Global Cosmic Rays Observatory (GCOS)

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Rafael Alves Batista, Antonella Castellina, Ralph Engel, Toshihiro Fujii, Jörg Hörandel, Karl-Heinz Kampert, Lu Lu, Shoichi Ogio, Julian Rautenberg, Takashi Sako, Fred Sarazin, Michael Unger

and all the GCOS workshop participants

UHECR Symposium, October 2022 l'Aquila

The second GCOS workshop in Wuppertal (13-15 July 2022)

https://agenda.astro.ru.nl/event/21/overview

resent and presenters: Pierre Billoir, Alan Watson, Eric Mayotte, Fred Sarazin, Dennis Soldin, Nonaka Roshiyuki, David Schmidt, Ioana Mariș, Markus Roth, Julian Rautenberg, Jorg Hoerandel, Washington Carvalho, Tomas Fodoran, Karl-Heinz Kampert, Anna Muller, Arjen Van Vliet, Armando di Matteo, Glennys Farrar, Louis Anchordoqui, Marco Muzio, Markus Risse, Teresa Bister, Vincent Pelgrims, Bruce Dawson, Shoichi Ogio, Michael Unger, Toshihiro Fuji, Pierre Sokolsky, Masaki Fukushima, Jose Bellido, Yuichiro Tameda, Francesco Salamida, Alexey Yushkov

and many others participating in the online discussions

Science case, surface particle detectors, telescopes and antennas

What is GCOS?

UHECRs observatory covering more than 60,000 km^2 (40,000 -80,000 km^2)

With $60,000$ km^2 we can reach the integrated Auger 2030-exposure in 1 years
AugerPrime expected exposure in 6 months

Targeting very good quality events for energies $\geq$ 30 EeV (5-fold) and full efficiency at 10 EeV (3-fold events)

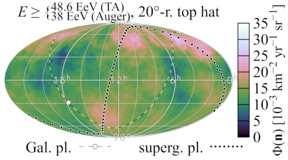
Resolutions per event: energy better than 10%, muon resolution better than 10%,
$X_{\rm max}$ better than 30 g/cm^2, and angular resolution better than 1°

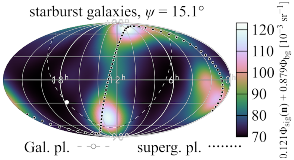
Full sky coverage with sites in both hemispheres and surrounded by mountains

What could you do with such a detector?

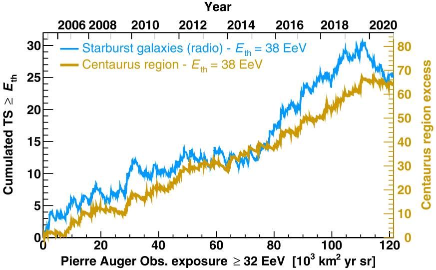
Anisotropies at small scales: correlations with catalogues

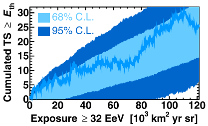
catalogue	$E_{min}^{(Auger)}$	$E_{min}^{(TA)}$	ψ [deg]	f [%]	TS	significance
all galaxies	40 EeV	51 EeV	29^{+11}_{-12}	41^{+29}_{-18}	14.3	$2.7\sigma_{global}$
starburst	38 EeV	49 EeV	$15.1^{+4.6}_{-3.0}$	$12.1^{+4.5}_{-3.1}$	31.1	$4.6\sigma_{global}$

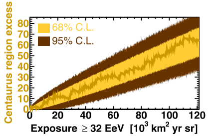




Assuming linear growth of the TS: expected to reach 5σ in 2025$\pm$2





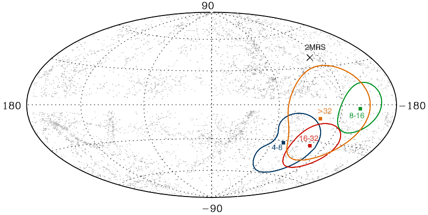


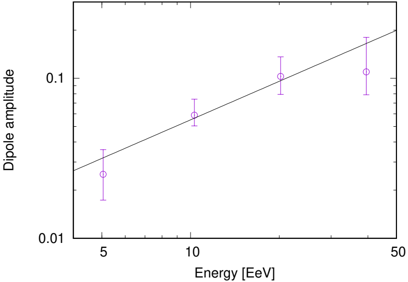
With 80,000 km^2 and full sky coverage we can reach 5σ in one year on both hot-spots and source-correlations

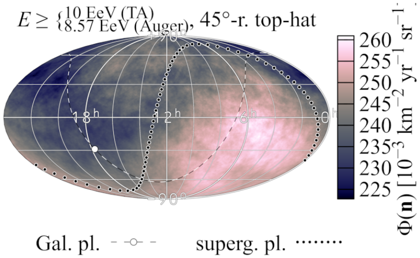
talks by F.Urban (Auger-TA WG), J.Kim (TA) and U. Giaccari (Auger)

Large scale anisotropies

Constant dipole amplitude disfavored at 3.7σ





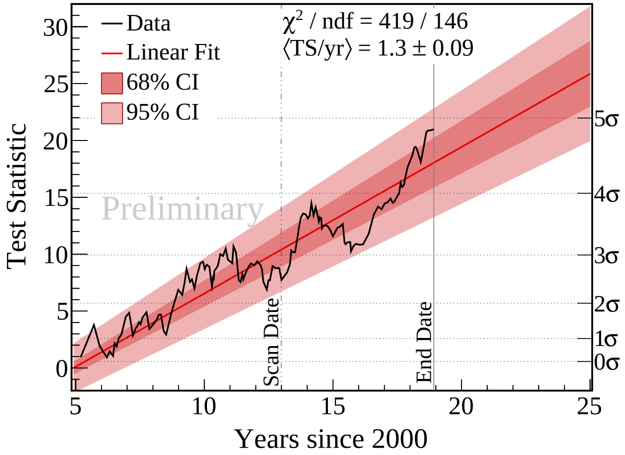


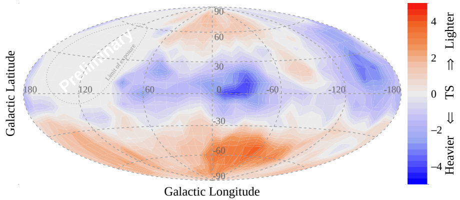
- Full sky coverage leads to a better constraint on the dipole direction
- By 2030 good precision also on the phase (TA$\times$ 4 + Auger) but probablly just at sub EeV energies
- Amplitude (Auger 2021) above 32 EeV: $A = 11.6 \pm 3.8 \pm 1.1\%$

A factor 10 in the exposure leads to 11σ measurement of the dipole above 32 EeV

Mass composition distribution over the sky

Systematic uncertainties not shown



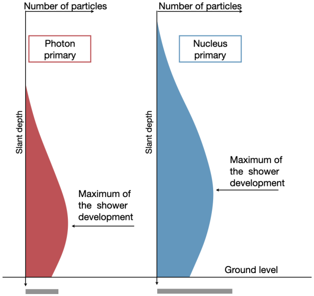


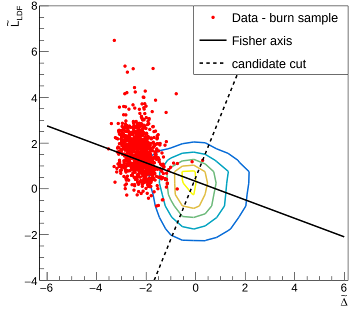
More data are needed (and more sensitivity), we might reach 5σ by 2030 with AugerPrime and other SD variables

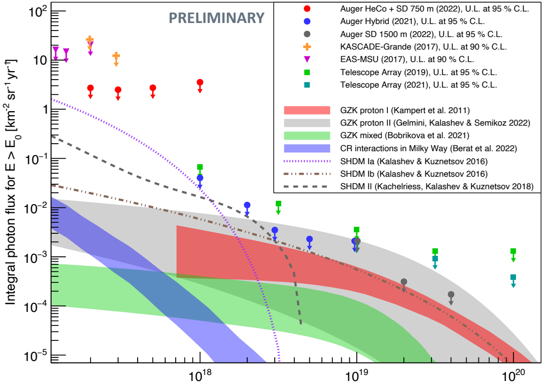
GCOS will have very good sensitivity to mass composition (at least as good as 30 g/cm^2 and 10% on muon number)

talk by E. Mayotte (Auger coll.)

Multimessenger: Ultra high energy photons



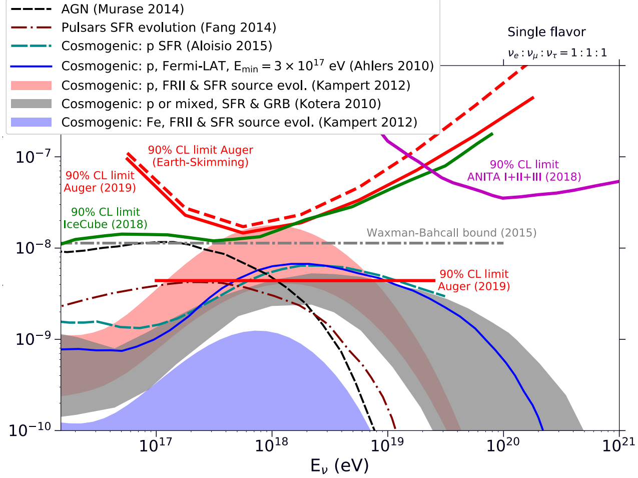




Besides exposure limitations, the background separation plays an important role in the photon searches

GCOS exposure and very good photon/hadron separation: first cosmogenic photons!

Multimessenger: Ultra high energy neutrinos



Mountains part of GCOS: EeV neutrinos

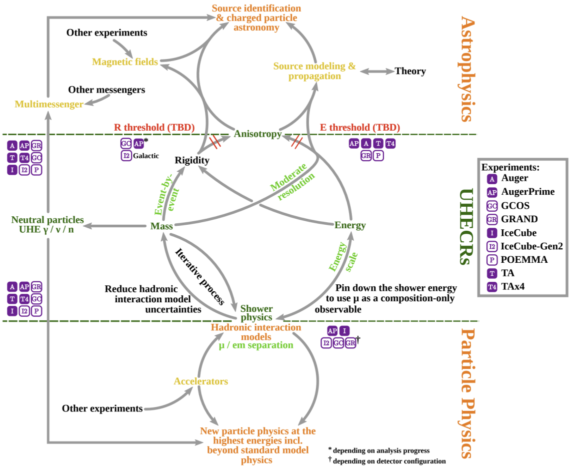
Auger: Surface array surounded by mountains, provides the largest instantenous exposure in preferential directions

Current limits start to cut into the cosmogenic neutrino predictions

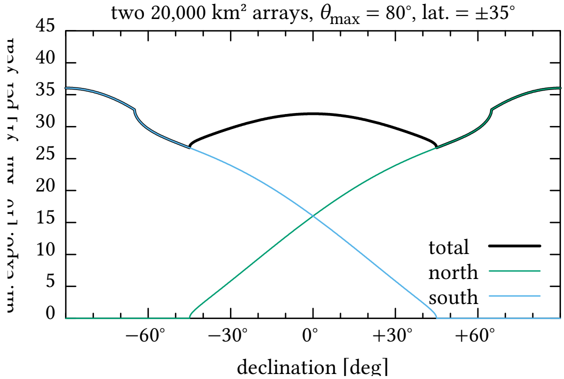
talks by M. Niechciol and L. Perrone (Auger coll.)

More on the science case

- Which is your favourite scenario and what precision is required?
- Particle interactions at the highest energies (p-Air cross-section)
- Understand magnetic fields and if there are any preferential directions in the sky
- Lorentz invariance tests (via air-showers development or cosmic rays propagation)
- Geophysics and atmospheric science: elves, gamma ray flashes, lightning



Where shall we build it?



At a latitude of 35 degrees, with air-showers up to 80 degrees, almost uniform exposure

A. di Matteo

Mountains in the area

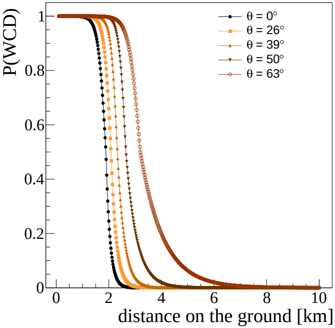
Use the geomagnetic field to enhance the mass composition particles separation

P. Billoir

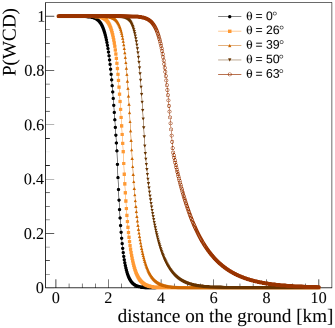
For covering 60.000 km^2 different sites will be needed (2-4)

How many detectors do we need?

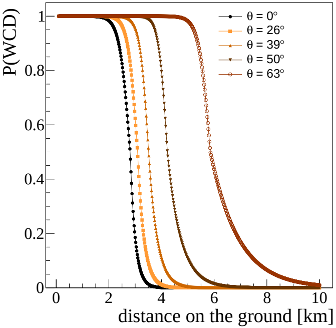
lg(E/eV)= 19



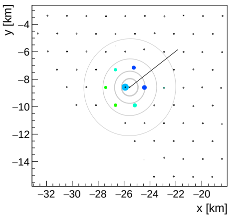
lg(E/eV)= 19.5



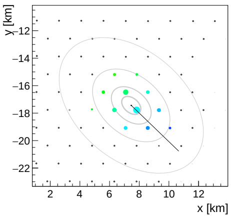
lg(E/eV)= 20



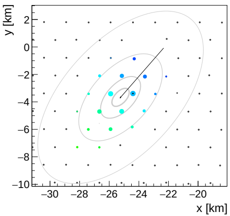
$\theta = 10^\circ$ lg(E/eV)= 19.5



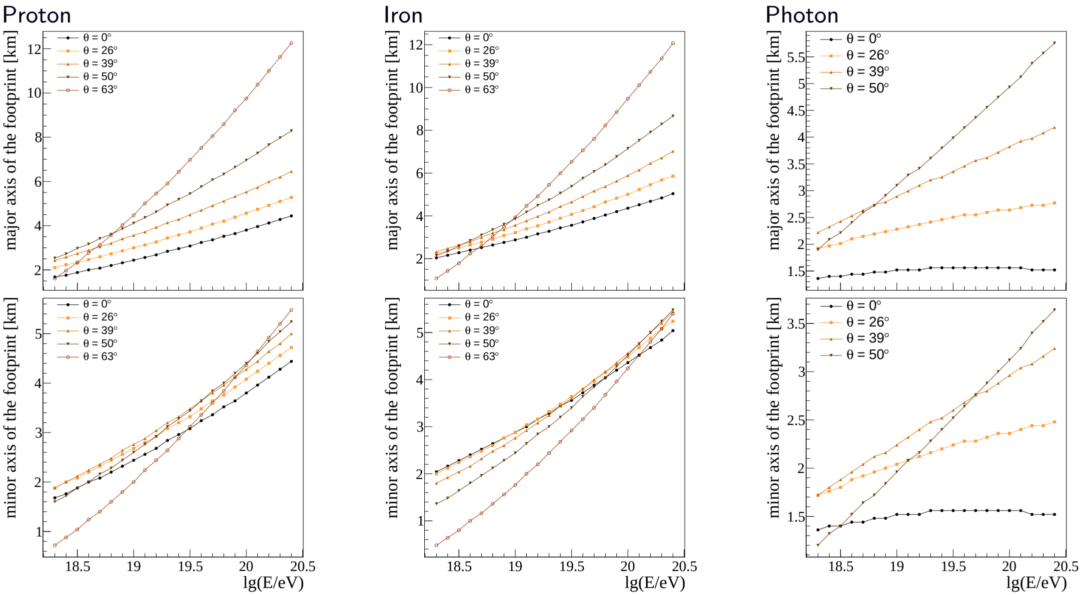
$\theta = 48^\circ$ lg(E/eV)= 19.5



$\theta = 60^\circ$ lg(E/eV)= 19.5

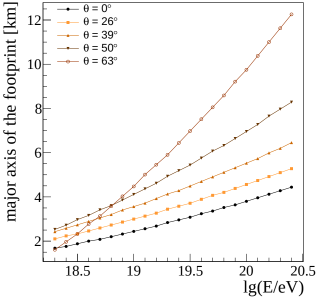


Spacing: How large is the air-shower footprint on the ground?

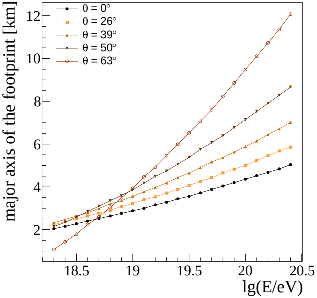


Spacing: How large is the air-shower footprint on the ground?

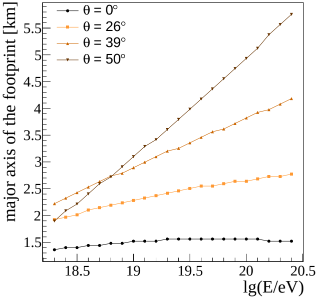
Proton

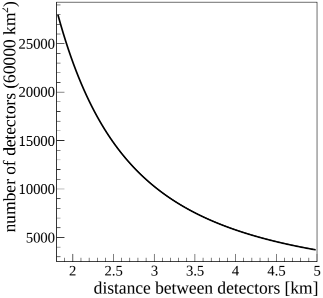


Iron



Photon





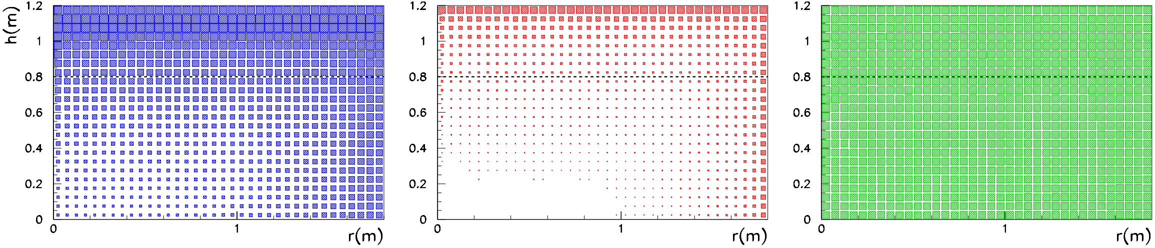
Spacing between detectors cannot be larger than about 2-2.5 km to reach 100% efficiency at 10-30 EeV

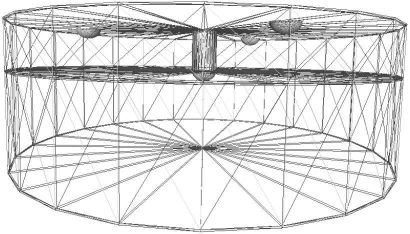
On an hexagonal grid: 15k-22k detectors for 60000 km^2
Need very robust detectors, no maintenance, industrial production

The idea: optical separation of a Water Cherenkov Tank

A water volume responds different to photons, $e^{\pm}$ and $\mu^{\pm}$

photons electrons muons



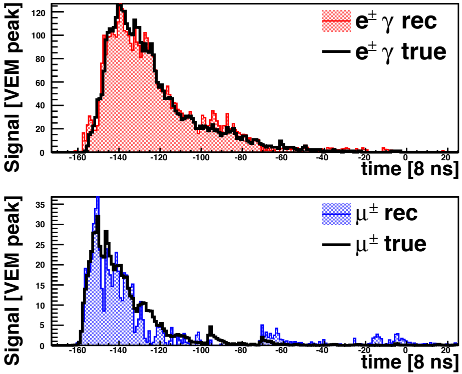


$$\begin{pmatrix} S_{\text{top}} \\ S_{\text{bot}} \end{pmatrix} = \mathcal{M} \begin{pmatrix} S_{\text{EM}} \\ S_{\mu} \end{pmatrix} = \begin{pmatrix} a & b \\ 1-a & 1-b \end{pmatrix} \begin{pmatrix} S_{\text{EM}} \\ S_{\mu} \end{pmatrix}$$

$$\begin{pmatrix} S_{\text{EM}} \\ S_{\mu} \end{pmatrix} = \mathcal{M}^{-1} \begin{pmatrix} S_{\text{top}} \\ S_{\text{bot}} \end{pmatrix}$$

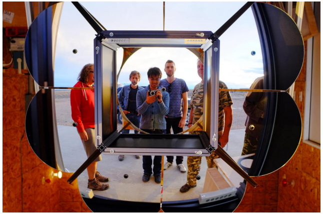
A. Letessier-Selvon, P. Billoir, M. Blanco, I. C. Mariș, M. Settimo

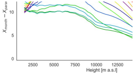
Segmented tank for the surface particle detectors

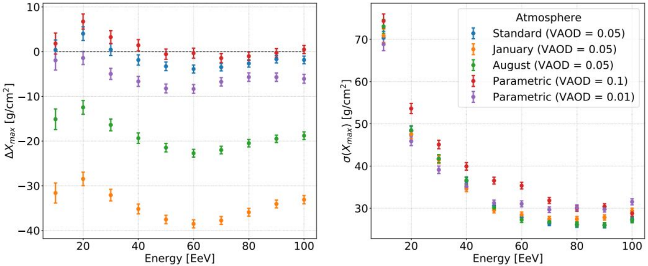


- Prototypes tested in the field (at Auger)
- Based on the different response of the Water Cherenkov tank to em and muons, very good resolution for muonic and electromagnetic signals at station level
- Robust and well-known detectors (Water Cherenkov technique)

Flourescence detector Array of Single-pixel Telescopes (FAST)?



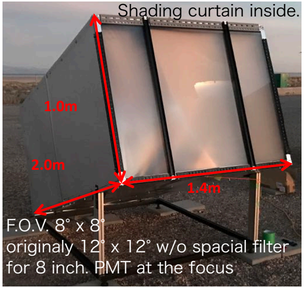




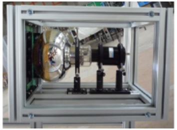
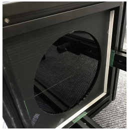
- Low cost fluorescence telescopes tested at Auger and TA sites
- 100% efficiency above 30 EeV for 3-fold coincidences
- Resolutions: 8% for energy, reaching 30 $\mathrm{g/cm^2}$, about 2 degrees for the angular resolution
- Near future: stand-alone operations of FAST array in the field

T. Fujii

Cosmic Ray Air Fluorescence Fresnel lens Telescope (CRAFFT)



Appearance of CRAFFT prototype.

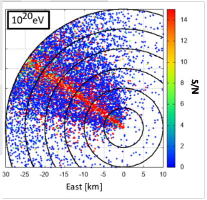



8 in. PMT with UV transmitting filter.
8° spacial filter for test observation.

For UHECR observation, we need a huge observatory with detectors which can measure Xmax such as FD.
We need reduce the cost.

- Simple structure, without container
- Easy to deploy
- No obstacle between lens and focus
- Necessity of multiple observation for geometrical determination
- Worse S/N compared to multi pixels.

Componen	Product	Specification	Cost/
Structure	MIWA	Aluminum	950
Fresnel lens	NTKJ, CF1200-B	$1 m^2$, f=1.2m	370
UV trans.	Hoya, UL330	~90%,300-360	3,000
PMT	Hamamatsu, R5921	8 inch	2,000
FADC	TokushuDenshiKairo,	80MHz, 12bit	290
Amplifier	Lecroy, 612AM		1,000
HV	CAEN, N1470AR	8kV, 3mA	1,600
		Total ($) :	9210



Detection efficiency.

Y. Tameda

GCOS Cyclops FD: Small elevation, large area, small pixels

e.g. MACHETE Design J. Cortina et al. APP (2016) 46

Nepomuk Otte PoS ICRC19

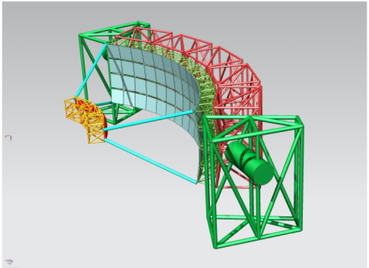


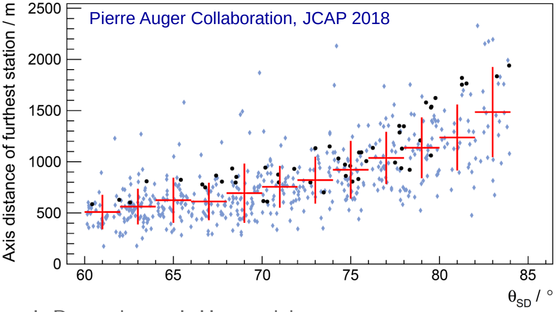
Figure 7: Proposed optics for *Trinity* based on the MACHETE optics. The primary mirror is composed of 68, 1 m^2 mirrors. the focal plane (red curved surface) is populated with 3,300 pixels each consisting of a solid non-imaging light concentrator coupled to an SiPM. The field of view covered by one telescope is $5° \times 60°$.

- 2 MACHETE rings $\rightarrow 360° \times 10°$ FoV
- cost: $\sim$ 10 M$ Trinity whitepaper arXiv:1907.08727
- $0.3°$ pixel, effective aperture 10 m^2
- $(S/N)_\text{FD} \propto \sqrt{A/\Omega_\text{pix}} \rightarrow (S/N)_\text{Cyclops} / (S/N)_\text{Auger} = \sqrt{10\text{ m}^2/0.3°^2} \Big/ \sqrt{3\text{ m}^2/1.5°^2}$ = **9**

$\rightarrow$ optimization for GCOS needed & check dual use ν+UHECR

Radio measurements

- to be combined with a particle detector
- GRAND will (hopefully) lead the path in the radio-only measurements
- Inclined air-showers with footprints of more than 2 km measured
- AugerPrime upgrade to confirm the solid angle for which reasonable mass composition and energy resolution can be achieved with large detector spacing



J. Rautenberg, J. Hoerandel,...

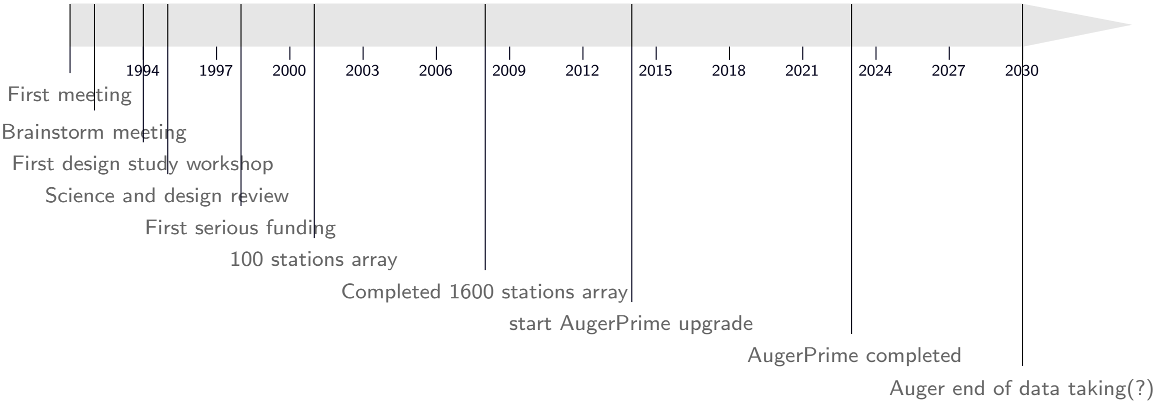
Energy resolution: 10%

Establish the absolute energy scale with less than 10% uceratinty

Build multiple antennas for each SD to compensate for the steep LDF

Multiple polarisation detectors and sub-ns time resolution (interferometry)

Auger timeline



Probable similar timeline needed for GCOS: 2035 engineering configuration, 2040 completed

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Targeting good quality events for energies $\geq$ 30 EeV (5-fold threshold 30 EeV, 3-fold threshold 10 EeV)

Resolutions at 30 EeV: energy better than 10%, muon resolution better than 10%, $X_{\max}$ better than 30 g/cm^2, and angular resolution better than 1°

Full sky coverage with sites in both hemispheres and surrounded by mountains

What could you do with such a detector?
How would you build it?

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People who say it cannot be done, should not interrupt those who are doing it. - Bernard Shaw