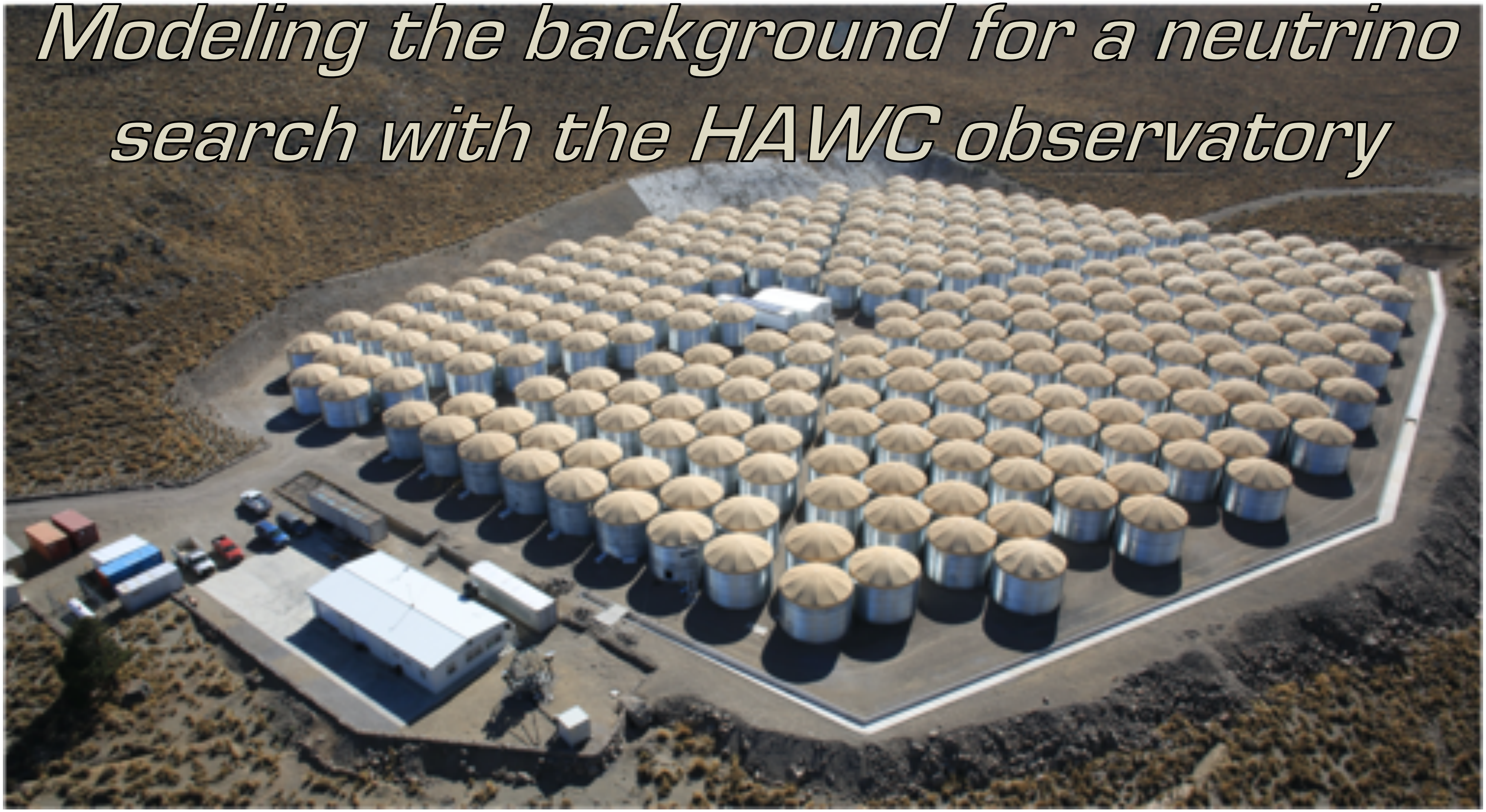
Modeling the background for a neutrino search with the HAWC observatory



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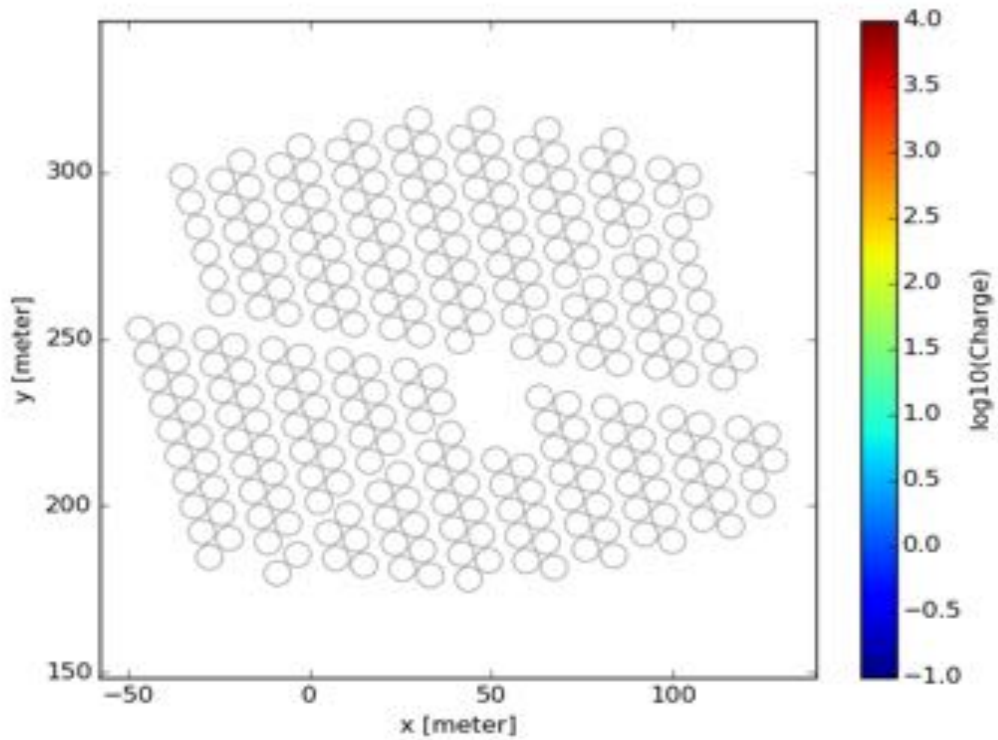
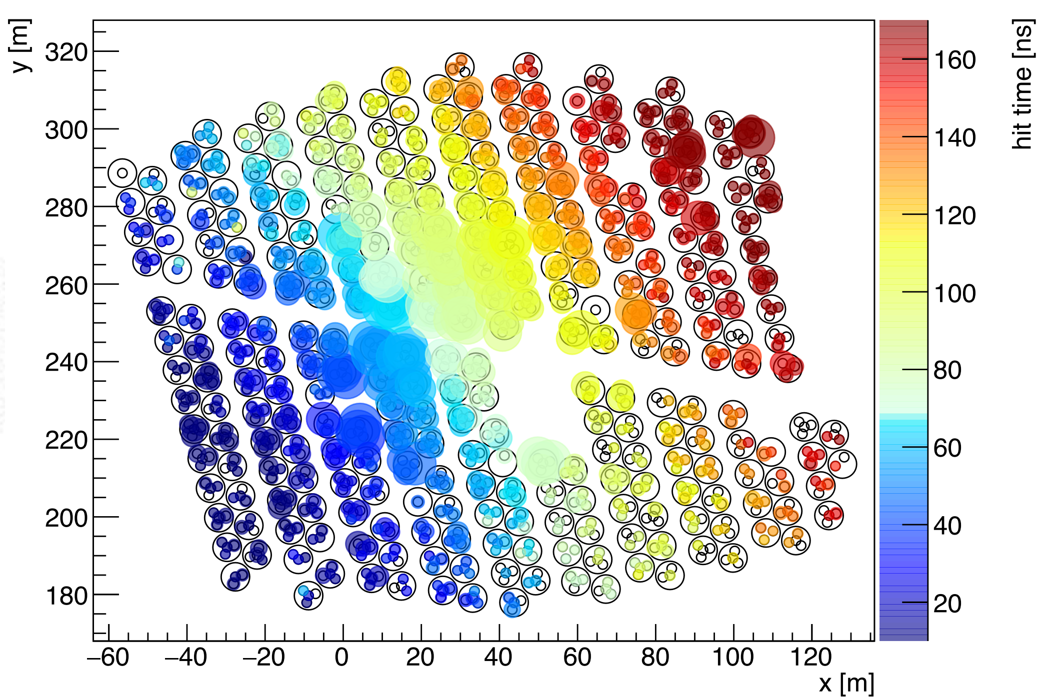
Universidad Nacional Autónoma de México

XIX International Workshop on Neutrino Telescopes
February 23, 2021

Detecting air showers with HAWC





- 300 WCDs: 5 m tall and 7 m diameter ~ 200,000 L, 4 PMTs each
- Fiducial water volume: 60 000 m^3
- Charge and time calibration with a dedicated laser system
- Timing accuracy ~ 1 ns

- Size of circles proportional to charge deposits
- Color code shows PMT hit time

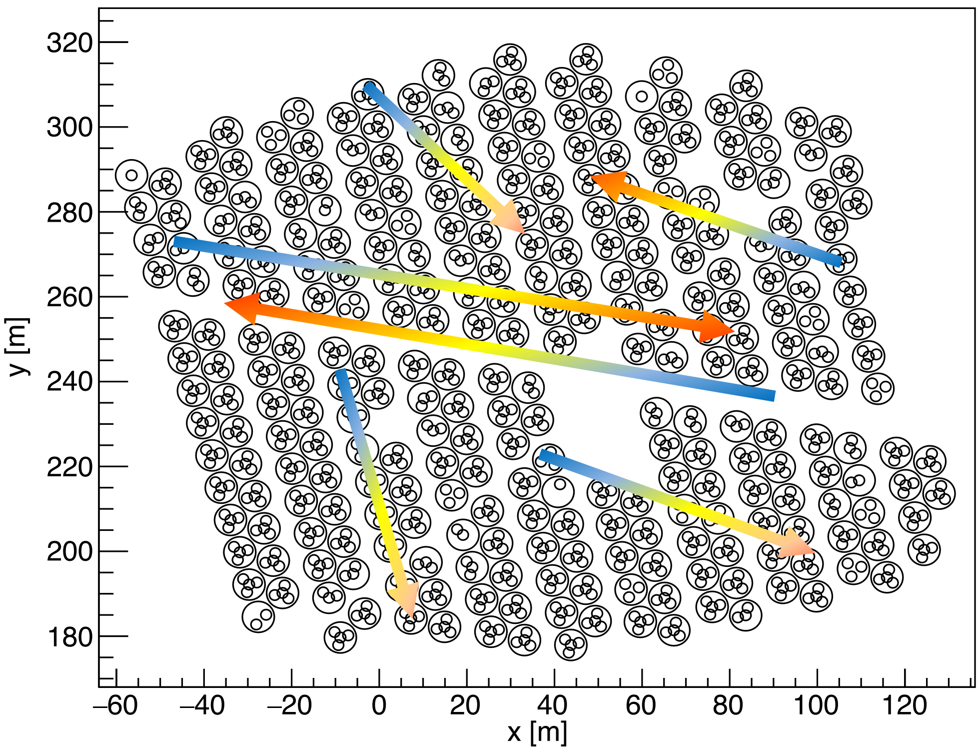
Earth-skimming neutrinos with HAWC

- Use the volcano as an absorber for atmospheric muons
- Use HAWC to measure the neutrino-induced muons produced within the volcano

HAWC as a particle tracker

Search algorithm:

- We use the standard HAWC triggered data
  - Trigger condition: ≥ 28 PMT hits in a 150 ns sliding time window
- Look for PMT hits in different WCDs consistent with speed of light propagation
- Store WCD information ($\langle T \rangle, \sum PEs$, NHits) ⟶ **Pixel** for tracking
- **Pixel**: WCD with at least 2 PMT hits with charge ≥ 4 PEs



Selection cuts:

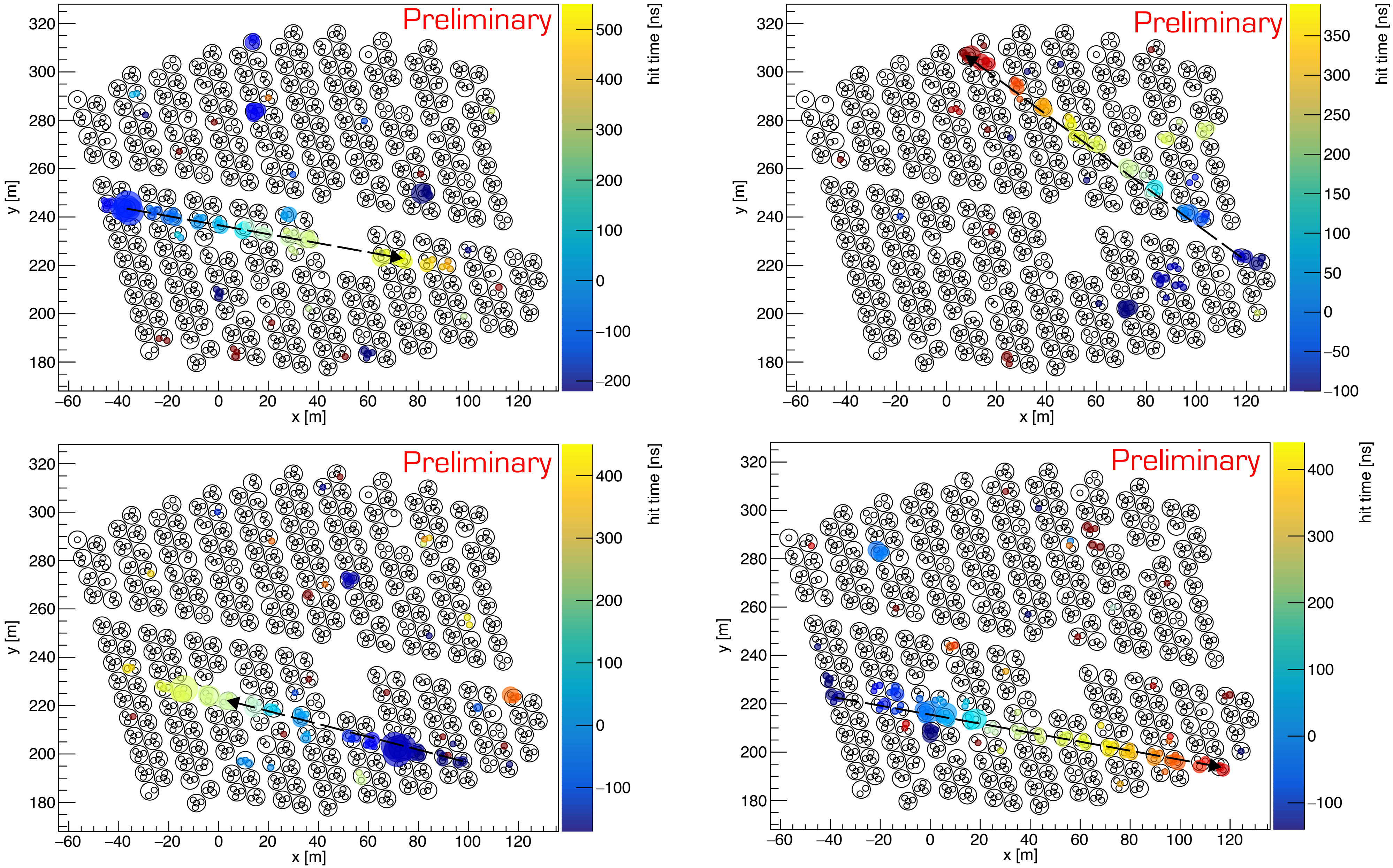
- Event activity (E_A < 5.65)

$$E_A = N_{WCDs} / N_{Pixel}^{Track}$$

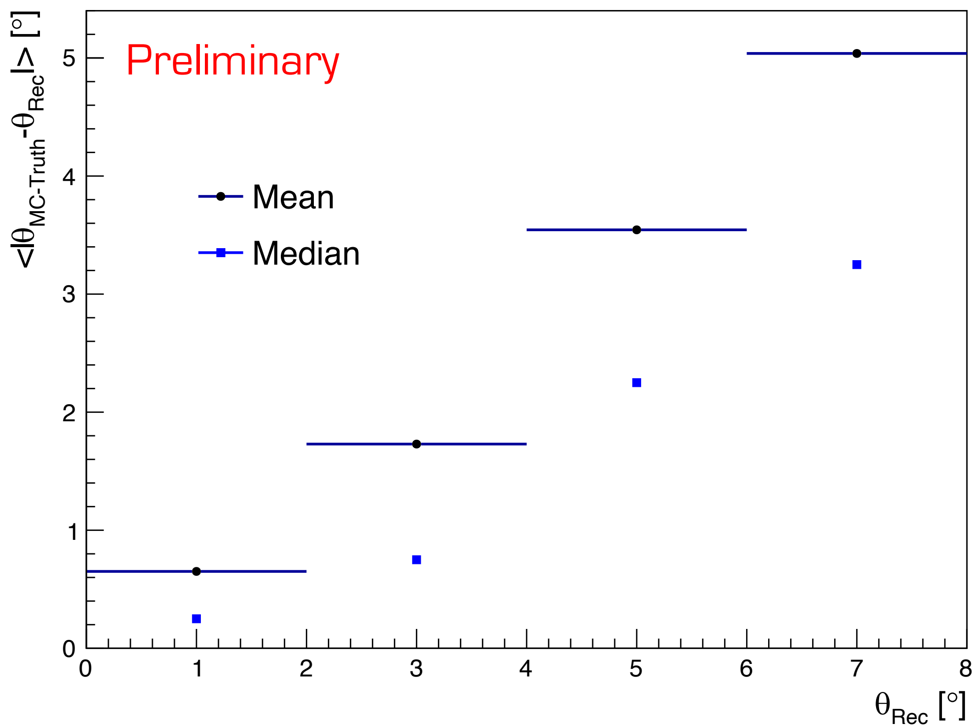
- Pixel activity (P_A < 1.5)

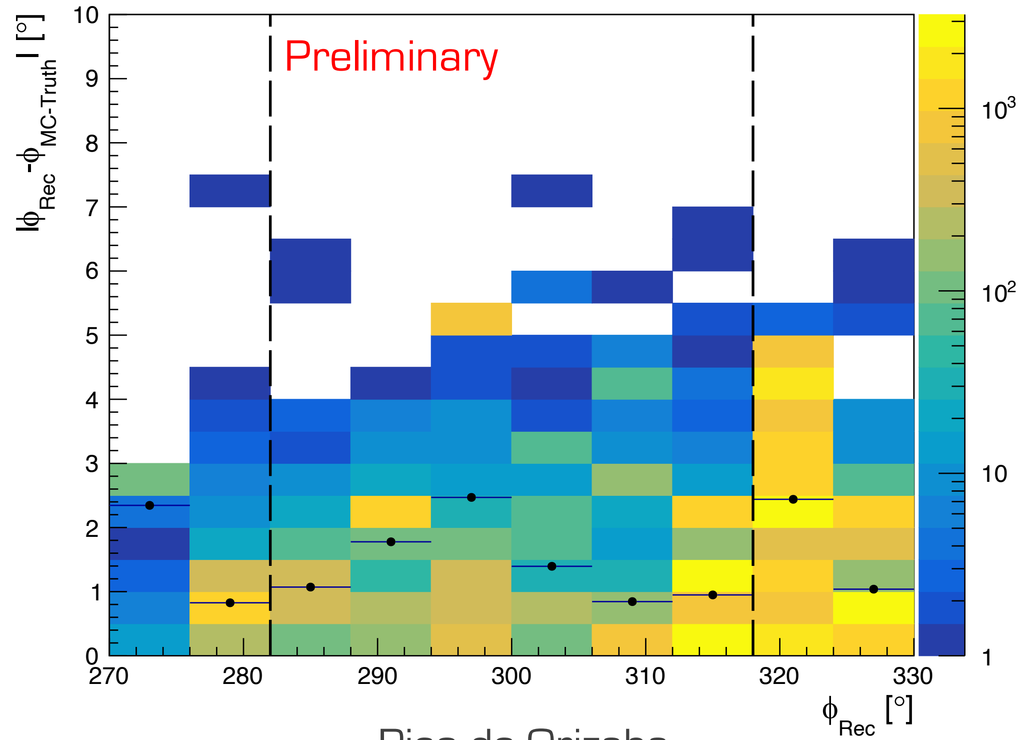
$$P_A = N_{Pixel}^{Tot} / N_{Pixel}^{Track}$$

Muon track candidates



Angular resolution of the tracker



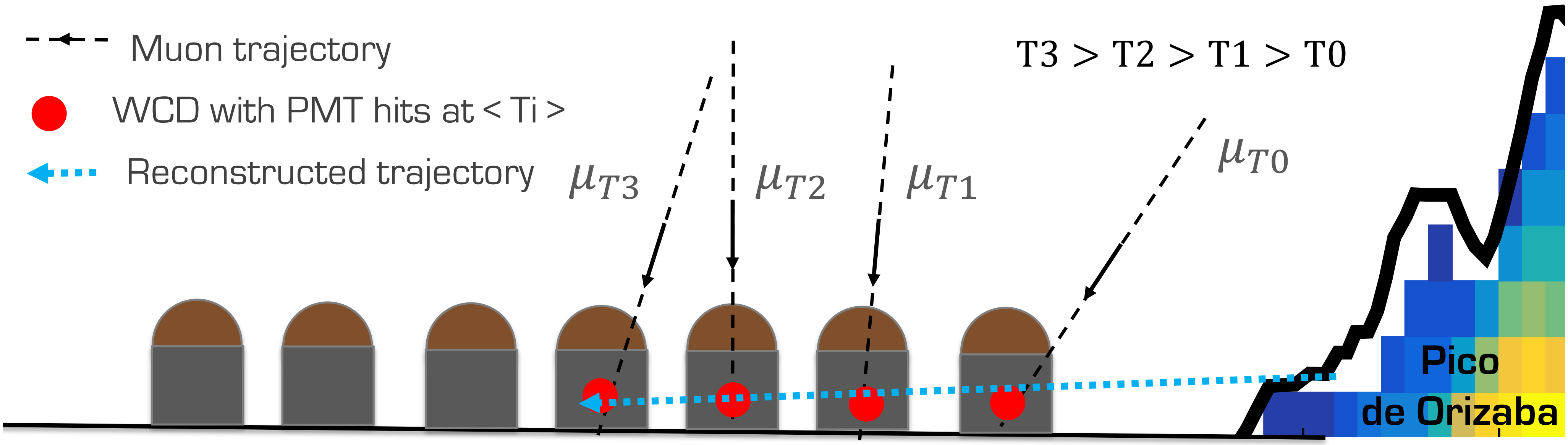


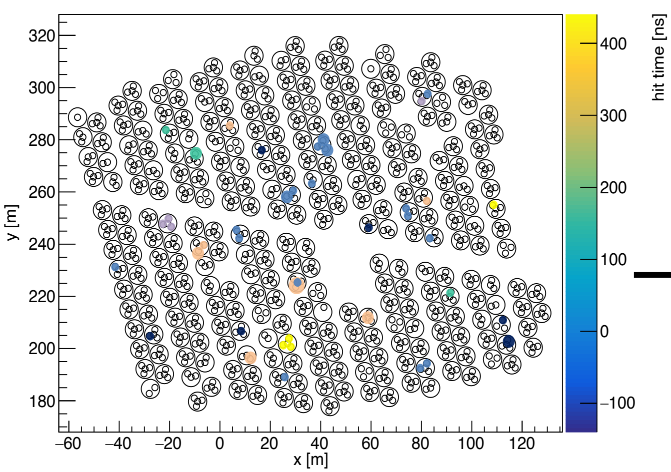
Pico de Orizaba
Analysis region

- HAWC is located on a flat surface. For a tracker this limits the accessible elevation angles.
- The nonuniform distribution of the WCD produces an irregular angular resolution in the azimuth angle.

Background sources: 1) Combinatorial background

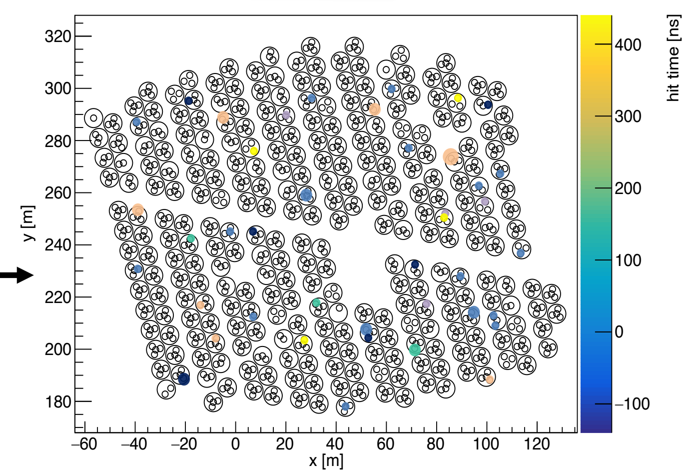
Multiple muons produce a signal that mimics an horizontal muon





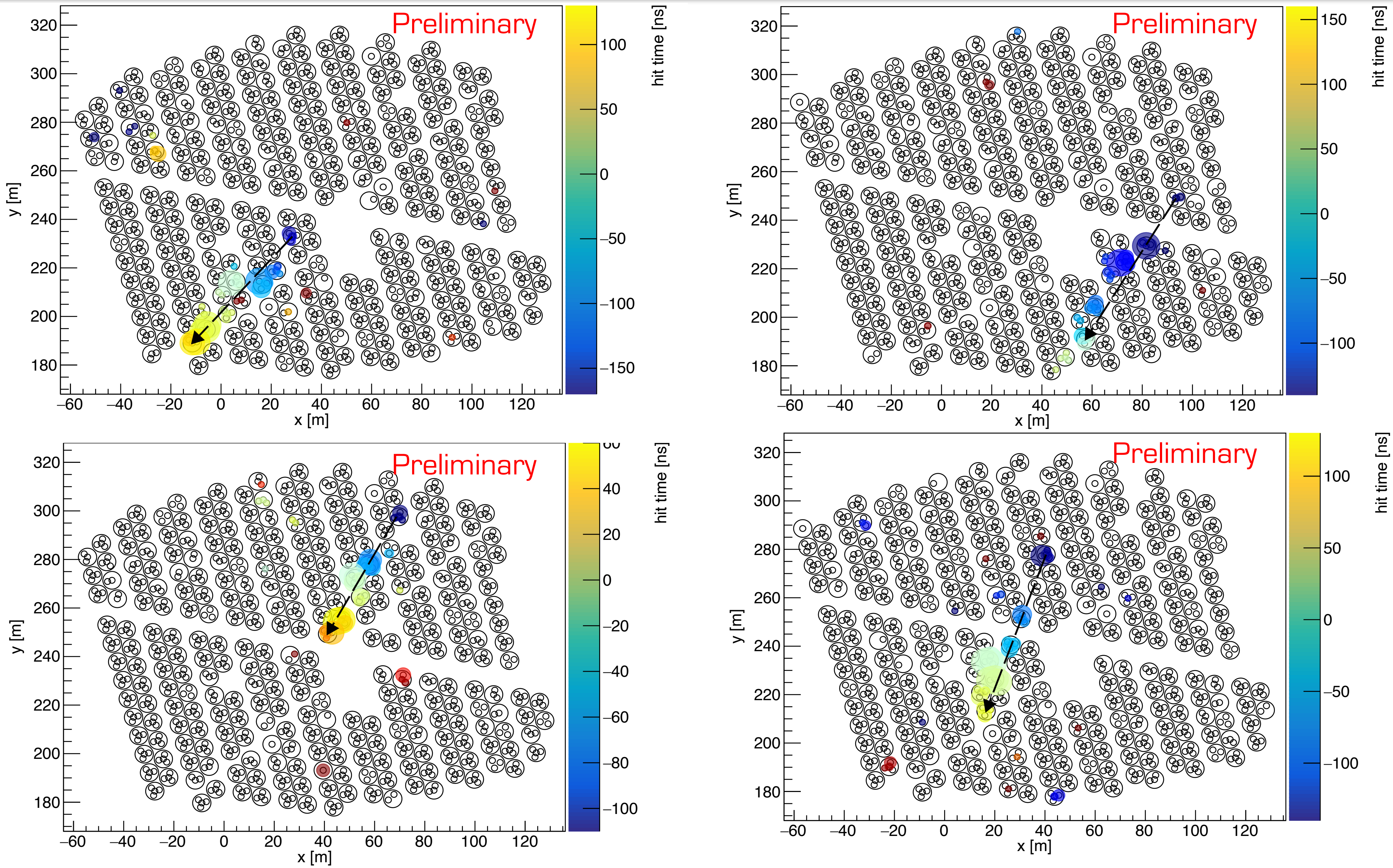
Randomization of the location of PMT hits in the whole data sample (6 months)

Longest random track has 3 pixels



Requirement of tracks with $N_{Pixel}^{Track} \geq 4$ to avoid this background

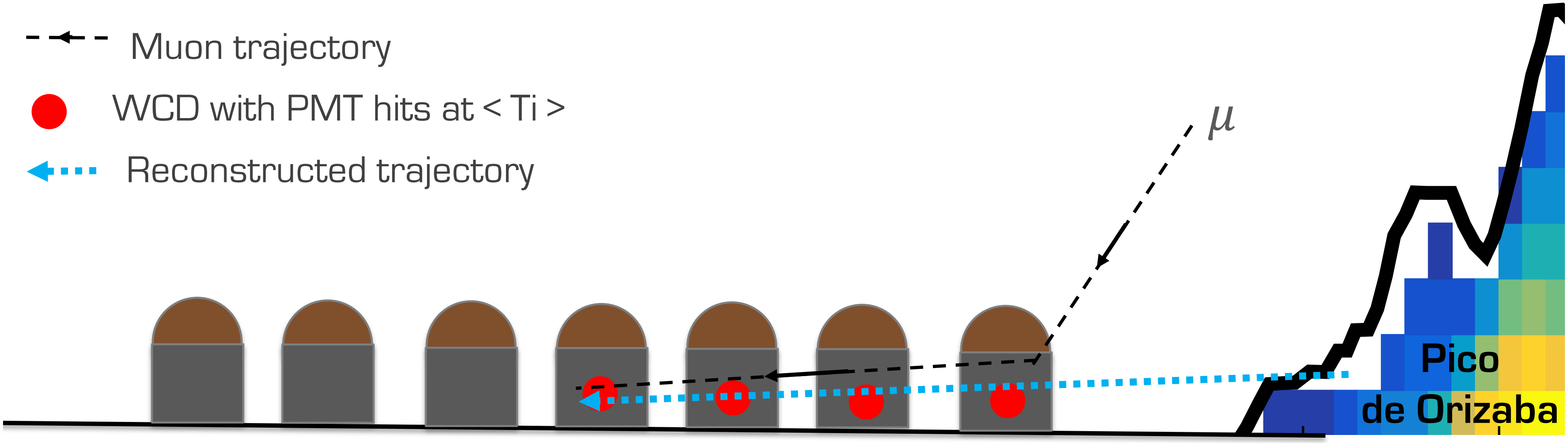
Tracks pointing to the volcano



Examples of track candidates found in data poiting to the analysis region

Background sources:
2) Scattering background

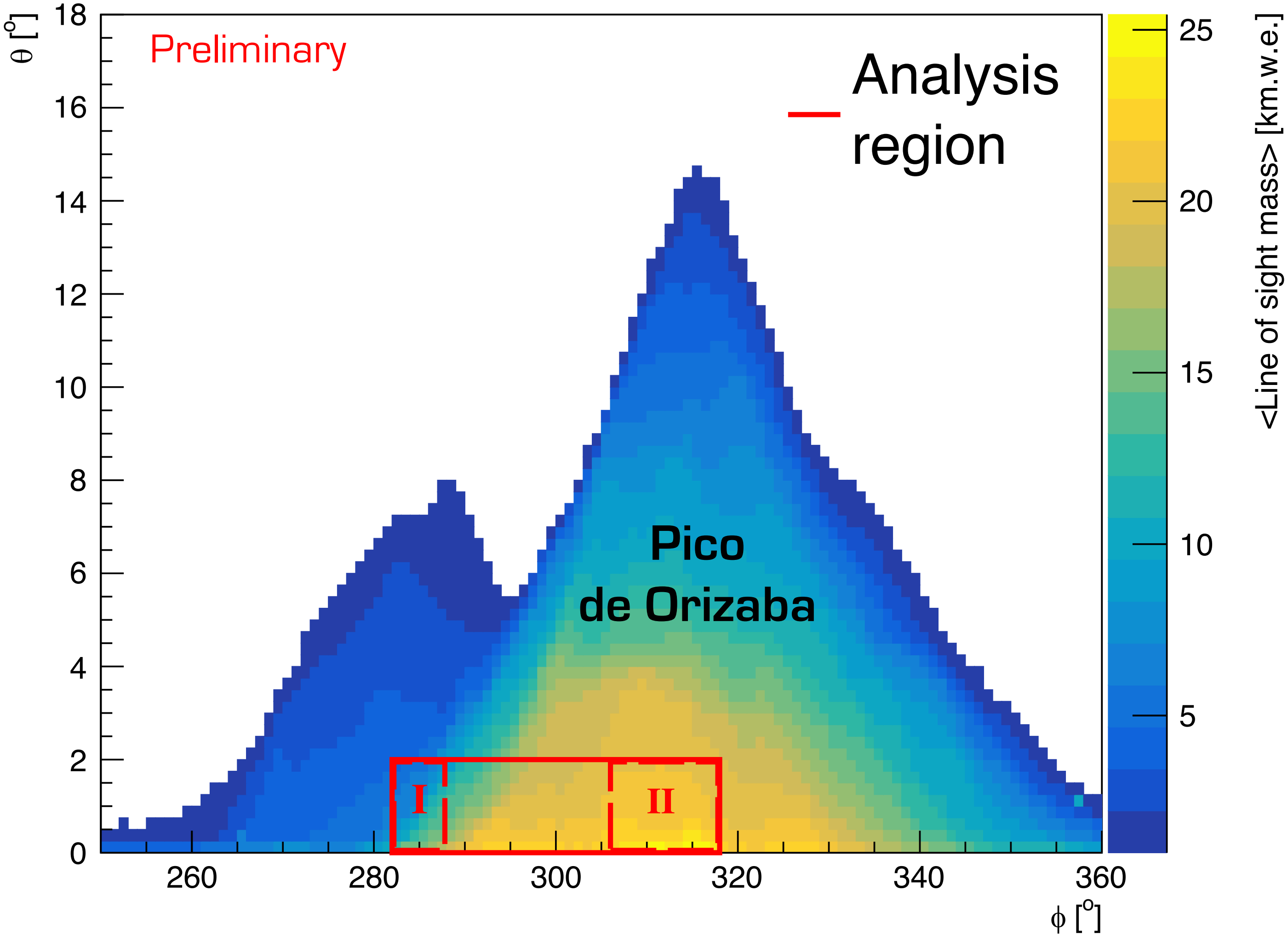
Single muons being scattered towards horizontal trajectories



- The intensity of this background has a strong dependence with the muon energy, i.e. for < 20 GeV[1]
- The scattering probability strongly depends on the incidence angle of the muons, i.e. muons closer to the horizon are more likely to scatter into the horizontal acceptance of HAWC

[1]The muon background from backscattered cosmic-ray muon in a Surface Neutrino detector. Europhys. Lett. 14 (1991) 181-186

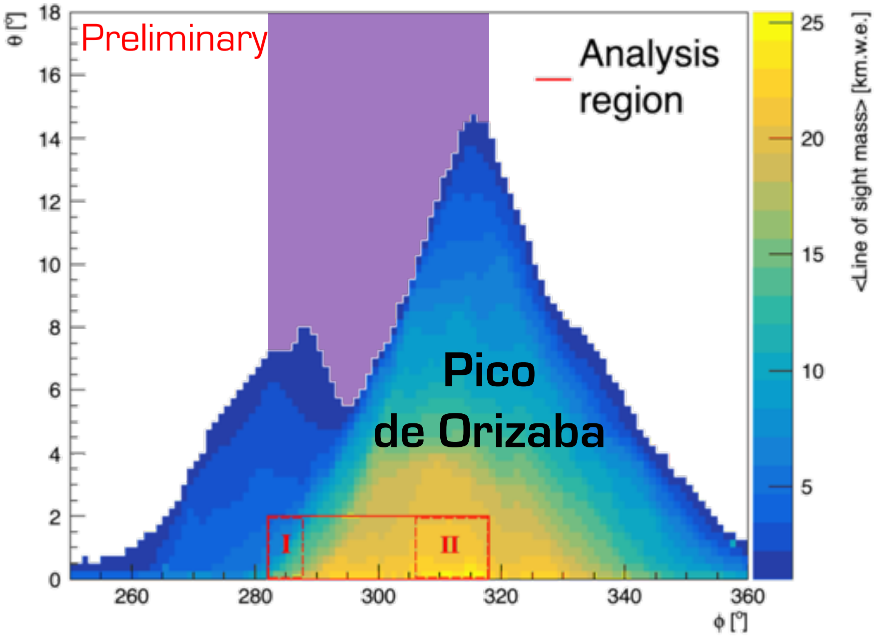
Pico de Orizaba profile

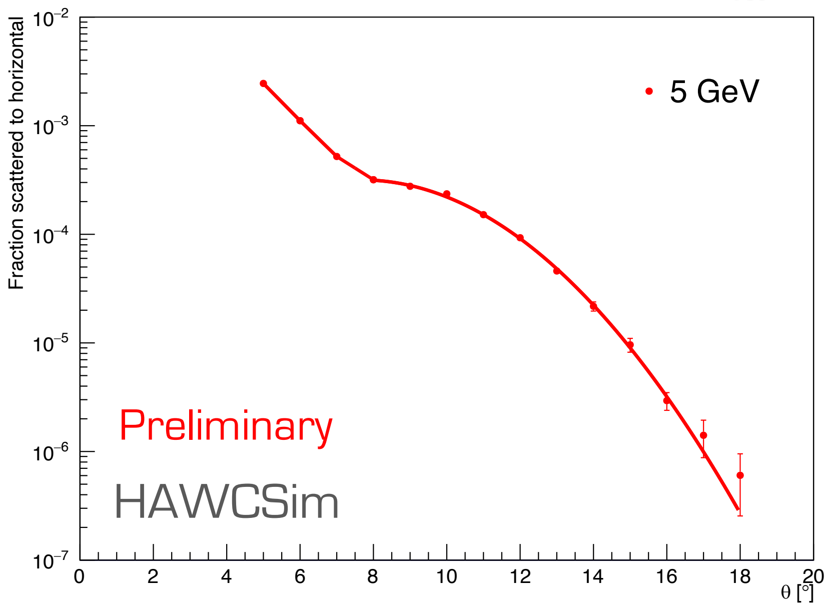


- Mountain profile as seen from the center of the detector array
- Conversion from geometry to LOSM using an average density for andesitic rocks ~ 2.6 g/cm^3

- The base of Pico de Orizaba provides a region with very large LOSM
- Search for muon tracks that point to the base of the volcano
- Analysis restricted to the [0°, 2°] elevation range

A simple scattering model





- The muons that scatter into the analysis region mainly come from the region not blocked by the volcano (shown in purple).
- The scattering probability was evaluated with a GEANT4 simulation of HAWC (HAWCSim).
- We use the data from Aragats[1] and the prediction from P. Lipari[2] to parametrize the zenith dependence of the muon intensity close to the horizon.

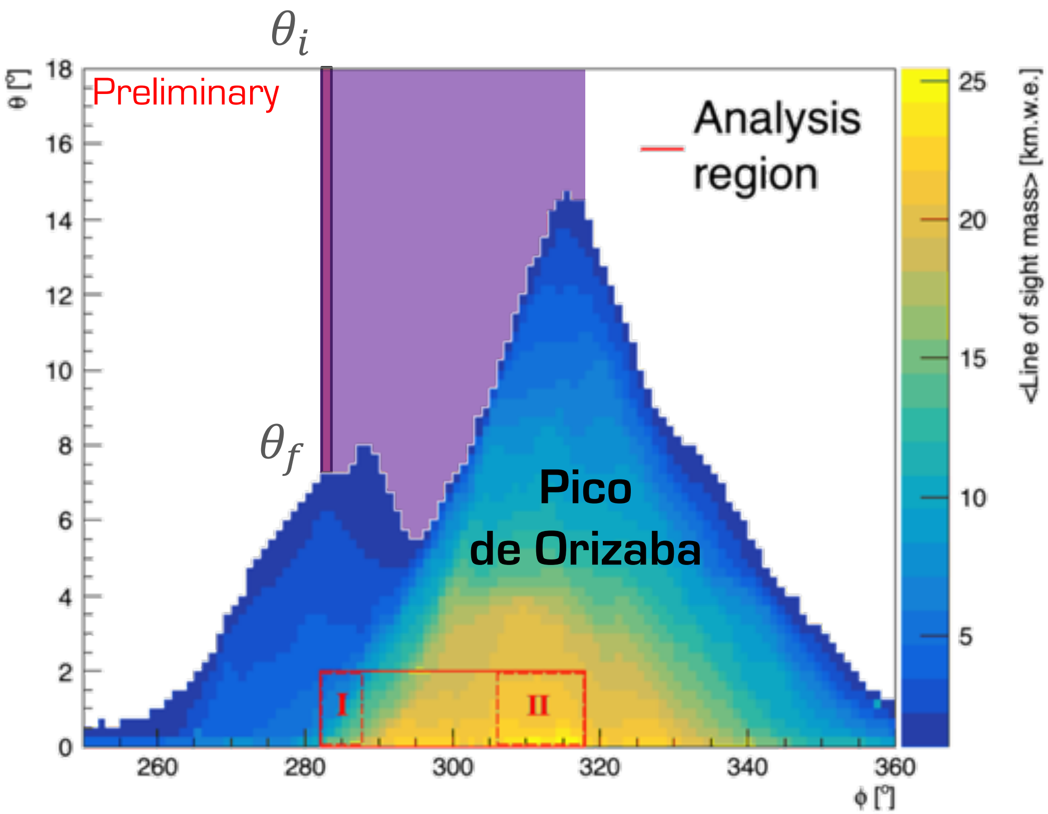
[1] Yerevan Physics Institute http://crd.yerphi.am/Muons

[2] Astropart. Phys. 1 (1993) 195-227

A simple scattering model

We calculate the intensity that produces scatterings in steps of 1° in azimuth and integrating over the angular region not covered by the volcano

$$F^{\phi}_{Scatt}(E = 5\ GeV) = \frac{\pi}{180}\int_{\theta_i}^{\theta_f} I_{hor}(E = 5\ GeV, \theta) \times P_{scatt}(E = 5\ GeV, \theta) \times \sin\theta d\theta$$



For region I (6° in azimuth):

$$F^{I}_{Scatt}(E = 5\ GeV) = \sum_{\phi=1}^{\phi=6} F^{\phi}_{Scatt}(E = 5\ GeV)$$

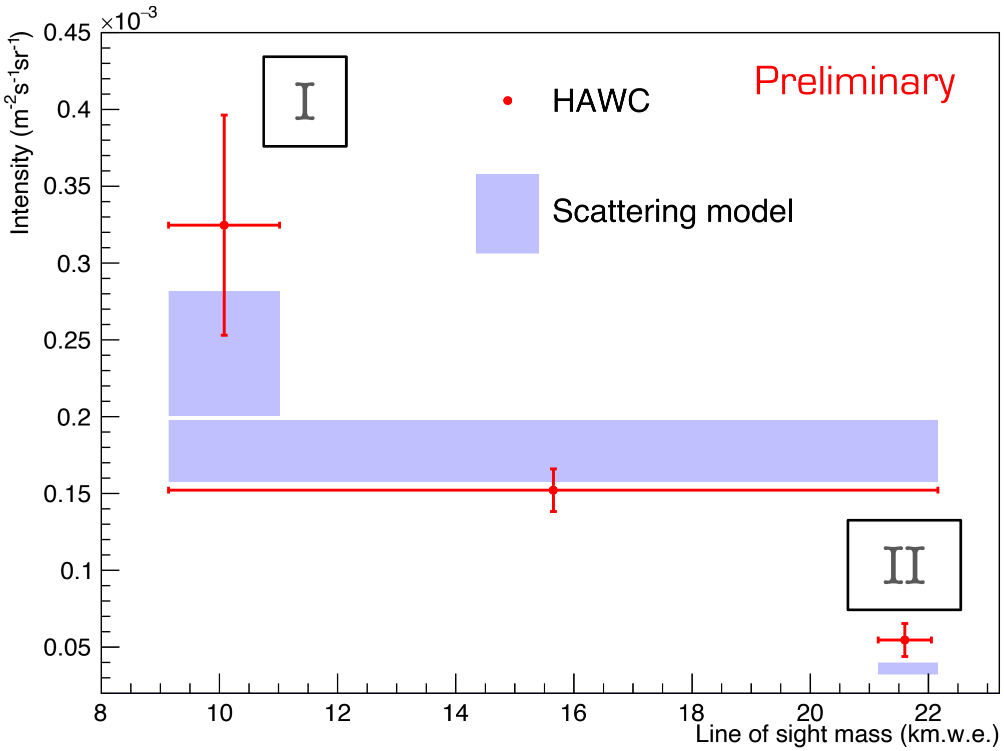
And adding the contributions from energies above the detection threshold:

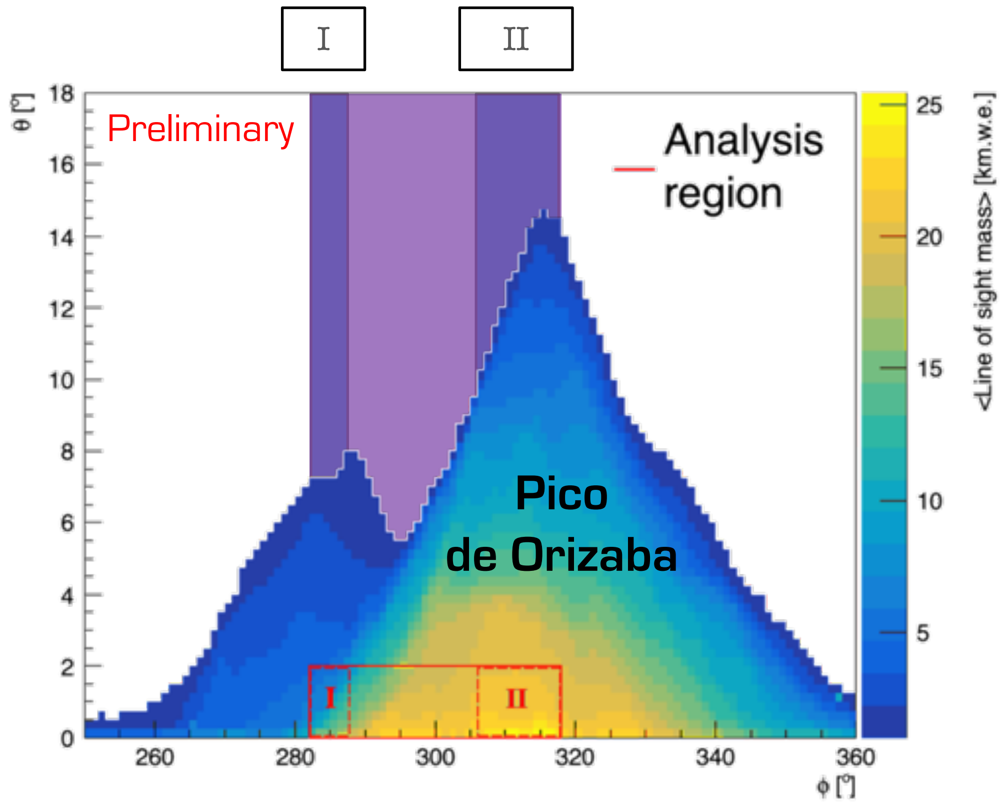
$$F^{I}_{Scatt} = \sum_{E=2,3,\ldots}^{E=100\ GeV} F^{I}_{Scatt}(E)$$

$$\mathrm{Intensity}(i) = \frac{F^{i}_{Scatt}}{\Omega_i}$$

A simple scattering model

The measured intensity in the analysis region is consistent with our simple three region scattering model



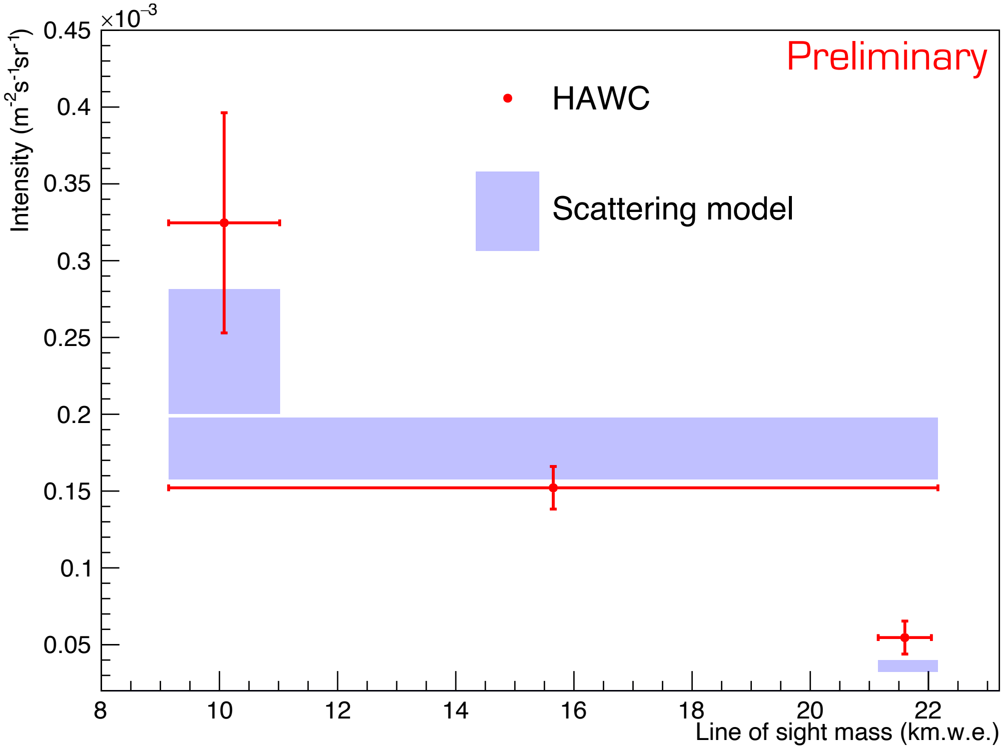


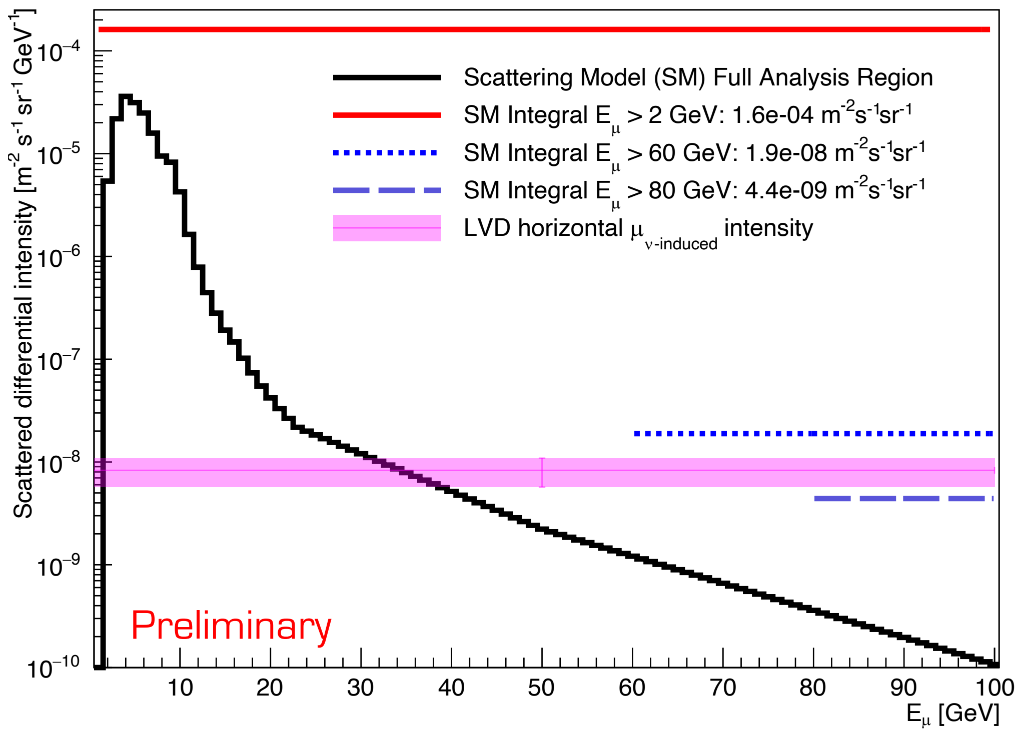
The muon tracks that point to the volcano are dominated by the scattering background

Searching for neutrino-induced muons

The strategy now is to increase the detection energy threshold in order to suppress the scattering background and to identify muons that originate from neutrino interactions in the mountain

Large Volume Detector
Astroparticle Physics 3 (1995)





Muons with energy greater than ~100 GeV would be above the scattering background ⟶ Neutrino-induced muons

Outlook

HAWC's main purpose is to measure electromagnetic and hadronic air showers at high altitude.

With this work we aim to try to detect neutrino-induced muons produced within the Pico de Orizaba volcano.

- Developed a reconstruction algorithm for horizontal tracks compatible with muon propagations.
- Investigated background sources, finding that low energy muons that scatter with almost horizontal trajectories are the main background.
- Currently working on a method to select high energy muons (>100 GeV) to suppress the scattering background.