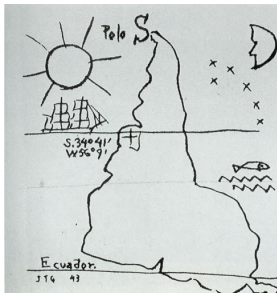


# International collaborations from the southern hemisphere: the Pierre Auger Observatory and the ANDES Deep Underground Laboratory



*América Invertida. Joaquín Torres García (1878-1949)*

Xavier Bertou

CNEA/CONICET  
Centro Atómico Bariloche

UZH Experimental Particle and Astro-Particle Physics Seminar  
Zoom, Feb 22, 2021



# Part One: the Pierre Auger Observatory

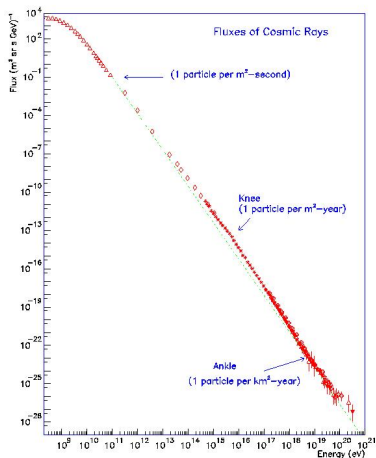


# Cosmic Rays

## Before the Pierre Auger Observatory Era



# Cosmic Rays Spectrum



- Power law with index 2.7
- 12 orders of magnitude in energy
- 32 orders of magnitude in flux
- only few features
  - Knee: 1 event/ $\text{m}^2/\text{sr}/\text{year}$
  - Ankle: 1 event/ $\text{km}^2/\text{sr}/\text{year}$

## UHECR

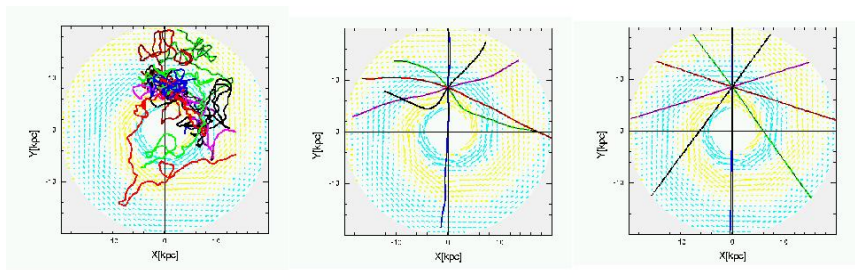
- At  $10^{20}$  eV: 1 event/ $\text{km}^2/\text{sr}/\text{century}$
- First event: Volcano Ranch, 1962

# UHECR Astronomy

## Magnetic fields

At low energies, CR are deflected by galactic and extra-galactic magnetic fields.

UHECR (protons in particular) should point to the source



$10^{18}$  eV

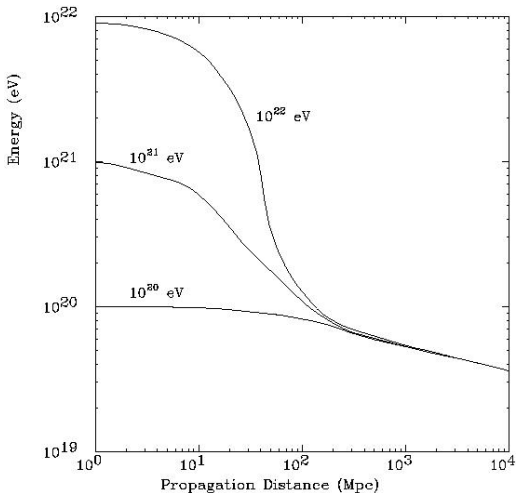
$10^{19}$  eV

$10^{20}$  eV

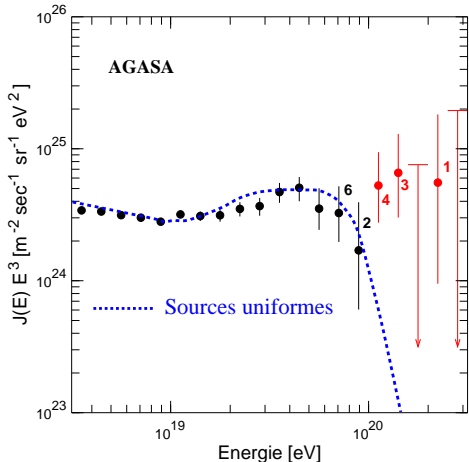
## GZK cut-off

At UHE, protons interact with CMB photons by photo production, and nuclei with CMB and IR photons through photo dissociation

UHECR should lose energy quickly on short distances ( $< 100$  Mpc)



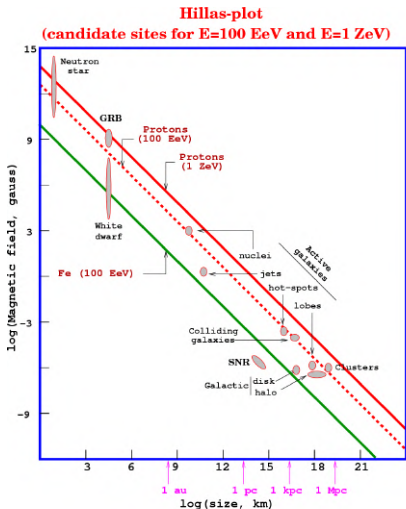
# AGASA Spectrum (2002)



## AGASA

- 111 scintillator detectors, over 100 km<sup>2</sup> for 11 years
- Exciting feature: softer slope at UHE
- Even better: post-GZK events

# UHECR Sources?



## Bottom-Up

- $E_{\text{max}} \approx Z B L$

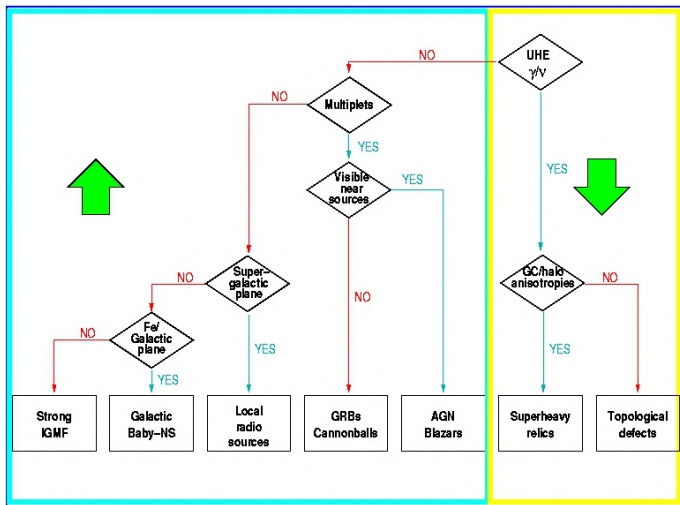
## Top-Down

- Super massive particle
- Topological Defect





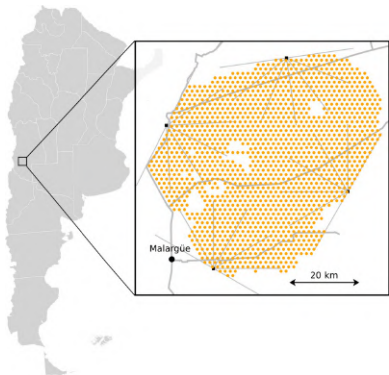
# The Model Killer



# the Pierre Auger Observatory



# The Pierre Auger Observatory



## Design

- UHECR study ( $E \geq 10^{18}$  eV)
- Construction over in 2008

## UHECR hybrid detection

- Ground detectors (SD): 1600 Water Cherenkov Detectors covering  $3000 \text{ km}^2$  on a 1500 m triangular grid
- Fluorescence detectors (FD): 24 fluorescence telescopes in 4 sites observing over the SD area

## In Malargüe (Argentina)

- $69.3^\circ$  W,  $35.3^\circ$  S
- 1400 m a.s.l. ( $870 \text{ g cm}^{-2}$ )



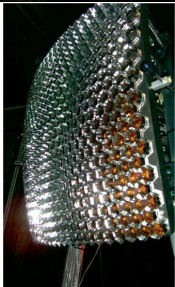
## Ground detectors: WCD

---

- 10 m<sup>2</sup> area rotationally molded polyethylene tanks
- 12 m<sup>3</sup> ultra pure water in a diffusive bag
- Cherenkov light collected by three 9" PMTs
- 40 MHz FADC digitization
- Radio wireless communication
- GPS based timing
- Battery and solar panel powered



# Fluorescence telescopes

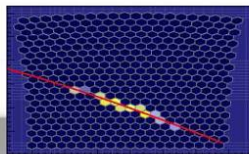


- 4 FD buildings
- 6 cameras per building
- UV filters
- 440 PMT per camera
  
- $180^\circ \times 30^\circ$  field of view
- 10% duty cycle
- Observes longitudinal development
- Calorimetric energy measurement
- Composition measurement ( $X_{\max}$ )

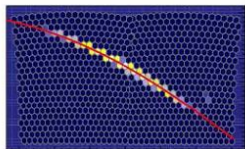
# Hybrid events

Event: 1364365

Los Morados

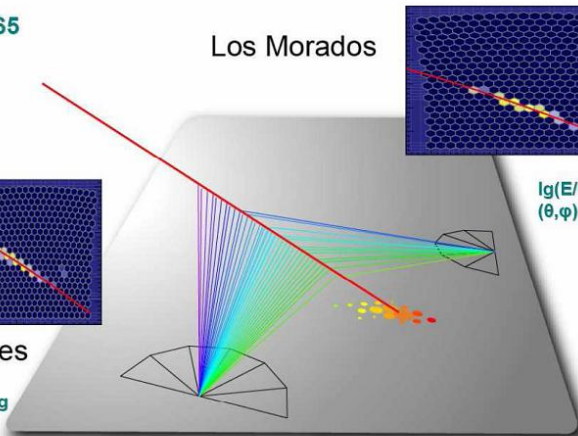


$\lg(E/eV) \sim 19.2$   
 $(\theta, \phi) = (63.7, 148.4)$  deg



Los Leones

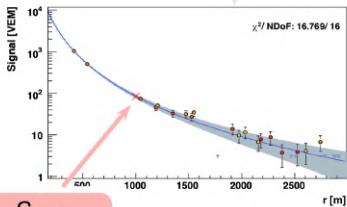
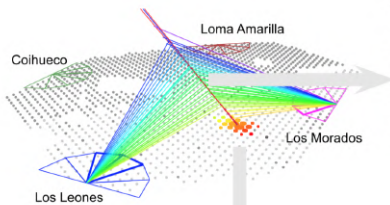
$\lg(E/eV) \sim 19.3$   
 $(\theta, \phi) = (63.7, 148.3)$  deg



SD array:  $\lg(E/eV) \sim 19.1$   
 $(\theta, \phi) = (63.3, 148.9)$  deg

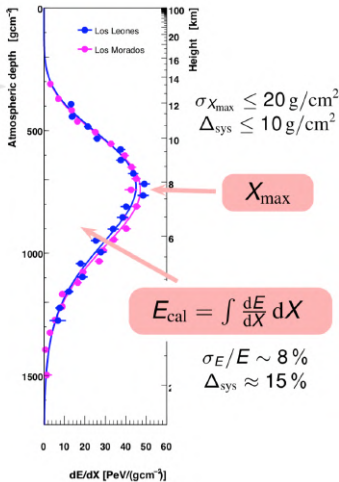


# Hybrid reconstruction



$S_{1000}$

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



$$\sigma_{X_{\text{max}}} \leq 20 \text{ g/cm}^2$$

$$\Delta_{\text{sys}} \leq 10 \text{ g/cm}^2$$

$X_{\text{max}}$

$$E_{\text{cal}} = \int \frac{dE}{dX} dX$$

$$\sigma_E/E \sim 8\%$$

$$\Delta_{\text{sys}} \approx 15\%$$

# The new Era for UHECR





# UHE Exposure

---

Auger Anisotropy ICRC17:  $9.0 \times 10^4 \text{ km}^2 \text{ sr yr}$

Auger Spectrum ICRC17:  $6.7 \times 10^4 \text{ km}^2 \text{ sr yr}$

TA Spectrum ICRC17:  
 $0.8 \times 10^4 \text{ km}^2 \text{ sr yr}$

AGASA

# The new Era for UHECR

Bottom Up vs Top Down

Spectrum

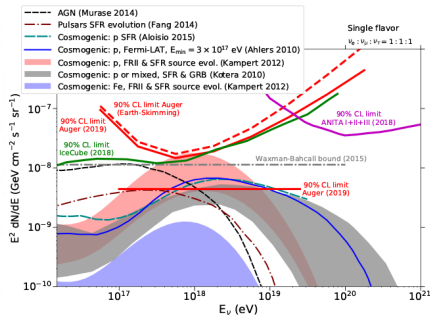
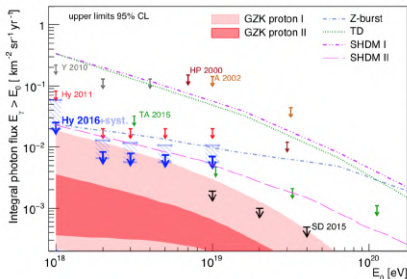
Composition

Looking for the sources

High Energy Physics



# No photons, no neutrinos



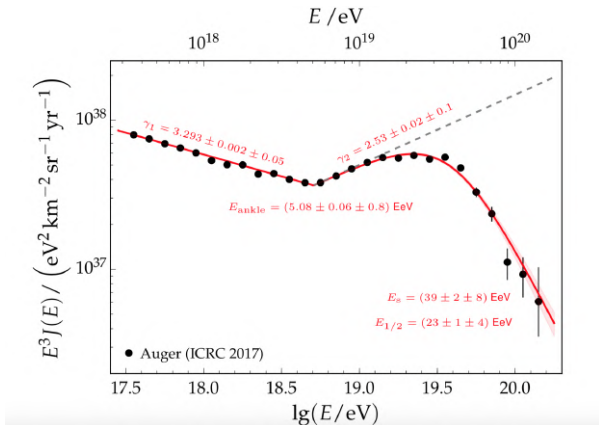
- Top Down model interpretation of UHECR rejected
- Search for Cosmogenic Photons and Neutrinos started
- Search for multimessenger (Ex: Binary Neutron Star Merger)

# The new Era for UHECR

Bottom Up vs Top Down  
Spectrum  
Composition  
Looking for the sources  
High Energy Physics



# Energy Spectrum



- Strong suppression at 40 EeV (GZK? Source limit?)
- below 1 event per km.sr per milenium at 100 EeV

# The new Era for UHECR

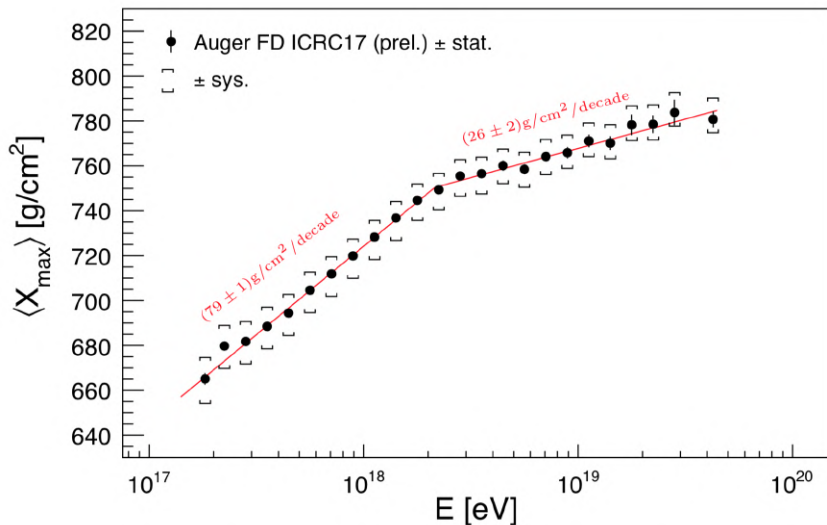
Bottom Up vs Top Down  
Spectrum

Composition

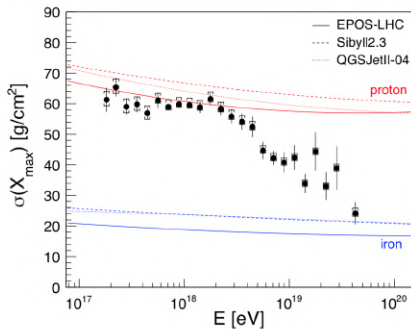
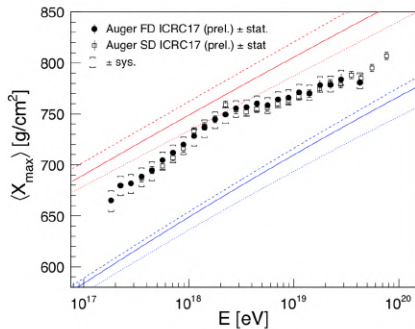
Looking for the sources  
High Energy Physics



# Average $X_{max}$ measured by FD



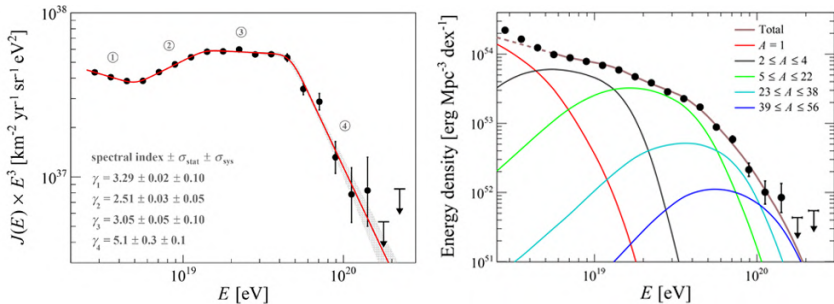
# Composition measurements



- Lines from post-LHC models
- Composition trend changes around ankle
- UHECR heavy



# Combining spectrum and composition



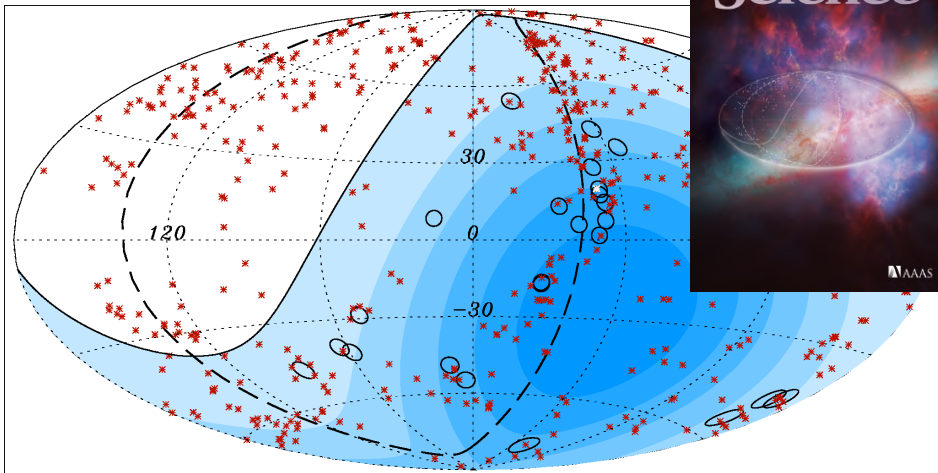
- Galactic - extragalactic transition likely below ankle
- Ankle corresponding to end of extragalactic proton flux

# The new Era for UHECR

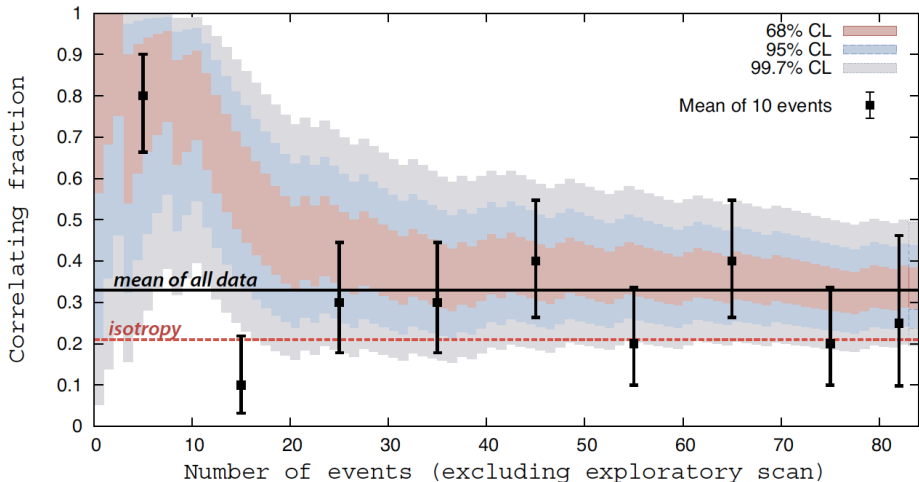
Bottom Up vs Top Down  
Spectrum  
Composition  
Looking for the sources  
High Energy Physics



## Correlation with close-by AGNs (2007)



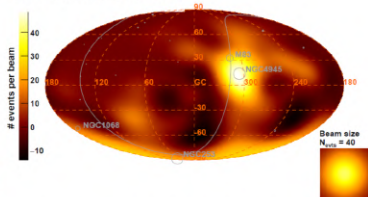
# Evolution of correlation with close-by AGNs



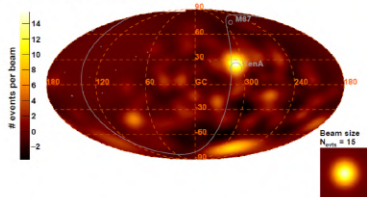
# Source catalogues comparison

preliminary

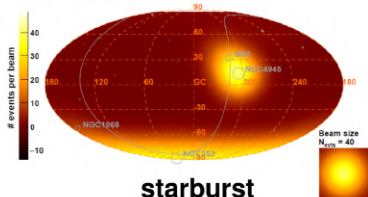
Observed Excess Map -  $E > 39$  EeV



Observed Excess Map -  $E > 60$  EeV

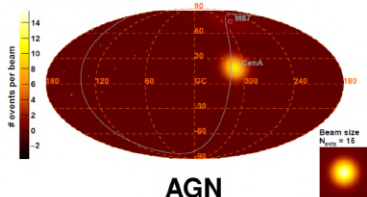


Model Excess Map - Starburst galaxies -  $E > 39$  EeV



starburst

Model Excess Map - Active galactic nuclei -  $E > 60$  EeV



AGN

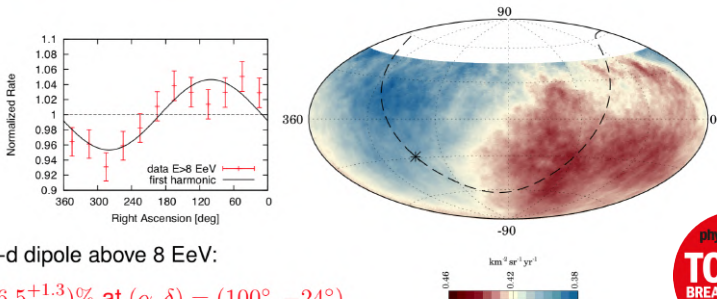
Post-trial significance  $3.9\sigma$  and  $2.7\sigma$  respectively

# Large scale anisotropies

Harmonic analysis in right ascension  $\alpha$

$E$ [EeV]	events	amplitude $r$	phase [deg.]	$P(\geq r)$
4-8	81701	$0.005^{+0.006}_{-0.002}$	$80 \pm 60$	0.60
$> 8$	32187	$0.047^{+0.008}_{-0.007}$	$100 \pm 10$	$2.6 \times 10^{-8}$

significant modulation at  $5.2\sigma$  ( $5.6\sigma$  before penalization for energy bins explored)

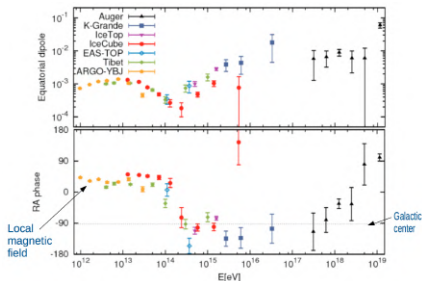
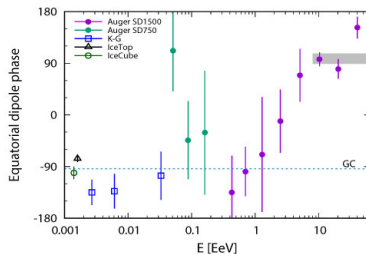
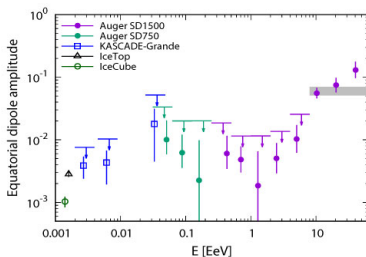


3-d dipole above 8 EeV:

$(6.5^{+1.3}_{-0.9})\%$  at  $(\alpha, \delta) = (100^\circ, -24^\circ)$



# Large scale anisotropies



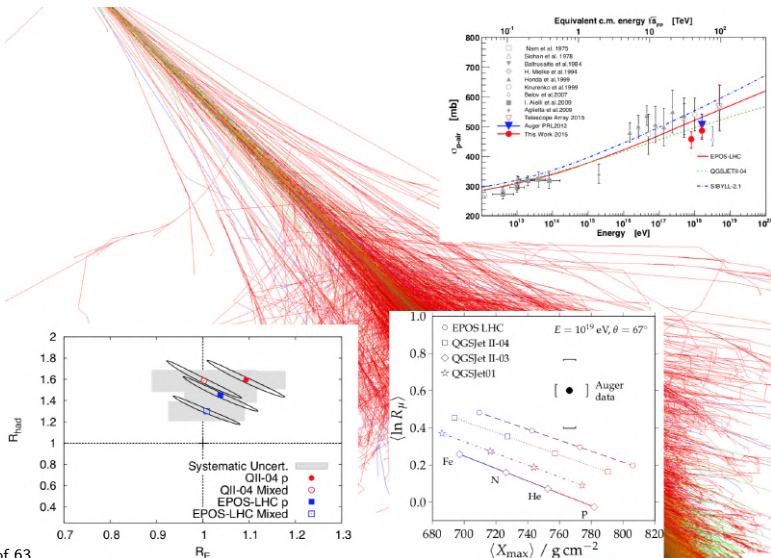
# The new Era for UHECR

Bottom Up vs Top Down  
Spectrum  
Composition  
Looking for the sources  
High Energy Physics

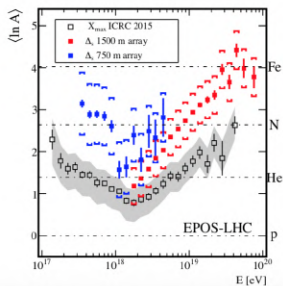
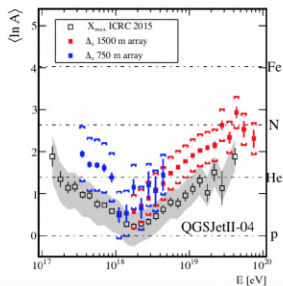
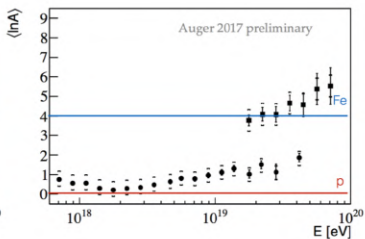
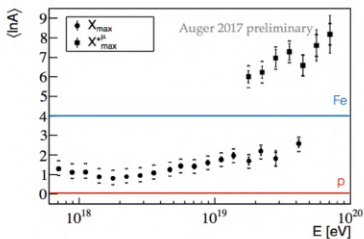




# HEP with Auger



# Still lacking coherent view



## Other results from the Pierre Auger Observatory

---

- No excess from Galactic Center
- Point sources with neutral primary (neutrons, photons)
- Multi-messenger source search
- Radio detection of EAS (geosynchrotron - MHz, molecular bremsstrahlung - GHz?)
- Atmospheric studies
- Solar physics
- TLE/Elves/Lightning physics
  
- Very active "side physics" tasks



## Take Home Message

---

- UHECR are accelerated in astrophysical sources
- Bottom-Up, no new physics
- Ankle likely end of extragalactic protons
- galactic-extragalactic transition likely at 1 EeV
- UHECR are extragalactic
- Strong suppression at UHE
- Muon deficit in models

It is called the disappointing model in the literature



## Take Home Message

---

- UHECR are accelerated in astrophysical sources
- Bottom-Up, no new physics
- Ankle likely end of extragalactic protons
- galactic-extragalactic transition likely at 1 EeV
- UHECR are extragalactic
- Strong suppression at UHE
- Muon deficit in models

It is called the disappointing model in the literature  
we should call that the standard model



# The next Era for UHECR

## Auger Prime



# What next?

- Origin of the flux suppression?
- Proton fraction at UHE?
- Rigidity-dependence of anisotropies?
- Hadronic physics above  $\sqrt{s} = 140$  TeV?

need large-exposure detector with  
composition sensitivity!

arXiv:1604.03637v1 [astro-ph.IM] 13 Apr 2016

## The Pierre Auger Observatory Upgrade

“AugerPrime”

Preliminary Design Report



The Pierre Auger Collaboration  
April, 2015

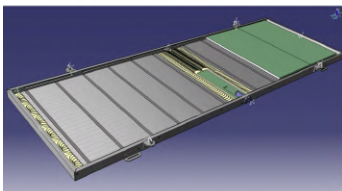


Observatorio Pierre Auger,  
Av. San Martín Norte 304,  
5613 Malargüe, Argentina



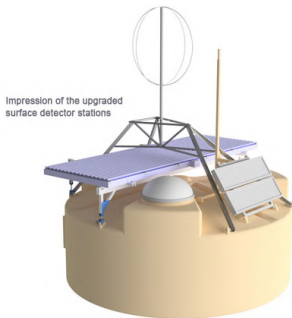
# New detectors to get composition event by event

- 3.8 m<sup>2</sup> scintillators (SSD) on each 1500-m array station
- upgrade of station electronics
- additional small PMT to increase dynamic range
- buried muon counters in 750-m array (AMIGA)
- increased FD uptime





# Upgrade up and running



- More than 1000 detectors with SSD (Scintillator Surface Detector)
- More than 100 in operation (new electronics being finalized)

# Auger Open Data



# DIY! 10% at [www.auger.org/opendata](http://www.auger.org/opendata)

Auger\_Open\_Data

Datasets Visualization Analysis Contact

## Pierre Auger Observatory Open Data

February 2021 release



The Pierre Auger 2021 Open Data is the public release of 10% of the Pierre Auger Observatory data presented at the 36<sup>th</sup> International Cosmic Ray Conference held in 2019 in Madison, USA, following the [Auger collaboration open data policy](#).

Auger Open Data release version 1, Feb 15 2021.

DOI: 10.5281/zenodo.4487613

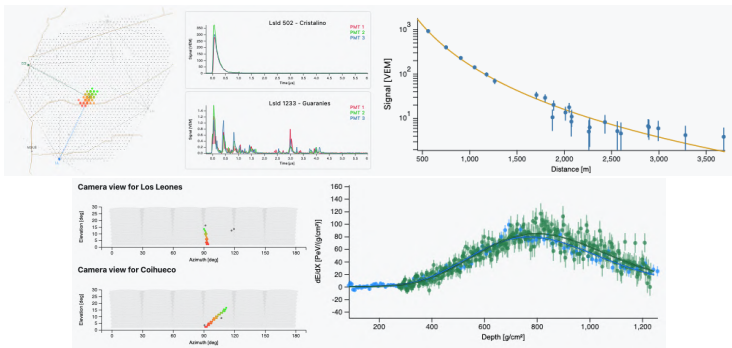
(<https://doi.org/10.5281/zenodo.4487613>)

43 of 63



# DIY! 10% at [www.auger.org/opendata](http://www.auger.org/opendata)

- 6000+ km<sup>2</sup>.sr.year of exposure
- 20k+ events above 2.5 EeV, 3k+ hybrid events
- summary CSV files and JSON pseudo-raw data for each event
- website with event display, data description and analysis notebooks





# Part Two: the ANDES Deep Underground Laboratory



# World map of underground laboratories - 2017

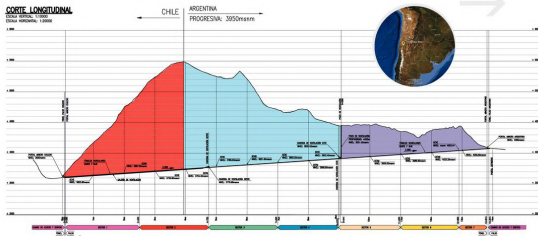


Aldo Ianni, TAUP 2017



# The Agua Negra tunnel (Coquimbo - San Juan)

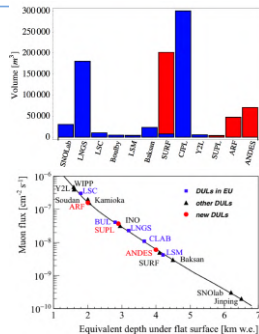
- Crossing the Andes is of strategic importance for the region to link productive areas to the Asian market
- 2 tunnels, 12 m  $\varnothing$  each, 60 m one from another,  $\approx$  14 km
- Deepest point at  $\approx$  1750 m depth
- International tender started in January 2013, construction 20??-20??+8





# A scientific opportunity in the south?

- Opportunity for a big AND deep laboratory
- Located in the south
  - opposite weather modulation (dark matter)
  - complementary for supernovae neutrinos
- Geoneutrinos  
(Low neutrino flux from nuclear power plants)
- Geoactive region  
→ Underground geophysics laboratory



## Manage it from an international consortium

- Opportunity to have not only international experiments but an international laboratory
- The consortium would be the seed of a “CERN” focused on underground science (high energies, geology, biology, technology...)

# Original scientific programme for ANDES

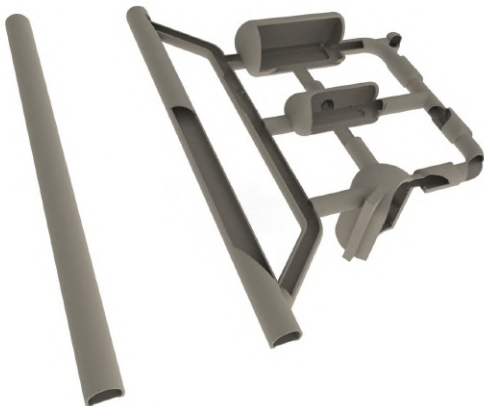
---

- Neutrino
  - host a double beta decay experiment
  - build a large neutrino detector as a flagship experiment
    - similar to KamLAND/Borexino?
    - focused on low energies
    - solar/supernovae/geo-neutrinos
- Dark Matter
  - modulation measurements
  - 4th generation
  - new technologies
- Geophysics
  - Natural link of seismograph networks
  - “flat slab” study
- Biology
- Low radiation measurements
- Accelerator
  - Nuclear astrophysics
  - DAR neutrino beam?

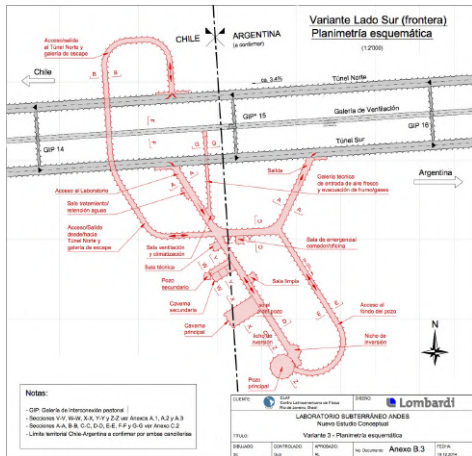


## First proposal for the ANDES laboratory (2011)

---

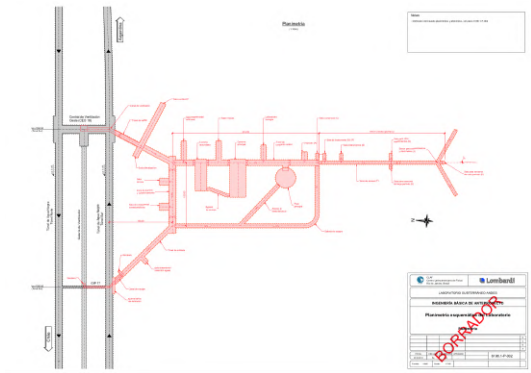


# Conceptual design for ANDES (2015-2016)



- main hall:  
(21×23×50) m<sup>3</sup>
- secondary hall:  
(16×14×40) m<sup>3</sup>
- small halls (office, workshop, clean room, ...):  
total 340 m<sup>2</sup>
- ultra-low radiation pit:  
∅9 m, 9 m depth
- single experiment pit:  
∅30 m, 30 m depth

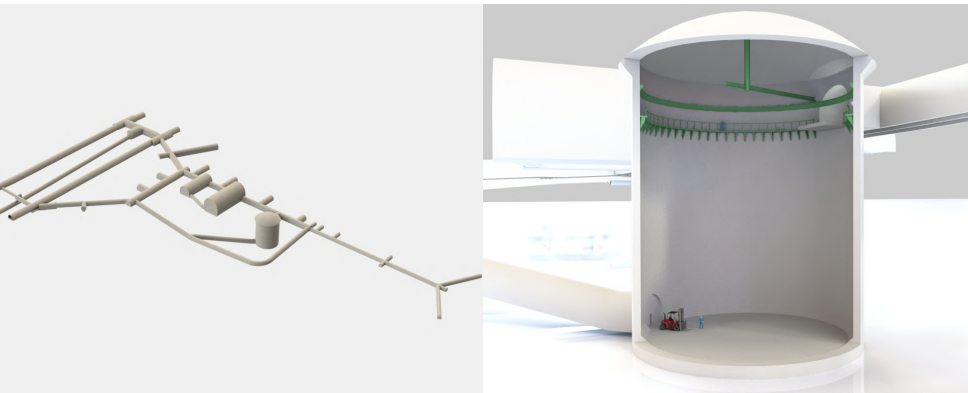
## Detailed engineering (2018-2019)



- Add GEO portion (inspired by BFO, Germany)
- Add BIO independent laboratory
- Reorder small rooms
- Add Accelerator room
- Cost 73.2 MUSD (including multidisciplinary platforms)

## Current design for the ANDES laboratory

---



Approved for inclusion in tunnel civil work by EBITAN

# International and institutional support

- Memorandum of Understanding signed during the first ANDES workshop (includes the signatures of the director of Modane, the emeritus director of Homestake, the spokespersons of SuperNEMO and Edelweiss II).
- EBITAN (Entidad Binacional Túnel Agua Negra), supported the ANDES laboratory in its Xth meeting and agreed on including it in the Agua Negra tunnel project in its XXXVth meeting
- Support and interest by latin american institutions:
  - CONICET, Argentina
  - MinCyT, Argentina
  - Universidad de La Plata, Argentina
  - Universidad de San Juan, Argentina
  - ANDES Unit in CLAF
  - Universidad La Serena, Chile
  - Gobierno de la provincia de San Juan, Argentina
  - CONICYT, Chile
  - Gobierno de la provincia de Elqui, Chile
  - Gobierno de la región de Coquimbo, Chile
  - CCHEN, Chile
  - MinRel, Chile
- Support and interest by representatives of latin american scientists and institutions:
  - Claudio Dib, representing groups from 4 Chilean universities
  - Juan Carlos D'Olivo, High Energy Physics Network, Mexico
  - Ronald Shellard, CBPF and SBF vice director, Brazil
  - Eduardo Charreau, ANCEFEN president, Argentina
  - Francisco Tamarit, AFA president, Argentina
- Support from scientists and international experiments:
  - Stephen Adler, Princeton
  - M. Miller, A. Garcia, University of Washington
  - Bob Svoboda, LNBE Spokesperson
  - Nigel Smith, SNOLAB Director
  - Kunio Inoue, KamLAND Spokesperson
  - Hiro Ejiri, Former RCNP Director
  - Yoichiro Suzuki, Kamioka Director, Super Kamiokande Spokesperson
  - Takaaki Kajita, ICRR Director
  - P. Brink et al., DM modulation
  - D.A. Harris, K. McFarland, MINERvA Spokespersons
  - A.B. McDonald, Nobel Physics Laureate



# Manifested interest in contributing to ANDES

- interest for collaboration and instrument installation in ANDES:

- Jennifer Thomas, SuperNEMO CB Chair
- Daniel Santos, MIMAC Spokesperson
- Kai Zuber, COBRA Spokesperson
- J. Conrad, M. Shaevitz, DAEDALUS Spokespersons
- A. Galindo-Uribarri et al., ORNL

Interest in collaborating to the construction and operation of the ANDES laboratory by latin american groups:

- Argentina:

- IFLP, UNLP
- Neutrones y Reactores, CAB
- Partículas y Campos, CAB
- Bajas Temperaturas, CAB
- Instituto Geofísico Sismológico Volponi, San Juan
- ITeDA, CNEA-CAC
- I&D - PNGRR, CNEA-CAC
- Física Experimental Altas Energías, UBA
- Instituto de Matemática Aplicada, San Luis
- Empresa SOLYDES

- Brasil:

- Rede Nacional de Física de Altas Energias
- ICE, UFRJ
- IFRW, UNICAMP
- ICRA, CBPF
- Neutrino Physics group, UFABC
- HEP, PUC Rio
- Instituto de Física, USP

- Chile:

- CCTVAL, UTFSM
- Pontificia Universidad Católica de Chile
- Universidad de Santiago de Chile
- Dpto Ciencias de la Tierra, Universidad de Concepción
- ICFM, Universidad Austral

- Mexico:

- Instituto de Biotecnología, UNAM
- Instituto de Ciencias Nucleares, UNAM
- Grupo Astropartículas, UMSNH
- FCFM, BUAP





## ANDES timeline

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- Project started in July 2010
- First 3 ANDES workshops in Buenos Aires, Argentina, April 2011, Rio de Janeiro, Brazil, June 2011, Valparaíso, Chile, January 2012
- approved by the Argentine MinCyT (CAGICyT) and EBITAN, March 2012
- Fourth workshop in Mexico City, Mexico, January 2014
- ANDES Unit in CLAF created, January 2014
- Laboratory New Conceptual Design ready, January 2016
- Fifth ANDES workshop in Buenos Aires, Argentina, June 2017
- ANDES proposed for the TAN civil work by EBITAN, July 2017
- Sixth ANDES workshop in São Paulo, Brasil, August 2018
  
- ▷ Detailed engineering (0.5 M\$) finished in May 2019
- ▷ Construction together with tunnel (20??+4-20??+10)



# LASF4RI



## Latin American Strategy Forum for Research Infrastructure

*Developing a strategy to strengthen Latin American Scientific Collaborations and their impact.*

The process for the first Latin American Strategy Forum for Research Infrastructure for High Energy, Cosmology and Astroparticle Physics (LASF4RI-HECAP) has come to a conclusion in October 2020. A **Physics Briefing Book** (PBB) was written by the Preparatory Group based on the 40 White Papers submitted by the community. The PBB served as the basis for the LASF4RI-HECAP **Strategy Document** that was endorsed in a **letter** by the High Level Strategy Group.

The Strategy Document was submitted to the IV Iberoamerican Science and Technology Ministerial Meeting that took place on October 27, 2020 where it was recognized in its **Declaration** that "The advancement in the establishment of the Iberoamerican Strategy Forum for Research Infrastructures with the pilot program in the area of high energy, cosmology and astroparticle physics, that resulted in the strategy document including a set of recommendations and a defining a roadmap for these disciplines."

<http://lasf4ri.org/>

# LASF4RI Strategic Document recommendations

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## Recommendation 1

*Support the development and operation of current- and next-generation projects in astronomy, cosmology and astroparticle physics located in Latin America, enhancing leadership roles in these strategic regional projects that drive capacity building and technological development.*

## Recommendation 2

*Pursue the establishment of the flagship international laboratory, ANDES, that will enable the region as a global center for underground physics and other sciences.*

## Recommendation 3

*Support the existing efforts in international projects in which Latin American groups are actively participating, and in some cases leading initiatives, as a strategy to position Latin America to key leadership roles in future international flagship projects in collider and neutrino physics.*

## En la agenda de la próxima generación

"De vez en cuando la vida" nos da una buena noticia. En mi caso tuvo nombre y apellido: Carmina Pérez Bertoli.

Carmina es tucumana, feminista y tiene 27 años. Se licenció en Física por la Universidad de Buenos Aires, y obtuvo su doctorado en la misma materia por el Instituto de Tecnologías en Detección y Astropartículas, que depende de la Comisión Nacional de Energía Atómica. Además, su tesis de licenciatura ganó la edición 2020 del Premio "Luis Misgeri", que otorga la Asociación Física Argentina.

La tesis laureada se titula "Estimación del flujo de muones en el laboratorio subterráneo ANDES". El laboratorio ANDES (Agua Negra Deep Experiment Site) será construido en el marco de la obra del Túnel Agua Negra, obra de infraestructura que mirará vialmente a Chile y Argentina por el paso homónimo, a la altura de Coquimbo y San Juan, respectivamente.

Así, bajo 1.700 metros de roca sudamericana, se alzará un laboratorio de 60.000 m<sup>3</sup> de volumen, que emprenderá experimentos de vanguardia en física del neutrino, búsqueda de la materia oscura, geofísica, biología, impacto ambiental; gracias —entre otras cosas— a su ambiente libre de radiación. Todo esto, guiado por un consorcio latinoamericano, con el apoyo de varios premios Nobel. Música para algunos oídos.

En su tesis, la Lic. Pérez Bertoli revisó las estimaciones realizadas originalmente respecto del flujo de muones (otra partícula subatómica que forma parte de la radiación cósmica) como factor de "ruido" para las mediciones que se proponen realizar desde el laboratorio ANDES.



Una nueva generación es premiada, y los que hace ya rato caminamos esta Tierra, tenemos el deber de hacer sitio de honor a las enseñanzas y la renovación que trae. En la región: ciencia binacional e igualdad de género.

Las nuevas camadas llevan la marca de un pensamiento que hace y hará a este planeta cada vez más igualitario. Muchas veces nos planteamos refundarlo, mientras dábamos oxígeno a la injusticia respecto de nuestras compañeras. Tratamos de aprender.

El mundo acelera cada vez más las brechas entre los países desarrollados y los que todavía estamos intentándolo. El capitalismo de plataformas exige un nivel de concentración de capital y de tecnología jamás visto. Si Chile y Argentina no nos unimos para producir conocimiento científico y tecnológico, no solo no alcanzaremos el desarrollo, sino que las asimetrías globales se volverán cada vez más pronunciadas sobre nosotros. ¿Cómo mantener el equilibrio de la estabilidad sistémica sin pérdida de autonomía? Esa es una buena pregunta, aunque no necesariamente nueva.

Tal vez la agenda de la generación que empieza a ocupar los espacios de toma de decisiones exija, para mayor bienestar y autonomía de todos, una inversión de polaridad radical: priorizar los proyectos científicos conjuntos por sobre las obras de infraestructura. En otros términos: hasta ahora las grandes obras contenían a la ciencia aplicada; la idea consiste en que los proyectos científicos abarquen a los emprendimientos infraestructurales, y los túneles.

Los túneles se postergan y tienen sus tiempos de maduración y ejecución. La ciencia, que no se pregunta "¿debo?" sino "¿puedo?", no tiene tiempo que perder. Avancemos con laboratorios, y que el resto venga por añadidura.

RAFAEL BIELSA

Embajador de Argentina en Chile

"Los túneles se postergan y tienen sus tiempos de maduración y ejecución. La ciencia, que no se pregunta "¿debo?" sino "¿puedo?", no tiene tiempo que perder. Avancemos con laboratorios, y que el resto venga por añadidura."

"Tunnels are delayed and have their maturation and execution times. Science, which does not ask "should I?" but "can I?", has no time to lose. Let us move forward with laboratories, and let the rest come in addition."

Rafael Bielsa, Argentine ambassador in Chile, Oct 24 2020



## ANDES Conclusion

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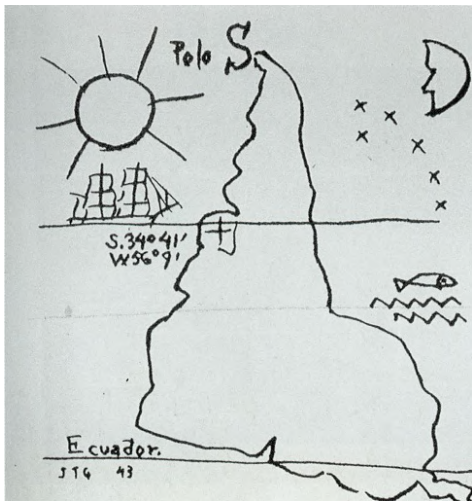
Underground Laboratory science is at the frontier.

There is a unique opportunity to build ANDES,  
a world class deep underground laboratory,  
one of a kind in the southern hemisphere,  
operated by an international consortium

<http://andeslab.org/>



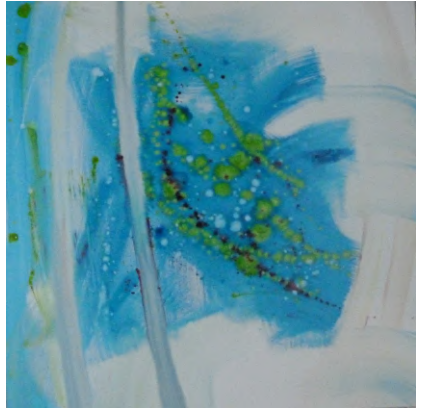
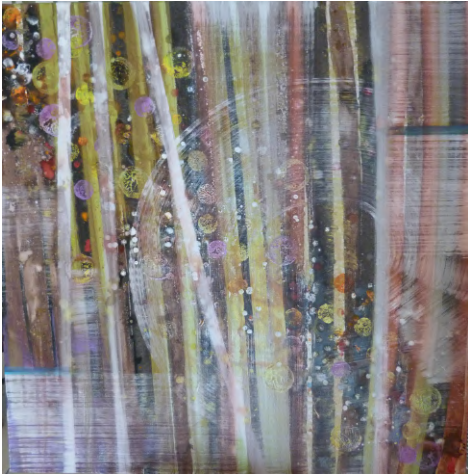
## International collaborations from the southern hemisphere



- Large astroparticle physics projects run in South America
- the Pierre Auger Observatory standardized UHECR
- much more to be done  
(CTA, SGSO...)
- ANDES for the future  
(10-15 years?)
- South America is closer to Europe than it seems  
(ignore COVID-19)  
Especially Argentina  
(and Bariloche for Zurich)



Thank you!



Neutrino search  
(Kay Quattrocchi, 2012)

