Photon/Hadron Discrimination in Hybrid Events at the Pierre Auger Observatory

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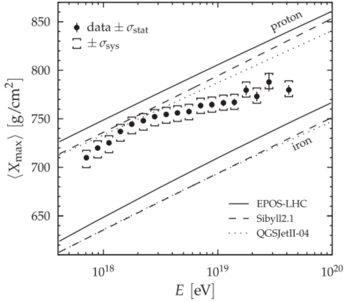
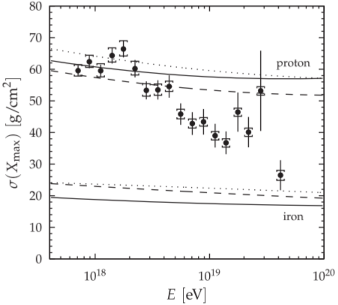
Allianz für Astroteilchenphysik

Short Digression: Chemical Composition at UHE

[Phys.Rev. D **90** 122005]





- UHECR: nuclei from p to Fe
- change of slope suggests heavier particles at higher energies
- X_{max} (later more...) data indicates increase of A with Energy

Why searching for photons...

Models predicting the existence of UHE photons

Top-Down models:

- Z-burst scenario
- super heavy dark matter (SHDM)
- topological defects

Bottom-Up models:

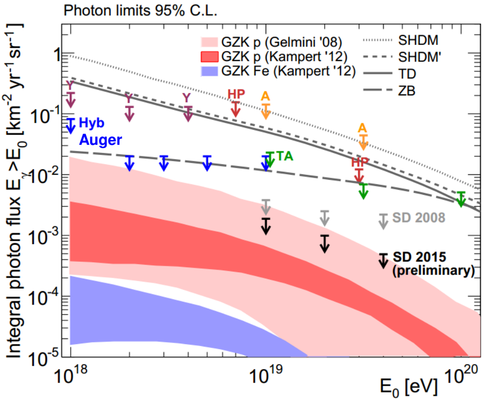
Acceleration of charged nuclear primaries in

- neutron stars / pulsars
- active galactic nuclei
- propagating shock fronts
- gamma ray bursts, etc.

and interaction with CMB ($p_{GZK} + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow \pi^{0(+)} + p(n)$) and $\pi^{0} \rightarrow 2\gamma$

Limits on Photon Flux

[C. Bleve for the Auger Collab., ICRC 2015]



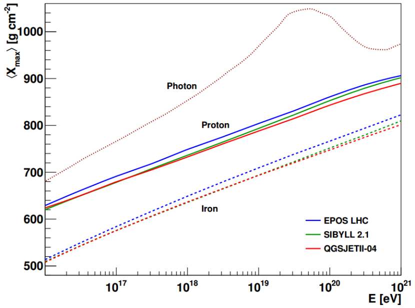
- many Top-Down models severly constrained
- if ∃ UHE protons ⇒ also bottom-up models predict photon flux caused by the GZK-effect at up to ∼ 1% CR fraction

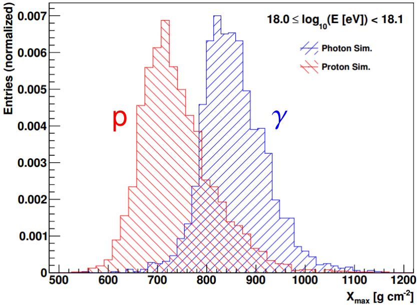
⇒ Update the limits using hybrid events

Discrimination between UHE photons and nuclei

X_{max}:

- atmospheric depth of the longitudinal shower maximum
- FD observable



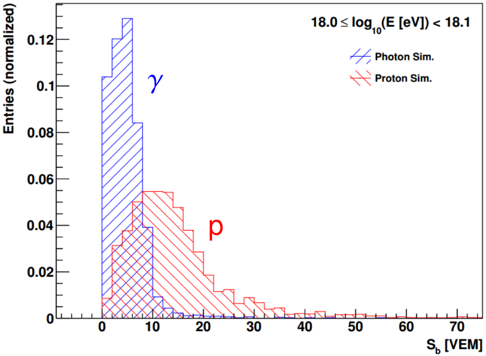


Add SD observables to improve separation power!

SD Observable: S_b

S_b:

- sum of signals S_i in stations with distances r_i from the core
- $S_b := \sum_{i=1}^{N} \left[S_i \times \left(\frac{r_i}{r_0} \right)^b \right]$ [M. Settimo for the Auger Collab., ICRC 2011]
- uses the difference in the lateral distribution function of showers initiated by different primary types



A New SD Observable F_γ

F_γ uses the lateral profile of EAS but takes advantage of hybrid measurement

$$F_\gamma := \frac{S_{1000|\gamma}}{S_{1000|Hybrid}}$$

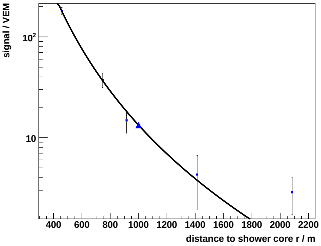
- $S_{1000|\gamma}$: the S_{1000} value obtained from fitting the SD data with a photon-like lateral profile
- $S_{1000|Hybrid}$: the S_{1000} value obtained by using the reconstructed Hybrid energy $E_{FD} \sim S^B_{1000|Hybrid}$ and inverting the standard SD reconstruction.

$S_{1000|\gamma}$

Parametrisation of the exponent of the LDF:

$$S(r) = S_{1000|\gamma} \left(\frac{r}{1000m}\right)^{\beta(E,\theta)} \left(\frac{r+700m}{1700m}\right)^{\beta(E,\theta)}$$

with $\beta(E,\theta)$ from photon simulations (CORSIKA + Offline, QGSJETII-04 + Fluka)



and fitting to data using the maximum likelihood method.
Extended likelihood function:

$$\mathscr{L} = \mathscr{L}_{small} \times \mathscr{L}_{large} \times \mathscr{L}_{non-trig} \times \mathscr{L}_{core} \times \mathscr{L}_{axis} \times \mathscr{L}_{\beta}$$

$\Rightarrow$ only free parameter is $S_{1000|\gamma}$
$\Rightarrow$ in principle applicable to events with only few triggered stations ($\rightsquigarrow$ later more)

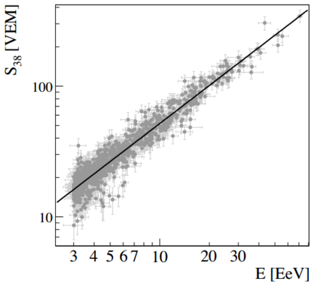
$S_{1000|Hybrid}$

First obtain $S_{38|Hybrid}$ from the reconstructed FD energy

$$S_{38|Hybrid} = \sqrt[B]{\frac{E_{FD}}{A}}$$

with $A = (1.68 \pm 0.05) \times 10^{17}$eV and
$B = 1.036 \pm 0.009$

[R. Pesce, ICRC 2011]

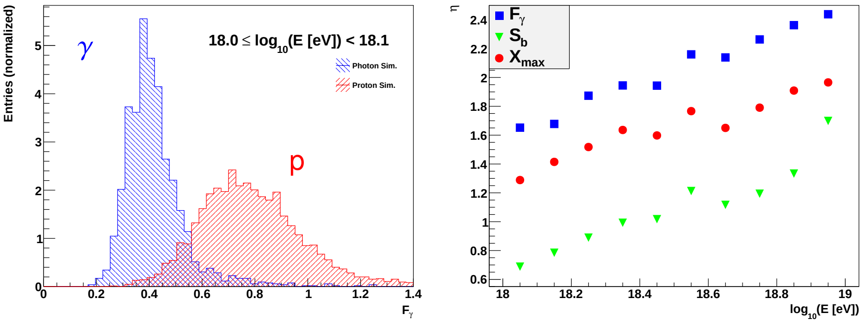


Then obtain $S_{1000|Hybrid}$ by using the reconstructed zenith angle

$$S_{1000|Hybrid} = CIC(\theta) \times S_{38|Hybrid}$$

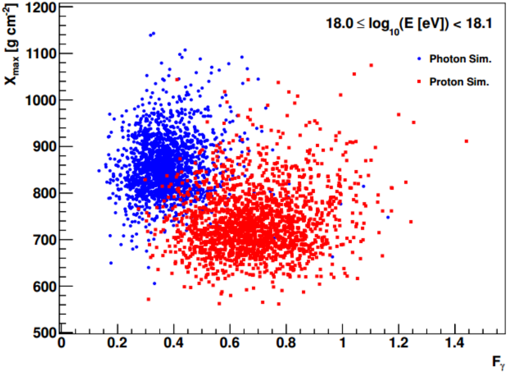
$CIC(\theta)$: 3rd order polynomial in $x = \cos(\theta) - \cos(38^\circ)$ and empiric coefficients

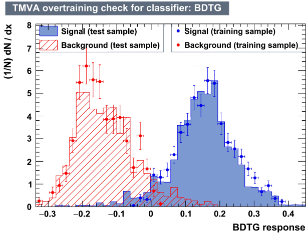
Separation Power of F_γ

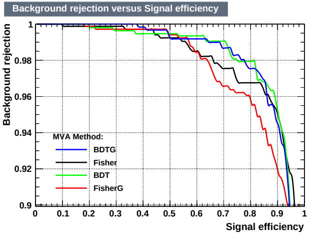


⇝ high separation power between photon and proton induced air showers!

Combination of F_γ and X_{max} in an MVA







99.5% background reduction at 50% signal efficiency using BDT/BDTG

Summary and outlook

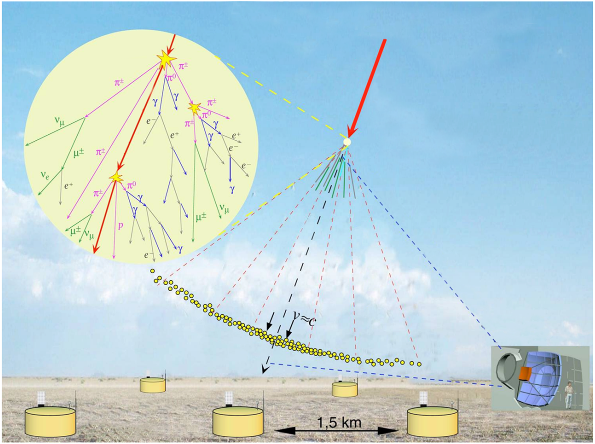
F_γ:

- high separation power between photon and proton induced showers
- useful for photon analysis especially at the lower energies measured at Auger
- combination with X_{max} allows better distinction between primary particles

next step:

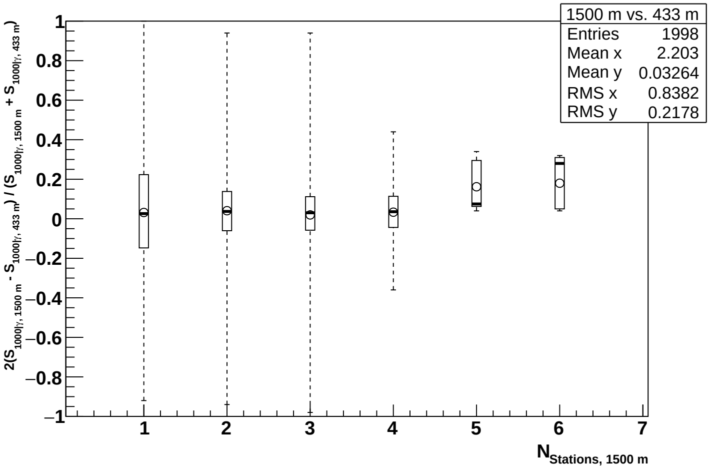
Compare the performances of F_γ and S_b with respect to an MVA to update the upper limits of UHE photon flux starting to probe the GZK region.

Backup - The Pierre Auger Observatory



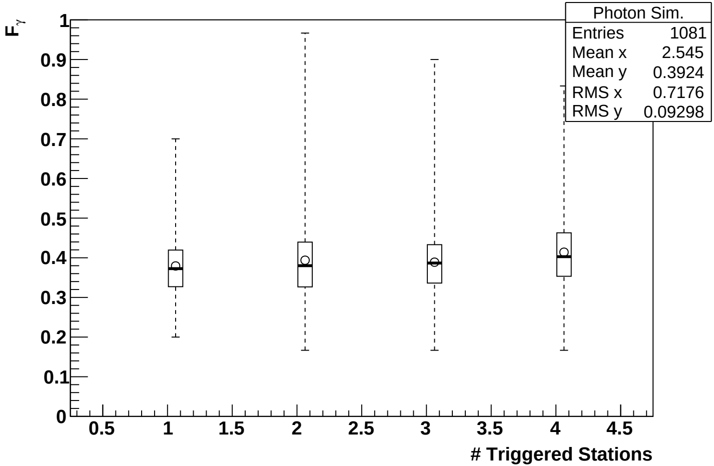
- surface detector (SD): 1660 water cherenkov tanks
- fluorescence detector (FD): 27 fluorescence telescopes at 4 locations
- simultaneous measurements with FD and SD (Hybrid Events)

Comparison With A Dense Array



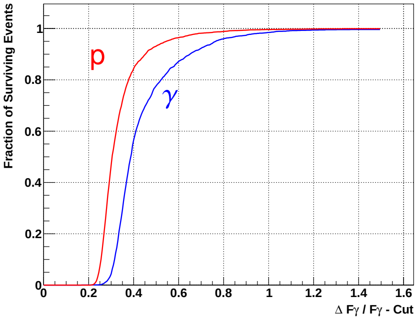
$\rightsquigarrow$ Mean value of F_γ is independent of the array geometry

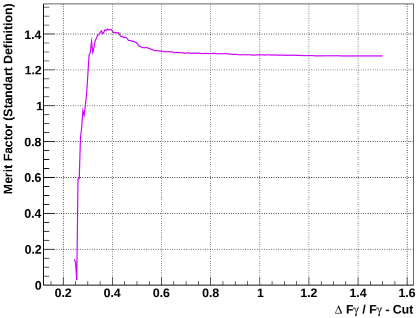
Consistency Check



$\rightsquigarrow$ advantage of F_γ: remains $\sim$constant in events with only one or two triggered stations

Quality Cut Analysis

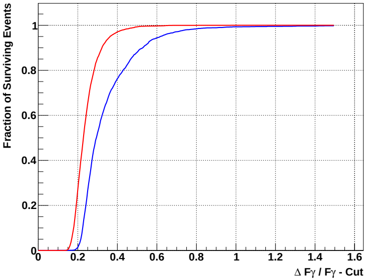


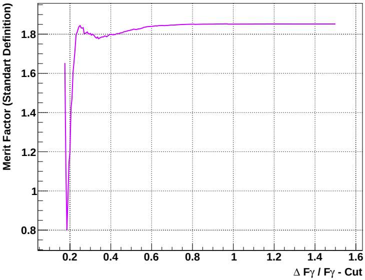


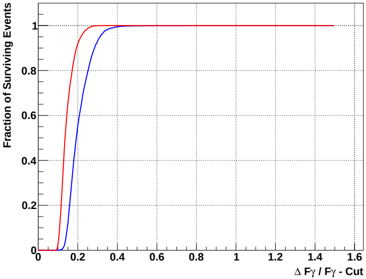
$$\eta := \frac{|\mu_p - \mu_\gamma|}{\sqrt{\sigma_p^2 + \sigma_\gamma^2}}$$

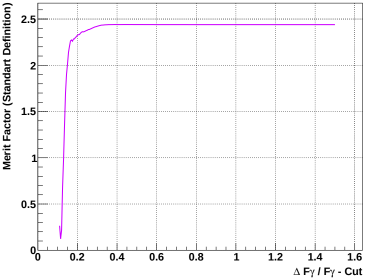
$$\Delta F_\gamma / F_\gamma < 0.5 \Rightarrow \text{Efficiency} > 80\%$$

Backup - Quality Cut Analysis

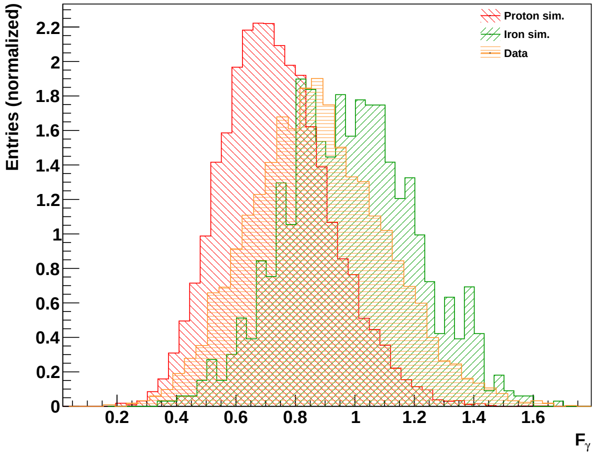








Backup - F_γ for heavier nuclei



larger F_γ values for higher nucleon numbers $\rightsquigarrow$ assume pure proton background for conservative estimation.