Search for Extremely Energetic Photons

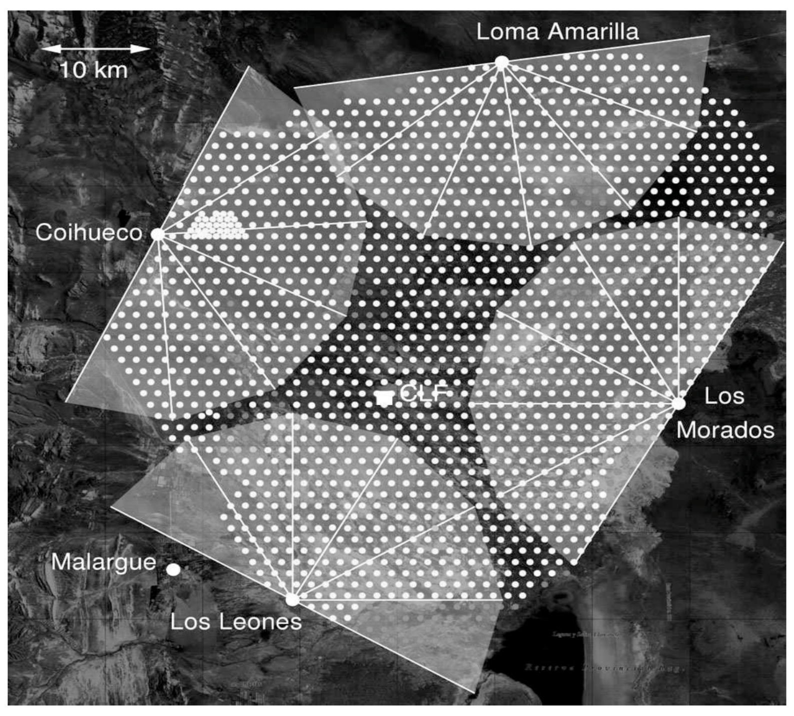
Níkolas Kemmerich[A], Ivone F.M.Albuquerque [A]
[A] Institute of Physics - University of São Paulo - USP.

Abstract

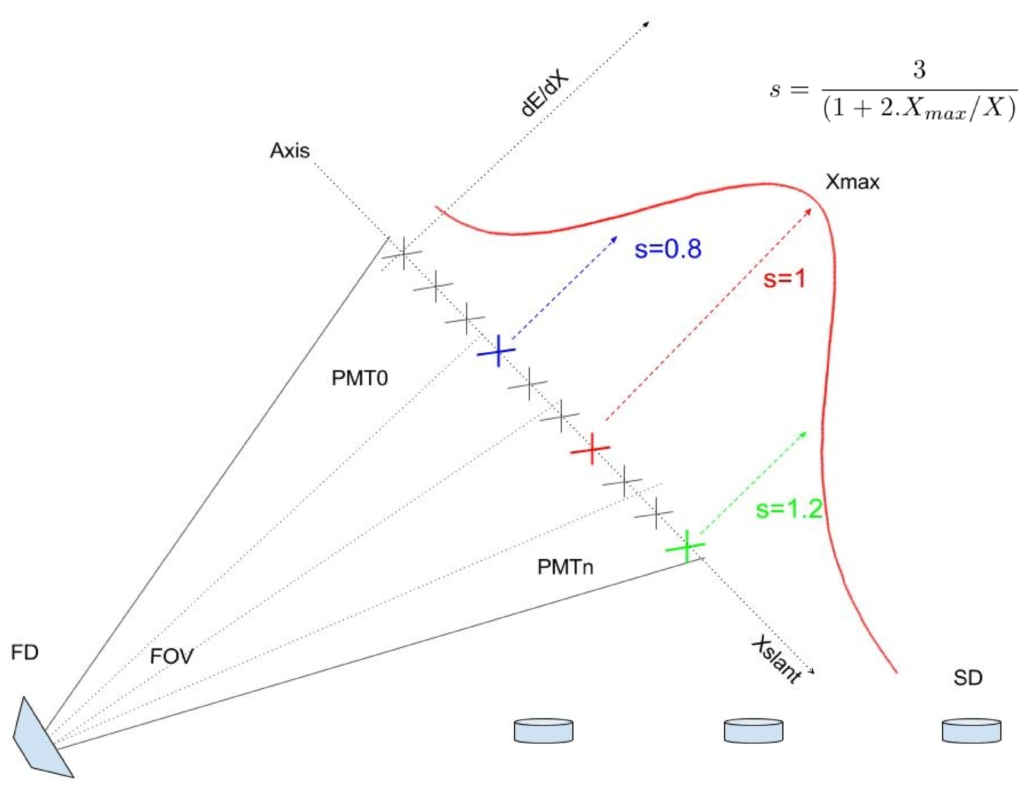
Ultra High Energy Cosmic Rays (UHECR) (E>10^{18} eV) are rare events and have low flux. The knowledge of their chemical composition would constrain models of their origin and sources since these are still a mystery. There is still a possibility that a minor fraction of these events are composed by photons [1] since most of models predicting high photonic flux were excluded [2]. The photonic component is important to track down sources (no magnetic bending). If this turns out to be the case, they will hint interesting features on the UHECR composition and propagation. The Observatory Pierre Auger (OPA) is currently the largest UHECR observatory [3]. It measures Extensive Air Showers (EAS) created due to the UHECR interaction with the atmosphere molecules. The atmospheric depth where the EAS reaches the maximum number of charged particles **Xmax** and the **Muons** content are parameters in the EAS related to UHECR composition. In our work we **simulate the detection and reconstruction** of EAS in order to determine a method to **discriminate photons induced shower from protons and heavier nucleons induced ones**.

Pierre Auger Observatory [3]

- WCD (3000 km^2, 1500 m).
- 4 Fluorescence Telescopes.
- Upgrade to measure Muon Content (2018).
- Measure GZK suppression [4] and Anisotropy of UHECR [5].
- Composition mostly nucleons.



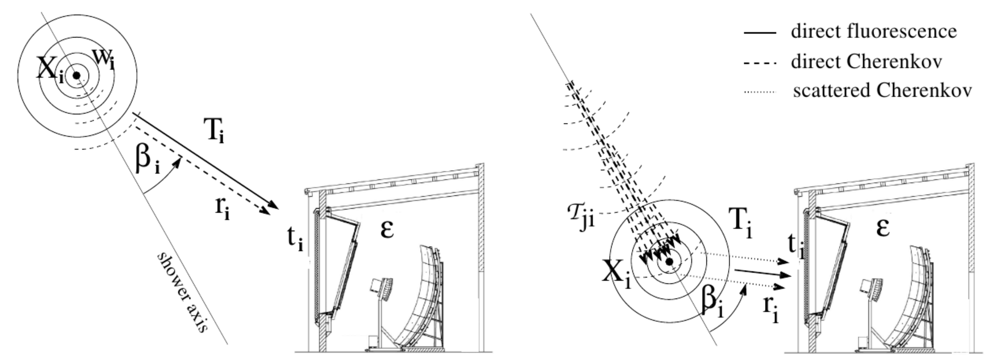
FD Detection Sim [6]



$$s = \frac{3}{(1+2.X_{max}/X)}$$

$$\frac{dE}{dX}(X) = \frac{dE}{dX}_{max}\left(\frac{X-X_0}{X_{max}-X_0}\right)^{\frac{X_{max}-X_0}{\lambda}} e^{\frac{X_{max}-X}{\lambda}}$$

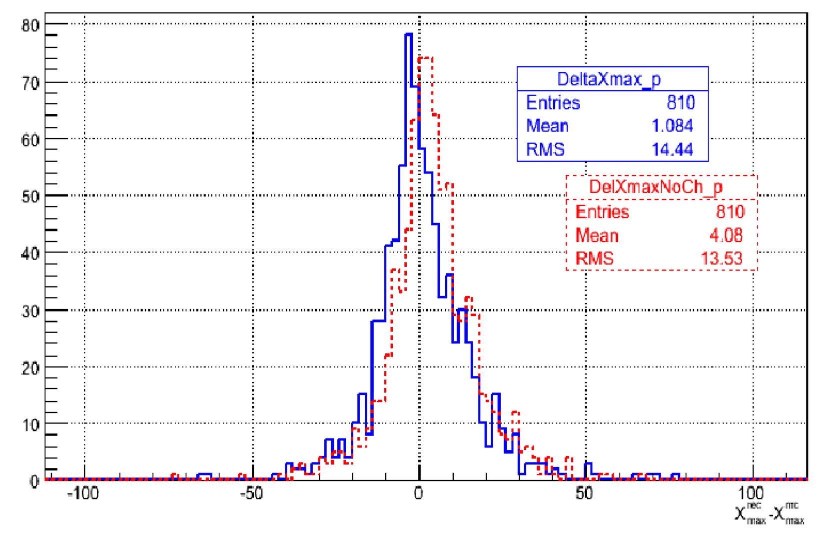
Fluorescence (Signal) + Cherenkov (contamination)[7]

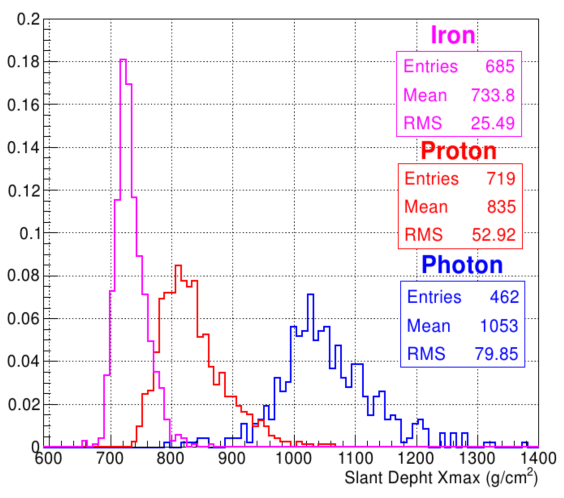


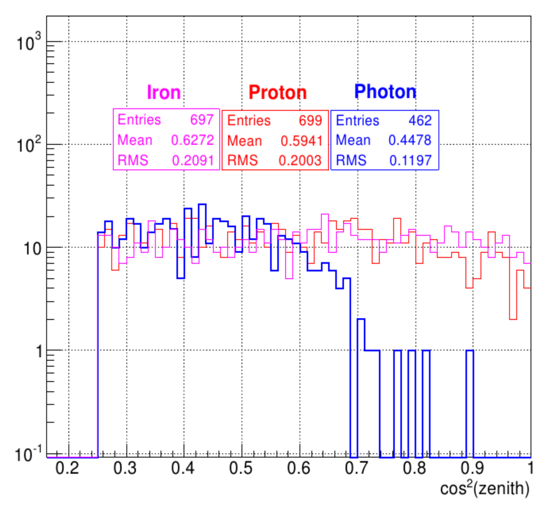
Detector	Auger
Altitude	1500 km
Efficiency	20%
Min Elevation	2°
Max Elevation	32°
Azimuth	360°
Diaphragm (m^2)	3.8
PMT view	1.5°

Parameter	selection
R_{core}	$< 10km$
Cherenkov	yes
Cherenkov Fraction	< 50%
θ_{Rec}	< 60°
Trigger	$> 5PMTs$
X_{max}	visível
χ^2(GH)	< 5

FD Reconstruction

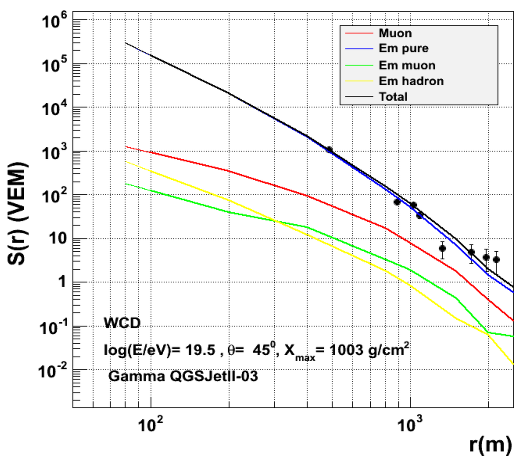


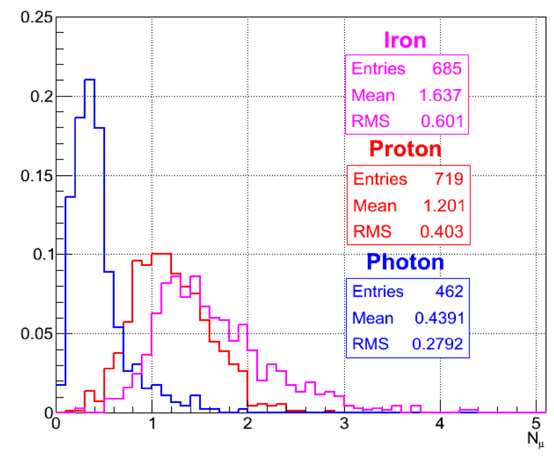




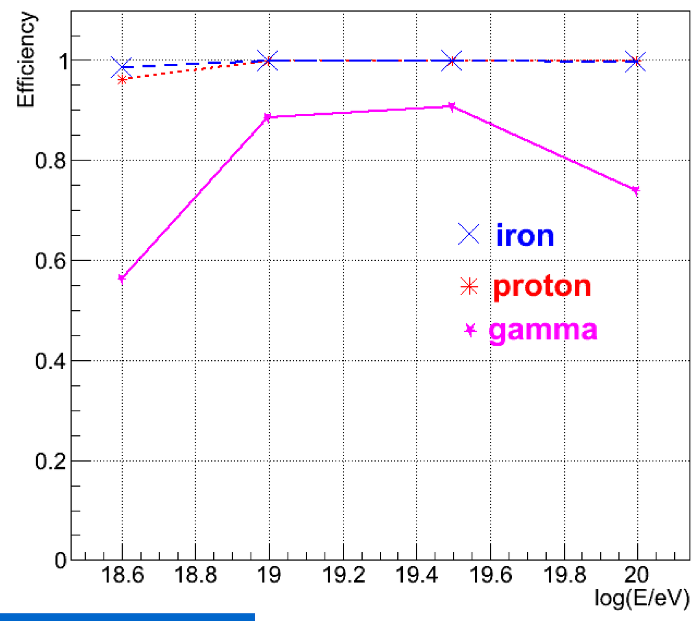
SD Detection Performance [8]

Generalized descriptions WCD signals (OPA)
Take muons from Lateral profile Reconstructions



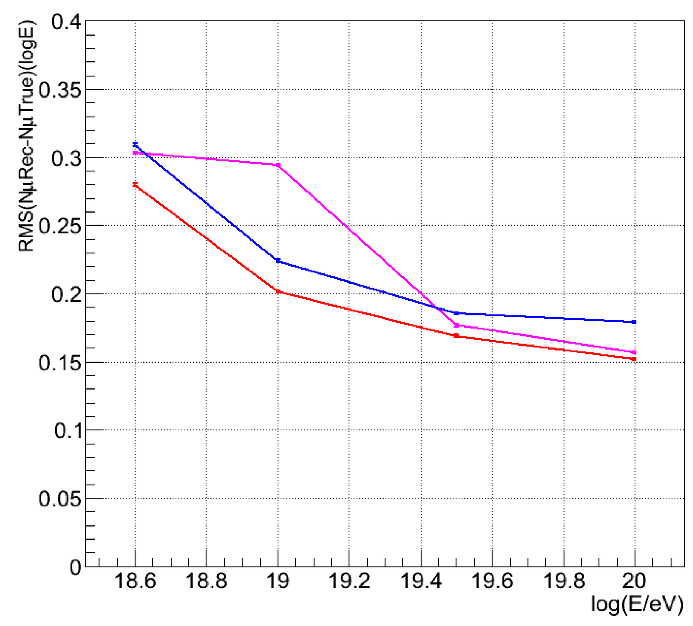


Efficiency Rec Nμ



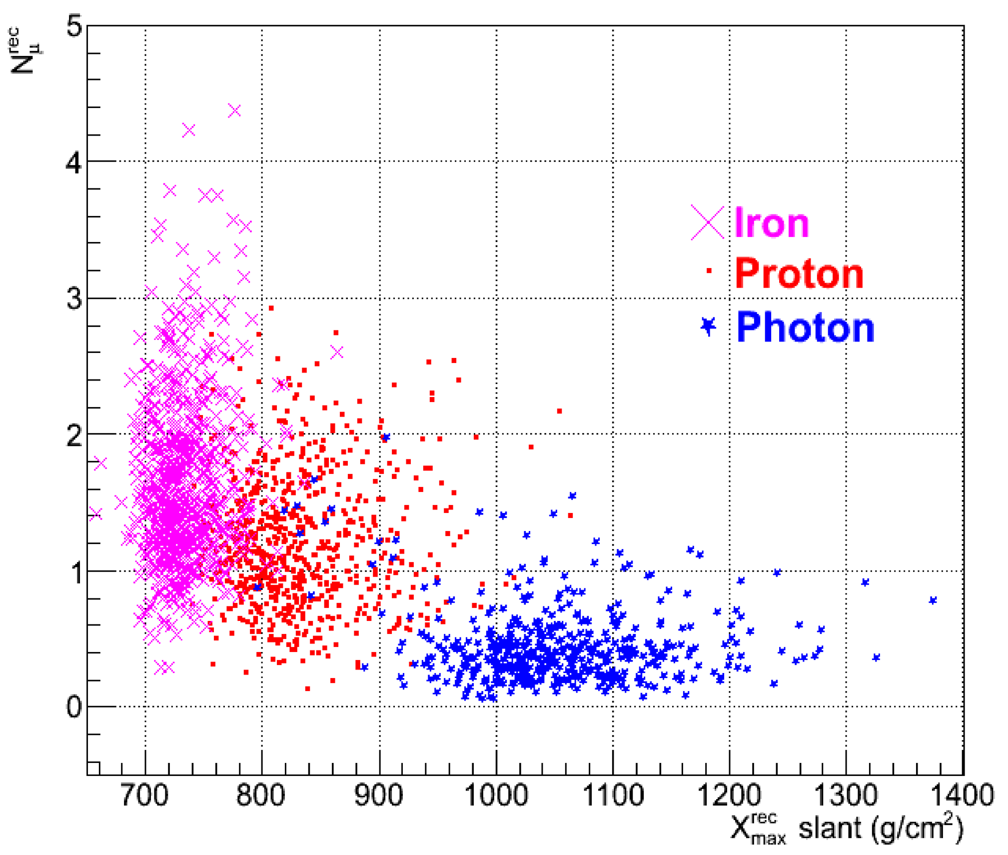
Resolution Nμ

~20% for all particles



Discrimination Methods

Space of Rec Parameters: Xmax and Nmu.
Improve latest discriminate parameters [2].
Statistical Discrimination: protons and photons Showers (ensure to discriminate heavy nucleons).
Estimate photon fraction in a given set of showers.



Methods → **Quality Factor**, **Fisher**

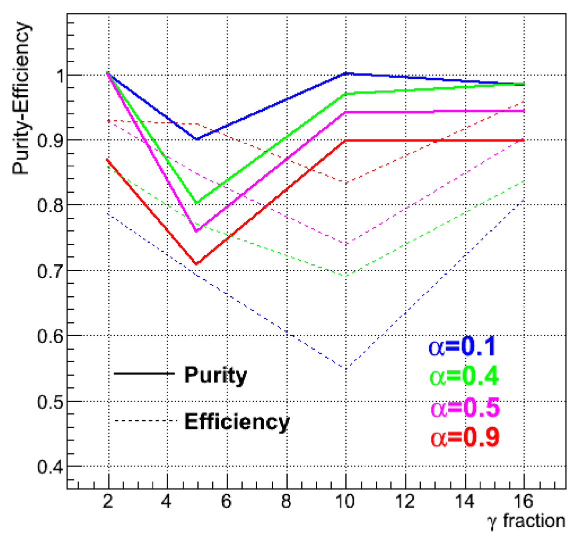
Quality Factor [9]

$$Q(X_c, N\mu_c) = \frac{\sum_{i=1}^{M} N'_{\gamma i}}{\sum_{i=1}^{M}(N'_{\gamma i}+N'_{pi})}\left(\sum_{i=1}^{M} N'_{\gamma i}\right)^{\alpha}$$

$$p = \frac{N'_\gamma}{N'_\gamma + N'_p}$$

Rectangular Cut in space parameters

$log(E/eV)$	$(X_c,N\mu_c)$	p_f	α
(18.6)	(860,0.08)	0.90	0.3
(19.0)	(880,0.14)	0.95	0.4
(19.5)	(950,0.5)	0.97	0.3
(20.0)	(890,1.18)	0.87	0.4



Systematics

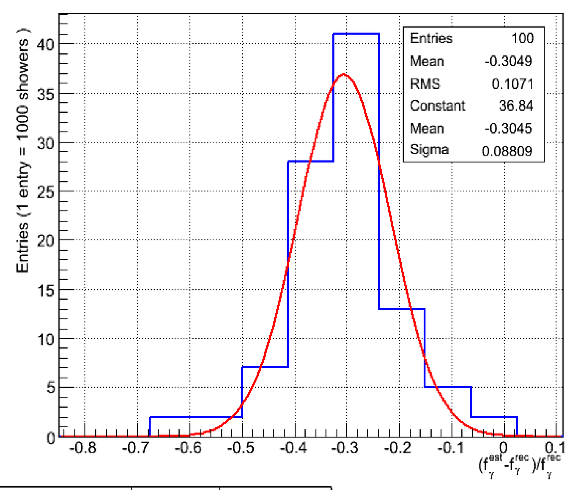
$$N'^{est}_\gamma = p_f.N'$$

$$f^{est}_\gamma = \frac{N'^{est}_\gamma}{N^{rec}}$$

Uncertainty

$$f'_\gamma = \frac{f^{ec}_\gamma}{\varepsilon}$$

$$\sigma_\gamma = \left(\frac{f^{ec}_\gamma}{\varepsilon}\right)\cdot\sqrt{\left(\frac{\sigma^{eq}}{f^{ec}_\gamma}\right)^2 + \left(\frac{\sigma_\varepsilon}{\varepsilon}\right)^2}$$

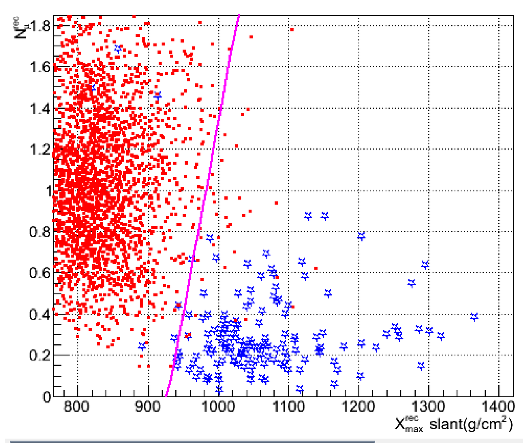


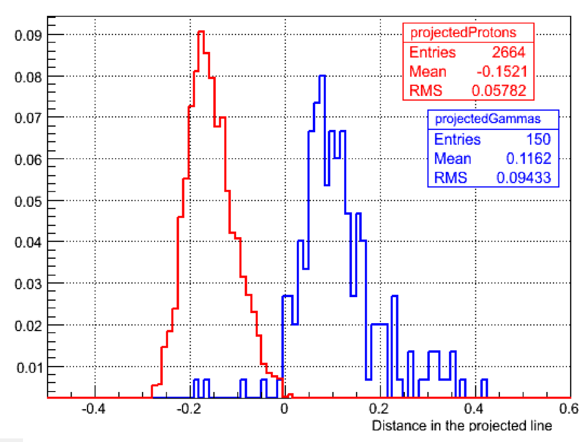
Blind Analysis

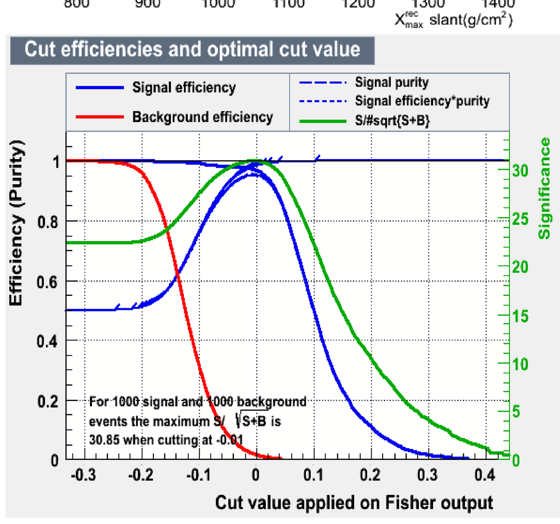
Set(gen=1000)	N'^{est}_γ	$f^{gen}_\gamma(\%)$	f'_γ	σ_γ
1	39	11.9	13.5	±2.47
2	8	2.4	2.43	±0.90
3	31	8.6	10.1	±2.01
4	7	2.4	2.12	±0.84
5	25	8.7	7.90	±1.72
6	21	7.2	6.74	±1.58
7	12	3.4	3.74	±1.15
8	30	8.6	9.37	±1.90
9	5	1.2	1.56	±0.72

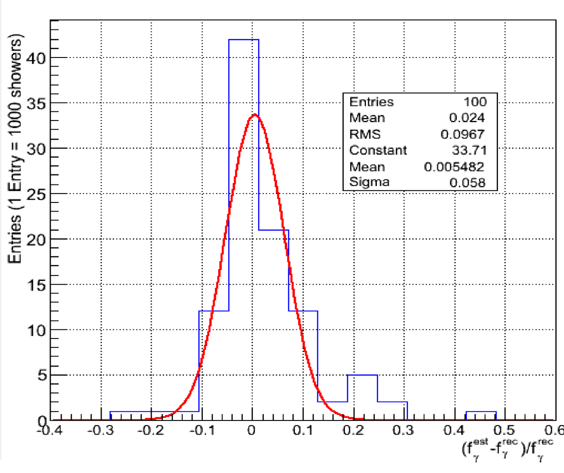
Fisher

$$J(v) = \frac{(\tilde{\mu}_1 - \tilde{\mu}_2)^2}{\tilde{S}_1^2 + \tilde{S}_2^2}$$









Set(gen=1000)	N'^{est}_γ	F(cut)	Purety	$f^{gen}_\gamma(\%)$	f'_γ	σ_γ
1	51	0.0252	0.93	11.9	12.5	1.9
2	11	0.0461	0.80	2.4	2.1	0.7
3	44	0.0252	0.93	8.6	10.1	1.7
4	12	0.034	0.90	2.4	2.6	0.8
5	42	0.0263	0.92	8.7	9.3	1.6
6	30	0.0311	0.91	7.2	6.6	1.3
7	18	0.036	0.89	3.4	4.00	1.0
8	45	0.0252	0.931	8.6	10.0	1.6
9	6	0.0535	0.81	1.2	1.2	0.5
10	15	0.0376	0.89	3.4	3.38	0.9

Conclusions: The discrimination power of Xmax and Nmu was tested in sets of mixed photon and proton showers. The estimation of the fraction in blind analysis brings the conclusion of great discrimination. With the Upgrade of WCD in OPA, muons will soon play a great deal in the search for Extremely Energetic Photons.

References:

[1] Pijushpani Bhattacharjee, arXiv:astro-ph/9811011, 2000.
[2] The Pierre Auger Collaboration, arXiv:1612.01517 [astro-ph.HE], 2017.
[3] The Pierre Auger Collaboration, arXiv:1604.03637 [astro-ph.IM], 2016.
[4] The Pierre Auger Collaboration, Physical Review Letters 101, 061101 (2008).
[5] The Pierre Auger Collaboration, Science 357 (2017).
[6] Washington Carvalho Jr., Ivone F. M. Albuquerque, Vitor de Souza, arXiv:astro-ph/0702123, 2007.
[7] M. Unger, B. R. Dawson, R. Engel, F. Schüssler, R. Ulrich, arXiv:0801.4309 [astro-ph], 2008.
[8] M.Ave, R. Engel,M.Roth, A.Schulz, Astroparticle Physics,Volume 87, January 2017, Pages 23-39.
[9] Washington Carvalho Jr., Ivone F. M. Albuquerque, Phys. Rev. D 80, 023006 (2009).

XIV ICFA School on Instrumentation in Elementary Particle Physics
27 November 2017 to 8 December 2017
La Habana, Cuba