

# 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

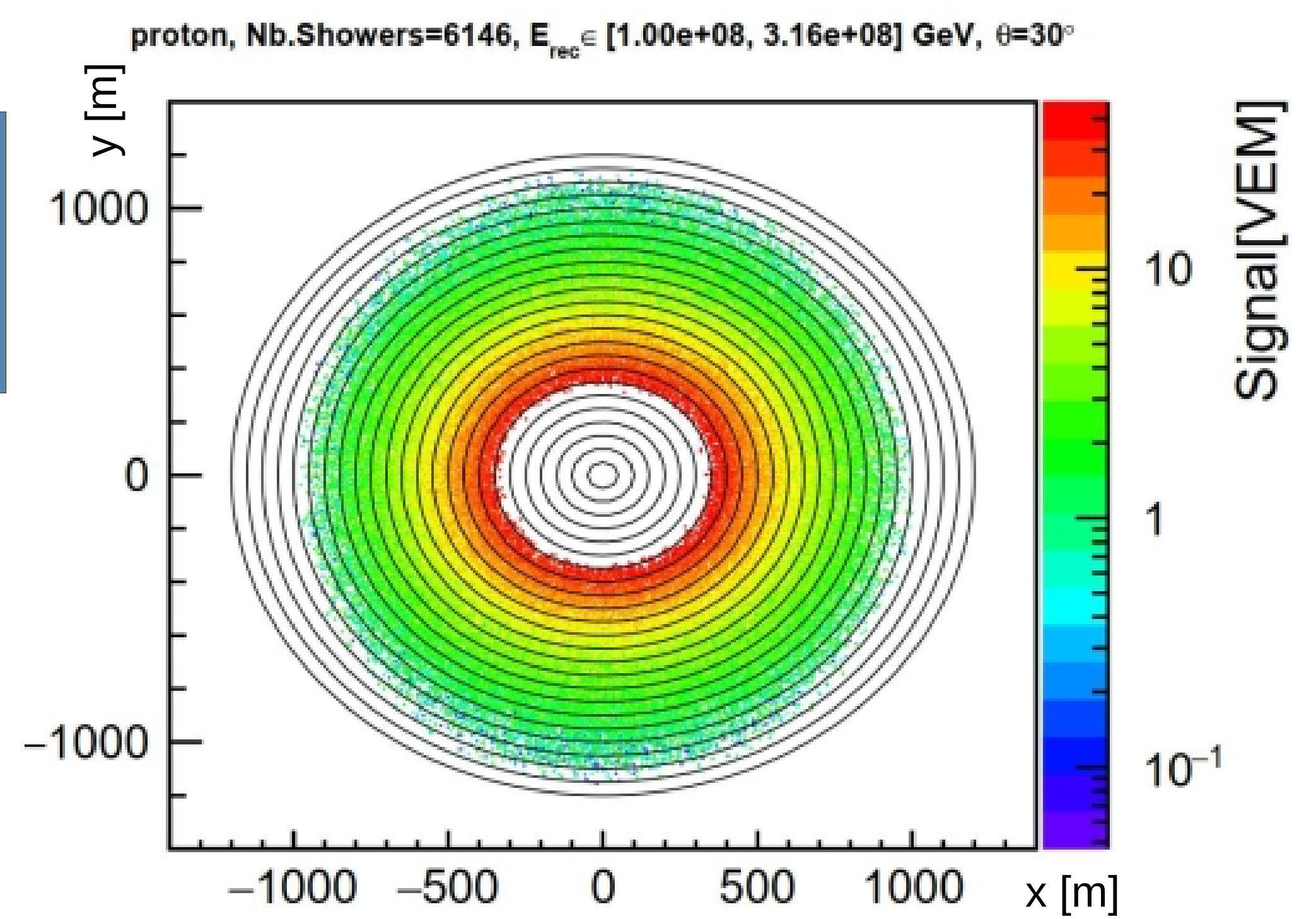
- 1000 proton and photon showers with energy about  $10^{17}$  eV were simulated with CORSIKA, and reconstructed with AugerOffline Software

## 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.

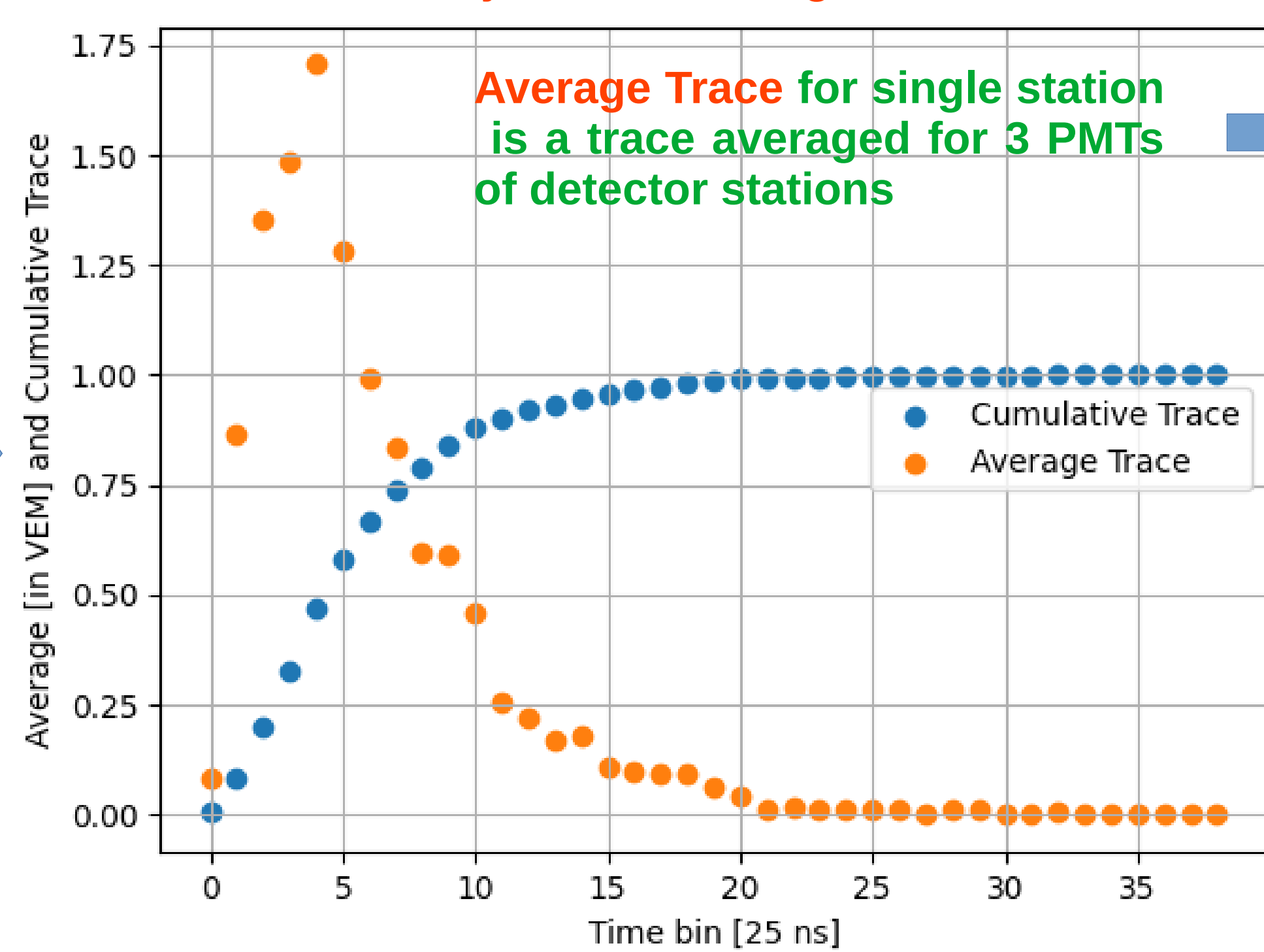
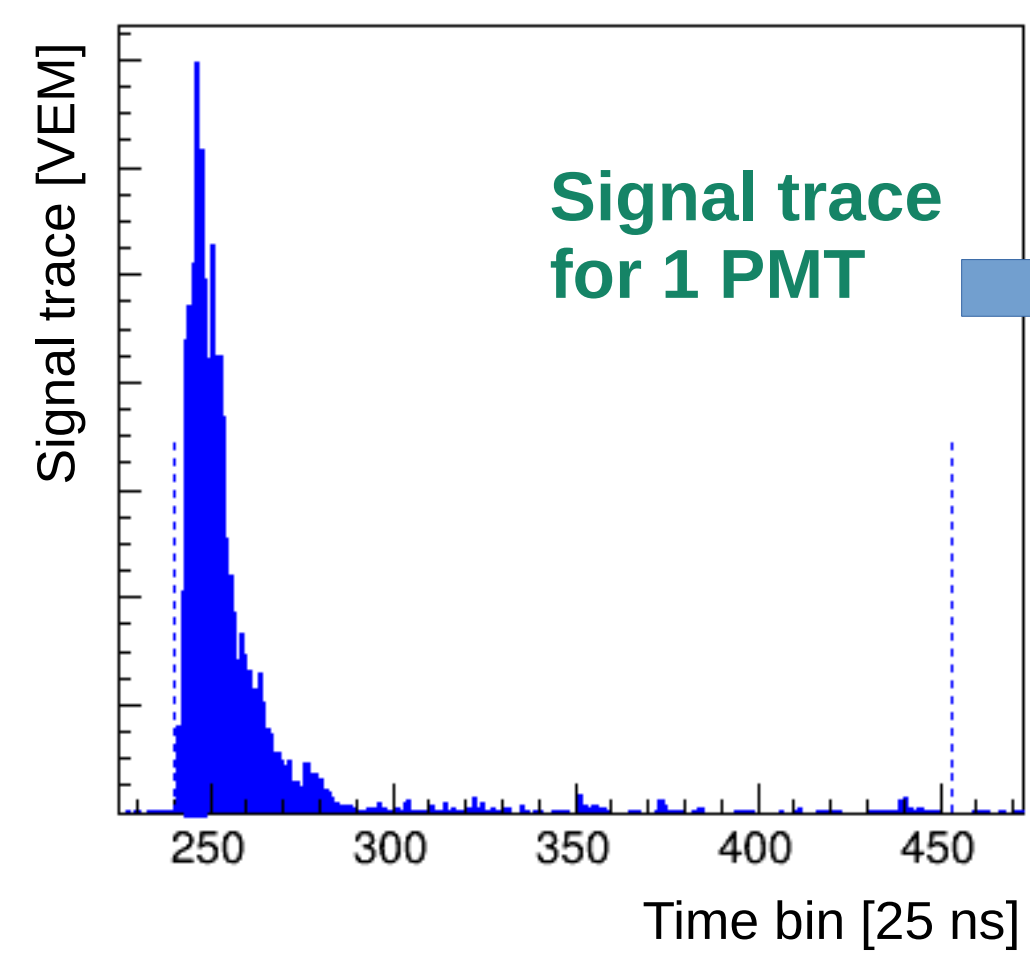
Credit to Pedro Costa (LIP, IST ULisboa, Portugal)

The rings are calculated from the distance of 200 m, so the 1<sup>st</sup> ring is from 200 to 250 m distance to shower core, the 2<sup>nd</sup> 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.

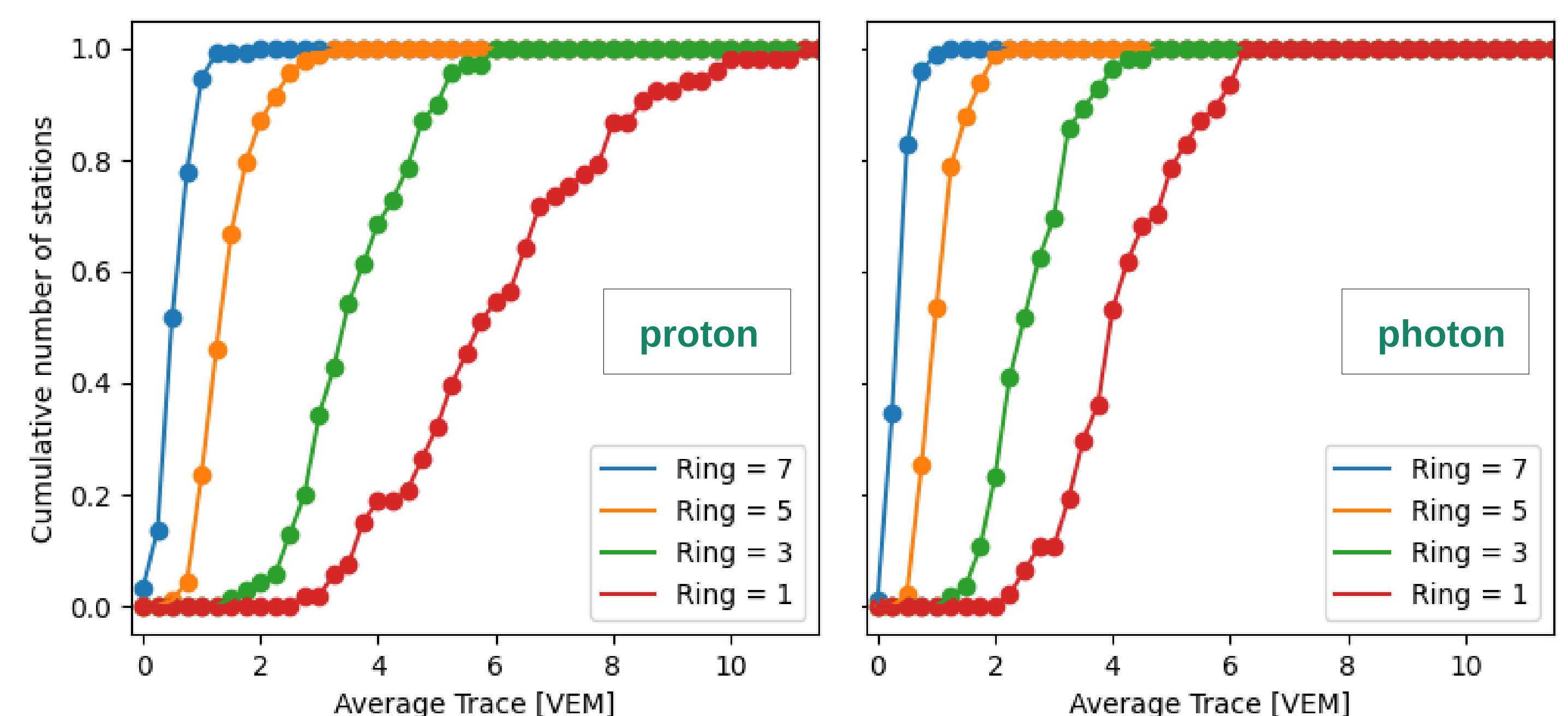
Time-based analysis for the Pierre Auger Observatory uses the detector traces of the signals instead of just the total signal.



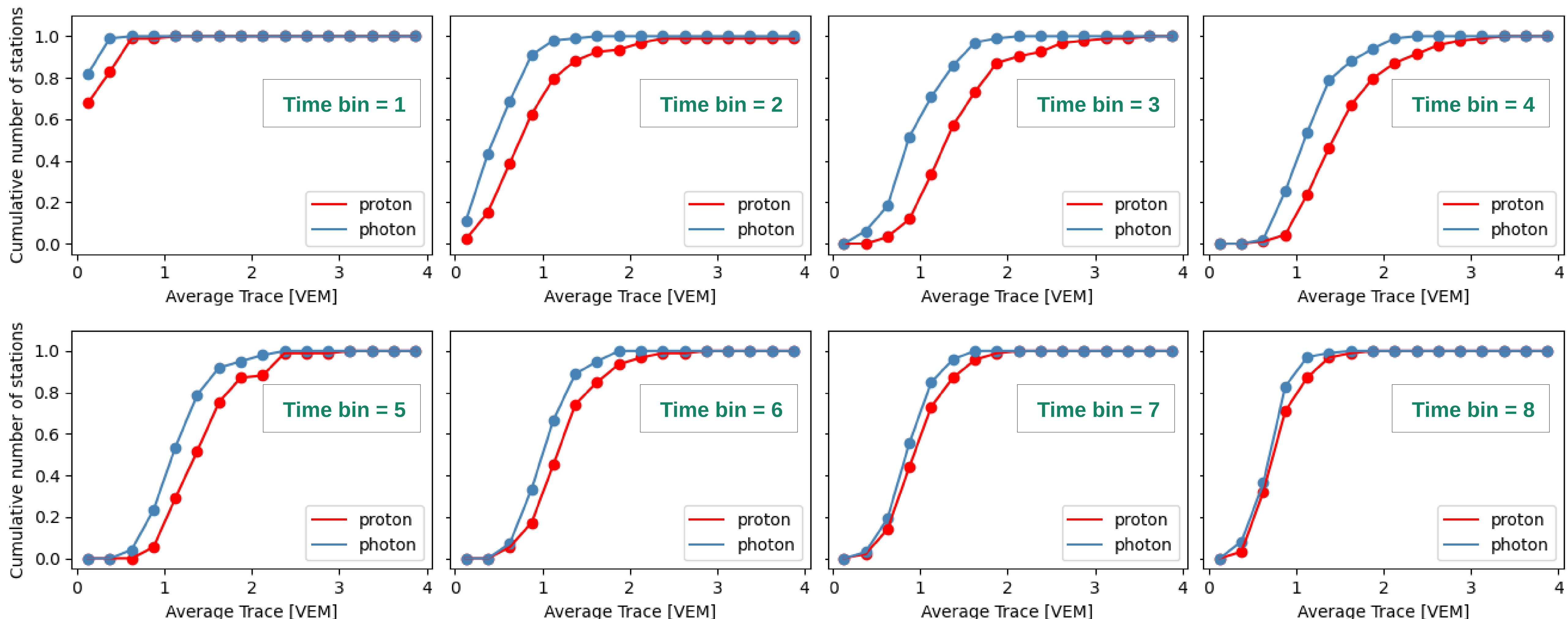
Cumulative distributions are produced for stations collected in each ring for the same time bins and for the same rings.

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

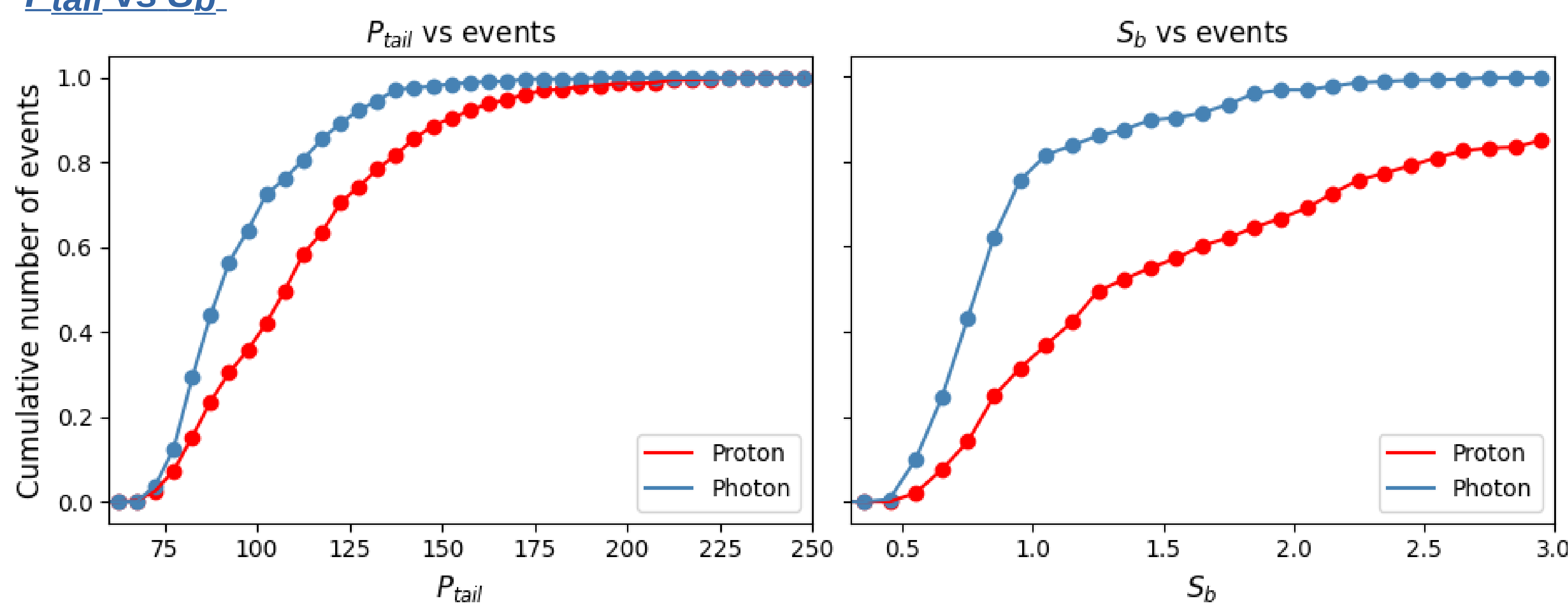


$S_b$  variable is used to discriminate between photons and background showers

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

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:

- $P_{tail}$  discriminator 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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