

Study of gamma/hadron discriminant variables in application to high-energy cosmic-ray air showers

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Motivation

Identification of primary cosmic rays on an event-by-event basis stands as one of the main goals for any cosmic-ray observatory.

Cosmic-ray air-shower experiments are looking for the best discriminators to be used, in particular, for gamma/hadron primary particle discrimination (photon tags).

Several photon tag discriminators were proposed. This study focuses on P_{tail} discriminator, developed in SWGO experiment, which is based on measured cosmic-ray signals and can be also determined based on signal time distributions (traces).

P_{tail} variable is a gamma/hadron discriminant variable for Water-Cherenkov Detector (WCD) cosmic-ray observatories.

P_{tail} is a sum of normalized cumulative signal distribution $C_{r_i, t_j}(S_{i, j})$ over rings r_i and time bins t_j

$$P_{tail} = \sum_{i, j} C_{r_i, t_j}(S_{i, j})$$

Simulation dataset

- produced for the WCD of the Infill array of the Pierre Auger Observatory
- 1000 proton and photon showers with energy about 10^{17} eV were simulated with CORSIKA, and reconstructed with AugerOffline Software

Method - P_{tail} computation

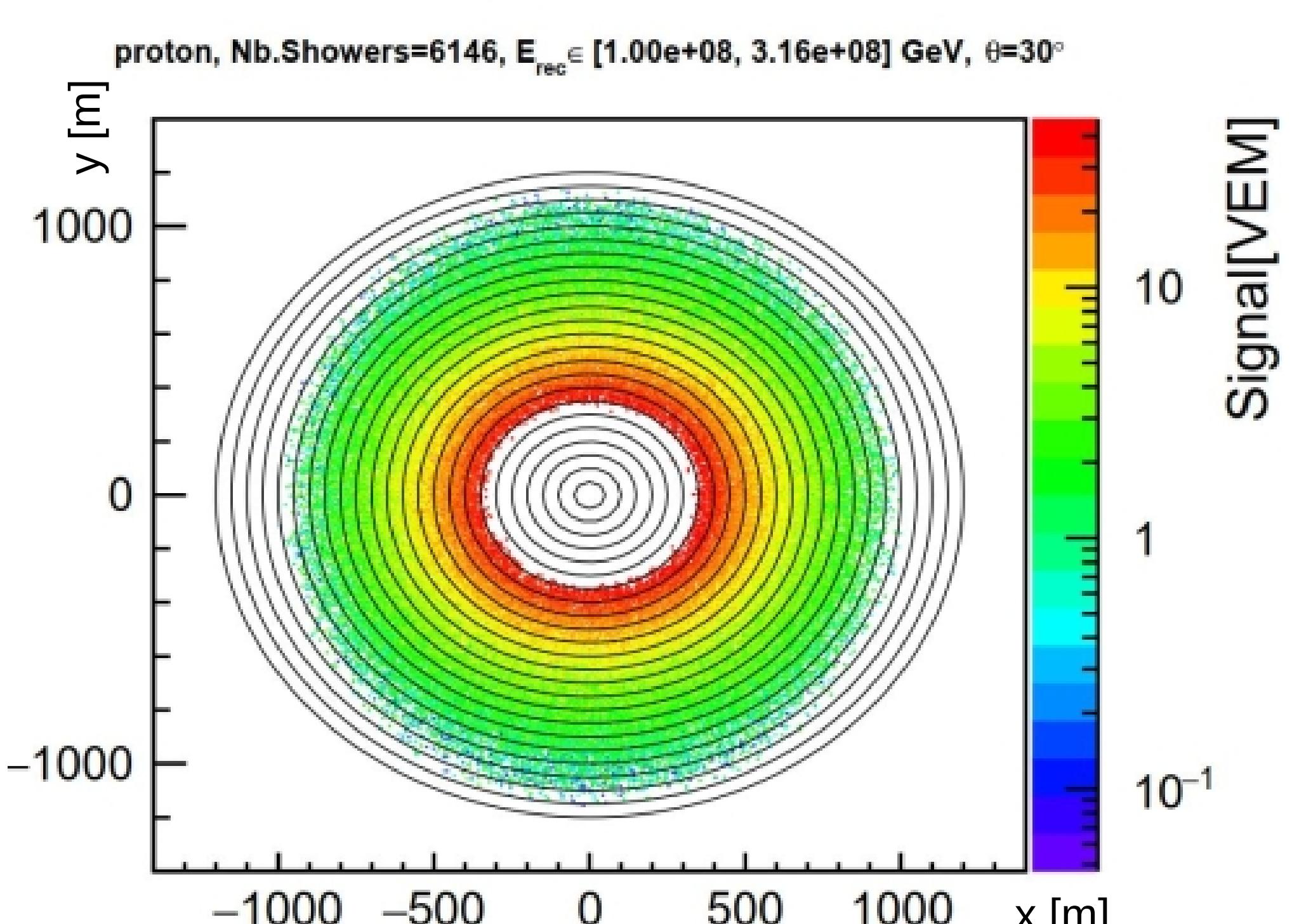
In shower plane:

Array's surface was divided into rings of equal width centered around the shower core

In each ring:

- Signal distribution of stations was built
- Cumulative distribution, normalized to 1 was computed

P_{tail} contribution:
value of corresponding ring's cumulative at station's signal



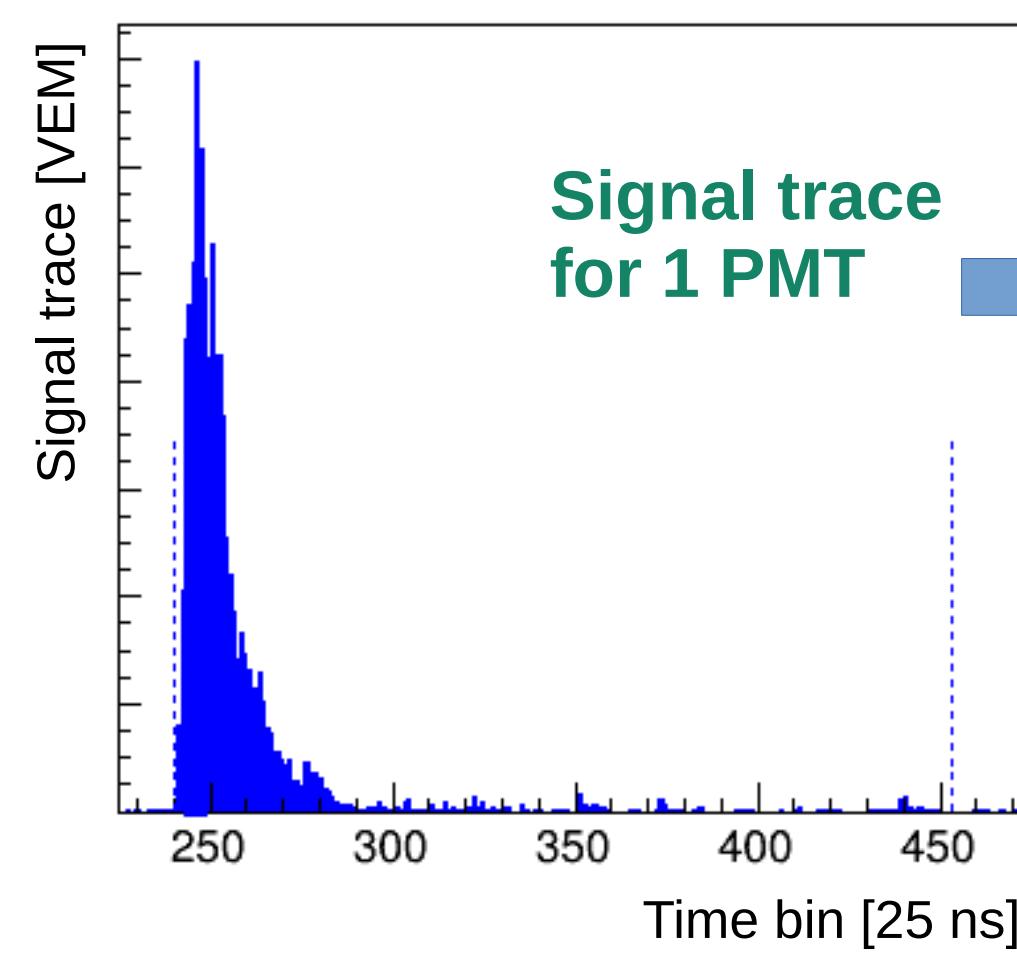
Concentric 50m wide rings superimposed over Average footprint for proton events with $E_{rec} \in [10^{17}, 10^{17.5}]$ eV. Saturated stations excluded.

Credit to Pedro Costa (LIP, IST ULisboa, Portugal)

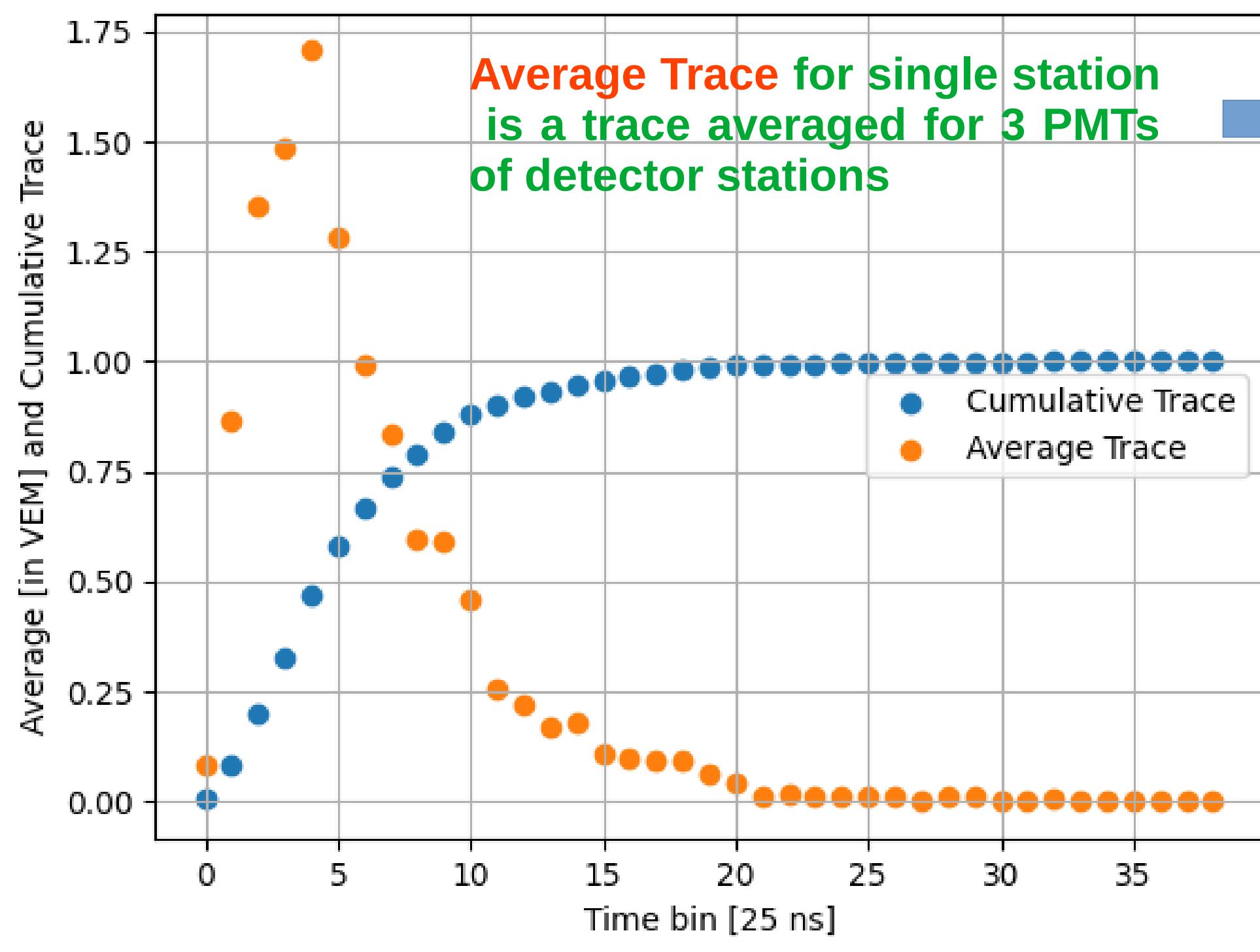
The rings are calculated from the distance of 200 m, so the 1st ring is from 200 to 250 m distance to shower core, the 2nd ring: 250 – 300 m, etc.

Application of P_{tail} discriminator to simulated events measured by WCD detectors of the Pierre Auger Observatory

P_{tail} originally (in SWGO experiment) was built from the total signals measured in an array of detectors and correlated with the total number of muons in the air shower.



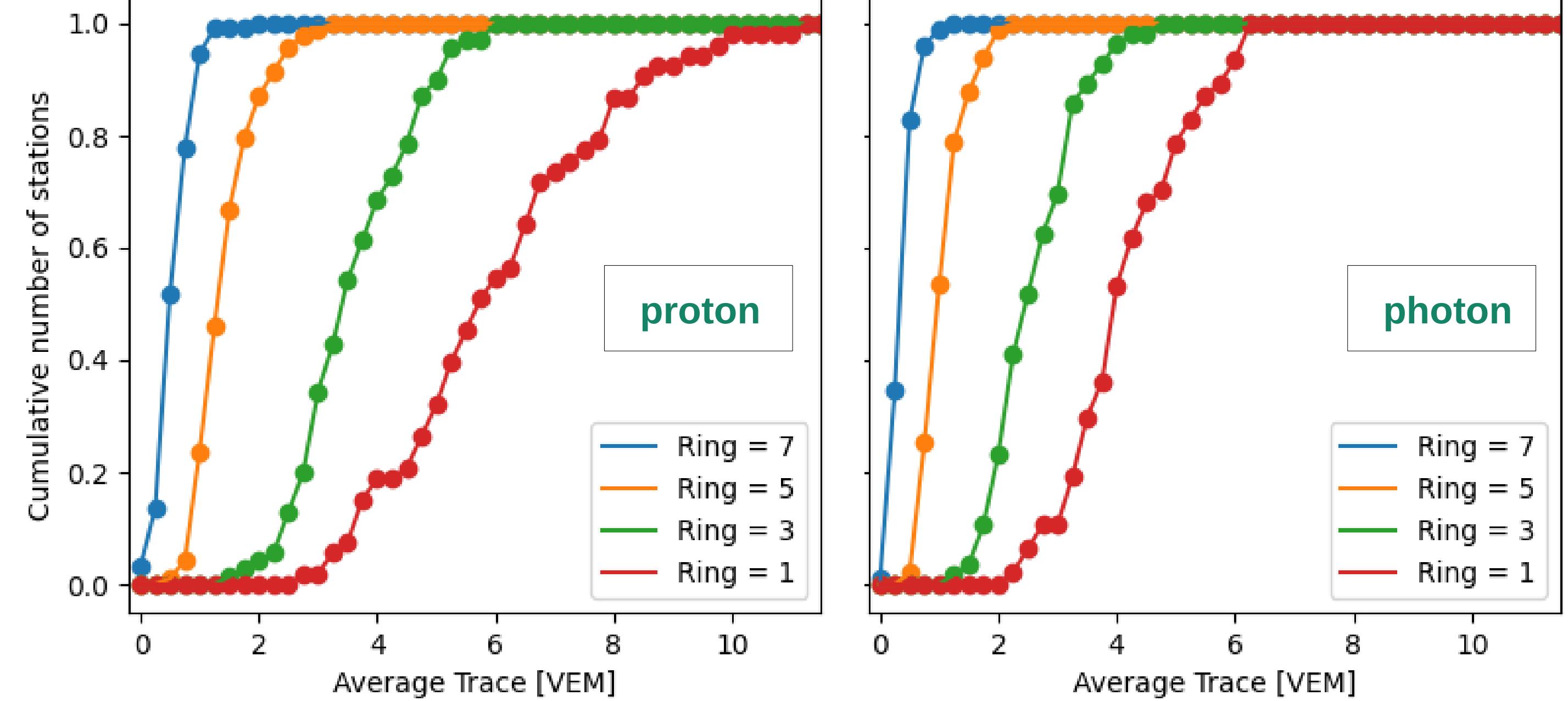
Time-based analysis for the Pierre Auger Observatory uses the detector traces of the signals instead of just the total signal.



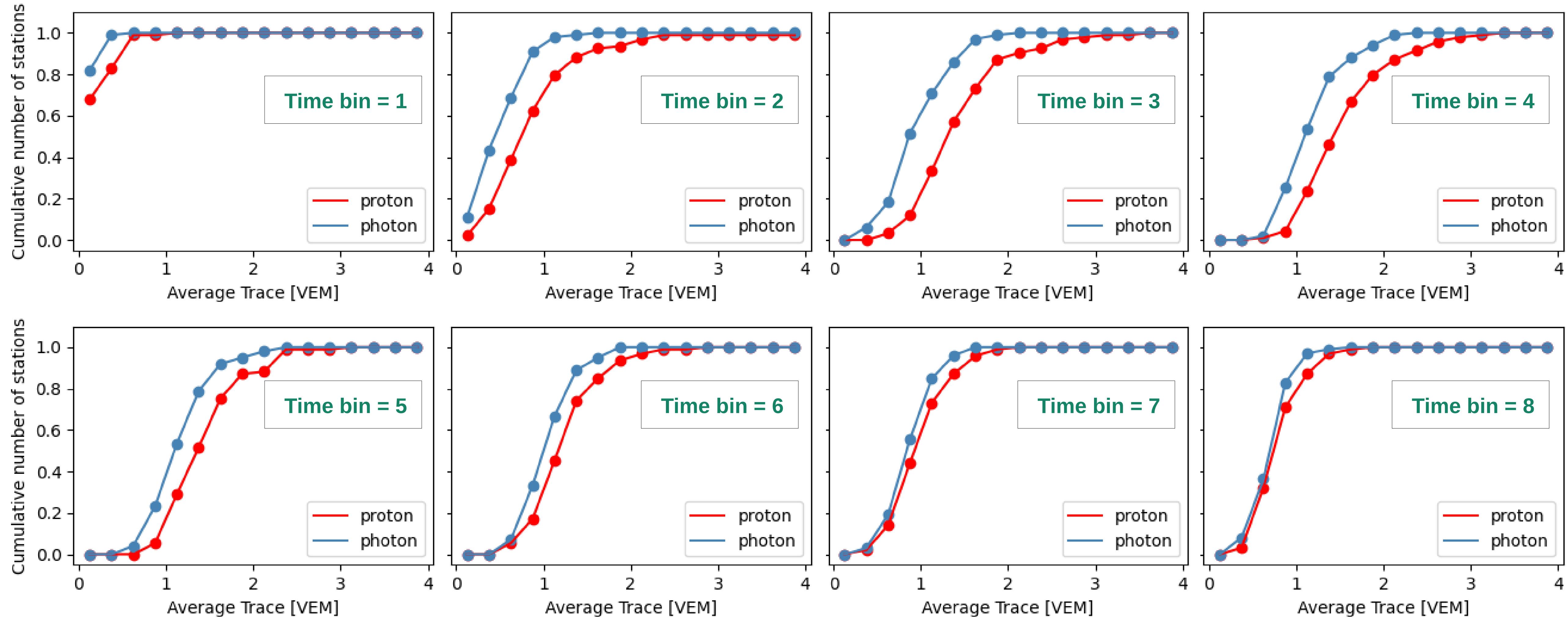
Cumulative distributions are produced for stations collected in each ring for the same time bins and for the same rings.

Cumulative histograms:

Number of detector stations for different rings for the same Time bin = 3



Cumulative histograms: Number of stations for different time bins of the traces in single ring 5 = 400-450 m from shower core, each time bin = 25 ns

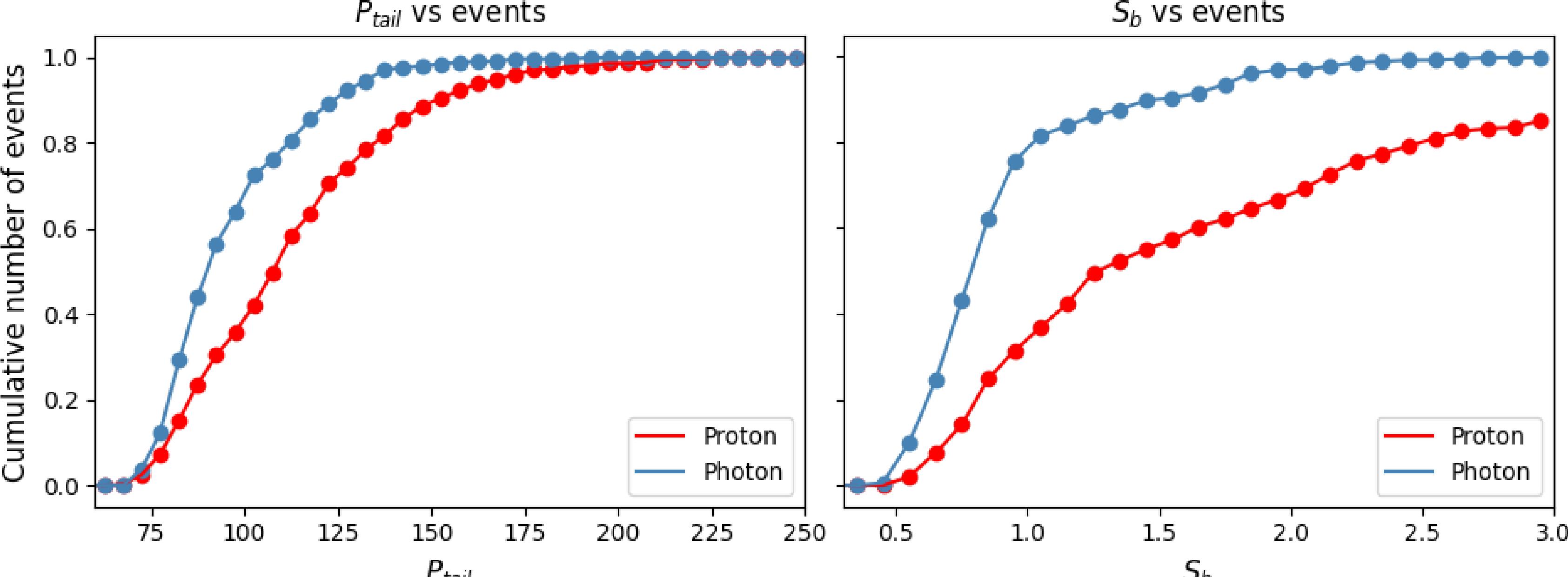


S_b variable is used to discriminate between photons and background showers

$$S_b = \sum_{i=1}^n S_i \left(\frac{R_i}{1000 \text{ m}} \right)^4$$

where S_i - detector signal, R_i - distance from shower axis

P_{tail} vs S_b



Summary

Applying the time based analysis to the simulated events of the Pierre Auger Observatory Infill Array we obtained:

- P_{tail} discriminant for events;
- comparison with S_b variable.

These discriminant variables are able to separate photon- and proton-initiated air showers for identification of primary cosmic rays.

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