Photon physics with AUGER

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• Motivation for UHE photon search
• Features of photon induced showers
• Pierre Auger Observatory: results & prospects
Why search for UHECR photons?

primary process:

acceleration of nuclear primaries + GZK-type process (conventional physics)
- suitable astrophysical site needed
- photon energies ~10 × 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

motivation for UHECR photon searches:
- multimessenger observations of the universe
- discriminating between different (classes of) scenarios
Effect important for $E_\gamma \geq 10^{19}$ eV, dependent on $E_\gamma$ and $B_\perp$
(and via $B_\perp$ also on arrival direction and geographic location).
LPM: $\sigma_{\text{Bethe-Heitler}}$ decreases with E, important for $E > 10^{19}$ eV
-> deep $X_{\text{max}}$, large $X_{\text{max}}$ fluctuations

PRESHOWER: E split -> reduced $X_{\text{max}}$, small fluctuations
Observable features of photon-induced showers

- $X_{\text{max}}$ (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)

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

\[ t_2' - t_2 > t_1' - t_1 \]
\[ \Delta t_1 < \Delta t_2 \]
\[ t_{1/2}(H_1) < t_{1/2}(H_2) \]
Pierre Auger Observatory

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

the biggest observatory ever: 3000 km² in Argentina + even 7 times more planned in USA
data selection: surface detector

photon detection and reconstruction efficiency

surface detector data selection:
\[ E \geq 10^{19} \text{eV}, \ 30^\circ < \text{zenith} < 60^\circ \]
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**

[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)

\[ \text{Photon Fraction for } E > E_0 \text{ [\%]} \]

\[ E_0 [\text{eV}] \]

\[ 10^{15} \quad 10^{20} \]

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
- If exotic scenarios are excluded we still should see photons!
- Nuclear primaries + GZK processes \( \rightarrow \) GZK photons (fraction < 1%)
- AUGER South at the edge of detecting GZK photons \( \text{(benchmark } \sim 0.1\% \text{)} \)
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 crosssections uncertainties (Risse '06)
AUGER North + South simulations: the complementarity

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

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

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

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

1% photon fraction assumed, uniform distribution of sources

protons

Homola, Risse et al. '07

Piotr Homola
21st European Cosmic Ray Symposium, Košice, 10.09.2008
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 $10^{19} \text{eV} \leq E \leq 4 \times 10^{19} \text{eV}$
  -> 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!
Simulated $X_{\text{max}}$ distributions for air showers initiated by primaries at $10^{20}$ eV

$\theta = 45^\circ$, coming from **North**  

$\theta = 45^\circ$, coming from **South**

**Photon-induced showers:**

- **expected $X_{\text{max}}$ distribution depends strongly on the observatory location**
  
  (Homola et al., Astropart. Phys. '07)
UHE photon conversion maps

AN, $10^{20.0}$ eV

AS, $10^{20.0}$ eV