# Photon physics with AUGER

Piotr Homola for the Pierre Auger Collaboration

*Institute of Nuclear Physics PAN, Kraków, Poland*

- Motivation for UHE photon search
- Features of photon induced showers
- Pierre Auger Observatory: results & prospects

# Why search for UHECR photons?

primary process $\rightarrow \pi^0 + \ldots \rightarrow \gamma_{\mathrm{UHE}} + \ldots$

<u>primary process:</u>

acceleration of nuclear primaries + GZK-type process (conventional physics)

- suitable astrophysical site needed
- photon energies ~10 $\times$ smaller than accelerated primaries
- small fractions of photons predicted

non-acceleration: decay/annihilation of primordial relics (new physics)

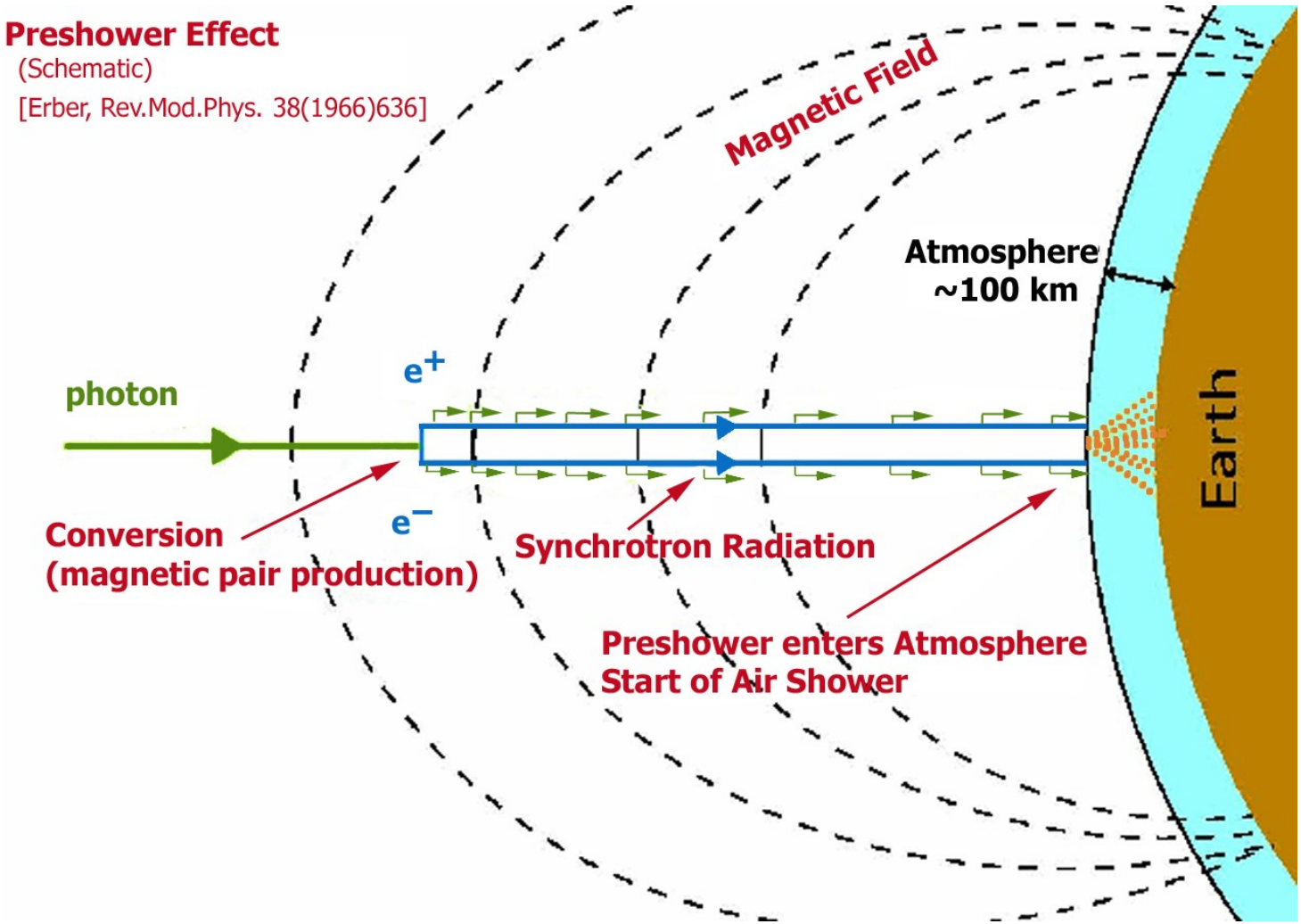
- topological defects (TD), super heavy dark matter (SHDM), Z-bursts (ZB)
- large fractions of photons predicted

<u>motivation for UHECR photon searches:</u>

-> multimessenger observations of the universe

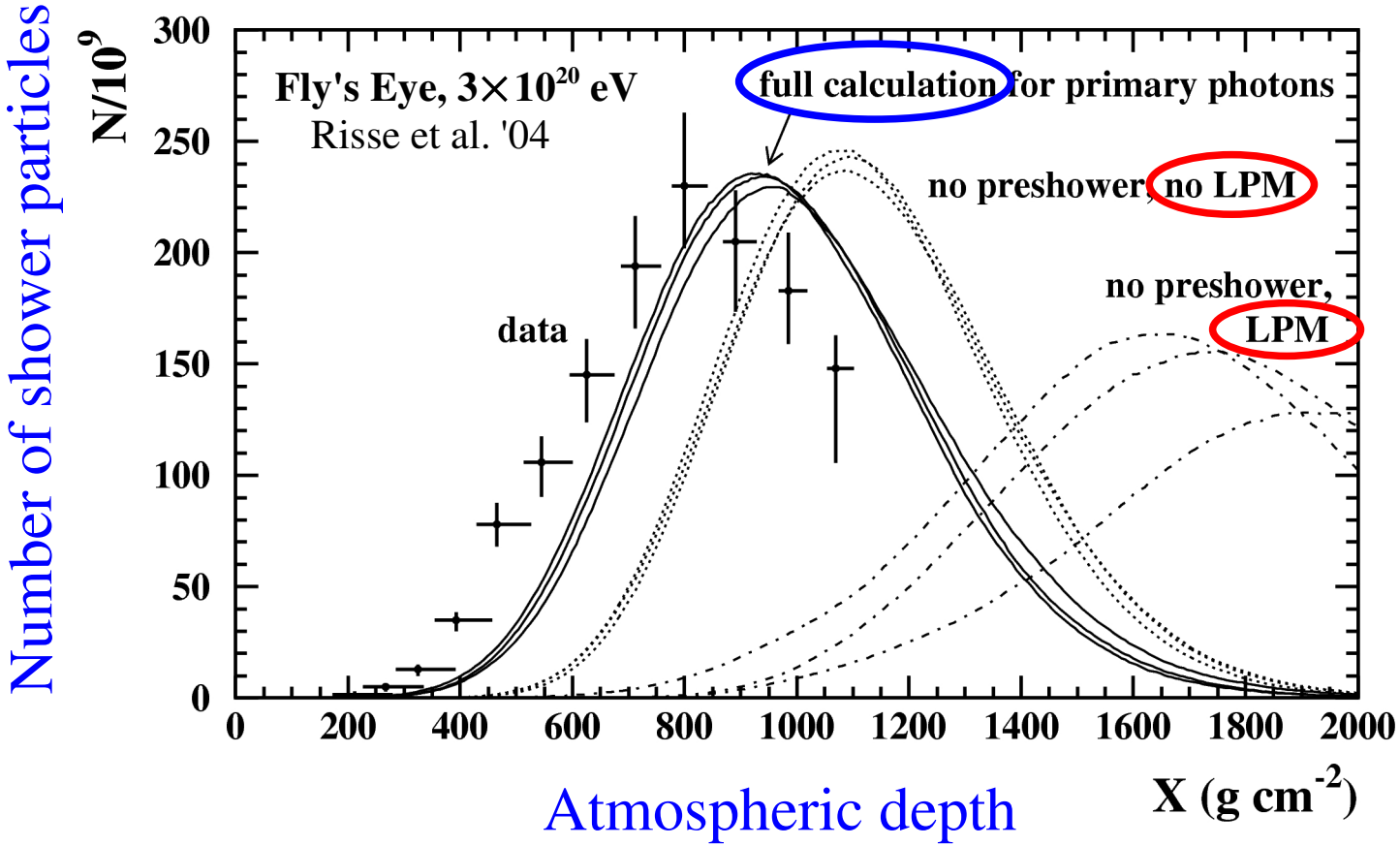
-> discriminating between different (classess of) scenarios

# UHE photons & GMF: preshower effect




- Effect important for $E_\gamma \geqslant 10^{19}$ eV, dependent on $E_\gamma$ and $B_\perp$ (and via $B_\perp$ also on arrival direction and geographic location).

# UHE photons as air shower primaries




LPM: $\sigma_{Bethe\text{-}Heitler}$ decreases with E, important for E > $10^{19}$ eV

-> deep $X_{max}$, large $X_{max}$ fluctuations

PRESHOWER: E split -> reduced $X_{max}$, small fluctuations

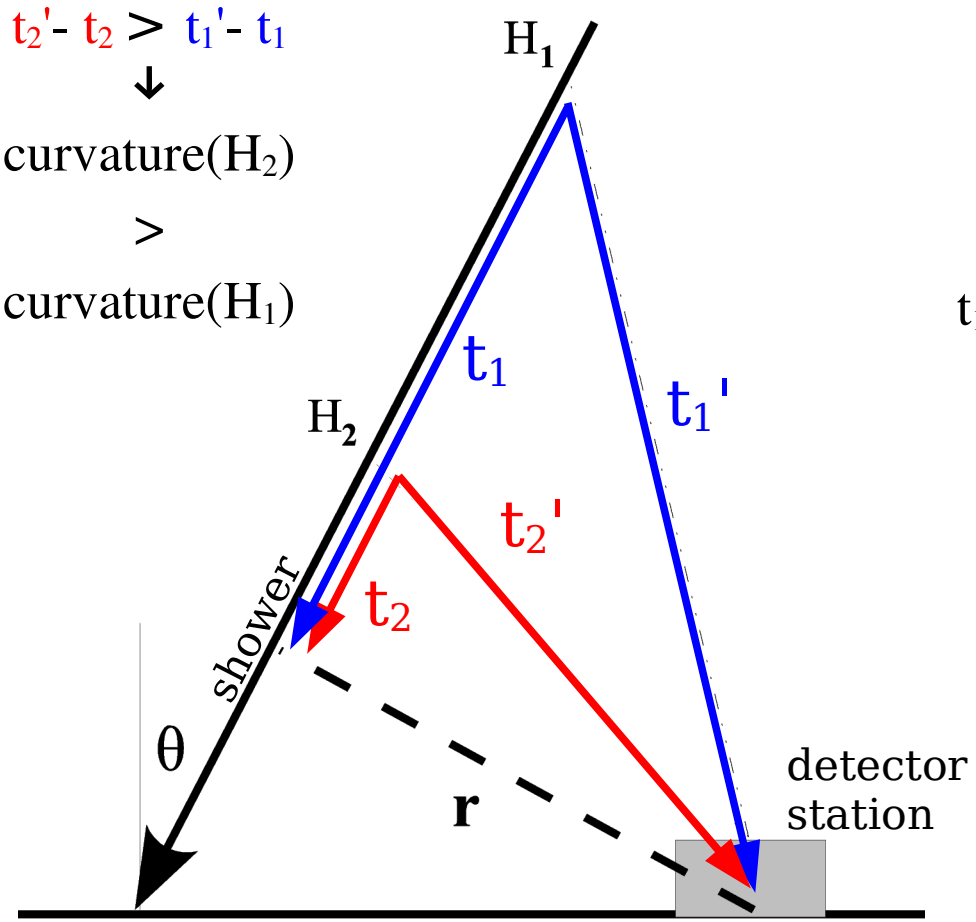
# Observable features of photon-induced showers

- $X_{max}$ (measured with fluorescence technique): very deep for *unconverted* photons; for *converted* photons (preshowers) still deeper than for protons
- $\rho_\mu$ or $N_\mu$ on ground (array of surface detectors): reduced
- Other – usually closely related to the above
  - radius of curvature of the shower front: small
  - risetime of the detector signal at certain core distance: increased
  - steepness of the lateral distribution of particles on ground
  - signal amplitude
  - ...

# photon primaries: surface detector observables

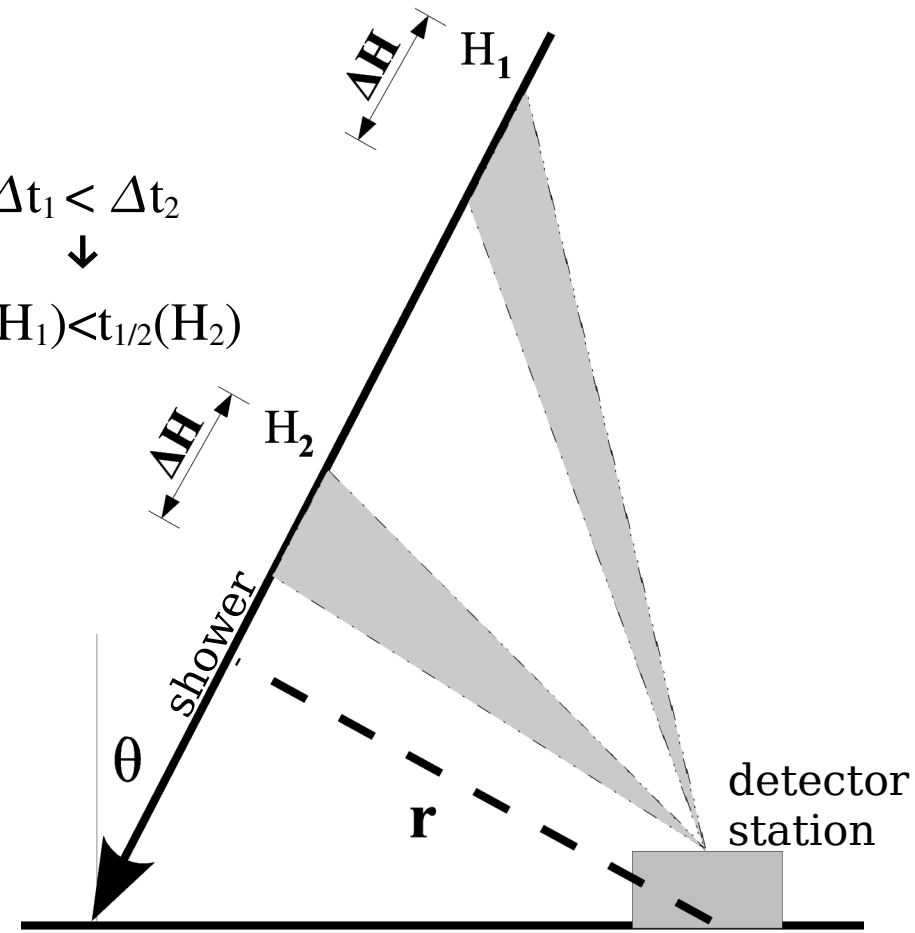
front curvature *larger*
for showers developing
deep (e.g. photon primaries)

$t_2' - t_2 > t_1' - t_1$
↓
curvature($H_2$)
>
curvature($H_1$)



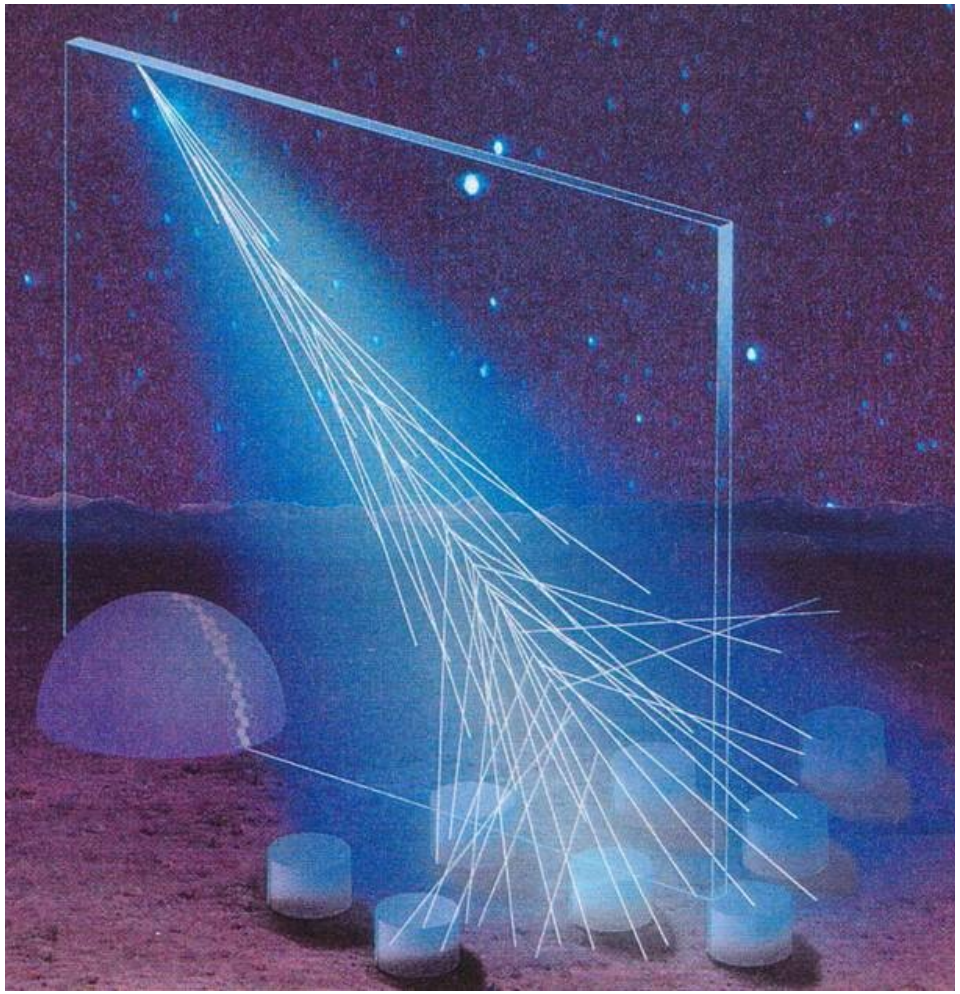

shower risetime *increased*
for showers developing
deep (e.g. photon primaries)

$\Delta t_1 < \Delta t_2$
↓
$t_{1/2}(H_1) < t_{1/2}(H_2)$

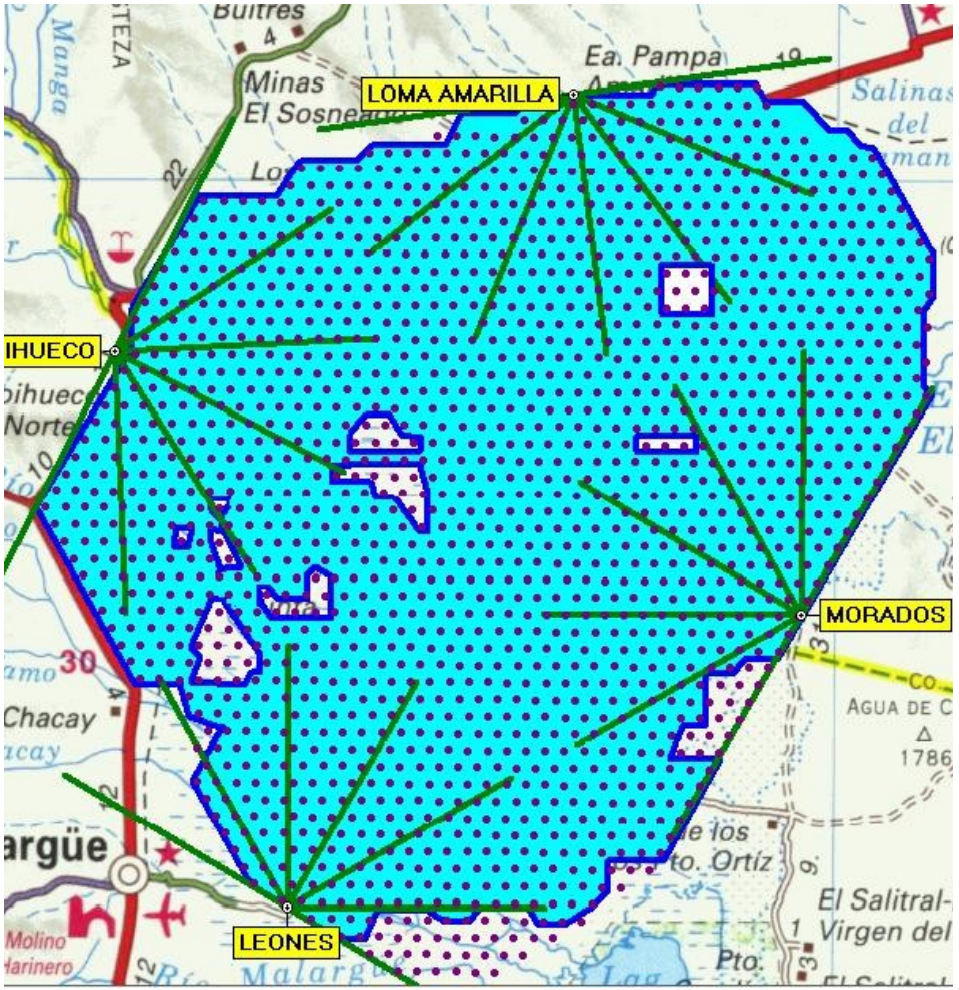


# Pierre Auger Observatory

hybrid technique:
fluorescence telescopes +
surface array of water
Cherenkov detectors

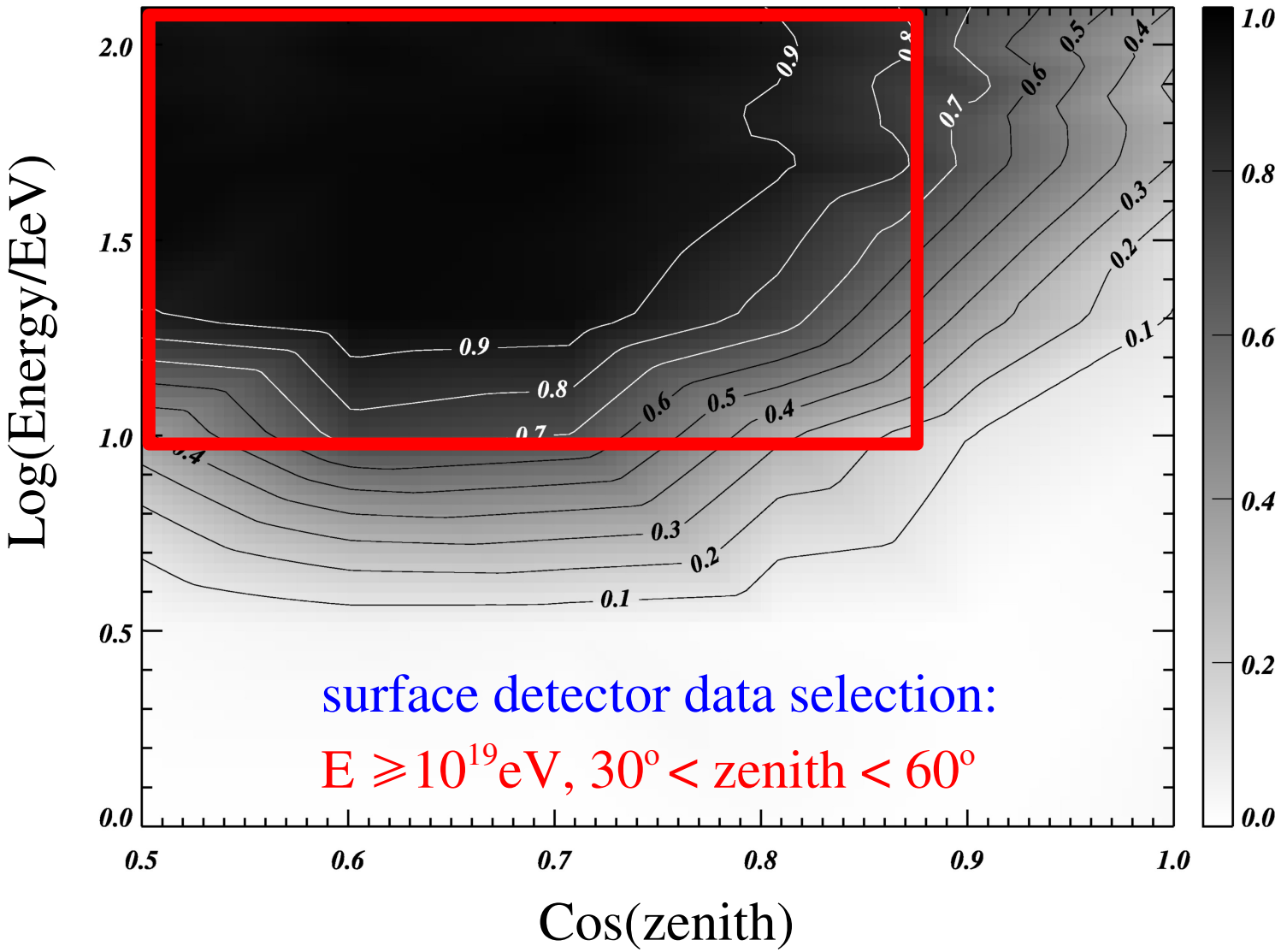


the biggest observatory ever:
3000 km$^2$ in Argentina +
even 7 times more planned
in USA

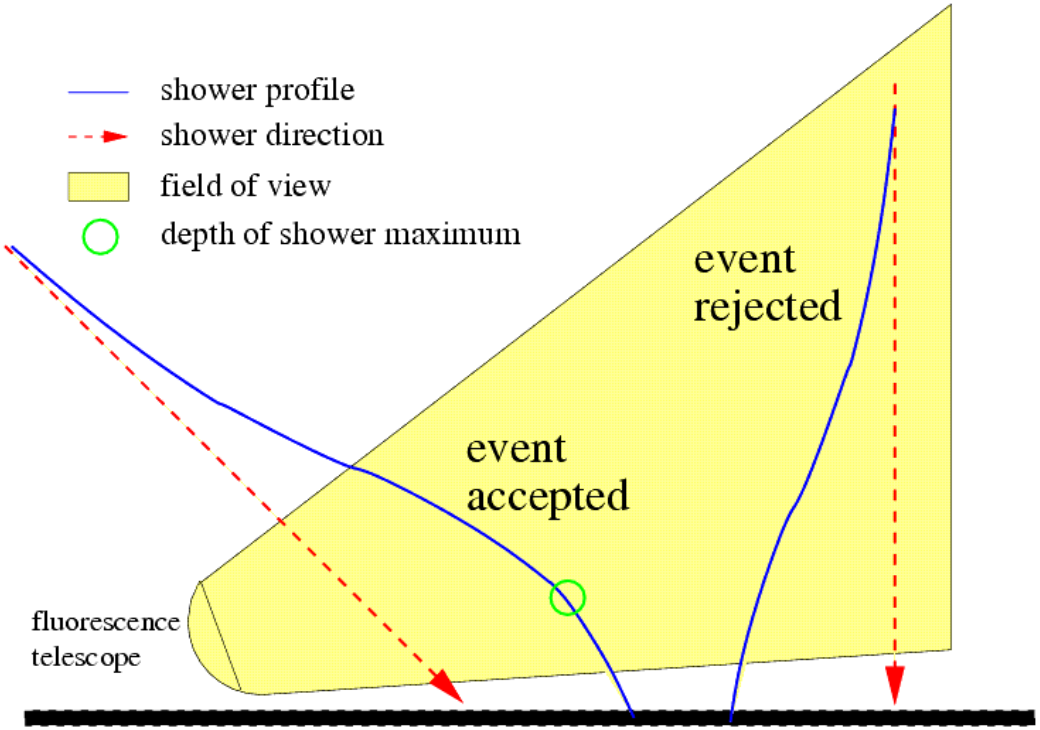


# data selection: surface detector

photon detection and reconstruction efficiency



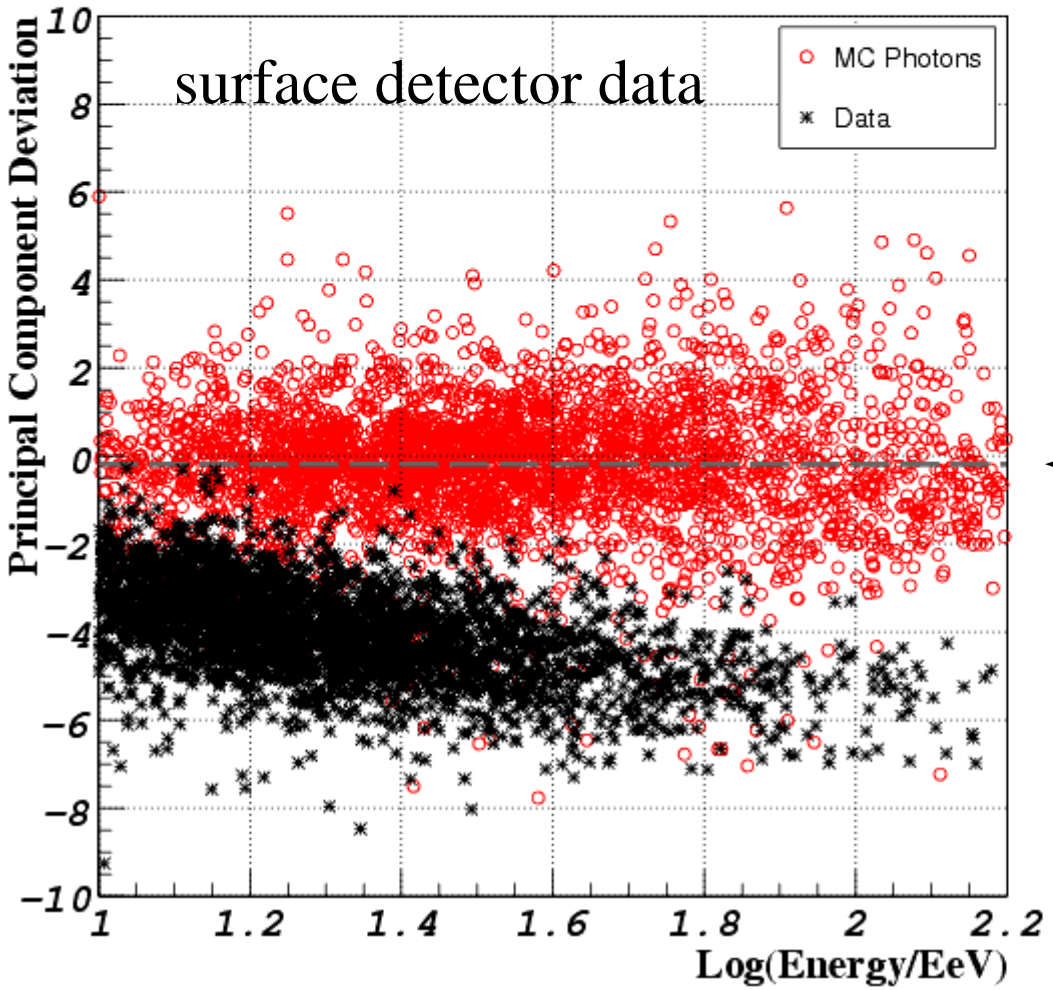
# data selection: fluorescence detector




zenith > 35° + 10[log(E/eV) -19.0]° for log(E/eV) ⩽19.7
zenith > 42° for log(E/eV) > 19.7,

maximum distance of telescope to shower impact point < 24 km + 12[log(E/eV)-19.0] km

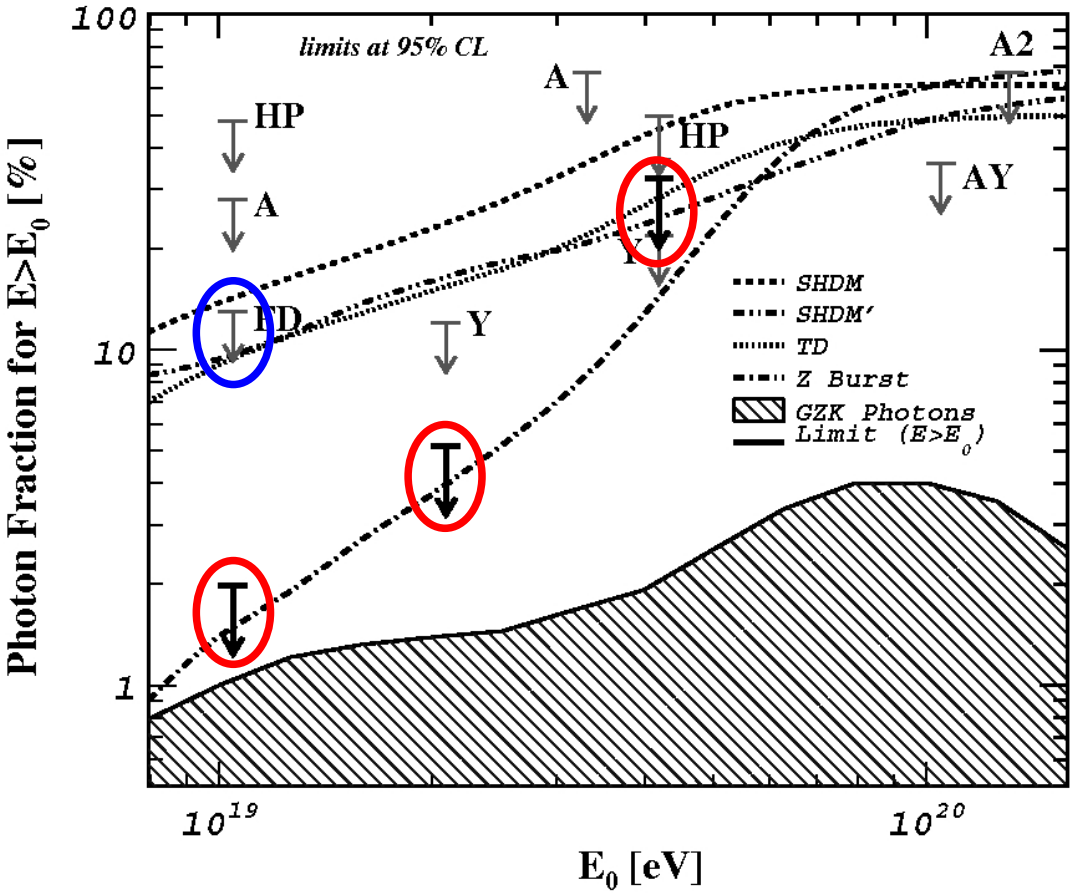
# Pierre Auger results: no photon candidates




mean of the photon distribution

*[photon candidates: points above the mean of the photon distribution]*

# Experimental status (AUGER hybrid & SD)



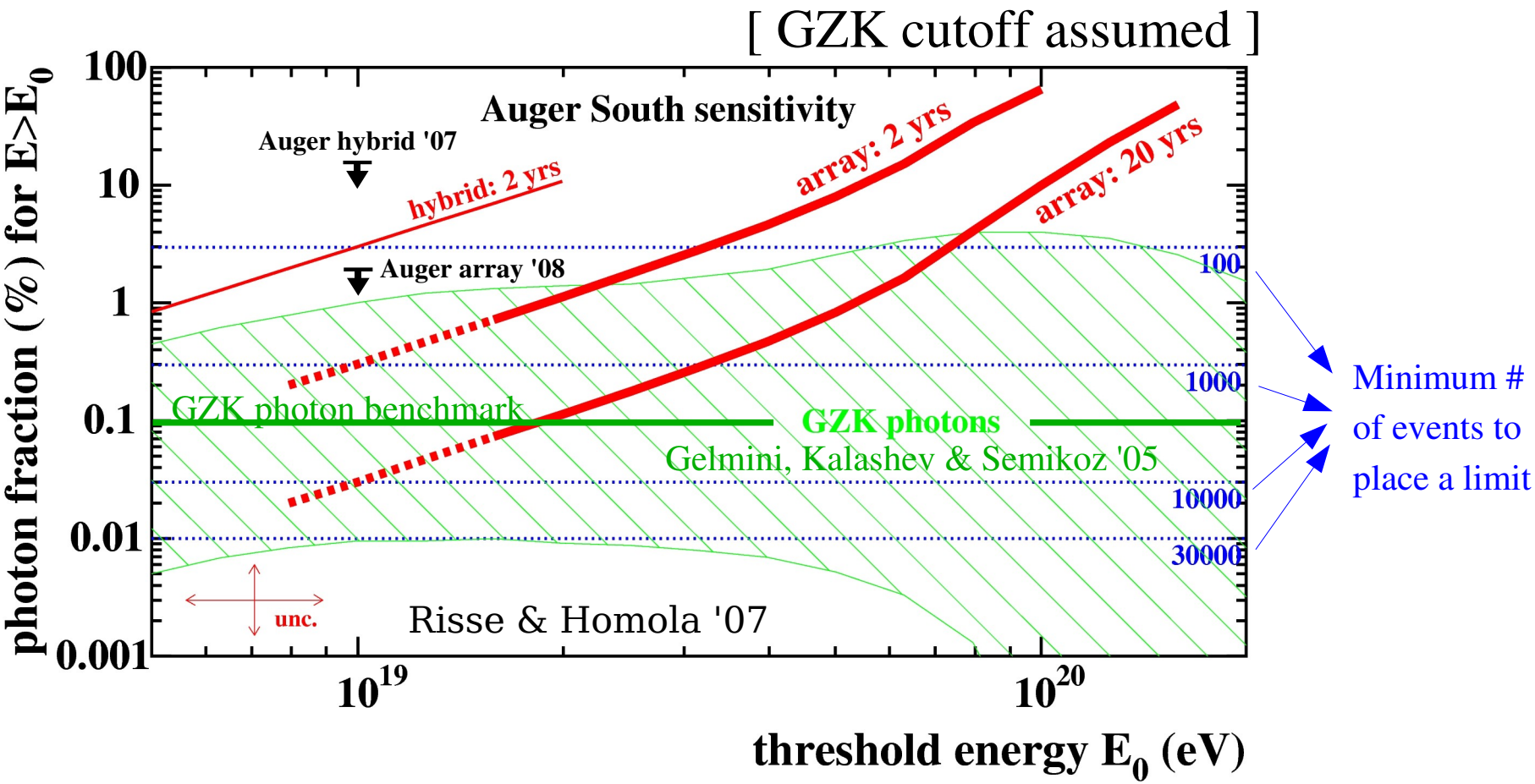

Pierre Auger Collab. '07 (hybrid detector)

Pierre Auger Collab. '08 (surface detector)

HP – Ave et al. '00 & '02
A – Shinozaki et al. '02
A2 – Risse et al. '05
AY – Rubtsov et al. '06
Y – Glushkov et al. '07
SHDM, TD, Z Burst: Gelmini et al. '05
SHDM': Ellis et al. '06

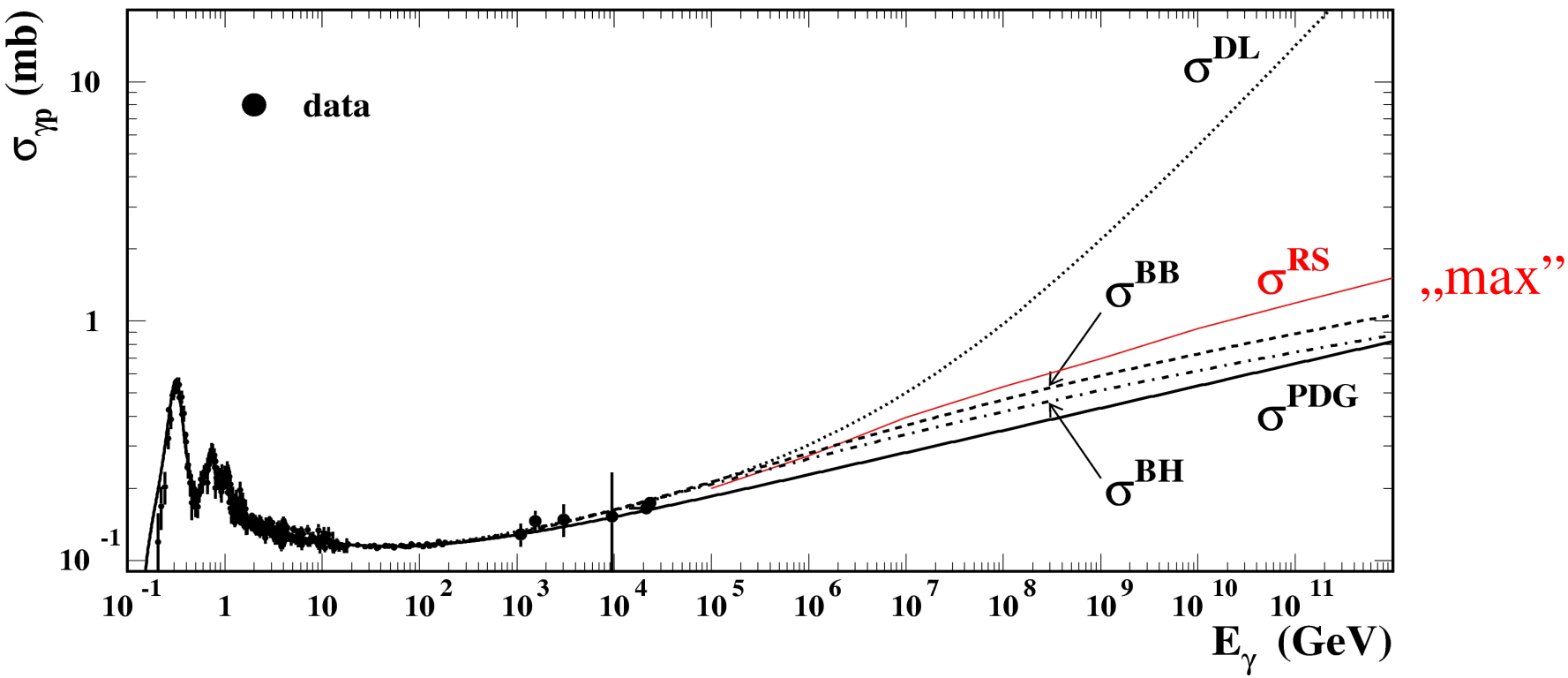
**-> Auger: strong constraints on non-acceleration scenarios**

# GZK photons and Auger South




- If exotic scenarios are excluded we still should see photons!
- Nuclear primaries + GZK processess -> GZK photons (fraction < 1%)
- AUGER South at the edge of detecting GZK photons **(benchmark ~0.1%)**

# UHE photons: testing photonuclear interactions

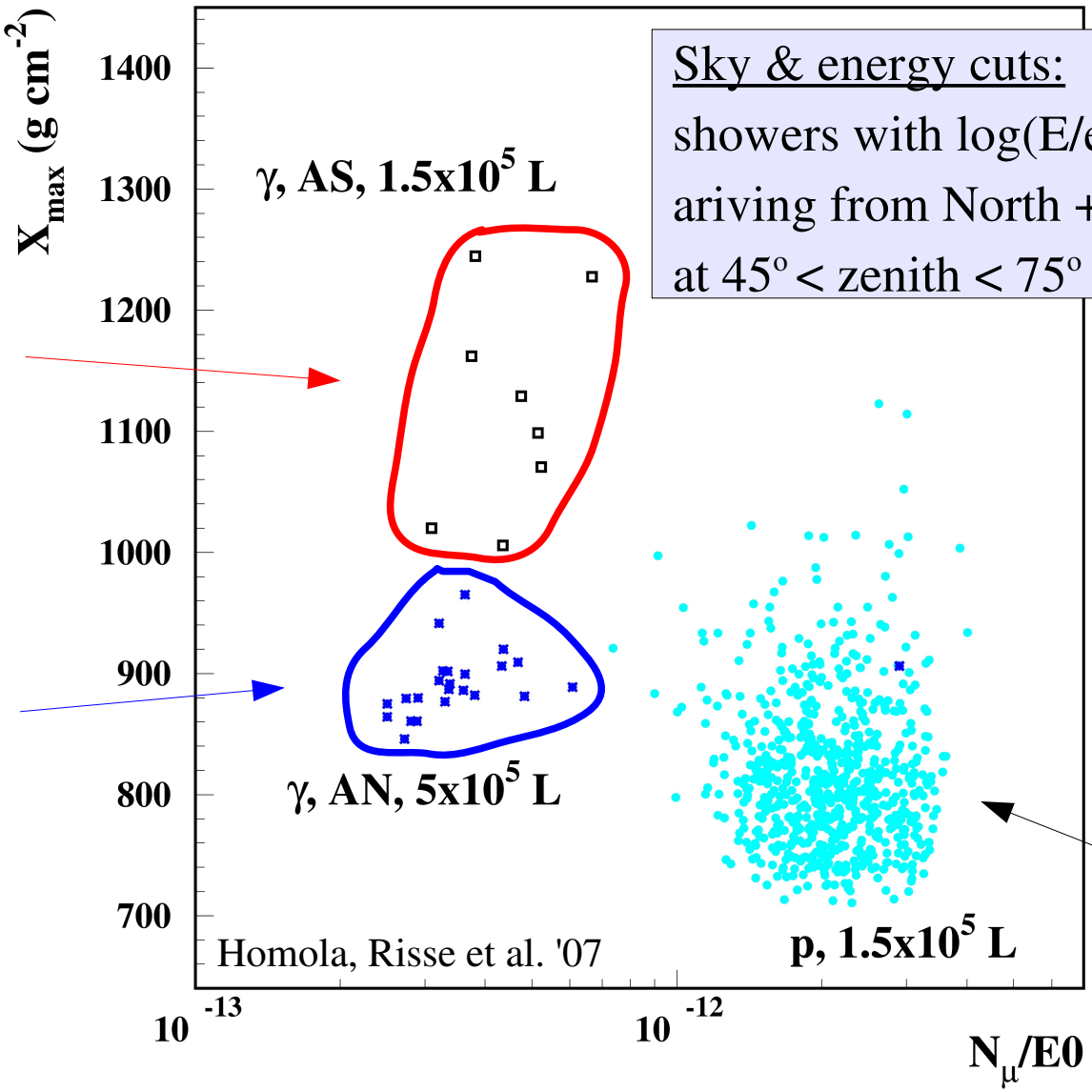



- Small chance (~1%) for hadron-like showers induced by photons
- Hadron dynamics at UHE not known: weakness of shower simulations
  -> uncertainties smaller for photons than for hadron primaries
- photonuclear cross-section at UHE not known
  -> additional uncertainties to some shower observables (ex. $N_\mu$)
  -> estimations of crossections uncertainties (Risse '06)

# AUGER North + South simulations: the complementarity

Auger South (Btr≈0.1 G): all photons unconverted, deep $X_{max}$

Auger North (Btr≈0.5 G): all photons converted, small $X_{max}$




Sky & energy cuts:
showers with log(E/eV) > 19.6,
ariving from North +/- 60°,
at 45° < zenith < 75°

**1% photon** fraction assumed, uniform distribution of sources

protons

The same regions of the *local* skies observed, shower properties differ at N and S
-> cross-check/confirmation of the photon signal

# Summary

- UHE photons: tracers of highest energy processes and new physics; UHE photon searches contribute to multimessenger observations of the universe

- Photon-induced showers can be well distinguished from those initiated by hadrons

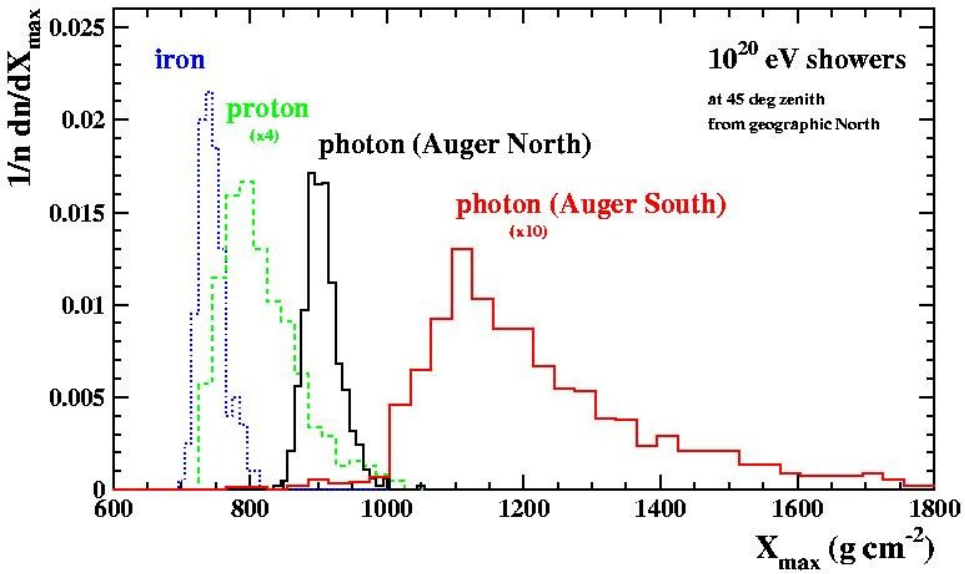
- Pierre Auger Observatory: no photon candidates, stringent upper limits to the photon flux/fraction at energies $10^{19}$ eV $\leqslant$ E $\leqslant$ $4\times10^{19}$ eV
  -> effective tests of exotic scenarios of UHECR origin

- prospects of photon physics with the Pierre Auger Observatory:
  -> more stringent photon upper limits (or identification) expected with increasing event statistics
  -> The Pierre Auger Observatory (northern and southern sites) is expected to be sensitive to photon fractions $\sim$ 0.1%
  -> observations of GZK photons are realistic!

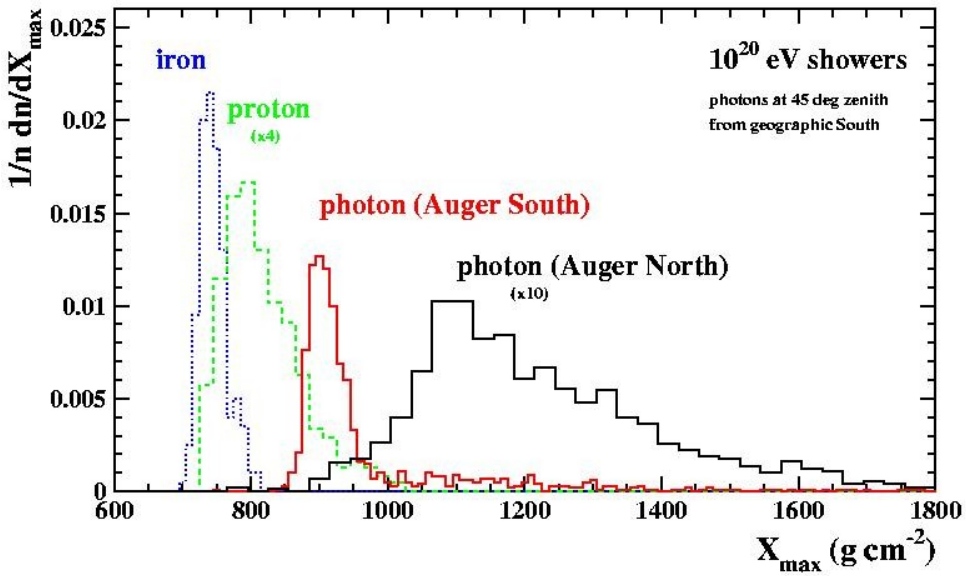
# Importance of the geomagnetic field

Simulated $X_{max}$ distributions for air showers initiated by primaries at $10^{20}$ eV

$\theta = 45^{o}$, coming from **North**




$\theta = 45^{o}$, coming from **South**




Photon-induced showers:

expected $\mathbf{X_{max}}$ distribution depends strongly on the observatory location

(Homola et al., Astropart. Phys. '07)

# UHE photon conversion maps