# EUSO

**E**xtreme **U**niverse **S**pace **O**bservatory

Simulation

*Vincent Van Gogh, "The starry night"*

Subsystem

**An Innovative Space Mission**
**doing Astronomy by looking downward**
**from the Space Station at the Earth Atmosphere**

***Approved by ESA for the "Phase A study" on the International Space Station***

# EUSO Simulation Subsystem

- Committed Institutions and contact-person

| | | | |
|---|---|---|---|
| ✓ | F, | Annecy, LAPP, | P. Nedelec |
| ✓ | F, | Paris/Orsay, IPN, | E. Plagnol |
| ✓ | I, | Florence University and INFN, | S.Bottai |
| ✓ | I, | Genova Univ. and INFN, | M. Pallavicini |
| ✓ | I, | Trieste Univ. and INFN, | G. Santin |
| ✓ | I, | Palermo Univ. and IFCAI/CNR, | G. D'Alì Staiti |
| ✓ | I, | Torino Univ. and INFN, | P. Vallania |
| ✓ | I, | Trieste Univ. and INFN, | G. Santin |
| ✓ | J, | Tokyo, RIKEN, | T. Ebisuzaki |
| ✓ | P | Lisboa, LIP, | P. Abreu |
| ✓ | USA, | Los Angeles CA, UCLA, | K. Arisaka |
| ✓ | USA, | Nashville TN, Vanderbilt Univ., | S. Csorna |
| ✓ | USA, | Huntsville AL, NASA/MSFC, | J. Watts |
| ✓ | USA, | Berkeley CA, LBNL, | H. Crawford |

# Simulation Strategy

- Simulate the Physics processes
- Simulate the experimental conditions
- Work out the expected signal
- Develop and optimise the reconstruction algorithms
- Work out the expected acceptance and resolution for the physics parameters

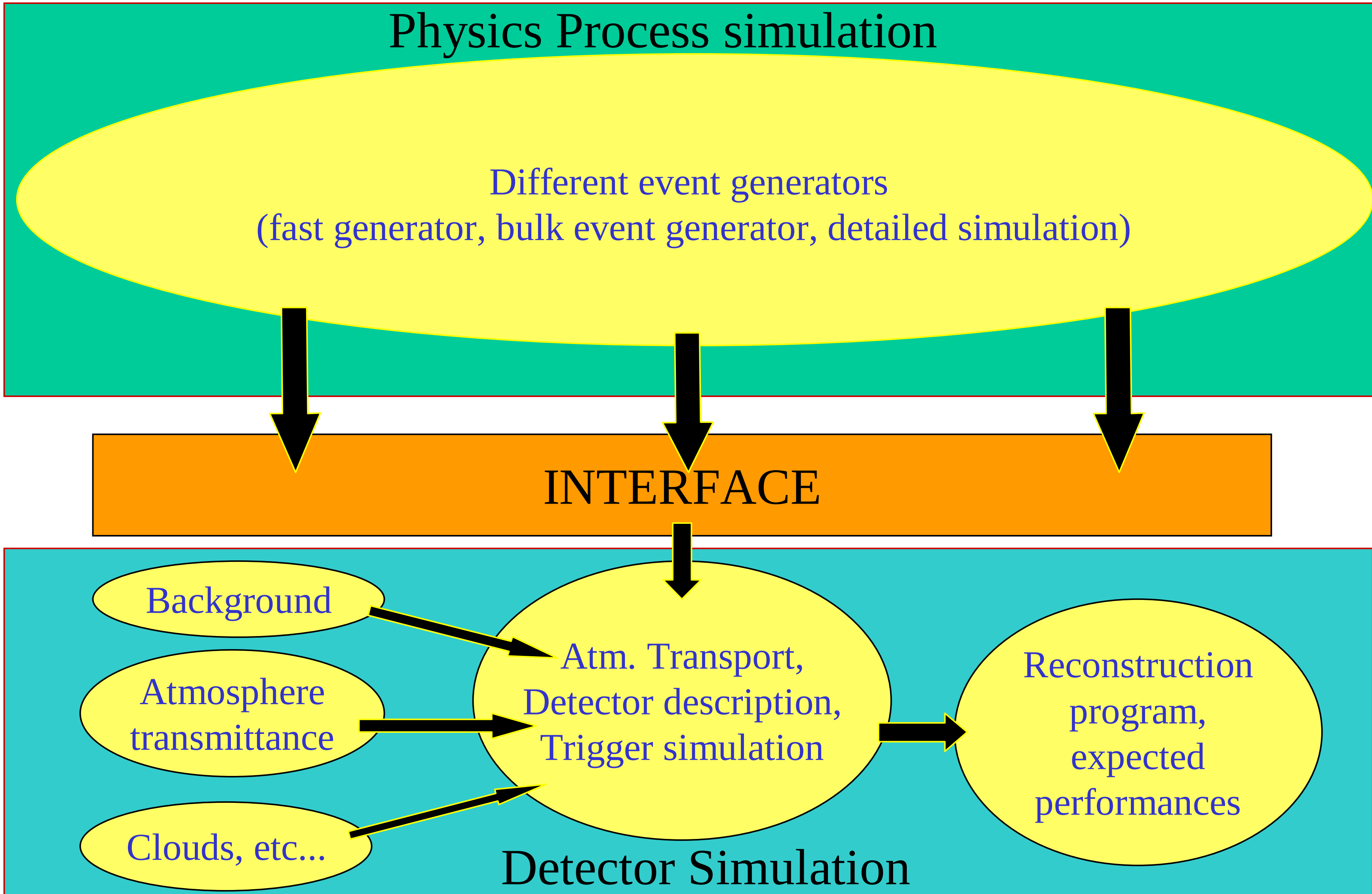
# Preliminary Simulation work

- SIMAW code, by O. Catalano based on analytical parameterisation
  - ✓Shower generation (J.Linsley, N.P. Il'ina)
  - ✓Fluorescence Yield (A. Bunner Ph.D. Thesis)
  - ✓Atmosphere transport ( Fly's Eye Ref.)
  - ✓Detector response (O. Catalano)
  - ✓Geometric Reconstruction (O. Catalano, M.C. Maccarone)

Used for F2/F3, ISS Acc. Study, etc., to predict EUSO acceptance and performances

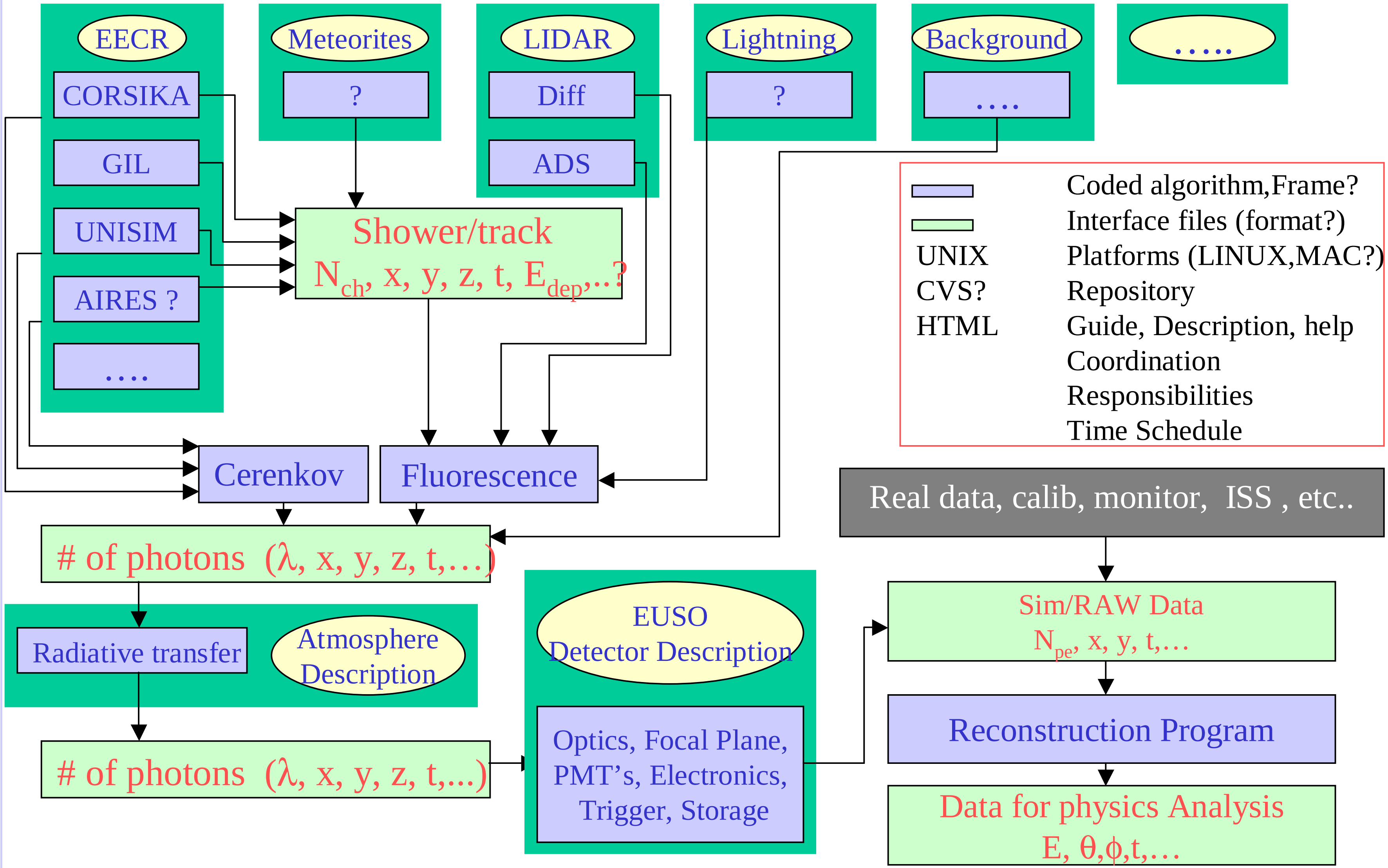
- UNISIM, ELEP codes, by Florence group
  - ✓Shower generation and development (hybrid montecarlo/param. method)
  - ✓Fluorescence yield (A. Bunner PhD Thesis)
  - ✓Atmosphere transport ( Fly's Eye Ref.)
  - ✓Detector response, trigger definition (O. Catalano, S. Bottai)

Used for acceptance and EECR performances checks, Cerenkov signal prediction, neutrino detection efficiency preliminary study



Physics Process simulation
Different event generators
(fast generator, bulk event generator, detailed simulation)
INTERFACE
Background
Atmosphere transmittance
Clouds, etc...
Atm. Transport, Detector description, Trigger simulation
Reconstruction program, expected performances
Detector Simulation

# Structure of the EUSO Simulation Program



# Result of Palermo Meeting – Actions to be taken

| | | |
|---|---|---|
| Define the Reference System | → | Mainly for simulation |
| Interface data format | → | Identify relevant variables<br>Build a portable structure<br>Build an effective book-keeping/ documentation repository system |
| S/W Module identification | → | Modular, structured, portable, coherent with the overall architecture |
| Event selection definition | → | Translate the hardware trigger requirements into software conditions |
| S/W environment | → | Report, both for simulation and data analysis, the ROOT environment for S/W development |

EUSO

# The interface data format

**Structure of the output file of the particle and Cherenkov photon**

**OUTPUT FORMAT FOR LONGITUDINAL SHOWER PROFILE**

Choosing a structure close to the CORSIKA one, a possible choice is:

| | |
|---|---|
| 1st record: | RUN HEADER (100 words) |
| For each event: | EVENT HEADER (100 words) |
| | SHOWER PROFILE, n blocks of 100 words with n variable according to the shower length along the shower trajectory. Each block contains 10 steps of 10 words. According to the present statistics, based on 50m long steps, 1000÷1500 steps is a reasonable mean value for the number of steps into which the profile is contained, which turns into a mean value of 12,500 kwords. A mean value of 12,500 kwords/event means, uncompressed, 5MB for a run containing 100event, which appears to be quite manageable. |

# The interface Data Format

## RUN HEADER

1. 'RUNH'
2. run number (nnmpeeaa)[1]
3. date of begin run (yymmdd)
4. version of program
5. number of observation levels (max 10)

5+i. height of level *i* in *cm*

16 slope of energy spectrum
17 lower limit of energy range
18 upper limit of energy range
19 flag for EGS4 treatment of em. component
20 flag for NKG treatment of em. Component
21 kin. energy cutoff for hadrons in *GeV*
22 kin. energy cutoff for muons in *GeV*
23 kin. energy cutoff for electrons in *GeV*
24 energy cutoff for photons in *GeV*
25 fraction of primary energy for thinning
26 lower limit for zenith angle range (≥0°)
27 upper limit for zenith angle range(≤90°)

<u>physical constants</u>

27+i C(i), i=1,50
77+i AATM(i), i=1,5
82+i BATM(i), i=1,5
87+i CATM(i), i=1,5
93 NFLAIN (as real)
94 NFLDIF (as real)
95 NFLPI0 + 100 * NFLPIF (as real)
96 NFLCHE + 100 * NFRAGM (as real)
97 Interaction Model
98÷ 100 EMPTY

[1] nn=run number (<100),
m=model (0=GIL,1=CORSIKA/QGSJET, 2=CORSIKA/SIBYLL, 3=…, 4=…, 5=UNISIM/SIBYLL,>5=…..),
p=primary (0=photon, 1=proton, 2=Oxygen, 3=Iron, …),
ee=energy (ee=$\log_{10}E$ for fixed energy, ee=99 for variable energy, limits to be read in words 17,18),
aa=zenith angle (aa=0÷90 for fixed zenith angle, aa=99 for variable angle, limits to be read in words 26,27

# The interface Data Format

## EVENT HEADER

1 'EVTH'
2 event number
3 particle id (particle code or A * 100 + Z for nuclei)
4 total energy in GeV
5 starting altitude in g/cm$^2$
6 number of first target if fixed
7 x coordinate of first interaction
8 y coordinate of first interaction
9 z coordinate of first interaction
10 px momentum in x direction in GeV
11 py momentum in y direction in GeV
12 pz momentum in -z direction in GeV
13 zenith angle in radian
14 azimuth angle in radian

15 x component of Earth's magnet field in T
16 z component of Earth's magnet field in T
17÷19 $X_0$, $X_{max}$, $N_{max}$ (by Gaisser-Hillas (CORSIKA) or by GIL)
20÷23 a, b, c, $^2$ (by Gaisser-Hillas (CORSIKA) or by GIL)
24 Step length along long. profile
21+4i height of i-th observation level in g/ cm$^2$ ($0< i \leq 10$)
22+4i number of Cerenkov photons at i-th observation level ($0< i \leq 10$)
23+4i arrival time since first interaction in nsec at i-th observation level ($0< i \leq 10$)
24+4i time spread of Cerenkov photons at i-th observation level ($0< i \leq 10$)

EUSO

# The interface Data Format

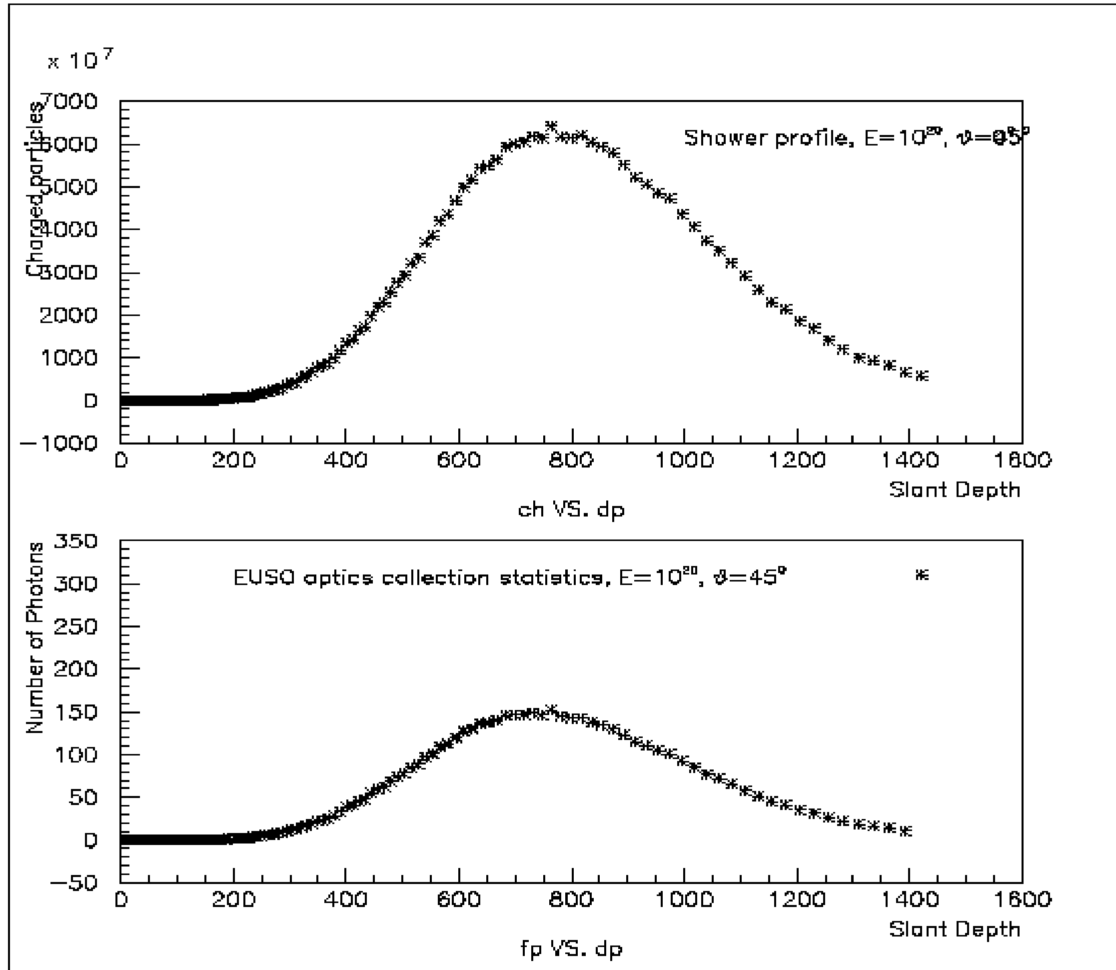
**SHOWER PROFILE (10 words/step, j=1,NSTEP)**

1. +(j-1)mean x-coordinate
2. +(j-1)mean y-coordinate
3. +(j-1)mean z-coordinate
4. +(j-1)mean time, with respect to the first interaction
5. +(j-1)mean height in g/cm$^2$
6. +(j-1)no. of charged particles
7. +(j-1)no. of muons
8. +(j-1)no of hadrons
9. +(j-1)no of emitted fluorescence photons
10. +(j-1)no of UV photons collected by the EUSO optical system

# CORSIKA Montecarlo

The Corsika 5.64 version has been modified in order to include the shower profile description along the slant depth and to write it to the output. Version 6.0n modification under analysis

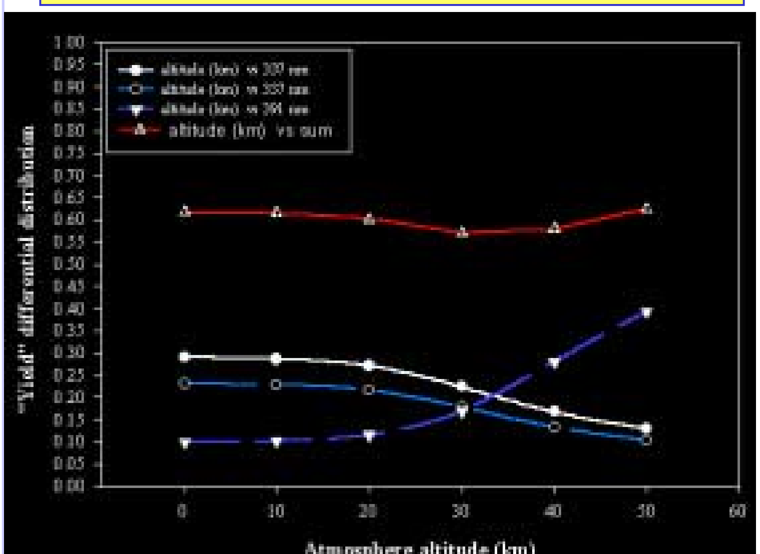
Fluorescence Yield and Cerenkov light content are generated and the transport module to EUSO is developed, including air attenuation, (Raleigh Scattering, Mie (Aerosol) scattering, Ozone absorption

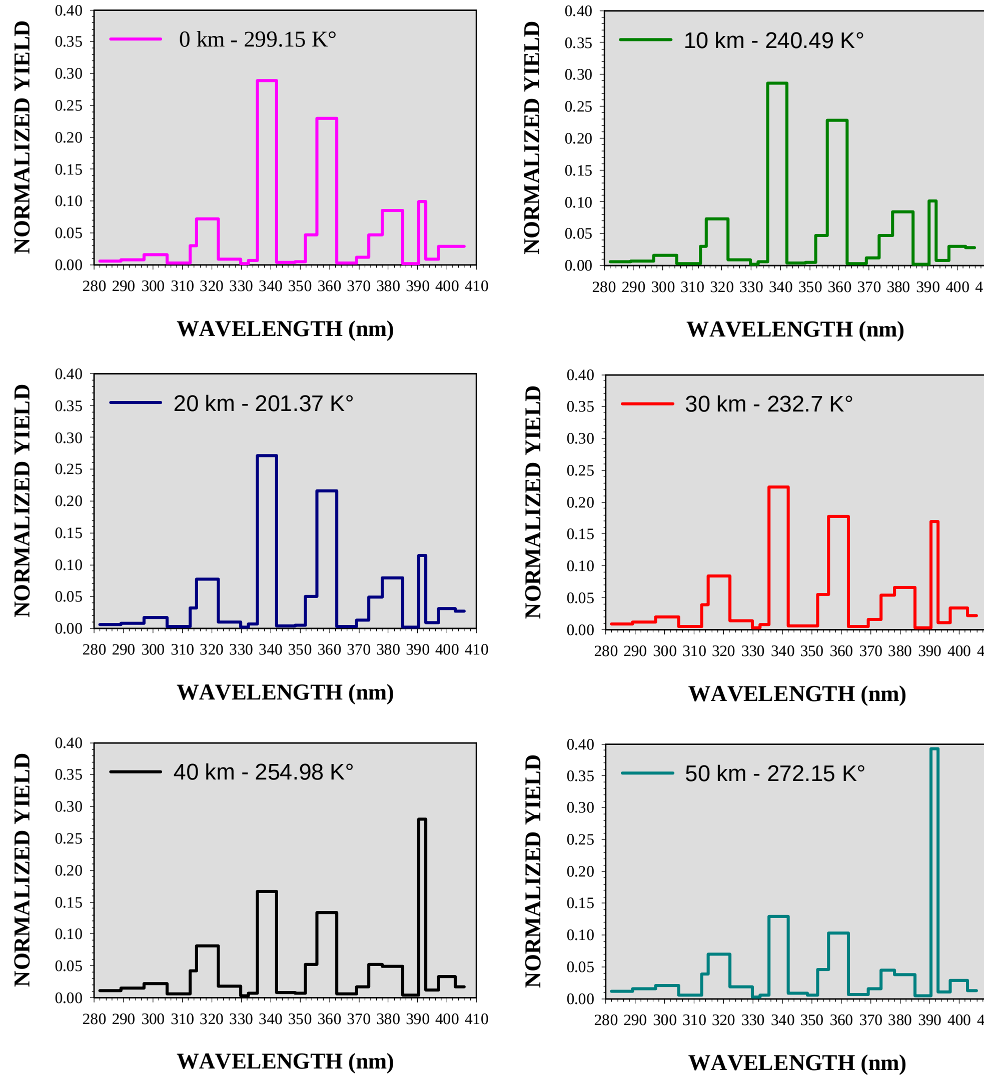


# The observable

## Fluorescence yield calculated from A. Bunner Ph.D. thesis

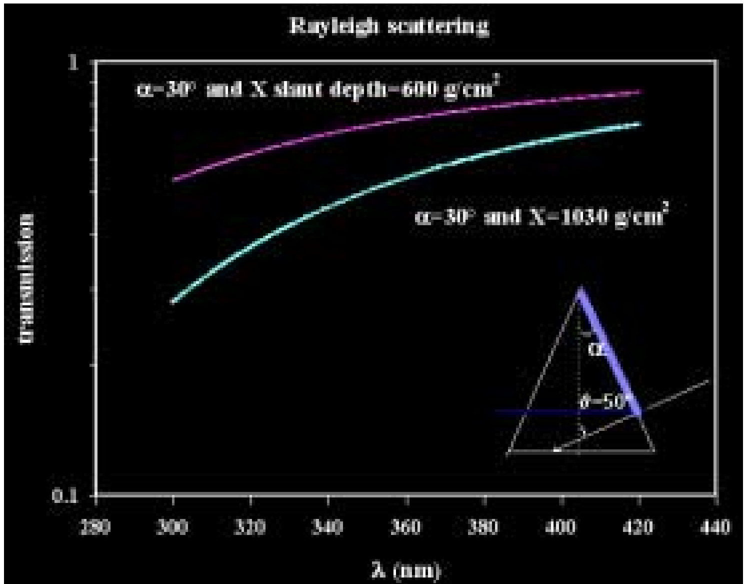
The sum of the three main emission lines give rise to the almost constant fluorescence yield of 4.7 ph/(m×particle).
In view of the different absorption power, the yield has however to be kept separated.

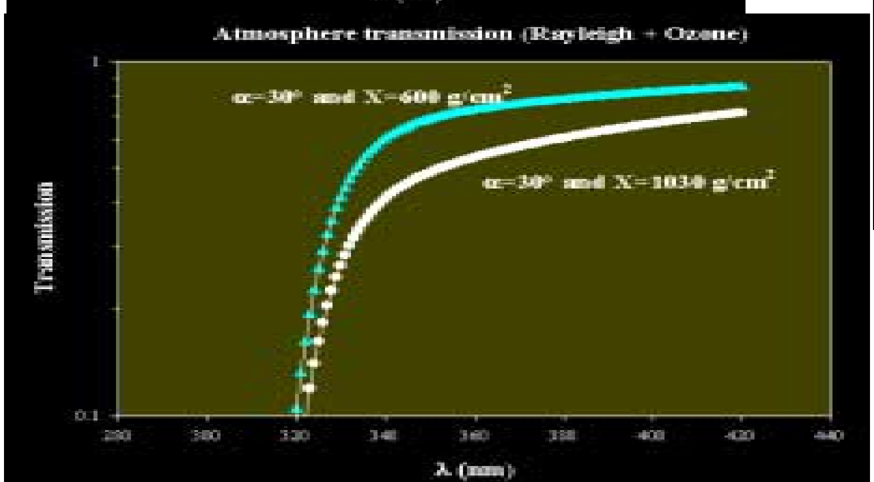


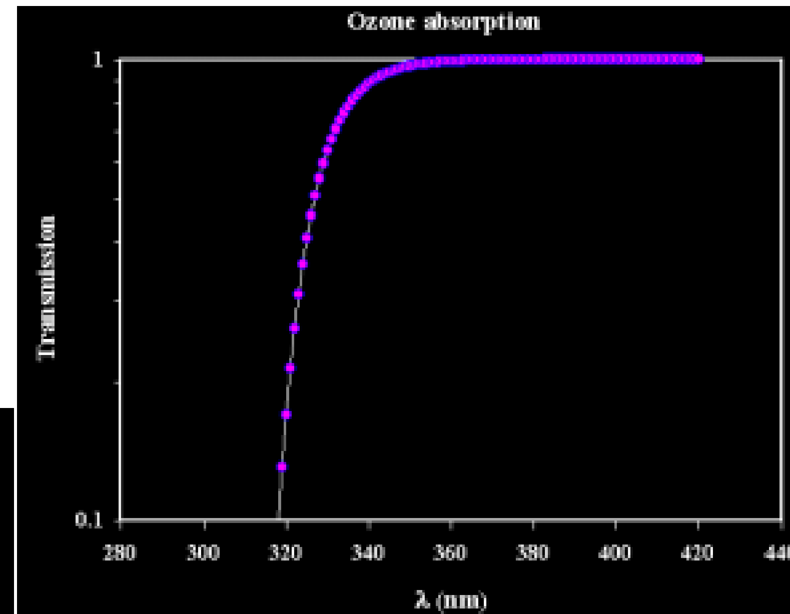
# THE NATURAL DETECTOR

## EARTH ATMOSPHERE




The converter/absorber property of the Earth atmosphere




**The main effects to the scattering and absorption of light in the atmosphere, after Fly’s Eye assumptions.**

# EUSO Simulation

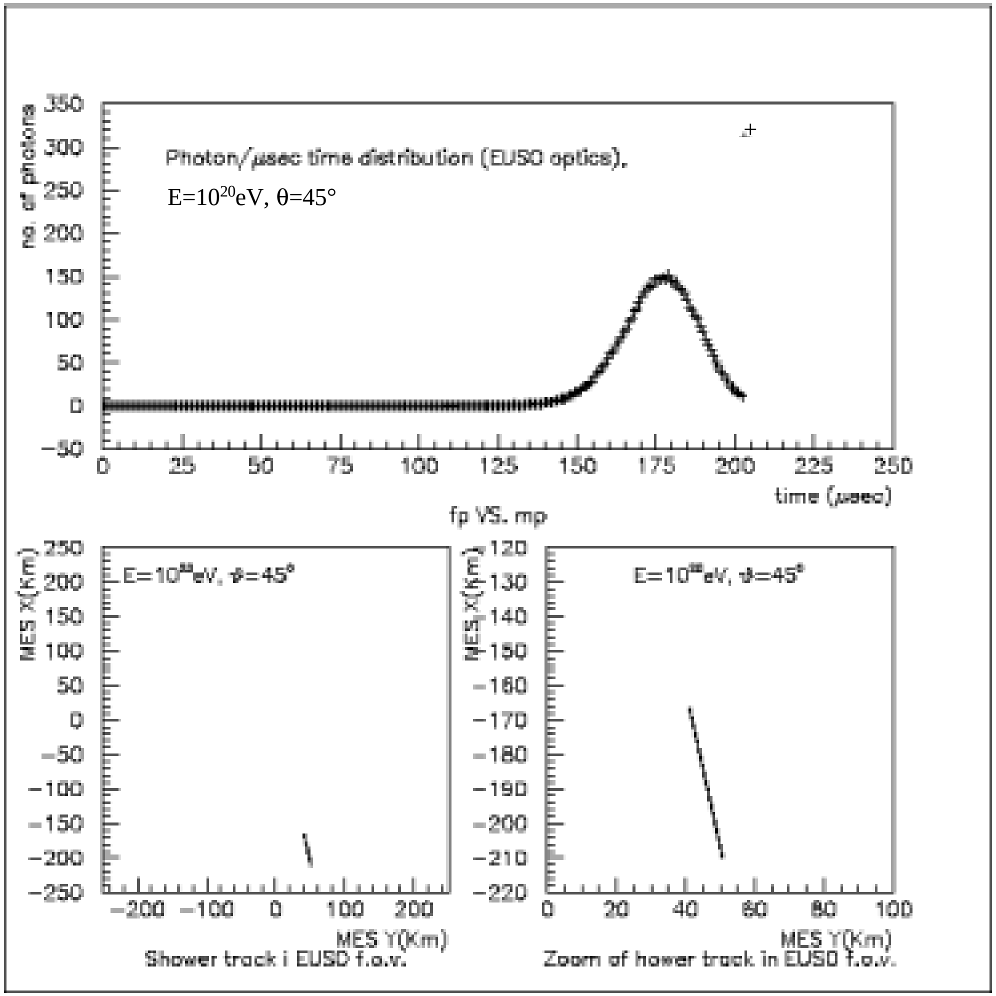
A - typical shower in the EUSO Main Reference system, as it appears to the optical collector.

Its time profile:

Its space pattern:

In the full f.o.v.

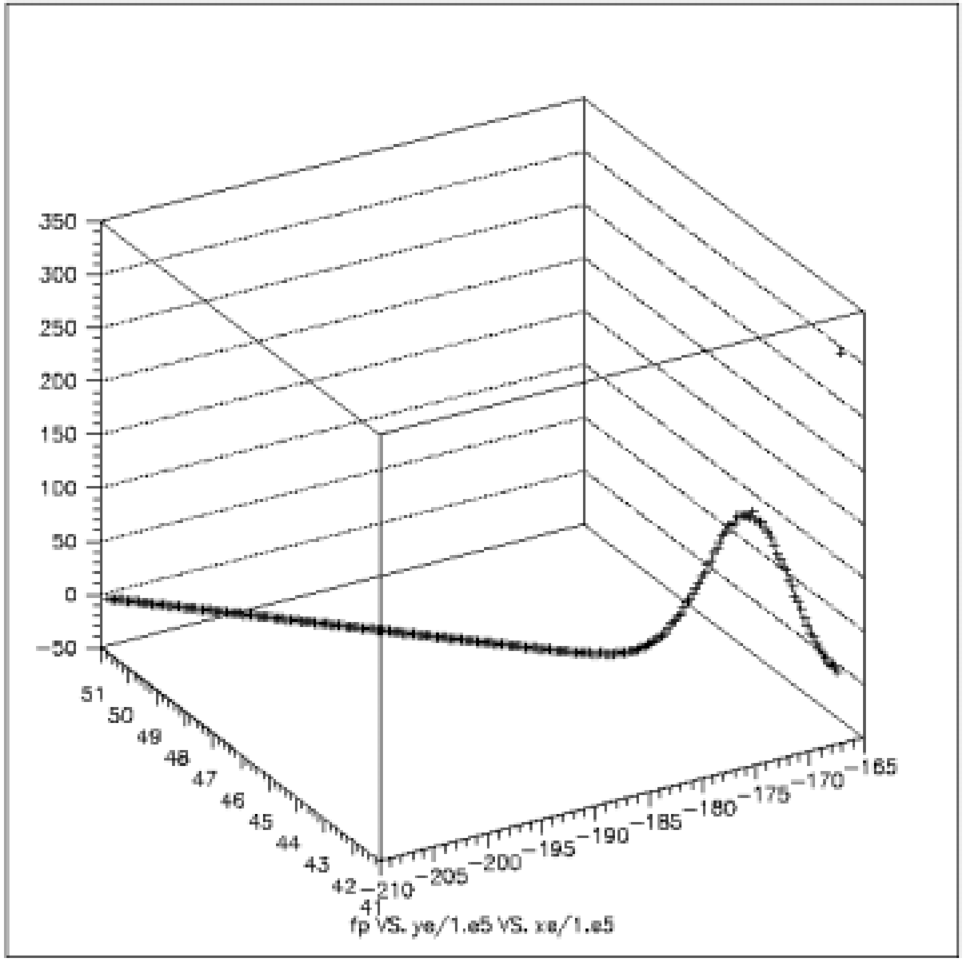
With a 1Km×1Km pixelisation



# EUSO Simulation

A three dimensional view of a – typical shower :

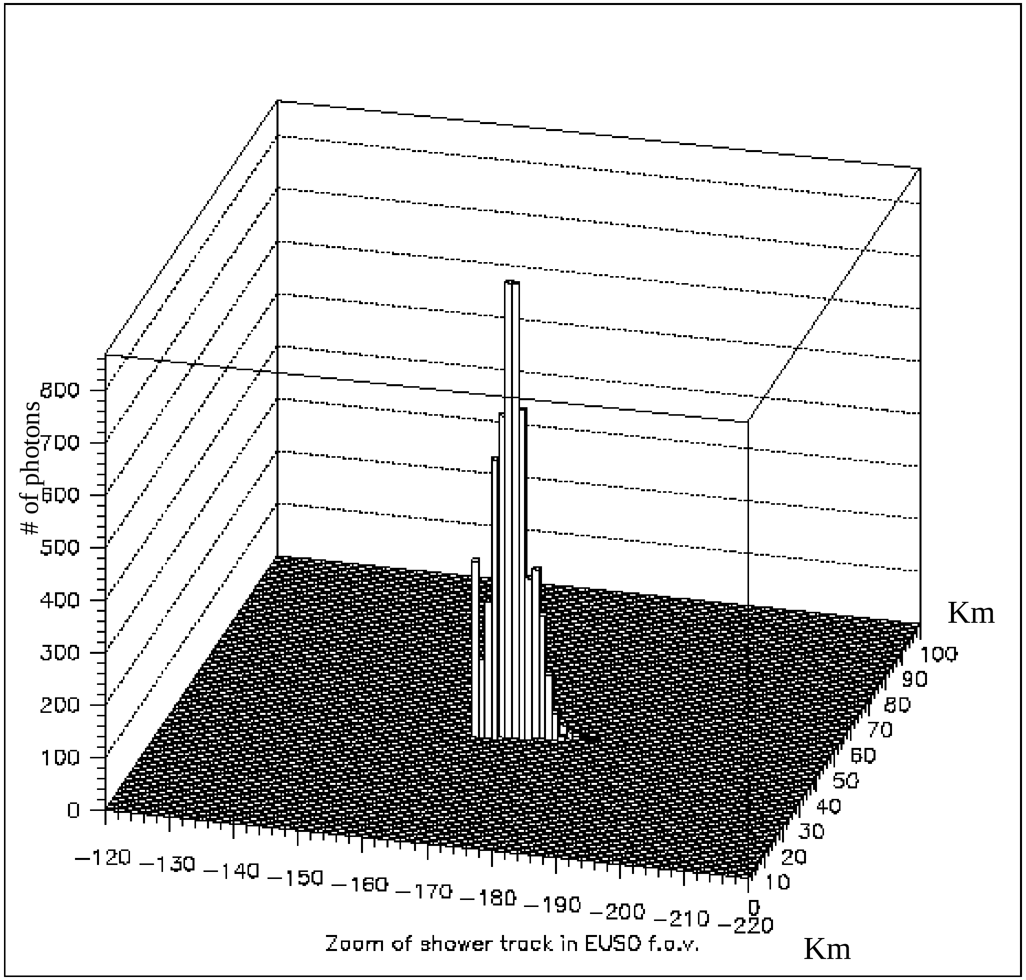
The expected number of photons collected by the optical system in each track segment corresponding to a GTU is shown on the z-axis. On x and y axes the x and y position of the shower in the f.ov., in the MES Reference system.



# EUSO Simulation

A pictorial view of the shower in the EUSO f.o.v..

The pixel size is 1Km×1 Km.

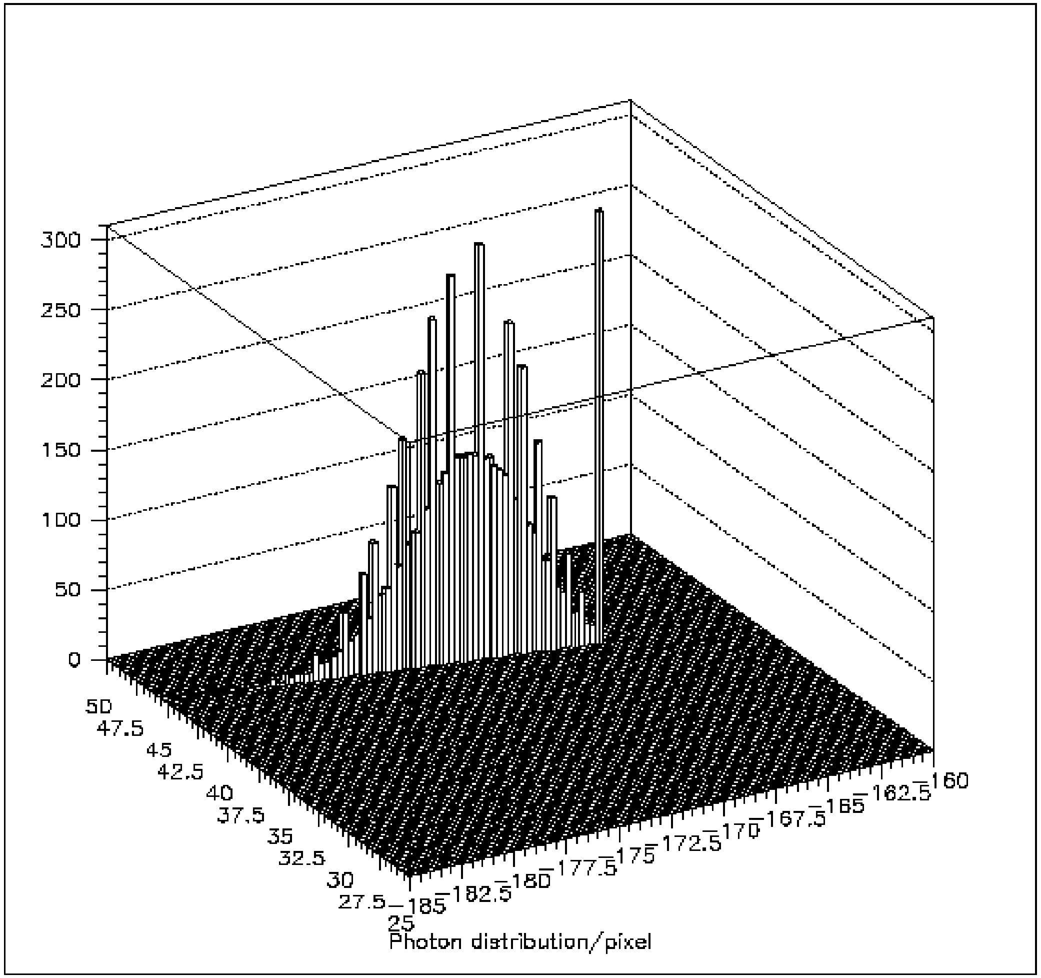


# EUSO Simulation

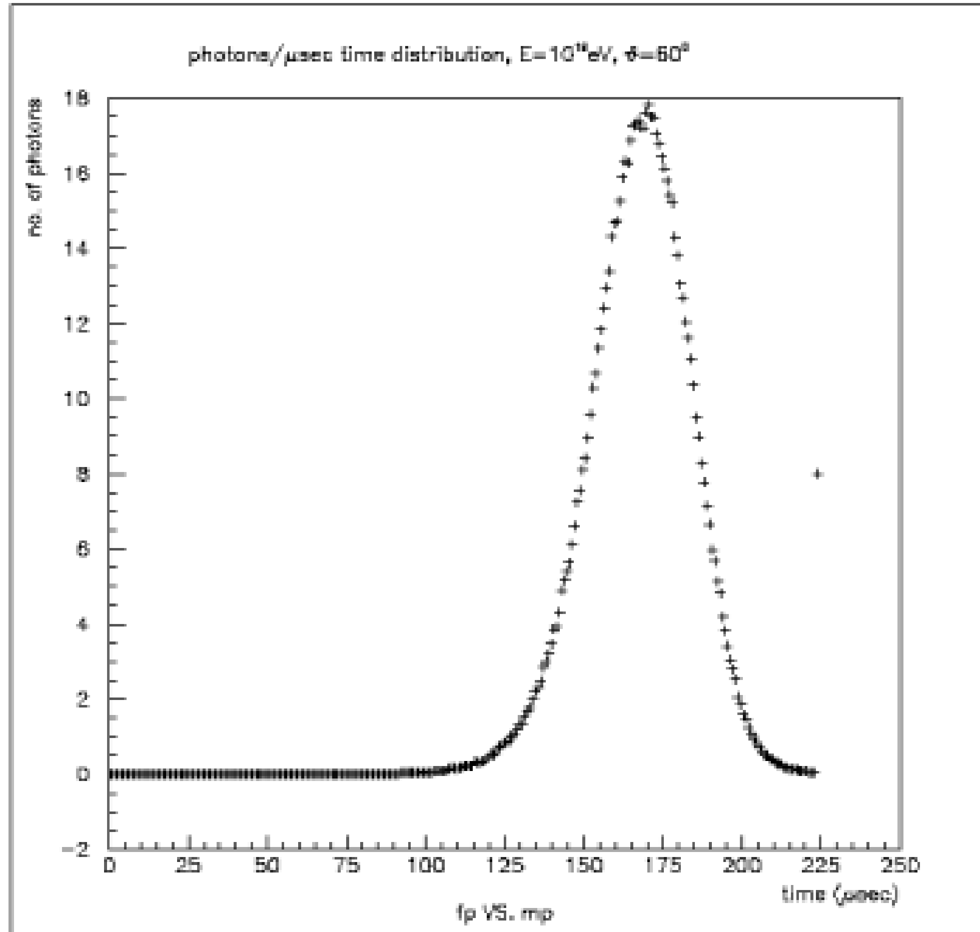
A pictorial view of the shower in the EUSO f.o.v..

The pixel size is 250m×250m, Comparable to the “GTU” size.

From a spectrum like this one, the detector simulation has to provide the expected signal, as in preliminary simulation work.



# EUSO Simulation



# EUSO Simulation Subsystem

- On-going work
  - ✓Standard EUSO Ref. Sys Definition
  - ✓Standard EUSO File Format and Distribution System
  - ✓EECR, CORSIKA/Fluorescence/ Detector Simulation Interface
  - ✓EECR, GIL/Fluorescence/Detector Simulation Interface
  - ✓EECR,ν, UNISIM/Fluorescence/Detector Simulation
  - ✓Common Software Environment definition (coord. with Data Analysis Subs.)
  - ✓Atmosphere description and transport algorithms improvement
  - ✓Detector simulation model, fast

- Planned work
  - ✓ν, CORSIKA full simulation
  - ✓Detector simulation model, full
  - ✓Reconstruction algortihms improvement( coord. with Data Analysis Subs.)
  - ✓Cerenkov Ocean/Forest/Desert/Ground/CloudsReflected signal simulation (coordinated work with Bkg., Env. and Atm. Sound. Subsystem)

# Conclusions

Phase A requirements as far as simulation is concerned:

**EUSO expected performances:**

- Criticality to atmosphere parameter knowledge.
- Criticality to background level.
- Expected effect of clouds.
- Cerenkov signal acceptance/efficiency improvement.
- Energy resolution.
- Position/direction resolution improvement.

(Common work with Data Analysis)

**Input needed from other subsystems**

- Detector simulation
- Atmosphere measurements and modeling

**Output to other subsystems**

- Data Analysis
- Detector Design