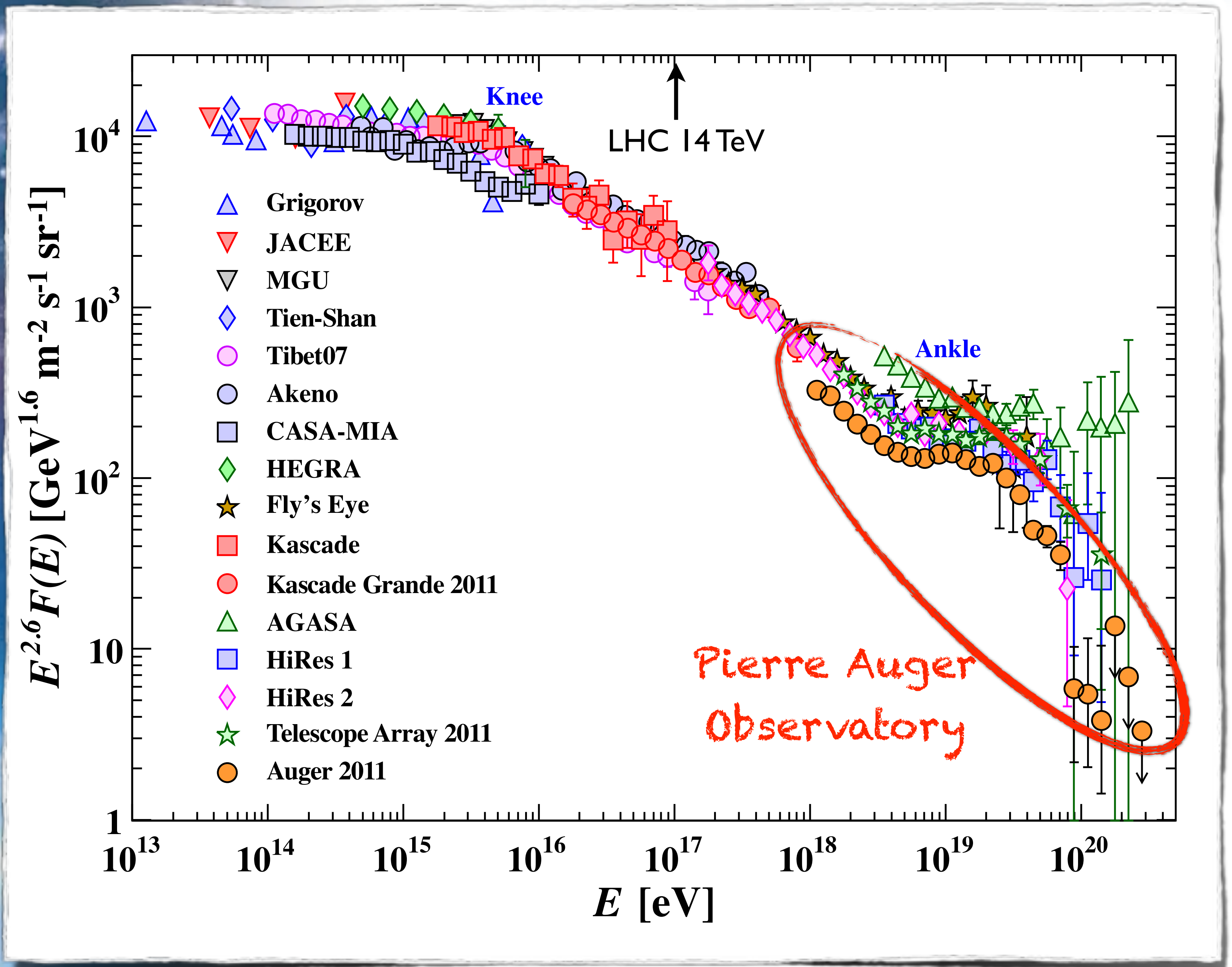
1st "ILP Day", Paris, 13 March 2014

Search for cosmogenic photons with the Pierre Auger Observatory

Mariangela Settimo

LPNHE, Universites Paris VI and Paris VII

The Ultra-High Energy (UHE) range



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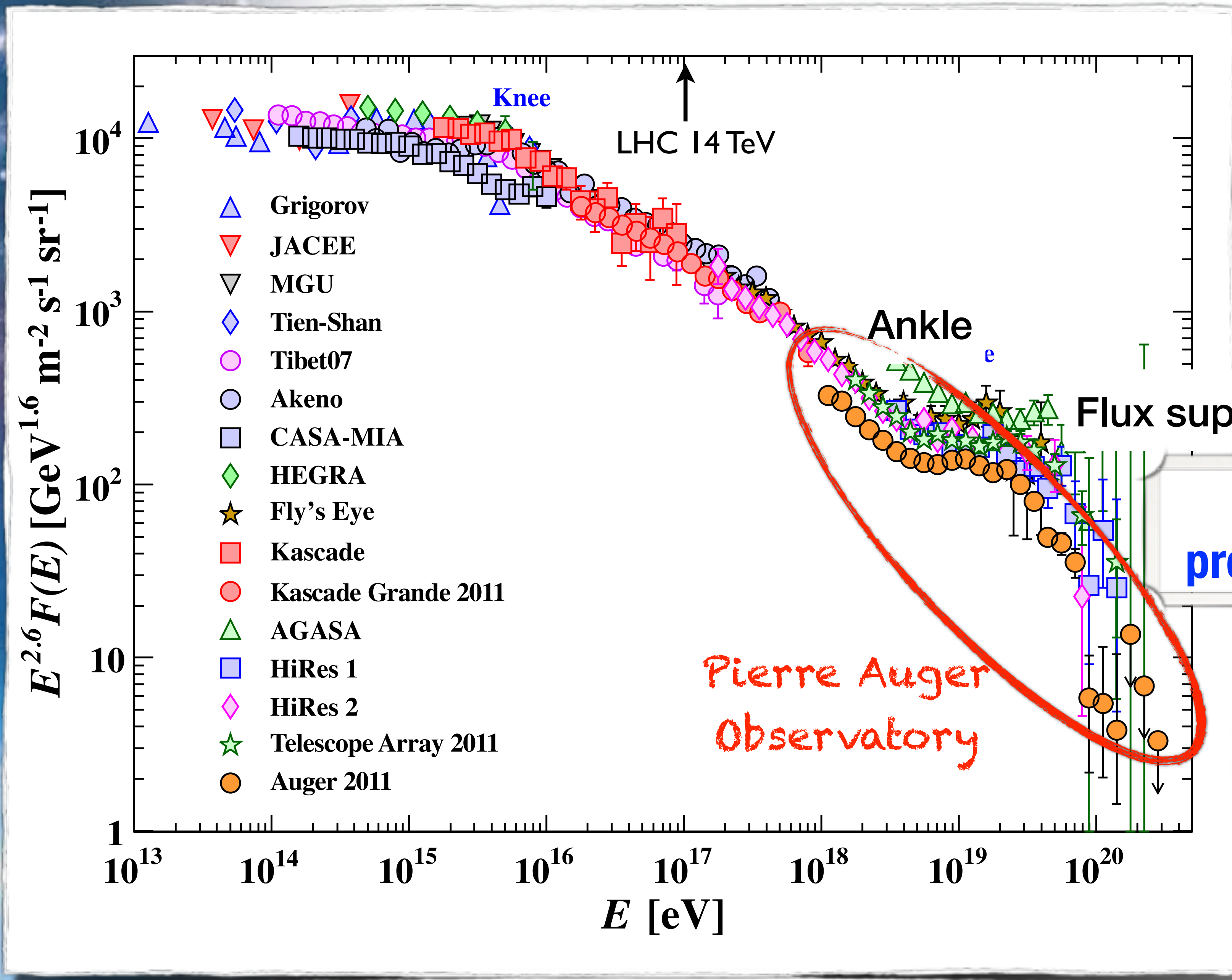

E_{max} @ source or propagat. effect (GZK) ?

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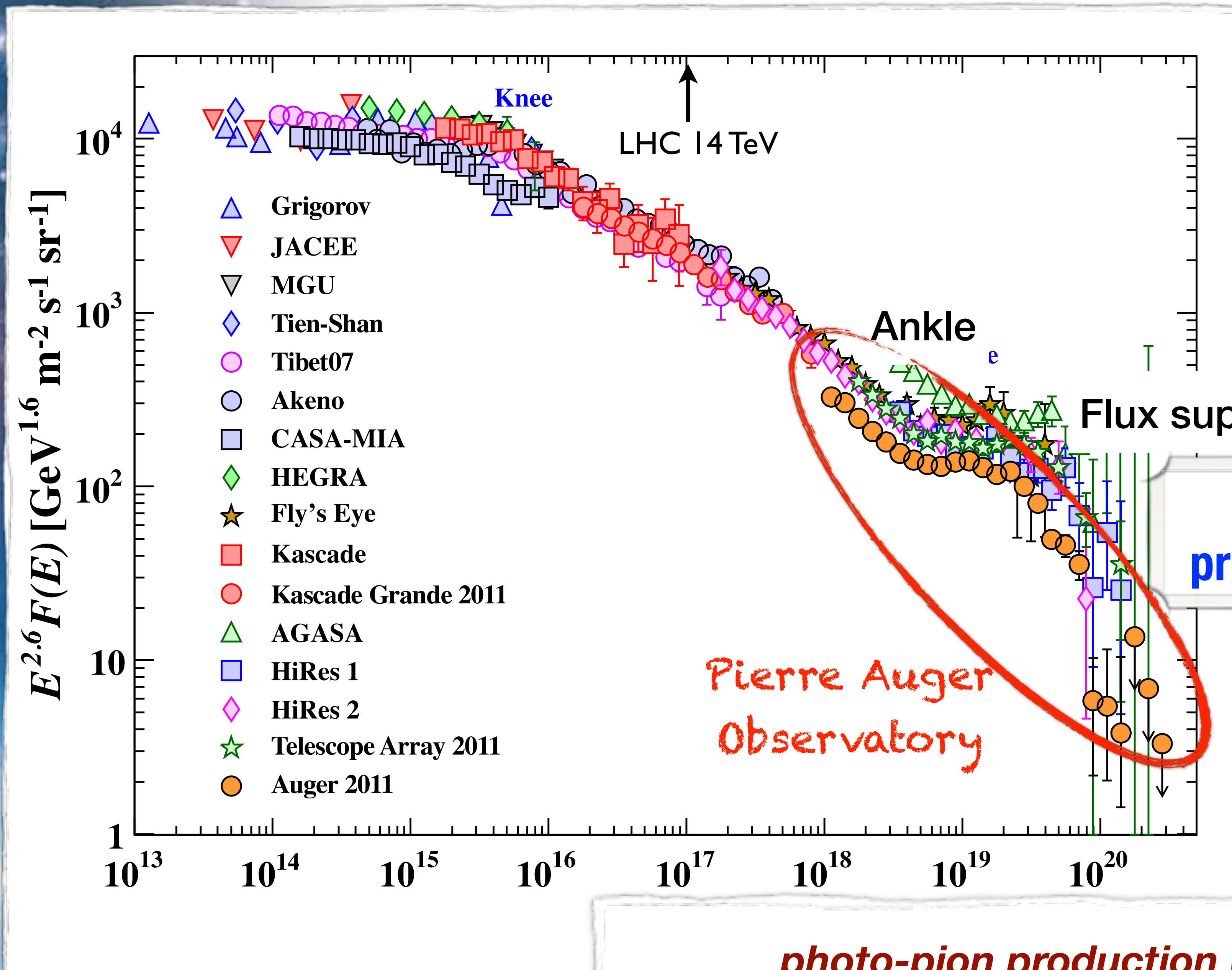
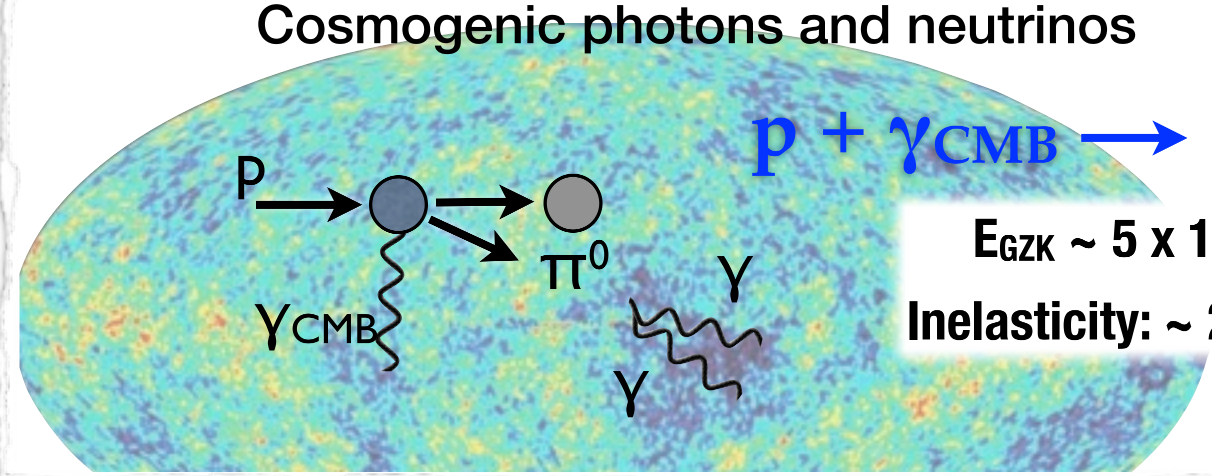


E_{max} @ source or propagat. effect (GZK) ?

photo-pion production (GZK effect)

Cosmogenic photons and neutrinos



$$p + \gamma_{CMB} \longrightarrow \Delta^+ \longrightarrow p + \pi^0$$

E_{GZK} ~ 5 x 10^{19} eV, λ ~ 6 Mpc

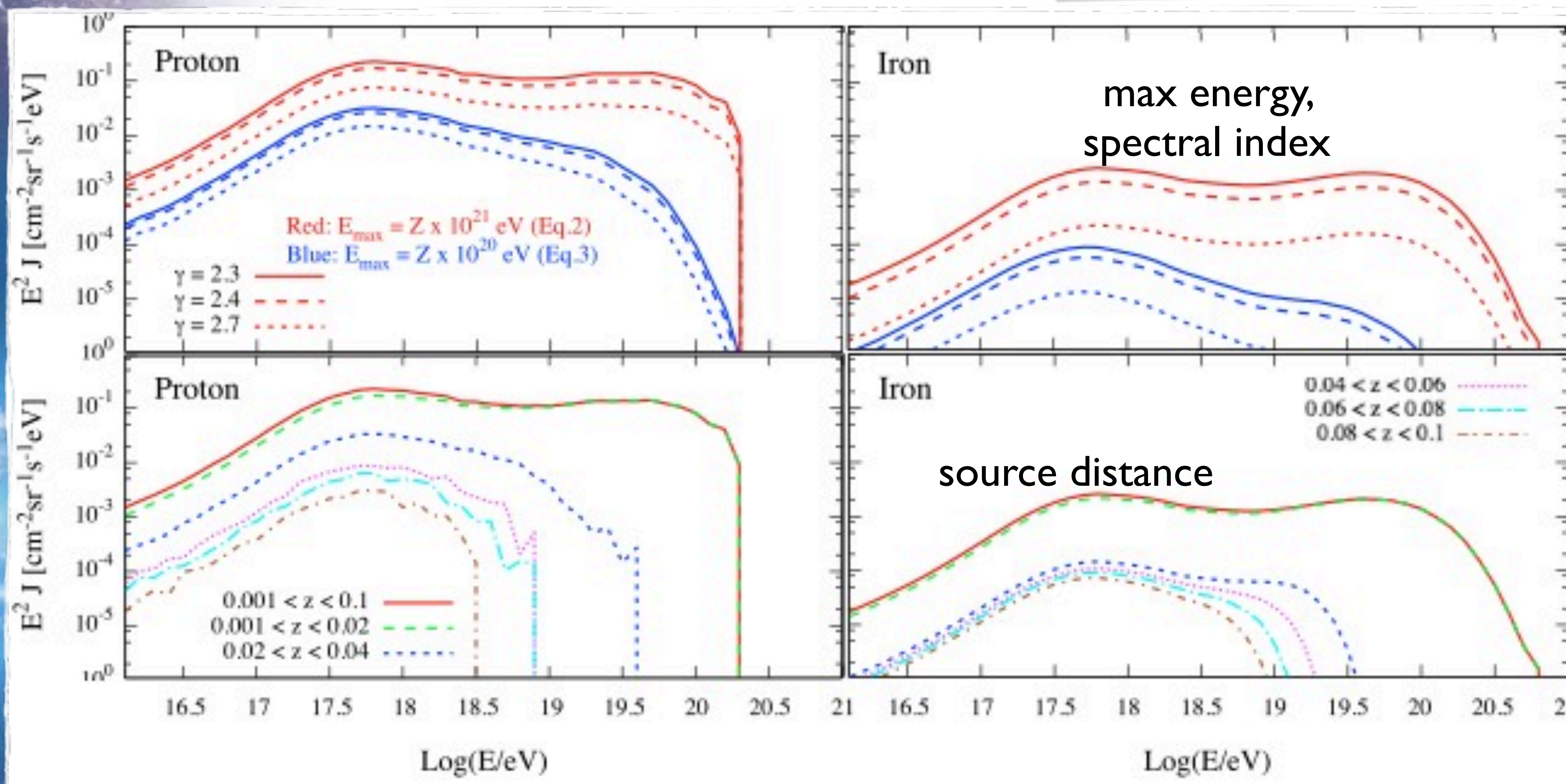
Inelasticity: ~ 20% (10% for each γ)

Flux predictions for cosmogenic photons

Photon flux predictions sensitive to:

- **source properties** (injection spectrum, maximum energy, primary types, source distrib./evol.)
- **propagation** (electromagnetic cascades in EBL, magnetic fields)

expected flux: ~ 0.1- 1% of the all-particle spectrum above 10^{19} eV

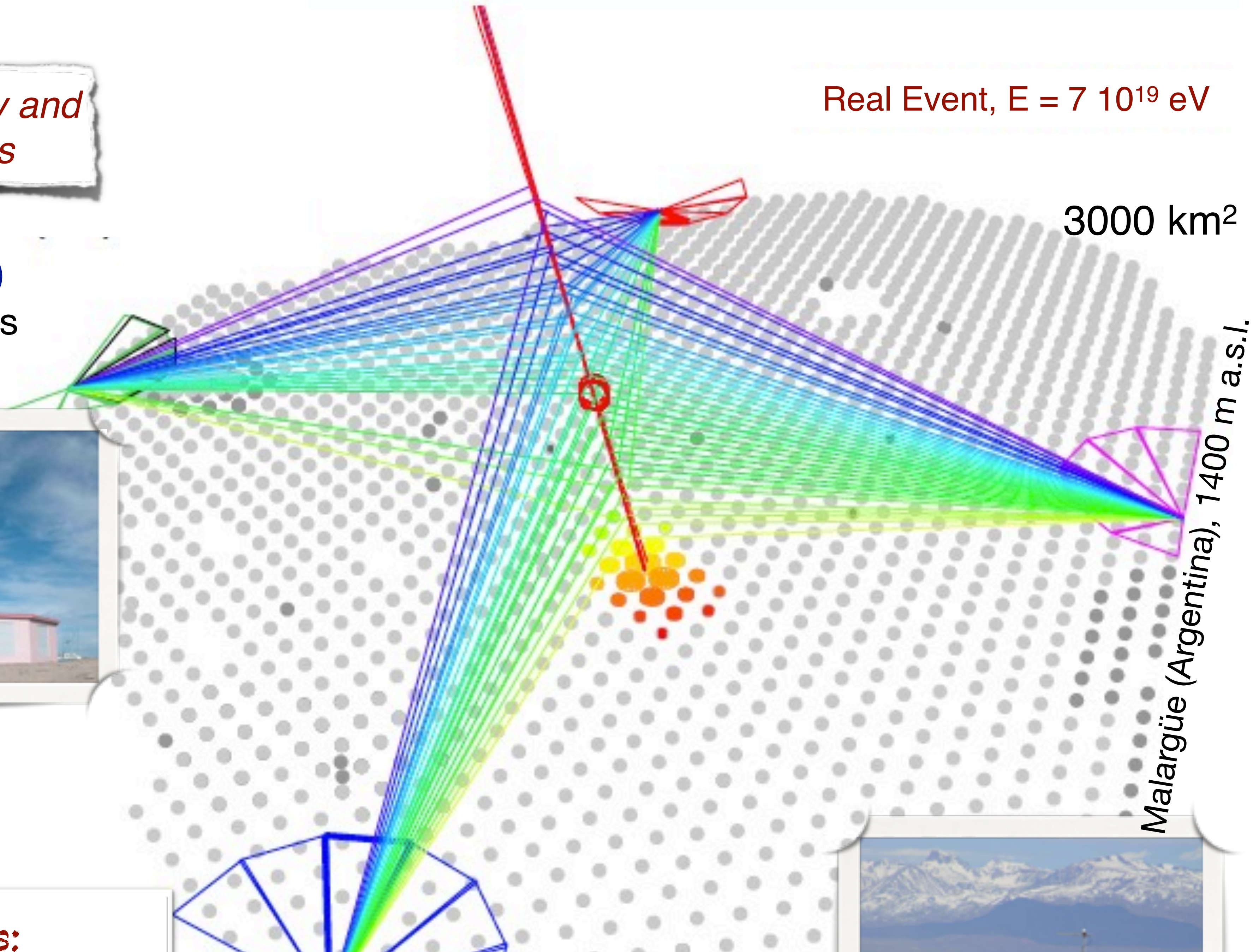


M.S., M.De Domenico, arXiv:1311.6140

depending on the observations, some astrophysical scenarios can be constrained/disfavored

The Pierre Auger Observatory: *the hybrid design*

Based on 2 complementary and independent techniques



Fluorescence Detector (FD)
24 + 3 telescopes in 4 sites
10-15% duty cycle

Hybrid events:
observed at the same time by at least 1 fluorescence telescope + 1 SD

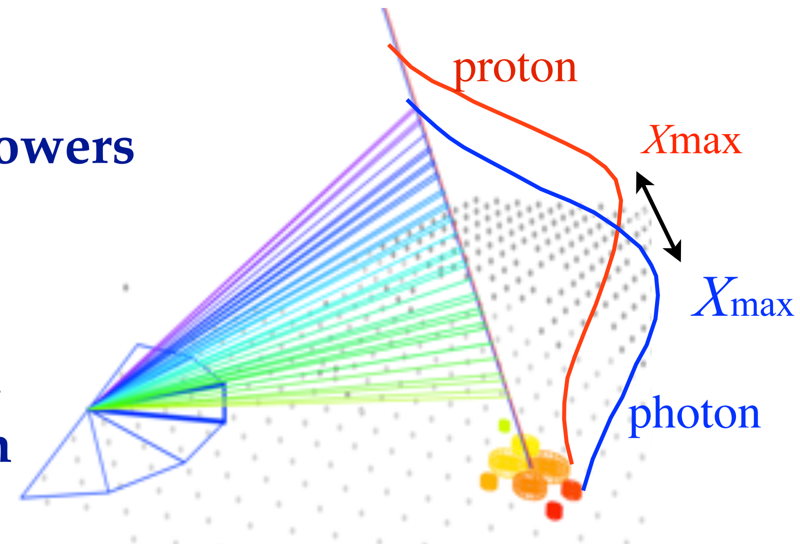
Surface Detector array (SD)
1600 + 60 water Cherenkov stations, 100% duty cycle

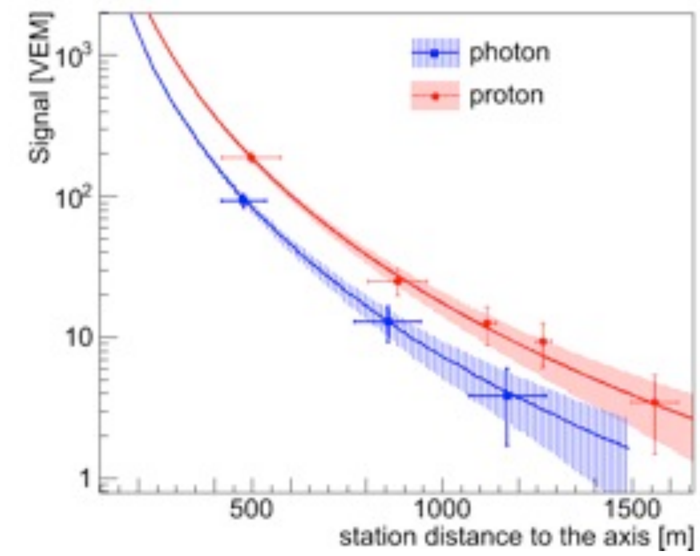
Photon identification

Hybrid events (E > 10^{18} eV):

- Deeper development of the air showers *(larger Xmax)*

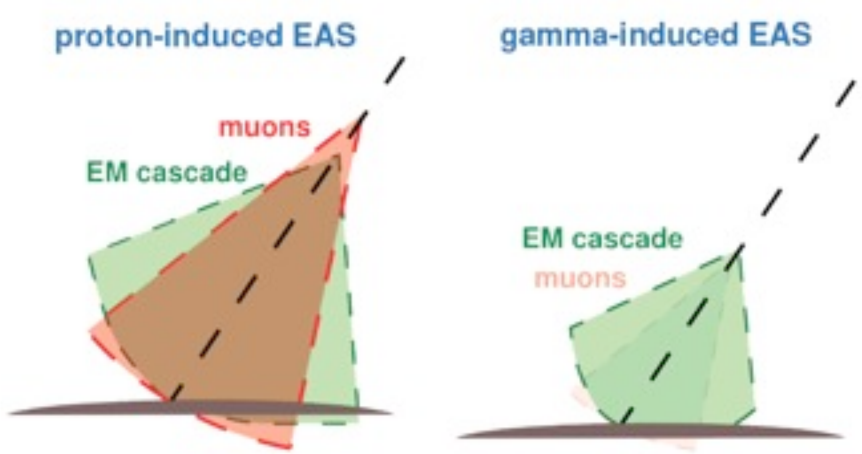
- Smaller detected signal in SD and steeper lateral distribution function



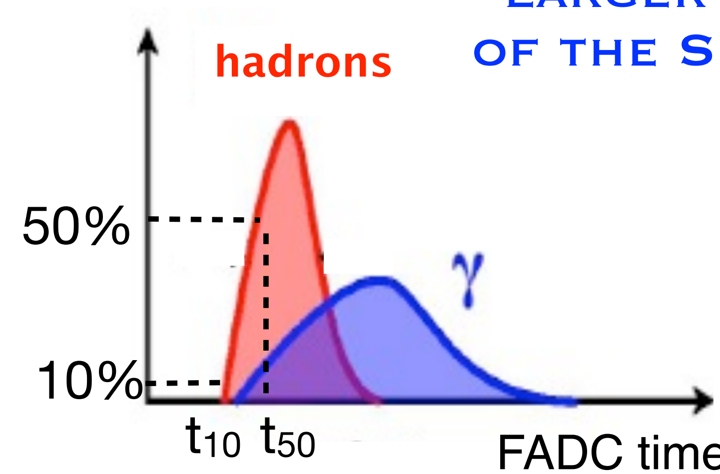


SD events (E > 10^{19} eV):

Deeper shower development and smaller number of muons



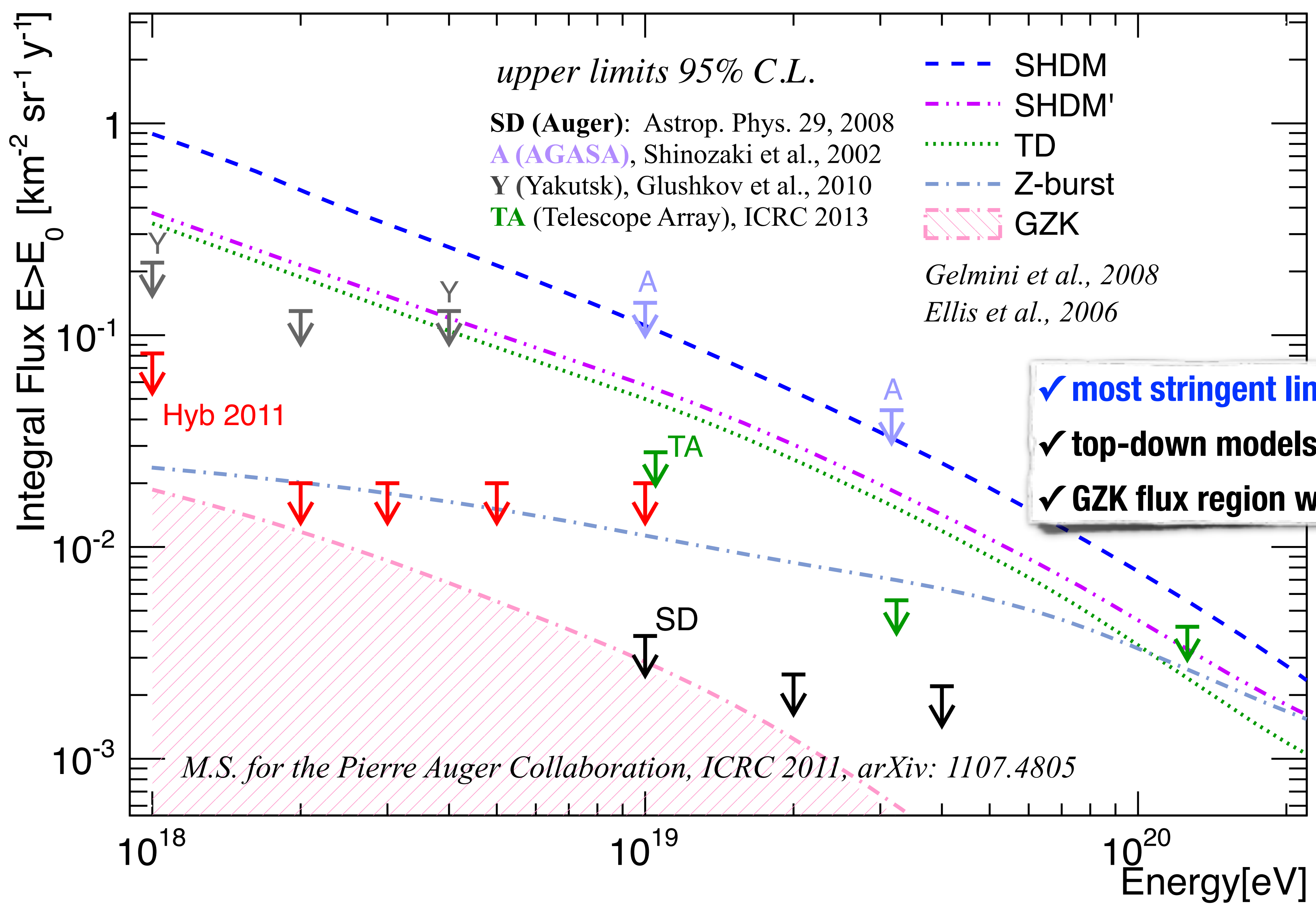
SMALLER RADIUS OF CURVATURE



LARGER RISETIME OF THE SD SIGNALS

Risetime: $t_{1/2} = t_{50\%} - t_{10\%}$

Upper limits on photon flux



- ✓ most stringent limits available in the EeV range
- ✓ top-down models disfavored
- ✓ GZK flux region within reach

Upper limits to the integral photon fraction:

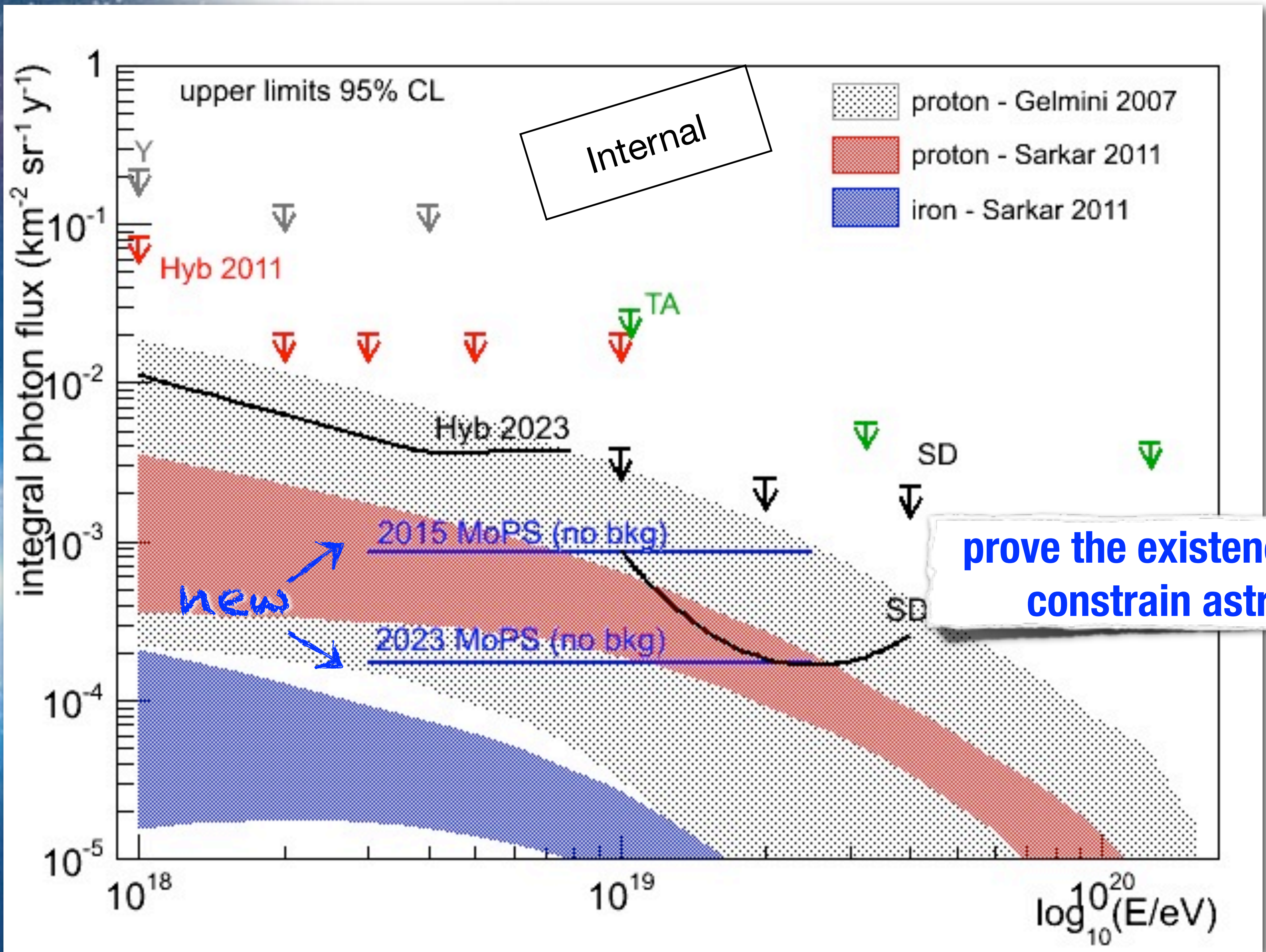
Hybrid: 0.4%, 0.5%, 1.0%, 2.6% and 8.9% @ E>1, 2, 3, 5 and 10 EeV

SD: 2.0%, 5.1%, 31% @ E > 10, 20, 40 EeV

Expected sensitivity in the near future

A new trigger designed (installed in the stations on June 2013):

- select station with small signals, not dominated by the muonic component
- **especially effective for photons**



Hy 2023, SD 2023:
current analysis
no additional bkg

no candidates
no background

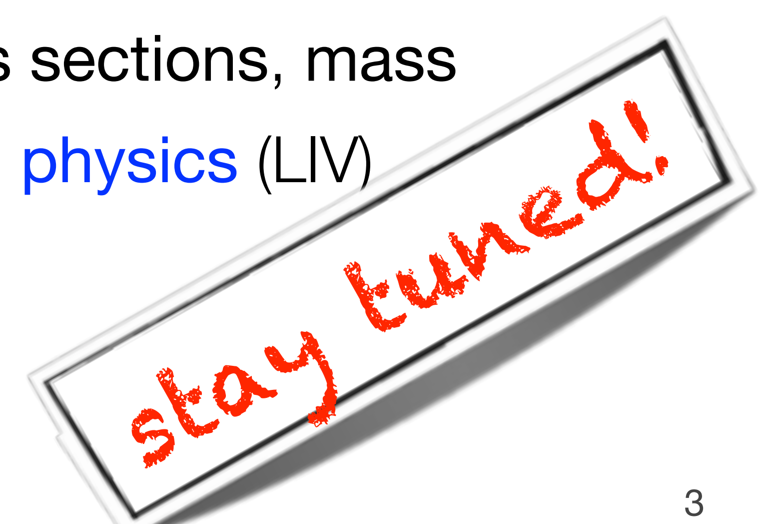
prove the existence of the GZK effect and constrain astrophysical scenarios

Data analysis in progress

Outlook

Observation/Non-observation of UHE photons:

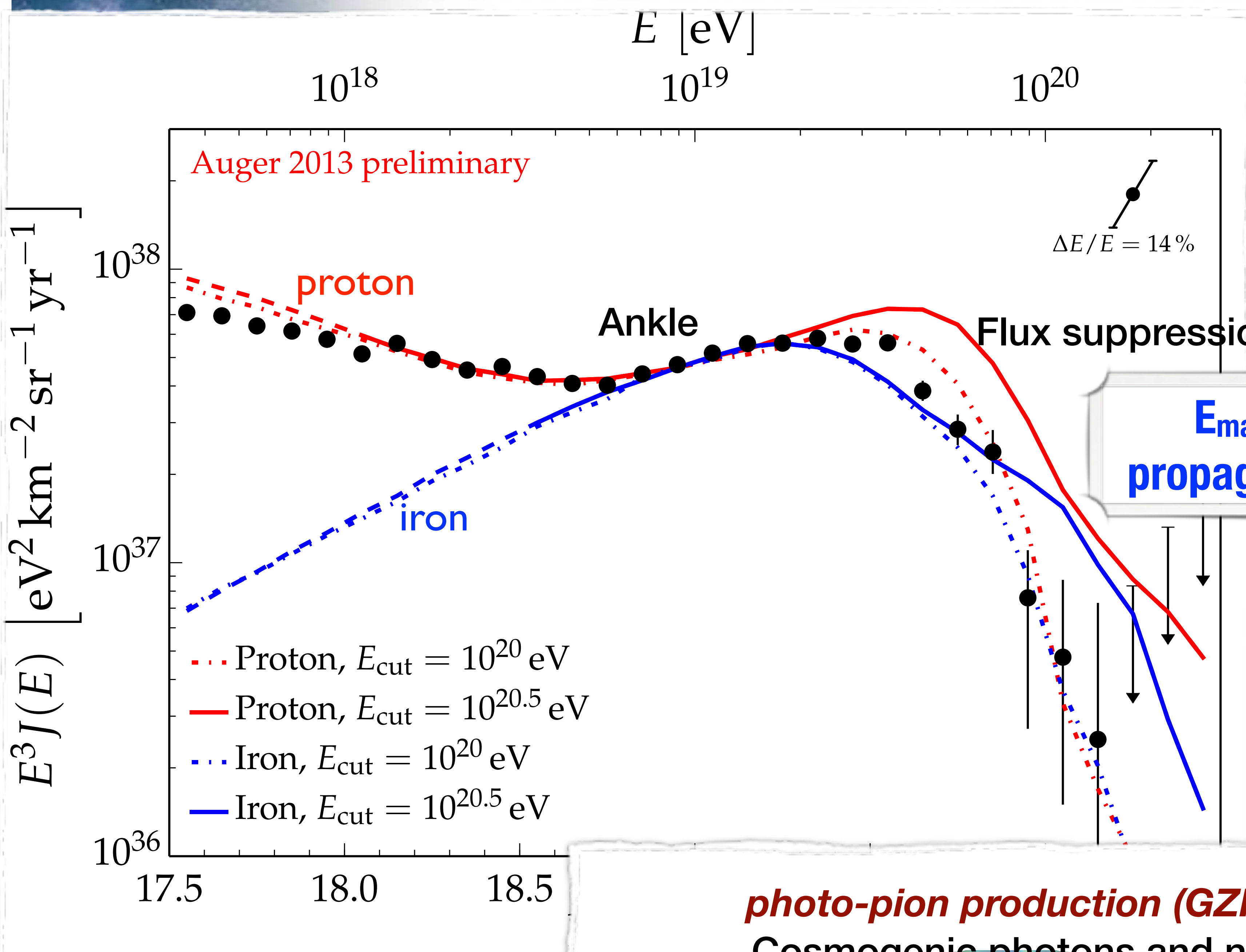
- Independent prove of the **GZK effect**
    - Clarify the nature of the observed flux suppression
- flux of cosmogenic photons sensitive to **source properties** (primary mass, injection spectra, distribution) and **extragalactic environment**
    - hints/constraints on **astrophysical scenarios for the origin of ultra-high energy cosmic rays**
- Disfavor/constrains **top-down models**
- Open the most extreme window for **astronomy**
- Impact on the measurements of **energy spectrum, cross sections, mass composition** and possible consequences for **fundamental physics** (LIV)



Thank you

Backup slides

The Ultra-High Energy (UHE) range



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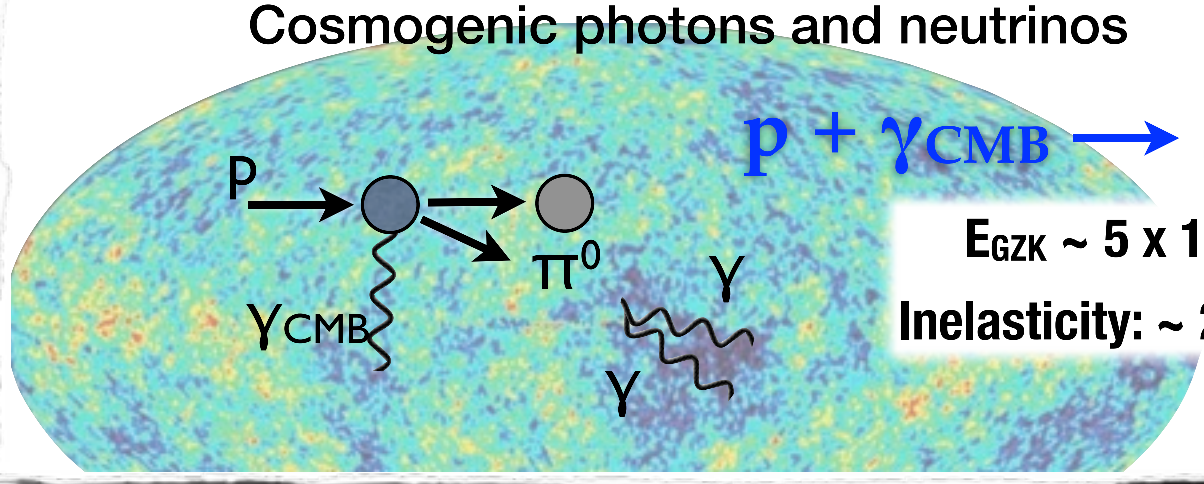

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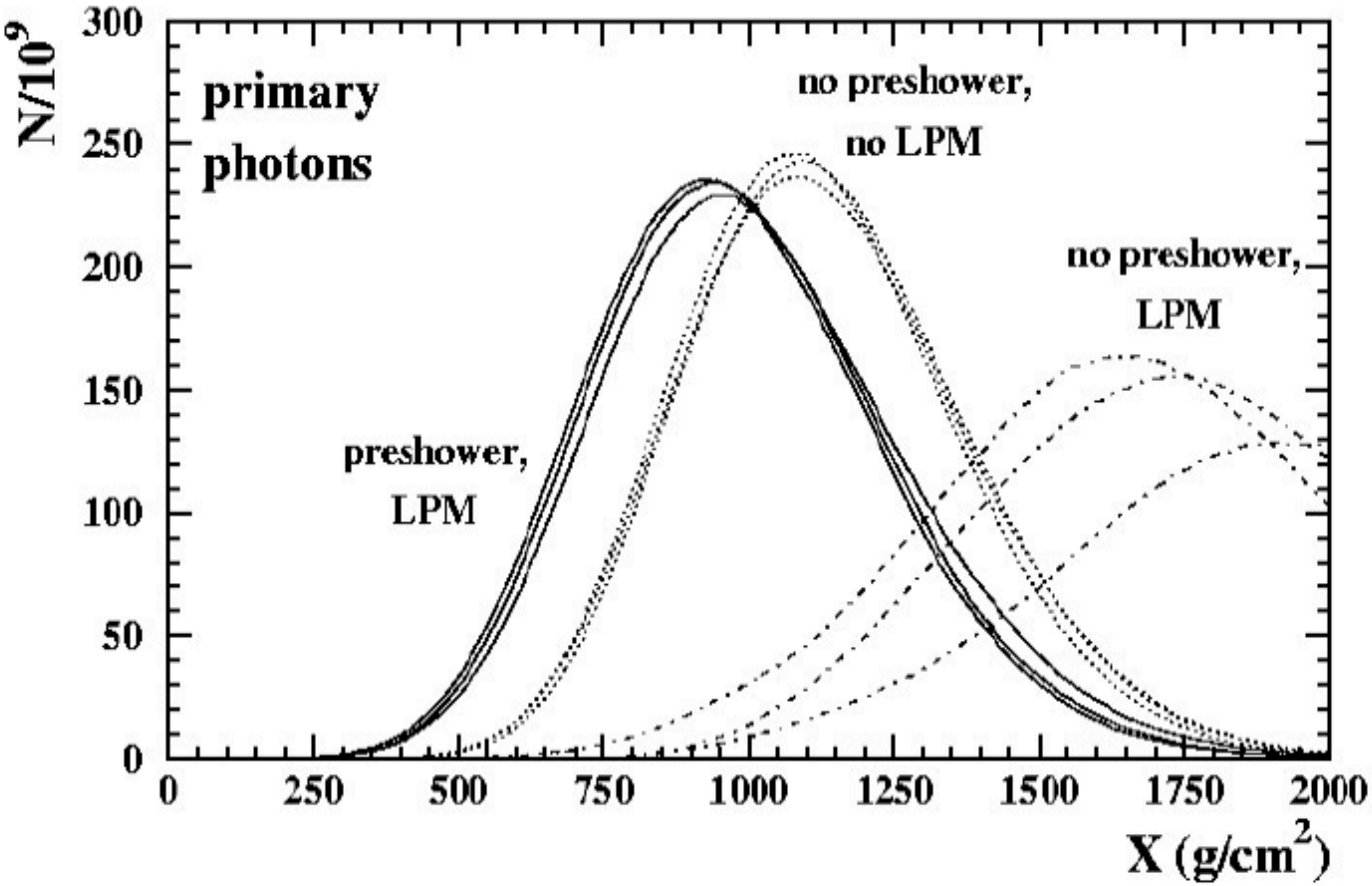
E_{GZK} ~ 5 x 10^{19} eV, λ ~ 6 Mpc

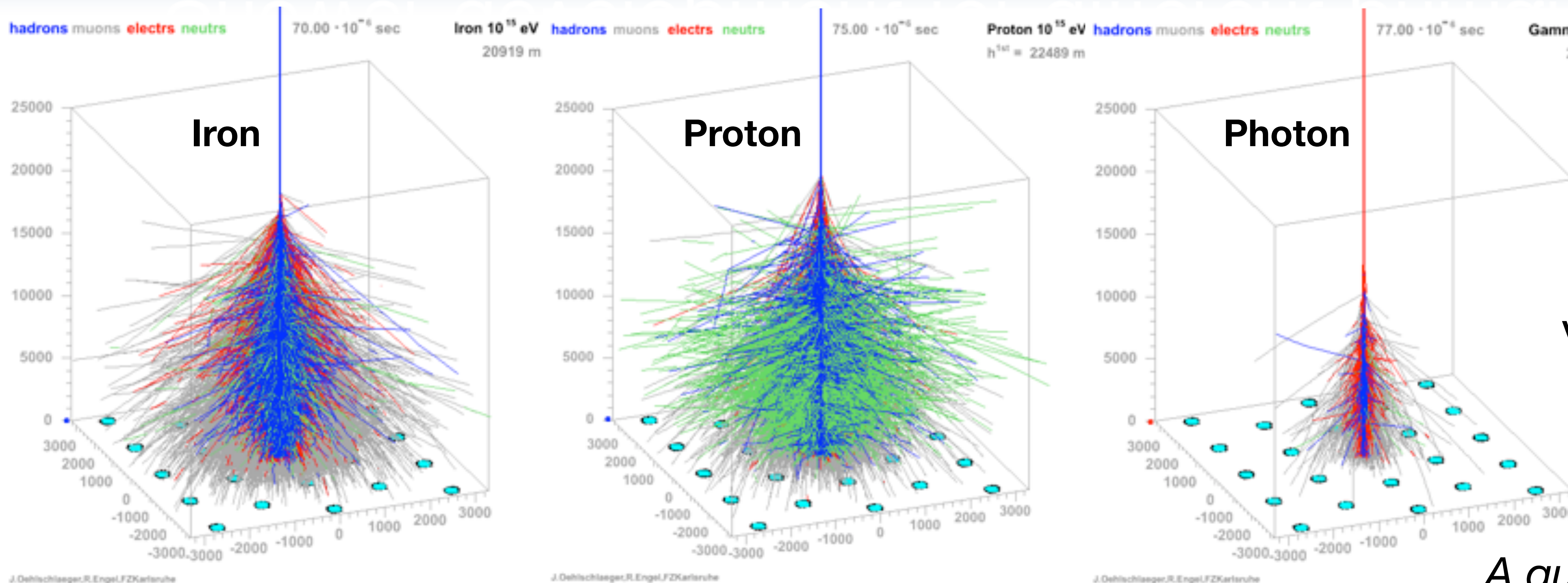
Inelasticity: ~ 20% (10% for each γ)

Pre-shower: impact on EAS development (II)



- faster shower development
- small shower-to-shower fluctuations
- competition of LPM and preshower

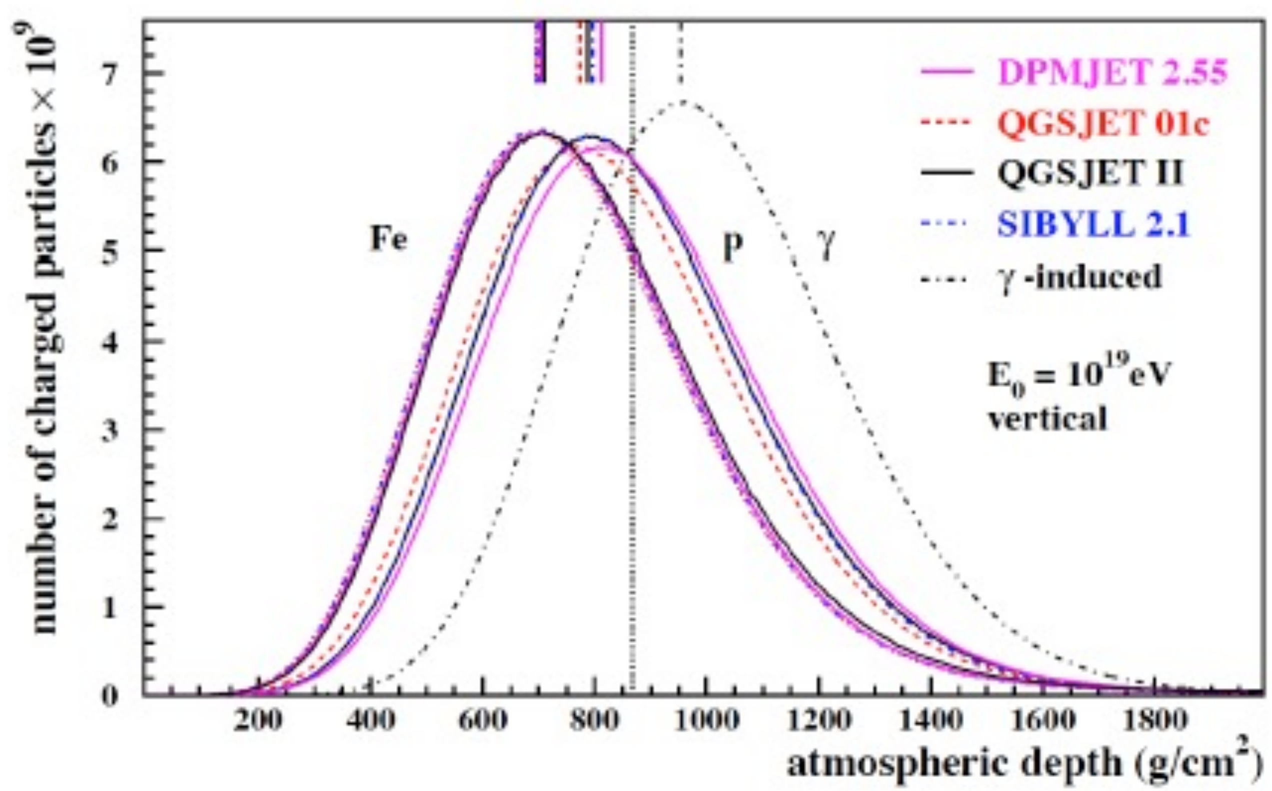
Shower development for different primaries



electrons muons
hadrons neutrons

vertical showers
E = 100 TeV

A qualitative view
(CORSIKA simulations: http://www-ik.fzk.de/corsika/)



Light primaries develop deeper than *heavy* component

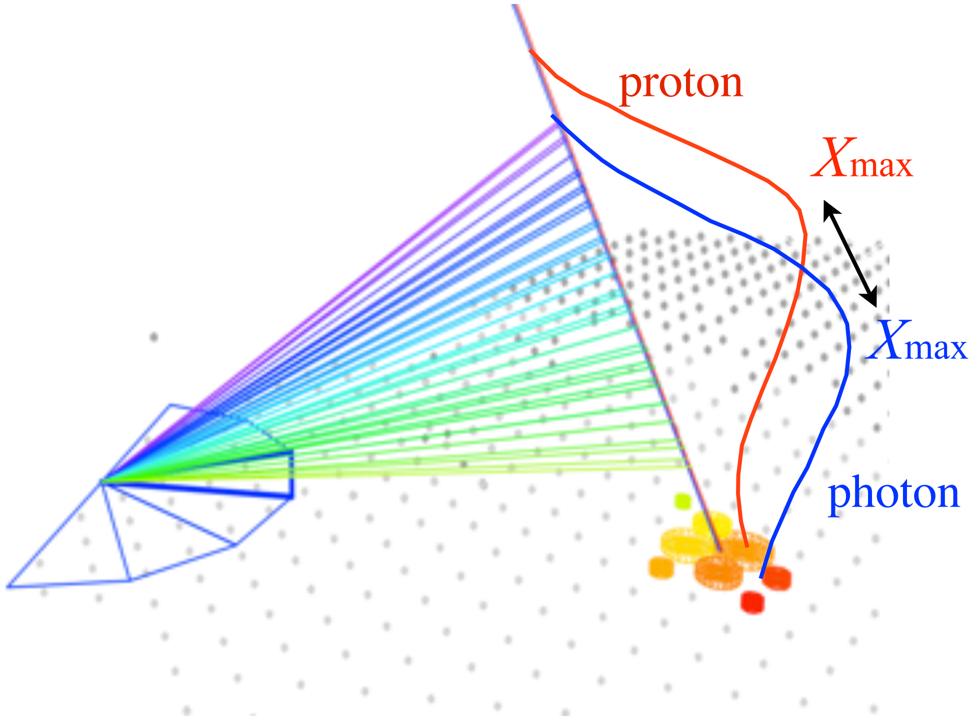
Photon induced showers deeper than hadrons (on average)

Photon search: the hybrid approach (E > 1EeV)

M.S. for the Pierre Auger Collaboration, ICRC 2011, arXiv: 1107.4805

- **FD:**
  - **Deeper development of the air showers**

→ **Larger X_{max}**



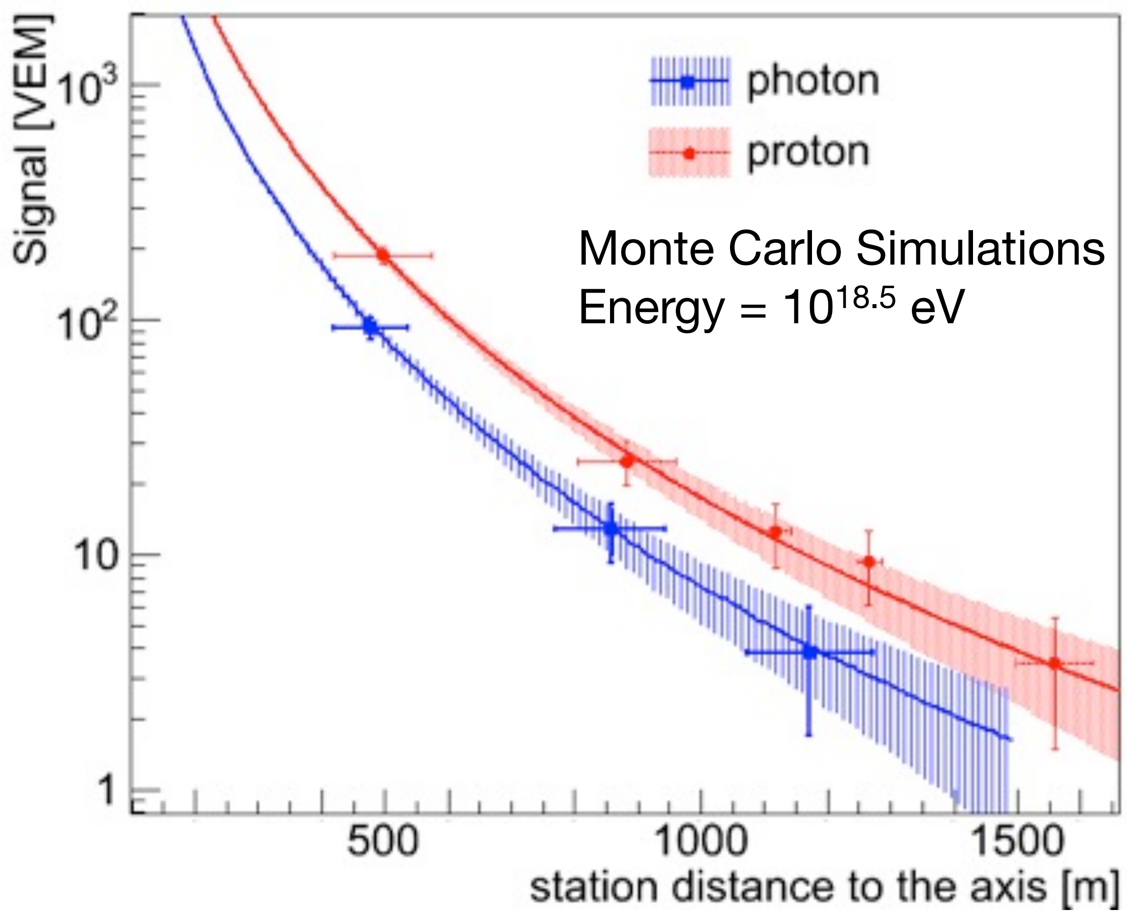
- **SD:**
  - **Smaller detected signal at a given distance**
  - **Fewer triggered stations**

$$S_b = \sum_i S_i \left(\frac{R_i}{1000}\right)^4$$

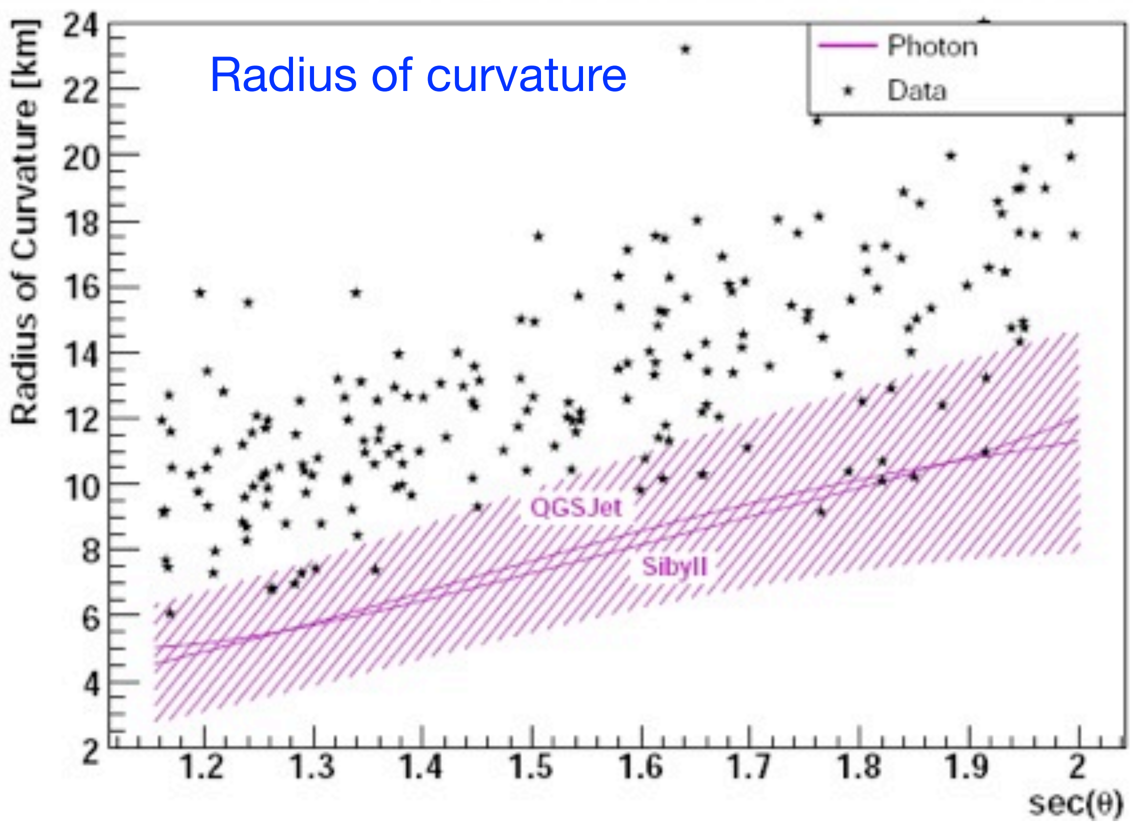
S_i : station signal [VEM]
R_i : station distance to the shower axis [m]

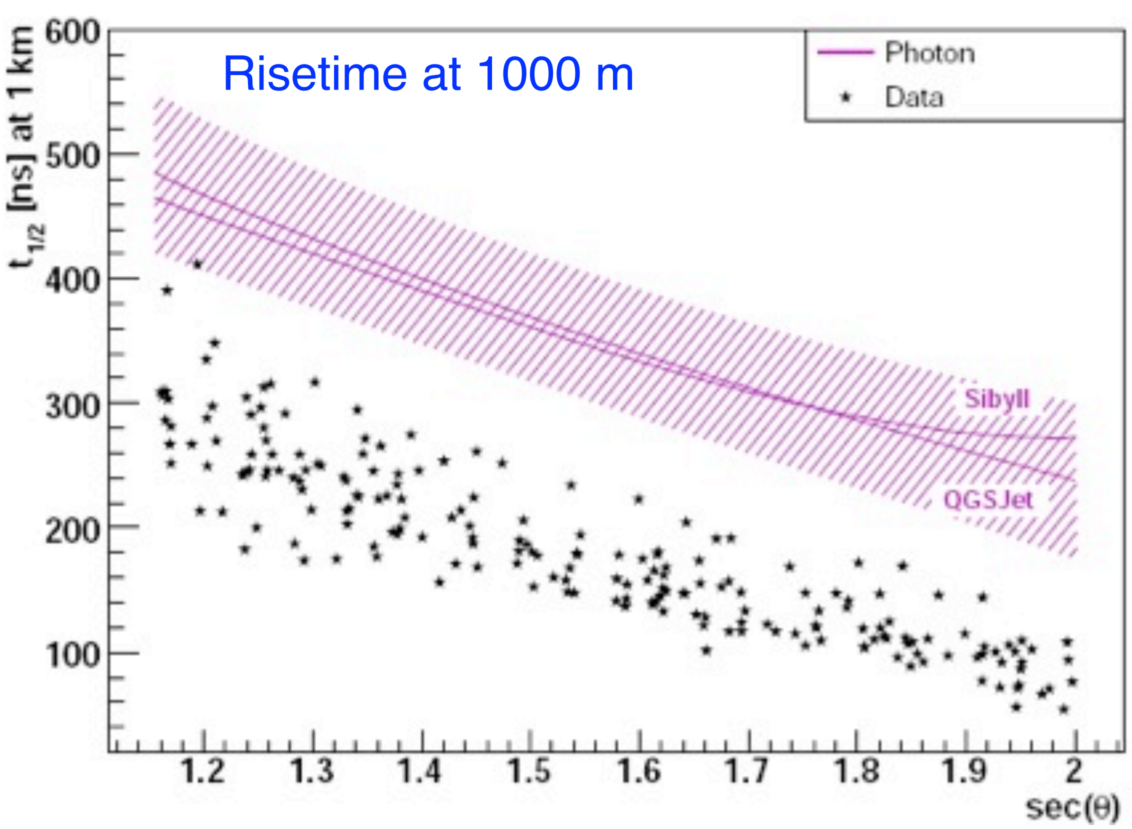
details on S_b: G. Ros et al., arXiv 1104.3399

→ **Smaller S_b**



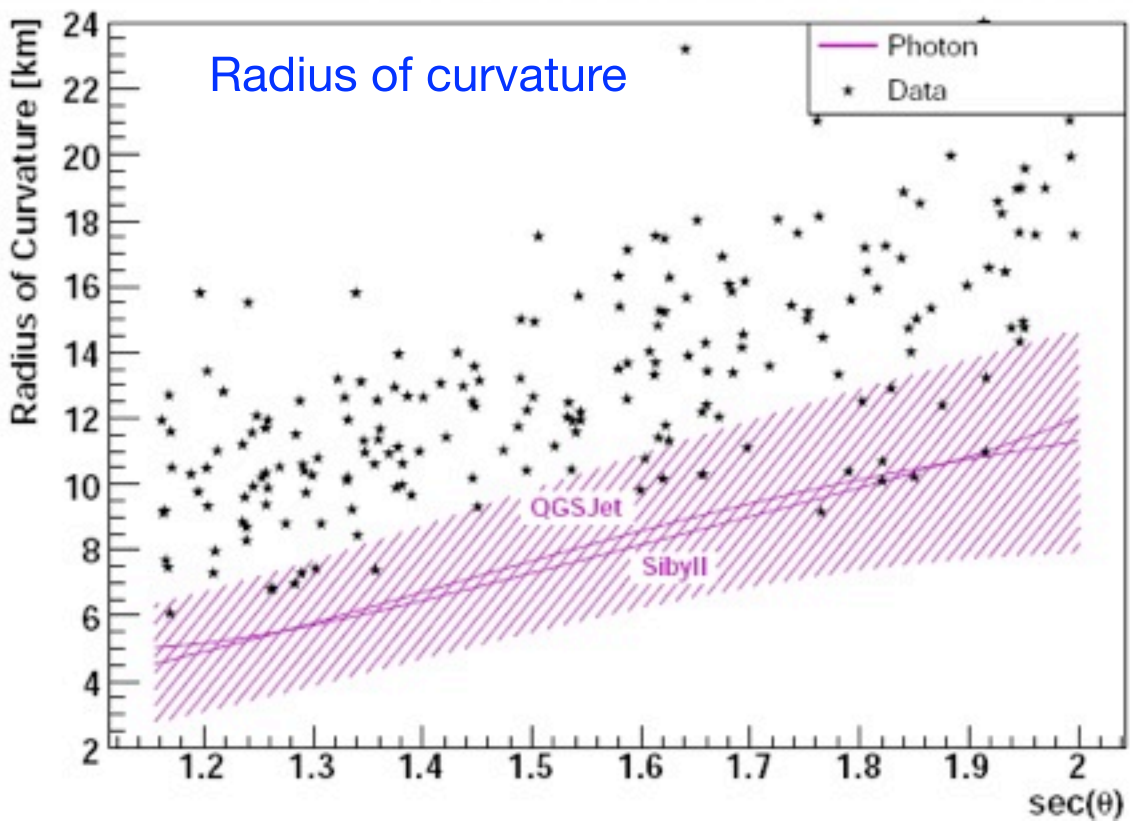
Search for photons with SD: E>10 EeV

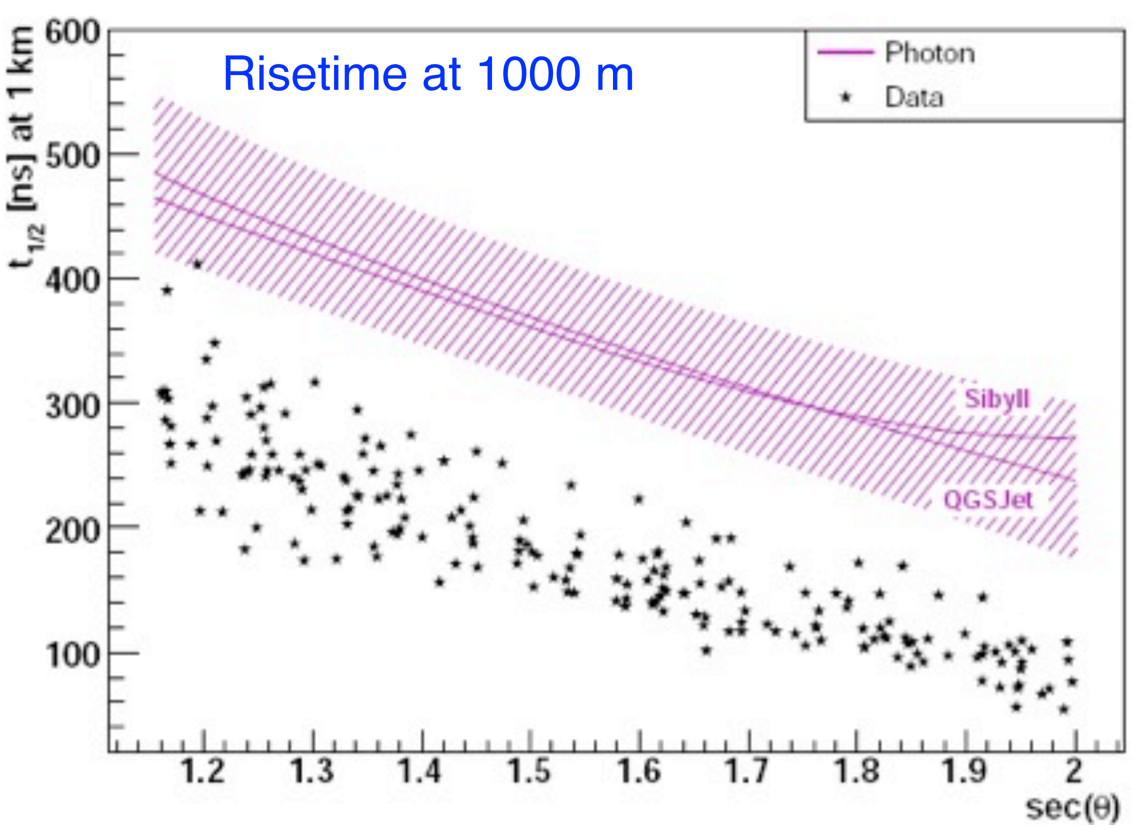




- Events observed by **SD**-alone
- **radius of curvature** and **risetime** $t_{1/2}$ at 1000 m used for photons identification

Search for photons with SD: E>10 EeV





- Events observed by **SD**-alone
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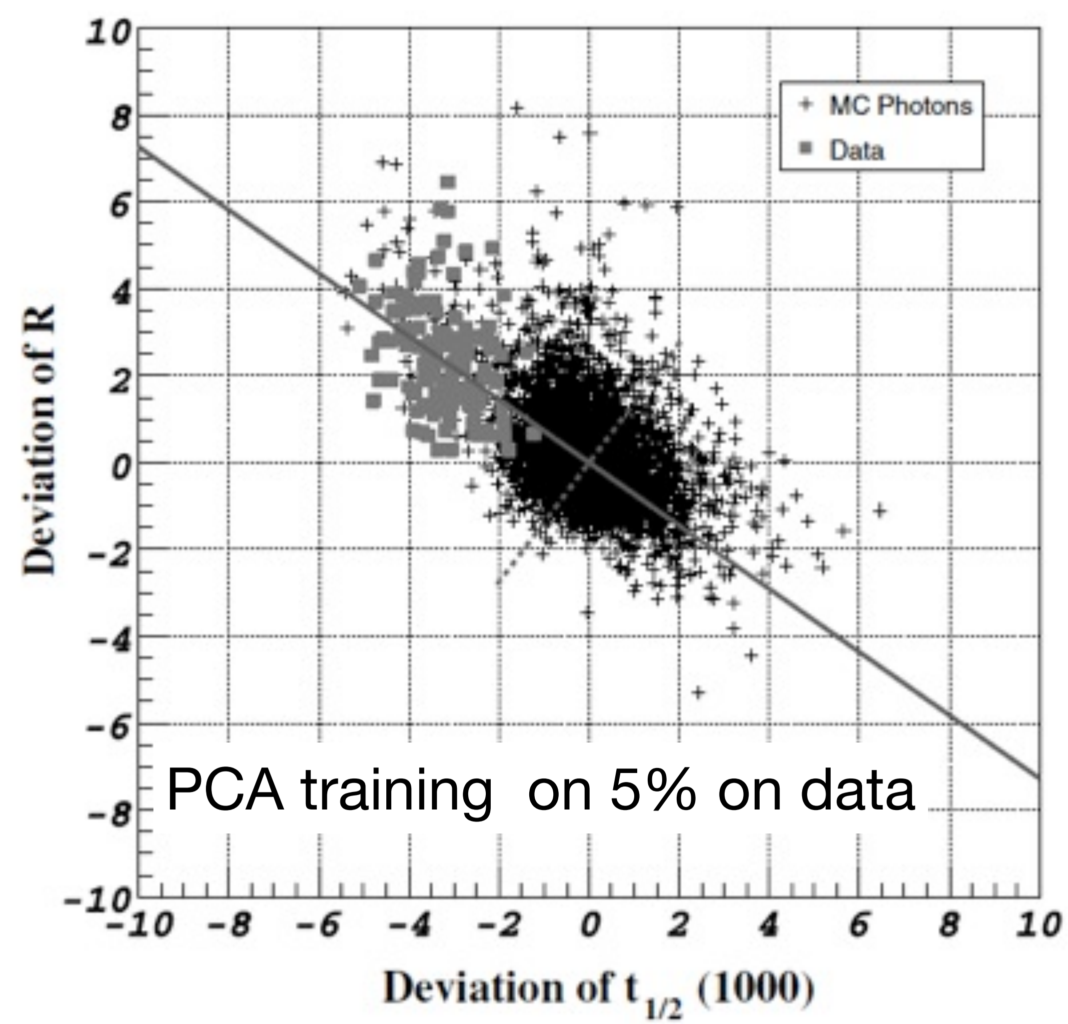
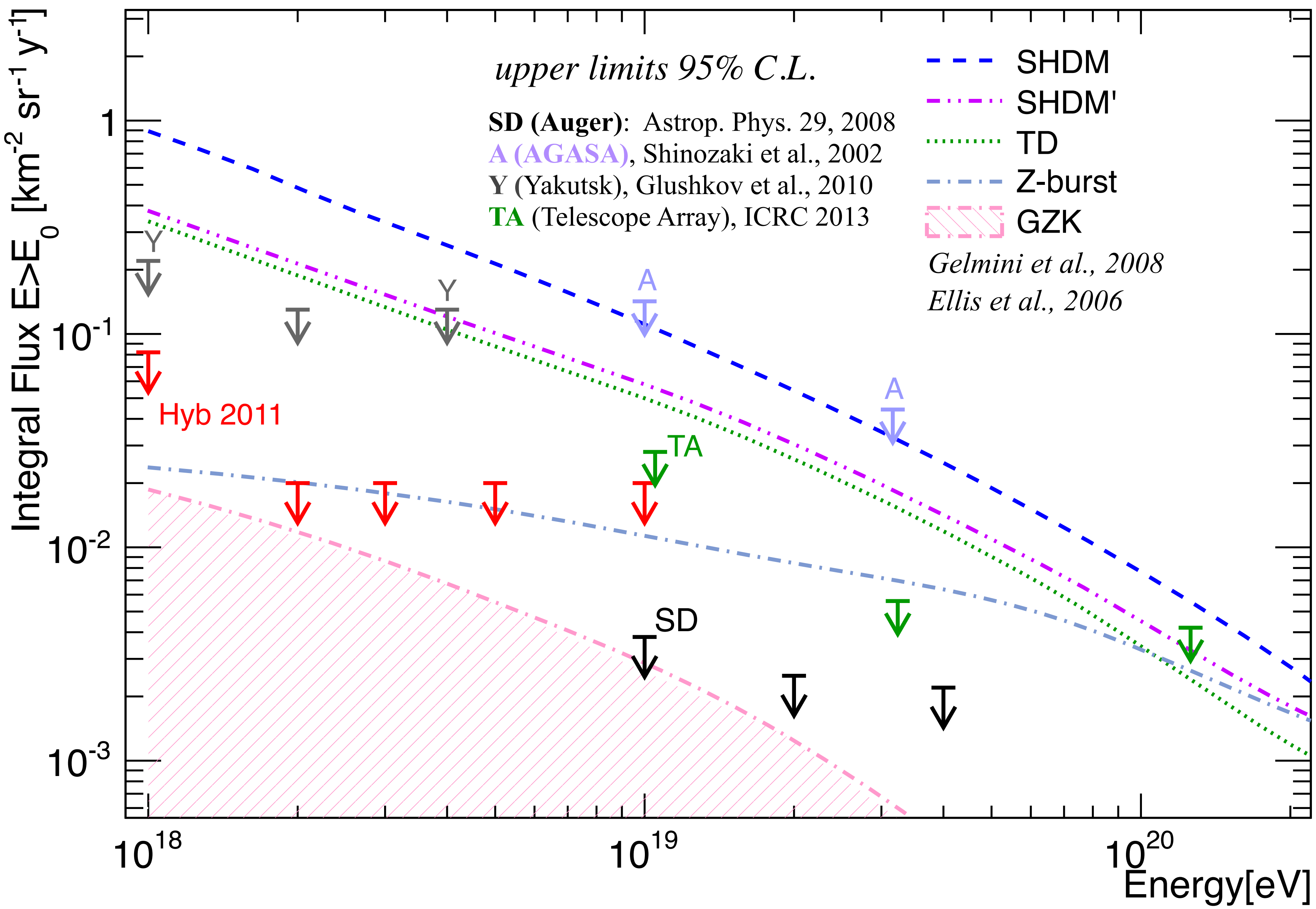
Deviations of data from the mean value of R and $t_{1/2}$ expected for photon showers combined with a **Principal Component Analysis**



Upper limits on photon flux



E_0 [EeV]	N_γ	$\phi_\gamma^{95CL}(E_\gamma > E_0)$ [$km^{-2}\,sr^{-1}\,y^{-1}$]
1	6	8.2×10^{-2}
2	0	2.0×10^{-2}
3	0	2.0×10^{-2}
5	0	2.0×10^{-2}
10	0	2.0×10^{-2}

Impact of systematic uncertainties

(Exposure, ΔX_{max}, ΔS_b, Energy scale, hadronic interaction model and mass composition assumptions)

$$^{+20\%}_{-64\%}\ (E_0 = 1\ \mathrm{EeV})$$

$$^{+15\%}_{-36\%}\ (E_0 > 1\ \mathrm{EeV})$$

Upper limits to the integral photon fraction assuming the **Auger Spectrum**

0.4%, 0.5%, 1.0%, 2.6% and 8.9% @ E>1, 2, 3, 5 and 10 EeV

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