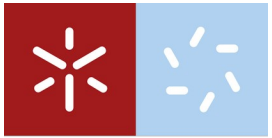




Universidade do Minho
Escola de Ciências

**7th PhD Student Workshop**

**LIP & IDPASC**

**Supervisor: Dr. Raul Sarmento**

**Co-supervisors: Prof. Dr. Ruben Conceição**

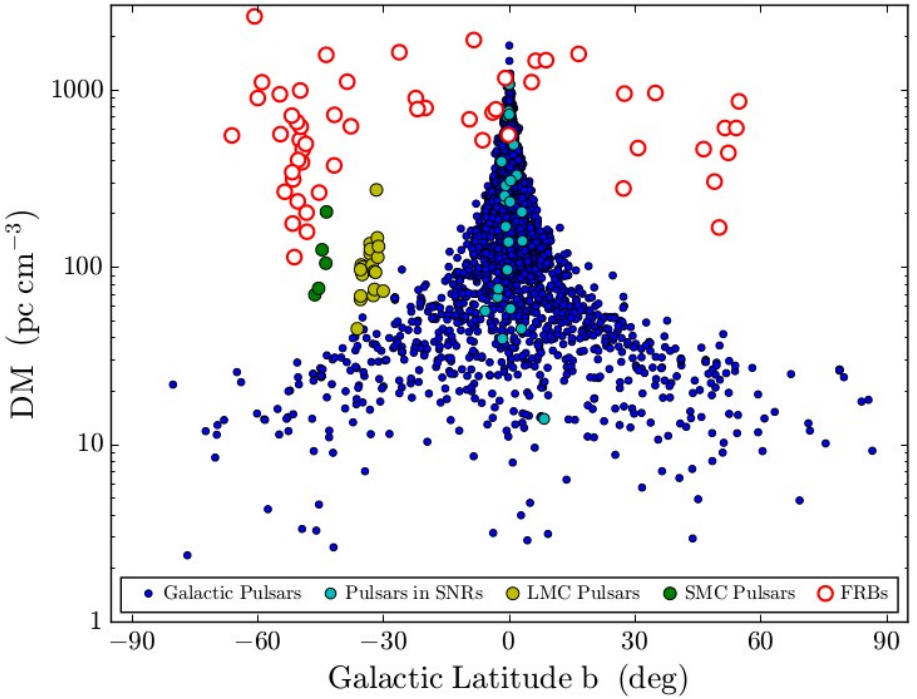
**Prof. Dr. Nuno Castro**

Alexandra Fernandes

# Enhanced Searches with the Pierre Auger Observatory in the Era of Multi-messenger Astrophysics

# Fast Radio Bursts (FRBs)

- **Millisecond extragalactic radio signals**
- **First discovered in 2007 with the detection of FRB010724**

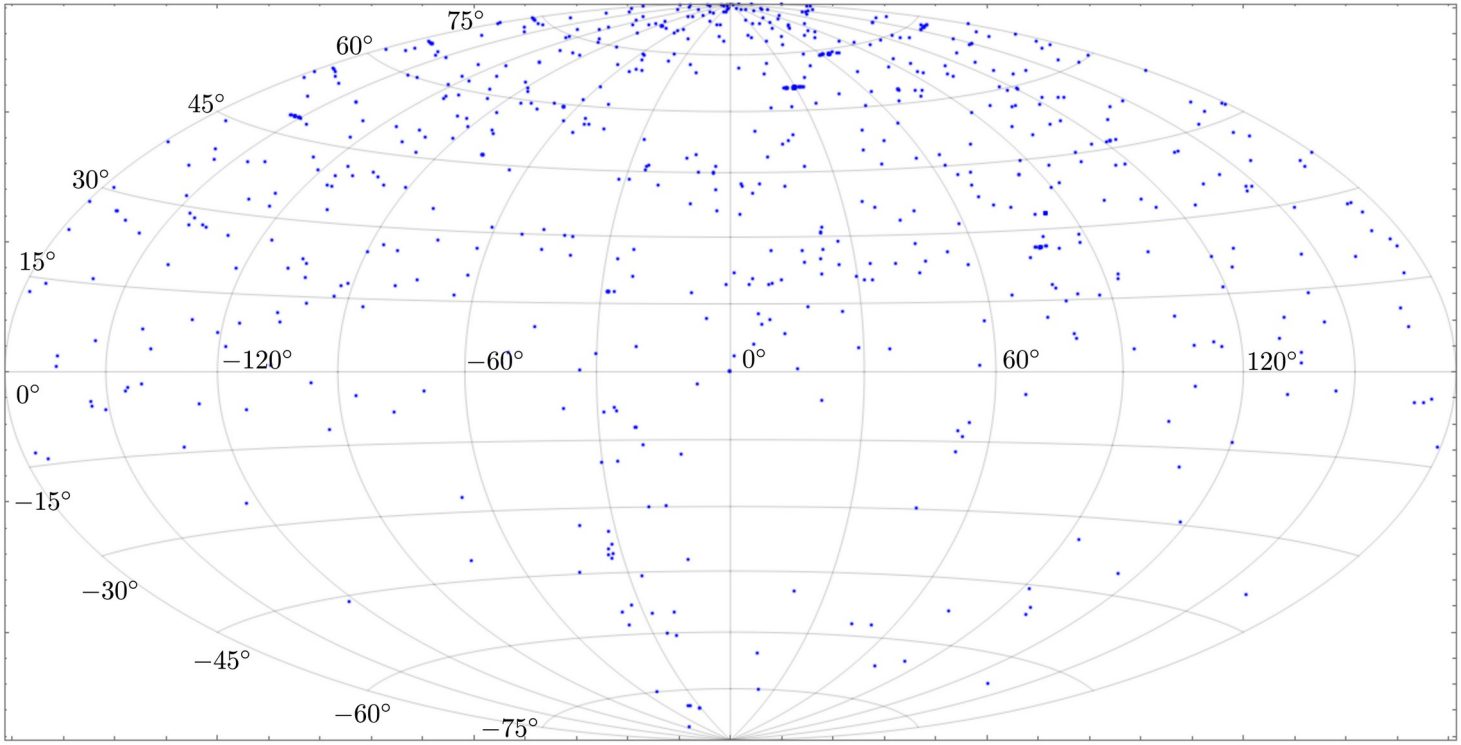



Dispersion measures plotted as a function of galactic latitude b for pulsars and FRBs.

Galactic Pulsars (2422), Galactic pulsars with supernova remnants (27), pulsars in the Large Magellanic Cloud (21), pulsars in the Small Magellanic Cloud (5) and FRBs (55).

Source: Cordes, James M., and Shami Chatterjee. "Fast radio bursts: an extragalactic enigma." (2019).

# Fast Radio Bursts (FRBs)




Localization of 774 fast radio bursts plotted using equatorial coordinates, 191 of which are repeaters of ~ 20 different sources

FRB Rate:

$$\sim 1000\ \mathrm{sky}^{-1}\mathrm{day}^{-1}$$

# Outstanding Energies

Estimated radiation energy densities at the source are approximately 10 billion times larger than a typical burst coming from a galactic pulsar

Isotropic-equivalent energy output of a typical FRB:

$$10^{38} - 10^{42}\mathrm{erg}$$

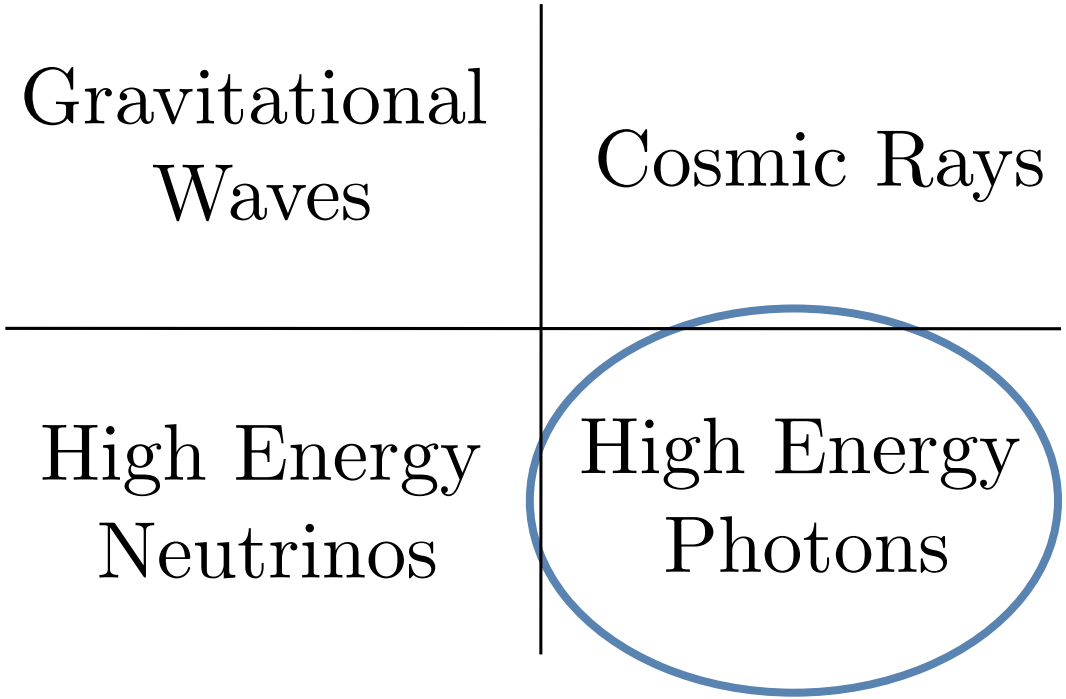
# Multi-messenger Studies

## Complementing Astronomy with:

| | |
|---|---|
| Gravitational Waves | Cosmic Rays |
| High Energy Neutrinos | High Energy Photons |

# Multi-messenger Studies

## Complementing Astronomy with:



# Model Predictions

## Baryon Loaded Shock Scenario

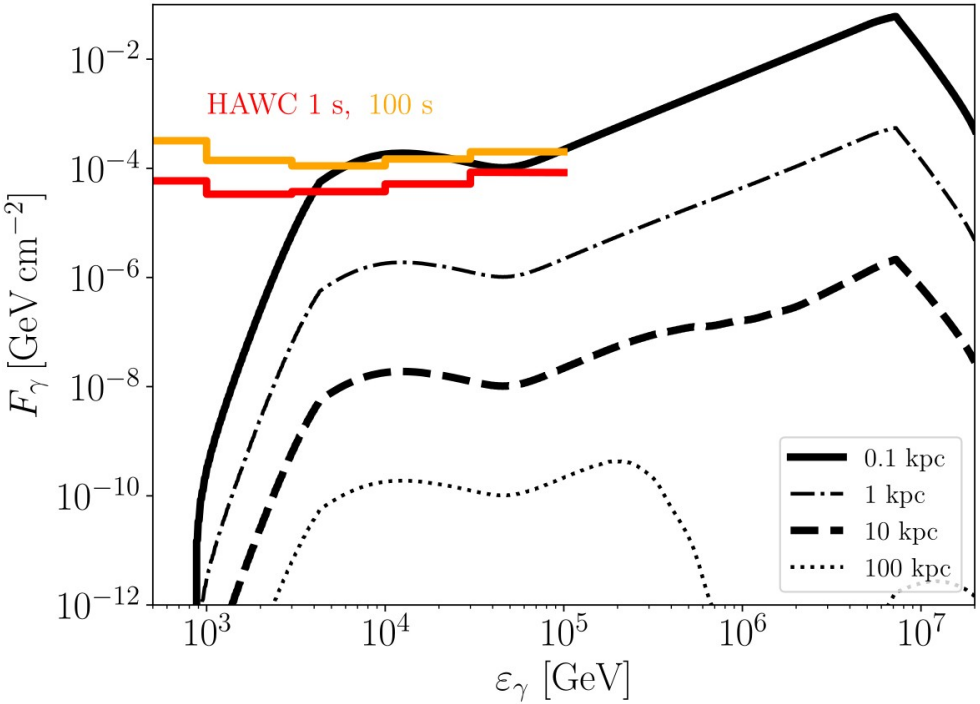
Flaring Magnetar emission model

Motivated by:

In 2020 a FRB was associated with X-ray emission from a galactic magnetar

Prediction for a fiducial burst:

$$1\text{ms duration} \quad \nu = 1\ \text{GHz} \quad \varepsilon_{\text{radio}} = 10^{40}\ \text{erg}$$




Total γ-ray fluence due to neutral pion decay compared to the sensitivities of the HAWC Observatory at 0º zenith angle.

Source: (Metzger, B. D., Fang, K., & Margalit, B. (2020))

# Latest Results

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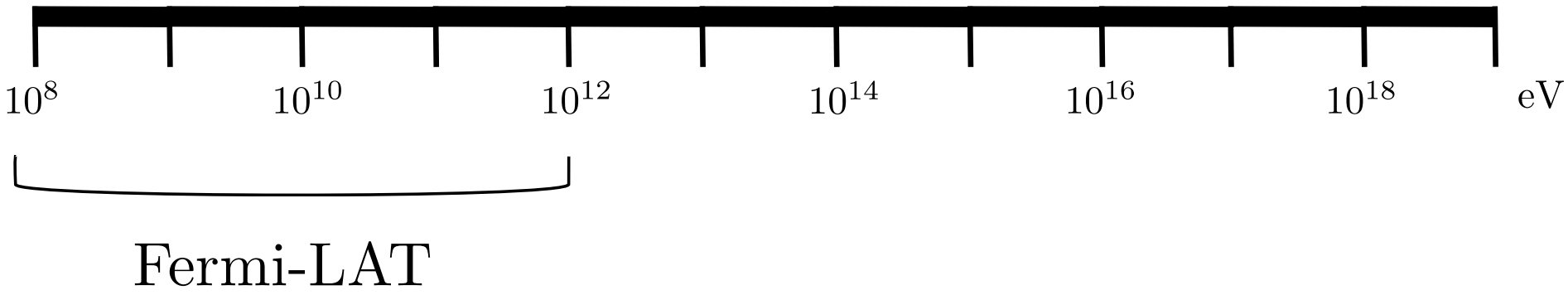

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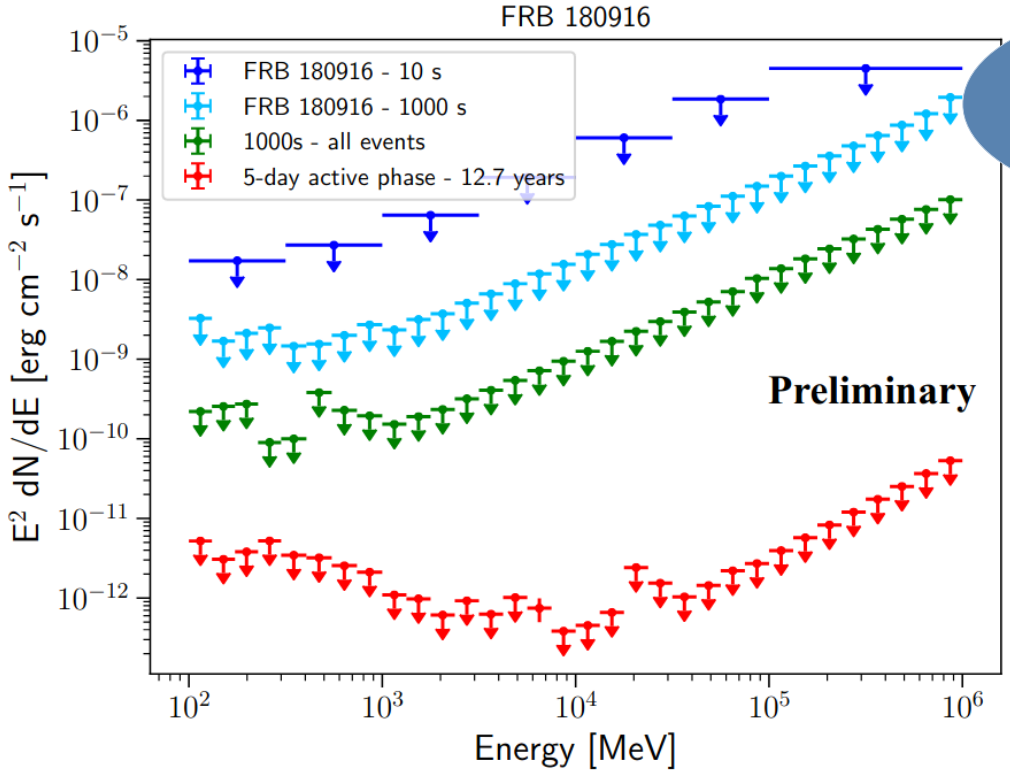


Results from 2021

Preliminary results of Fermi-LAT's sensitivity to the periodic FRB180916.
(Principe, Giacomo et al, in 37th International Cosmic Ray Conference (ICRC 2021))

# Latest Results

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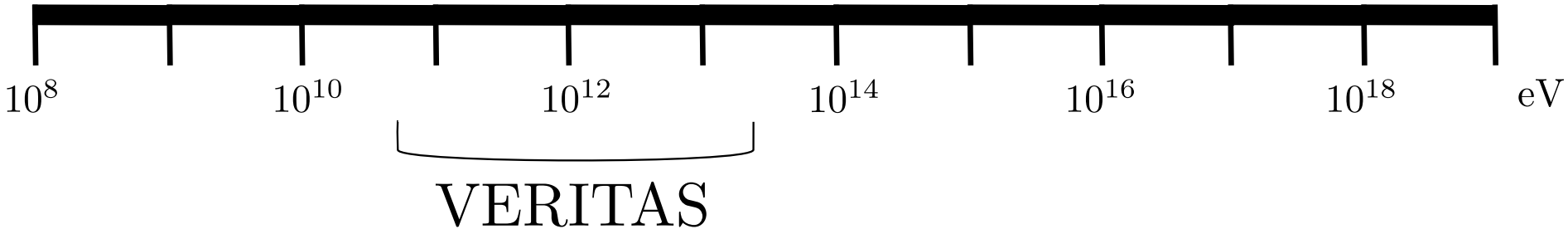

# High Energy Photon Counterparts
# Latest Results

Since 2016

- **VERITAS has engaged in an FRB observing campaign for high energy photons**
- **Integrated search for emission around the source location using a cumulative exposure.**

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Between

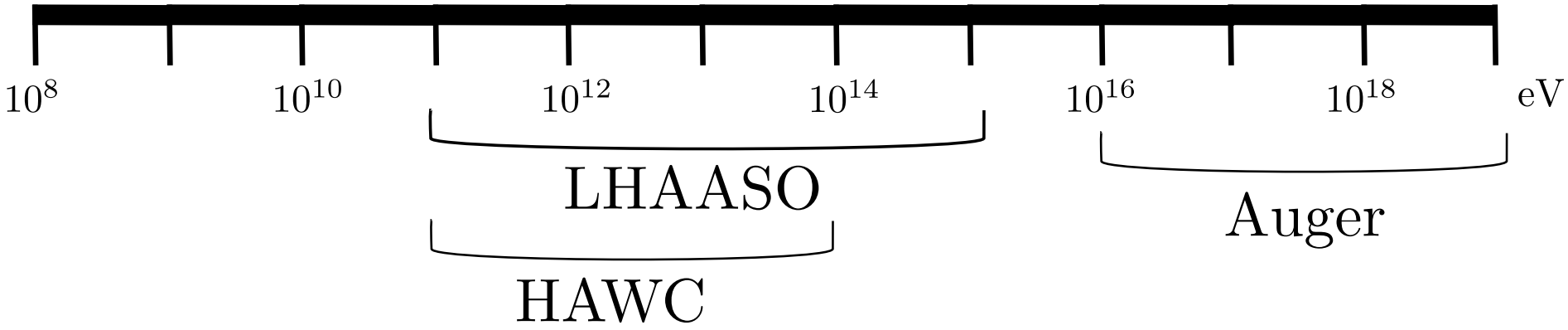
85 GeV and 30 TeV

VERITAS and CHIME possess a very similar localization

# Latest Results

# Latest Results

No counterpart searches yet



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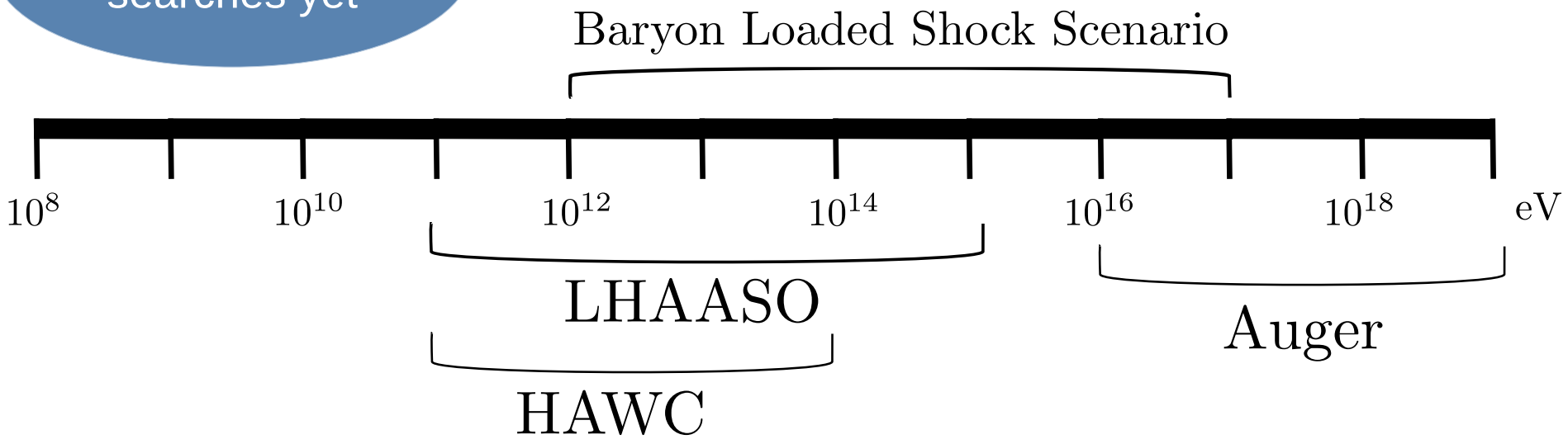

# High Energy Photon Detection

2021 – Photon detections up to a few PeVs

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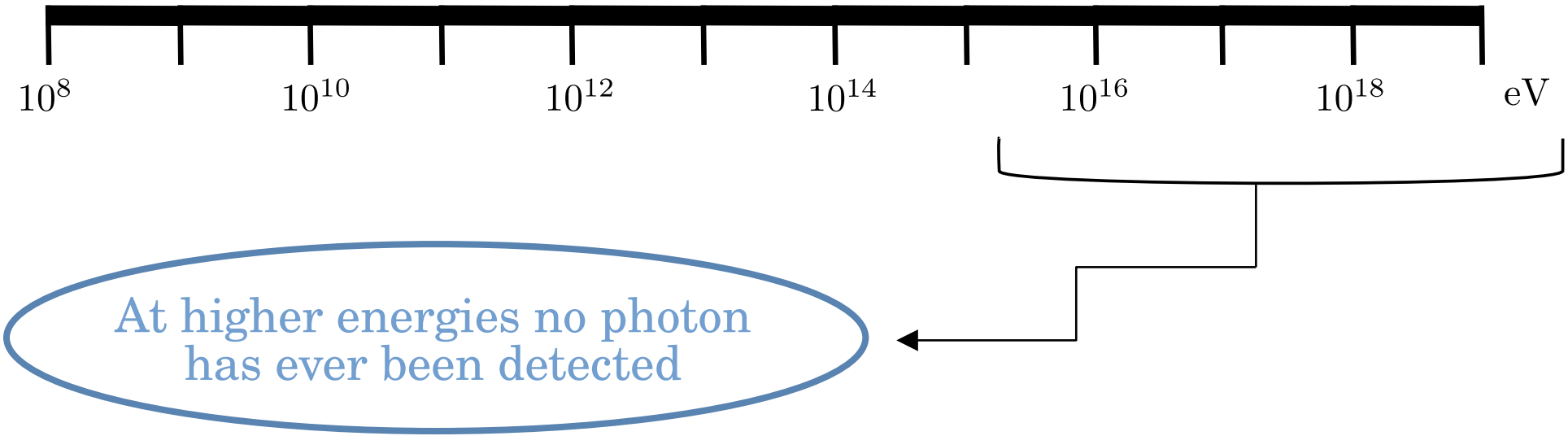

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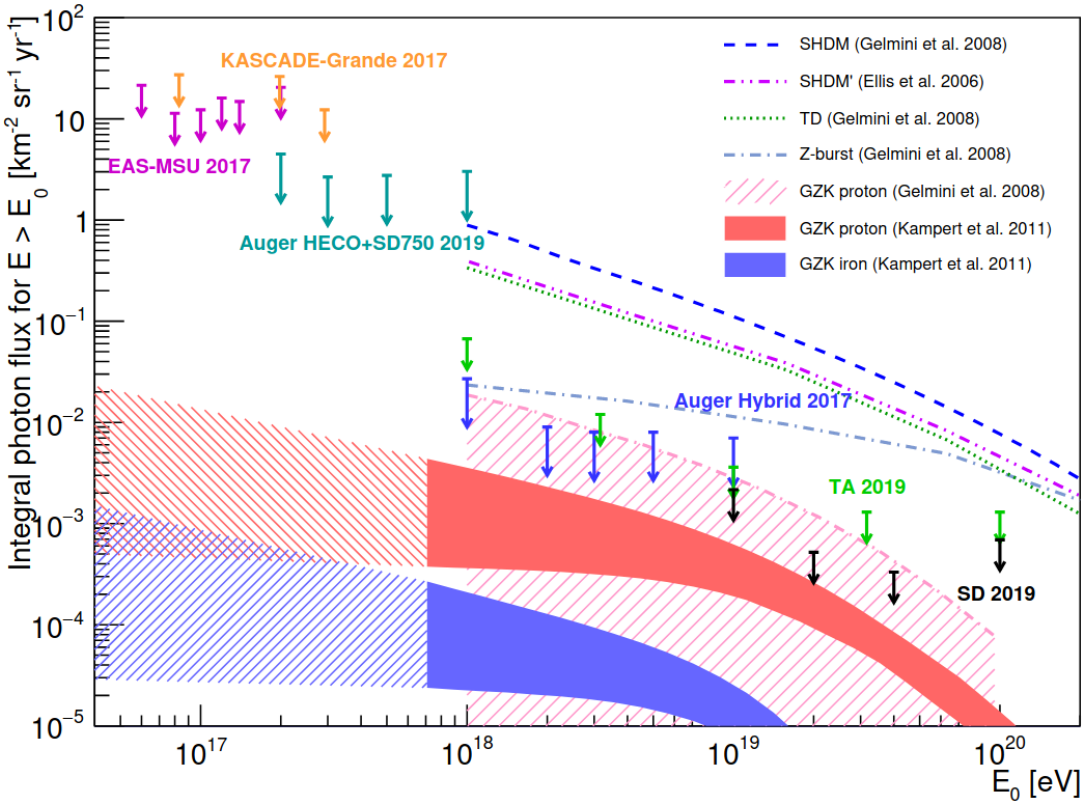


Upper limits (UL) from several experiments for the spectrum of ultra-high energy photons compared to different model predictions

(Rautenberg, Julian et al, in 36th International Cosmic Ray Conference (ICRC 2019))

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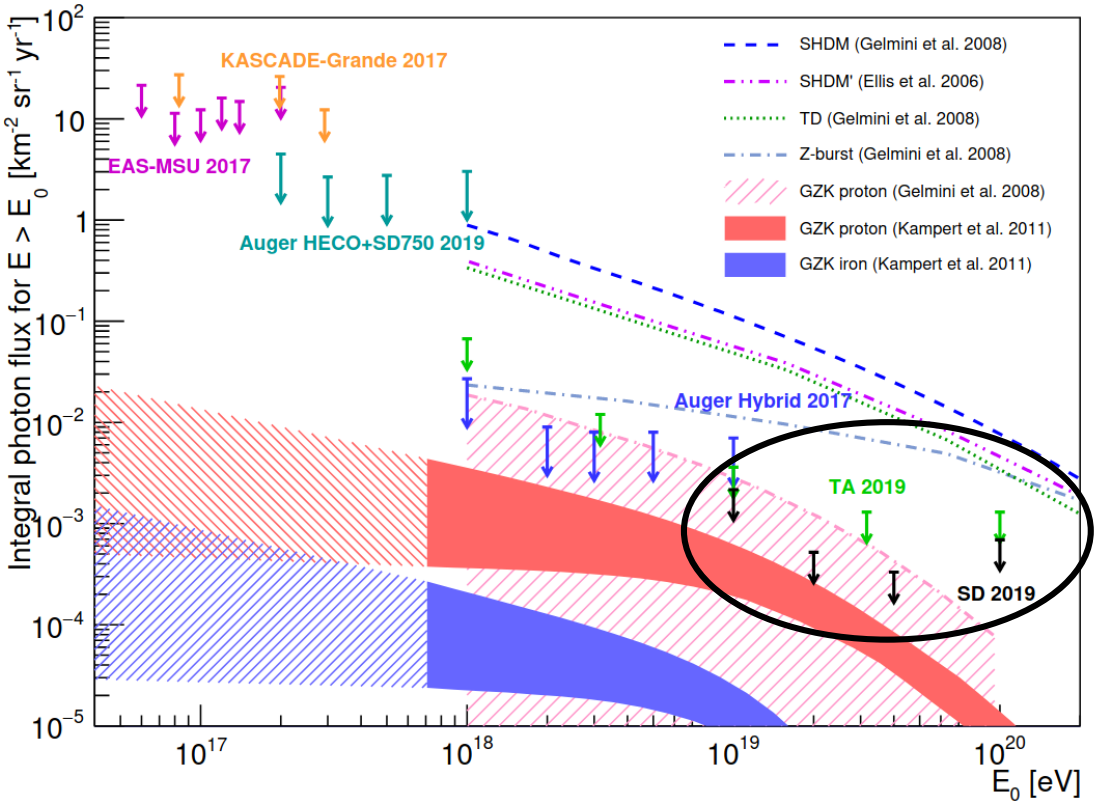


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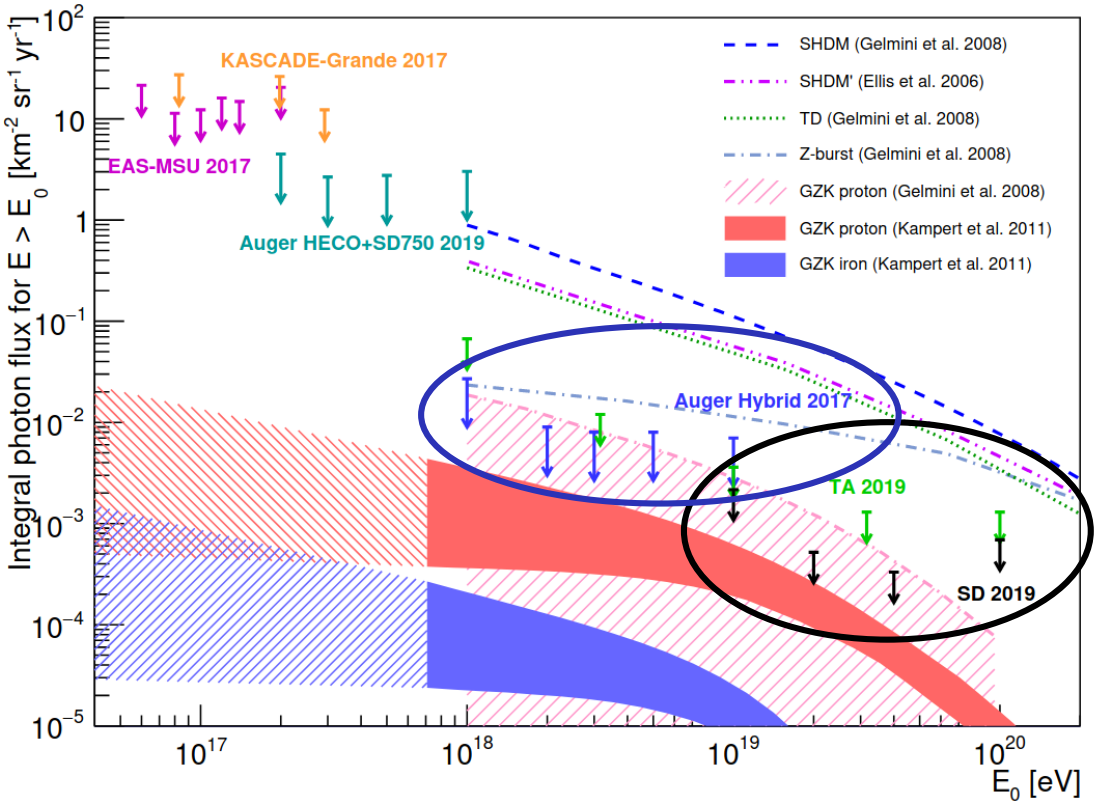


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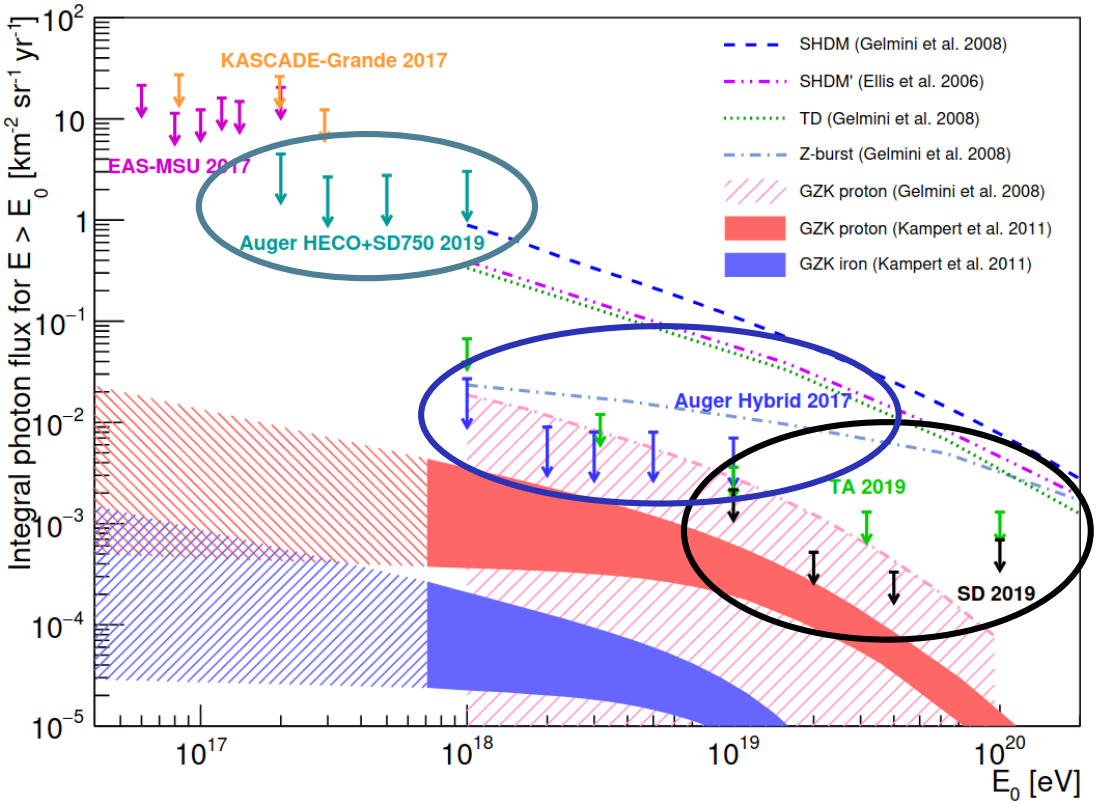


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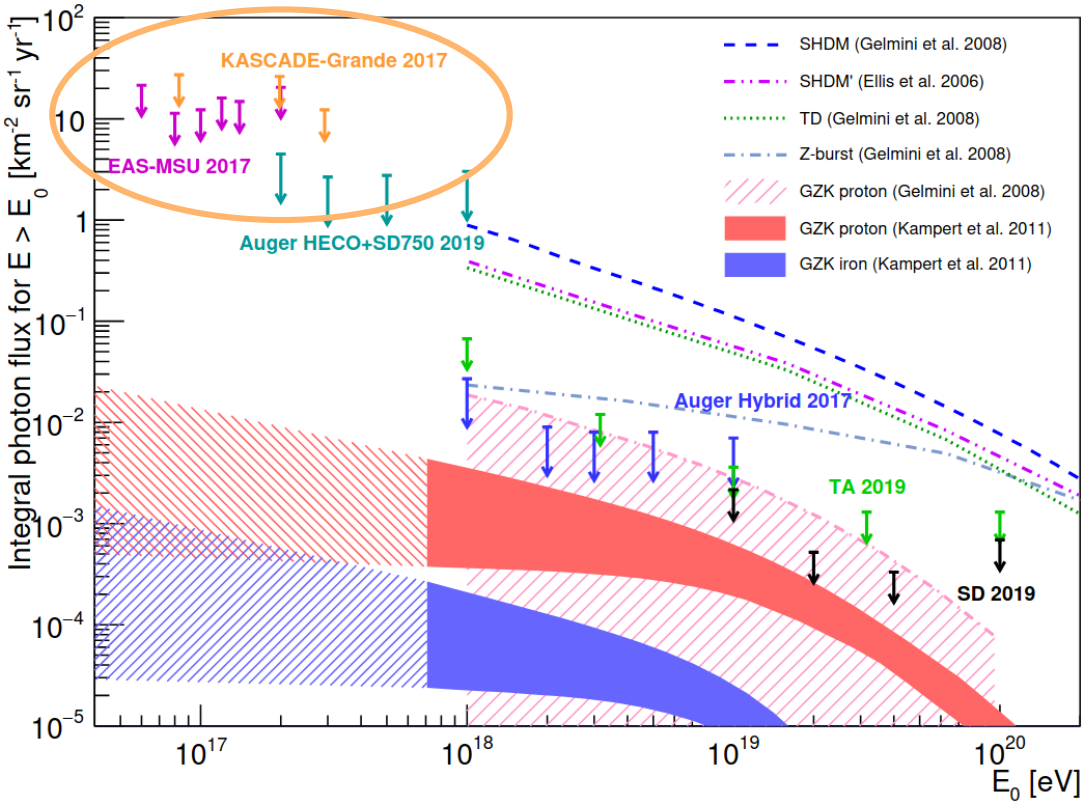


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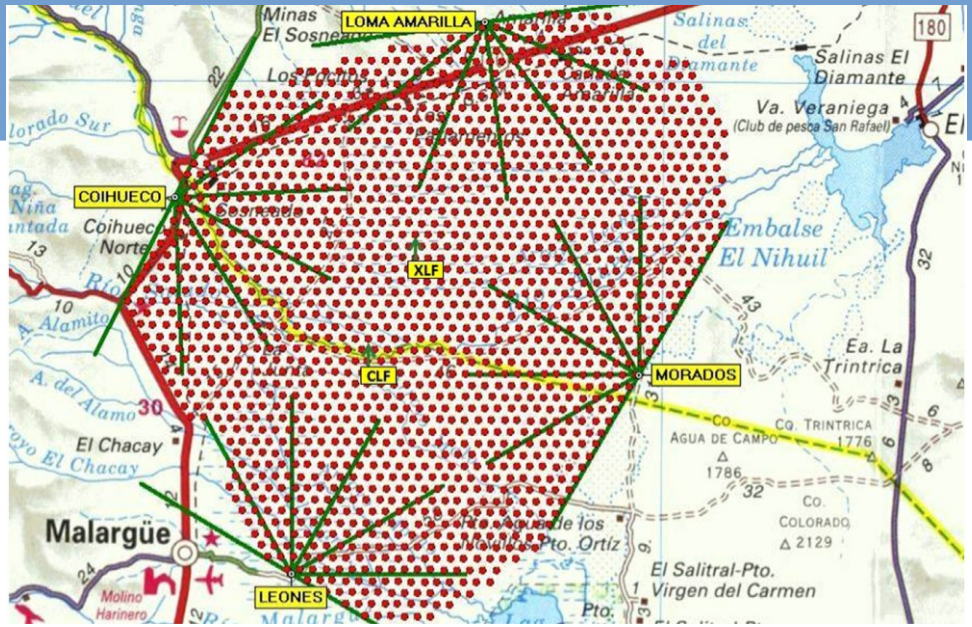
# The Pierre Auger Observatory

- 3000 km$^2$ ground array
- designed to detect ultra high energy cosmic rays, $10^{18}$ eV
- detecting the secondary particles of the shower

Using the observatory to:

- **detect high energy photons**
- **energies above $10^{16}$ eV**




Map of the Pierre Auger Observatory
Source: Pierre Auger Collaboration. "The Pierre Auger cosmic ray observatory". (2015)

High energy particles interact in the atmosphere creating an **extensive air shower (EAS)**

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Using the observatory to:

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- **energies above $10^{16}$ eV**

**by taking advantage of new instruments in the observatory**

# Discriminant Analysis

Distinguishing between:

Cosmic Ray showers

Photon showers

Using:

- **Lateral profile of the air shower**
- **Deepness of the shower maximum**
- **Number of triggered stations**

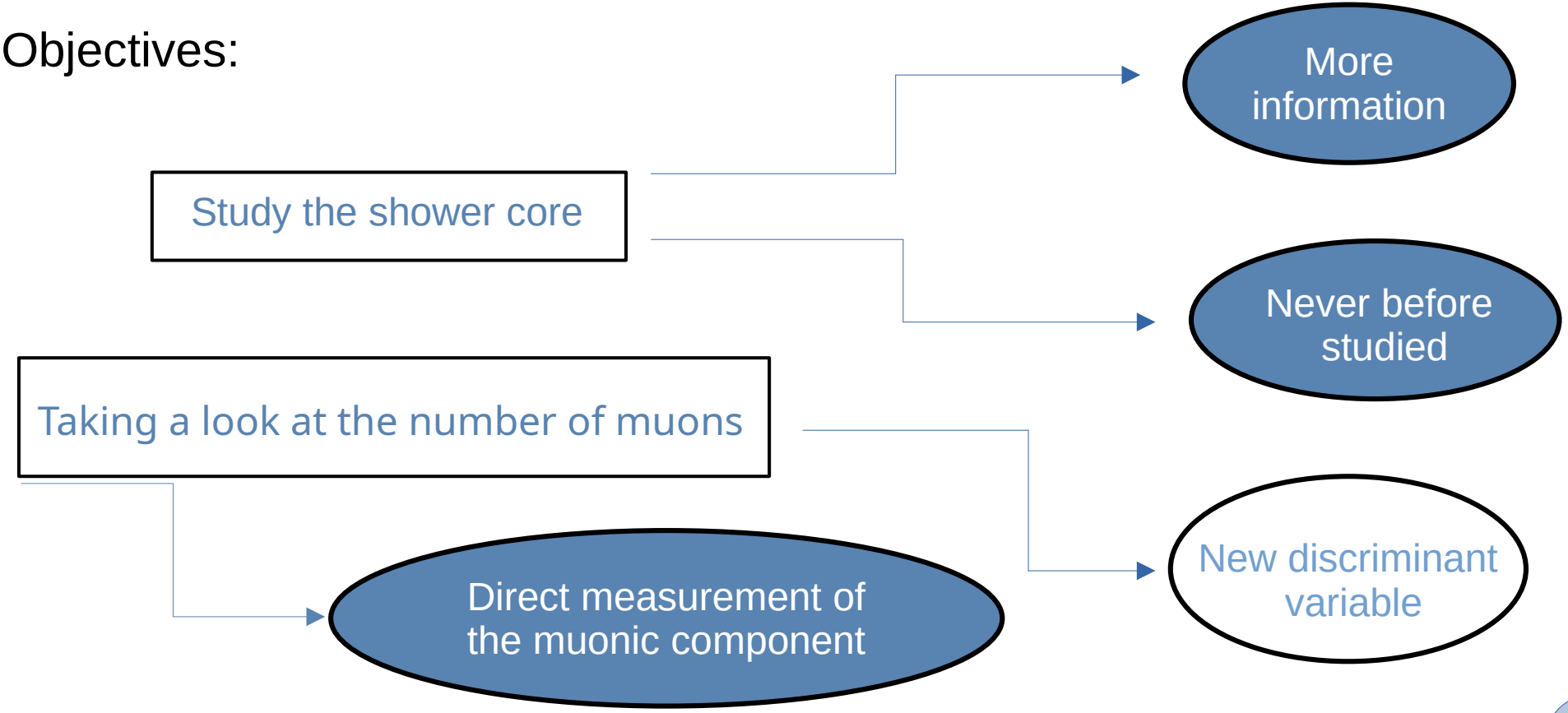

It has two main components:

muonic

electromagnetic

# Phenomenology Studies
## Another discriminant property

Objectives:



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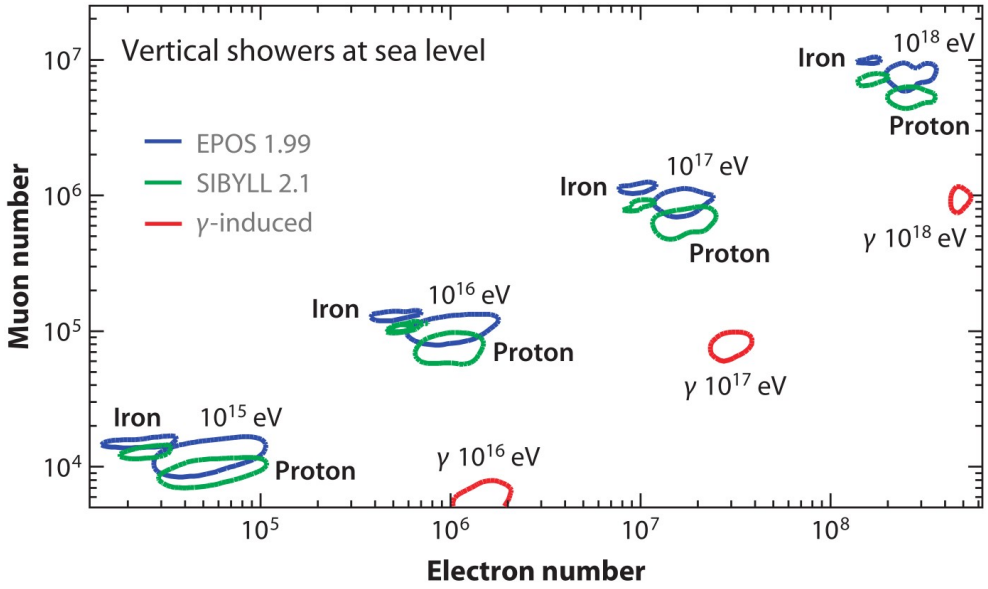
Study the shower core

Taking a look at the number of muons




Predictions for the correlation between the number of electrons and the number of muons at sea level.
(Annu. Rev. Nucl. Part. Sci. 2011. 61:467–89 (2018)
Doi:10.1146/annurev.nucl.012809.104544 )

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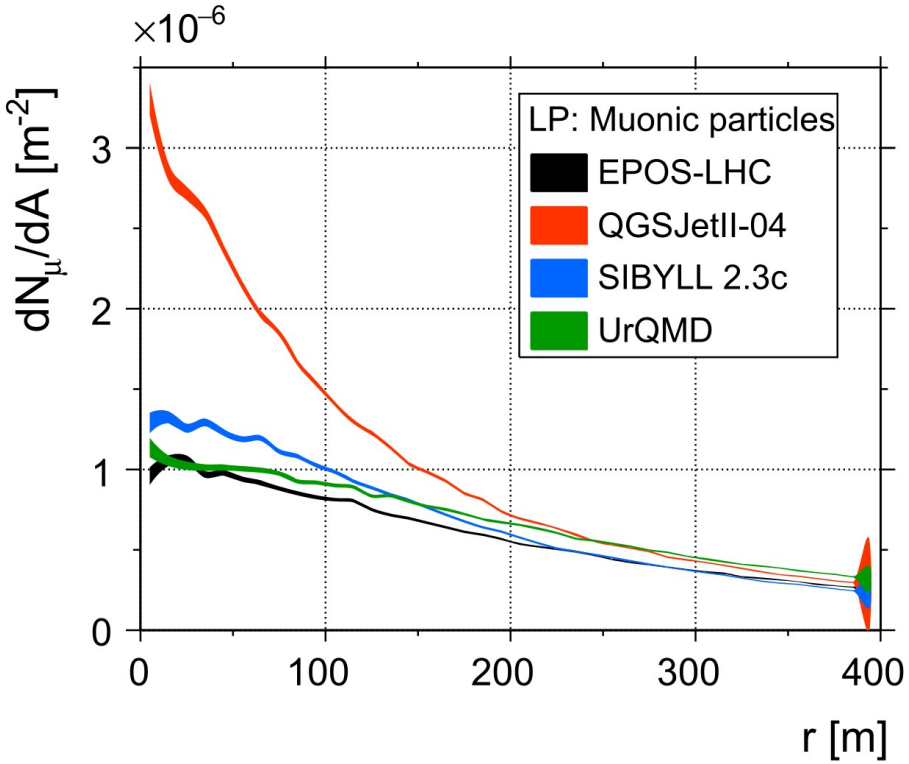


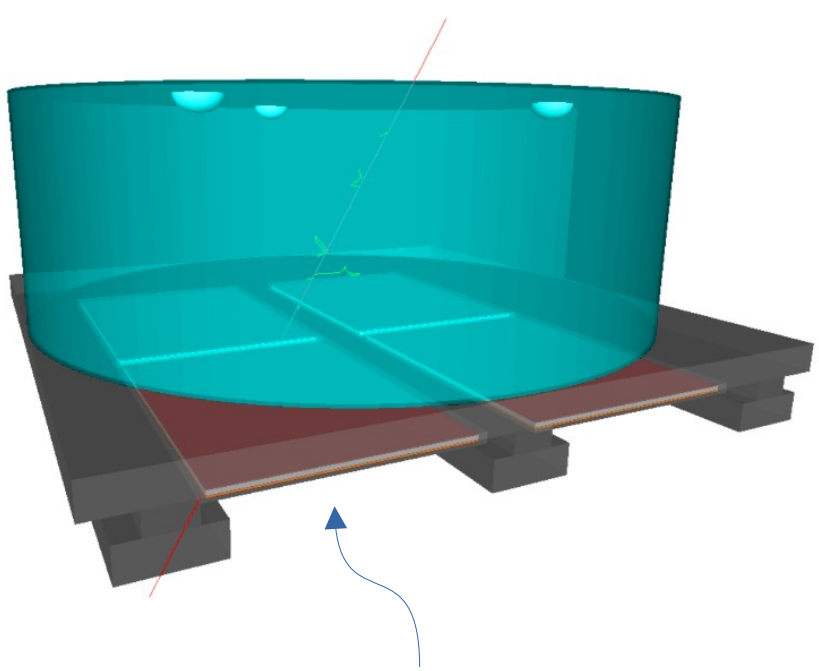

Muon LDF contribution from events lead by muonic family particles.

(Eur. Phys. J. C (2021) 81:369
https://doi.org/10.1140/epjc/s10052-021-09160-2)

# MARTA
## Upgrade to the Observatory

To be implemented in 2022

Water Cherenkov Tank



**Segmented nature of the RPC detectors:**

- High-resolution time and position information of individual muons in EASs will be available for the first time

Resistive Plate Chambers (RPC's)

directly measure the number of muons

# MARTA
## Upgrade to the Observatory

To be implemented in 2022

Seven stations:

- 3 of the 433 m array
- 4 of the 750 m array

**Segmented nature of the RPC detectors:**

- High-resolution time and position information of individual muons in EASs will be available for the first time

Energy range:

**10 PeV to 300 PeV**

# Next Steps and Goals

**Starting with:**

Phenomenology Study

**Extensive Air Showers:**

- Physics – core of the shower
- Simulations - CORSIKA

↓

Looking at the muon measurements near the shower core

**Using what was learned to:**

- Construct a discriminant analysis for MARTA using muon measurements

**And then:**

- Search for high energy photon counterparts of Fast Radio Bursts

# Thank you!

This work is supported by FCT under the grant PRT/BD/153345/2021