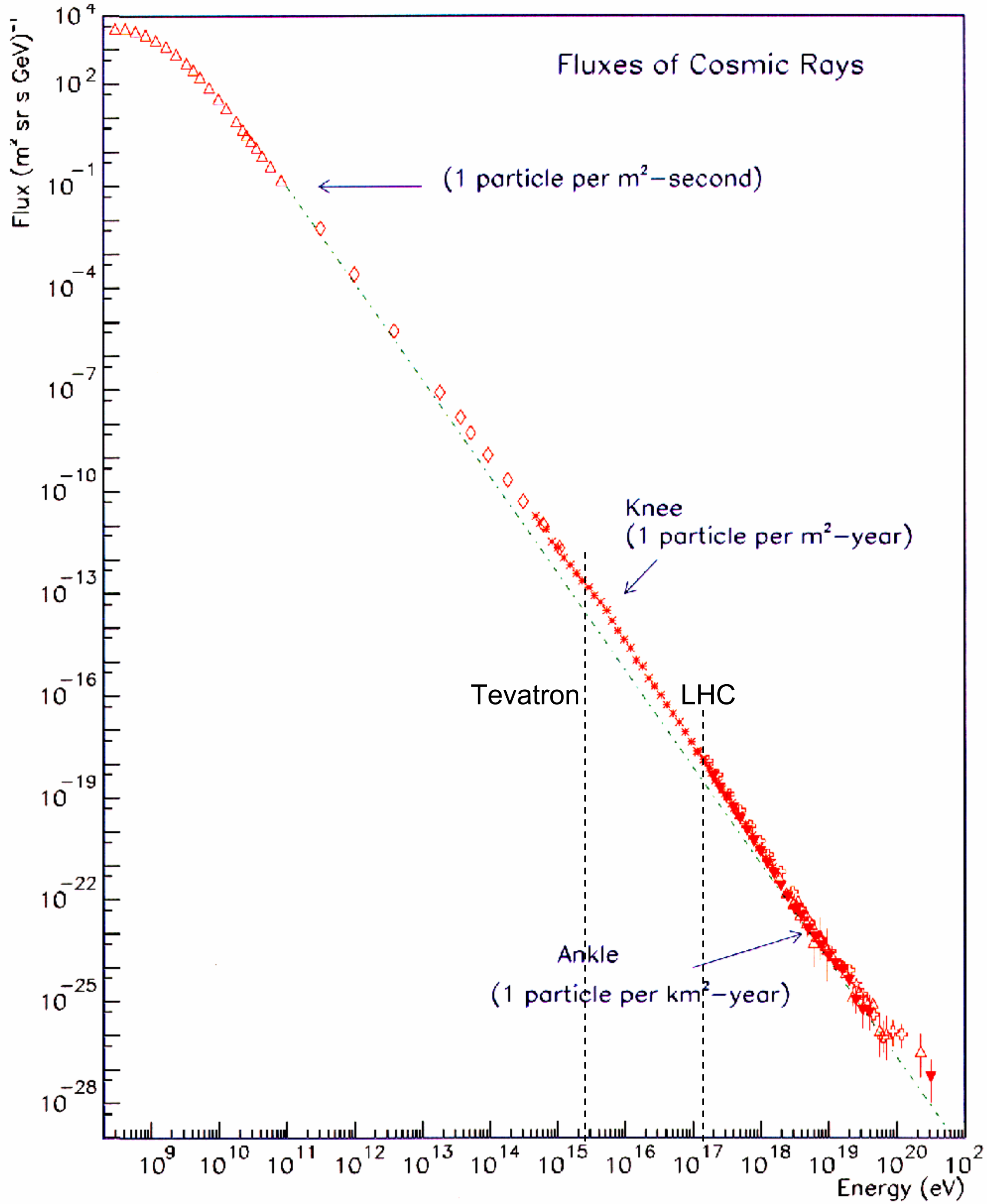
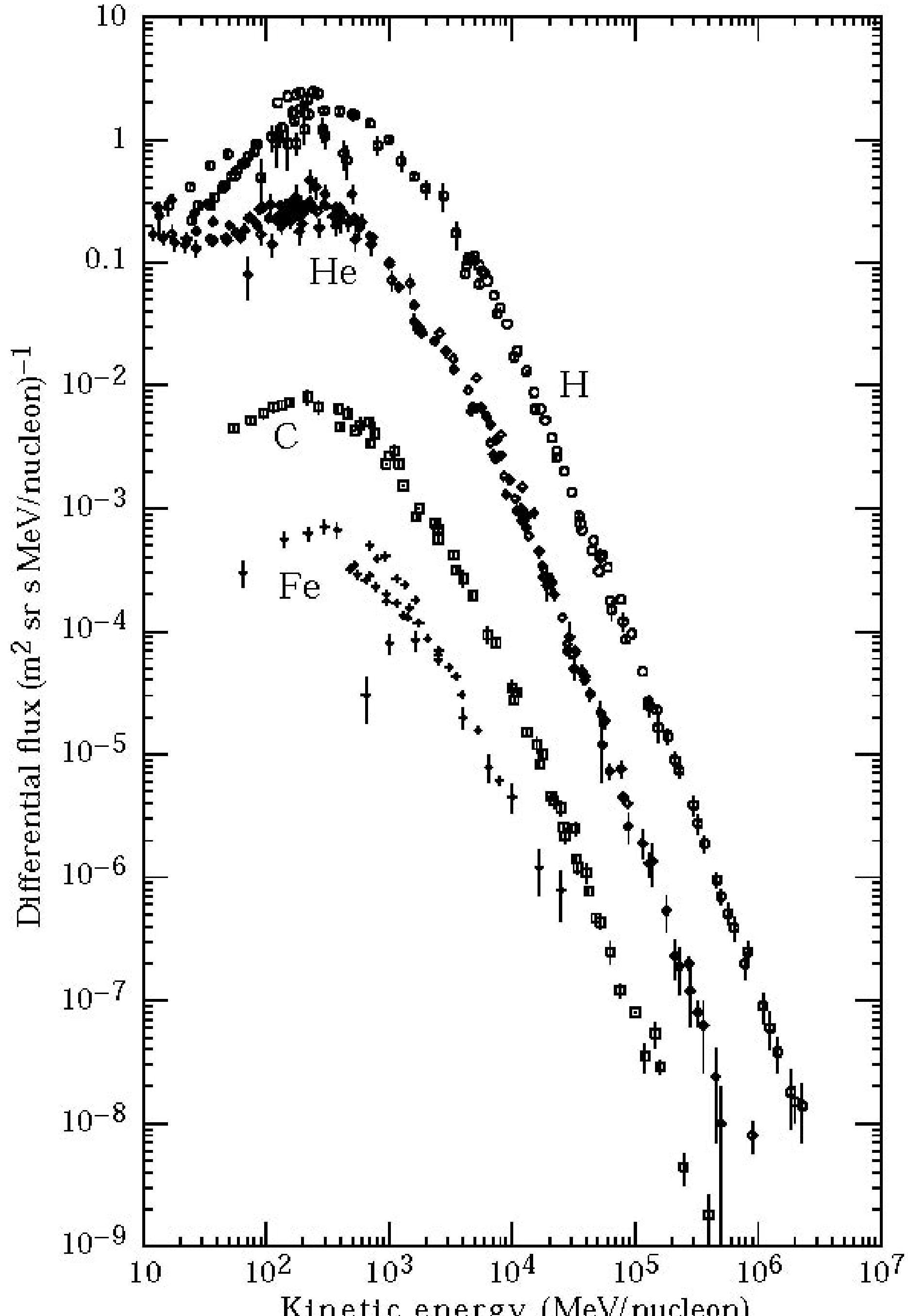
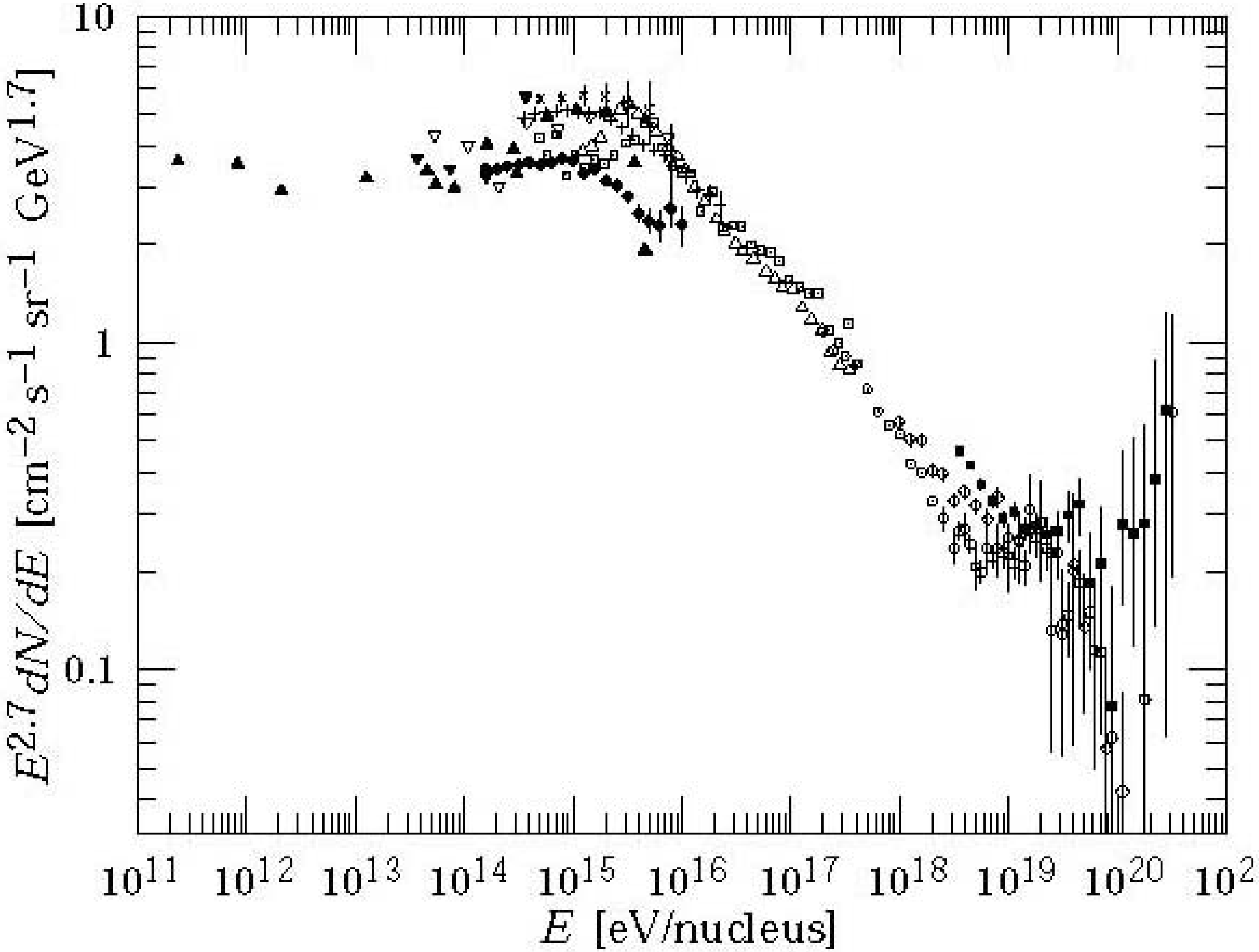


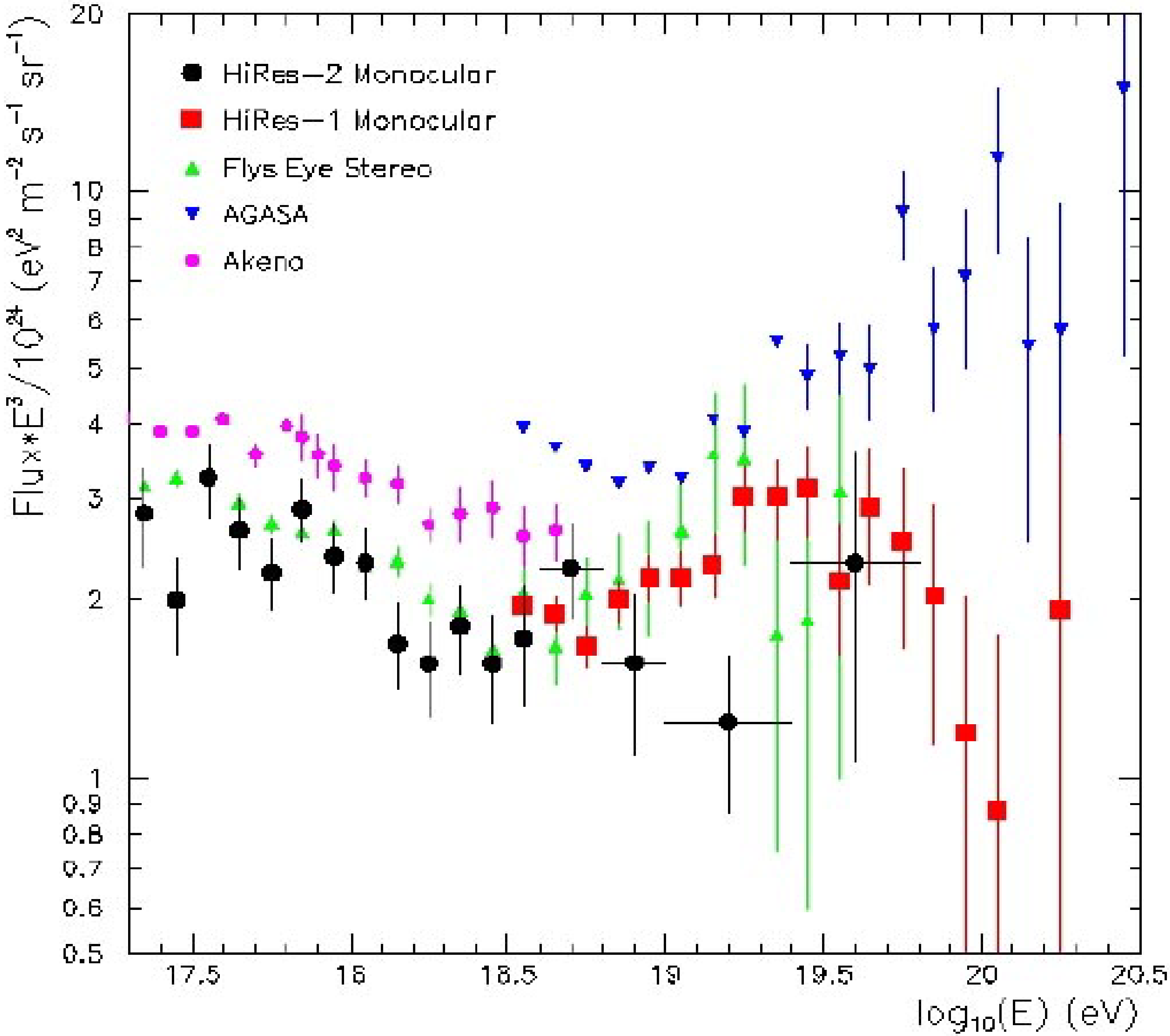
Fluxes of Cosmic Rays
(1 particle per m²−second)
Knee
(1 particle per m²−year)
Tevatron
LHC
Ankle
(1 particle per km²−year)
Flux (m² sr s GeV)⁻¹
Energy (eV)



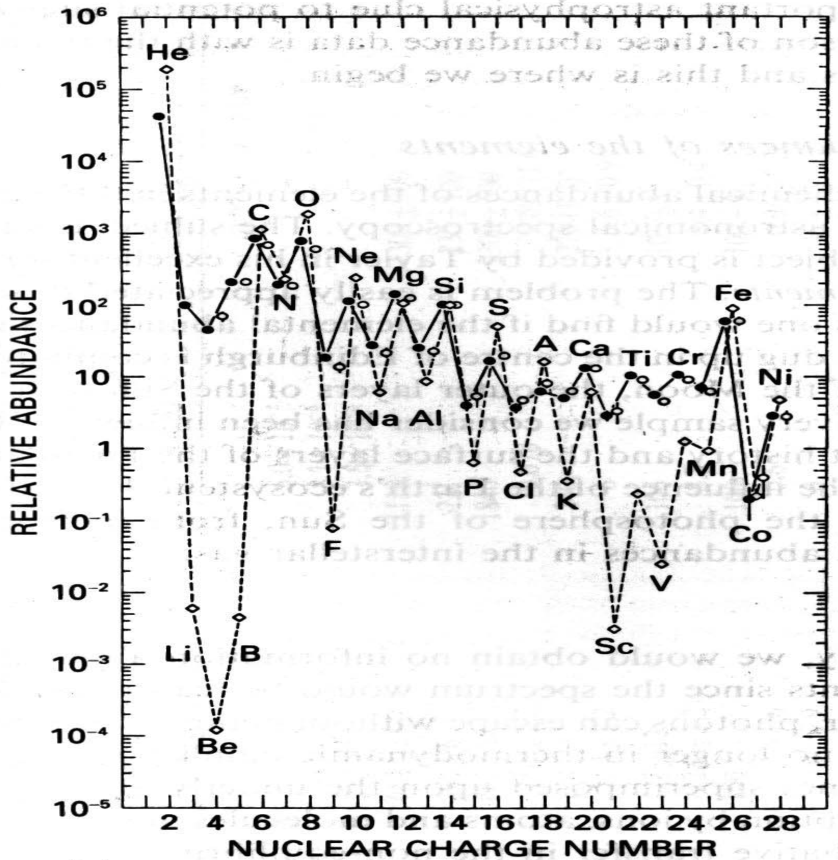
He
H
C
Fe
Differential flux (m^2 sr s MeV/nucleon)$^{-1}$
Kinetic energy (MeV/nucleon)
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10
10^2
10^3
10^4
10^5
10^6
10^7



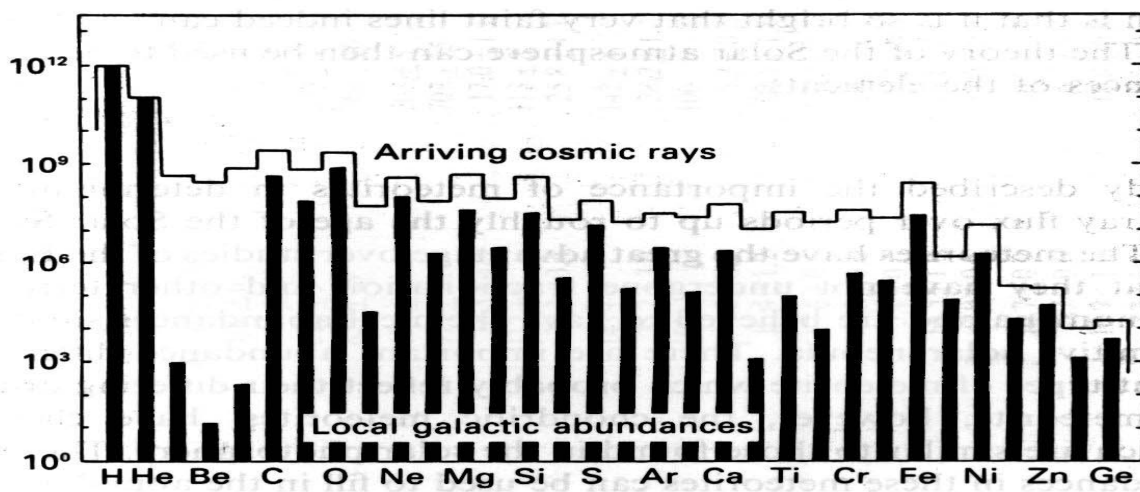
10
1
0.1
$E^{2.7}\,dN/dE$ [cm^{-2} s^{-1} sr^{-1} GeV1.7]
10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}
E [eV/nucleus]



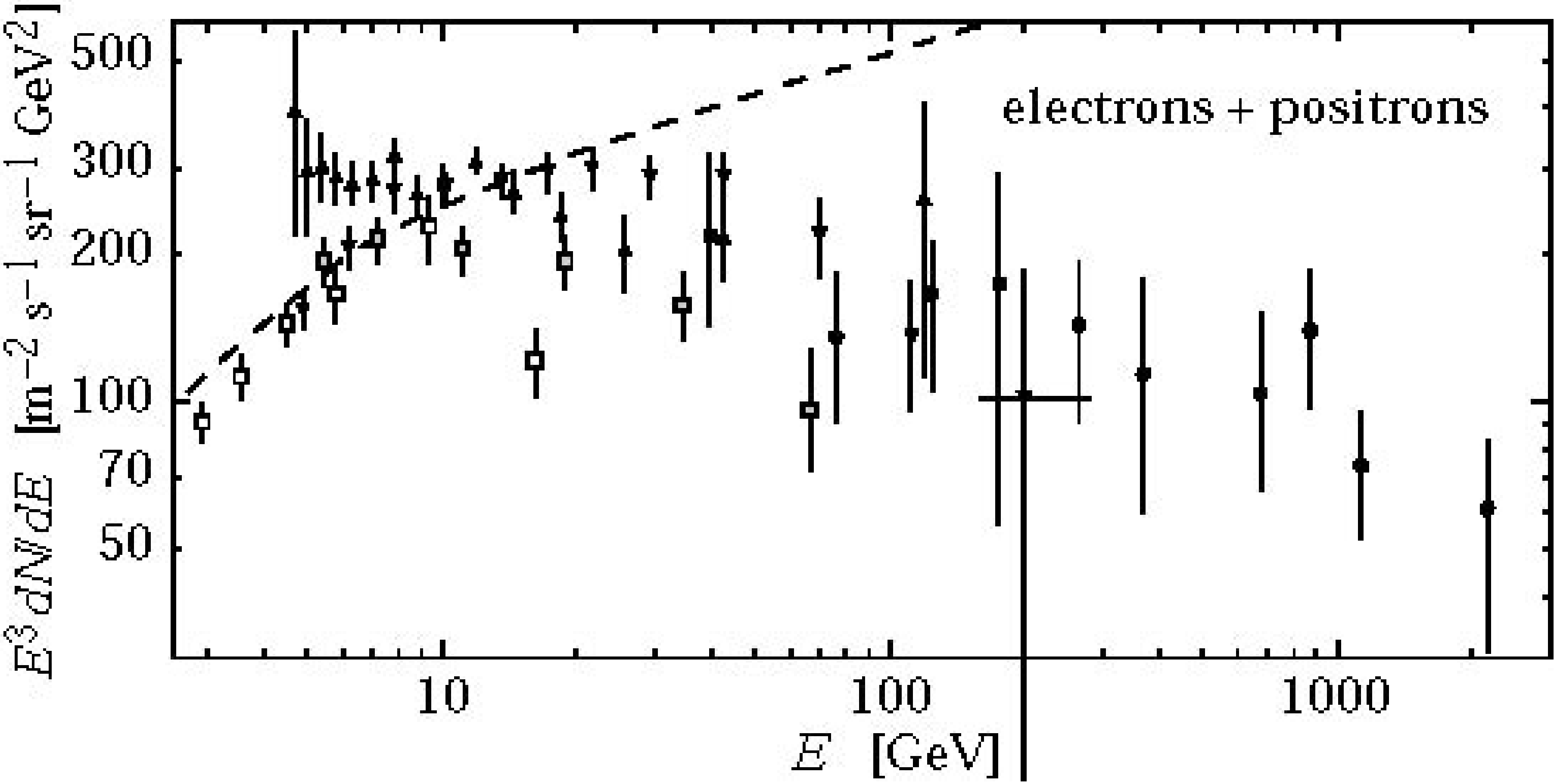
HiRes−2 Monocular
HiRes−1 Monocular
Flys Eye Stereo
AGASA
Akeno
Flux*E^3/10^24 (eV^2 m^-2 s^-1 sr^-1)
log10(E) (eV)
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
17.5
18
18.5
19
19.5
20
20.5


RELATIVE ABUNDANCE
NUCLEAR CHARGE NUMBER
10⁶
10⁵
10⁴
10³
10²
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
2 4 6 8 10 12 14 16 18 20 22 24 26 28
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Al
Si
P
S
Cl
A
K
Ca
Sc
Ti
V
Cr
Mn
Fe
Co
Ni

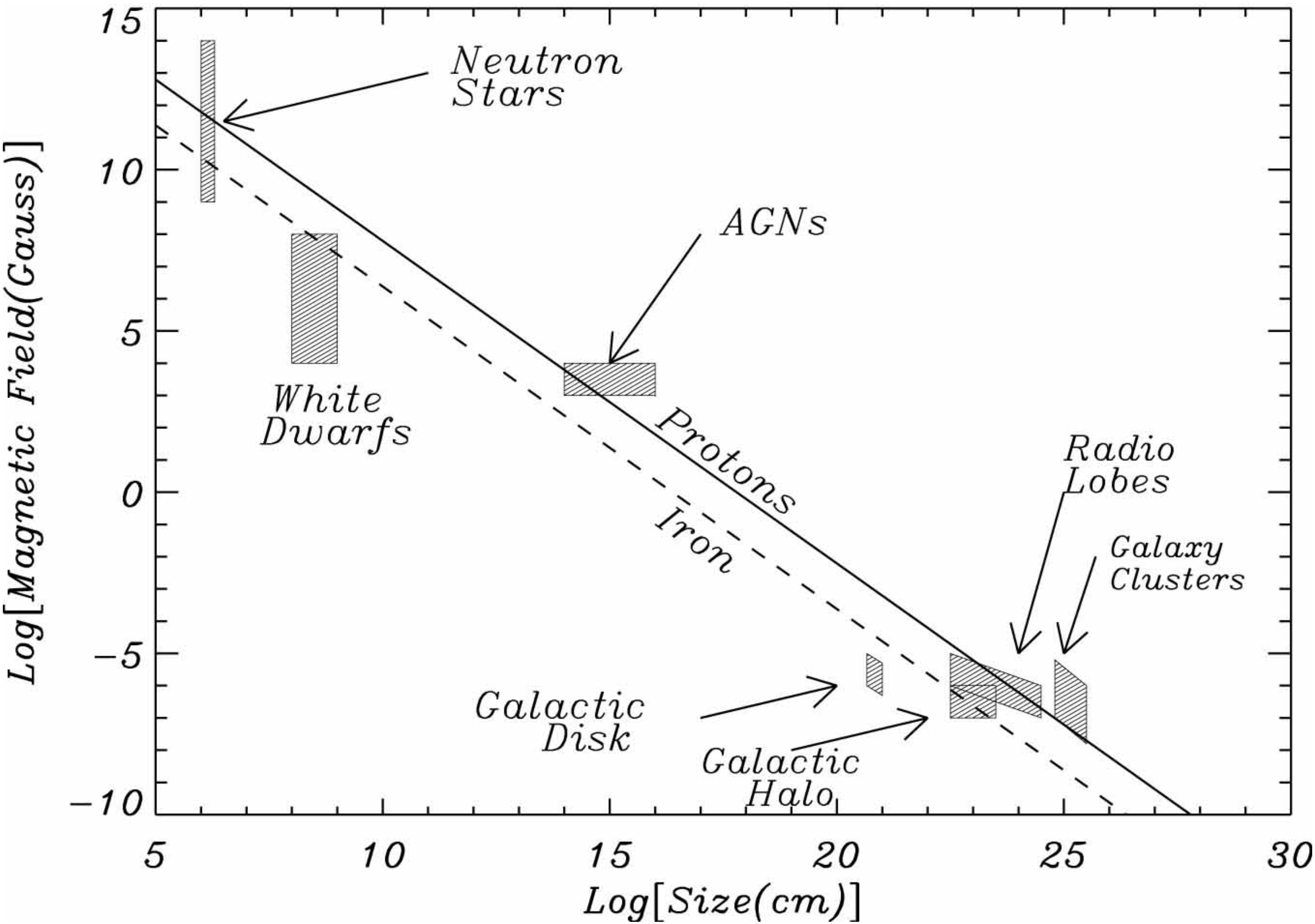
(*a*)


10¹²
10⁹
10⁶
10³
10⁰
Arriving cosmic rays
Local galactic abundances
H He Be C O Ne Mg Si S Ar Ca Ti Cr Fe Ni Zn Ge

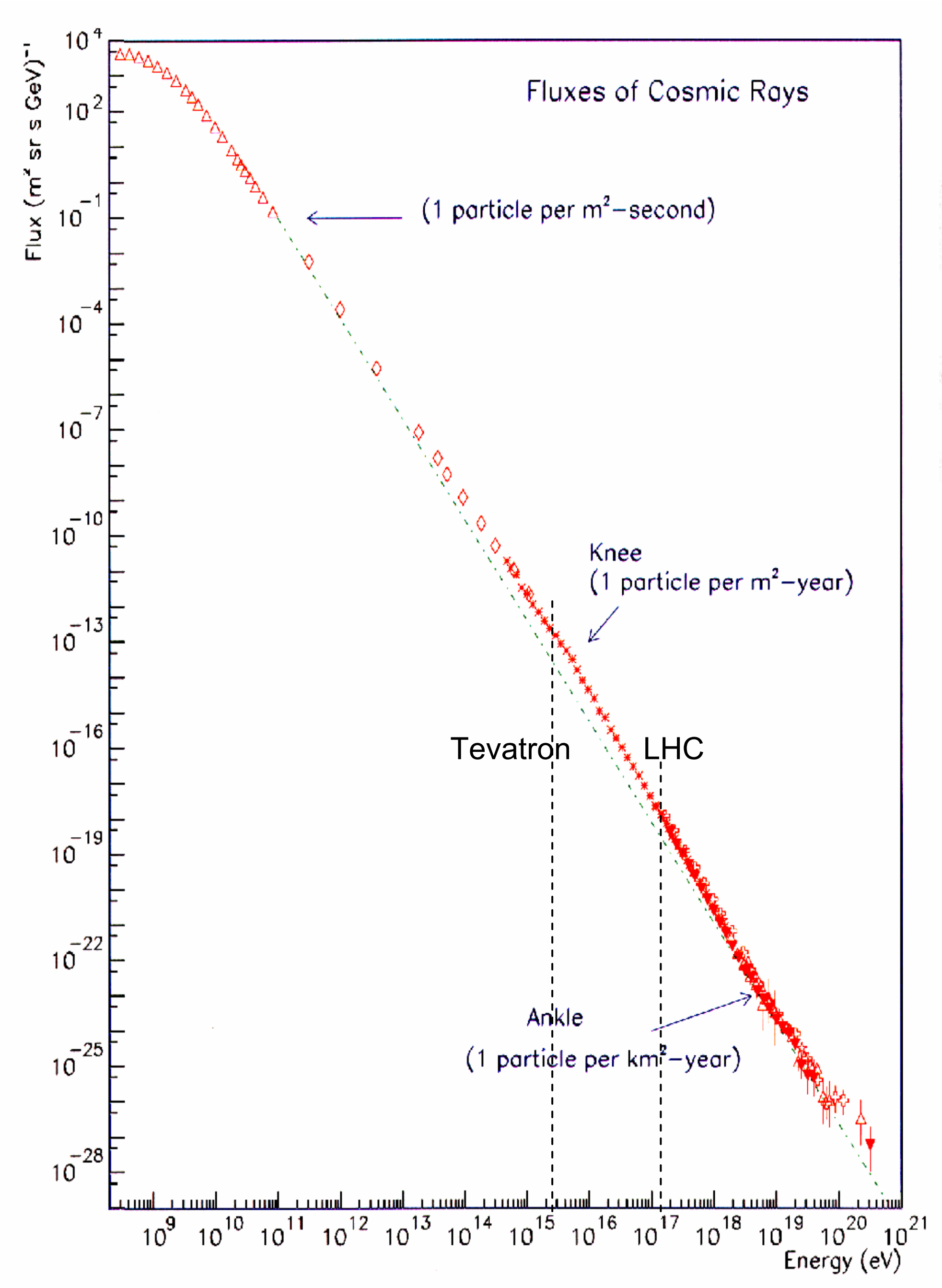
(*b*)



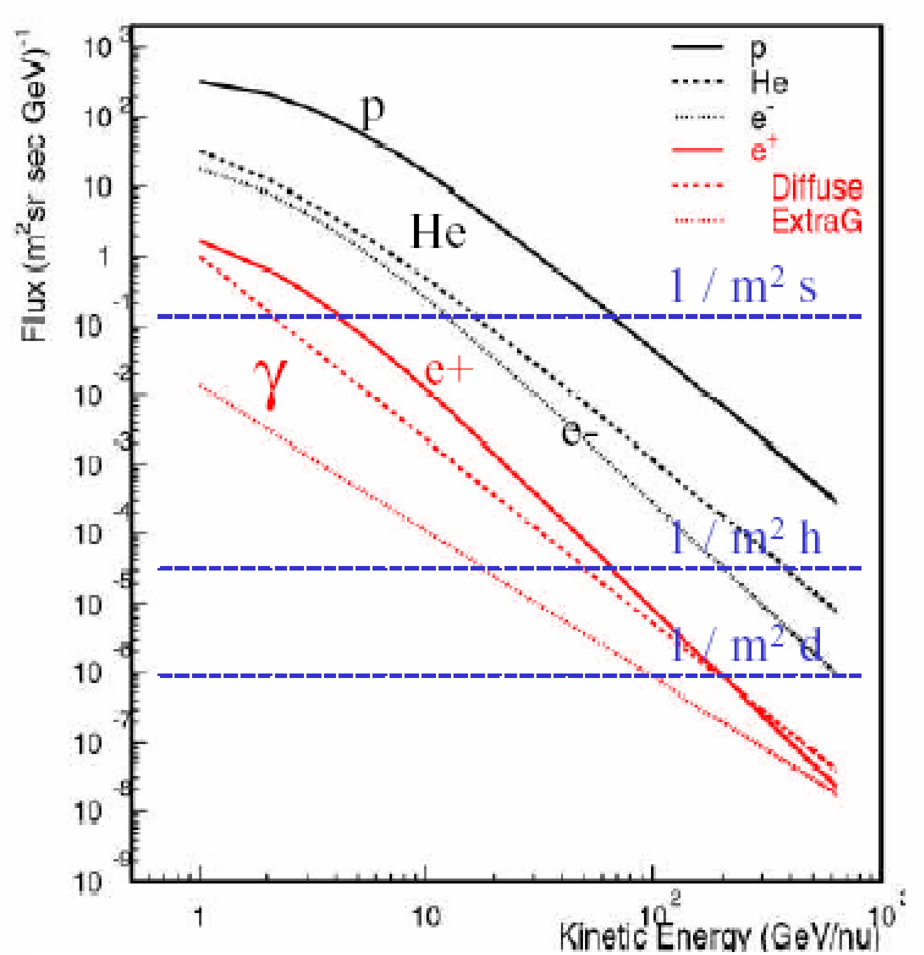
electrons + positrons
500
300
200
100
70
50
10
100
1000
$E^3 dN/dE$ [m^{-2} s^{-1} sr^{-1} GeV^2]
E [GeV]



Neutron Stars
White Dwarfs
AGNs
Protons
Iron
Radio Lobes
Galaxy Clusters
Galactic Disk
Galactic Halo
Log[Magnetic Field(Gauss)]
Log[Size(cm)]
15
10
5
0
−5
−10
5
10
15
20
25
30



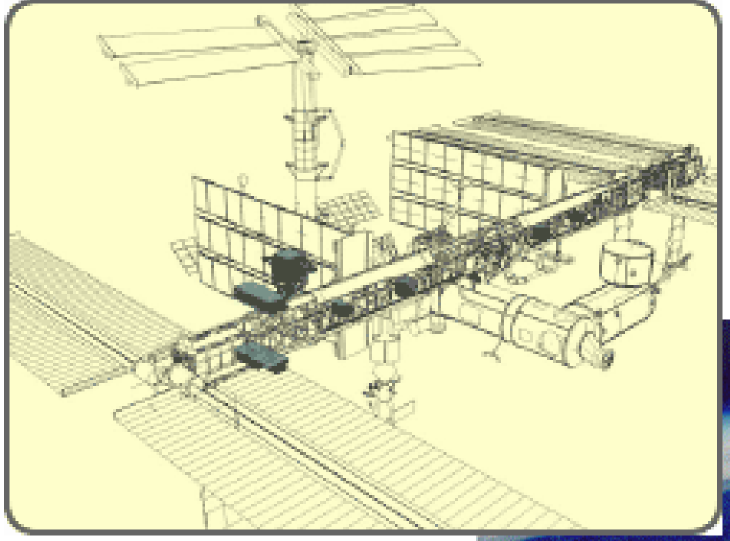
Fluxes of Cosmic Rays
(1 particle per m²−second)
Knee
(1 particle per m²−year)
Tevatron
LHC
Ankle
(1 particle per km²−year)
Flux (m² sr s GeV)⁻¹
Energy (eV)

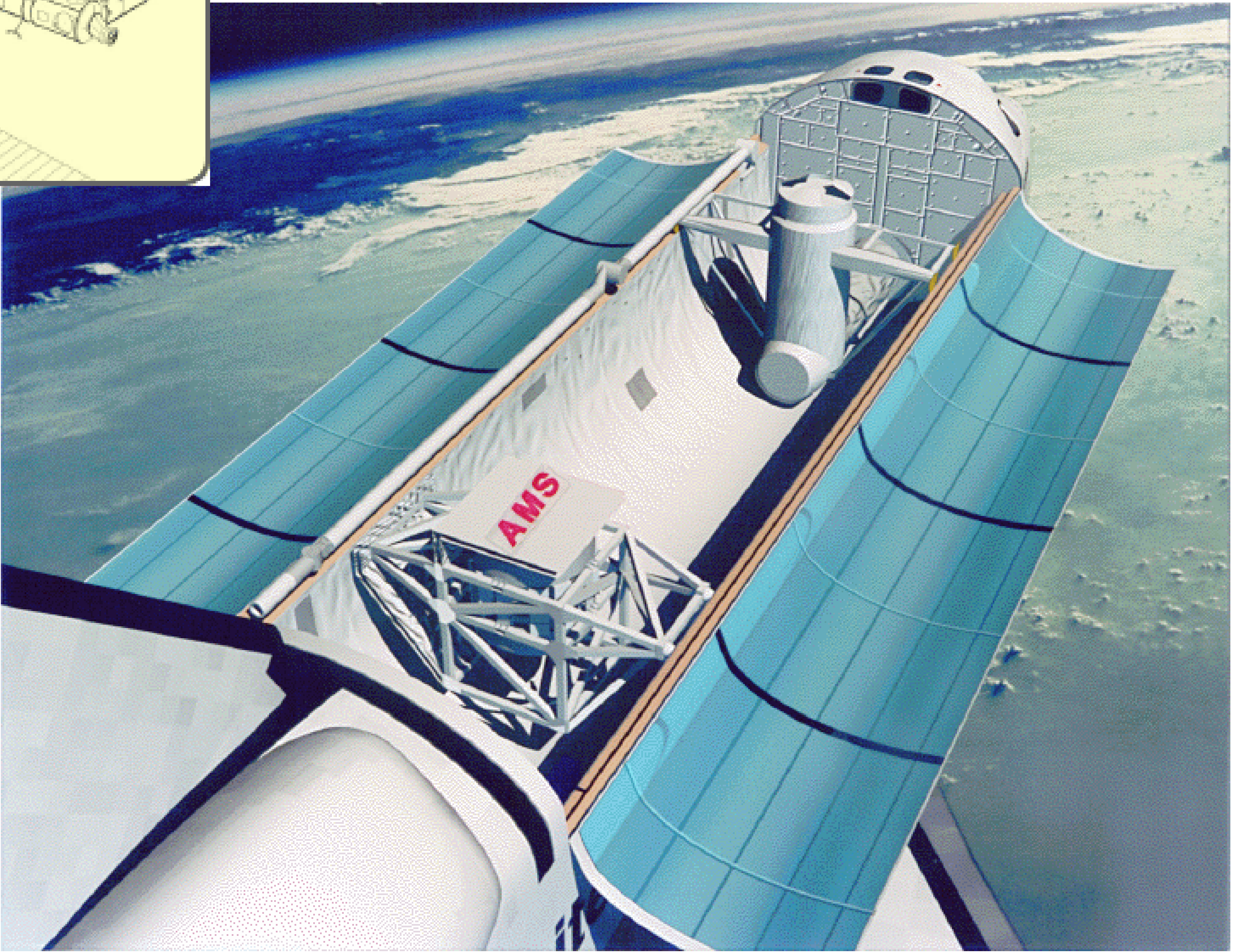


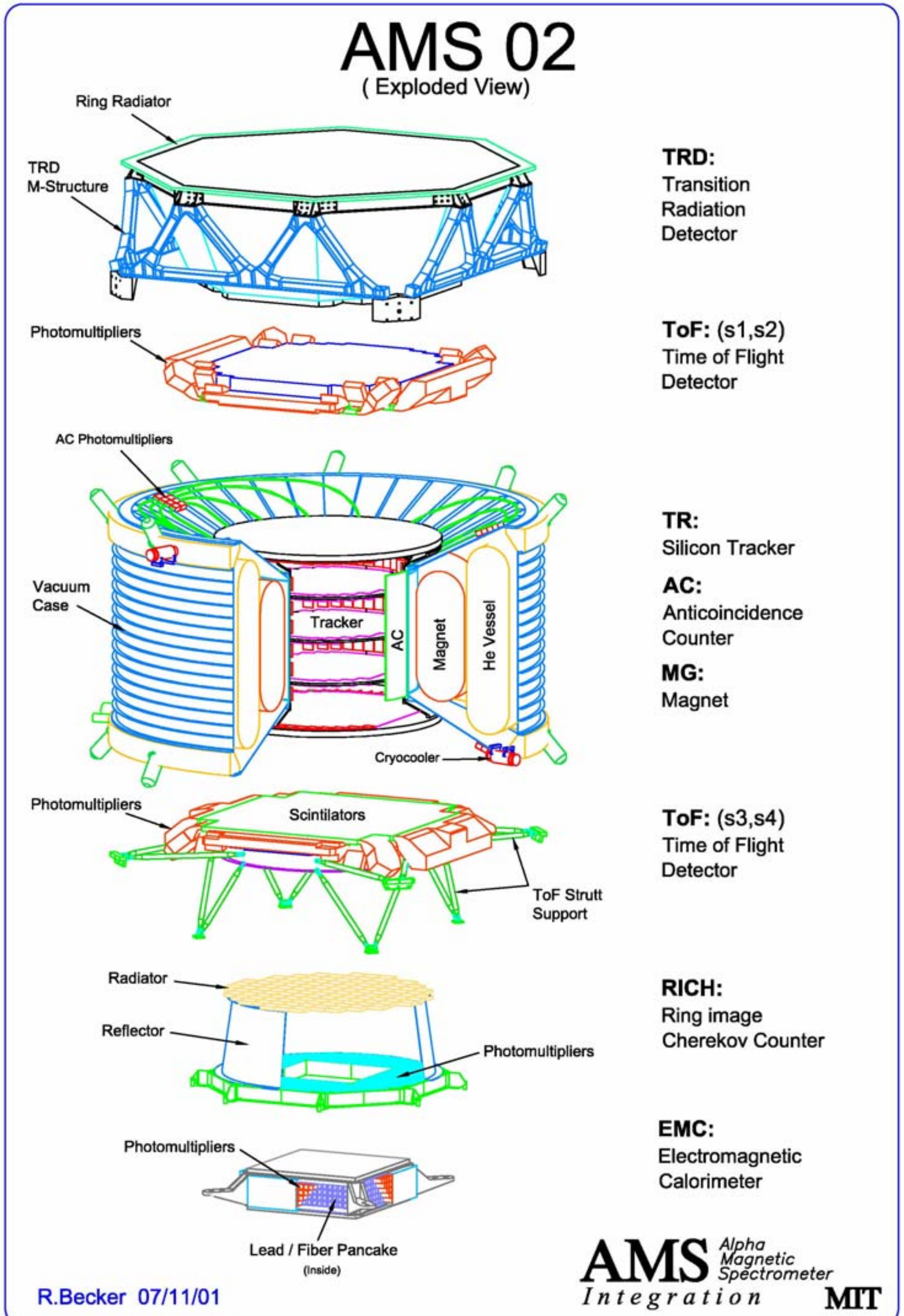
p
He
e⁻
e⁺
Diffuse
ExtraG
1 / m² s
1 / m² h
1 / m² d
γ
e+
e-
Flux (m²sr sec GeV)⁻¹
Kinetic Energy (GeV/nu)

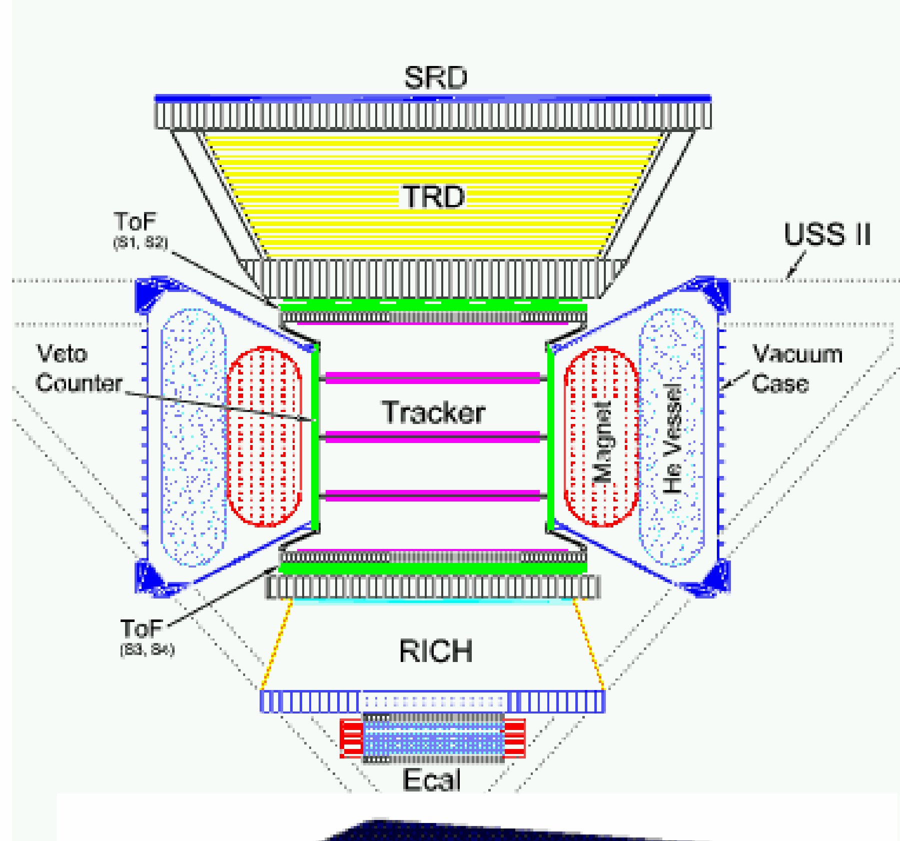
AMS

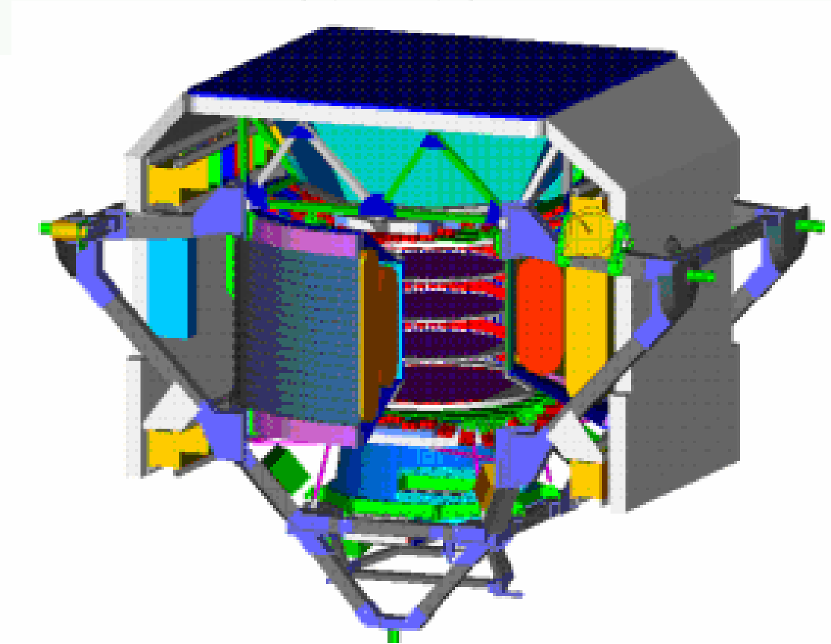
Alpha Magnetic Spectrometer



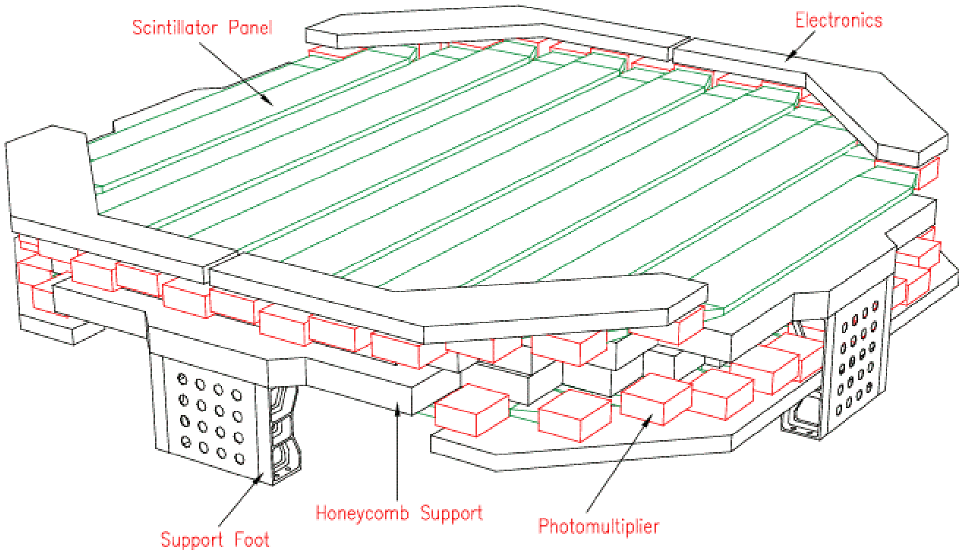


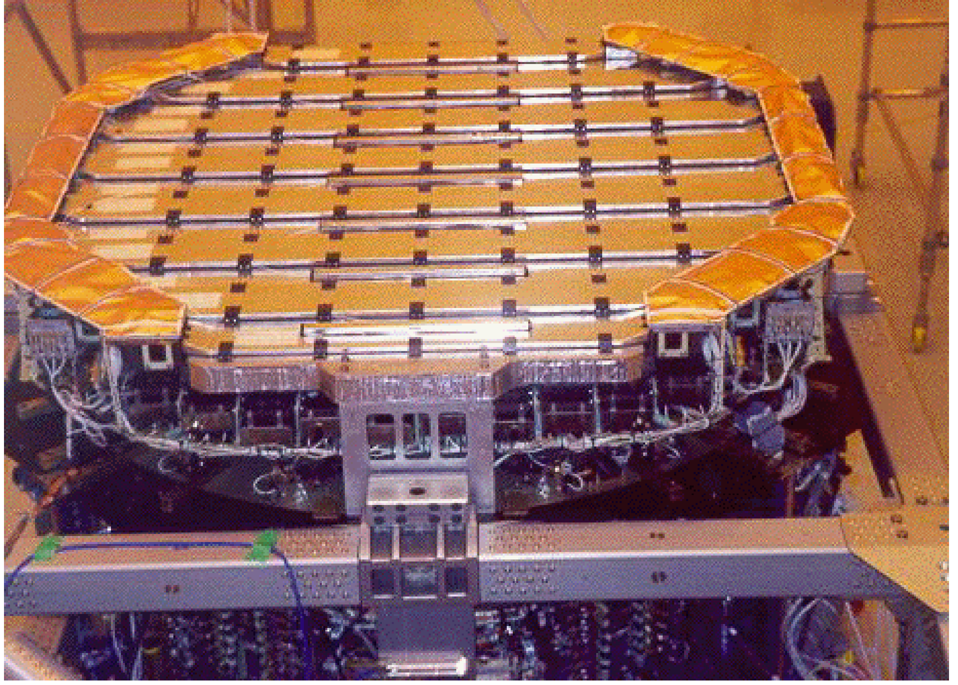

AMS 02
(Exploded View)
Ring Radiator
TRD
M-Structure
TRD:
Transition
Radiation
Detector
Photomultipliers
ToF: (s1,s2)
Time of Flight
Detector
AC Photomultipliers
Vacuum
Case
Tracker
AC
Magnet
He Vessel
Cryocooler
TR:
Silicon Tracker
AC:
Anticoincidence
Counter
MG:
Magnet
Photomultipliers
Scintilators
ToF Strutt
Support
ToF: (s3,s4)
Time of Flight
Detector
Radiator
Reflector
Photomultipliers
RICH:
Ring image
Cherekov Counter
Photomultipliers
Lead / Fiber Pancake
(inside)
EMC:
Electromagnetic
Calorimeter
AMS Alpha Magnetic Spectrometer
Integration
MIT
R.Becker 07/11/01


SRD
TRD
ToF
(S1, S2)
USS II
Veto
Counter
Tracker
Magnet
He Vessel
Vacuum
Case
ToF
(S3, S4)
RICH
Ecal

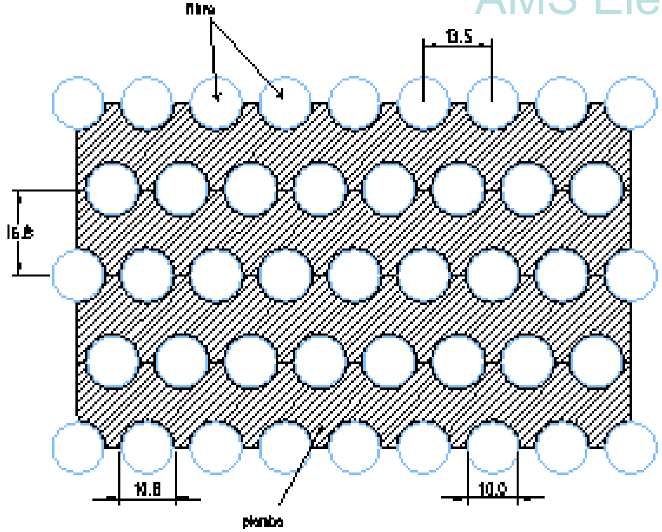


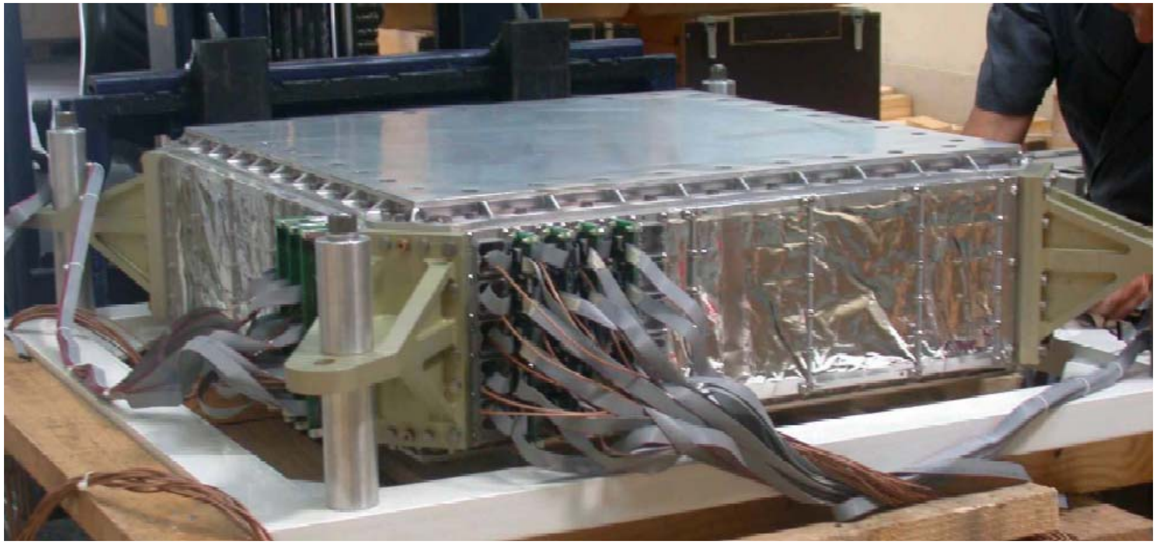
AMS Time-Of-Flight System
INFN Bologna and University of Bologna, Italy

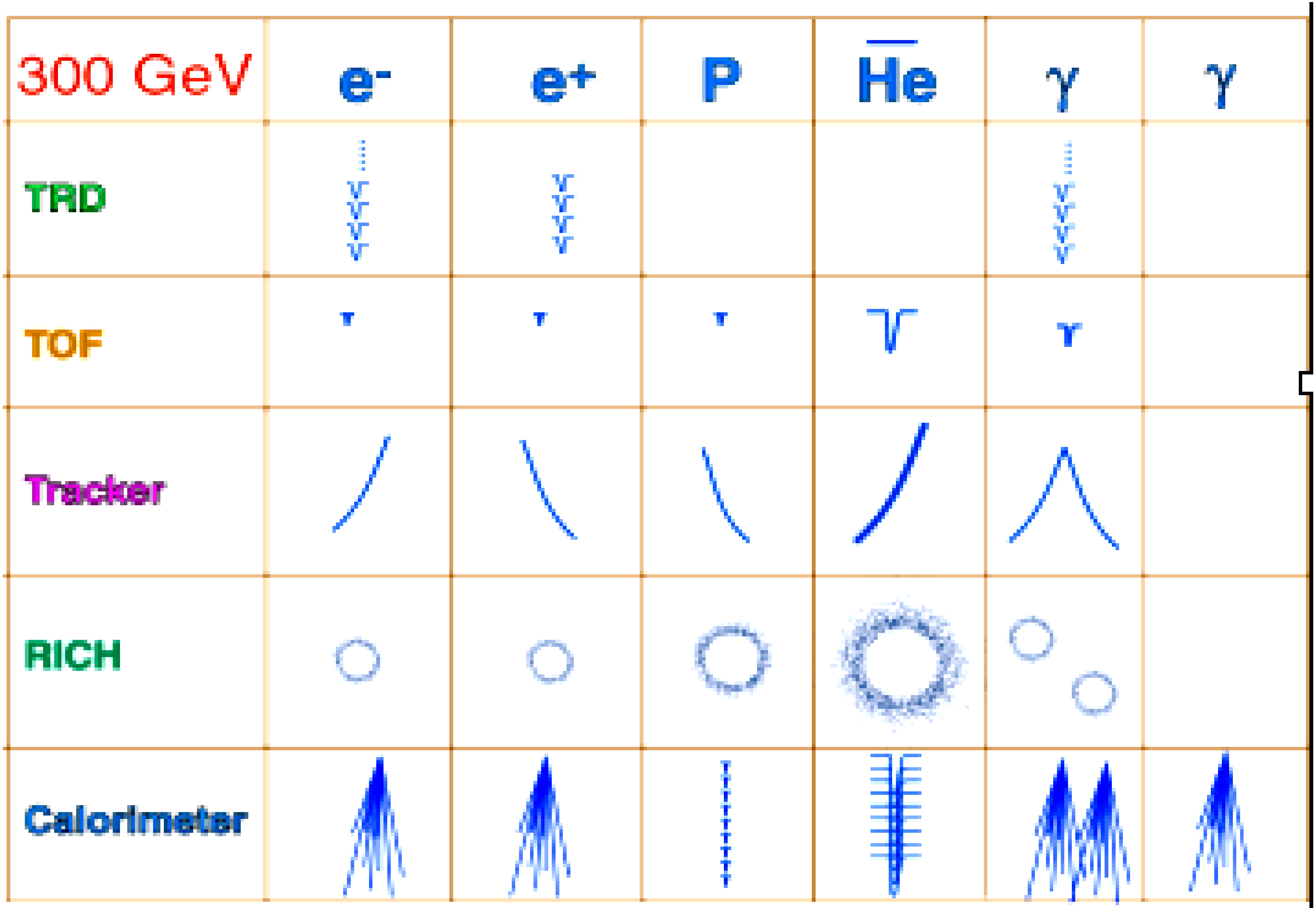


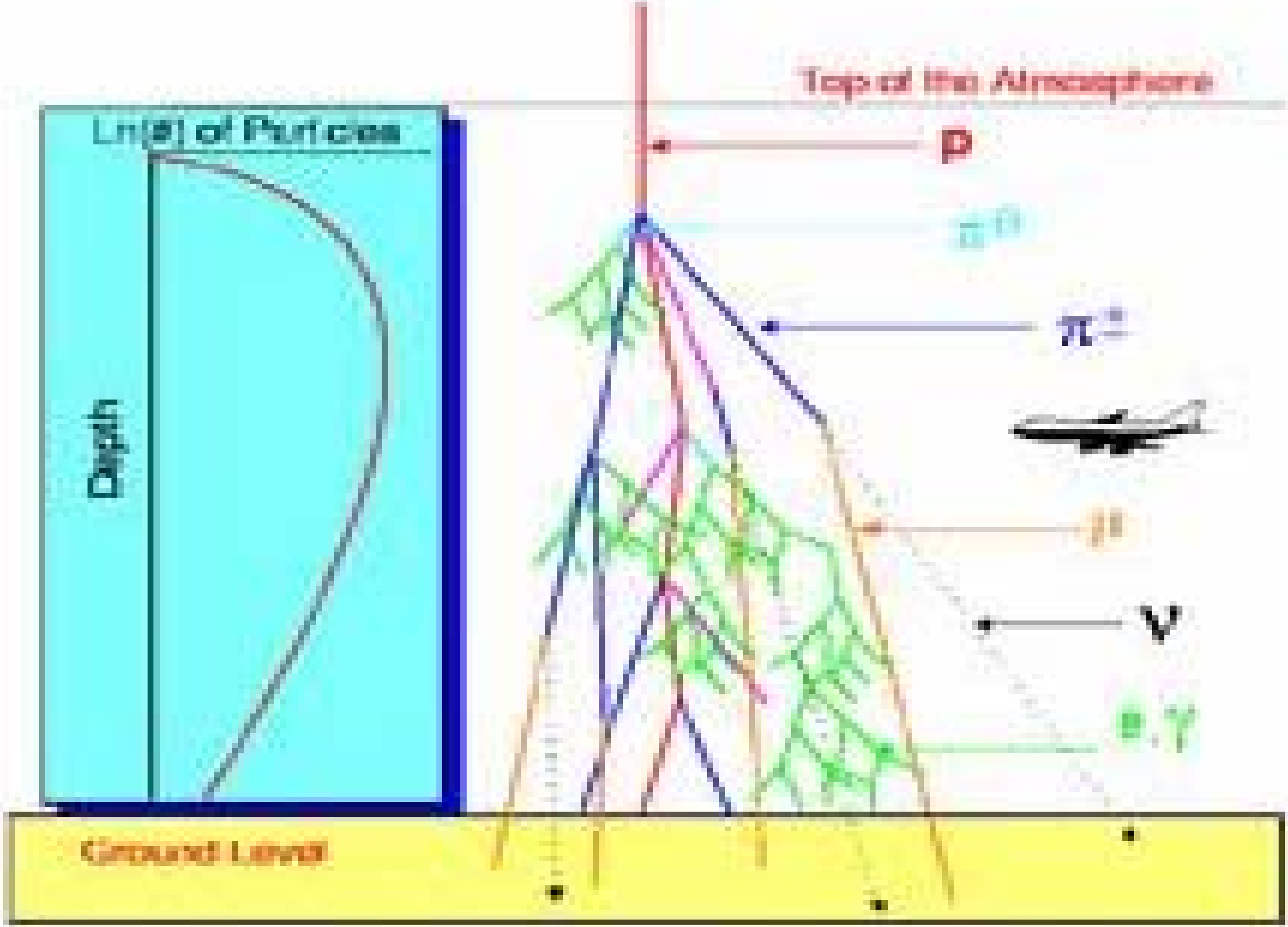


AMS Electromagnetic Calorimeter

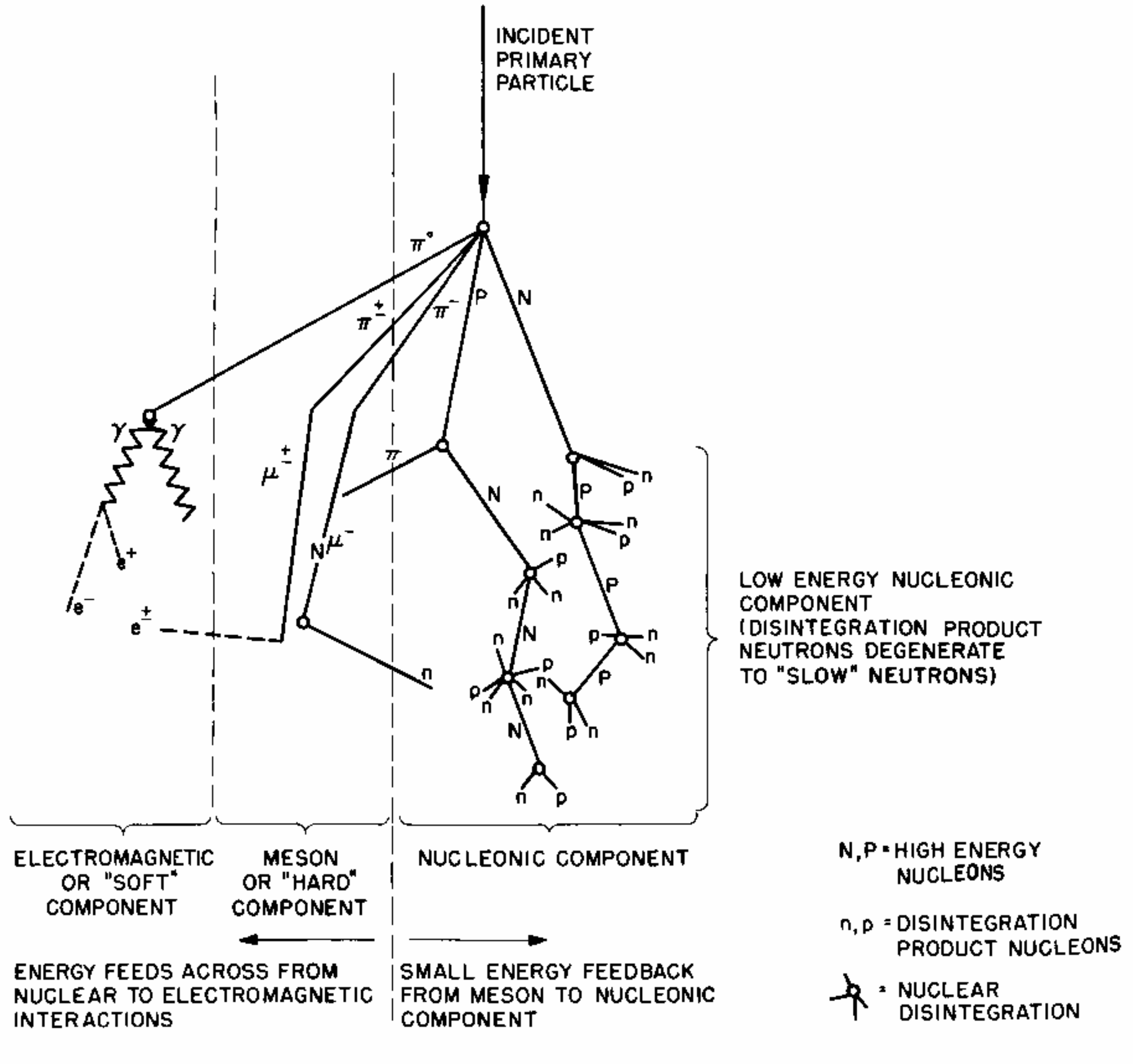




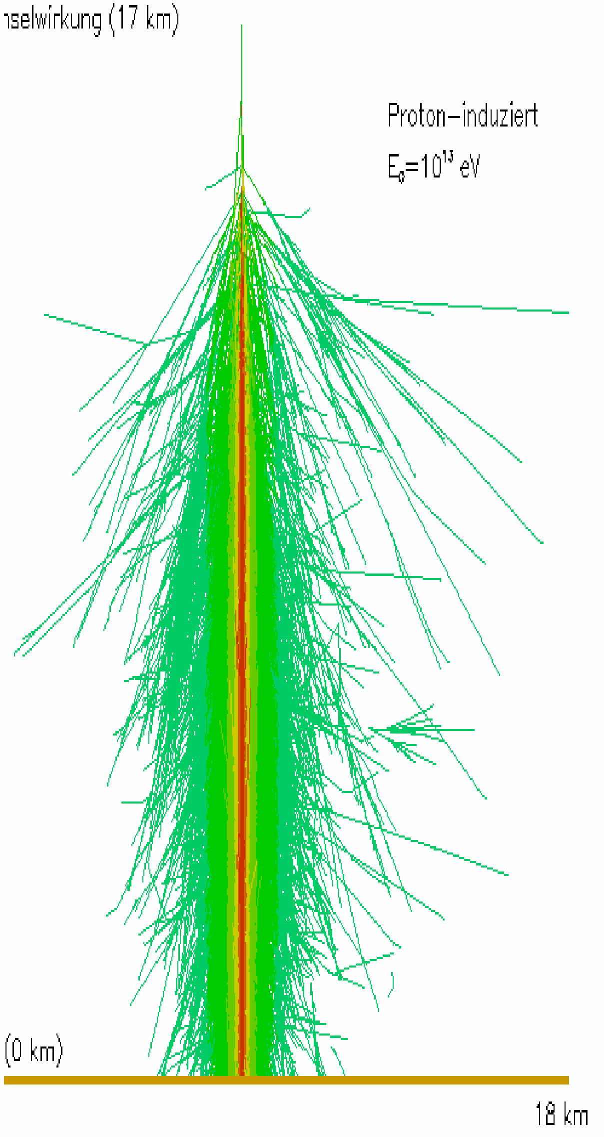

300 GeV
e-
e+
P
He
γ
γ
TRD
TOF
Tracker
RICH
Calorimeter

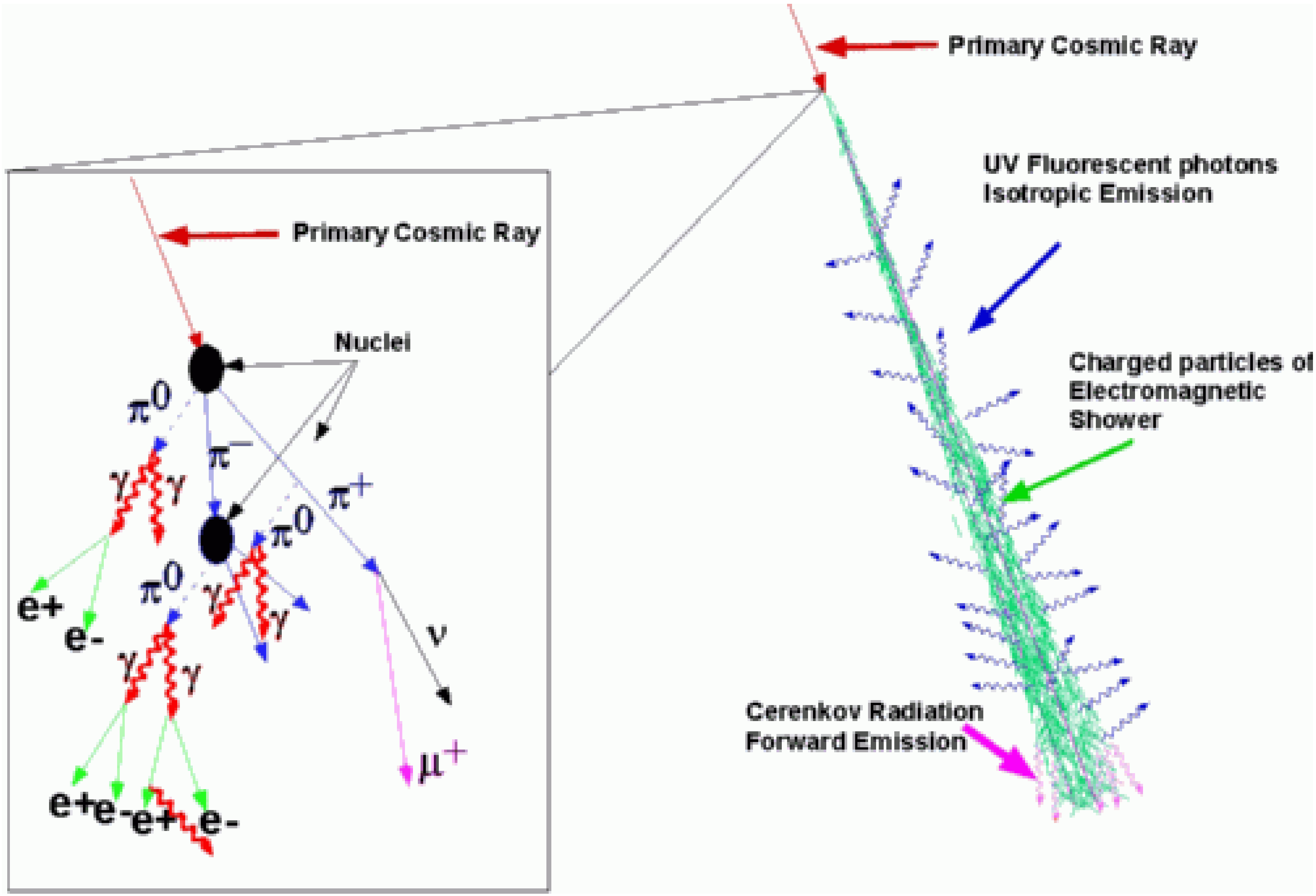


Extensive Air Showers

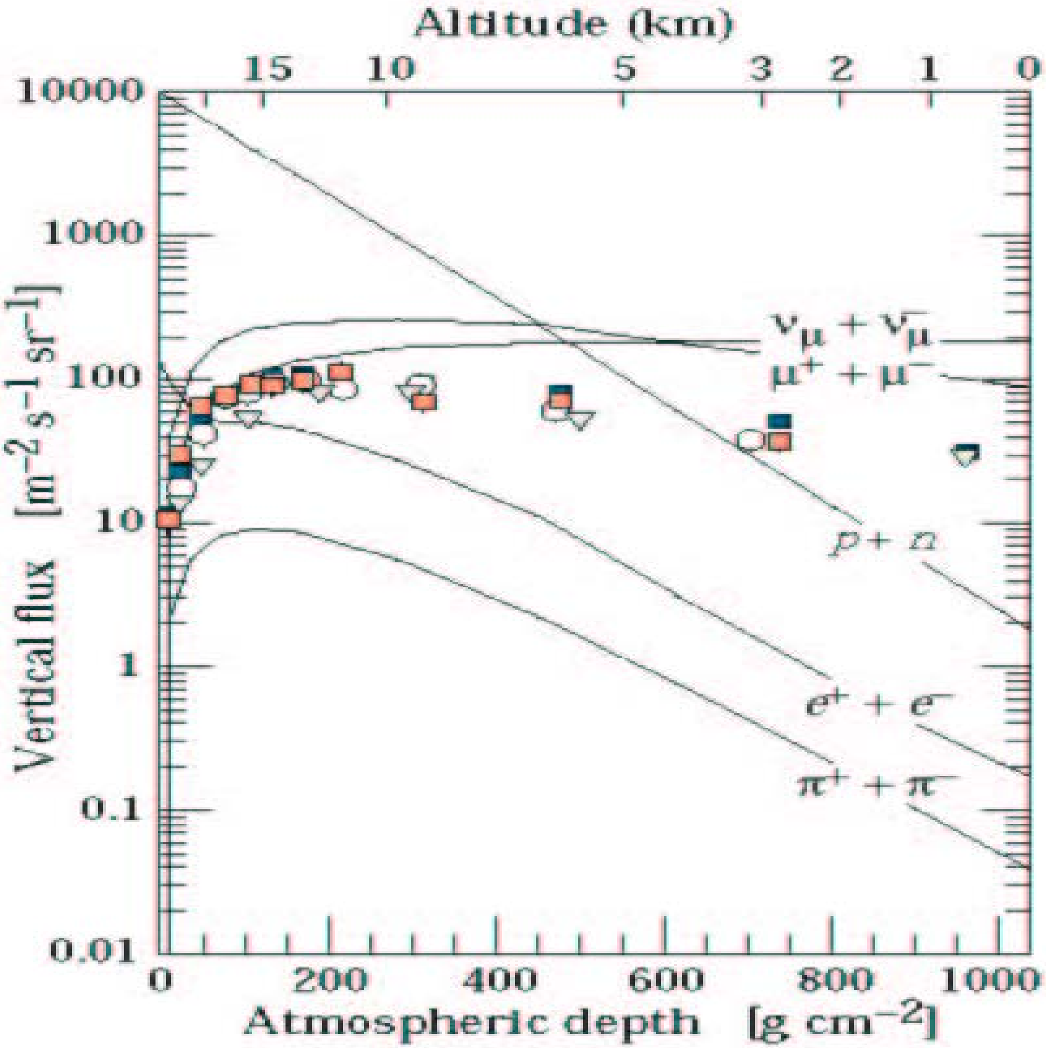


Schematic Diagram of Cosmic Ray Shower



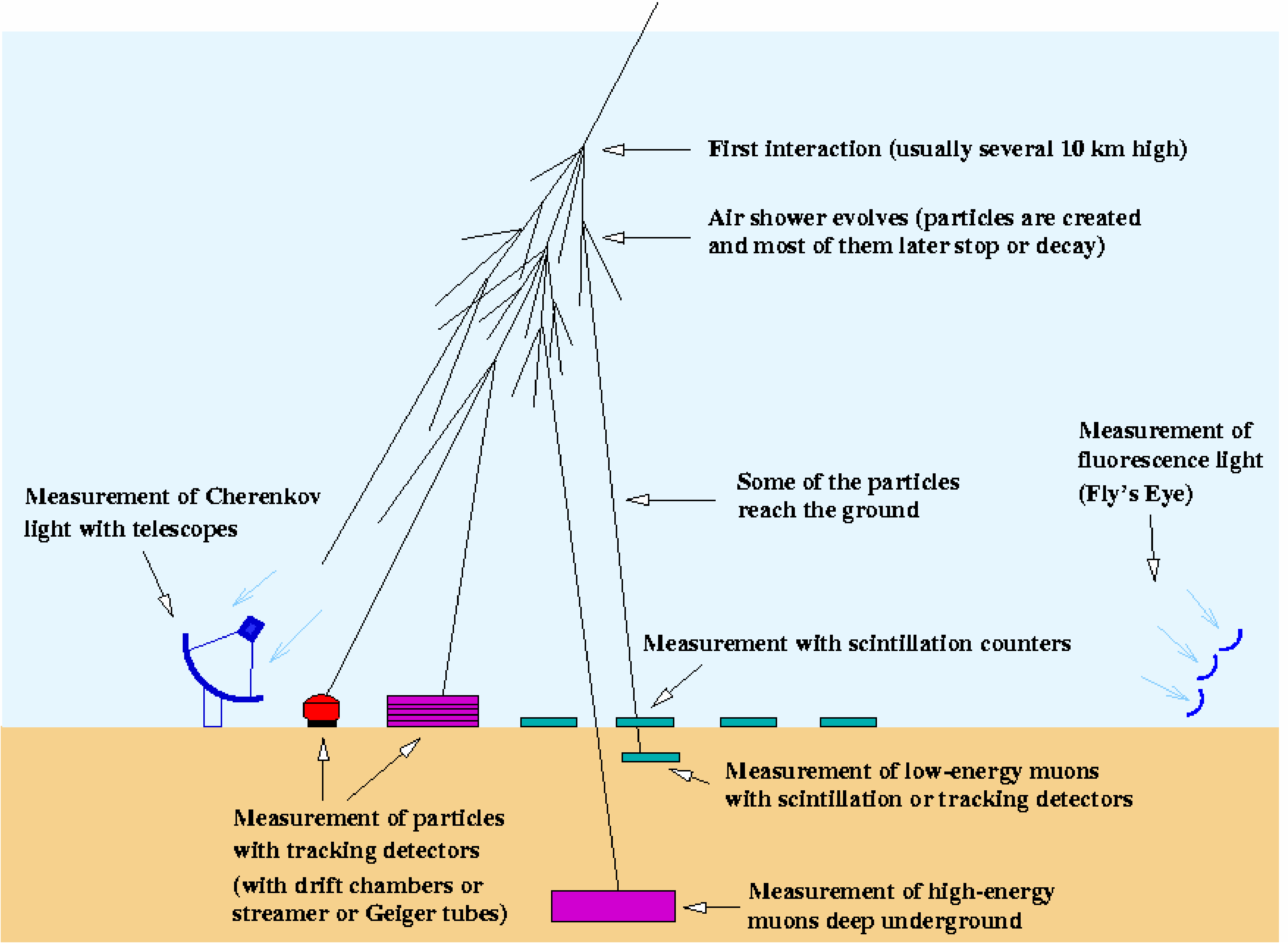


Primary Cosmic Ray
UV Fluorescent photons
Isotropic Emission
Charged particles of
Electromagnetic
Shower
Cerenkov Radiation
Forward Emission
Primary Cosmic Ray
Nuclei
π0
π−
π+
γ
γ
π0
π0
γ
γ
γ
γ
e+
e-
ν
μ+
e+e-e+e-

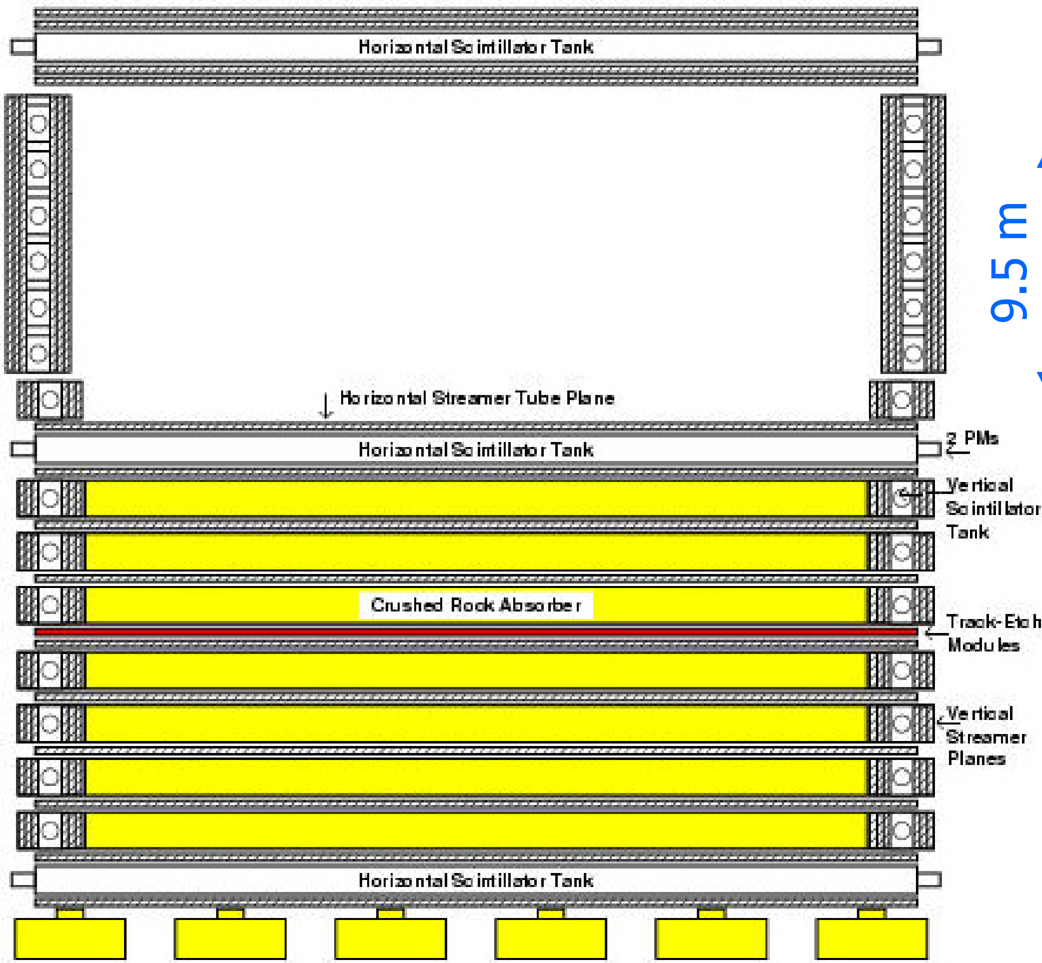


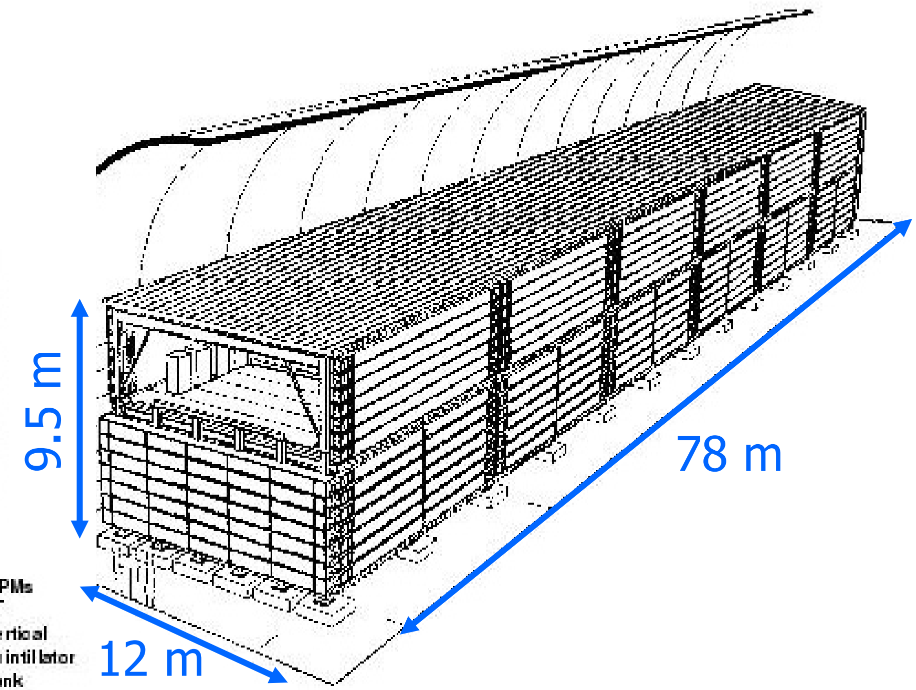
Altitude (km)
15
10
5
3
2
1
0
10000
1000
100
10
1
0.1
0.01
Vertical flux [m^{-2} s^{-1} sr^{-1}]
$\nu_\mu + \bar{\nu}_\mu$
$\mu^+ + \mu^-$
$p + n$
$e^+ + e^-$
$\pi^+ + \pi^-$
0
200
400
600
800
1000
Atmospheric depth [g cm^{-2}]

Measuring cosmic-ray and gamma-ray air showers



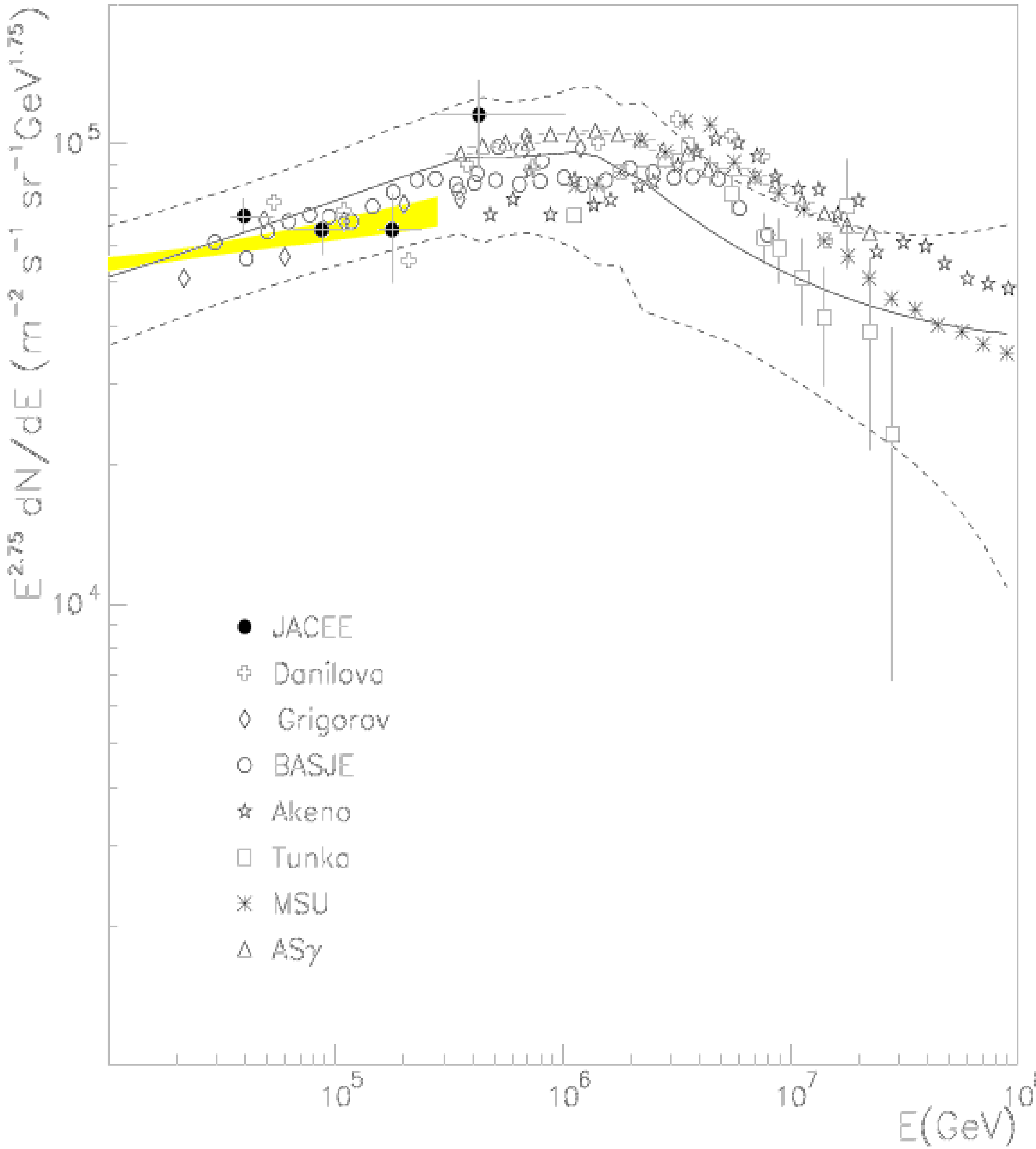
The MACRO detector



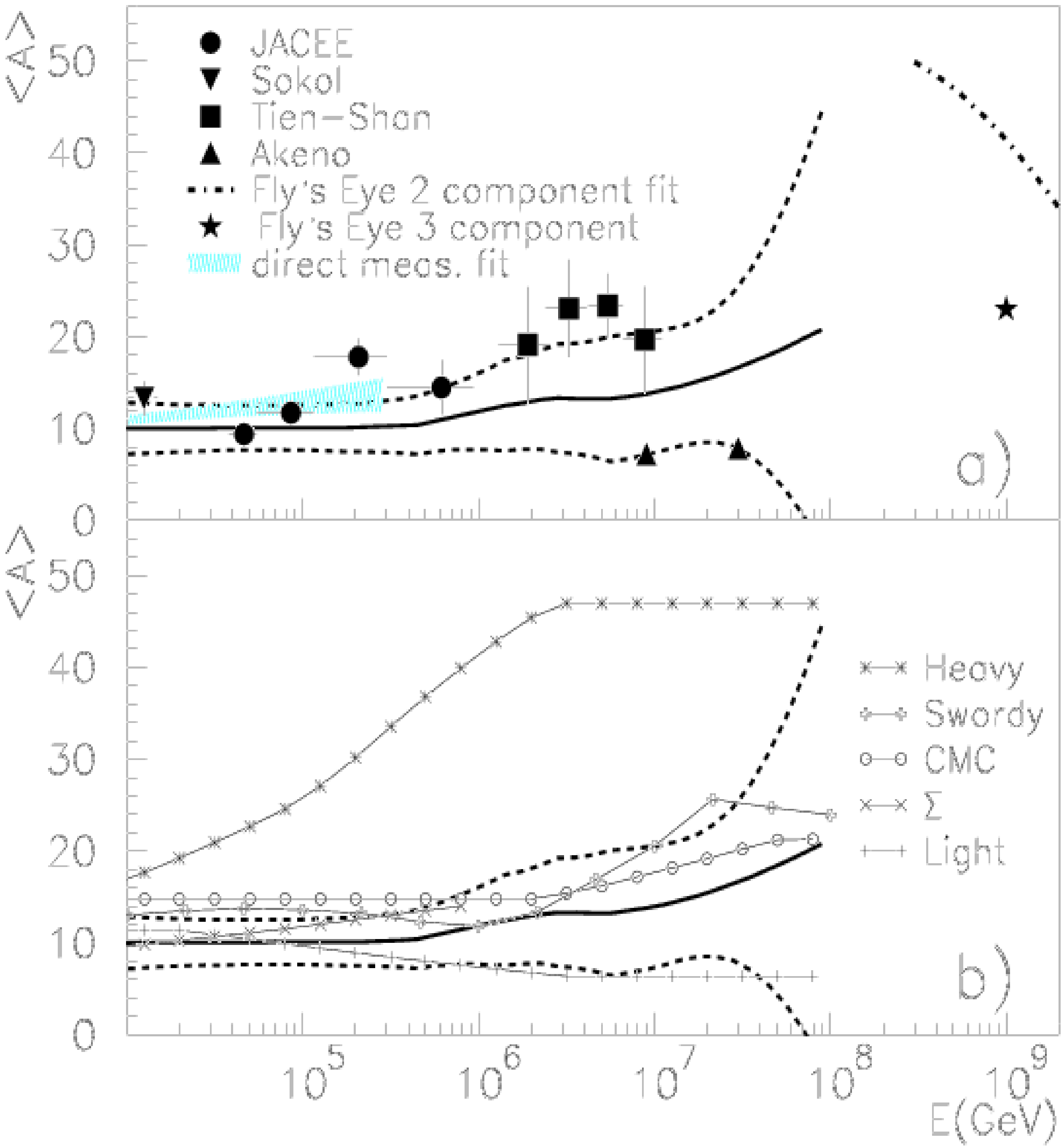


A ~ 10000 m²sr <h> ~3800 mwe

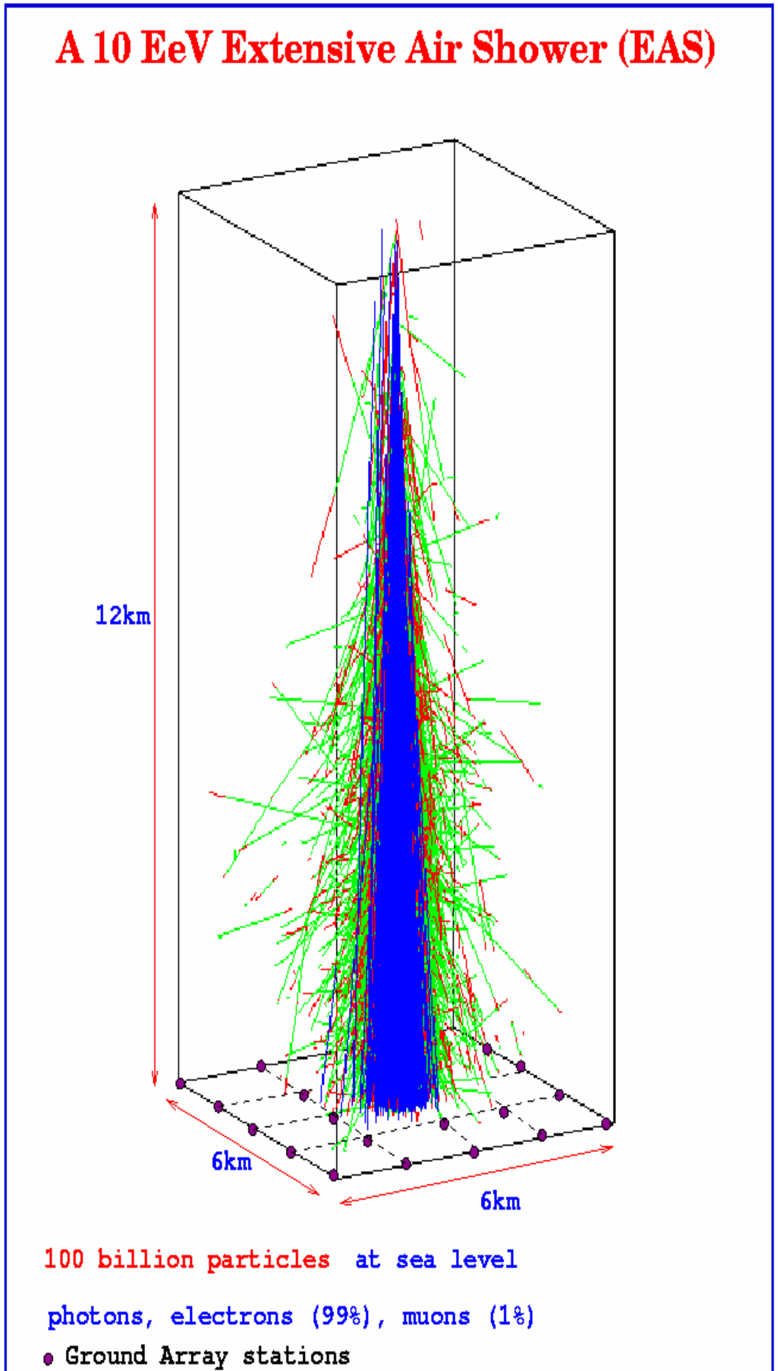
- Liquid scintillators
- Streamer tubes
- Nuclear track-etch

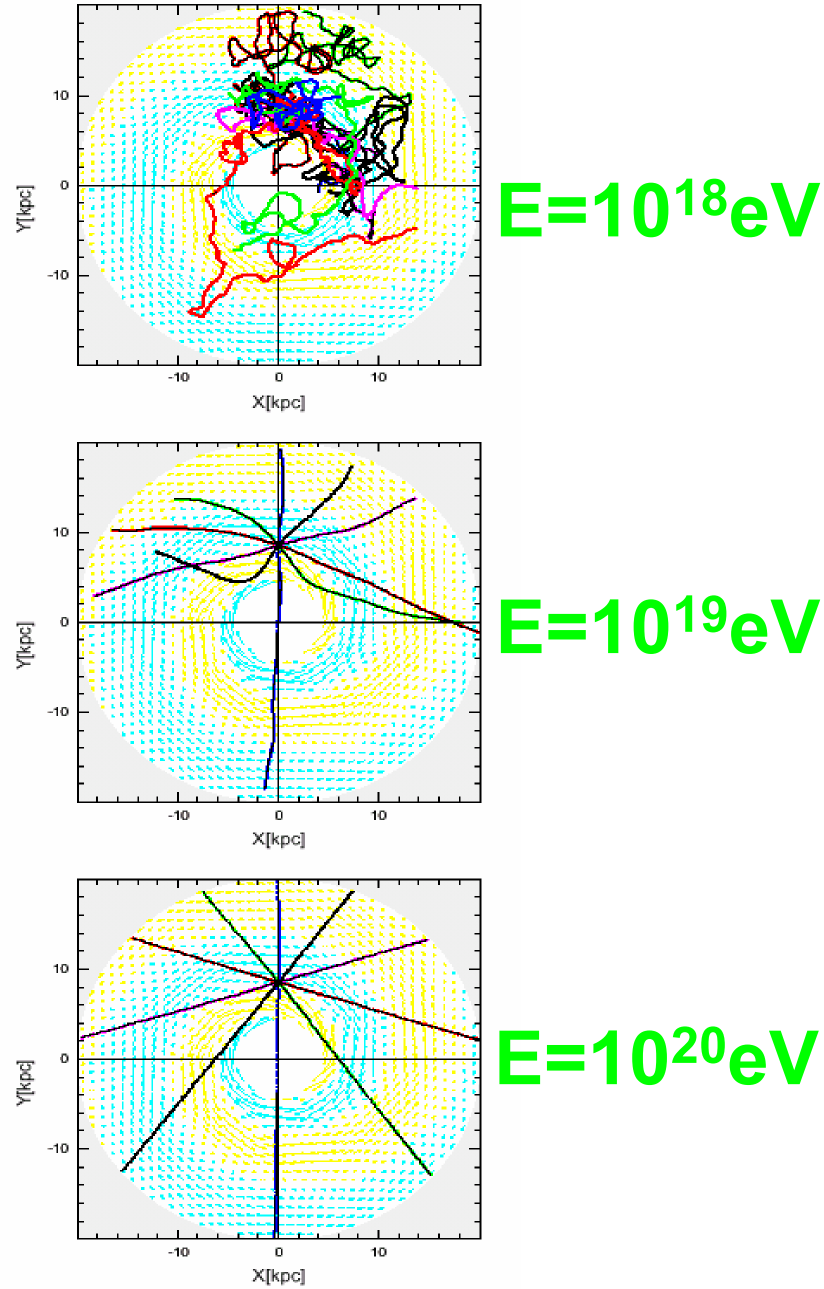


$E^{2.75}$ dN/dE (m^{-2} s^{-1} sr^{-1} $GeV^{1.75}$)
10^5
10^4
JACEE
Danilova
Grigorov
BASJE
Akeno
Tunka
MSU
ASγ
10^5
10^6
10^7
10^8
E(GeV)

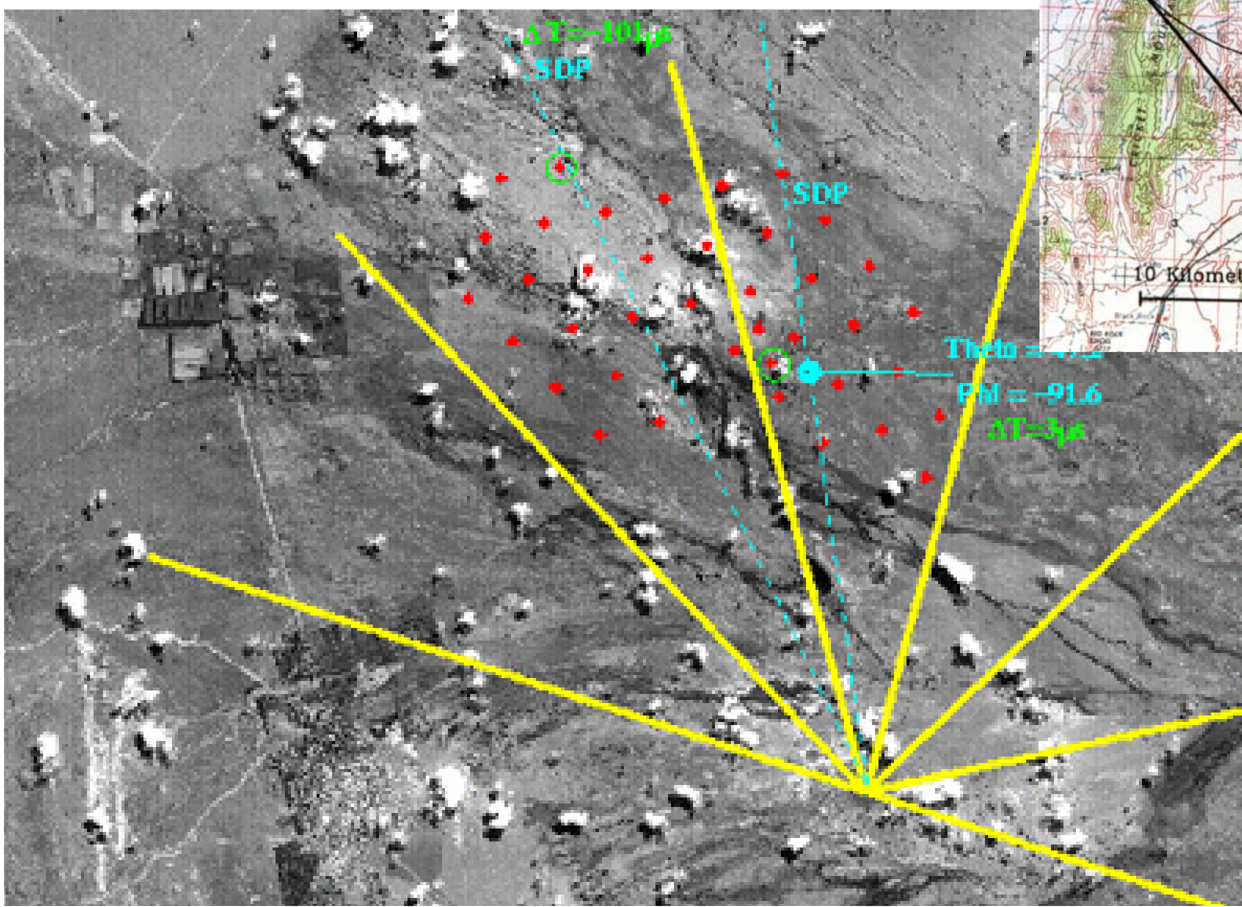


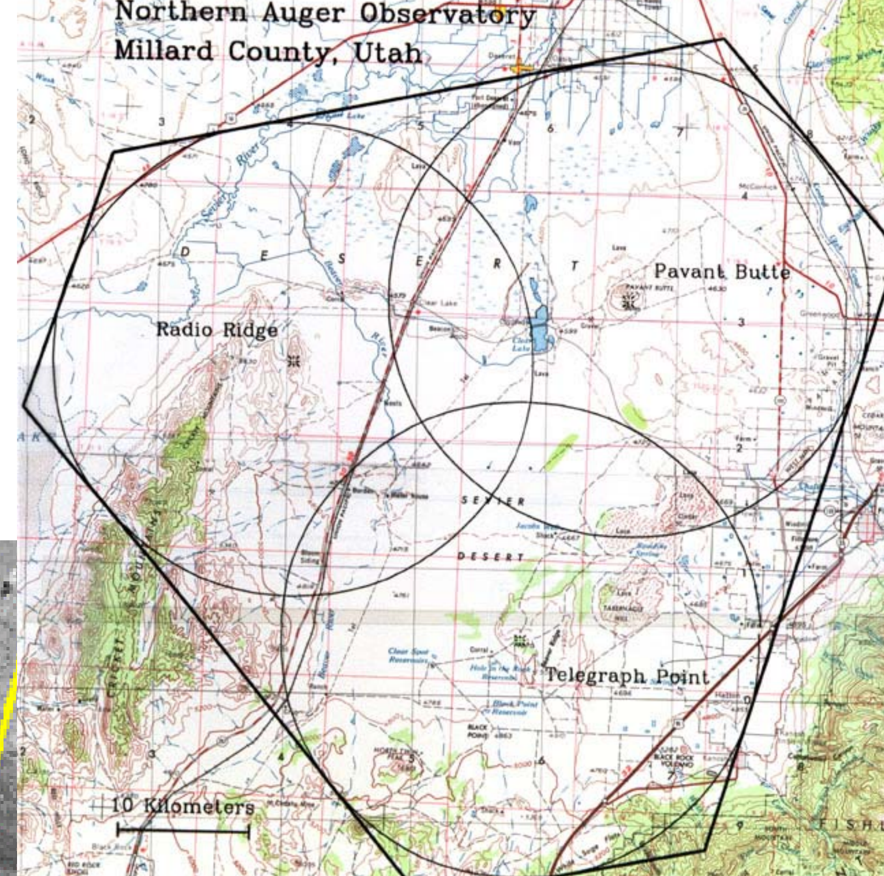
<A>
JACEE
Sokol
Tien-Shan
Akeno
Fly's Eye 2 component fit
Fly's Eye 3 component
direct meas. fit
a)
Heavy
Swordy
CMC
Σ
Light
b)
E(GeV)

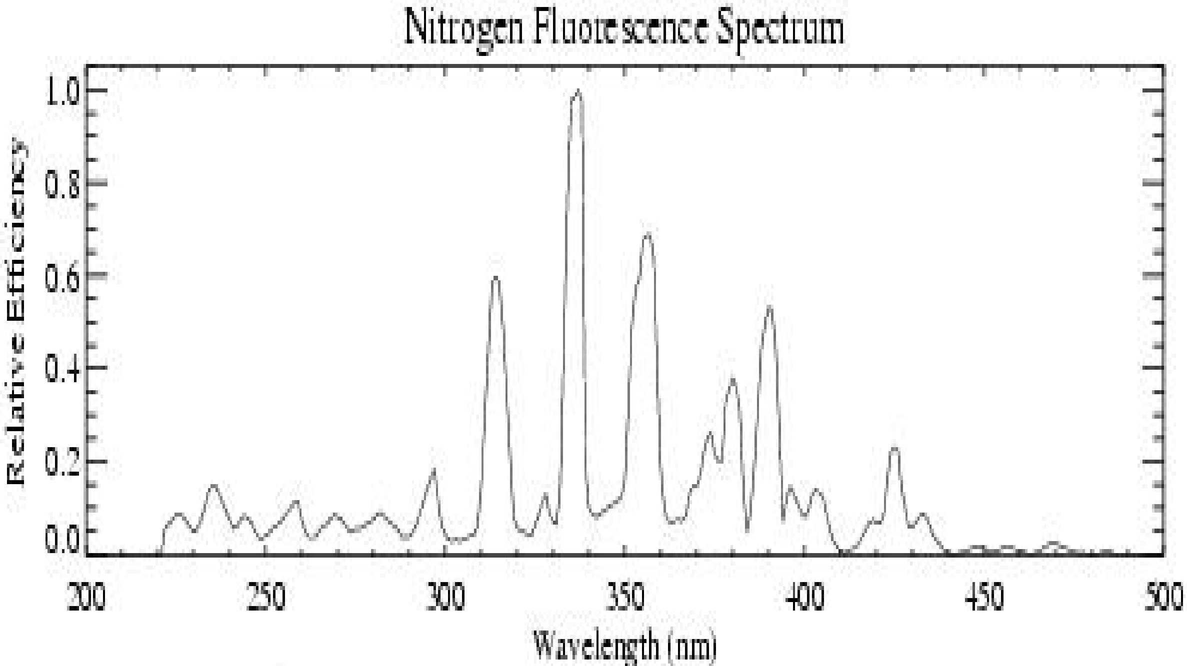

A 10 EeV Extensive Air Shower (EAS)
12km
6km
6km
100 billion particles at sea level
photons, electrons (99%), muons (1%)
Ground Array stations

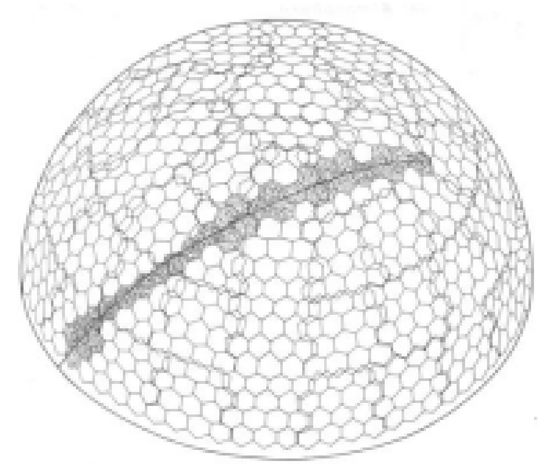

Y[kpc]
X[kpc]
E=10^18eV
E=10^19eV
E=10^20eV

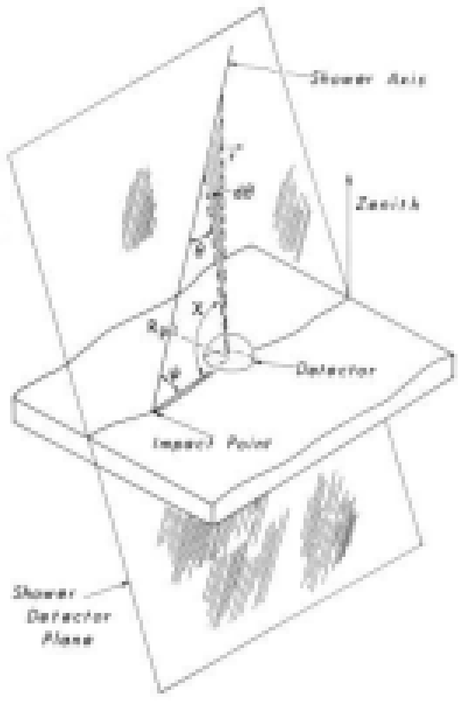
AUGER

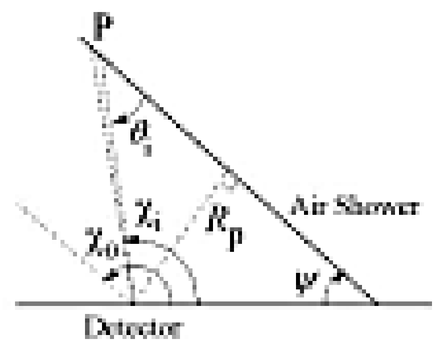

SDP
SDP
Phi = -91.6


Northern Auger Observatory
Millard County, Utah
Pavant Butte
Radio Ridge
Telegraph Point
10 Kilometers

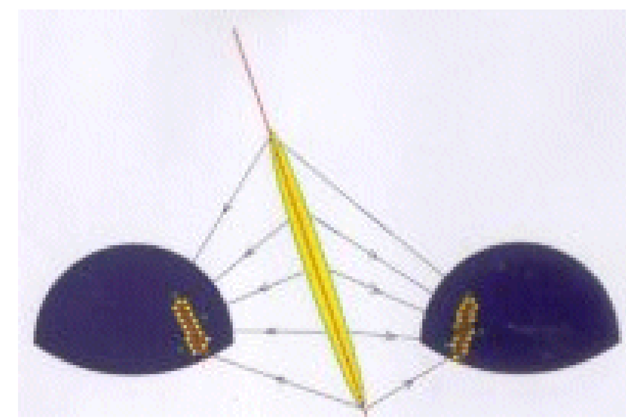


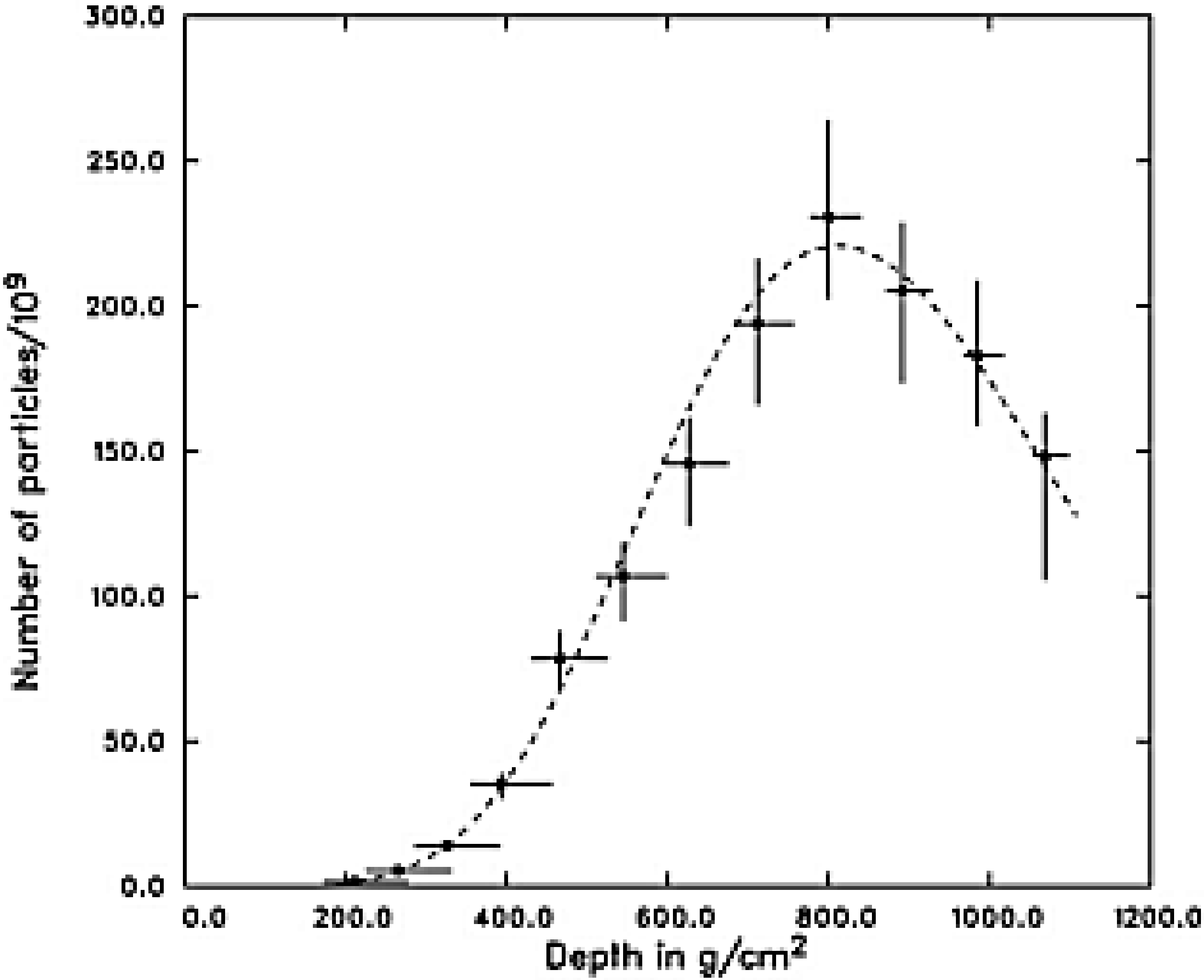






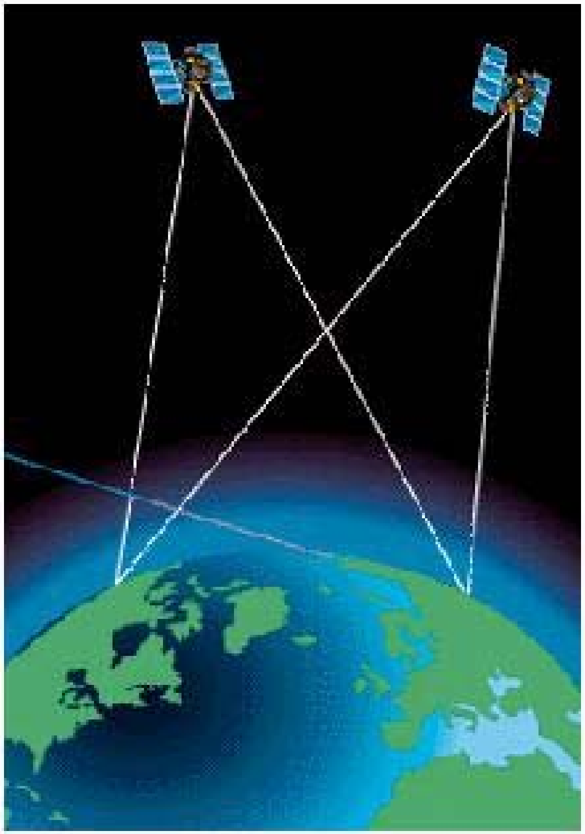
Fit: $t_i = t_0 + (R_p/c)\, tan(\chi_0/2 - \chi_i/2)$





300.0
250.0
200.0
150.0
100.0
50.0
0.0
Number of particles/10^9
0.0
200.0
400.0
600.0
800.0
1000.0
1200.0
Depth in g/cm^2

The OWL Concept



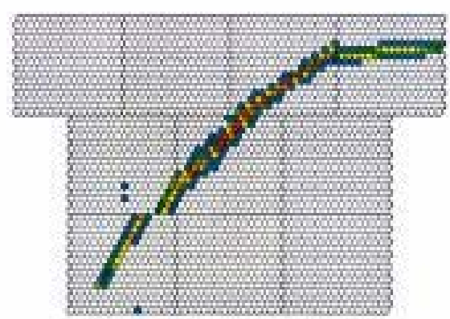
Use air fluorescence technique to image 300 → 400 nm photons in ~ 0.1° pixels (with 10 ns → μs timing), from low Earth, equitorial orbit, airshowers induced by E ≳ 10^{19} eV cosmic rays

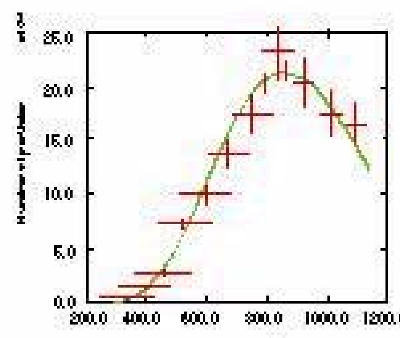
Wide angle (~ 60° full, FOV) optics at a 640 km orbit in a stereo configuration → an asymptotic, *instantaneous* aperture ~ 3 x 10^6 km^2-ster

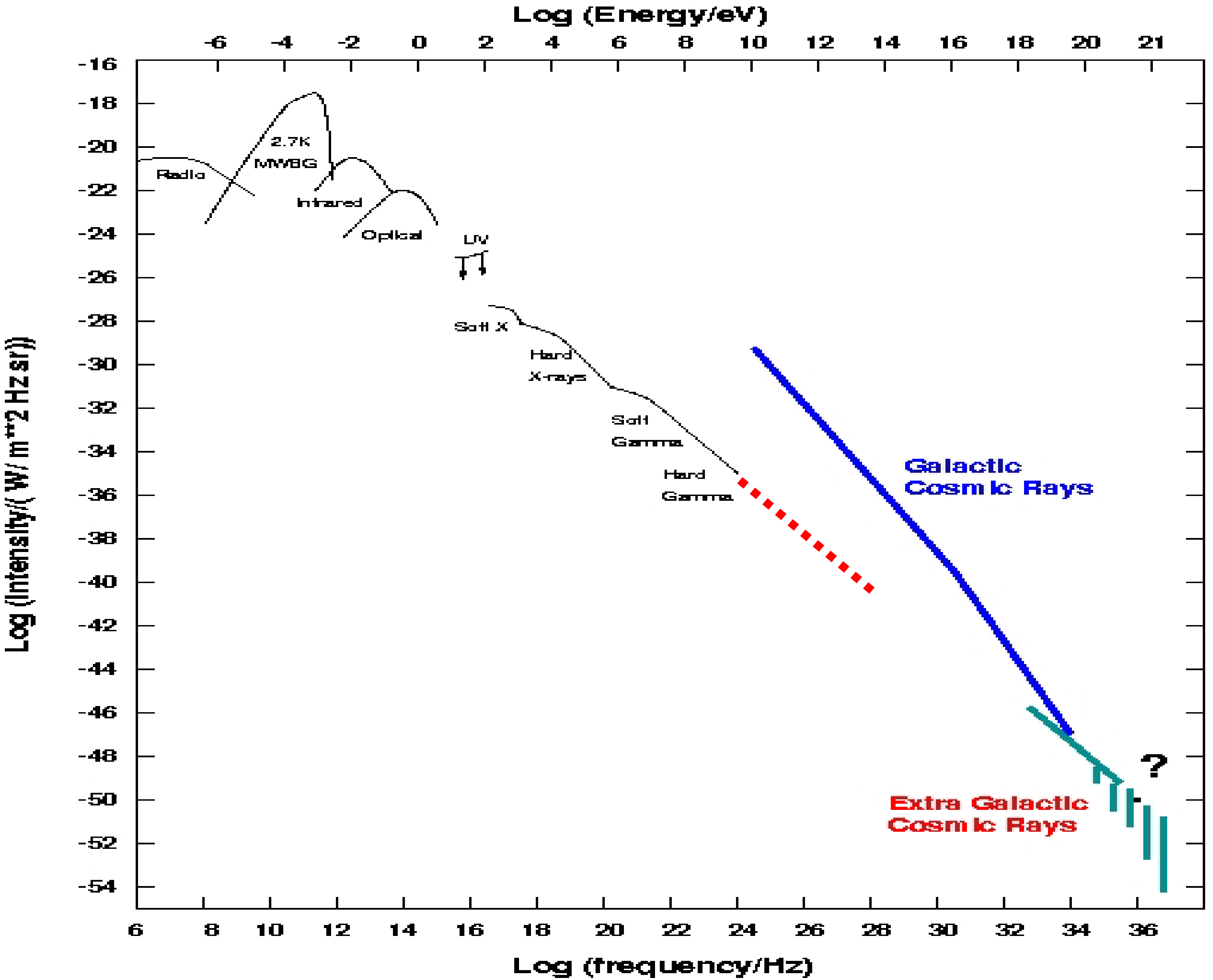
10% duty cycle → *effective* aperture ~ 3 x 10^5 km^2-ster

Assuming Φ_{CR} (E) ~ $E^{-2.75}$, the asymptotic OWL stereo aperture leads to ~ 3000 events/year with E ⩾ 10^{20} eV

OWL could be a stepping stone to viewing majority of night side atmosphere

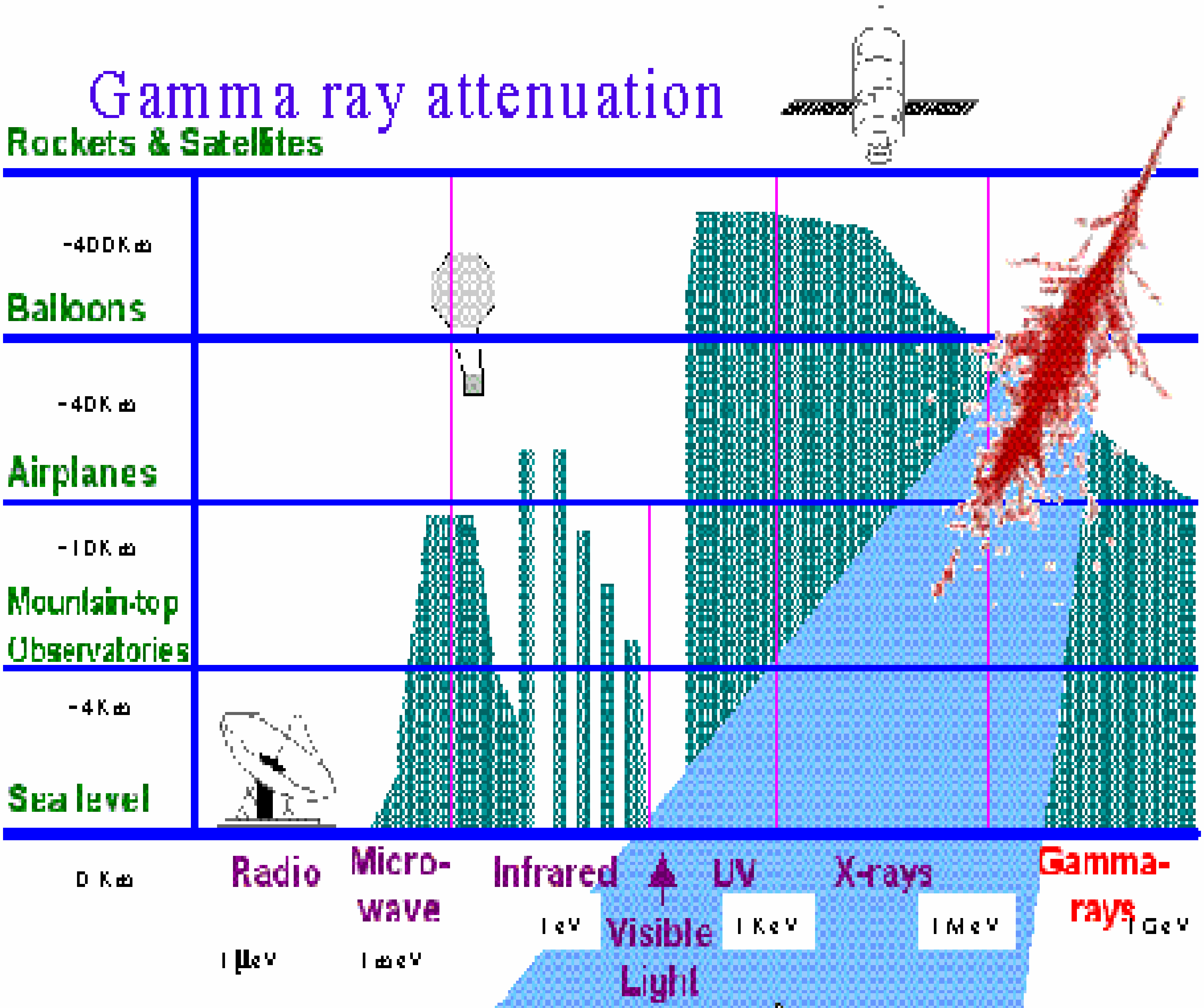






Log (Energy/eV)
Log (Intensity/(W/ m**2 Hz sr))
Log (frequency/Hz)
Radio
2.7K
MWBG
Infrared
Optical
UV
Soft X
Hard
X-rays
Soft
Gamma
Hard
Gamma
Galactic
Cosmic Rays
Extra Galactic
Cosmic Rays
?

Gamma ray attenuation



γ-ray production mechanisms

accelerated electrons

accelerated protons

Inverse Compton scattering

local photon fields

or

electron induced synchrotron radiation

$p\ \gamma \rightarrow \Delta \rightarrow p\ \pi^0$

$p\ \gamma \rightarrow \Delta \rightarrow n\ \pi^+$

γ from neutral π

ν from charged π

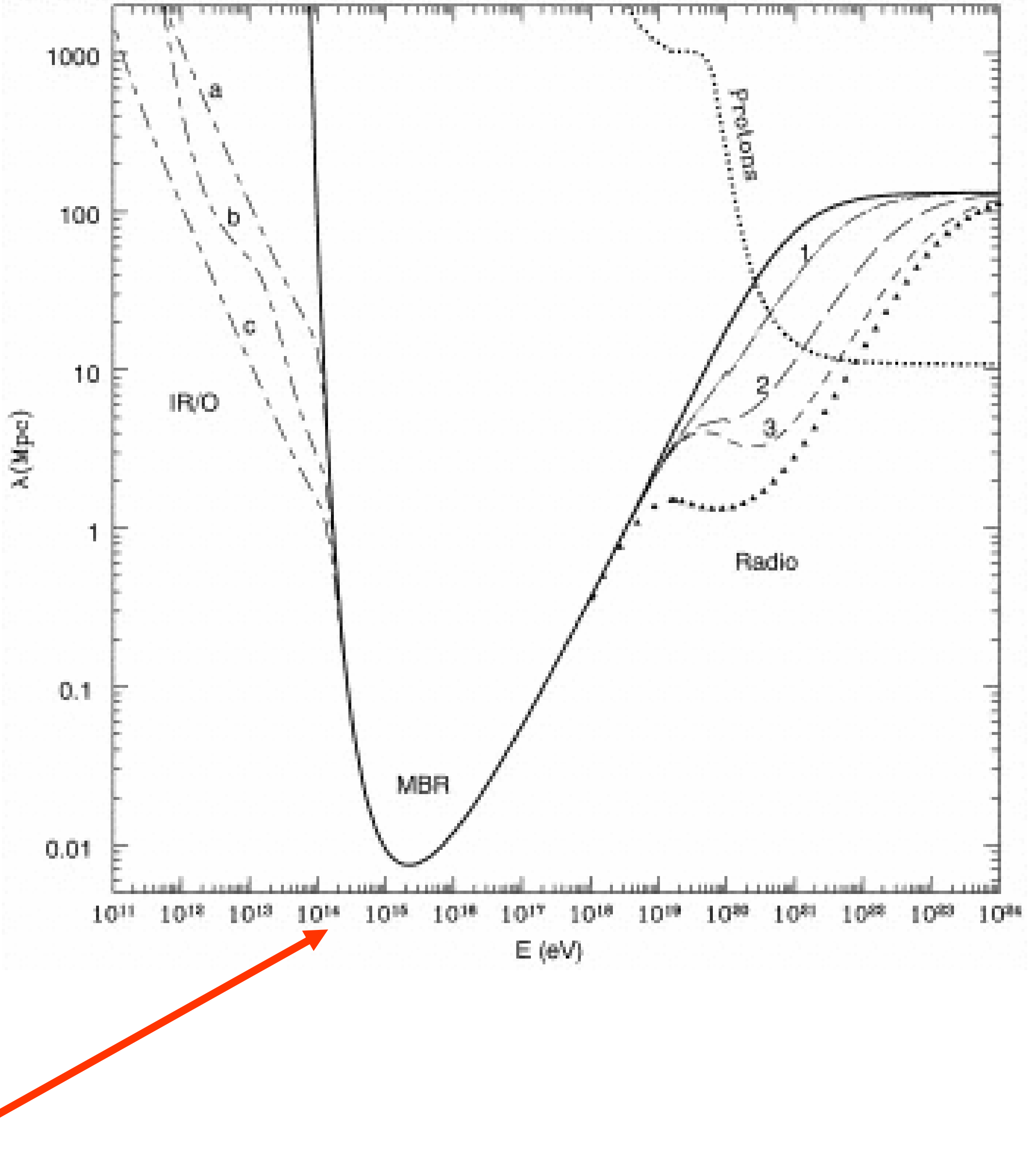
High energy γ-rays

Absorption

High energy γ-rays are absorbed via interaction with several photon fields:

- InfraRed/Optical background
- Radio halos
- Cosmic Microwave Background

The last one put a stringent cutoff above 100 TeV



Experimental Techniques

The Earth atmosphere is opaque to high energy gamma ray.
It corresponds to about 28 radiation lengths.

Only experiments performed above the atmosphere, on balloons or satellites, can detect the primary gamma rays

The gamma ray fluxes are very low and decreases rapidly with energy.

Example: γ-rays from Vela

Φ (E_γ>100MeV) ~ 10^{-5} photons/cm^2/s and $d\Phi/dE \sim K \cdot E^{-1.89}$

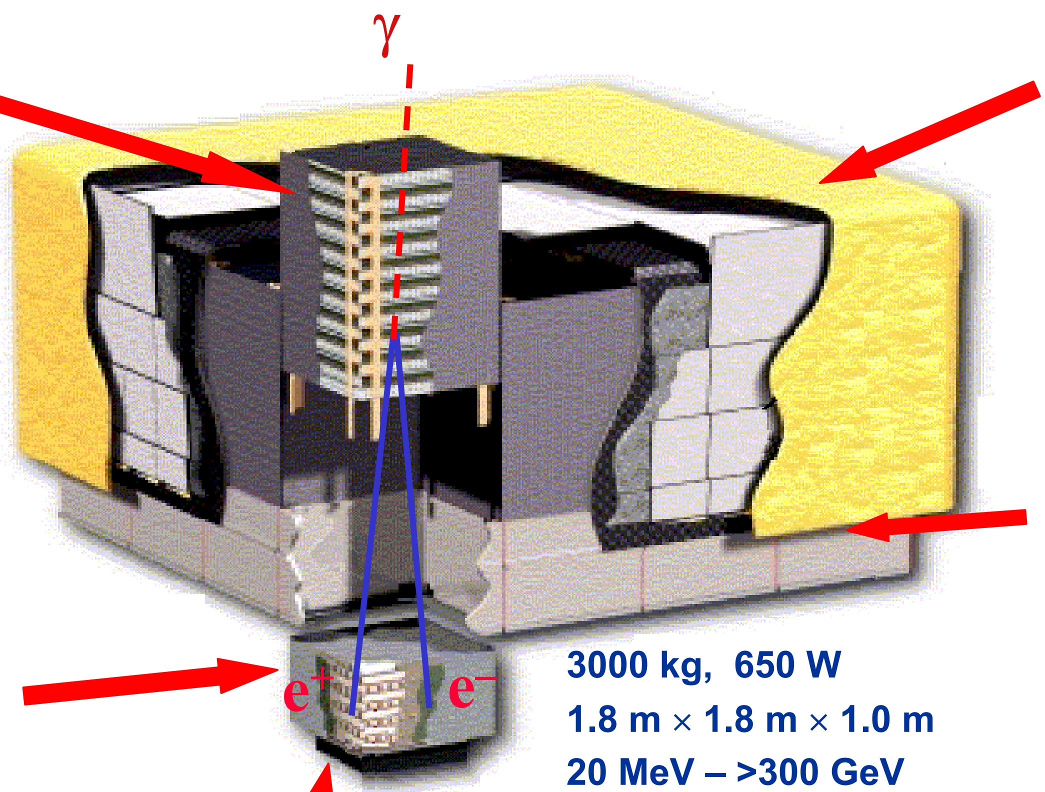
A ~ 1000cm^2 $\Rightarrow$ few photons/day above 10 GeV

gamma ray astronomy above ~ 100 GeV can be done only with ground based detectors

GLAST - LAT

Si Tracker
pitch = 228 µm
8.8 10^5 channels
12 layers × 3% X_0
+ 4 layers × 18% X_0
+ 2 layers

ACD
Segmented scintillator tiles
0.9997 efficiency



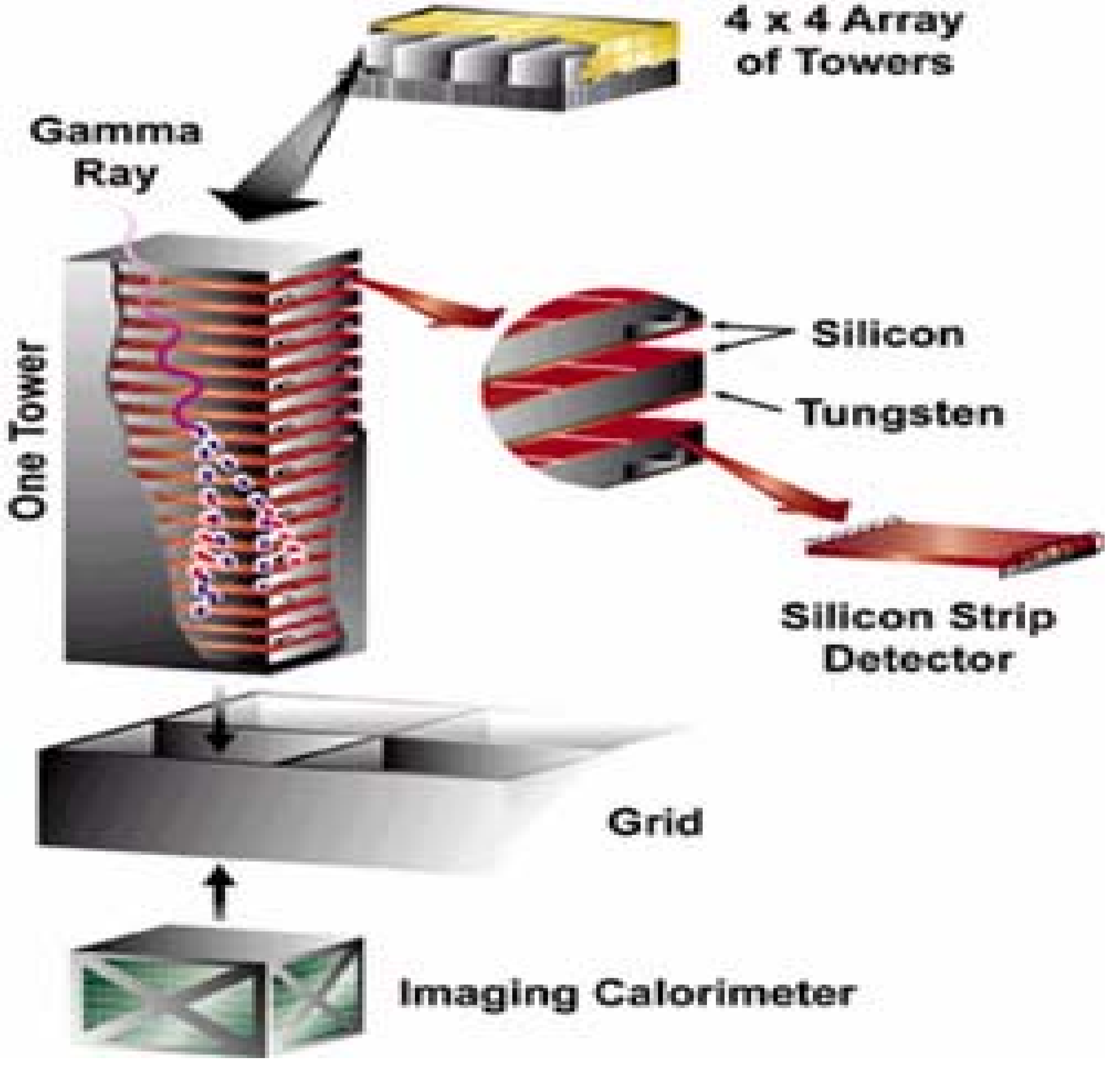
Grid (& Thermal Radiators)

CsI Calorimeter
Hodoscopic array
8.4 X_0 8 × 12 bars
2.0 × 2.7 × 33.6 cm

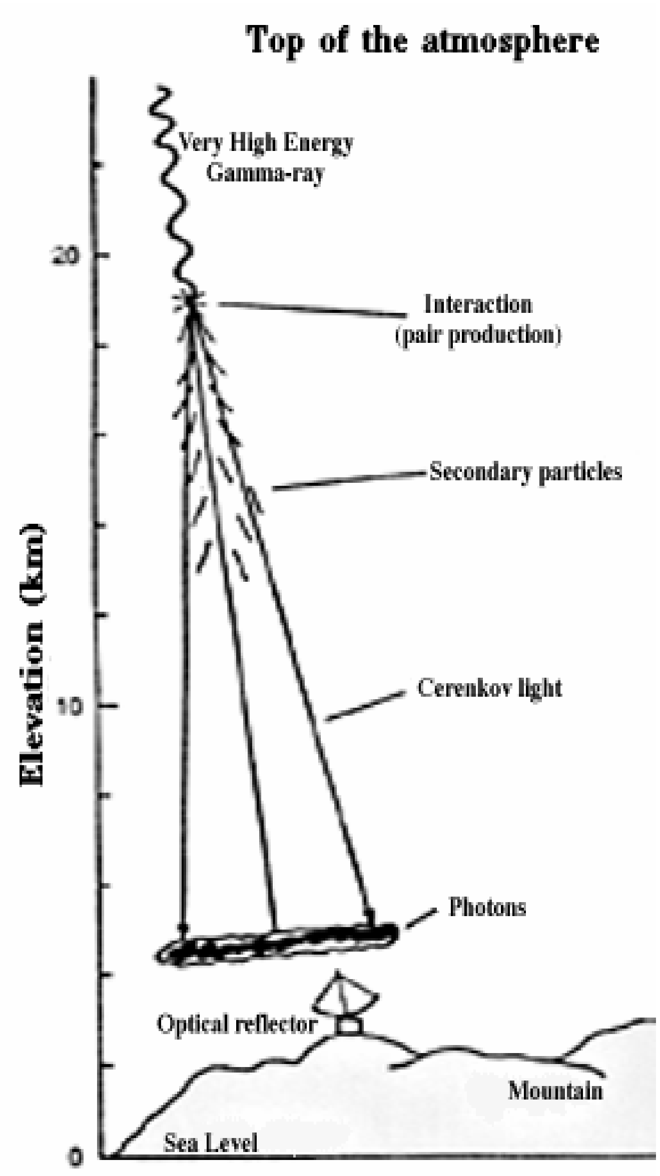
3000 kg, 650 W
1.8 m × 1.8 m × 1.0 m
20 MeV – >300 GeV

Data acquisition

Flight Hardware & Spares
16 Tracker Flight Modules + 2 spares
16 Calorimeter Modules + 2 spares
1 Flight Anticoincidence Detector
Data Acquisition Electronics + Flight Software


4 x 4 Array
of Towers
Gamma
Ray
One Tower
Silicon
Tungsten
Silicon Strip
Detector
Grid
Imaging Calorimeter

IACT detectors



- Fast light pulse (~ 5ns)
- Small angular size (<1°)
- Short wavelengths with respect to night sky background

Low energy threshold

Example:

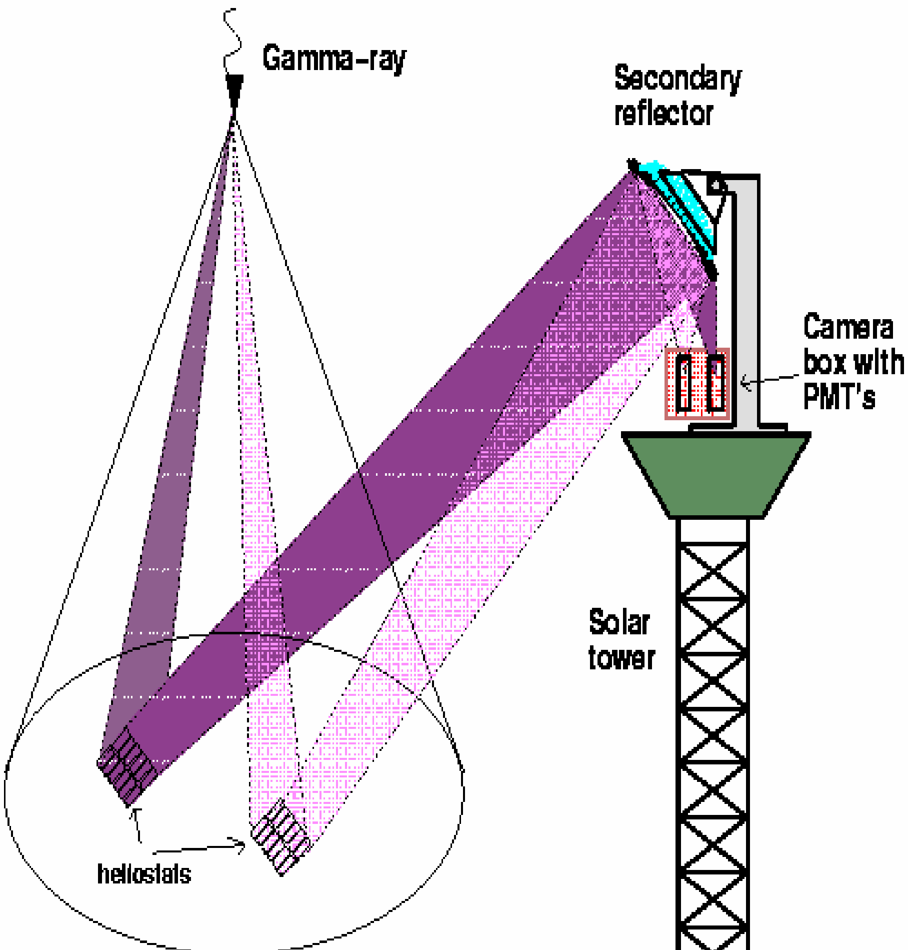
Night sky background (300-500 nm): ~$2 \cdot 10^{12}$ photons/m^2/s/sr

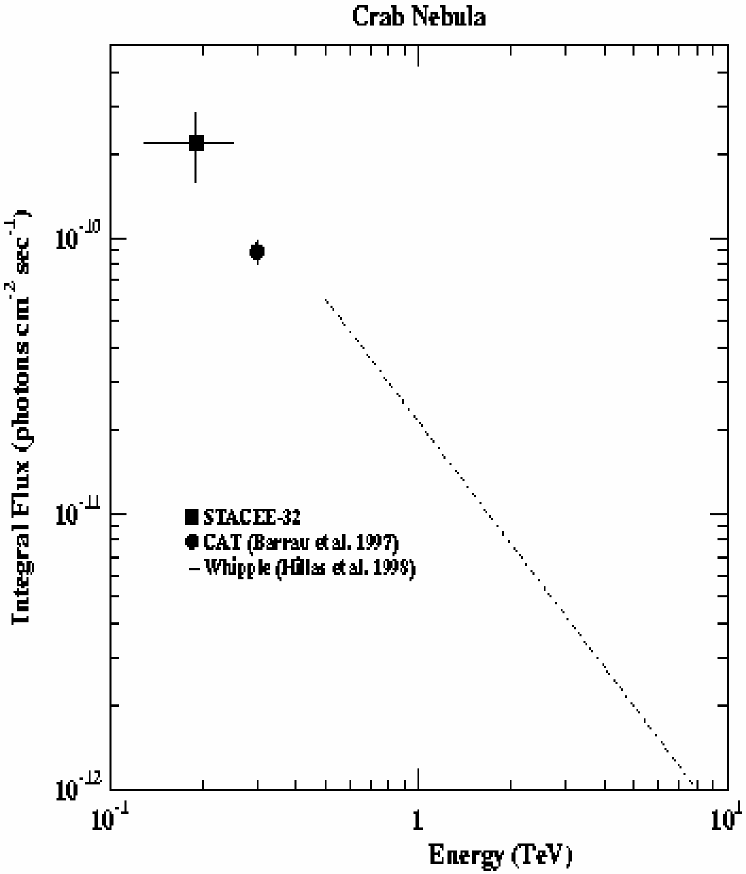
If FOV~1° and T~10ns $\Rightarrow$ background ~ 5 photons/m^2

For a 1 TeV shower the signal is ~ 70 photons/m^2

E ~ 1TeV is a reasonable threshold for a 1m^2 mirror telescope

STACEE CONCEPT



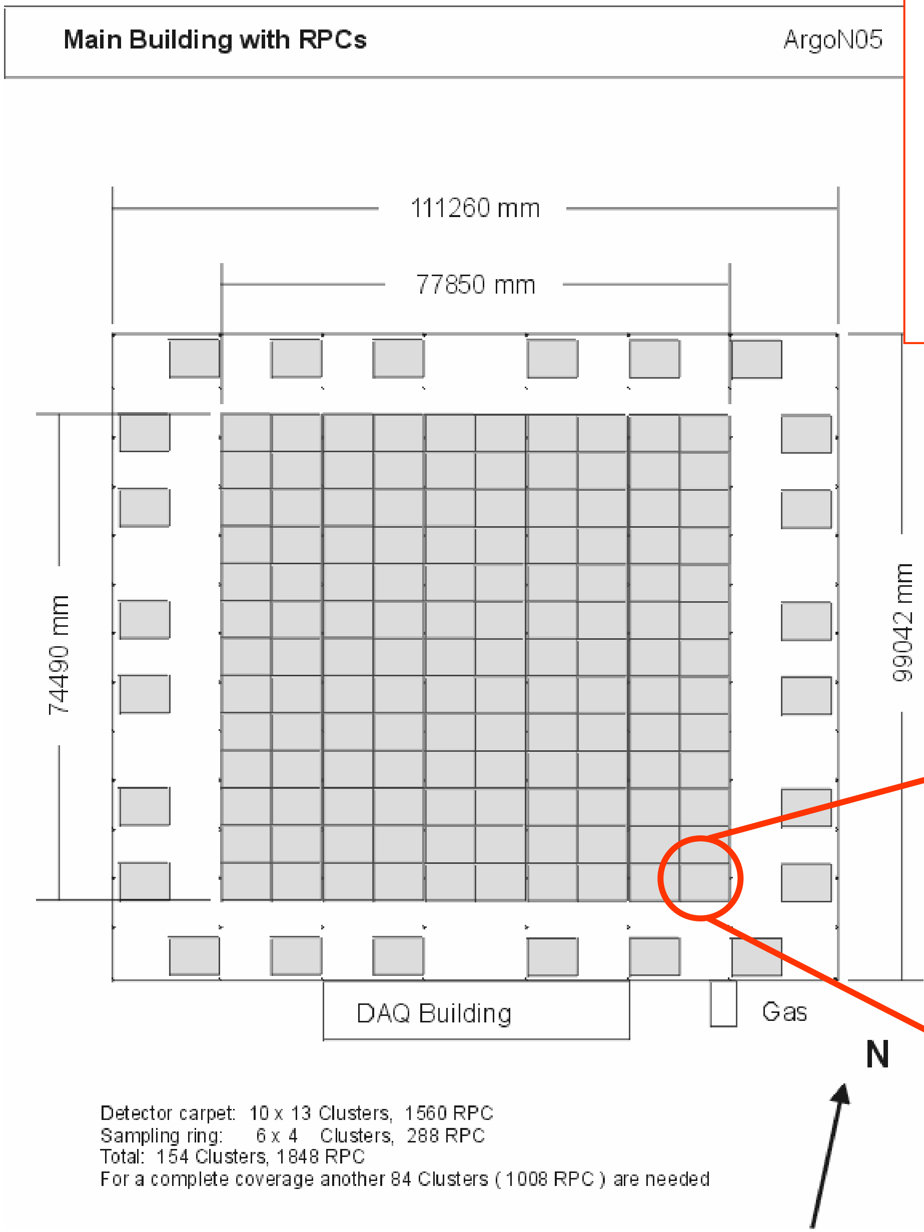


Measured Crab Integral Flux

$E_{th} = 190 \pm 60$ **GeV**

$I(E > E_{th}) = (2.2 \pm 0.6 \pm 0.2) \times 10^{-10}$ **photons cm^{-2} s^{-1}**

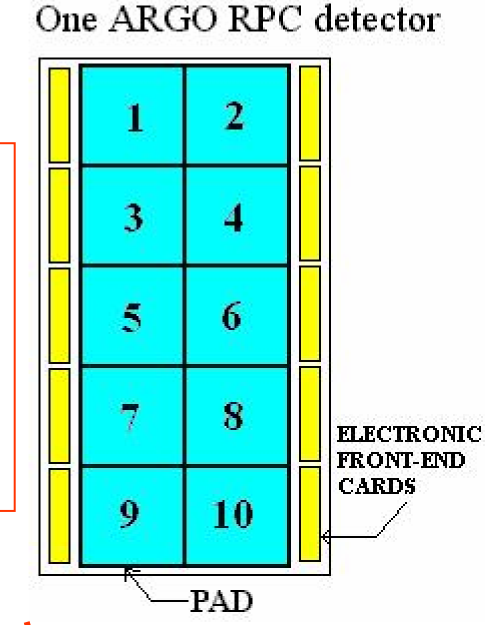
ARGO-YBJ

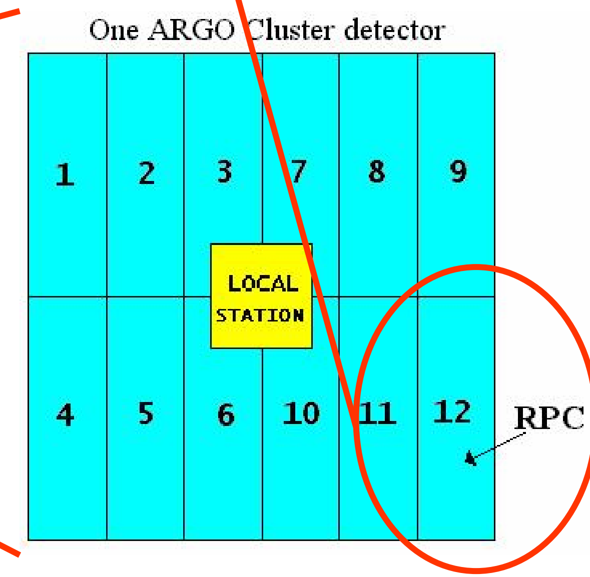


Resistive Plate Chamber carpet

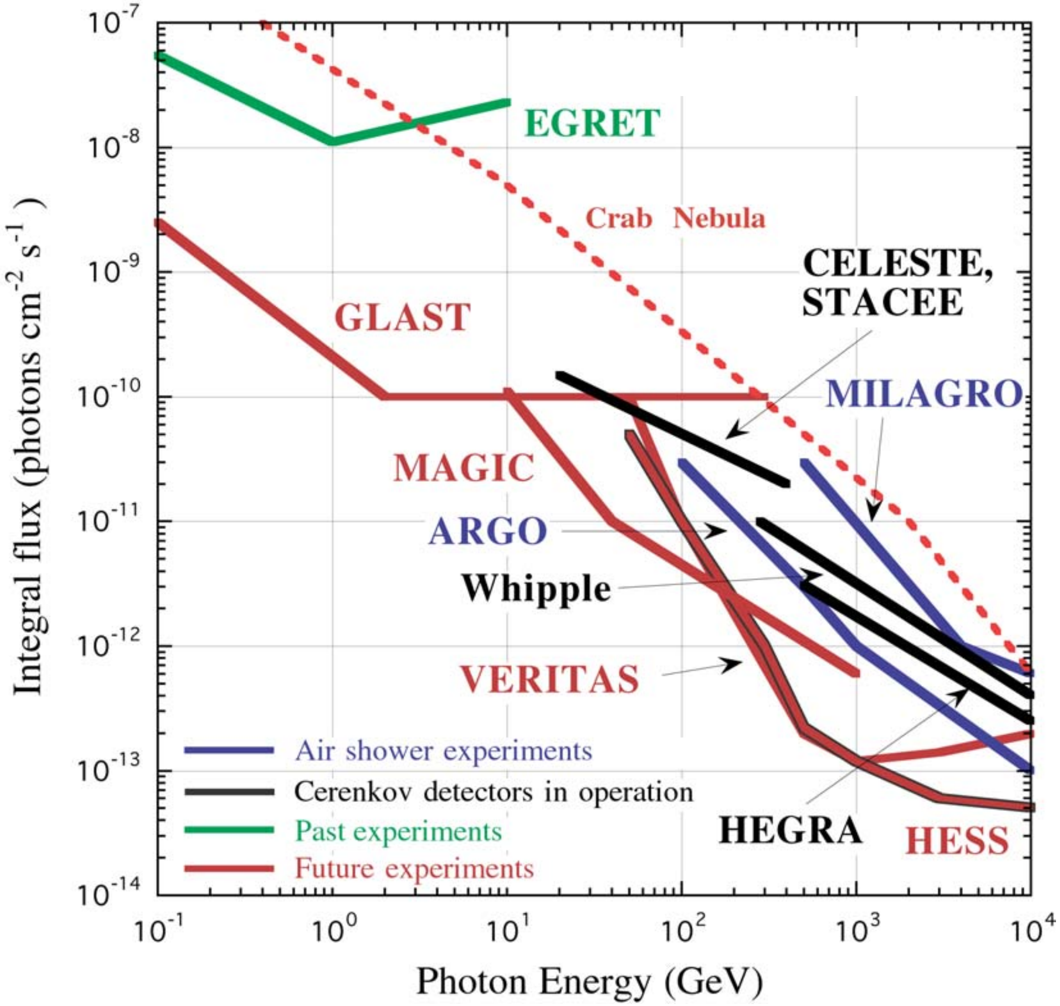
Resolutions: σ_t ~1ns $\Rightarrow$ σ_θ~ 1°

Energy: 100GeV-10TeV





Flux sensitivities

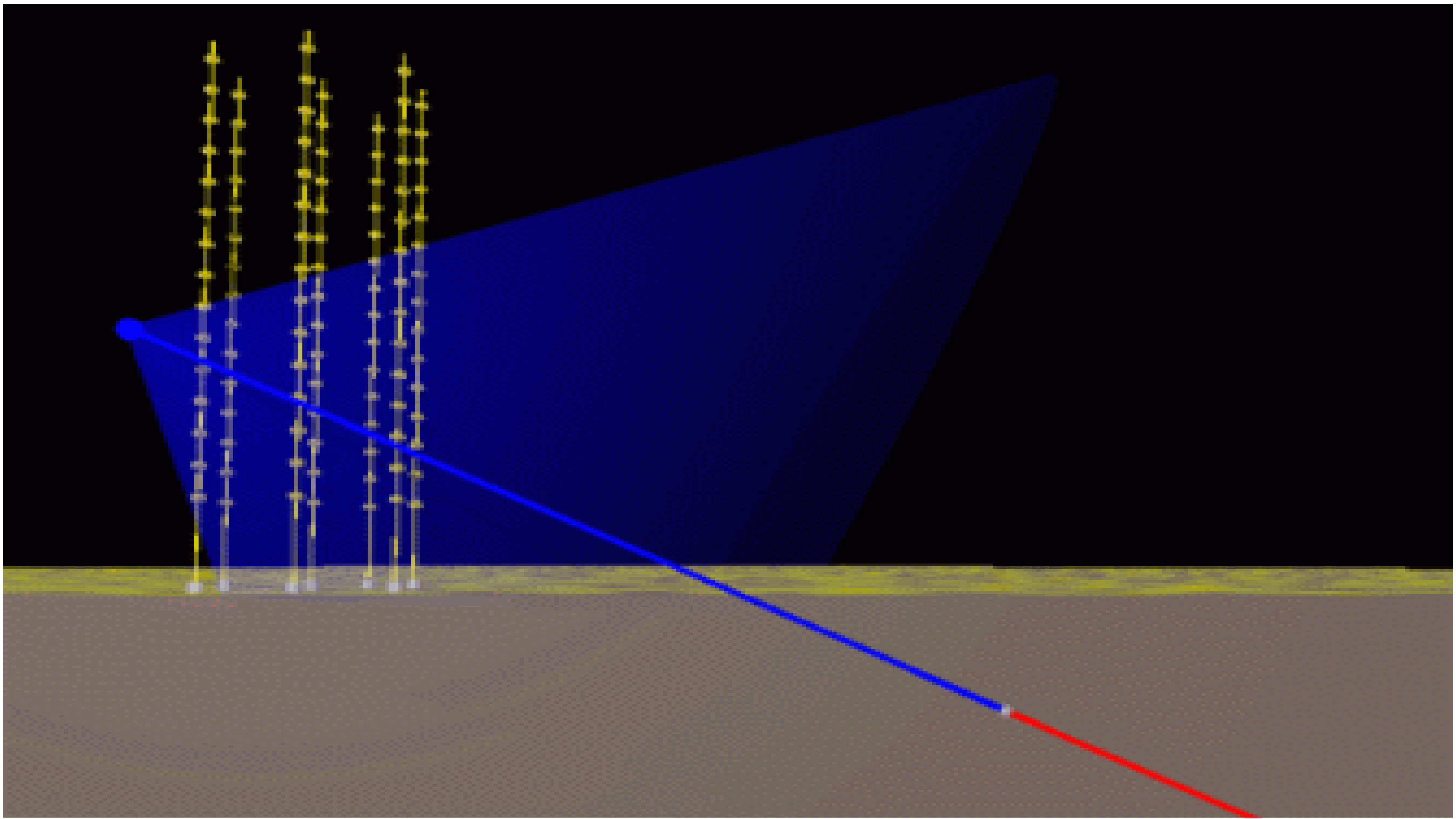


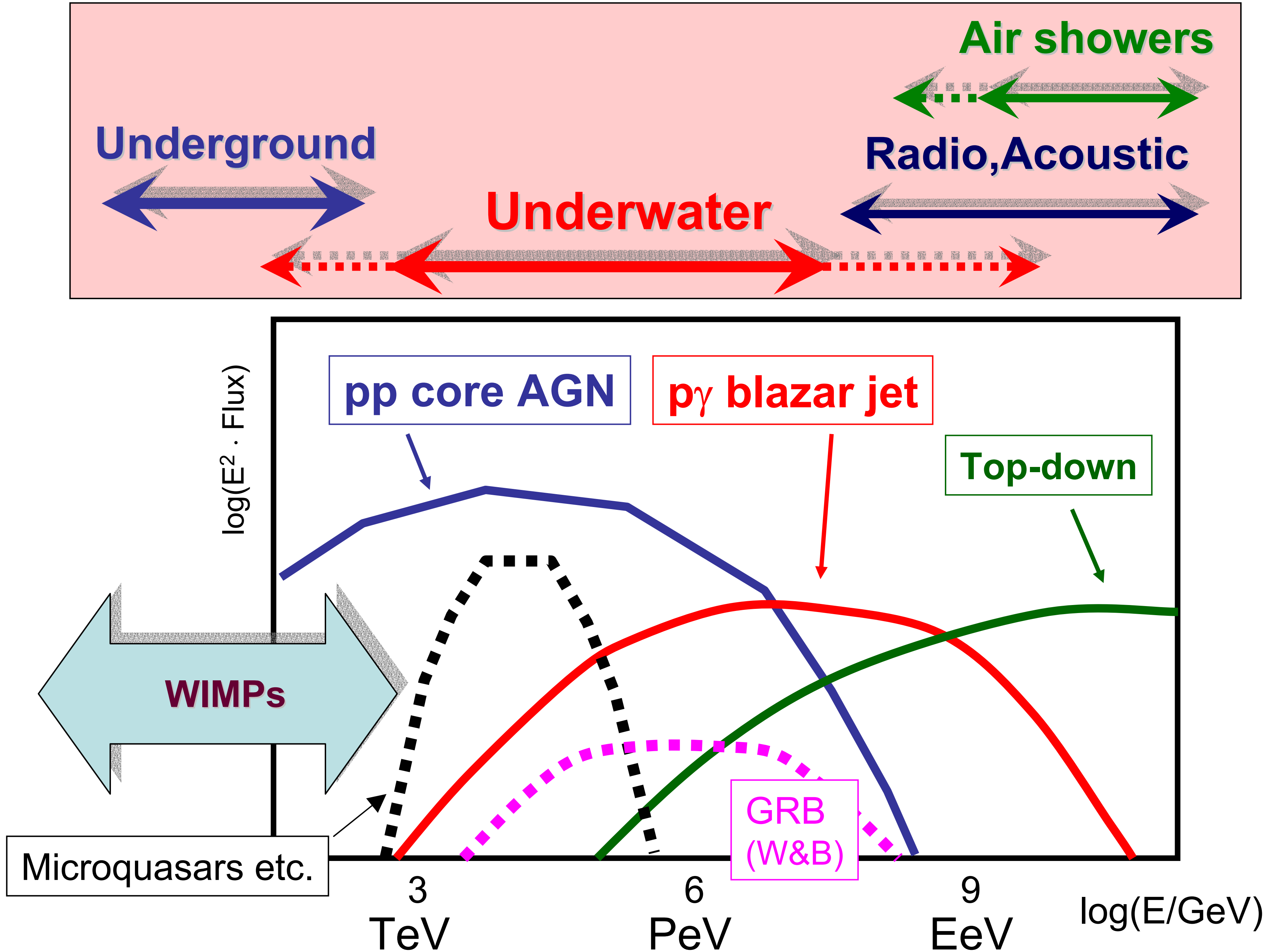
Complementary capabilities

	ground		space
	ACT	EAS	Pair
angular resolution	good	good	good
duty cycle	low	high	high
area	large	large	small
field of view	small	large	large
energy resolution	good	fair	good

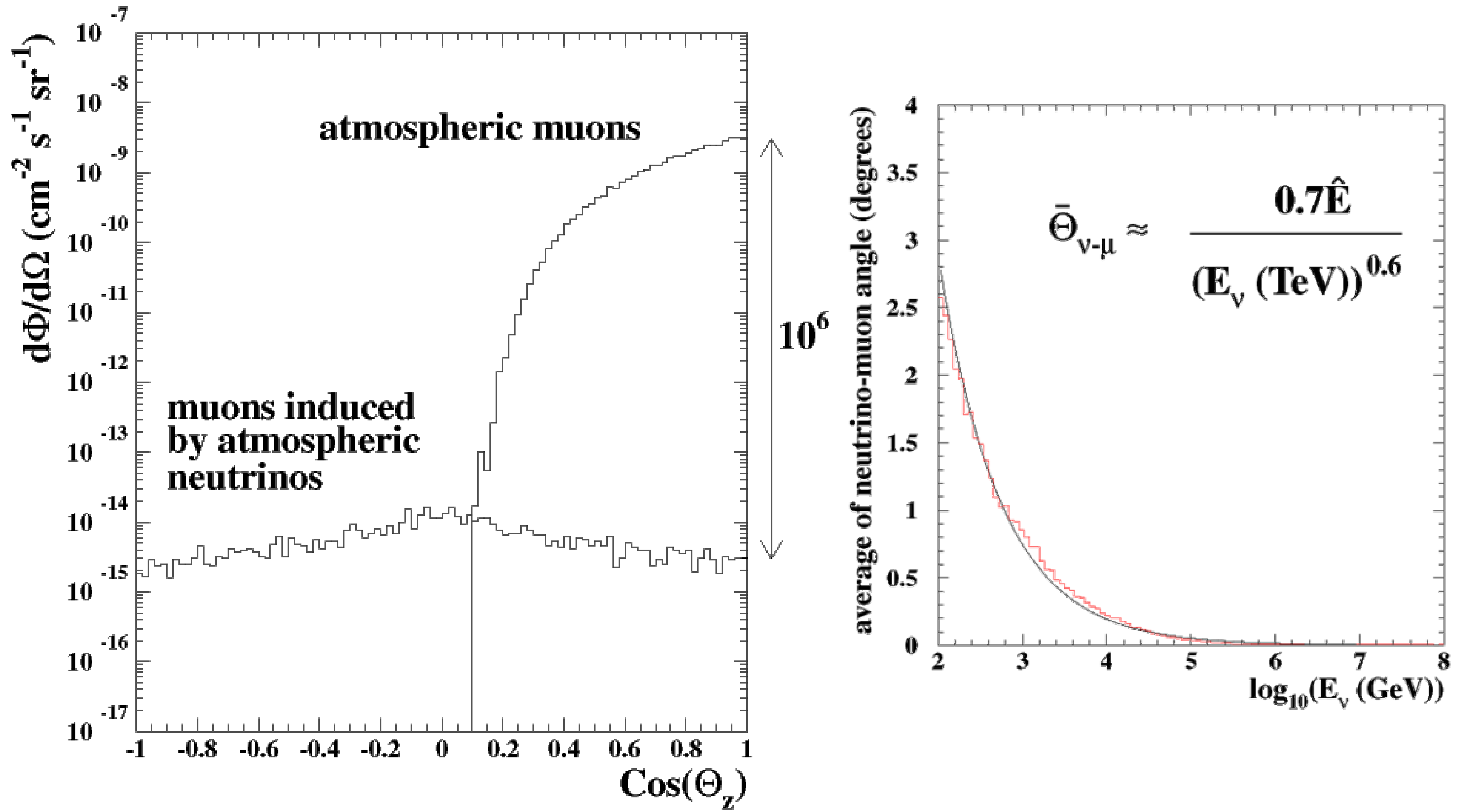
The next-generation ground-based and space-based experiments are well matched

Underwater/Ice Cherenkov Telescopes



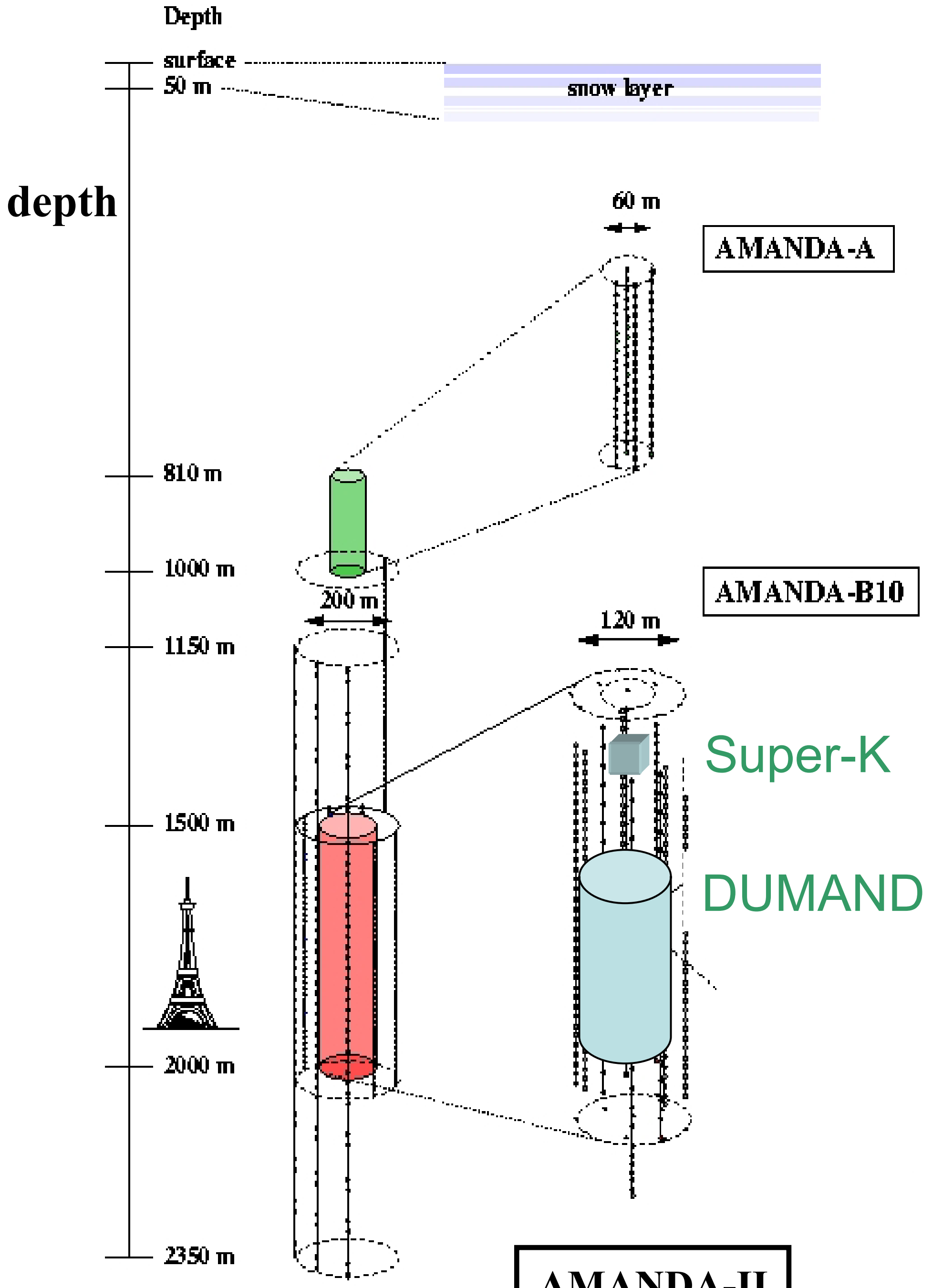


Air showers
Underground
Radio,Acoustic
Underwater
log(E² · Flux)
pp core AGN
pγ blazar jet
Top-down
WIMPs
GRB
(W&B)
Microquasars etc.
3
TeV
6
PeV
9
EeV
log(E/GeV)



dΦ/dΩ (cm^-2 s^-1 sr^-1)
atmospheric muons
muons induced by atmospheric neutrinos
10^6
Cos(Θz)
average of neutrino-muon angle (degrees)
Θ̄ν-μ ≈ 0.7Ê / (Eν (TeV))^0.6
log10(Eν (GeV))

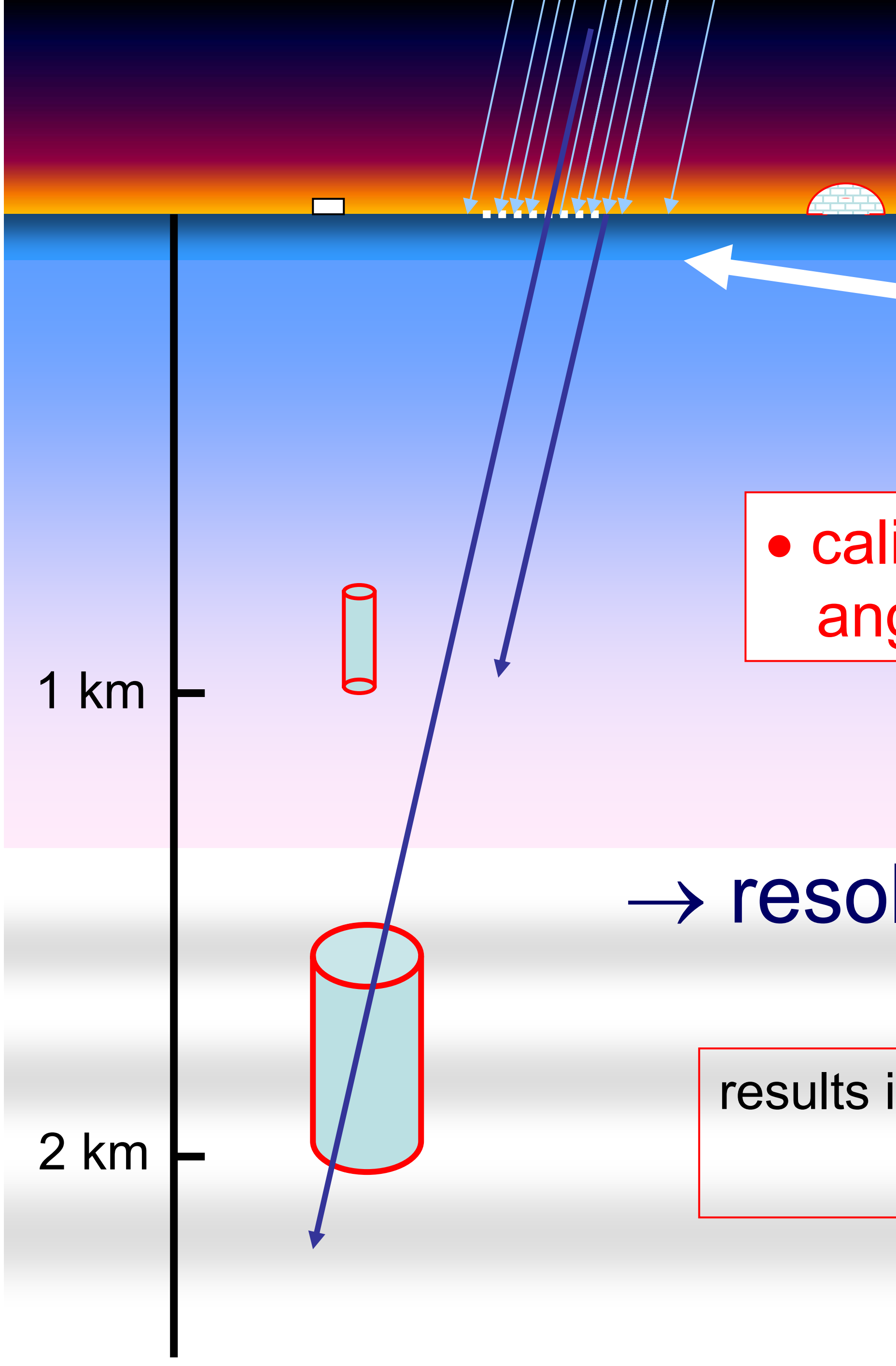
AMANDA



Amanda-II:
677 PMTs
at 19 strings

(1996-2000)

Unique:



SPASE air shower arrays

- calibration of AMANDA angular resolution and pointing !

→ resolution Amanda-B10 ~ 3.5°

results in ~ 3° for upward moving muons

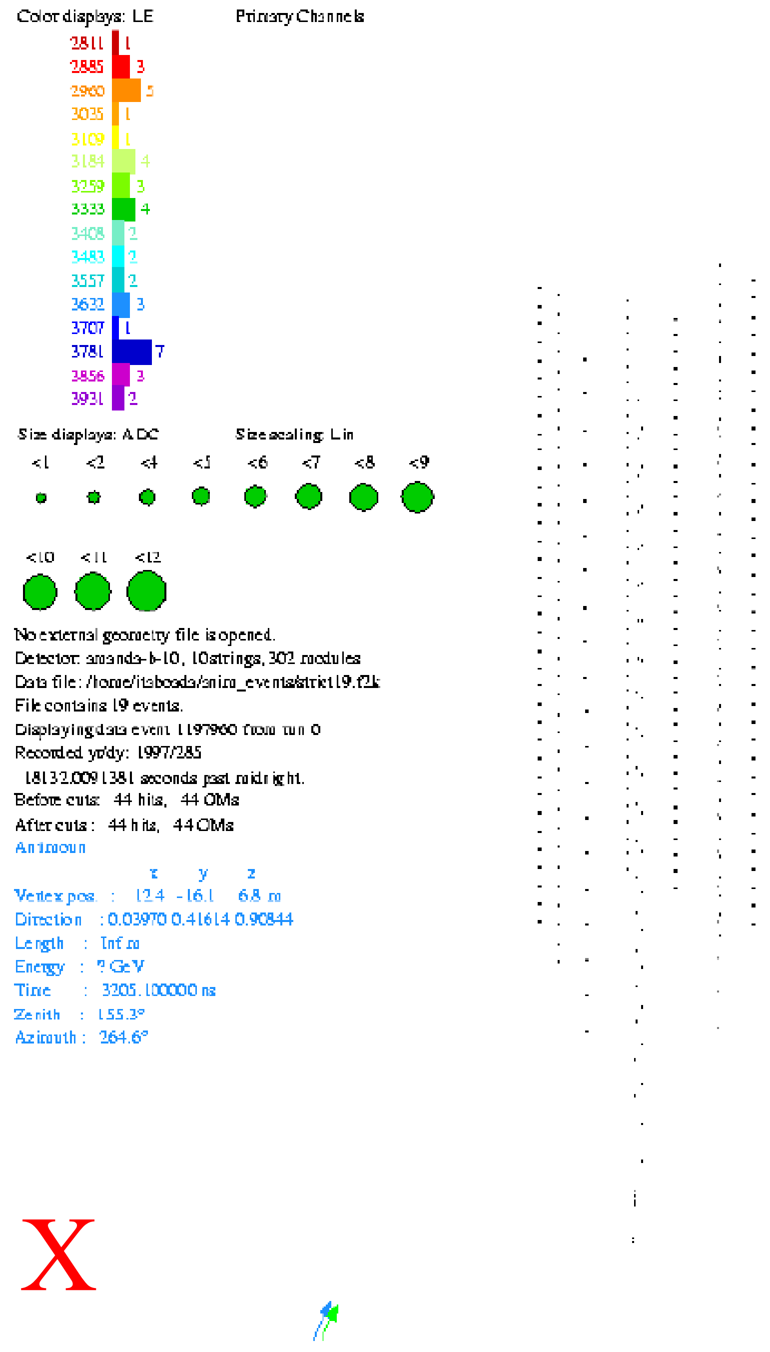
(Amanda-II: < 2°)

AMANDA Event Signatures: Muons

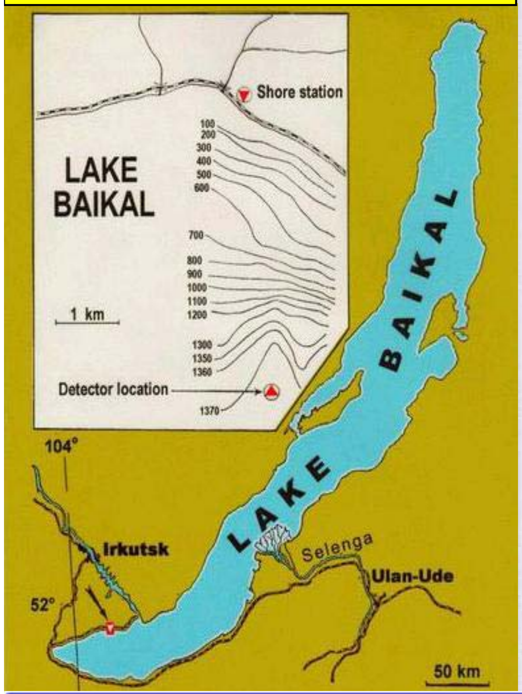
CC muon neutrino interaction

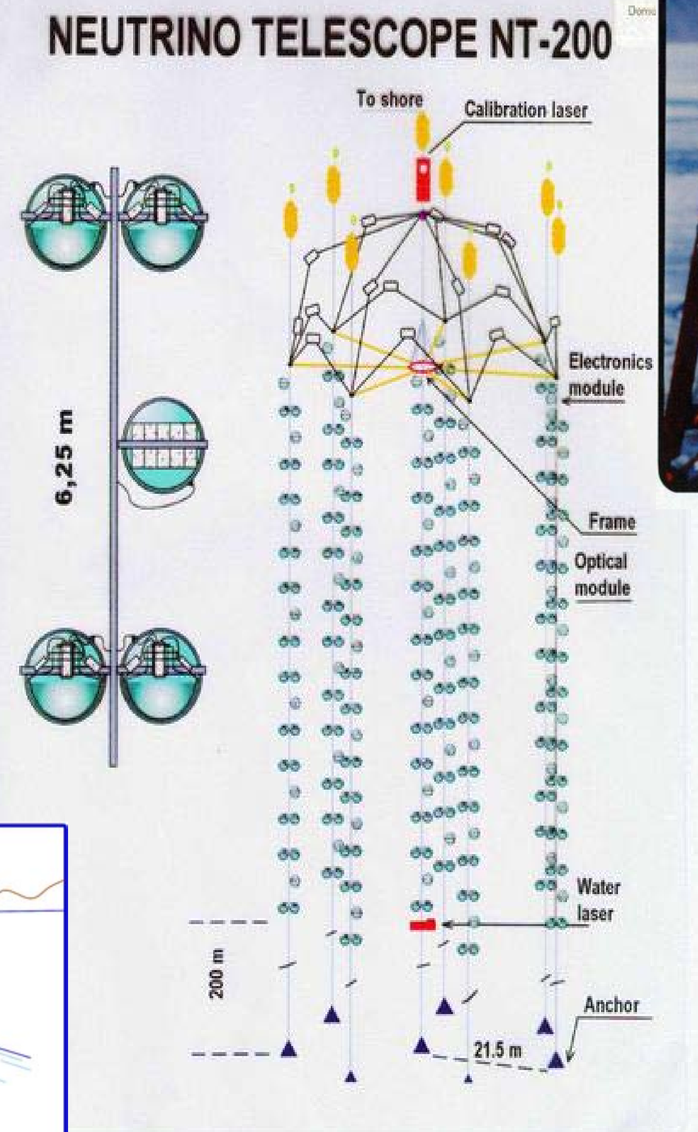
→ **track**

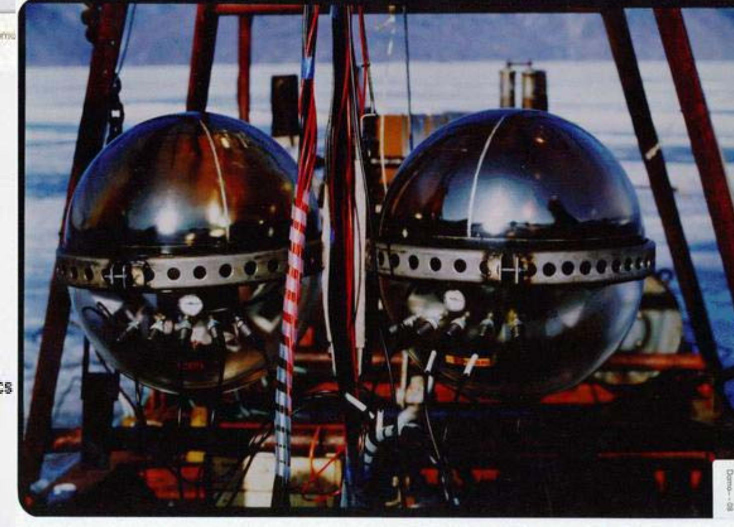
$$\nu_\mu + N \rightarrow \mu + X$$

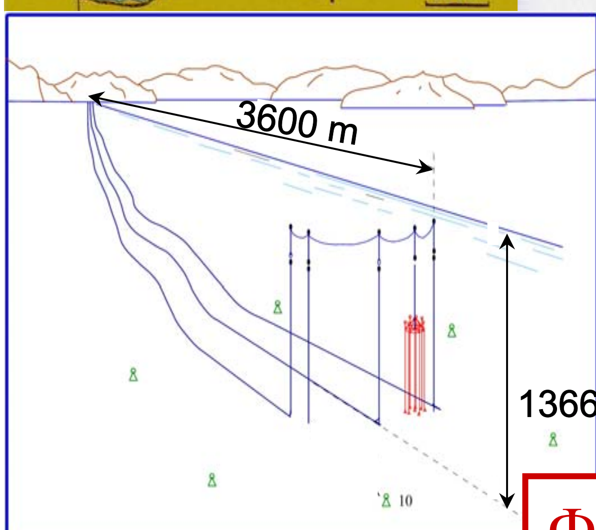


Baikal



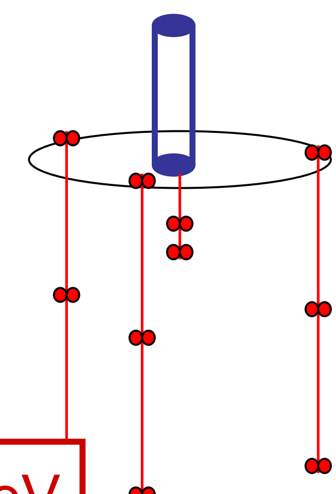






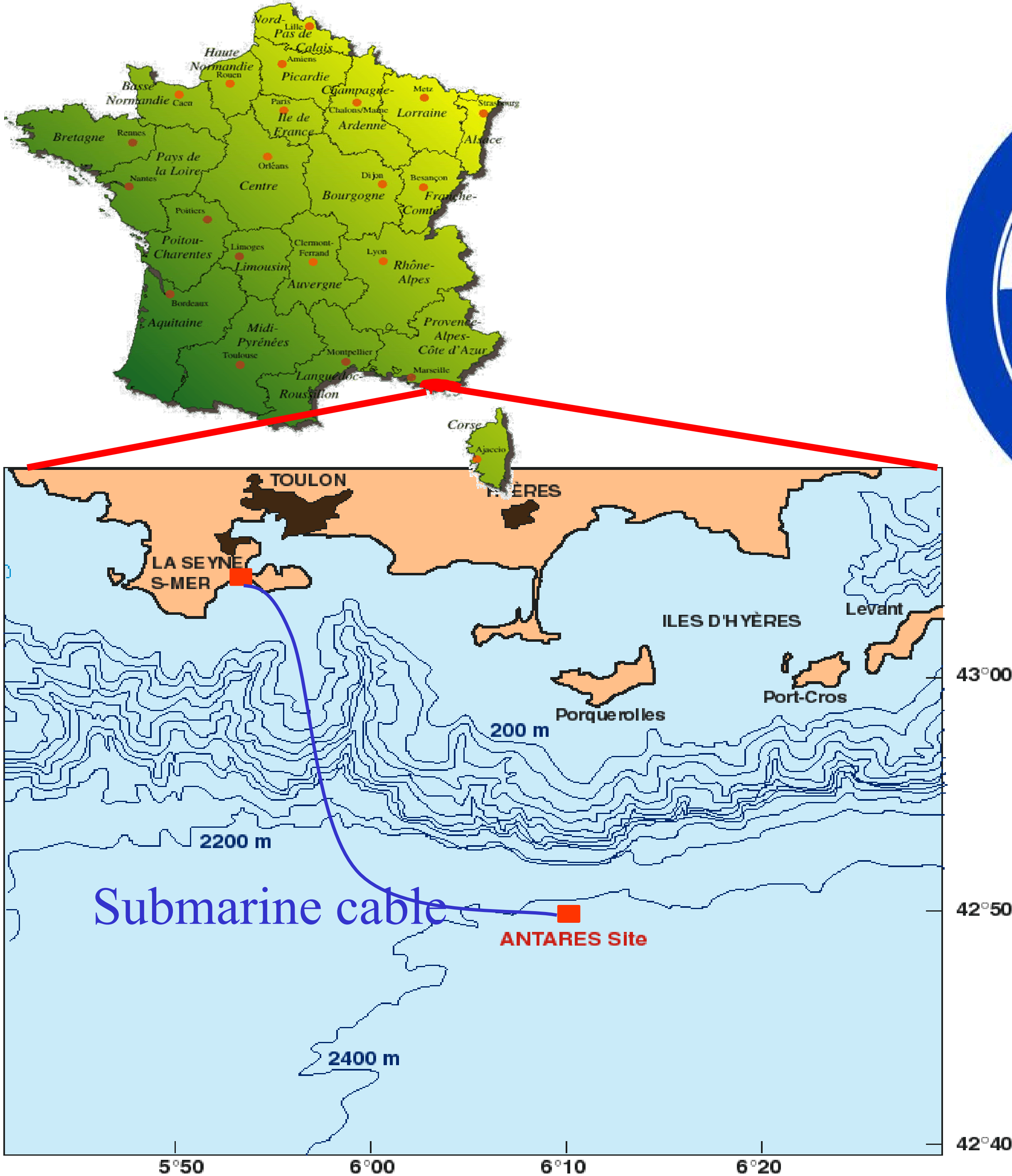
NT-200+

Upgrade with only 22 PMTs
→ factor 4 in sensitivity

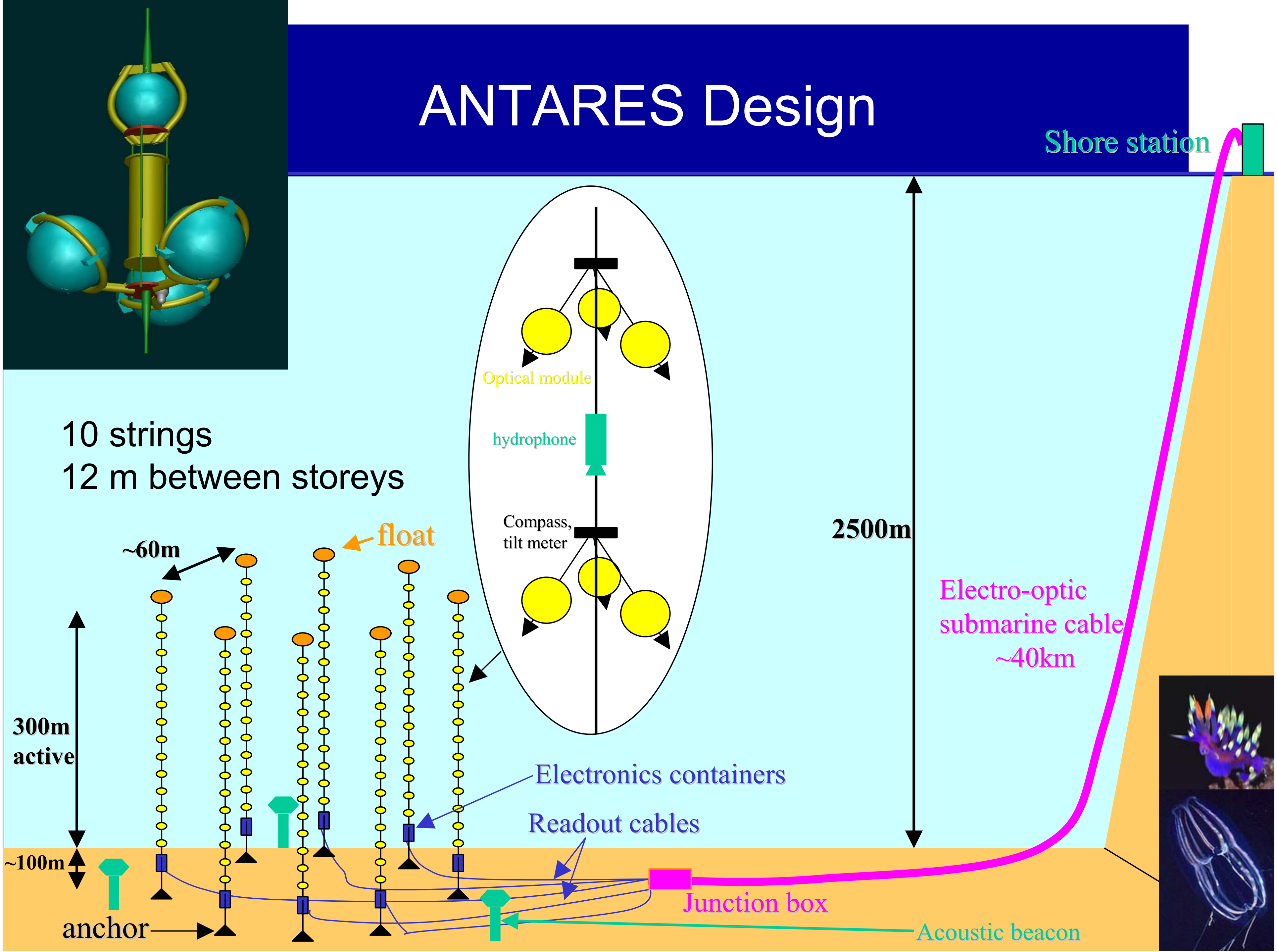


Limit on diffuse fluxes

$$\Phi \cdot E^2 < 1.9 \cdot 10^{-6} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ GeV}$$


Nord-Pas de Calais
Haute Normandie
Basse Normandie
Picardie
Champagne-Ardenne
Lorraine
Alsace
Bretagne
Pays de la Loire
Île de France
Centre
Bourgogne
Franche-Comté
Poitou-Charentes
Limousin
Auvergne
Rhône-Alpes
Aquitaine
Midi-Pyrénées
Languedoc-Roussillon
Provence-Alpes-Côte d'Azur
Corse
TOULON
LA SEYNE S-MER
ILES D'HYÈRES
Levant
Port-Cros
Porquerolles
200 m
2200 m
2400 m
Submarine cable
ANTARES Site
43°00
42°50
42°40
5°50
6°00
6°10
6°20

ANTARES


ANTARES Design
Shore station
10 strings
12 m between storeys
Optical module
hydrophone
Compass,
tilt meter
2500m
~60m
float
300m
active
~100m
anchor
Electro-optic
submarine cable
~40km
Electronics containers
Readout cables
Junction box
Acoustic beacon

Point sources: detector South + detector North