Lepton - Photon 01

Francis Halzen

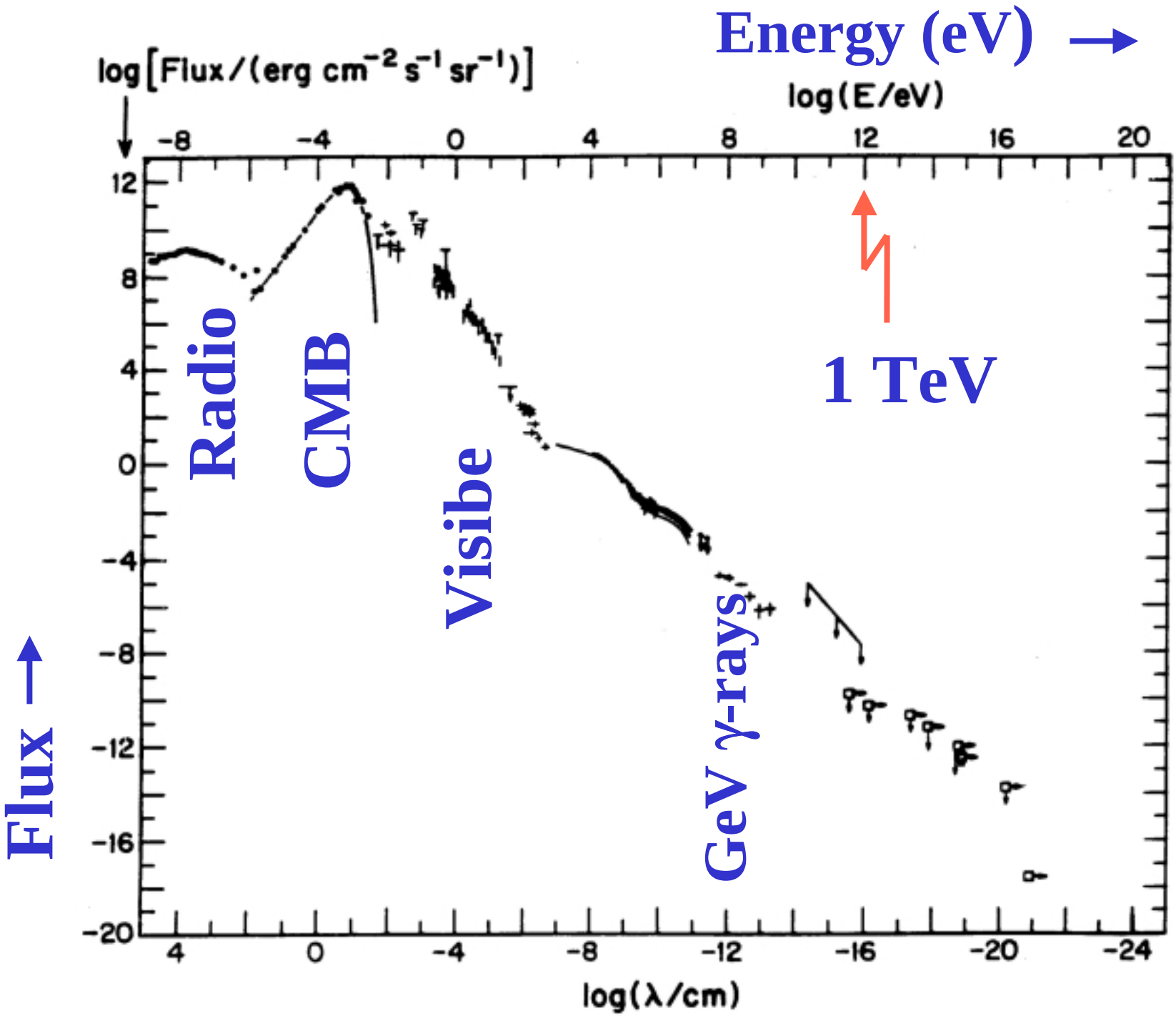
- **the sky** > 10 GeV photon energy

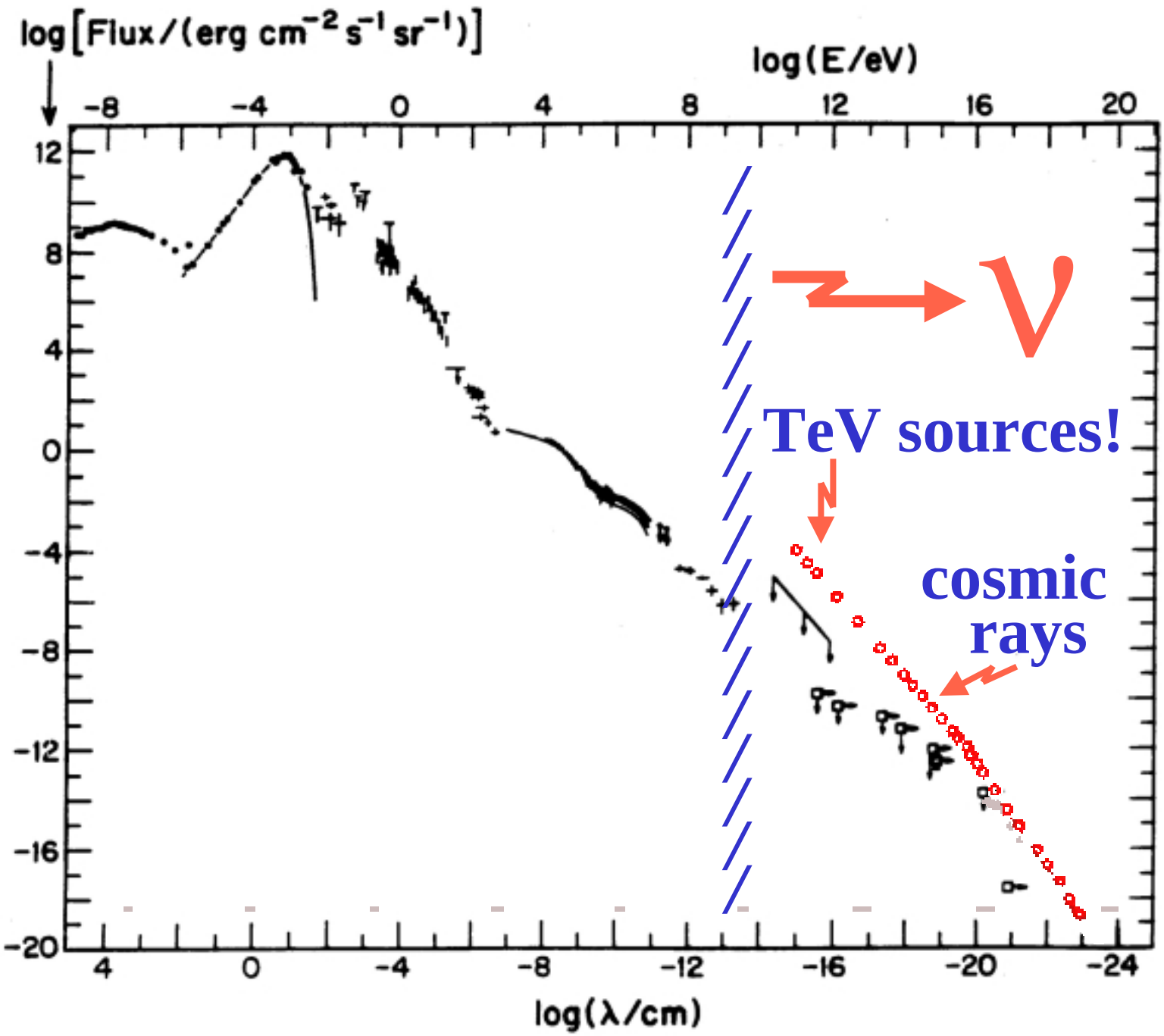
  $< 10^{-14}$ cm wavelength

- **$> 10^{8}$ TeV particles exist**

  Fly's Eye/Hires

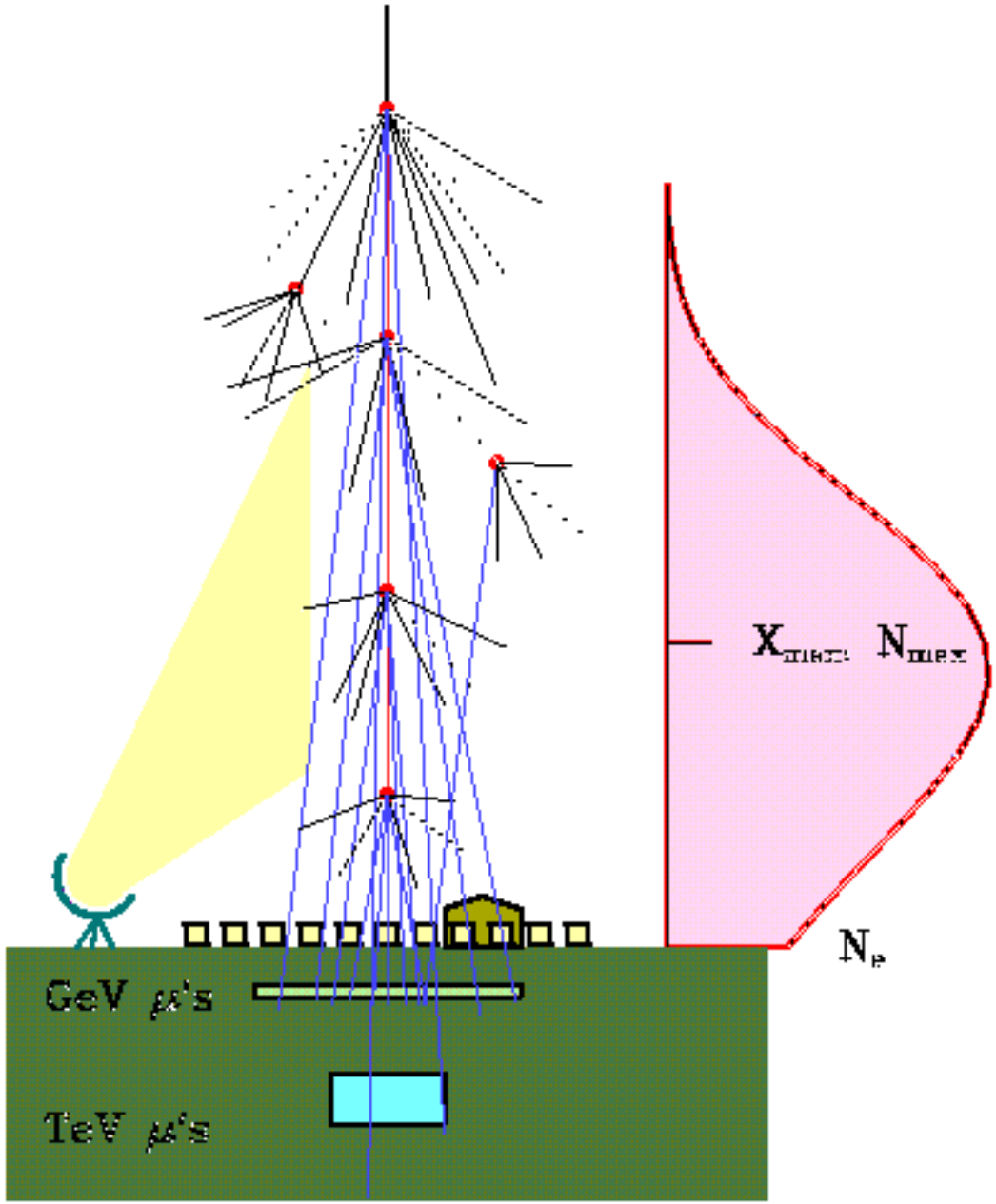
- **they should not**
- **more/better data**
  - → arrays of air Cherenkov telescopes
  - → 10^{4} km^{2} air shower arrays
  - → ~ km^{3} neutrino detectors

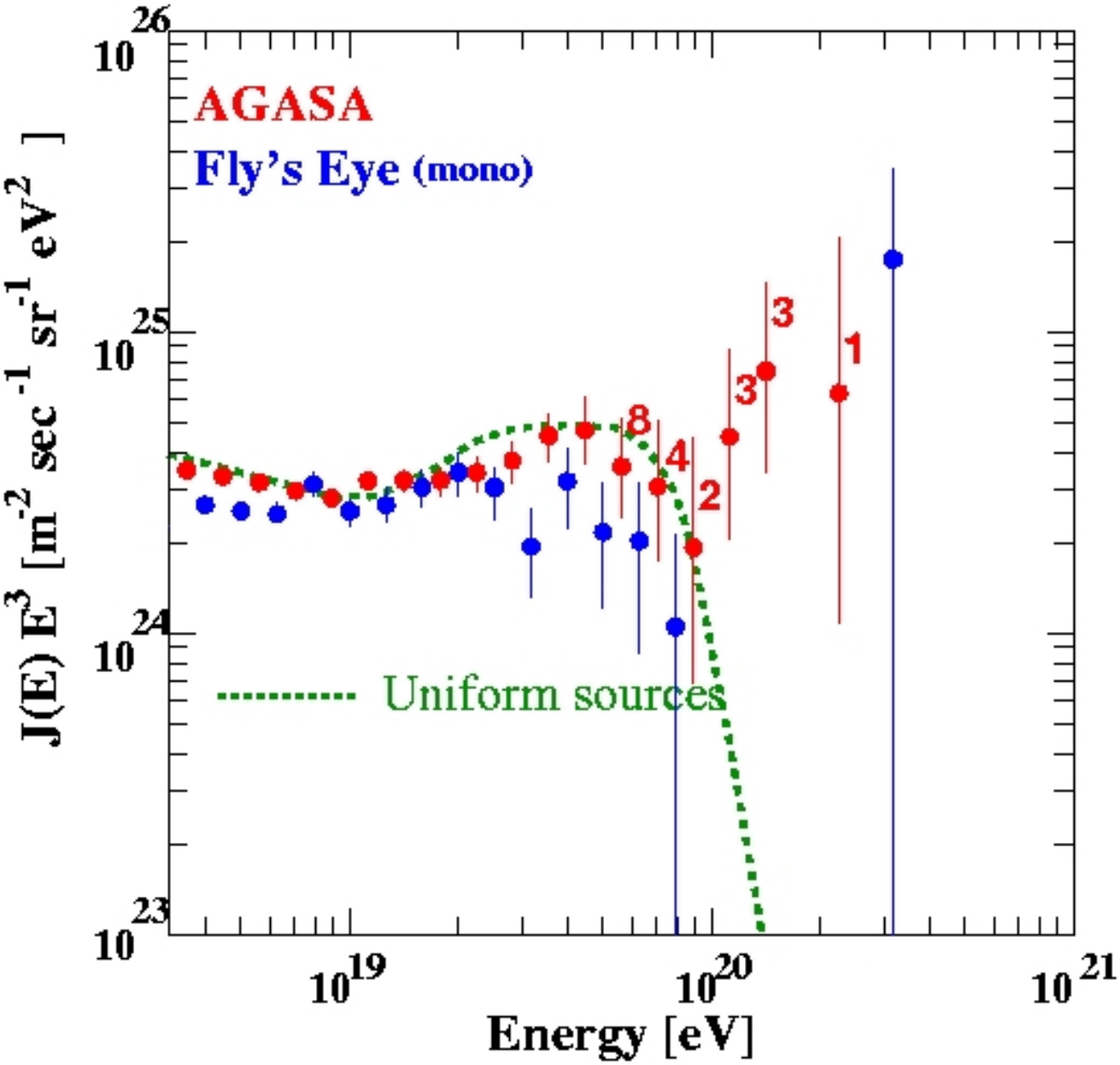

Energy (eV) →
log[Flux/(erg cm⁻² s⁻¹ sr⁻¹)]
log(E/eV)
-8
-4
0
4
8
12
16
20
12
8
4
0
-4
-8
-12
-16
-20
Radio
CMB
Visibe
GeV γ-rays
1 TeV
Flux →
4
0
-4
-8
-12
-16
-20
-24
log(λ/cm)


log [Flux / (erg cm^{-2} s^{-1} sr^{-1})]
log (E/eV)
-8
-4
0
4
8
12
16
20
12
8
4
0
-4
-8
-12
-16
-20
ν
TeV sources!
cosmic rays
4
0
-4
-8
-12
-16
-20
-24
log (λ/cm)

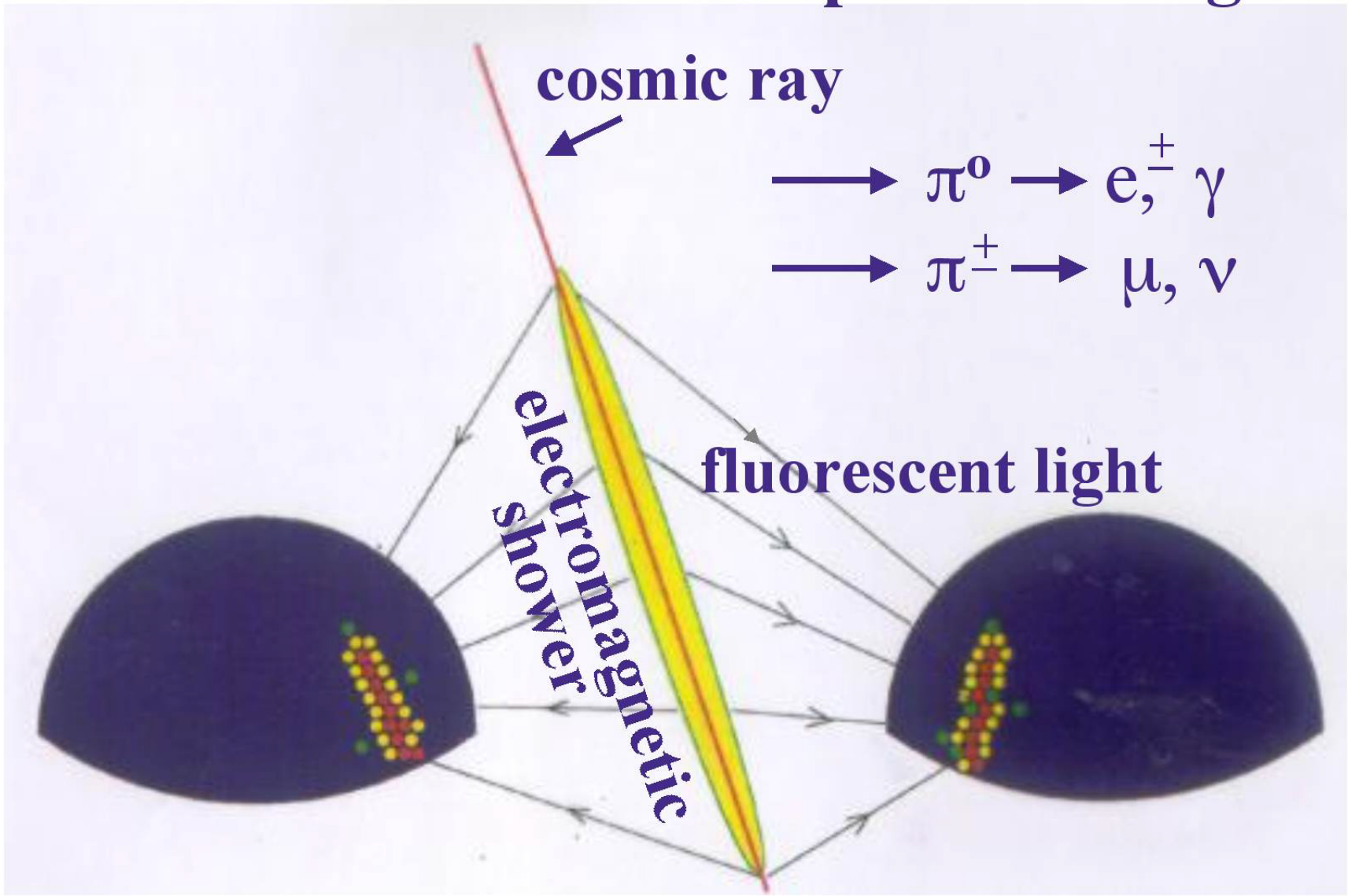
With 10^3 TeV energy, photons do not reach us from the edge of our galaxy because of their small mean free path in the microwave background.

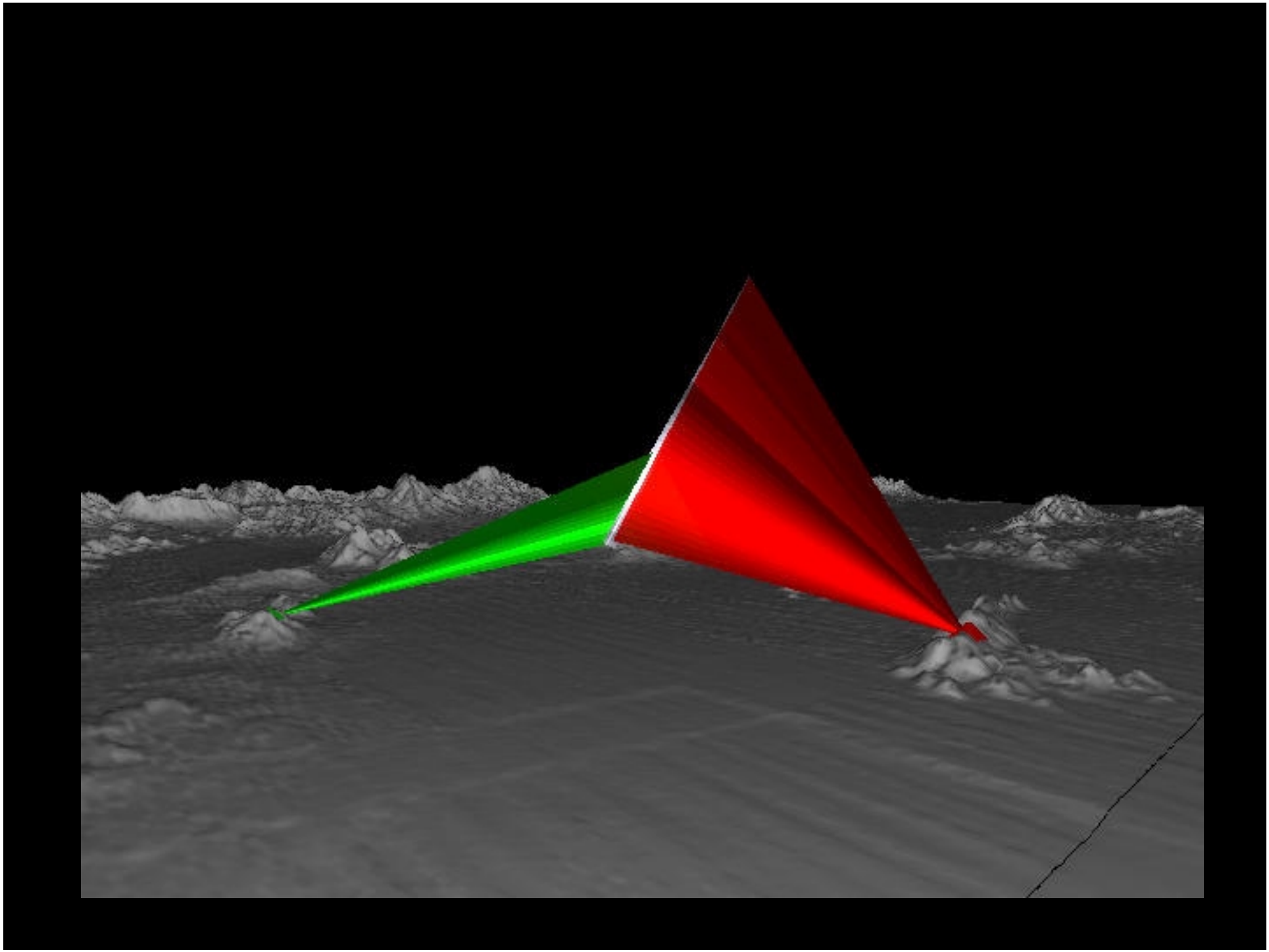
$$\gamma + \gamma_{CMB} \longrightarrow e^+ + e^-$$

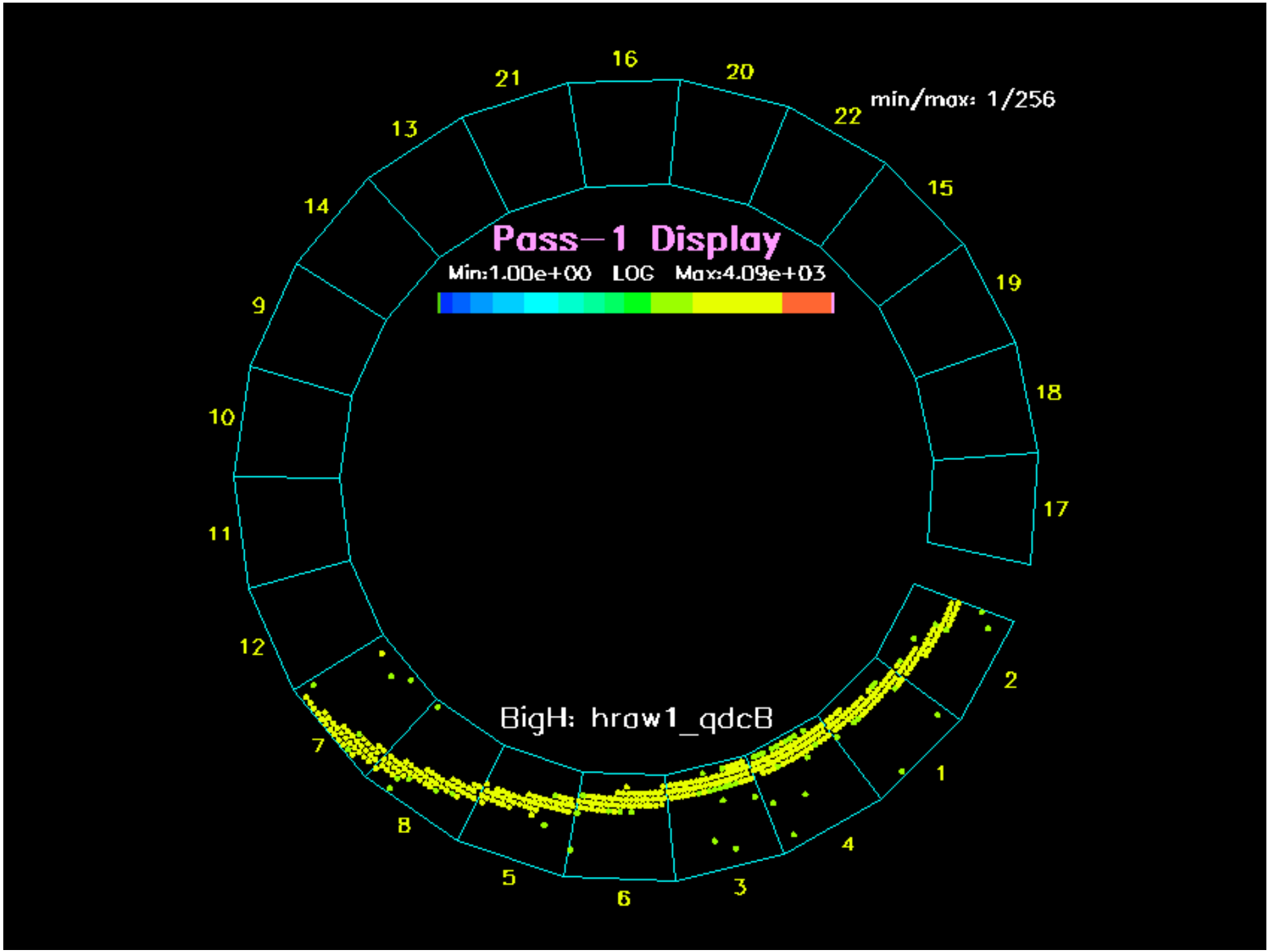

X_{max}, N_{max}
N_e
GeV μ's
TeV μ's

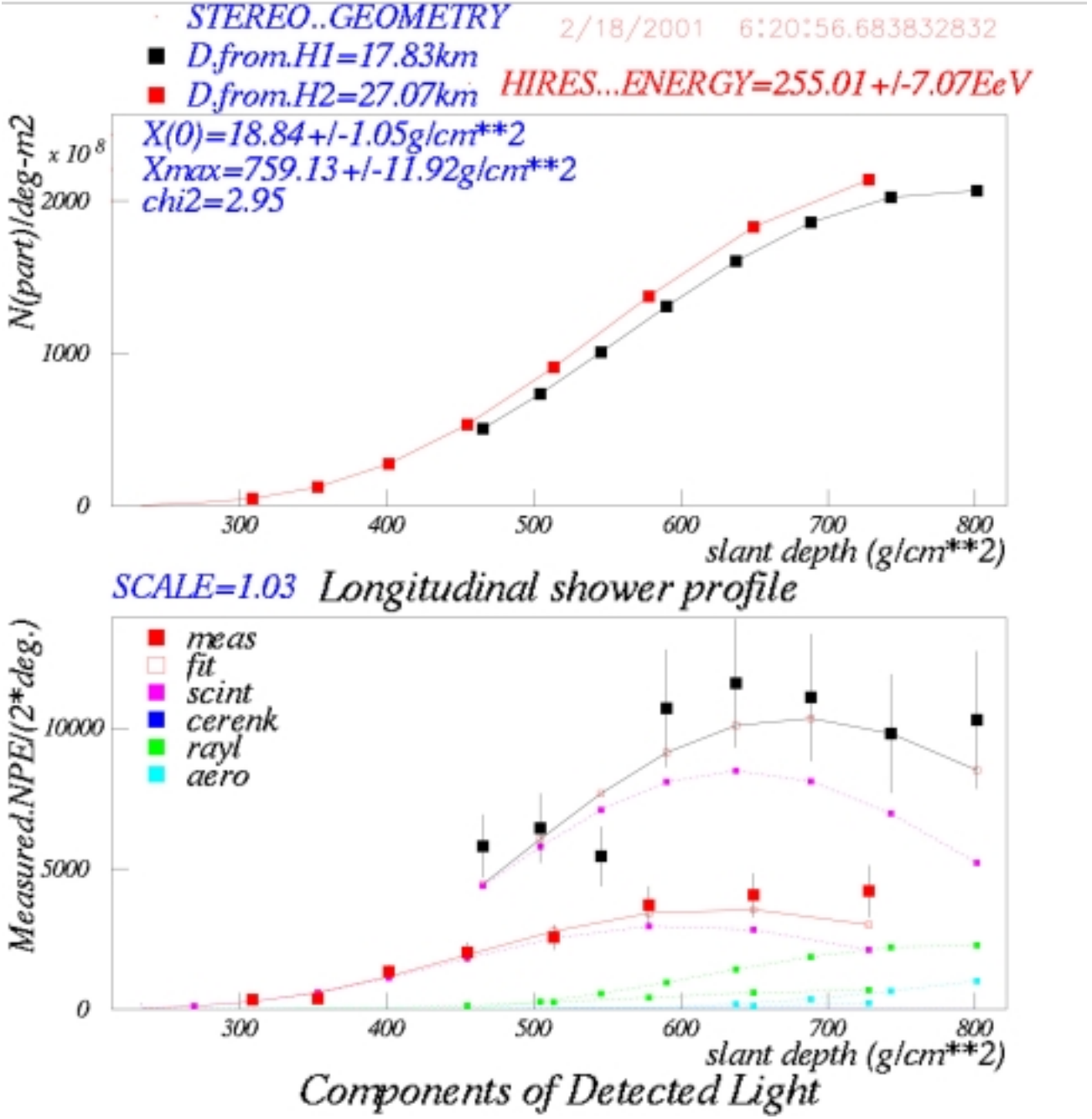

AGASA
Fly's Eye (mono)
Uniform sources
8
4
2
3
3
1
J(E) E^3 [m^-2 sec^-1 sr^-1 eV^2]
Energy [eV]
10^26
10^25
10^24
10^23
10^19
10^20
10^21

fluorescence from atmospheric nitrogen






Pass-1 Display
Min:1.00e+00 LOG Max:4.09e+03
min/max: 1/256
BigH: hraw1_qdcB
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22


STEREO..GEOMETRY
2/18/2001 6:20:56.683832832
D.from.H1=17.83km
D.from.H2=27.07km
HIRES...ENERGY=255.01+/-7.07EeV
X(0)=18.84+/-1.05g/cm**2
Xmax=759.13+/-11.92g/cm**2
chi2=2.95
N(part)/deg-m2
x 10^8
2000
1000
0
300
400
500
600
700
800
slant depth (g/cm**2)
SCALE=1.03
Longitudinal shower profile
meas
fit
scint
cerenk
rayl
aero
Measured.NPE/(2*deg.)
10000
5000
0
300
400
500
600
700
800
slant depth (g/cm**2)
Components of Detected Light

Acceleration to 10^{21}eV?

~10^2 Joules

~ 0.01 M_{GUT}

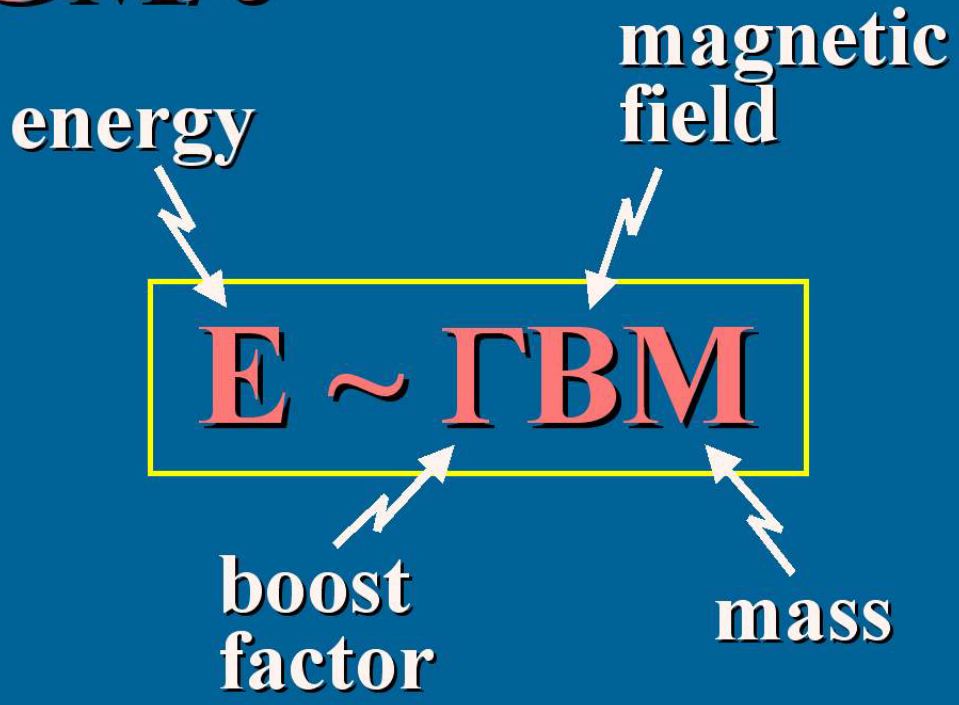
dense regions with exceptional gravitational force creating relativistic flows of charged particles, e.g.

- **annihilating black holes/neutron stars**
- **dense cores of exploding stars**
- **supermassive black holes**

Cosmic Accelerators

$$E \sim \Gamma c B R$$

$$R \sim GM/c^2$$

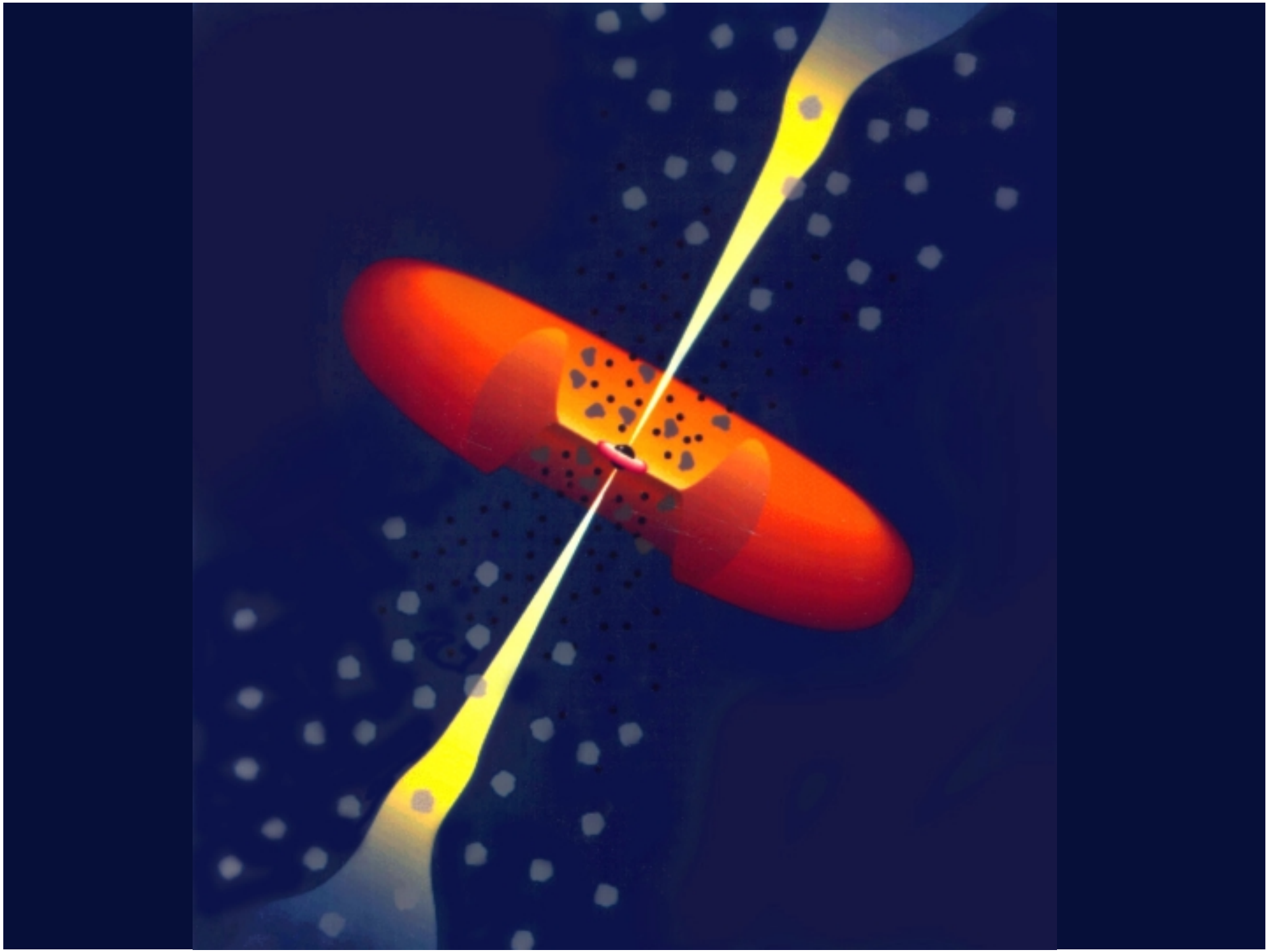


$E \sim \Gamma B M$

$E > 10^{19}$ eV ?

•quasars	$\Gamma \cong 1$	$B \cong 10^3$G	$M \cong 10^9 M_{sun}$
•blasars	$\Gamma \gtrsim 10$		
•neutron stars	$\Gamma \cong 1$	$B \cong 10^{12}$G	$M \cong M_{sun}$
black holes			
:			
•grb	$\Gamma \gtrsim 10^2$		

emit highest energy γ's!

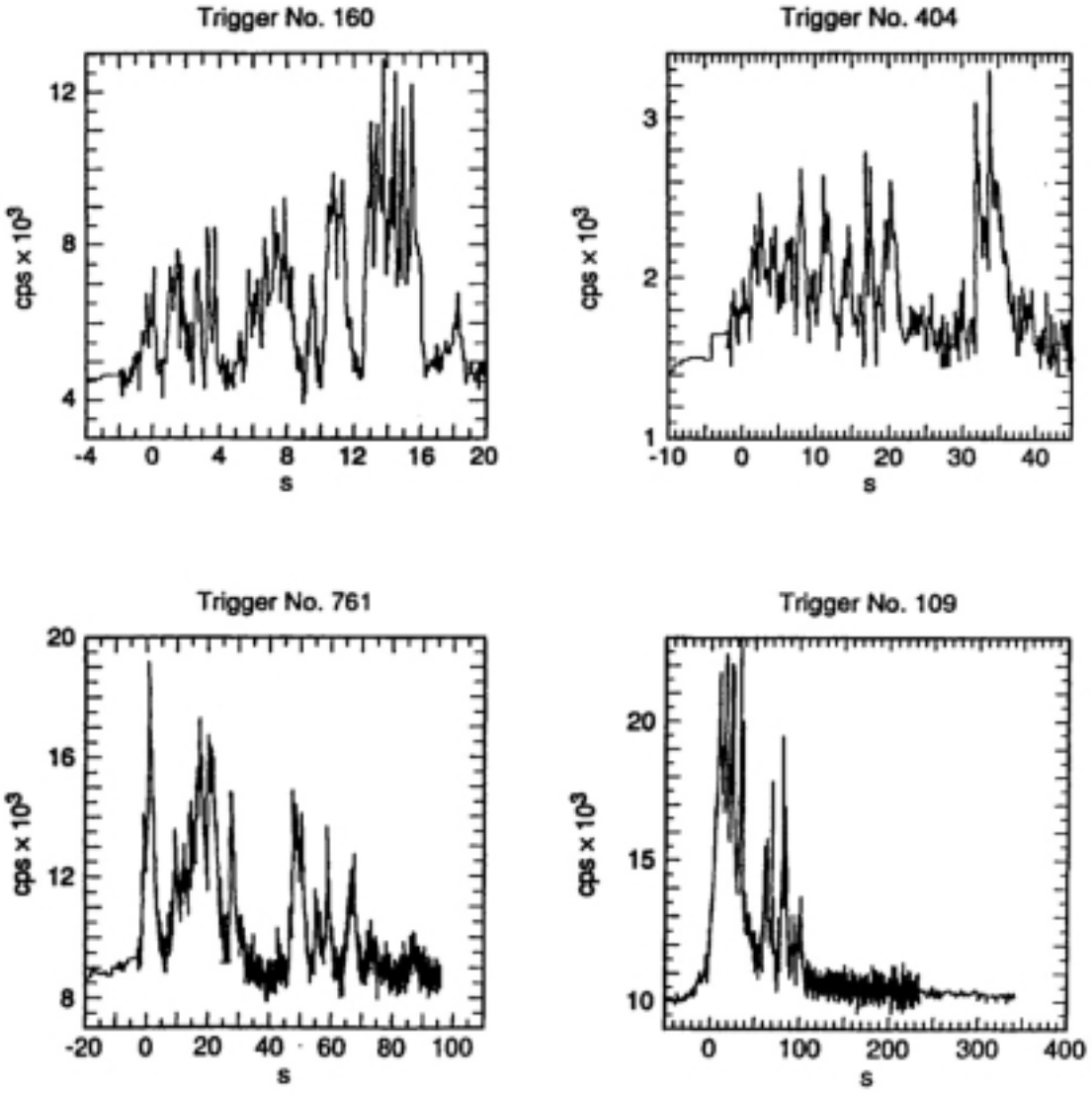


Profile of Gamma Ray Bursts

- Total energy: one solar mass
- Photon energy: 0.1 MeV to TeV
- Duration: 0.1 secs -- 20 min
- Several per day
- Brightest object in the sky
- Complicated temporal structure:

  no ‘typical’ burst profile

Examples of gamma-ray bursts with extremely complex temporal structures



seconds

A few more results …

- Gamma Ray Bursts (GRBs)
  - Observation of single 3 σ excess (GRB 970417a) within 1997 BATSE trigger.
- Flux limit for unidentified TeV point sources
  - For E spectrum

Flux (>1 TeV) < 2 – 30 x 10^{-7} cm^{-2} s^{-1} @ 90%

AMANDA II will probe this flux for

$$\nu/\gamma = 1$$

However, γ spectrum probably softer due to reprocessing (core) and absorption in photon BG

Particles > 10^{20} eV ?

- **not protons**
  - cannot reach us from cosmic accelerators
  - $\lambda_{int} < 50$ Mpc
  - no diffusion in magnetic fields
  - doublets, triplet
- **not photons**
  - $\gamma + B_{earth} \rightarrow e^+ + e^-$ not seen
  - showers not muon-poor
- **not neutrinos**
  - $\sigma_{\nu p} \cong 10^{-5}\, \sigma_{pp} \rightarrow$ no <u>air</u> showers

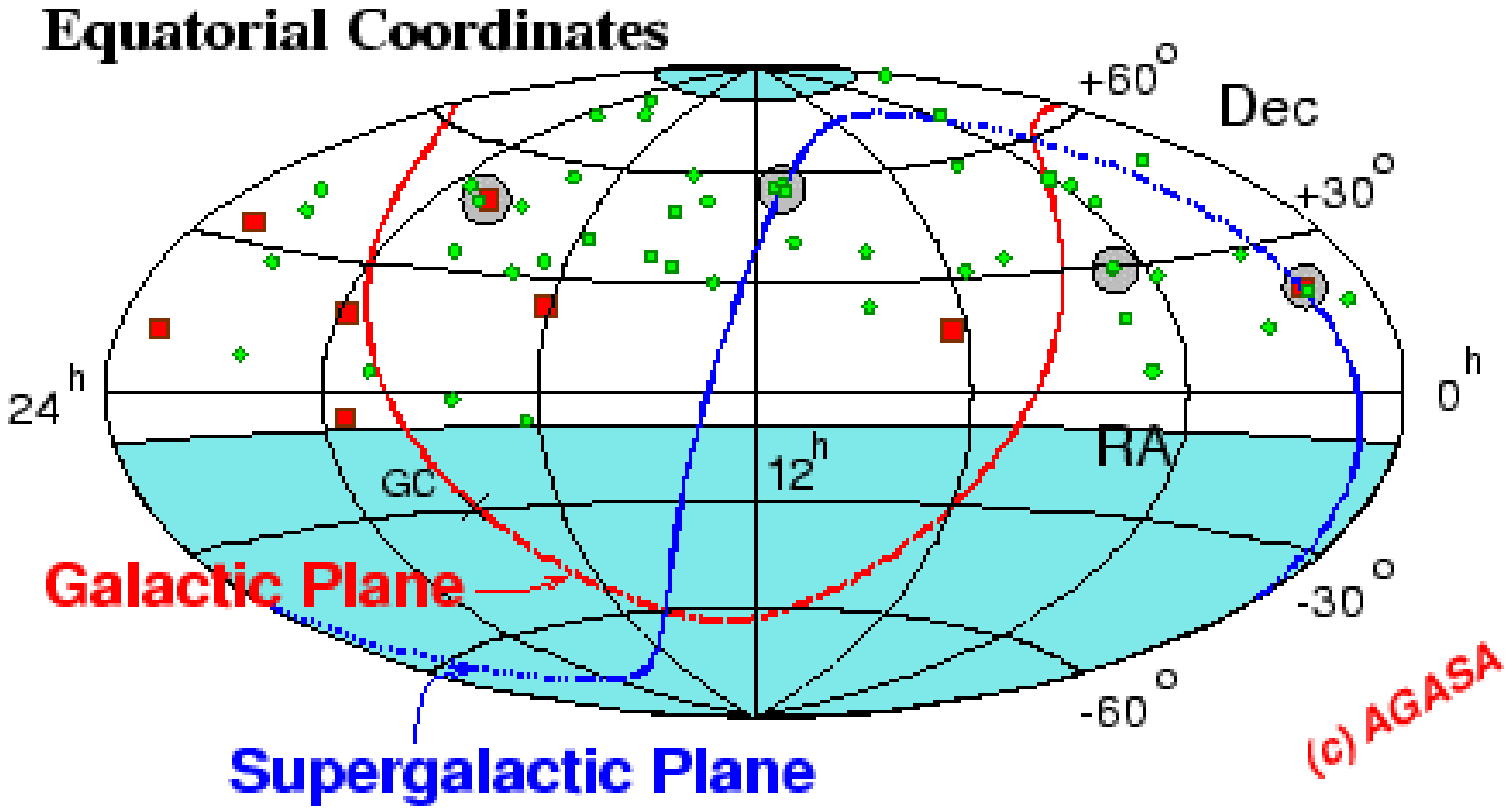
Interaction length of protons in microwave background

$$p + \gamma_{CMB} \rightarrow \pi + \ldots.$$

$$\lambda_{\gamma p} = (n_{CMB}\, \sigma_{p+\gamma_{CMB}})^{-1}$$

$$\cong 10 \text{ Mpc}$$

GZK cutoff


Equatorial Coordinates
+60°
Dec
+30°
24h
0h
12h
RA
GC
-30°
-60°
Galactic Plane
Supergalactic Plane
(c) AGASA

Forthcoming AGASA Results

- The highest energy cosmic rays do come from point sources: 5 sigma correlation between directions of pairs of particles. Birth of proton astronomy!
- Are the highest energy cosmic rays Fe?

  ⟶ GKZ cutoff at ~2 10^{20} eV ?

Particles > 10^{20} eV ?

new astrophysics?

- **not protons**

  cannot reach us from cosmic accelerators

  $\lambda_{int} < 50$ Mpc

  no diffusion in magnetic fields

  doublets, triplet

trouble for top-down scenarios

- **not photons**

  $\gamma + B_{earth} \rightarrow e^+ + e^-$ not seen

  showers not muon-poor

- **not neutrinos**

  $\sigma_{\nu p} \cong 10^{-5}\, \sigma_{pp} \longrightarrow$ no air showers

$\sigma_{\nu p} \cong \sigma_{pp}$ with TeV - gravity unitarity?

10^{24} eV = 10^{15} GeV ≃ M_{GUT}

are cosmic rays the decay product of

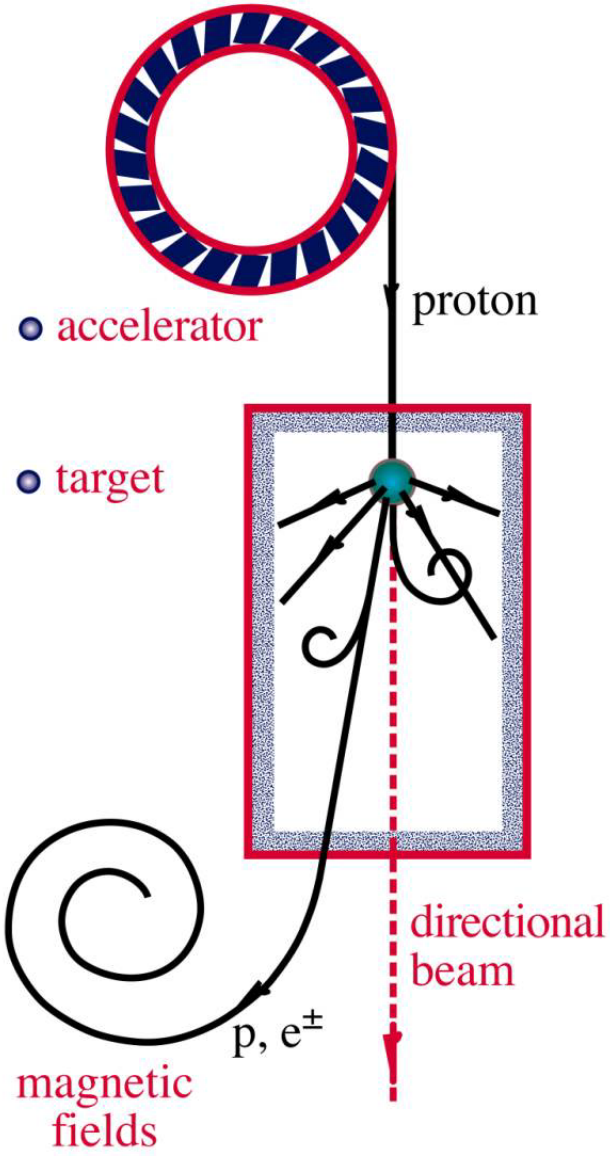
- **topological defects**
  (vibrating string, annihilating monopoles)
- **heavy relics?**

Top. Def. → X,Y → W, Z → quark + leptons

$\gamma >> p$ $\nu >> \gamma$

- top-down spectrum
- hierarchy $\nu >> \gamma >> p$

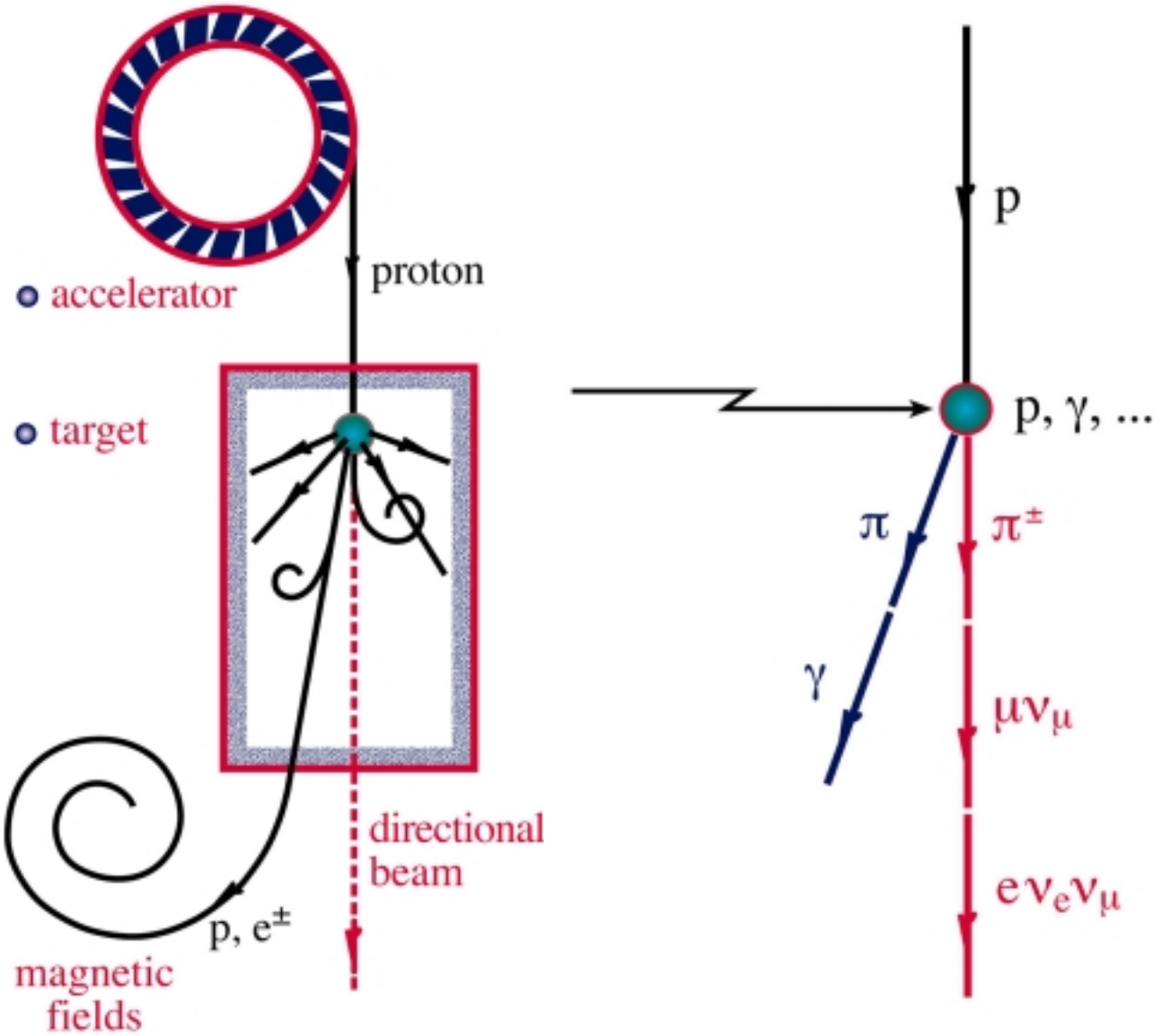
NEUTRINO BEAMS: HEAVEN & EARTH



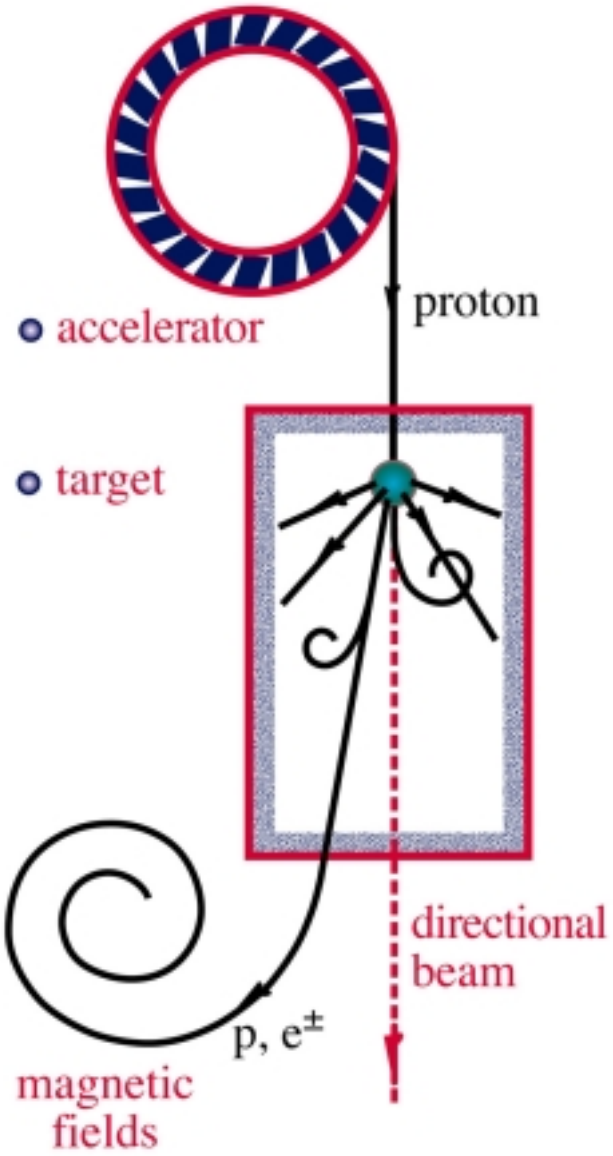
black hole

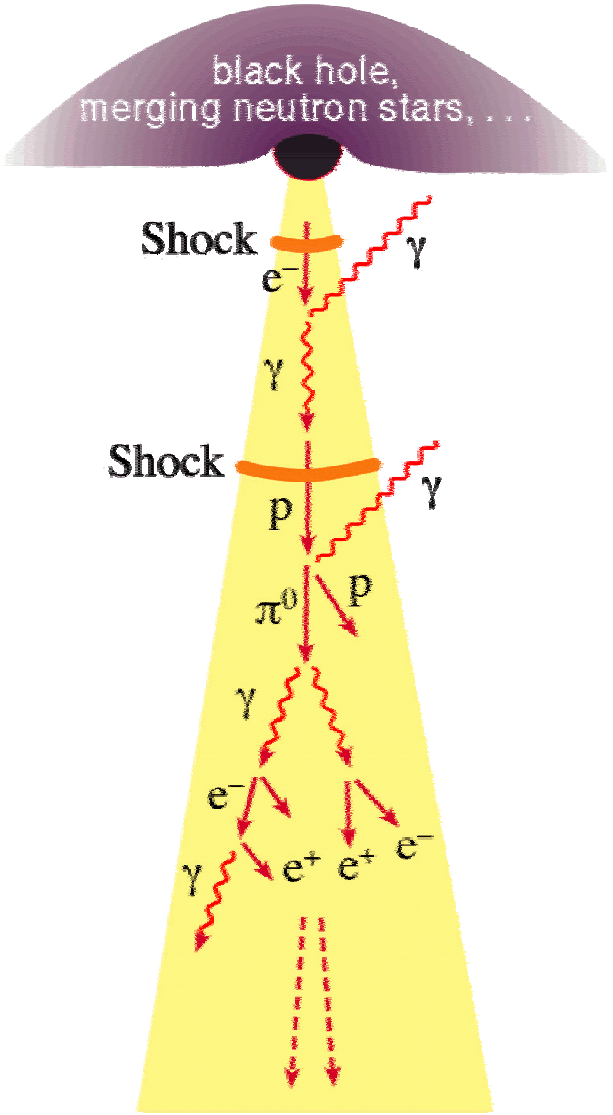
radiation
enveloping
black hole

NEUTRINO BEAMS: HEAVEN & EARTH



NEUTRINO BEAMS: HEAVEN & EARTH





cosmic ray puzzle

protons

~ 10^4 km^2 air shower arrays

e.g. •Hi Res, Auger, Airwatch, OWL, TA…

also

TeV γ - rays

•atmospheric Cherenkov

•space-based

•Veritas, Hess, Magic …

•GLAST…

•short-wavelength study of supernova remnants and galaxies

neutrinos

~ 1 km^3 high energy detectors

•AMANDA / Ice Cube Antares, Nestor, NEMO

•particle physics and cosmology

•dark matter search

•discovery

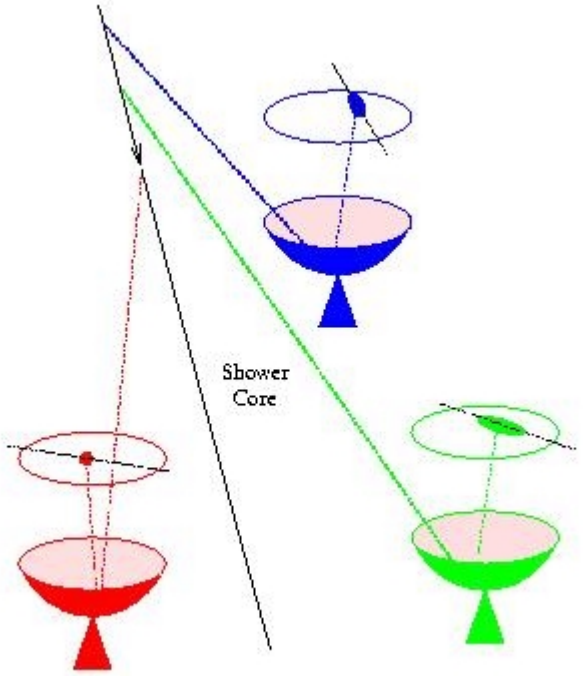
Array

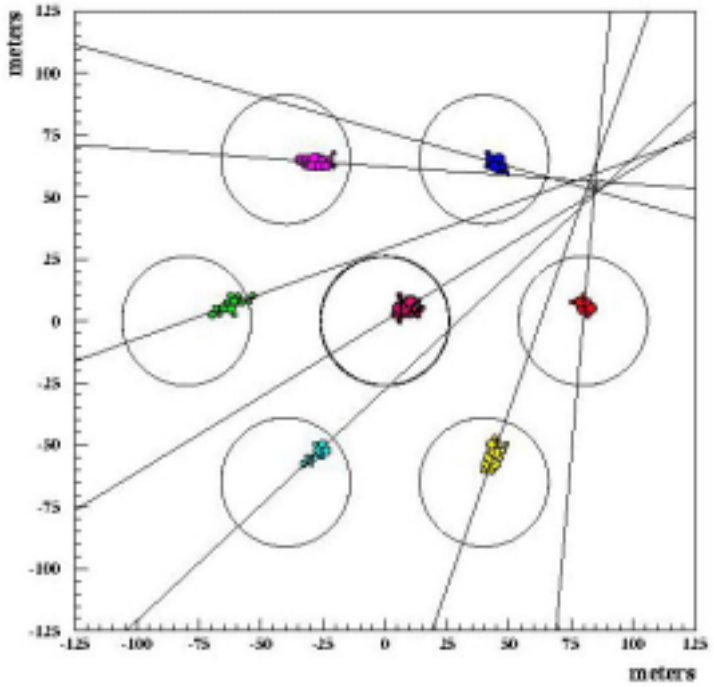
=> Very large effective area (10^5 m^2)

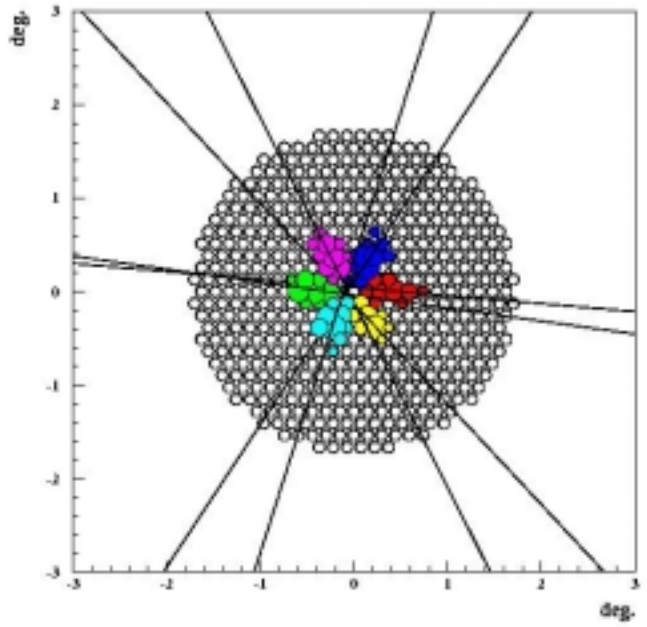
=> 3-dim shower reconstruction

=> Dramatic improvements in

- Energy Resolution
- Background Rejection



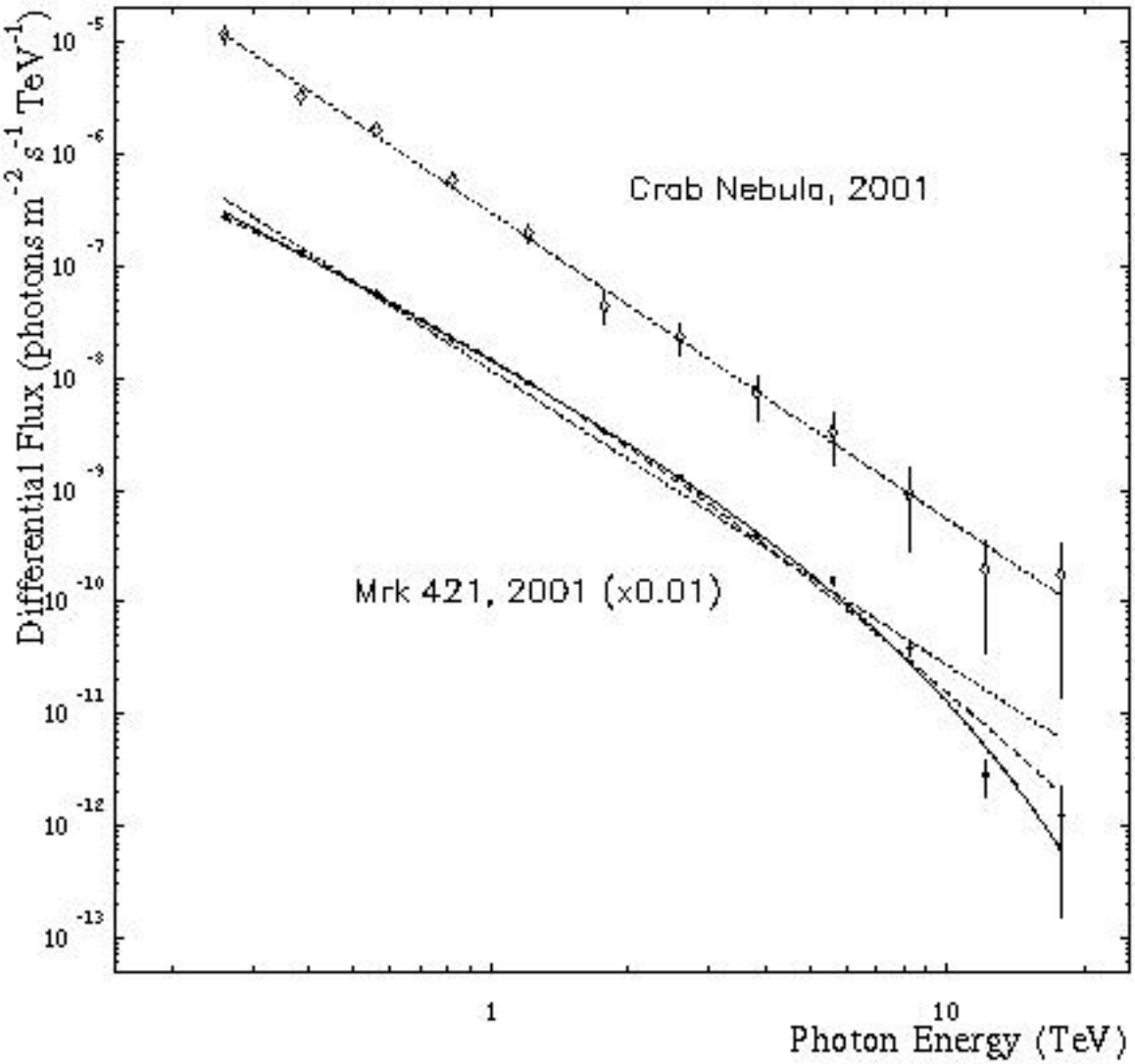


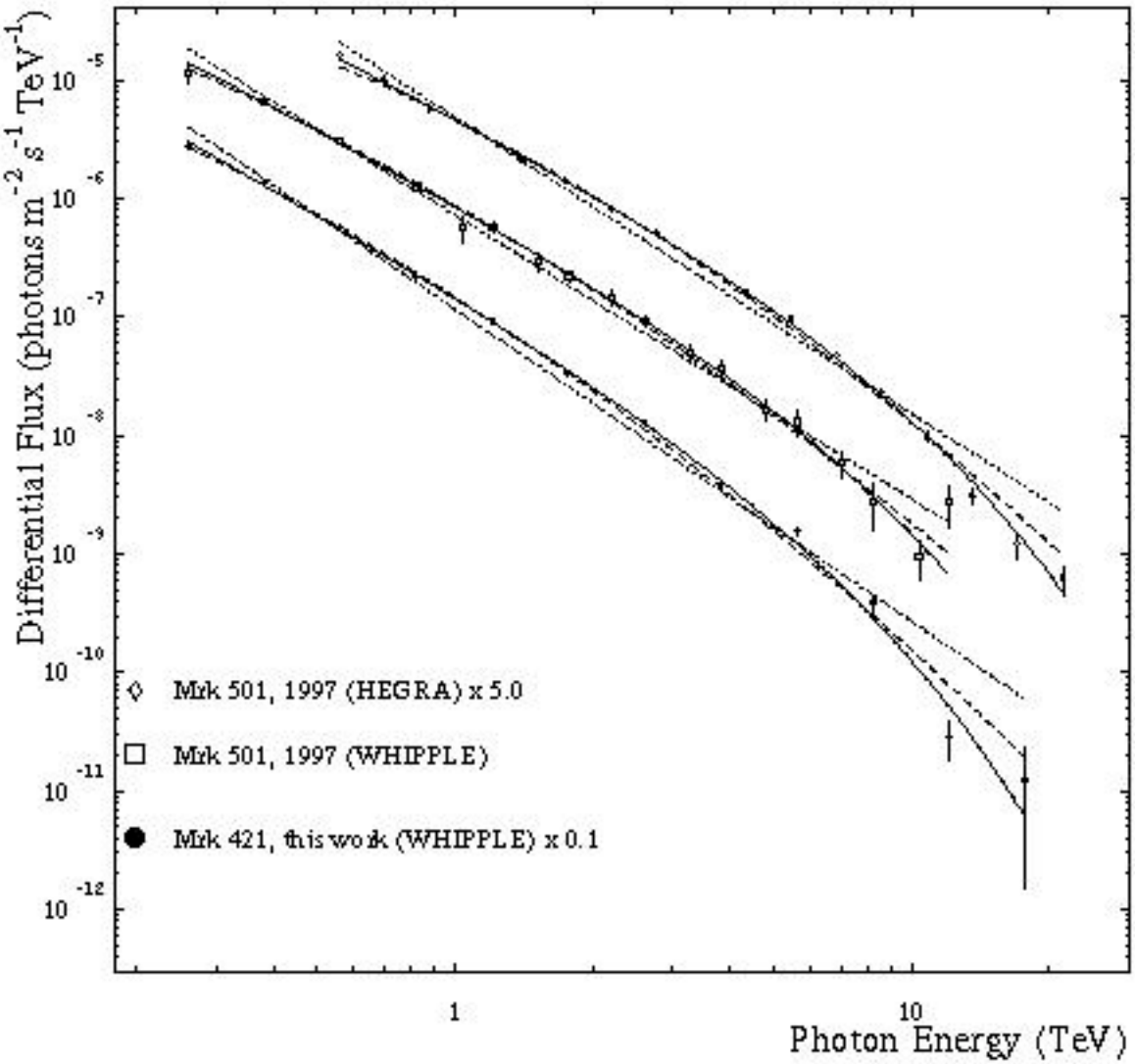


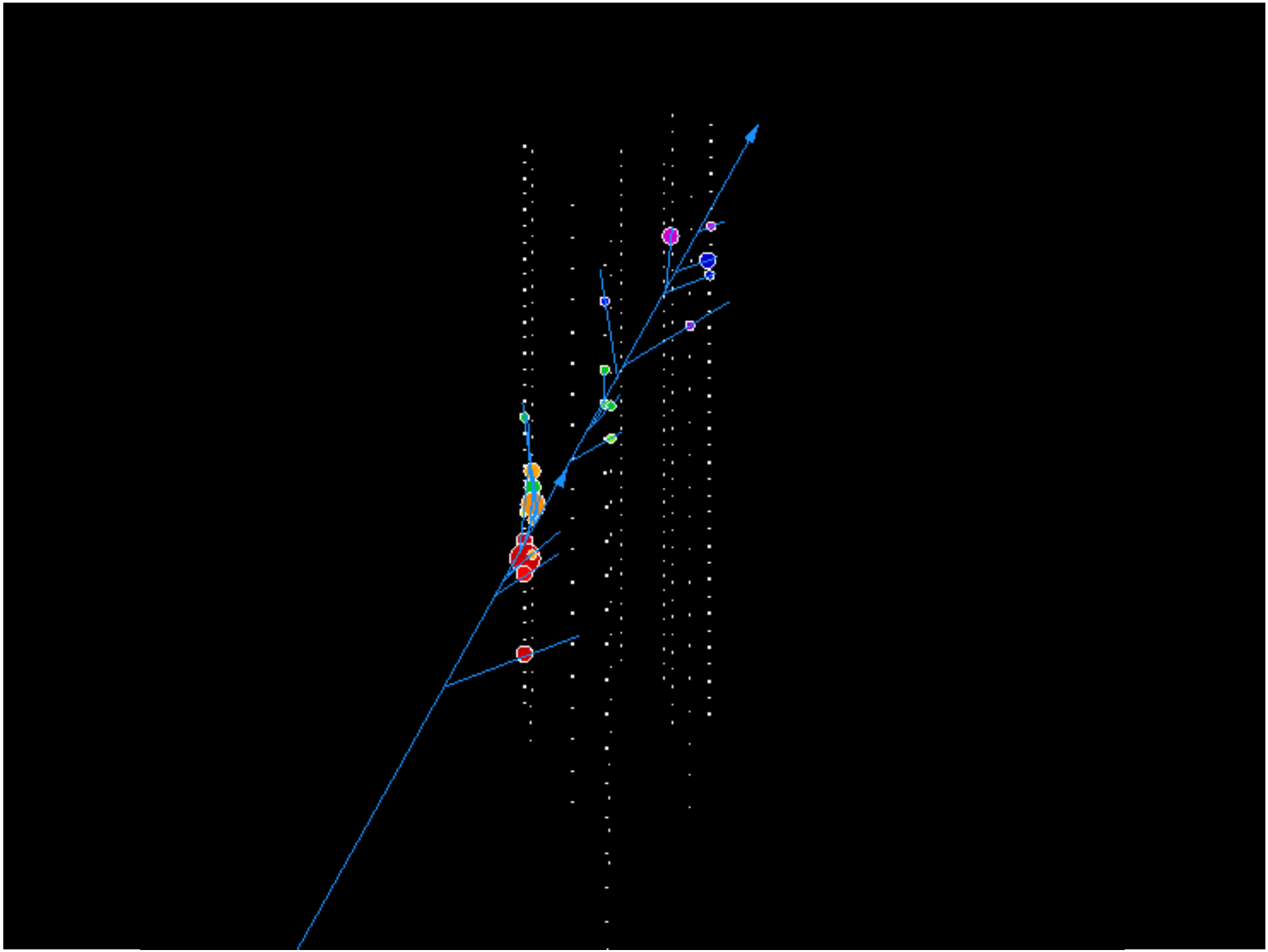
STACEE

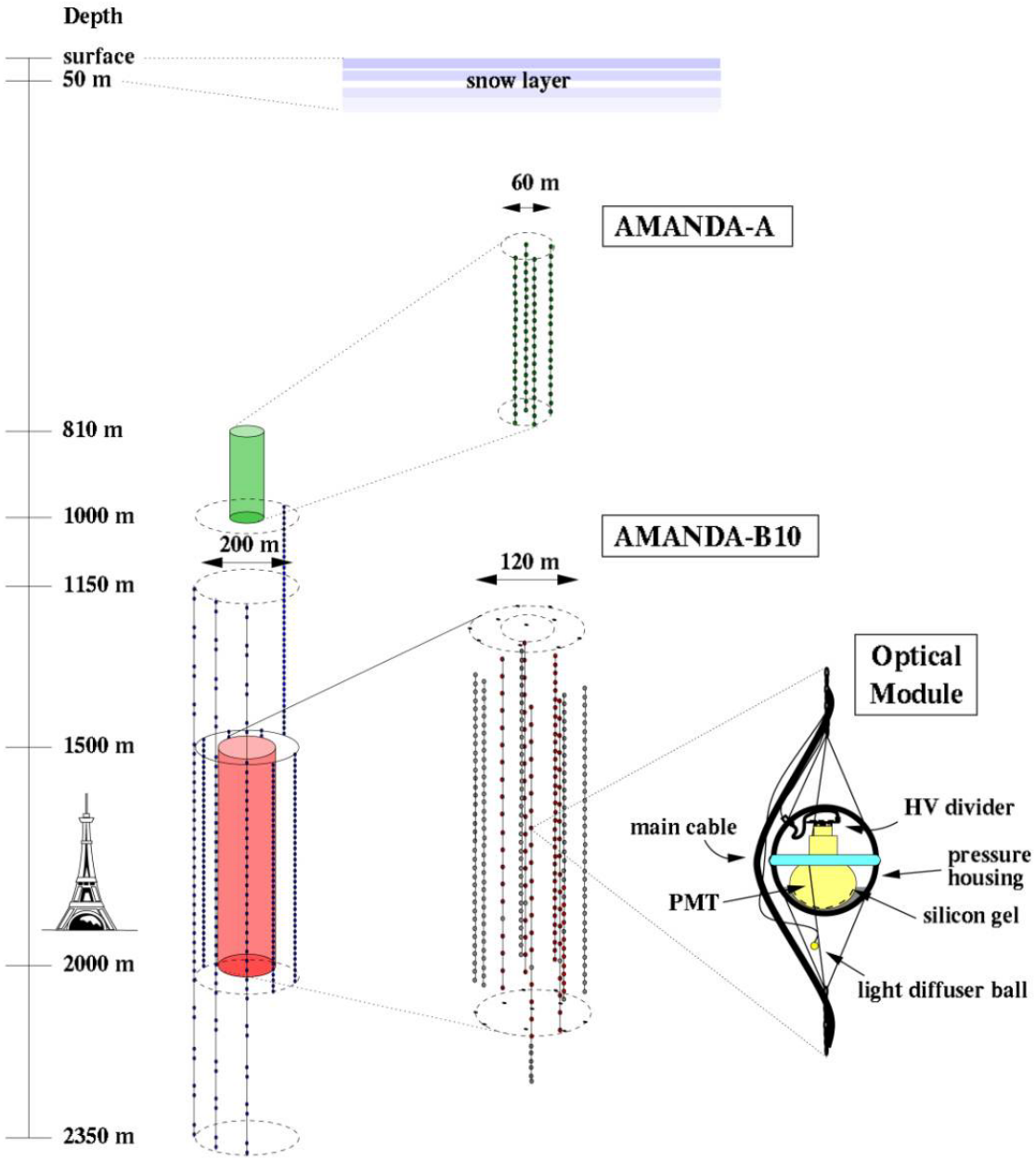
Solar Tower Atmospheric Cherenkov Effect Experiment

Gamma-ray Astrophysics between 50-500 GeV


Crab Nebula, 2001
Mrk 421, 2001 (x0.01)
Differential Flux (photons m^{-2} s^{-1} TeV^{-1})
Photon Energy (TeV)
1
10


Differential Flux (photons m^{-2} s^{-1} TeV^{-1})
Photon Energy (TeV)
Mrk 501, 1997 (HEGRA) x 5.0
Mrk 501, 1997 (WHIPPLE)
Mrk 421, this work (WHIPPLE) x 0.1

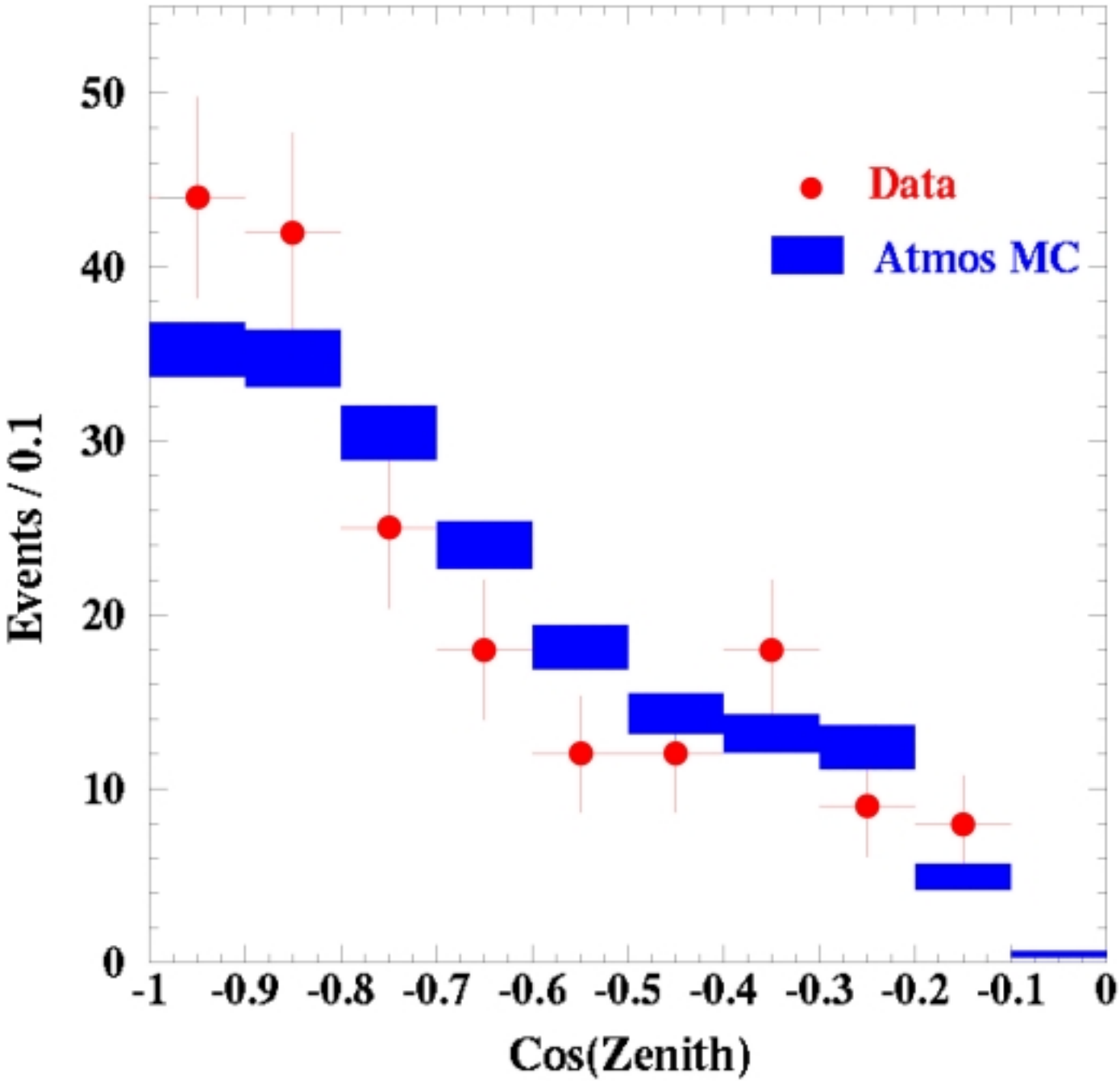


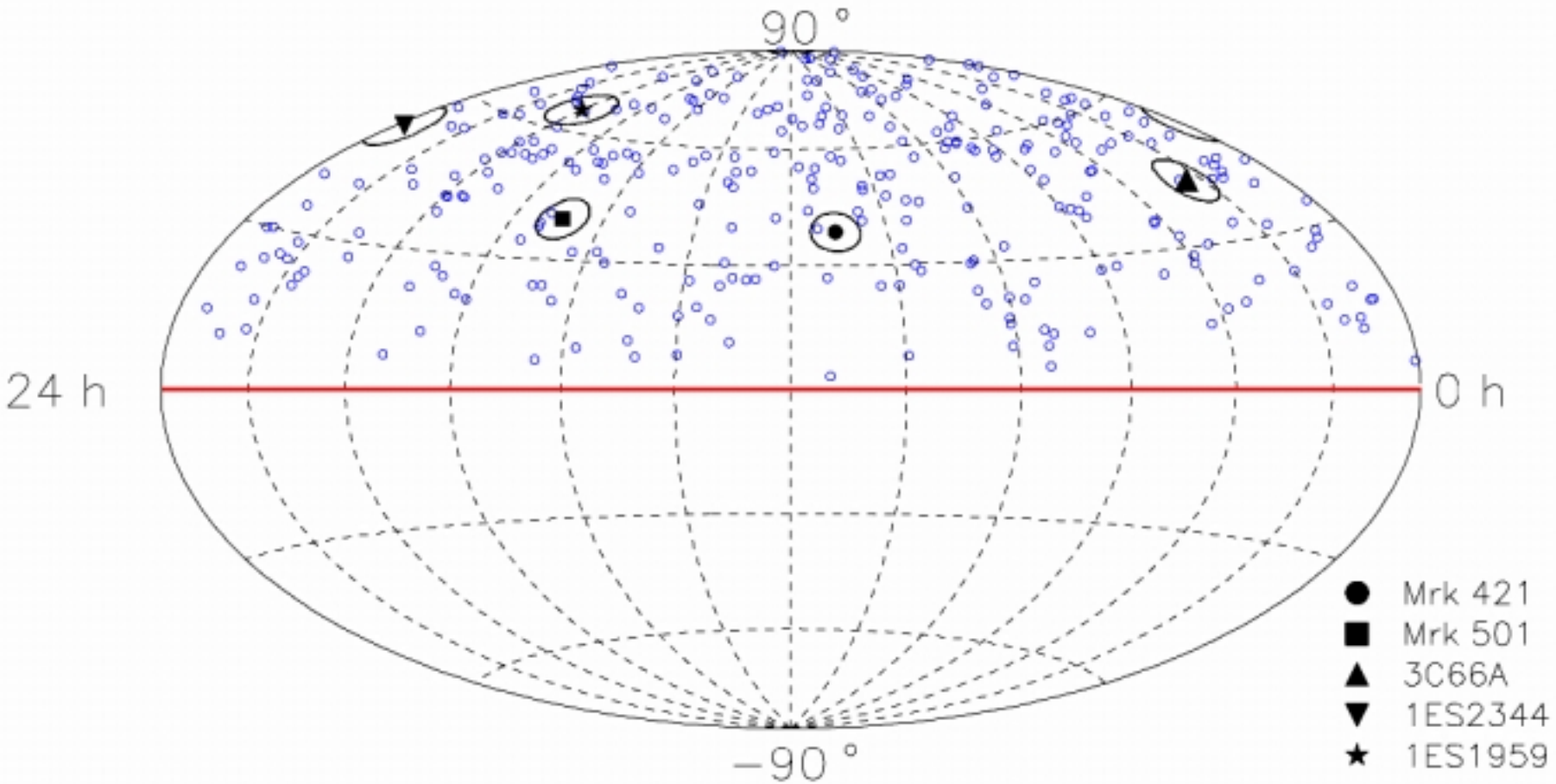


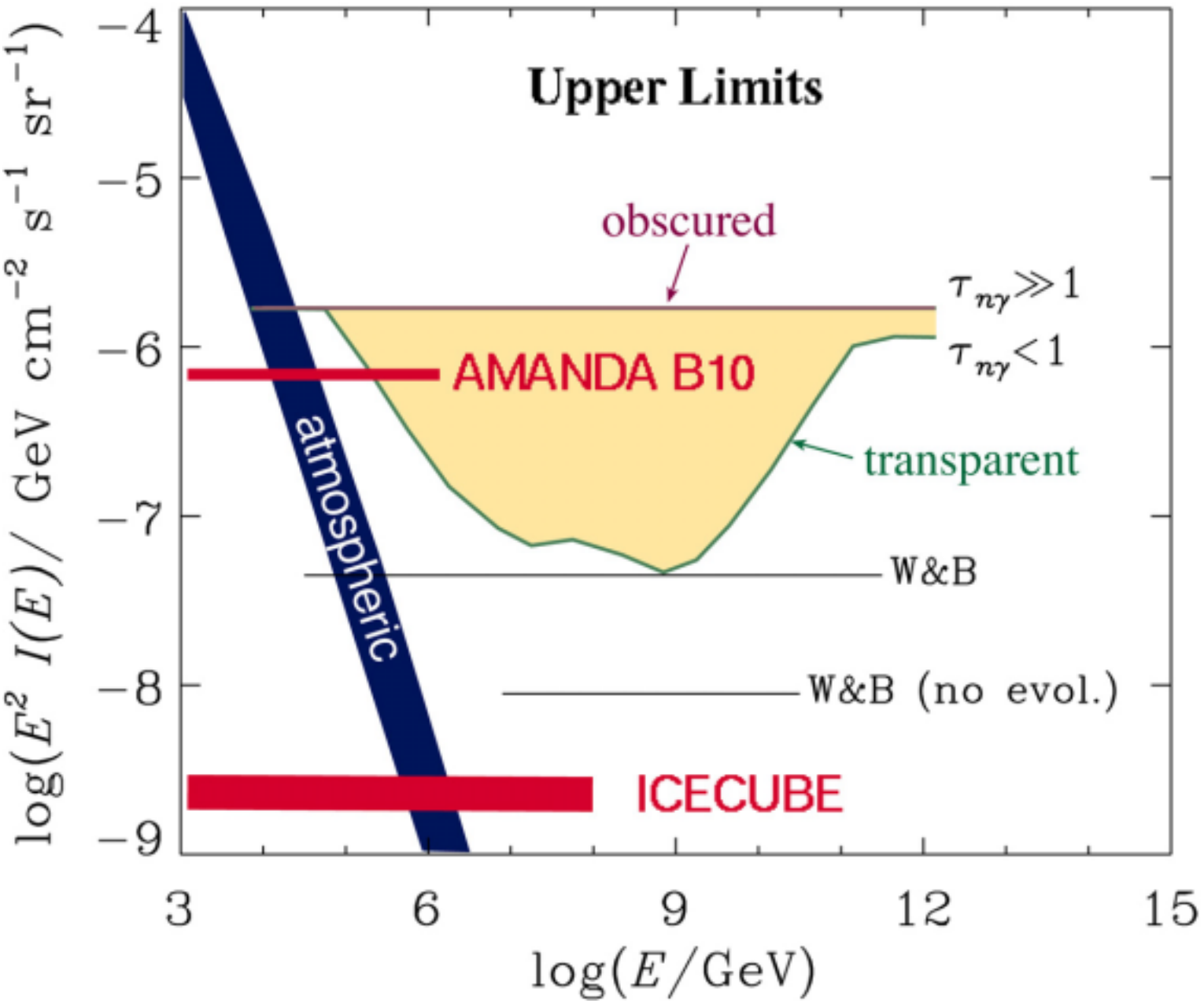
AMANDA as of 2000
Eiffel Tower as comparison
(true scaling)

zoomed in on
AMANDA-A (top)
AMANDA-B10 (bottom)

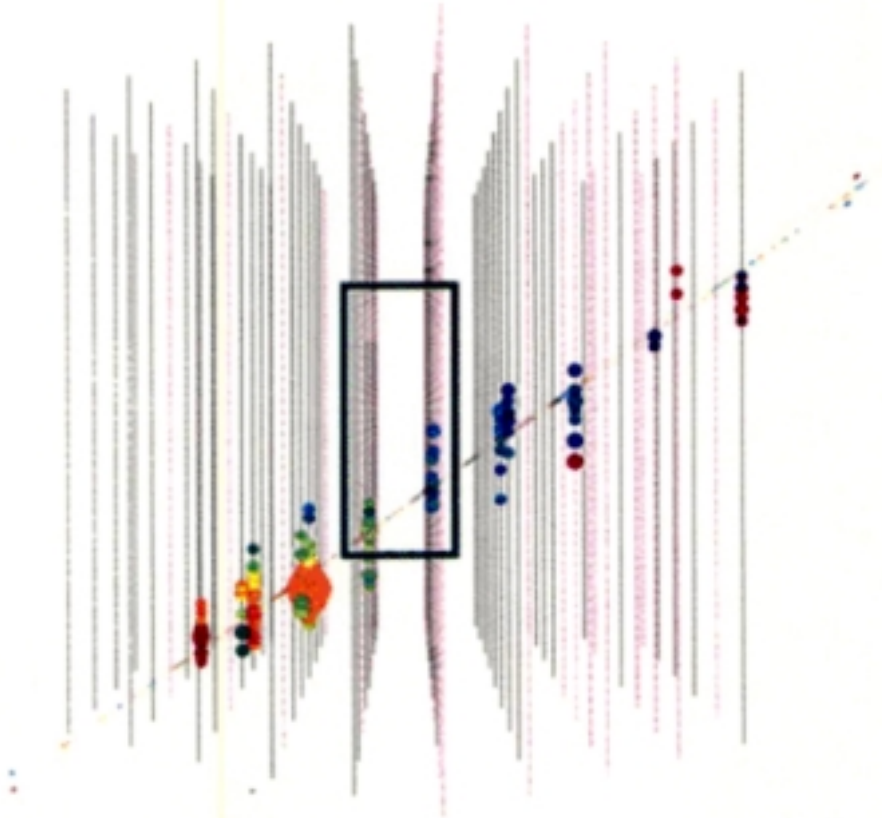
zoomed in on one
optical module (OM)


Data
Atmos MC
Events / 0.1
Cos(Zenith)
0
10
20
30
40
50
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0


90 °
24 h
0 h
−90 °
Mrk 421
Mrk 501
3C66A
1ES2344
1ES1959


Upper Limits
obscured
$\tau_{n\gamma} \gg 1$
$\tau_{n\gamma} < 1$
AMANDA B10
transparent
atmospheric
W&B
W&B (no evol.)
ICECUBE
$\log(E^2\ I(E)/\ \mathrm{GeV\ cm^{-2}\ s^{-1}\ sr^{-1}})$
$\log(E/\mathrm{GeV})$
−4
−5
−6
−7
−8
−9
3
6
9
12
15

Amanda ⇒ Ice Cube



Amanda-B10

302 OMs

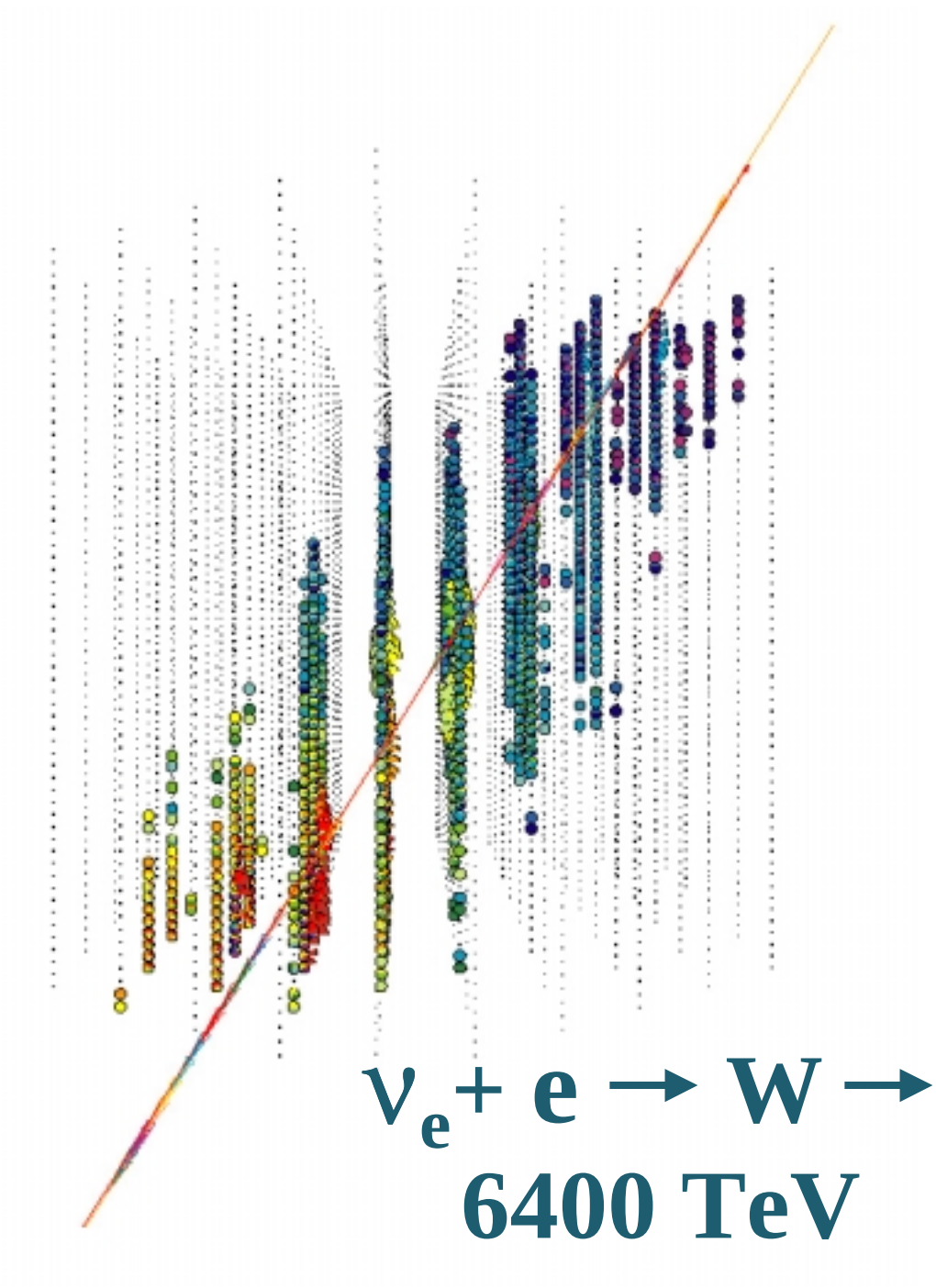
200 ν_{atm} in

130 days

Ice Cube

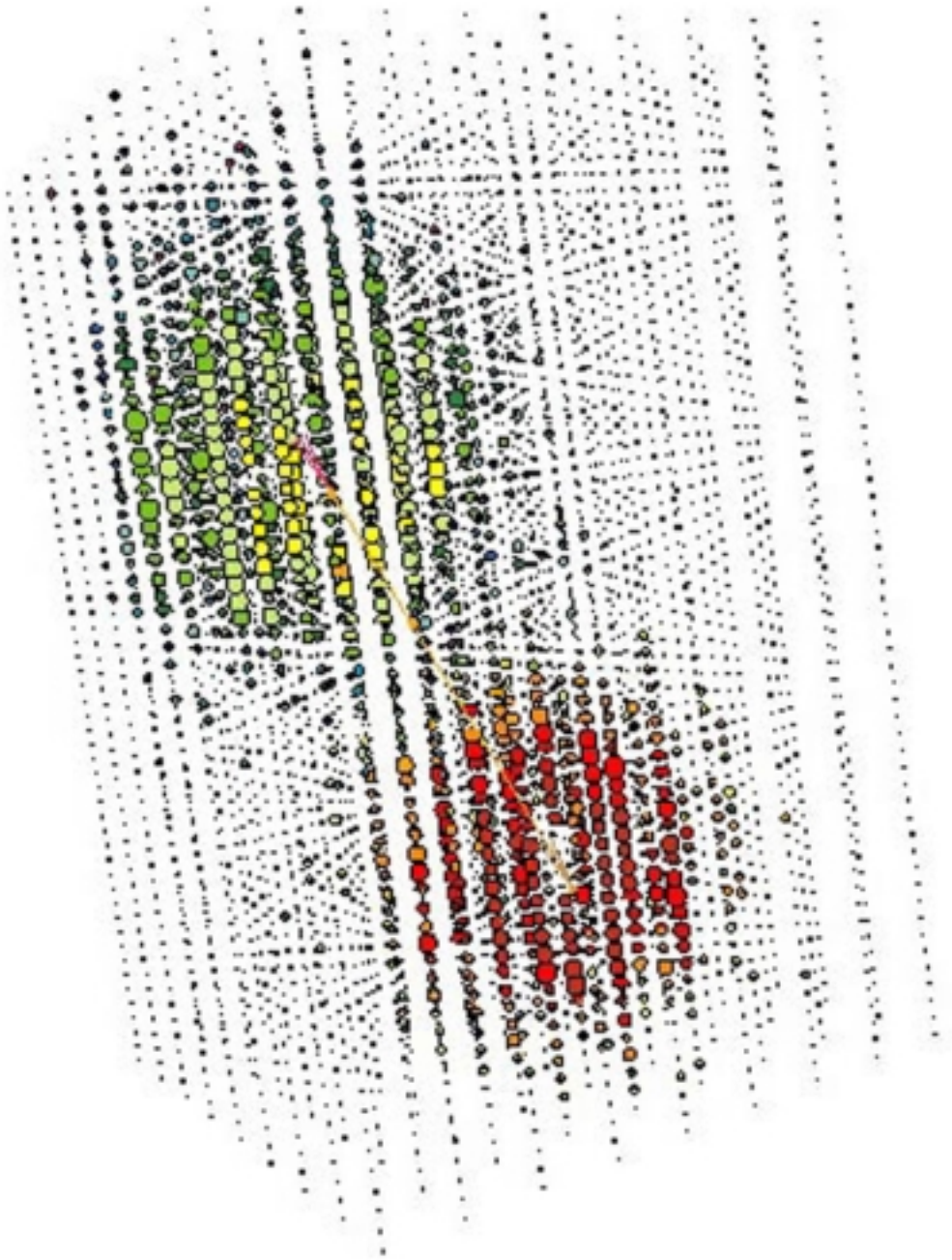
5000 OMs

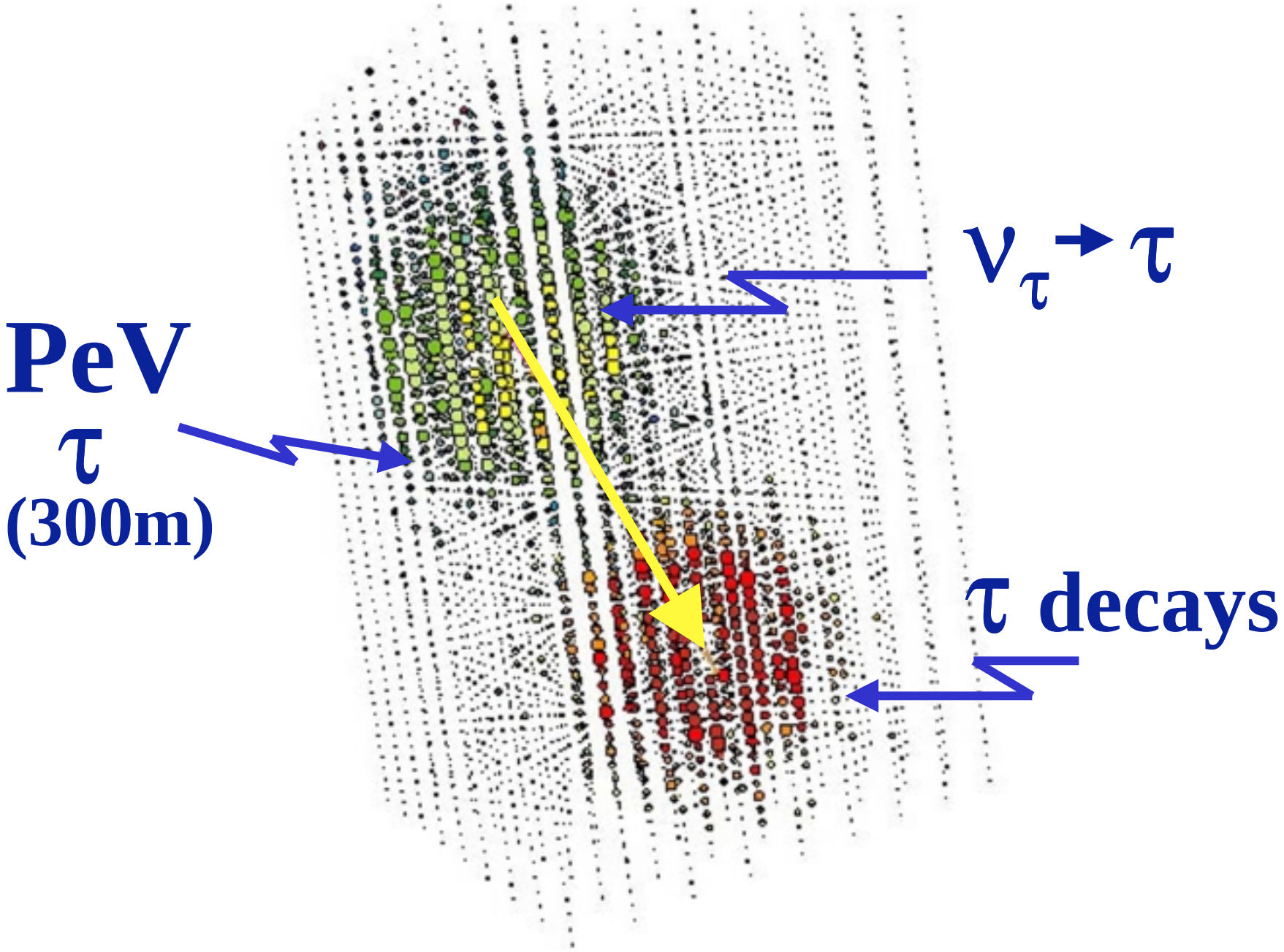
250 ν_{atm} per day



$\nu_e + e \rightarrow W \rightarrow \mu + \nu_\mu$

6400 TeV




PeV
τ
(300m)
$\nu_\tau \rightarrow \tau$
τ decays

Why is Searching for ν's from GRBs of Interest?

- Search for vacuum oscillations ($\nu_\mu \rightarrow \nu_\tau$):
  $\Delta m^2 \gtrsim 10^{-17}$ eV^2
- Test weak equivalence principle: 10^{-6}
- Test $\dfrac{C_{photon} - C_\nu}{C_\nu}$: 10^{-16}

Lepton - Photon 01

Francis Halzen

- **the sky** > 10 GeV photon energy

  $< 10^{-14}$ cm wavelength

- **$> 10^{8}$ TeV particles exist**

  Fly's Eye/Hires

- **they should not**
- **more/better data**

  → arrays of air Cherenkov telescopes

  → 10^{4} km^{2} air shower arrays

  → ~ km^{3} neutrino detectors