Influence of Cherenkov light on the width of optical images of extensive air showers

M. Giller and **G. Wieczorek**

Division of Experimental Physics,
University of Lodz, Poland

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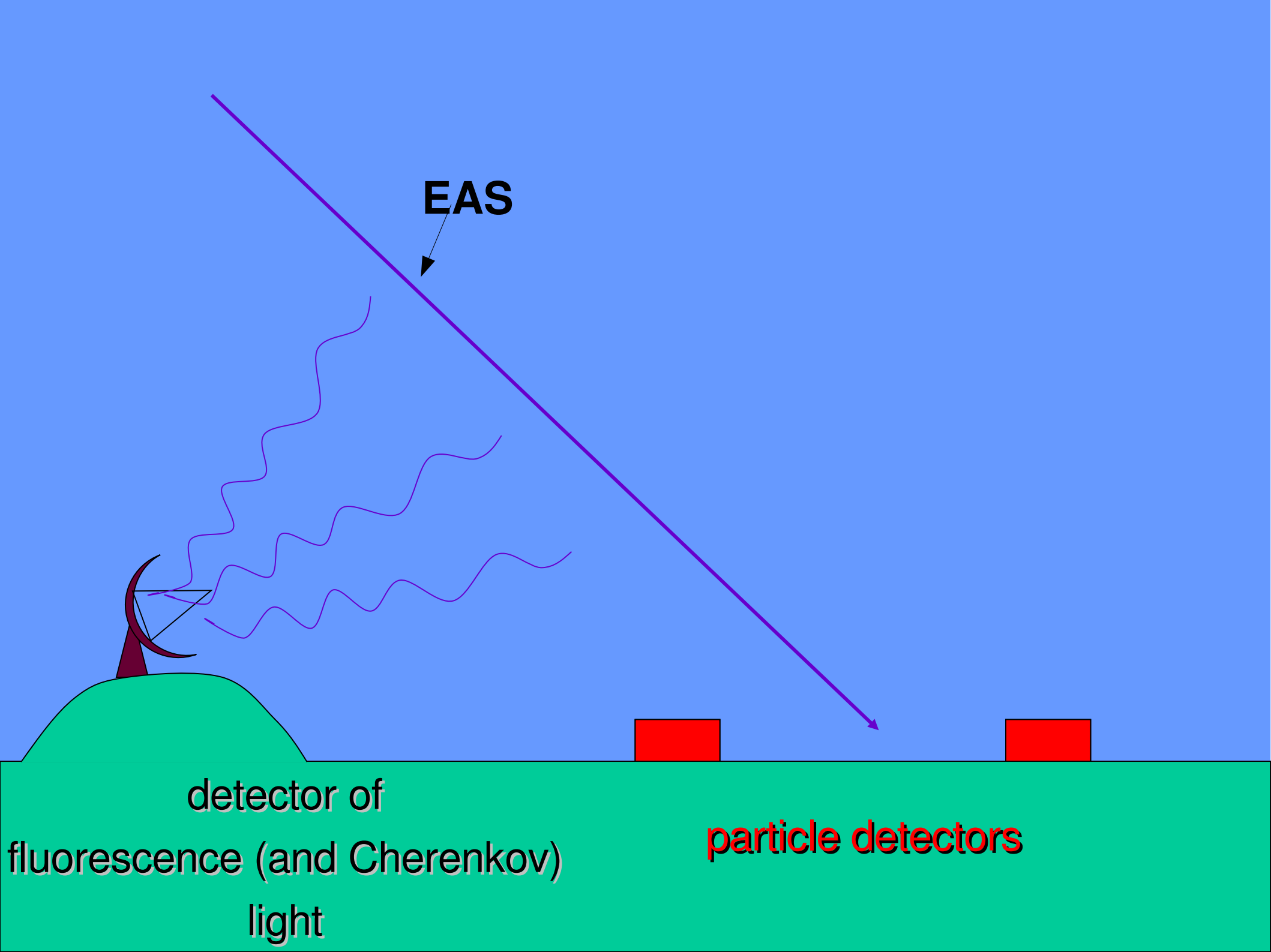
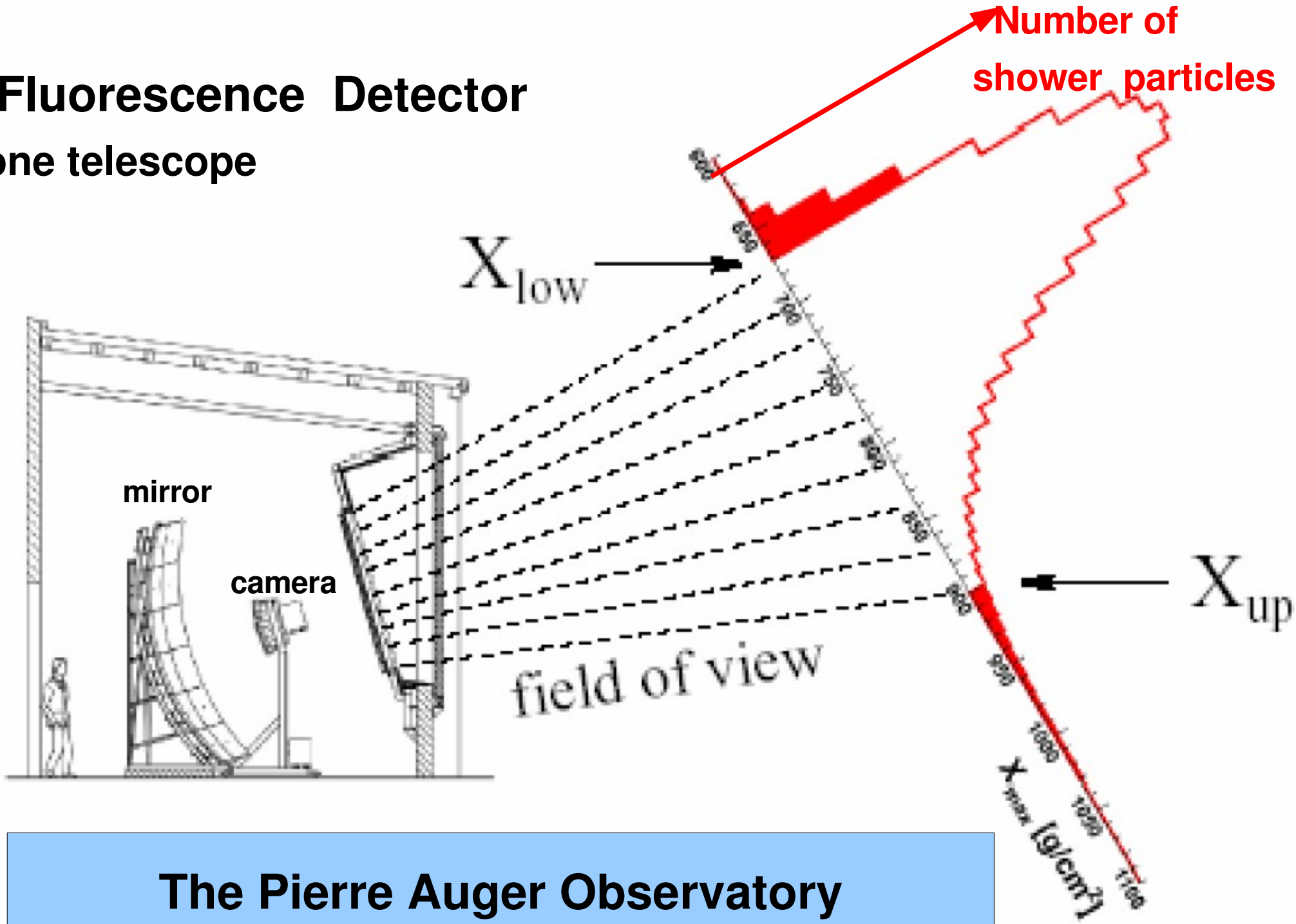

EAS
detector of
fluorescence (and Cherenkov)
light
particle detectors

Fluorescence Detector

one telescope



The Pierre Auger Observatory

Camera with 440 PMT

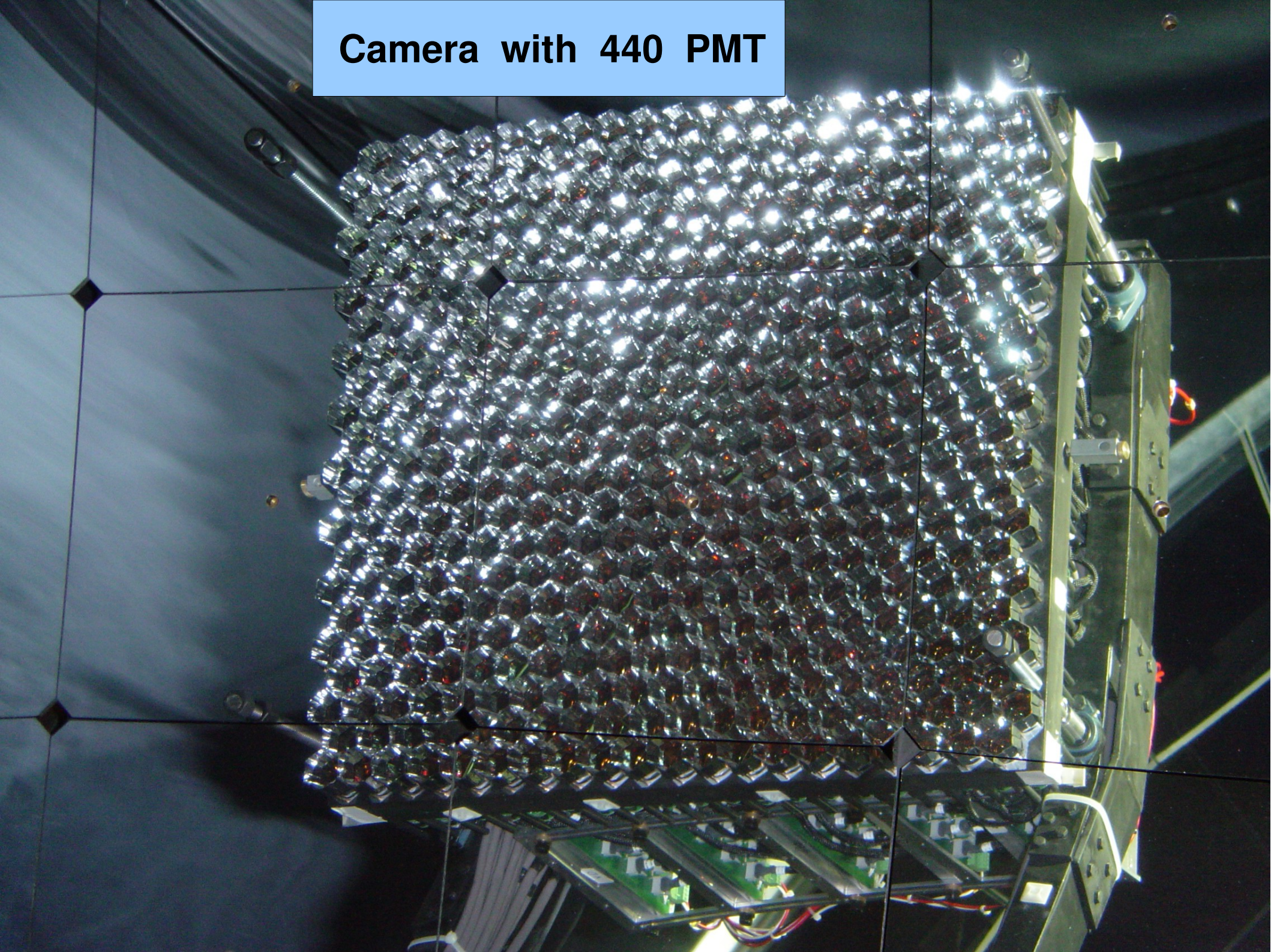
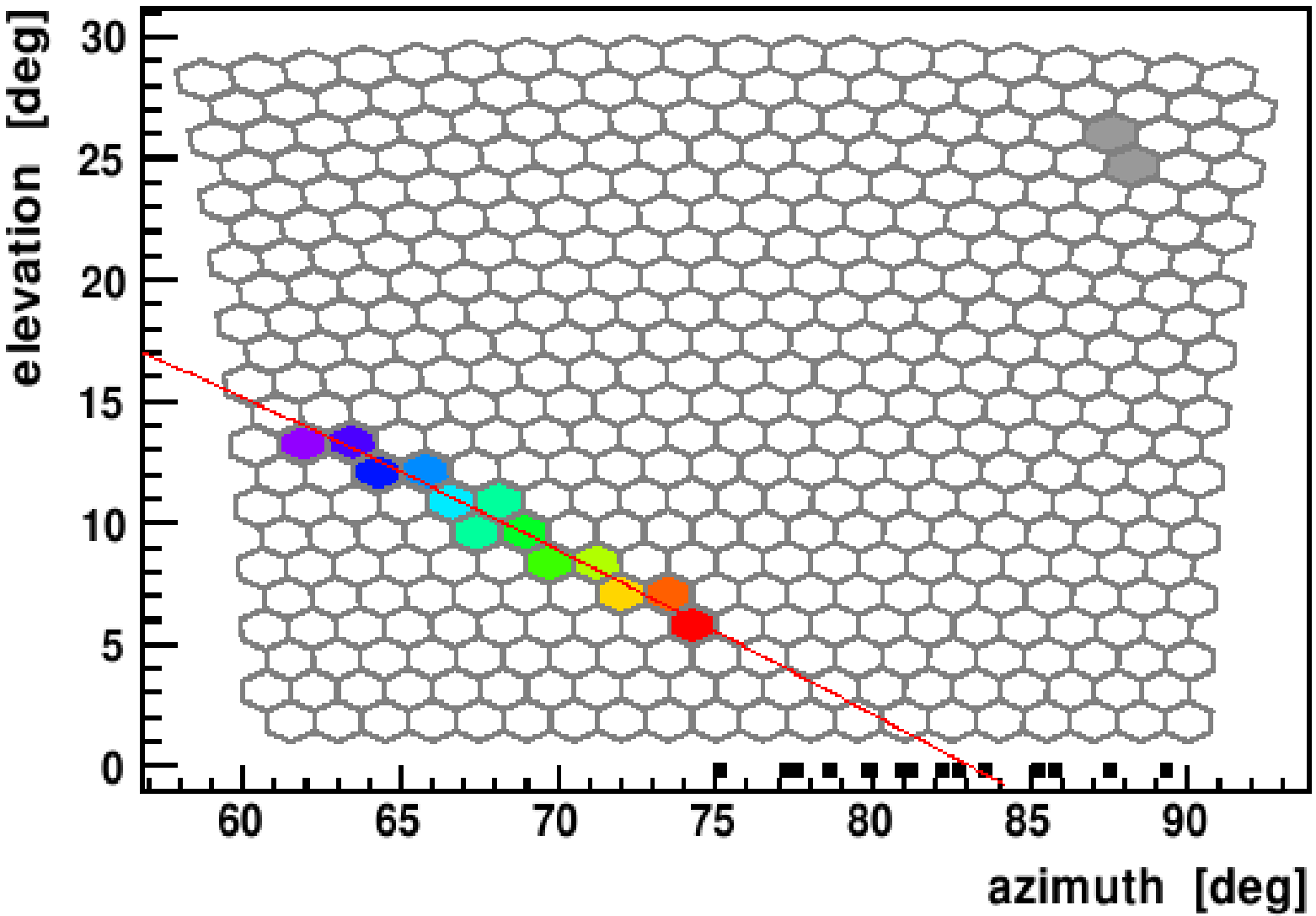


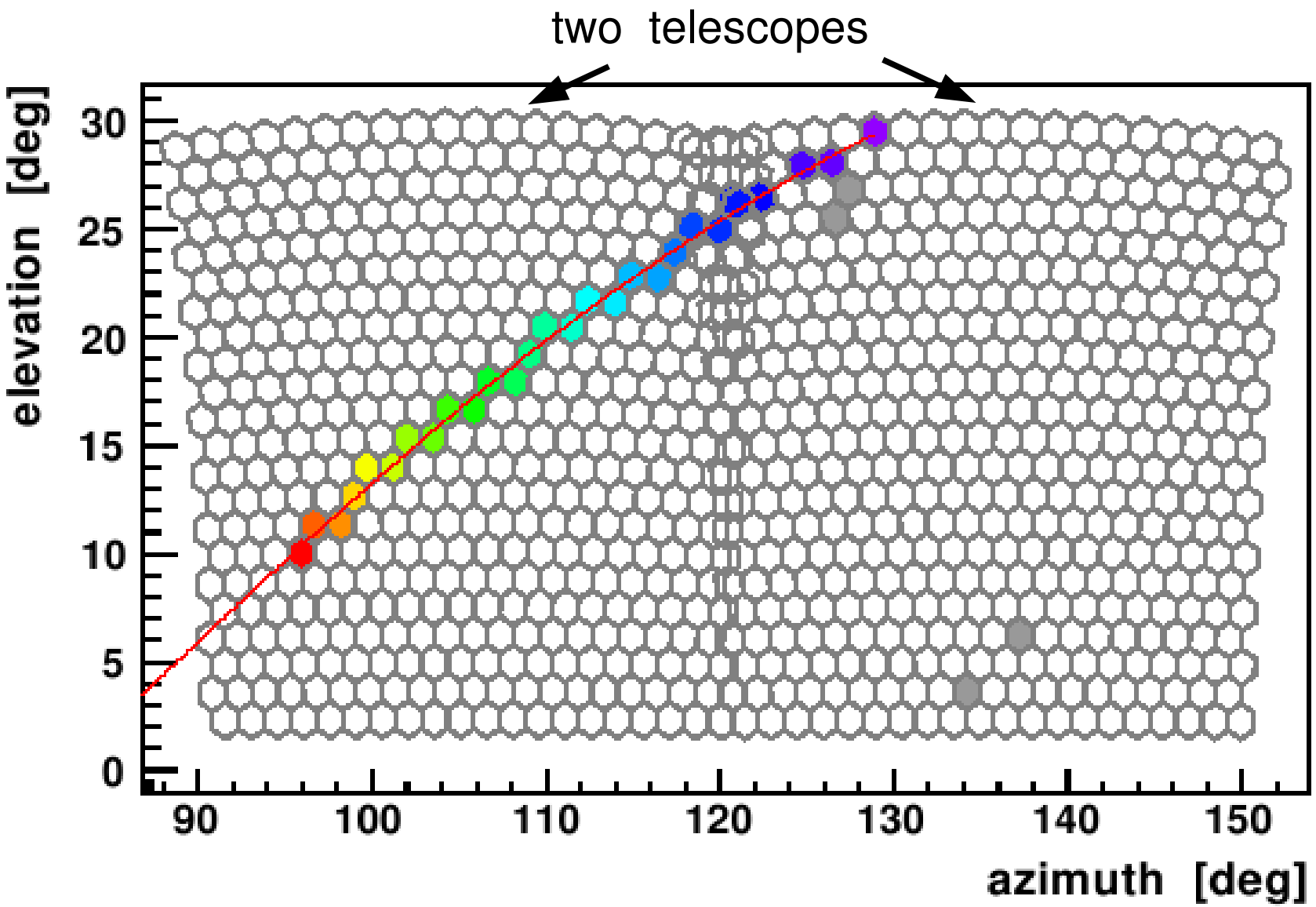
Image of a shower on the Fluorescence Detector camera - 440 PMT

(Auger experiment)

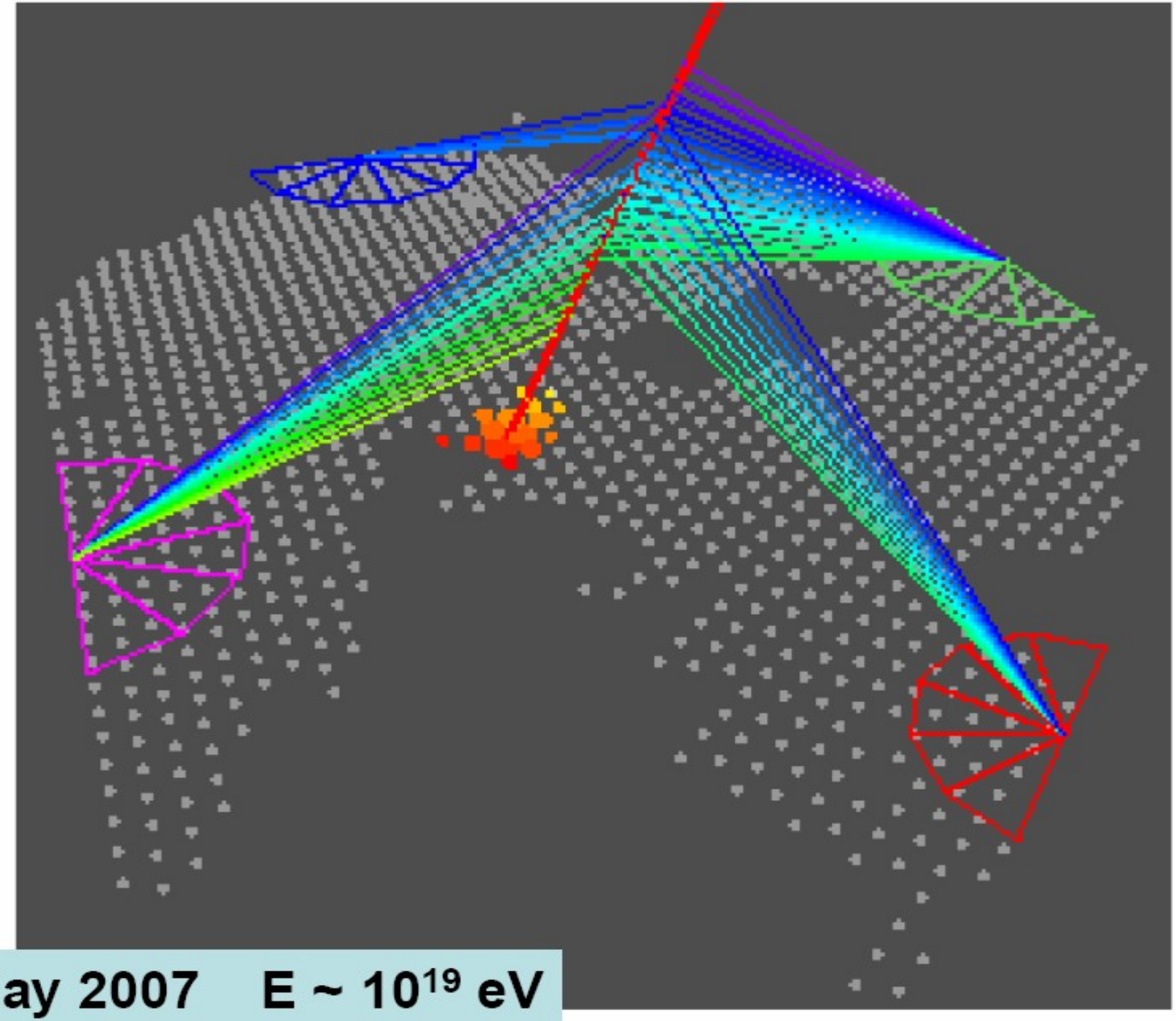


each pixel -
- 1.5 deg

The same shower seen by another Eye

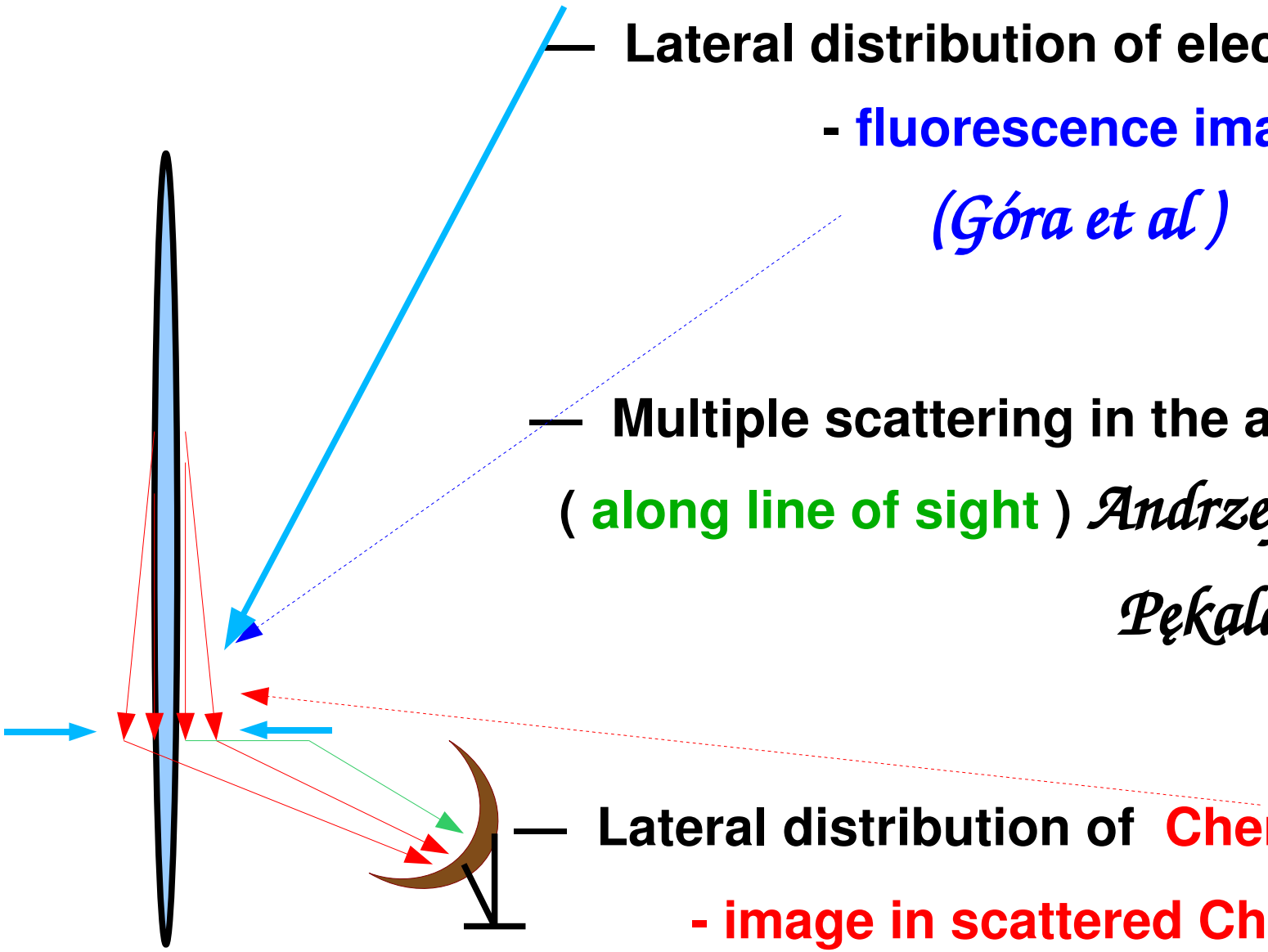


First Shower seen by all 4 Eyes



20 May 2007 E ~ 10^{19} eV

What determines the width of the optical image of a shower ?



— Lateral distribution of electrons – ?

- fluorescence image

(Góra et al)

— Multiple scattering in the atmosphere -?

(along line of sight) *Andrzej Smialkowski*

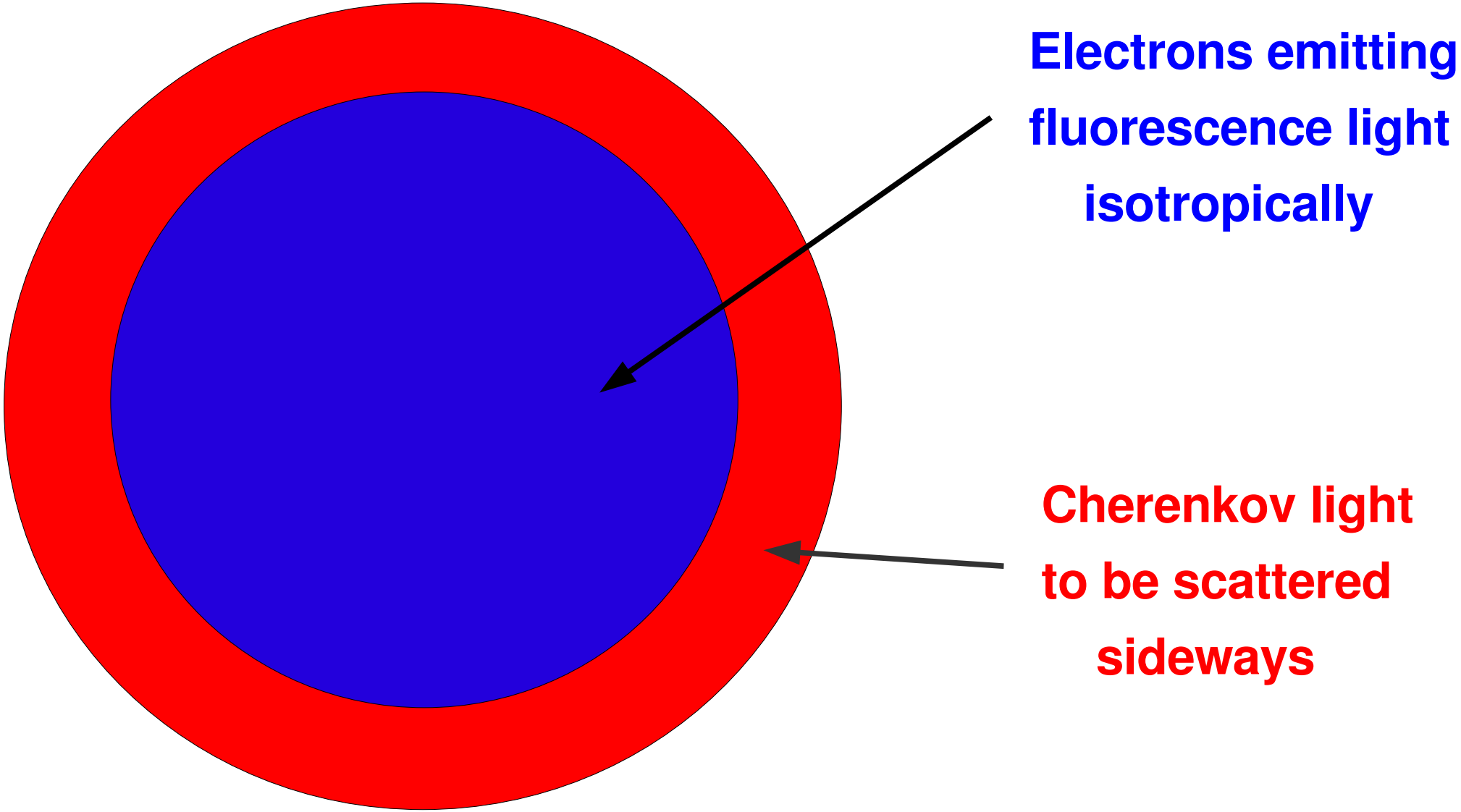
Pękala et al.

— Lateral distribution of Cherenkov light -

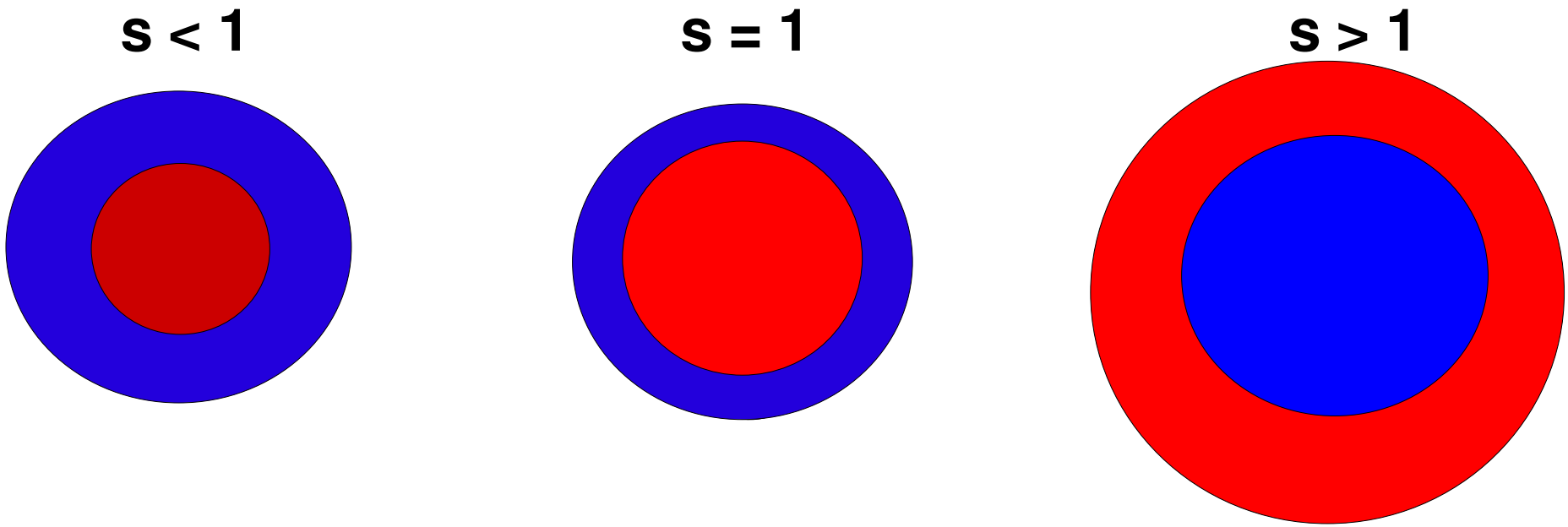
- image in scattered Ch light ?

our present calculations

Lateral cross-section of a shower



As shower age s increases



lateral distribution of Cherenkov light

becomes broader than

lateral distribution of electrons

↓

Cherenkov light scattered sideways

determines the width of shower optical image

below its maximum (s >1)

Width of shower optical image

is determined by

- **lateral distribution of electrons**

- **lateral distribution of Cherenkov light**

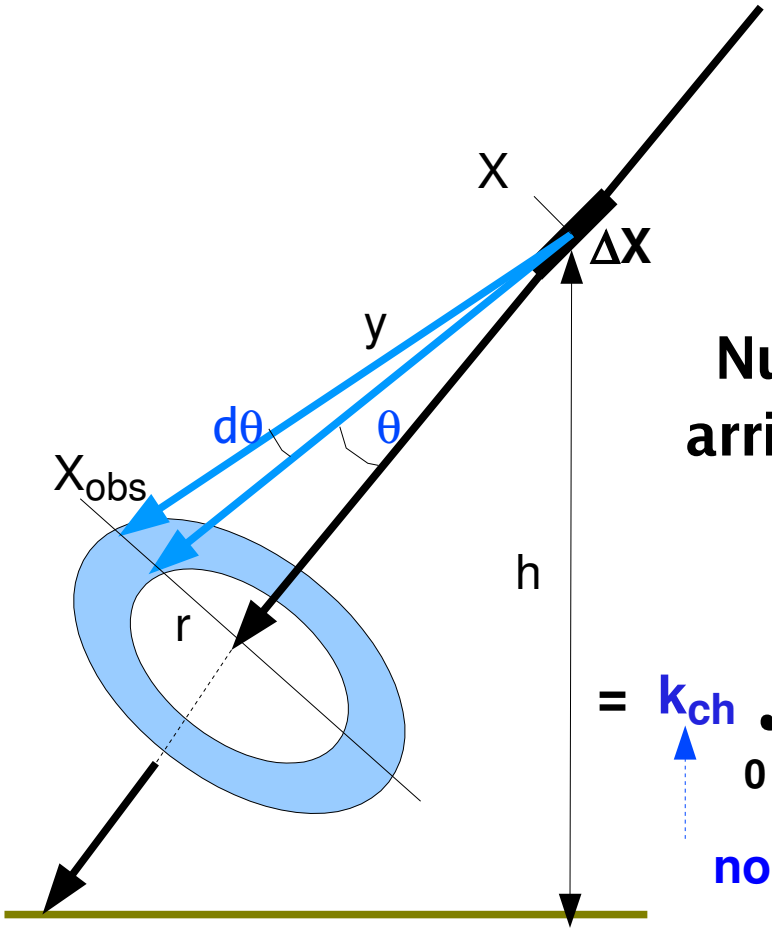
lateral distribution of electrons -

- shown to **depend on s only** (if in Moliere radius units) - **MG. *et al* ,**
- parametrized by **Góra *et al***

Calculation of the LDCh

(Lateral Distribution of Cherenkov light)

- from the known distributions (E, θ, r) of electrons



Angular distribution of Cherenkov electrons

$f_{ch}(\theta; s,h)$ – determined

by MG and G.Wieczorek (JPhys 2005)

Number of Cherenkov photons $\Delta Ch(r)$ arriving at distance ring $(r, r+\Delta r)$ at depth X_{obs} :

$$\Delta Ch(r) =$$

$$= k_{ch} \int_0^{X_{obs}} T[(X_{obs}-X)/\cos\theta]\, N_e(X)\, f_{ch}(\theta; s,h)\; 2\pi \sin\theta\, d\theta\, \Delta X$$

attenuation factor

no of Ch photons produced per unit path per 1 electron

$= 172 / g\ cm^{-2}$

What do we need to calculate the lateral distribution of Ch light at a given level ?

* **Angular distribution** of Ch light – to obtain this we need :

- angular distribution of Ch electrons $f(\theta; \boldsymbol{s}, \boldsymbol{h})$ (*Giller et al. JPhys. 2005*) , - smeared with Ch angle - ;

* **Lateral distribution** of Ch light - $G(r; \boldsymbol{s}, \boldsymbol{h})$

integration of $LD(r/r_E; \boldsymbol{E}, \boldsymbol{s})$ for **fixed** electron energy $\boldsymbol{E}$ (*Giller et al, ICRC Merida*) over electron energy distr. $g(\boldsymbol{E}; \boldsymbol{s})\, d\boldsymbol{E}$, above the Ch threshold $\boldsymbol{E}_{th}(\boldsymbol{h})$.

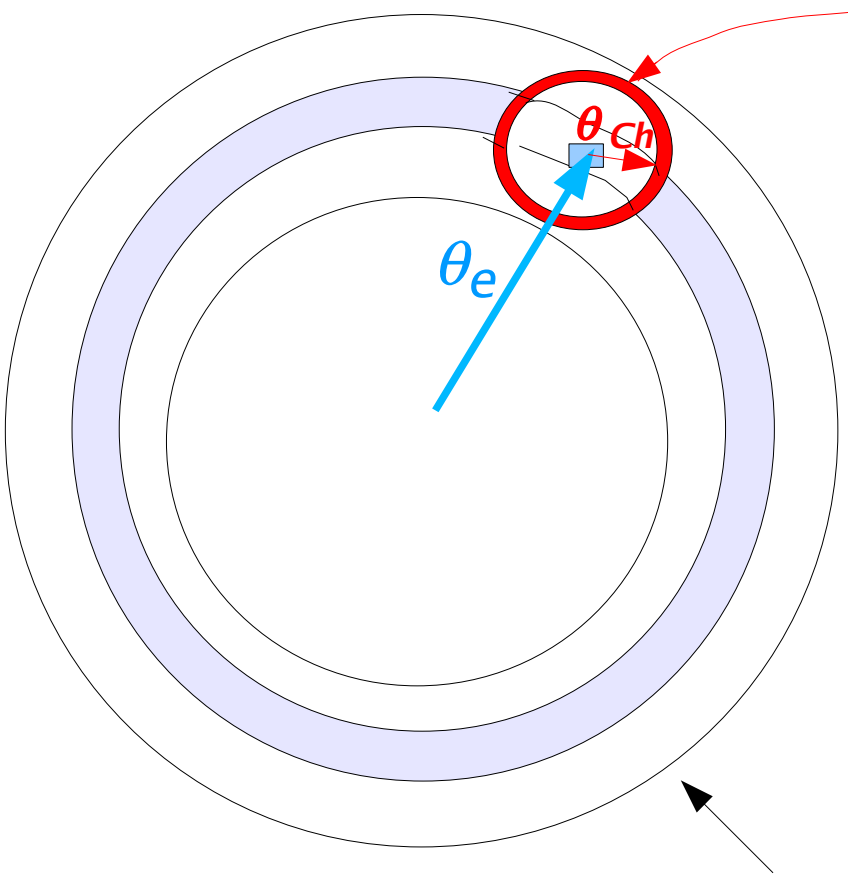
at all levels above the observed one.

* **Atmosphere transmission -**

– to integrate the **arriving** Ch light over the levels above, **this has to be done at reconstruction**

Taking into account the Cherenkov cone

(not very important but easy to do)



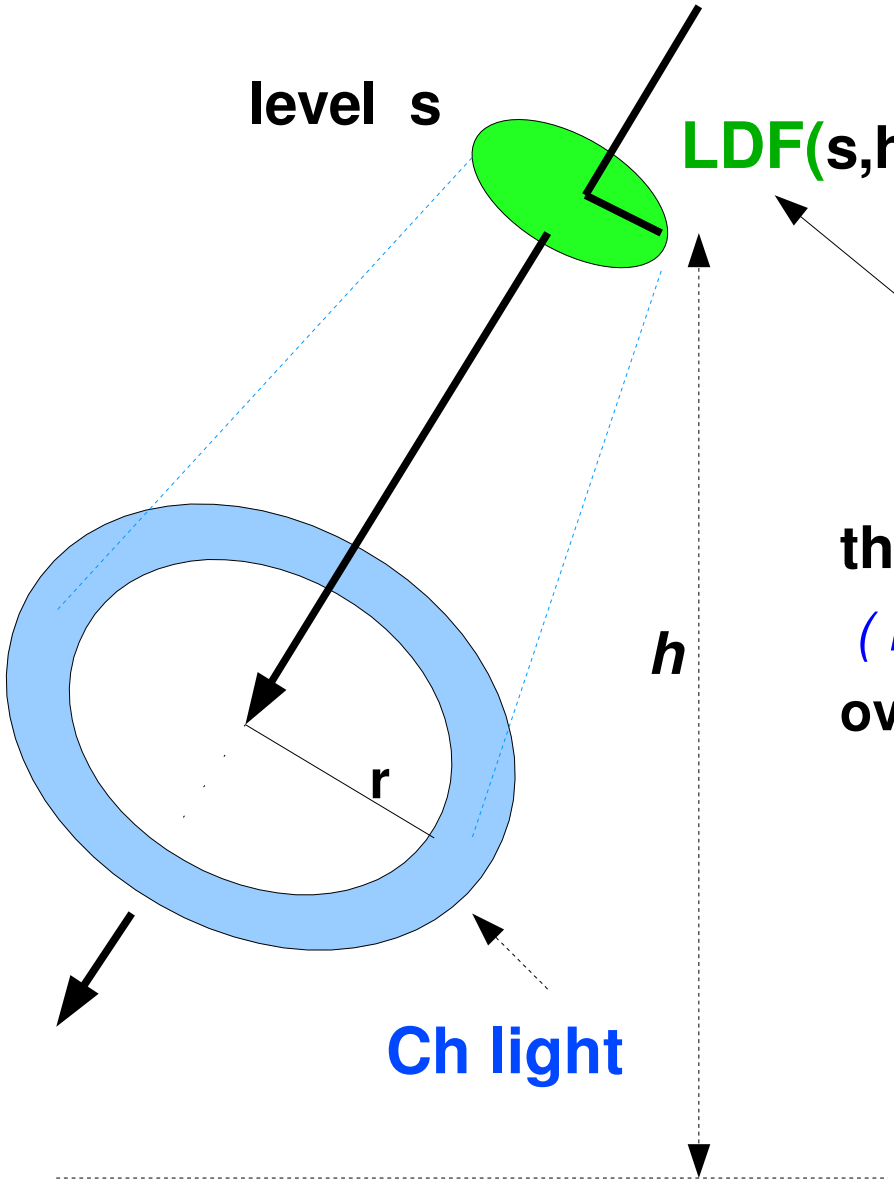
$\Delta N_e(\theta_e)$ - these electrons emit Ch light into the red cone θ_{Ch}.

Easy to calculate what part of Ch light falls into particular bands of θ_e.

The final angular distribution of the emitted Ch light depends on **s** and **h** only

Angular distribution of Cherenkov electrons

Taking into account the lateral distribution of electrons



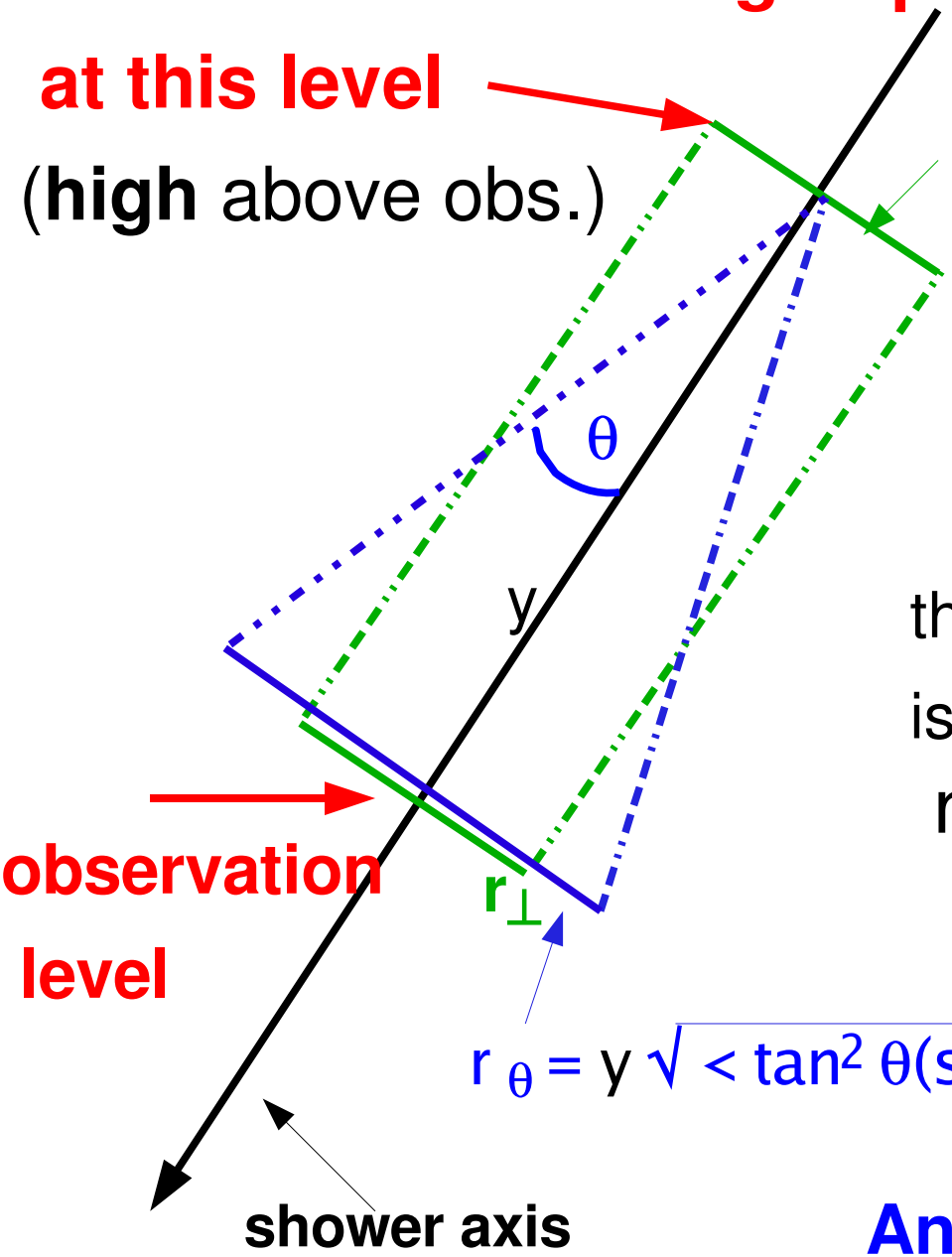
Obtained by integrating the LDF ' s for fixed electron energies

(MG, Kacperczyk & Tkaczyk, ICRC Merida)

over energy distribution above $E_{th}(h)$

Contribution of Ch light produced at this level

(**high** above obs.)



$r_\perp = \sqrt{< r^2(s,h)>}$ -- from lateral distrib. of Cherenkov electrons

if $r_\theta > r_\perp$ (mostly)

then LDCh from $f(\theta)$ only

is **broadened** by **replacing**

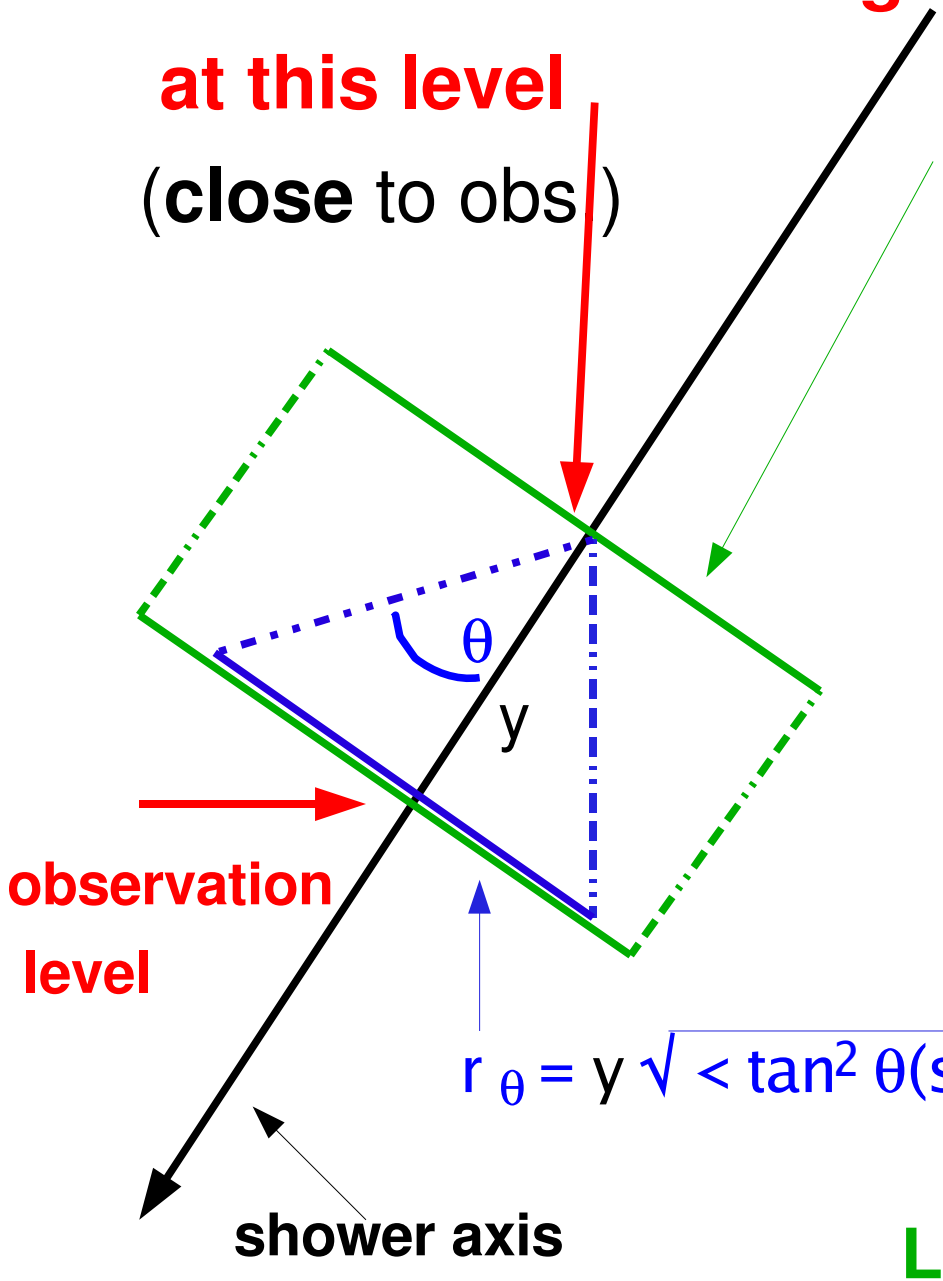
$$r \longrightarrow r\sqrt{1 + (r_\perp / r_\theta)^2}$$

$$r_\theta = y\sqrt{< \tan^2\theta(s,h)>}$$

Angular distribution of electrons dominates the lateral one

Contribution of Ch light produced at this level

(**close** to obs)



$r_\perp = \sqrt{\langle r^2(s,h)\rangle}$ -- r m s for Cherenkov electrons

if $r_\theta < r_\perp$

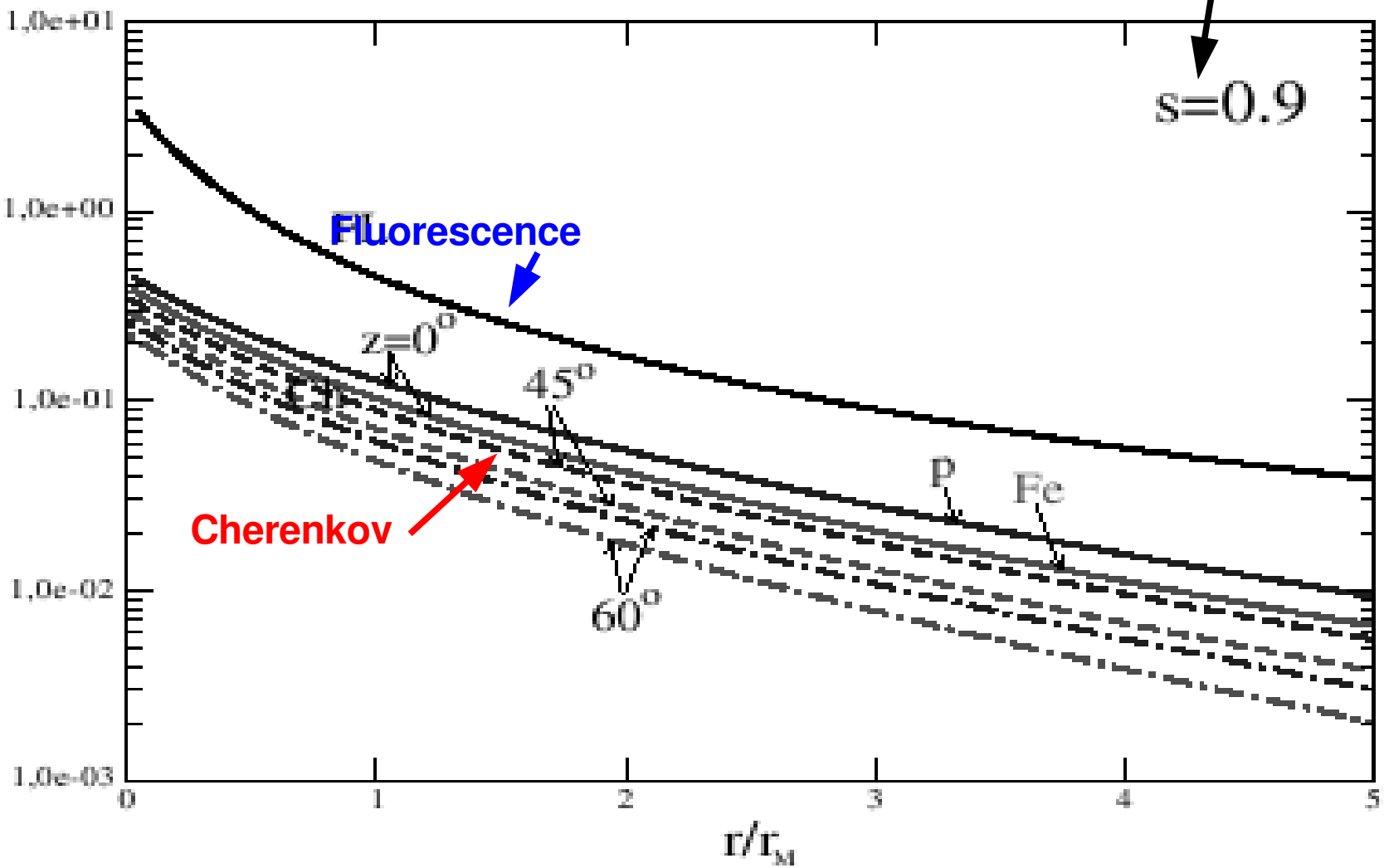
then LDCh from **f(r)** only is broadened by replacing

$$r \longrightarrow r\sqrt{1 + (r_\theta / r_\perp)^2}$$

$$r_\theta = y\sqrt{\langle \tan^2\theta(s,h)\rangle}$$

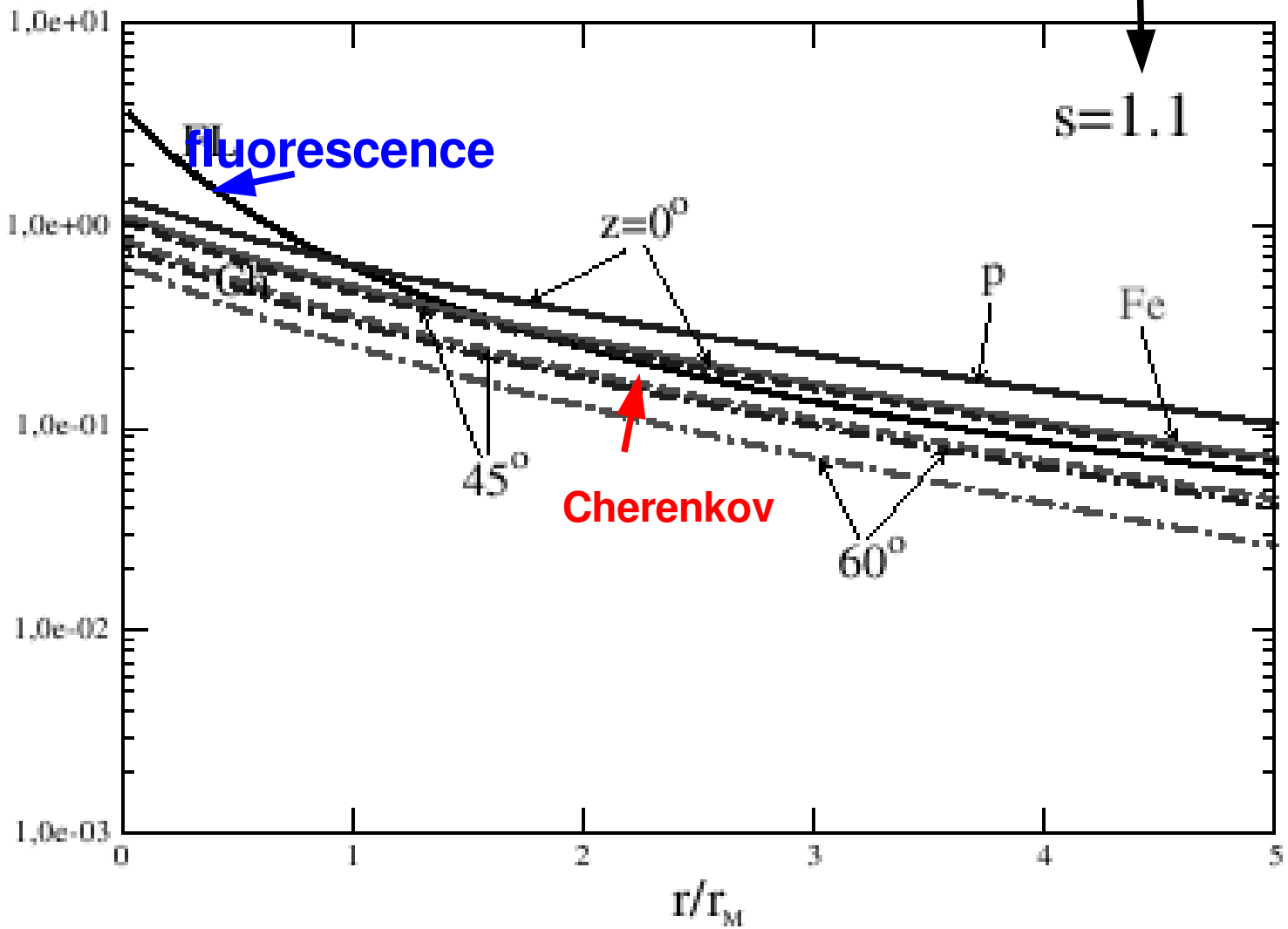
Lateral distribution of electrons dominates the angular one

Number of fluorescence and Cherenkov photons (per 1 electron) **scattered in all directions per 1 m of shower track, at radial distances > r/r_M for proton and iron showers**



distance in Moliere radius

Number of fluorescence and Cherenkov photons (per 1 electron) **scattered in all directions per 1 m of shower track, at radial distances > r/r_M for proton and iron showers**



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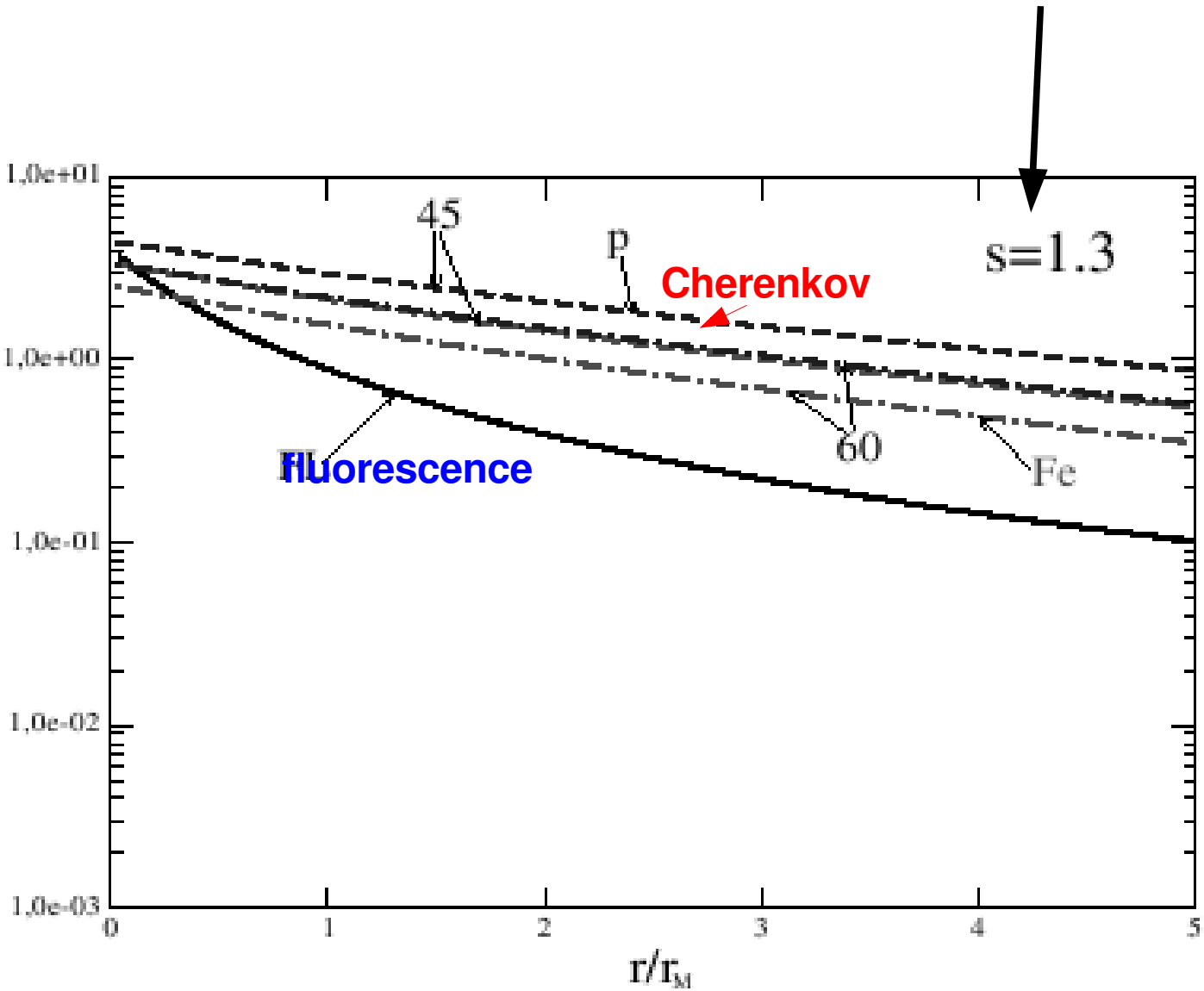

Conclusion

- Scattered Cherenkov light determines the width of the optical image of shower track below maximum .

- LDCh depends on age s and absolute height h of the level and , once N(X) is known (assumed), it can be easily calculated numerically (no MC) based on universal distributions of electron E, θ, r/r_M ;

  for all electrons - functions of s only,

  for Cherenkov electrons - functions of s and h .

- Relative contributions of Fluorescence and Ch light depend on s and h only (Fl – depends on s only)

- Reconstruction of shower energy deposit

  dE/dX ~ Fl only - in progres