Software per Esperimenti di Fisica Astroparticellare

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LECCE

Seminario sul Software per la Fisica Nucleare,
Subnucleare e Applicata

Alghero, 4-9 giugno 2008

Contents

- Astroparticle Physics
- A specific case: Cosmic Ray Physics
- Example #1: ARGO-YBJ inTibet
- Example #2: AUGER in Patagonia

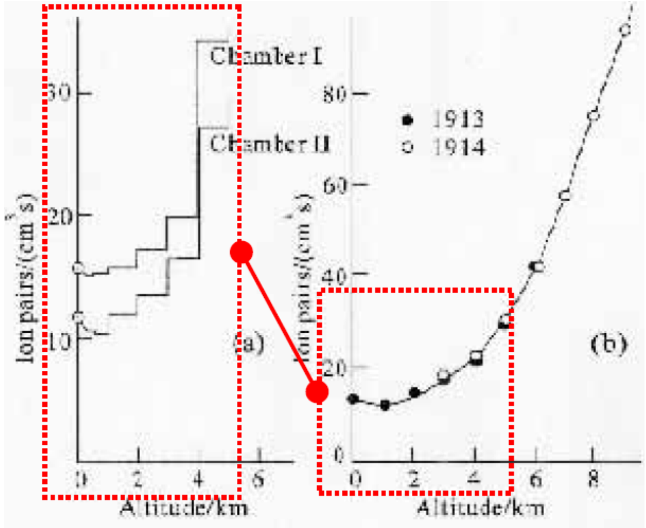
Astroparticle Physics

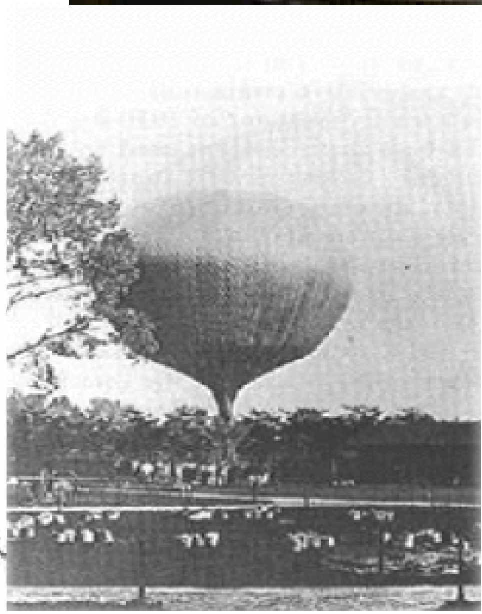
- Cosmic Rays
- Atmospheric neutrinos
- Solar neutrinos
- Supernova neutrinos
- Dark matter searches
- High energy neutrino astronomy
- Very high energy gamma ray astronomy
- Gravitational waves
- Exotica: axions, proton decay, magnetic monopoles, …
- …

Cosmic

Rays

..the beginning





MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

PROF. RUSSELL ELECTED

Astronomer Heads Association—Secret of Purple Gold in Tomb of Tut-ankh-Amen Rediscovered.

By WILLIAM L. LAURENCE.
Special to THE NEW YORK TIMES.

ATLANTIC CITY, Dec. 30.—Professor Robert A. Millikan, who won the Nobel Prize in physics for being

MILLIKAN DENIES 'CLASH' ON THEORY

Scientist Protests That the Word 'Incautious' Was Not Aimed at Compton.

DISCLAIMS ANY COOLNESS

Holds The Times Report Stated *"Exactly the Opposite"* of the Findings He Presented.

By Telegraph to the Editor of THE NEW YORK TIMES.

WASHINGTON, D. C., Dec. 31.—It is not customary for me to attempt to correct erroneous newspaper reports, and that for the simple reason that with many newspapers it is a well-nigh hopeless undertaking. But THE NEW YORK TIMES is usually so dependable that I assume it will welcome correction and also will know how to effect the remedy for its error.

MILLIKAN'S DATA CONFIRM COMPTON

Results of Cosmic Ray Study at Panama Tend to Back Rival's Ideas.

RAY INTENSITY VARIES

Strength Is Greater at the Poles—Equatorial Tests Are Now Projected.

PASADENA, Cal., Feb. 4 (AP).—The stratosphere above equatorial regions of the earth should be the next scene of exploration in the quest of the secrets of the cosmic ray, Dr. Robert A. Millikan said here today.

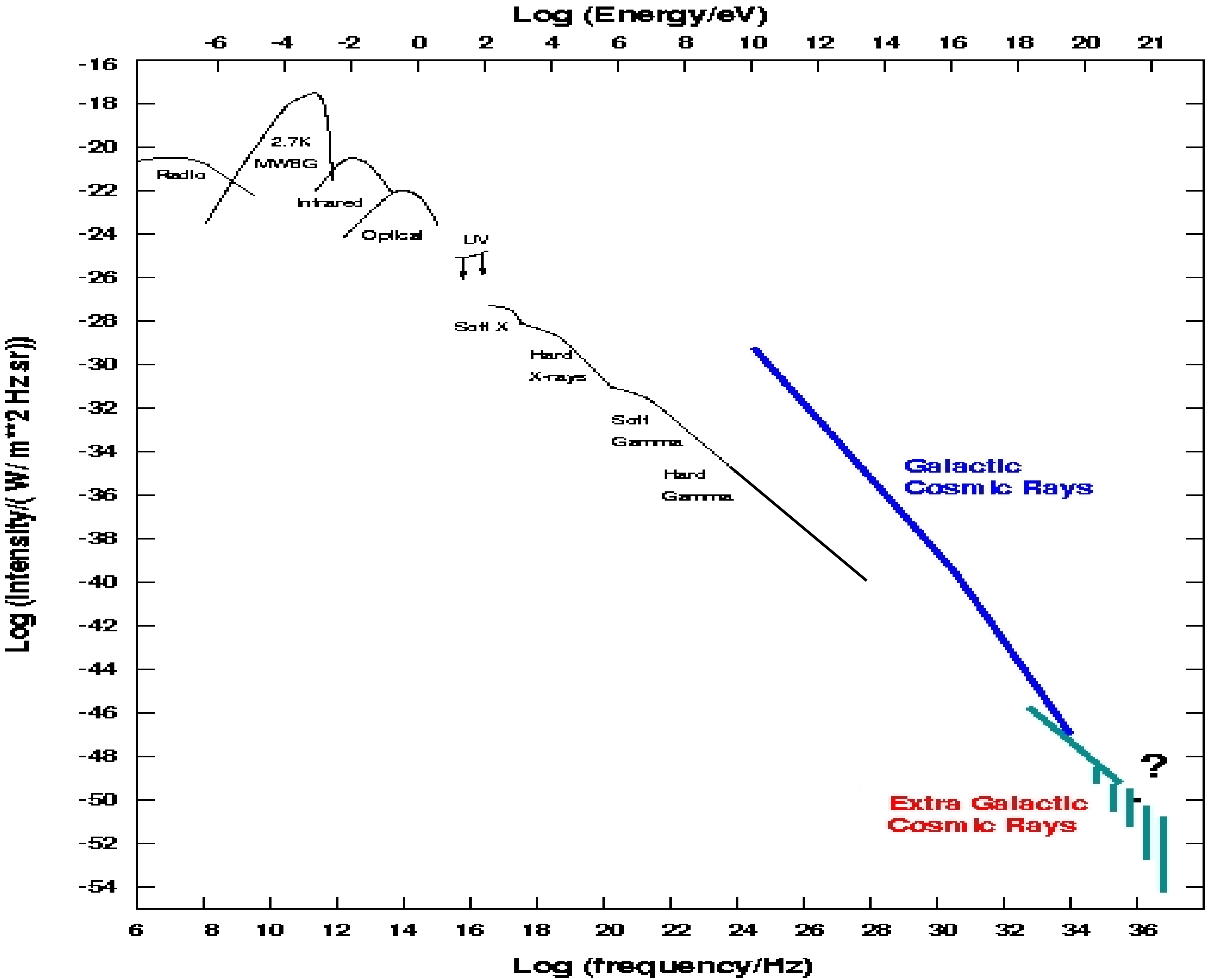
Announcing that observations of his co-workers at Panama confirmed the earlier reports of Dr. Arthur H. Compton of Chicago that the rays from interstellar space showed latitude effects, Dr. Millikan disclosed that the variance was as high as 8 per cent.

Questions

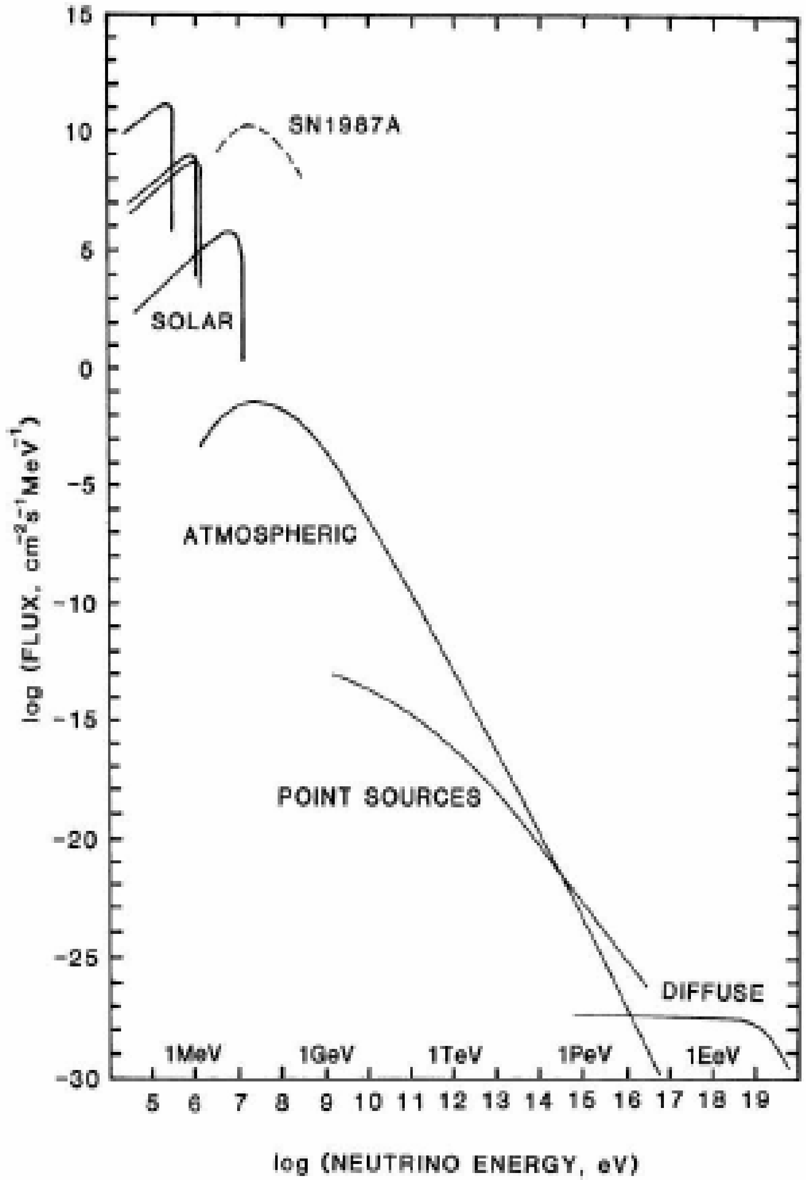
- What are cosmic ray sources ?
- How do cosmic accelerator work ?
- What are the propagation mechanisms ?
- New physics at high energies ?
- …

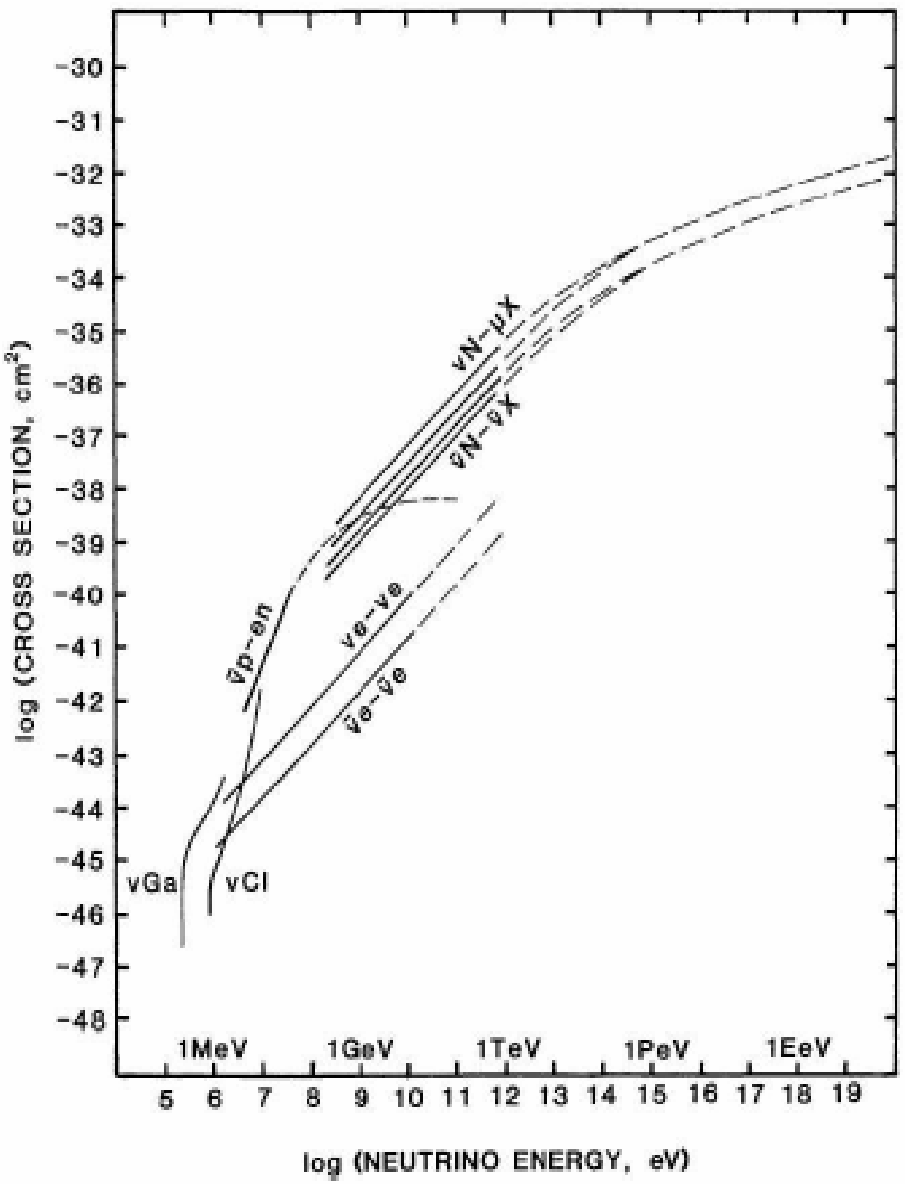
Observables

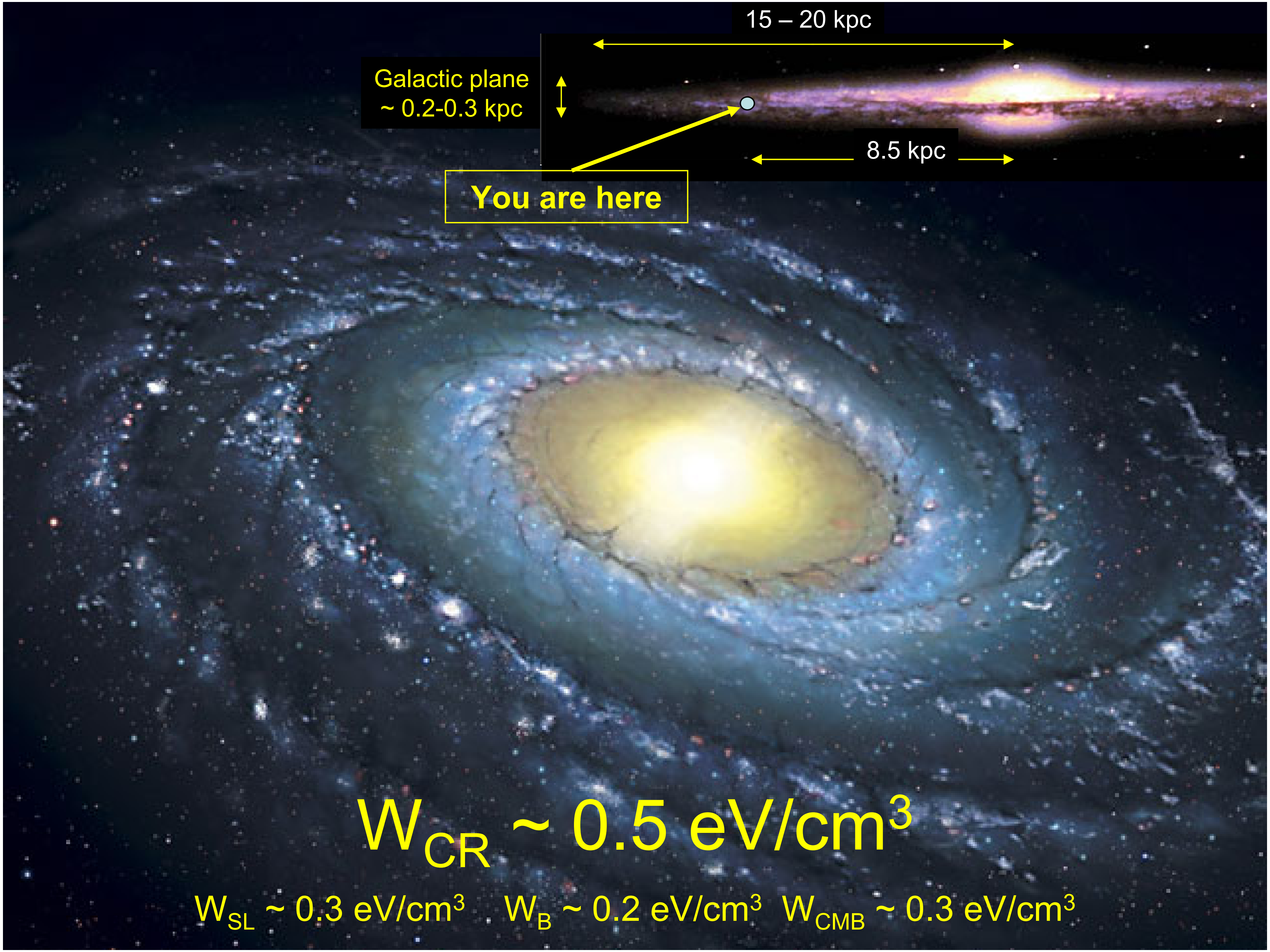
- Energy spectra
- Arrival directions
- Primary particle ID
- …………


Log (Energy/eV)
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
21
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
-42
-44
-46
-48
-50
-52
-54
Log (Intensity/(W/ m**2 Hz sr))
2.7K
MWBG
Radio
Infrared
Optical
UV
Soft X
Hard
X-rays
Soft
Gamma
Hard
Gamma
Galactic
Cosmic Rays
?
Extra Galactic
Cosmic Rays
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Log (frequency/Hz)

…and neutrinos



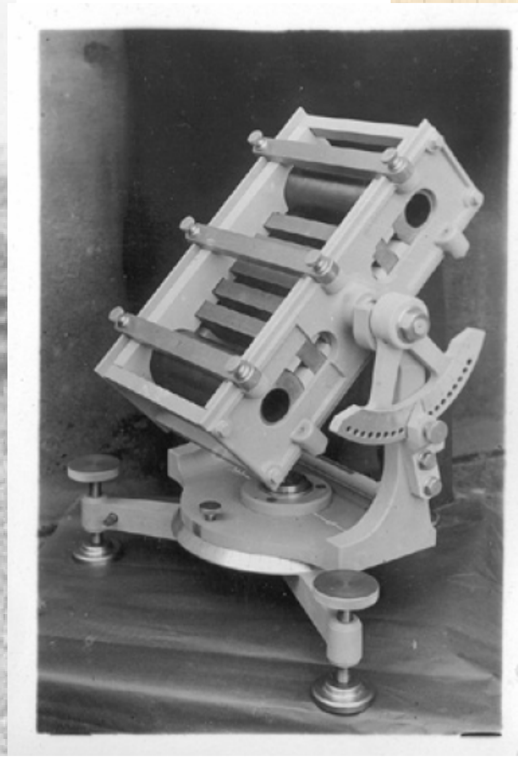


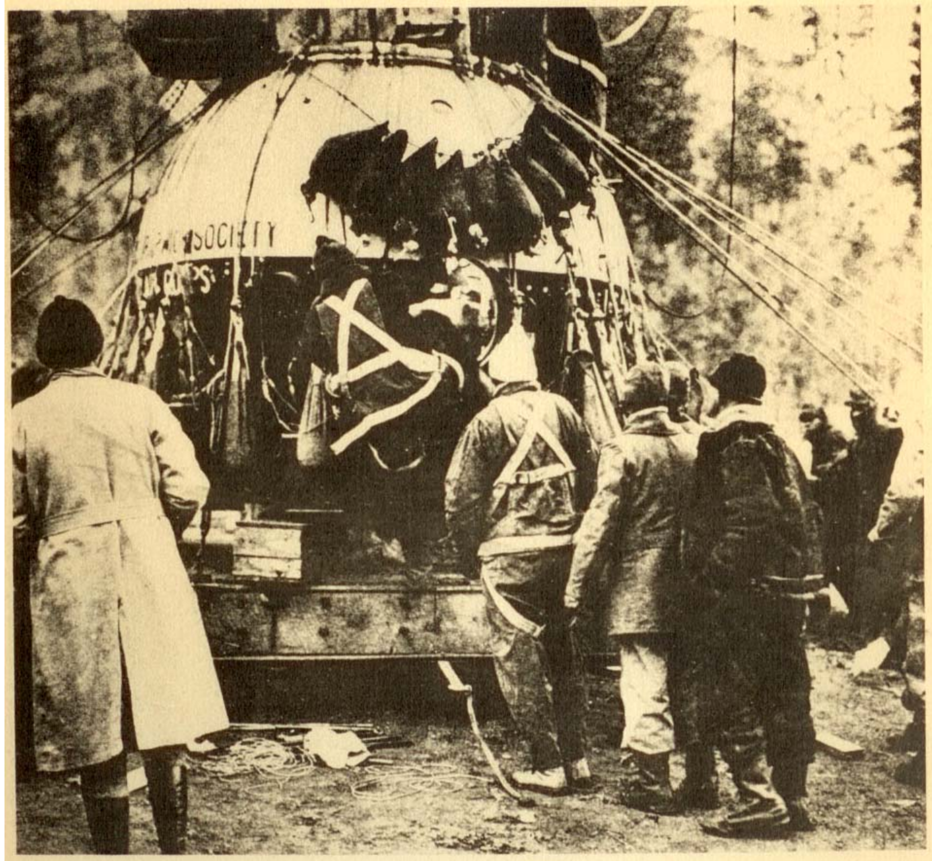

15 – 20 kpc
Galactic plane
~ 0.2-0.3 kpc
8.5 kpc
You are here
$W_{CR} \sim 0.5$ eV/cm^3
$W_{SL} \sim 0.3$ eV/cm^3
$W_B \sim 0.2$ eV/cm^3
$W_{CMB} \sim 0.3$ eV/cm^3

The Italians :

Fermi, Rossi, Occhialini, Conversi, ...

“ parrebbe … che di tanto in tanto giungessero sugli apparecchi degli sciami molto estesi di corpuscoli i quali determinavano coincidenze fra contatori, anche piuttosto lontani l’uno dall’altro. Mi è mancato purtroppo il tempo di studiare più da vicino questo fenomeno …”
Bruno Rossi, Asmara (Eritrea) 1933



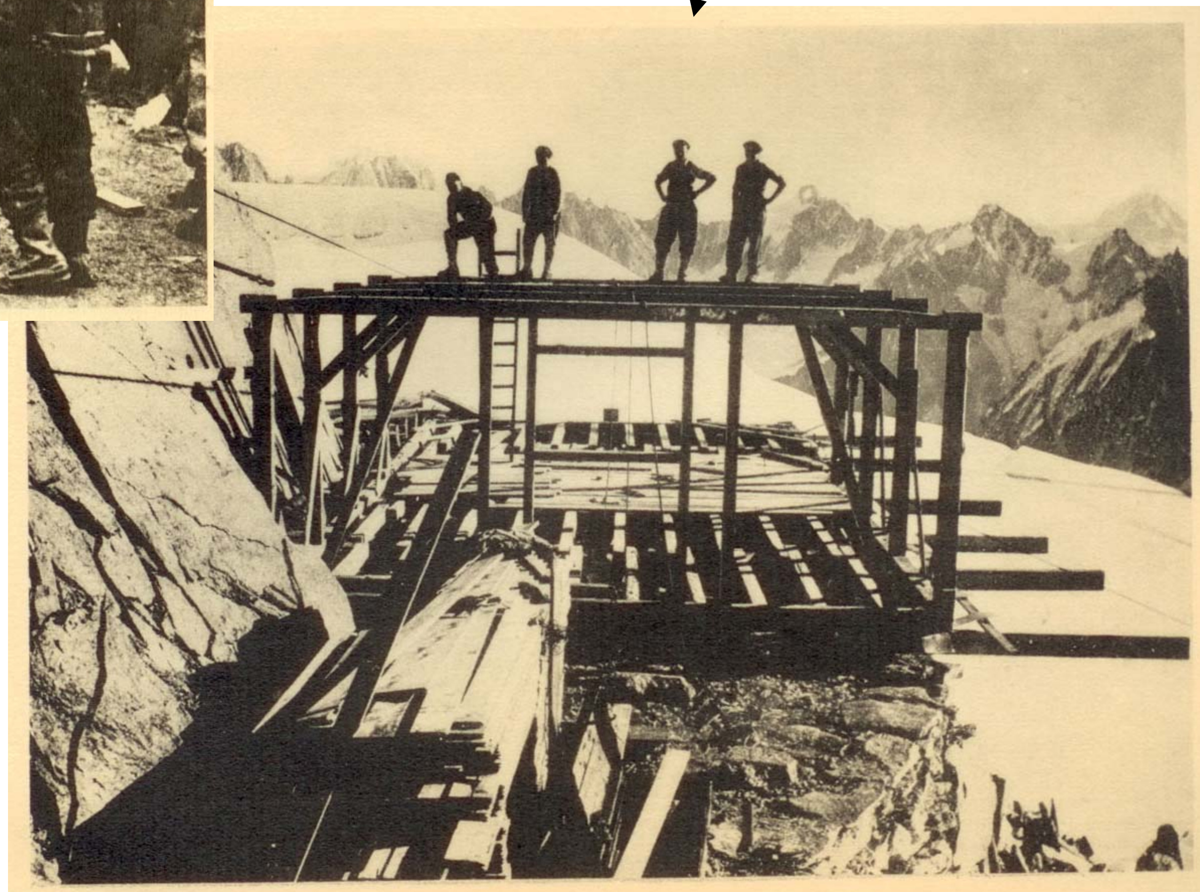


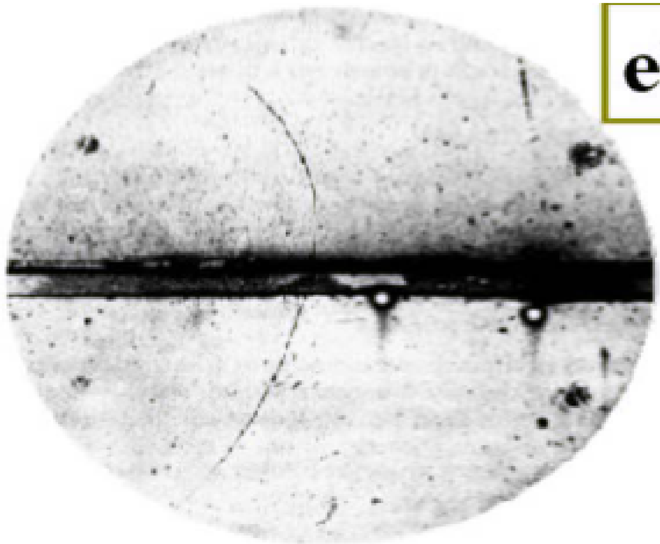
1935

Explorer II . 22000 m

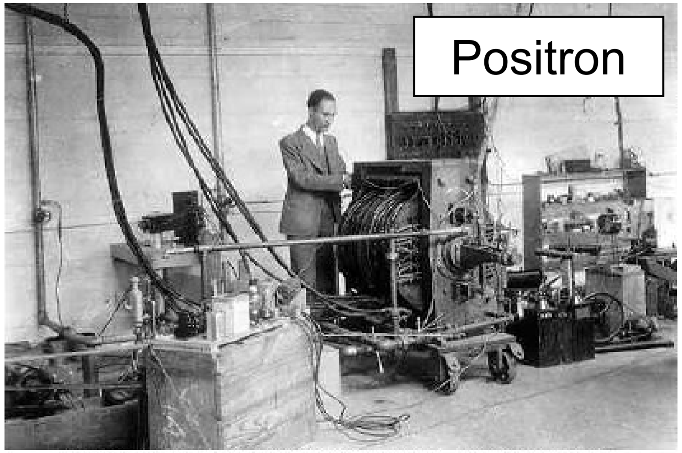
1942

Aiguille du Midi - Chamonix 3650 m

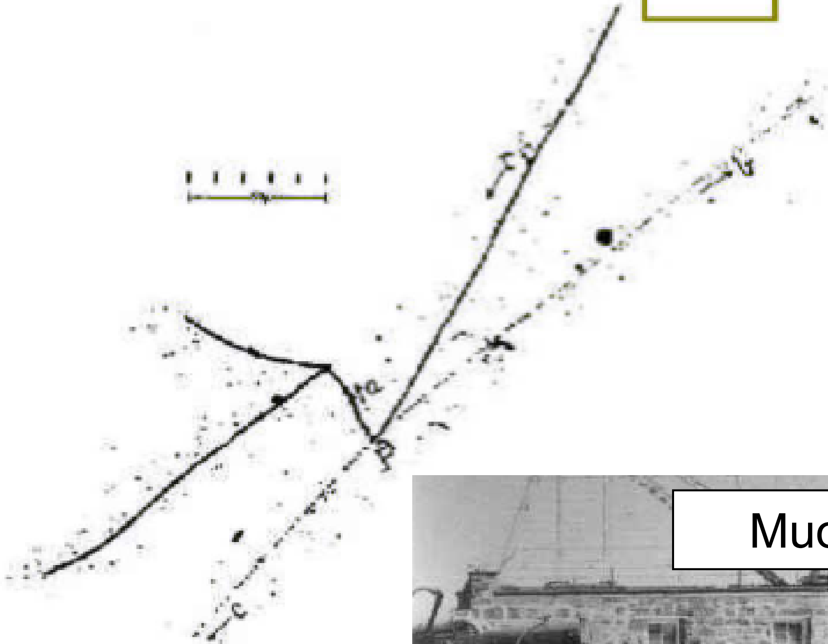


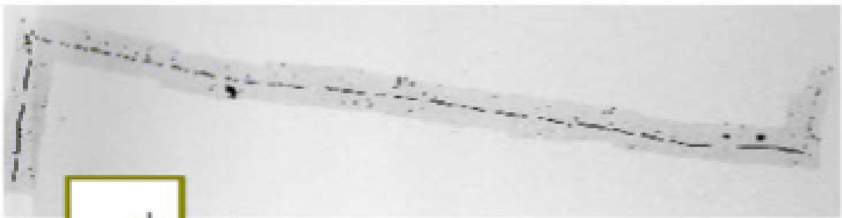


e^+

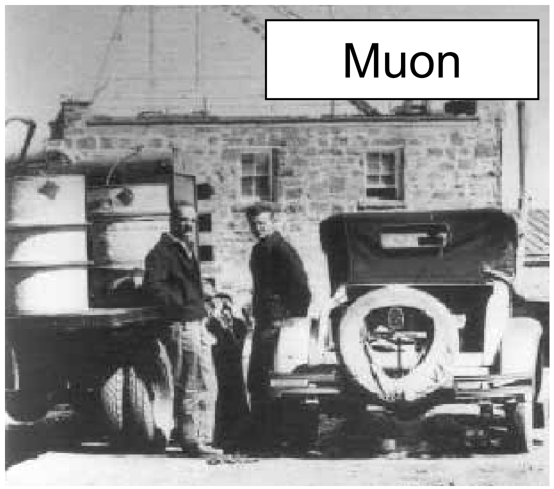


$K^\pm$





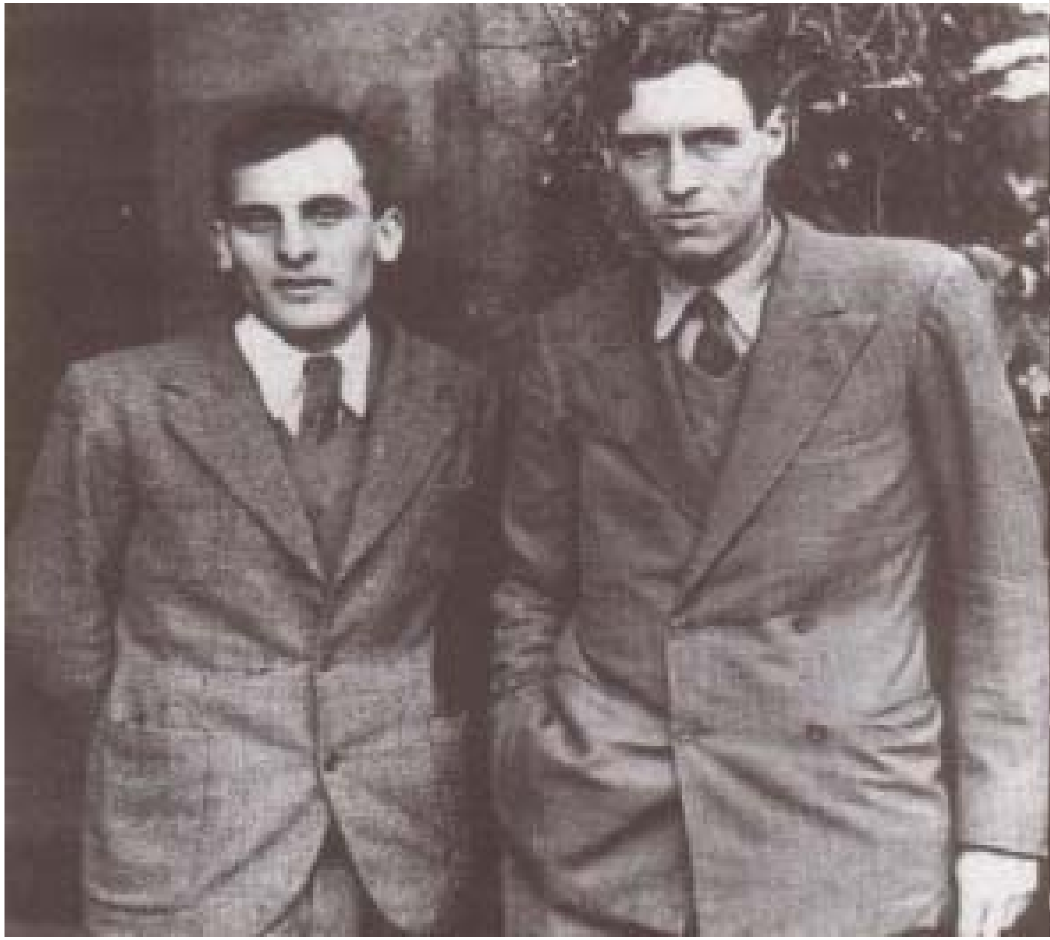
$\pi^\pm$

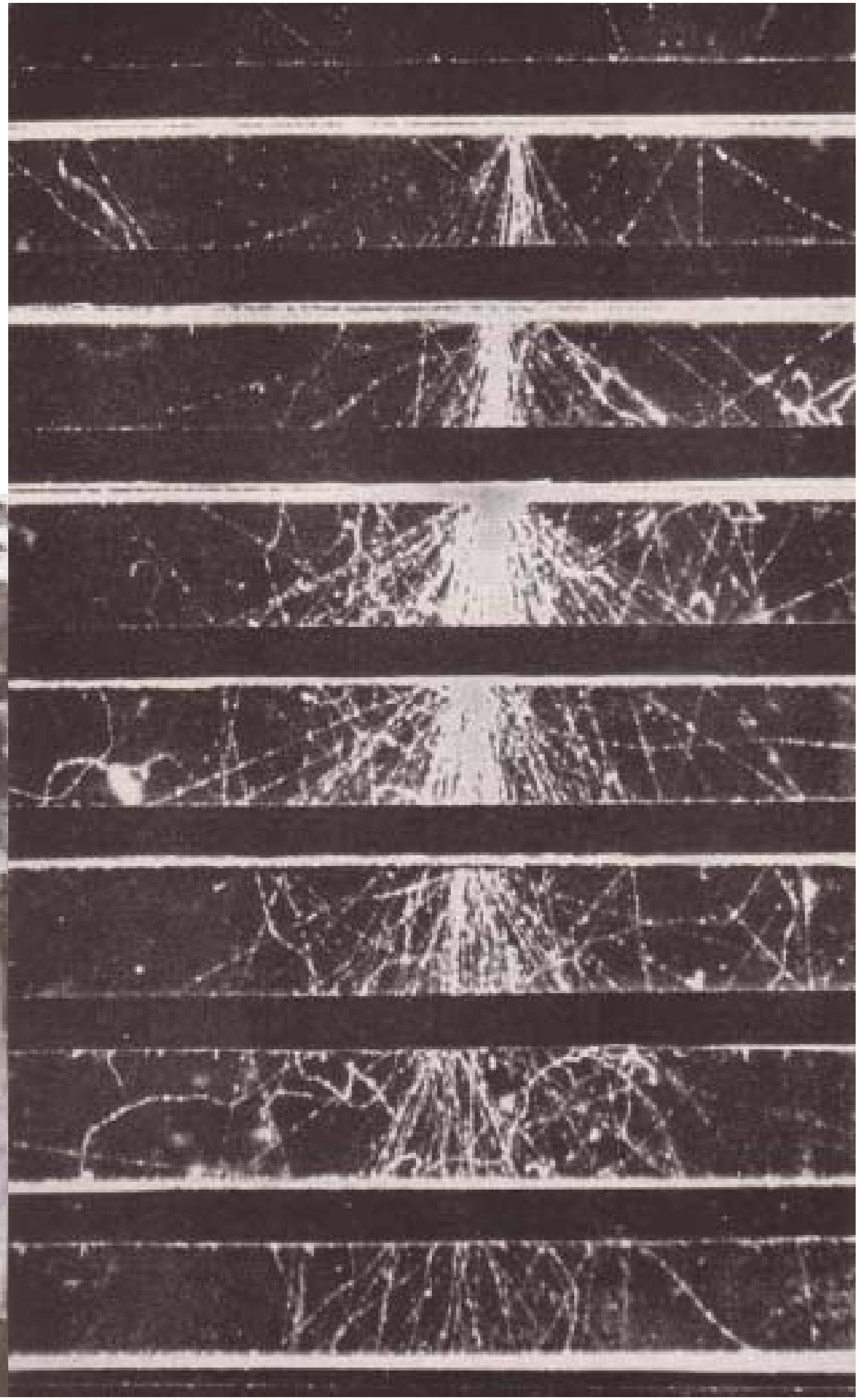


Particle	Year	Discoverer (Nobel Prize)	Method
e^-	1897	Thomson (1906)	Discharges in gases
p	1919	Rutherford	Natural radioactivity
n	1932	Chadwik (1935)	Natural radioactivity
e^+	1933	Anderson (1936)	Cosmic Rays
$\mu^\pm$	1937	Neddermeyer, Anderson	Cosmic Rays
$\pi^\pm$	1947	Powell (1950) , Occhialini	Cosmic Rays
$K^\pm$	1949	Powell (1950)	Cosmic Rays
π^0	1949	Bjorklund	Accelerator
K^0	1951	Armenteros	Cosmic Rays
Λ^0	1951	Armenteros	Cosmic Rays
Δ	1932	Anderson	Cosmic Rays
Ξ^-	1932	Armenteros	Cosmic Rays
$\Sigma^\pm$	1953	Bonetti	Cosmic Rays
p^-	1955	Chamberlain, Segre' (1959)	Accelerators
anything else	1955 $\Longrightarrow$ today	various groups	Accelerators
$m_\nu \neq 0$	2000	KAMIOKANDE	Cosmic rays

First showers …

Occhialini uses the word **“sciame”**
talking with Bruno Rossi

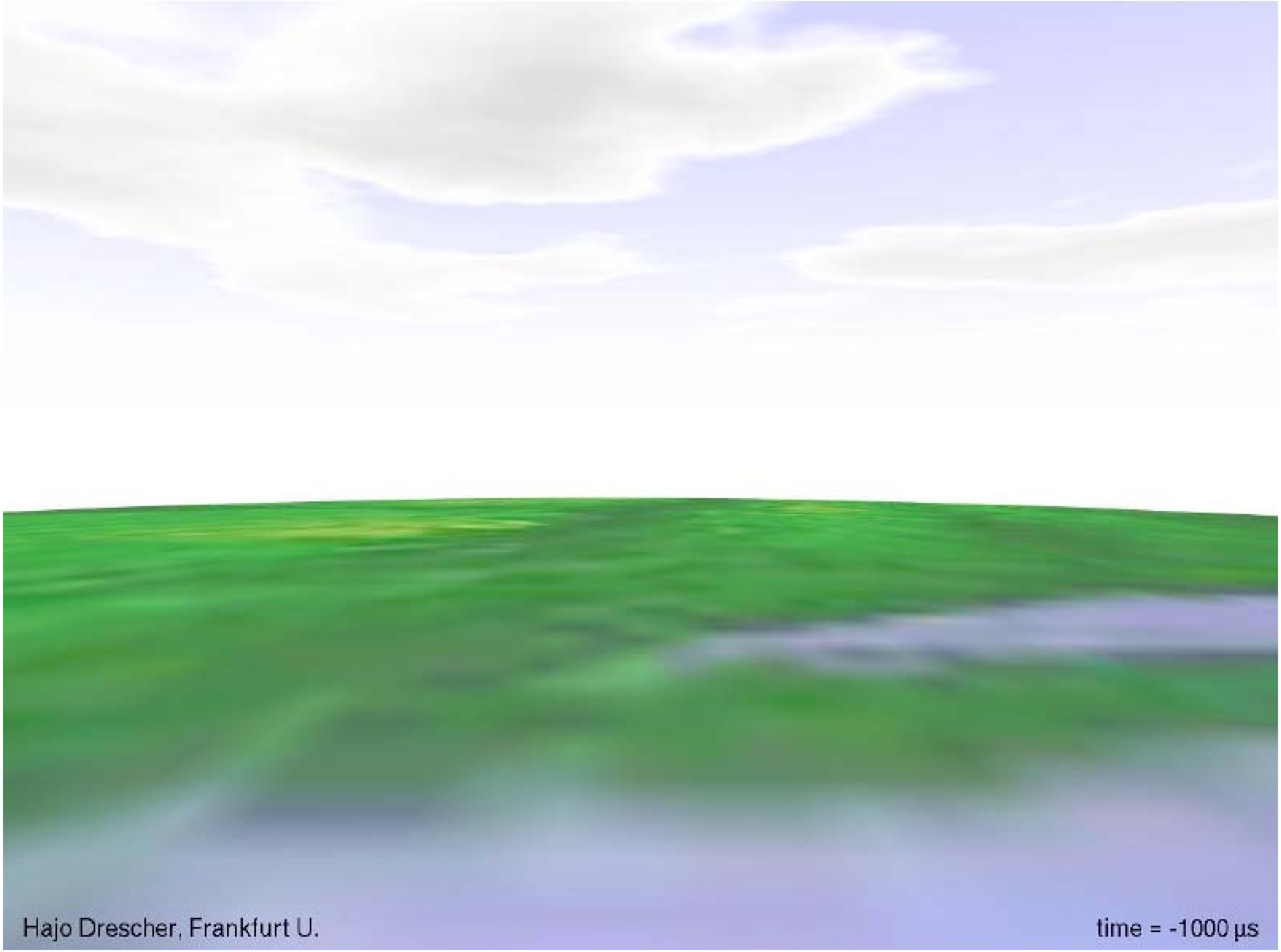


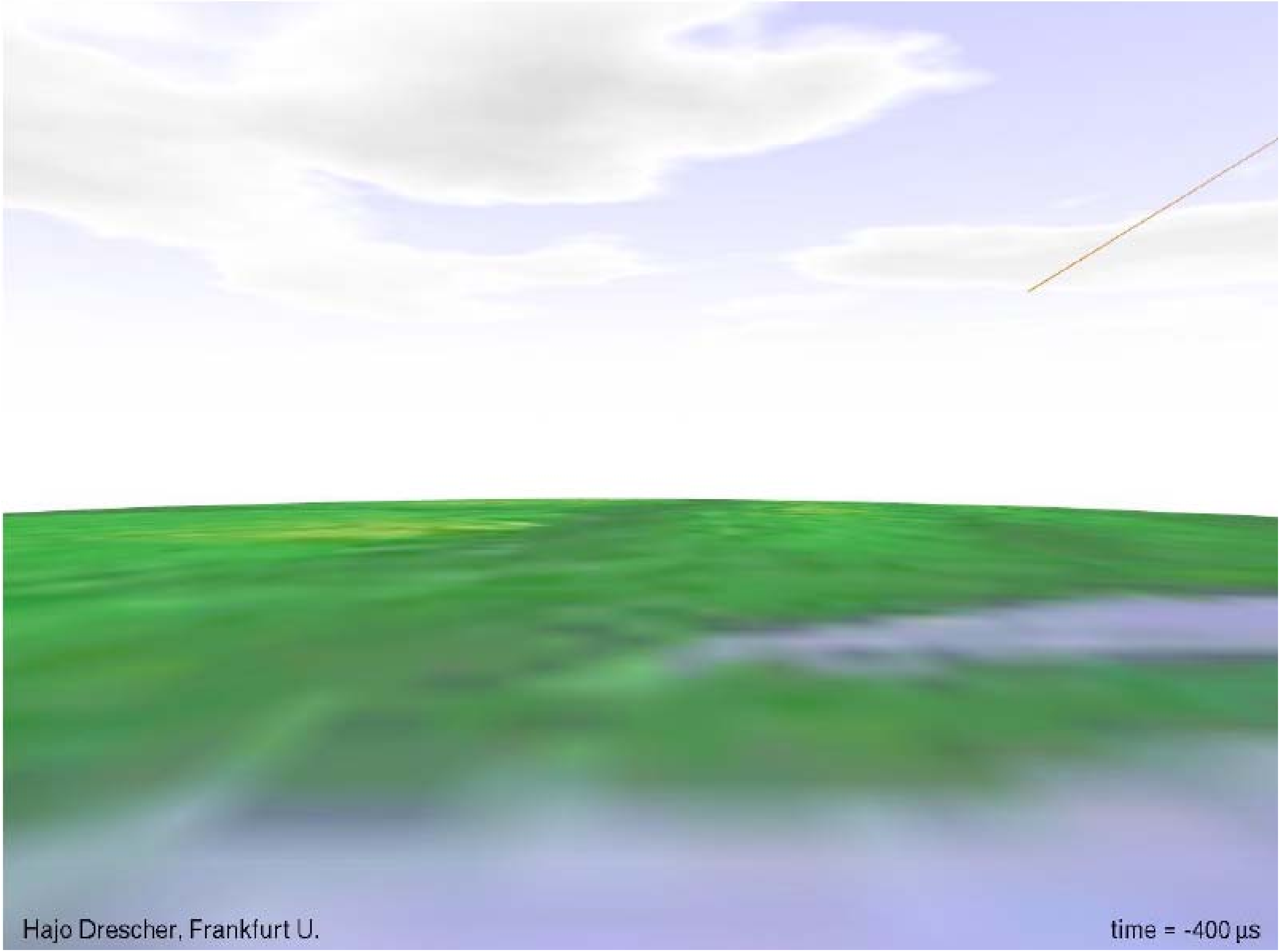


Extensive Air Showers are observed

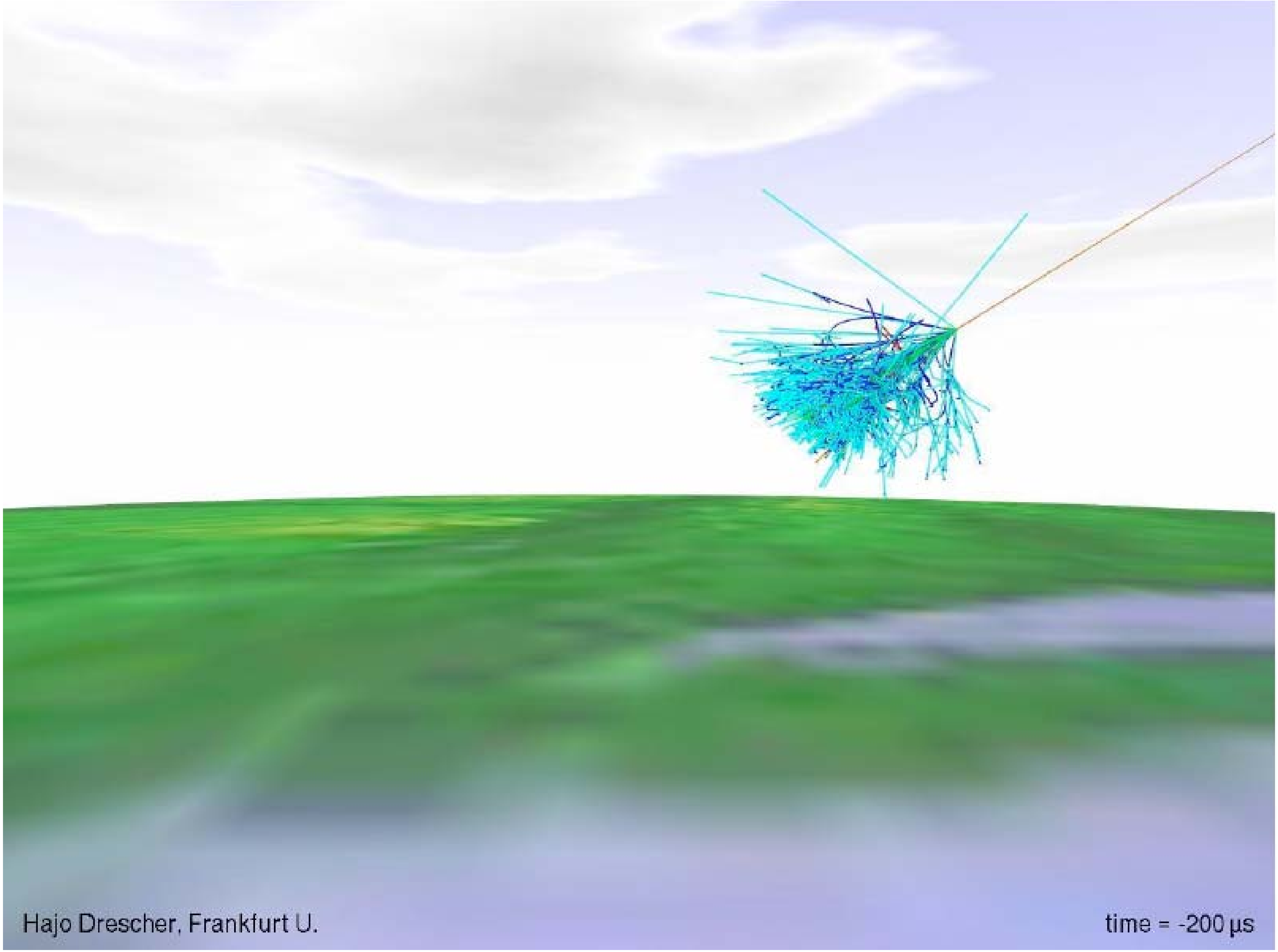
EAS observed with detectors spread over more than 100m distances

First event with E > 10^{19} eV


Hajo Drescher, Frankfurt U.
time = -1000 µs


Hajo Drescher, Frankfurt U.
time = -400 µs


Hajo Drescher, Frankfurt U.
time = -300 µs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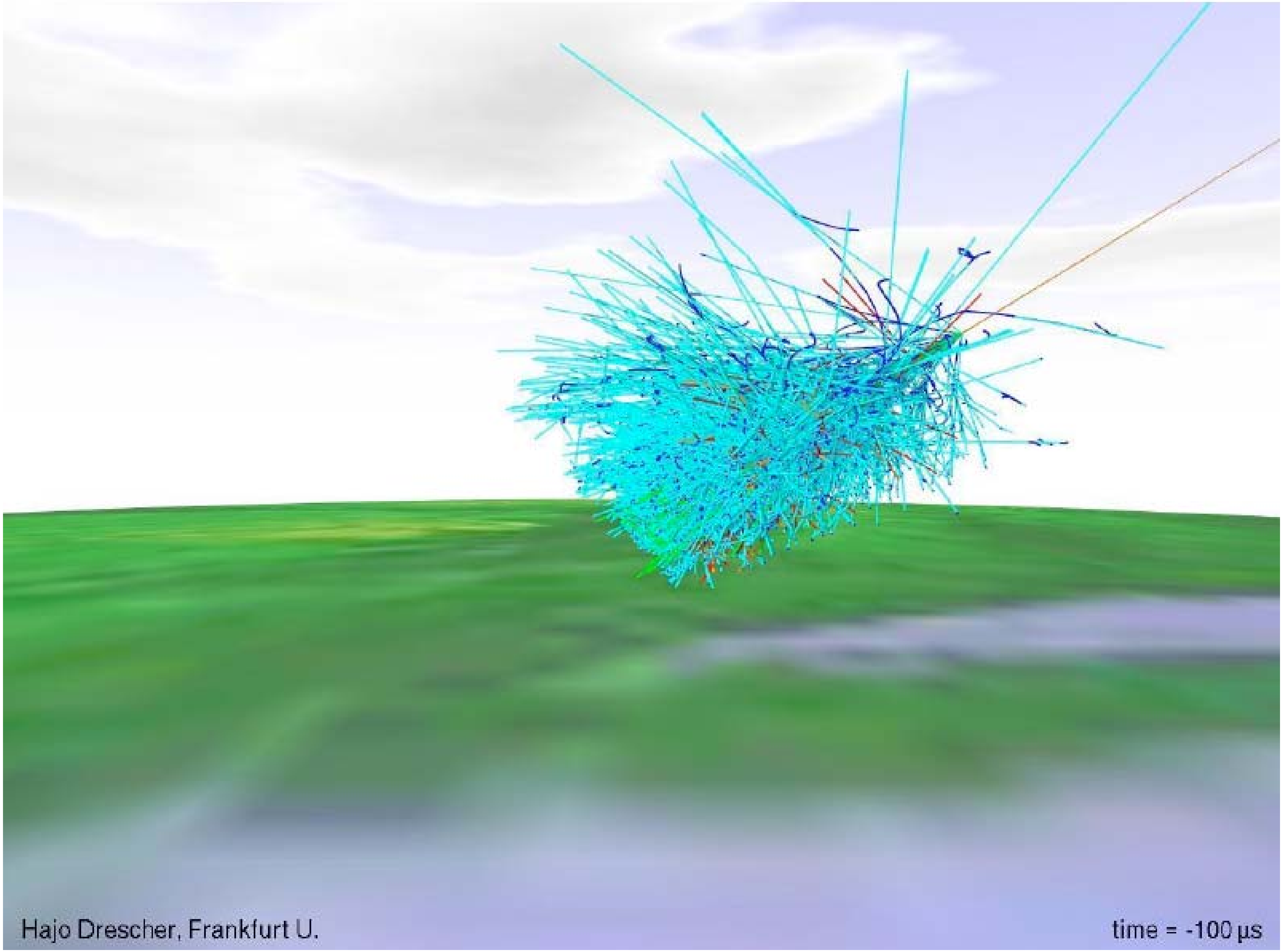
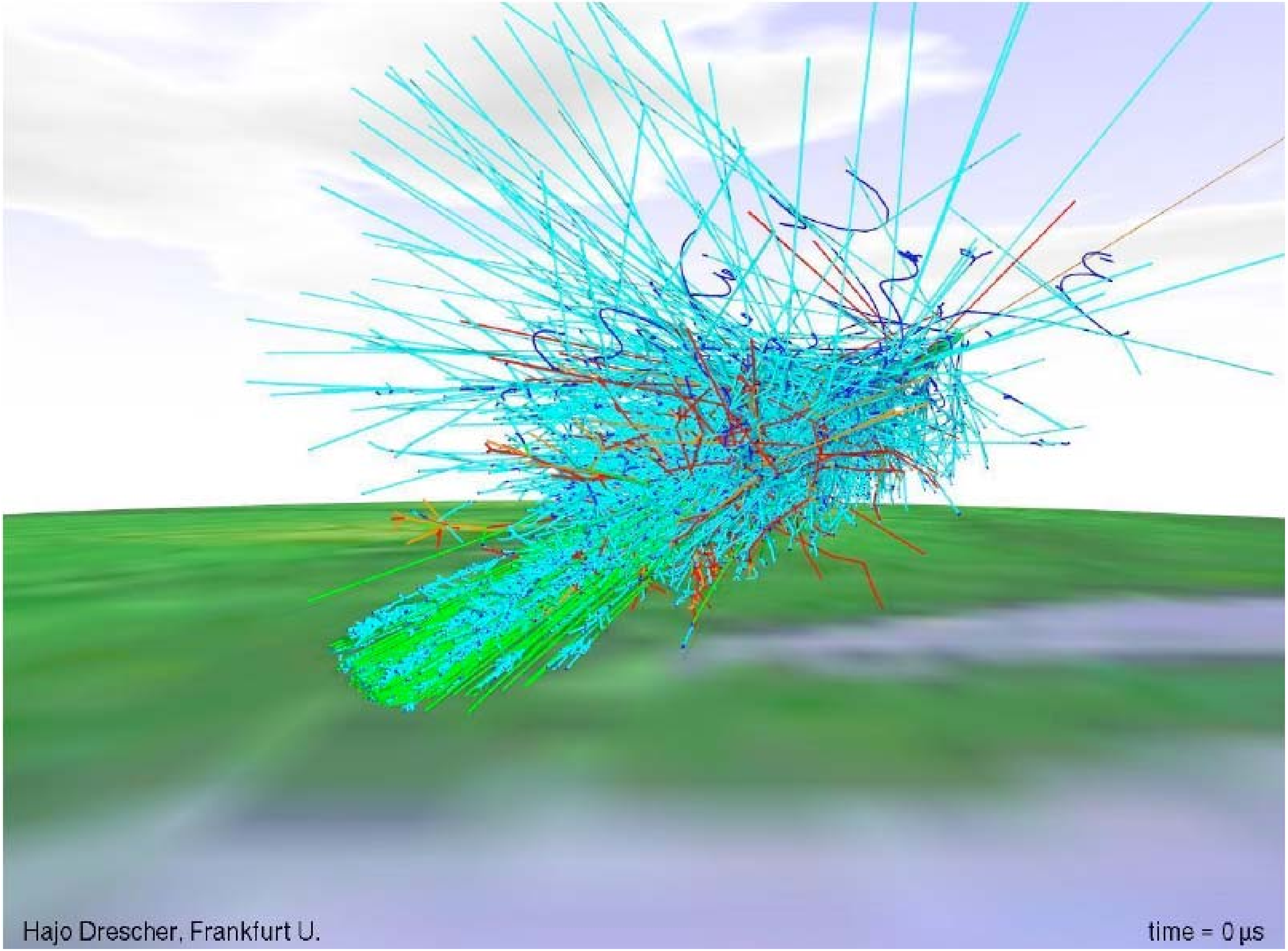
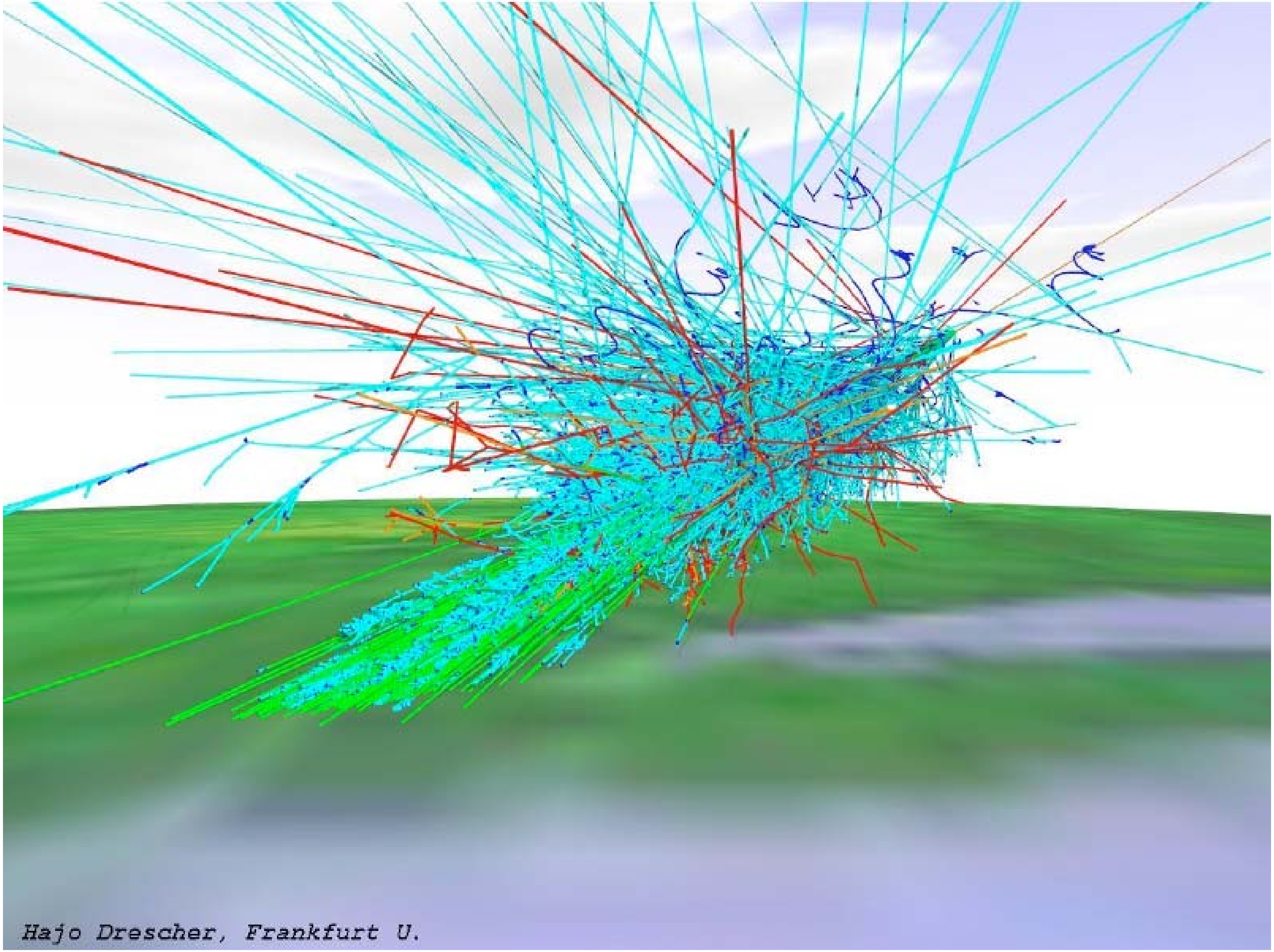
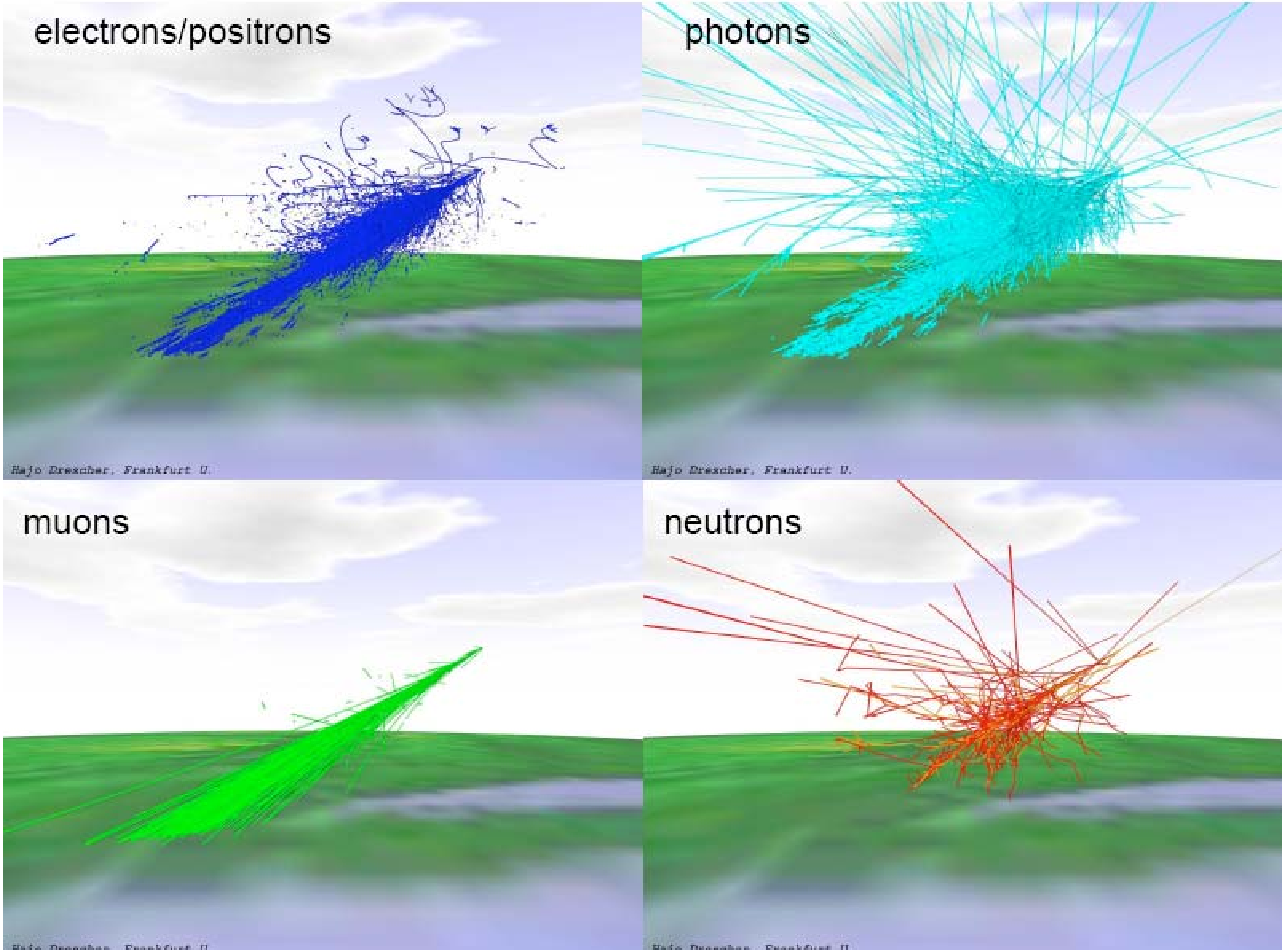
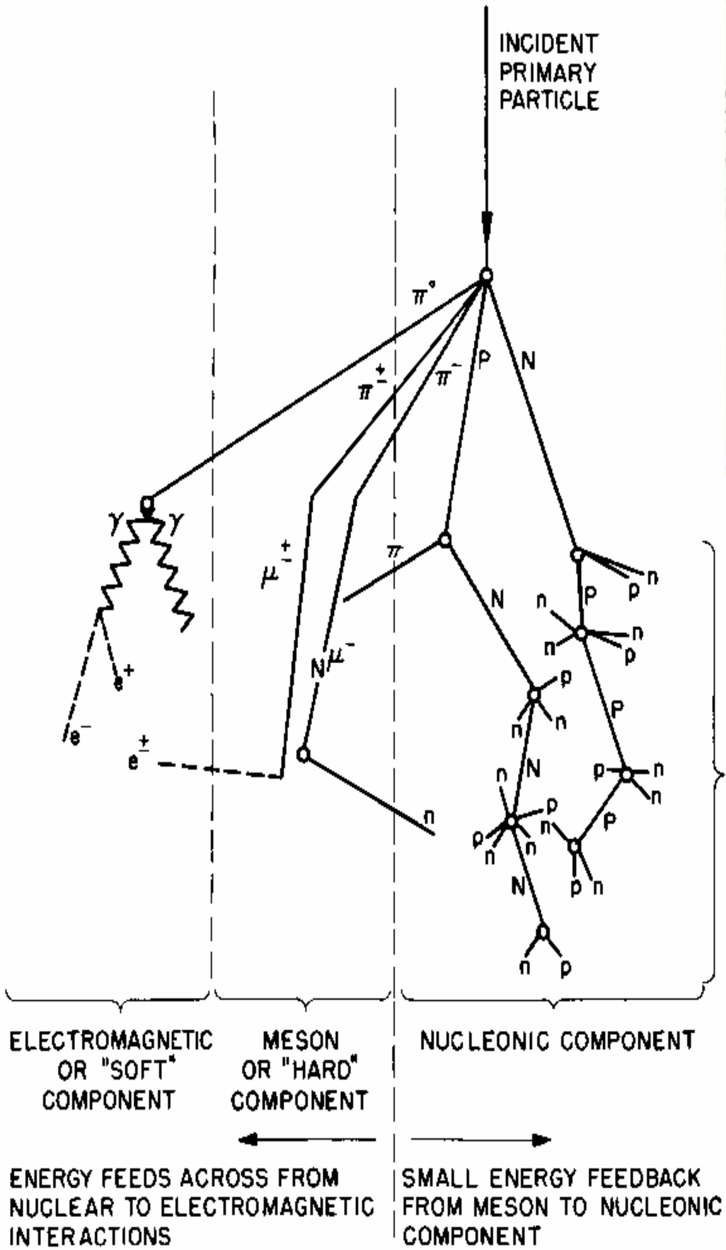
time = -200 μs


Hajo Drescher, Frankfurt U.
time = -100 µs

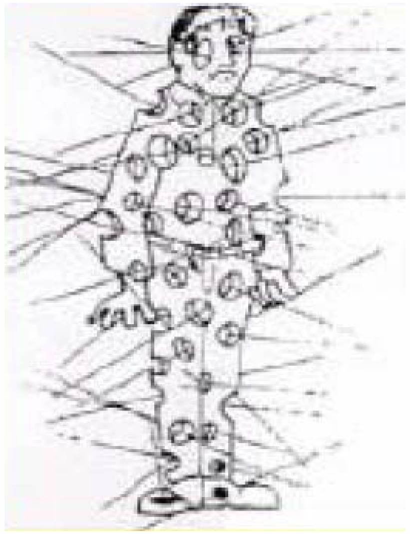

Hajo Drescher, Frankfurt U.
time = 0 μs

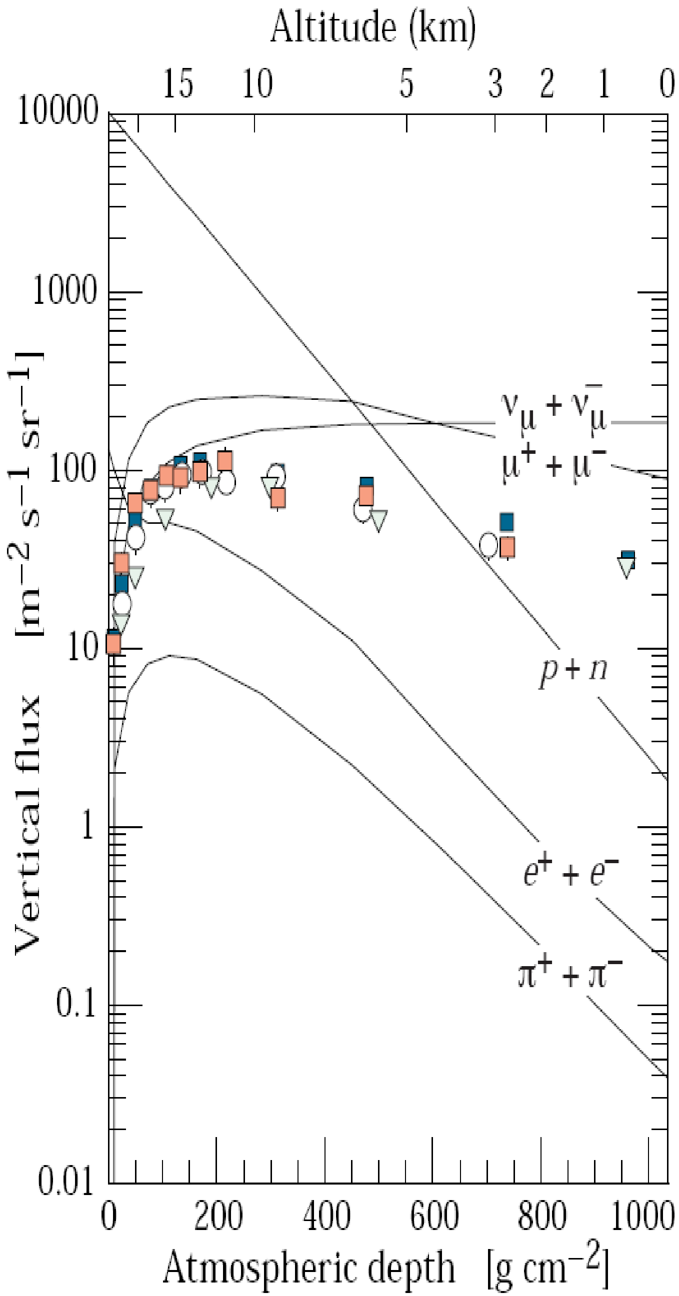

Hajo Drescher, Frankfurt U.


electrons/positrons
photons
muons
neutrons
Hajo Drescher, Frankfurt U.
Hajo Drescher, Frankfurt U.

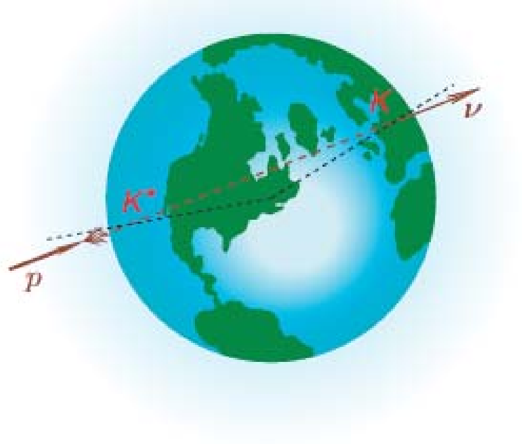


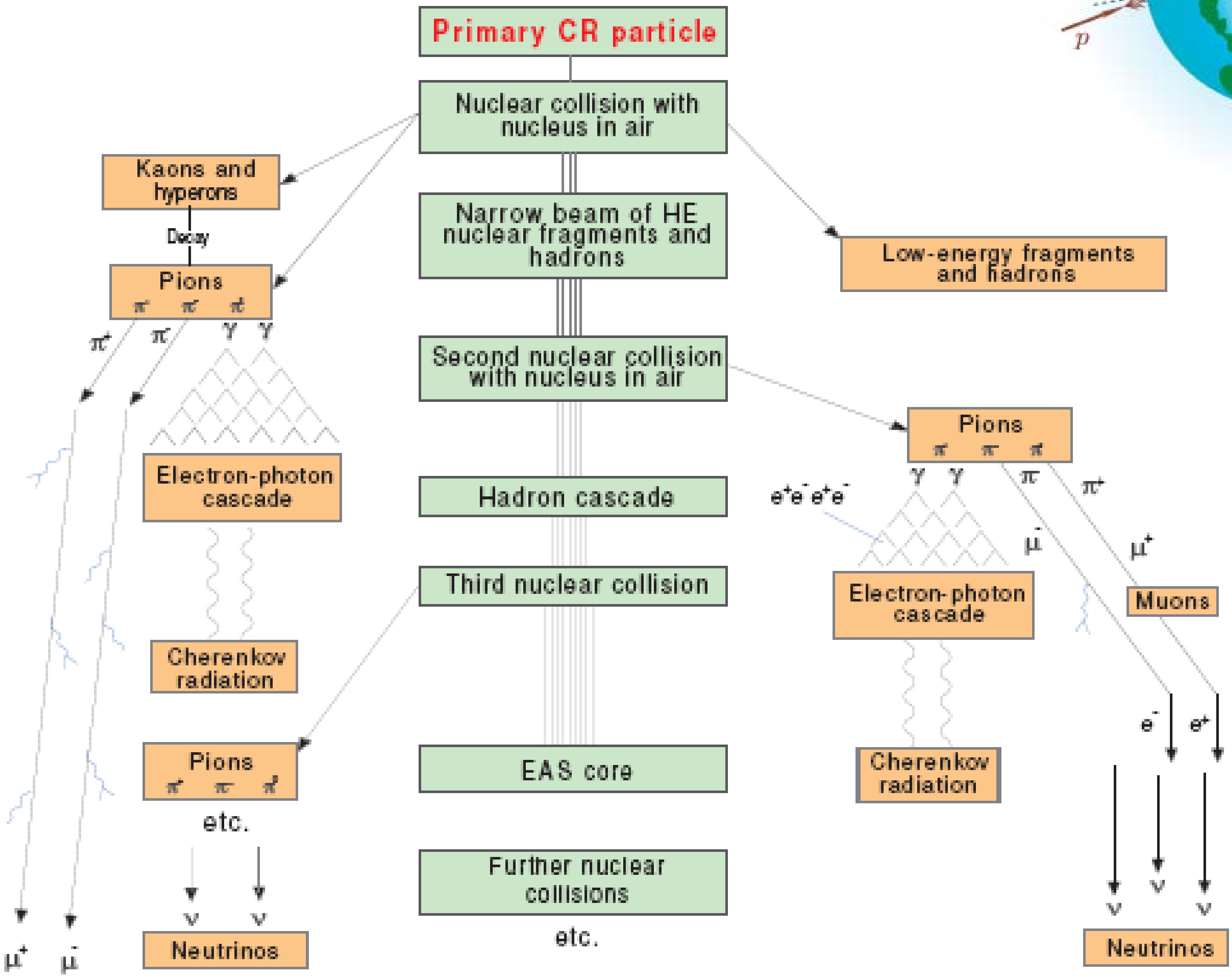
Schematic Diagram of Cosmic Ray Shower

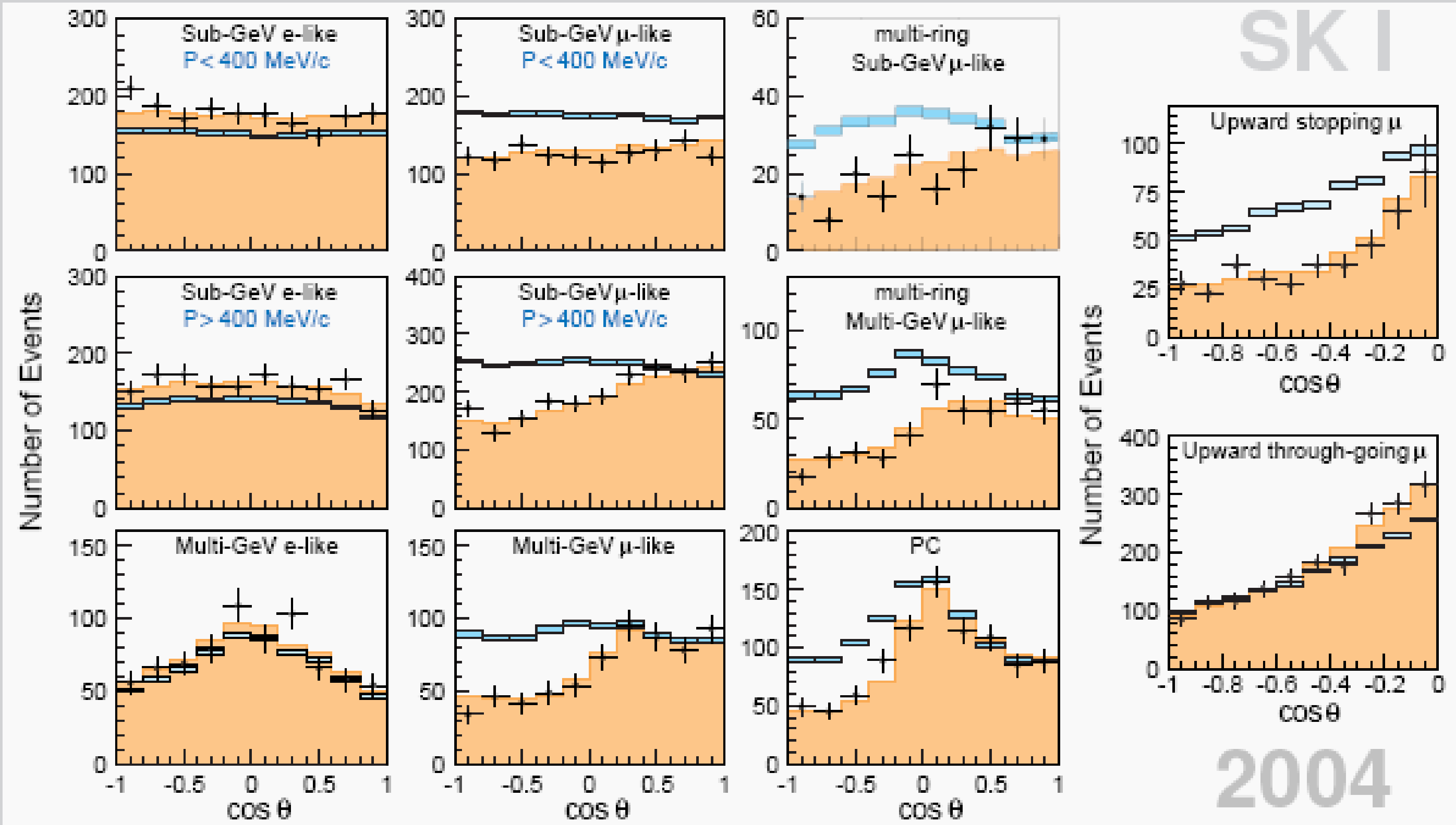




Atmospheric neutrinos



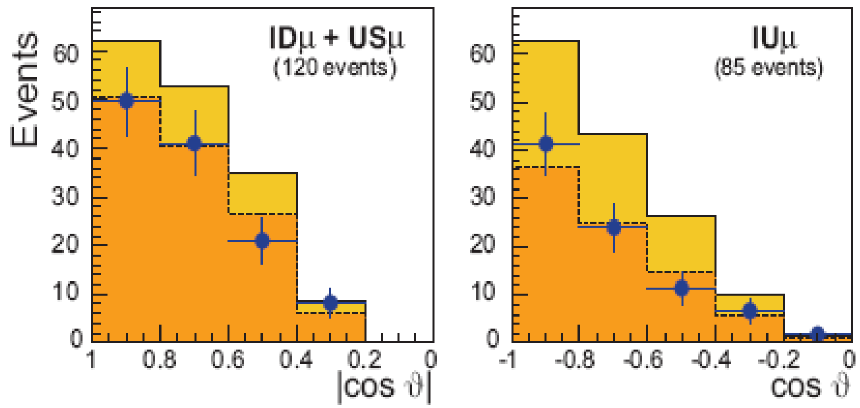




SuperKamiokande

Neutrinos have a mass !

MACRO



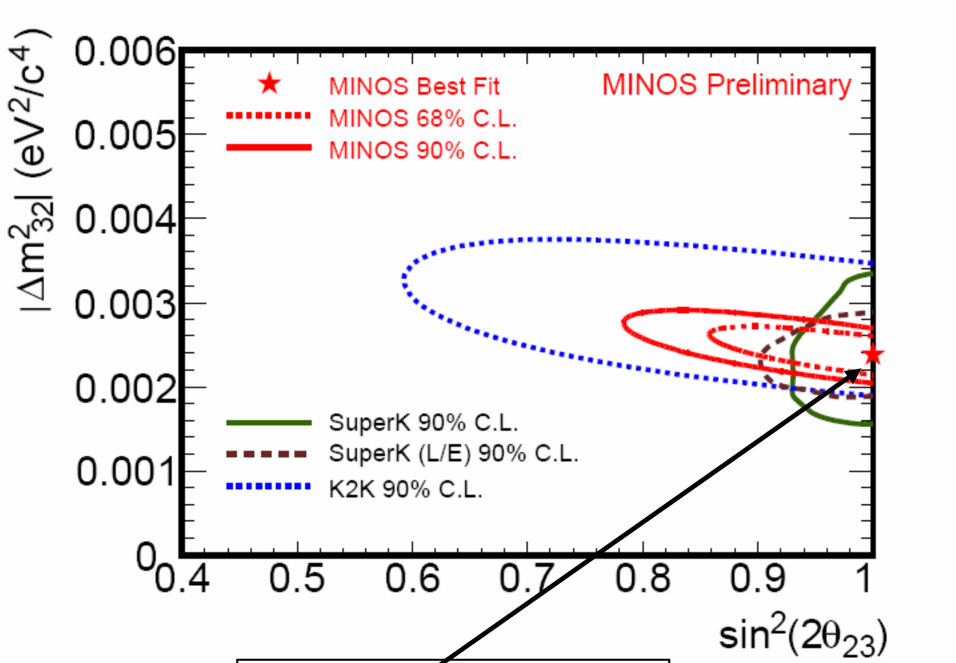
Mixing Matrix

$$U = \overbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}^{\text{atmospheric}} \times \overbrace{\begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix}}^{\text{cross-mixing}}$$

$$\times \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{solar}} \times \underbrace{\begin{pmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\text{majorana phases}}$$

- 3 angles : ϑ_{12} ϑ_{23} ϑ_{13}

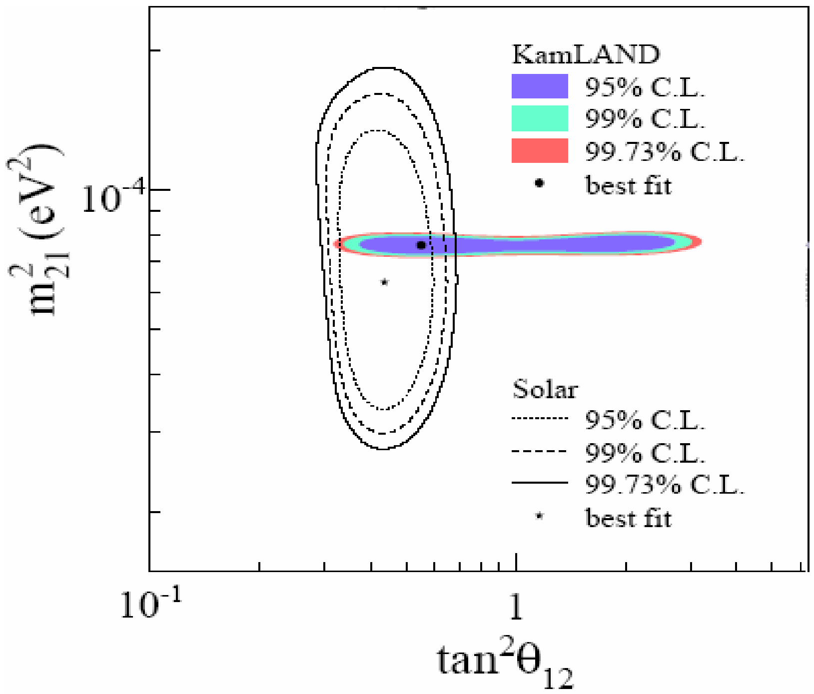
- 1 phase δ_{CP}: CP violations if not zero
- 2 phases α_1 α_2 if neutrinos are Majorana particles



$|\Delta m^2_{32}|$ = $2.38^{+0.20}_{-0.16}$ x 10^{-3} eV^2

$\sin^2 2\vartheta_{32} = 1.00_{-0.08}$

χ^2 / n.d.f = 41.2 / 34



Δm^2_{21} = $7.59^{+0.21}_{-0.21}$ x 10^{-5} eV^2

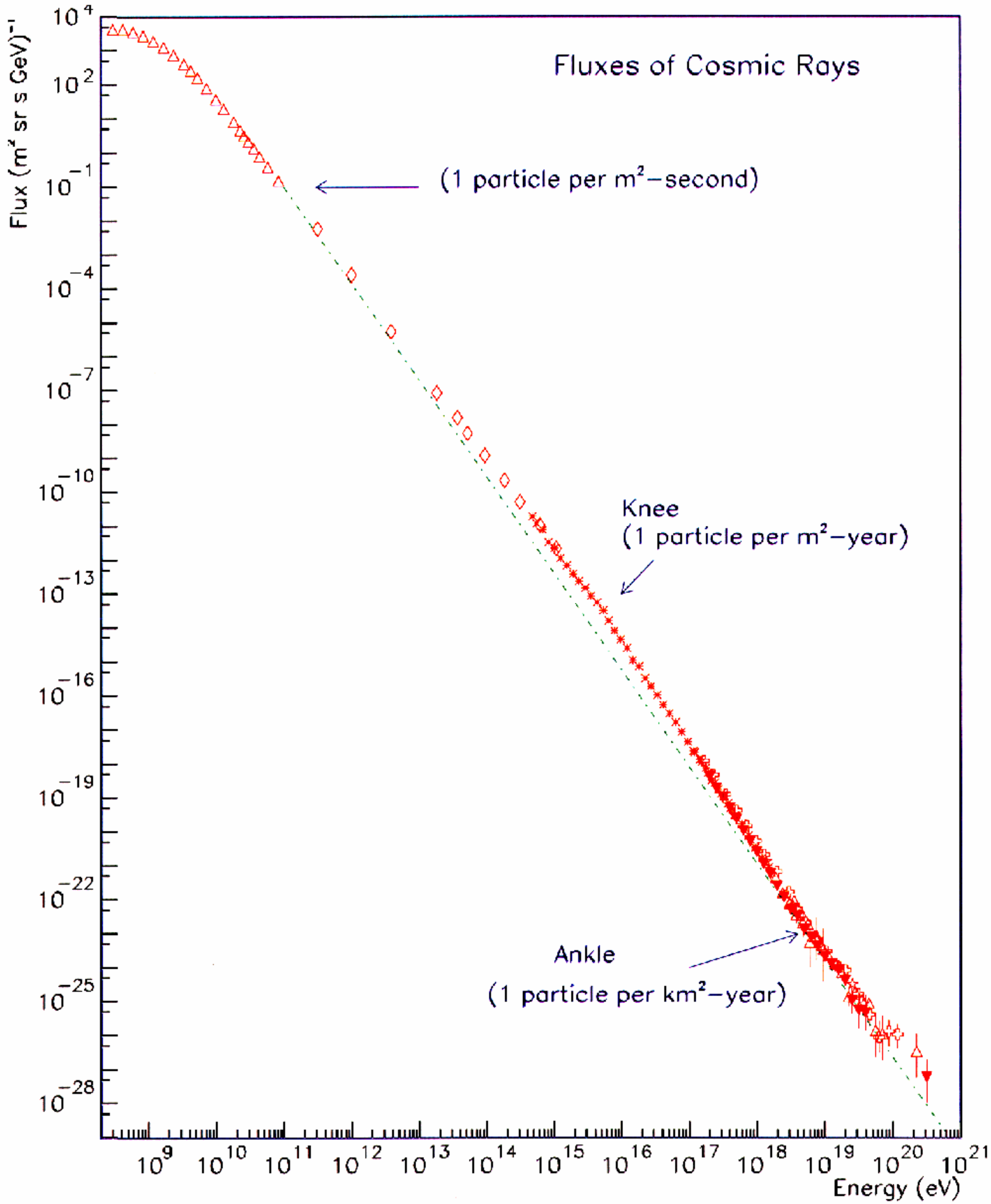
$\tan^2 \vartheta_{21}$ = $0.47^{+0.06}_{-0.05}$

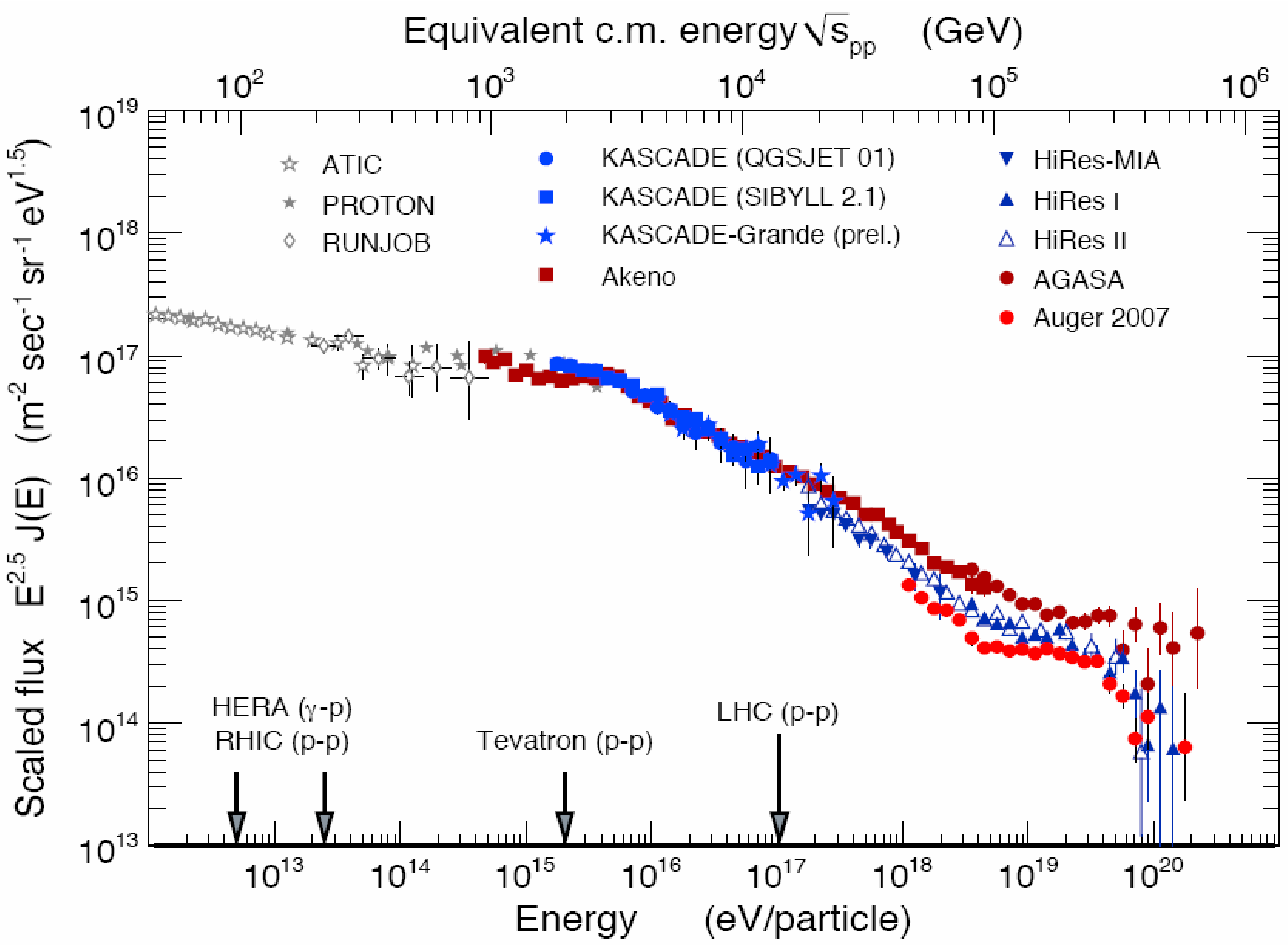
Neutrino oscillations confirmed by accelerator (and nuclear reactors) experiments

Still missing:

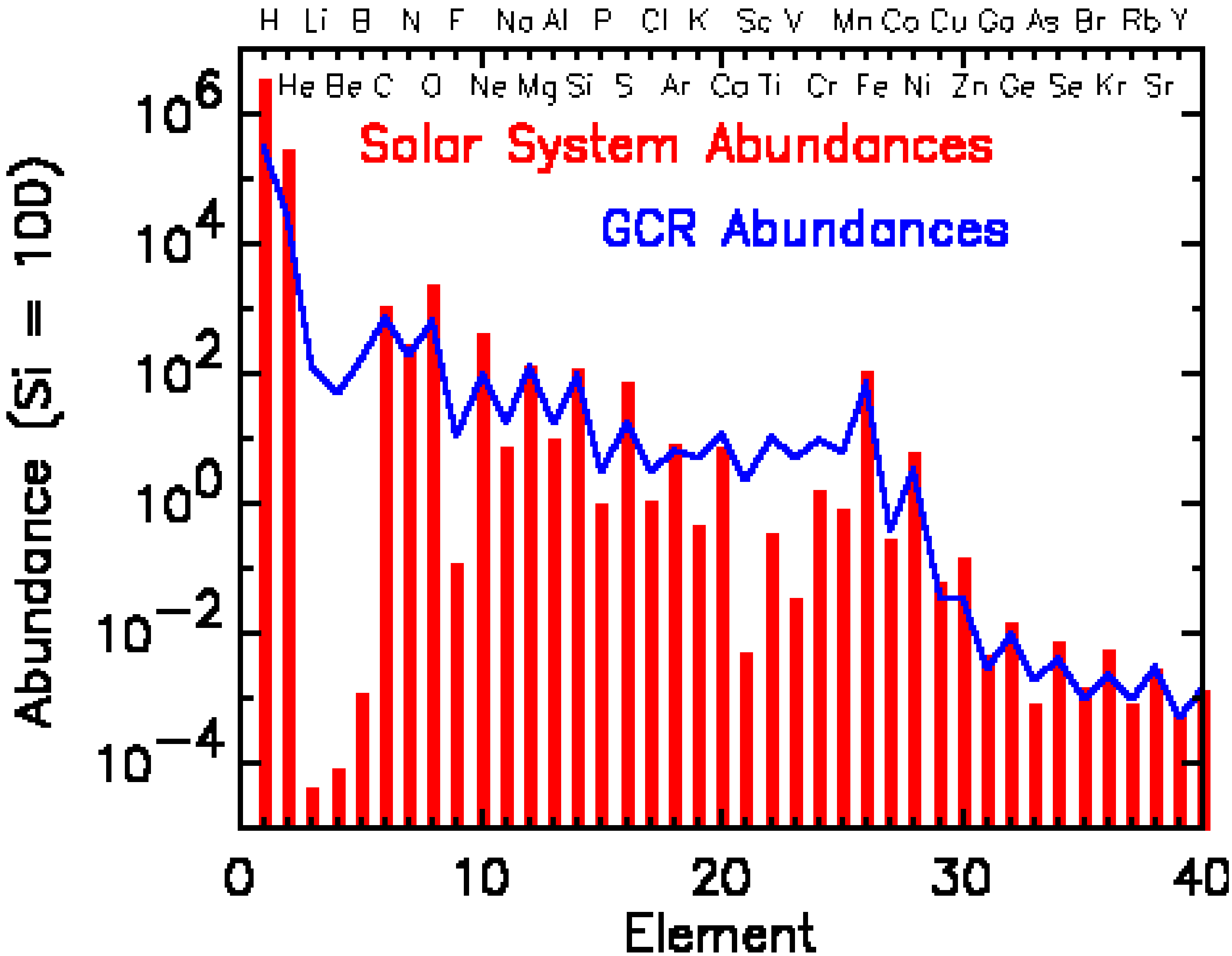
- **precision measurements of oscillation parameters**
- **$\theta_{13} = 0$?**
- **mass hierarchy (sign of Δm^2_{23})**
- **CP violation ?**

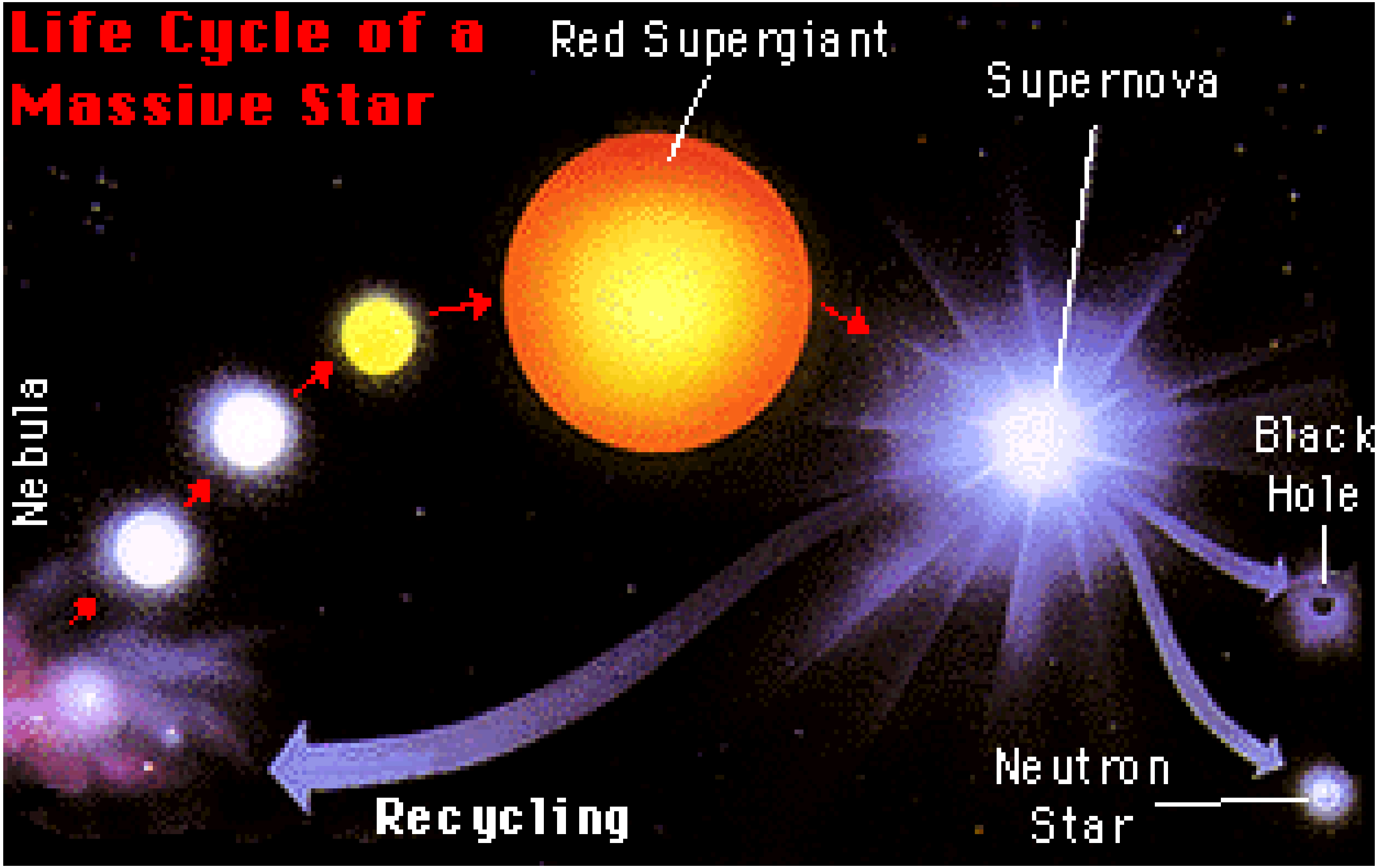
Back to cosmic rays

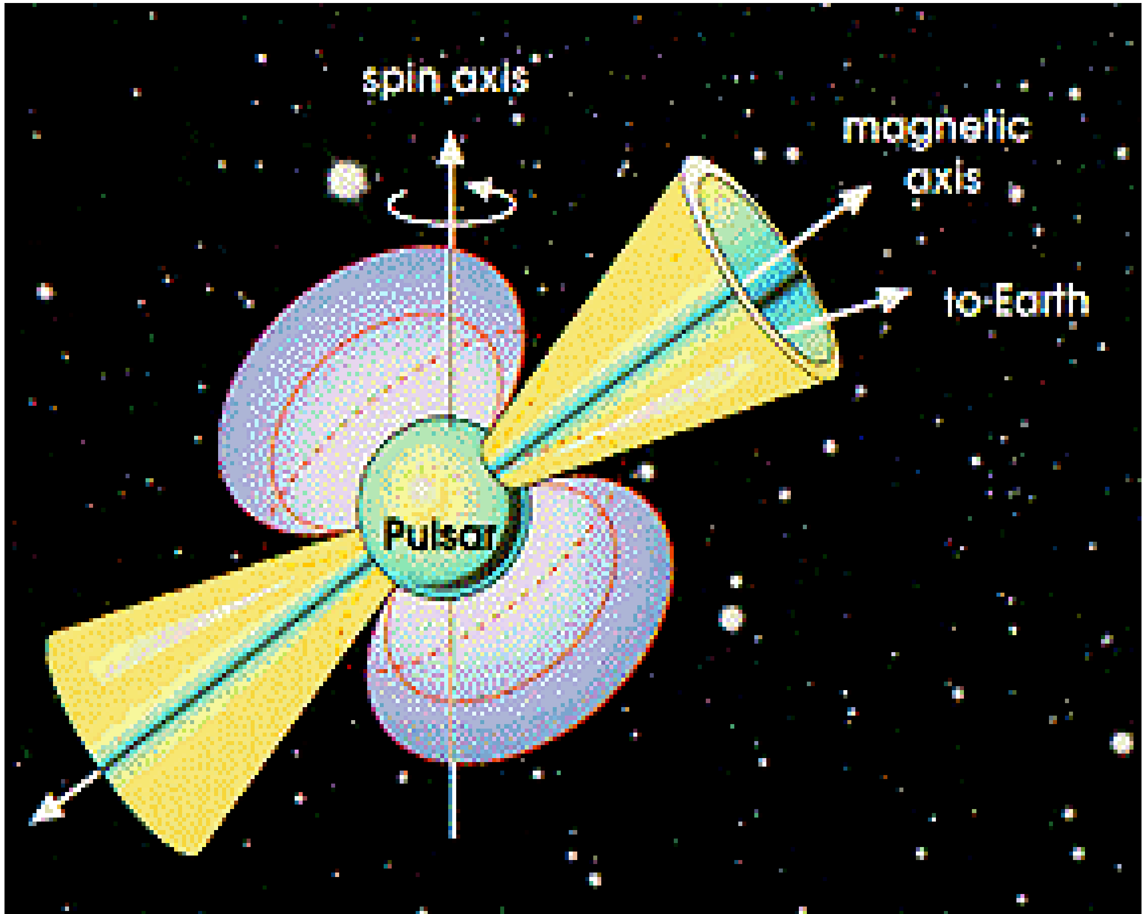




Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
Scaled flux $E^{2.5}$ J(E) (m^{-2} sec^{-1} sr^{-1} $eV^{1.5}$)
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande (prel.)
Akeno
HiRes-MIA
HiRes I
HiRes II
AGASA
Auger 2007
HERA (γ-p)
RHIC (p-p)
Tevatron (p-p)
LHC (p-p)
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
Energy (eV/particle)


Solar System Abundances
GCR Abundances
Abundance (Si = 100)
Element
H He Li Be B C N O F Ne Na Mg Al Si P S Cl Ar K Ca Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge As Se Br Kr Rb Sr Y
10^6
10^4
10^2
10^0
10^−2
10^−4
0
10
20
30
40


Life Cycle of a Massive Star
Red Supergiant
Supernova
Nebula
Black Hole
Neutron Star
Recycling



Fastly rotating neutron star

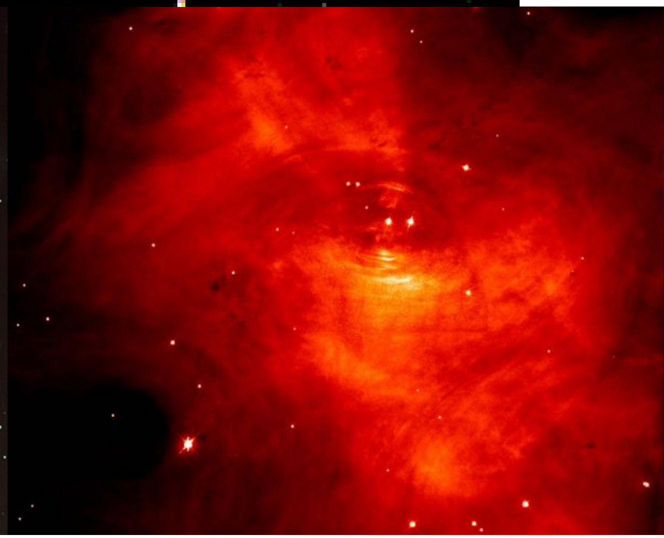
($T \sim 10^{-3}$ –1 s).

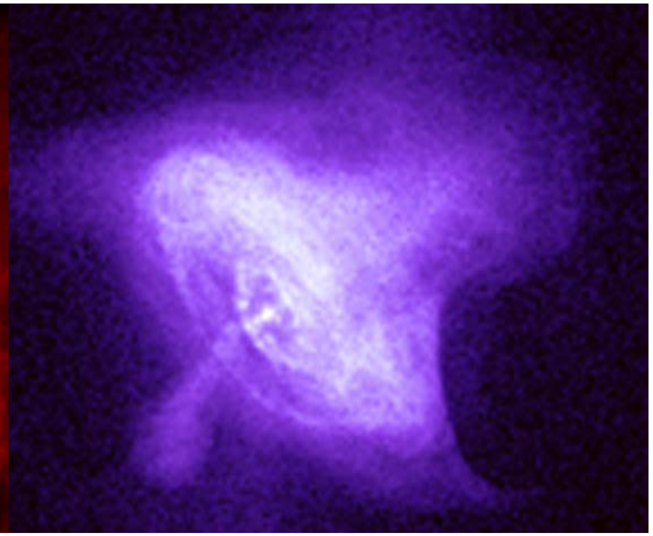
Huge magnetic field

($B \sim 10^{12}$ gauss).

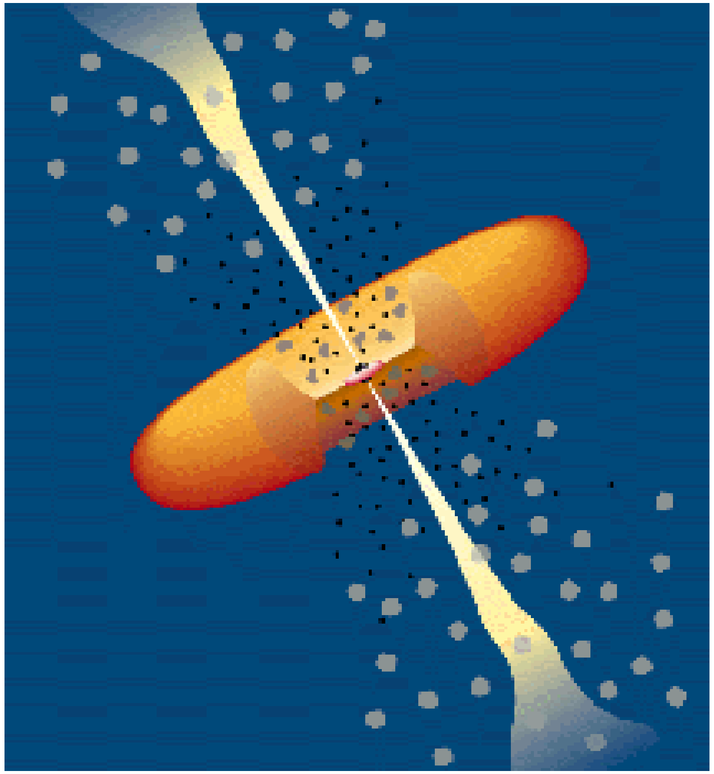
Observed in SNR.
“Pulsed” emission observed up to GeV energies.

“Continuous” emission at TeV energies



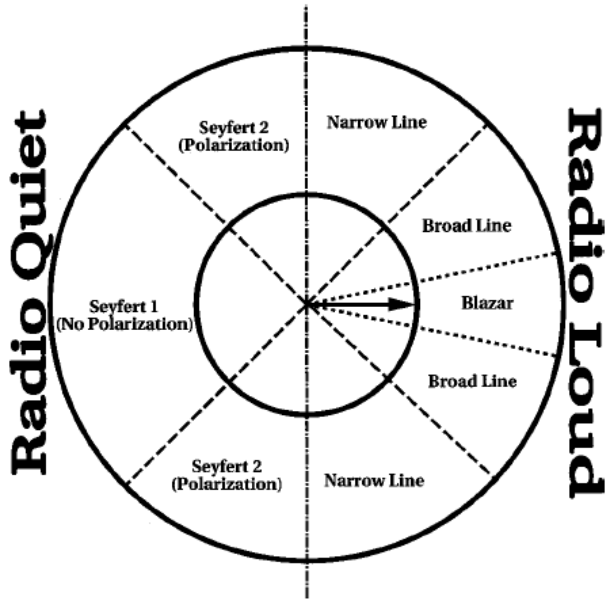


Unified AGN Model



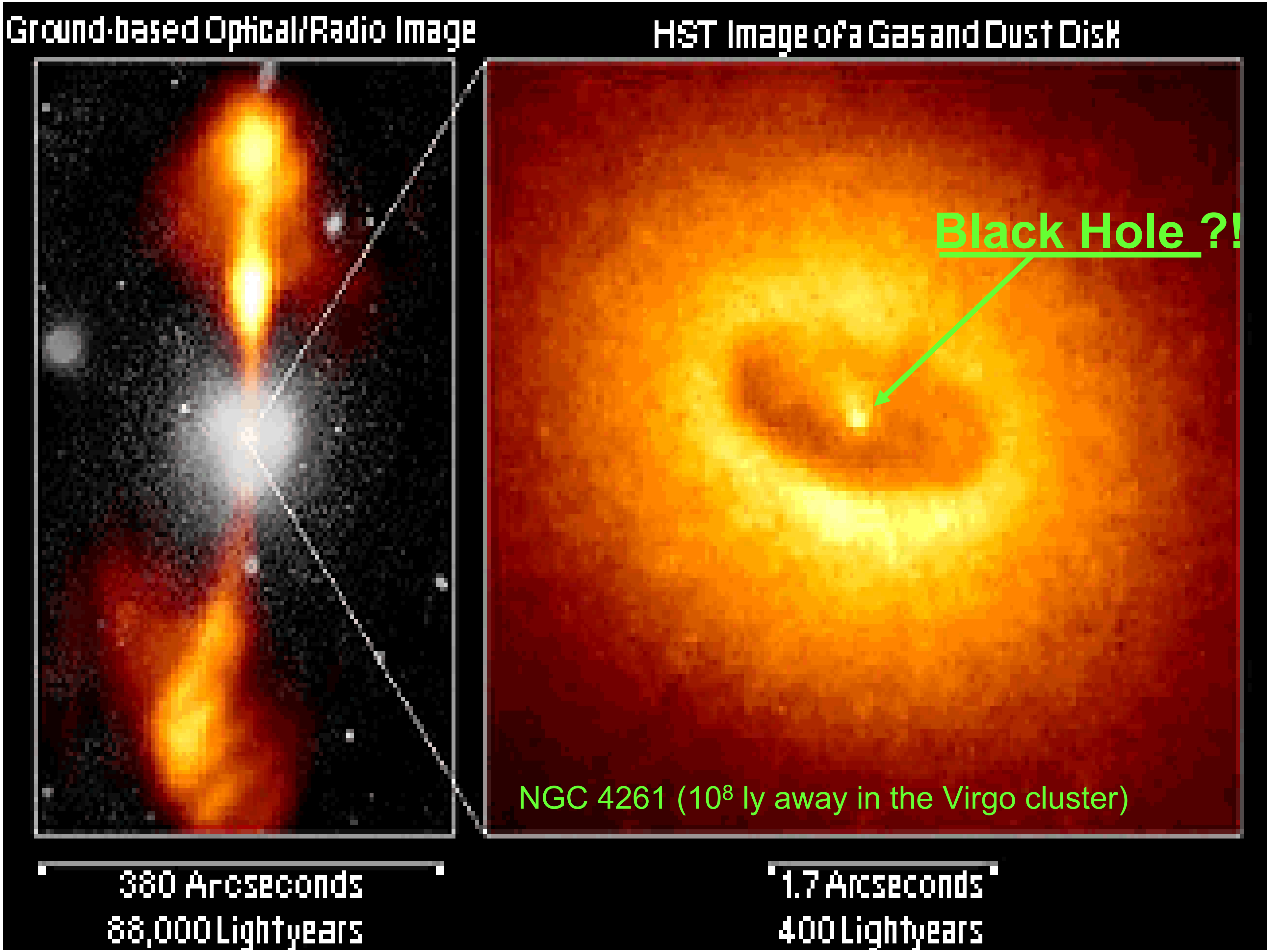
Super heavy Black Hole surrounded by accretion

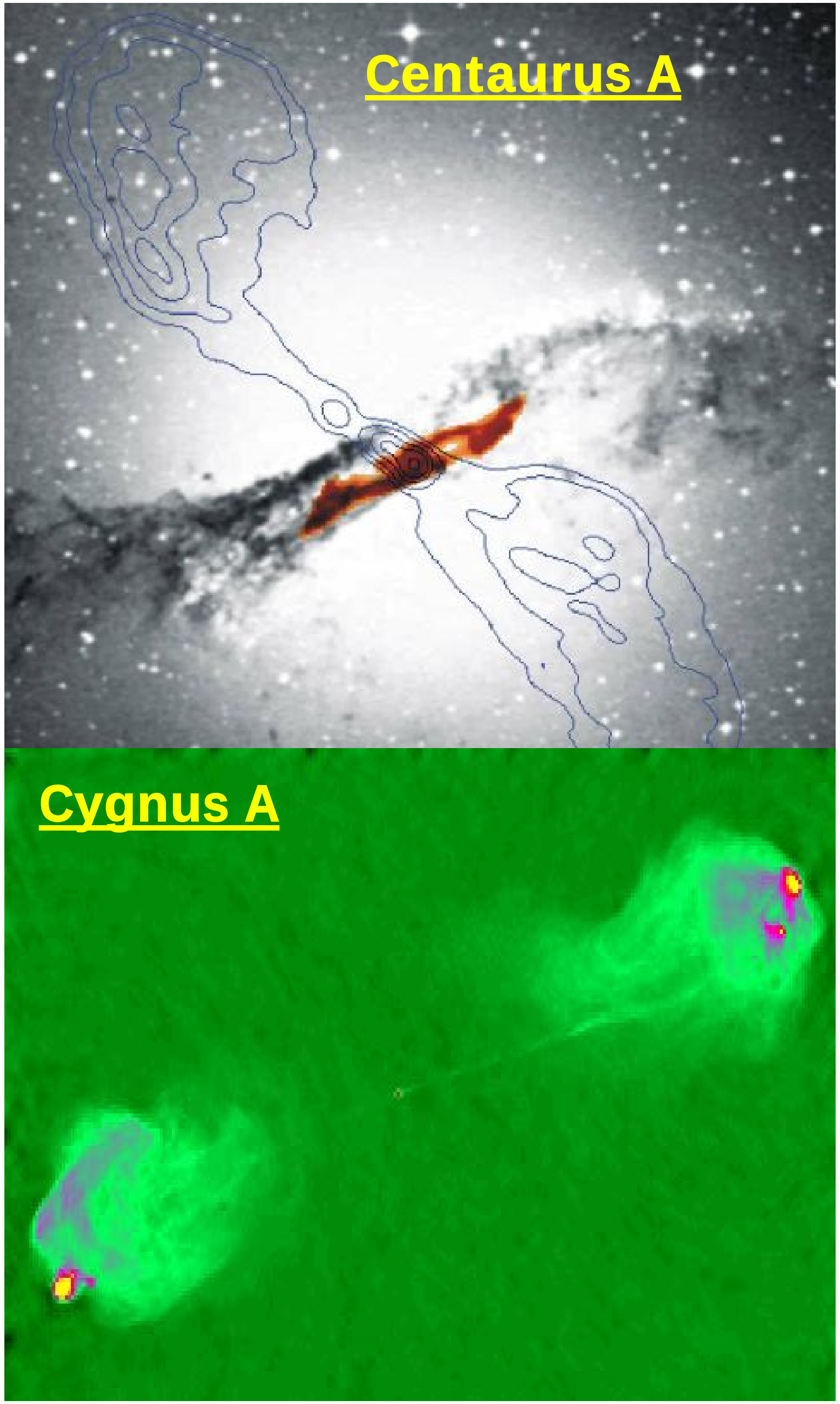
Particle acceleration and production of high energy photons (and neutrinos)

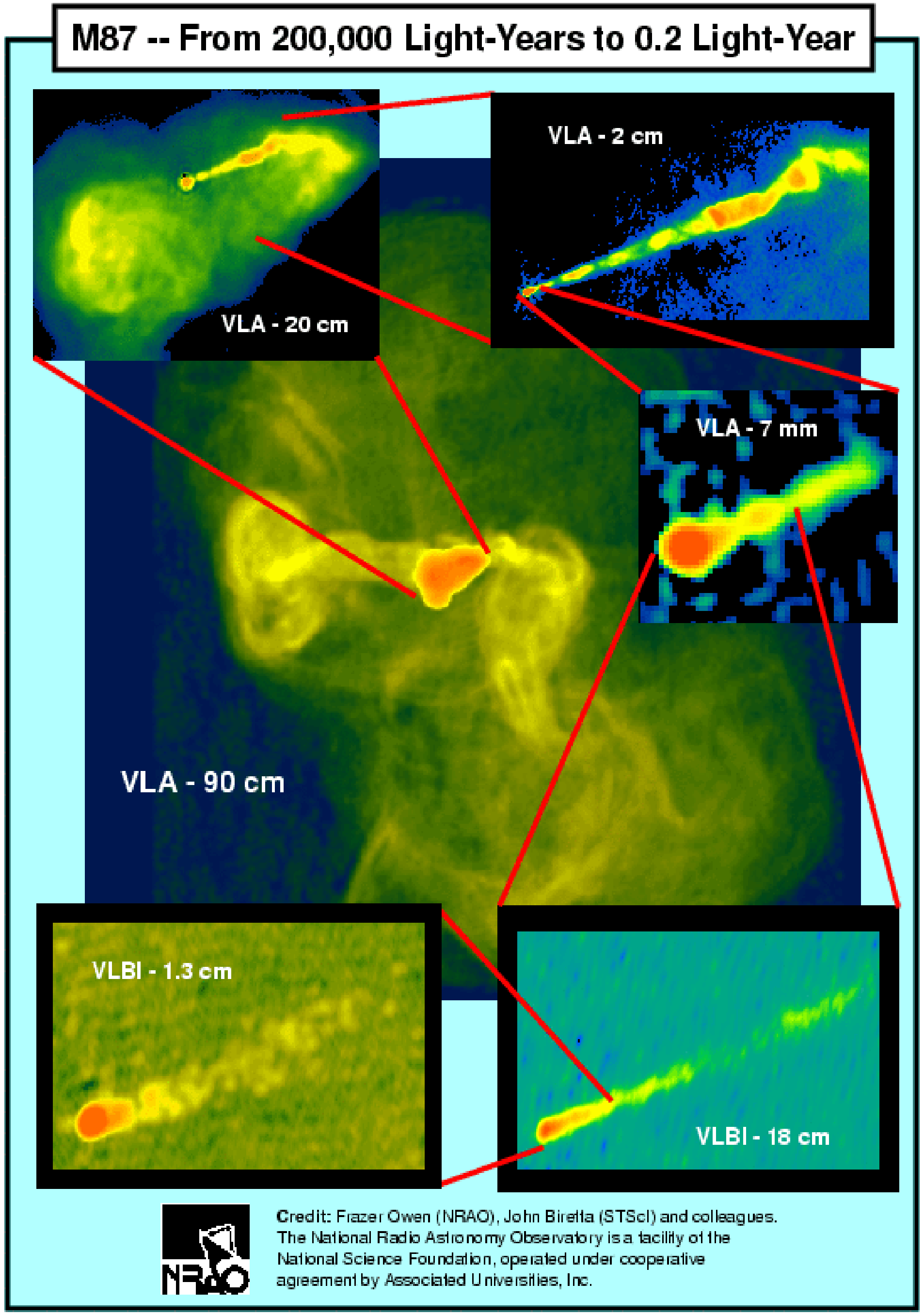


Unification of several models

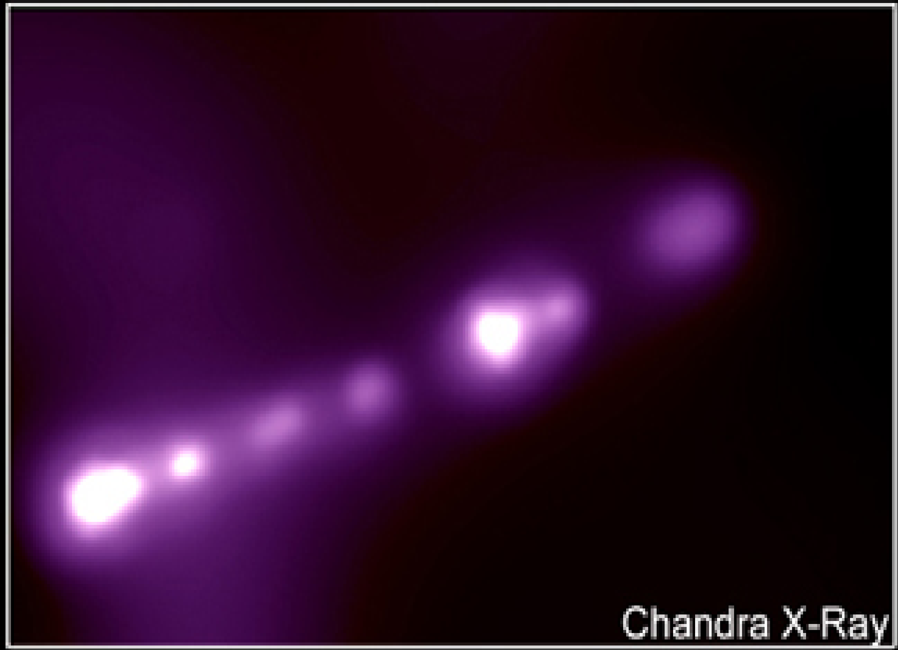
quasars, Seyfert galaxies (types I and II), radio-quiet or radio-loud galaxies, Faranoff-Riley galaxies (types I and II), narrow line, broad line, no lines, highly polarized lines, flat spectrum, steep spectrum, optically violent variables, BL-Lac's, ...

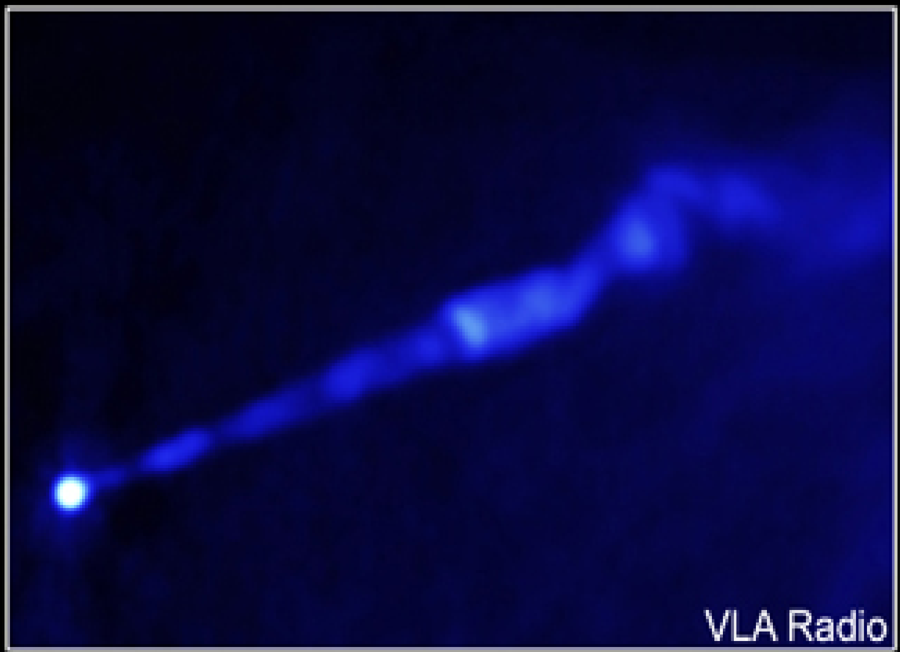

Ground-based Optical/Radio Image
HST Image of a Gas and Dust Disk
Black Hole ?!
NGC 4261 (10^8 ly away in the Virgo cluster)
380 Arcseconds
88,000 Lightyears
1.7 Arcseconds
400 Lightyears

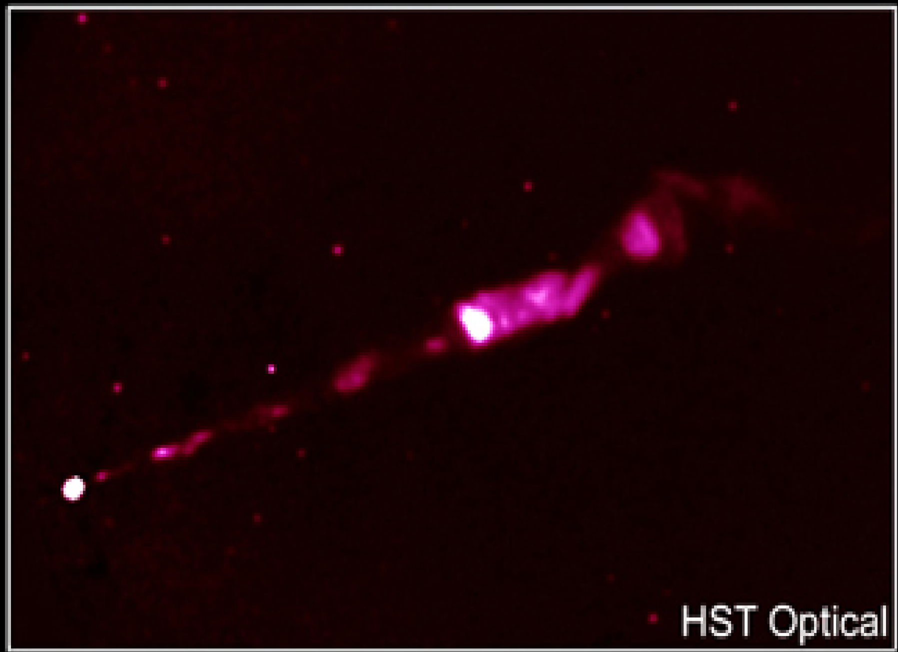

Centaurus A
Cygnus A


M87 -- From 200,000 Light-Years to 0.2 Light-Year
VLA - 20 cm
VLA - 2 cm
VLA - 7 mm
VLA - 90 cm
VLBI - 1.3 cm
VLBI - 18 cm
Credit: Frazer Owen (NRAO), John Biretta (STScI) and colleagues.
The National Radio Astronomy Observatory is a facility of the
National Science Foundation, operated under cooperative
agreement by Associated Universities, Inc.
NRAO

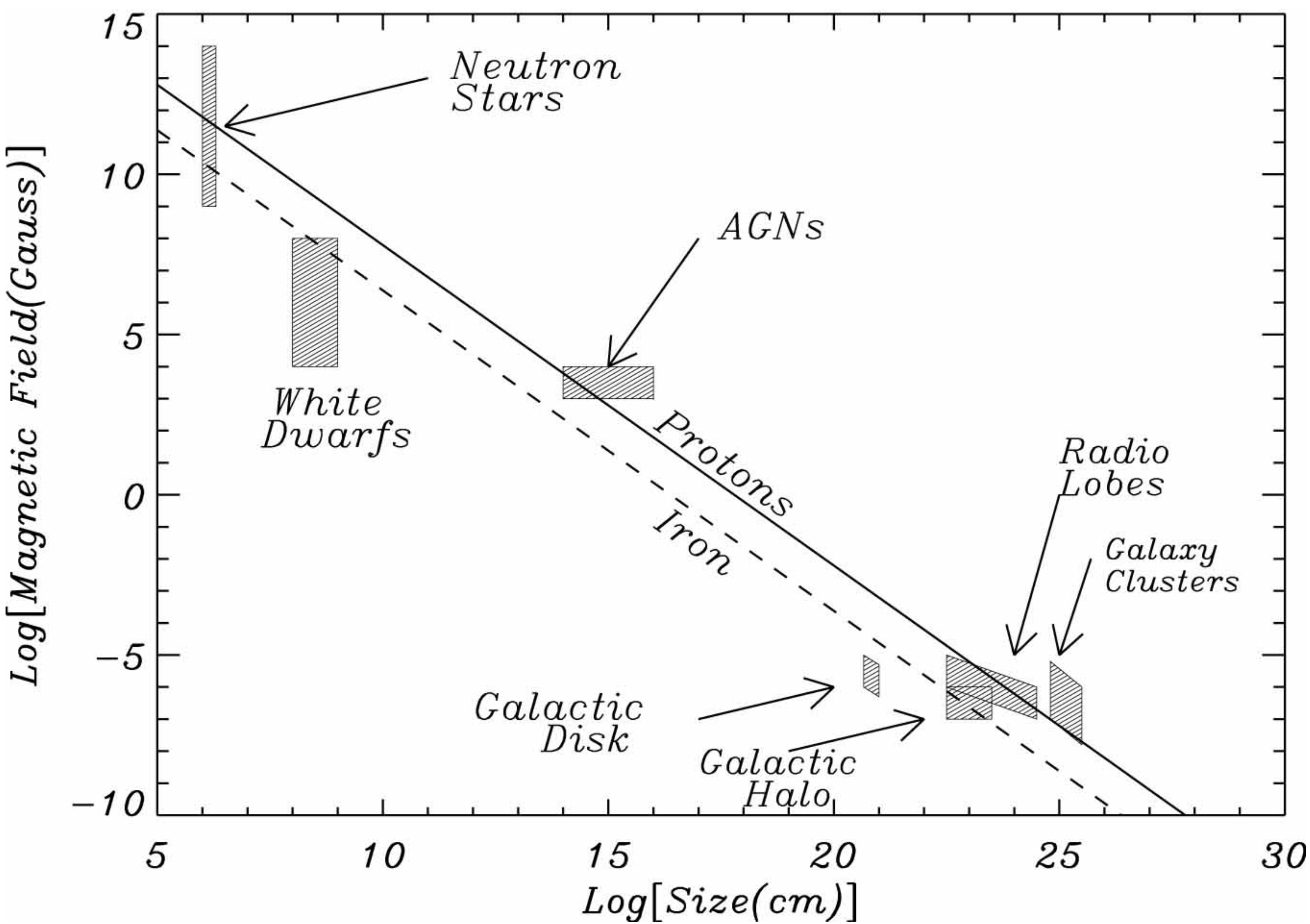
M87 jets







The Hillas plot



Cosmic Ray

Indirect Measurements

Physical Motivation(s)

To study and understand:

- CR origin (production sites, acceleration mechanisms,…)
- High Energy Astrophysics and Cosmology
- Particle physics at c.m. energies up to 1000 TeV
- …….

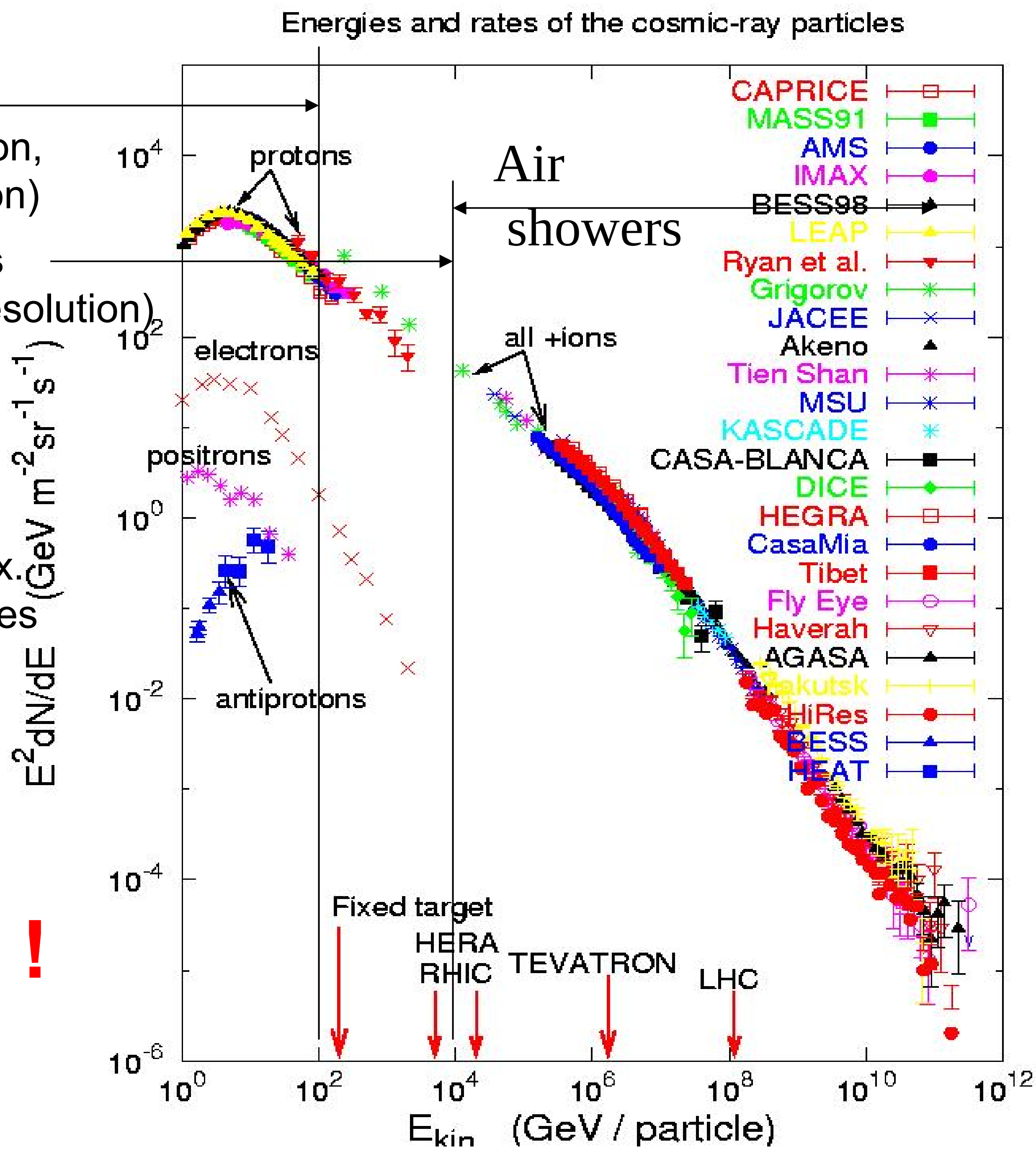
Through the measurement of:

- Energy spectra
- Chemical composition
- Arrival directions
- …..

Spectrometers
($\Delta A = 1$ resolution, good E resolution)

Calorimeters
(less good resolution)

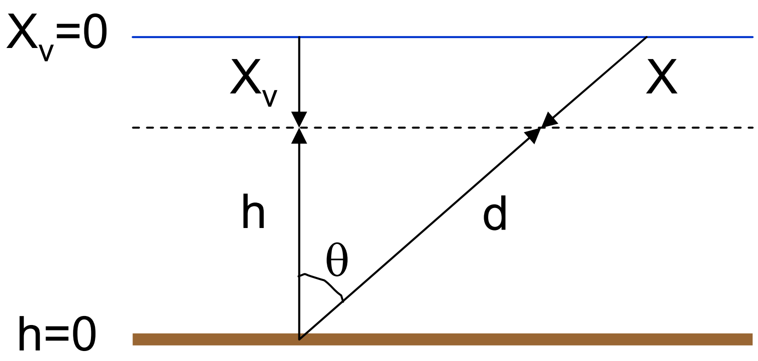
EAS arrays
on the ground to overcome low flux. Don't see primaries directly.



The beam !

The (high energy physicist) **atmosphere**

The target !



"*Standard*" atmosphere :

$X_v = X_0 \exp(-h/h_0)$

$X_0 \approx 1030\ \mathrm{g/cm^2}$

$h_0 \approx 6.4 – 8.4\ \mathrm{km}$

$\sigma_{p\text{-}Air} \sim 300\ \mathrm{mb}$ @ $E \sim 1\text{-}100\ \mathrm{TeV}$

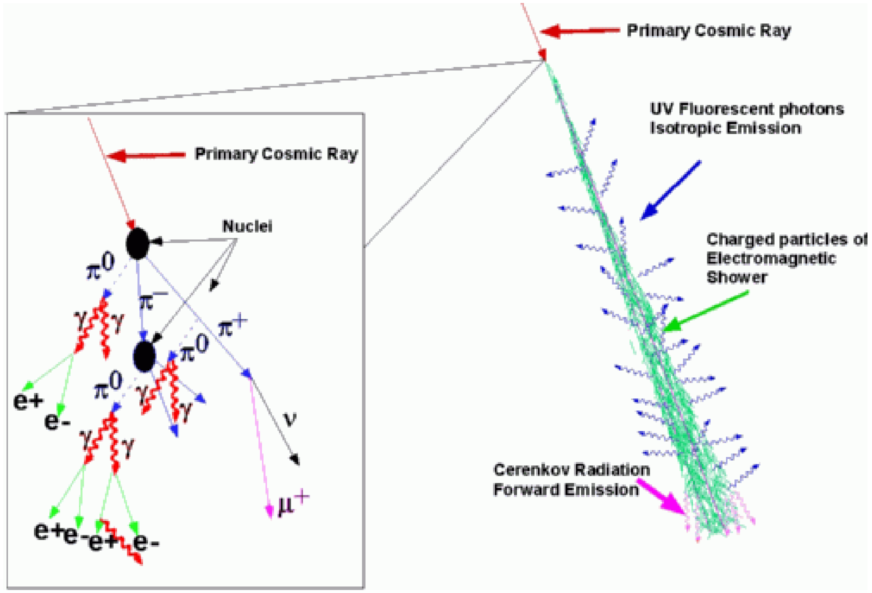
$\Lambda_p \sim 80\ \mathrm{g/cm^2}$ $\Lambda_{Fe} \sim 2\text{-}3\ \mathrm{g/cm^2}$ $\Lambda_{rad} \sim 37\ \mathrm{g/cm^2}$

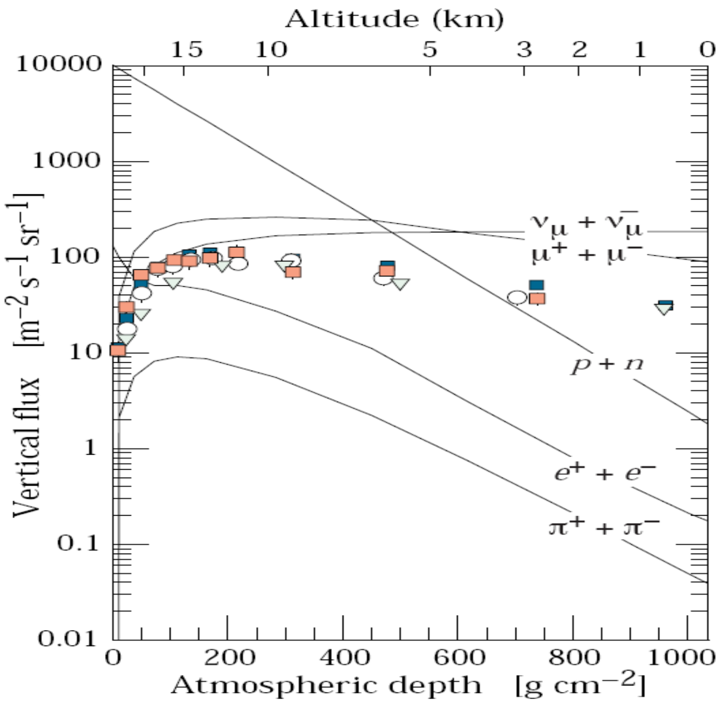
$X_0 \sim 13\Lambda_p \sim 28\ \Lambda_{rad}$

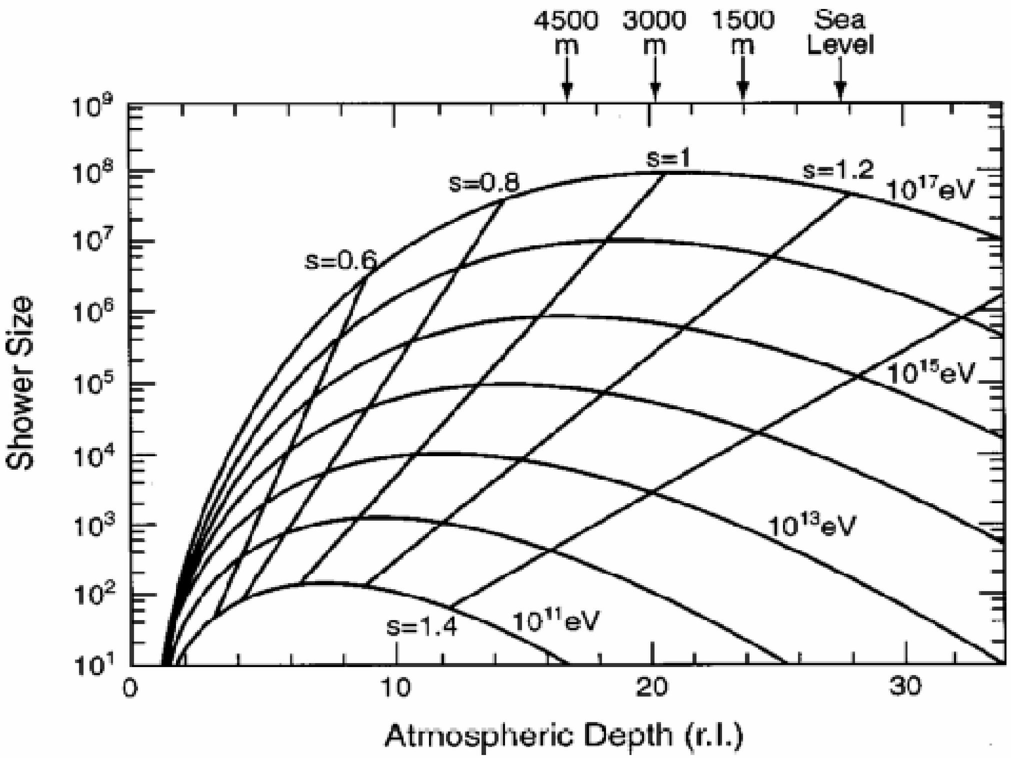
$X_v \sim \Lambda_p \Leftrightarrow h \sim 18\mathrm{km}$

EAS Components

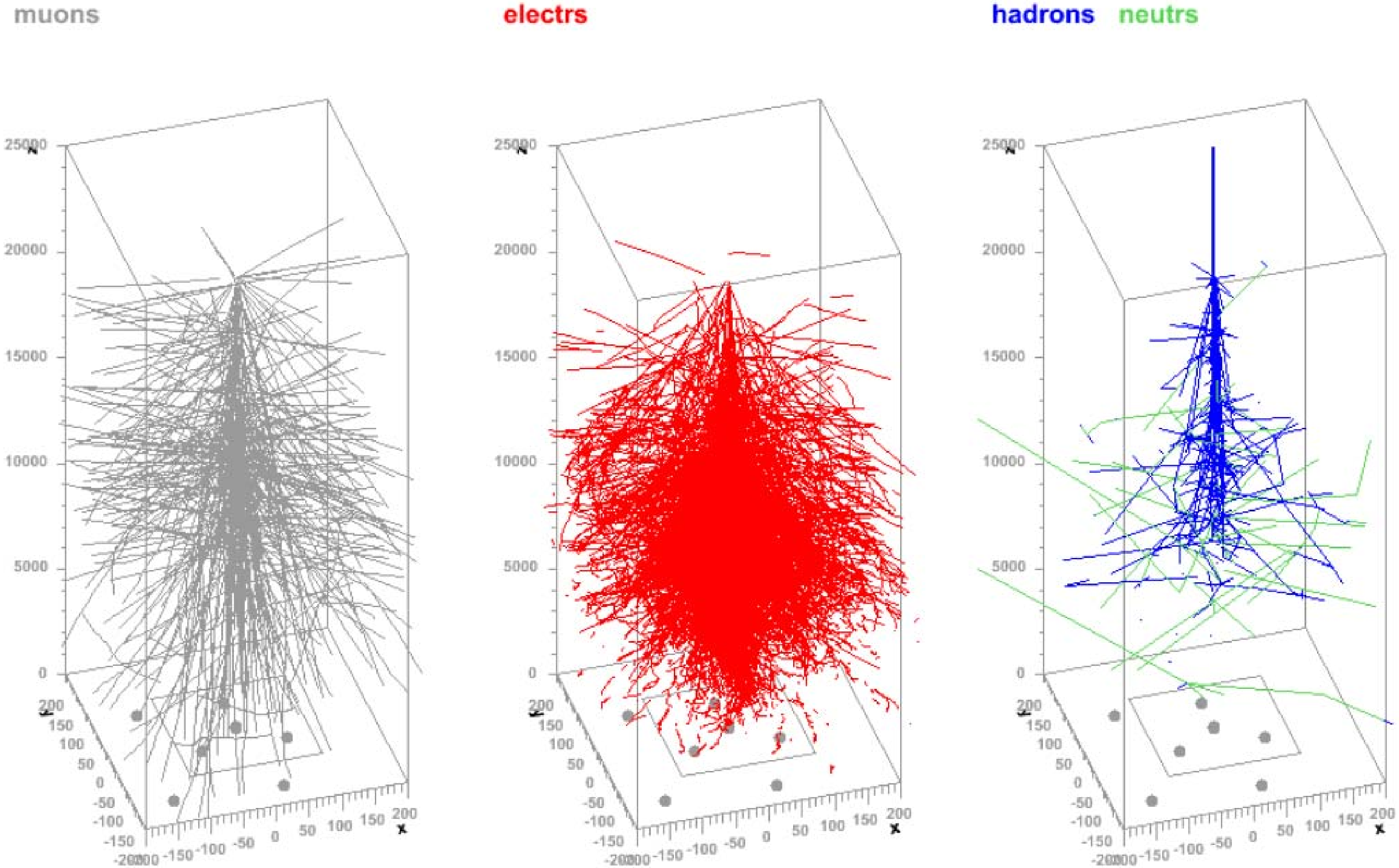
- Soft: p, n, π, e, γ,..
- Hard: μ, ν
- Čerenkov light (mainly produced by electrons)
- Fluorescence light







Shower particle tracks: proton



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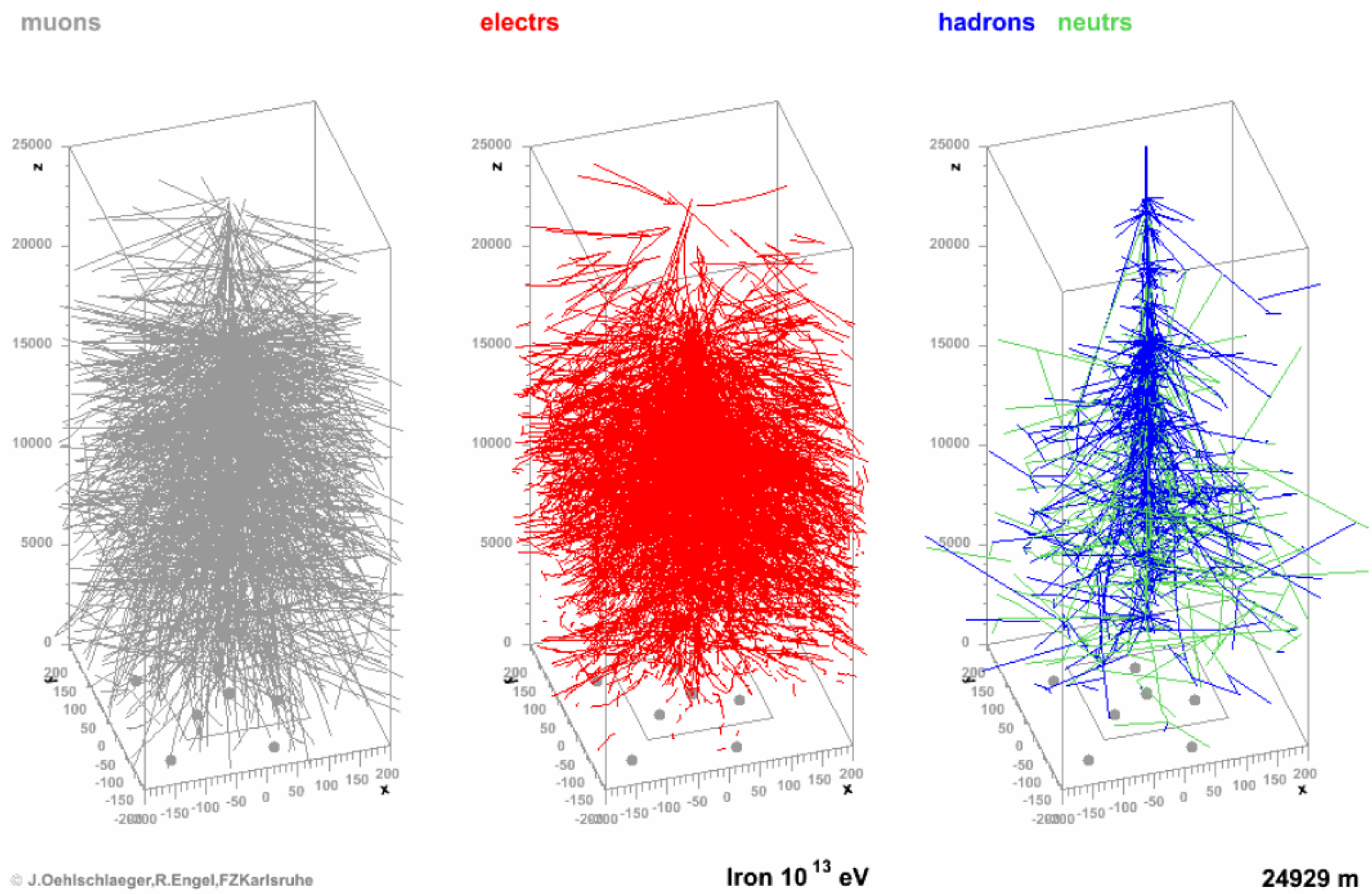
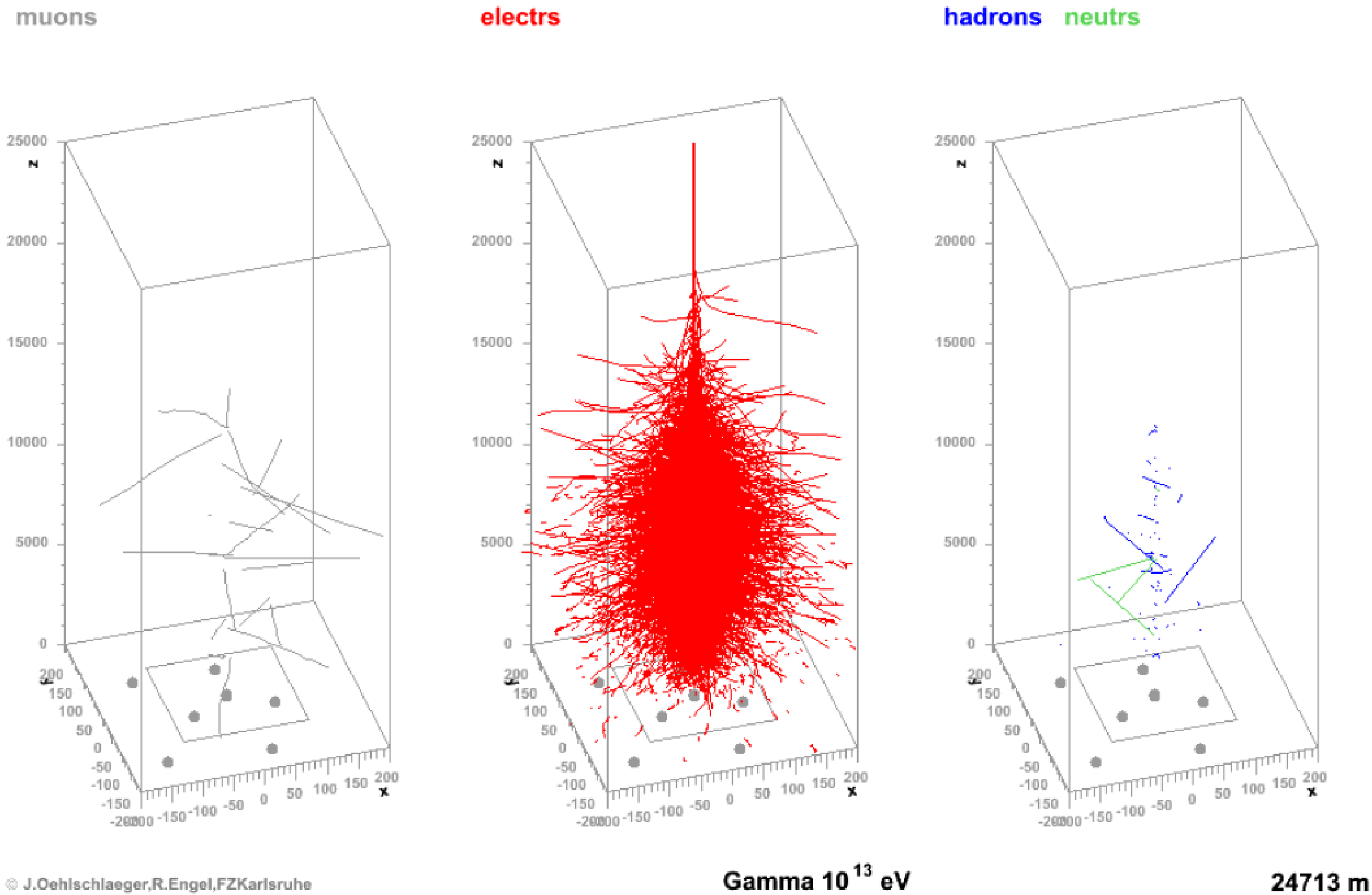
Proton 10^{13} eV

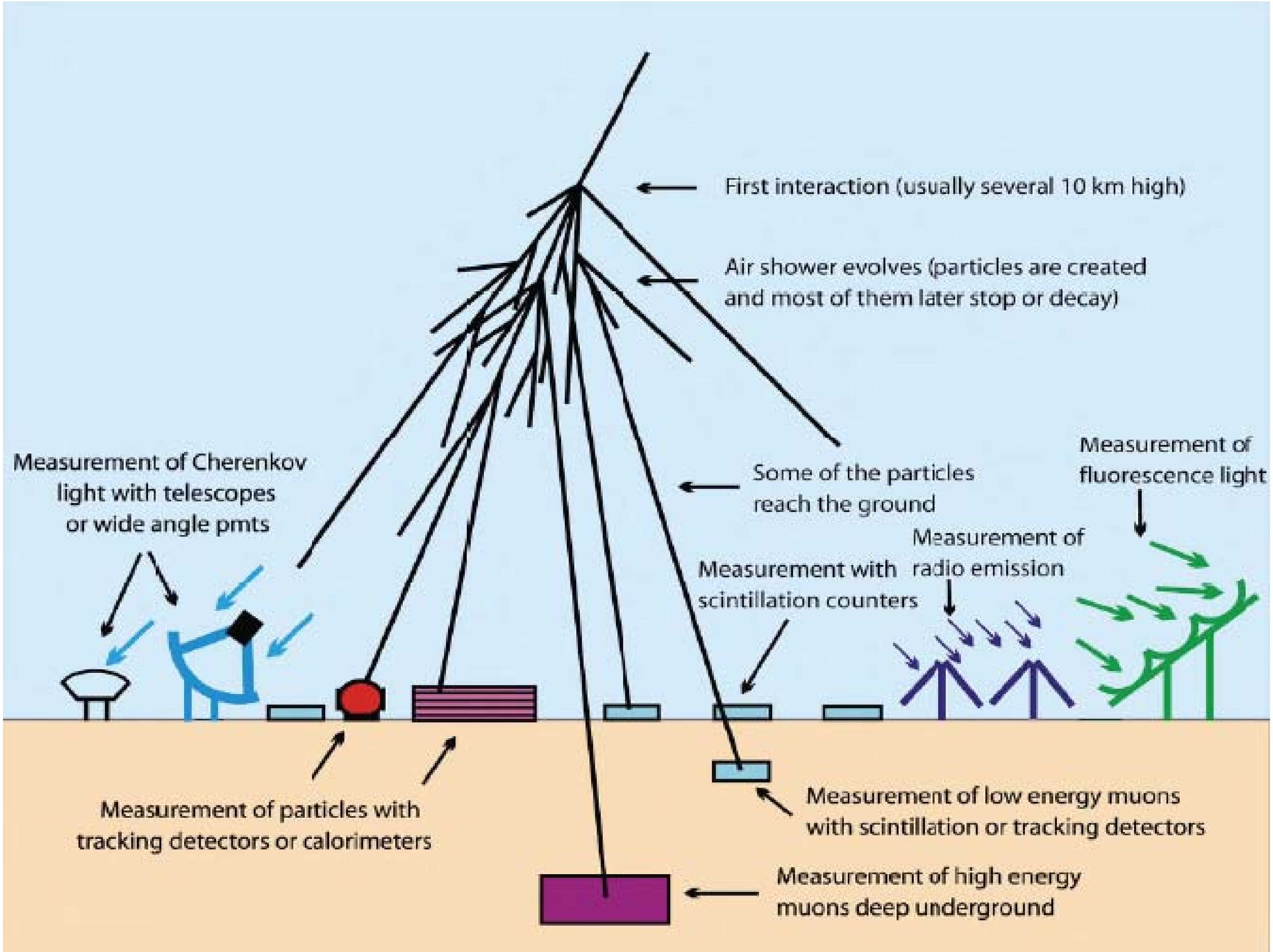
21336 m

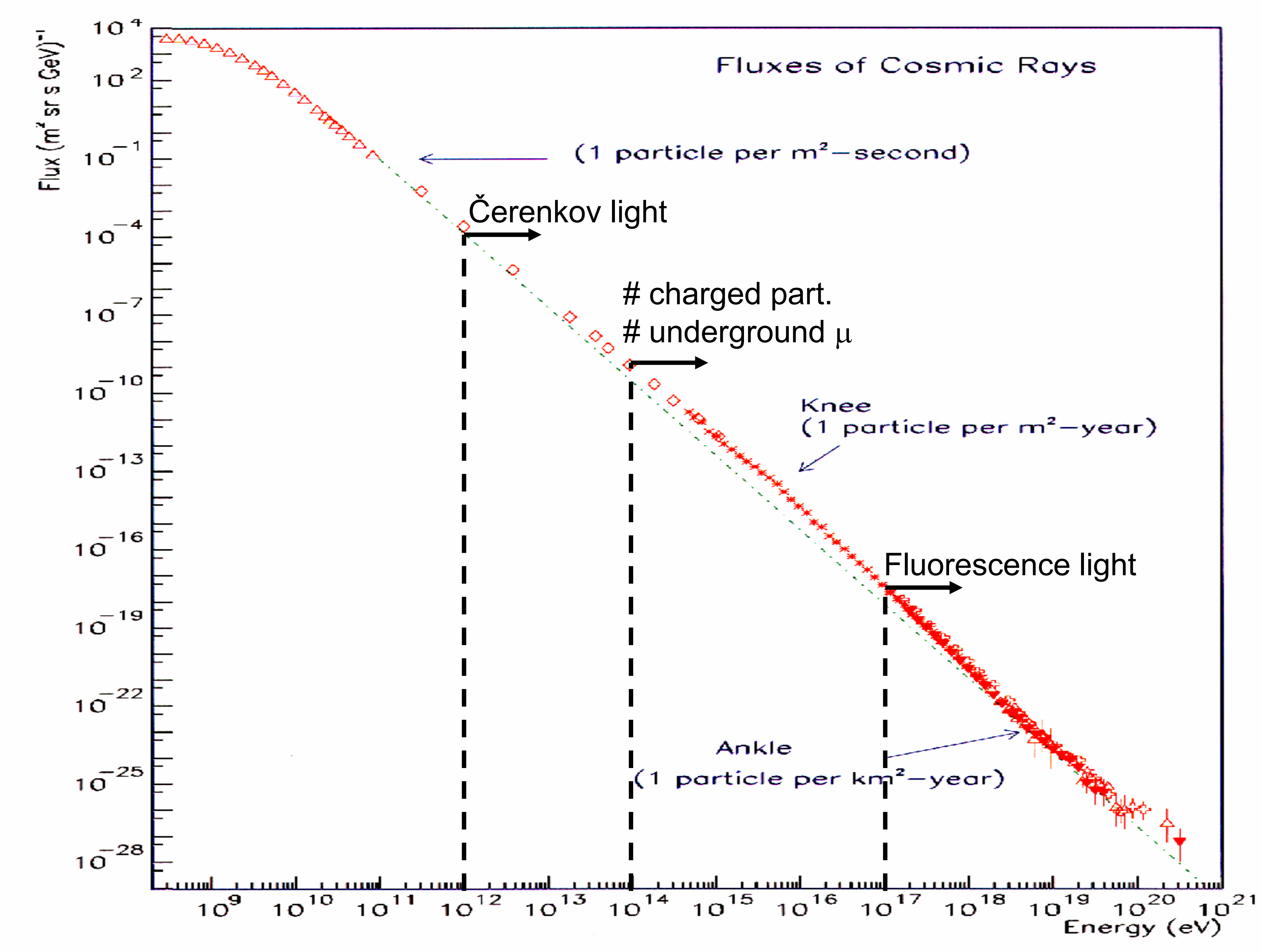
Shower particle tracks: iron

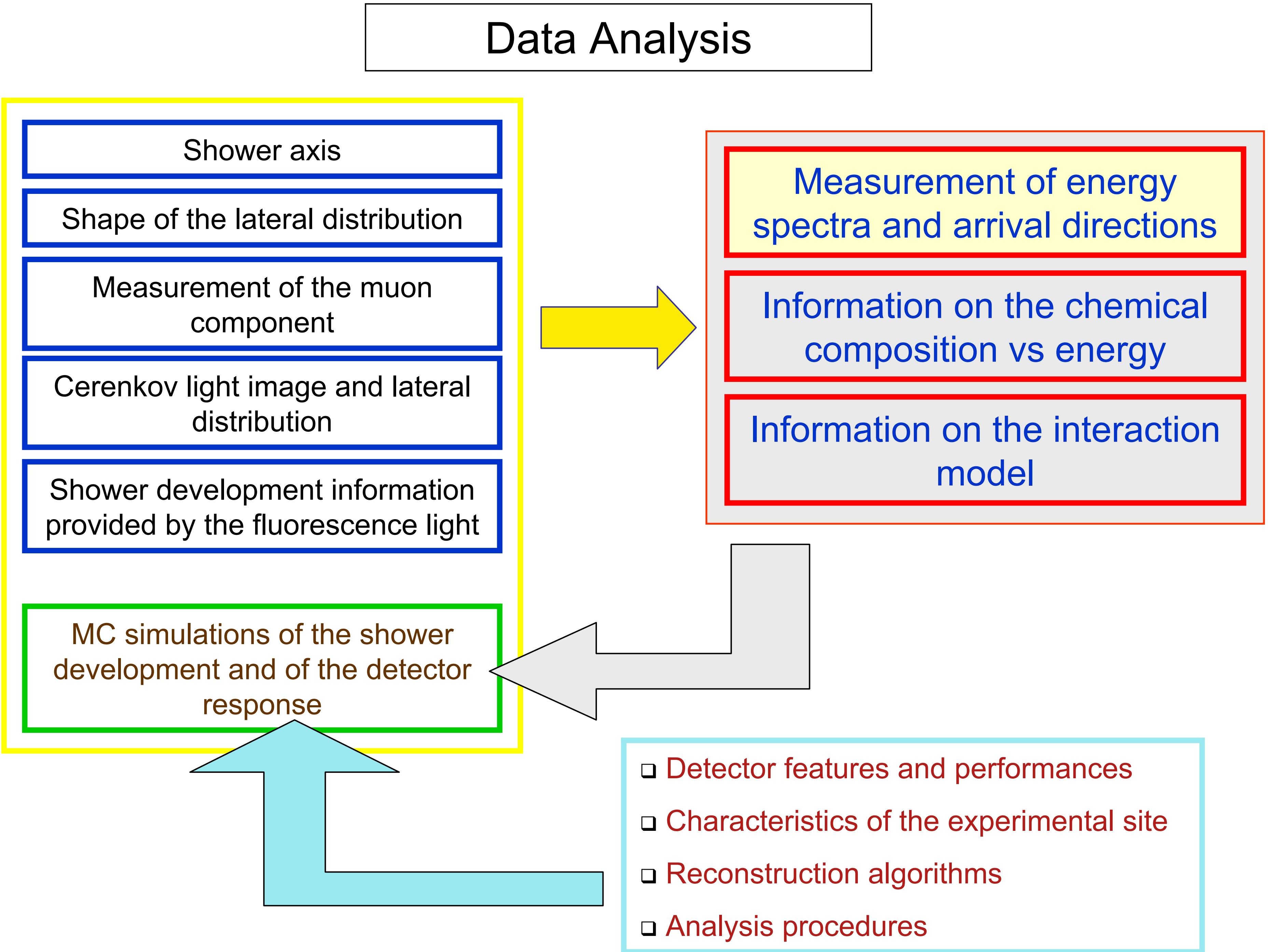


Shower particle tracks: photon




First interaction (usually several 10 km high)
Air shower evolves (particles are created and most of them later stop or decay)
Some of the particles reach the ground
Measurement of Cherenkov light with telescopes or wide angle pmts
Measurement of fluorescence light
Measurement of radio emission
Measurement with scintillation counters
Measurement of particles with tracking detectors or calorimeters
Measurement of low energy muons with scintillation or tracking detectors
Measurement of high energy muons deep underground

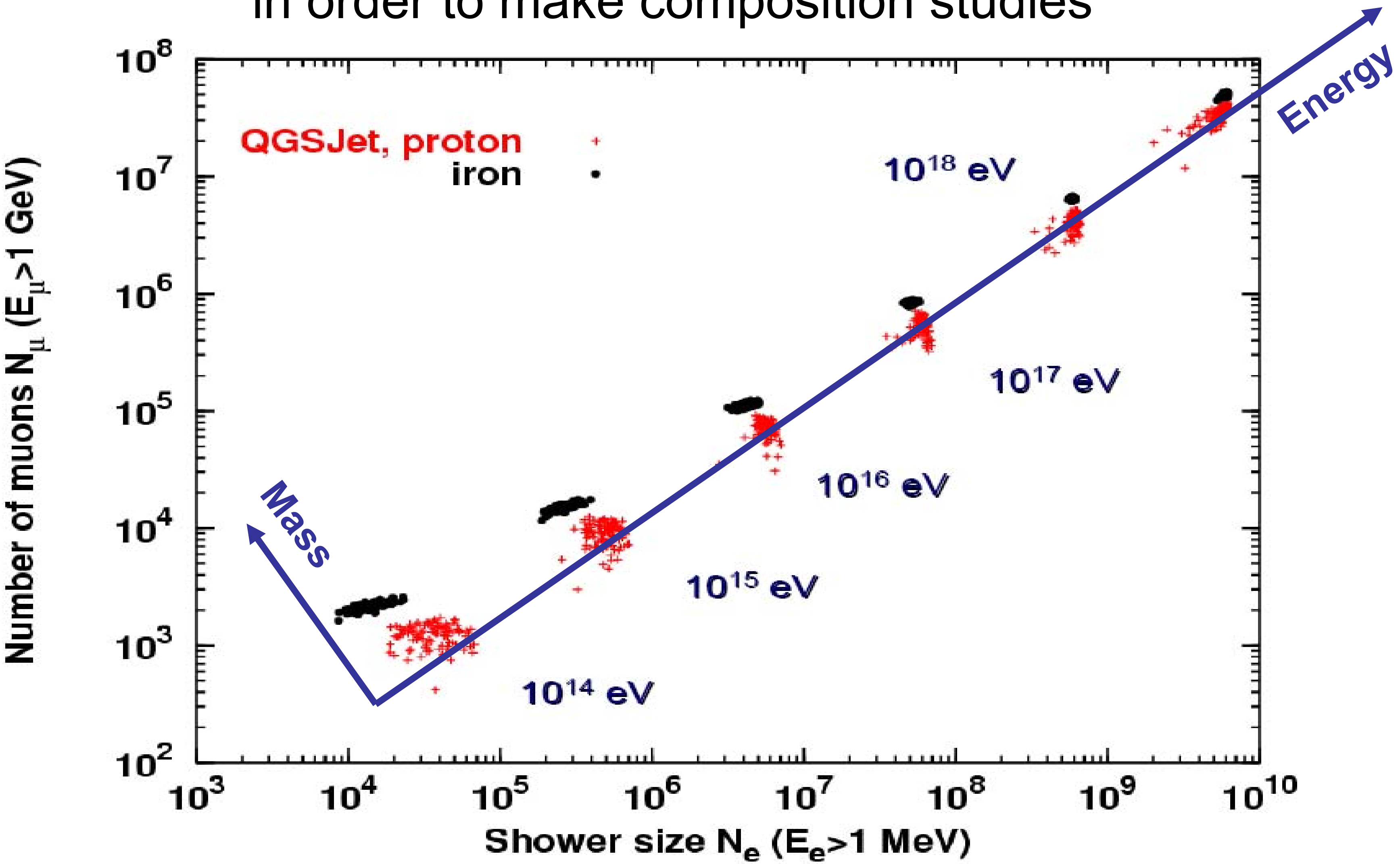

Fluxes of Cosmic Rays
Flux (m² sr s GeV)⁻¹
(1 particle per m²−second)
Čerenkov light
charged part.
underground μ
Knee
(1 particle per m²−year)
Fluorescence light
Ankle
(1 particle per km²−year)
Energy (eV)


Data Analysis
Shower axis
Shape of the lateral distribution
Measurement of the muon component
Cerenkov light image and lateral distribution
Shower development information provided by the fluorescence light
MC simulations of the shower development and of the detector response
Measurement of energy spectra and arrival directions
Information on the chemical composition vs energy
Information on the interaction model
Detector features and performances
Characteristics of the experimental site
Reconstruction algorithms
Analysis procedures

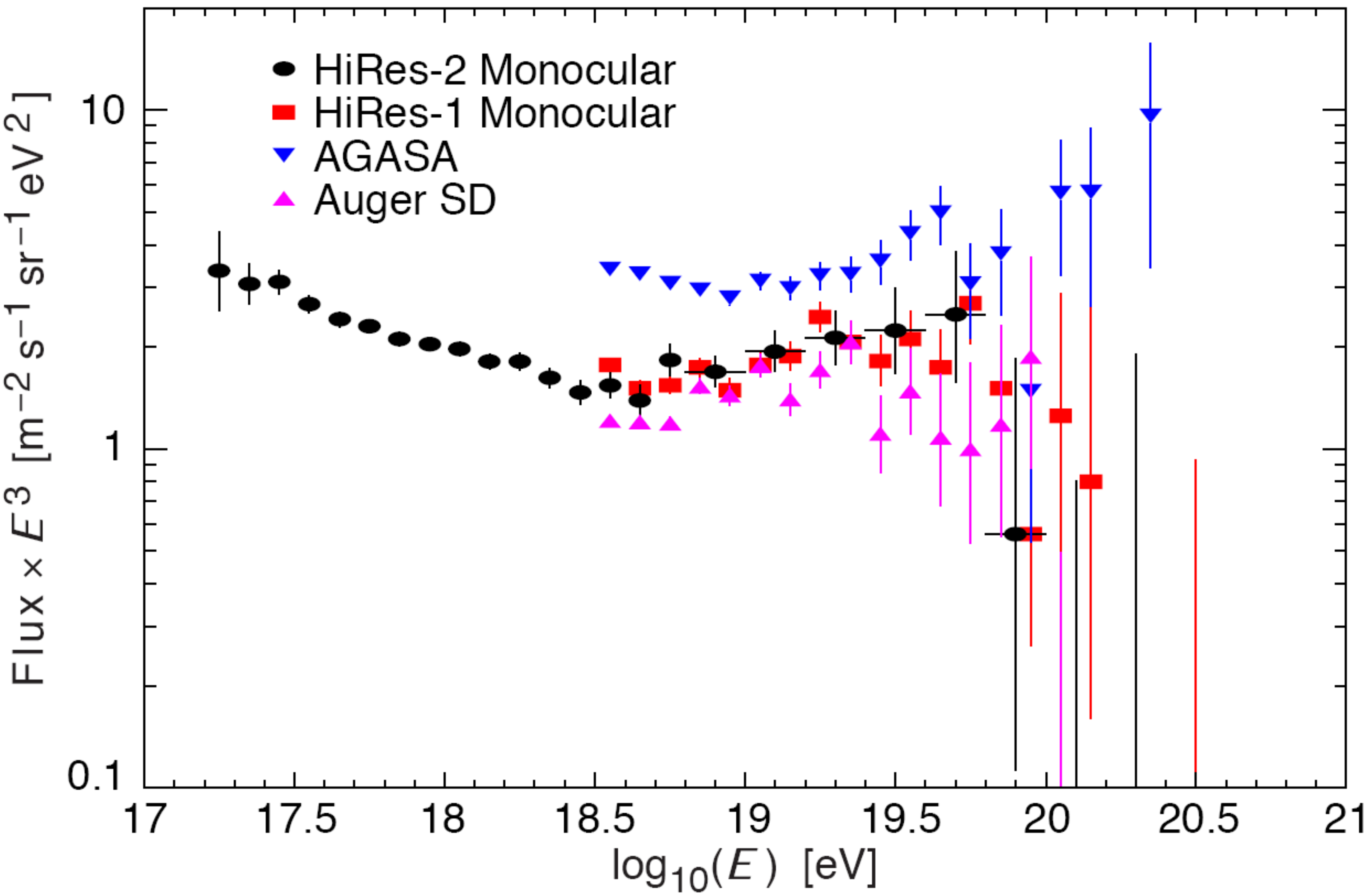
Use differences in muon yeld for different primaries

+ unfolding methods

in order to make composition studies



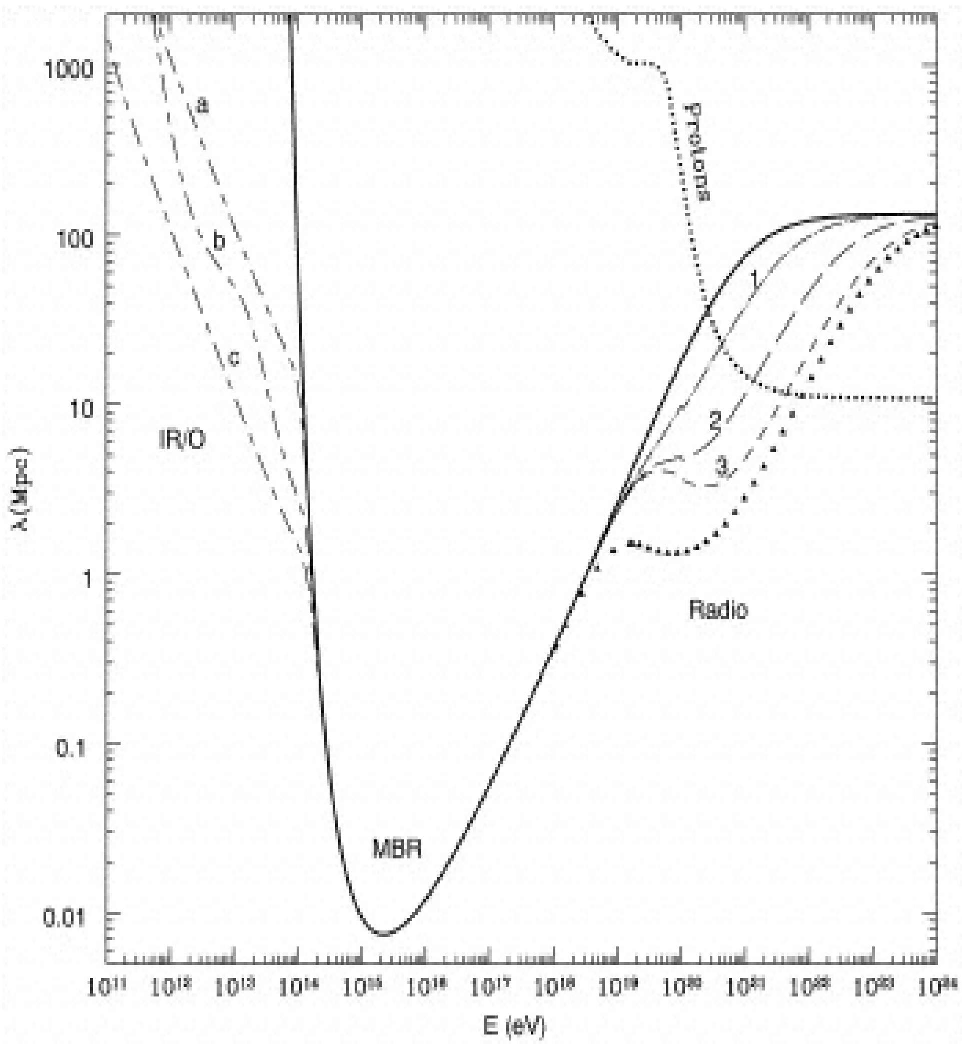
What happens at extreme energies ?

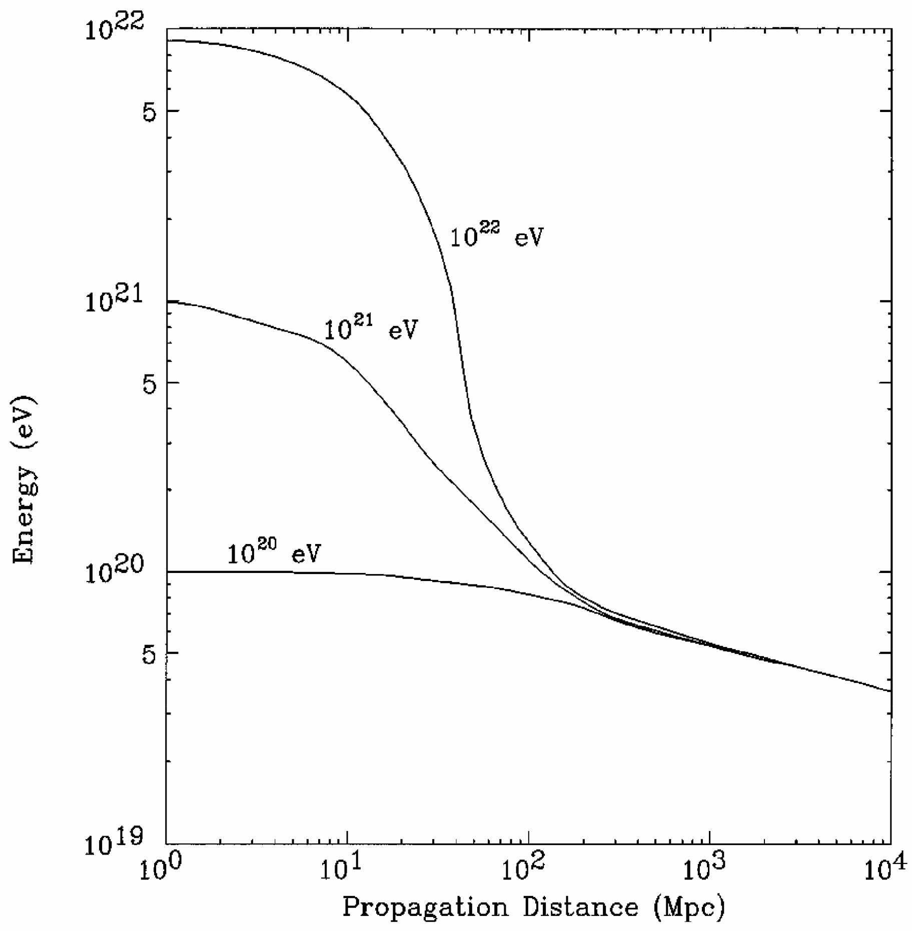


GZK cutoff for protons with $E > 5 \cdot 10^{19}$eV

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

$$p\ \gamma_{CMB} \rightarrow \Delta^+ \rightarrow n\ \pi^+$$





Cutoff for photons with $E > 10^{14}$eV

$$\gamma\ \gamma_{CMB} \rightarrow e^+\ e^-$$


TST 208
16 Dec/06
羊八井宇宙线观测站 ARGO
ARGO LABORATORY
MACRO

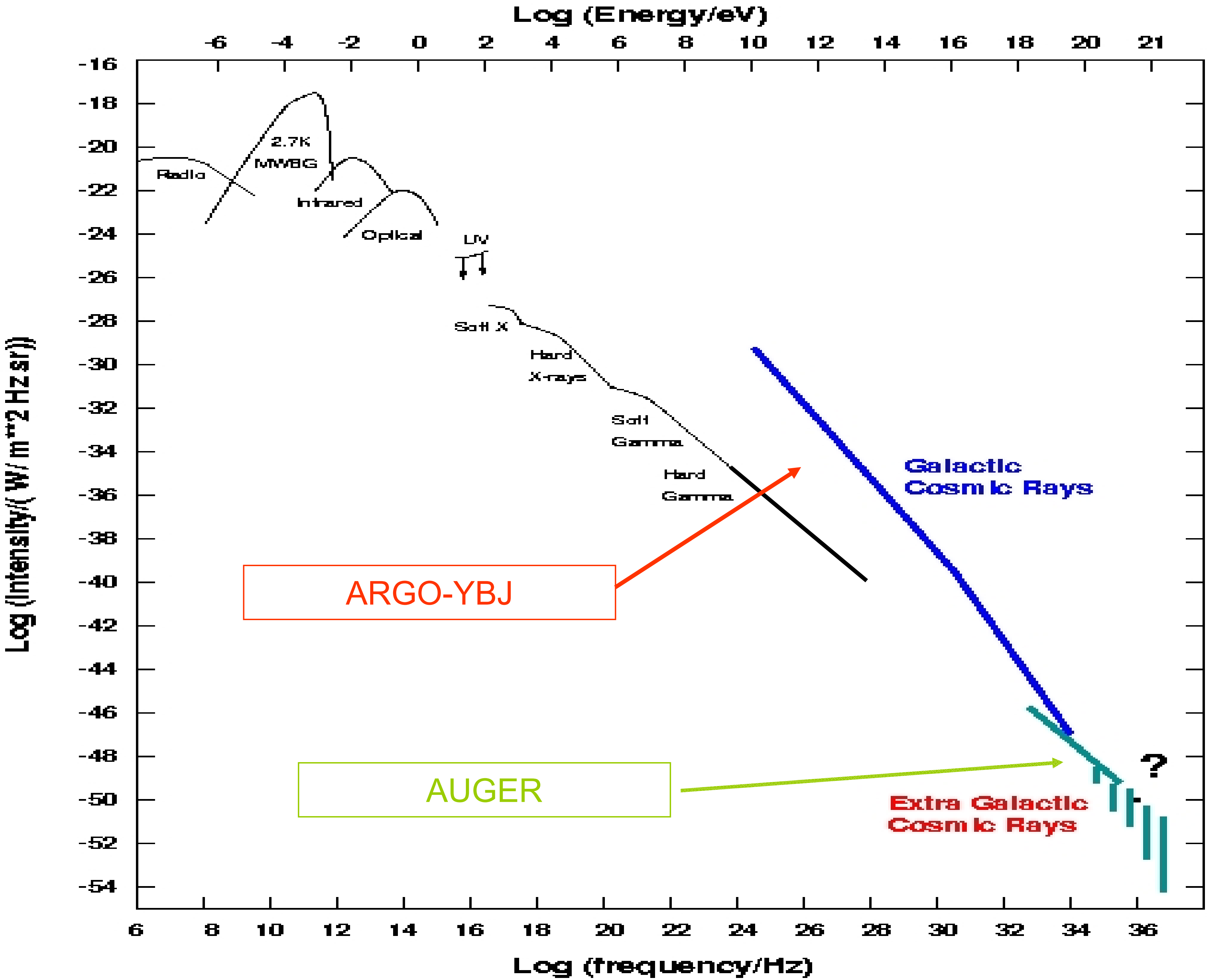
Two Examples

- Example #1:
  ARGO-YBJ inTibet

- Example #2
  AUGER in Patagonia

Example #1

ARGO-YBJ

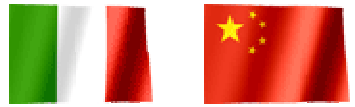


Log (Energy/eV)
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
21
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
-42
-44
-46
-48
-50
-52
-54
Log (Intensity/(W/ m**2 Hz sr))
Radio
2.7K
MWBG
Infrared
Optical
UV
Soft X
Hard
X-rays
Soft
Gamma
Hard
Gamma
Galactic
Cosmic Rays
ARGO-YBJ
AUGER
?
Extra Galactic
Cosmic Rays
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Log (frequency/Hz)

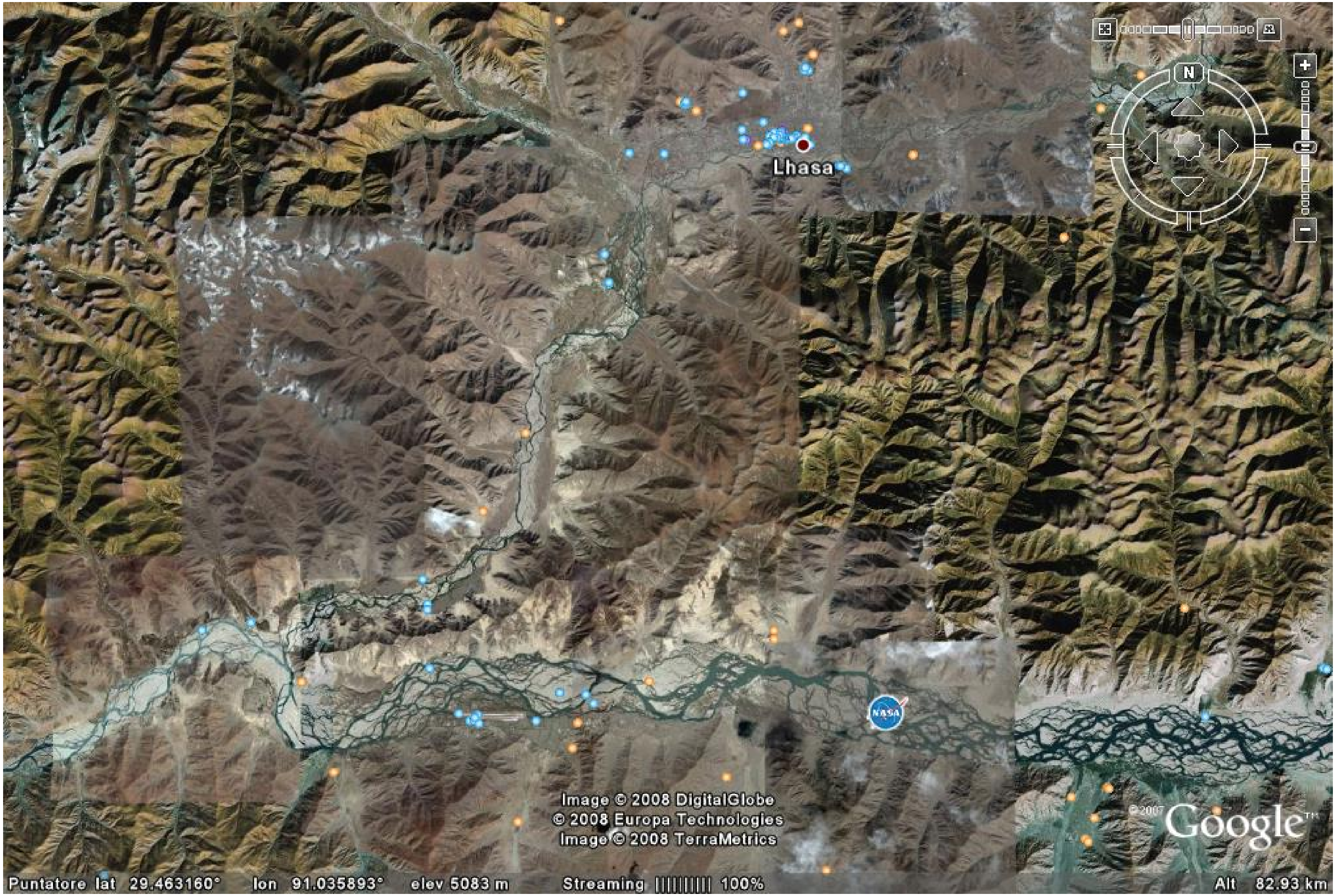
The ARGO-YBJ experiment

Collaboration between:

- Istituto Nazionale di Fisica Nucleare (INFN) – Italy
- Chinese Academy of Science (CAS)



Site: Cosmic Ray Observatory @ Yangbajing (Tibet), 4300 m a.s.l.


Lhasa
Image © 2008 DigitalGlobe
© 2008 Europa Technologies
Image © 2008 TerraMetrics
© 2007 Google
Puntatore lat 29.463160° lon 91.035893° elev 5083 m
Streaming |||||||||| 100%
Alt 82.93 km

ARGO-YBJ
Lhasa
Image © 2008 DigitalGlobe
© 2008 Europa Technologies
Image © 2008 TerraMetrics
© 2008 NFGIS
Google
Puntatore lat 30.180676° lon 90.778907° elev 4848 m
Streaming |||||||||| 100%
Alt 212.06 km

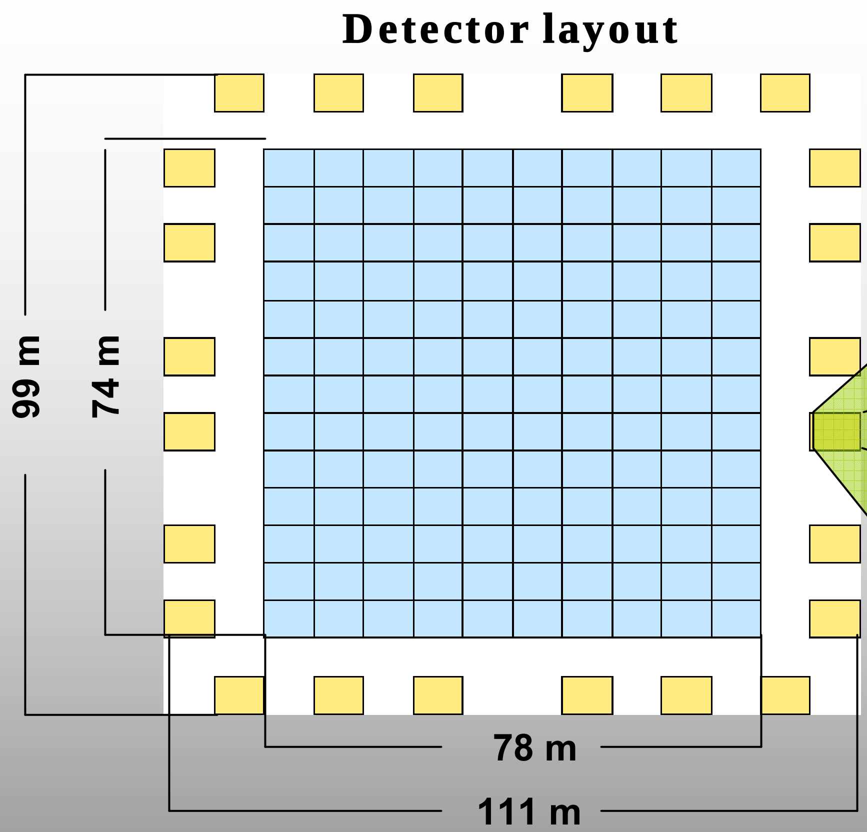
High Altitude Cosmic Ray Laboratory @ YangBaJing

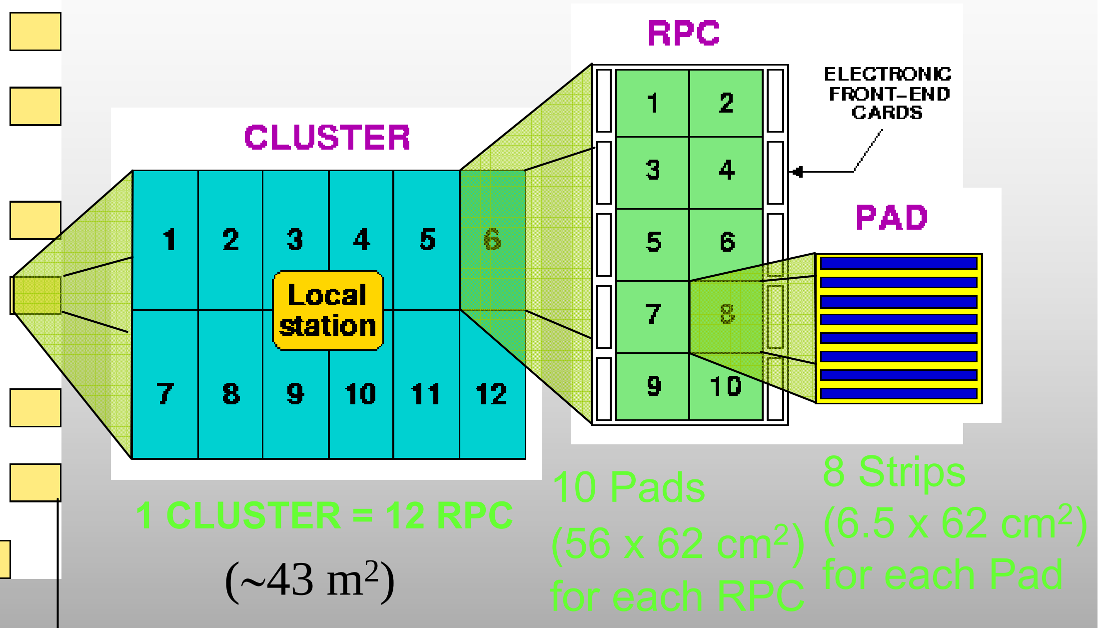
Site Altitude: 4300 m a.s.l. , ~ 600 g/cm^2

Site Coordinates: longitude 90° 31’ 50” E, latitude 30° 06’ 38” N

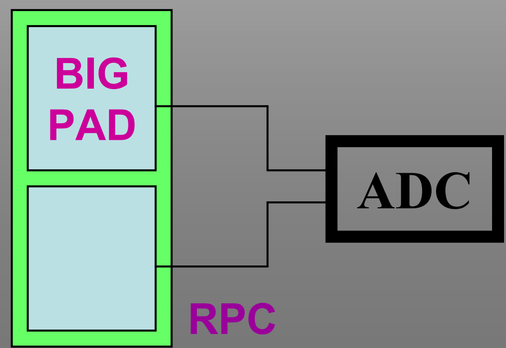
ARGO-YBJ layout

time resolution ~1 ns
space resolution = strip





Layer (~92% active surface) of Resistive Plate Chambers (RPC), covering a large area (5600 m^2)
+ sampling guard ring
+ 0.5 cm lead converter

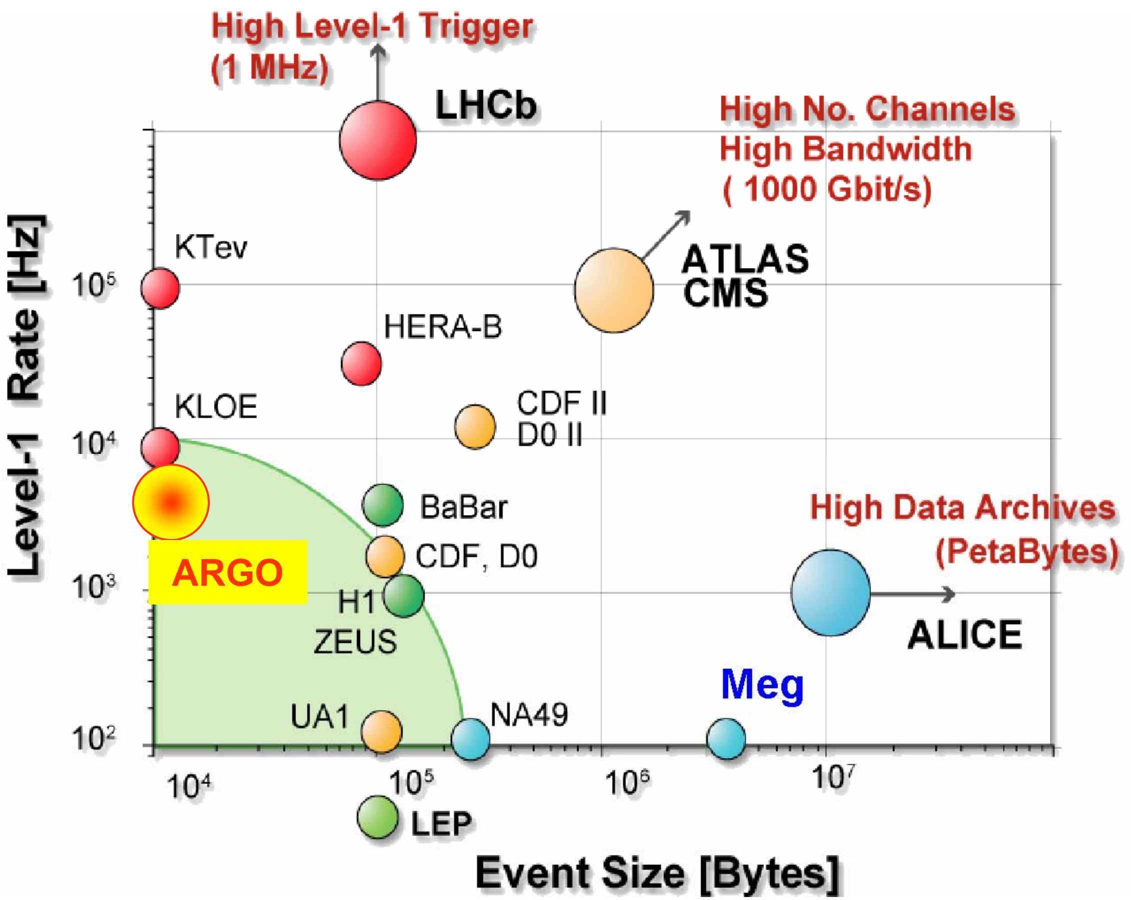


Read-out of the charge induced on "Big Pads"

Experiment Hall

Data Handling

Heavy data handling with respect to other Cosmic Ray experiments and comparable to HEP standard

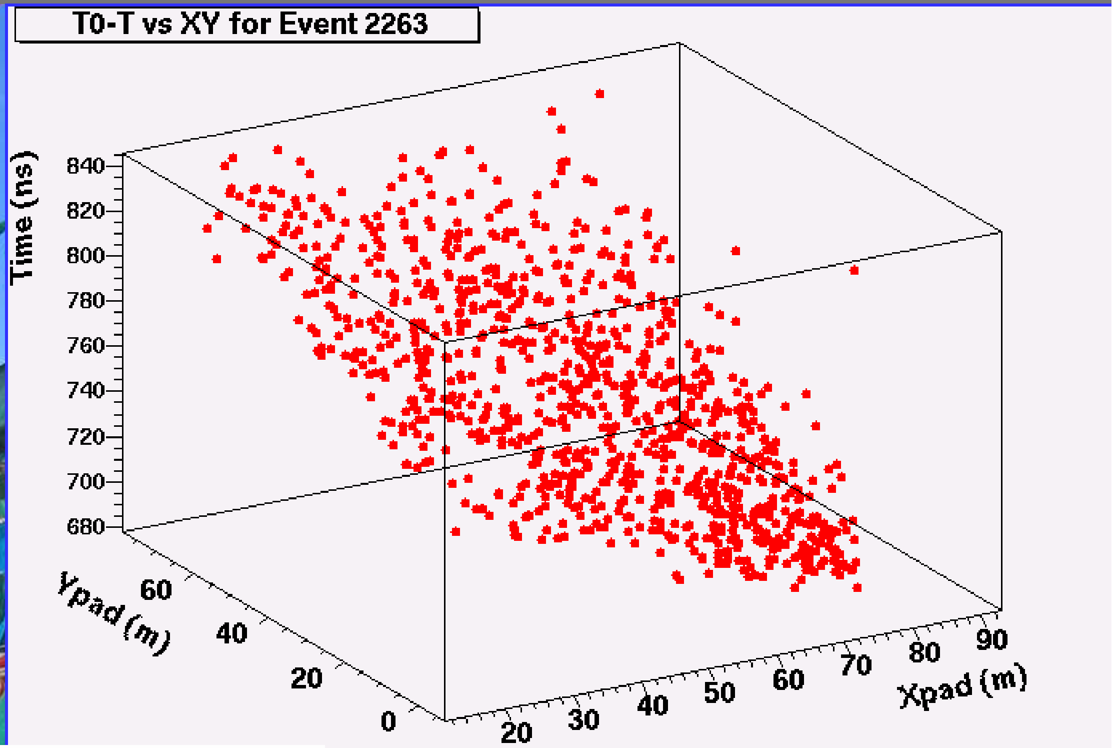


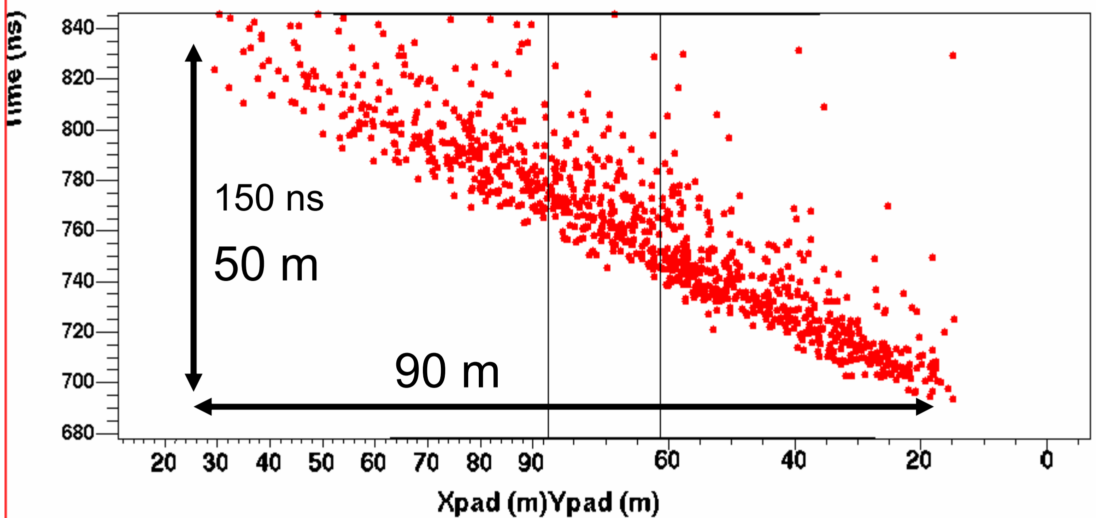
- Raw event size about 10kB
- <u>Trigger rate of few kHz</u>
- Data compression on site
- <u>Site link up to 155 Mb/s</u>
- Data processing in Beijing
- Data processing in Bologna
- <u>Use of GRID technologies</u>
- Dynamic storage (CASTOR)
- Back-up on DLT and LTO
- Use of C++ and OO technology

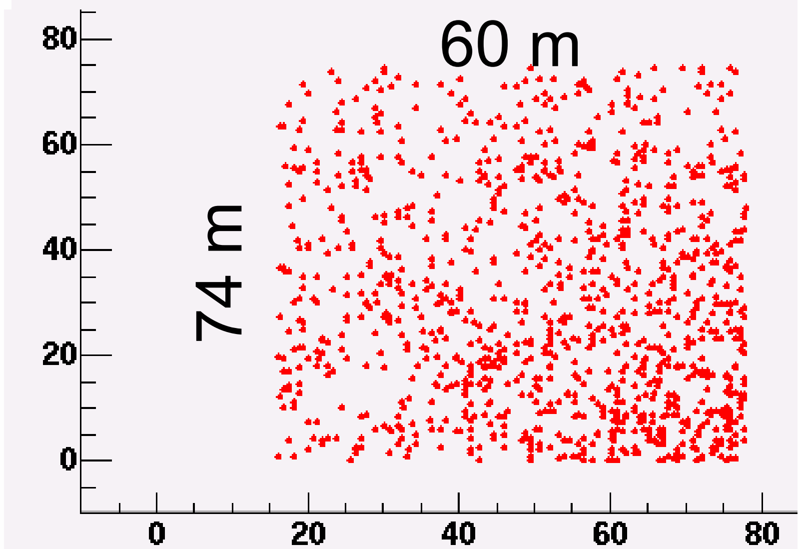
Some events

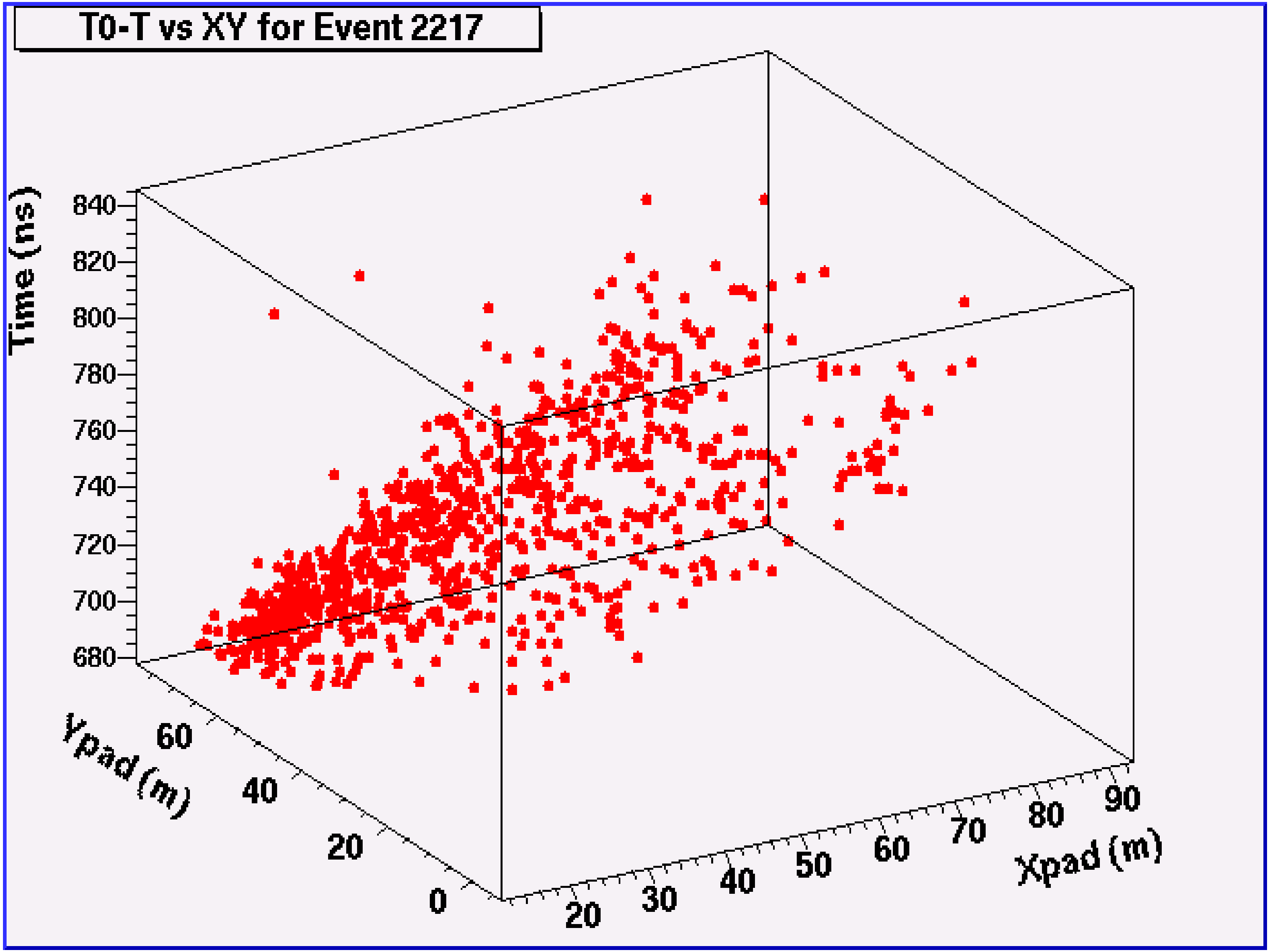
A unique way to study EAS

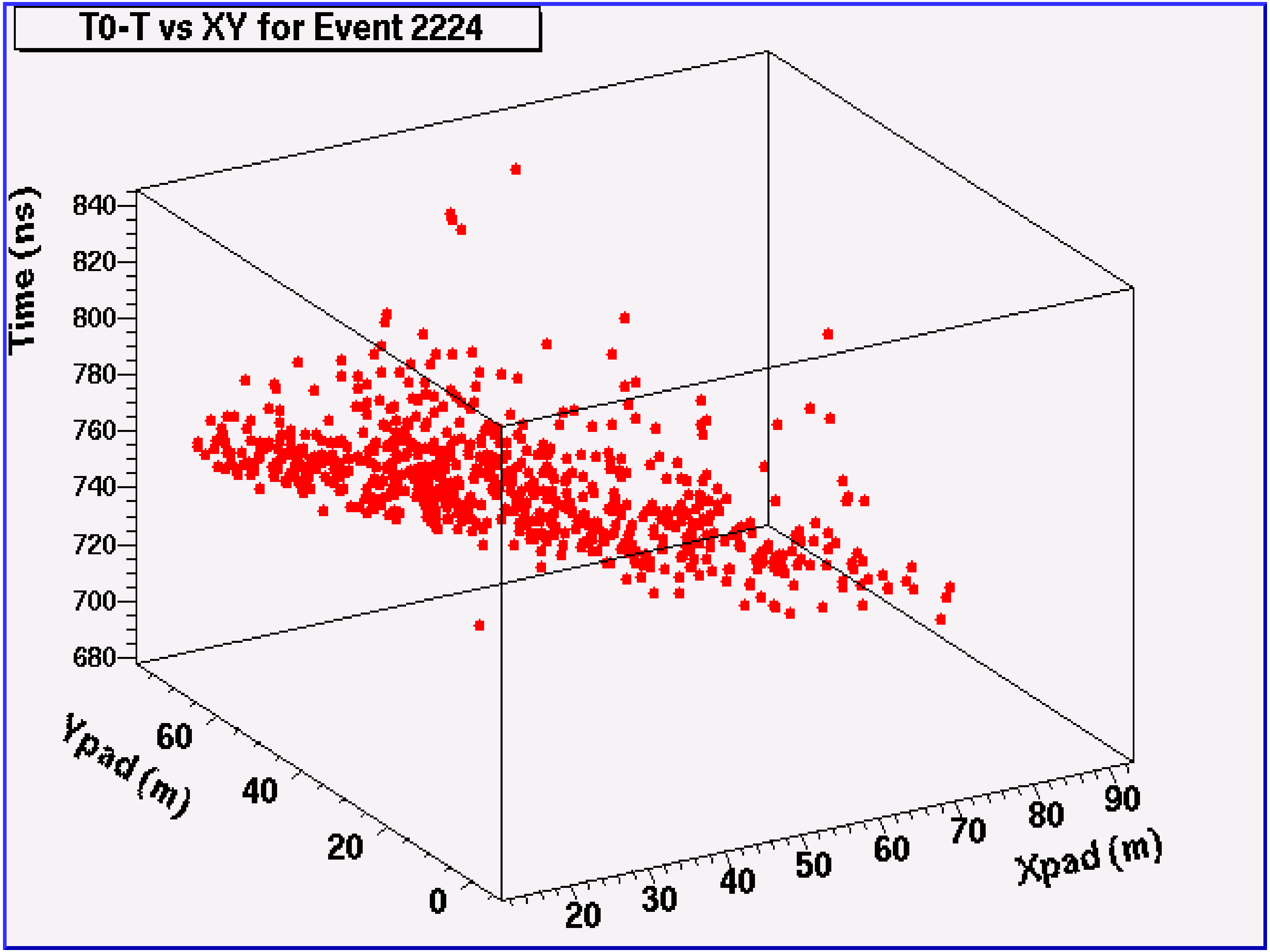
- Full space-time reconstruction
- Shower topology
- Structure of the shower front
- ……..



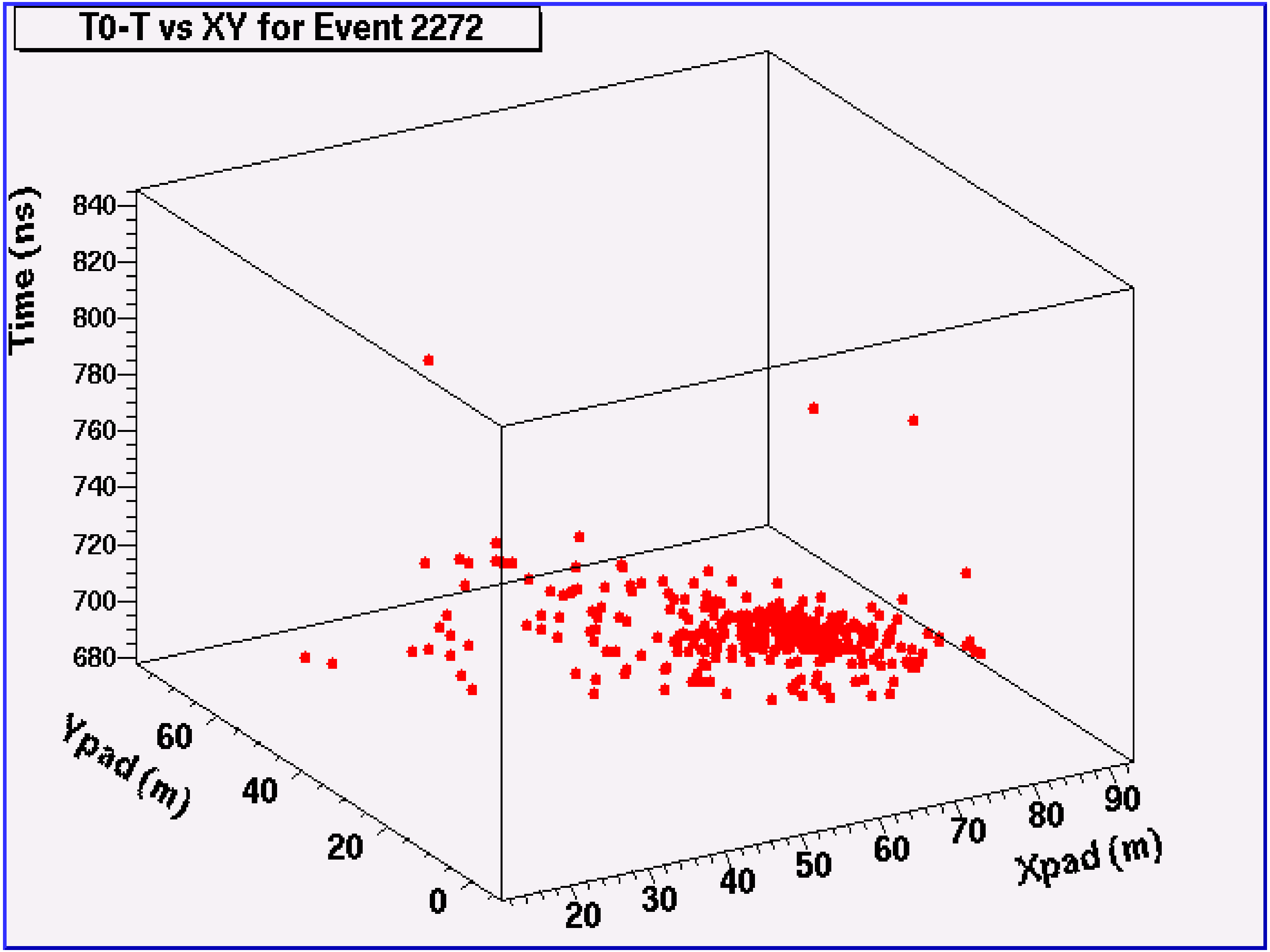




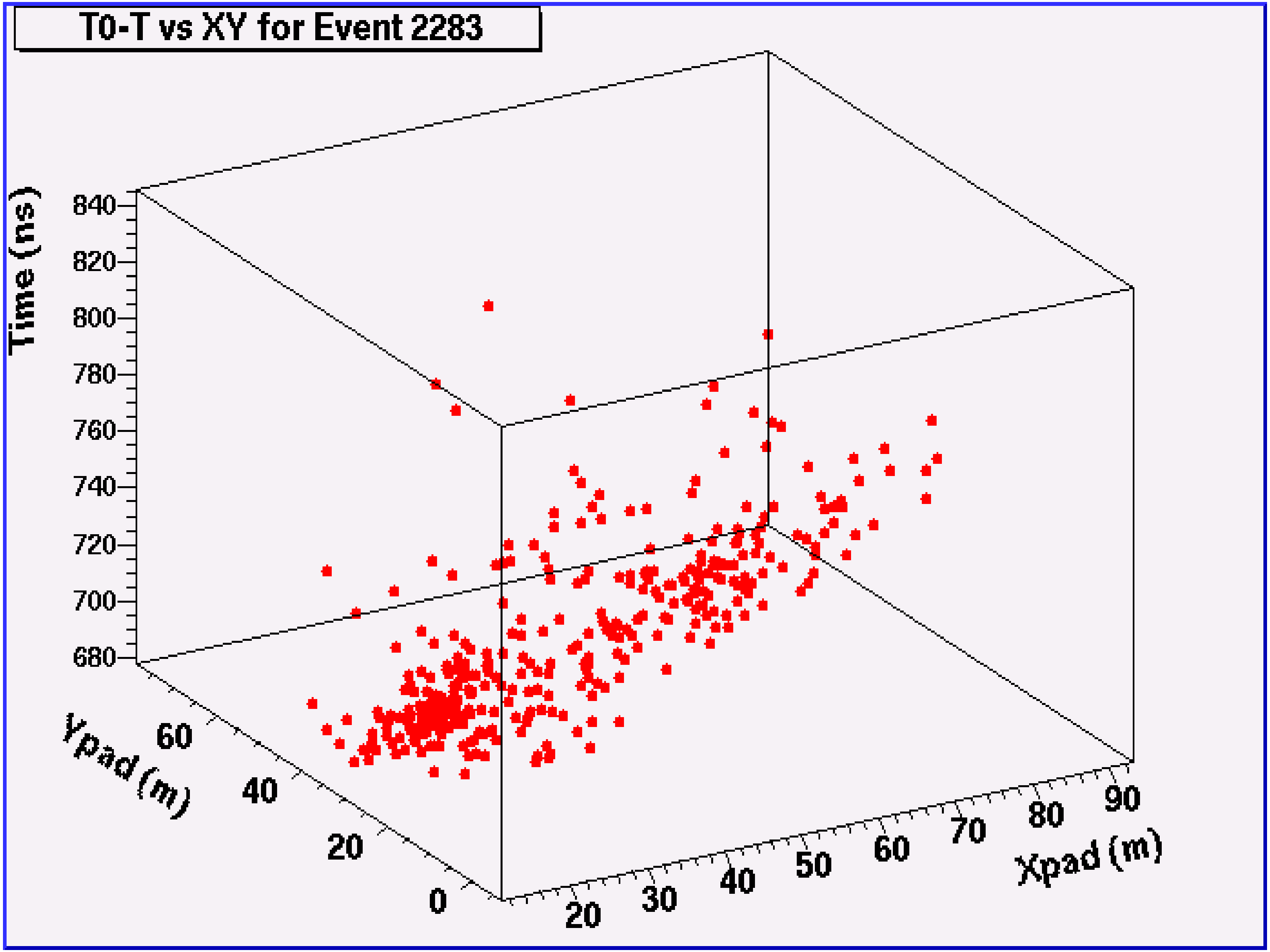

T0-T vs XY for Event 2217
Time (ns)
840
820
800
780
760
740
720
700
680
Ypad (m)
60
40
20
0
20
30
40
50
60
70
80
90
Xpad (m)

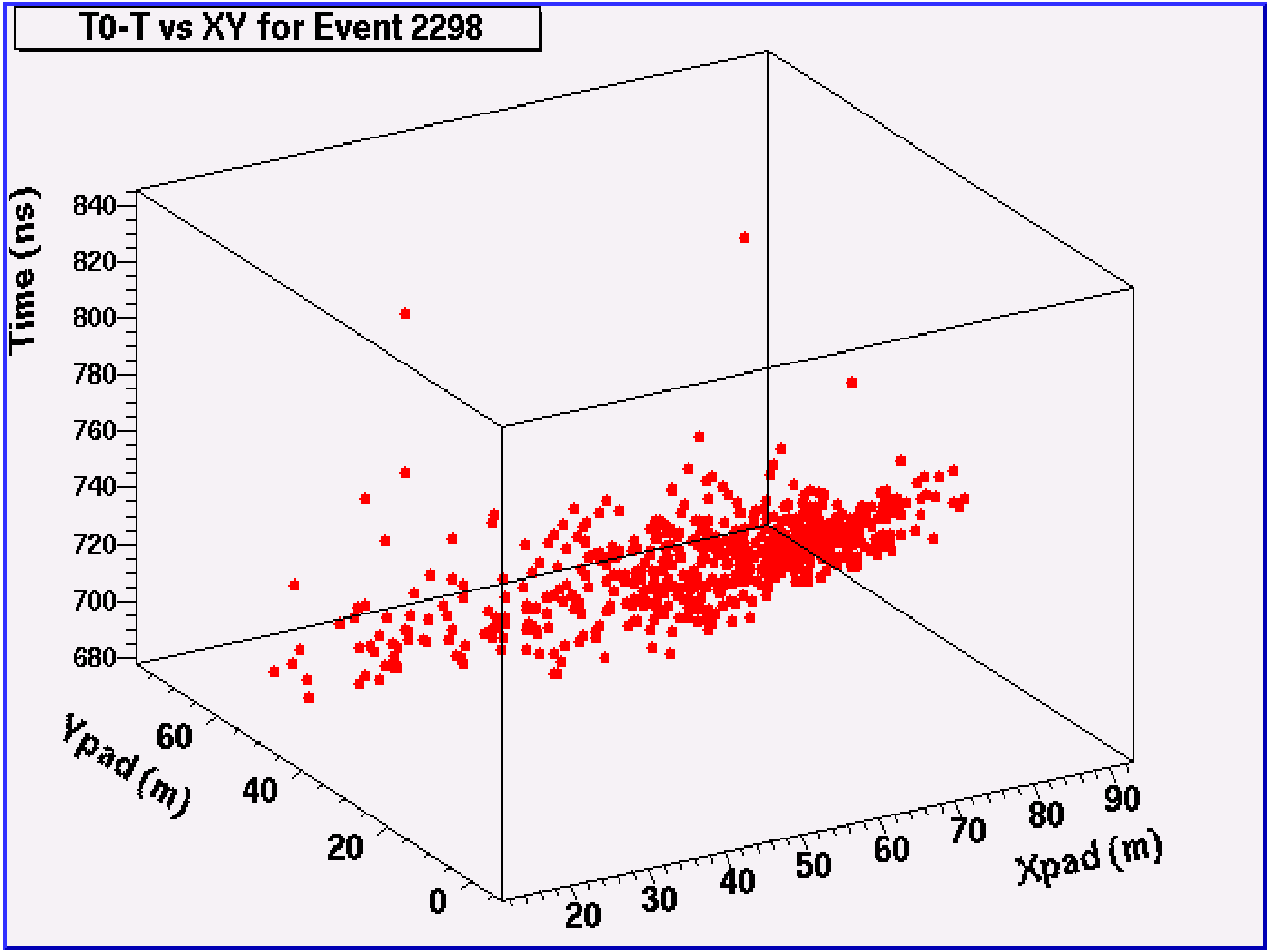


T0-T vs XY for Event 2224
Time (ns)
840
820
800
780
760
740
720
700
680
Ypad (m)
60
40
20
0
20
30
40
50
60
70
80
90
Xpad (m)



T0-T vs XY for Event 2272
Time (ns)
840
820
800
780
760
740
720
700
680
Ypad (m)
60
40
20
0
Xpad (m)
20
30
40
50
60
70
80
90


T0-T vs XY for Event 2283
Time (ns)
840
820
800
780
760
740
720
700
680
Ypad (m)
60
40
20
0
20
30
40
50
60
70
80
90
Xpad (m)



T0-T vs XY for Event 2298
Time (ns)
840
820
800
780
760
740
720
700
680
Ypad (m)
60
40
20
0
Xpad (m)
20
30
40
50
60
70
80
90

The simulation tool: ARGO-G

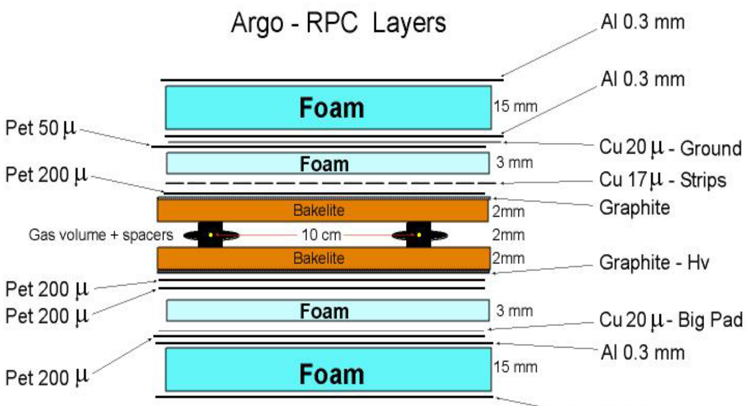
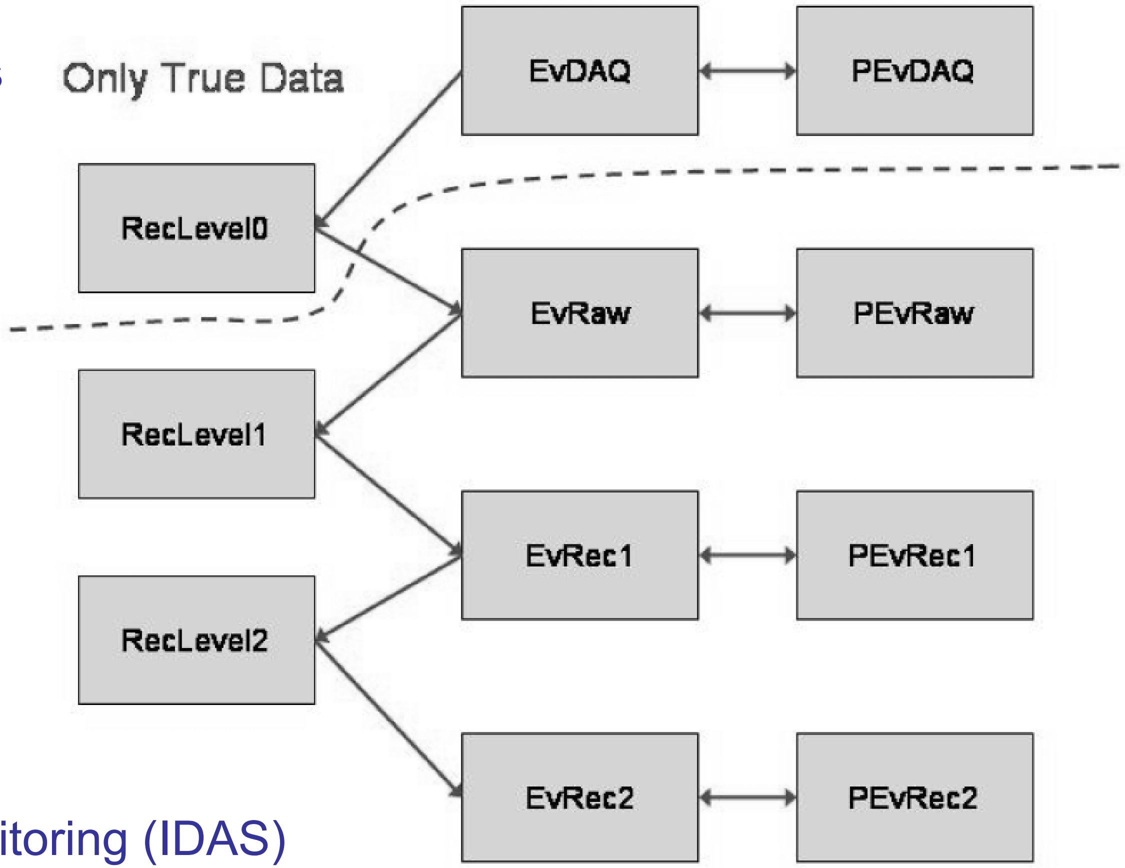


Figure 4

- ✓ Detector stratigraphy and layout
- ✓ Tracking of particles in the detector volumes
- ✓ Background and trigger simulation
- ✓ Simulation of the intrinsic RPC time resolution (1 ns smearing of particle times)

The analysis tool : Medea++

- OO technology
- Persistency : ROOT
- Several reconstruction levels



- Other tools:
  - Data Check Manager
  - Set of scripts for offlne monitoring (IDAS)

RECONSTRUCTION LEVEL 0 (applied only to true data)

The RecLevel0 reconstruction makes decoding of the DAQ input file and building an event in a format useful for the next processing.
The events reconstructed at this level are called EvRaw.

RECONSTRUCTION LEVEL 1

Starting from this level, Monte Carlo and true data follow the same way and pass through the same algorithms.
The RecLevel1 reconstruction performs five operations:

1. Connect each hit to the pad to which it is associated.
2. Reject hits that are in detector element not active, broken or just not properly working.
3. Sort the hits in time.
4. Apply the noise filter.
5. Correct the hit time by using the calibration information associated to the detector element

RECONSTRUCTION LEVEL 2

RecLevel2 performs the reconstruction of the direction and core position of the air showers in three steps:

1. Fitting all the hits selected by the Noise Filter to a plane.
2. Compute the core position.
3. Fitting all the hits used by the planar fit computation to a cone using the core position estimated at step 2.

The final results of the RecLevel2 reconstruction are stored in a Shower object that can be retrieved by the EvRec2 event using the shower() methods.

The simplest example:

Looping on EvRec2 events

```
#include "Run/Run.h"
#include "EvRec2/EvRec2.h"
int main (int argc, char** argv) {
   int nev_max=0;
   if (argc > 1)  nev_max=atoi(argv[1]);
   Run * r = Run::factory(0,"none");
   if (r!=0) {
      EvRec2 * evrec2 = EvRec2::getEvRec2(”persistent”);
      int nev_cur=0;
      bool eof = false ;
      while (!eof && (nev_cur++ < nev_max || nev_max<=0) ) {
         eof = r->nextevf();
      }
   }
   return 0;
}
```

Very simple example:

identify and print cluster info of a given hit

```
# include "Hit/AHlist.h"
# include "EvRec1/EvRec1.h"
....
// access to the EvRec1 object
   EvRec1 * evr = EvRec1::getEvRec1();

// access to the EvRec1 list of hits
   AHlist * ListaHit=evr->hitlist()

// loop on the RecLevel1 selected hits (hits that are accepted
// by the NoiseFilter)
   for(AHConItor q=ListaHit->selbegin(); q!=ListaHit->selend(); q++)
{
     // access to the Pad associated to the hit
      Pad * hitpad=(*q)->pad();

     // access to the Cluster in which the pad is located
      Cluster * hitcluster = dynamic_cast<Cluster *> (hitpad->parent("Cluster"));

   // print the Cluster absolute identification number
      cout<<"The hit is in the cluster N.: "<<hitcluster->idabsolute()<<endl;
      cout<<"The Cluster coord. are: "<<hitcluster->xabsolute()<<"," <<hitcluster->yabsolute()<<endl;
}
```

A complex example: the DISPLAY Tool

- **Detector Monitoring**
  - TDC distributions
  - Detector Maps (cluster occupancy, pad occupancy , strip...)
  - Multiplicity distributions (absolute rates, ...)
  - Trigger rates
  - Event timing vs space topology (correlated noise , ...)
  - ....
- **Analysis Tool**
  - Event Display (2D - 3D, zoom, ...)
  - Display reconstructed quantities (shower axis, core position,...)
  - χ^2 distributions
  - ....

Technical Solutions

Use of the **ROOT GUI classes** for user interface.

Implemented in all the versions of medea++ (i.e. OnLine, Workstation, Server).

Conceived as a singleton observer of EvRec1:

```
EvRec1  *evrec1   = EvRec1::getEvRec1();
ARGODisEvt *evd = ARGODisEvt::getARGODisEvt(run);
```

A set of ROOT objects (histograms, graphs,...) are created and subsequently updated at each event.

Everything is passed to the `ARGODisTools.cc` classes that provide the display and the user interface.

Implemented Plots:
DAQ Data

- ✓ Event X-Y
- ✓ Event T-X and/or T-(XY)
- ✓ Global Occupancy map
- ✓ TDC integral distribution
- ✓ Pad Multiplicity distribution (Hz)
- ✓ Trigger Rate and average χ^2 as a function of Time
- ✓ Cluster Occupancy maps (for each cluster)
- ✓ Pad Multiplicity distributions (for each cluster)
- ✓ Strip Occupancy maps (for each cluster)

Implemented Plots:
MC Data

- ✓ Event X-Y
- ✓ Event T-X and/or T-(XY)
- ✓ Global Occupancy map
- ✓ Time integral distribution
- ✓ Pad Multiplicity distribution
- ✓ Energy distribution
- ✓ Cluster Occupancy map (<u>for each cluster</u>)
- ✓ Pad Multiplicity distribution (<u>for each cluster</u>)
- ✓ Strip Occupancy maps (<u>for each cluster</u>)

Tools:

- ✓ Use ROOT Editable Plots (zoom, 2D, 3D, drawing options …)
- ✓ Enable/Disable Event Dump
- ✓ View the shower front in 2D or 3D
- ✓ Open a dedicated window for 3D shower display
- ✓ Navigate through different Clusters
- ✓ Skip events / Go to a given event / Go to End Of File
- ✓ Save Plots as .ps, .eps or .gif files
- ✓ Save all the plots as TObjects in a ROOT file that can be subsequently read and analyzed
- ✓ ………

Working Mode

✓ **Standard Mode:**

Sequentially read all the event in DAQ or MC file.

✓ **Sampling Mode:**

Sequentially read only one event every N in a DAQ or MC file.

Example: int EvtReadEach = 100;

✓ **SpyMode 2:**

Acces to the file tail, find an event a process it. If left in “free run” one event is taken every T μs.

Example: int SpyMode = 1000000;

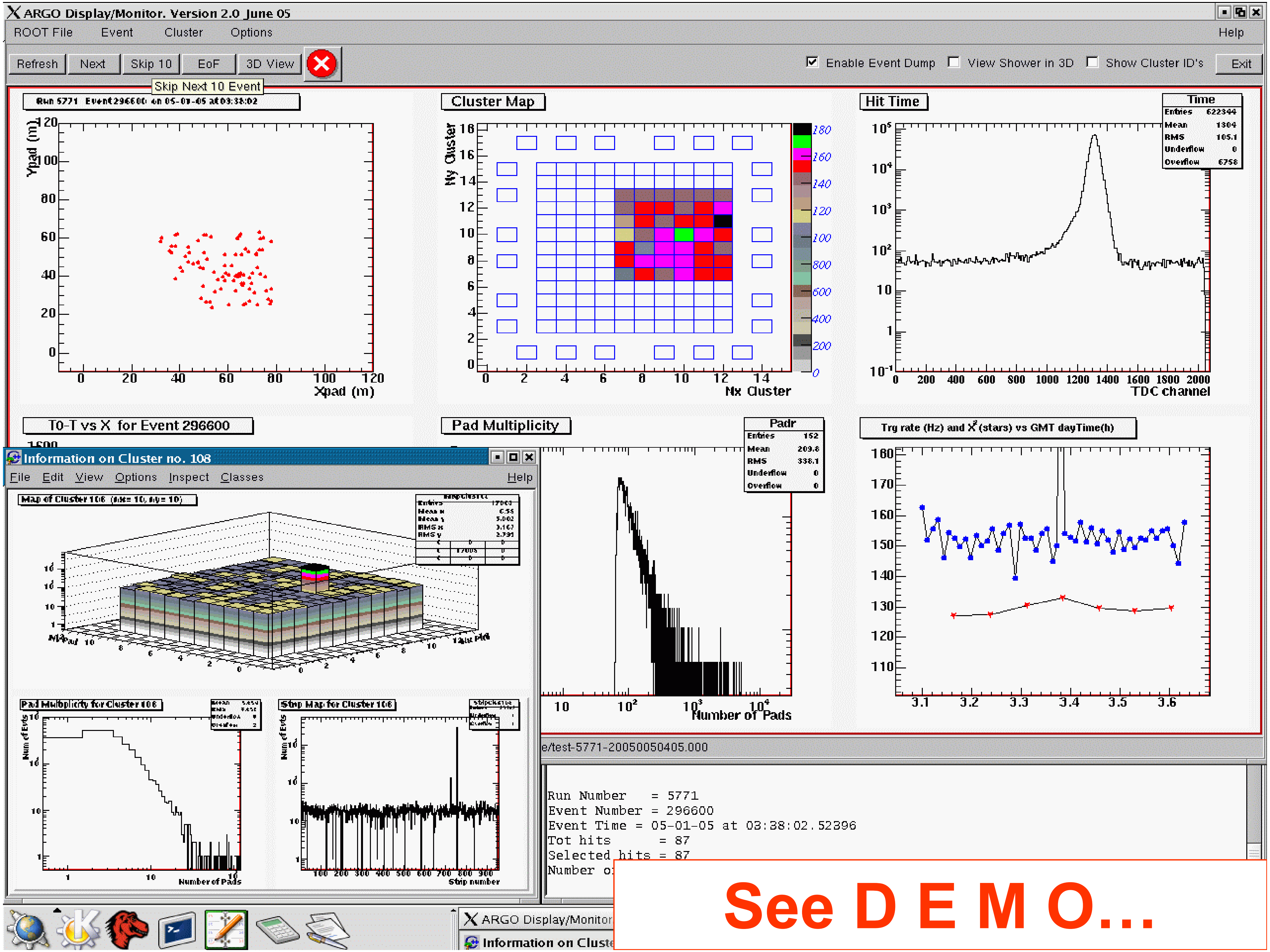
✓ **SpyMode 2:**

The display is embedded in a higher level process that gets sample events form the DAQ circular buffer

In all the three cases, in the “free run” mode:

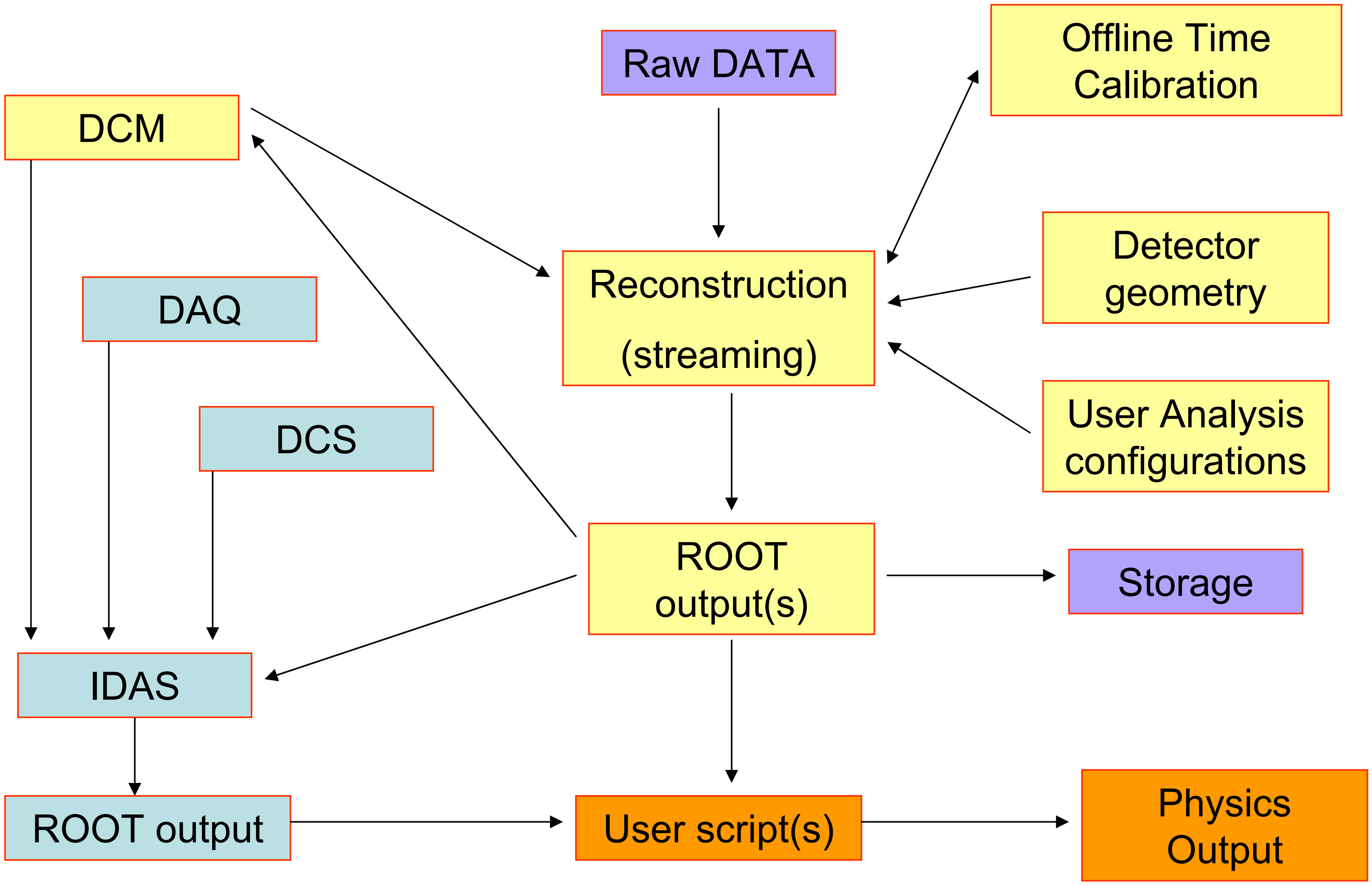
- the screen is updated with a frequency given by the user

- the event loop can be broken any time to give the control to the user


ARGO Display/Monitor. Version 2.0 June 05
ROOT File
Event
Cluster
Options
Help
Refresh
Next
Skip 10
EoF
3D View
Enable Event Dump
View Shower in 3D
Show Cluster ID's
Exit
Skip Next 10 Event
Cluster Map
Hit Time
Ypad (m)
Xpad (m)
Ny Cluster
Nx Cluster
TDC channel
T0-T vs X for Event 296600
Pad Multiplicity
Trg rate (Hz) and X (stars) vs GMT dayTime(h)
Number of Pads
Information on Cluster no. 108
File
Edit
View
Options
Inspect
Classes
Help
Run Number = 5771
Event Number = 296600
Event Time = 05-01-05 at 03:38:02.52396
Tot hits = 87
Selected hits = 87
ARGO Display/Monitor
Information on Cluste

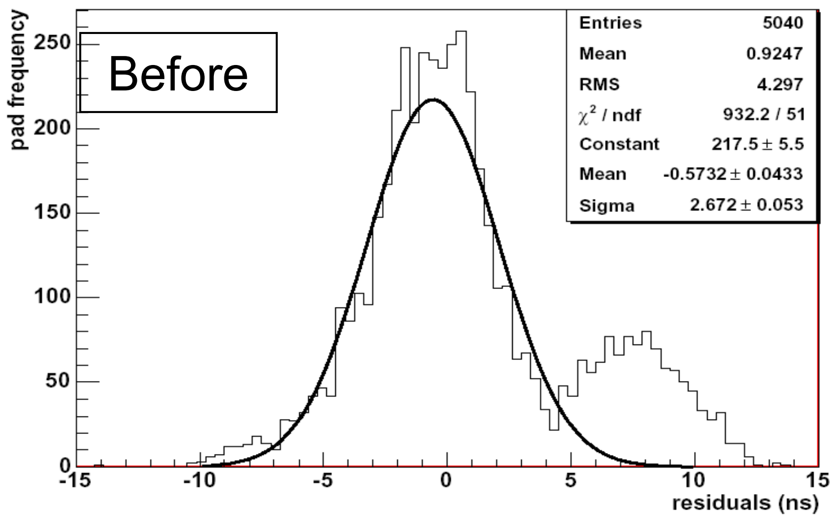
See D E M O...

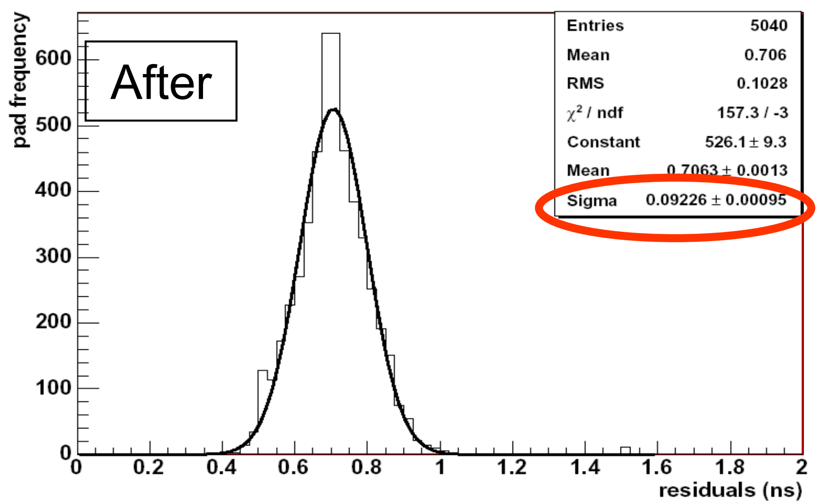
Event Processing @ CNAF

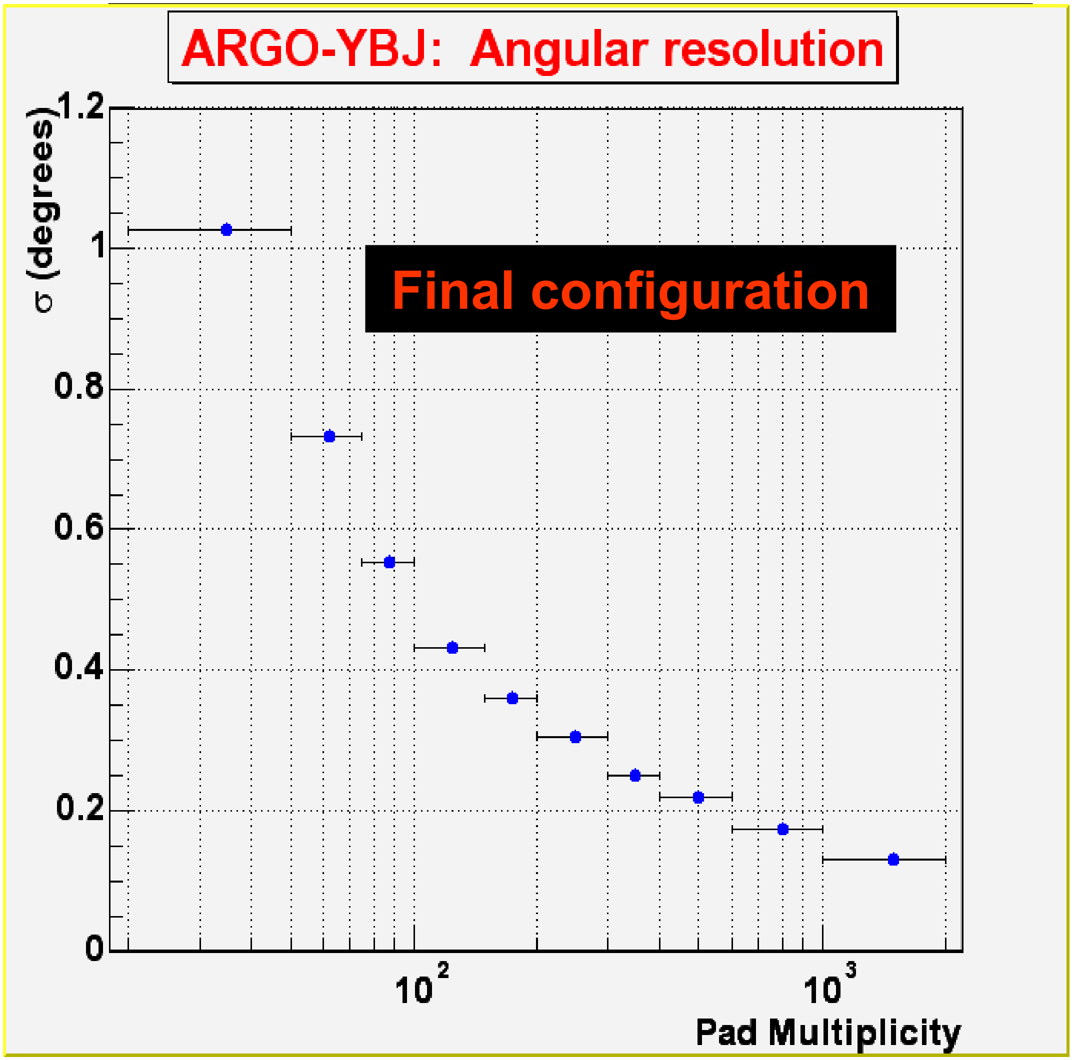


OffLine Time Calibration & Angular Resolution

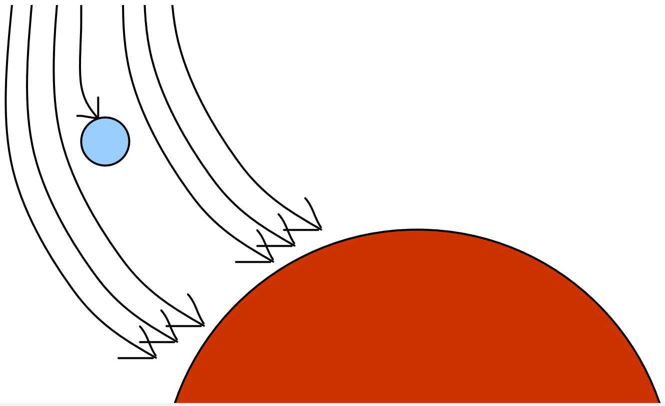
- ✓ Use the events to calibrate the detector.
- ✓ The measured angular resolution is in agreement with expectations.

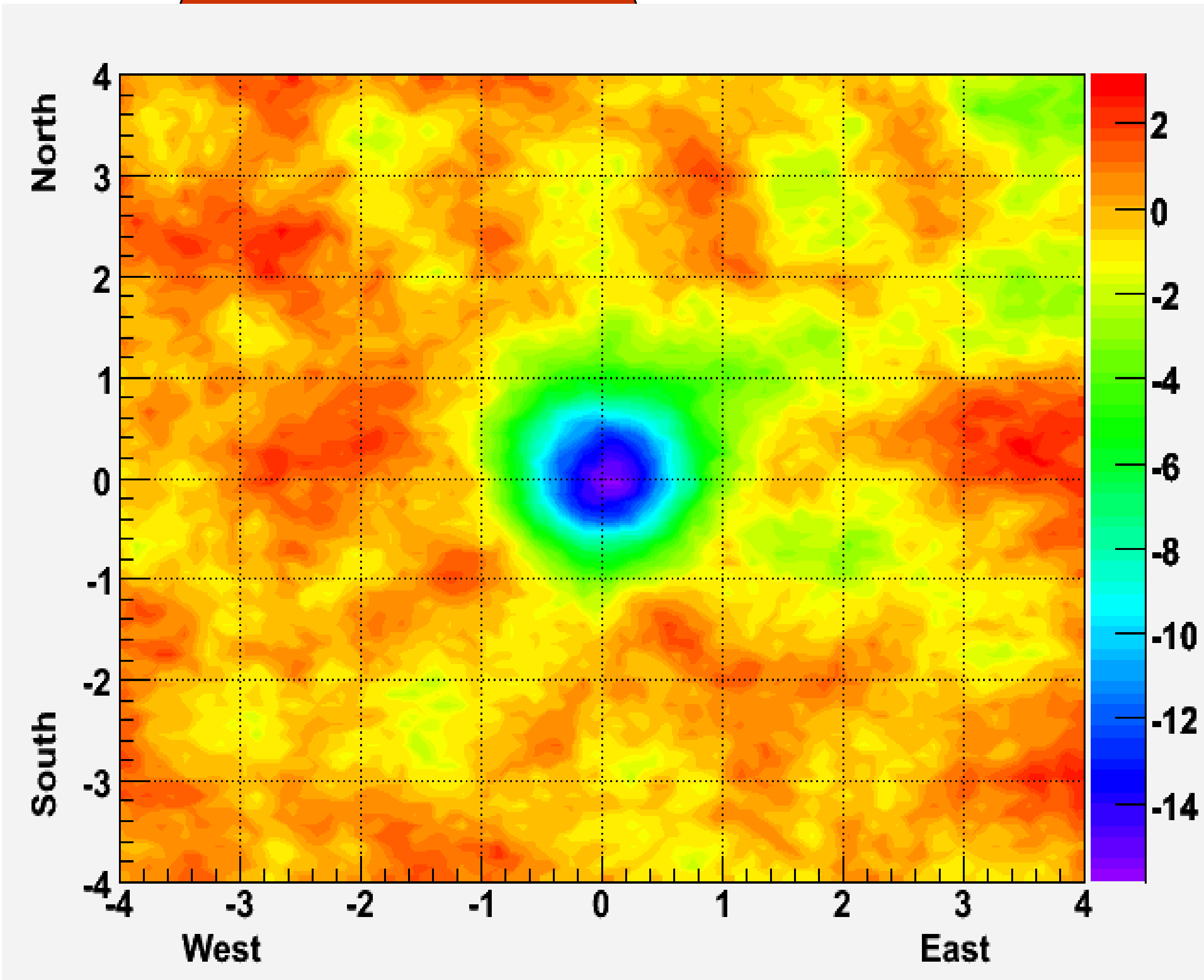


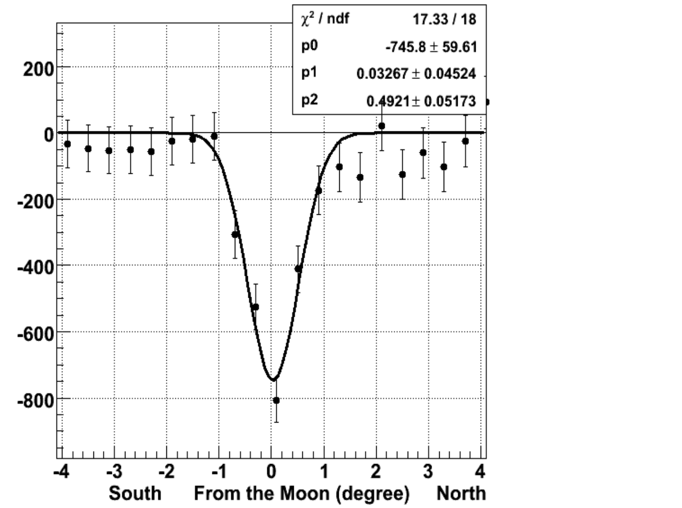


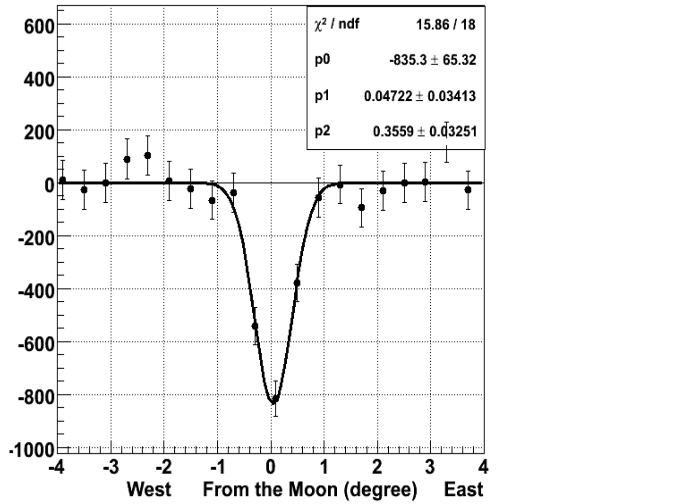


Moon shadow in cosmic ray flux









Inelastic proton-air cross section measurement

Use the shower frequency vs ($\sec\theta$ -1)

$$I(\theta) = I(0) \cdot e^{-\frac{h_o}{\Lambda}(\sec(\theta)-1)}$$

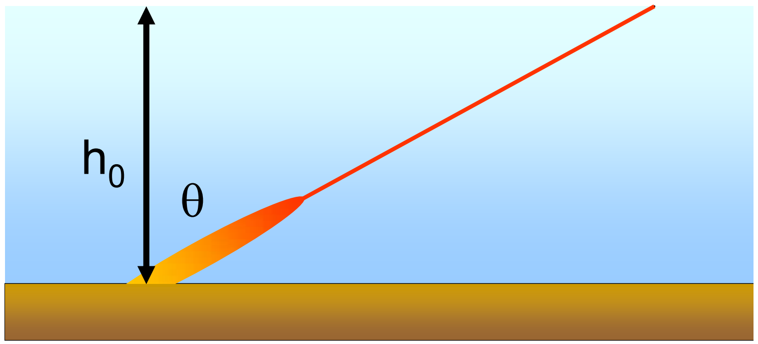
for fixed energy and shower age.

However Λ **= k** λ_{int} mainly because of shower fluctuations.

It is determined by simulations and depends on:

- interaction model
- actual set of experimental observables
- energy
- ……..

Then: $\boldsymbol{\sigma_{p\text{-}Air}}$ **(mb) = 2.4 10⁴ /** $\boldsymbol{\lambda_{int}}$**(g/cm²)**

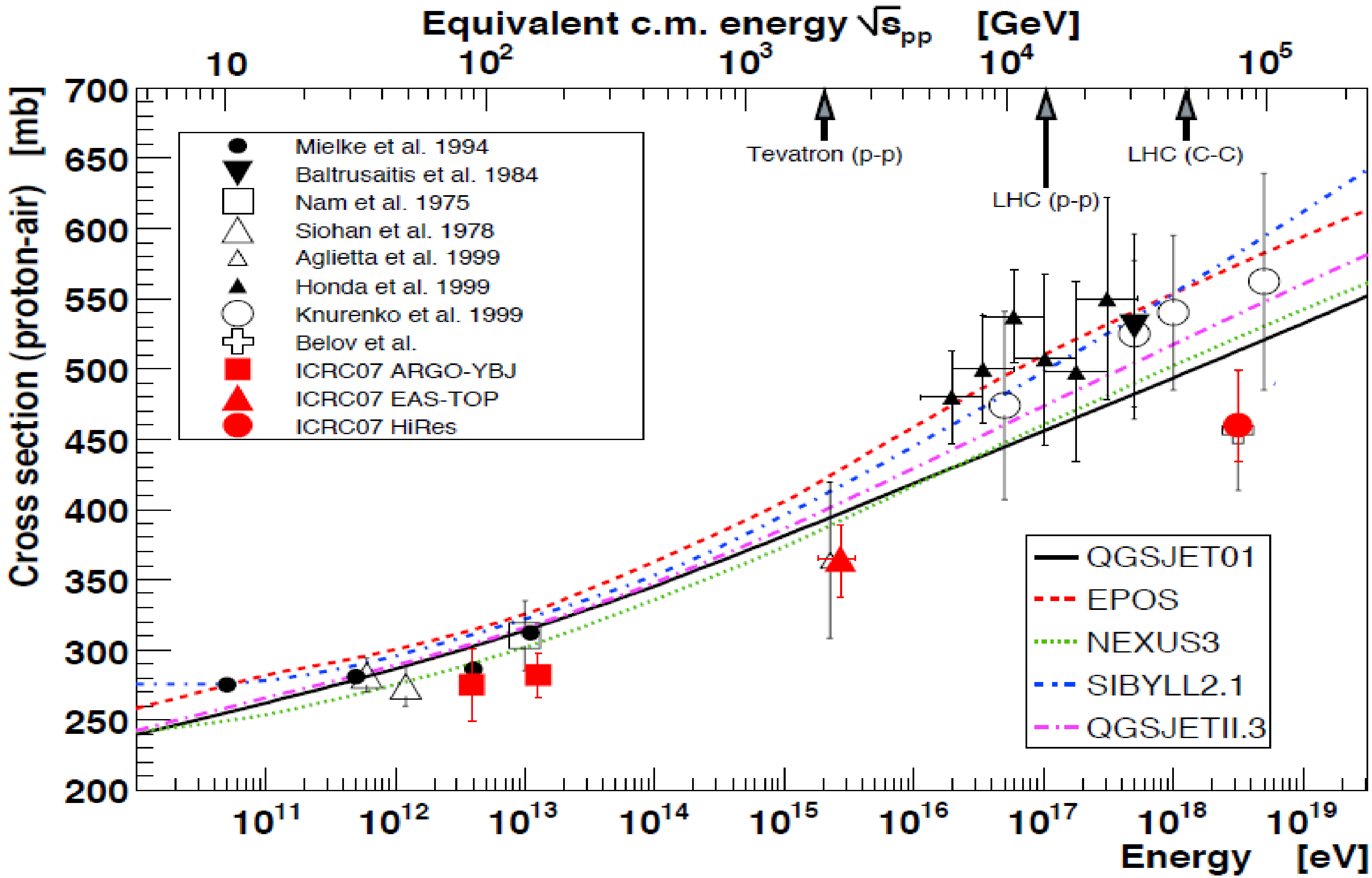


Warning

Take care of shower fluctuations

- **Constrain** $X_{DO} = X_{det} - X_0$ or better $X_{DM} = X_{det} - X_{max}$
- **Select** deep showers (large X_{max}, i.e. small X_{D0} or X_{DM})
- **Exploit** detector features (space-time pattern) and location (depth).

Inelastic proton-air cross section measurement

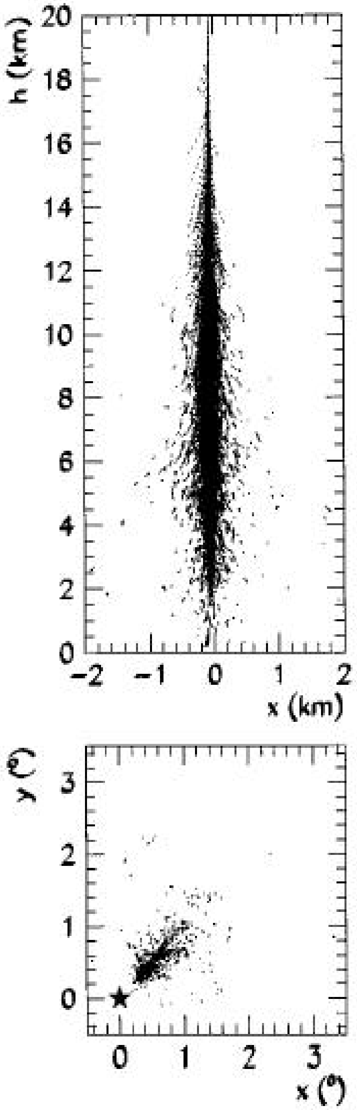


Example of Analysis:

gamma/hadrons discrimination

Gamma/hadron discrimination

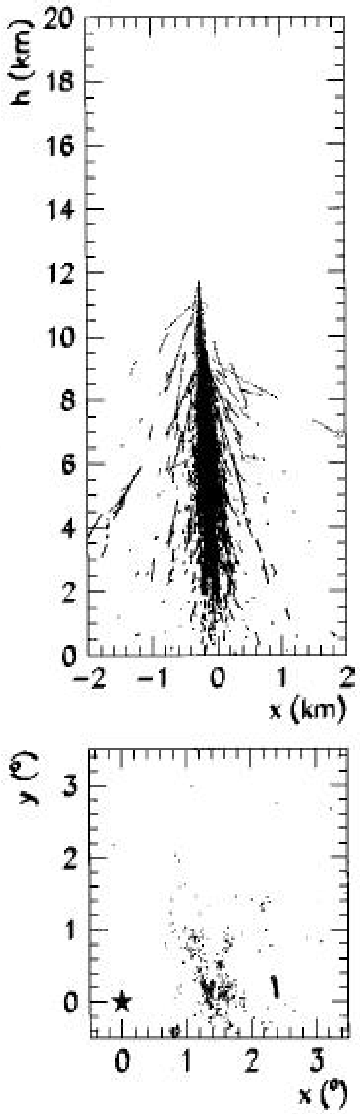
Photon Shower



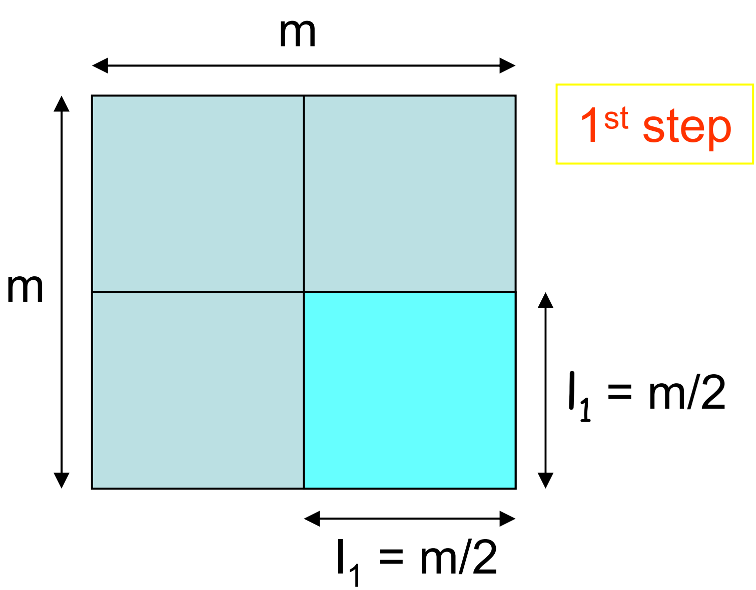
The photon signal is statistically identified by looking for an excess, coming from a given direction, over the isotropic background due to charged cosmic rays (H, He, Li, .. nuclei)

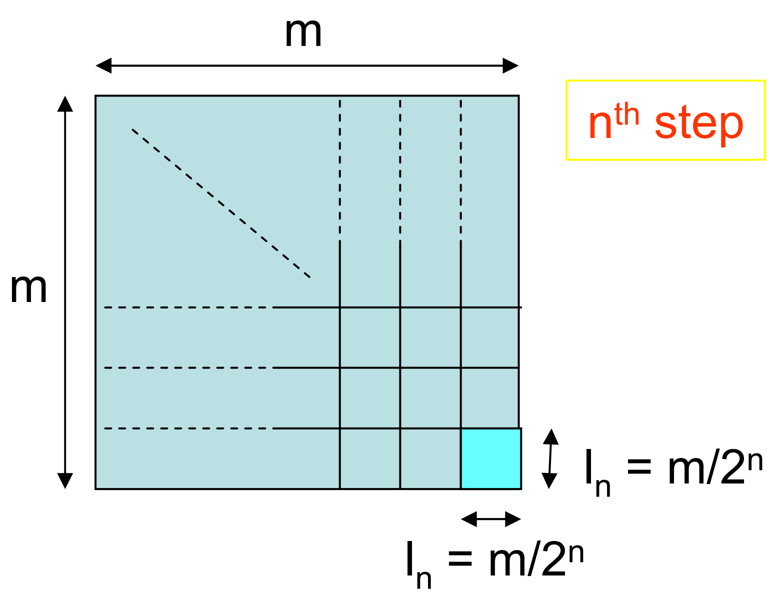
In addition to this tool the study of the shower image can be useful to have higher discrimination power and then a larger sensitivity

Proton Shower



The multiscale approach

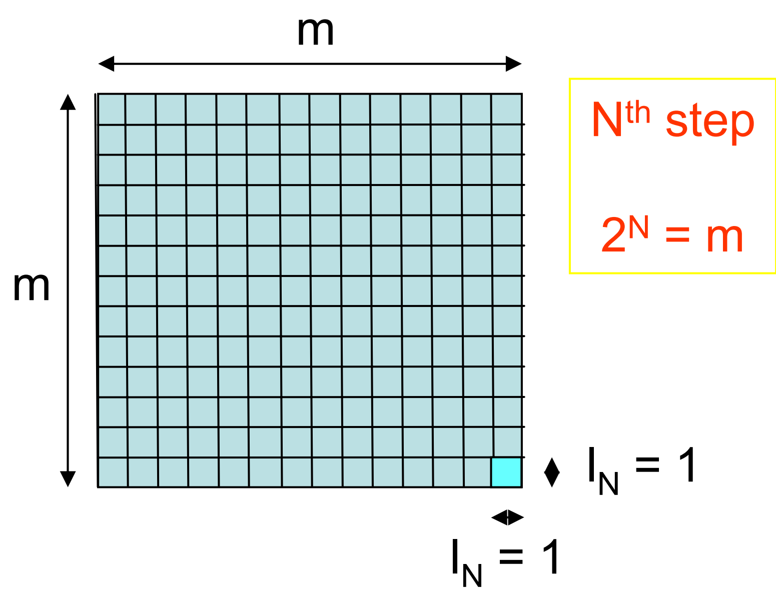




$$p(x,y,l) = \frac{\phi(x,y,l)}{N_{tot}}$$

$\phi(x,y,l) =$ content of the cell at position (x,y) as seen at scale length l

N_{tot} = total map content



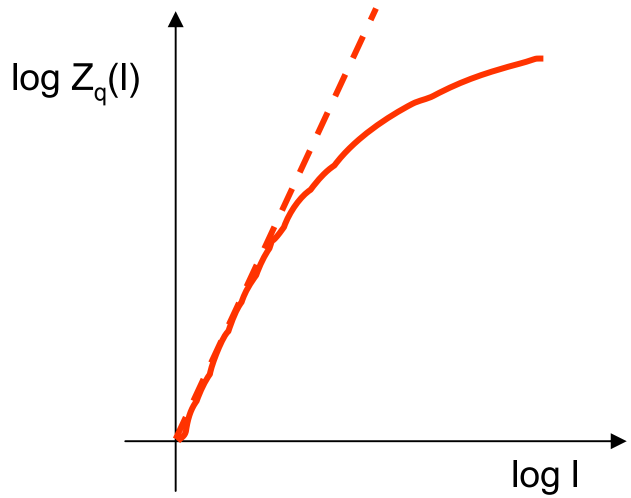
The multifractal analysis (MFA)

Structures displaying self-similar properties are called fractals.
They can be quantitatively described by their **fractal dimension**.
To fully characterize self-similar distributions an infinite number of fractal dimensions is required.
Multifractals can be analyzed with the box-counting method.

The MFA moment of order q at length scale l is defined by:

$$Z_q(l) = \sum_{\{x,y\}} \left| p(x,y,l) \right|^q$$

When scaling is observed $Z_q(l) \xrightarrow{l \to 1} \sim l^{\tau(q)}$

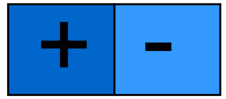


The dependence of the MFA scaling exponent τ(q) on the order q, gives the main information on the image.

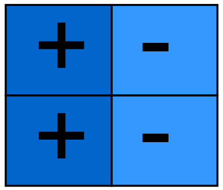
The discrete wavelet analysis (DWA)

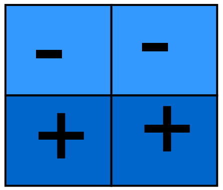
The DWA moment of order q at length scale l is directly related to the coefficients of the DW transform of $\phi(x)$. It is defined by:

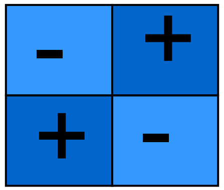
$$W_q(l) = \sum_{\{x\}} \left| p(x,l) - p(x+l,l) \right|^q \xrightarrow{l \to 1} \sim l^{\beta(q)}$$



In the 2-D case, three Haar mother wavelets can be used:







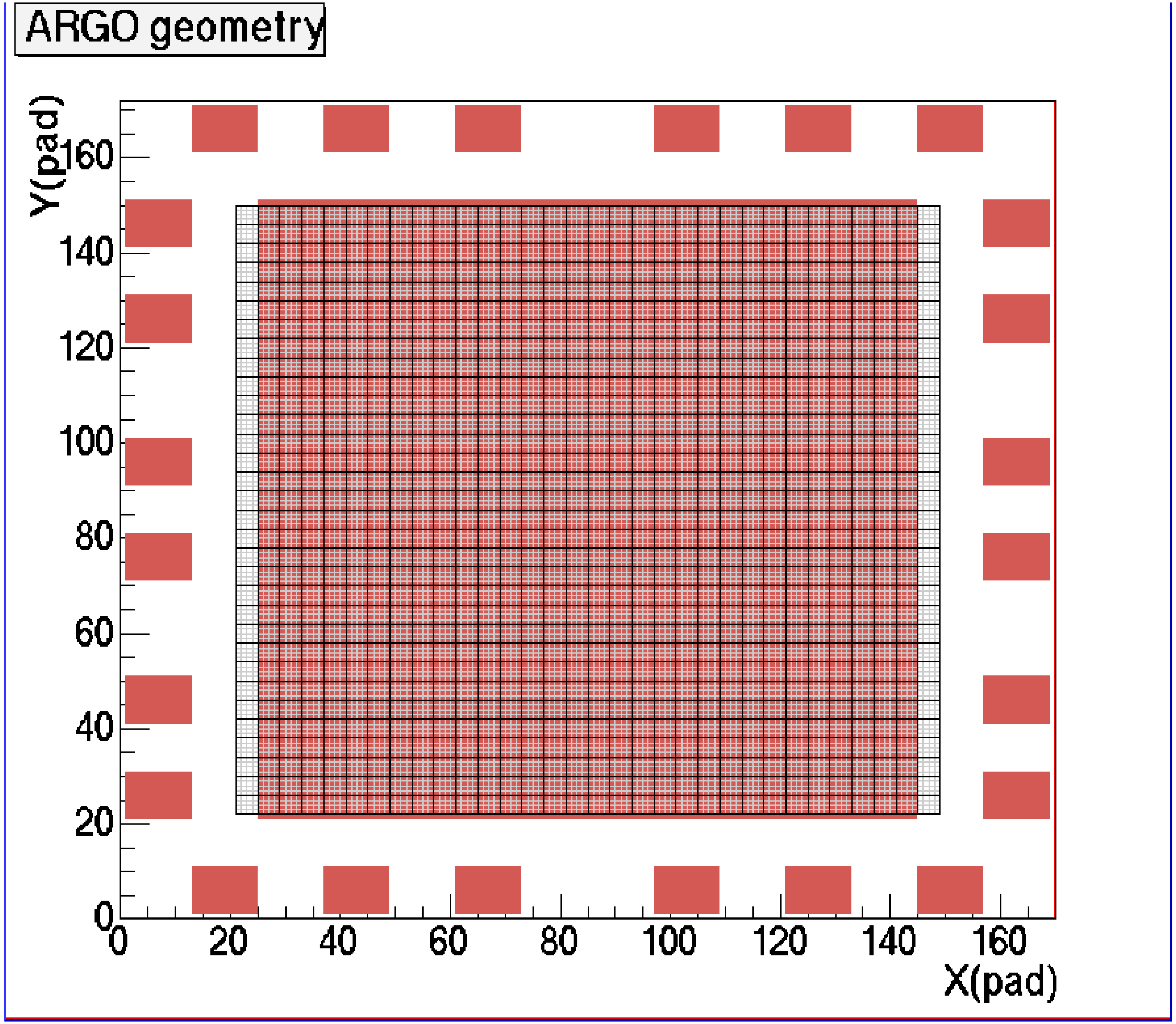
$$W_q^{(1)}(l) \xrightarrow{l \to 1} \sim l^{\beta^{(1)}(q)}$$

$$W_q^{(2)}(l) \xrightarrow{l \to 1} \sim l^{\beta^{(2)}(q)}$$

$$W_q^{(3)}(l) \xrightarrow{l \to 1} \sim l^{\beta^{(3)}(q)}$$

For *isotropic* cases $\beta^{(1)}(q) = \beta^{(2)}(q) = \beta^{(3)}(q) \equiv \beta(q)$

The dependence of the DWA scaling exponent $\beta(q)$ on the order q, gives the main information on the image.



The smallest pixel is taken at (2 $\times$2) pad ~ 1m^2

Simulated data sample

Gamma and proton induced showers have been simulated with CORSIKA + ARGOG

with the following characteristics:

- power spectrum between 10GeV and 300TeV with a spectral index γ = -2.5 and -2.7 for photons and protons respectively
- azimuth between 0 and 15 degrees
- core at the detector center

Since the photons and hadrons of the same energy produce different pad multiplicities, the data sample has been divided into five multiplicity windows

N_{pad}	$<E_\gamma>$ (TeV)	N_γ	$<E_p>$ (TeV)	N_p
50 – 100	0.5	6955	0.8	4160
100 - 500	1.1	11902	1.7	7601
500 - 800	2.9	2885	4.9	1951
800 - 1500	4.6	3397	7.7	2770
1500 - 6000	11.3	5145	18.0	3367

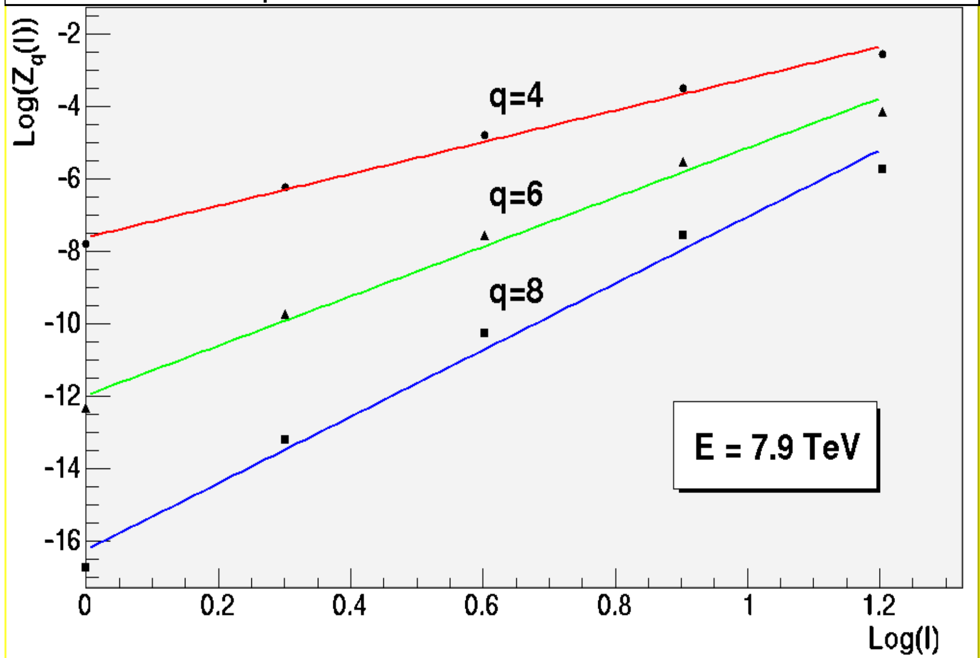
Single Event Analysis

Compute the MFA and DWA moments as a function of the scale length for different values of the order q.

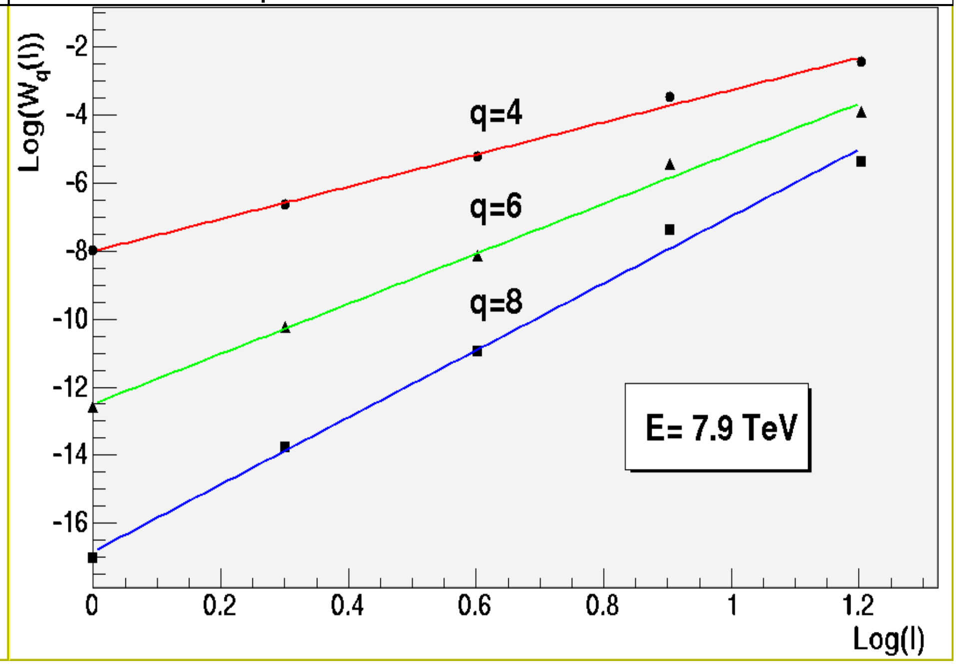
Fit these curves and get the scaling exponents τ and β

Example for a 7.9TeV photon initiated shower……

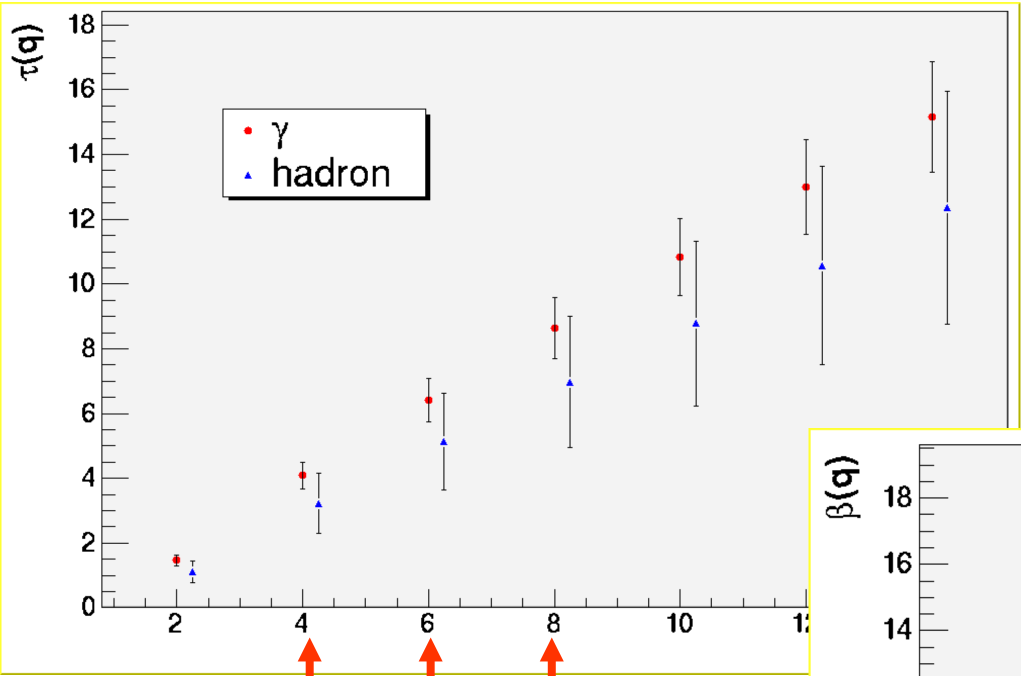
Z_q vs the scale length l



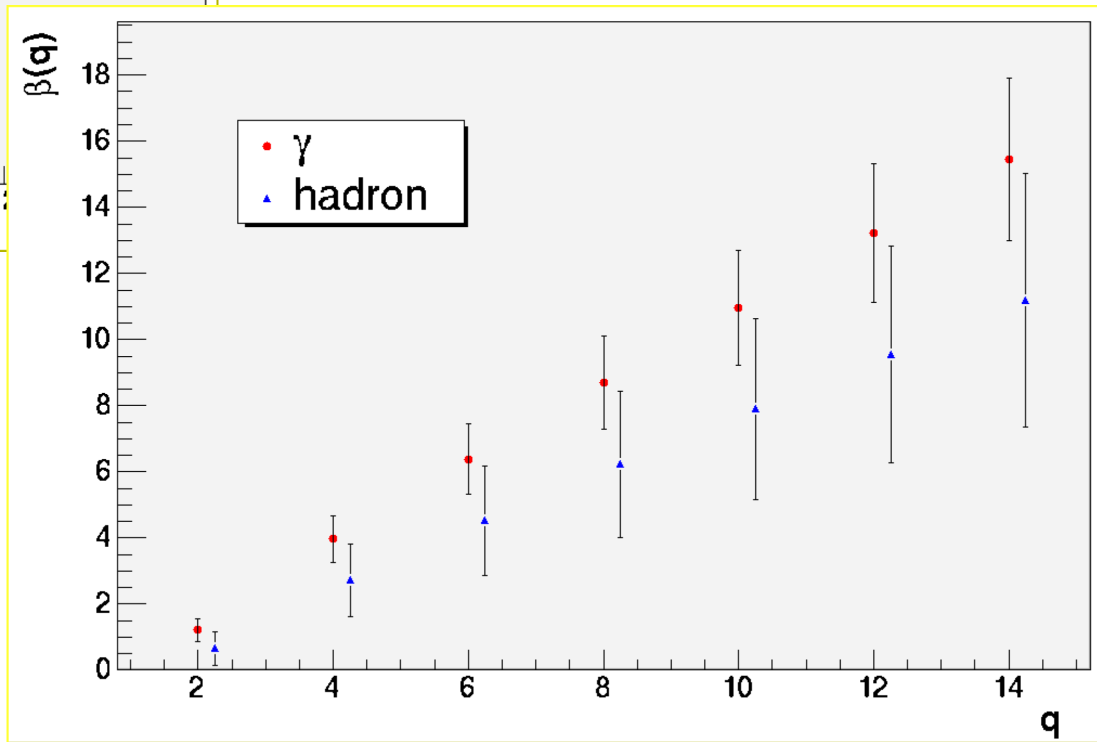
W_q vs the scale length l



Study of the scaling exponents



The linear dependence of τ and β on q allows the analysis just for three sample values.

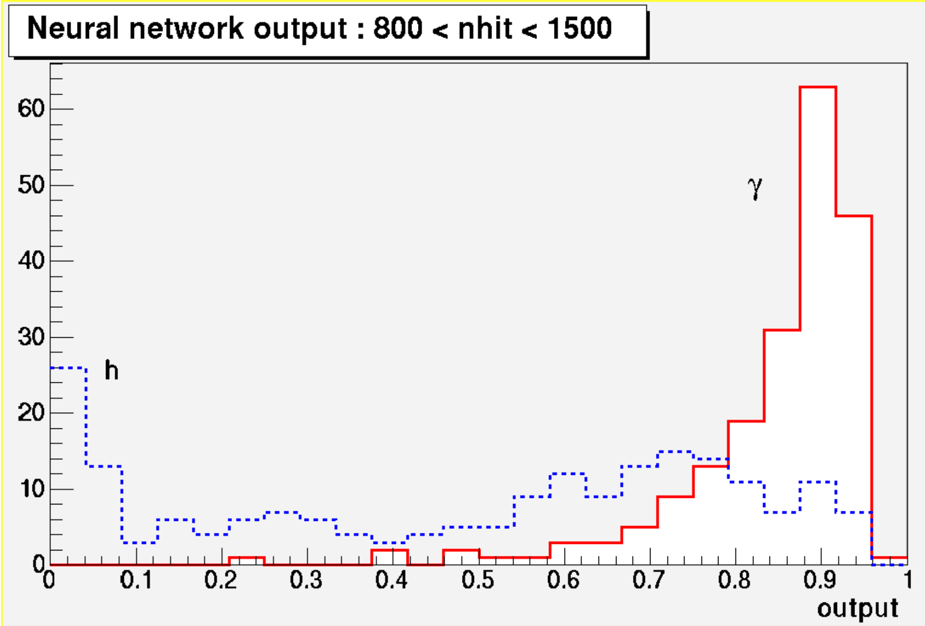


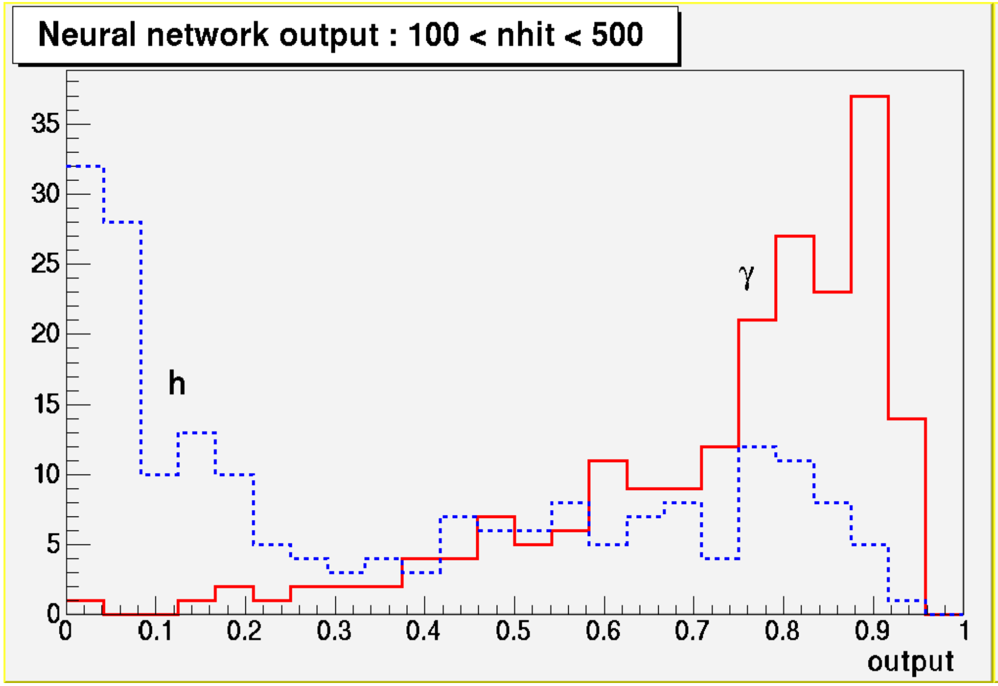
q = 4, 6, 8

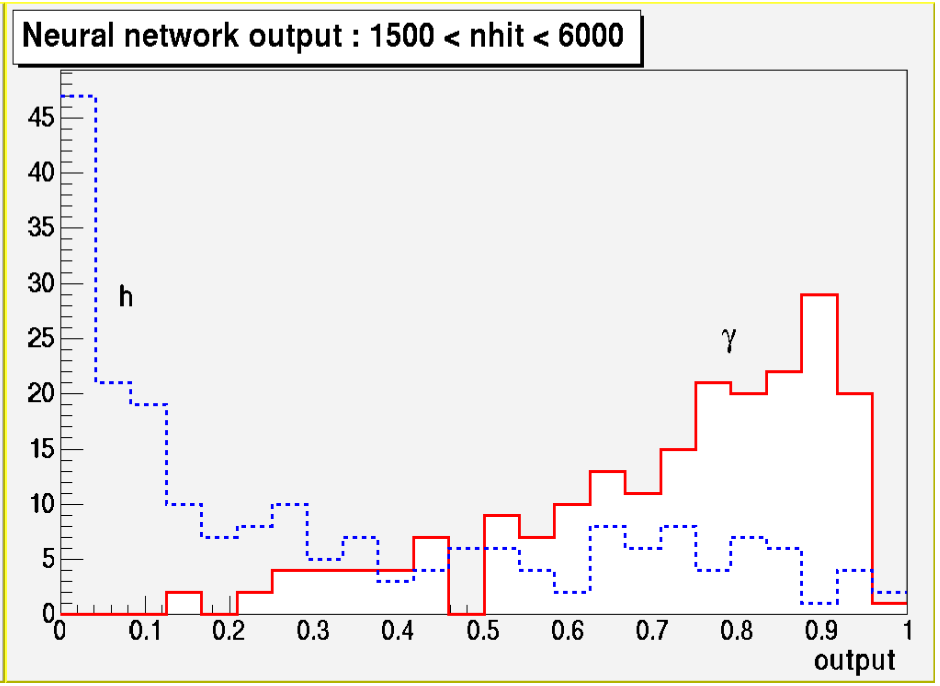
ANN results

Results have been obtained by using, in each multiplicity window, 400 events (200 γ + 200 p).

Fluctuations here are essentially due to this limited statistics.

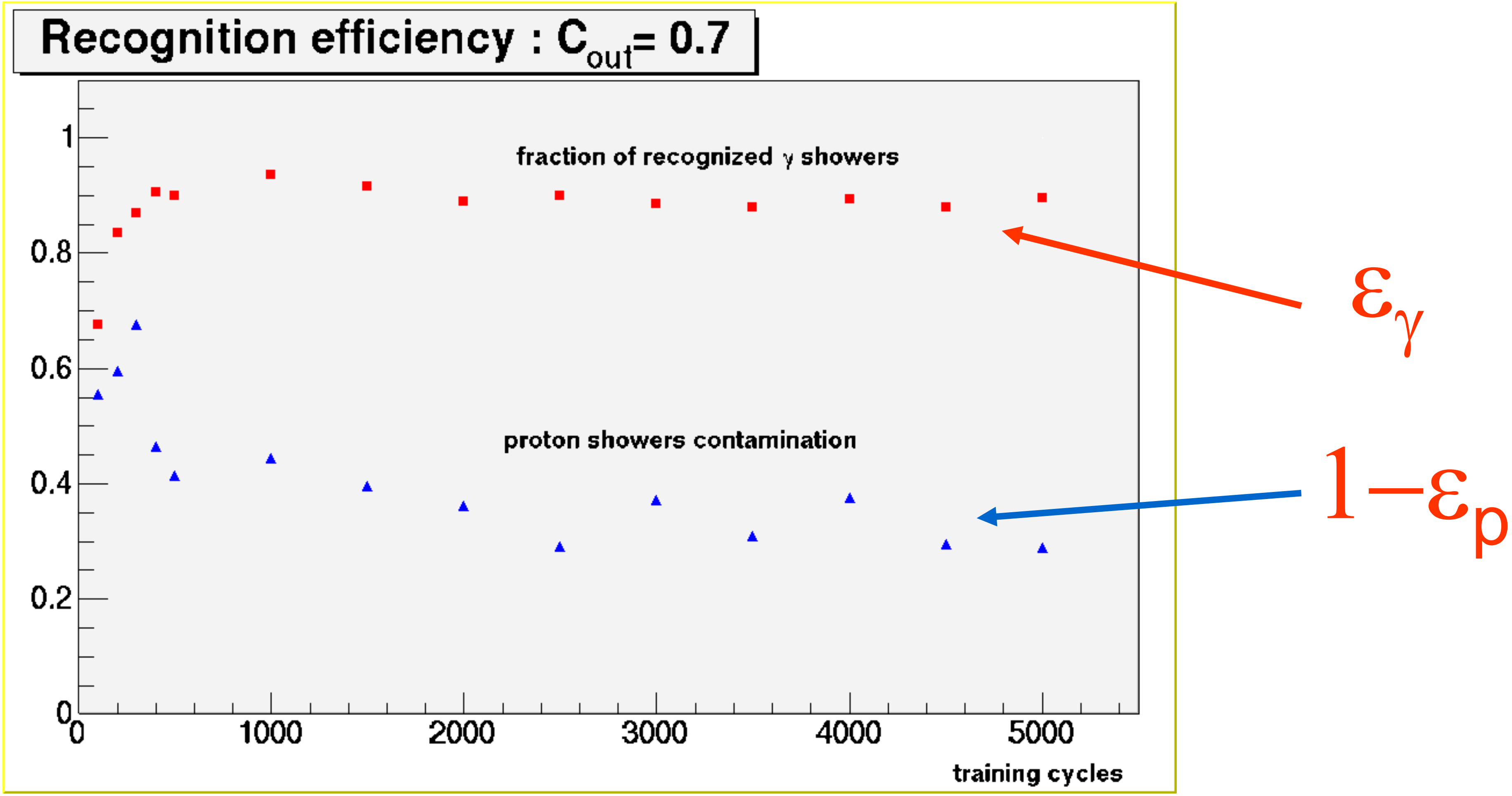






Artificial Neural Network training

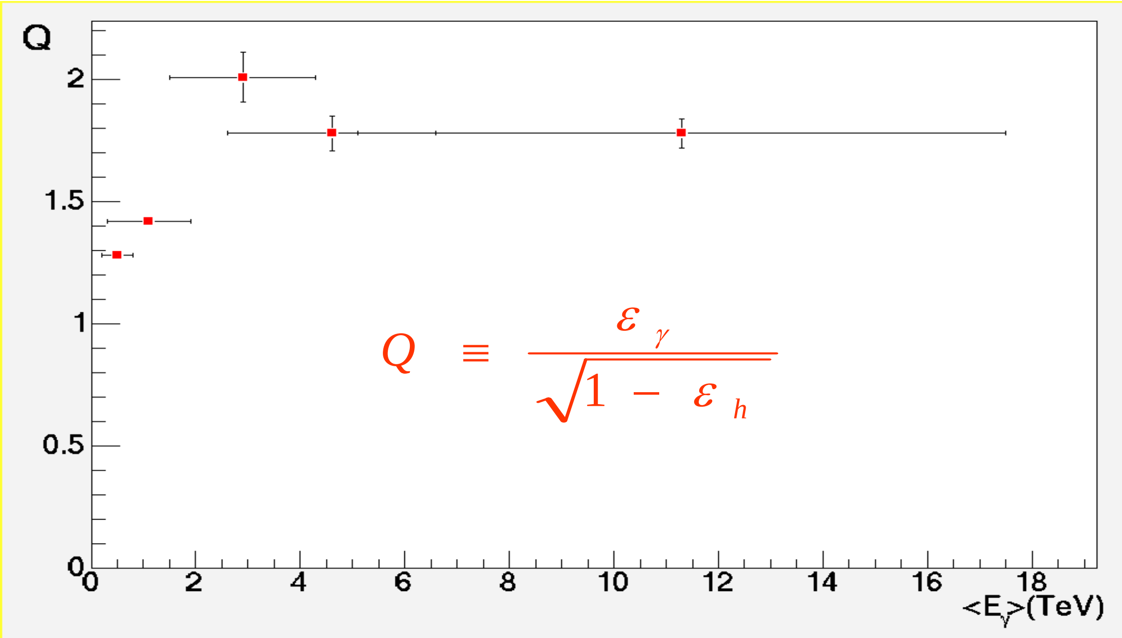
Different ANN's (with the same topology) have been trained in the different multiplicity windows. The number of training epochs has been optimized in order to maximize the efficiencies and minimize the processing times.



ANN results

$$S \equiv \frac{N_\gamma}{\sqrt{N_h}} \times \frac{\varepsilon_\gamma}{\sqrt{1-\varepsilon_h}}$$

$$Q \equiv \frac{\varepsilon_\gamma}{\sqrt{1-\varepsilon_h}}$$



$$T_{Crab}^{5\sigma}(Q=1) = 120 days$$

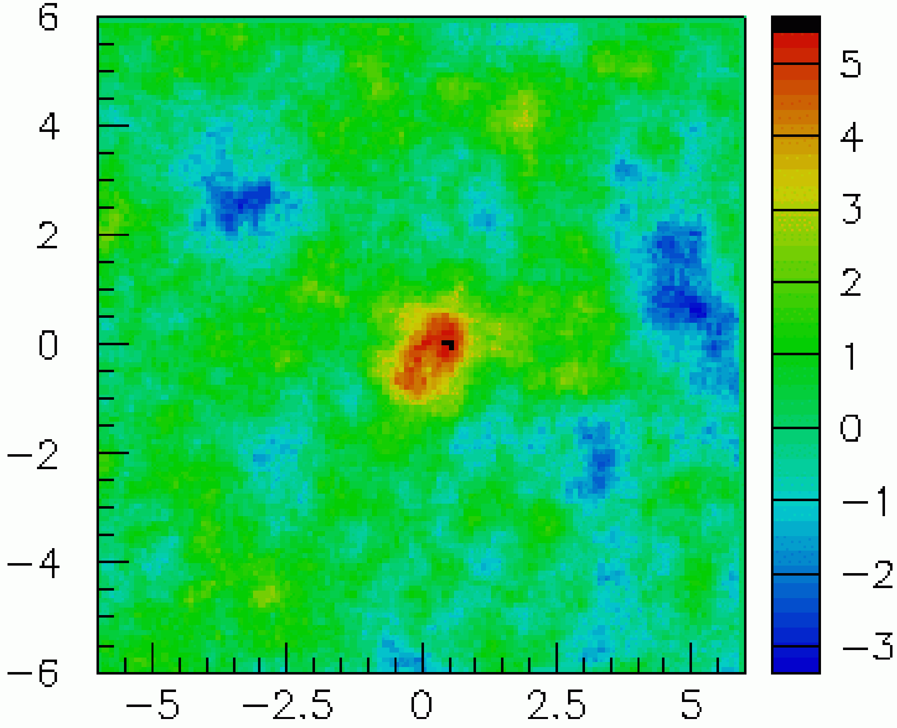
$$T_{Crab}^{5\sigma}(Q=2) = 30 days$$

- ✓ Reduced time interval needed to identify sources
  - ✓ Larger equivalent effective area
    - ✓ Sensitivity to smaller fluxes

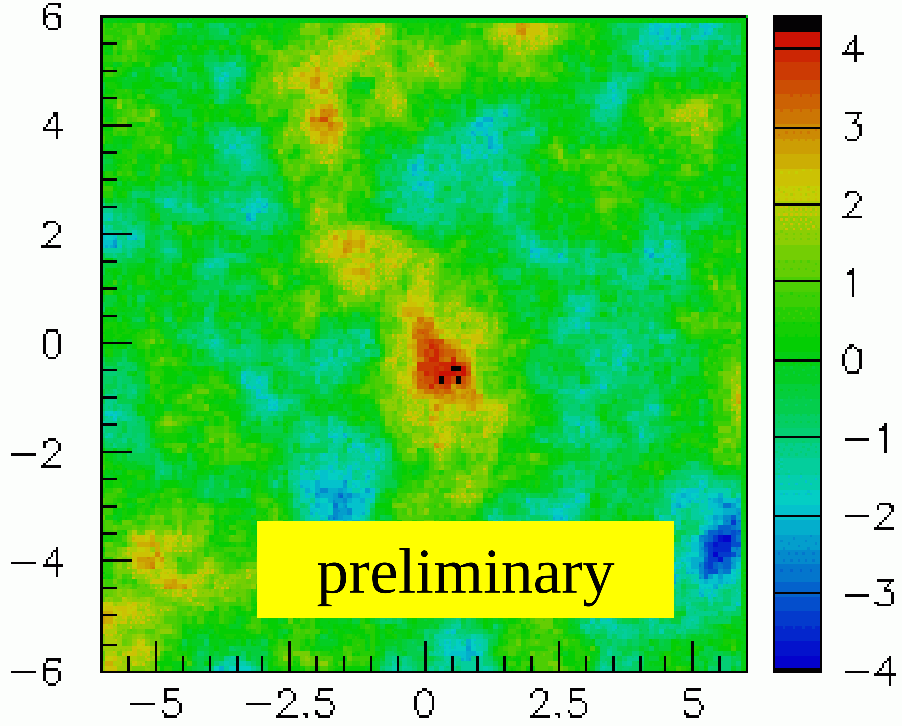
The Crab Nebula

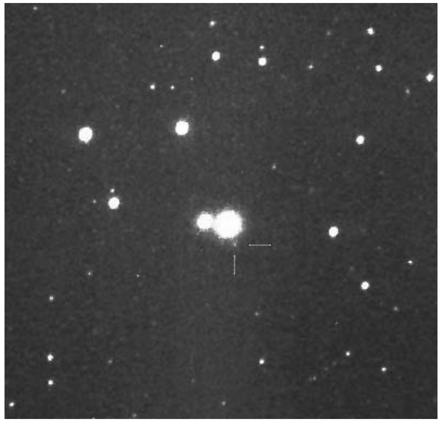
Remnants of SN1054
6500 lyr away

2007 (241 h)



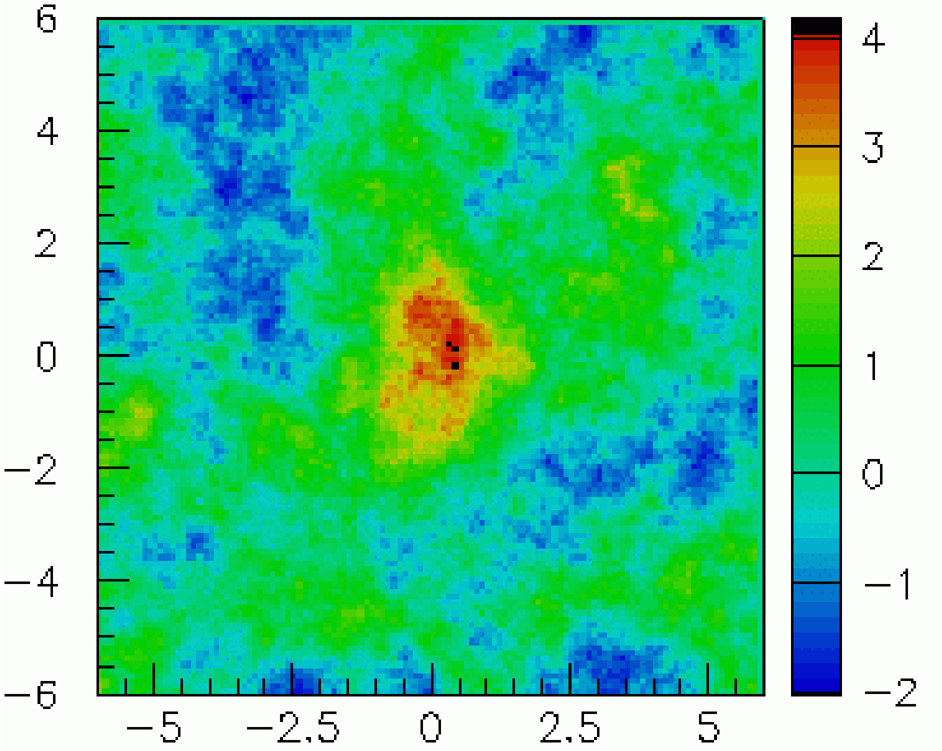
2008 (247 h)



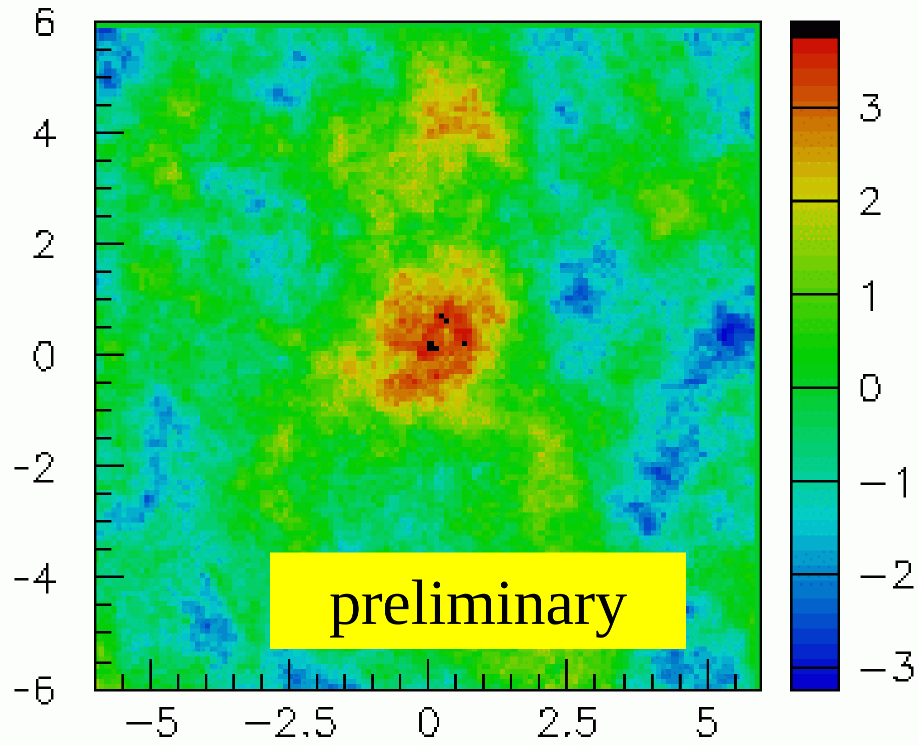


Markarian 421
(quasar 360 Mlyr)

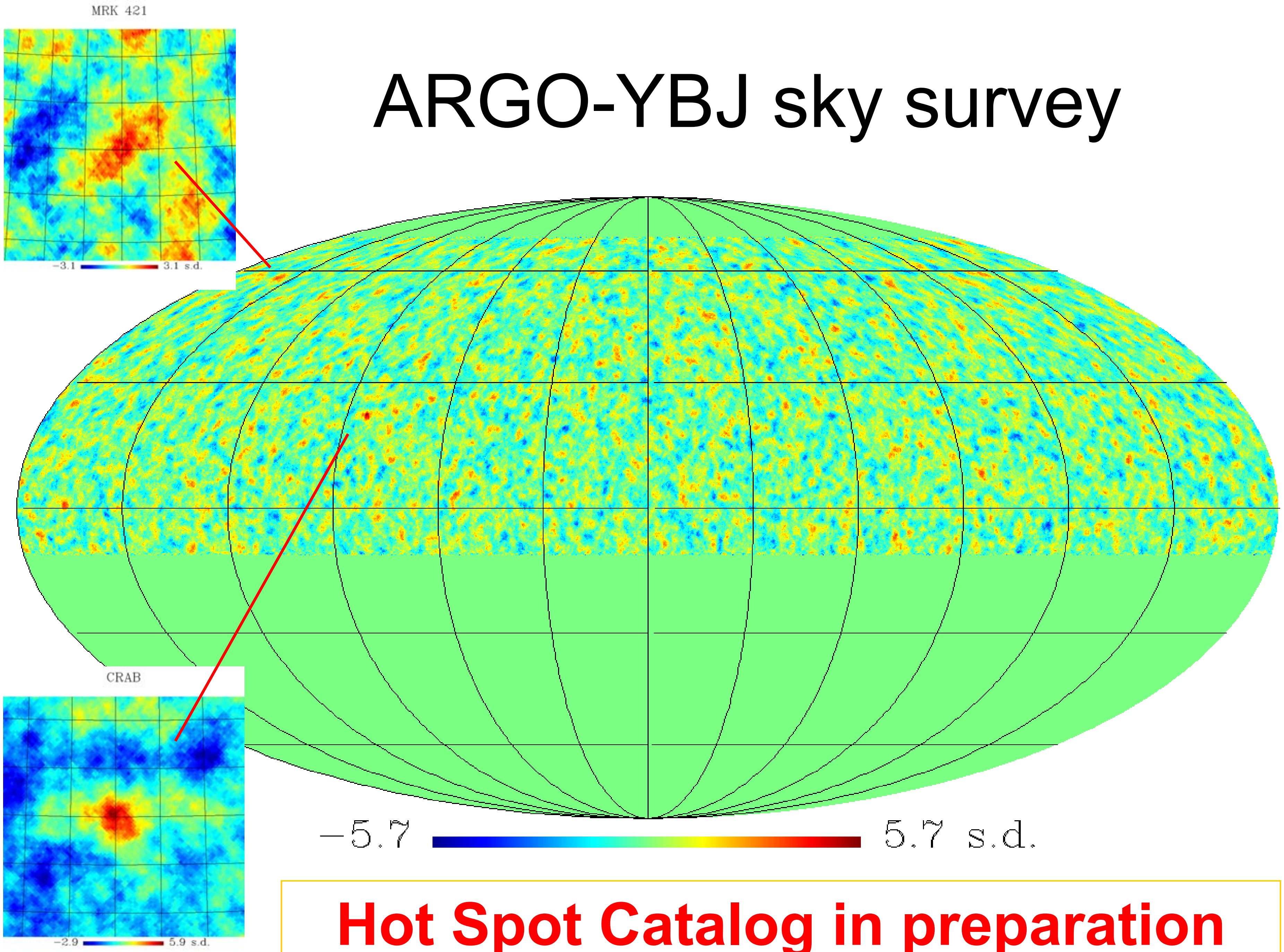
2006 day 187-245
(137 hours)



2008 day 1-55
(232 hours)



ARGO-YBJ sky survey

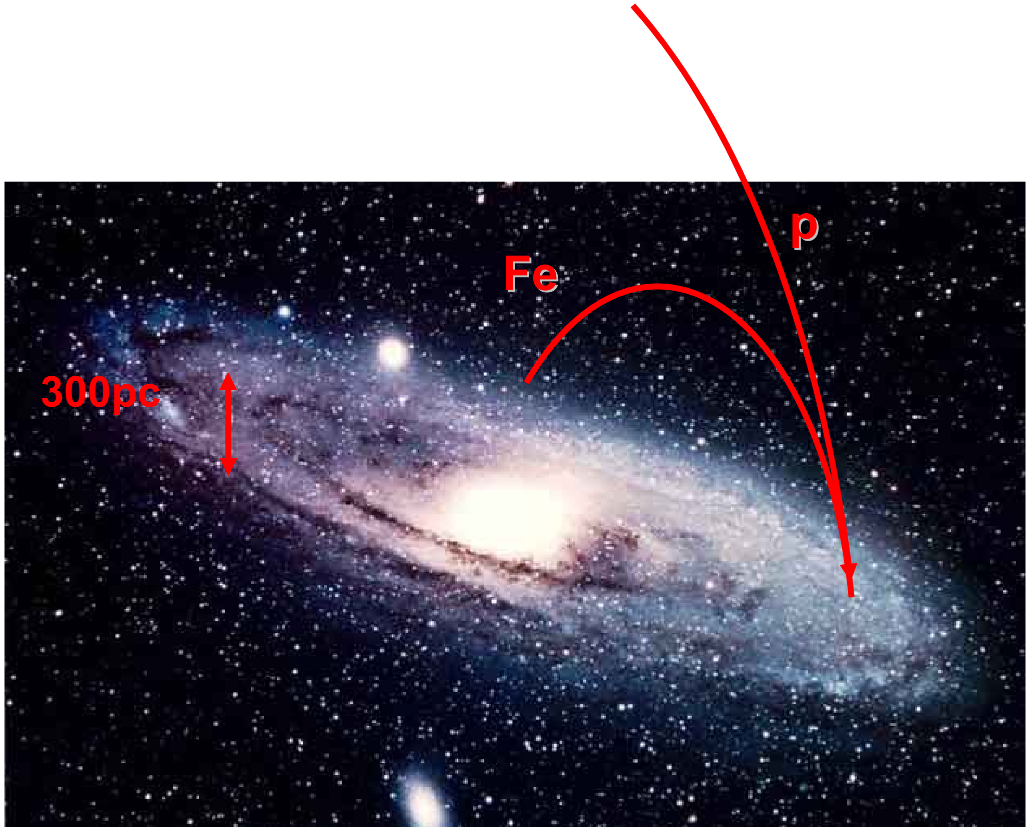


Hot Spot Catalog in preparation

Example #2

AUGER

Propagation in the galactic magnetic field ...



The Larmor radius for protons with $E>10^{19}$ eV is larger than the galactic scale

$$r_L \sim \frac{E_{18}}{Z B_{\mu G}} kpc$$

High energy protons are not confined in the Galaxy.

They are probably of extragalactic origin

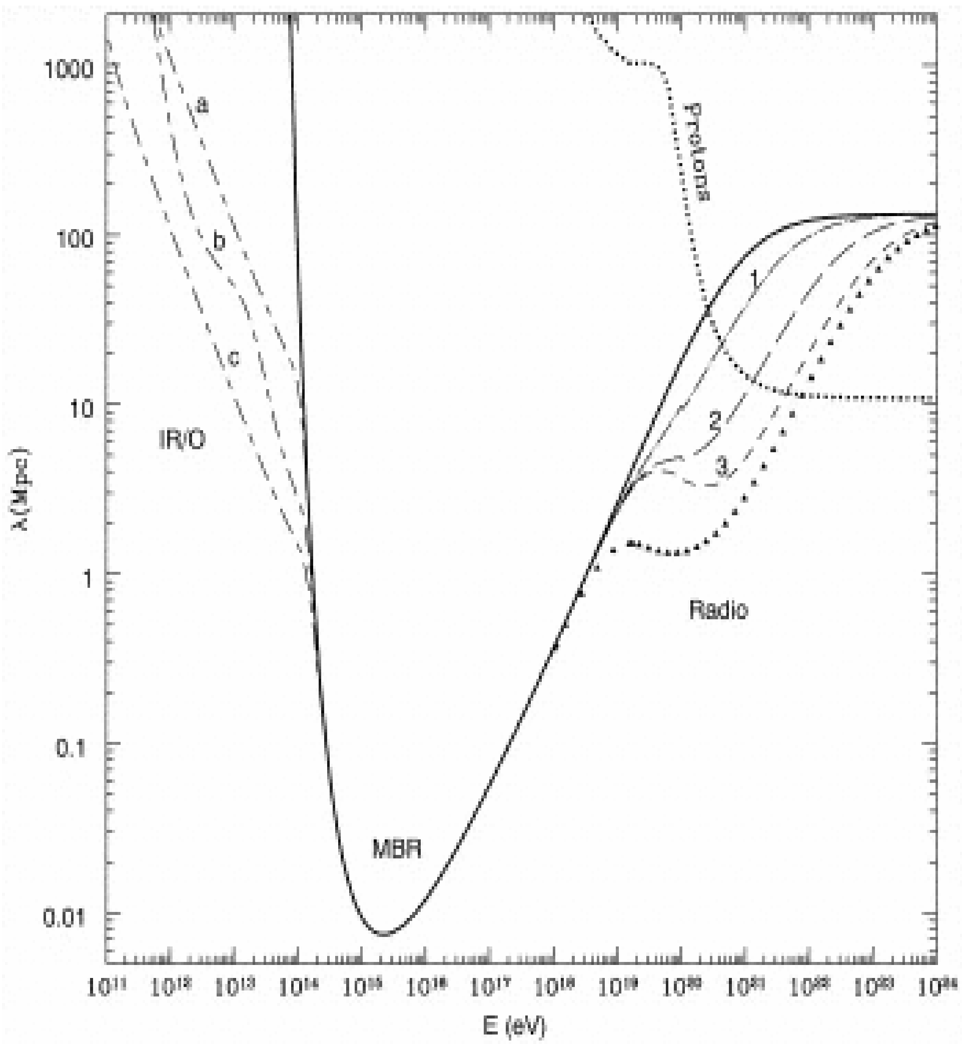
Moreover, at high energy the primary arrival directions points backwards to the source

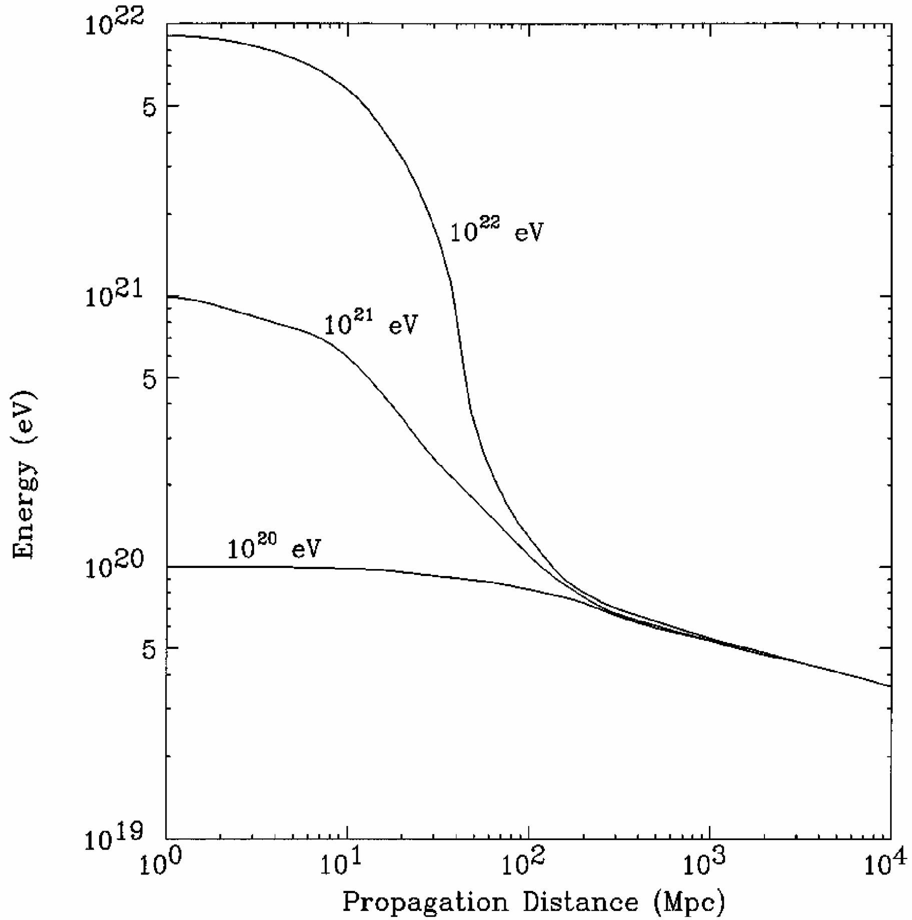
Astronomy with charged particles !

GZK cutoff for protons with $E > 5 \cdot 10^{19}$eV

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

$$p\ \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n\ \pi^{+}$$





Cutoff for photons with $E > 10^{14}$eV

$$\gamma\ \gamma_{CMB} \rightarrow e^{+}\ e^{-}$$

Study of Ultra High Energy Cosmic Rays (UHECR)

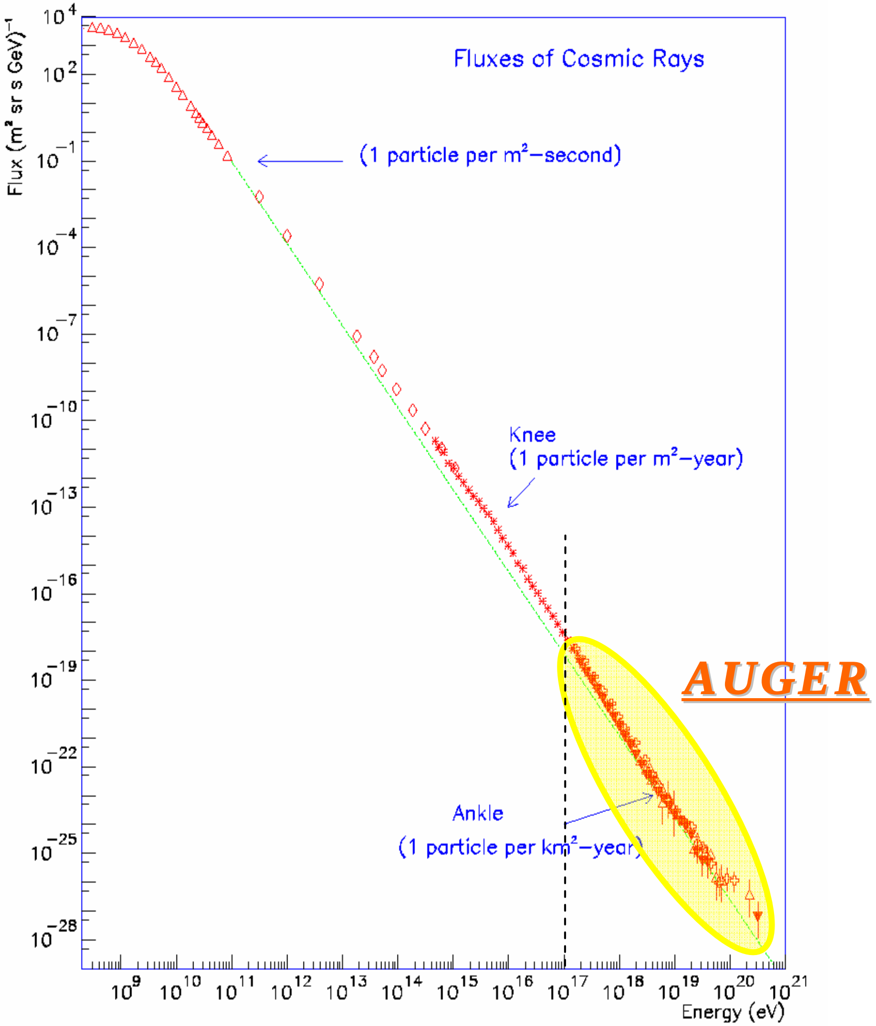
(10^{17}-10^{21}) eV

The flux at E>$10^{19.5}$ eV is extremely small

1 particle / (km² sr secolo)

Large surface array: 3000 km² (Auger)

30 events/yr above 30EeV




COMIENZA
CAMINO DE TIERRA
CAMINO EN REPARACION
DIQUE AGUA
DEL TORO 7
MALARGUE 22
40
ATENCION
40

AUGER

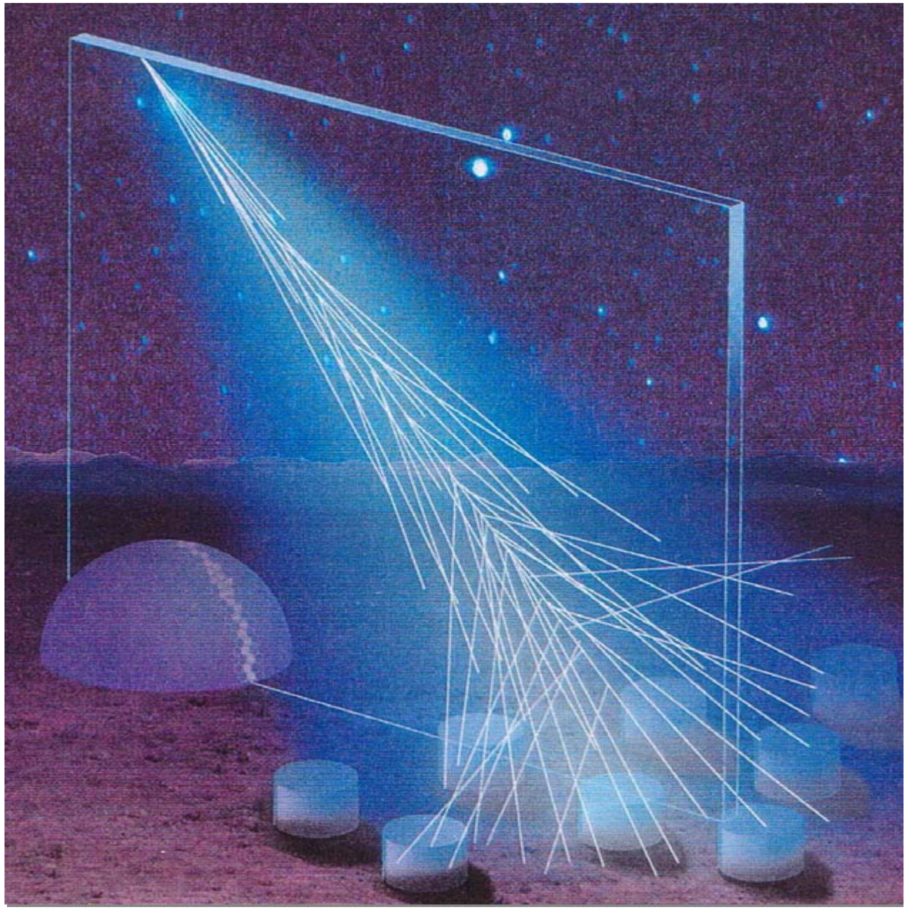
Fluorescence Detector (FD)

- Longitudinal development of the shower
- Calorimetric measurement of the energy

  Calibration of the energy scale

- Direction of the shower

  12% duty cycle !



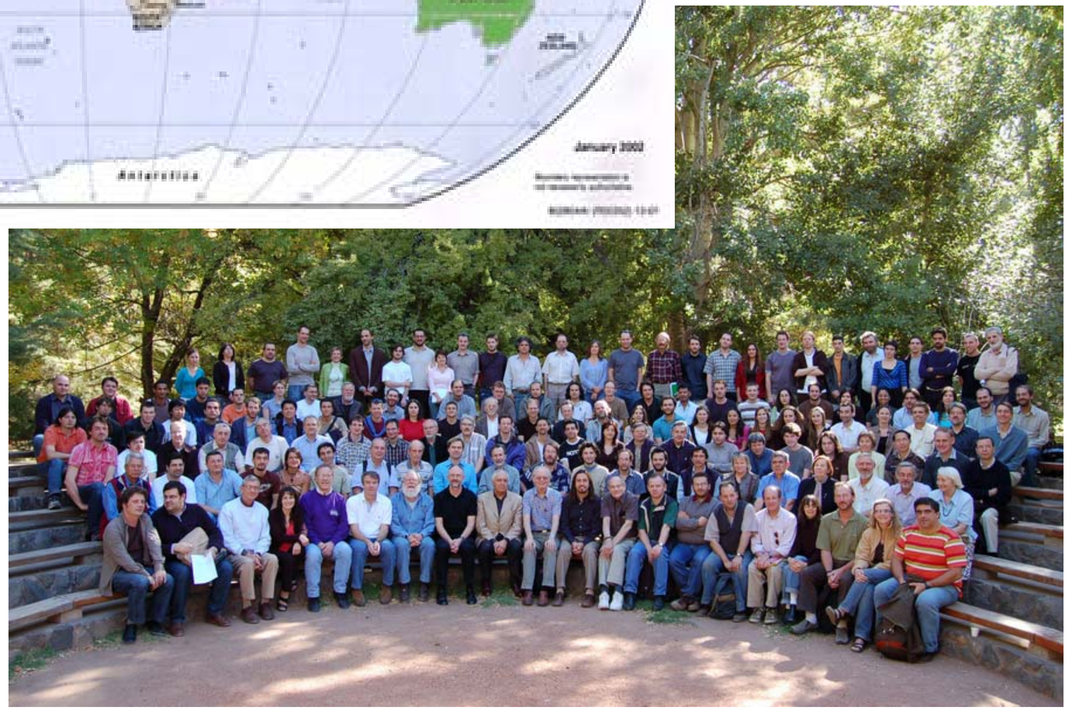
Surface Detector (SD)

- Front of shower at ground
- Direction of the shower
- “High” statistics

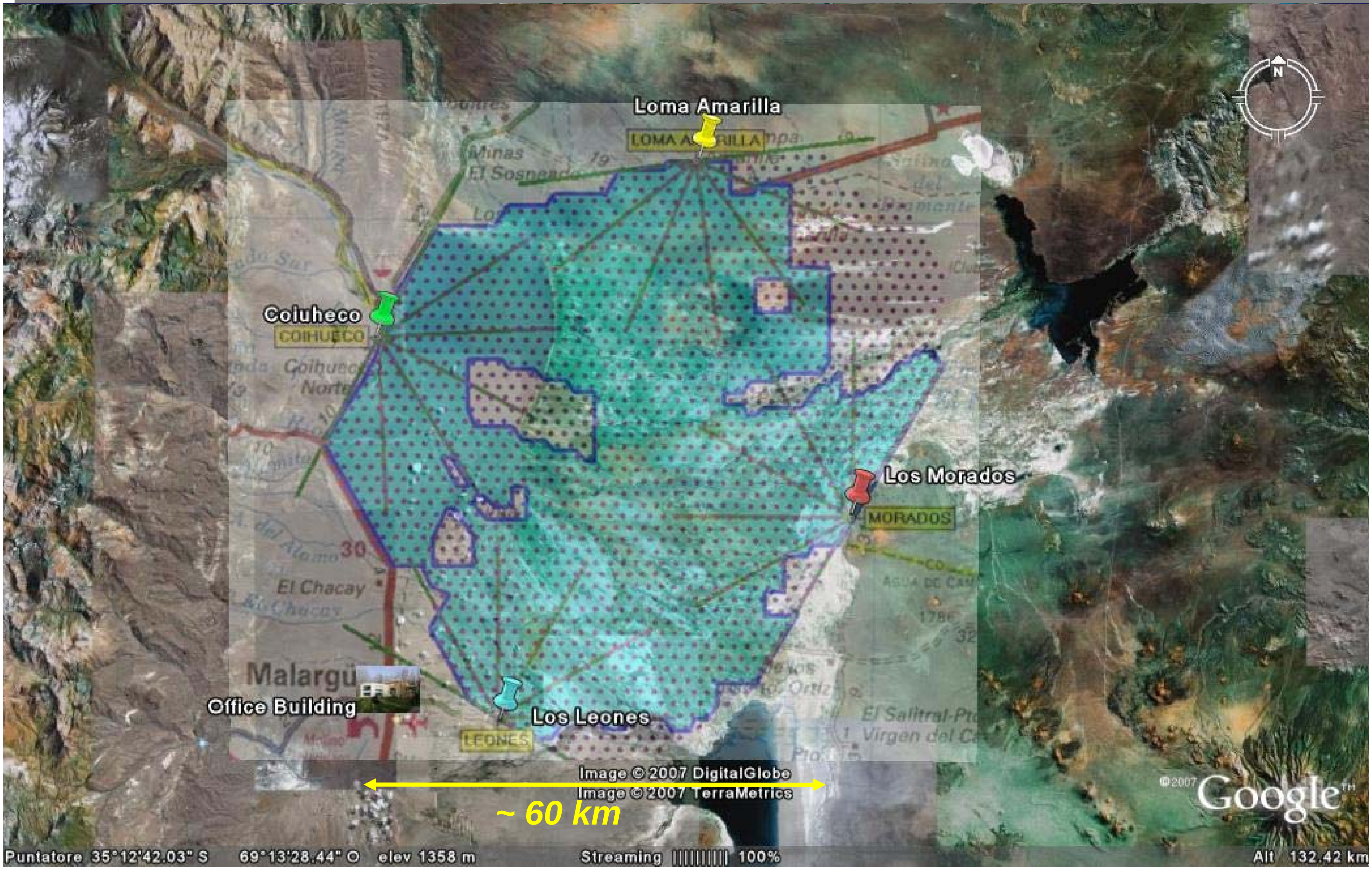
The Pierre Auger Collaboration

Argentina
Australia
Bolivia
Brazil
Czech Rep.
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Slovenia
Spain
UK
USA
Vietnam

17 Countries
63 Institutions
~ 350 members

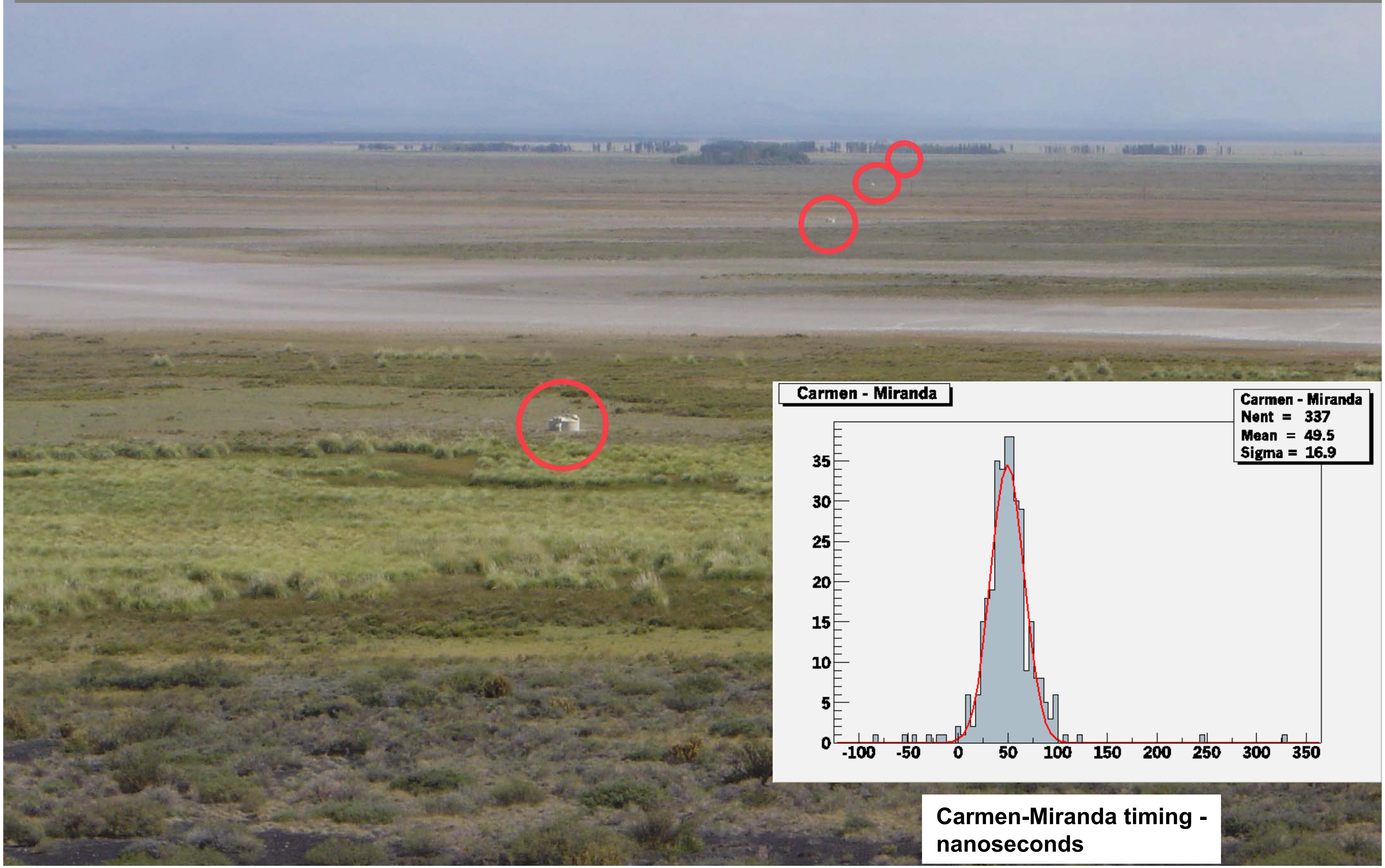


The expeimental site




Isola Maddalena
Isola Asinara
Isola Tavolara
Sassari
Alghero
Alghero SS
Sardegna (Sardinia)
Sardegna (Sardinia)
Image © 2008 DigitalGlobe
© 2008 Europa Technologies
© 2008 Tele Atlas
Image NASA
©2007 Google™
Puntatore lat 40.706244° lon 8.441441° elev 81 m Streaming |||||||||| 100%
Alt 241.10 km

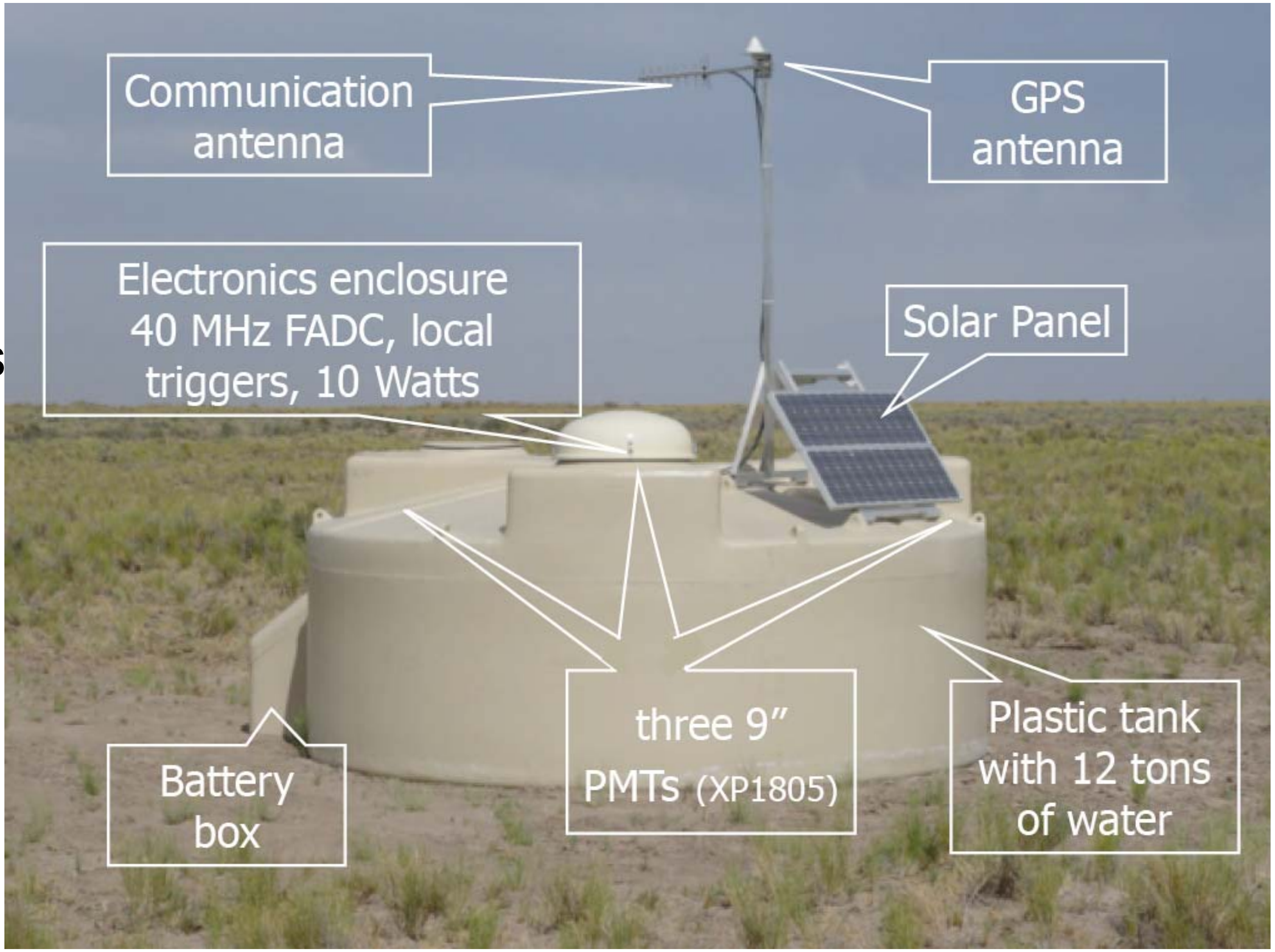
The Surface Detector (SD)



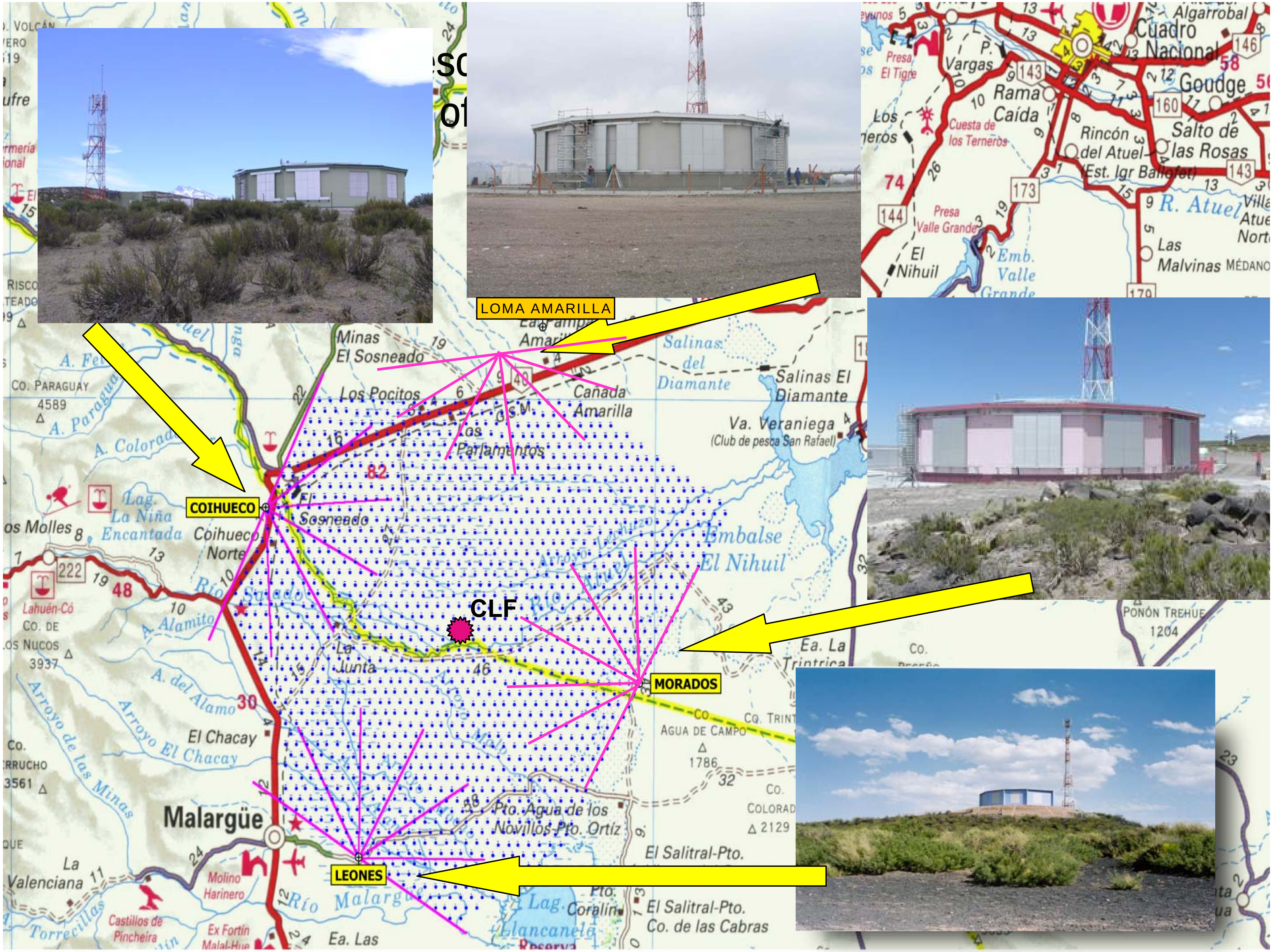
Carmen-Miranda timing - nanoseconds

The SD station

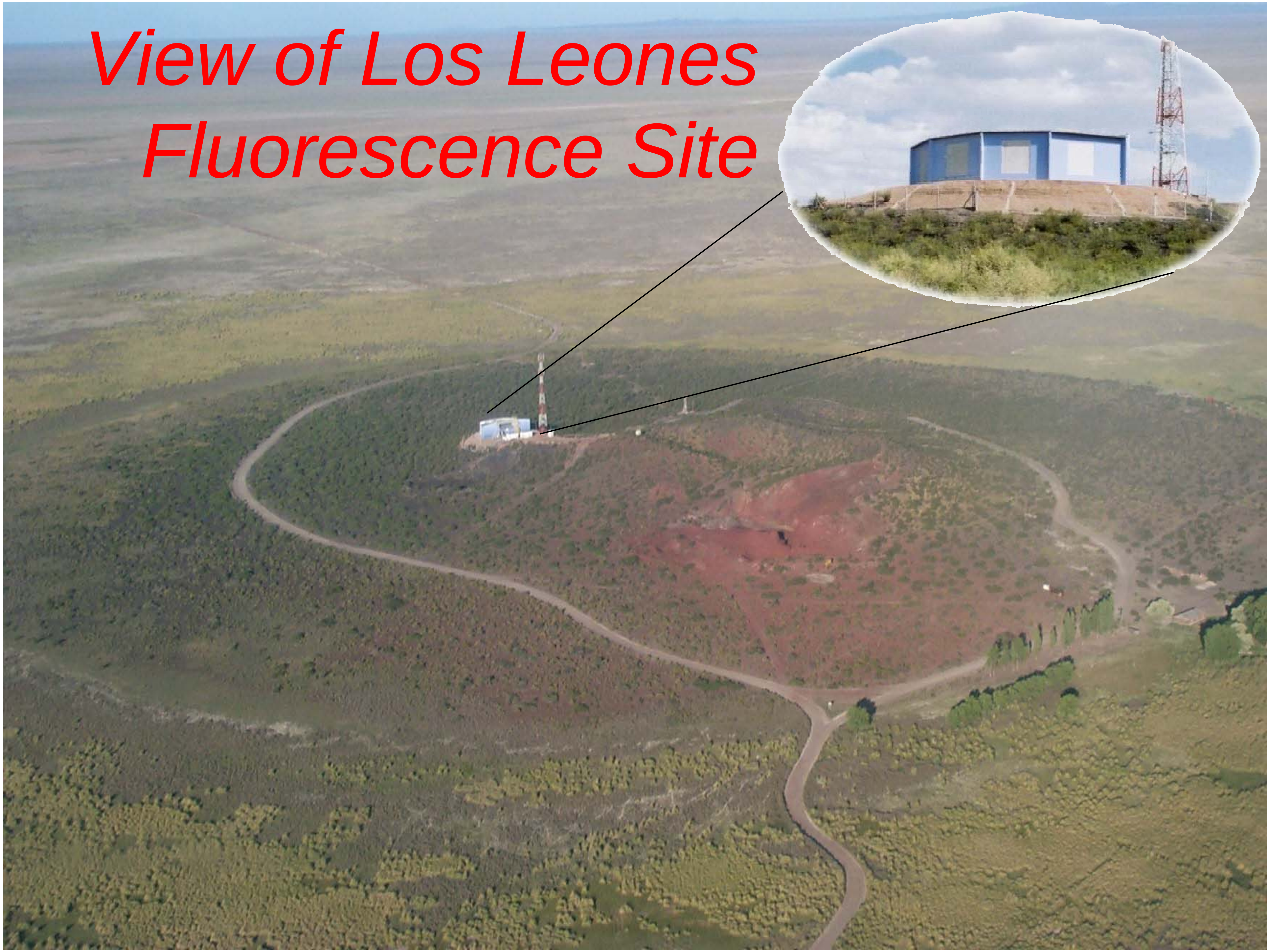
- Polyethylene Tank
- 12 m^3 of purified water
- High reflectivity walls
- 3 PMTs 9''
- 2 solar panels and 1 battery
- GPS Antenna
- Communication Antenna



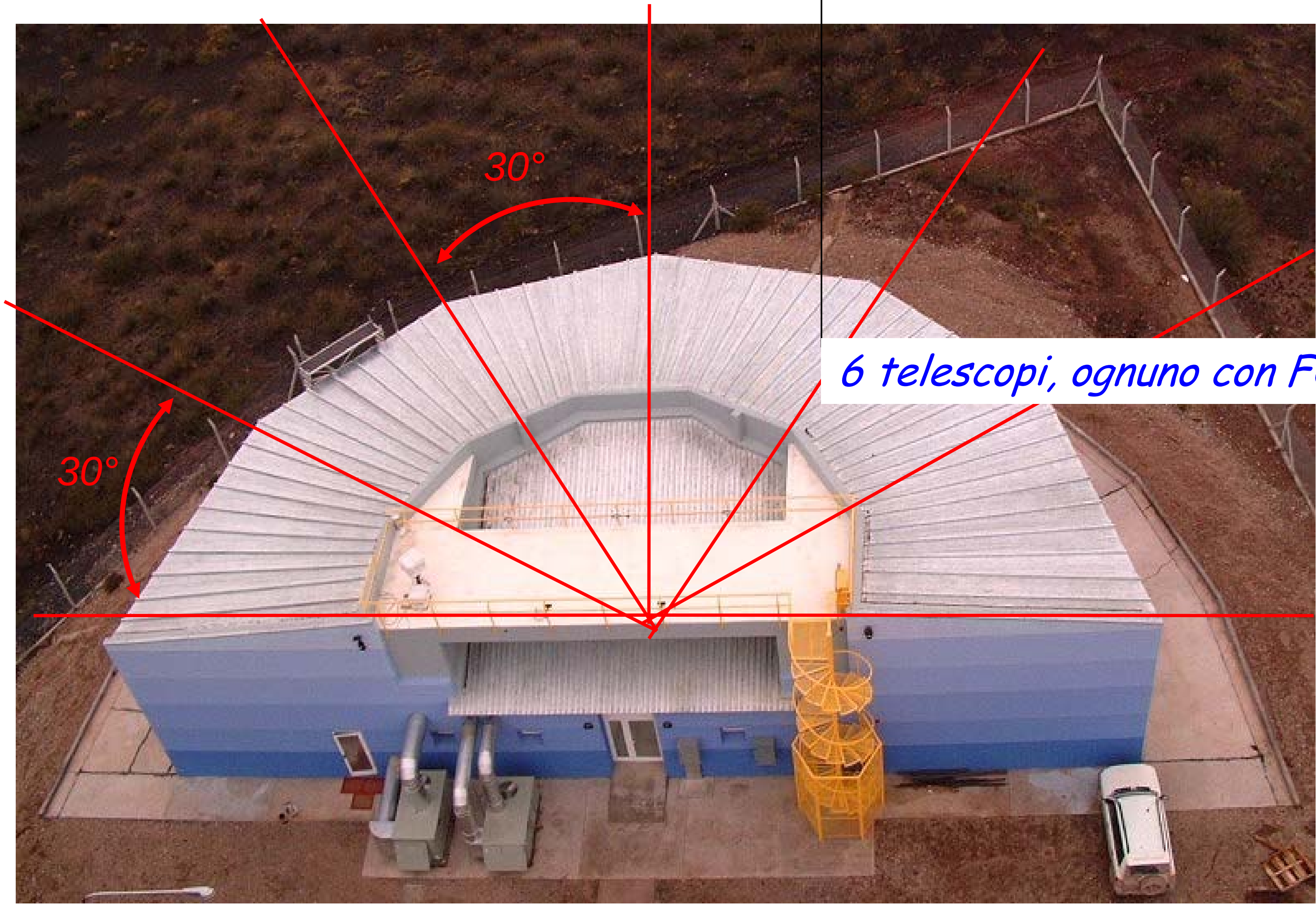
SD station installation


LOMA AMARILLA
COIHUECO
CLF
MORADOS
LEONES
Malargüe

View of Los Leones Fluorescence Site



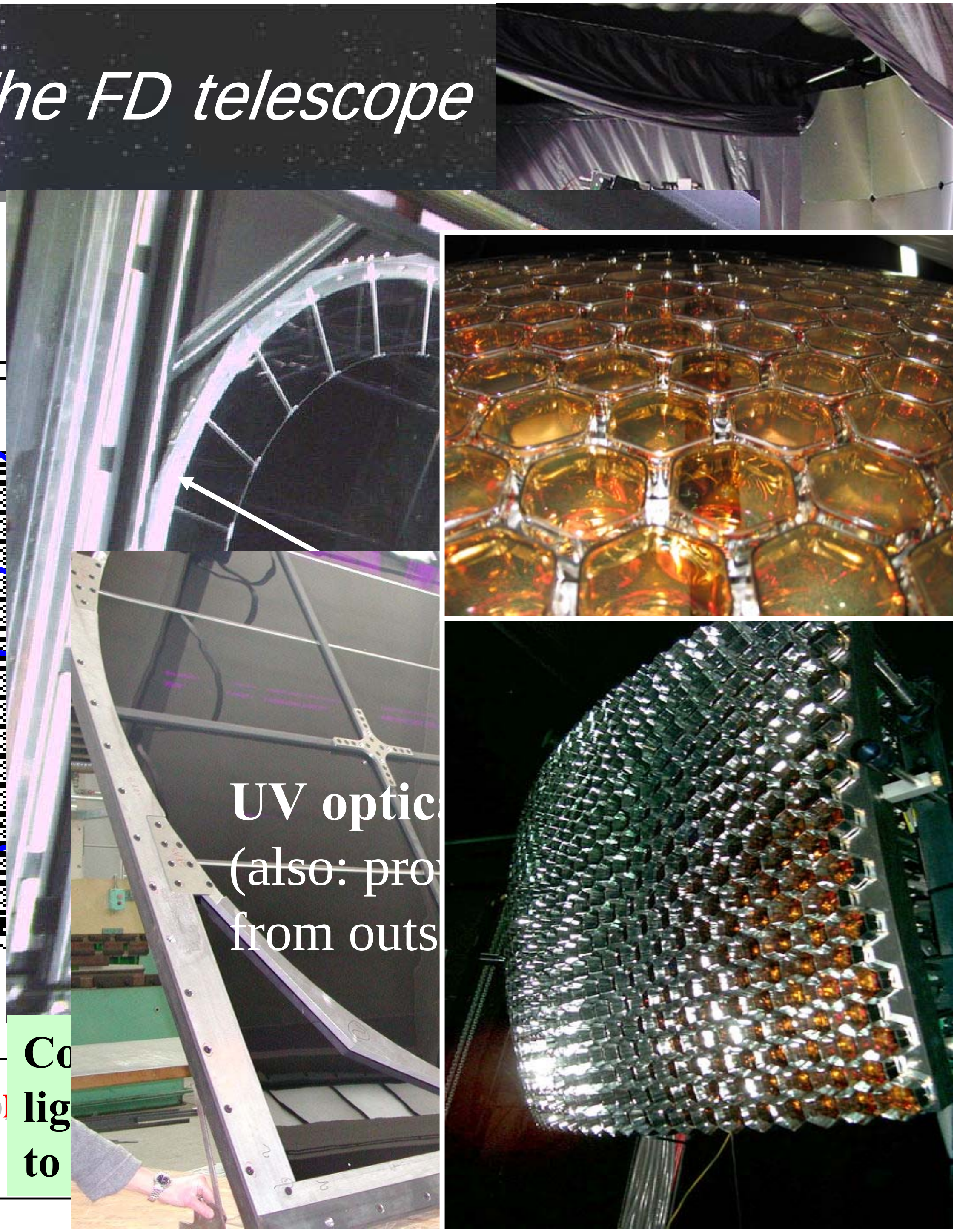
The Fluorescence Detector (FD)



6 telescopi, ognuno con FOV 30° x 30°

The FD telescope

- ✓Diaphragm + corrector ring (diametro 2.2 m)
- ✓UV Filter
- ✓Spherical mirror with radius 3.4m
- ✓Camera with FOV $30^o x 30^o$

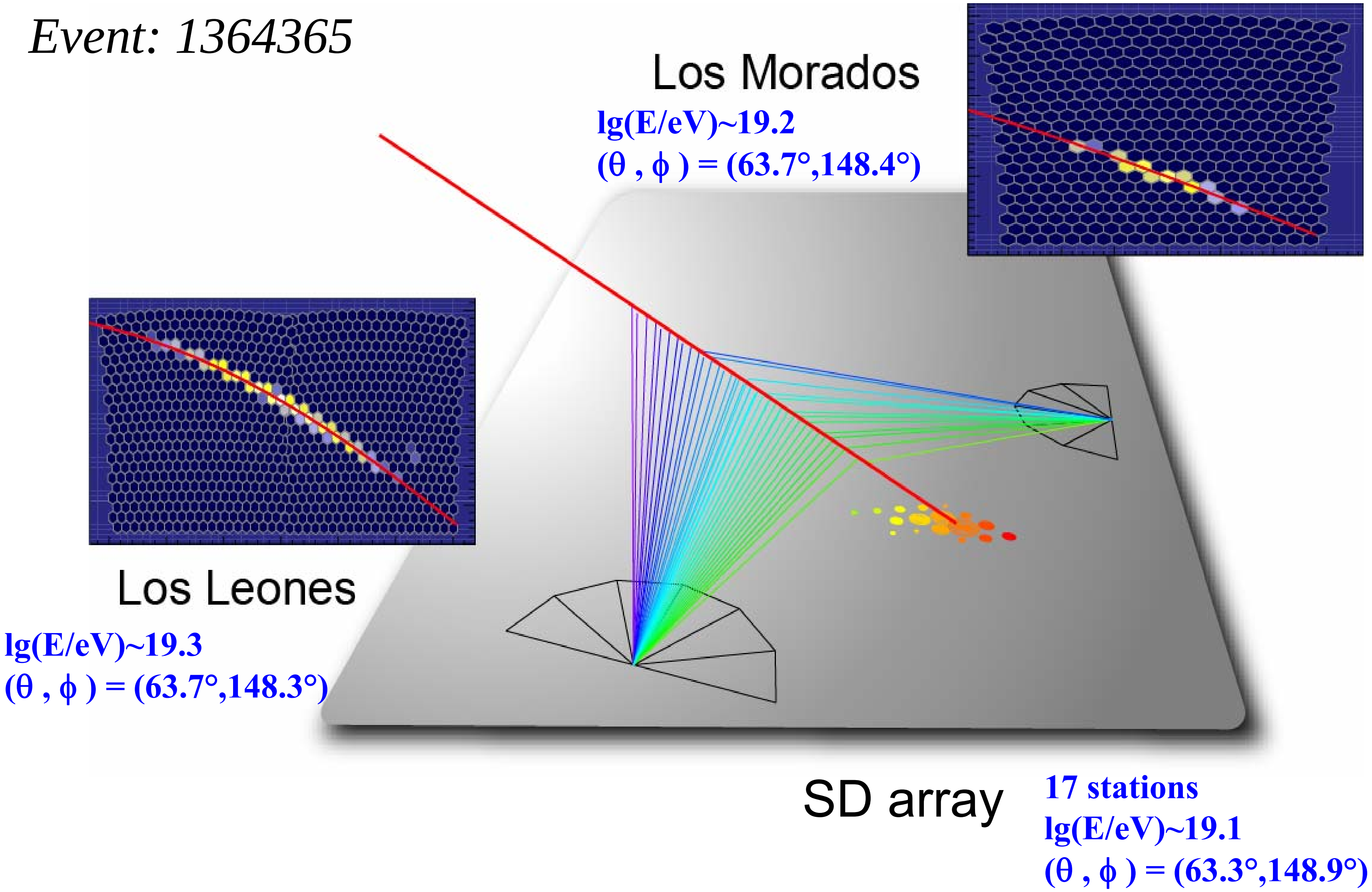


Duty cycle 10-14%

It works in cloudless and moon nights

An hybrid stereo event

Event: 1364365



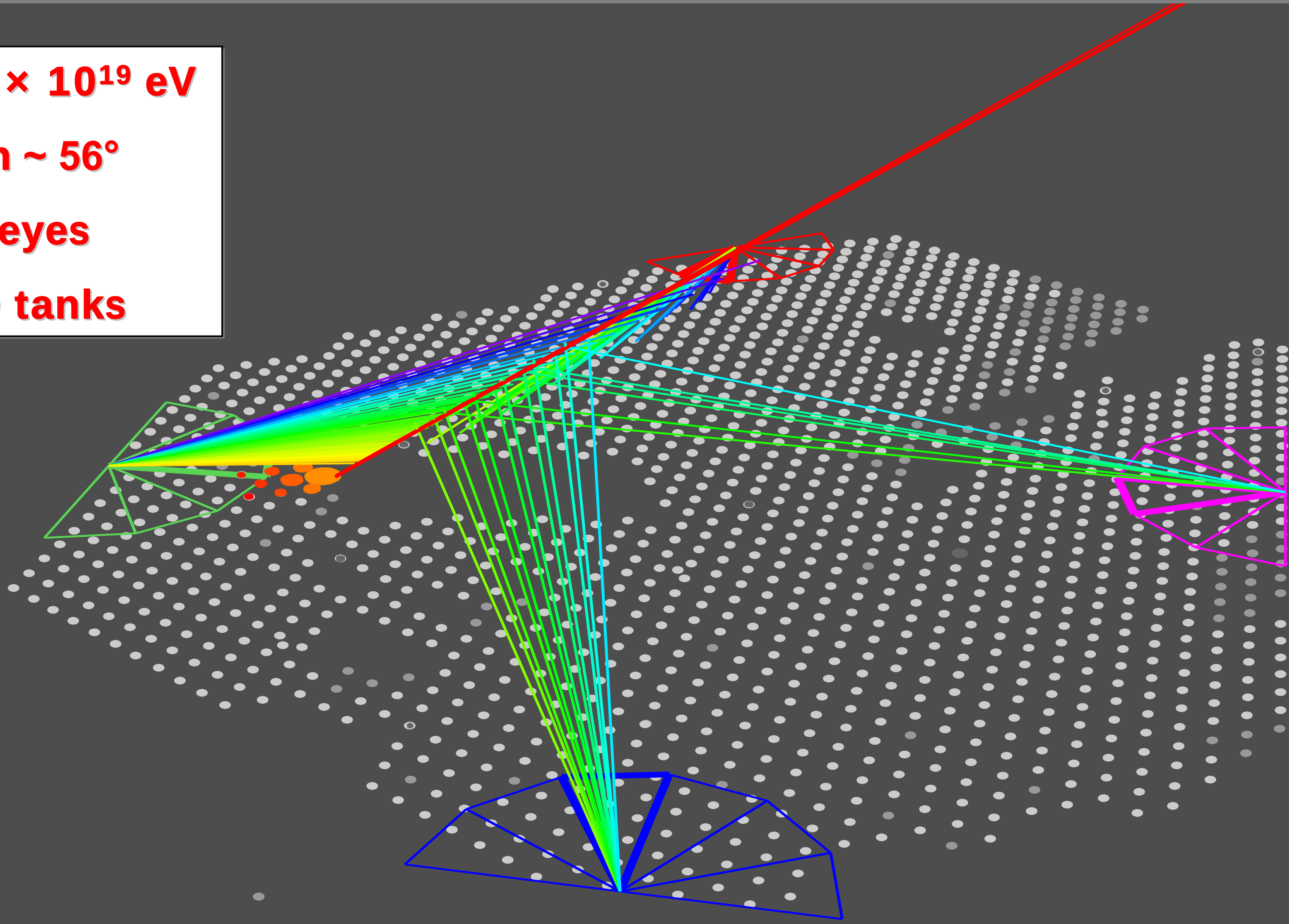
A fourth-fold hybrid event

E ~ 4 × 10^{19} eV

Zenith ~ 56°

4 FD eyes

10 SD tanks



AUGER DATA Flow

- Shower rate:

  SD ~ 10^5 evt/yr

  FD ~ 10^6 evt/yr

  (ARGO ~ 10^{11} evt/yr !)

- Total amount of data:

  SD ~ 45 GB/yr

  FD ~ 60 GB/yr

  (ARGO ~ 100 TB/ yr)

- Total amount of monitoring data (Calibrations, Atmosphere, …)

  ~ 60 GB/yr

Offline Software Objectives

- Provide collaboration with common framework for analysis
  - ~400 collaborators, widely dispersed

- Encourage independent analysis and comparisons
  - "Exposed" physics code
  - Well-defined way for collaborators to contribute to common code base

- Enough flexibility for
  - Event simulation, reconstruction, analysis
  - Atmospheric monitoring analysis
  - "Special" applications (calibration simulations, preprocessing, ...)

- Reasonably simple user-side
  - Many collaborators are C++ novices

What the framework provides

- Event data model
  - Communication backbone between algorithms
  - Ability to read/write various formats

- Detector description
  - Unified access to time-dependent detector data in various sources/formats

- Plug-in framework for *modules*
  - Physics algorithms for simulation and reconstruction
  - Service modules for I/O, event selection, visualization
  - Module sequencing control

- Configuration management

- Utilities
  - Geometry, Error logging, XML parsing, Math, Physics, ...

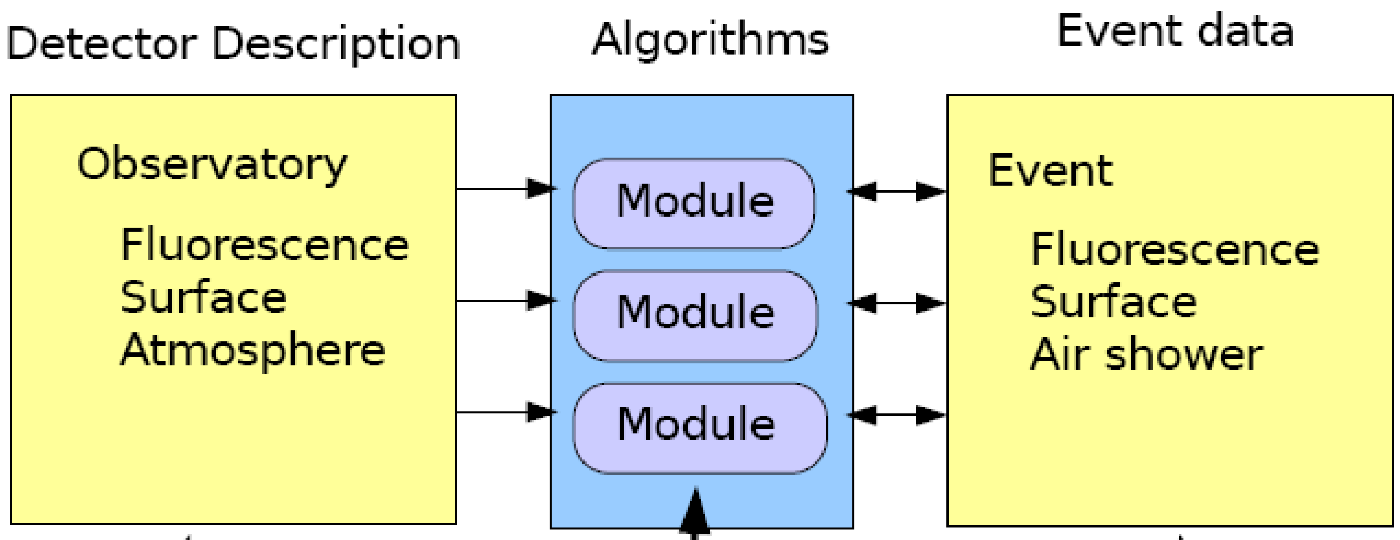
Technology choices

- Rely on open, well-supported standards
  - C++, XML, SQL

- Avoid locking to single-provider solutions
  - Development might cease or go in undesired direction
  - Insulate from this using wrappers, managers, ...

- Dependencies
  - Xerces for XML parsing
  - ROOT for serialization
  - MySQL for databases
  - CLHEP for geometry foundations
  - Geant4 (optional) for simulation modules
  - BOOST extensions of C++ (for convenience)

Overview of offline components



Sequence controlled by XML file, or Python

```
<loop>
  <module> A </module>
  <loop>
    <module> B </module>
    <module> C </module>
  </loop>
</loop>
```

Configuration and performance
of observatory with time

Simulations progressively build up an event

- Raw data
- Monte Carlo truth
- Reconstructed quantities

- Bootstrap information passed to executable:

```
userAugerOffline -b bootstrap.xml
```

```
\begin{verbatim}
<bootstrap>
  <centralConfig>
    <configLink
        id          = "ModuleSequence"
        type        = "XML"
        xlink:href  = "./ModuleSequenceExample.xml" />

    <configLink
        id          = "MyModuleConfig"
        type        = "XML"
        xlink:href  = "./MyModuleConfig.xml" />
  </centralConfig>
</bootstrap>
```

Modules and Sequencing

- Physicist writes module and registers it with RunController
  - Macro in class declaration registers a factory function which instantiates the module when requested

- For most applications, XML used to control run sequence

```
<sequenceFile>
  <loop numTimes="unbounded">
    <module> SimulatedShowerReader </module>
    <loop numTimes="10" pushToStack="yes">
      <module> EventGenerator     </module>
      <module> TankSimulator      </module>
      <module> TriggerSimulator   </module>
      <module> EventExporter      </module>
    </loop>
  </loop>
</sequenceFile>
```

attributes detail looping behavior

SD simulation example

```
<loop numTimes="unbounded">

  <module> EventFileReader </module>
  <loop numTimes="10" save="yes">
  <!-- Generate new event from Aires/Corsika
       data stored in Event -->
  <module> EventGenerator     </module>
  <module> Simulator          </module>
  <module> EventFileExporter  </module>
  </loop>
</loop>
```

FD reconstruction example

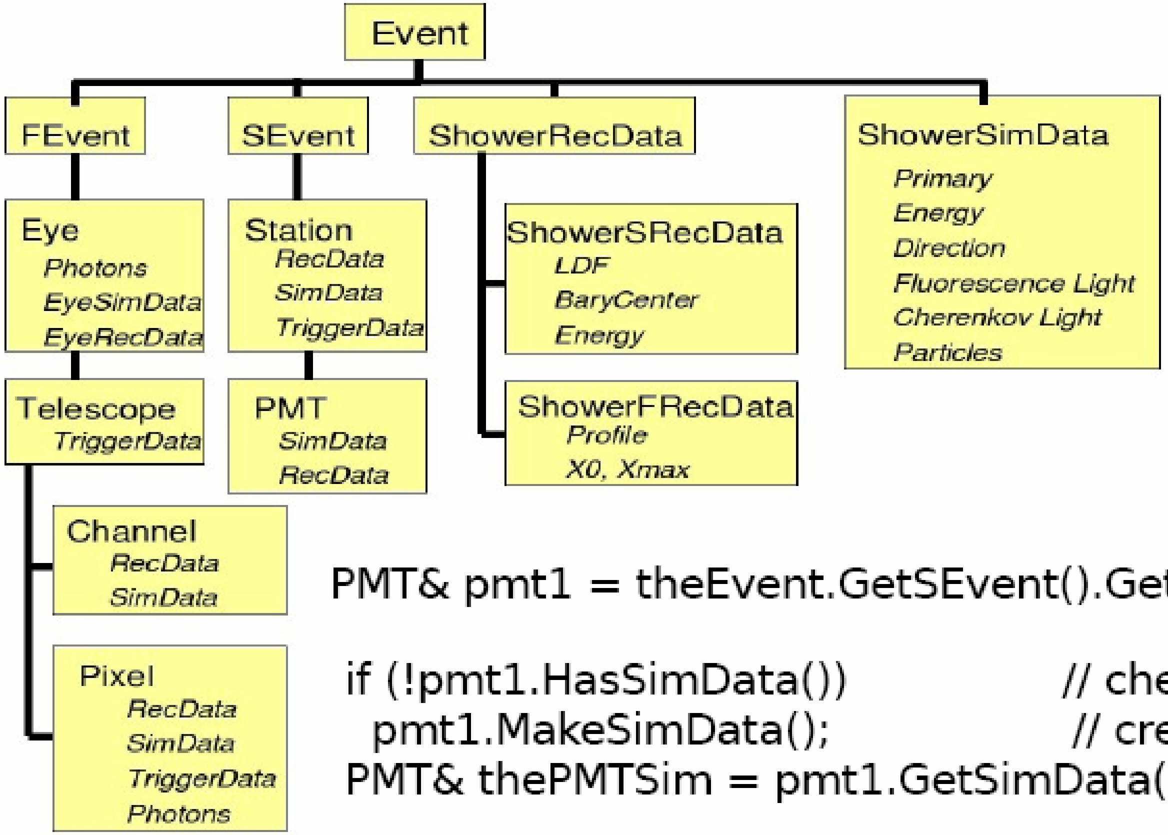
```
<loop numTimes="unbounded">

  <module> EventFileReader        </module>
  <module> GeometryFinder         </module>
  <module> ProfileFinder          </module>
  <module> EnergyFinder           </module>
  <loop numTimes="10">
  <!-- Iterative Cherenkov subtraction -->
    <module> CherenkovFinder      </module>
    <module> CherenkovSubtracter  </module>
    <module> ProfileFinder        </module>
    <module> EnergyFinder         </module>
  </loop>
  <module> Analysis               </module>
</loop>
```

- `<module>` tag for selecting modules
- `<loop>` tag for simple looping control

Event

- Provides data access to raw data, MC truth, reconstructed quantities
- Hierarchy follows detector hardware
- Principal communication backbone between modules
- Simple protocol to interrogate state of the event

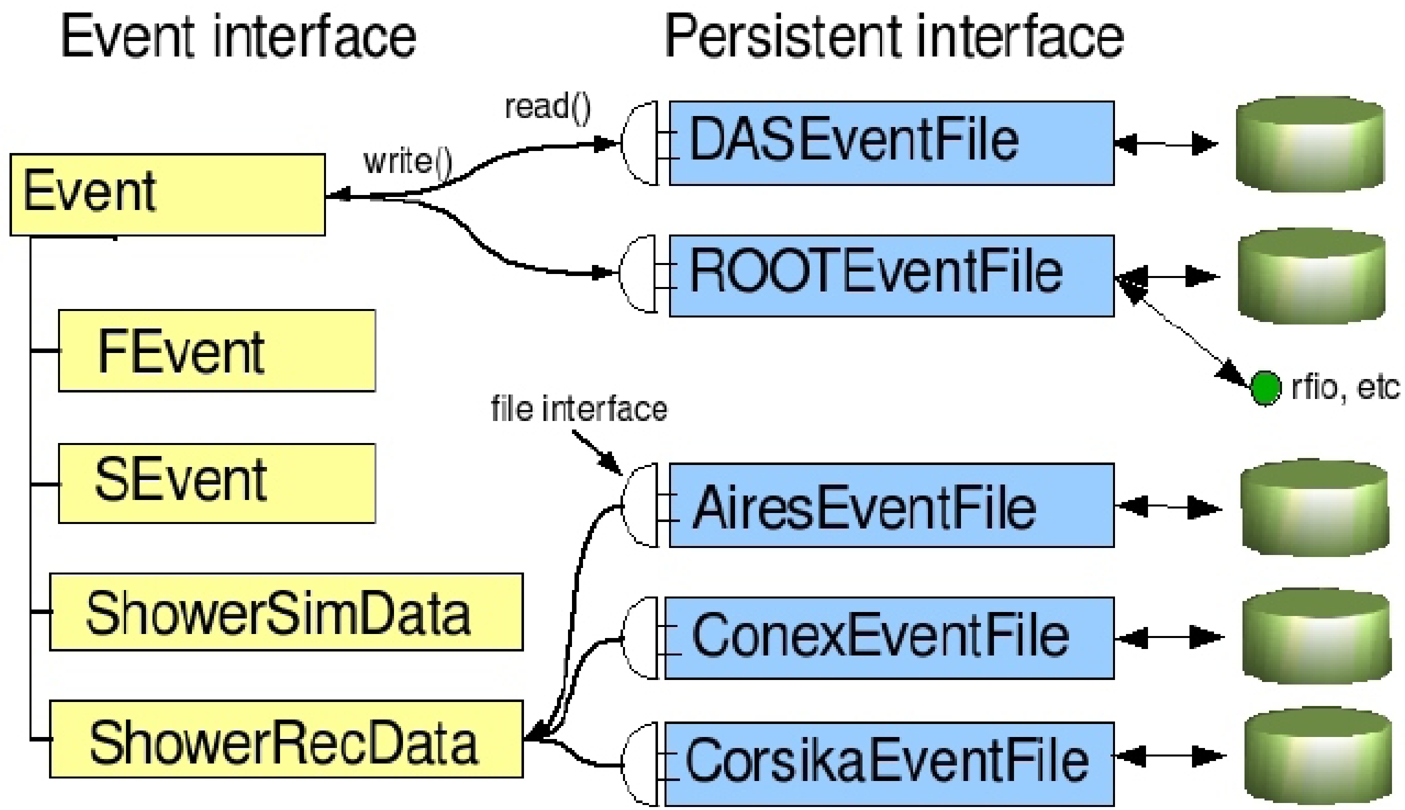



```
PMT& pmt1 = theEvent.GetSEvent().GetStation(157).GetPMT(1);

if (!pmt1.HasSimData())              // check for SimData
  pmt1.MakeSimData();                // create SimData
PMT& thePMTSim = pmt1.GetSimData();
```

Event I/O

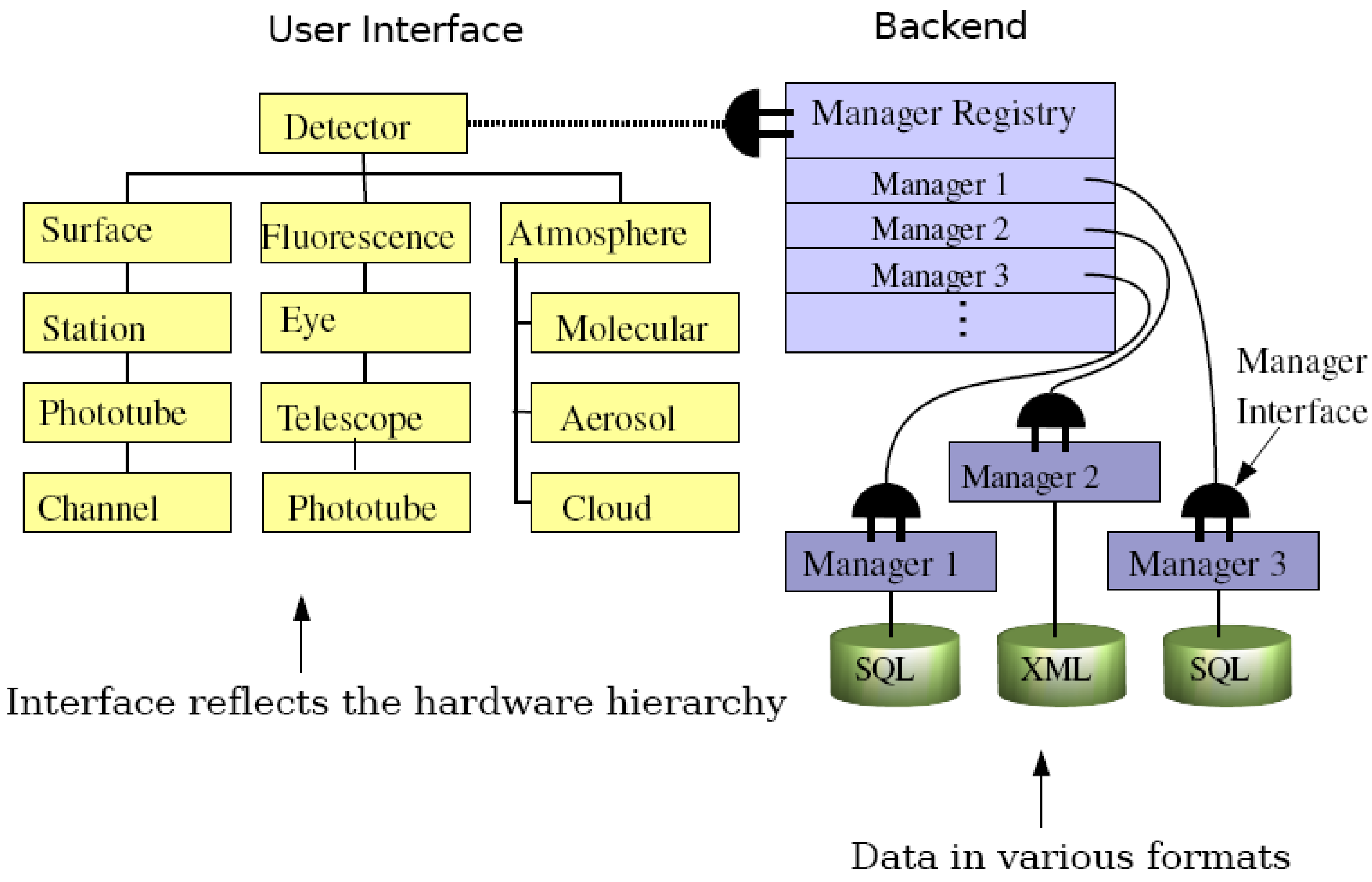
- Separate persistent and transient events



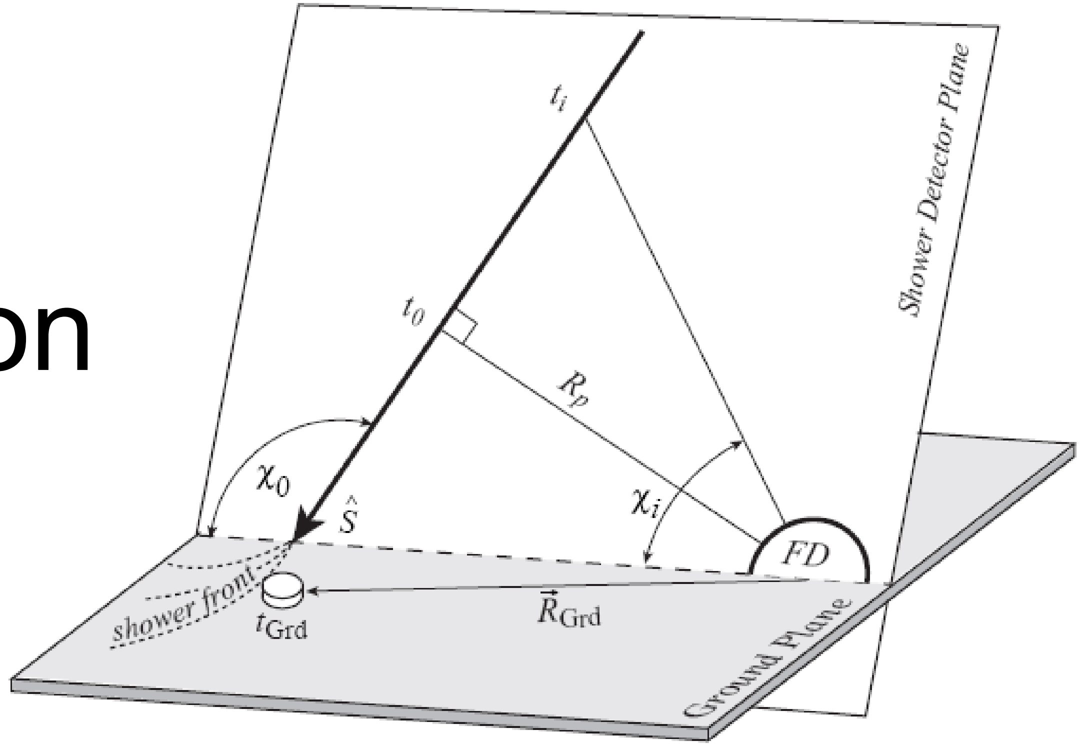
- Event can be written to file at any stage in procesing

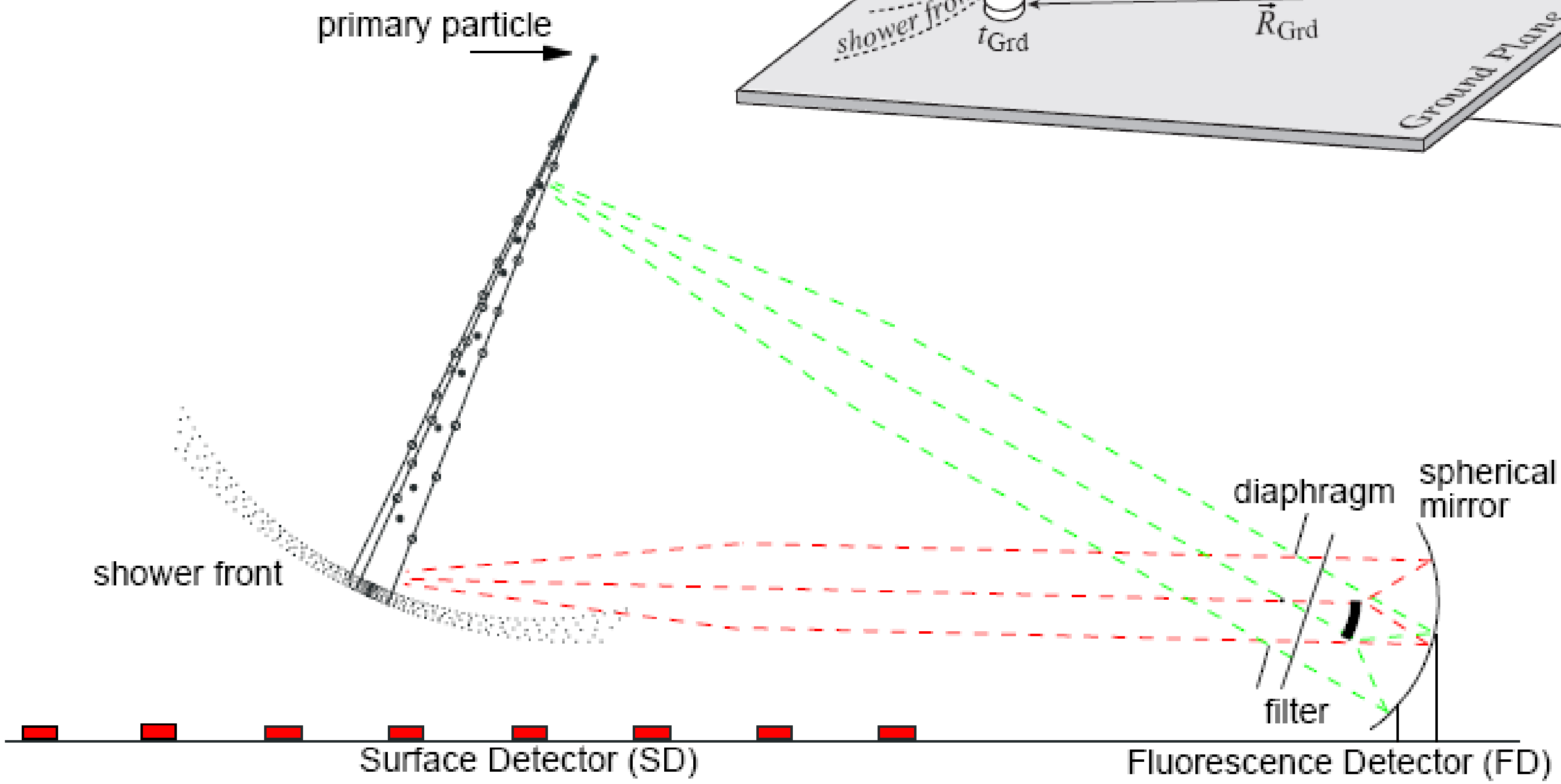
Detector Description

- Detector information may reside in multiple sources/formats
- User interface relays requests to registry of *managers*

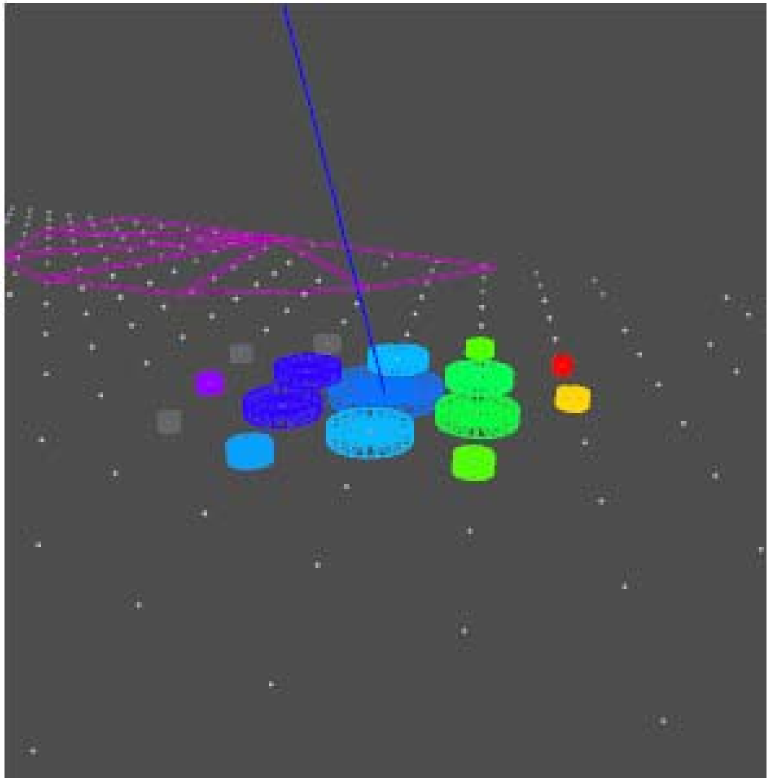


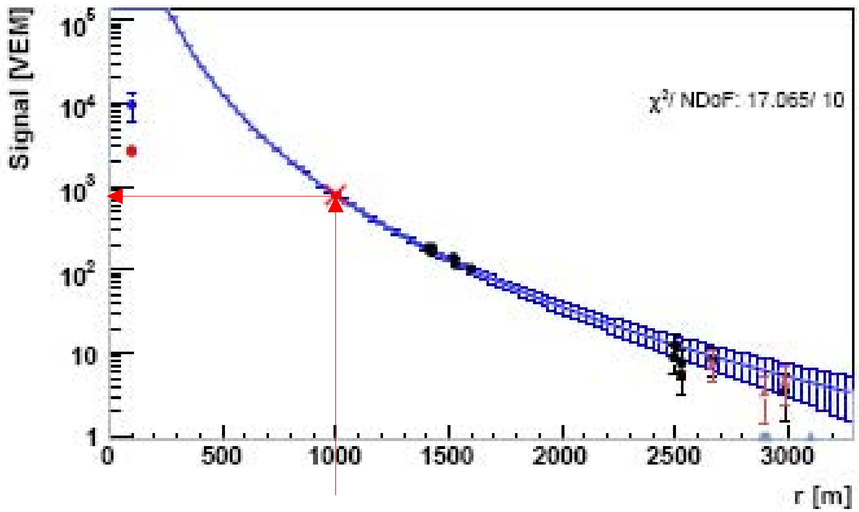
Event Reconstruction





SD reconstruction





Event 3036270 :-)

3TOT & 4C1; T5

Candidate stations: 13(4 acc)

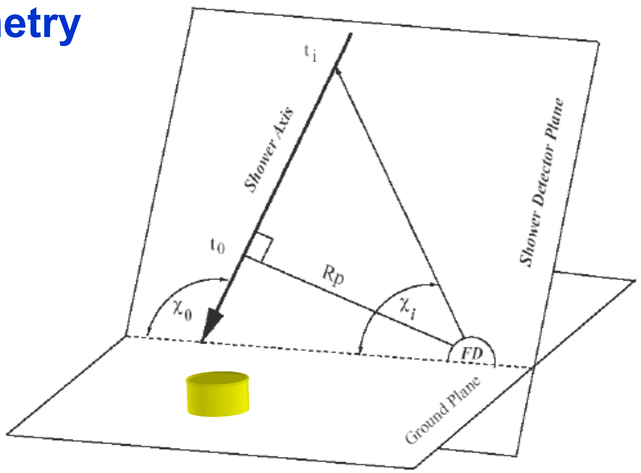
S(1000 m) = 794.3 ± 21.0 (±75.6) VEM

θ = 14.22 ± 0.11 deg

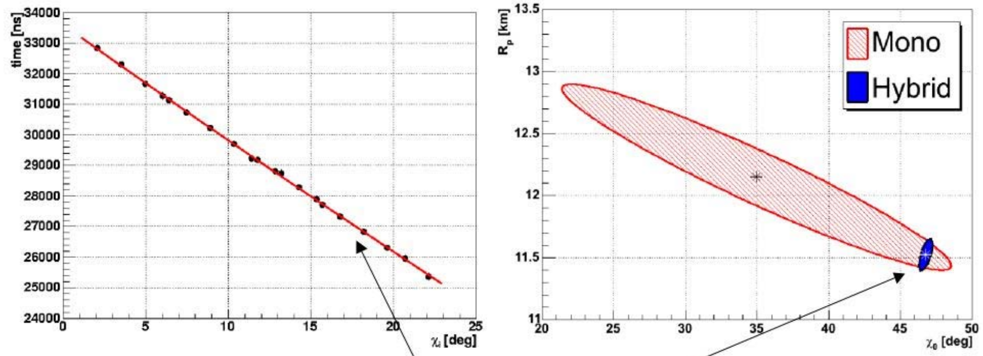
ϕ = 86.80 ± 0.47 deg

FD (hybrid) reconstruction

Geometry



Hybrid vs Monocular

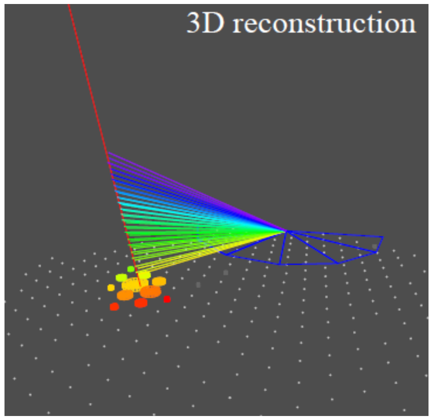


≈ line but
3 free parameters

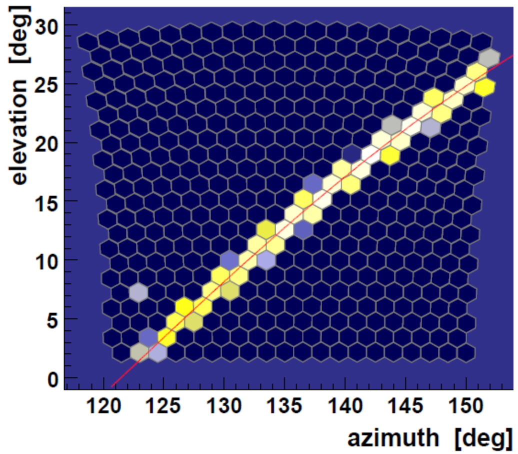
T_0 from tank!

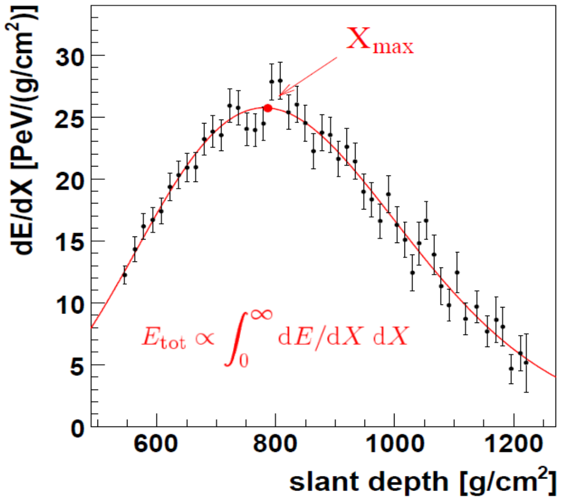
$$t(\chi) = T_0 + \frac{R_p}{c}\tan\left[\frac{(\chi_0-\chi)}{2}\right]$$

Energy and X_{max}



camera view





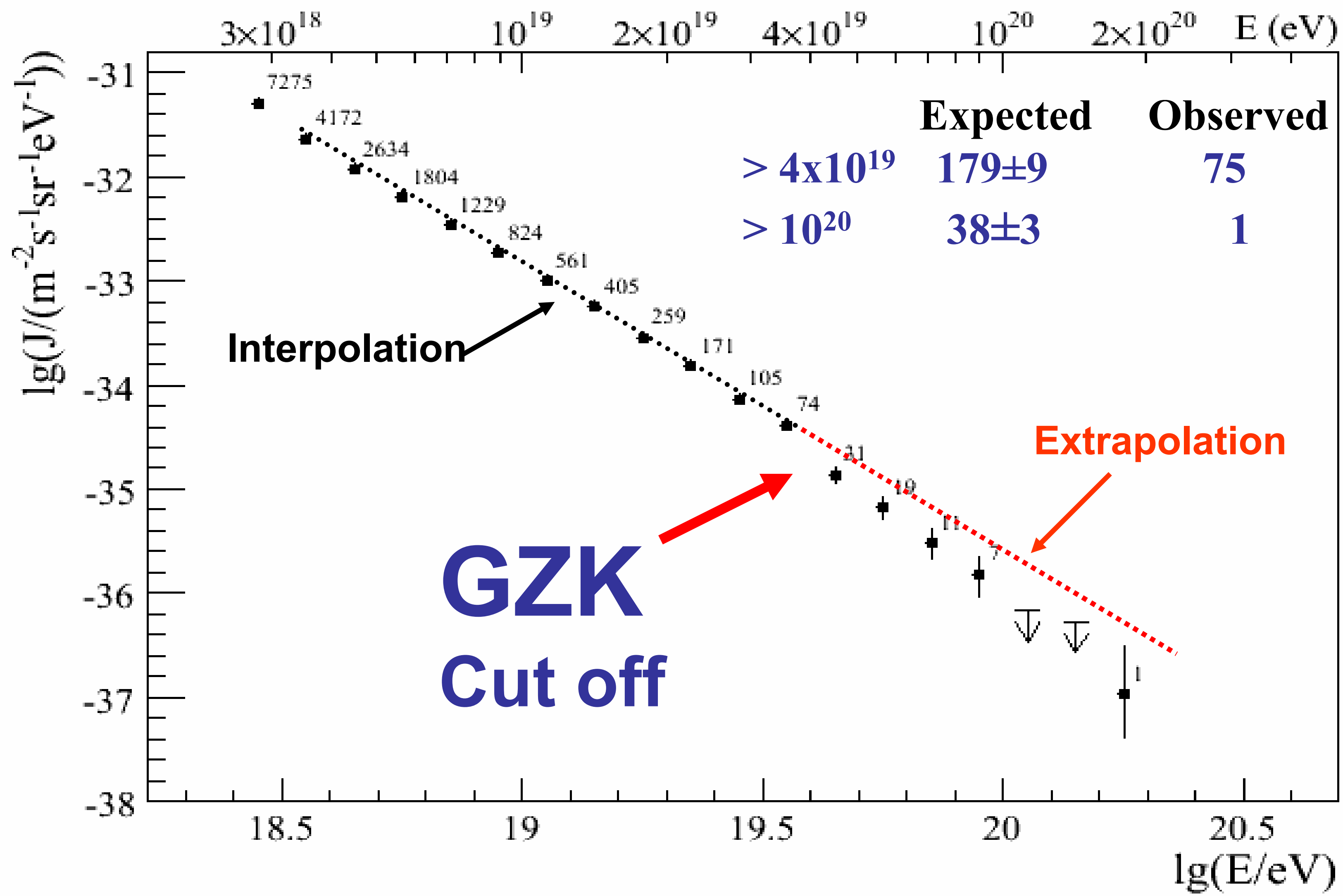
Example: the DISPLAY Tool

- Based on ROOT GUI classes
- Many user inputs and choices
- Possibility to change reconstruction parameters ….
- …..

See D E M O…

Energy spectrum ($\theta < 60^0$)

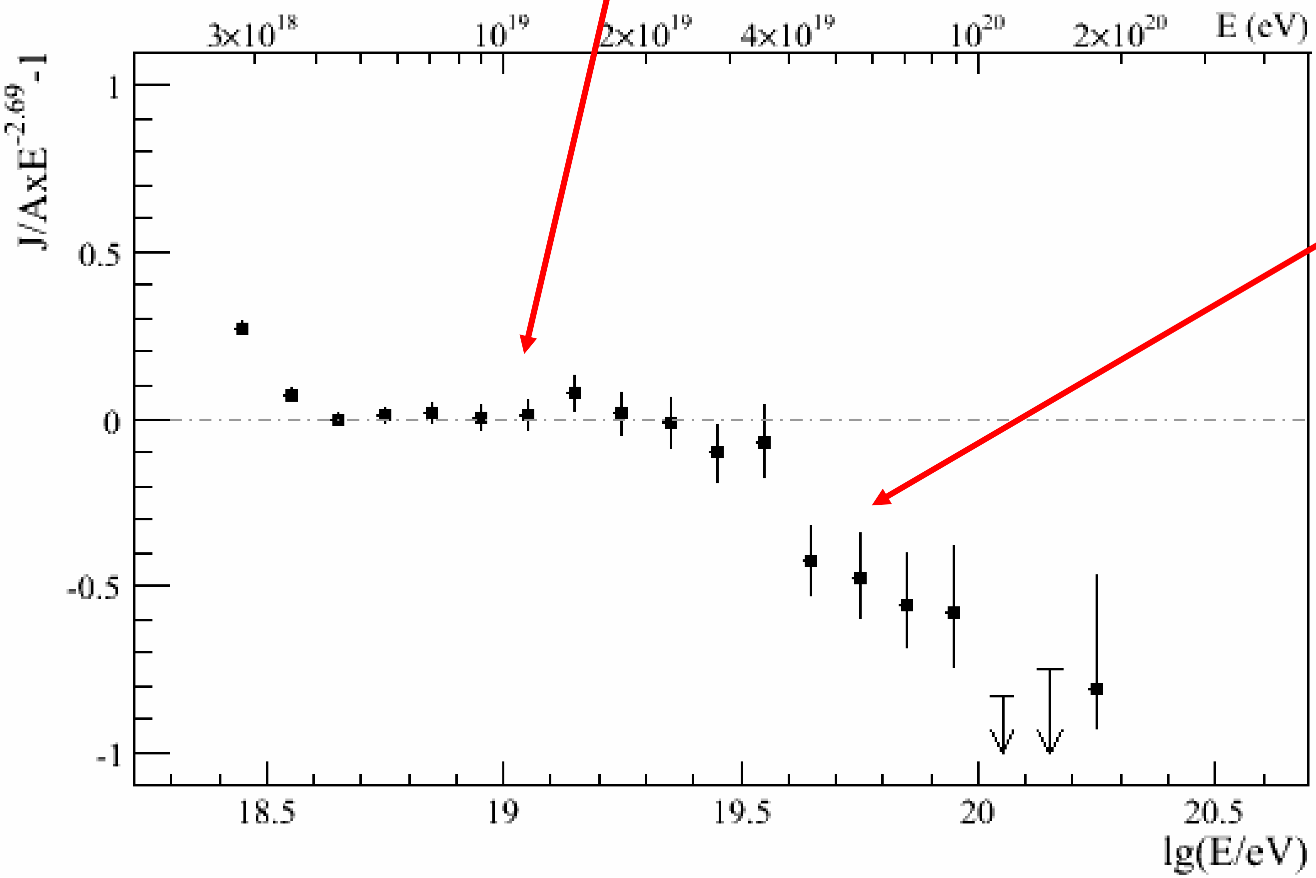
Exposure 7000 km^2 sr yr (3% error) (~ 1 year Auger completed)



Detailed features of the spectrum better seen by taking difference with respect to reference shape $J_s = A \times E^{-2.69}$

Fit $E^{-\gamma}$

$\gamma = 2.69 \pm 0.02$



GZK cut off

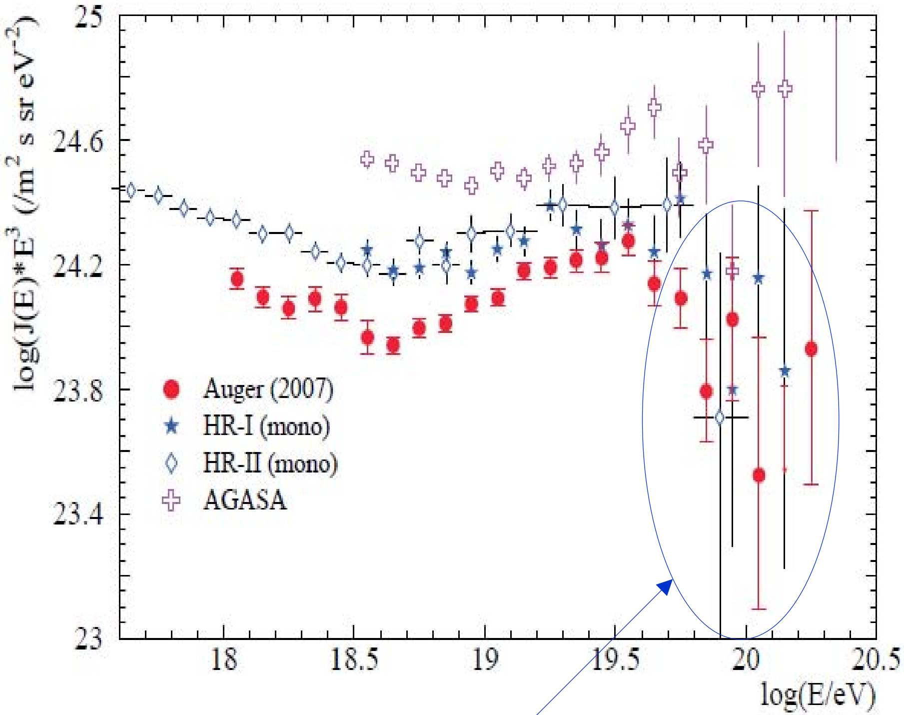
Slope γ above $4\text{x}10^{19}$ eV:

4.0 ± 0.4

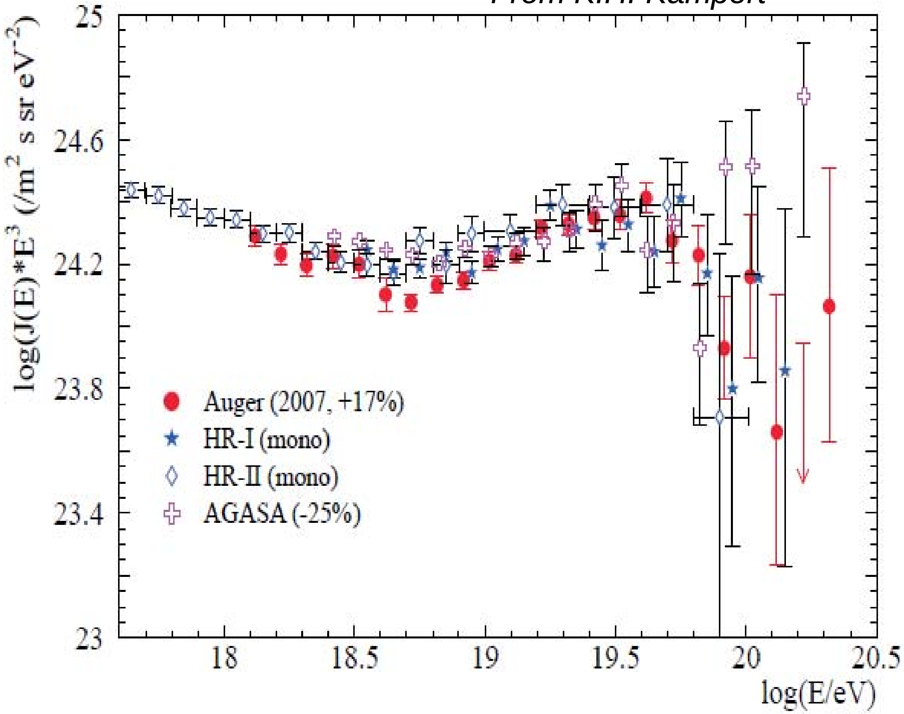
HiRes:

5.1 ± 0.7

Summary of the UHECR spectrum



From K.H. Kampert



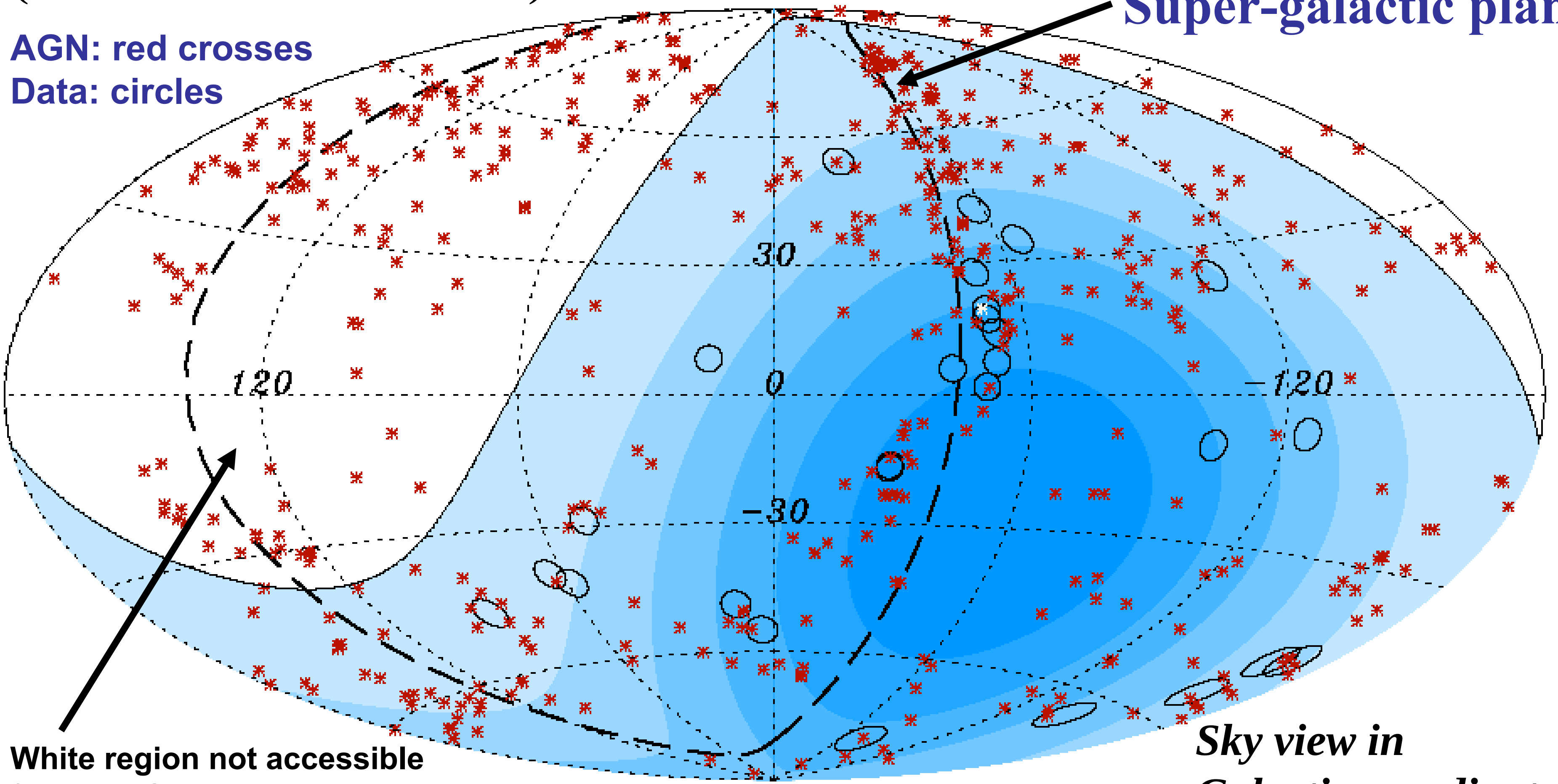
GZK cutoff?
Acceleration limit?
Drop off of lighter elements?

Energy scale problem !

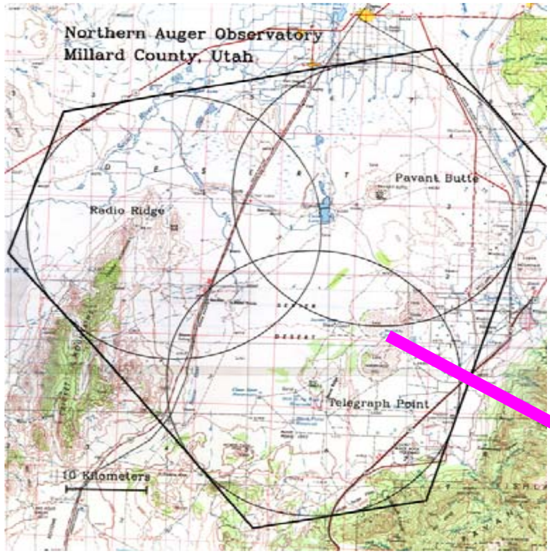
Anisotropy – extragalactic sources

Véron &Véron-Cetty AGN catalogue. 27 events with E > 47 EeV. 20 events correlate with AGN at z<0.017 (71 Mpc), within 3.1^0 (maximum correlation)

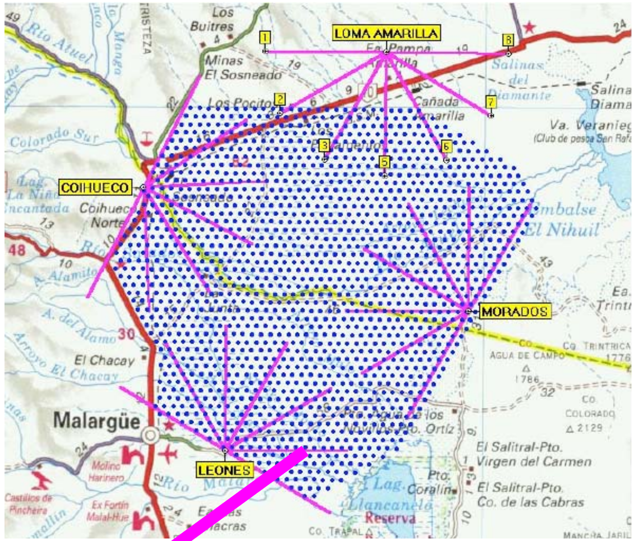
AGN: red crosses
Data: circles

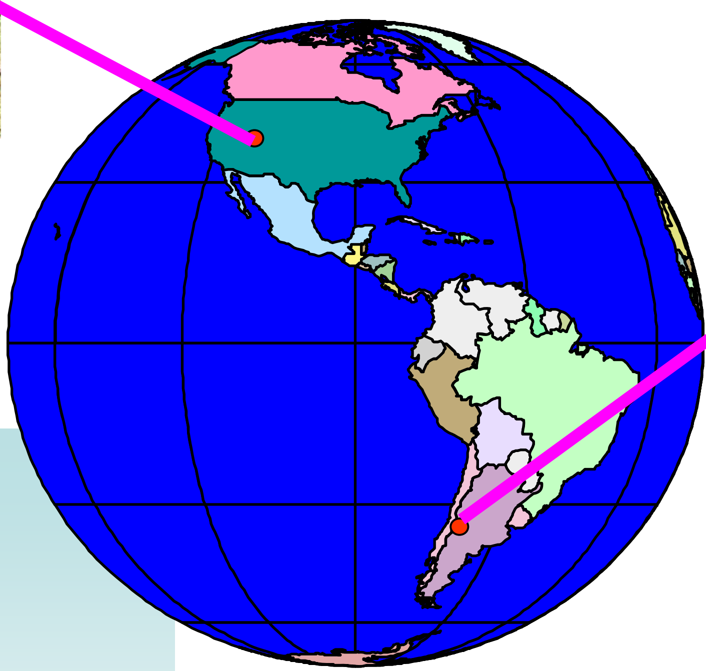


Doublet from Centaurus A, the nearest AGN (~ 3.8 Mpc) strong radiosource (white cross)



Northern hemisphere
Colorado,USA





- *Large plateau*
- *Low population density (artificial lightening)*
- *Clear astmosphere*

Southern hemisphere
Malargüe (Mendoza)
Argentina

35° S latitude,
69° W longitude
Altitude ≈ 1.4 km

Mass composition with Xmax

primary protons:

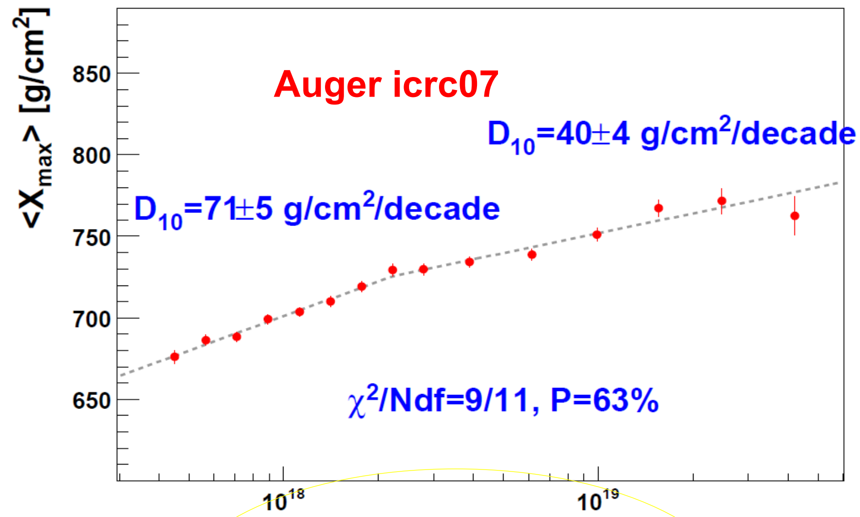
$$\langle X_{\max} \rangle = D_{10} \lg(E) + \text{const}$$

superposition model:

$$\langle X_{\max} \rangle = D_{10} \lg(E/A) + \text{const}$$

elongation rate theorem:

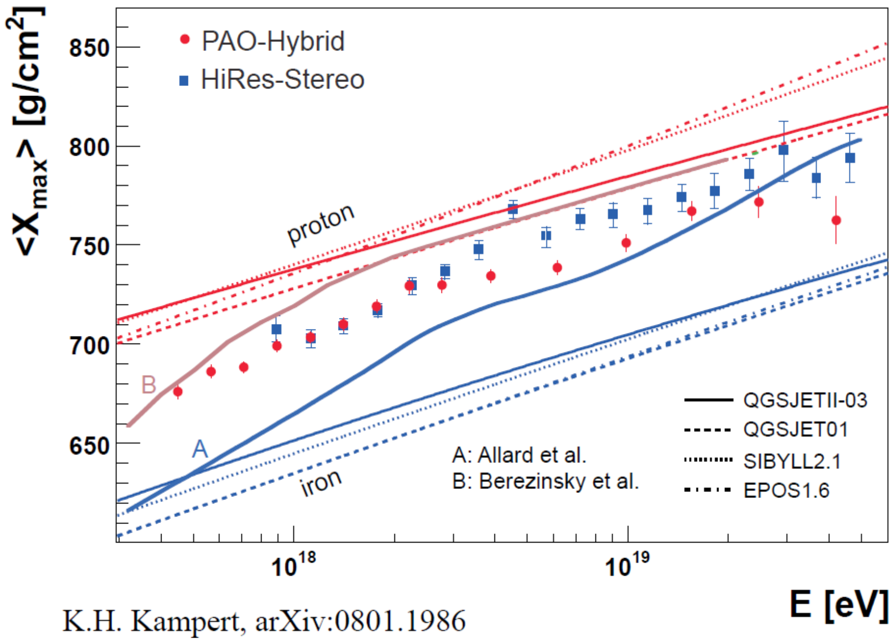
$$D_{10} \leq X_0 \ln(10)$$



High quality data

Total systematic uncertainty:

$\leq$ 15 g/cm^2 (E$<$ 10^{18} eV)
$\leq$ 12 g/cm^2 (E$>$ 10^{18} eV)



K.H. Kampert, arXiv:0801.1986

- Hint of a mixed composition
- Composition is changing?

(also: stringent neutrino and photon limits)

Credits & Acknowledgements

- ARGO-YBJ and AUGER collaborators
- T. Paul, ICHEP07
- C.Bleve,IFAE08
- D. Martello, ARGO note
- L.Perrone, M.Settimo, AUGER note
- …….and many others..