Photon Search @ the Pierre Auger Observatory

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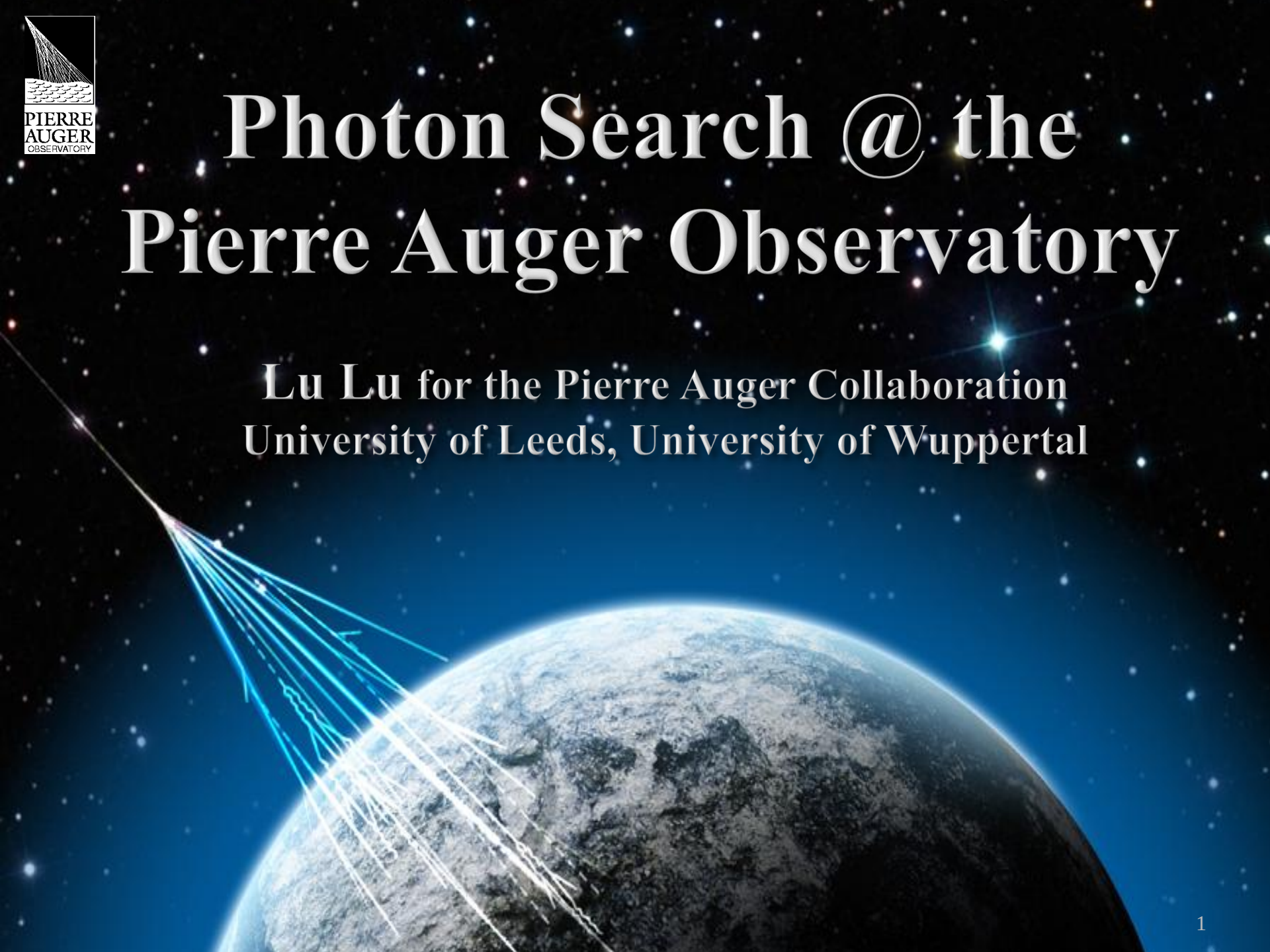


Photon energy goes to an extreme

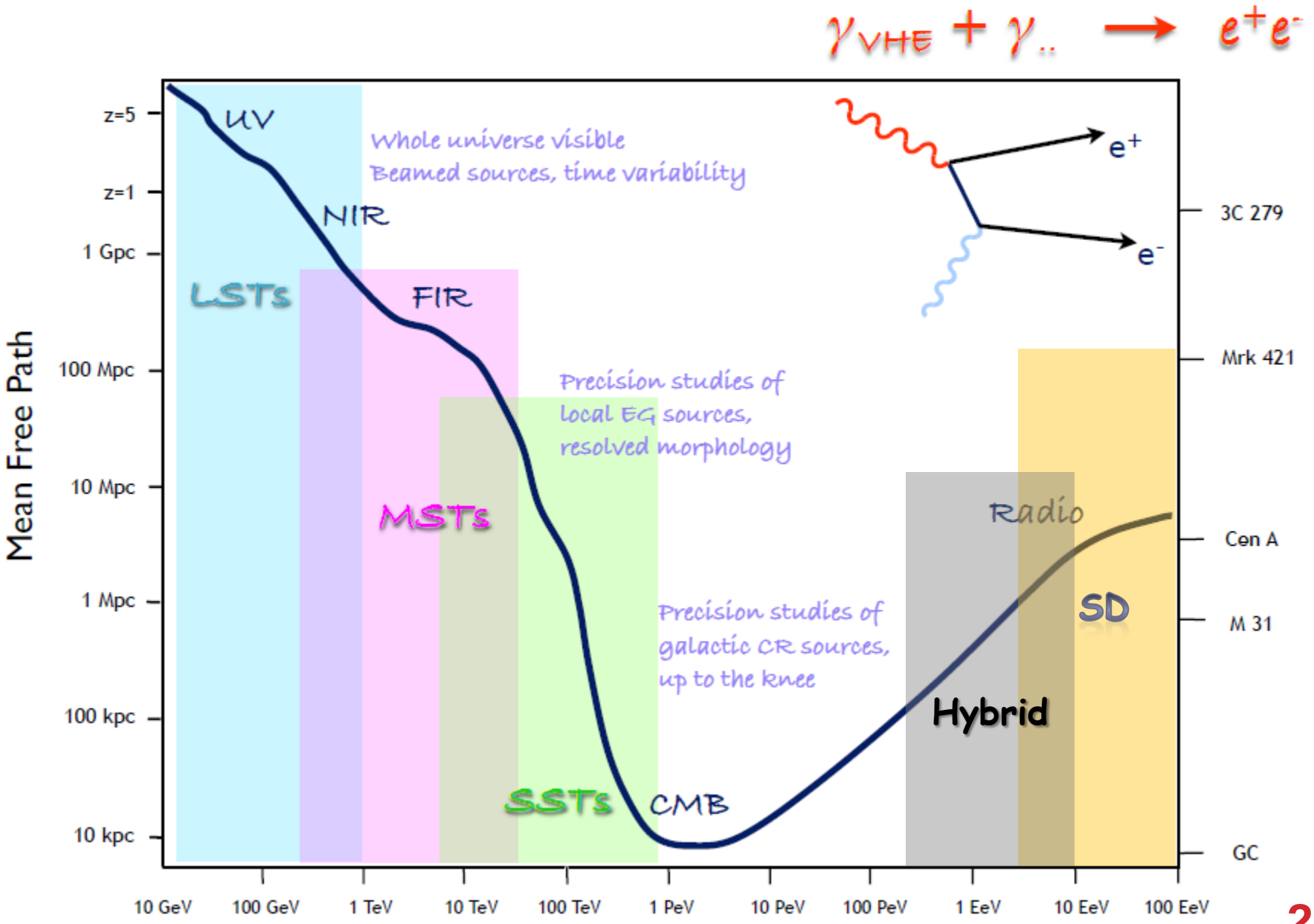


Figure from J.Knapp

Why do we study ultra high energy photons?

- Pointing back to the UHECR source

$$p + p \rightarrow p + p + \pi^0$$

- Indirect **test of mass composition** and without relying on the hadronic models

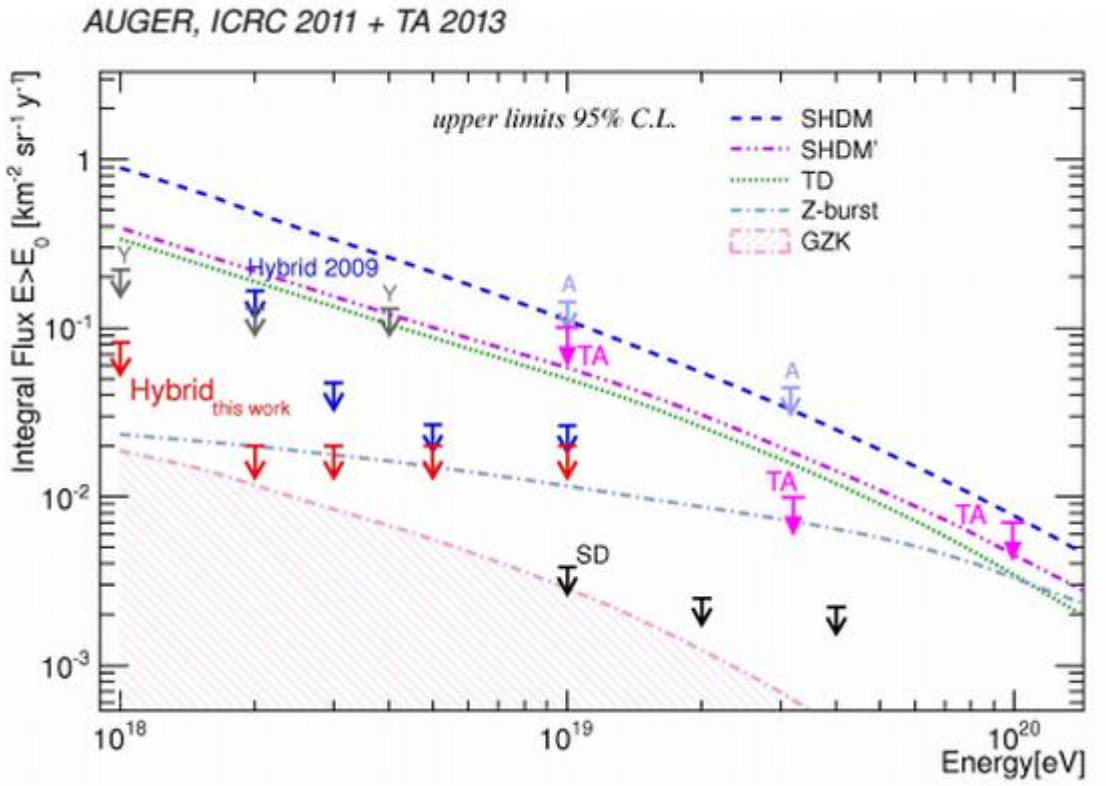
$\gamma_{2.7\,K} + {}^{56}Fe \rightarrow {}^{55}Fe + n$ photo-disintegration

$\gamma_{2.7\,K} + p \rightarrow \Delta^+ \rightarrow p + \pi^0$ (↗ γ) or $n + \pi^+$ (↗ ν) photo-pion interaction, GZK

- Possible new physics? (Lorentz invariance violation)

Galaverni, Sigl PRL 2008

Why do we study ultra high energy photons?

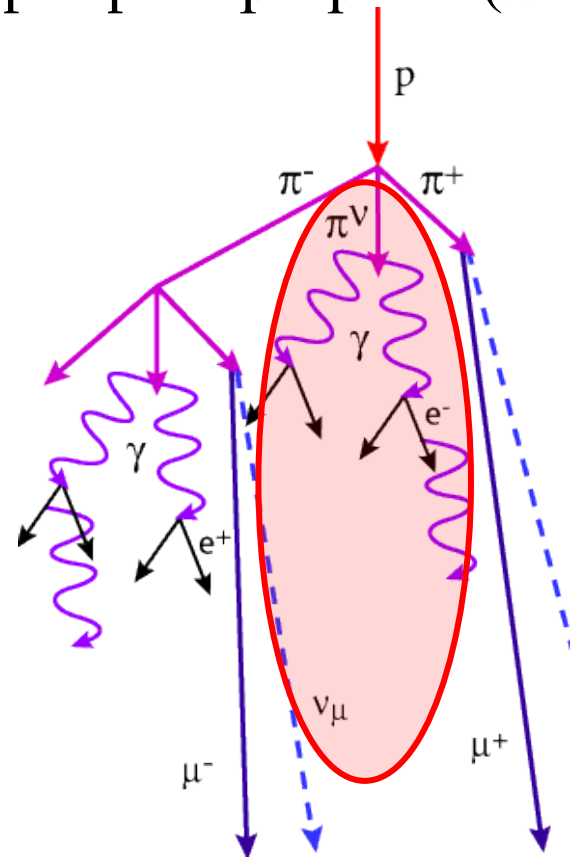


- Verify cosmological models (decay of Super Heavy Dark Matter / relic ν interact with UHE ν and create Z - Burst)

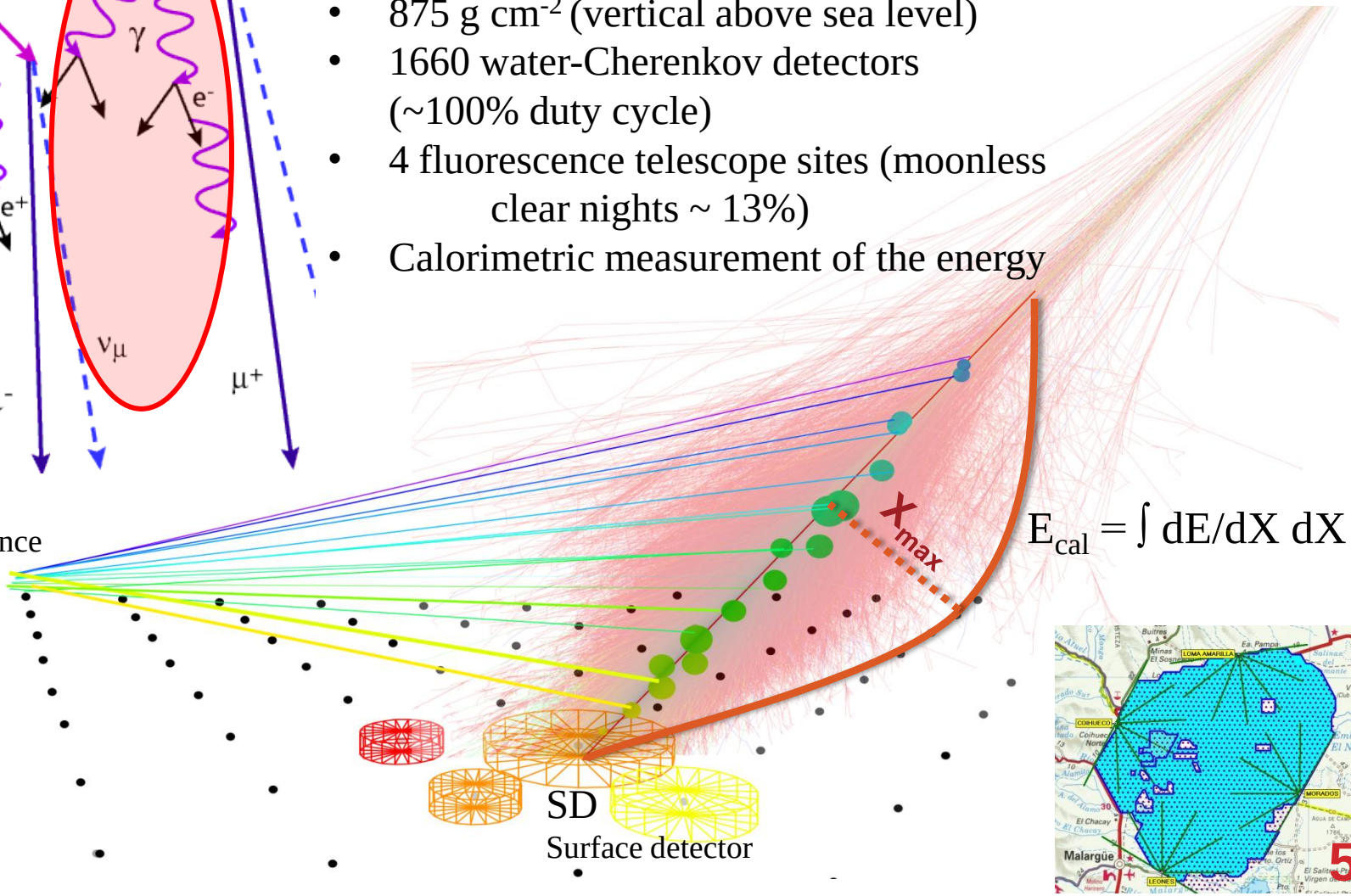
- Constrain astrophysical scenarios such as source energy spectrum, extragalactic magnetic field

$p + p \rightarrow p + p + N(\pi^+ + \pi^- + \pi^0)$

The Pierre Auger Observatory -A hybrid detection



- 3000 km^2 located in Argentina
- 875 g cm^{-2} (vertical above sea level)
- 1660 water-Cherenkov detectors (~100% duty cycle)
- 4 fluorescence telescope sites (moonless clear nights ~ 13%)
- Calorimetric measurement of the energy



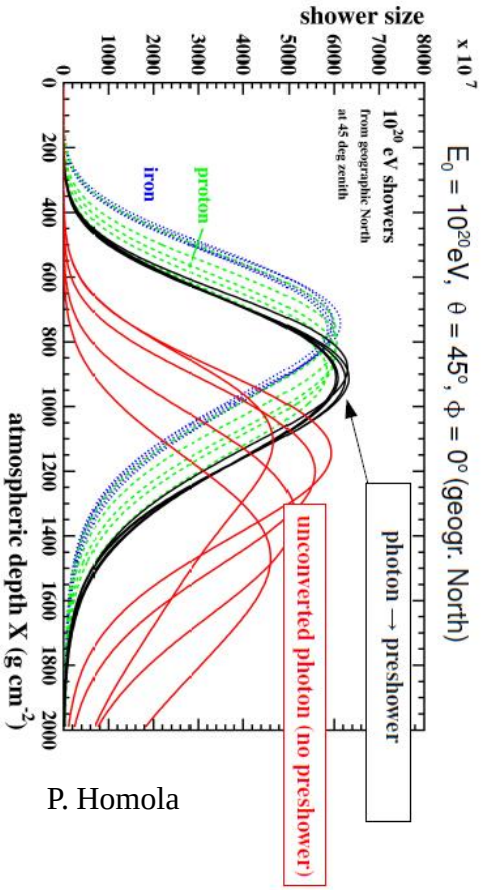
FD
Fluorescence detector

SD
Surface detector

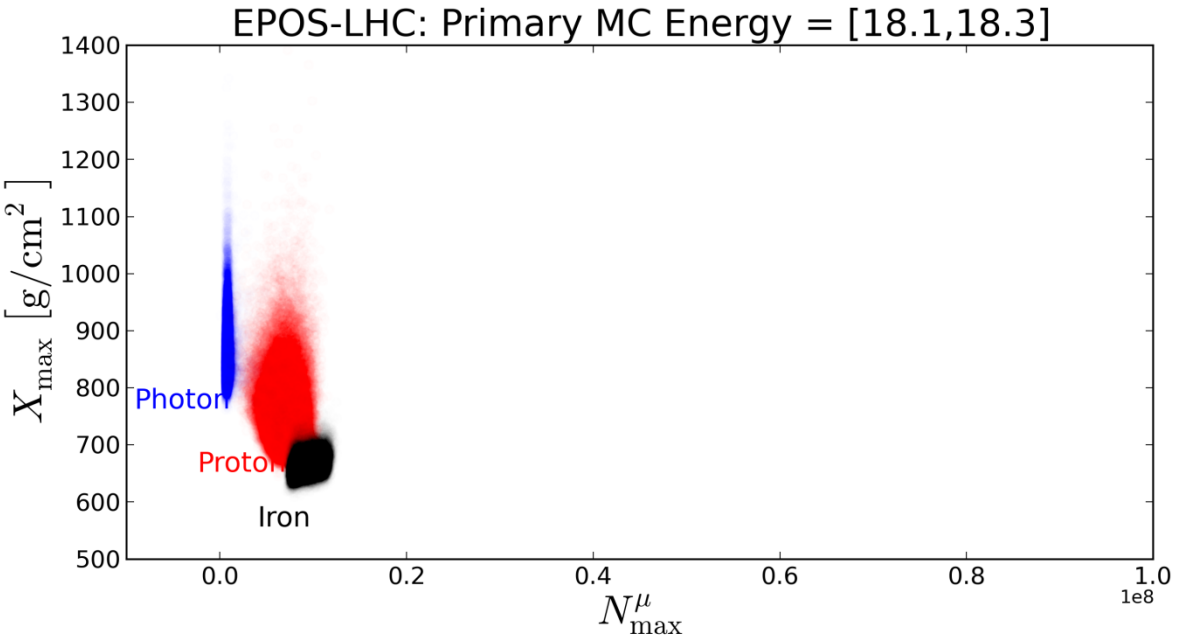
$E_{cal} = \int dE/dX \, dX$

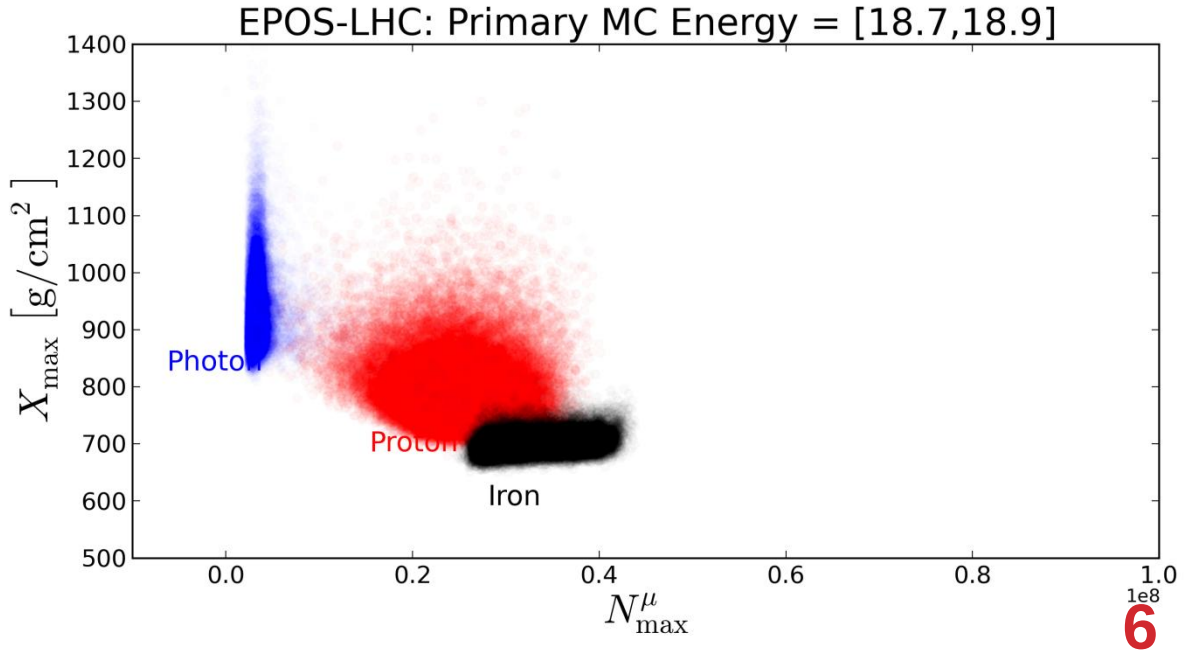
Photon induced air shower signature:

* larger X_{max}
* smaller N_{μ}

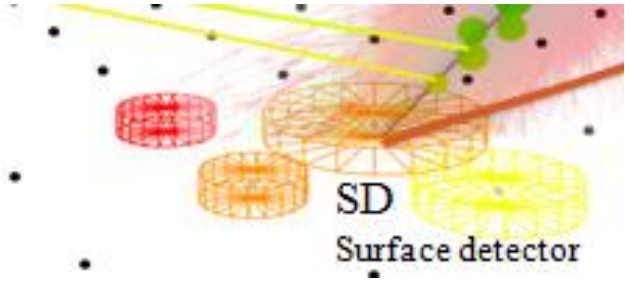


P. Homola

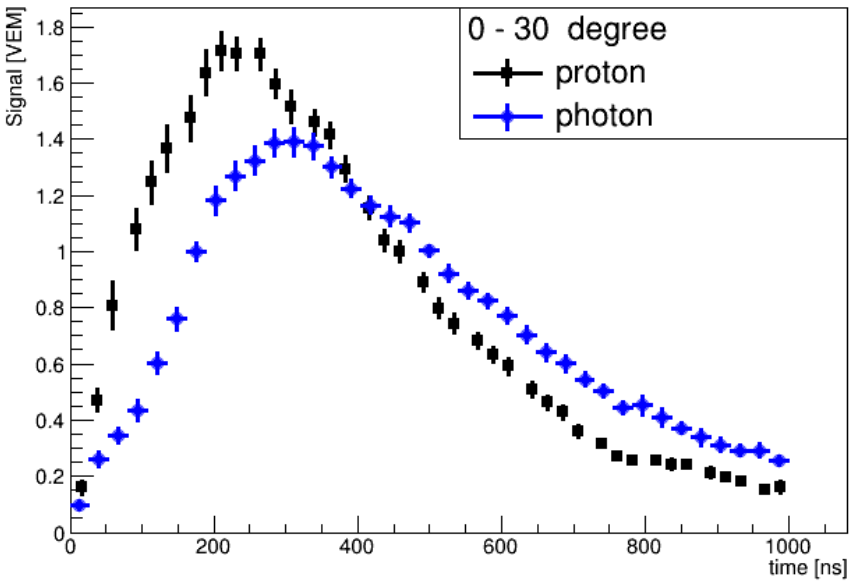


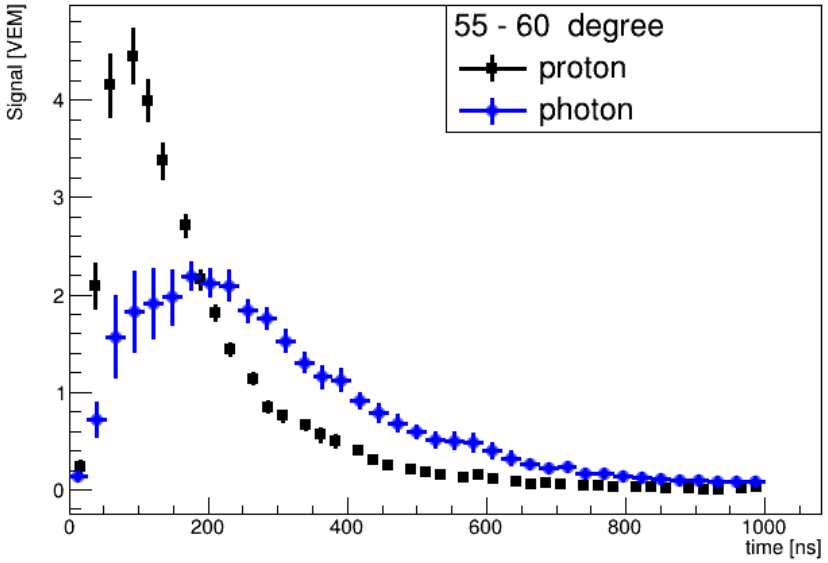


Photon signature: FADC time trace in the water-Cherenkov detector



proton and photon simulations

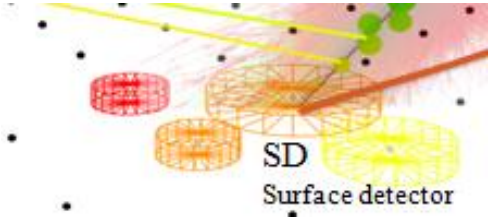


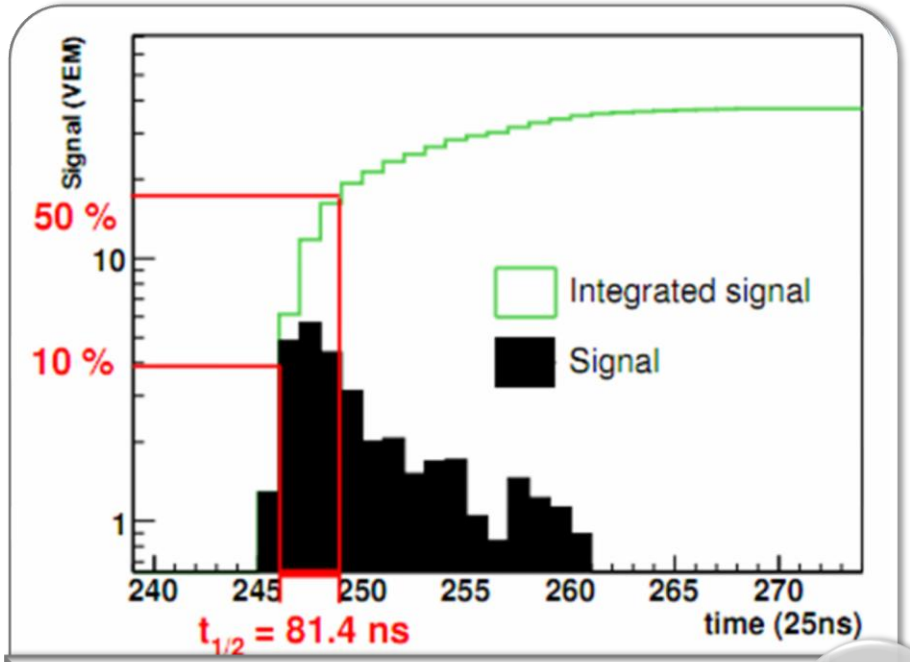


Vertical shower **Inclined shower**

30 < S < 40 VEM, 650 < r < 700 m

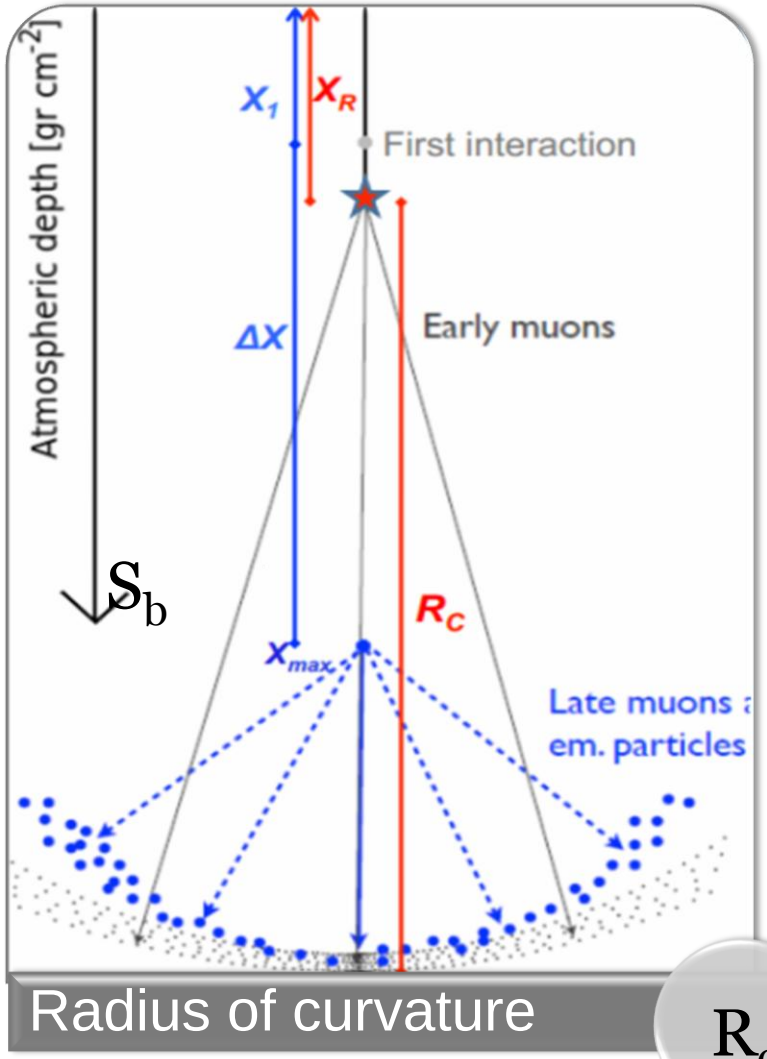
‘Traditional’ methods for SD photon searches





Signal risetime $t_{1/2}$

Δ



Radius of curvature

R_c

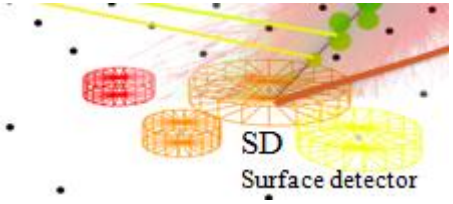
Challenges:

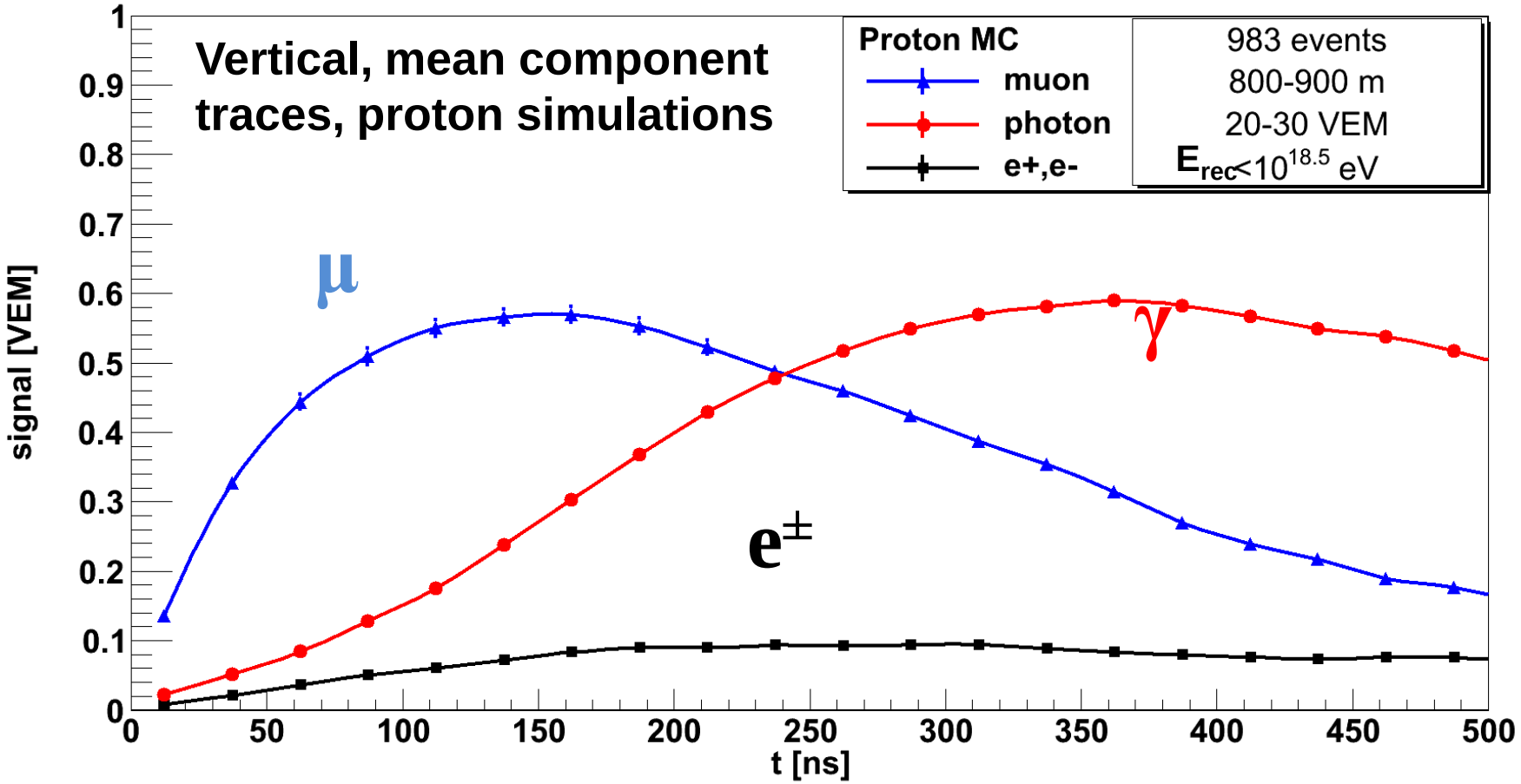
-Photons may have X_{max} below ground

-Problems of thinning etc to get reliable simulations ...

A new SD method – the **entity** method

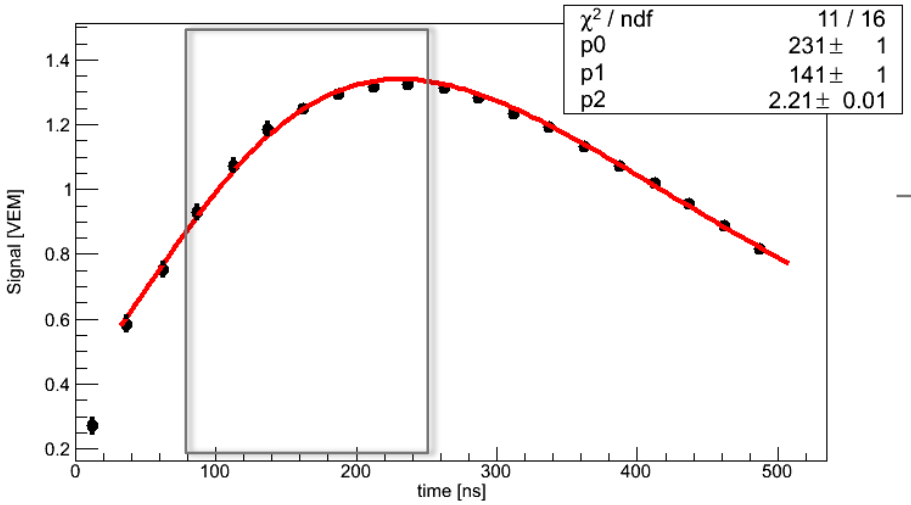
- **A parameter based on information from the beginning of the time trace**
  - **Muons arrive earlier than the EM component**



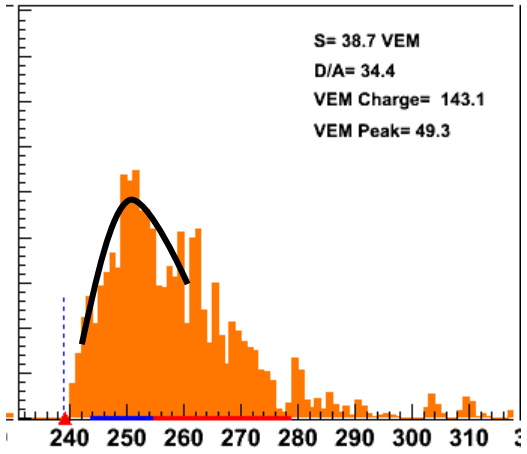


Procedure for calculating the entity parameter

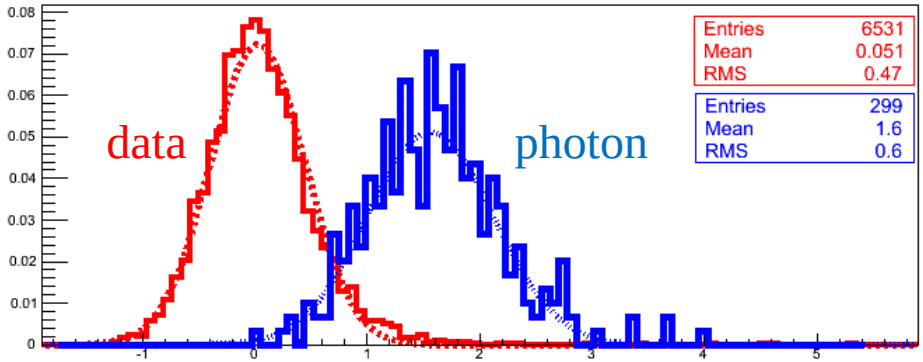
1. Use data to parameterise the mean FADC trace and signal variances.



2. Calculate for the time-trace at a station with r, S, θ and polar angle.

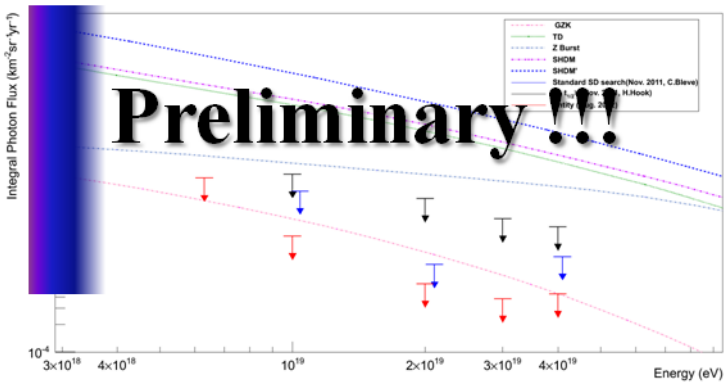


3. Calculate mean for lg(χ^2 / NDF) from data and photon for stations at r, S, θ and polar angle

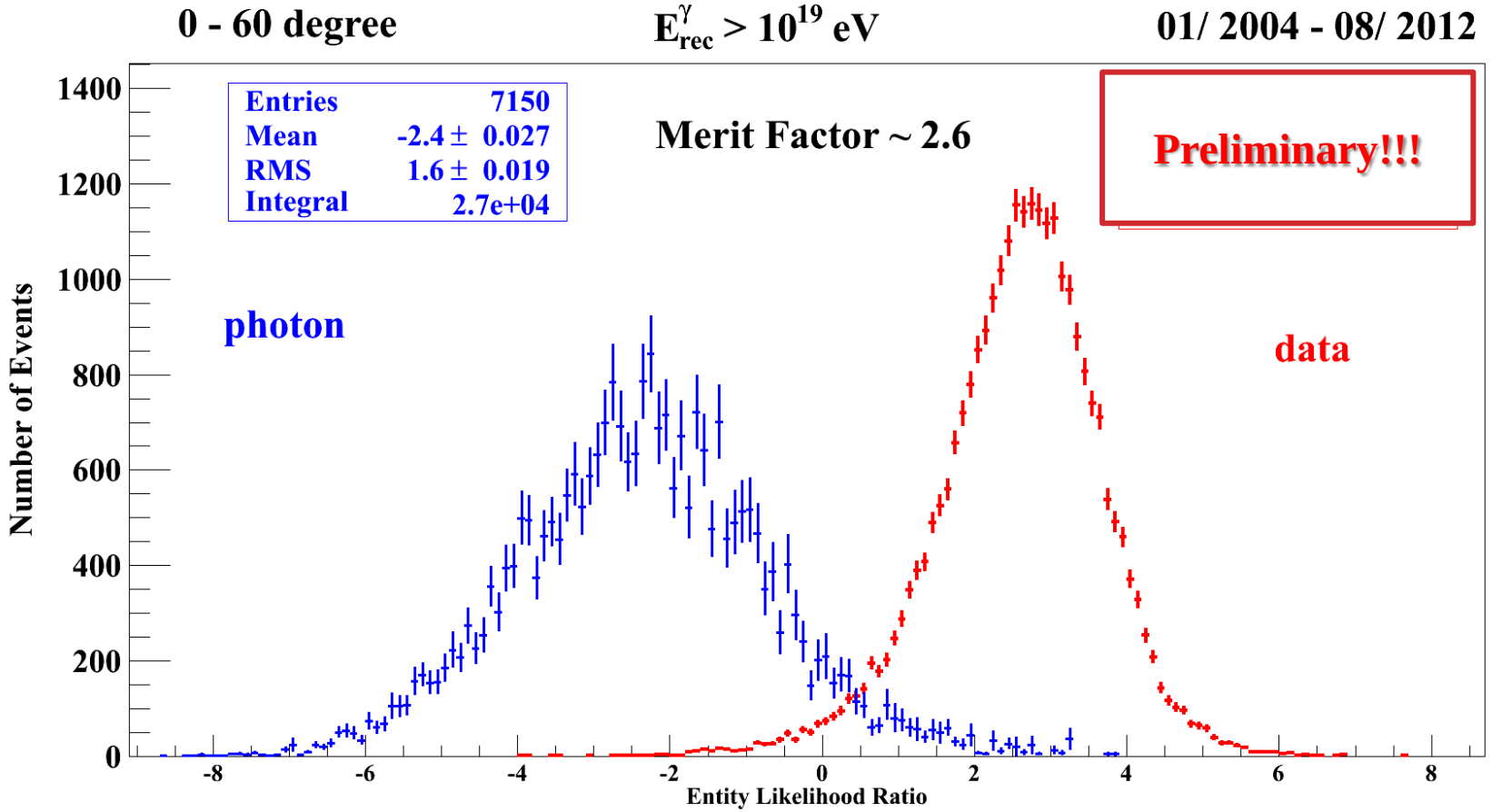


4. Likelihood ratio

$$LL_{normalised} = \lg \frac{\prod_{1}^{n}(P_1, P_2 \ldots)}{\prod_{1}^{n}(P_1^{\gamma}, P_2^{\gamma} \ldots)} \div n$$

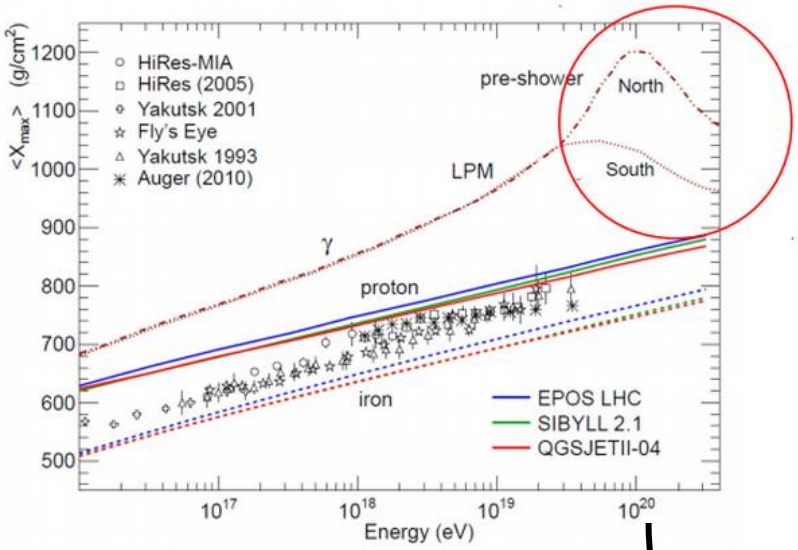


The entity method: photon-hadron separation



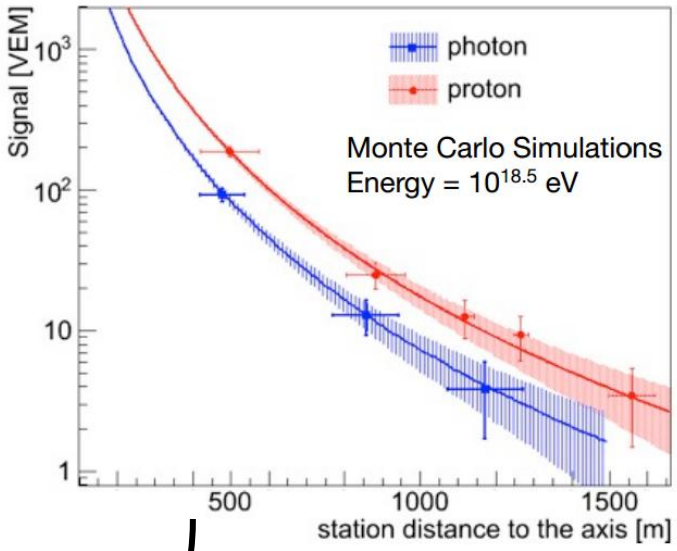
Hybrid search (florescence telescope + surface detector)

(lateral distribution function)



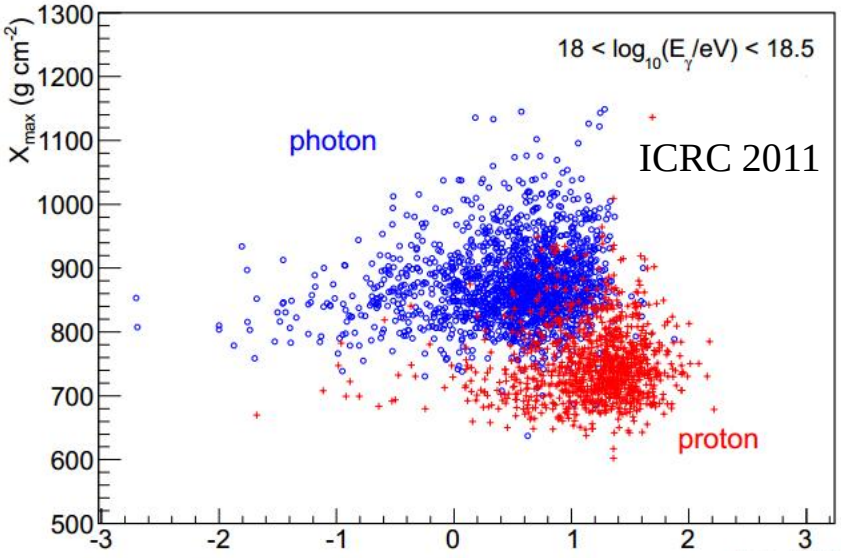
M. Settimo

+



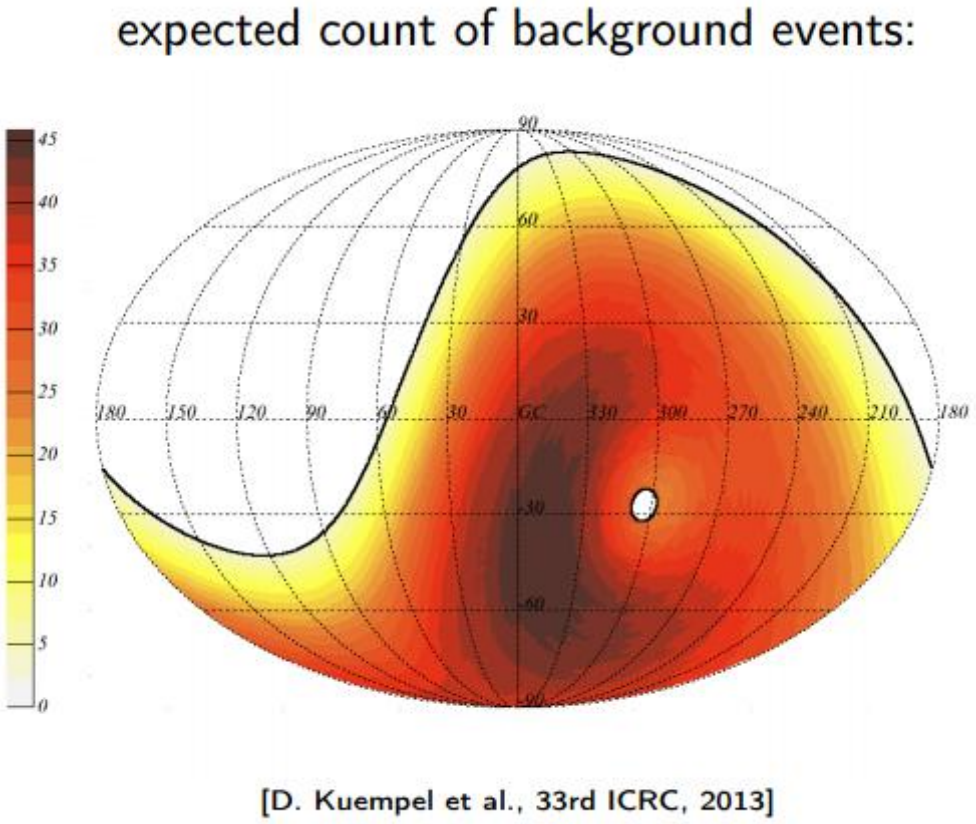
X_{max}

LDF



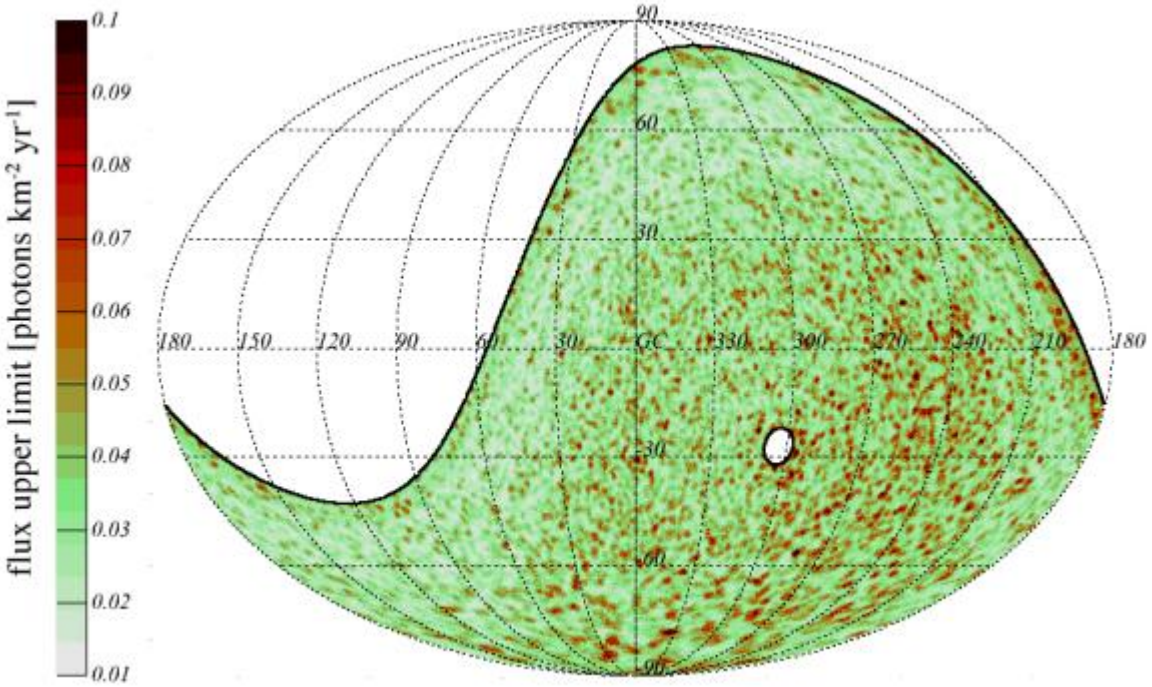
Directional photon search

- Hybrid data
- Multivariate analysis only select a subset of data that is photon-like
- $10^{17.3} – 10^{18.5}$ eV
- 0.7˚ angular resolution
- Background estimated using scrambling method.



[D. Kuempel et al., 33rd ICRC, 2013]

Directional photon search



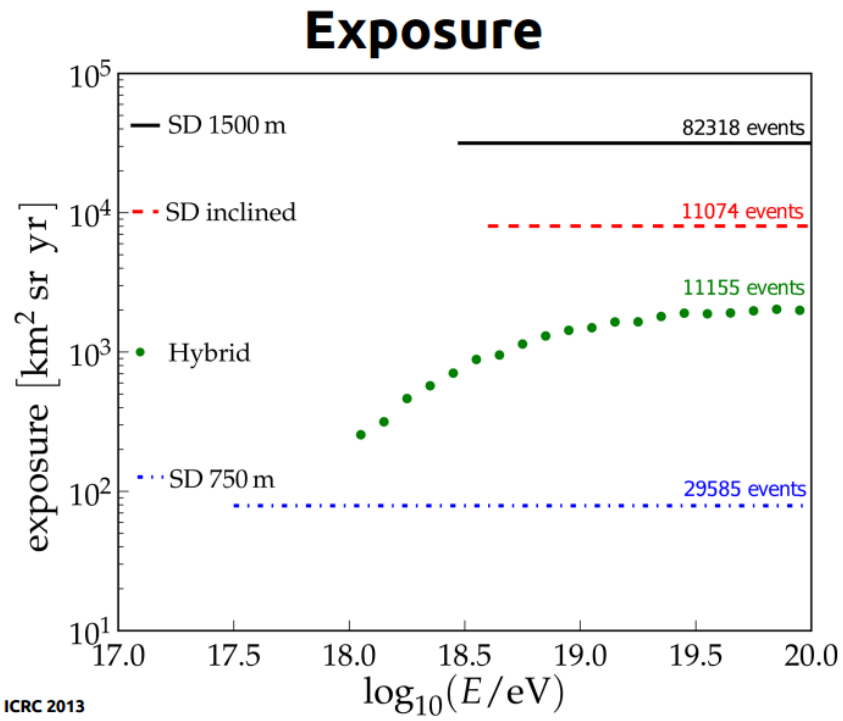
• Upper limit on regularly emitting non-beamed photon source in the galaxy: 0.25 eV cm^{-2} s^{-1} (spectrum index γ = -2)

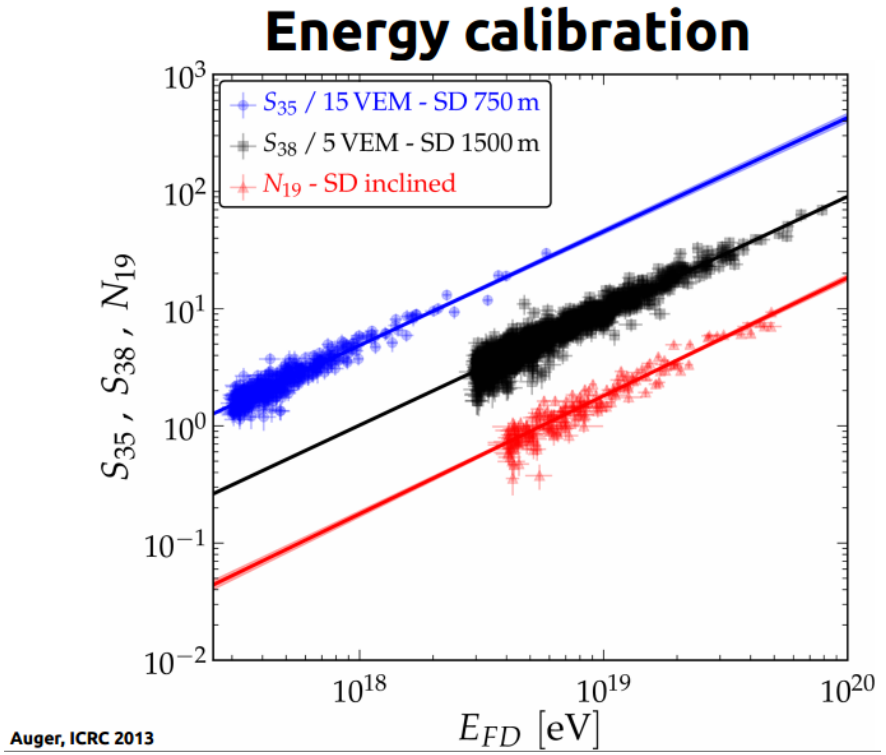
more from: D. Kuempel et al. ICRC 2013

Conclusions

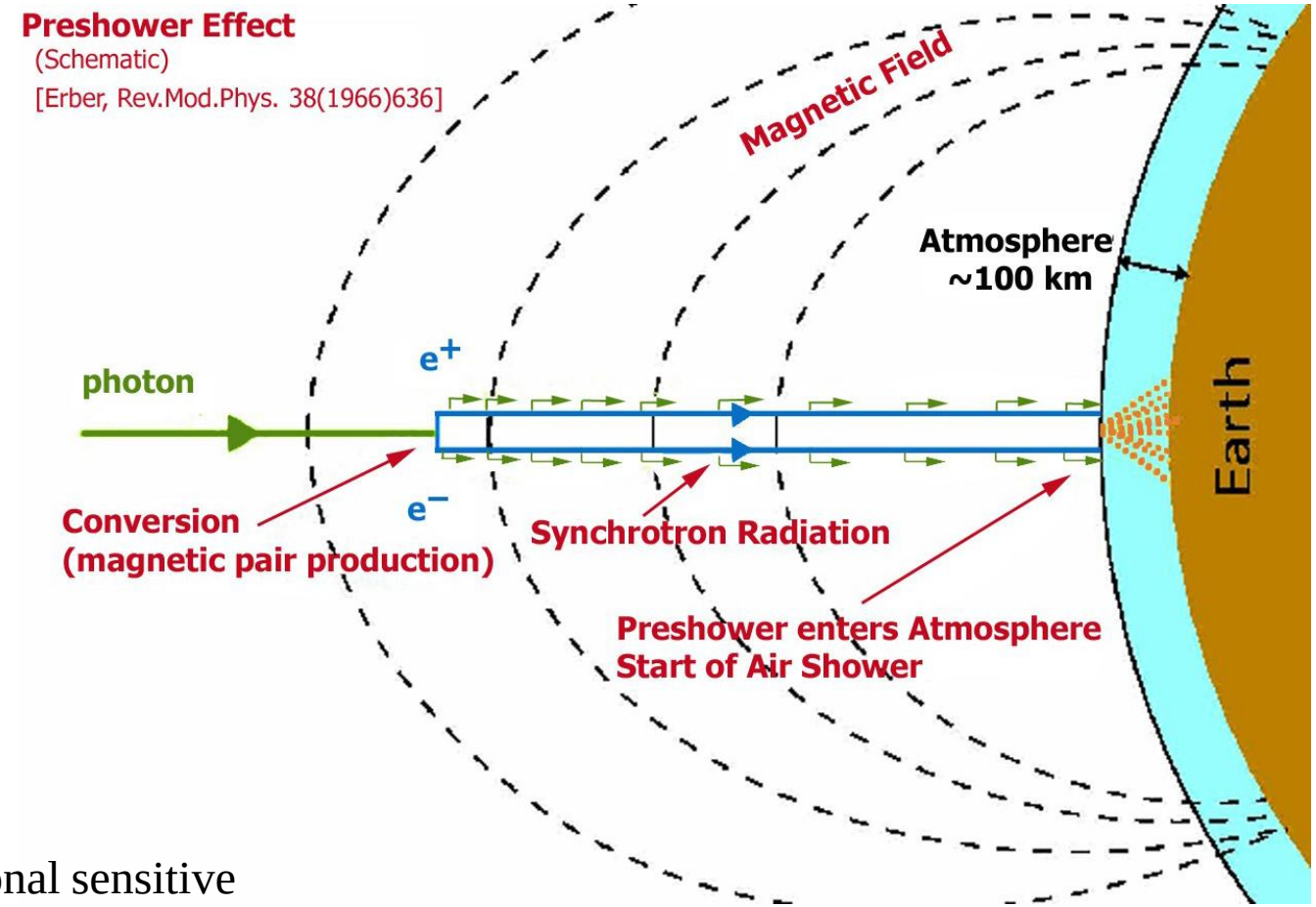
- **The Pierre Auger Observatory is *the* project that is most sensitive to ultra-high energy photons**
  - ✓ **Previous diffuse photon searches used both FD and SD variables**
  - ✓ **A new method – the entity method - covers $0 < \theta < 60^{\circ}$ with high-separation power for photon-hadron discrimination**
  - ✓ **Photon directional search sets limits on energy flux densities**

Back up


Exposure
SD 1500 m
82318 events
SD inclined
11074 events
11155 events
Hybrid
SD 750 m
29585 events
exposure [km² sr yr]
log10(E/eV)
ICRC 2013


Energy calibration
S35 / 15 VEM - SD 750 m
S38 / 5 VEM - SD 1500 m
N19 - SD inclined
S35 , S38 , N19
EFD [eV]
Auger, ICRC 2013

Back up

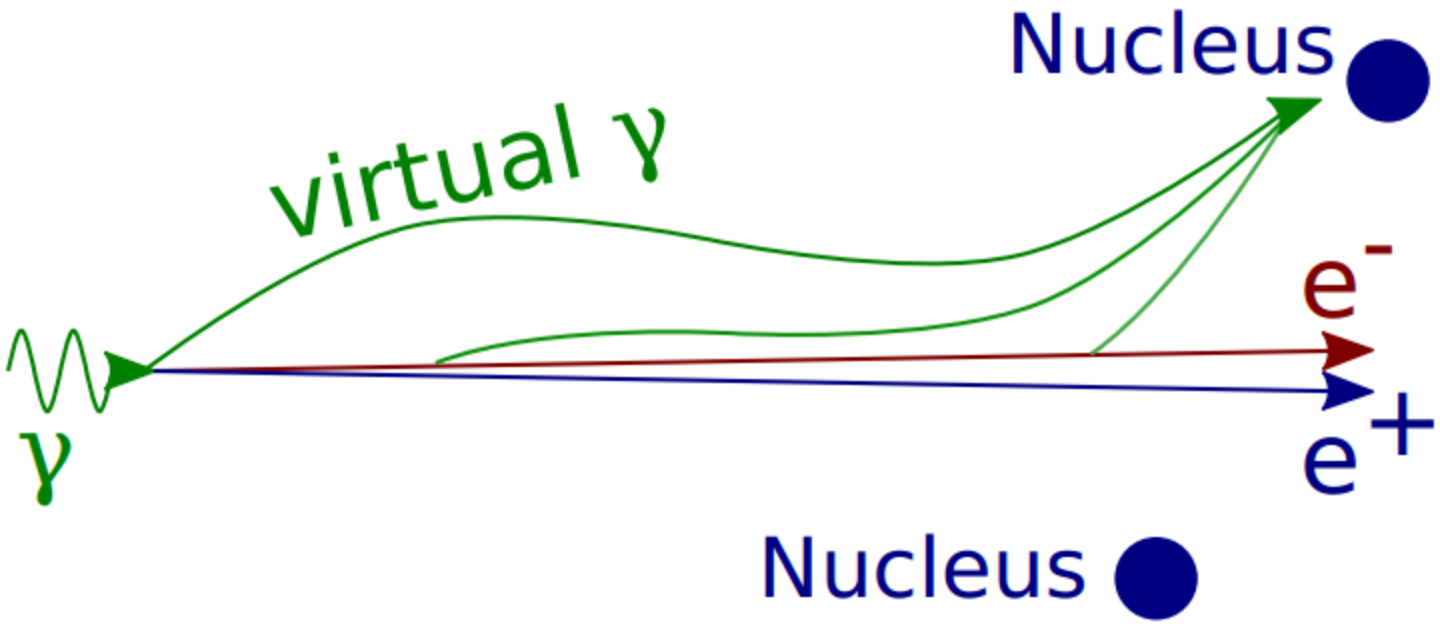


Directional sensitive
40% for 100EeV photons from the whole sky

Figure from P. Homola

Landau–Pomeranchuk–Migdal (LPM) effect

- reduces cross section for pair production (γ) and bremsstrahlung (e)
- destructive interference between interactions at multiple nuclei
- relevant at high energy (greater than 10^{18} eV) of primary particle
- in simulations mostly implemented through a *suppression factor* that statistically discards interactions



Super-Heavy Relic Particles

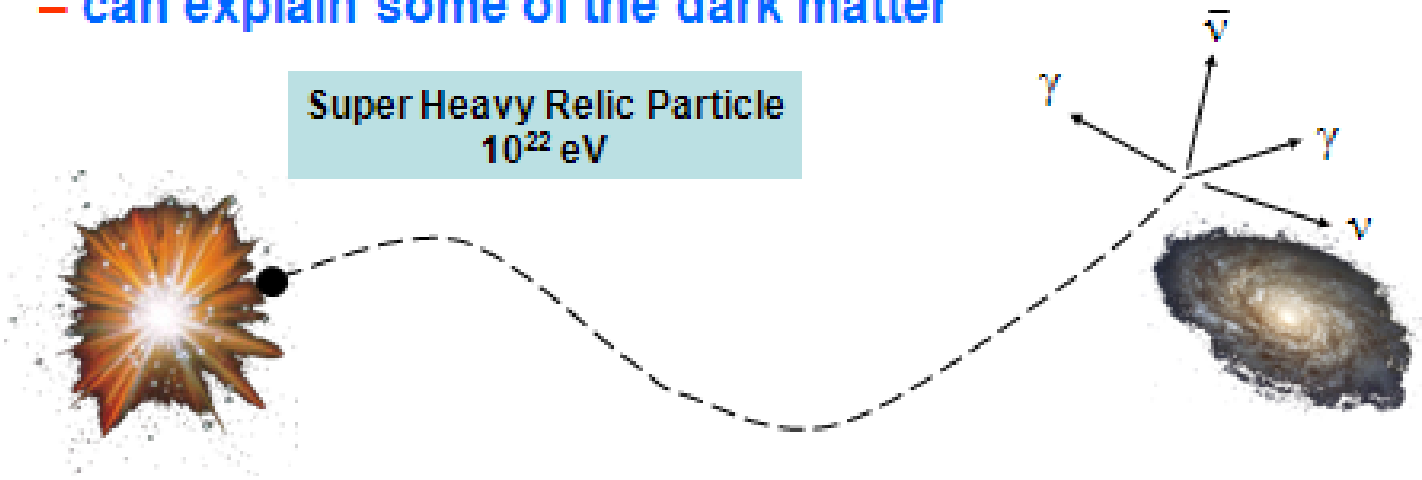
(John Ellis, Rocky Kolb, Luis Masperi…)

Cryptons/Wimpzillas/Vortons

– can explain some of the dark matter

dσ/dy

Super Heavy Relic Particle
10^{22} eV



(i) preferential decay to quark-- anti-quark pairs rather than quark triplets

(ii) Can **TEST** predicted high flux of photons **NOW** (– neutrinos later)

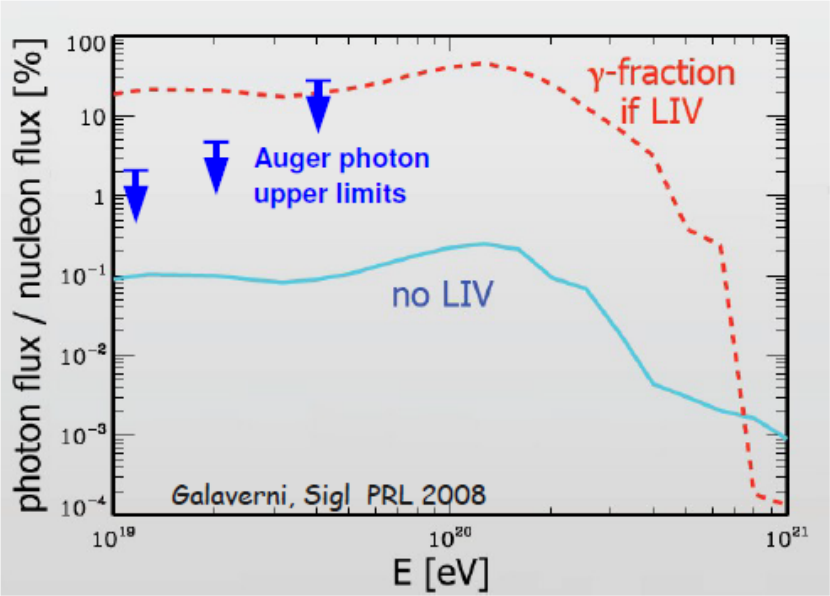
Thanks to Chris Wileman

Back up - LIV

Testing Lorentz Invariance Violation (LIV) → photon dissperssion relation modified?

$\omega^2 = k^2 + \xi_n k^2 (k/M_{Pl})^n$ → e^+e^- production threshold modified

e.g. $\pi^0 \rightarrow \gamma\gamma$ $\quad \gamma \not\rightarrow e^+e^-$ cascading of photons supressed



If LIV:

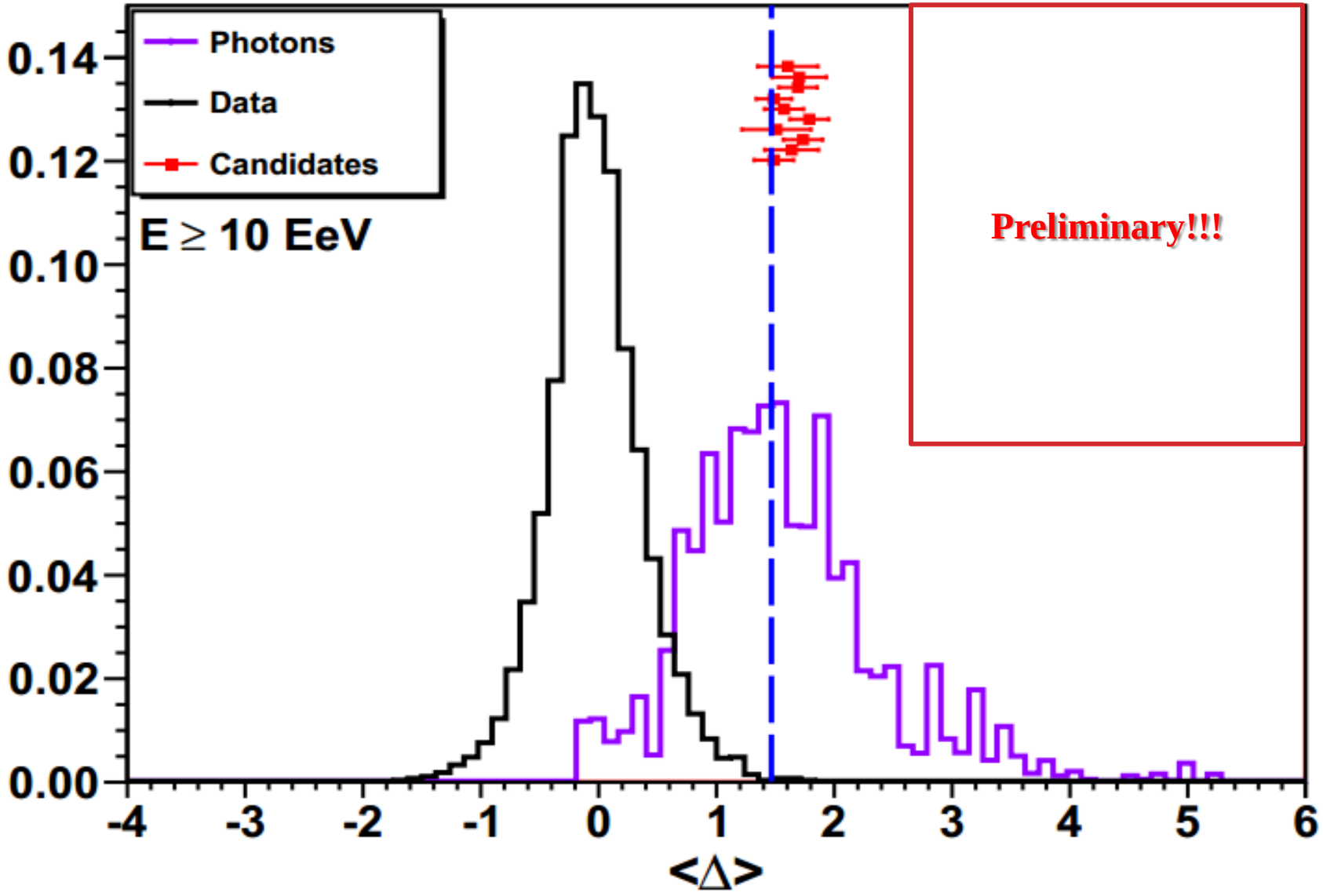
$\xi_1, \xi_2 > 0$

Upper limits based on UHECR observations:

$\xi_1 < 2.4 \times 10^{-15}$

$\xi_2 < 2.4 \times 10^{-7}$

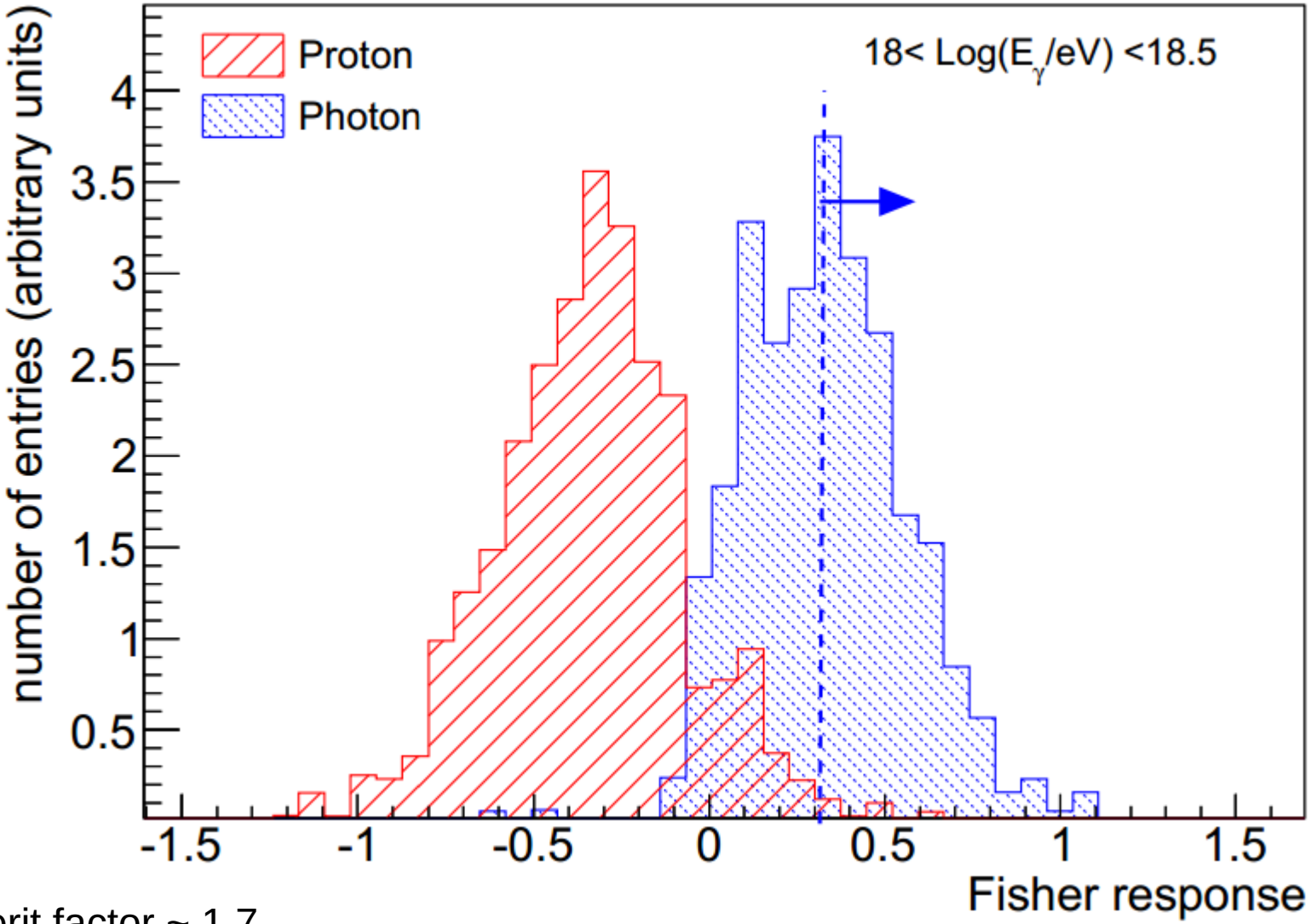
Back up: the risetime delta method from H.Cook (PhD thesis)



Merit factor ~ 1.7

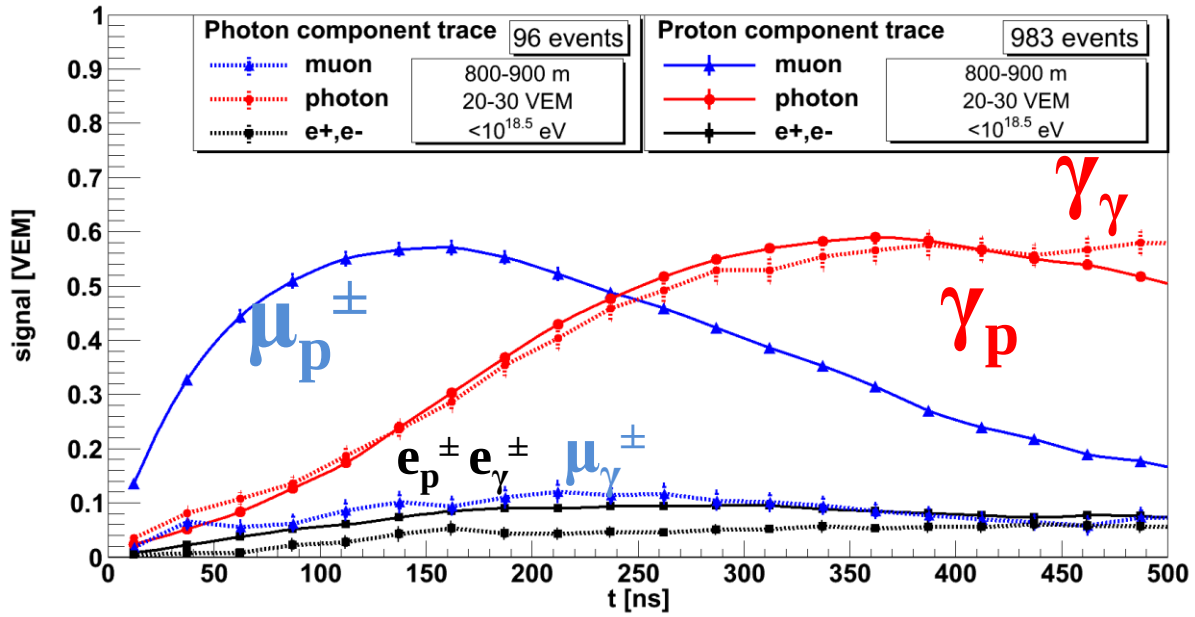
Photon Spectrum is E^{-2}

Back up: the Fisher response of hybrid analysis. M.Settimo, ICRC 2011

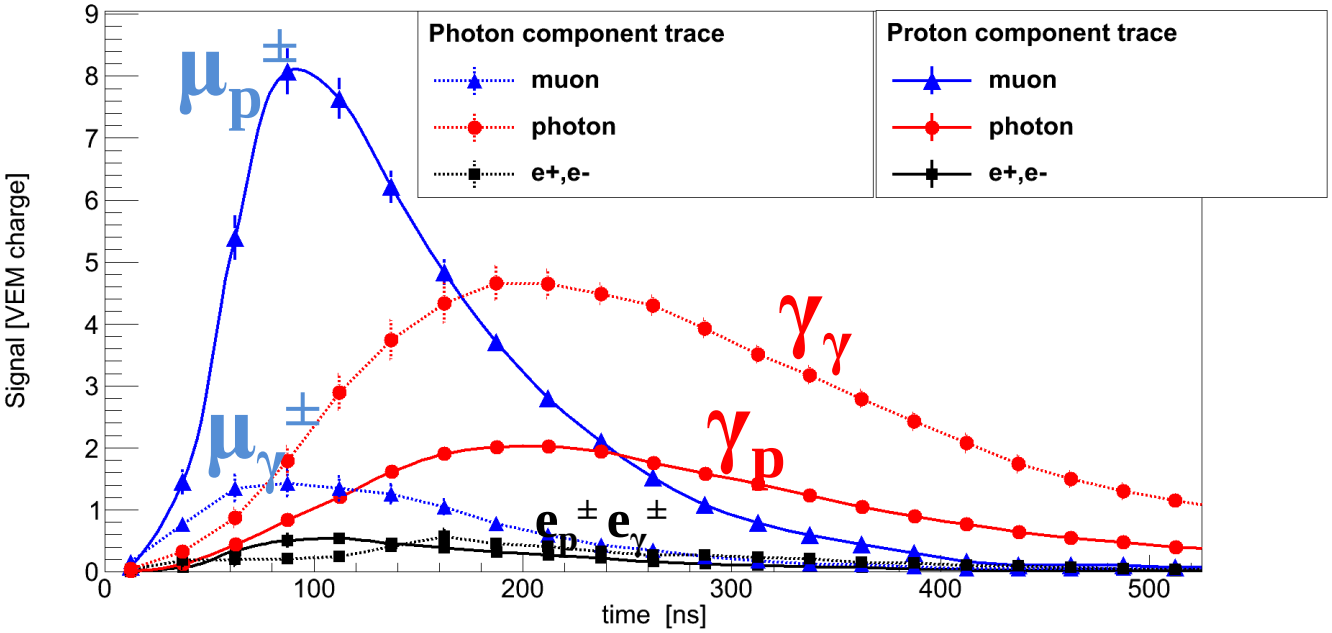


Merit factor ~ 1.7

Back up: component traces for proton and photon



θ ~ 0°
r ~ 850 m
S ~ 25 VEM
~Only difference is μ



θ ~ 60°
r ~ 550 m
S ~ 70 VEM

Possible background form leading π^0 protons. N_μ and X_{max}