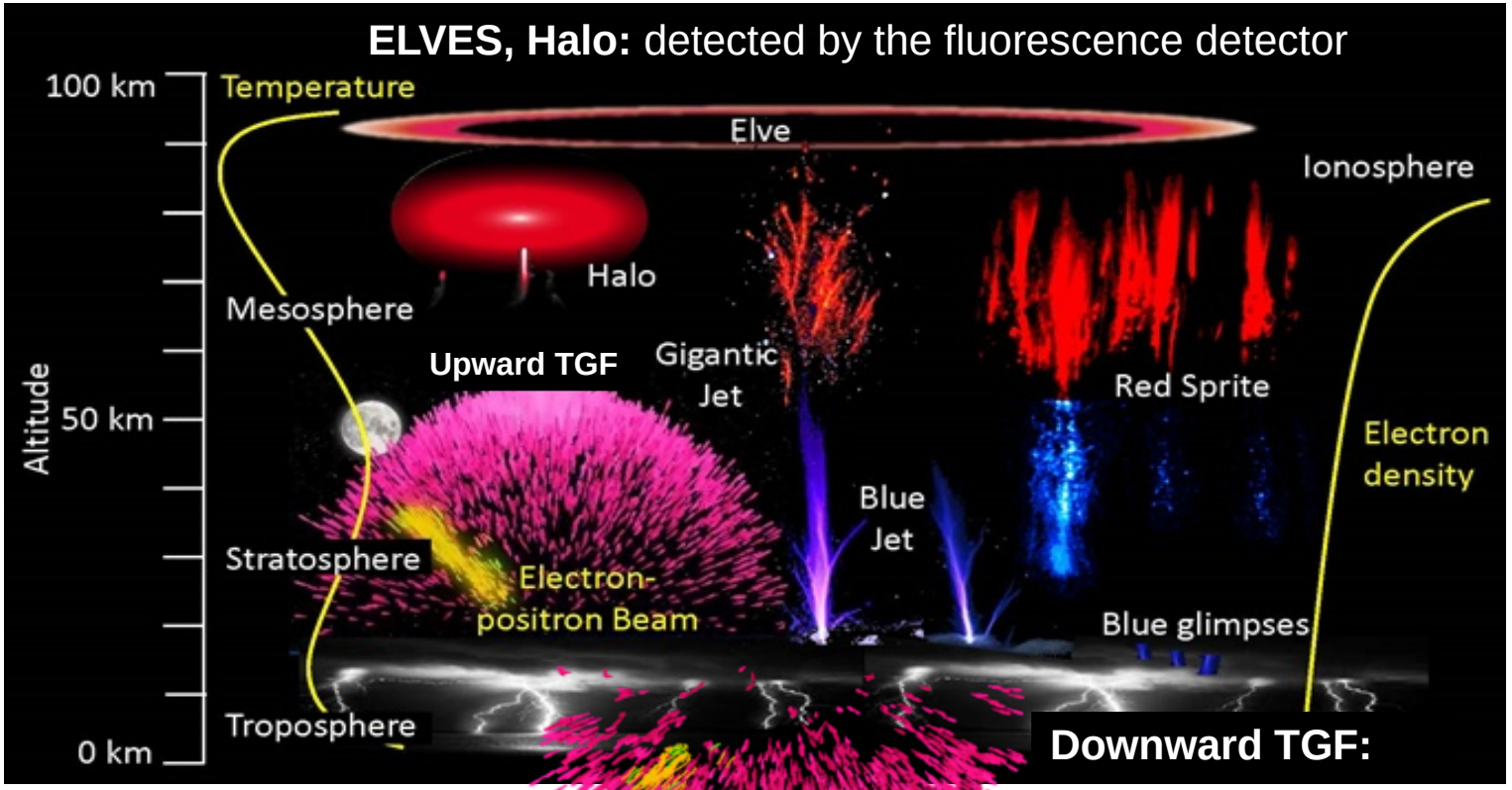
Our test facility

1600 PMTs
Tested!!!



Ready for shipping

Not only cosmic rays …
… bright events produced by lightning

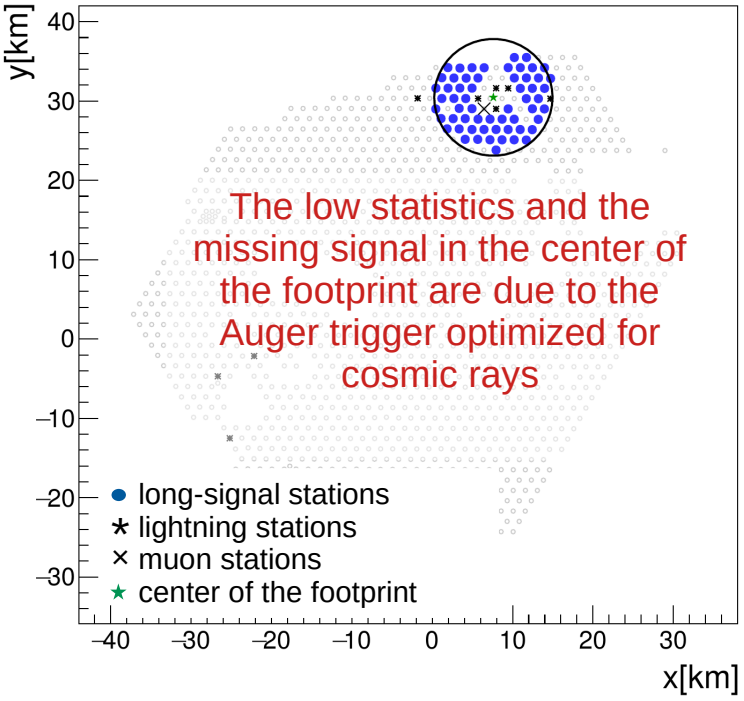


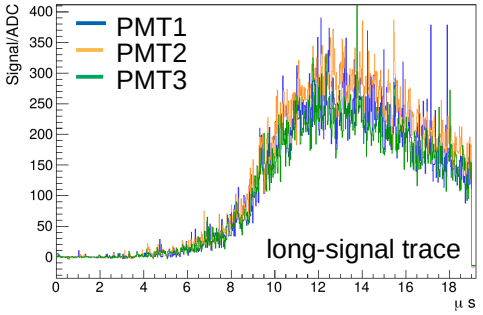
sub-millisecond pulses
of gamma rays detected
By the surface detector

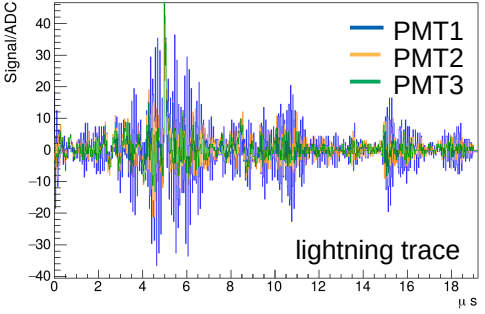
“TGF events”

R. Colalillo at al., AtmoHEAD 2018,
https://doi.org/10.1051/epjconf/201919703003
R. Colalillo et al., PoS(ICRC2021)395,
https://doi.org/10.22323/1.395.0395

23 peculiar events collected from 2005 to 2017 (change in the SD trigger).

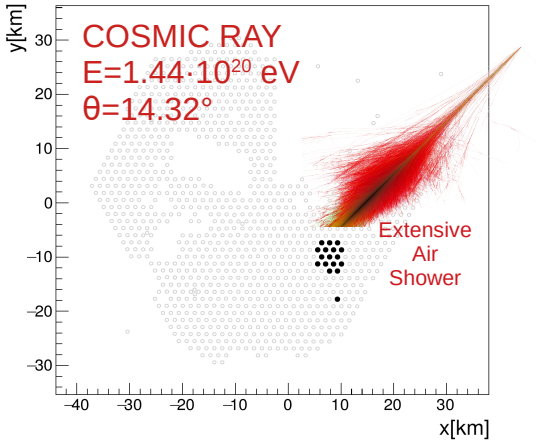


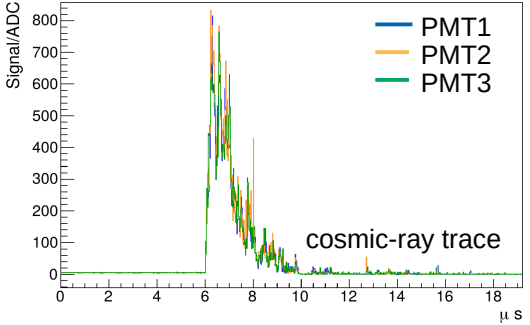


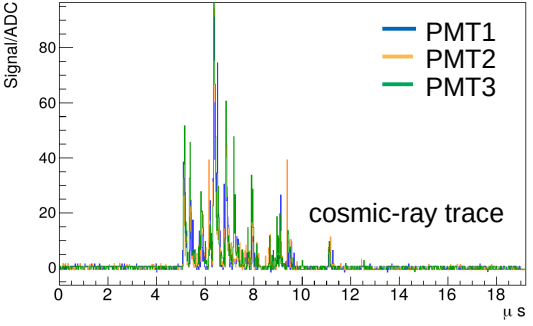


A dedicated algorithm to increase the TGF event detection was designed and installed.

Other work is necessary because the Pierre Auger Observatory is being upgraded and the TGF algorithm needs to be optimized according to the new electronics.



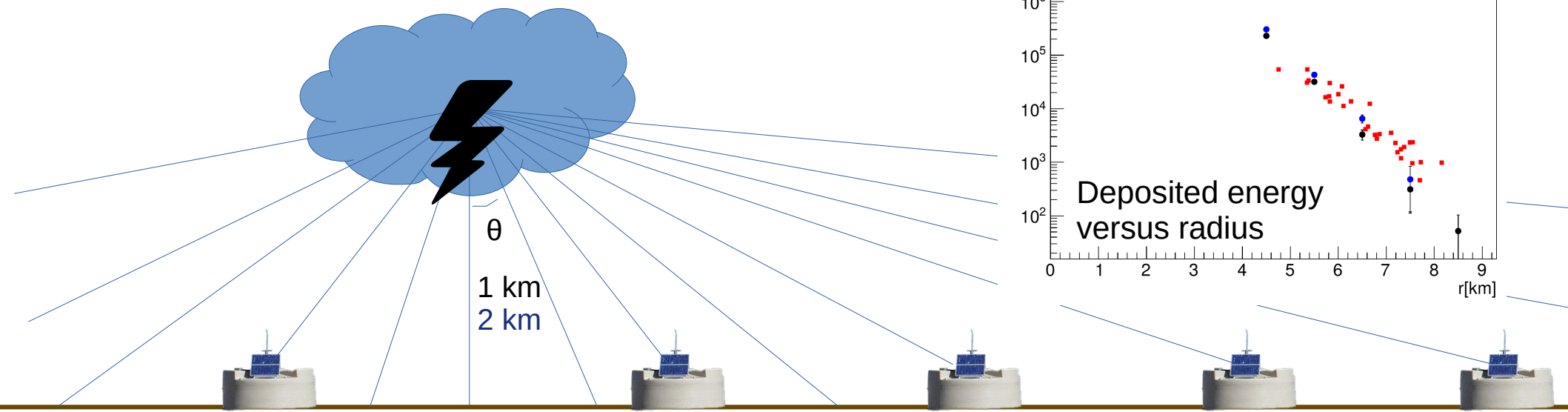




TGF interpretation

- Simulation produced assuming a standard (10^{17} runaway electrons) downward TGF at 1 and 2 km above the ground
- Isotropic emission into the lower hemisphere is assumed.

Collaboration with American TGF experts



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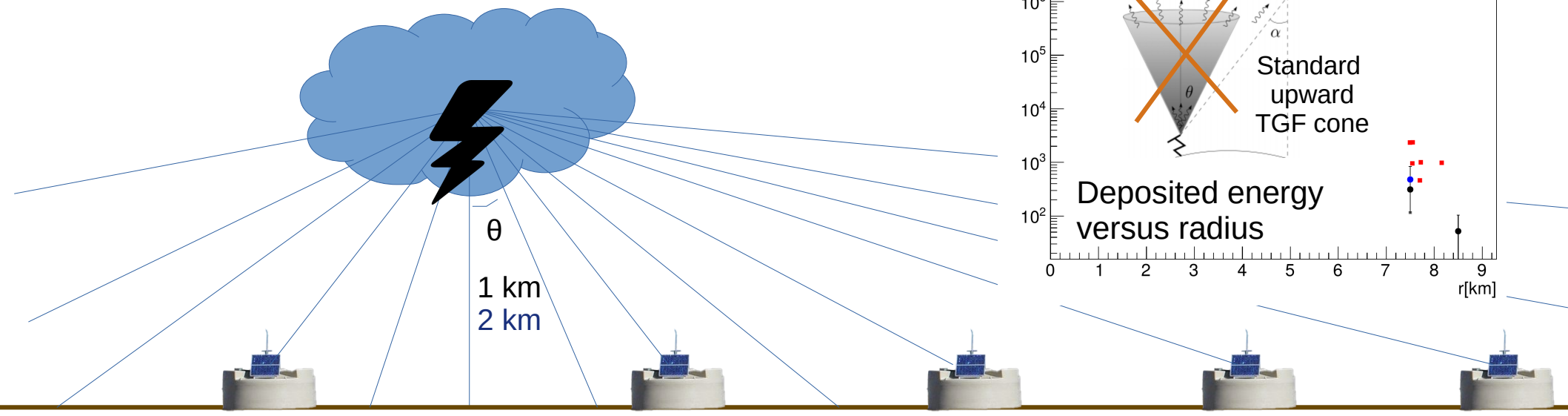
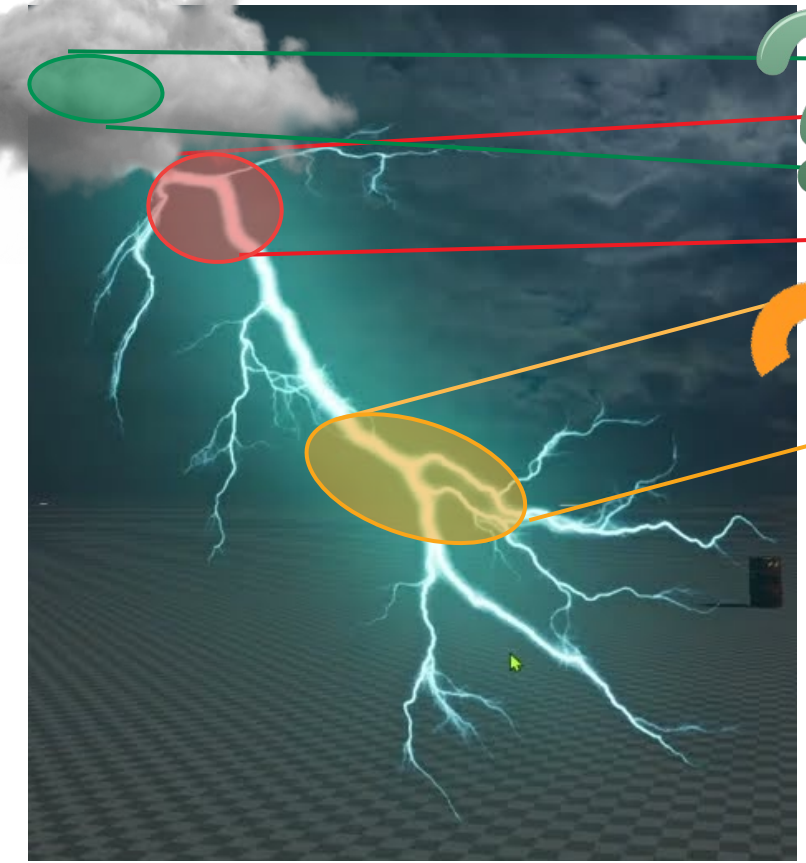
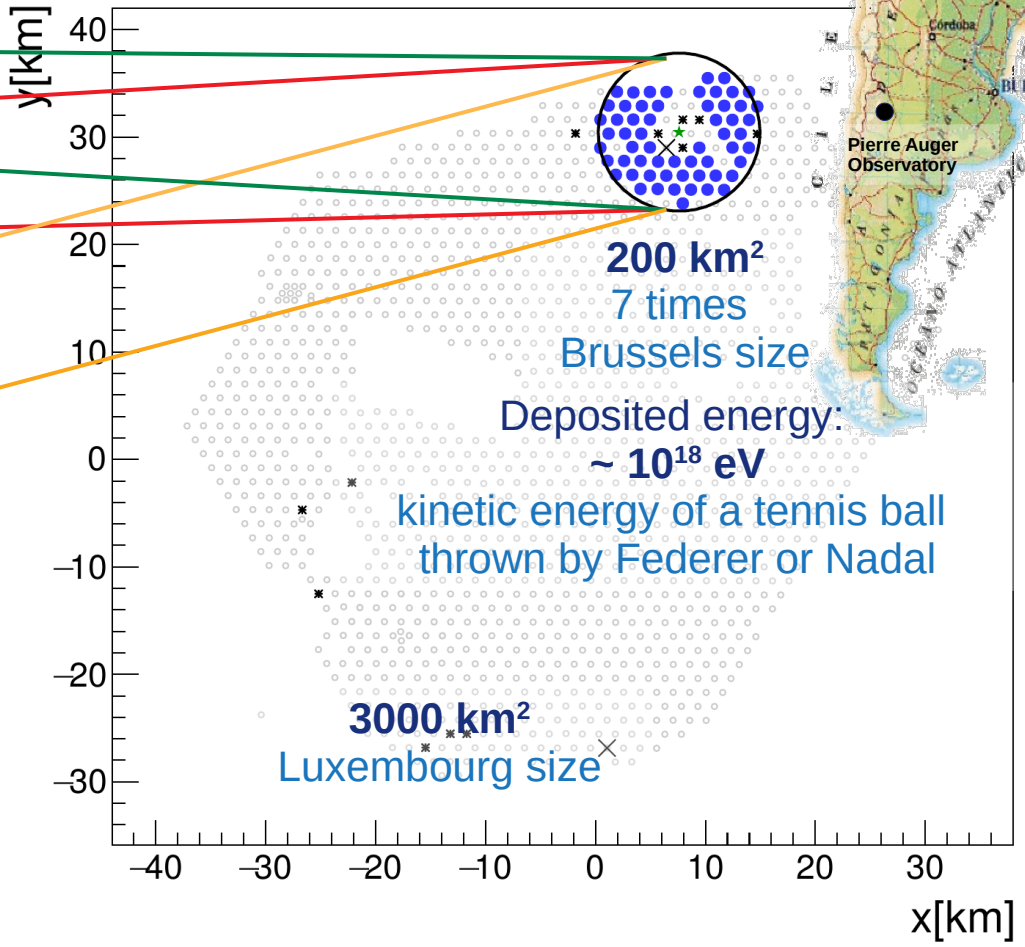


ERC proposal: **FULGORA**

At what stage in lightning development is a TGF produced?





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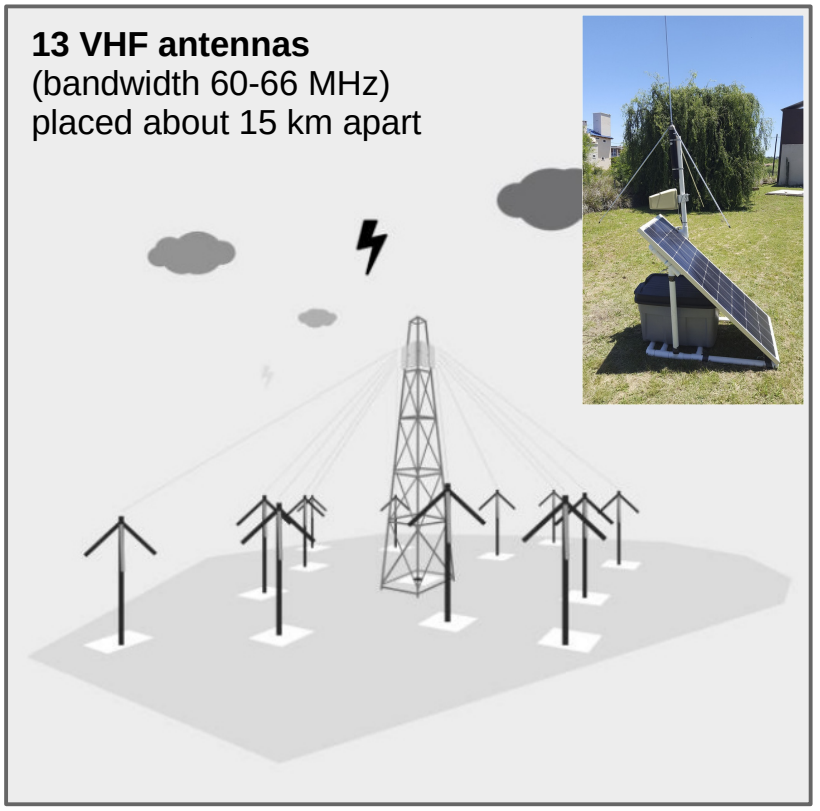


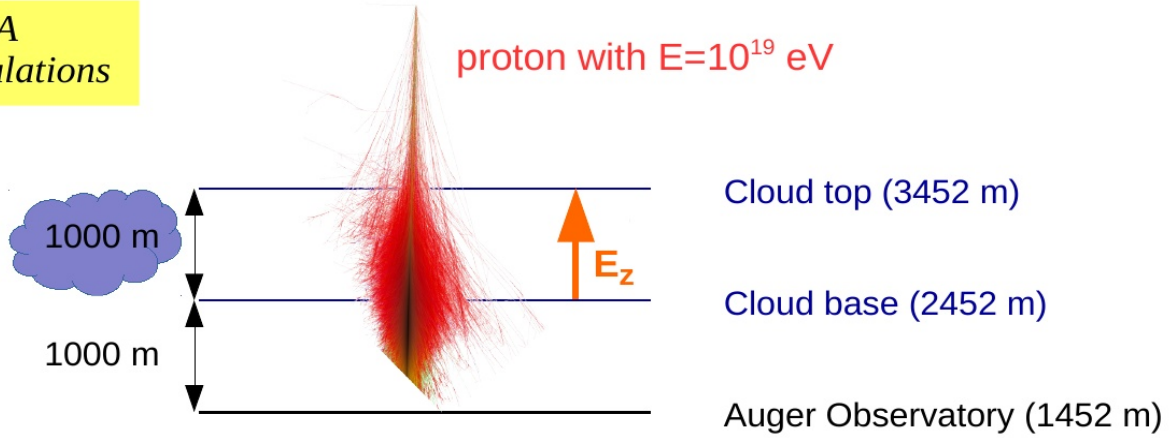
Adaptation of the world-largest Cosmic-Ray Observatory
to study TGFs sistematically.
Observations made there have been serendipitous thus far

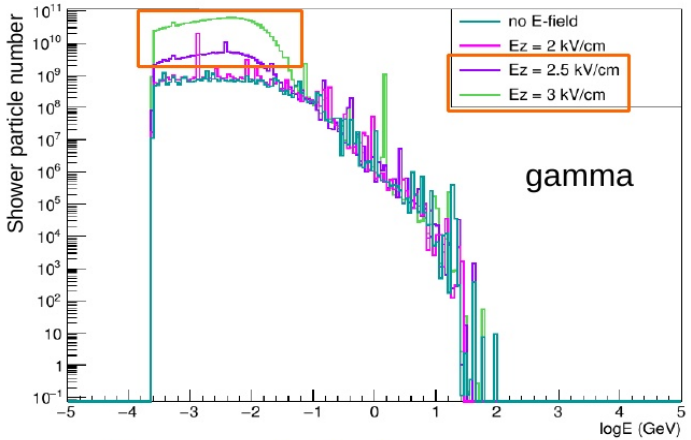
Installation of a Lightning Mapping Array (LMA) at the Pierre Auger Observatory
to study the lightning development

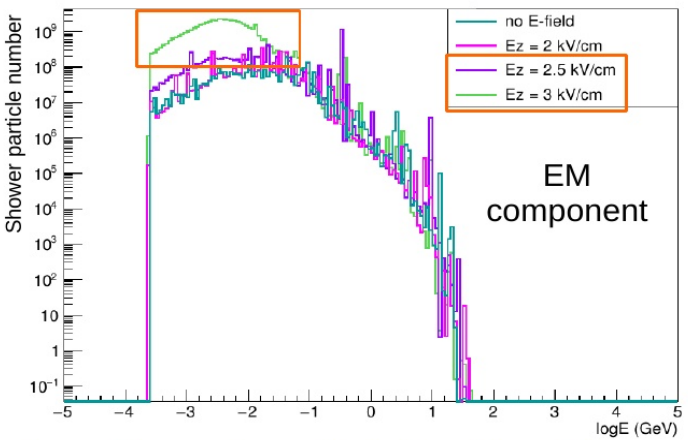
Up to 8 lightning/km^2/year are expected over the Auger Observatory
(https://doi.org/10.1016/j.epsr.2022.108704)
~ ***24000 lightning/year*** *of which* ***~ 24 are expected to produce TGFs***

Effect of thundercloud electric field on cosmic-ray measurements

CORSIKA
MC Simulations







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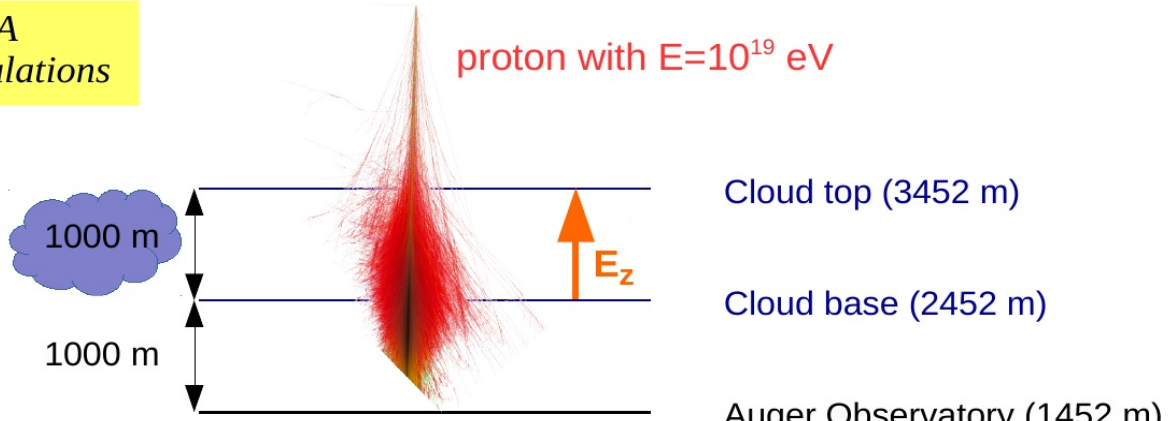
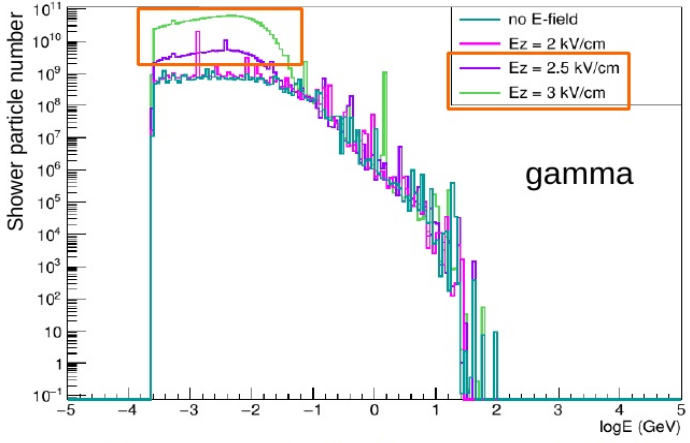
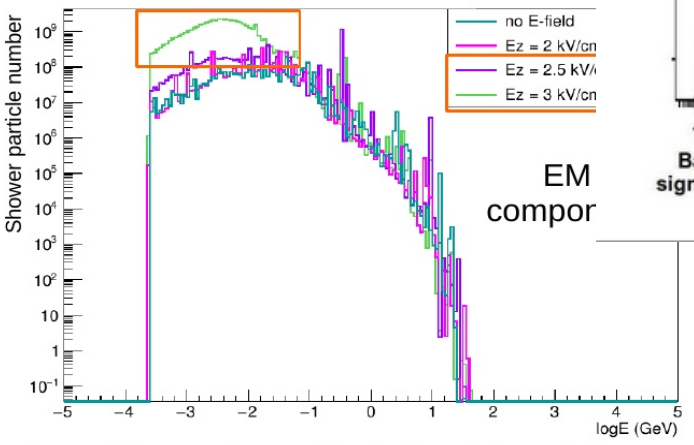
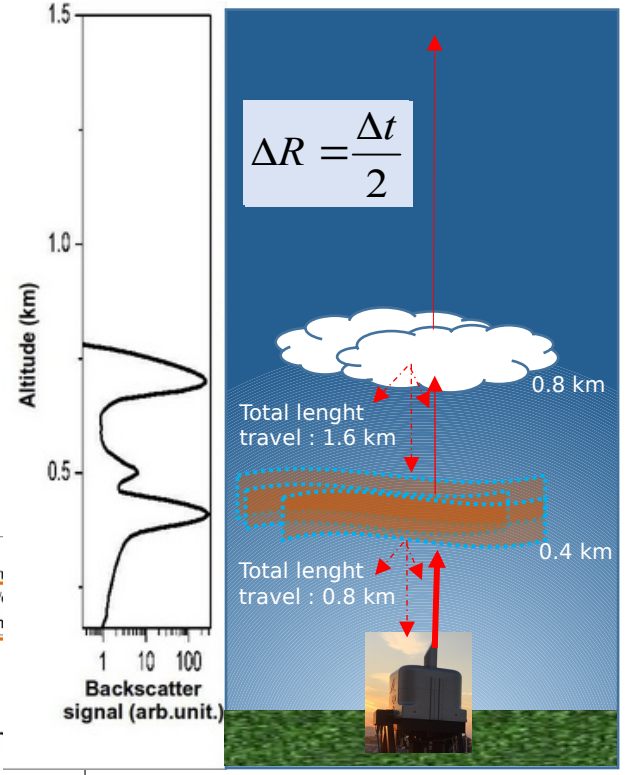


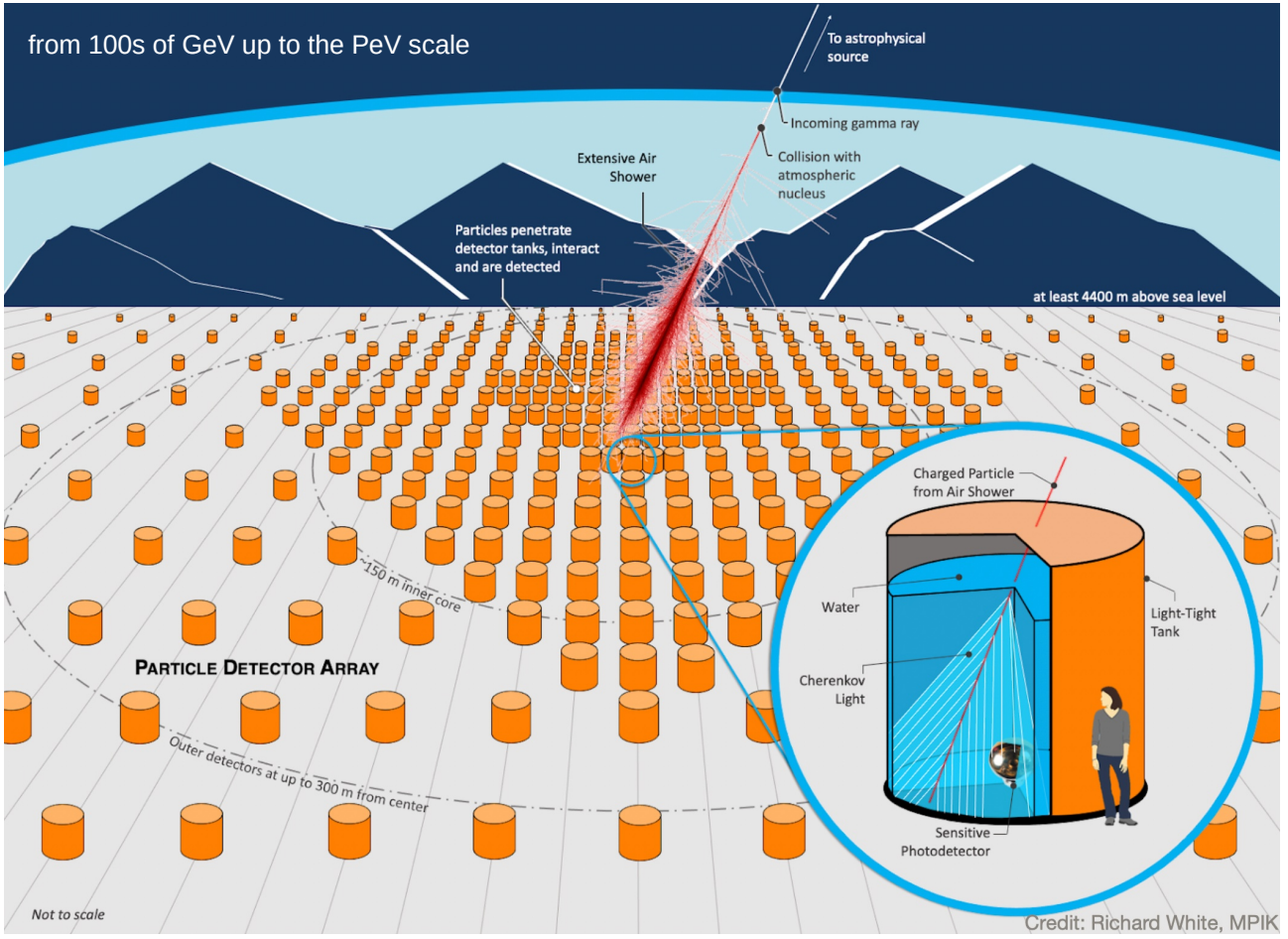






Measurements will be performed in Napoli with the LIDAR group (ACTRIS National facility)

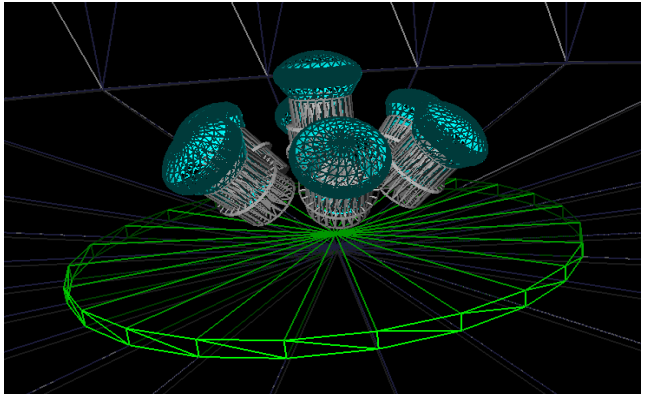
New adventures !!!

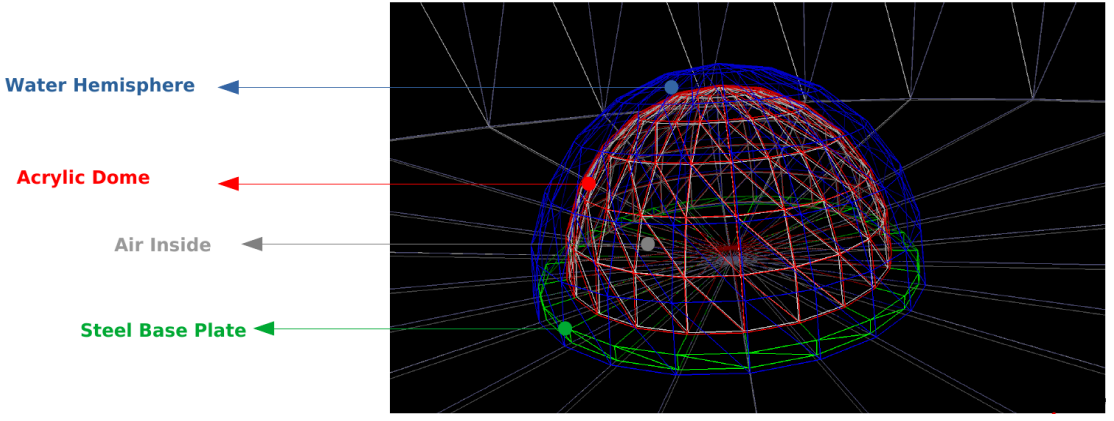


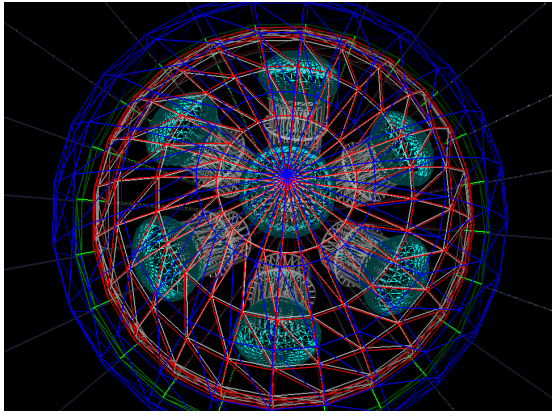
Exploiting previous experiences:

- Deep knowledge of Auger Water-Cherenkov tanks
- Gamma/hadron discrimination
- PMT measurements

New adventures !!!







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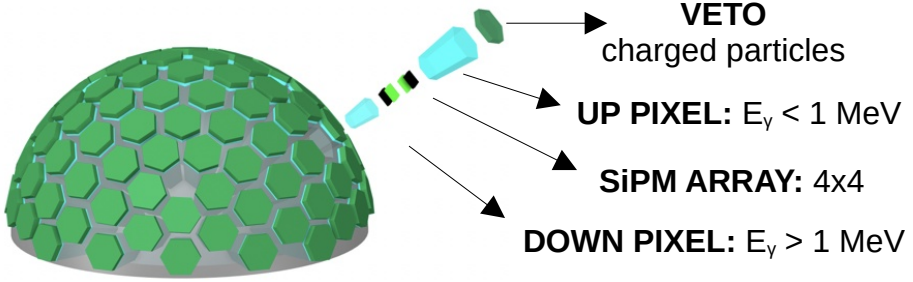


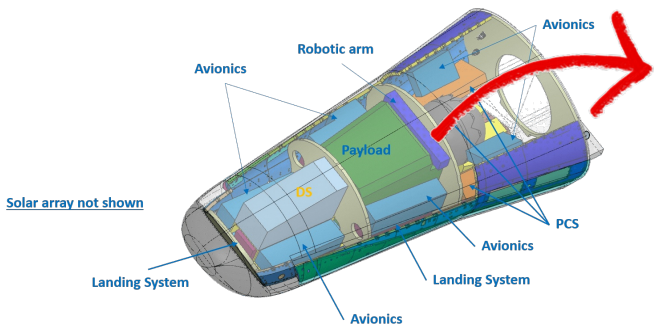
For the detection of
Gamma-ray bursts and TGF
from space → 10 keV – 30 MeV

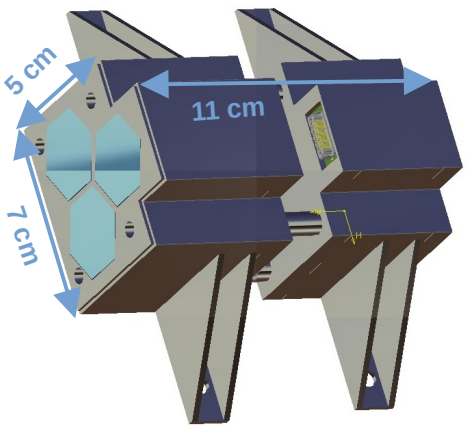
A Crystal Eye constellation in the future?

WINK (PRIN 2022):
the Crystal Eye pathfinder

3 full scale Crystal Eye pixels

WINK will flight for 2 months onboard of Space Rider at the beginning of 2025






Strange clouds waiting for us
at the Pierre Auger Observatory
THANK YOU