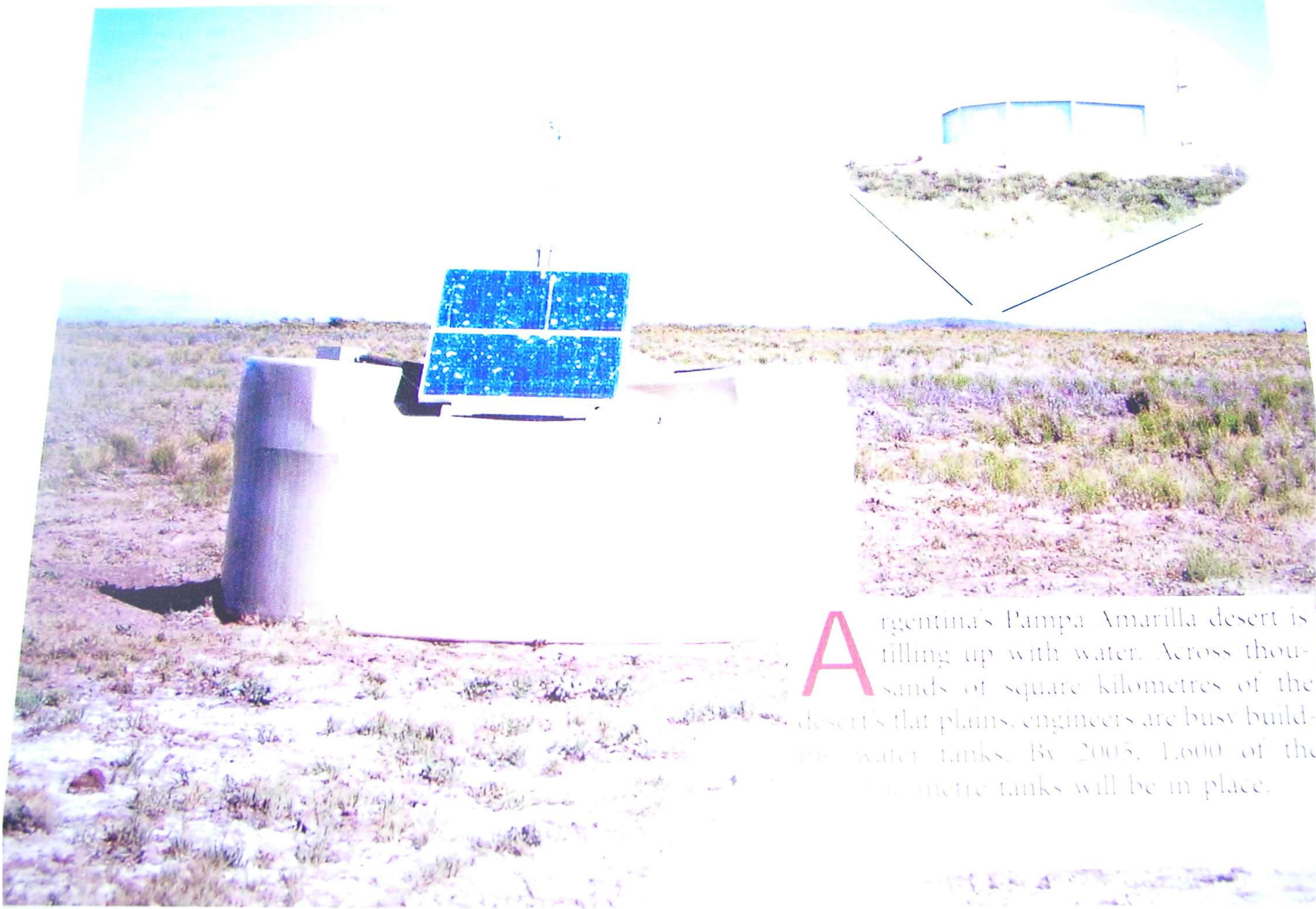
The Pierre Auger Observatory

* **South Site:**
  - Argentina, Mendoza Province, – Malargüe
  - total surface: 3000 km^2 covered by 1600 surface detectors, SD, with 1.5 km spacing
  - 4 fluorescence detectors, FD, × 6 telescopes each, with field of view 30° × 30° each
  - to be completed by 2005/06

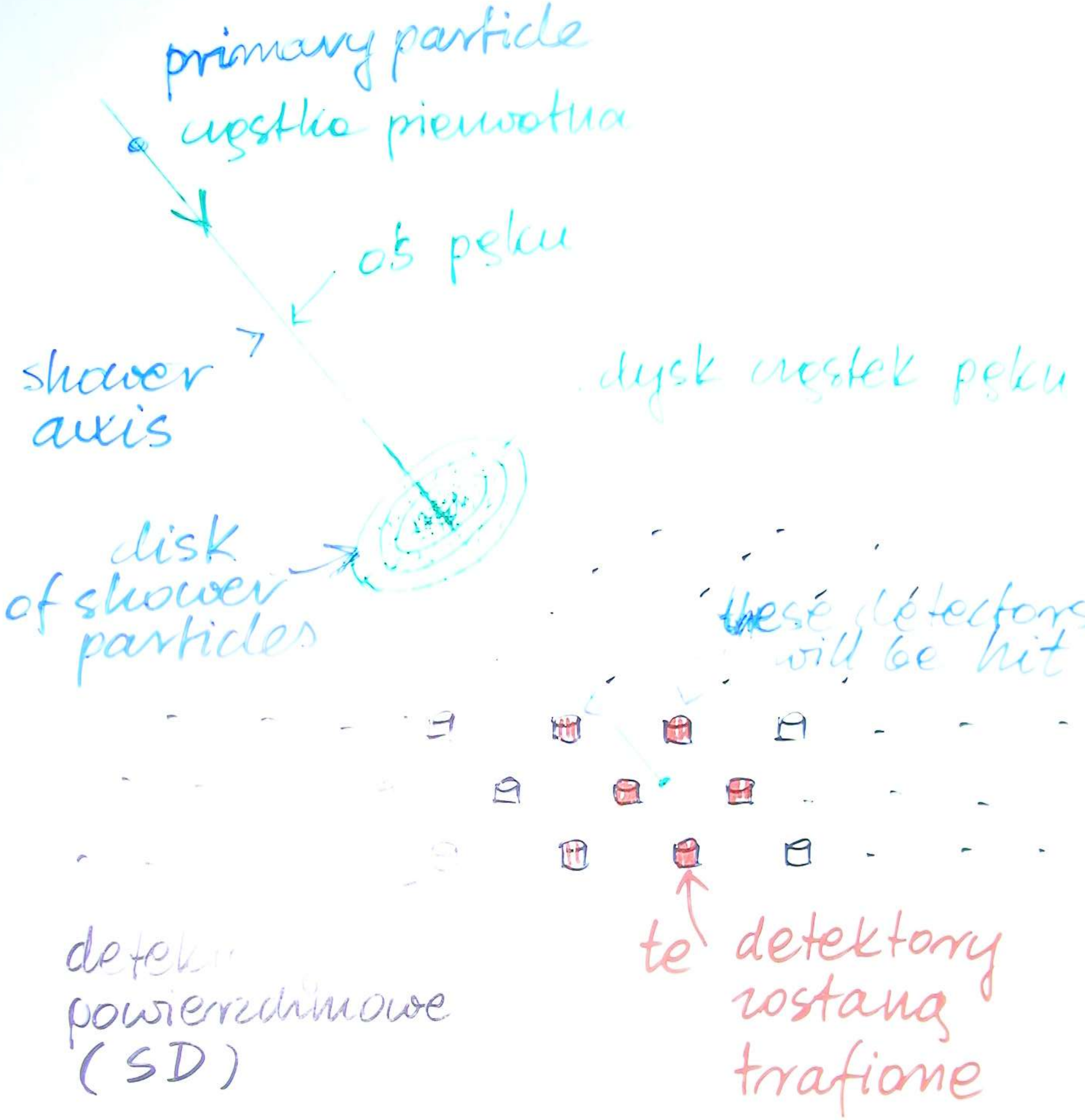
    cost [illegible] US$ [illegible])

* **North Site** [illegible] USA

  [illegible]ecided where)



Argentina's Pampa Amarilla desert is filling up with water. Across thousands of square kilometres of the desert's flat plains, engineers are busy building water tanks. By 2005, 1,600 of the [illegible] metre tanks will be in place.



Δt_{ij} → axis direction
kierunek osi

$S(1000) \rightarrow E_0$

sygnał w detektorze w odległości at $r = 1000$ m

signal in detector as would be

Sygnał w detektorze powierzchniowym Auger

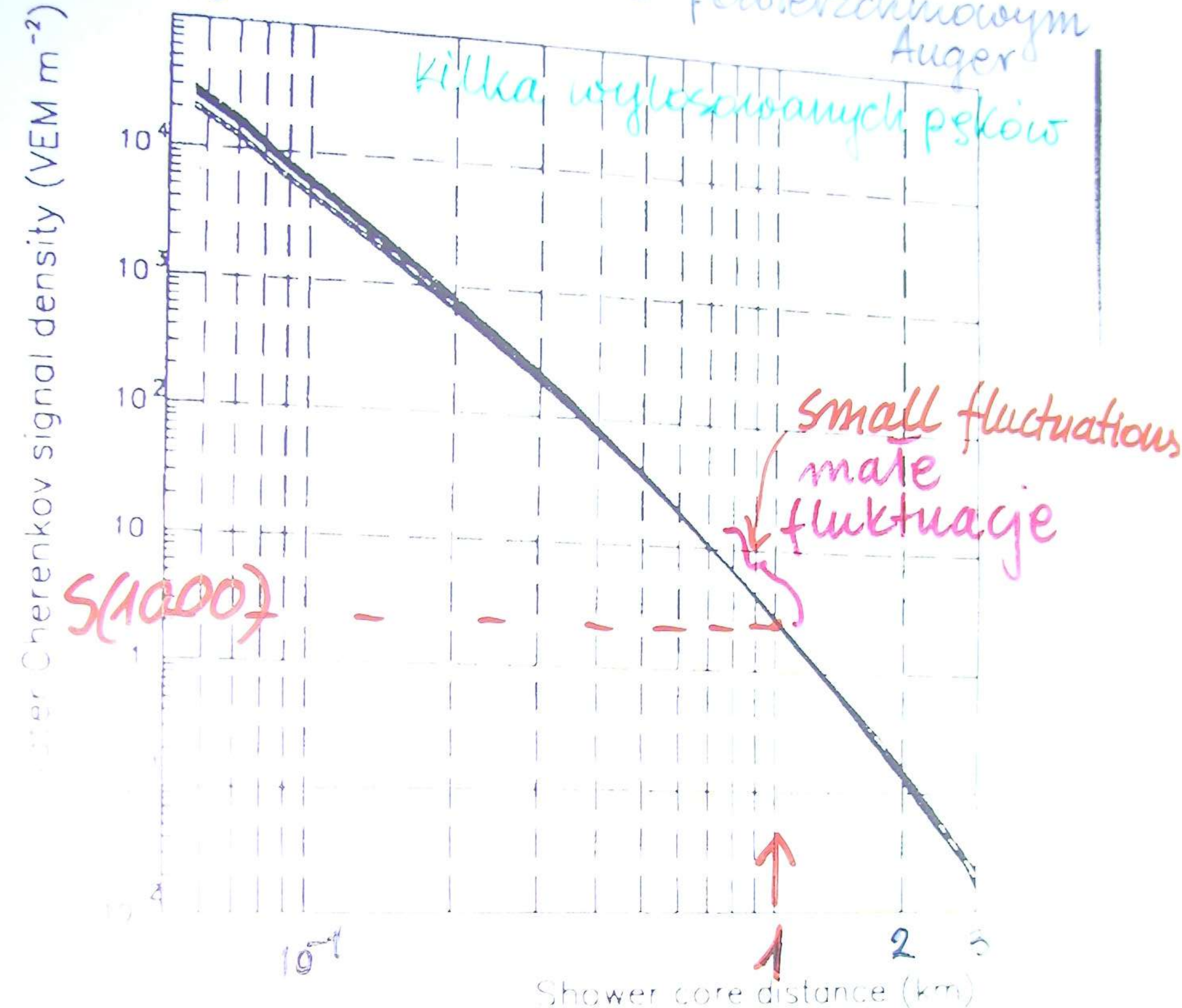


FIG. 20. Several examples of lateral distributions of water Čerenkov detector signals [$\rho(r)$] in units of energy loss of vertically penetrating muons (250 MeV), which shows that the fluctuation of $\rho(r)$ between 600 and 1000 m from the shower core is less than 15%. From Pierre Auger Project Design Report, 1997.

Symulacje M-Carlo

VEM → Vertical Equivalent Muon

Sygnał w detektorze powierzchniowym Auger

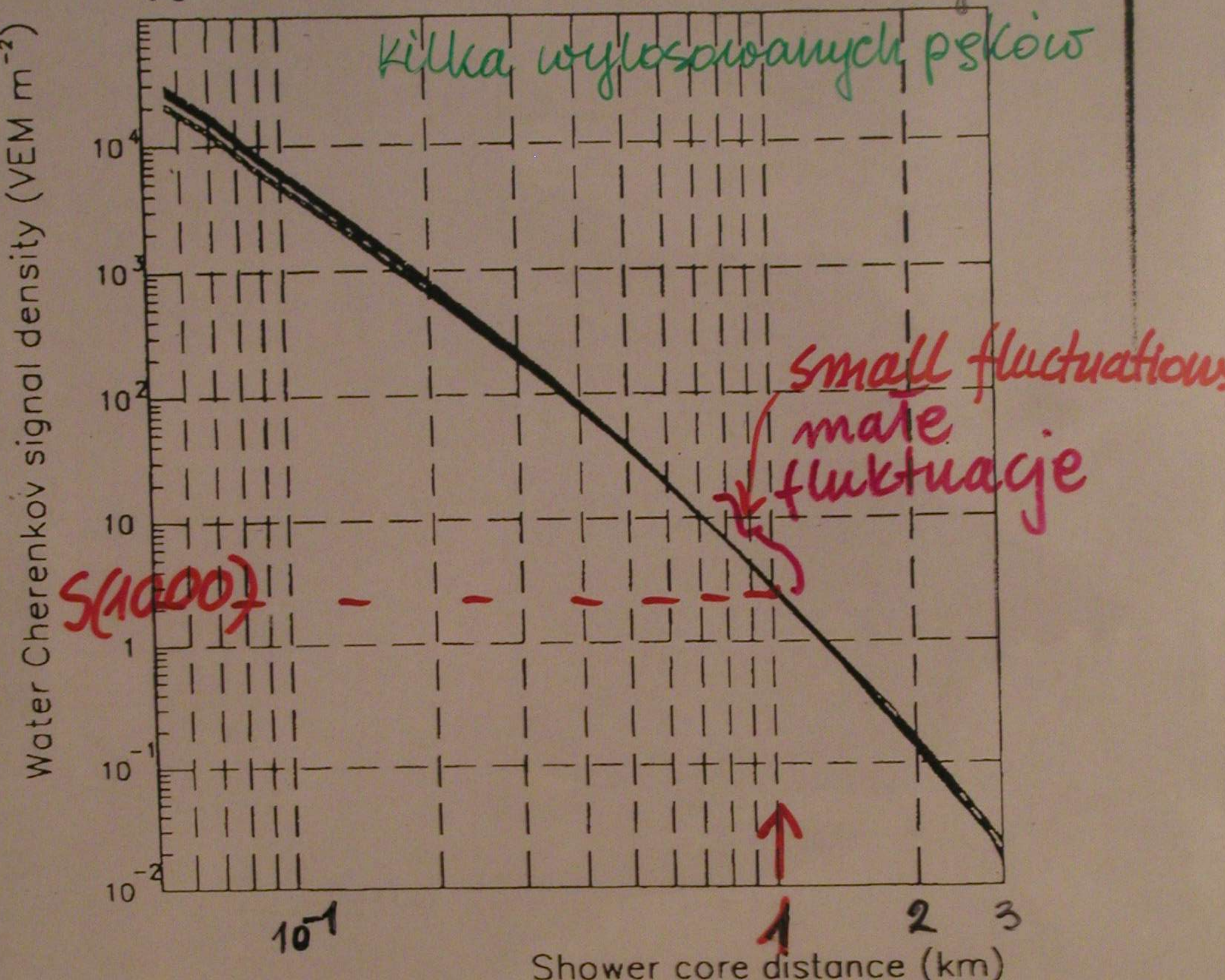


FIG. 20. Several examples of lateral distributions of water Čerenkov detector signals [$\rho(r)$] in units of energy loss of vertically penetrating muons (250 MeV), which shows that the fluctuation of $\rho(r)$ between 600 and 1000 m from the shower core is less than 15%. From Pierre Auger Project Design Report, 1997.

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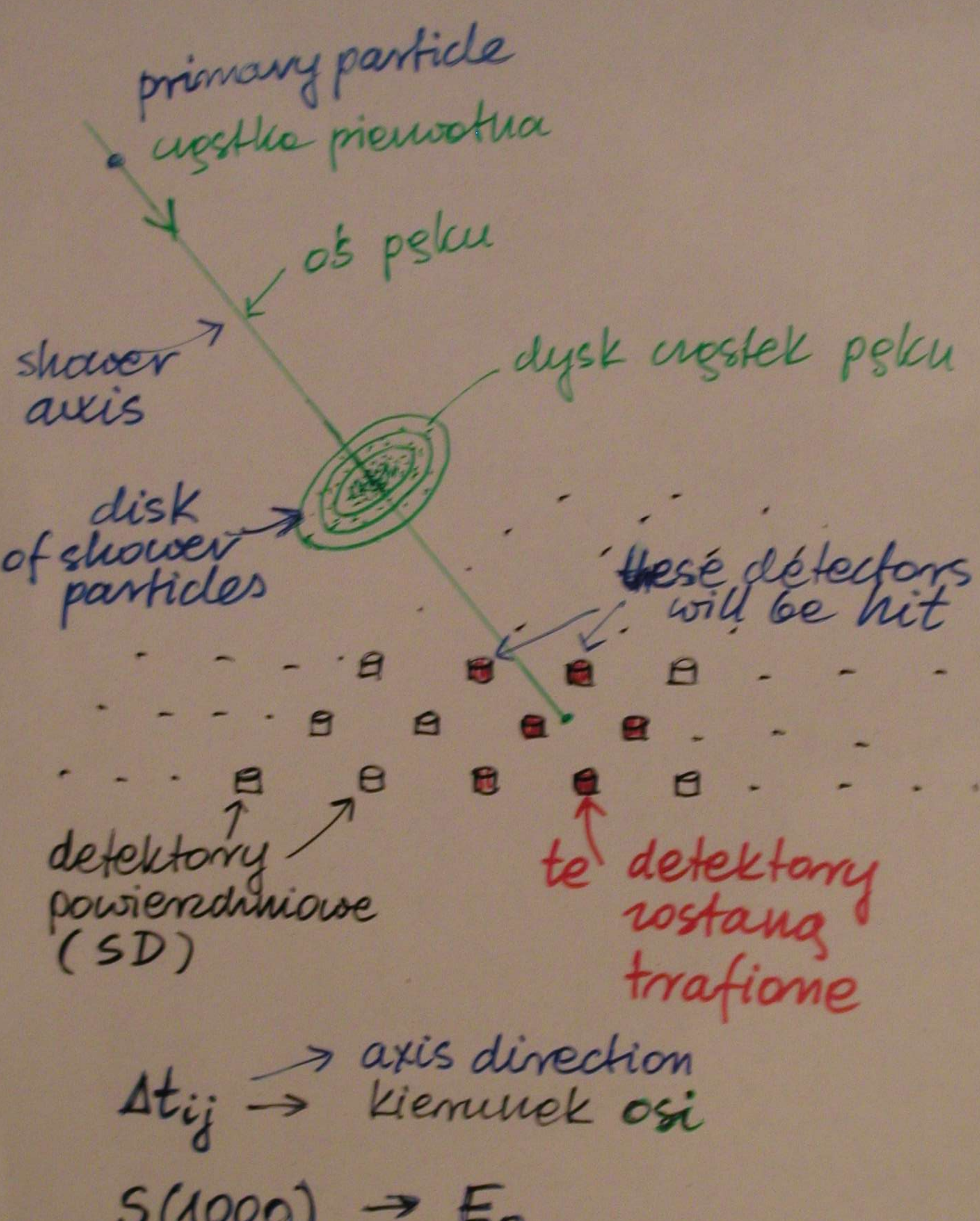
VEM → Vertical Equivalent Muon



Δt_{ij} → axis direction

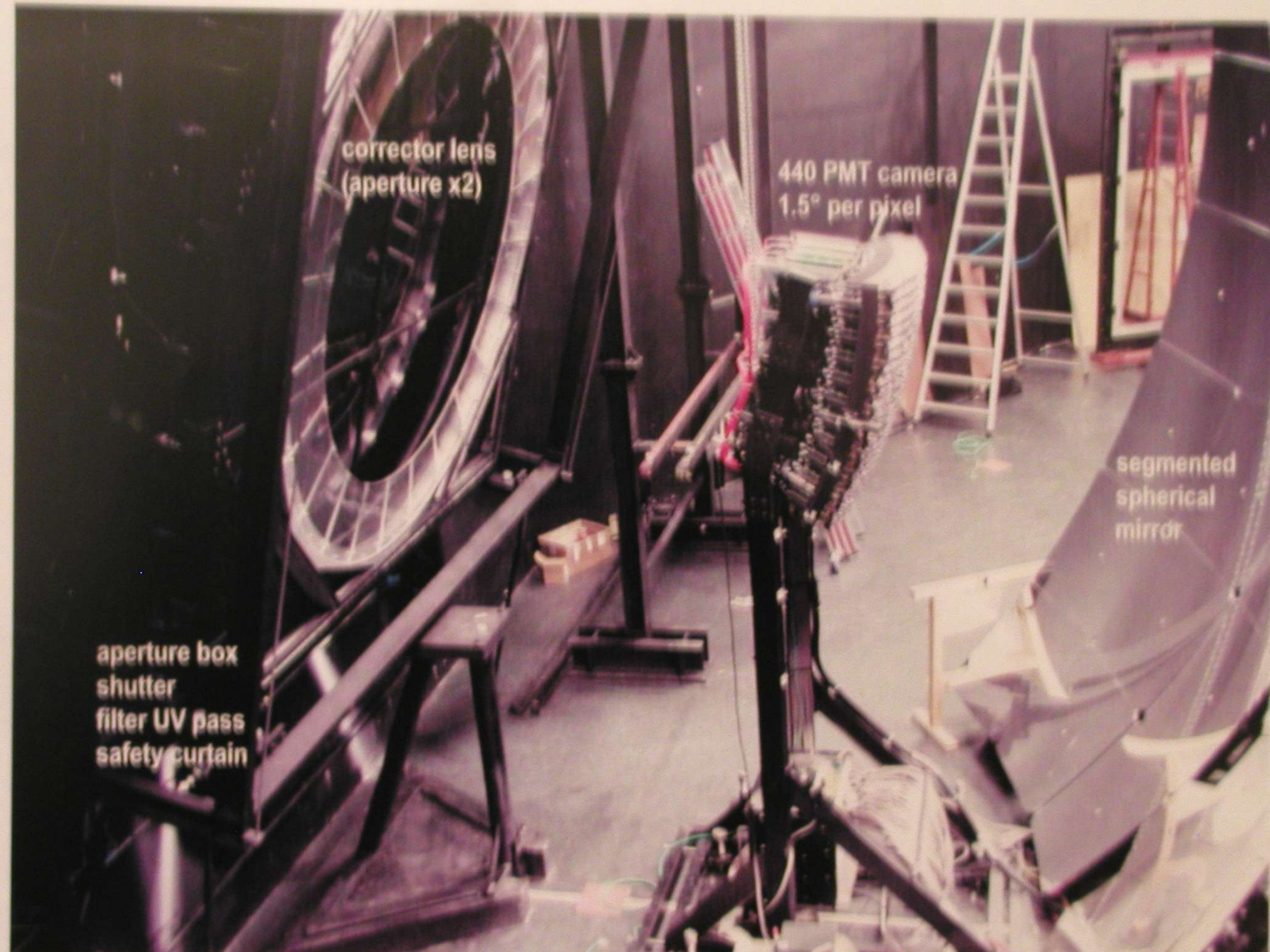
→ kierunek osi

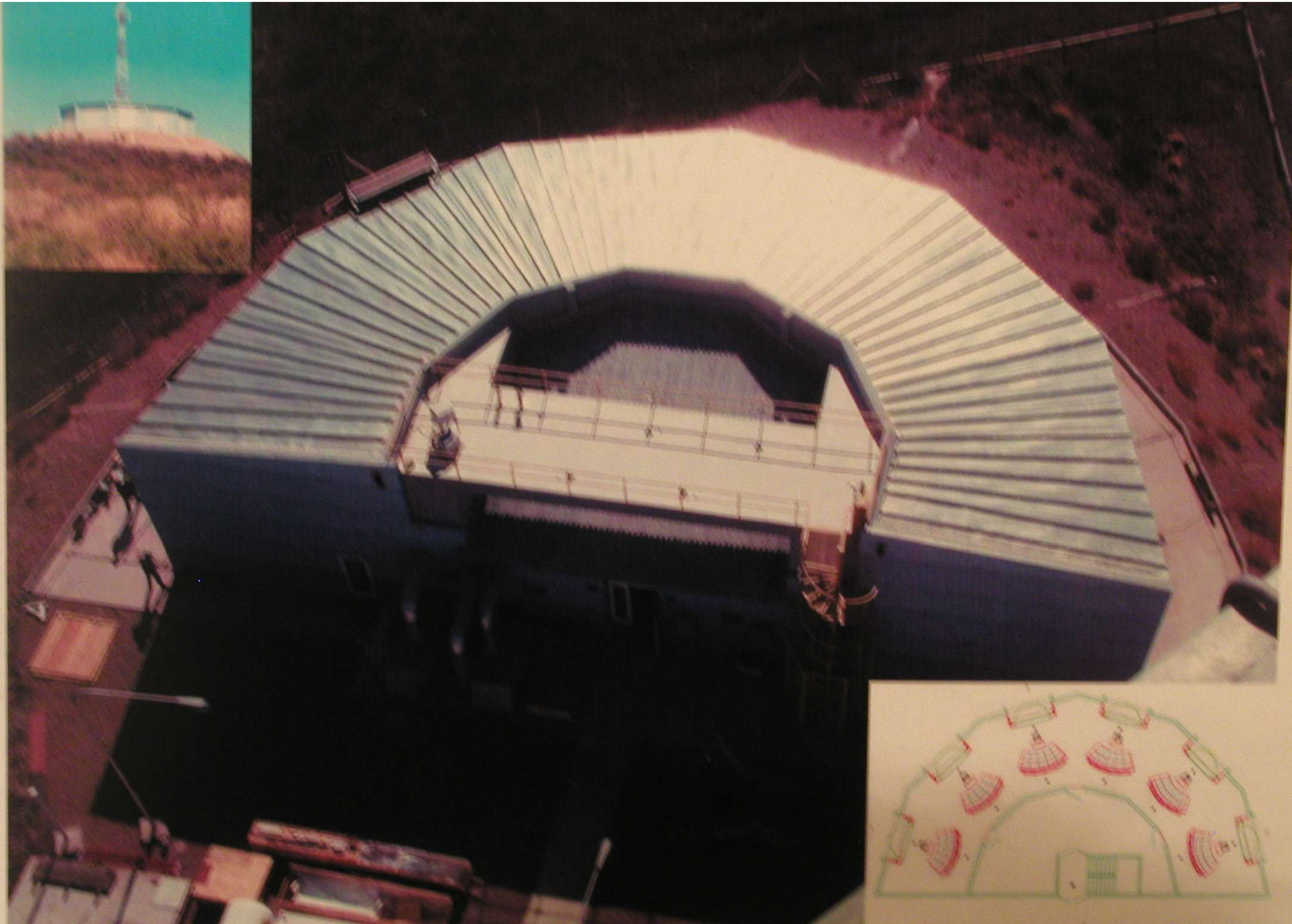
$S(1000) \rightarrow E_0$

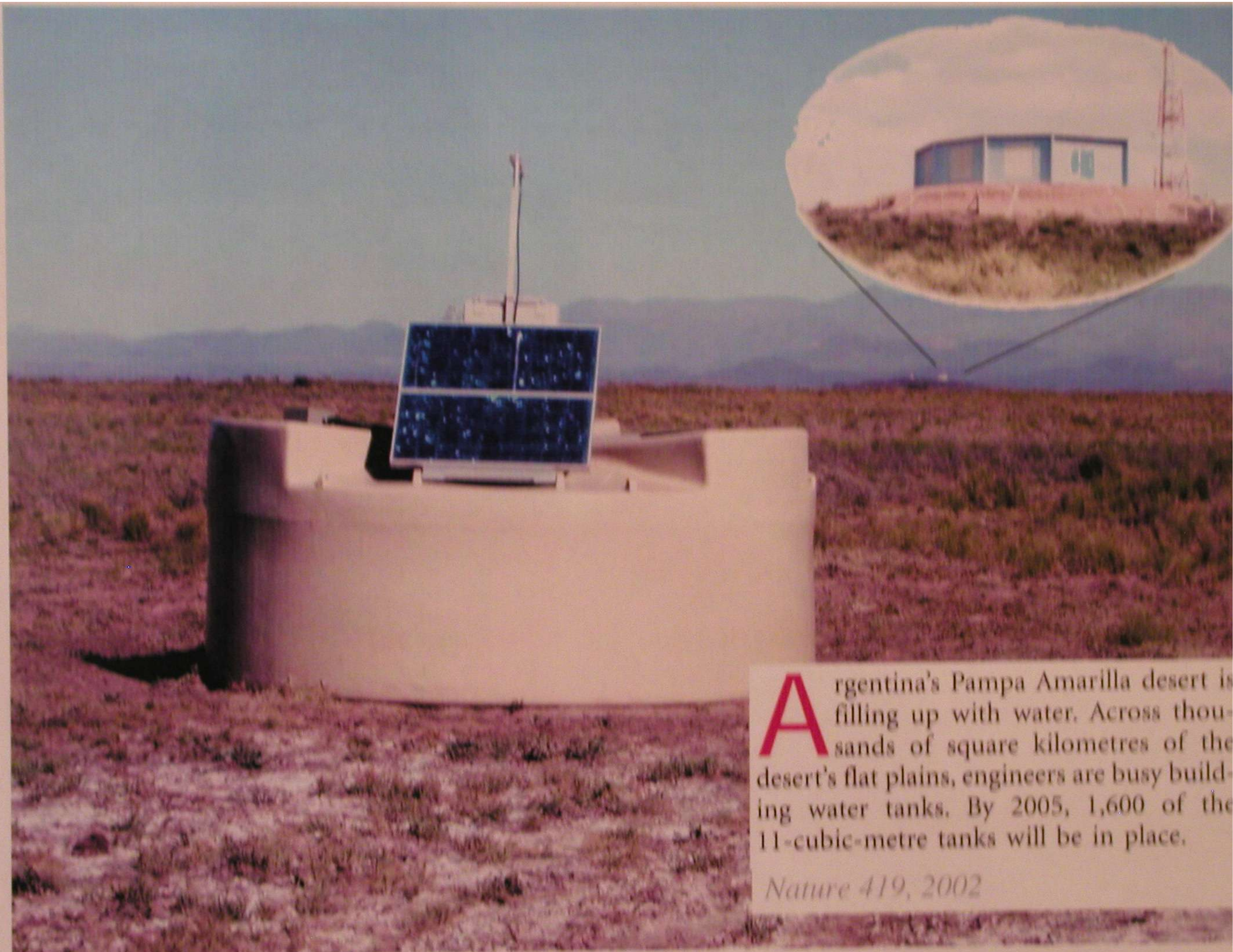
sygnał w detektorze w odległości

signal in detector at $r = 1000\,m$

(as would be)


corrector lens
(aperture x2)
440 PMT camera
1.5° per pixel
segmented
spherical
mirror
aperture box
shutter
filter UV pass
safety curtain

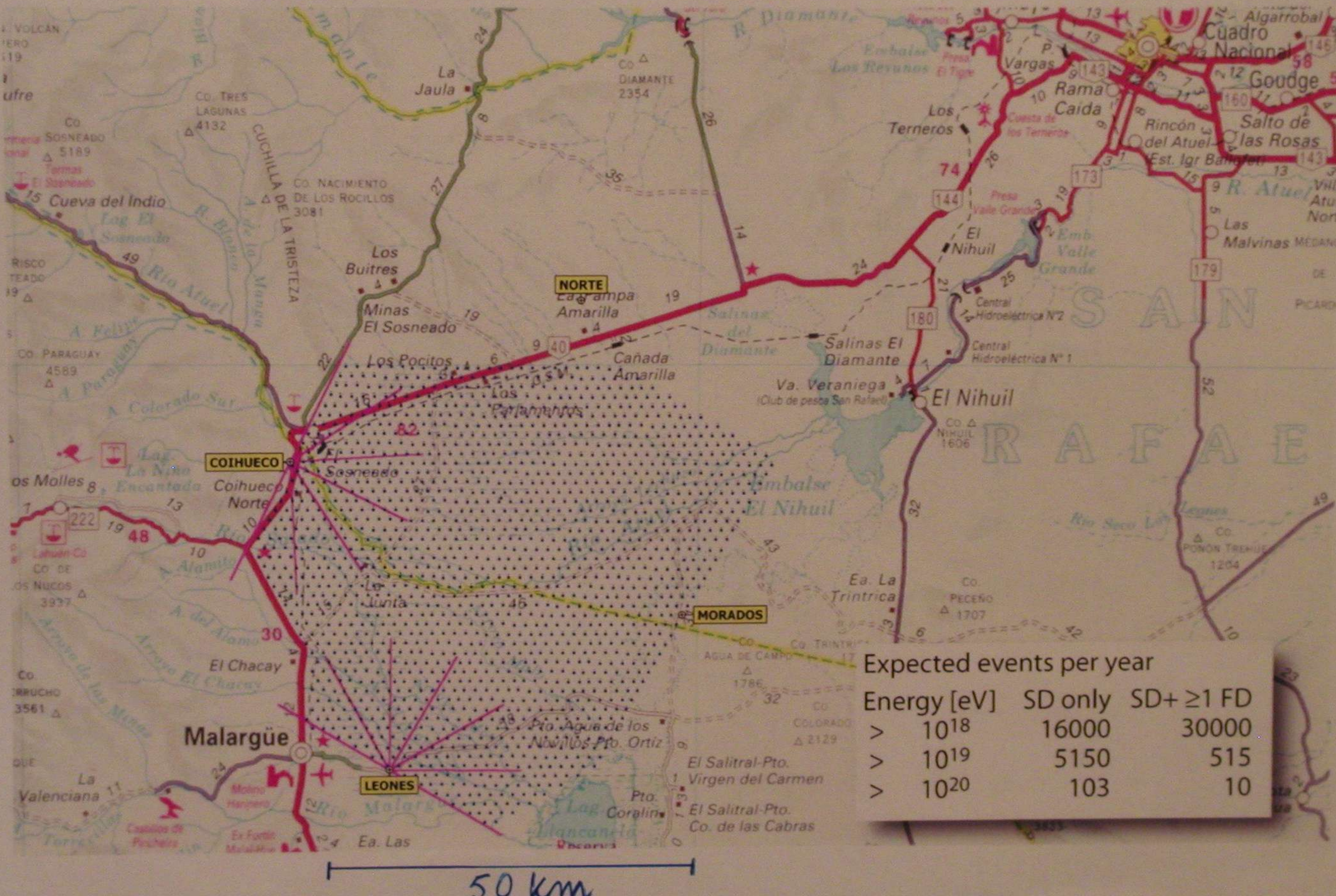




Argentina's Pampa Amarilla desert is filling up with water. Across thousands of square kilometres of the desert's flat plains, engineers are busy building water tanks. By 2005, 1,600 of the 11-cubic-metre tanks will be in place.

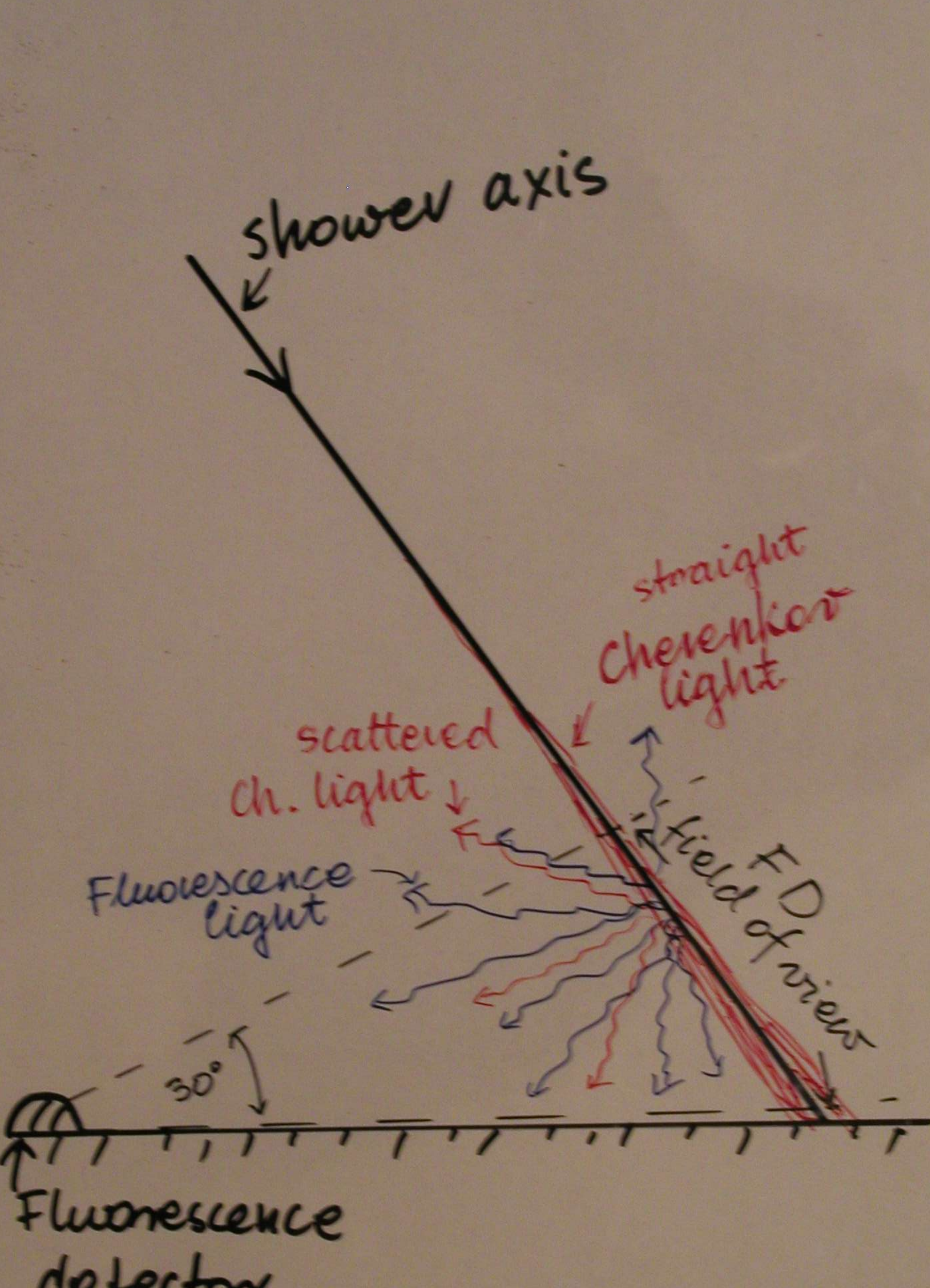
Nature 419, 2002

1600 water Cherenkov detectors with 1.5 km spacing on 3000 km^2
4 stations with 24 fluorescence telescopes



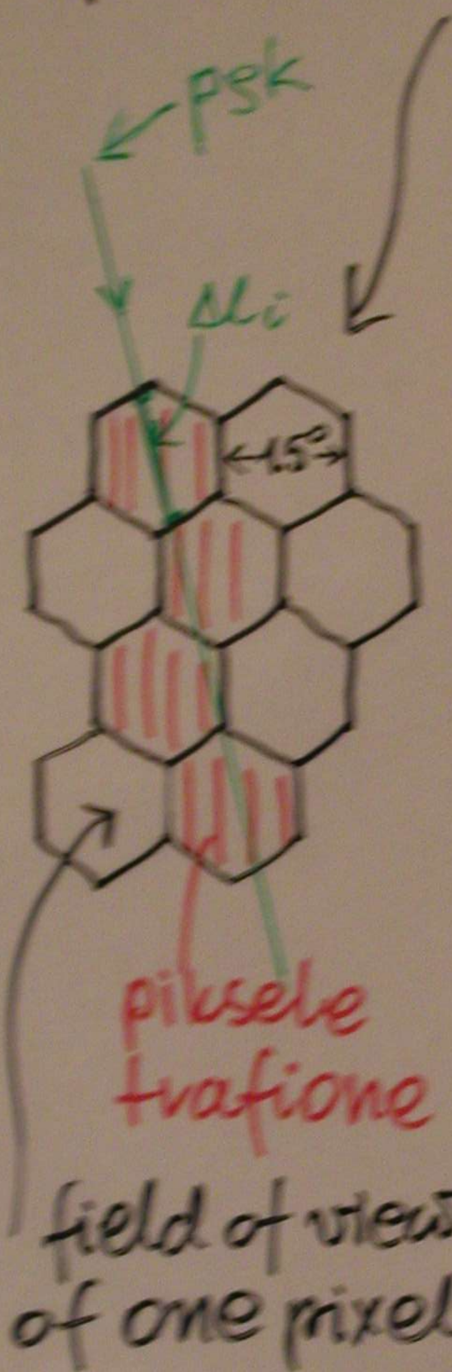
Expected events per year

Energy [eV]	SD only	SD+ ≥1 FD
> 10^{18}	16000	30000
> 10^{19}	5150	515
> 10^{20}	103	10



shower axis
straight
Cherenkov
light
scattered
Ch. light
Fluorescence
light
FD
field of view
30°
Fluorescence
detector

A part of Field of View of FD camera



Sygnał z piksela S_i

$S_i \rightarrow \Delta n_f^{(i)}$ (liczba fotonów fluorescenc.)

$$\Delta n_f^{(i)} = N_e(x_i) \cdot \Delta l_i \cdot k \frac{A_{zw}}{4\pi R_i^2}$$

$k \simeq 4.5$ fot/m

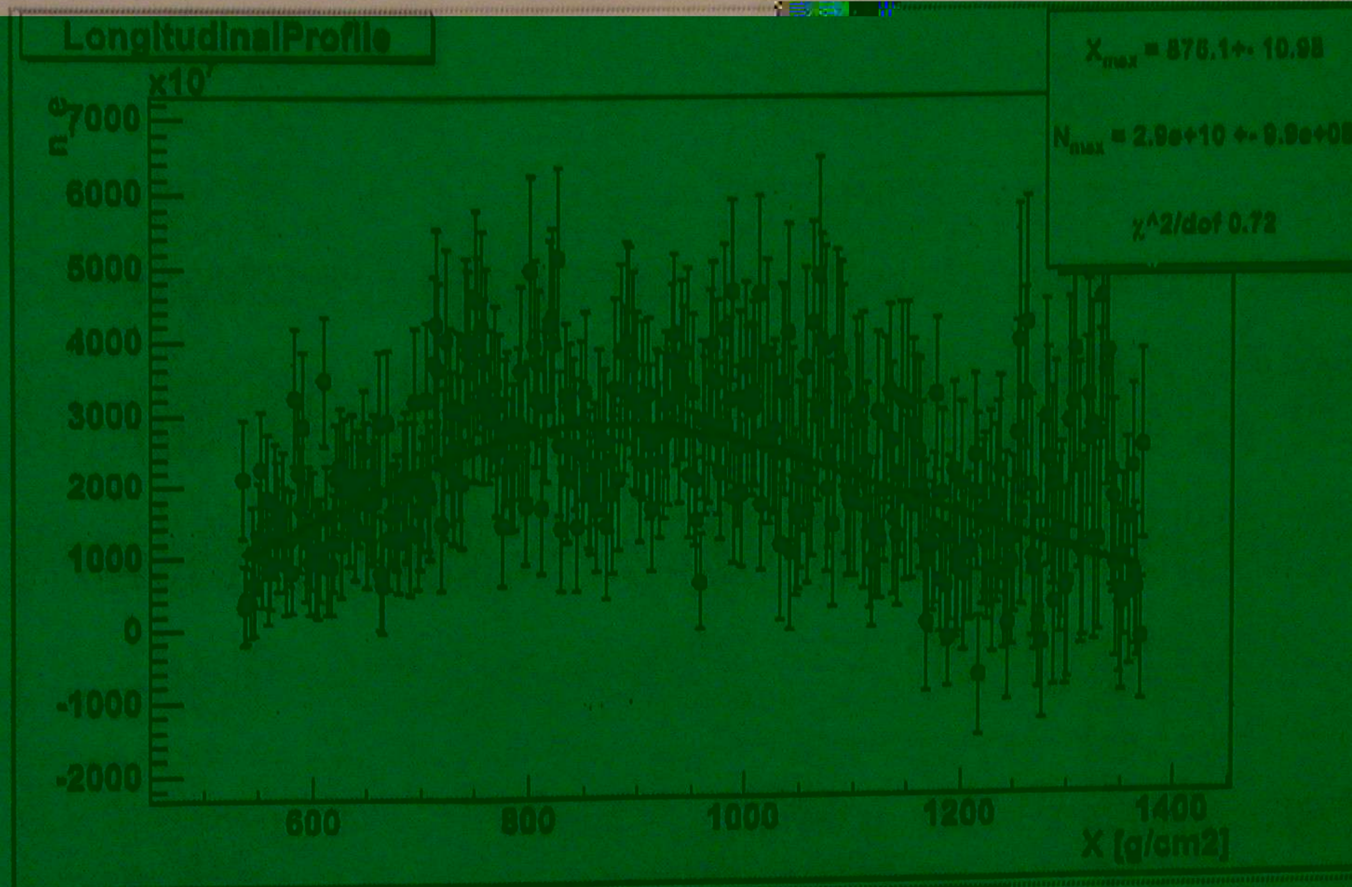
A_{zw} – powierzchnia zwierciadła

R_i – odległość elementu Δl_i od detektora

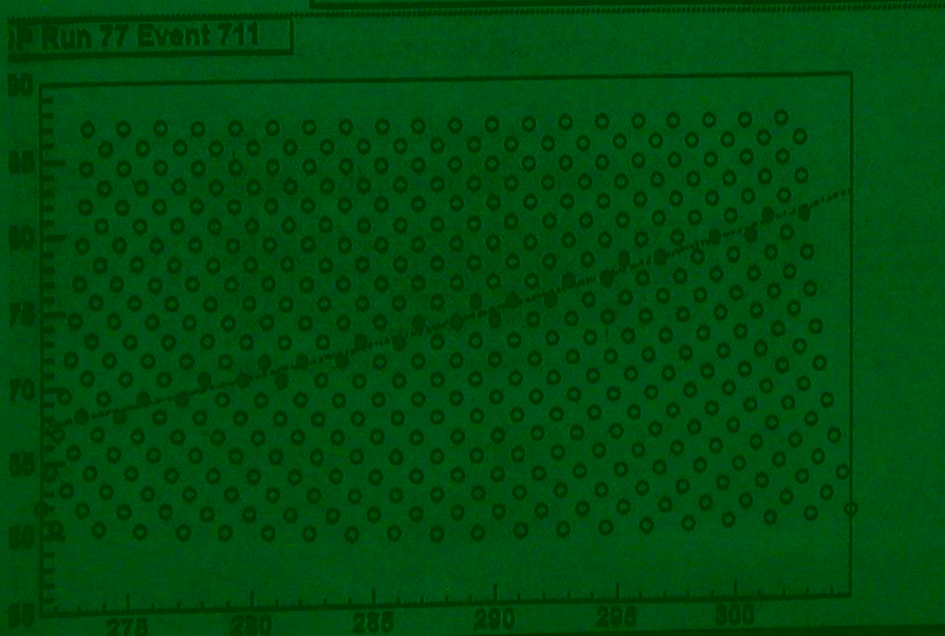
$$E_0 \simeq \int \beta \cdot N_e(x) \cdot dx$$

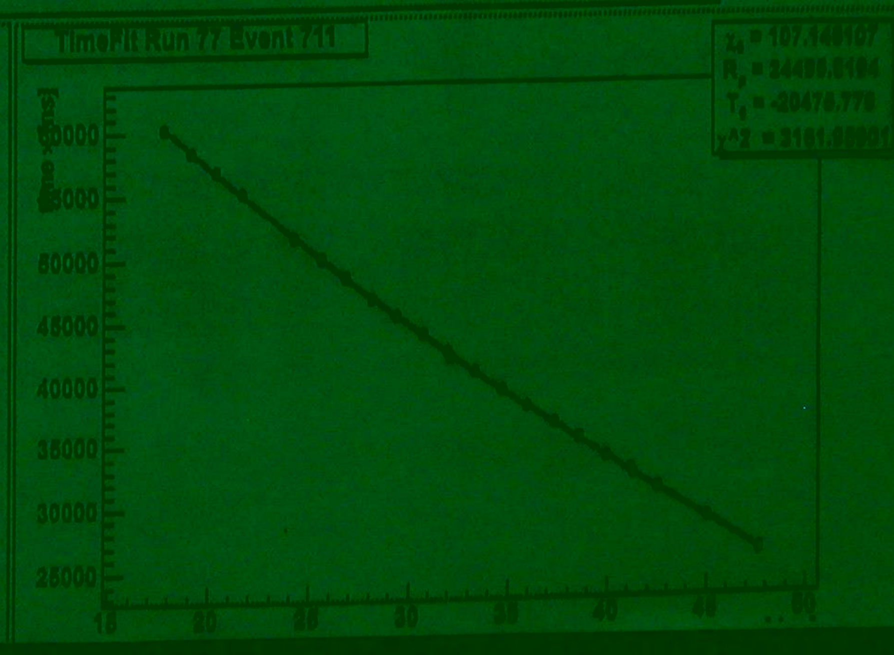
(critical energy of the air

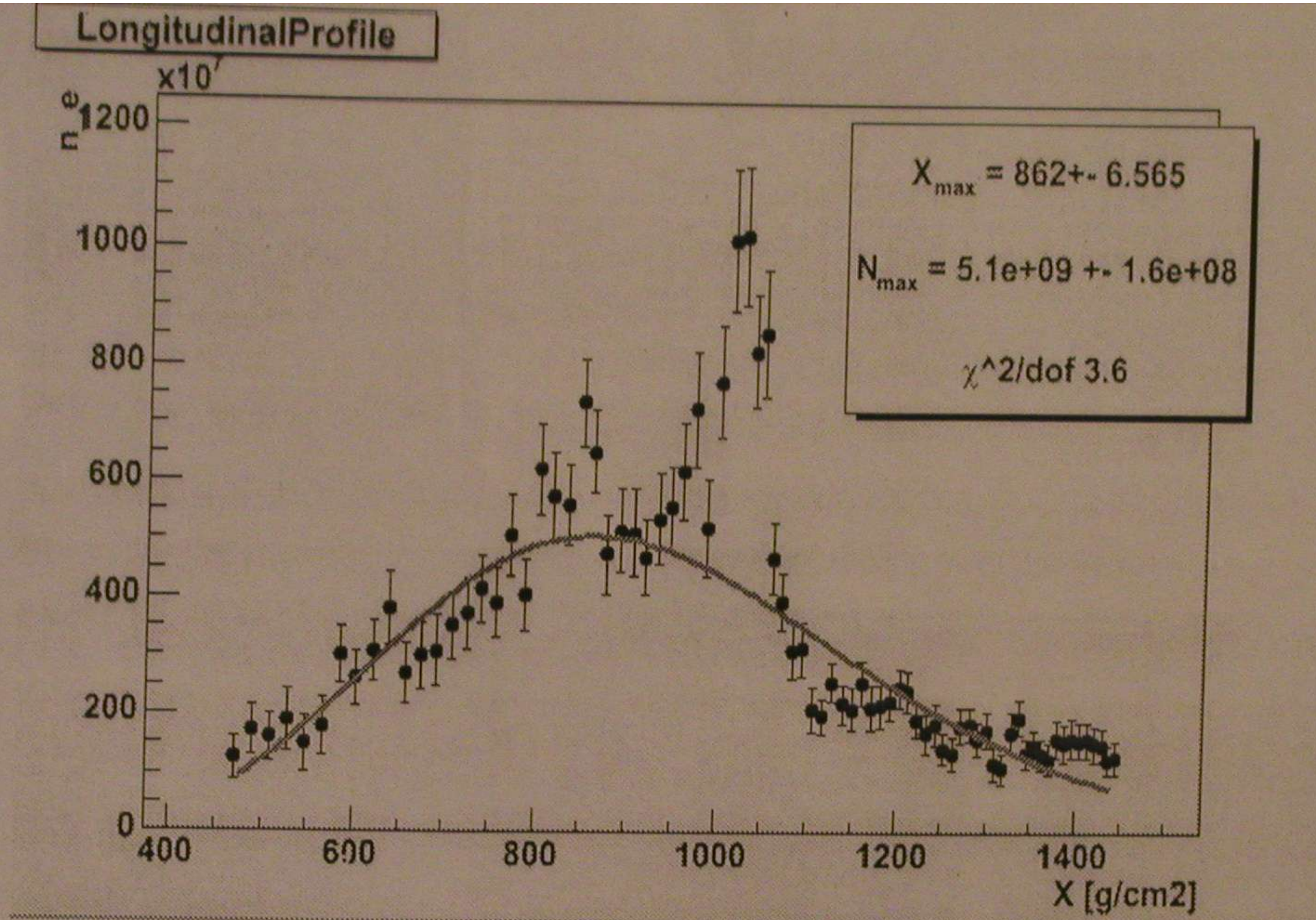
$\beta \simeq 80$ MeV


LongitudinalProfile
X_max = 876.1 +- 10.98
N_max = 2.9e+10 +- 9.9e+08
χ^2/dof 0.72
n_e
X [g/cm2]

Co 2

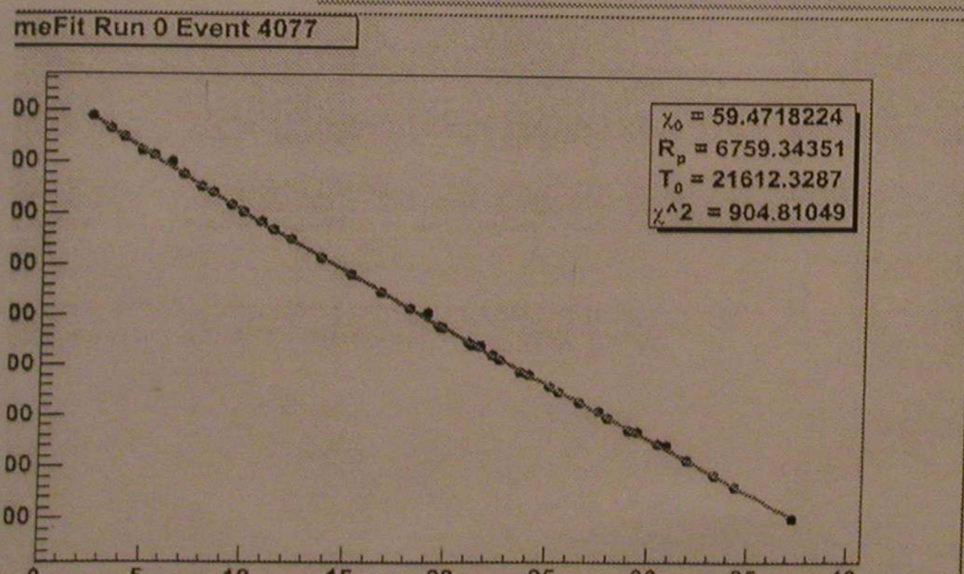

Run 77 Event 711


TimeFit Run 77 Event 711

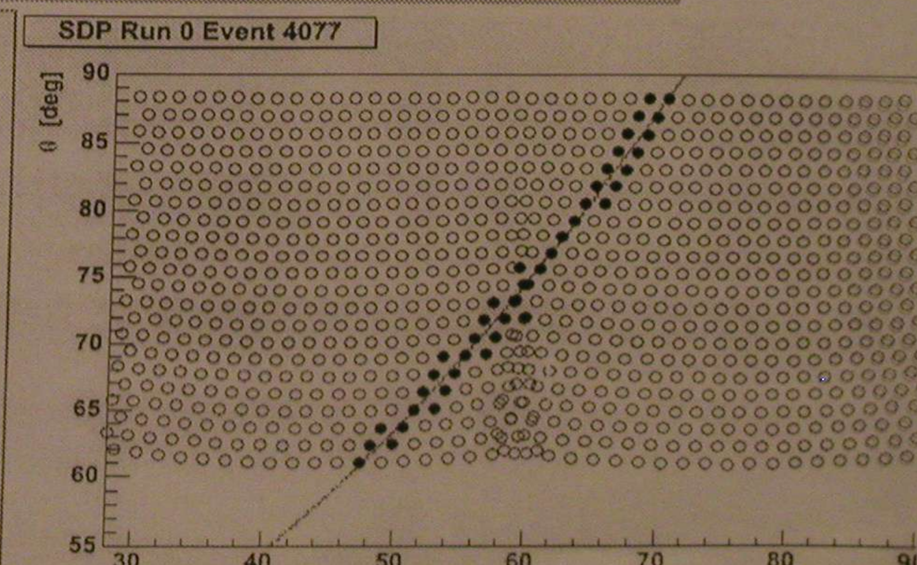


LongitudinalProfile
x10^7
n_e
X [g/cm2]
X_max = 862+- 6.565
N_max = 5.1e+09 +- 1.6e+08
χ^2/dof 3.6

LL 3,4



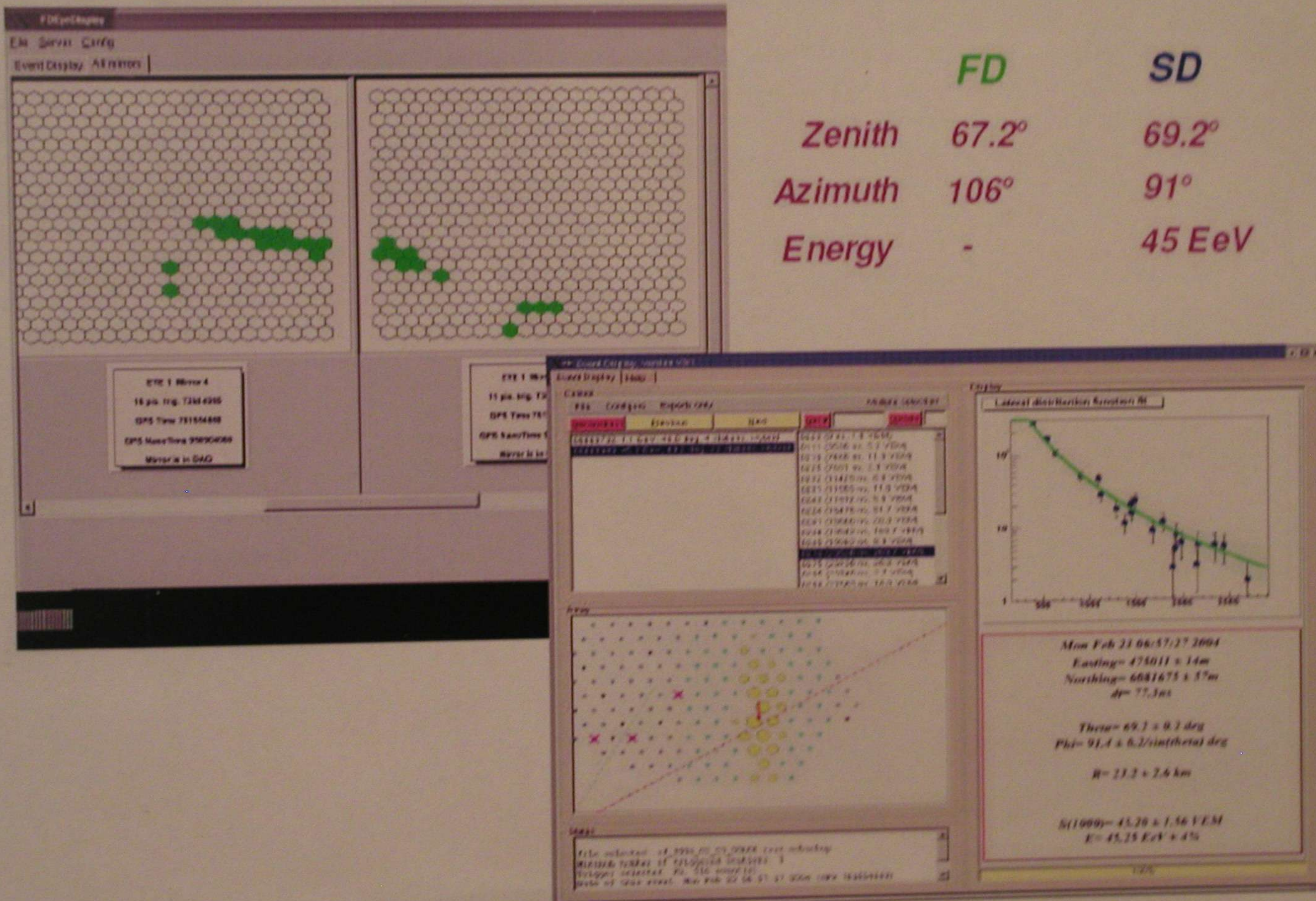
meFit Run 0 Event 4077
χ_0 = 59.4718224
R_p = 6759.34351
T_0 = 21612.3287
χ^2 = 904.81049

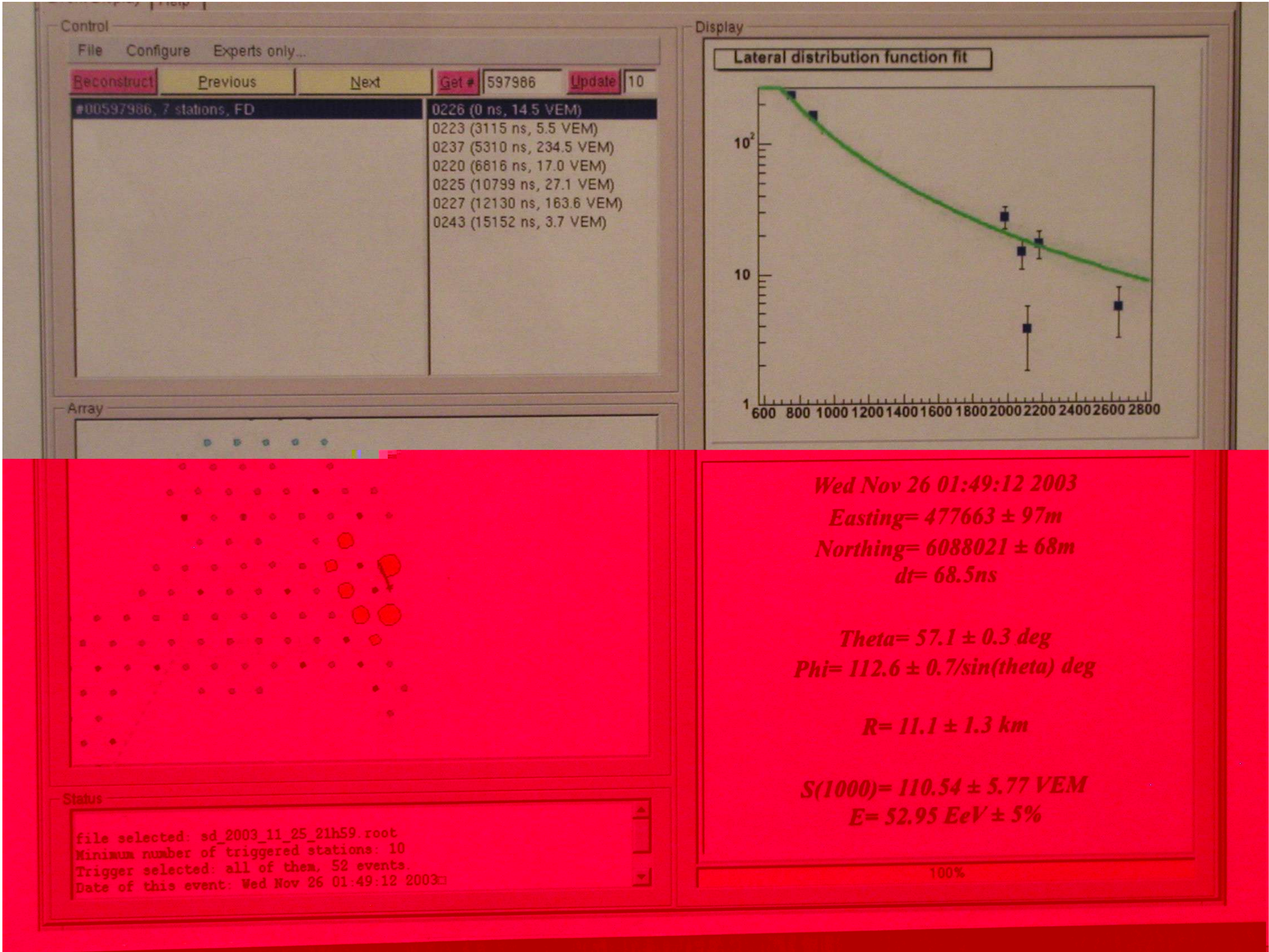


SDP Run 0 Event 4077
θ [deg]

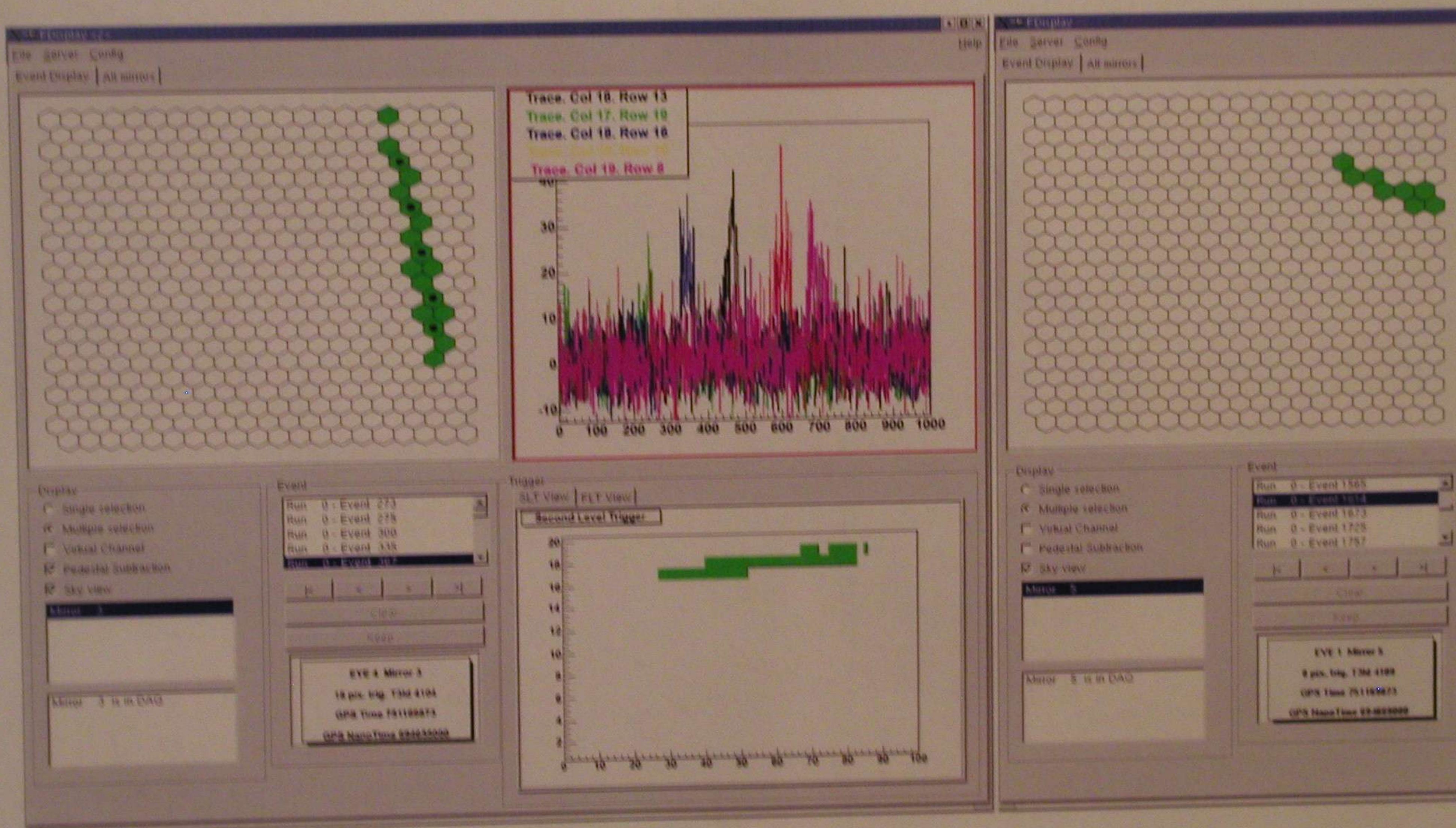
23 February ...multi-mirror-hybrid

	FD	SD
Zenith	67.2°	69.2°
Azimuth	106°	91°
Energy	-	45 EeV




Control
File
Configure
Experts only...
Reconstruct
Previous
Next
Get #
597986
Update
10
#00597986, 7 stations, FD
0226 (0 ns, 14.5 VEM)
0223 (3115 ns, 5.5 VEM)
0237 (5310 ns, 234.5 VEM)
0220 (6816 ns, 17.0 VEM)
0225 (10799 ns, 27.1 VEM)
0227 (12130 ns, 163.6 VEM)
0243 (15152 ns, 3.7 VEM)
Display
Lateral distribution function fit
10²
10
1
600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800
Array
Wed Nov 26 01:49:12 2003
Easting= 477663 ± 97m
Northing= 6088021 ± 68m
dt= 68.5ns
Theta= 57.1 ± 0.3 deg
Phi= 112.6 ± 0.7/sin(theta) deg
R= 11.1 ± 1.3 km
S(1000)= 110.54 ± 5.77 VEM
E= 52.95 EeV ± 5%
Status
file selected: sd_2003_11_25_21h59.root
Minimum number of triggered stations: 10
Trigger selected: all of them, 52 events.
Date of this event: Wed Nov 26 01:49:12 2003
100%

Pierwszy przypadek **Hybrydowy – Stereo.** Wielki pęk atmosferyczny zarejestrowany przez obydwa detektory fluorescencyjne oraz przez detektory powierzchniowe.
25 październik 2003 23:17:40 (czas lokalny). E0=2*10^19 eV




Event Display, version v3r1
Event Display
Help
Control
File
Configure
Experts only...
Reconstruct
Previous
Next
Get #
584032
Update
0
#00584047, 2 stations, DIA_NOCHE
#00584048, 2 stations, MOULIN_ROUGE
#00584030, 5 stations, 3C2&4C4
#00584031, 1 stations, FD
#00584032, 8 stations, FD
#00584033, 0 stations, 3C2&4C4
#00584034, 3 stations, FD
#00584035, 1 stations, FD
#00584036, 2 stations, FD
#00584037, 1 stations, FD
#00584038, 4 stations, 3C2&4C4
#00584039, 1 stations, FD
#00584040, 1 stations, FD
#00584041, 3 stations, FD
0157 (0 ns, 2.7 VEM)
0155 (2130 ns, 2.9 VEM)
0154 (6014 ns, 13.8 VEM)
0169 (8063 ns, 11.0 VEM)
0168 (10156 ns, 89.2 VEM)
0167 (12389 ns, 31.0 VEM)
0220, station deleted
0186, station deleted
Array
Status
file selected: sd_2003_10_25_23h06.root
Minimum number of triggered stations: 0
Trigger selected: all of them. 454 event(s)
Date of this event: Sun Oct 26 02:17:40 2003 (GPS 751169873)
Display
Quechubil (157)
Signal: 2.7 VEM
Area/Peak: 2.32
Time Over Threshold
Mawen Lufke (155)
Signal: 2.9 VEM
Area/Peak: 2.26
Time Over Threshold
La Paz (154)
Signal: 13.8 VEM
Area/Peak: 4.33
Threshold
Irini (169)
Signal: 11.0 VEM
Area/Peak: 2.81
Threshold
Paix (168)
Signal: 89.2 VEM
Area/Peak: 2.63
Threshold
Qasikay (167)
Signal: 31.0 VEM
Area/Peak: 3.75
Threshold
PMT
100%

27 February ...nice hybrid

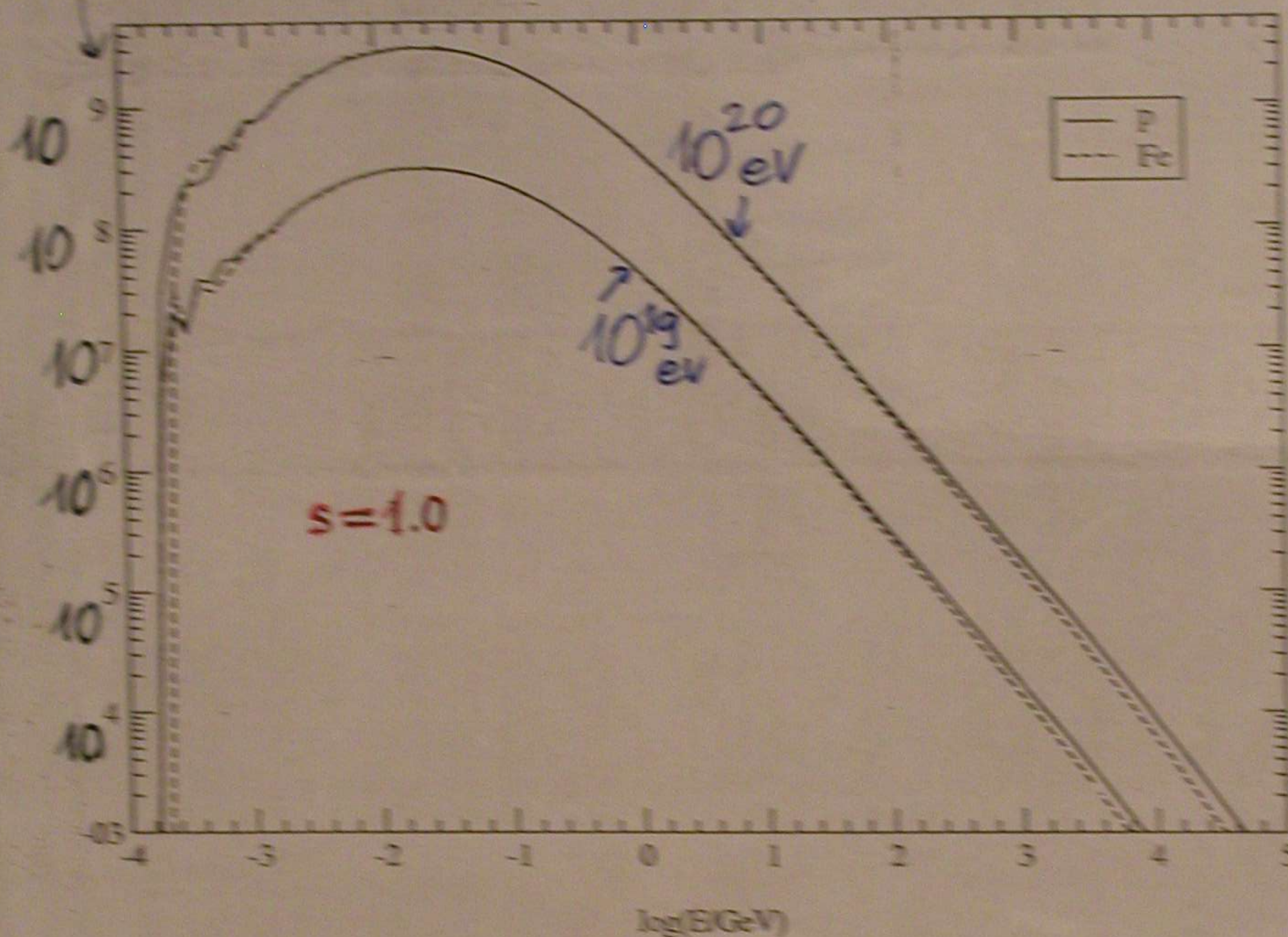
	FD	SD
Zenith	36.9°	35,8°
Azimuth	-173°	-173°
Energy	21.7 EeV	19.3 EeV

How to take into account the contribution of the Cherenkov light in the total flux measured by Fluorescence Detector ?

M.Giller
G. Wieczorek
with help
of the Auger
Lodz group

electron energy spectra
in shower maxima

ΔN in ΔlogE=0.1

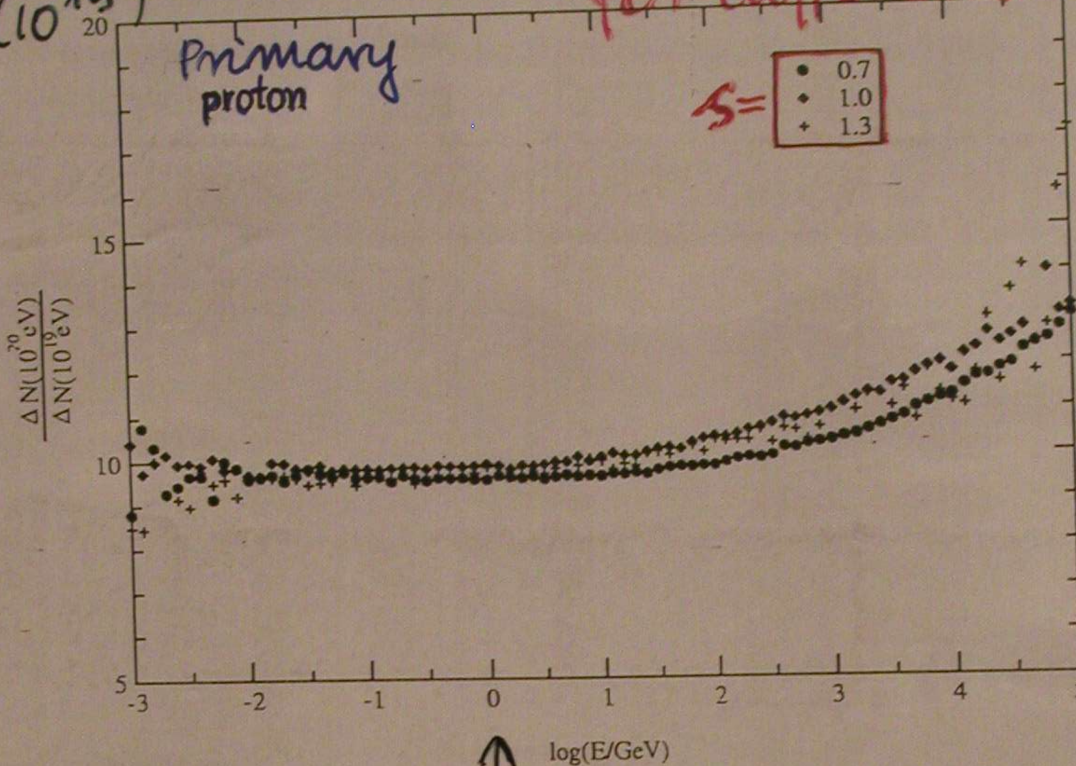


Shapes are the same!

from CORSIKA simulations

Ratios of energy spectra ~~for~~ for different ages s

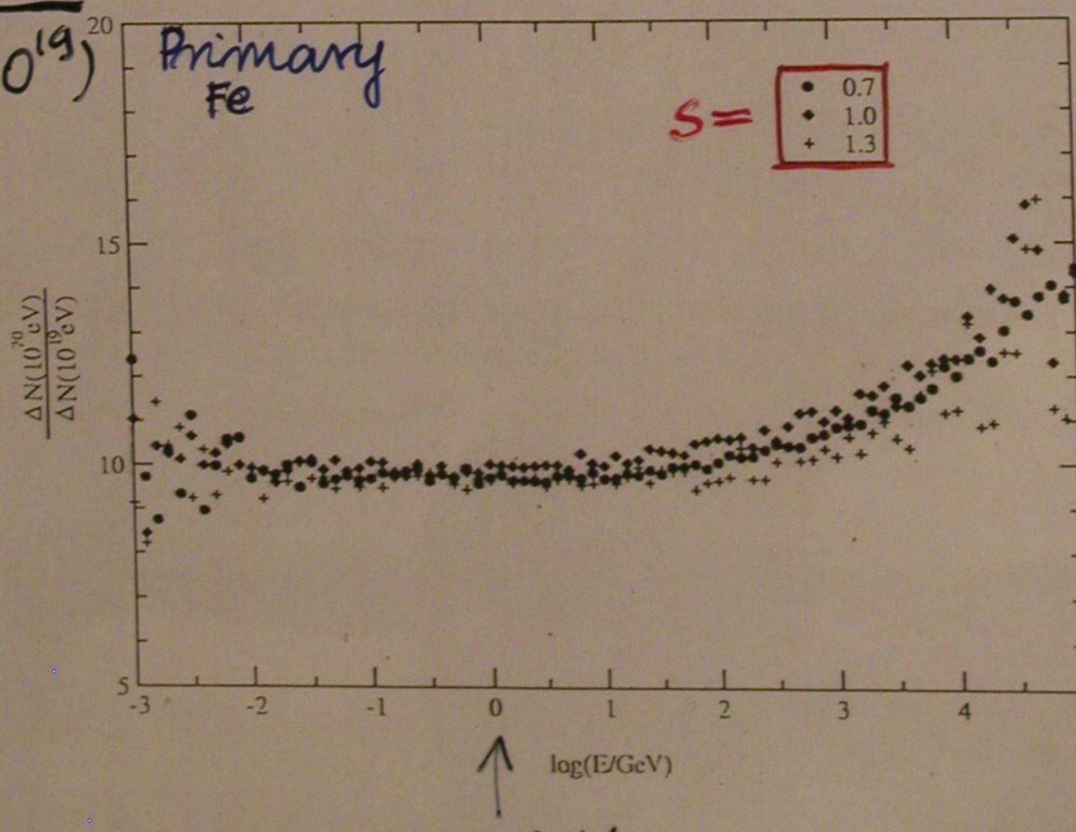
$\frac{\Delta N(10^{20})}{\Delta N(10^{19})}$



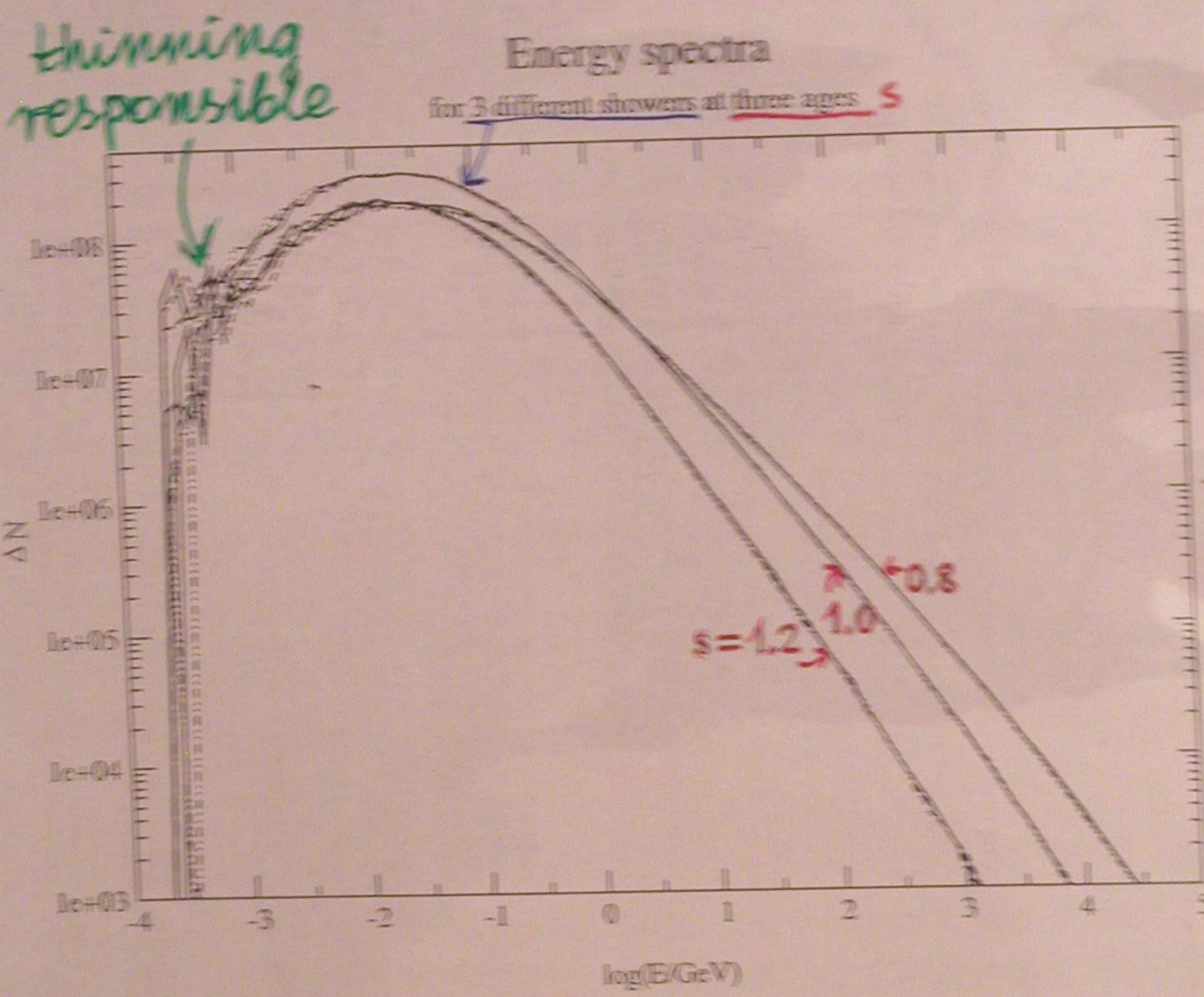
1 GeV

$$s = \frac{3x}{x + 2x_{max}}$$

$\frac{\Delta N(10^{20})}{\Delta N(10^{19})}$



1 GeV



Energy spectrum
does not fluctuate
from one shower to another

Analytical formula for the energy spectrum of electrons

$$\frac{dN}{d\log E} = N_{tot}(s) \cdot C(s) \cdot \left[1 - a \cdot \exp\left(-f(s)\frac{E}{E_{cr}}\right)\right] \cdot \left(1 + \frac{E}{E_{cr}}\right)^{-\left(s + b\ln\frac{E}{cE_{cr}}\right)}$$

$a = 1.015$

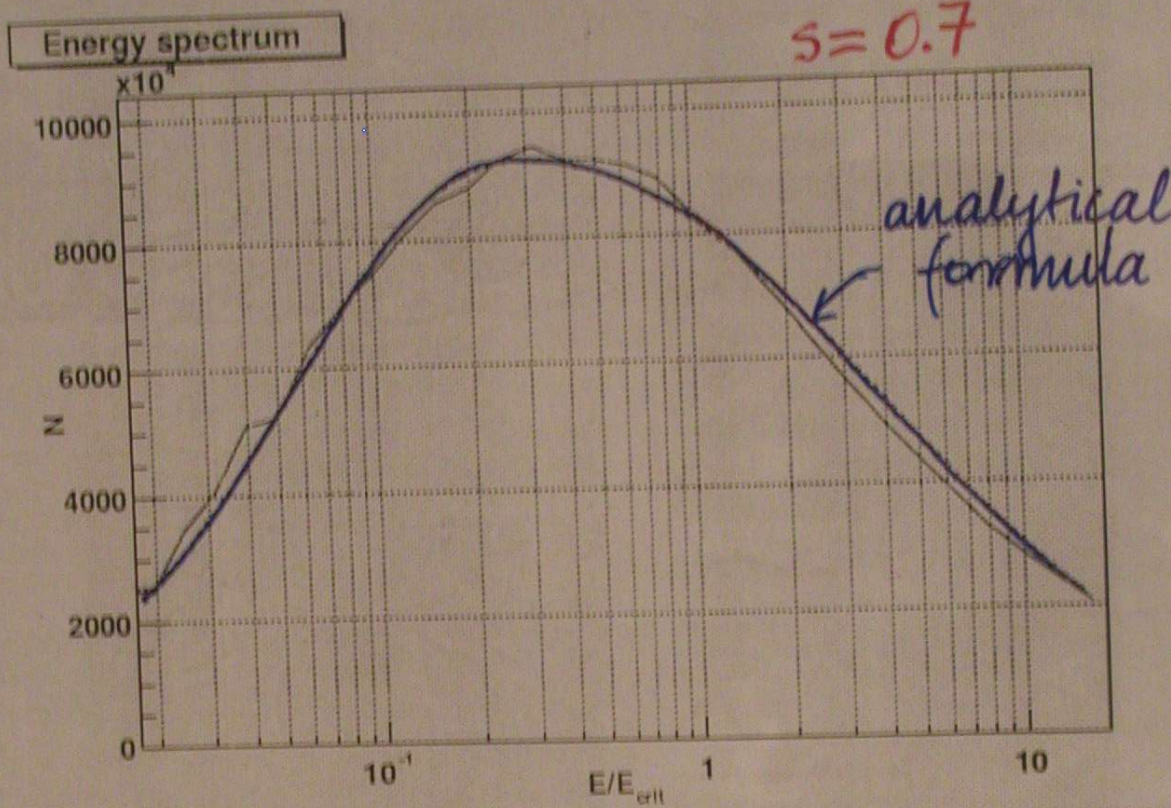
$b = 0.13$

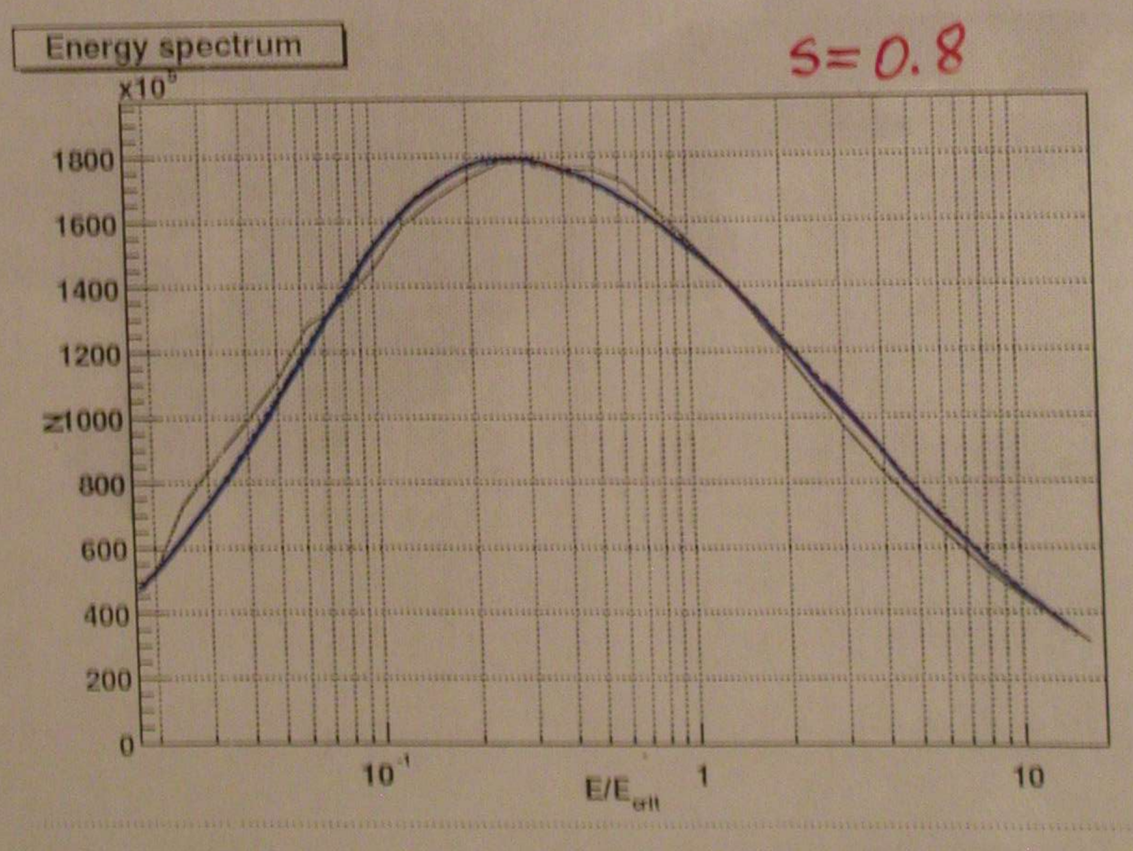
$c = 60.6$

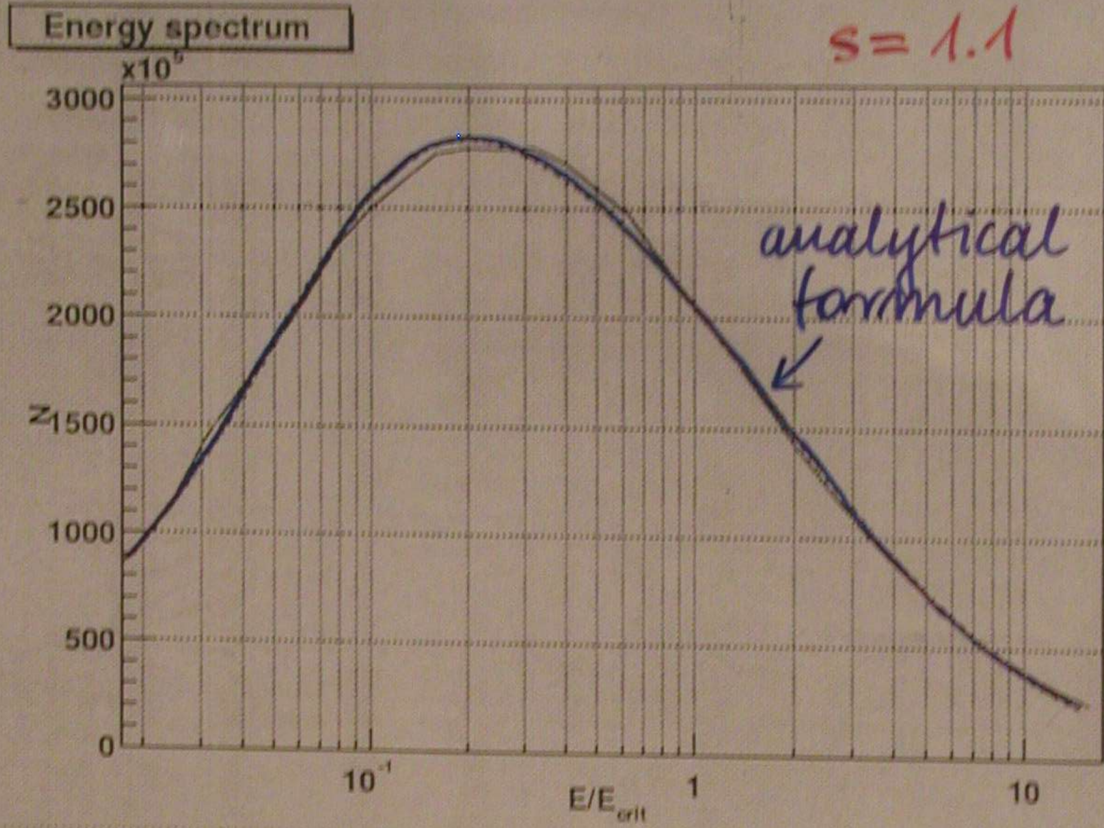
$f(s) = 11.84 + 6.84 \cdot s$

$E_{cr} = 80\ \mathrm{MeV}$

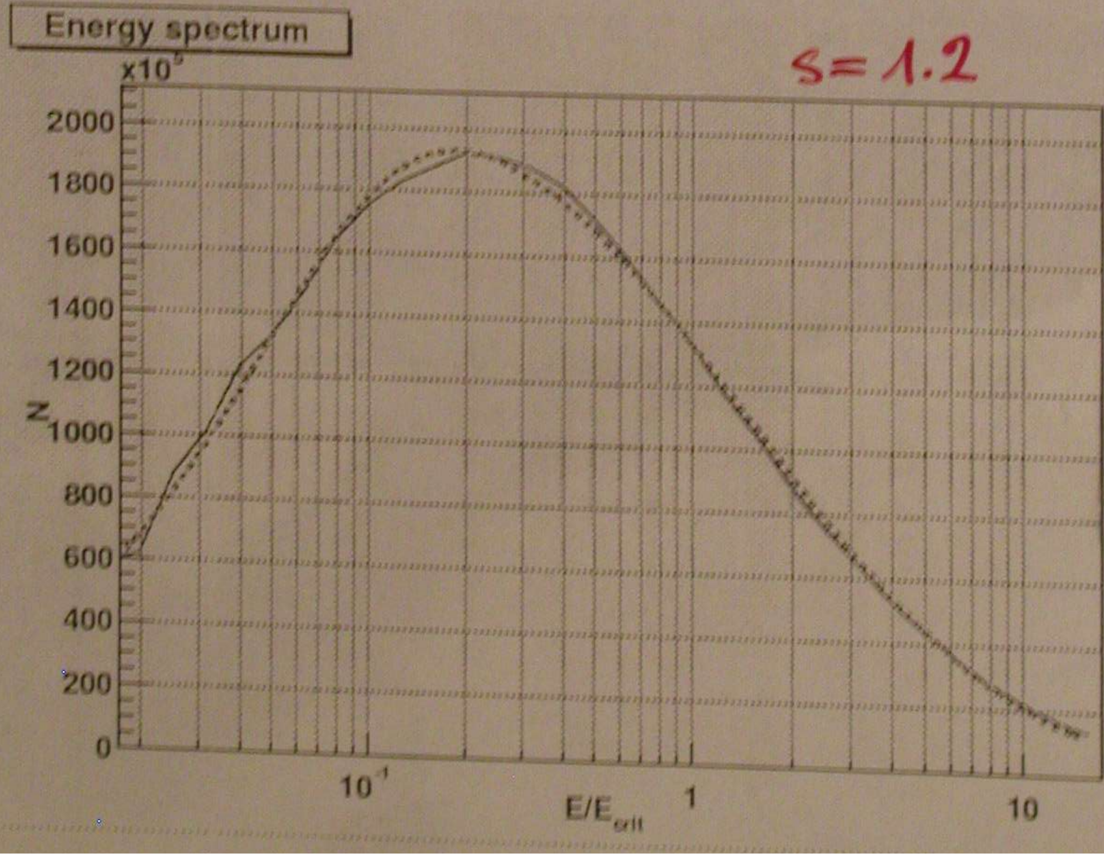
$C(s) = 0.262 \cdot s + 0.270$


Energy spectrum
s=0.7
x10
10000
8000
6000
4000
2000
0
N
10
1
10
E/E
analytical formula


Energy spectrum
s=0.8
x10
1800
1600
1400
1200
1000
800
600
400
200
0
N
10
1
10
E/E

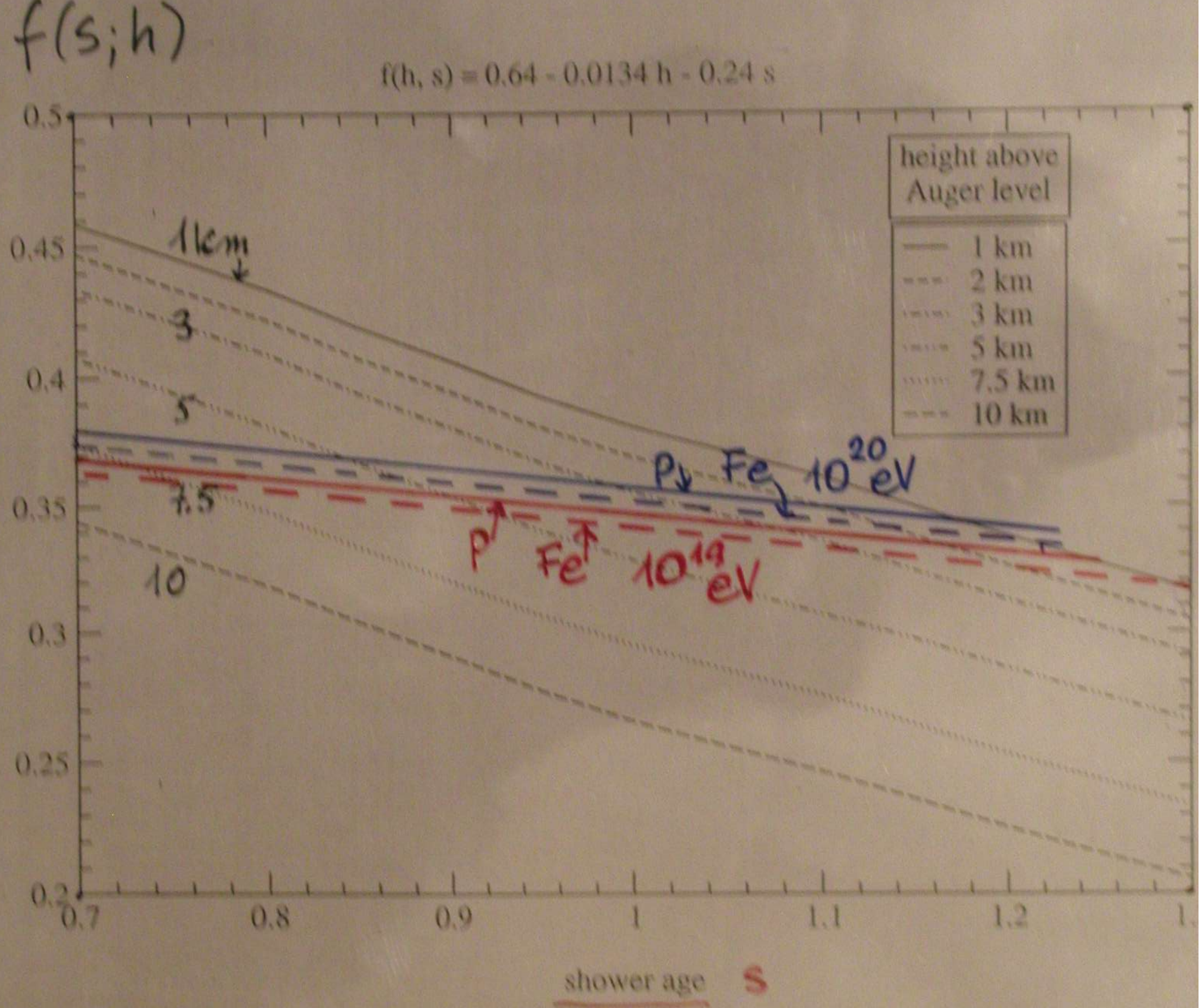


Energy spectrum
s= 1.1
x10^5
3000
2500
2000
1500
1000
500
0
N
analytical formula
10^-1
1
10
E/E_crit



Energy spectrum
s= 1.2
x10^5
2000
1800
1600
1400
1200
1000
800
600
400
200
0
N
10^-1
1
10
E/E_crit

Fraction of electrons emitting Chevenkov light



$$f(s;h) = 0.64 - 0.24 \cdot s - 0.0134 \cdot h\,(\mathrm{km})$$

Our aim:

Calculate the contribution of Cherenkov light:

* scattered Cherenkov light

  already done:

  effective fraction of Ch. electrons $\simeq f(s,h)$ only (~0.36)

  J Phys G 30 (2004) 97

  ↑

  energy spectrum of electrons depends on showerage s only

  ↓

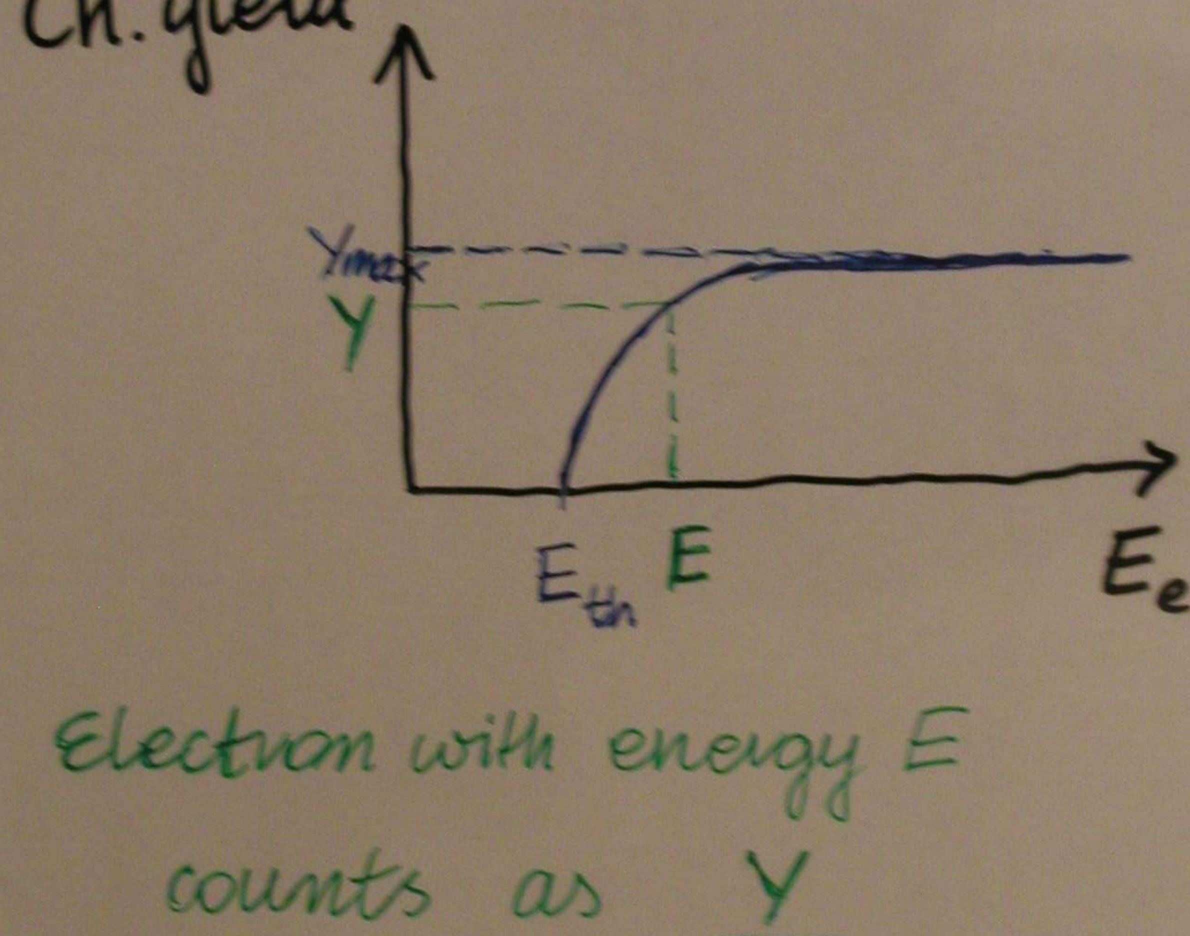
* direct Ch. light

  needed:

  angular distribution of Ch. electrons

  $\simeq$ angular distribution of Ch. light

What is a „Cherenkov electron"?

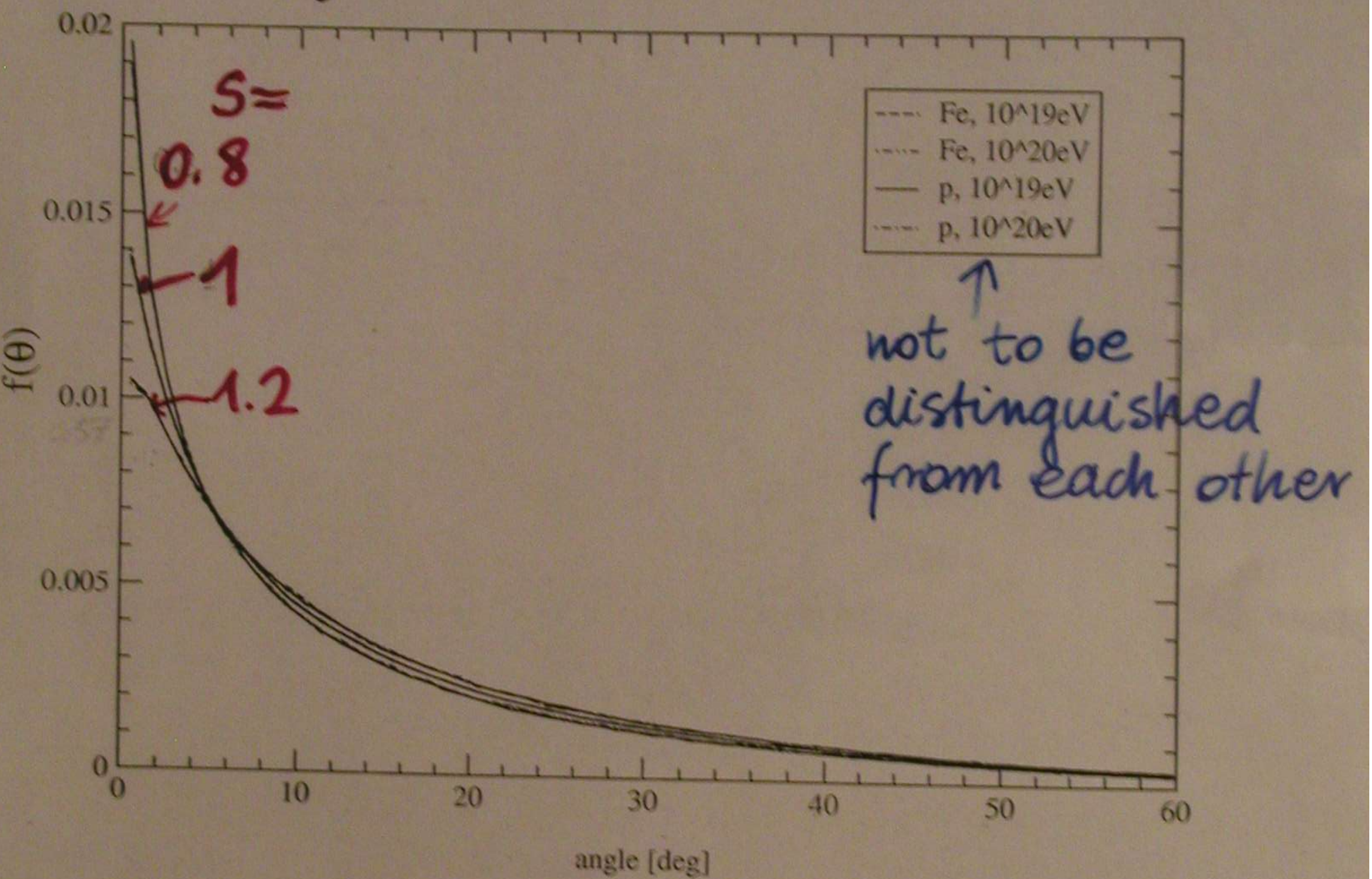


Electron with energy E counts as $\frac{Y}{Y_{max}}$

From CORSIKA

Angular distribution of all electrons $f(\Theta)$,

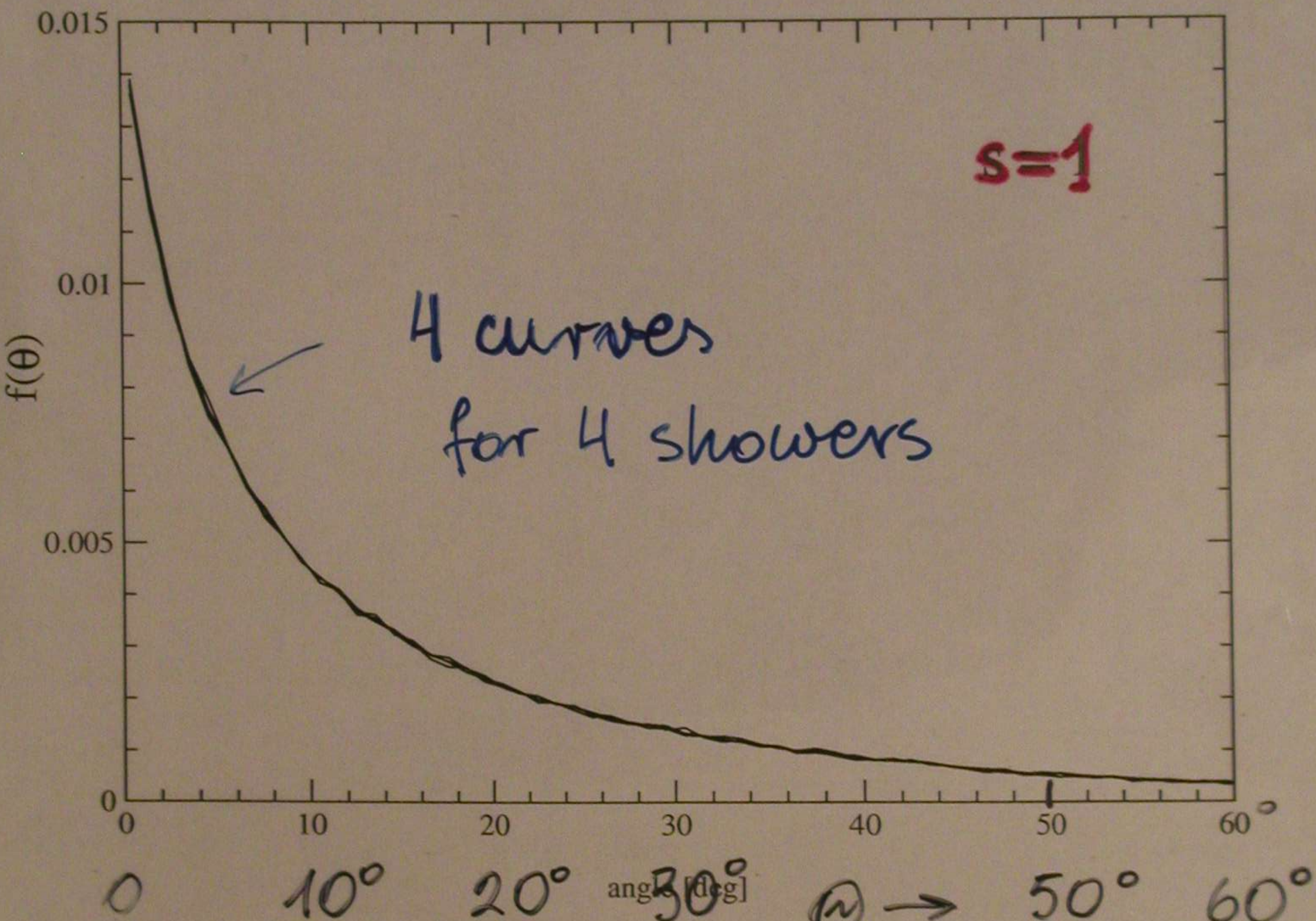
$$\int_0^{\pi} f(\Theta)\cdot 2\pi \sin\Theta \, d\Theta = \cancel{1}\,\mathrm{const}$$



Each curve is an average over 10 showers

M. Giller
& G. Wieczorek

Are there any fluctuations of $f(\Theta)$ from shower to shower?

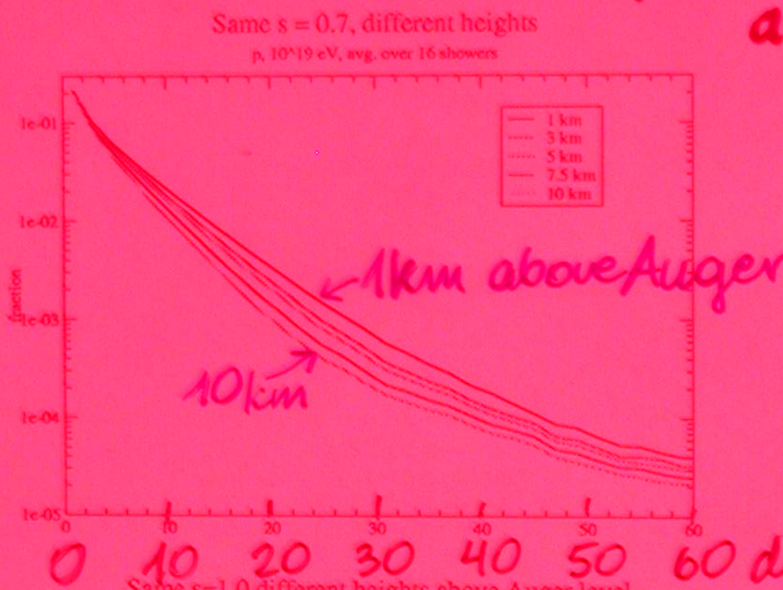


very small !

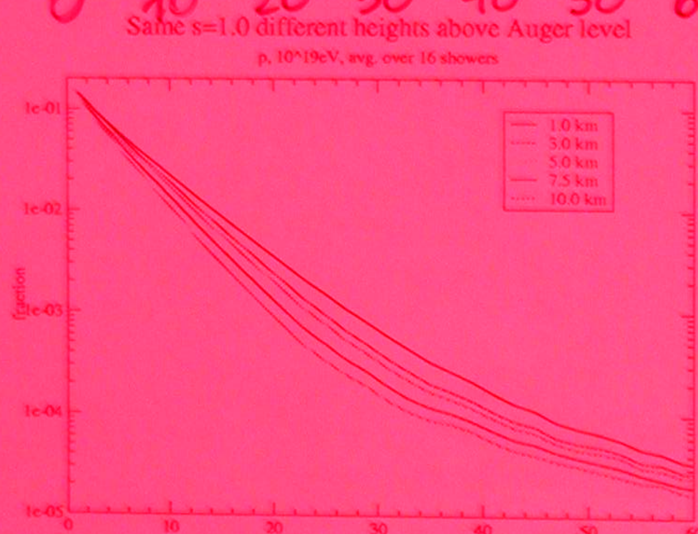
M. Giller
& G. Wieczorek

$\int f(\theta;s,h)\cdot 2\pi \sin\theta\, d\theta$ = fraction of Ch. electrons at the level

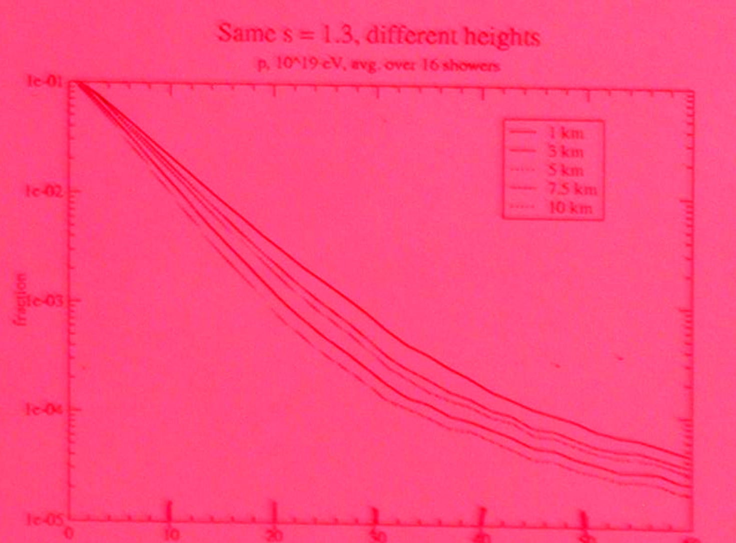
$f(\theta;s,h)$



s=0.7



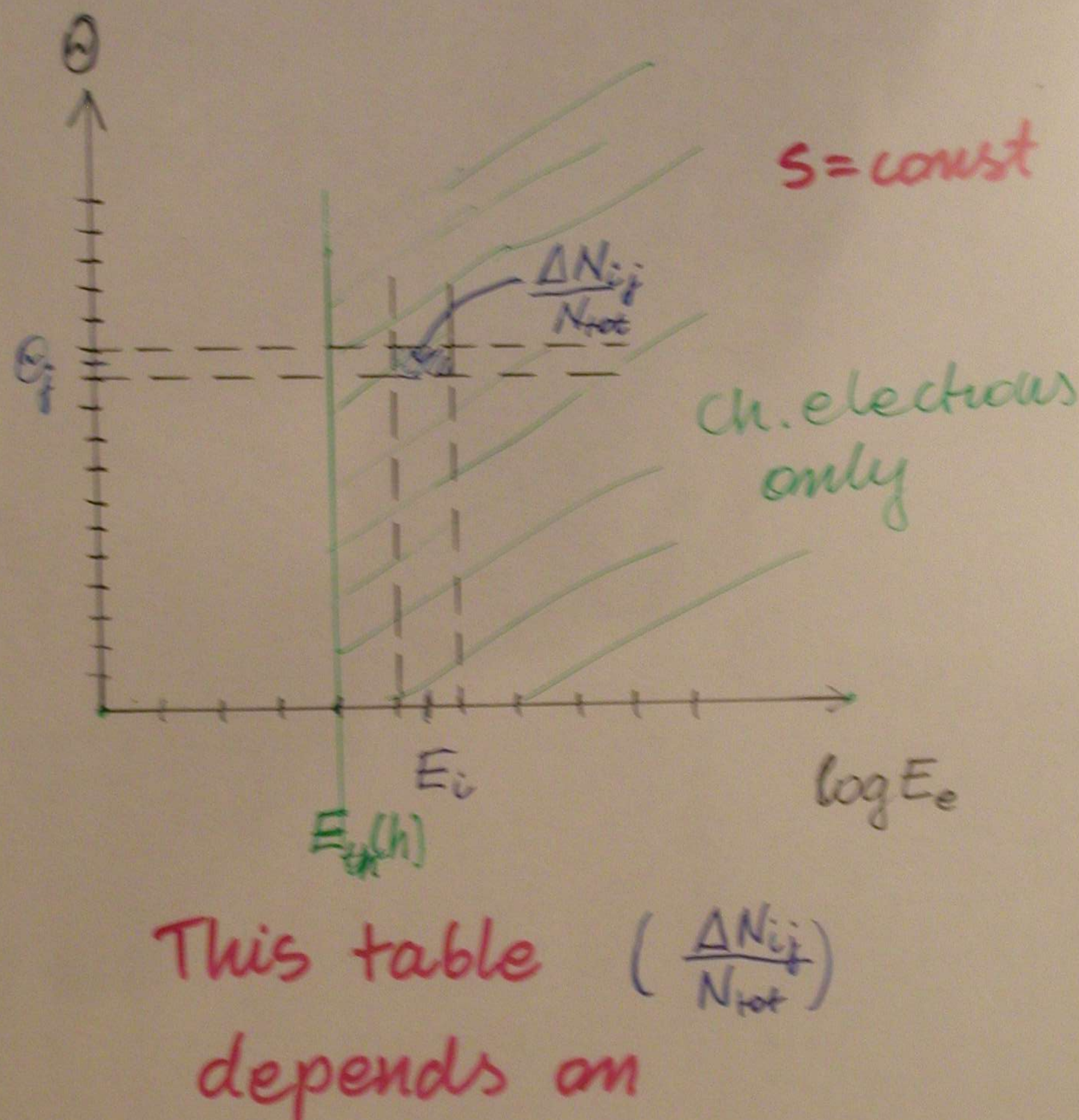
s=1



s=1.3

$\Theta \longrightarrow$

Energy & angle distribution of electrons



This table $\left(\frac{\Delta N_{ij}}{N_{tot}}\right)$ depends on shower age s only

(does NOT depend on primary particle M & E_0)

Application to account for the direct Chevenkov light in shower reconstruction

* $f(\Theta; s) \longrightarrow f_{ch}(\Theta; s, h)$

  electrons of <u>all</u> energies $\qquad E > E_{th}(h)$

where

$$f_{ch}(\Theta; s, h) = \int_{E_{th}(h)}^{E_0} F(\Theta, E) \cdot \frac{dn_{ch}(E,h)}{dx} \Big/ \frac{dn_{ch}^{max}}{dx} \cdot dE$$

a weight ≤ 1

$\div$

* As Chevenkov emission angle $\lesssim 1°$

  $\Downarrow$

  Angular distr. of Ch. light $\approx$

  $\approx$ angular distr. of Ch. electrons $=$

  $= f_{ch}(\Theta; s, h)$

* Find analytical form of $f_{ch}(\Theta; s, h)$

M. Giller & G. Wieczorek

M. Giller
& G. Wieczorek

Finally

* Angular distr. $G(\Theta; x)$ of Ch. photons at level x:

$$G(\Theta; x) = \underbrace{\frac{dn_{ch}^{max}}{dx}}_{const} \cdot \int_0^x N_e(x') \cdot f_{ch}(\Theta; s, h') \cdot T(x', x)\, dx'$$

$N_e(x')$ — total no. of elections at x'

$T(x', x)$ — light transmission from x' to x

$N_e(x)$ — e.g. a Gaisser-Hillas form with 4 (more?) parameters

to be fitted to total light track:

* fluorescence
* scattered Cherenkov
* direct Cherenkov

not necessarily small

(as with iterations)

Conclusion

Once $N_e(x)$ is assumed

$\downarrow$

Cherenkov light

(both scattered & direct)

can be calculated easily

for any pixel (function of s & h, will be parametrised soon)

The Pierre Auger Observatory

* South Site :

- Argentina, Mendoza Province,
  - Malargüe
- total surface : 3000 km^2
  covered by
  1600 surface detectors, SD,
  with 1.5 km spacing
- 4 fluorescence detectors, FD,
  × 6 telescopes each,
  with field of view $30^\circ \times 30^\circ$ each
- to be completed by 2005/06
  cost ~ 50 M USD

* North Site - in USA
(to be decided where)