TÉCNICO LISBOA

LIP

Development of a next-generation detector concept to detect astrophysical gamma-rays

The possibility of detecting high-energy astrophysical neutrinos

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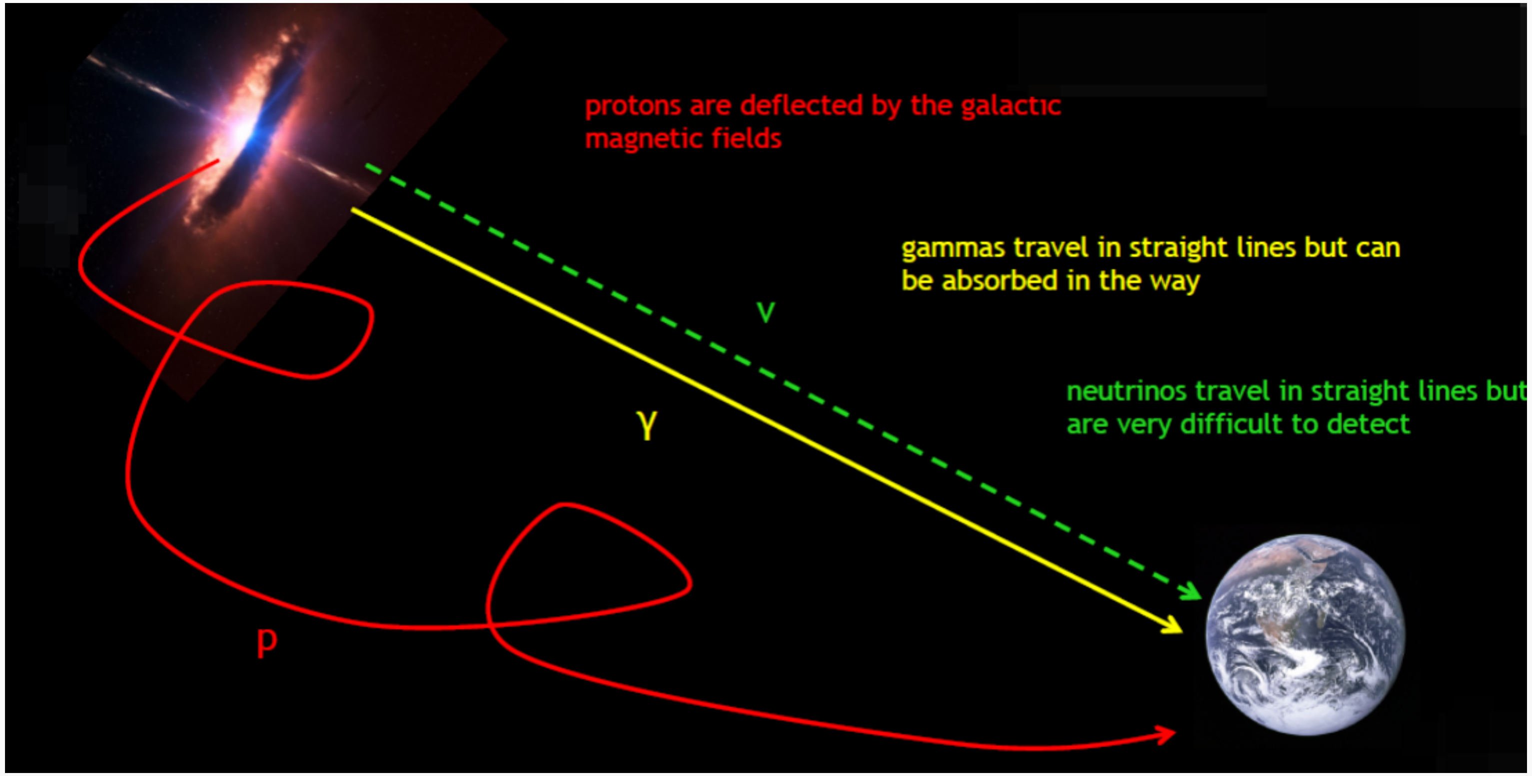
Why Gamma-Rays?

- Gammas travel long distances in straight lines, and point to their production source, but can be absorbed along the way;
  - Photons can be of extremely high energies, from a few GeV to a few hundreds of TeV;
  - Scientific interest:
    - Key to understanding the acceleration mechanism of cosmic rays in our galaxy;
    - **Violent astrophysical phenomena, i.e. pulsars and black holes**;
    - Galactic magnetic fields;
    - Photon radiation fields in the Universe;
    - **Indirect search of dark matter** (interactions involving WIMPs);
    - Test fundamental properties of quantum gravity;(...)
    - ...

Why Gamma-Rays?

- Protons suffer a considerable amount of defelection due to magnetic fields. Their trajectory is highly irregular;

- Neutrinos also travel in straight lines. Less likely to be absorbed, yet harder to detect;



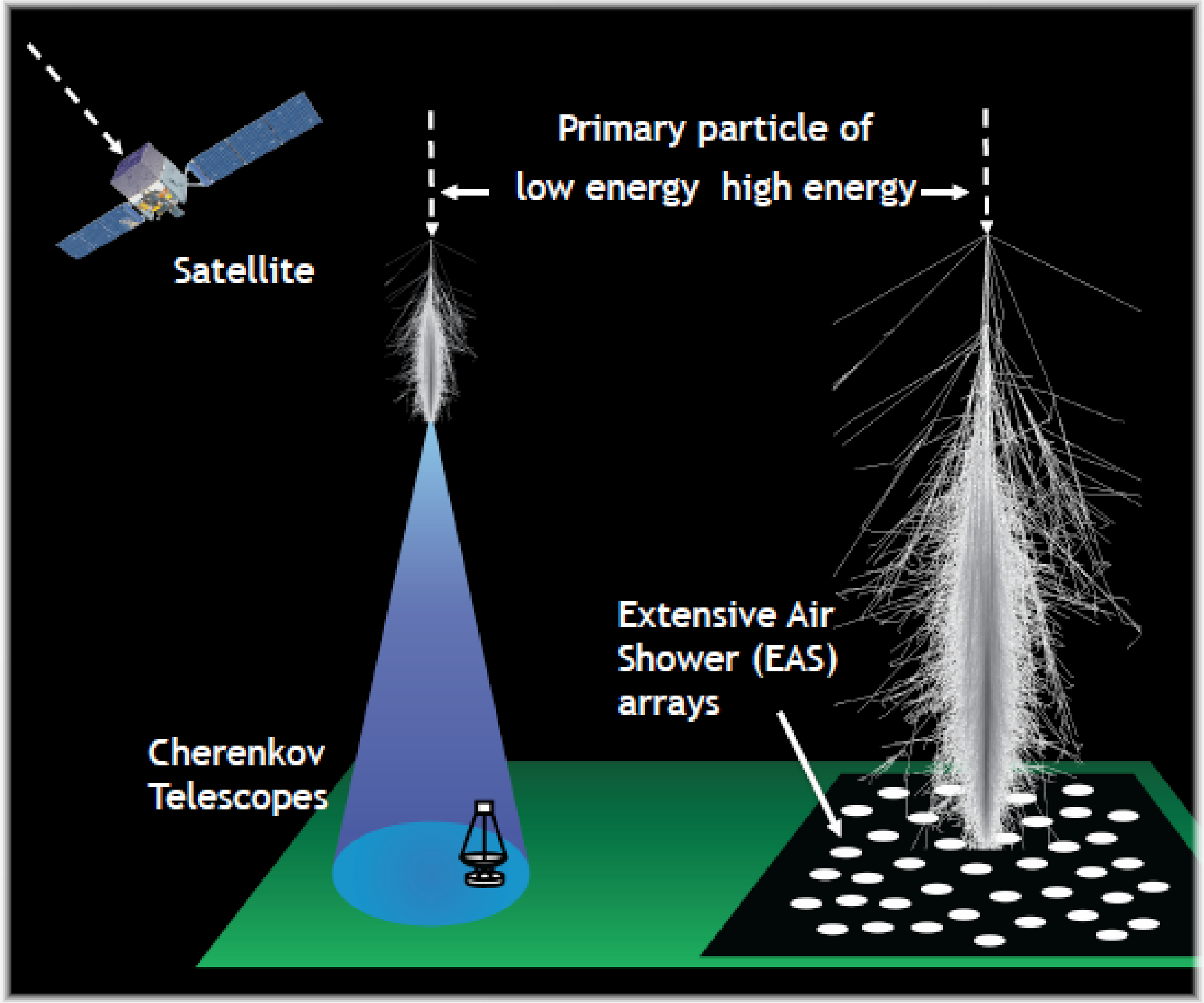
Detection techniques

High-energy (HE) gamma rays
(10 MeV - 100 GeV):

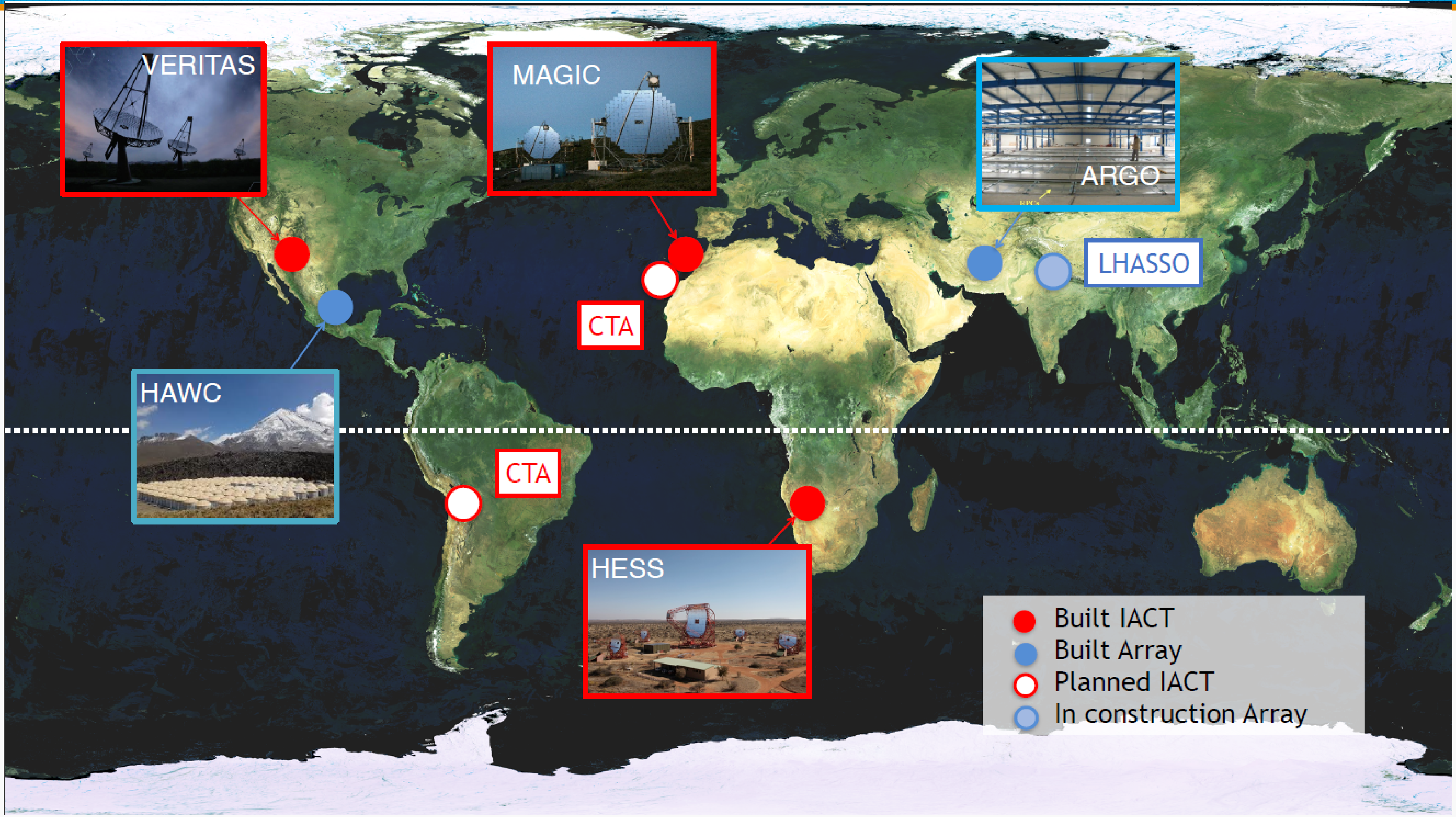
- Satelite-based telescopes;

Very-High-energy (VHE) gamma rays
(100 GeV - 100 GeV):

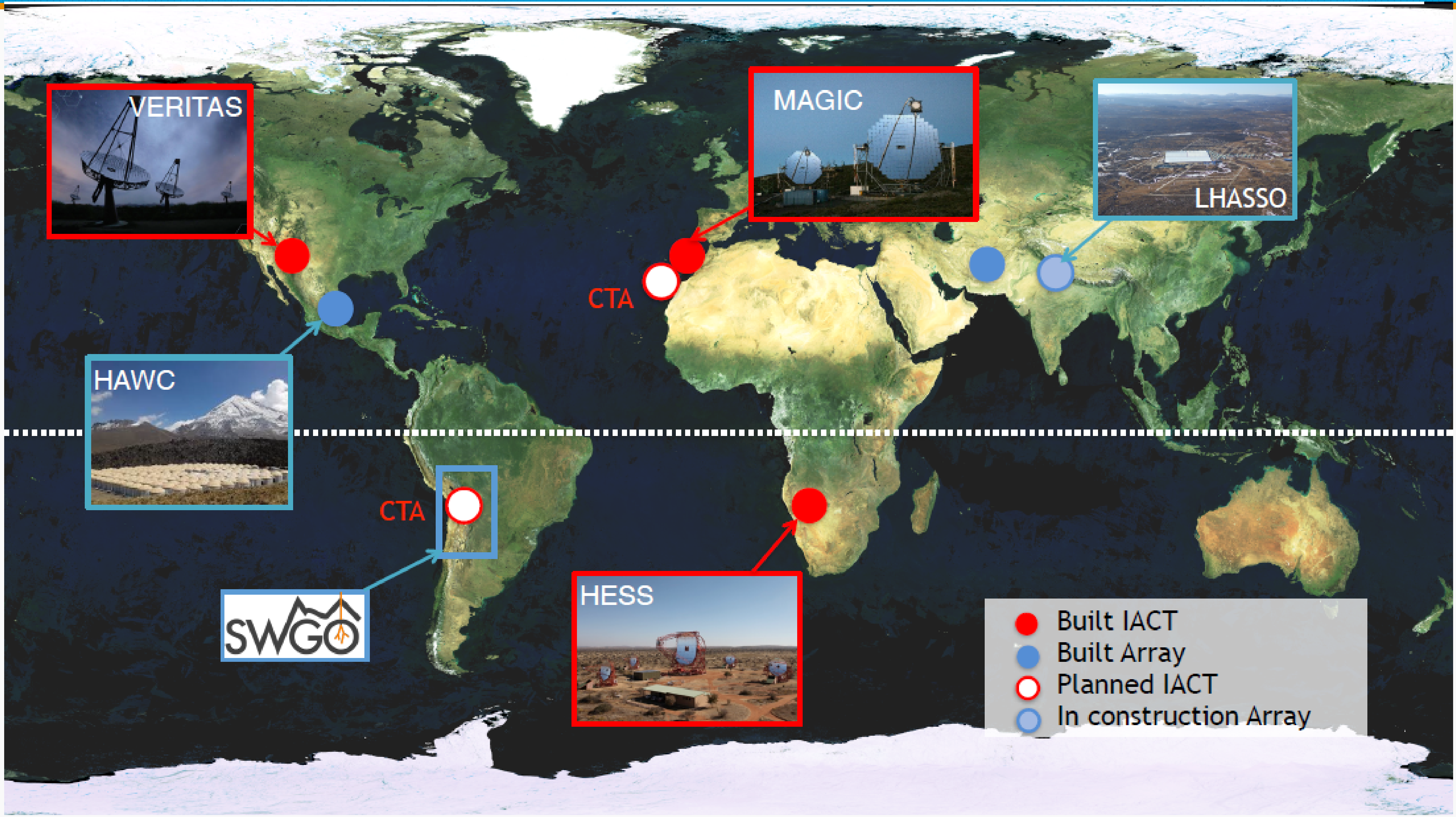
- Ground-based telescopes:
  - IACT (Imaging Atmosphere Cherenkov Telescopes);
  - EAS (Extensive Air Shower) arrays of detectors.



Current Experimental Panorama

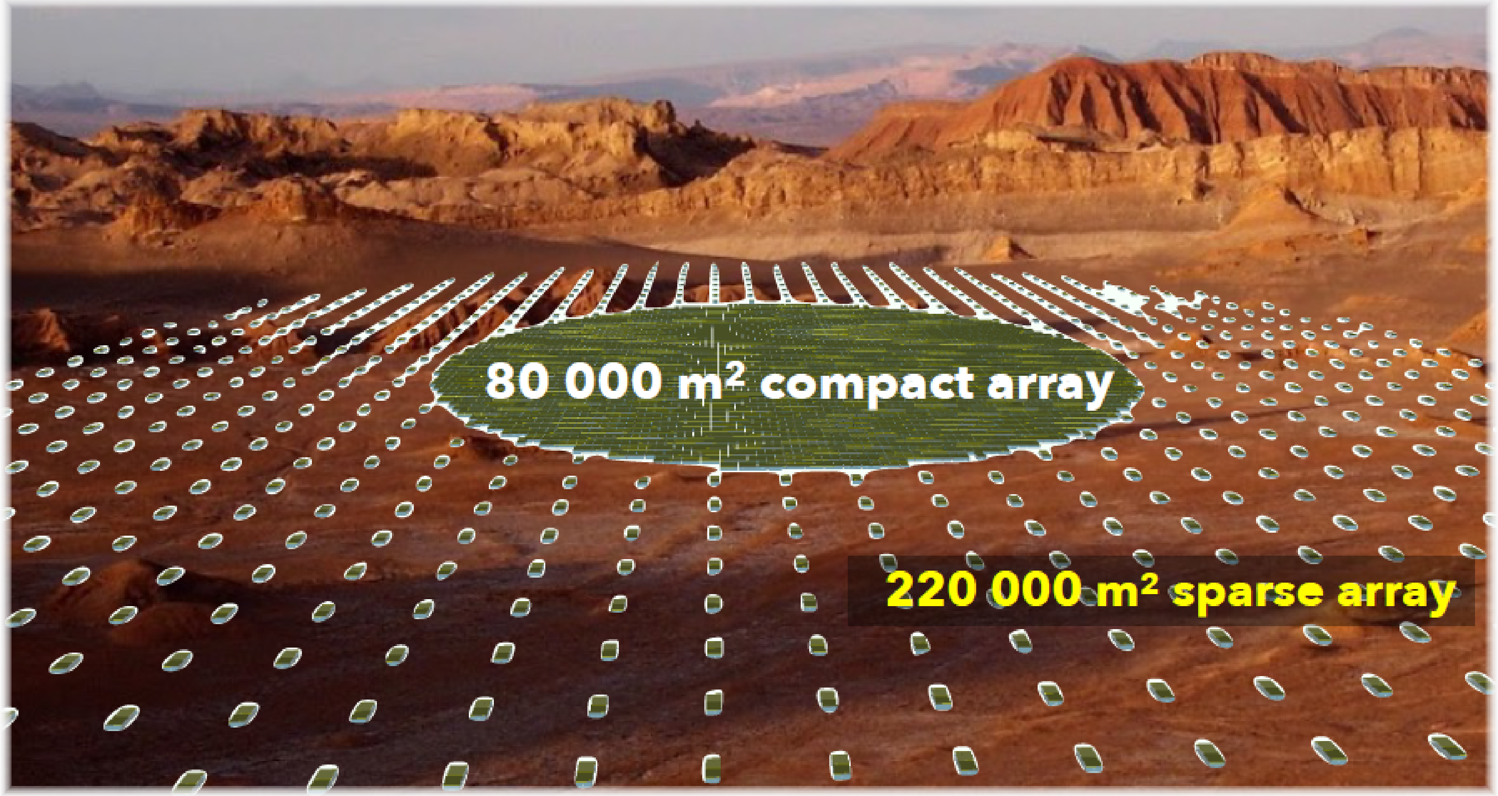


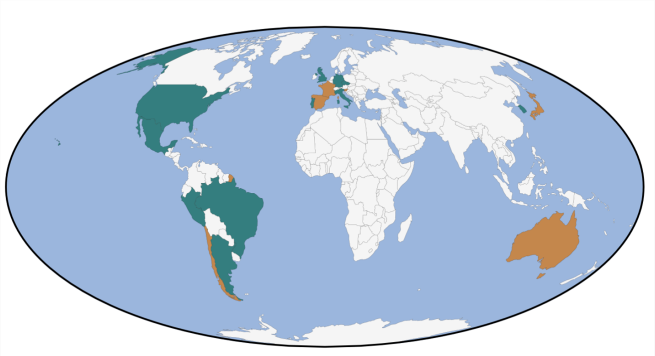
Current Experimental Panorama



What is SWGO?

- **S**outhern **W**ide-Field **G**amma-ray **O**bservatory
- 42 research institutions from 11 countries
- Large compact array located at an altitude of 5000m, with an area of 80 000 m^2





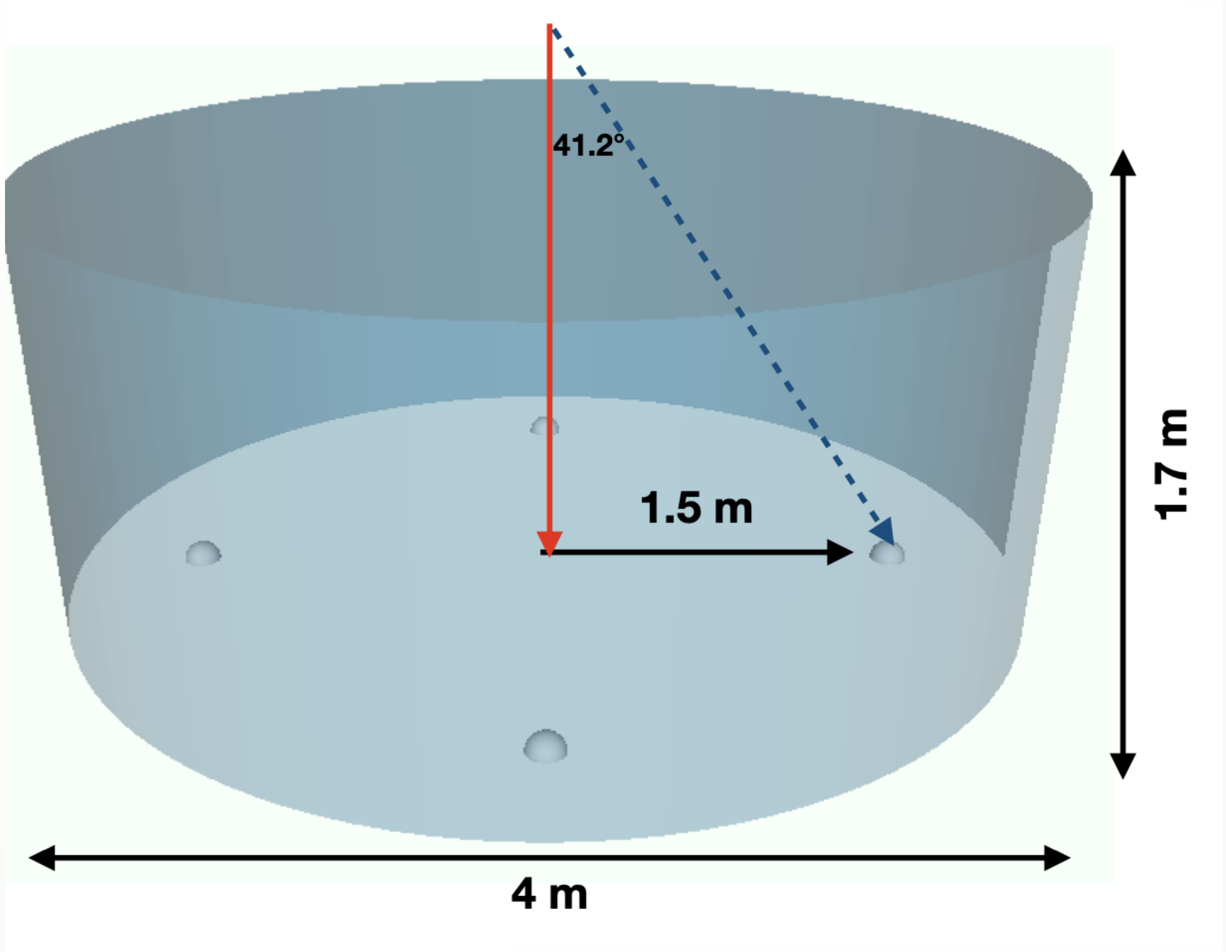
3-year R&D project to design and plan the next generation wide field-of-view gamma-ray able to survey and monitor the Southern sky

What is SWGO?

- Based on the Water Cherenkov Detection (WCD) calorimetric measurement technology

- Modular (station as a basic unit)

- Covers an energy range from hundreds of GeV to hundreds of TeV



Current LIP station concept. The tank is filled with water, and at the bottom are placed 4 PMTs

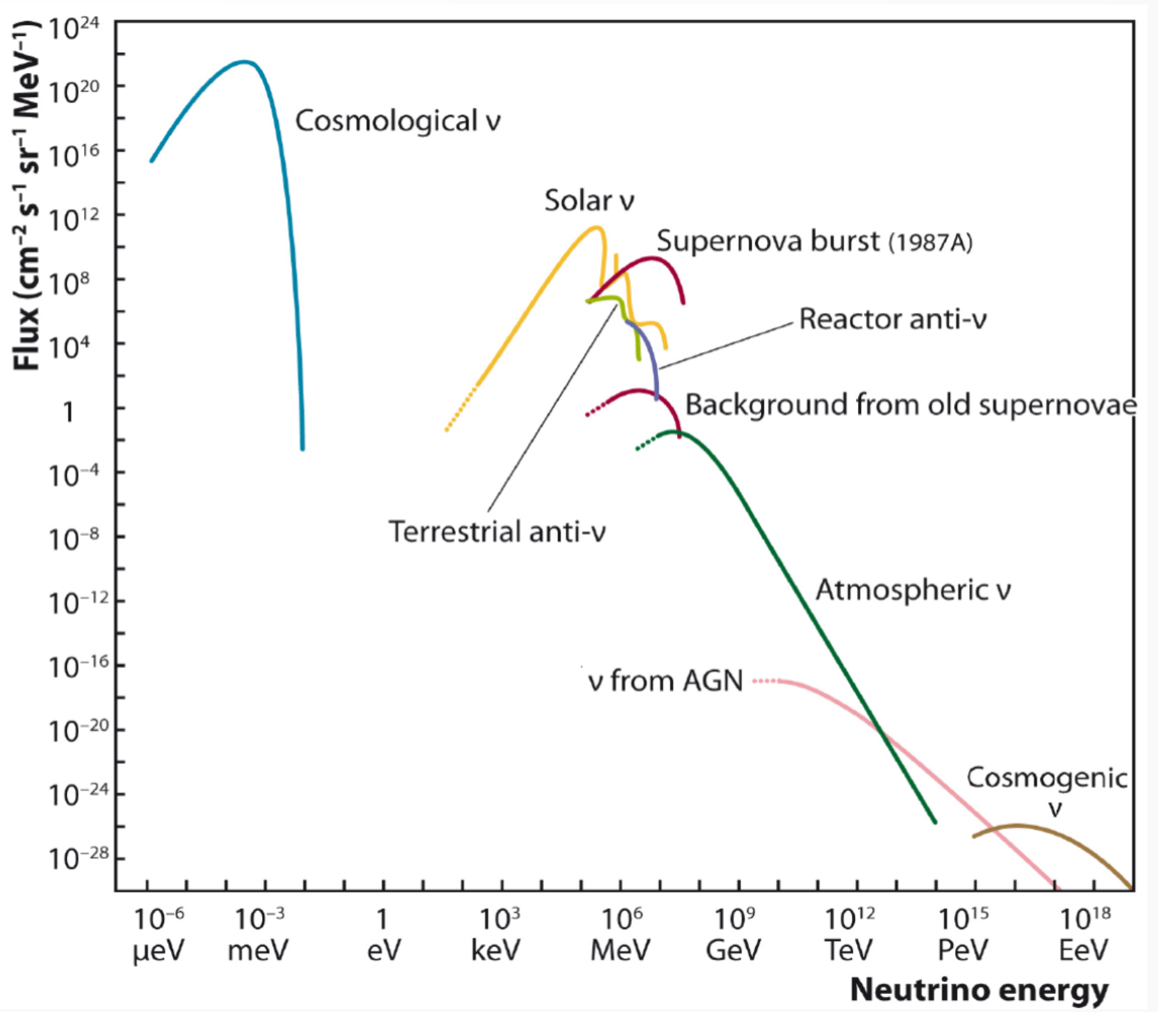
Can neutrinos be measured at SWGO?

Astrophysical neutrinos:

- Can carry extremely high energy (i.e. of the order of PeV or even EeV);
- Point to intense events in the cosmos, such as black holes , pulsars, remnants of supernovae, gamma-ray bursts, active galactic nuclei and possibly binary black hole mergers.

The most energetic neutrinos witnessed thus far were **astrophysical neutrinos** captured by the IceCube experiment.

Due to the characteristics of the SWGO, neutrino detection is an interesting possibility.

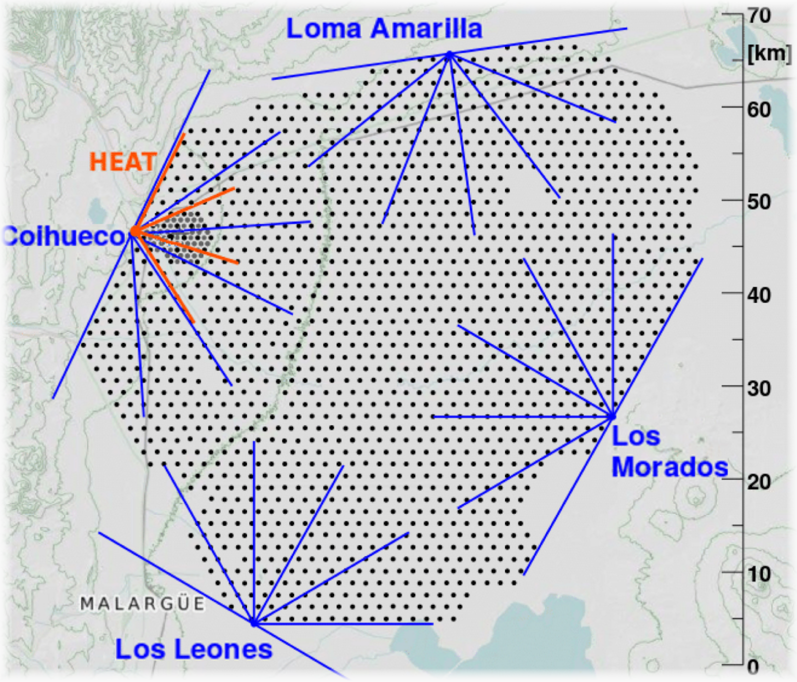


Neutrino energy spectrum.
SWGO:10^11 to 10^15 eV

Astrophysical neutrino experiments

- **IceCube** (range of PeV);
  - July 2018, IceCube announced the detection of neutrinos and photons from blazar TXS 0506+056;

- **Pierre Auger Observatory** (range of EeV);
  - No UHE neutrinos have been measured thus far.



Map of the Pierre Auger Observatory.

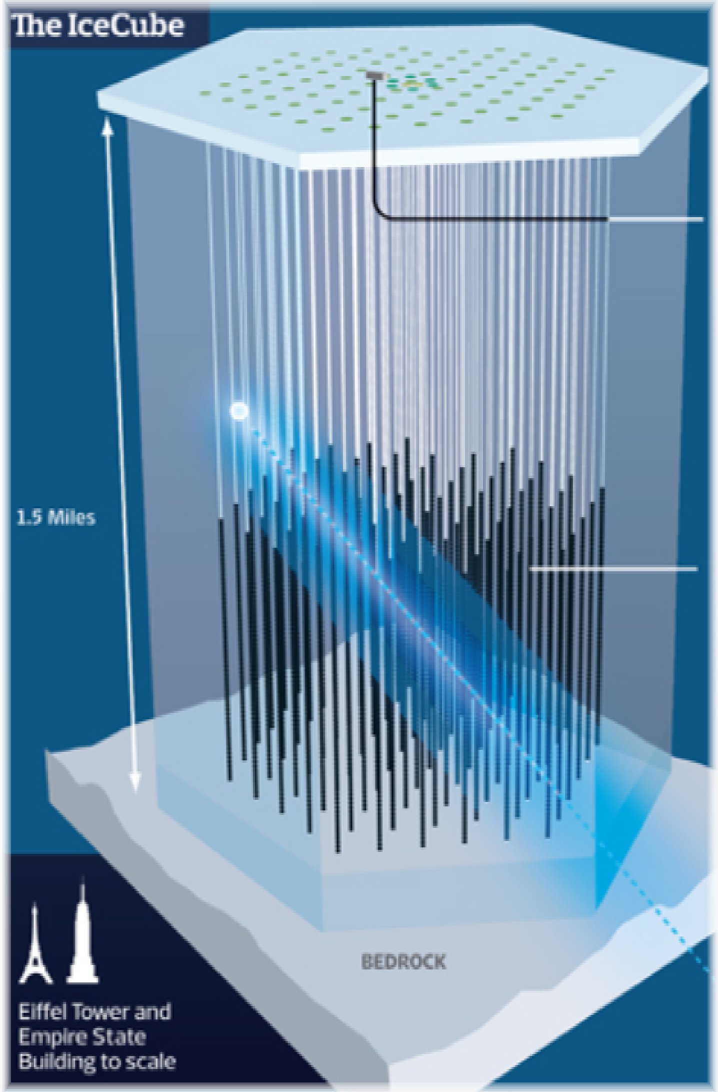
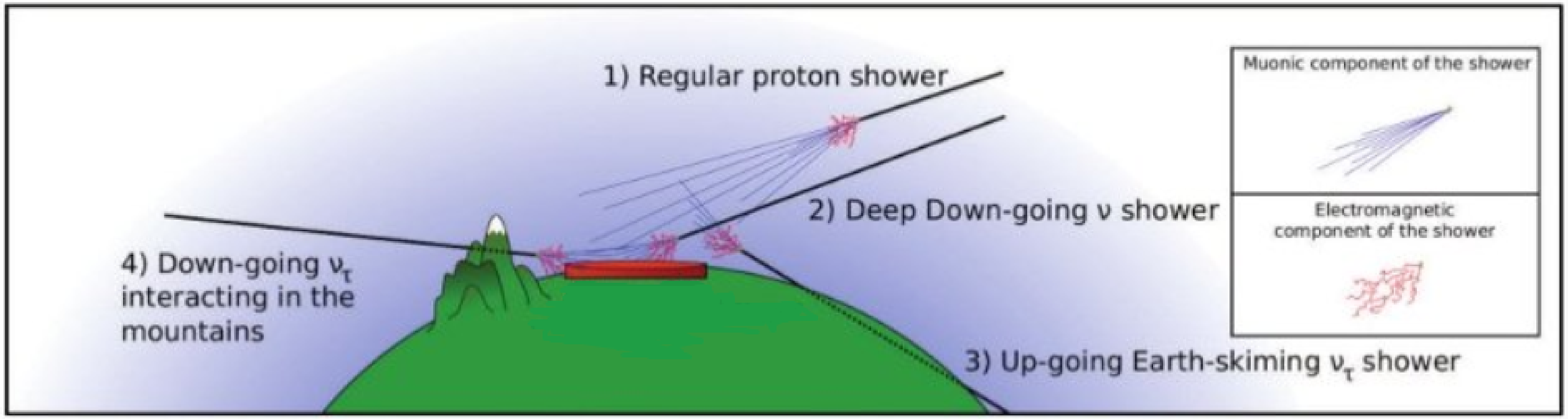


Diagram of the IceCube neutrino observatory

Possible Experimental Signatures

The signature of a neutrino events is likely to fit into one of two cases:

- A **single station with a high signal**;
- The presence of **very inclined showers** produced close to the ground (i.e. after having traversed a large amount of atmosphere)



Is this measurement possible at SWGO?

- Estimation of fluxes and neutrino cross-sections;

- Estimation of background due to extensive air showers induced by gamma-rays and cosmic rays (protons);

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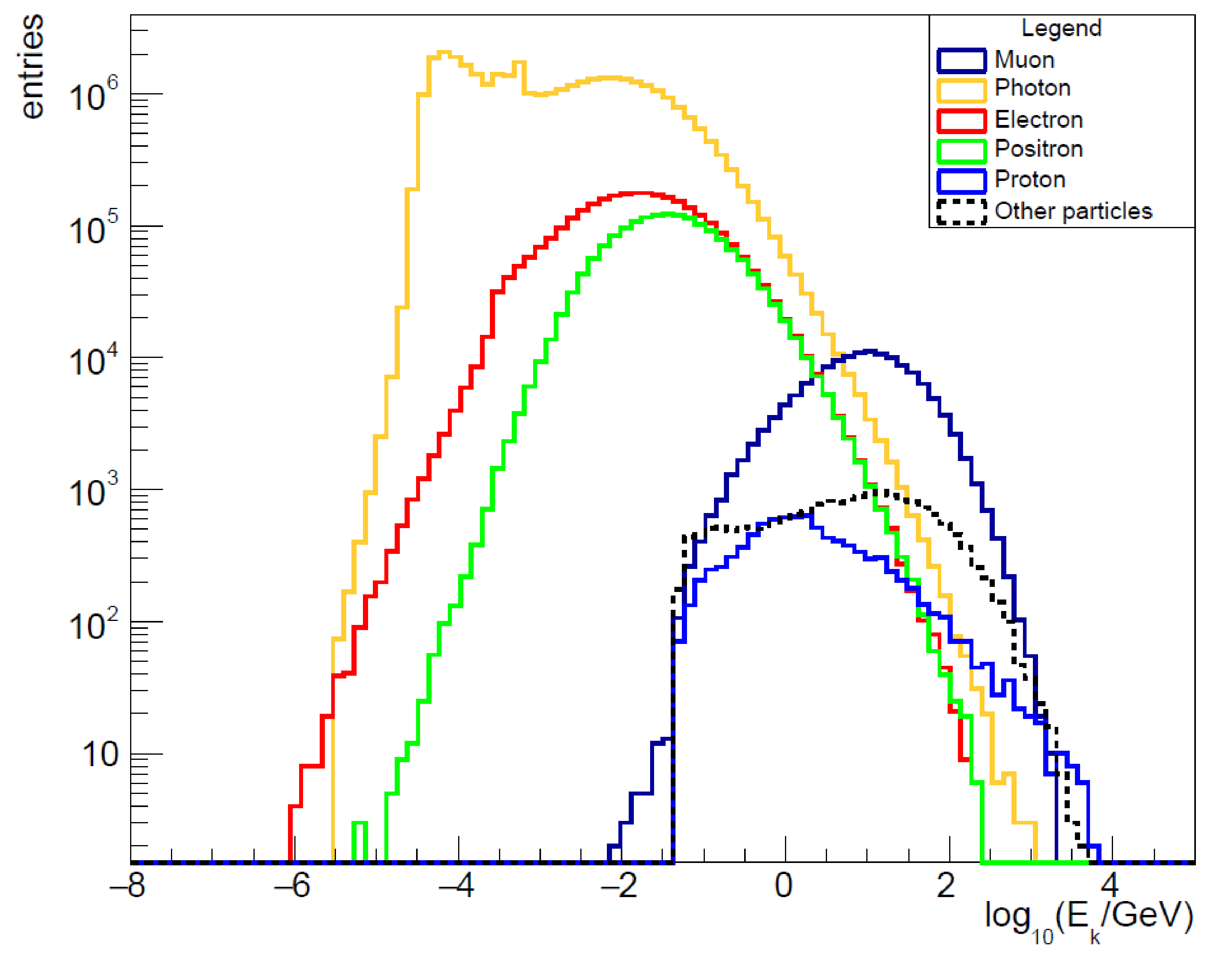
Showers generated using **CORSIKA** (**CO**smic **R**ay **SI**mulations for **KA**scade), detector response simulated via **Geant4**

Shower Particles at the Ground



Proton energy E =4 TeV
4000 showers

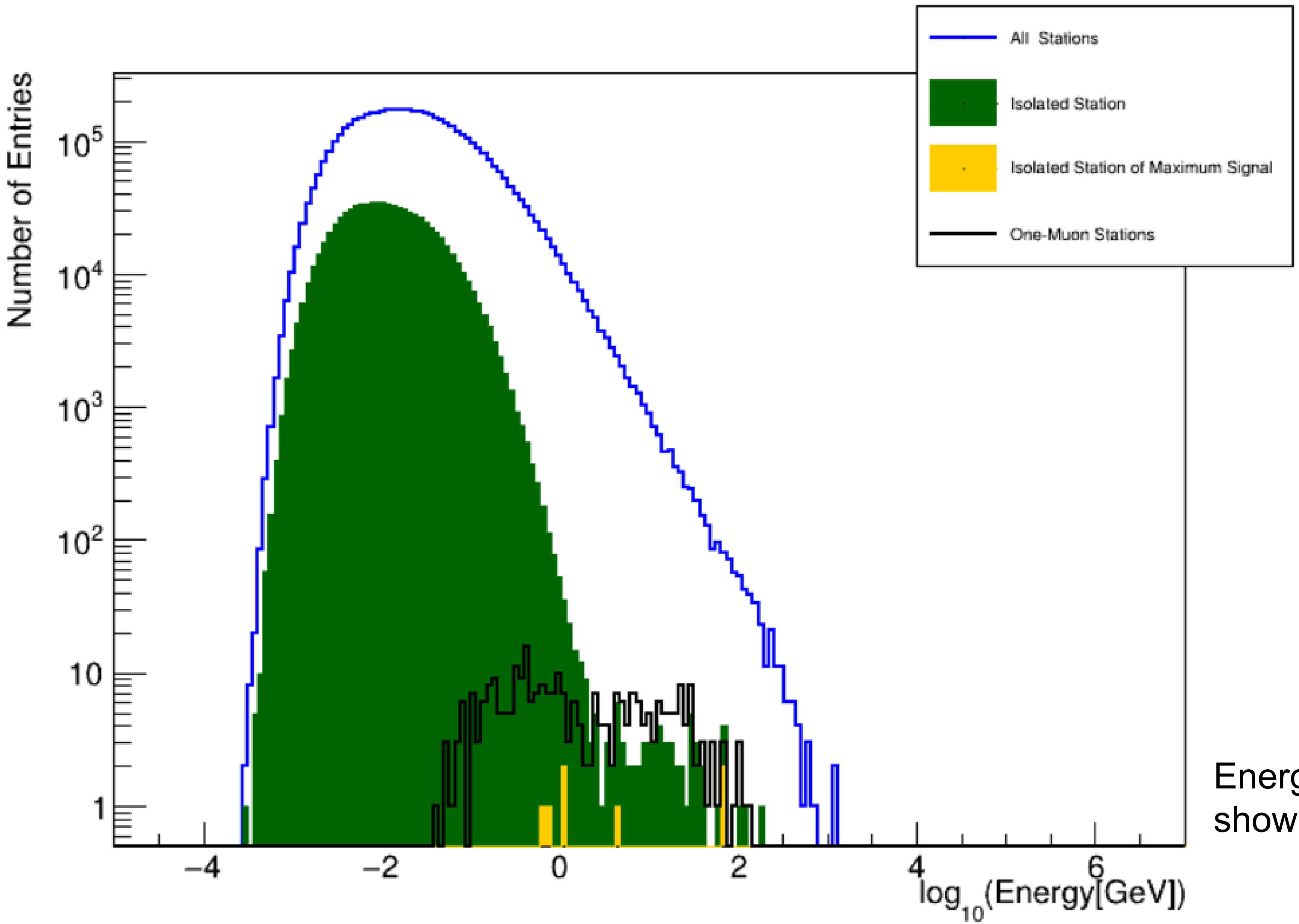
Procedure

- Isolated stations: no other nearby stations register any signal.

    - Isolated stations of maximum signal: in an event, an isolated station registers the maximum signal;

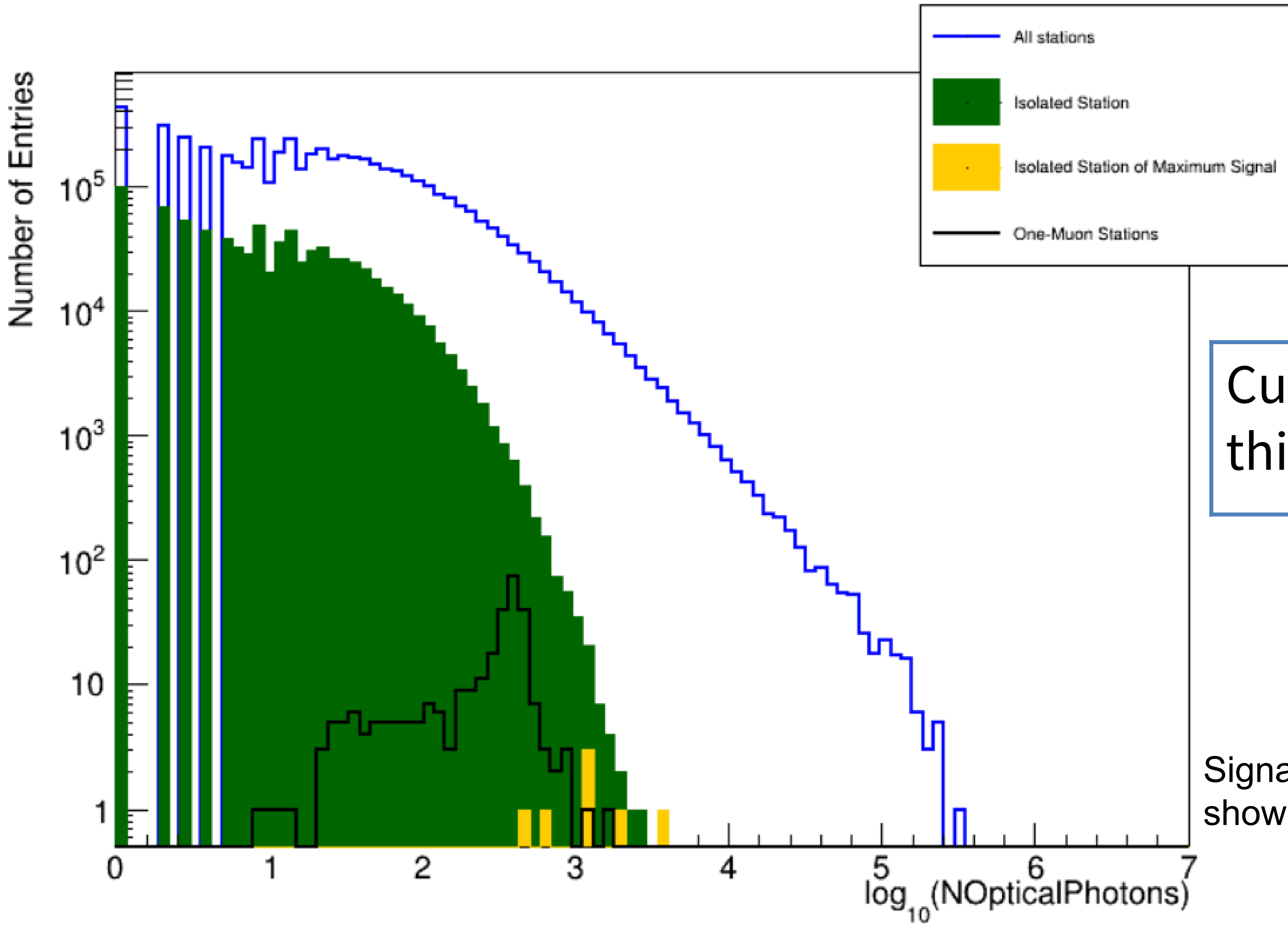
- One muon stations: register only a single muon.

Energy in WCD Stations



Energy spectrum for the case of a shower generated by a 1 TeV photon.

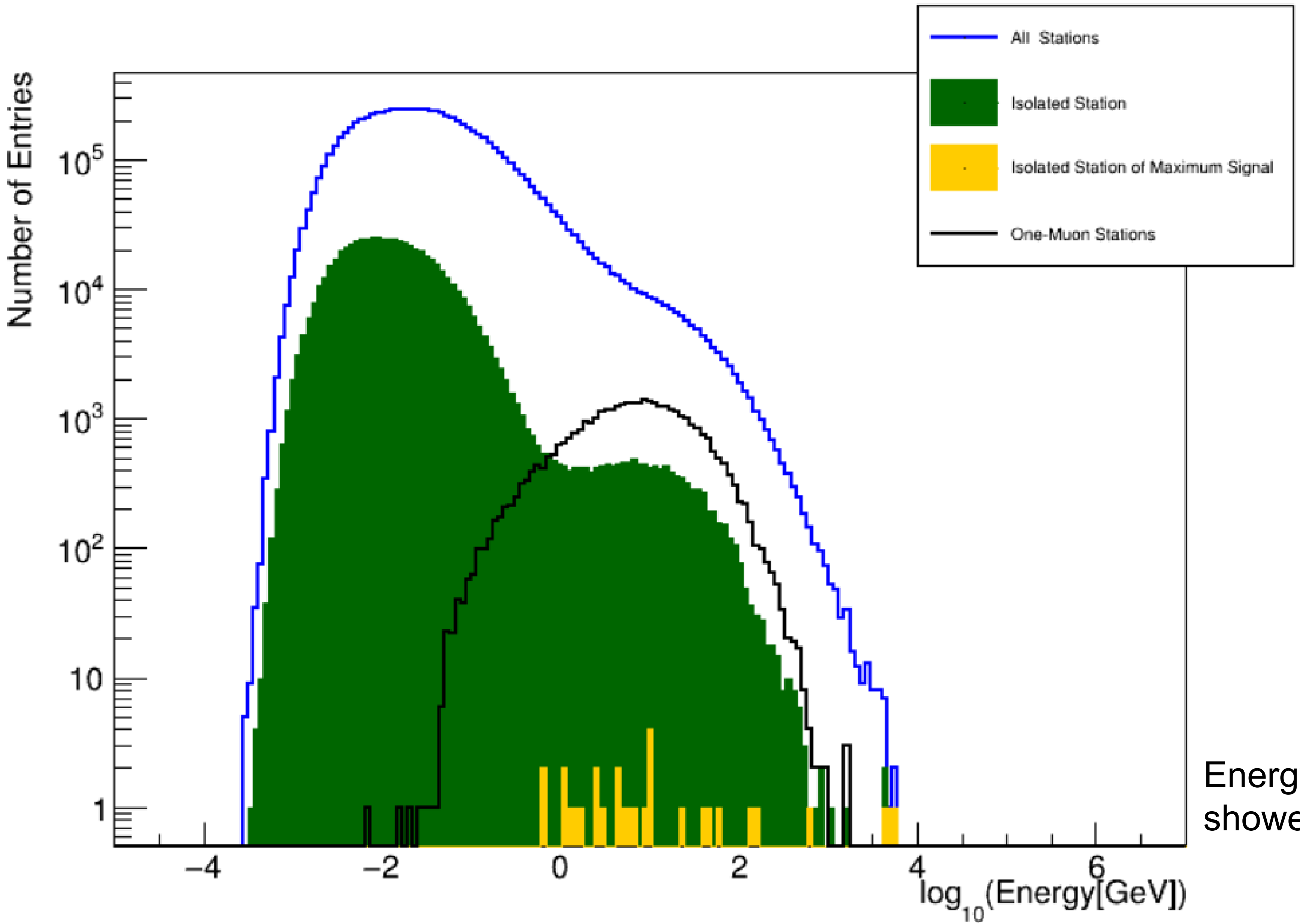
Signal at the Ground



Cut at x = 4 would remove this source of background.

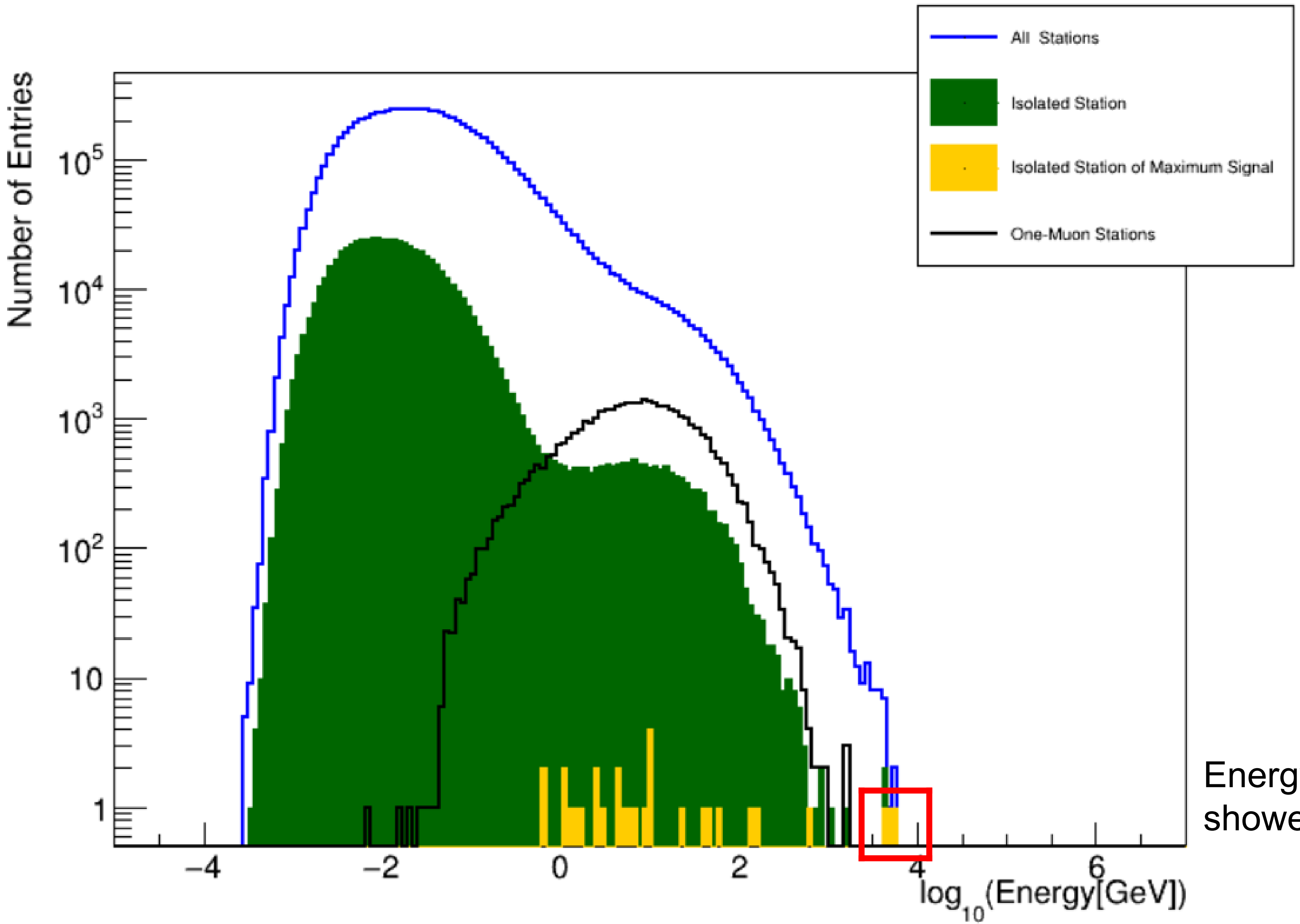
Signal spectrum for the case of a shower generated by a 1 TeV photon.

Energy in WCD Stations



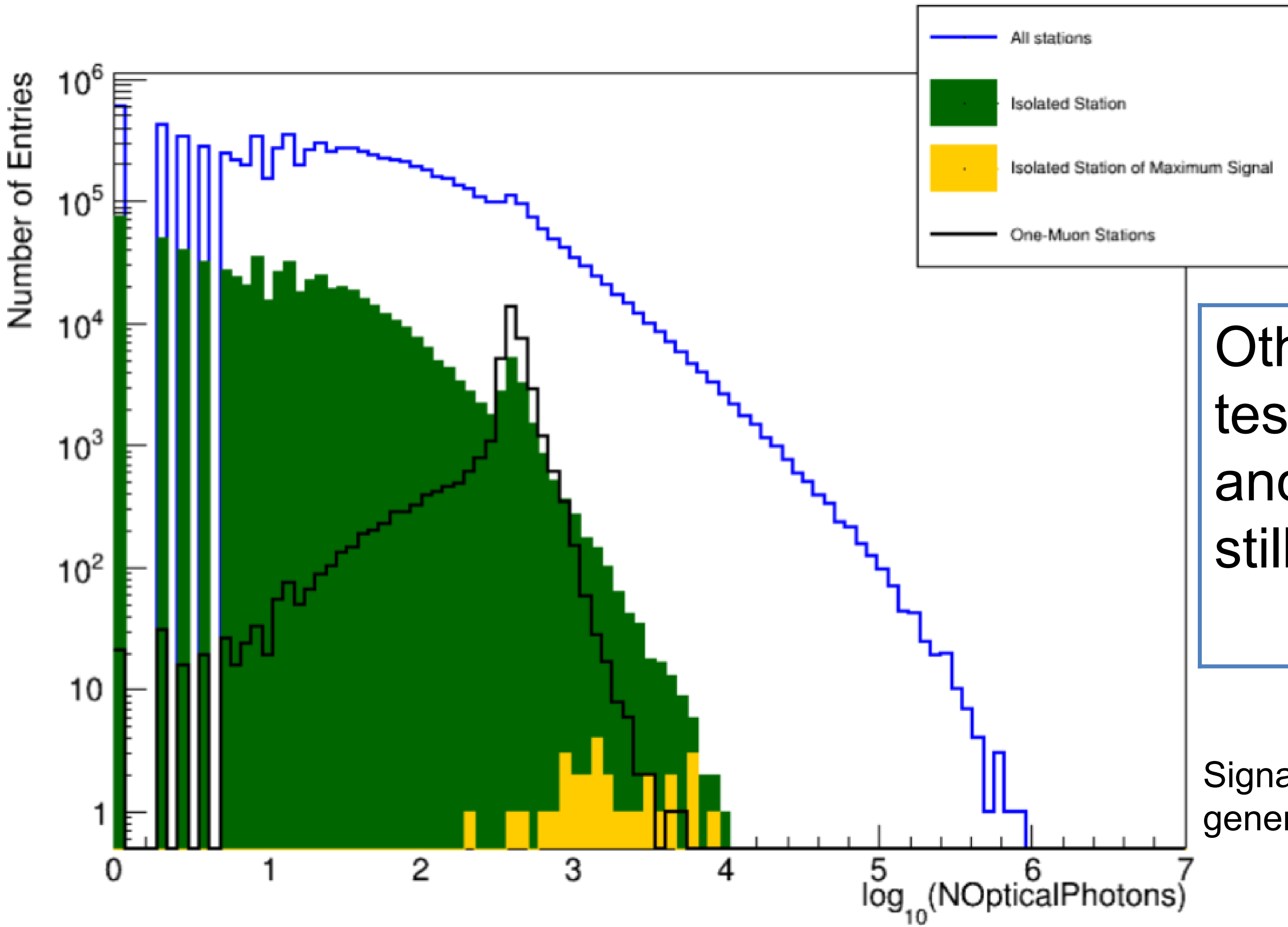
Energy spectrum for the case of a shower generated by a 4 TeV proton.

Energy in WCD Stations



Energy spectrum for the case of a shower generated by a 4 TeV proton.

Signal at the Ground

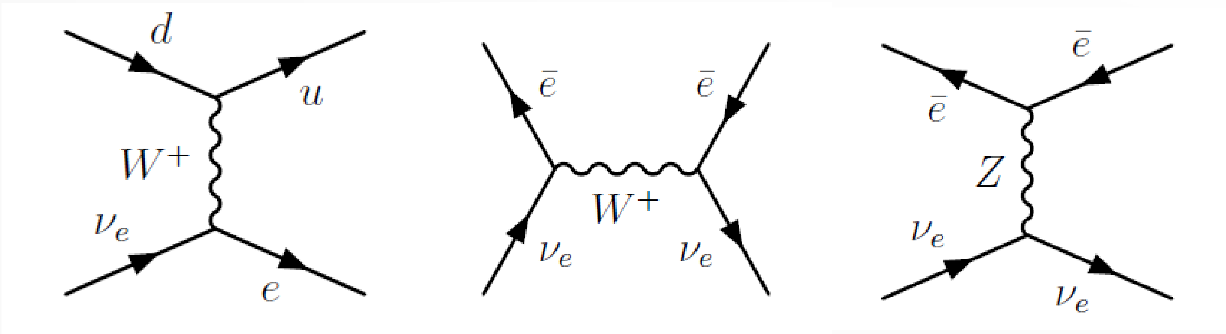


Other energies were tested, between 150GeV and 40TeV. Cut at x = 4 still holds.

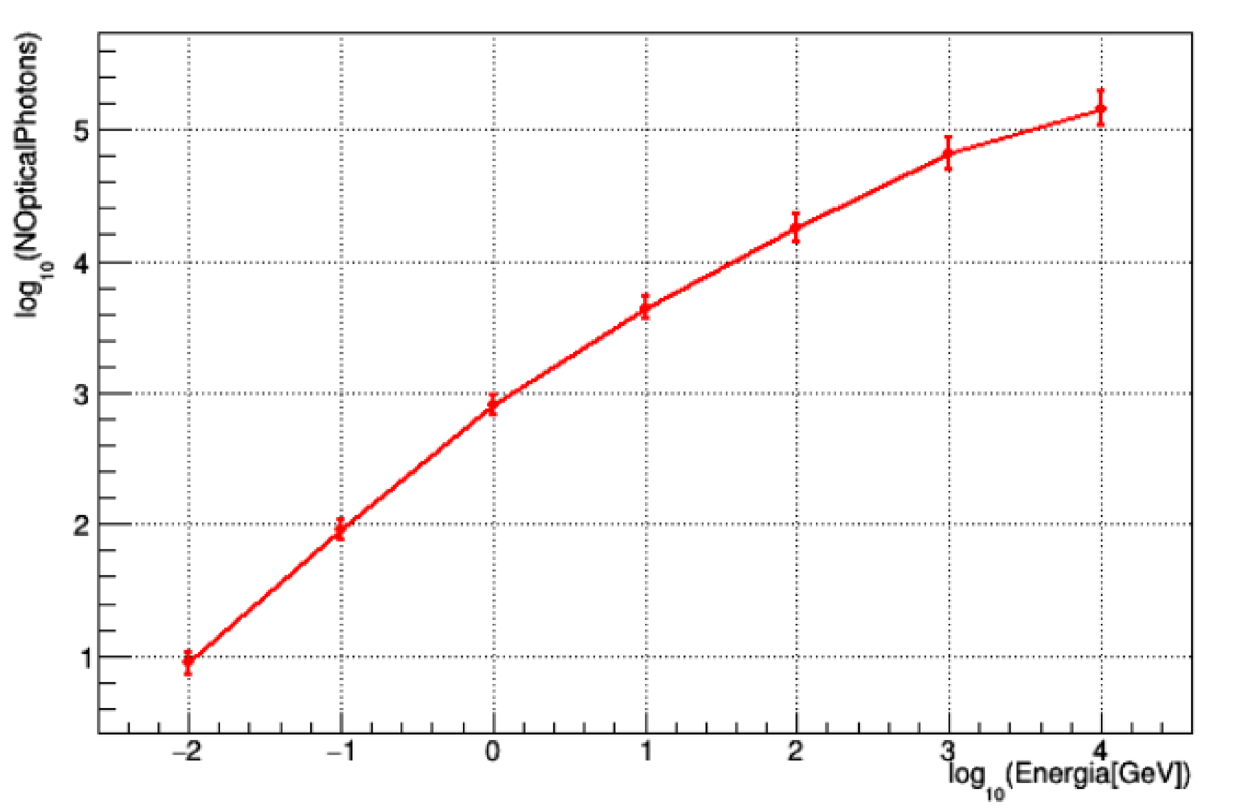
Signal spectrum for the case of a shower generated by a 4 TeV proton.

WCD Signal from neutrino shower

- Neutrino interaction can produce a high energy electron:



- Inject single electrons into WCD .
- Log(Signal)>4, then E > 100GeV.



Mean Signal - Energy relation for several one-electron scenarios, of different energies.

What we have learned, and future work

- Given the morphology of the spectra obtained, it is confirmed that gamma-rays are not a source of background;

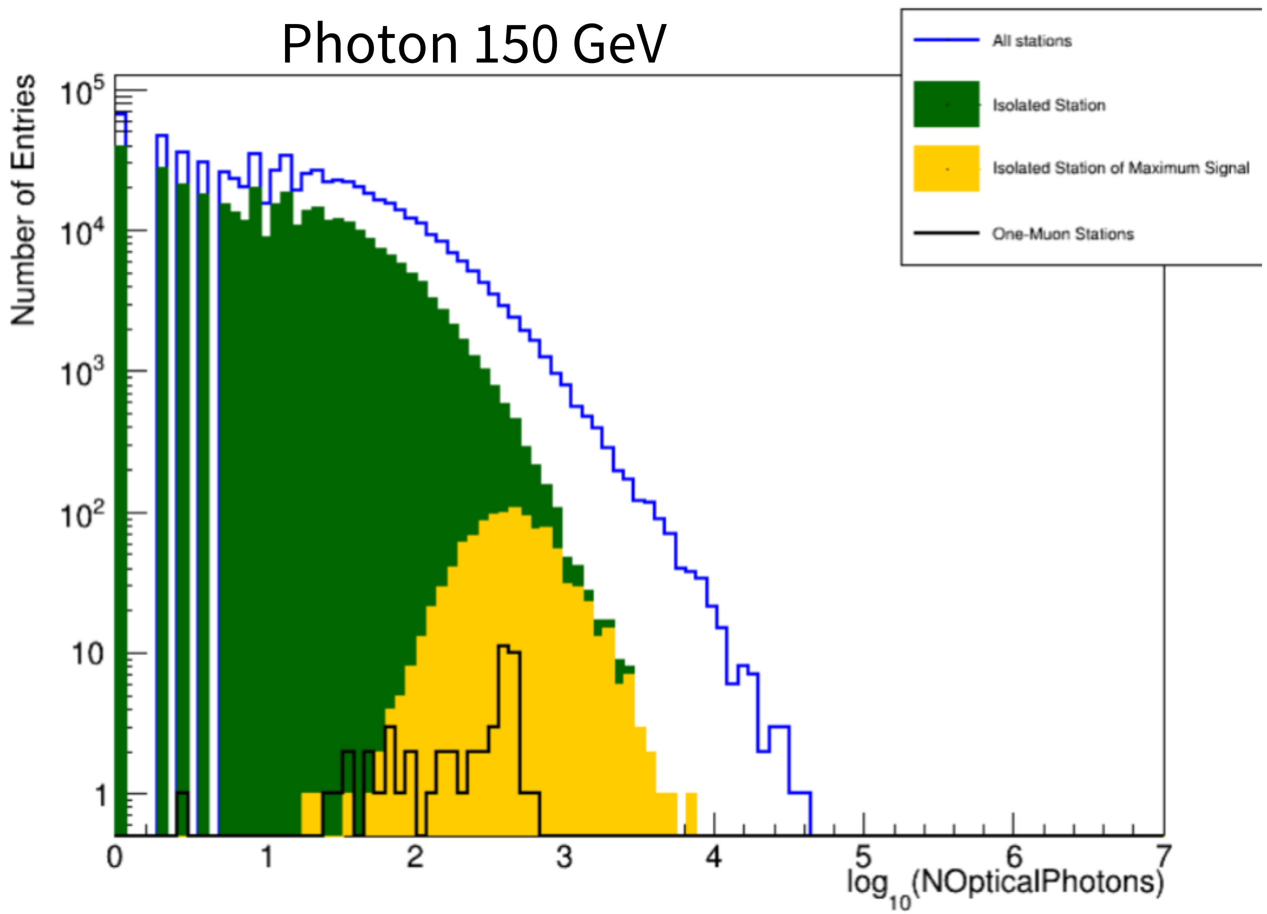
- Protons with an energy of the order of a few TeV can, in fact, reach the ground (very rarely) ;

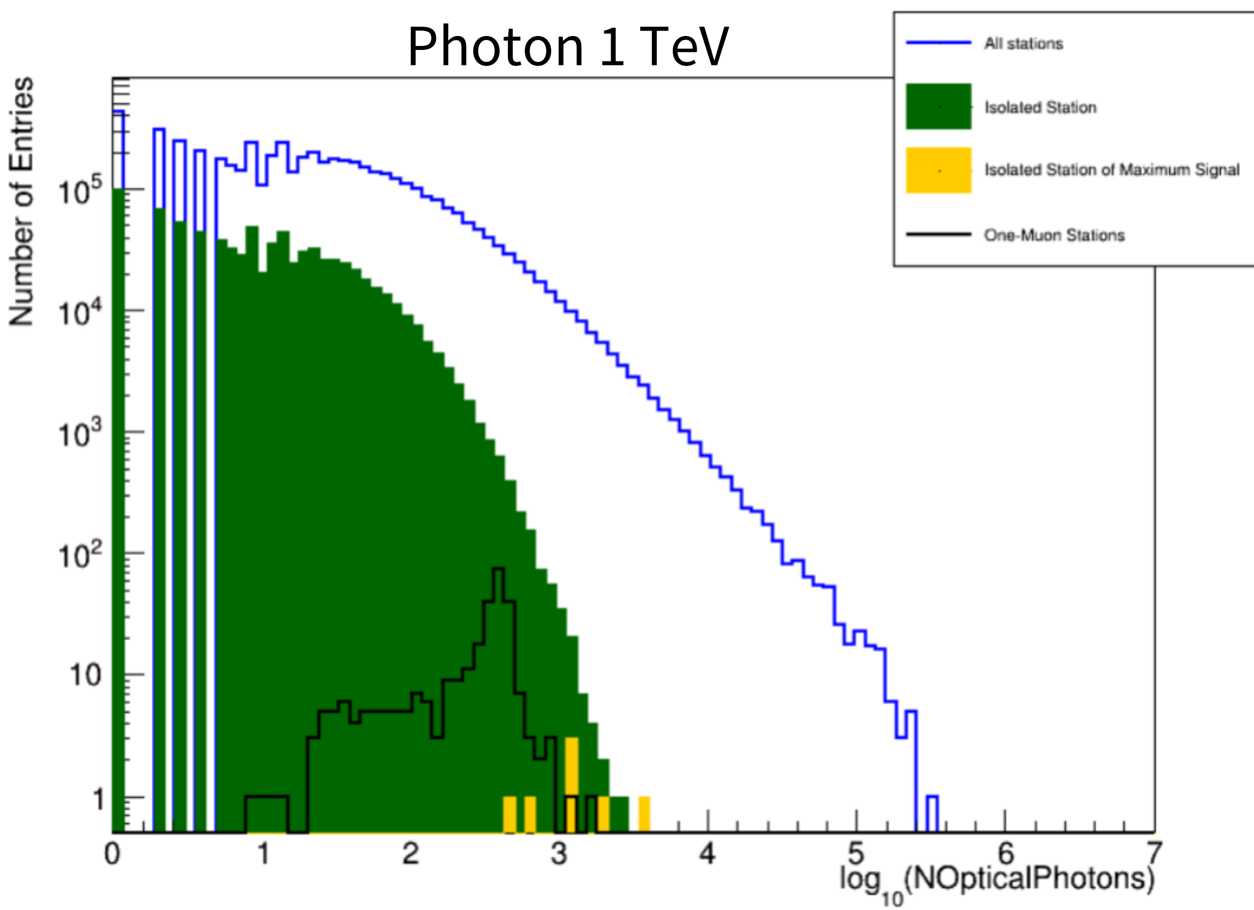
- **Requiring Log(Signal)>4 in isolated stations seems to allow the observation of TeV neutrinos**

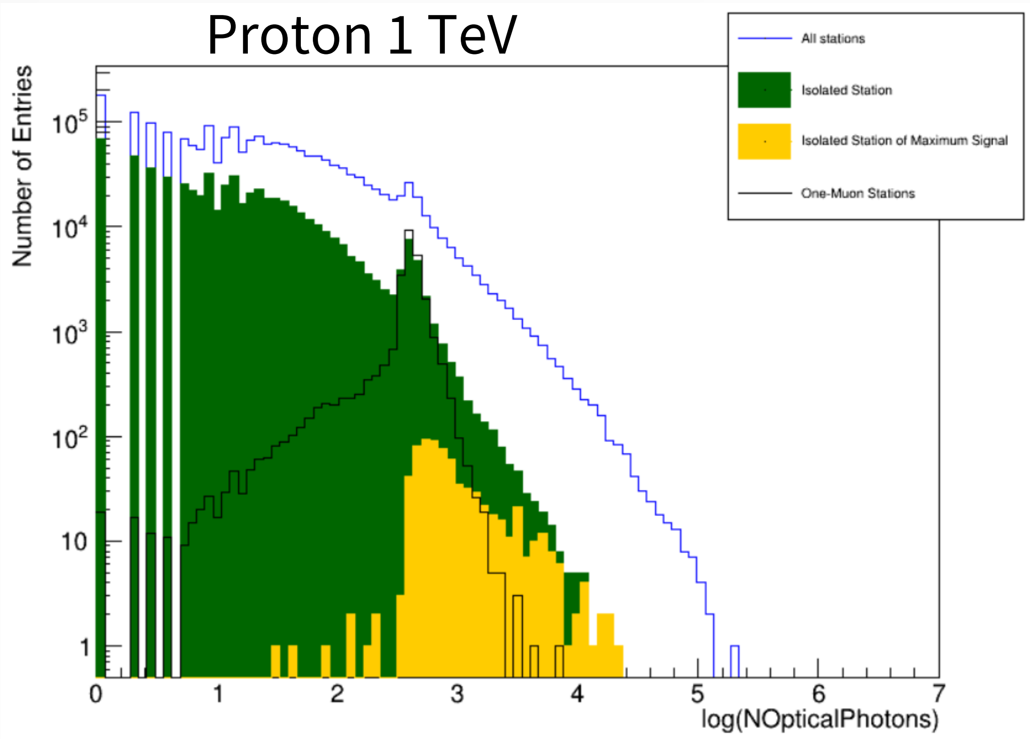
- Very promising results but it is still a work in progress.

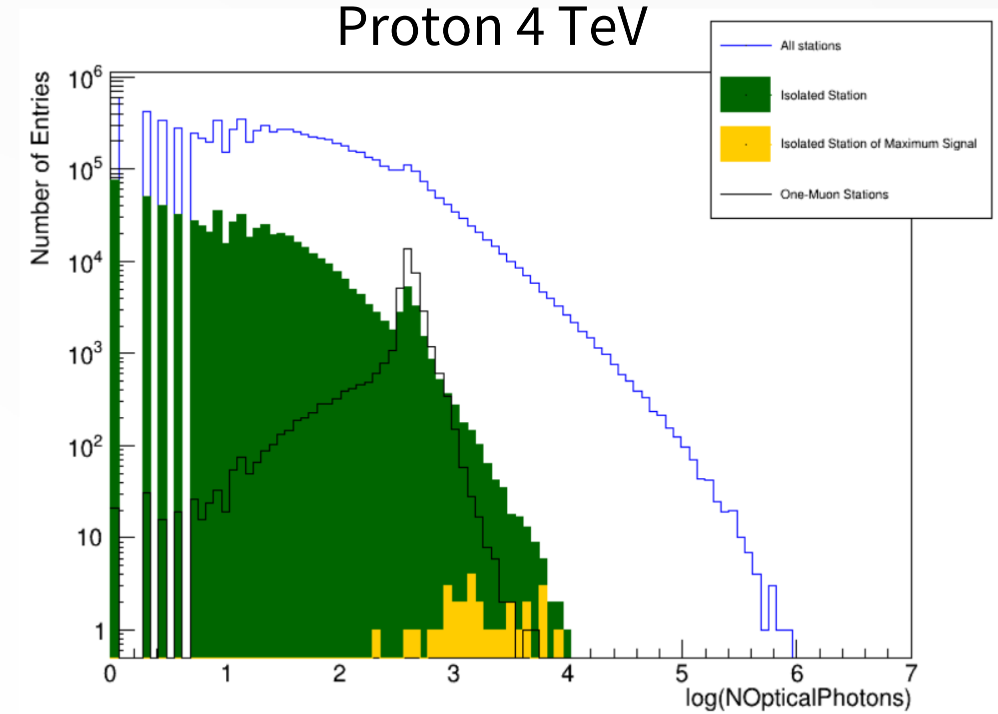
Thank your for your time!

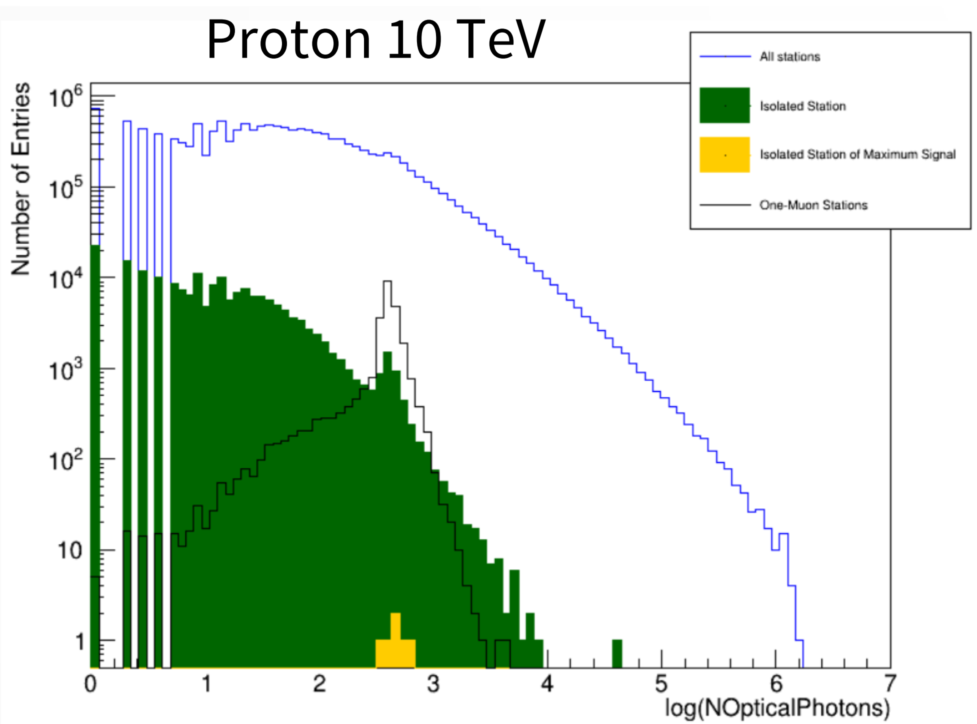
Extra Slides

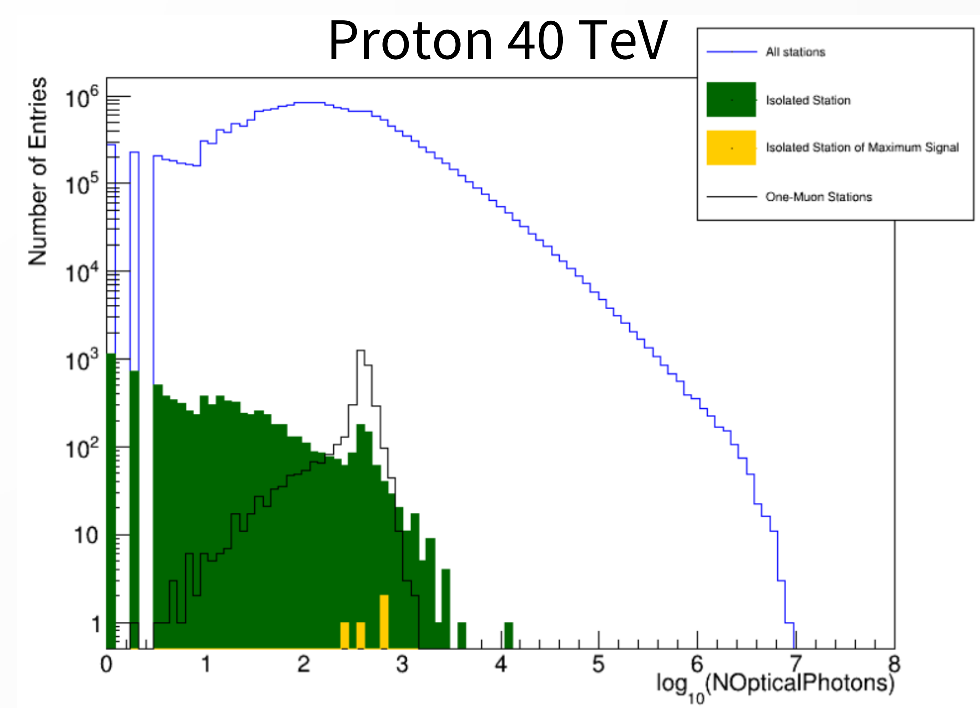

Photon 150 GeV
All stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log10(NOpticalPhotons)


Photon 1 TeV
All stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log10(NOpticalPhotons)

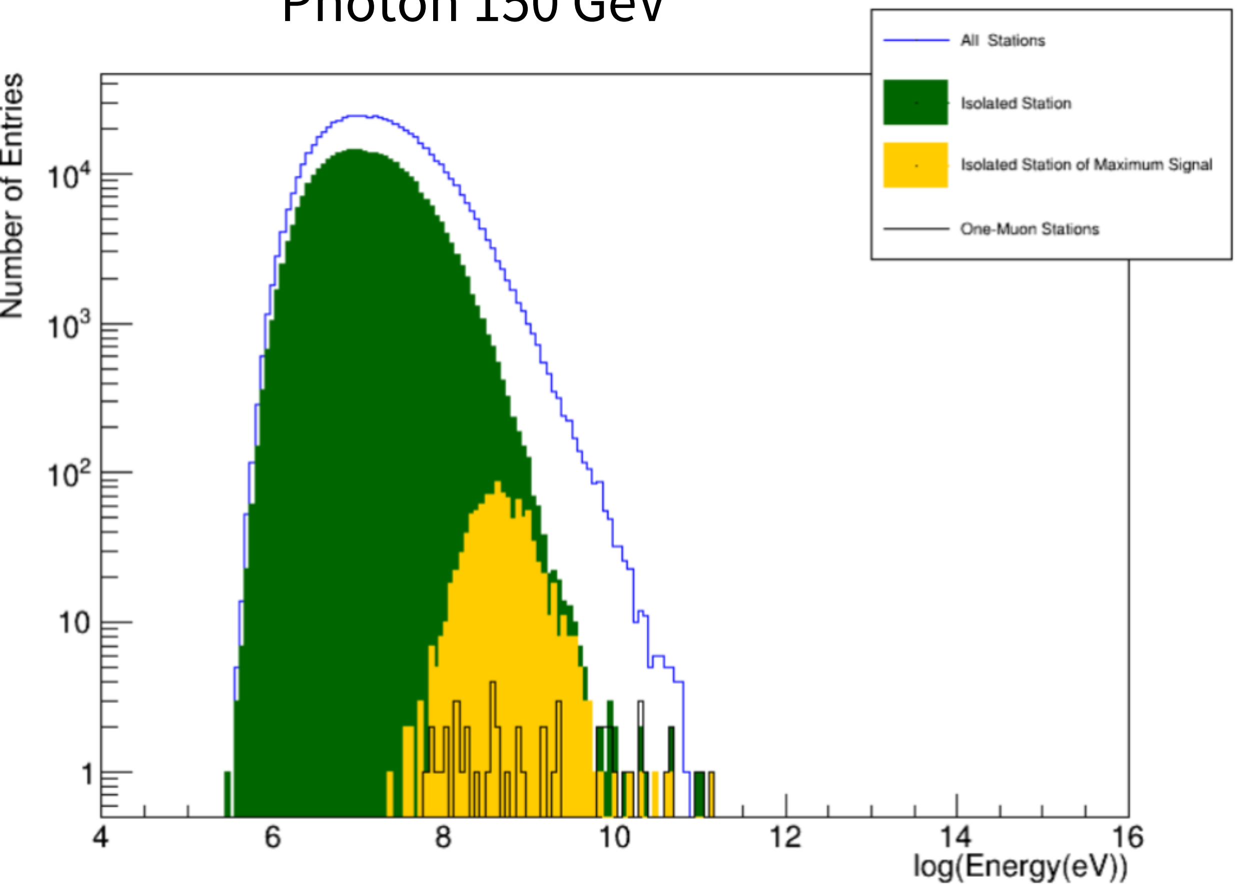

Proton 1 TeV
All stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log(NOpticalPhotons)


Proton 4 TeV
All stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log(NOpticalPhotons)

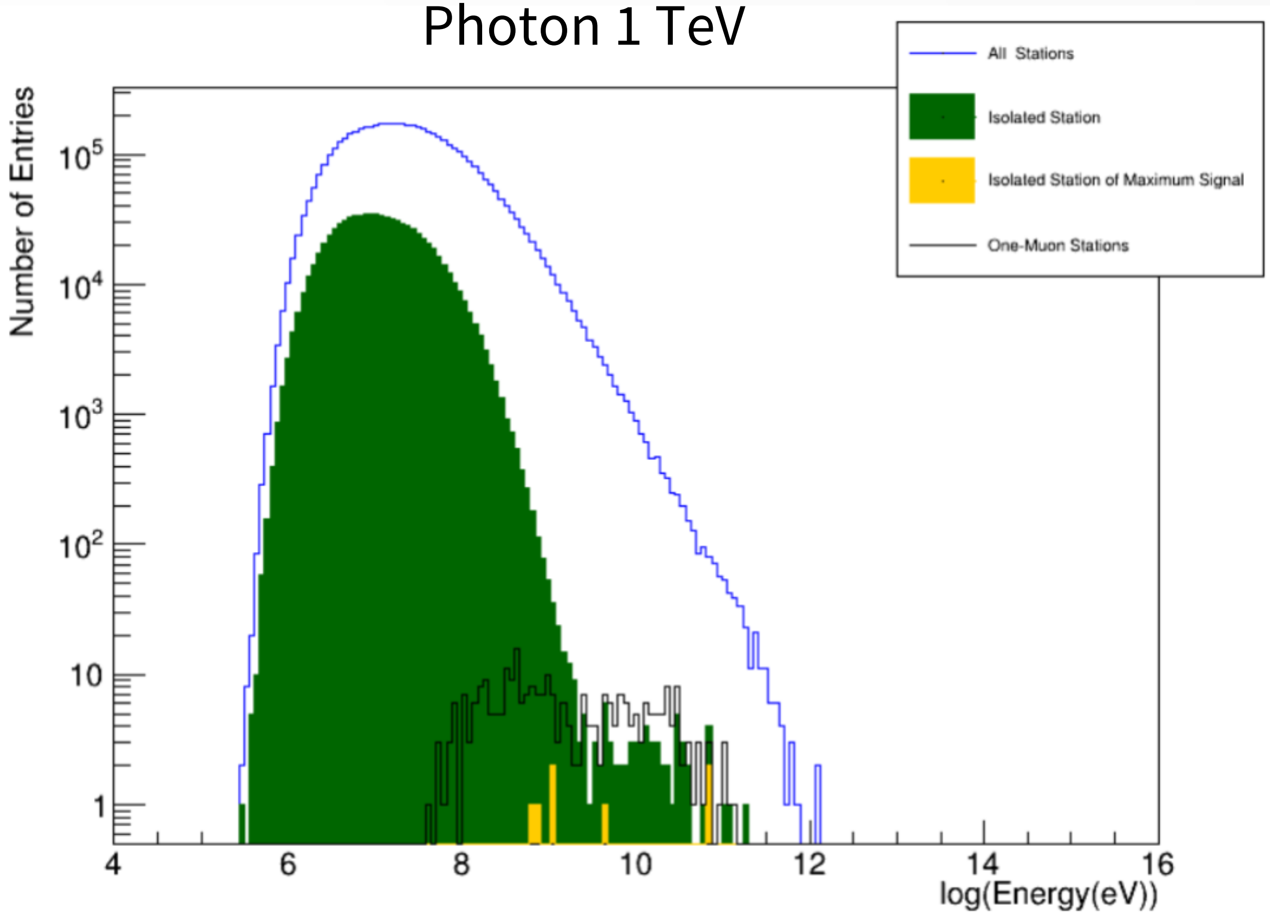

Proton 10 TeV
All stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log(NOpticalPhotons)

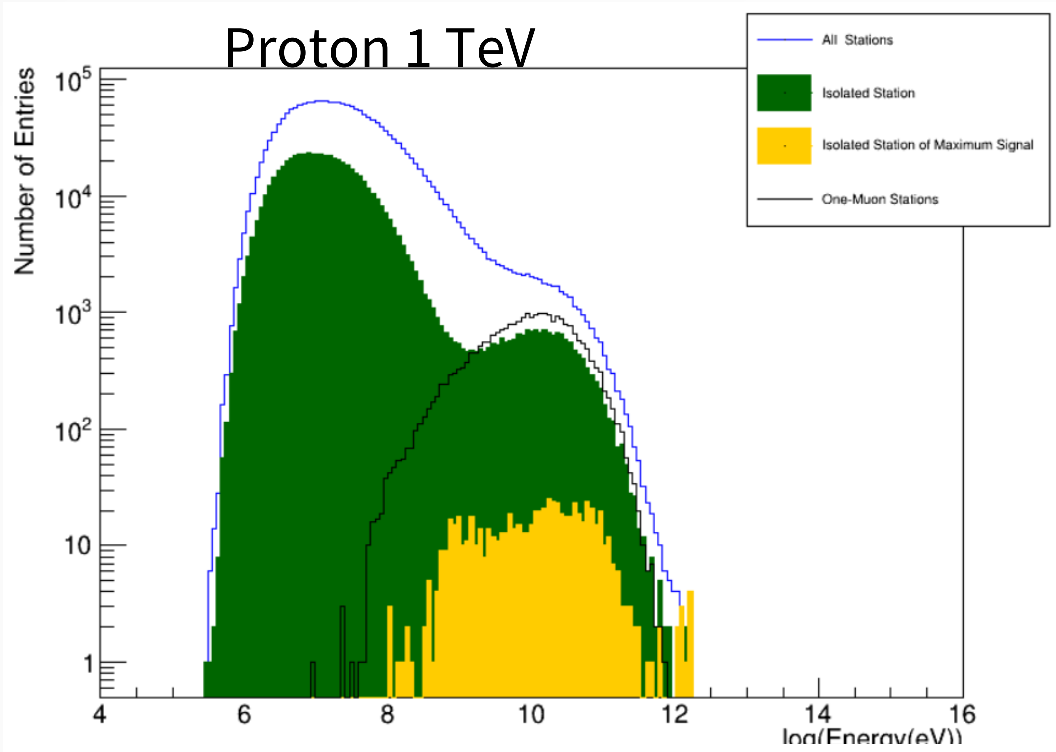

Proton 40 TeV
All stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log10(NOpticalPhotons)

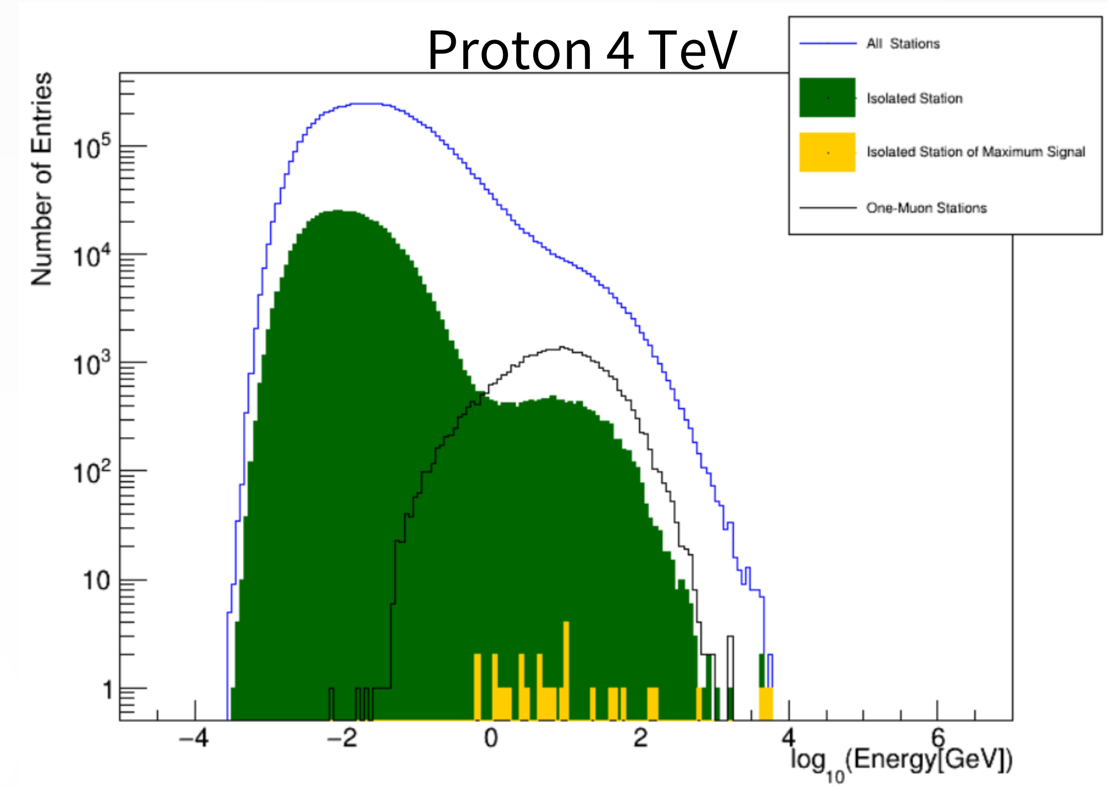
Photon 150 GeV

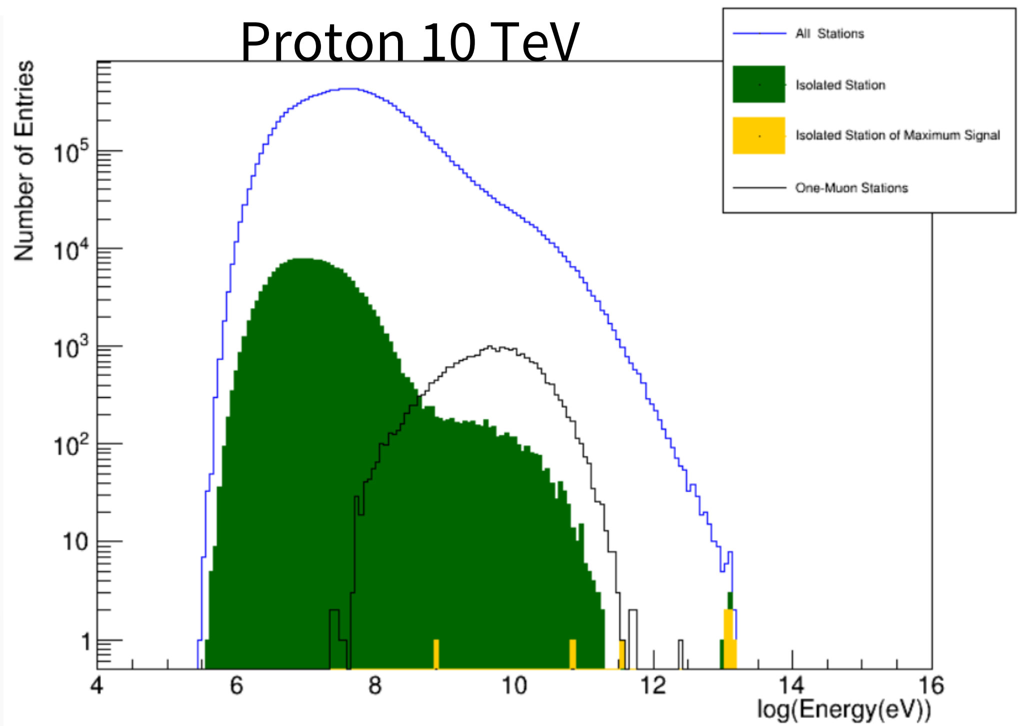


Photon 1 TeV




Proton 1 TeV
All Stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log(Energy(eV))


Proton 4 TeV
All Stations
Isolated Station
Isolated Station of Maximum Signal
One-Muon Stations
Number of Entries
log10(Energy[GeV])


Proton 10 TeV
All Stations
Isolated Station
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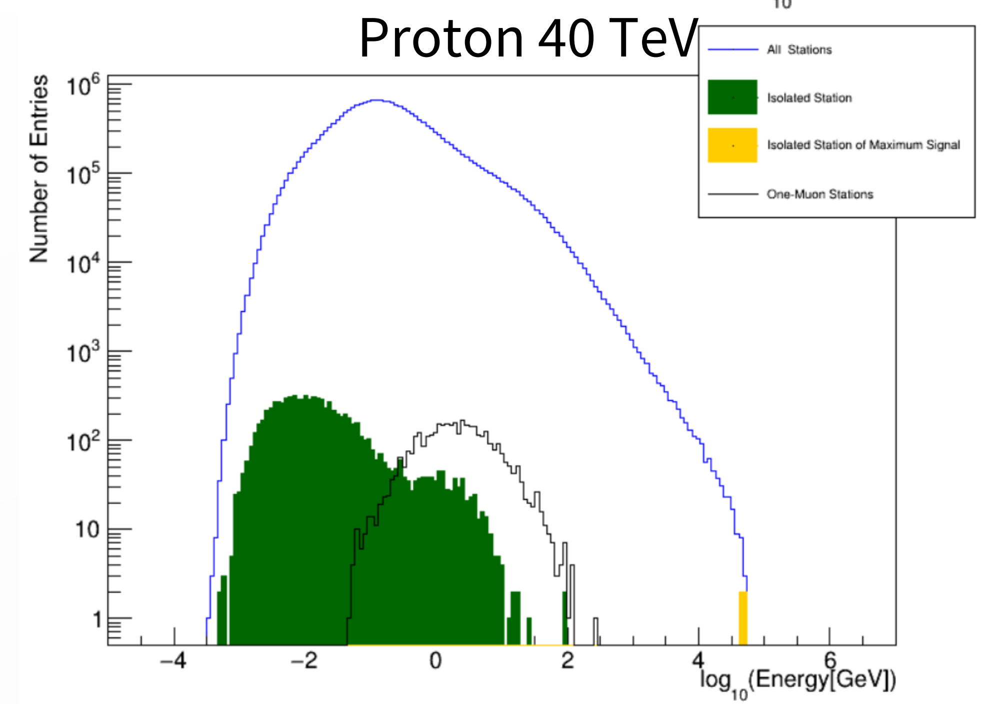
One-Muon Stations
Number of Entries
log(Energy(eV))


Proton 40 TeV
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Isolated Station
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log10(Energy[GeV])