From cosmic rays to high-energy physics in Brazil

Carola Dobrigkeit Chinellato (Instituto de Física Gleb Wataghin, UNICAMP)

The pioneers

Bernhard Gross 1933

Bernhard Gross

- A physicist and engineer from Stuttgart, Germany, Bernhard Gross disembarked in the city of Rio de Janeiro in 1933.
- He started to work at the Escola Politécnica do Largo de São Francisco in Rio and in the later years, at the Instituto Nacional de Tecnologia.
- He soon build a research group, gathering around him a group of young interested students dedicated to studying cosmic rays, a subject he knew extremely well from his PhD thesis presented ealier in Germany in 1931.

Bernhard Gross

- **Already in 1934, his measurements of cosmic rays in the stratosphere and underwater were published in the Brazilian Review of Engineering (1934).**
- **These measurements had been done earlier in Germany with balloons (20,000 m height) and at Lake Constance (at a depth of 250 m).**
- **Gross used ionization chambers following the tradition of Erich Regener, whose assistant he had been in Germany.**
- **He got his first job at the Institute of Meteorology in 1934.**

Bernhard Gross

- **He worked in cosmic rays for a time and wrote the Gross Transformation, an important contribution mentioned in the literature.**

- **This transformation relates the absorption of isotropic and unidirectional beams of radiation/particles and is applied in the interpretation of absorption curves of cosmic rays detected by ionization chambers.**

Bernhard Gross

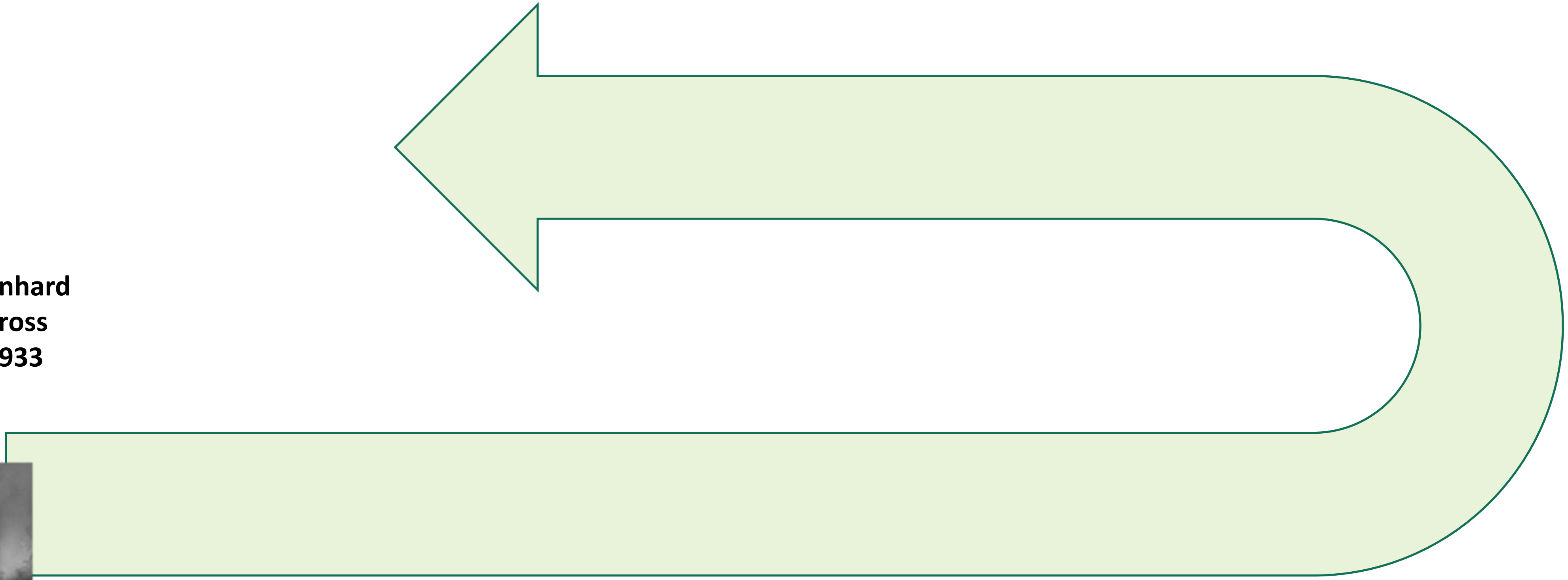
- **One of the qualities of his work was interdisciplinarity and his ability to perform both as an experimentalist and theoretician. These qualities arose from his genuine interest, motivation and curiosity for investigating Nature.**
- **Science, for him, was a way to satisfy this curiosity, not a collection of compartmentalized disciplines.**
- **Later, he worked in dielectrics, viscoelasticity, applied mathematics and instrumentation.**
- **The advancement promoted by Gross in research on electrets was recognized worldwide.**

Bernhard Gross

Gross working on a Helmholtz pendulum

Gross at work at the Instituto Nacional de Tecnologia (1953)

The pioneers



Bernhard
Gross
1933

Gleb
Wataghin
1934

Gleb Wataghin

- **Born in Ukraine in 1899.**
- **His father was an engineer in charge of the imperial railroads south of the Russian empire.**
- **The family fled in 1919, arriving in Italy through Crimea and Greece.**
- **Established in Turin, he graduated in Physics and later in Mathematics.**
- **During his studies, he earned his living as a cinema pianist, accompanying silent films.**

Gleb Wataghin

- **In 1934, Professor Teodoro Ramos received the incumbency to invite eminent scientists in Europe to come to Brazil and participate in the construction and implementation of the Faculdade de Filosofia, Ciências e Letras of the recently founded University of São Paulo.**

- **Wataghin's name had been suggested by Enrico Fermi. Although many friends told him against it, he accepted the invitation and the challenge: he accepted the invitation and came to São Paulo to join other important personalities.**

Gleb Wataghin in São Paulo

- **Once in São Paulo, he started lecturing physics to engineers and physicists: many potential engineers changed to Physics, and many began to learn Italian because of his lectures!**

- **He introduced Modern Physics to his students (as he used to say, in his second “evangelization” mission, as Fermi named the job of introducing Quantum Mechanics into a new environment – the first one had been in Turin).**

Gleb Wataghin in São Paulo

- **He organized a group working in experimental physics, with the collaboration of his young assistants Marcello Damy e Paulus Aulus Pompéia to study interactions induced by cosmic-ray particles.**
- **The instrumentation and electronics developed by this group was competitive with those used in Europe and the USA, as were their research results.**
- **Wataghin had many acquaintances and friends in Europe and the USA and invited many of them to visit Brazil. Also, he sent many of his students abroad to increase their experience working with famous researchers.**

Arthur Compton visiting Brasil in 1940

Visit of the Nobel Prize winner 1927 Arthur Compton: in the first row, from right to left, Arthur Compton and Gleb Wataghin are the second and fourth, respectively.

The next generation

Bernhard Gross
1933

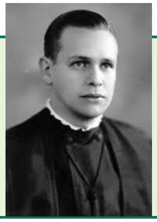
Gleb Wataghin
1934


Paulus Aulus Pompeia &
Marcello Damy
1939-1940

The next generation

Gross
1933

Wataghin
1934



Paulus Aulus Pompeia &
Marcello Damy
1939-1940

Cesare Lattes
1943-1949

Cesare Lattes

- **Lattes became Wataghin's assistant right after graduating in Physics at the University of São Paulo in 1943.**
- **In 1946, he went to Bristol joining the group of Cecil Powell investigating cosmic rays using nuclear emulsions exposed at mountain altitudes.**
- **These studies rendered a series of publications and finally, the award of the Nobel Prize in Physics of 1950 for Cecil Powell:**

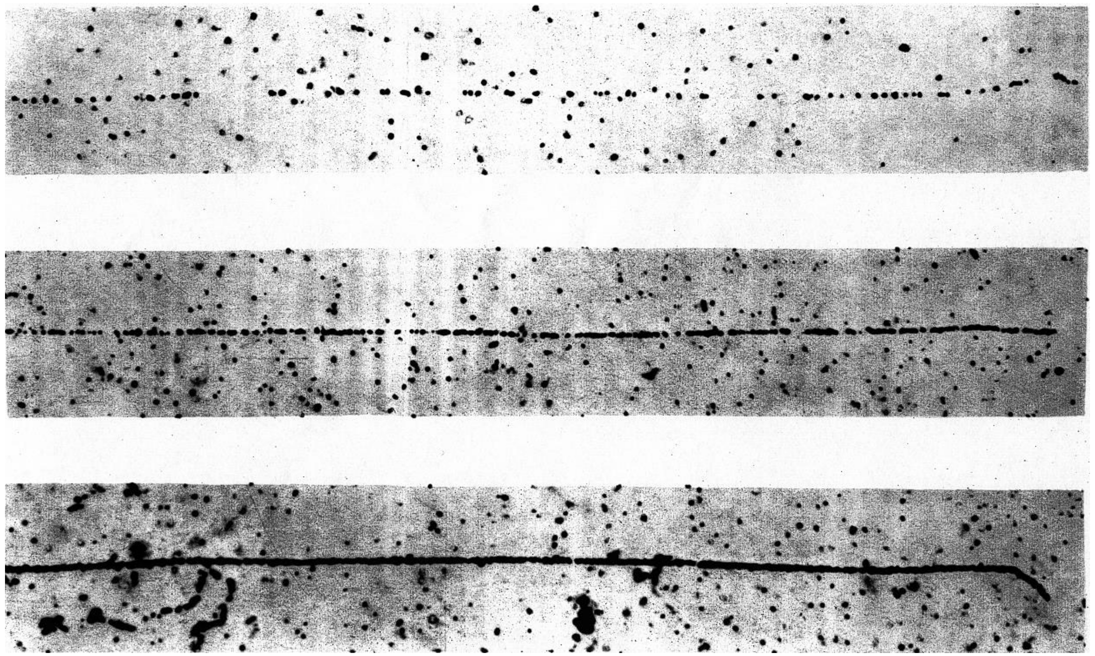
  - **C. M. G. Lattes, H. Muirhead, G. P. S. Occhialini and C.F. Powell, *Processes involving charged mesons*, Nature 159 (1947) 694-697.**
  - **C. M. G. Lattes and G. P. S. Occhialini, *Determination of the Energy and Momentum of Fast Neutrons in Cosmic Rays*, Nature 159 (1947) 331-332.**
  - **C. M. G. Lattes, G. P. S. Occhialini and C. F. Powell, *Observation on the Tracks of Slow Mesons in Photographic Emulsions*, Nature 160 (1947) 453-456.**
  - **C. M. G. Lattes, G. P. S. Occhialini and C. F. Powell, *Observation on the Tracks of Slow Mesons in Photographic Emulsions Part 2*, Nature 160 (1947) 486-492].**

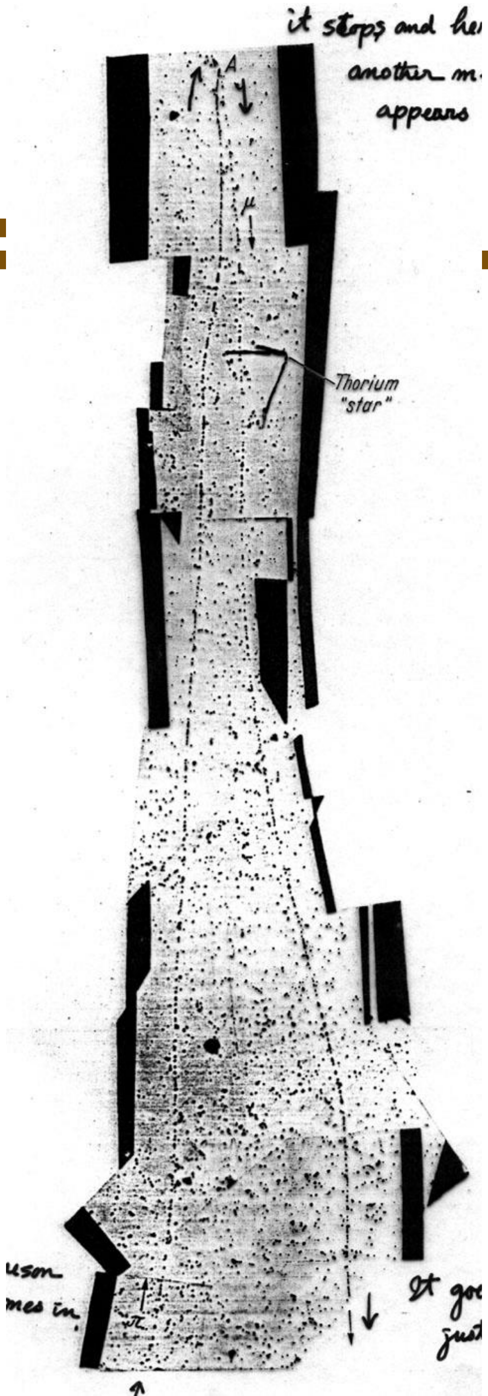
The Bristol group of Cecil Powell (at the left), with Lattes in the center.

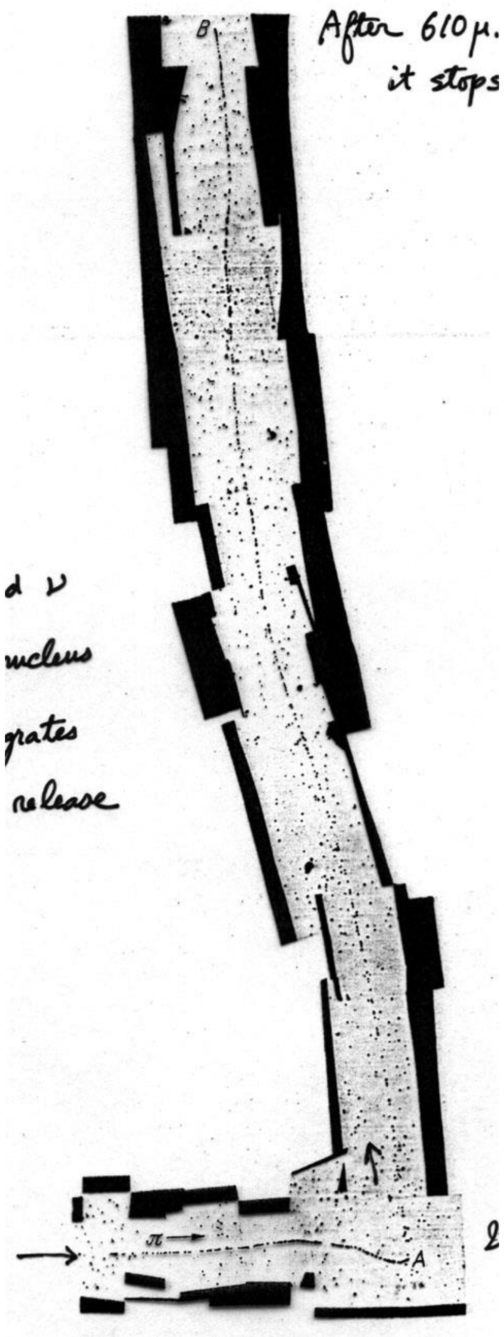
Cesare Lattes

Nuclear emulsions

- **Nuclear emulsions were explored mainly from 1935 on and improved after 1946. Lattes, Occhialini & Powell exposed some of them to cosmic rays at mountain altitudes and discovered the pions.**




A
appears
μ
Thorium "star"
π


B
After 610μ.
it stops
π
A

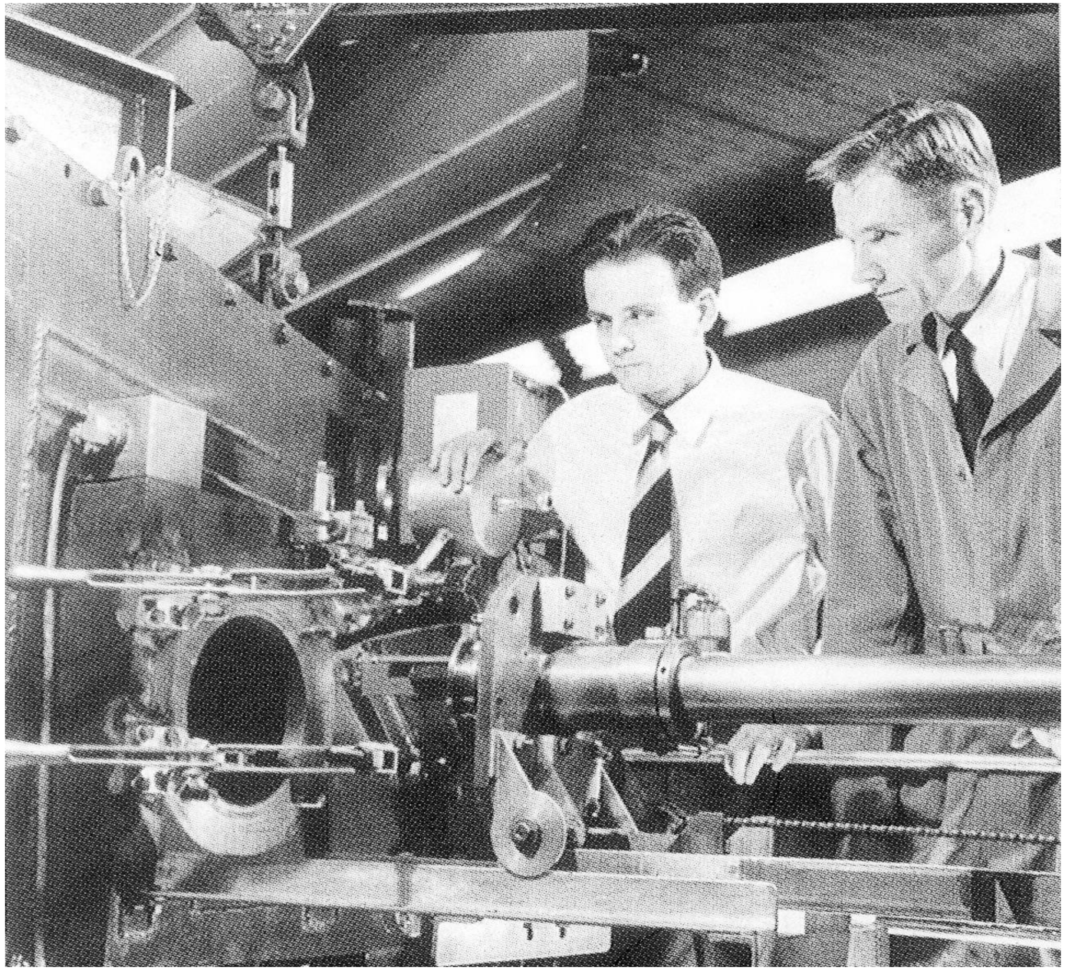
The discovery of the pions in 1947

The traces in emulsions exposed at high altitudes revealed successive decays of “mesotrons” pions → muons → → electrons.

Producing pions at accelerators

- **Lattes took some emulsions to the USA and exposed them at the cyclotron of 380 MeV (alpha particles colliding with a carbon target) (1948-1949).**

- **Cesar Lattes and Eugene Gardner showed that pions were being artificially produced at the Berkeley Lab.**

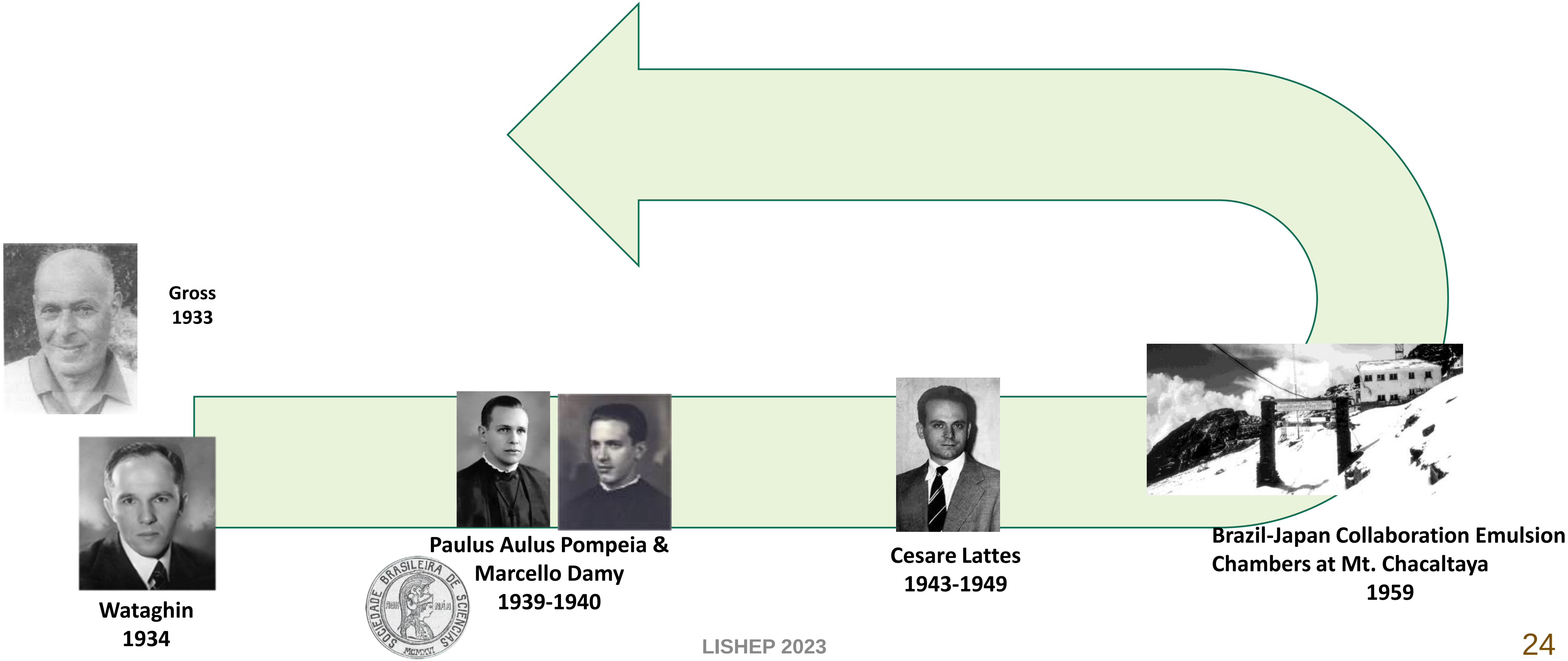


Gardner, E., Lattes, C. M. G. (1948). «*Production of mesons by the 184-inch Berkeley cyclotron*». *Science*. 107 (2776): 270–271.

In1949, ..

- Lattes also participated with Edwin McMillan at the first observation of pion photoproduction at the synchrotron accelerating electrons at 300 MeV at the University of California.
- Lattes immediately found dozens of pions in the emulsions exposed to the gamma rays of the accelerator.
- Unfortunately, this result was never published.

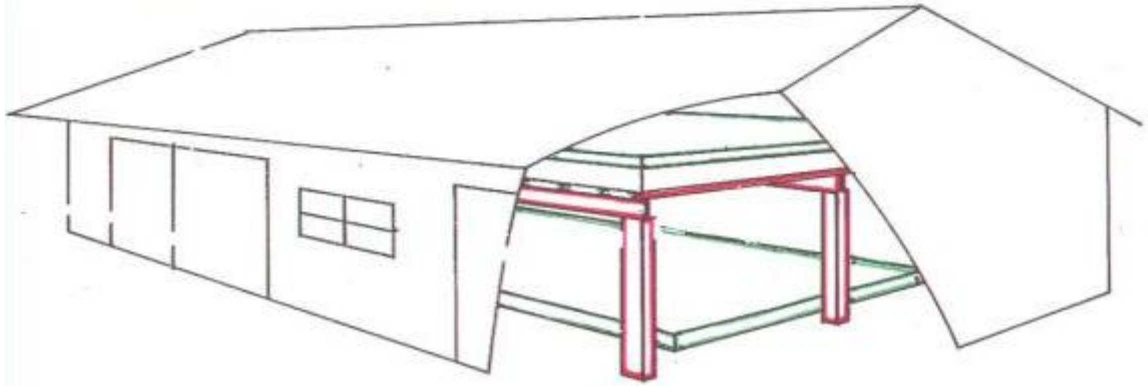
The first international collaboration



Brazil-Japan Collaboration

- At the end of the 1950s, Hideki Yukawa and Cesar Lattes were the leading authorities in pions in Japan and Brazil.
- In 1959, Yukawa wrote a letter to Lattes, reporting the activities of a group of young Japanese physicists at Mt Fuji related to cosmic rays and suggesting a collaboration with Brazilian physicists at Mt. Chacaltaya.
- The first emulsion chamber was exposed there in 1962, and twenty more in the following decades.
- Yoichi Fujimoto and Shun-ichi Hasegawa were the main forces behind the Japanese team.

The Laboratory of Cosmic Rays at Mt. Chacaltaya (Bolivia) at 5220 m a.s.l.



An emulsion chamber

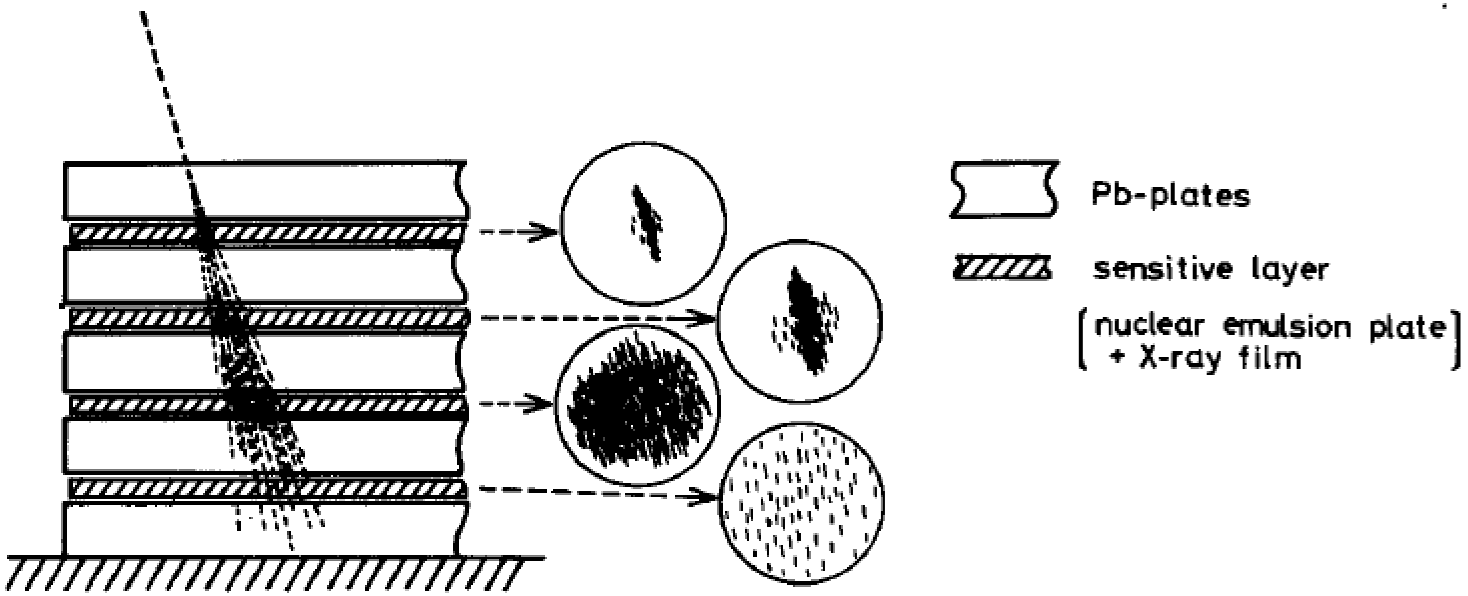
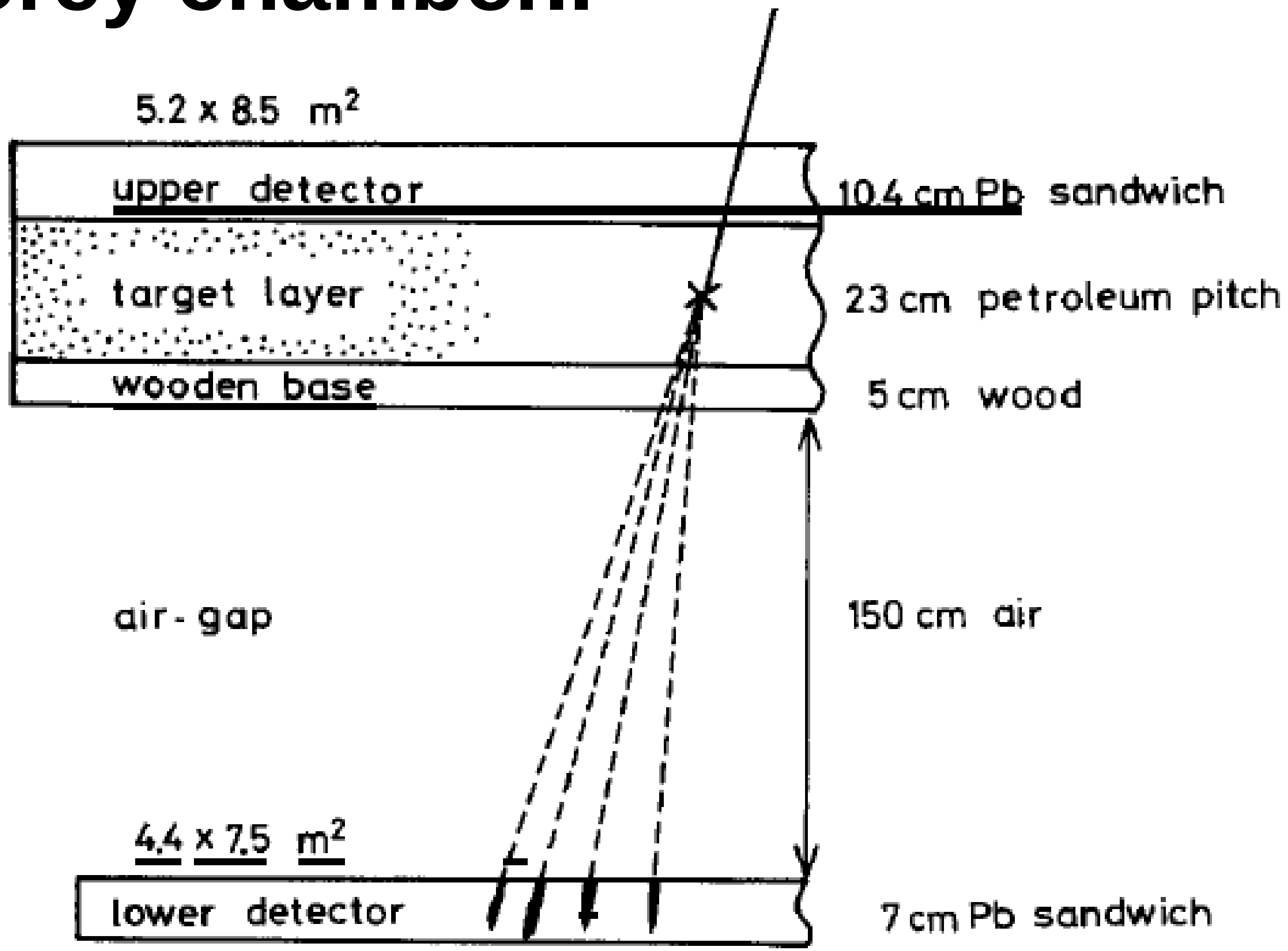


Fig. 1. Basic structure of emulsion chamber as electron shower detector.

An emulsion chamber...

A two-storey chamber..



Chacaltaya emulsion chamber of two-storey structure

The event Andromeda

This result and others are published in Physics Reports (Review Section of Physics Letters) 65, No. 3(1980) 151-229.

CÂMARA DE EMULSÕES

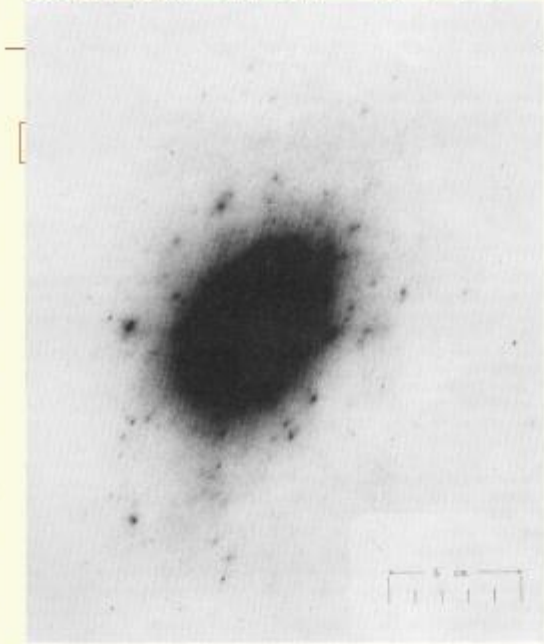


Fig. 54. The photograph shows the largest family "Andromeda" recorded under 11 radiation length of Pb in chamber No. 14. The chamber has thickness of 12 cm of Pb interleaved with 10 layers of X-ray films and nuclear emulsion plates. The family is visually composed of the following three parts. A. Halo with black nucleus at the center. The total energy is estimated as 20000 TeV after multiplying the critical energy of Pb, 7.4 MeV by the total track length, which is obtained by integration of the darkness in X-ray films. B. Very high energy gamma-rays and hadrons in the black nucleus. With microscopic observation one recognizes very high energy electron showers in a stream of numerous background shower tracks. The amount of energy carried by hadrons is estimated as approximately 20000 TeV, after the correction for the detection efficiency. One sees that the hadronic core is still in a very young state. C. Associated particles of (e, γ) and hadron component in the outer region. Outside a distance 2 cm from the family center, we recognize 322 particles of (e, γ) component carrying 833 TeV in total. The hadron component contains about 4700 TeV after the detection efficiency correction.

The first Centauro event

The event was found first during X-ray film scanning of the lower chamber for the C-jet study. In the X-ray film, there was a group of a few tens of shower spots clustering in a narrow region of diameter ~1 cm, with total visible energy well over one hundred TeV. In appearance, it was similar to a large air shower core in its earliest stage, composed of numerous high-energy (e, γ)'s, but its arrival direction showed that, geometrically, it must have penetrated through both the target layer and upper detector containing 7.8 cm of Pb. These facts were mutually contradicting.

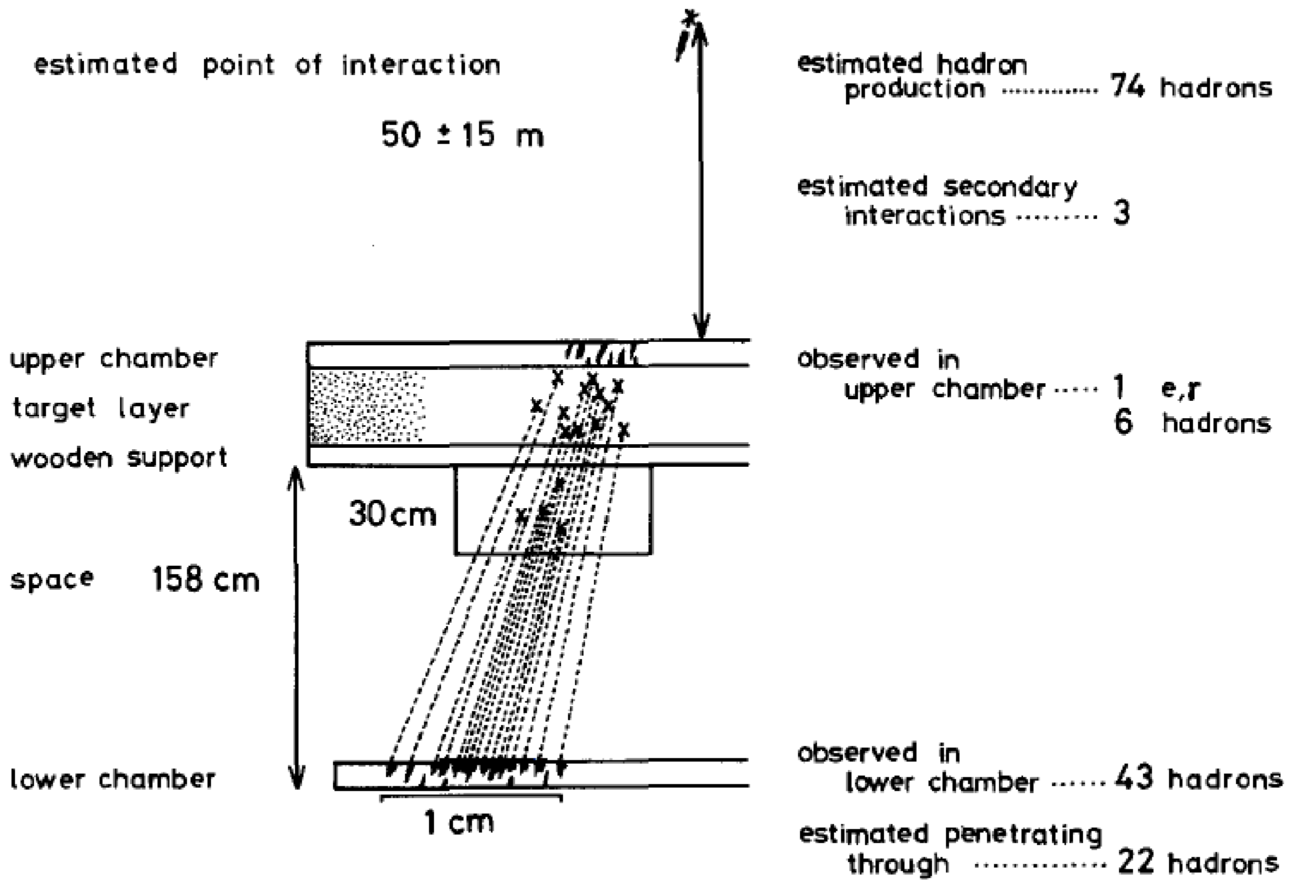


Fig. 38. Illustration of Centauro I.

New century, new collaborations

PIERRE AUGER OBSERVATORY
1999 -

Gross
1933

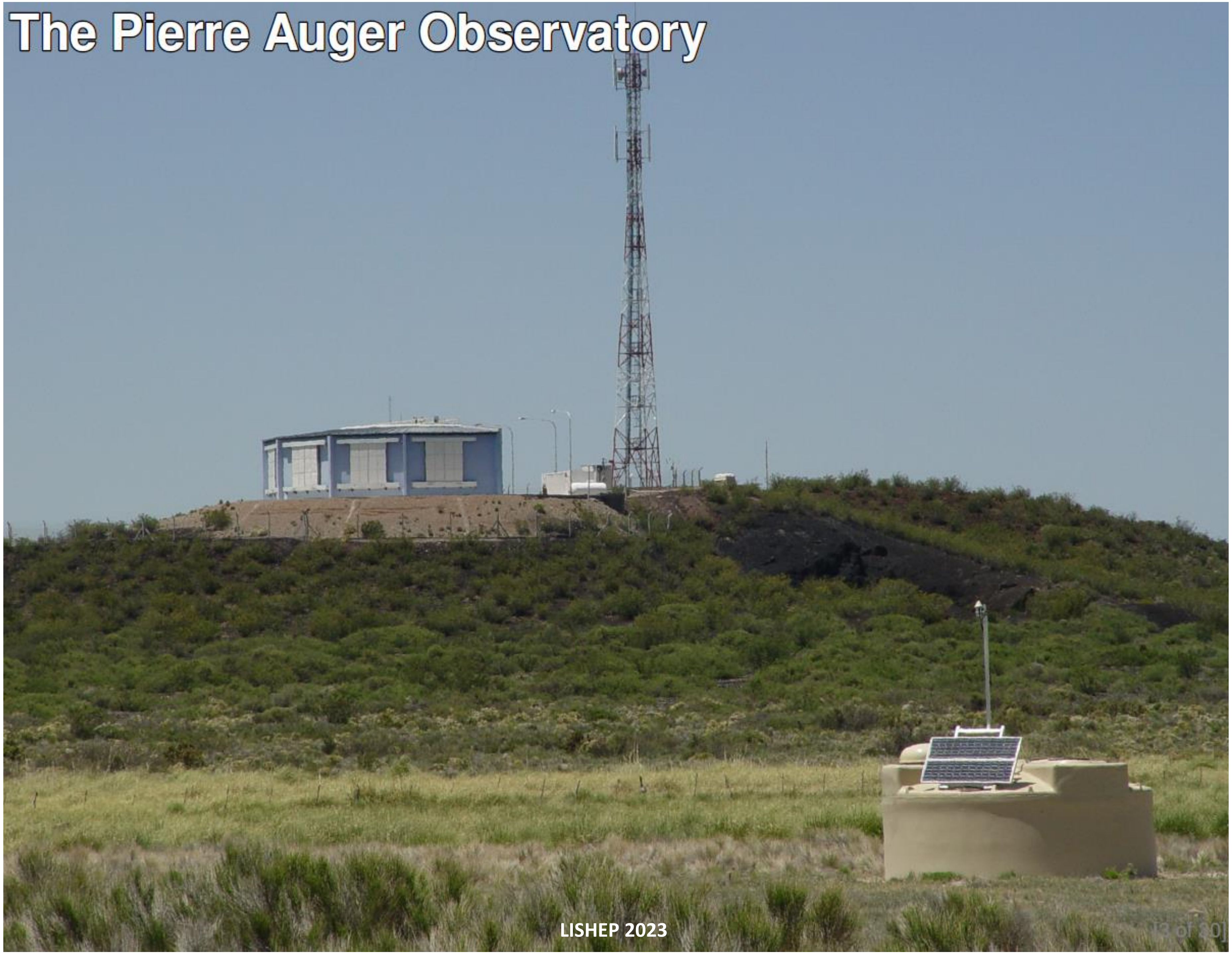
Wataghin
1934

Paulus Aulus Pompeia &
Marcello Damy
1939-1940

Cesare Lattes
1943-1949

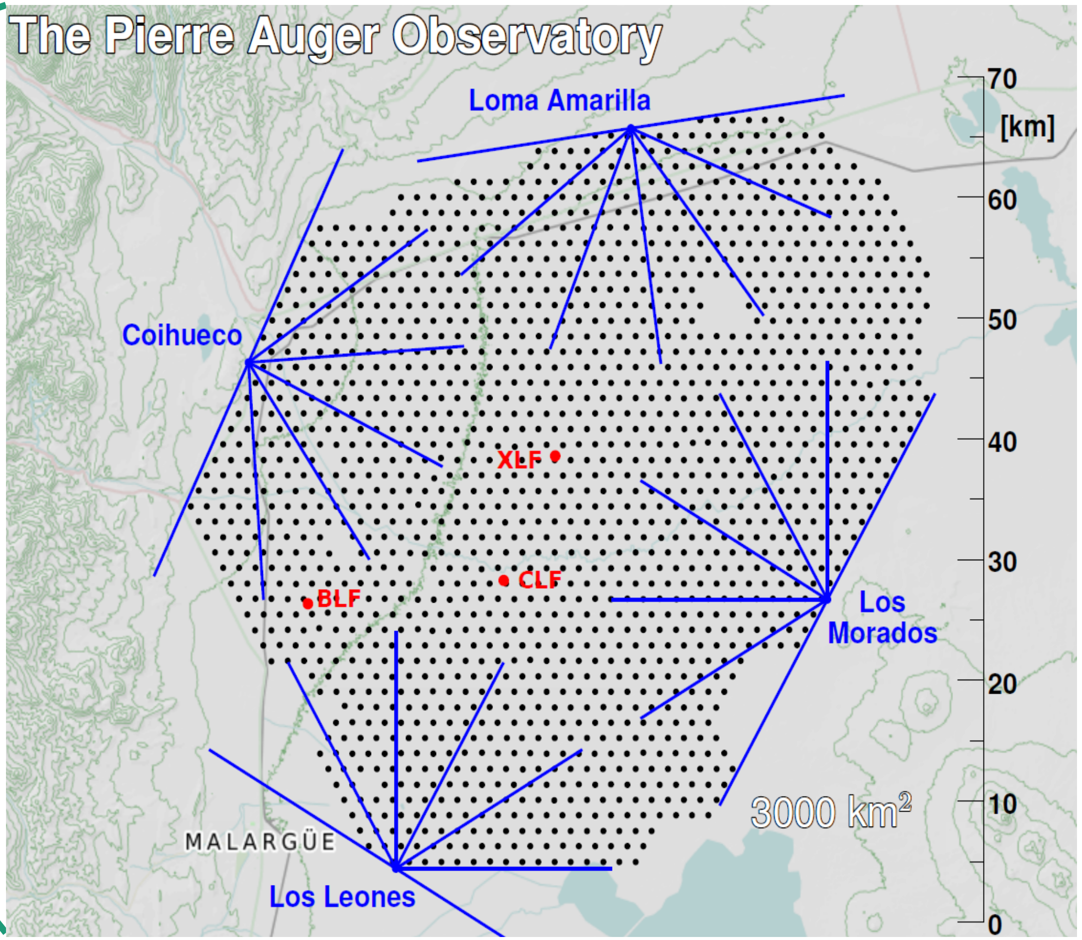
Brazil-Japan Collaboration Emulsion Chambers at Mt. Chacaltaya
1959

PIERRE
AUGER
OBSERVATORY



The Pierre Auger Collaboration

The Pierre Auger Observatory

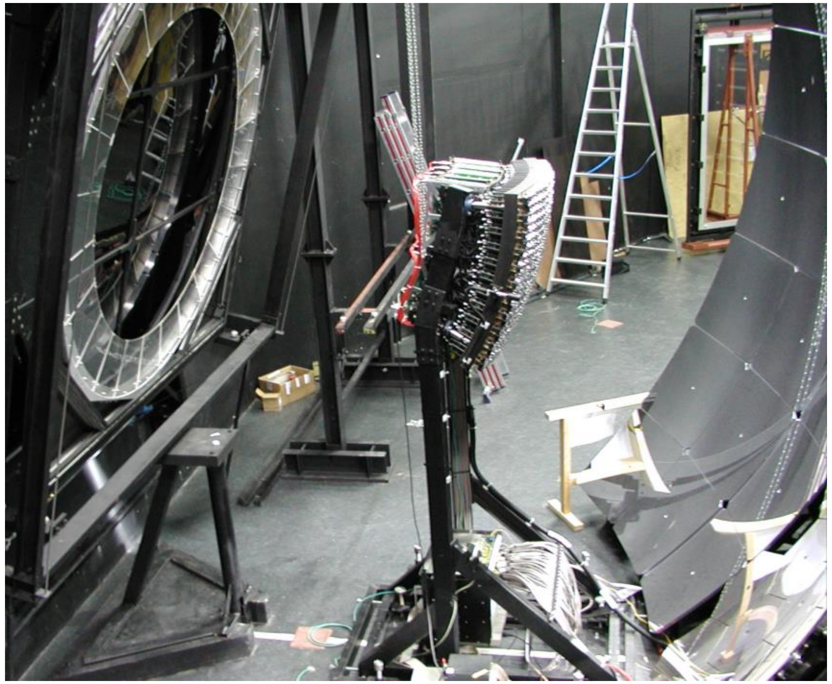


- Area: 3000 km^2 (4×Berlin, 3×Rome, 2×São Paulo)
- Taking data since 01.01.2004

The Pierre Auger Observatory

1600 water-Cherenkov stations (1500 m)
60 water-Cherenkov stations (750 m)
~ 100% duty cycle

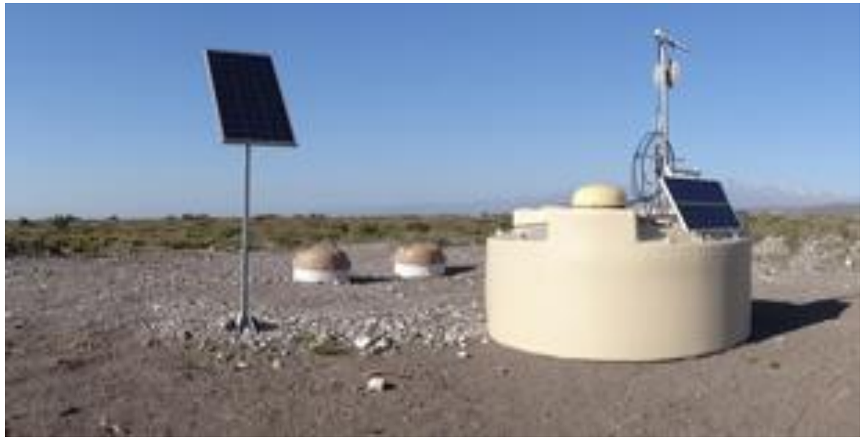
Four sites housing fluorescence telescopes



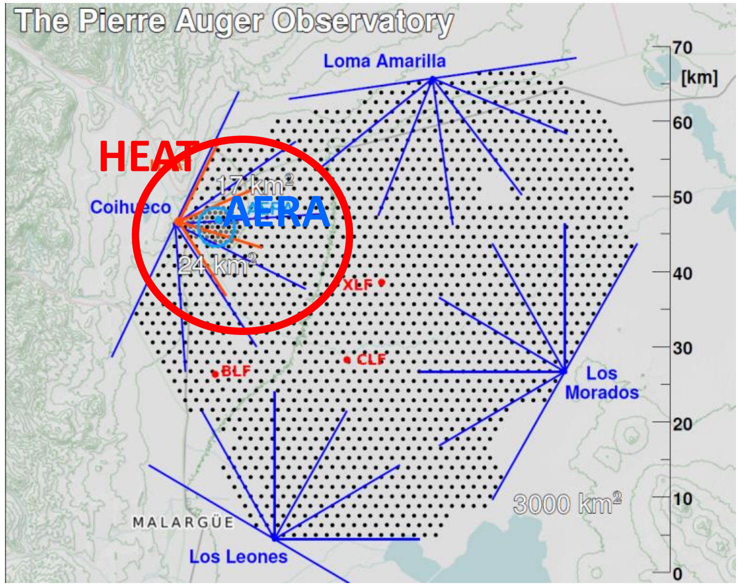
24 Schmidt telescopes, ~13-15% duty cycle

HEAT

AERA

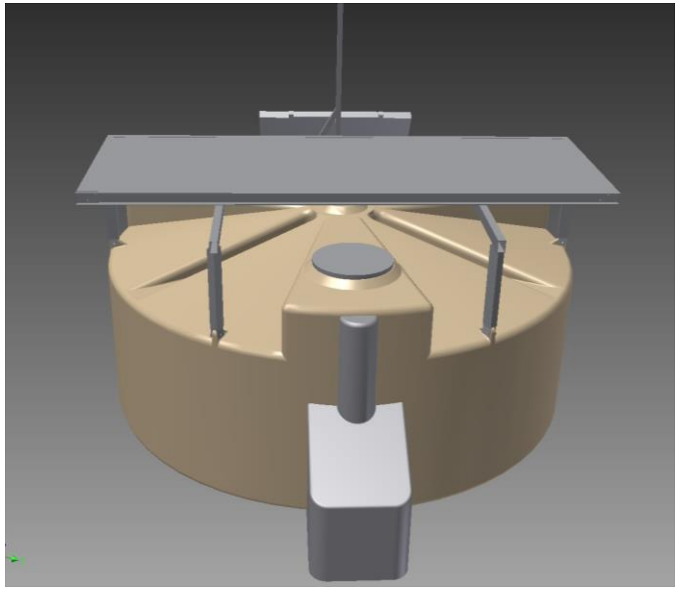


AMIGA

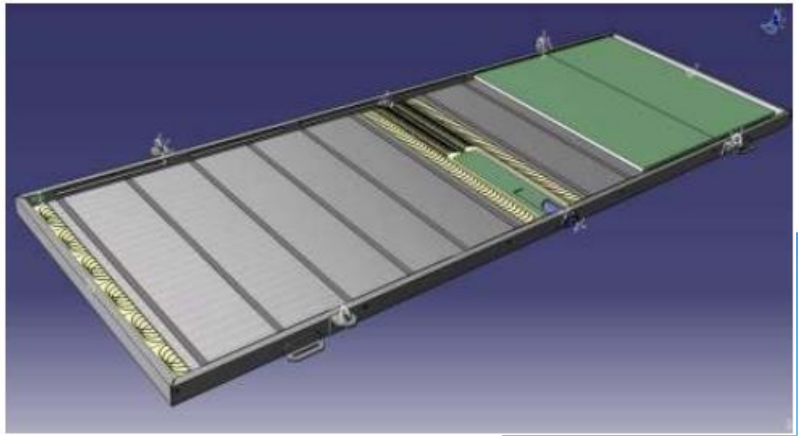


Now undergoing an upgrade: AugerPrime

- Adding scintillators on top of the water-Cherenkov detectors,
- Adding a small PMT in each water-Cherenkov detector, improving the reconstruction of the most energetic showers when normal PMTs saturate,
- Updating the DAQ electronics,
- Adding underground muon detectors,
- Extending the period of FD operation to periods of brighter night-sky background.



Prototypes already working



Highlights from Auger

- Target search for neutron sources
- Target search for gamma-ray sources
- Upper limits on neutrino flux
- Neutrino coincidence with gravitational waves
- Hadronic interaction tests
- Radio signal from air-showers
- Atmospheric science
- Upper limits for magnetic monopoles
- Exotic scenarios ruled out
- Unexpected mass composition

https://www.auger.org/index.php/science/journal-articles

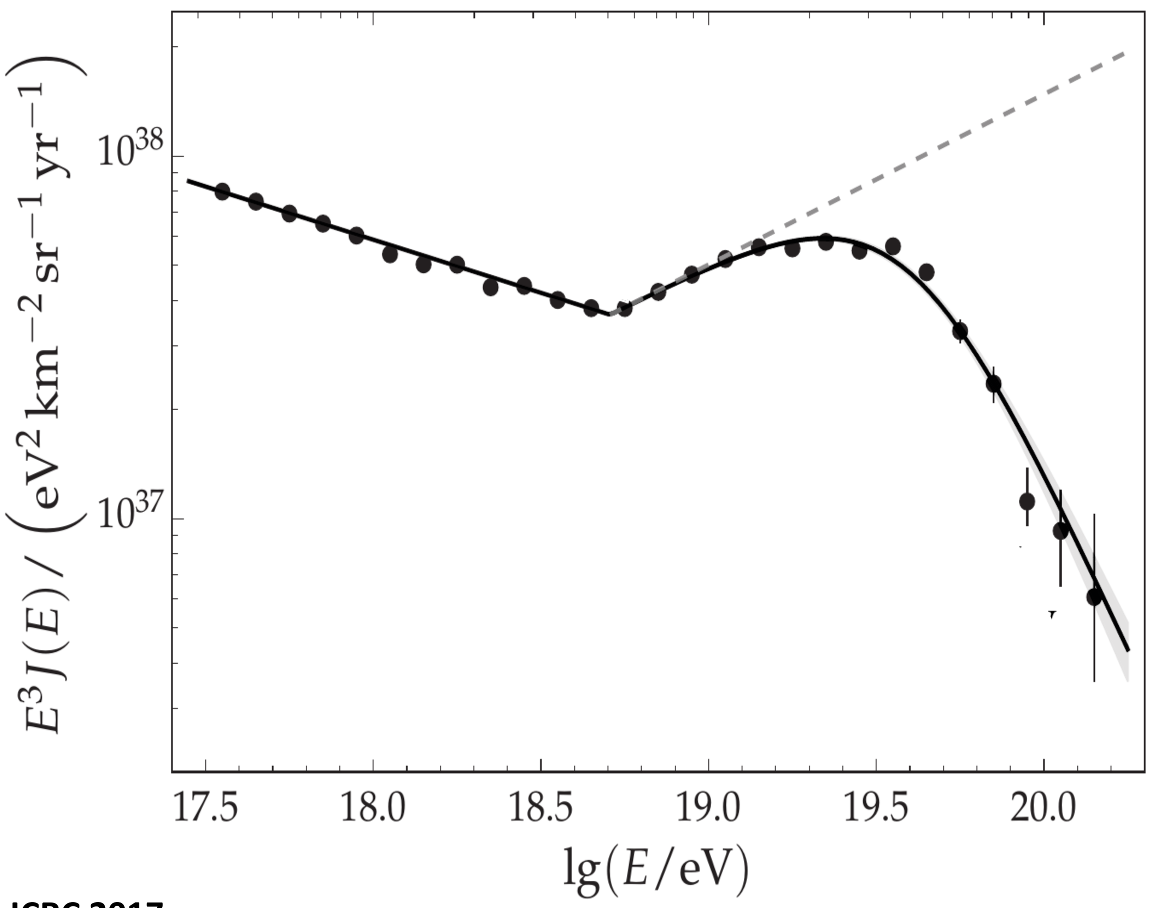
Thanks to
Vitor de Souza

Highlights from Auger
mentioned in this talk

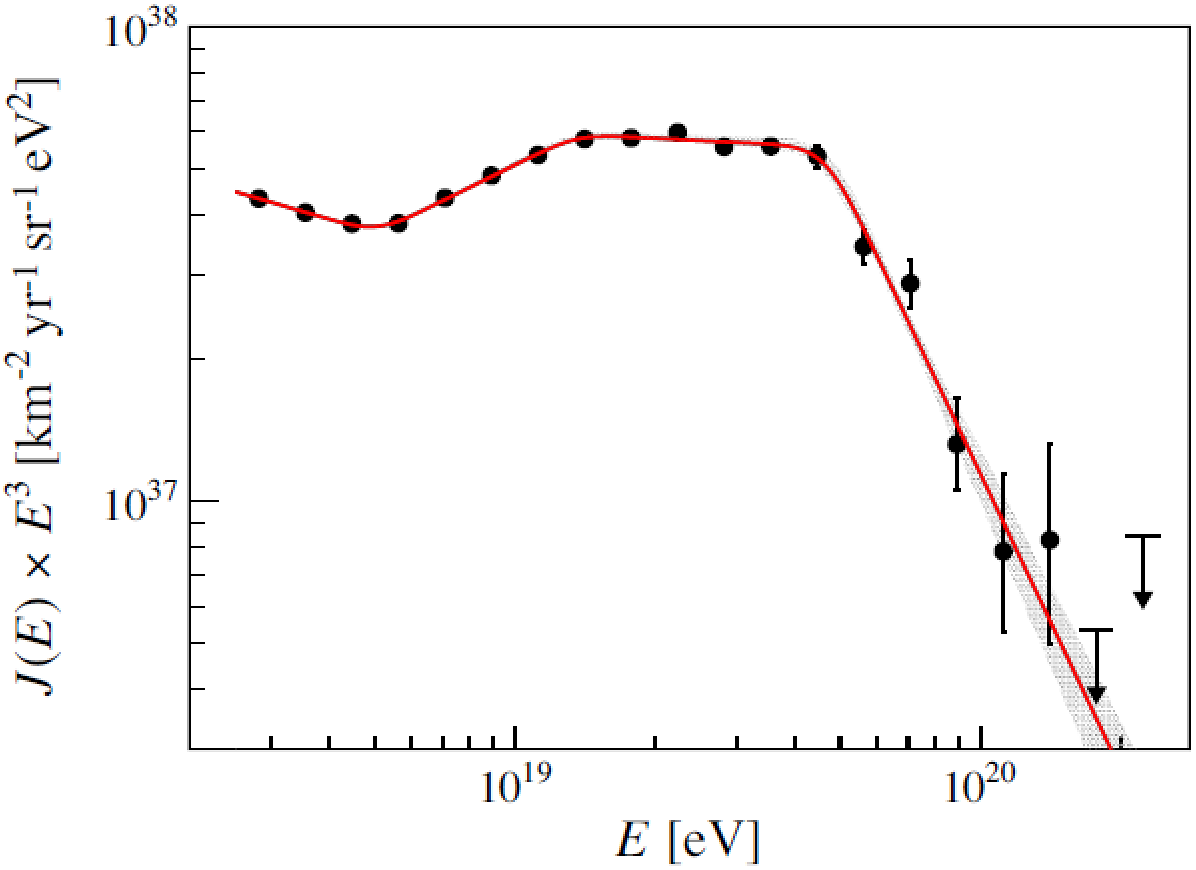
1. Energy spectrum and Flux supression
2. Proton-air cross section @ $\sqrt{s} = \mathbf{57\ TeV}$
3. Air showers with muons excess
4. Challenging level of isotropy with a dipole

Thanks to
Vitor de Souza

The energy spectrum

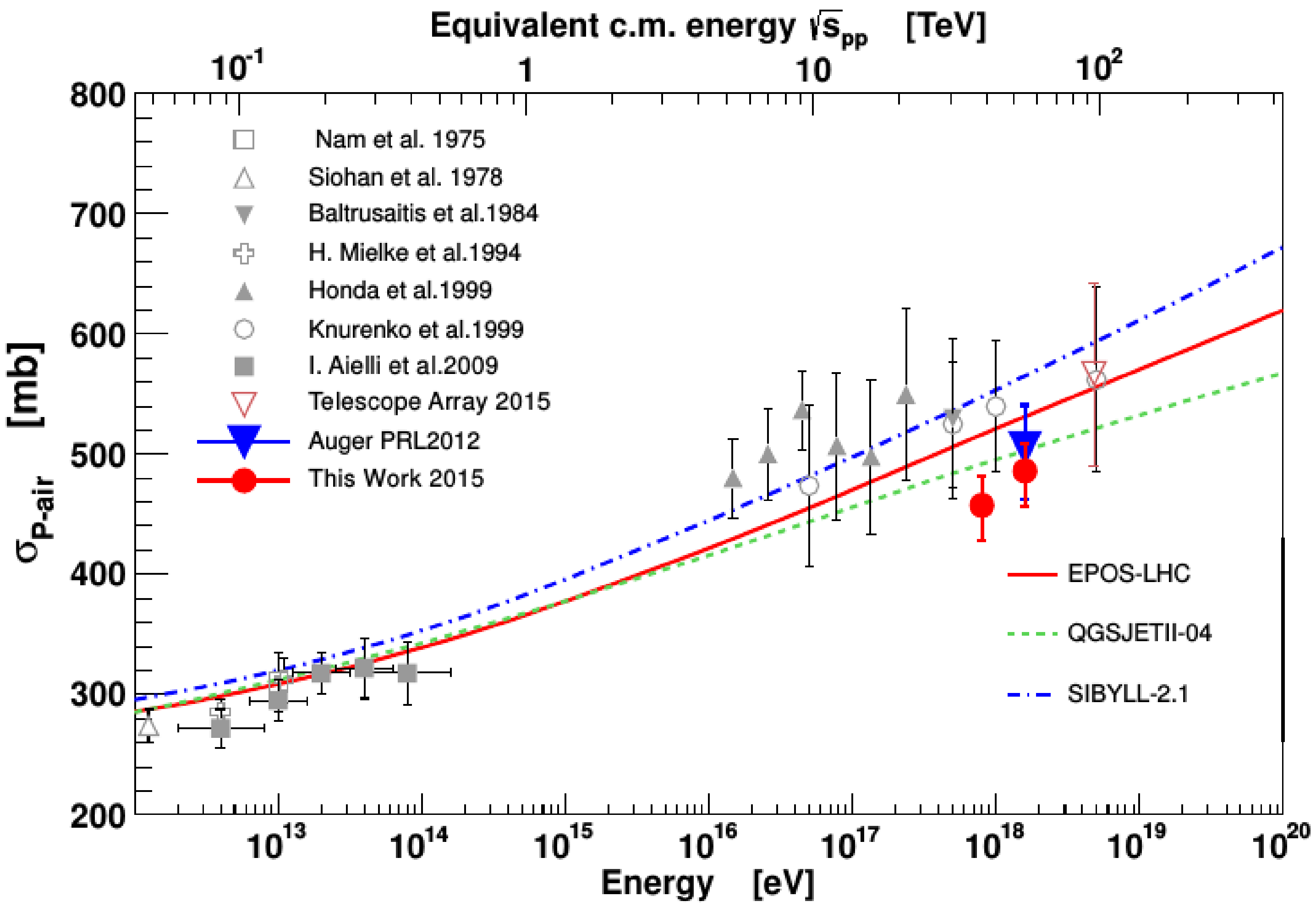


ICRC 2017



Phys. Rev. D 102 (2020) 062005

Proton-air cross section @ $\sqrt{s} = 57\ \mathrm{TeV}$

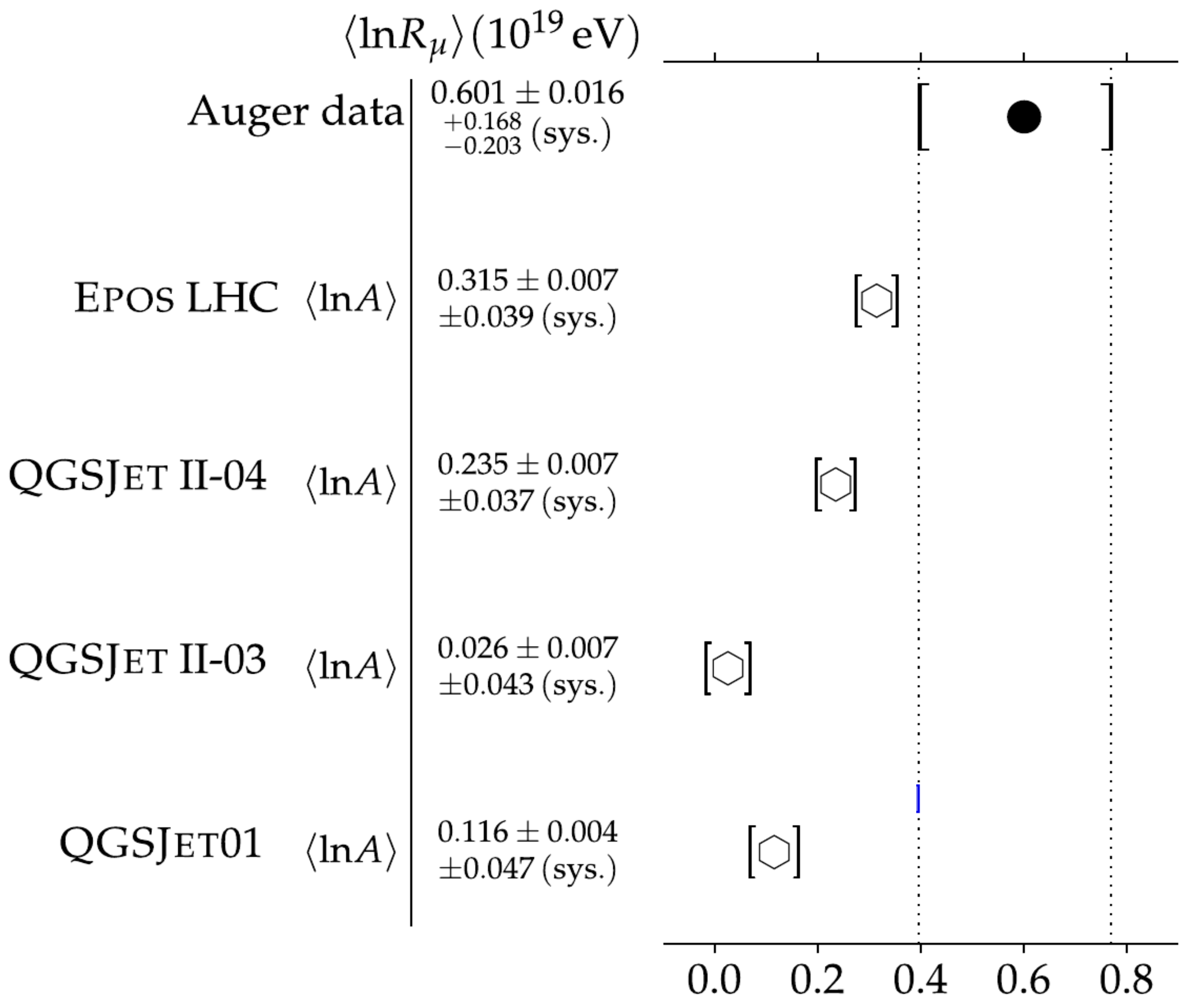


Phys. Rev. Lett. 109, 062002 (2012)

ICRC 2015

Highlights from Auger

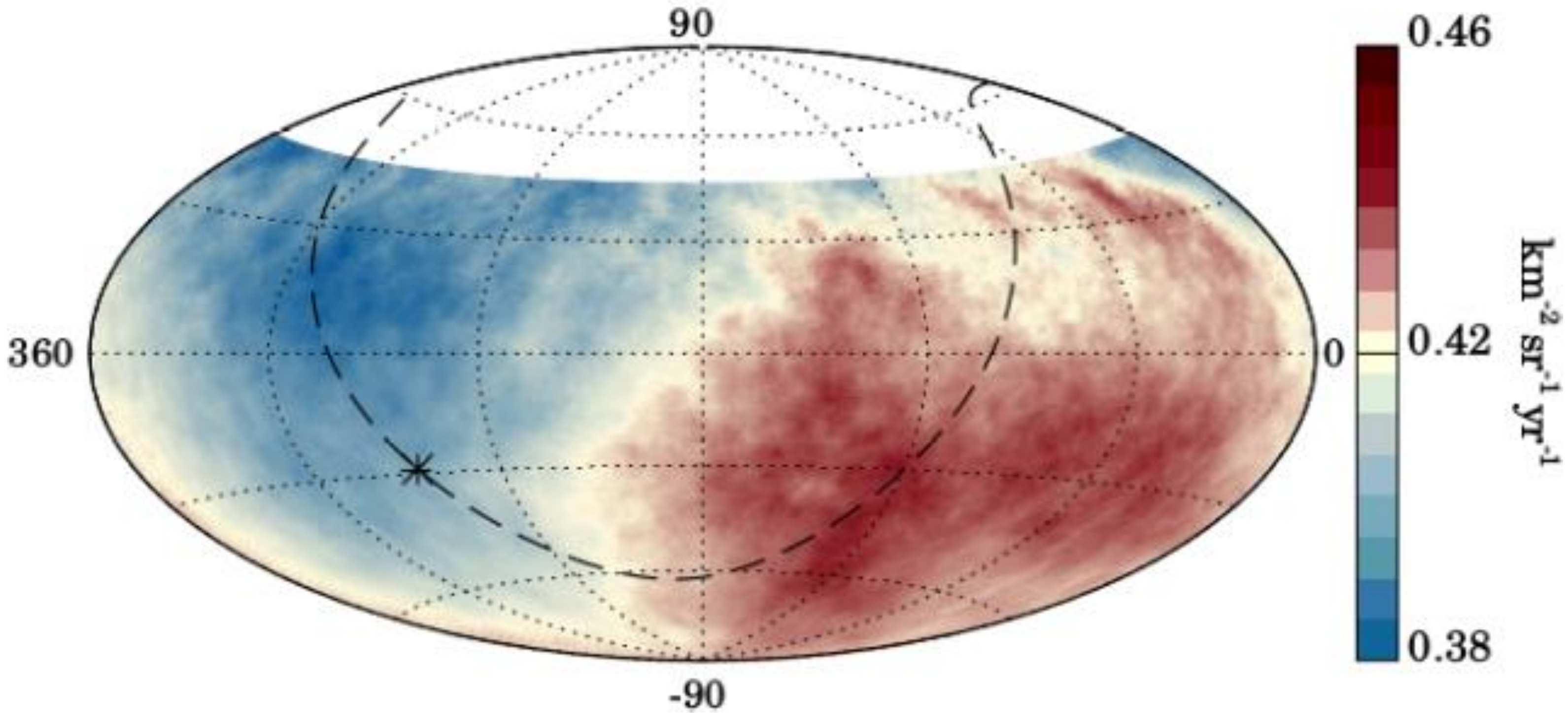
3/4 Air showers with muon excess



Physical Review D 91, 032003 (2015)

Thanks to Vitor de Souza

4/4 Challenging level of isotropy with a dipole

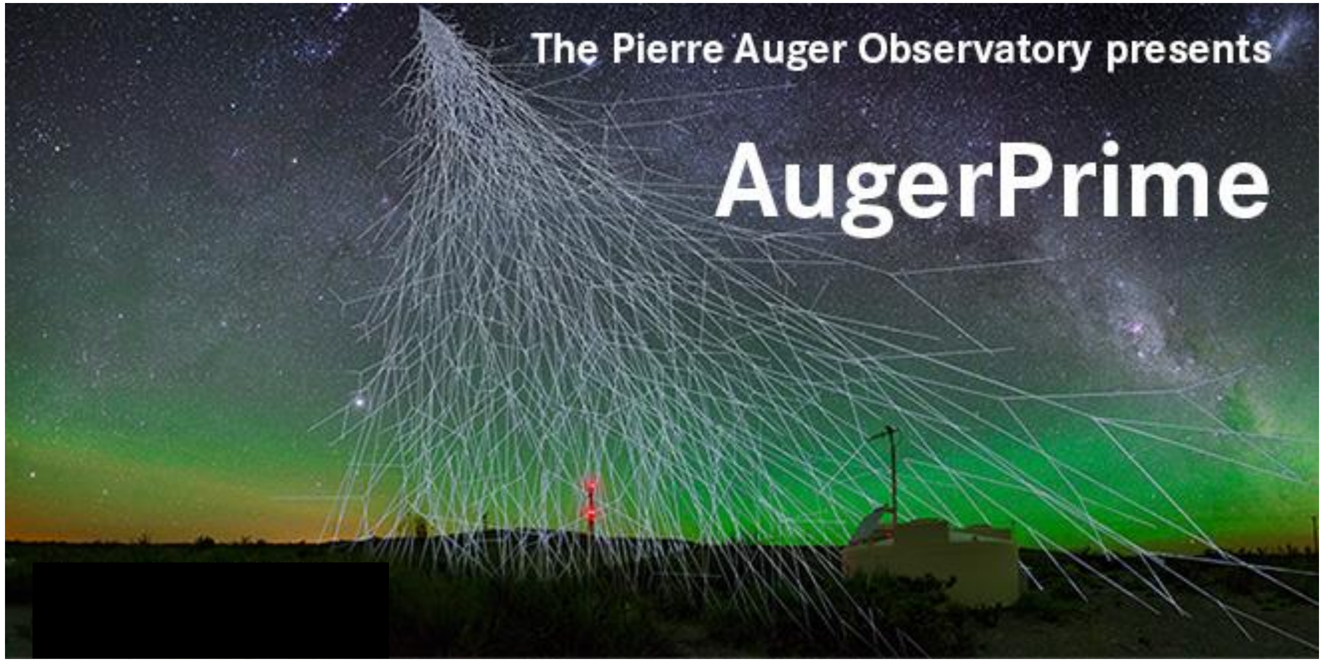


Equatorial coordinates - Hammer projection - E > 8 EeV

* Galactic center

- - - Galactic plane

The Pierre Auger Collaboration, SCIENCE 357 (2017) 1266



New muon detectors:

- select 10% of pure proton showers
- composition $E > 10^{19}$ eV
- muon excess: particle physics

The future

cherenkov telescope array

Under construction

PIERRE AUGER OBSERVATORY

1999 -

The Southern Wide-field Gamma-ray Observatory

Project

Gross
1933

Wataghin
1934

Paulus Aulus Pompeia &
Marcello Damy
1939-1940

Cesare Lattes
1943-1949

Brazil-Japan Collaboration Emulsion
Chambers at Mt. Chacaltaya
1959

Gamma-ray astronomy

Status summary of the field

Thanks, Ulisses Barres

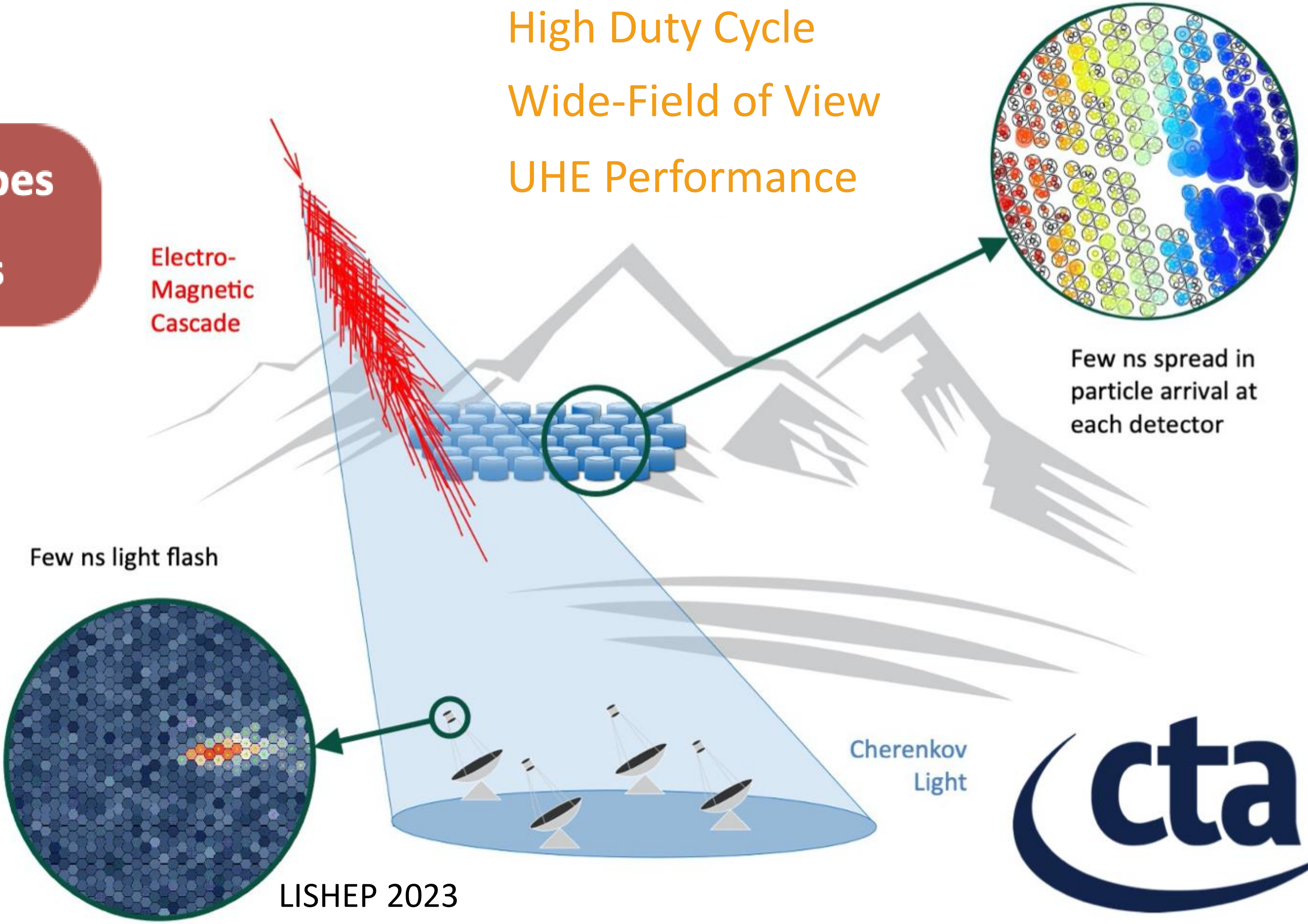
Two techniques:

1. **Air-Cherenkov telescopes**
2. **Altitude particle arrays**

High Duty Cycle

Wide-Field of View

UHE Performance



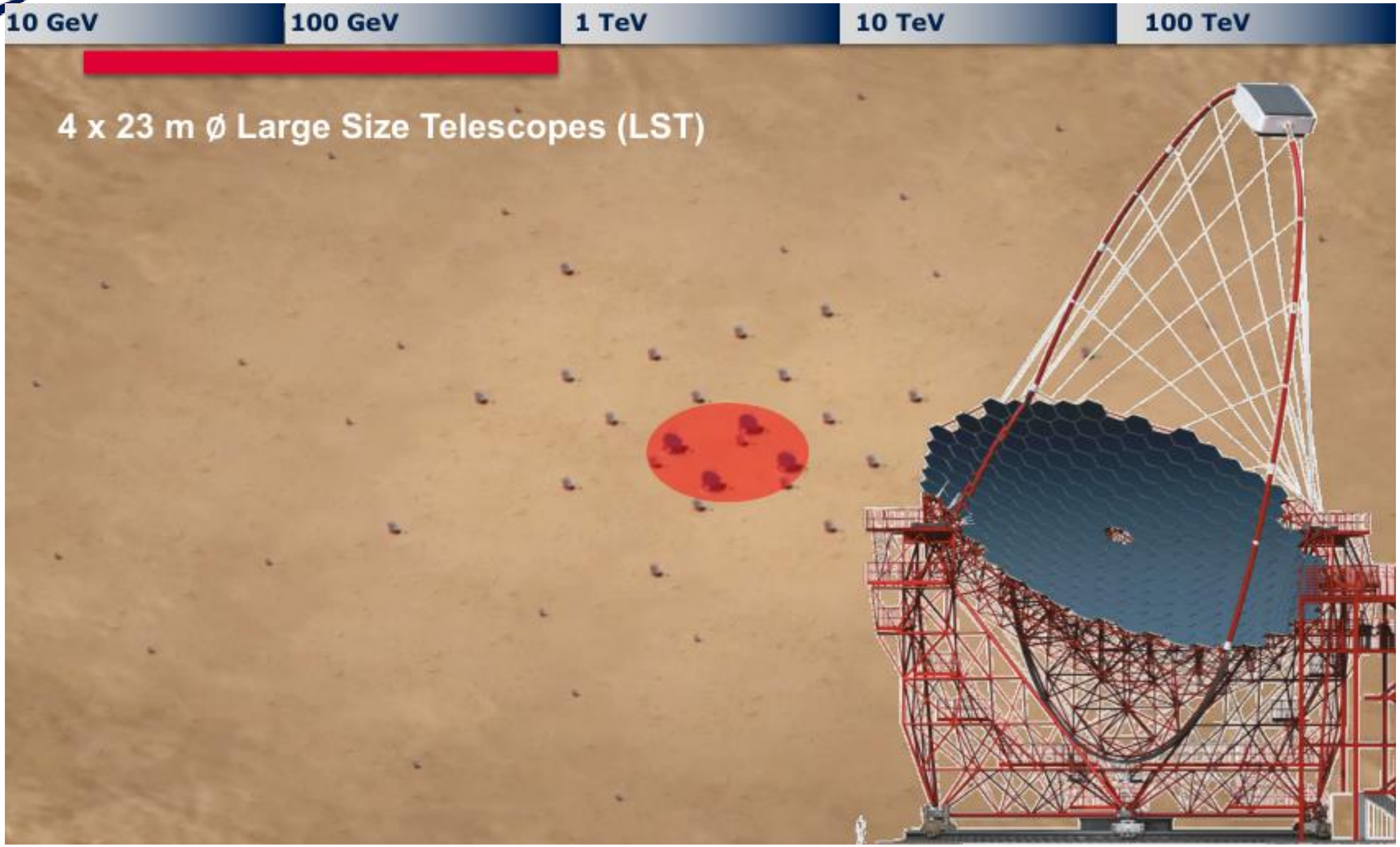
Low Duty Cycle

Pointing instruments

Precision Astronomy at VHE

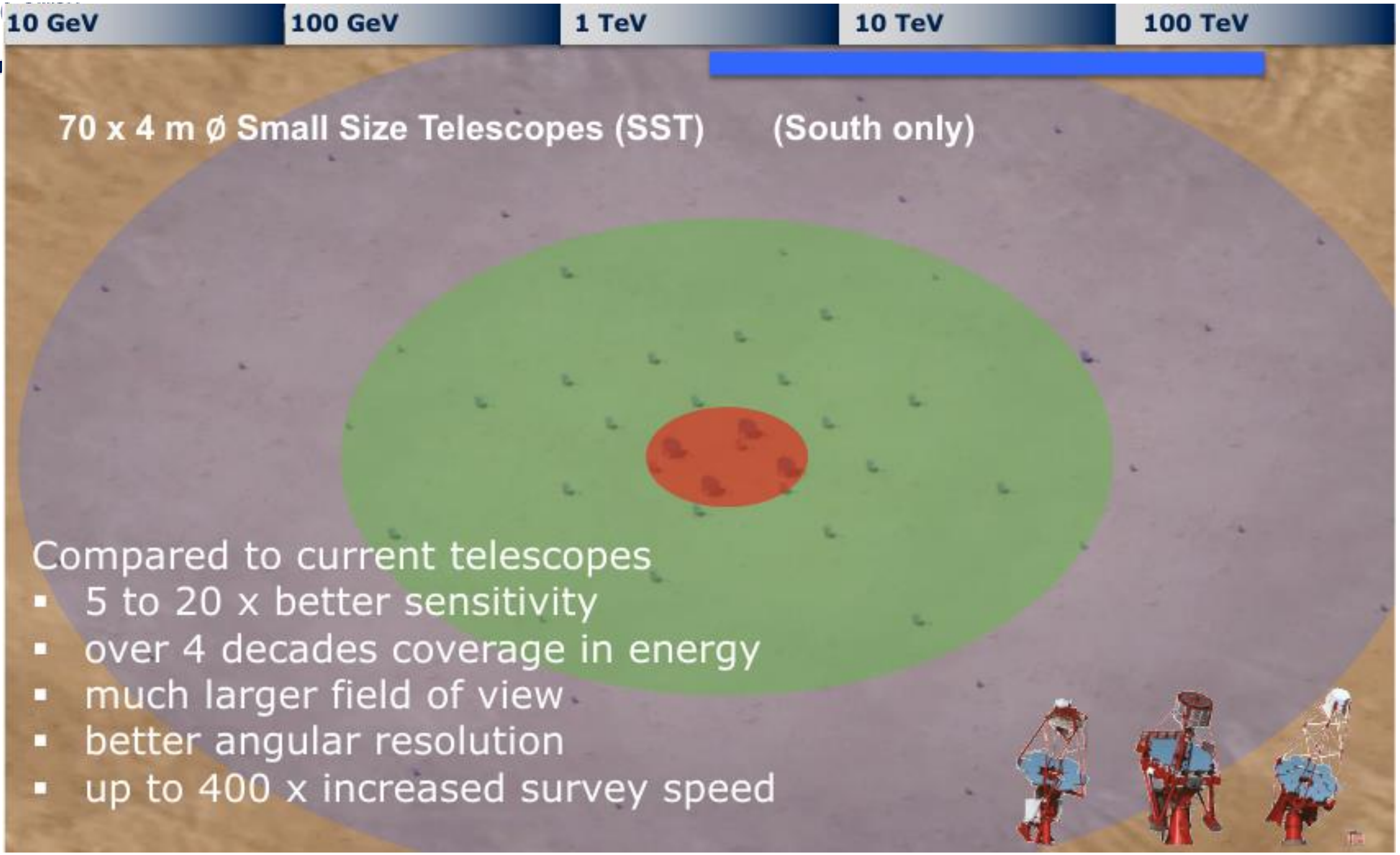
CTA

- **The Cherenkov Telescope Array is a multinational, worldwide project to build a new generation of ground-based gamma-ray instrument in the energy range extending from some tens of GeV to about 300 TeV.**



Slide by Werner Hofmann

Slide by Werner Hofmann



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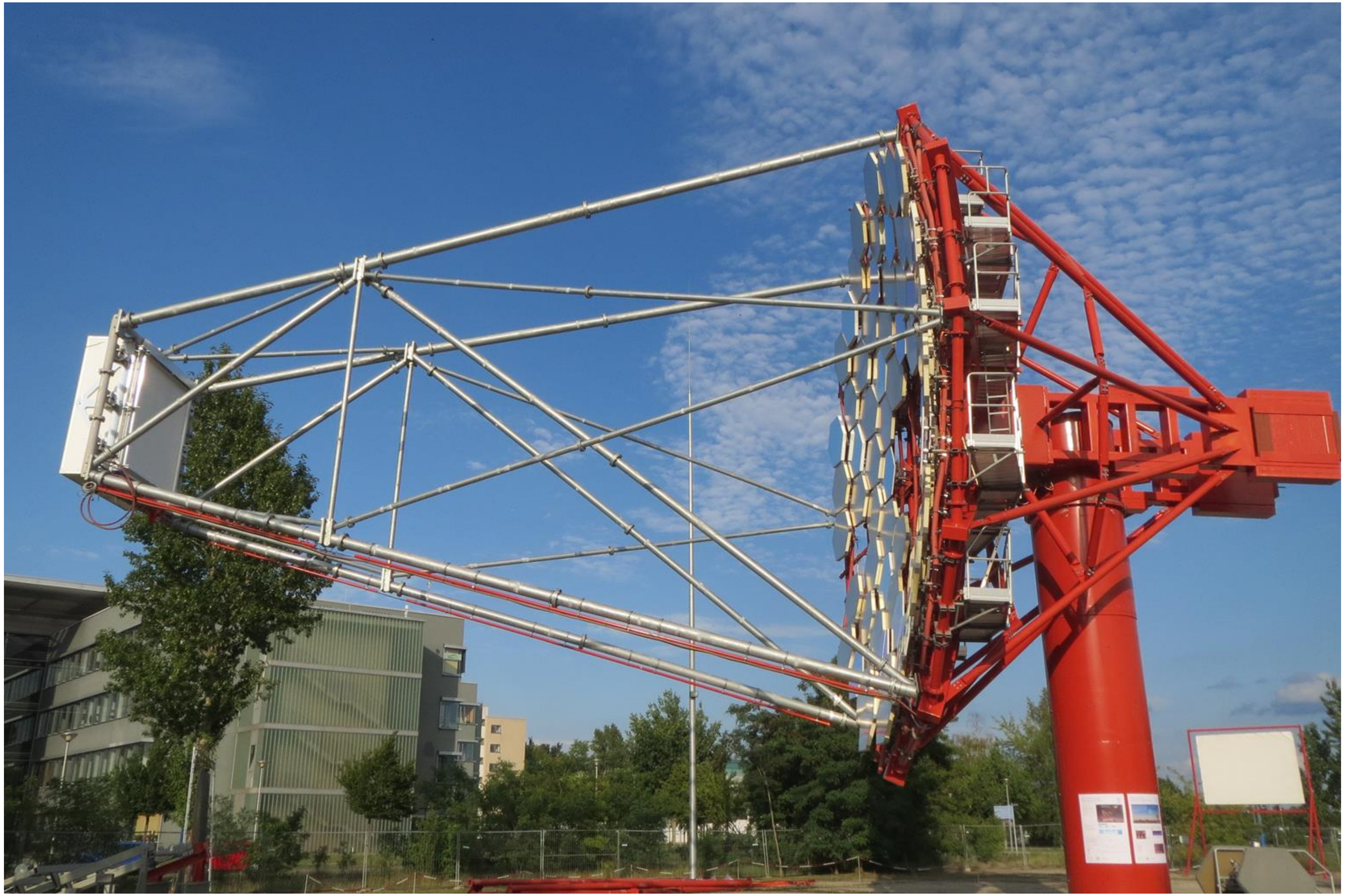
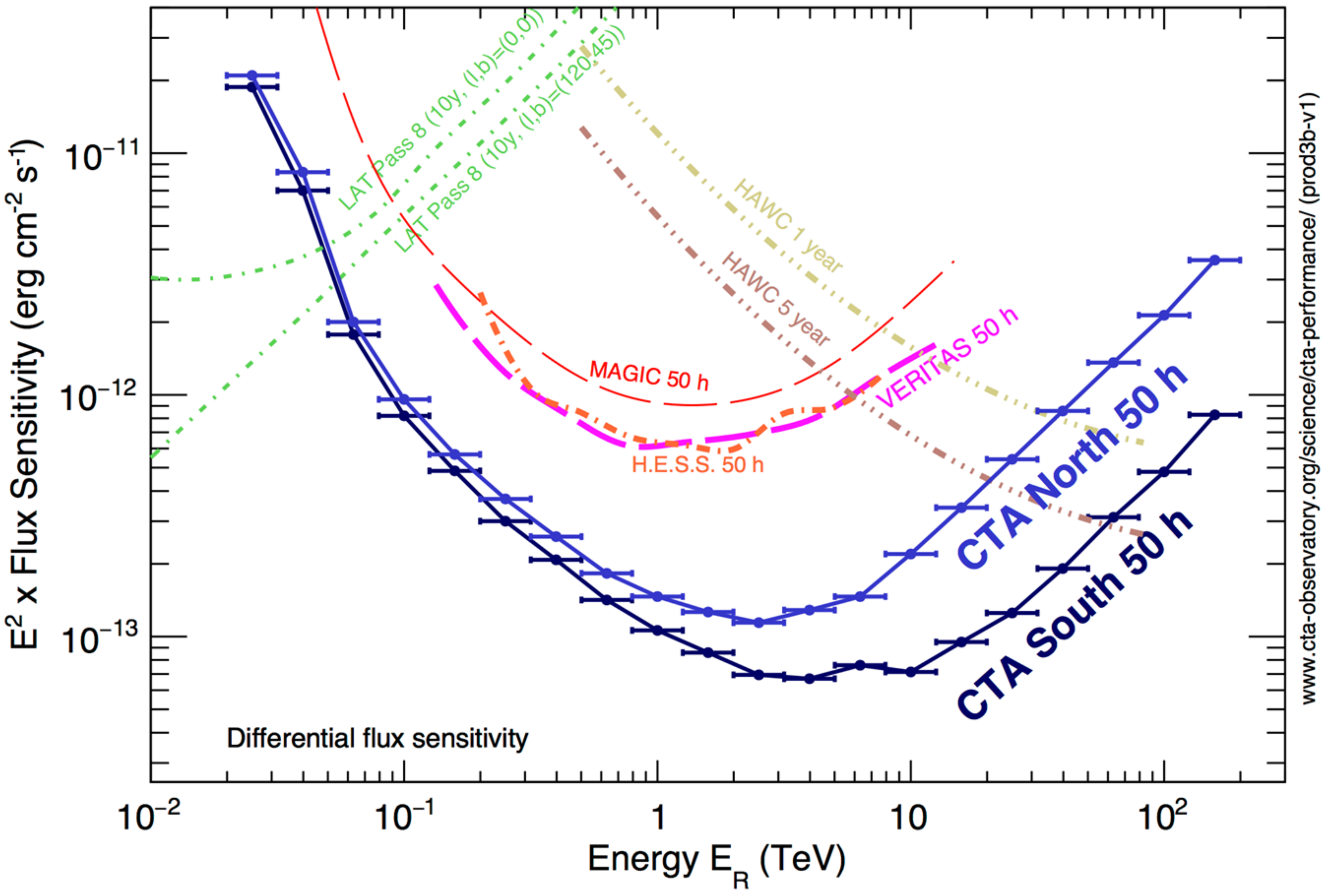


Thanks, Vitor de Souza

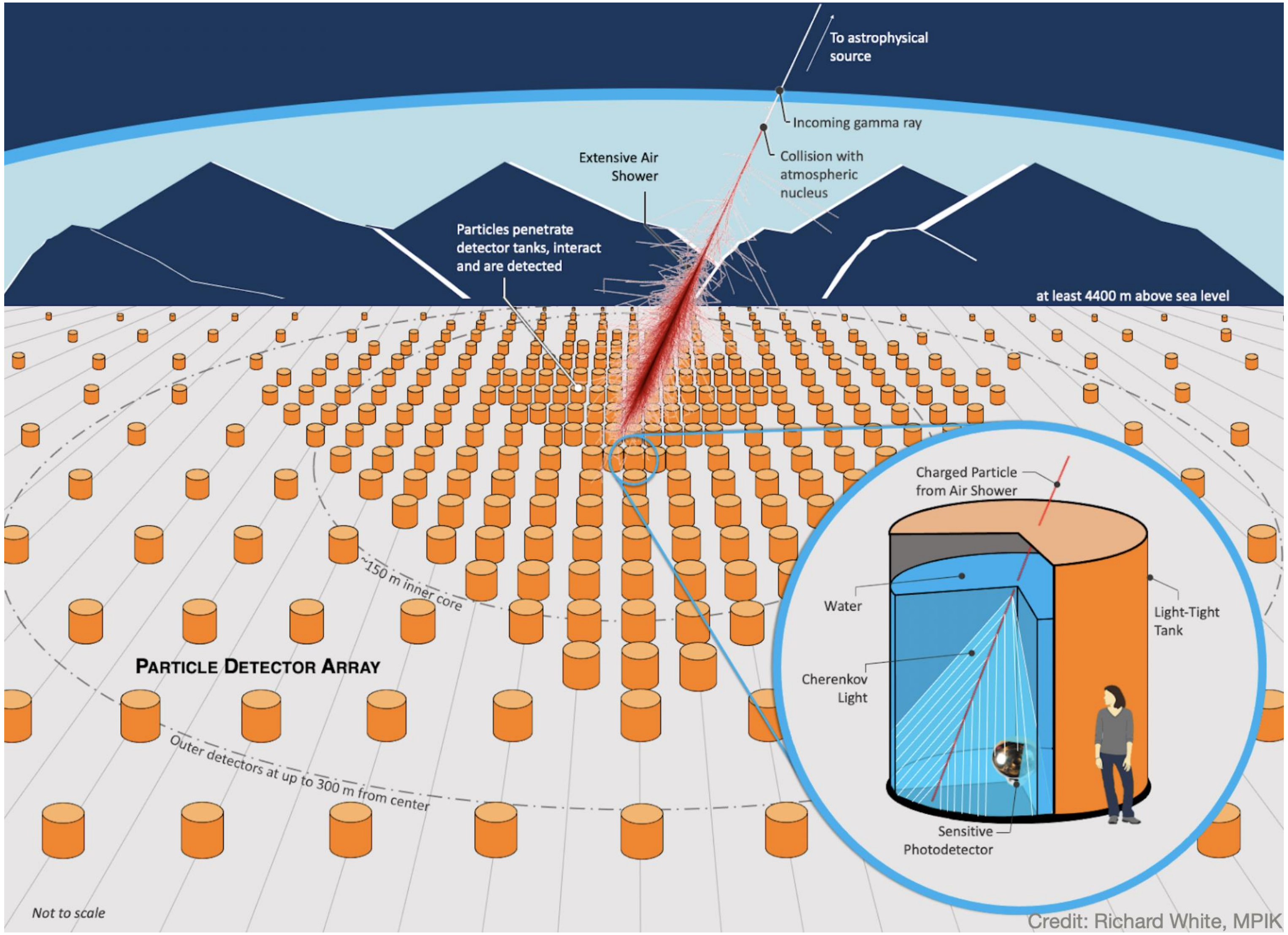


E^2 x Flux Sensitivity (erg cm^{-2} s^{-1})
Energy E$_R$ (TeV)
LAT Pass 8 (10y, (l,b)=(0,0))
LAT Pass 8 (10y, (l,b)=(120,45))
HAWC 1 year
HAWC 5 year
MAGIC 50 h
VERITAS 50 h
H.E.S.S. 50 h
CTA North 50 h
CTA South 50 h
Differential flux sensitivity
www.cta-observatory.org/science/cta-performance/ (prod3b-v1)

SWGO

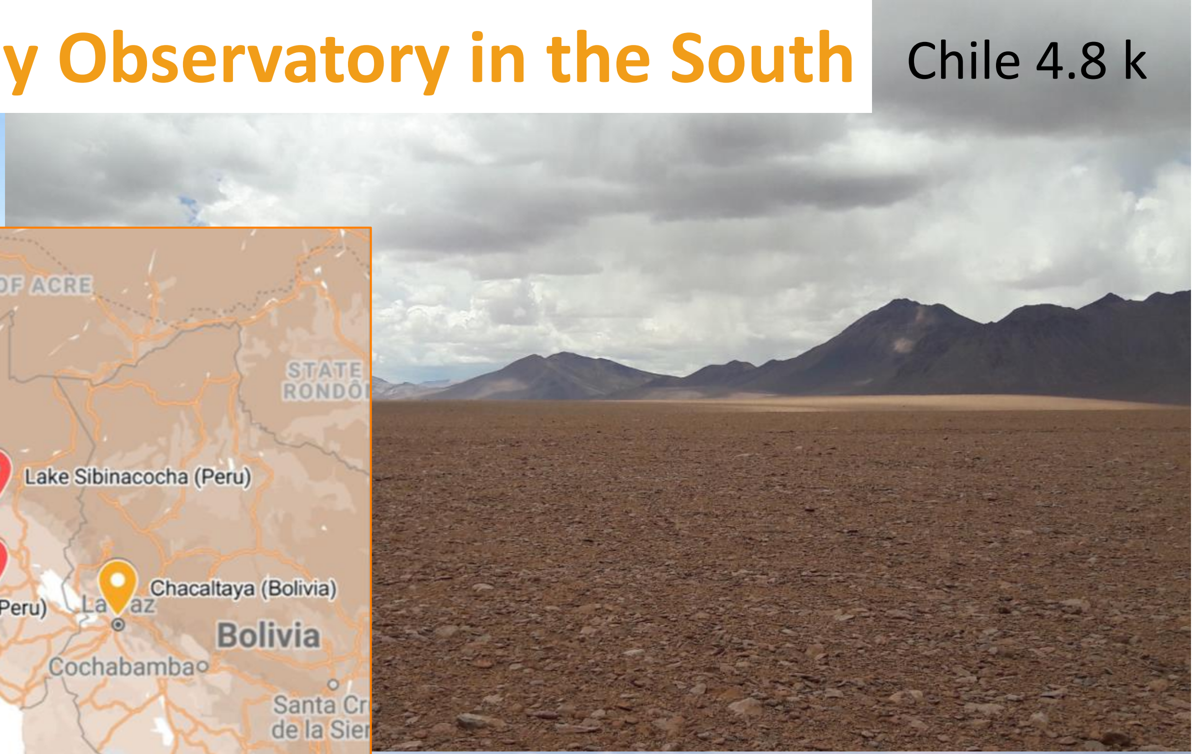
- The scientific potential of a wide field of view, and very high duty cycle, ground-based gamma-ray detector has been demonstrated by the current generation instruments HAWC and ARGO and is being extended in the Northern hemisphere by LHAASO.
- No such instrument exists in the southern hemisphere, where great potential exists for the mapping of large-scale emission as well as providing access to the full sky for transient and variable multi-wavelength and multi-messenger phenomena.
- **Access to the Galactic Centre and complementary with the major facility CTA-South are key motivations for such a gamma-ray observatory in the south. There is also significant potential for cosmic ray studies, including anisotropy.**

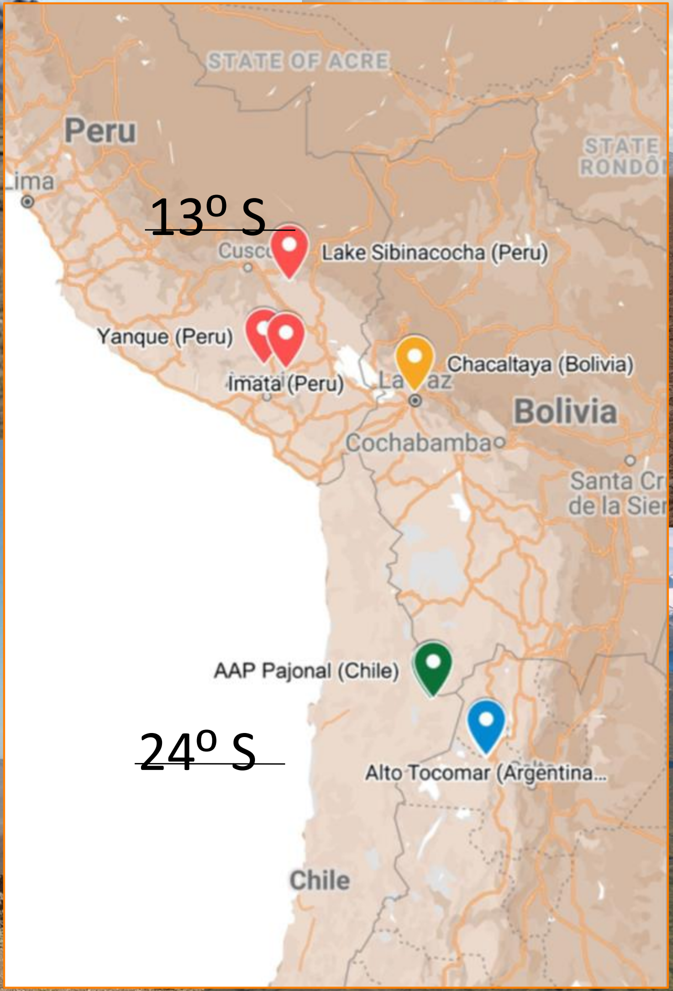
SWGO



To astrophysical source
Incoming gamma ray
Collision with atmospheric nucleus
Extensive Air Shower
Particles penetrate detector tanks, interact and are detected
at least 4400 m above sea level
~150 m inner core
PARTICLE DETECTOR ARRAY
Outer detectors at up to 300 m from center
Charged Particle from Air Shower
Water
Light-Tight Tank
Cherenkov Light
Sensitive Photodetector
Not to scale
Credit: Richard White, MPIK

A Wide-field Gamma-ray Observatory in the South





The future looks bright!

I thank you very much for your attention.
My apologies that the lack of time prevented me from addressing all experiments.

Acknowledgements