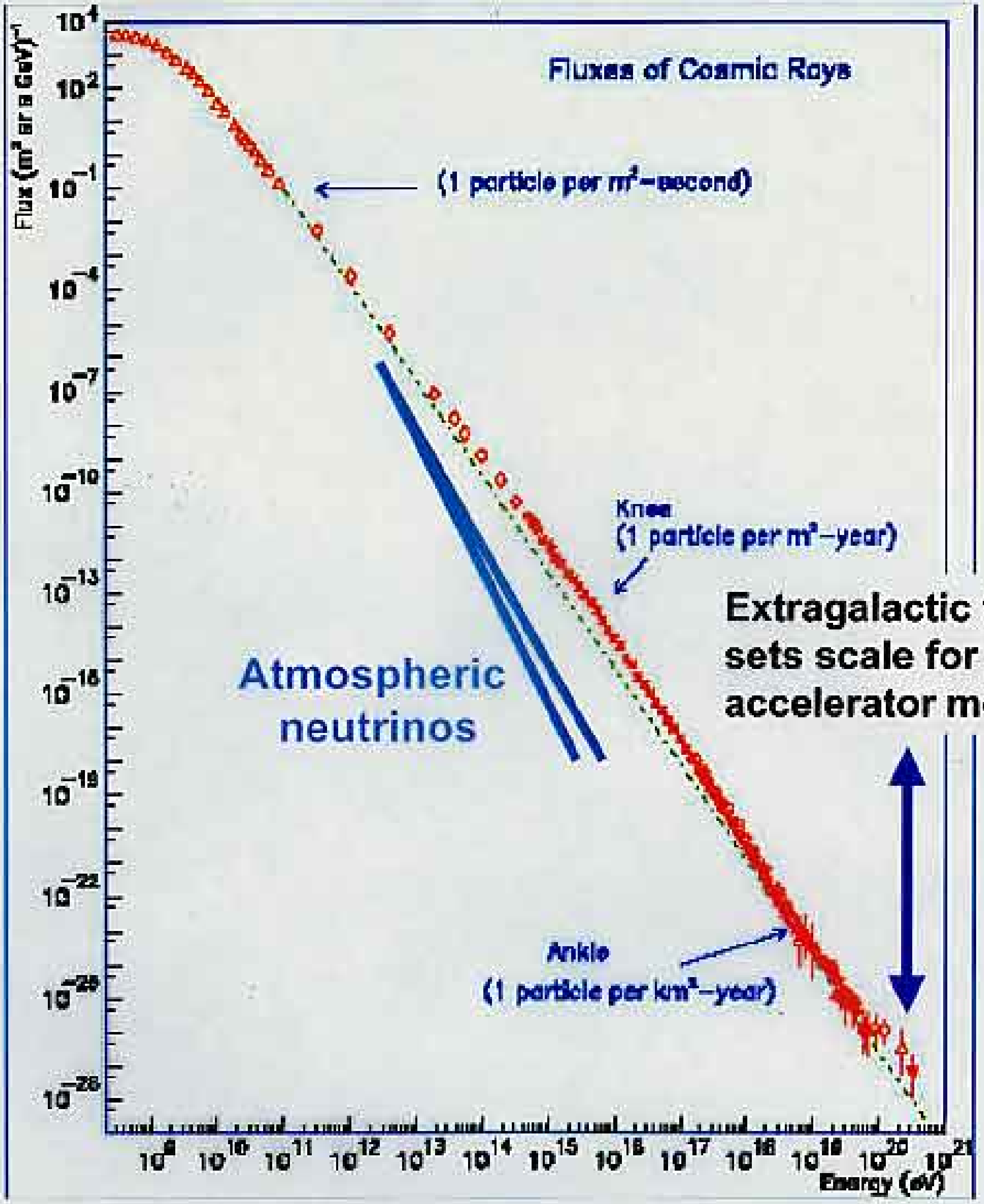
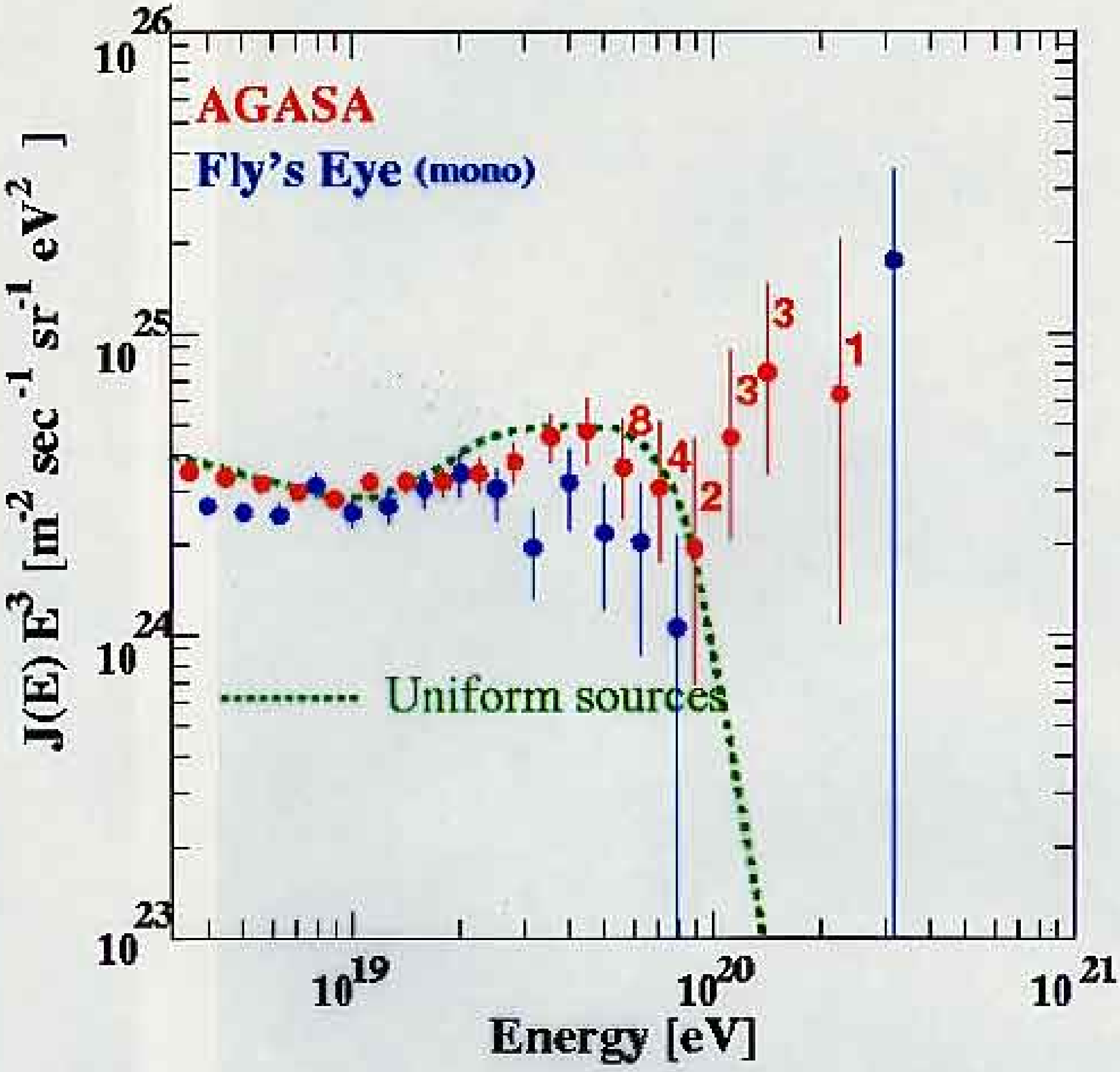
ULTRA HIGH ENERGY NEUTRINOS

- Motivate ν astronomy
- UHE νN cross sections
- Transparency of earth → ν_τ
- Detection of UHE ν_τ's

Alan Martin
WIN02

Cosmic Ray spectrum




AGASA
Fly's Eye (mono)
Uniform sources
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
8
4
2
3
3
1

Origin of UHE cosmic rays? a mystery

Bottom Up

V. powerful astrophysical objects may accelerate particles to $\gtrsim 10^{20}$ eV, but

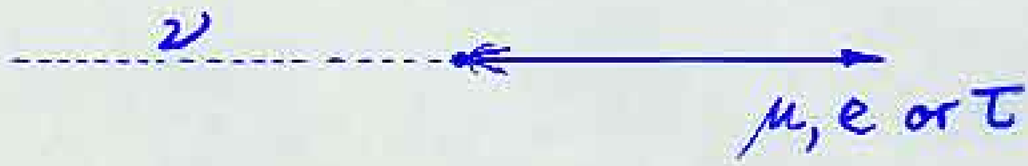
- source environment degrades energy
- GZK cut-off: γ_{CMB} prevents p, nuclei, γ's reaching us if $E \gtrsim 10^{20}$ eV (unless source 'nearby')

Top Down

Collapse of topological defects / Decay of super massive relic particles } attractive possibilities, but

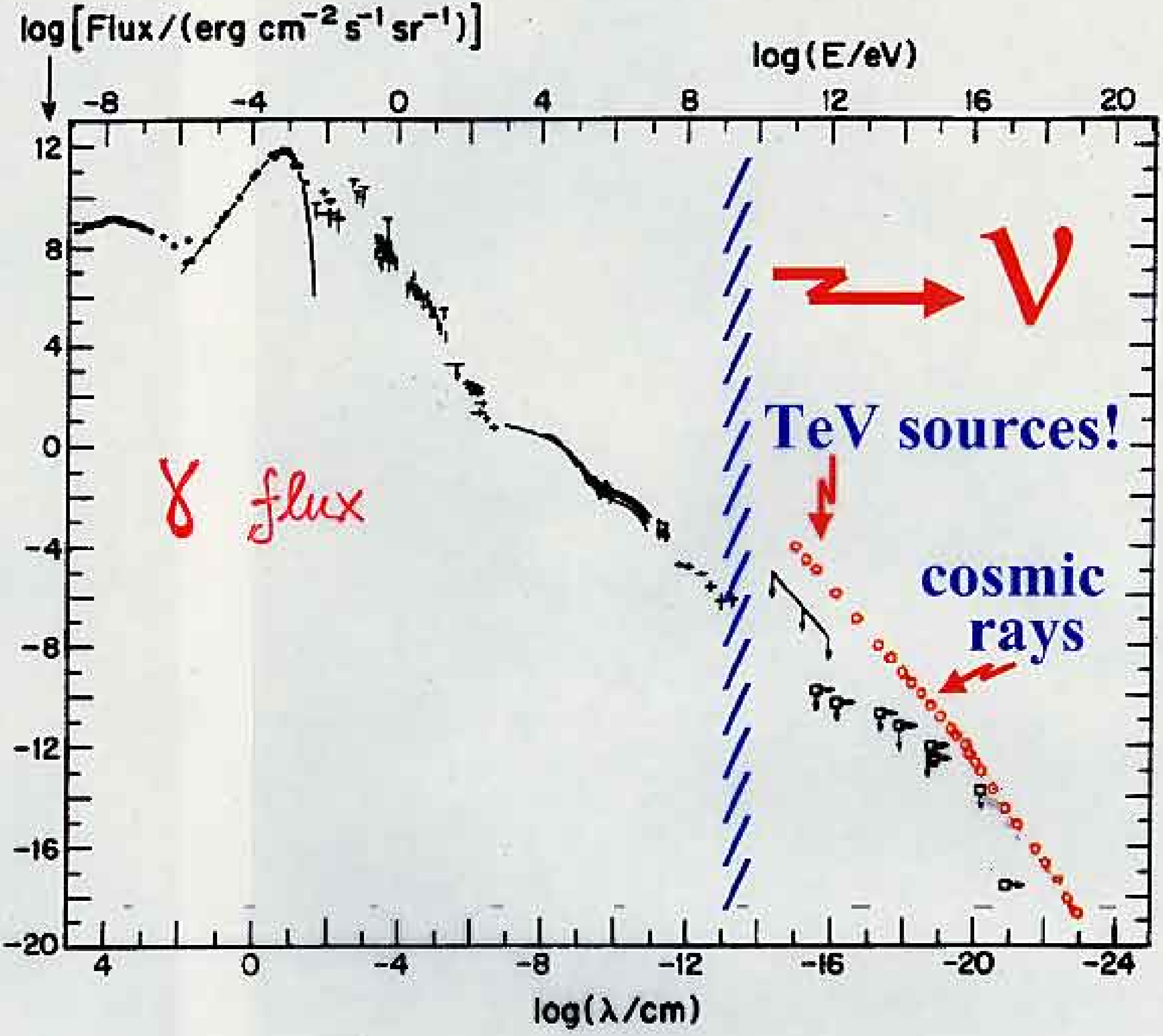
severe constraints from observed γ flux.

→ UHE ν astronomy



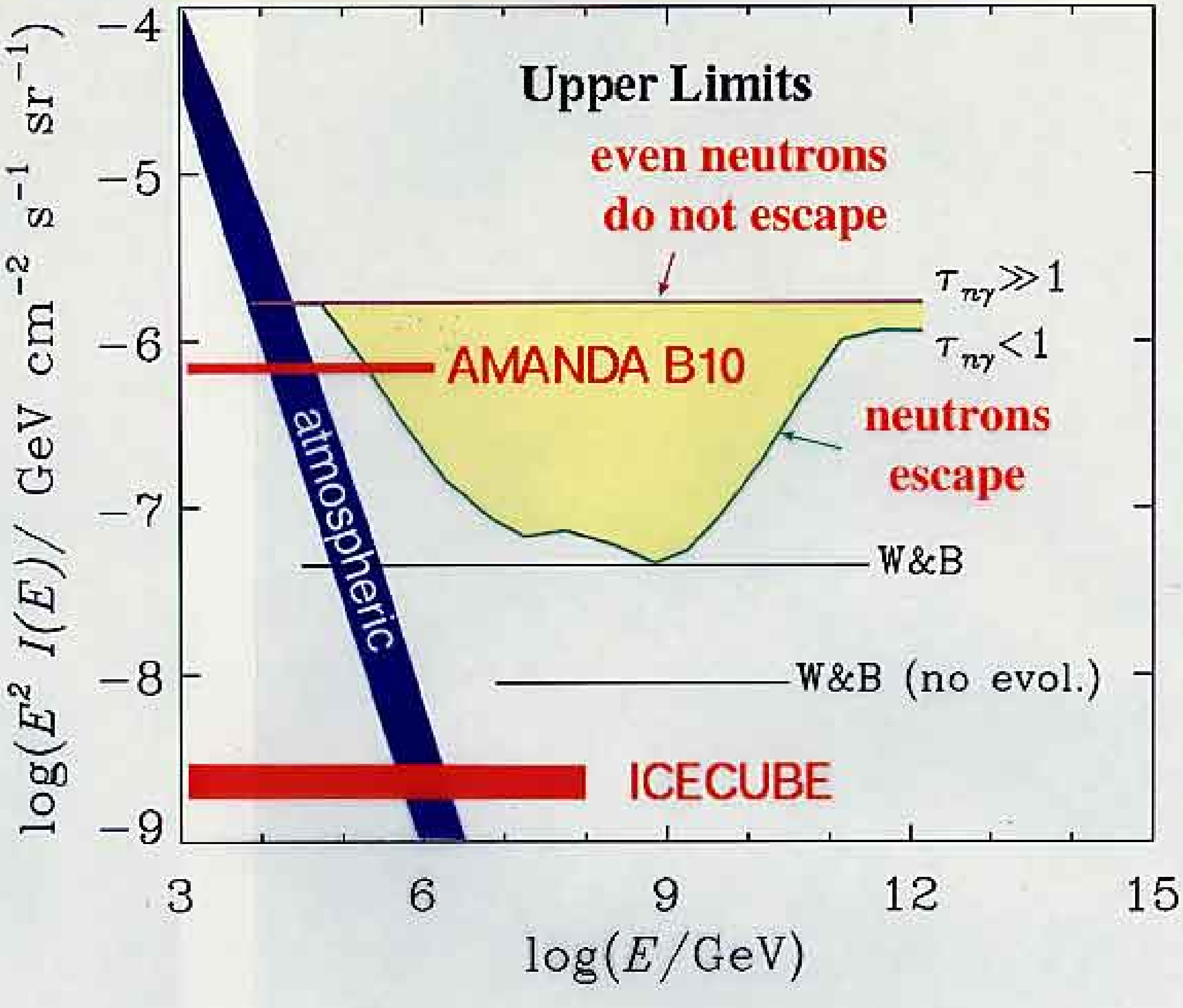
$\gtrsim 1$ TeV

direction ~ conserved



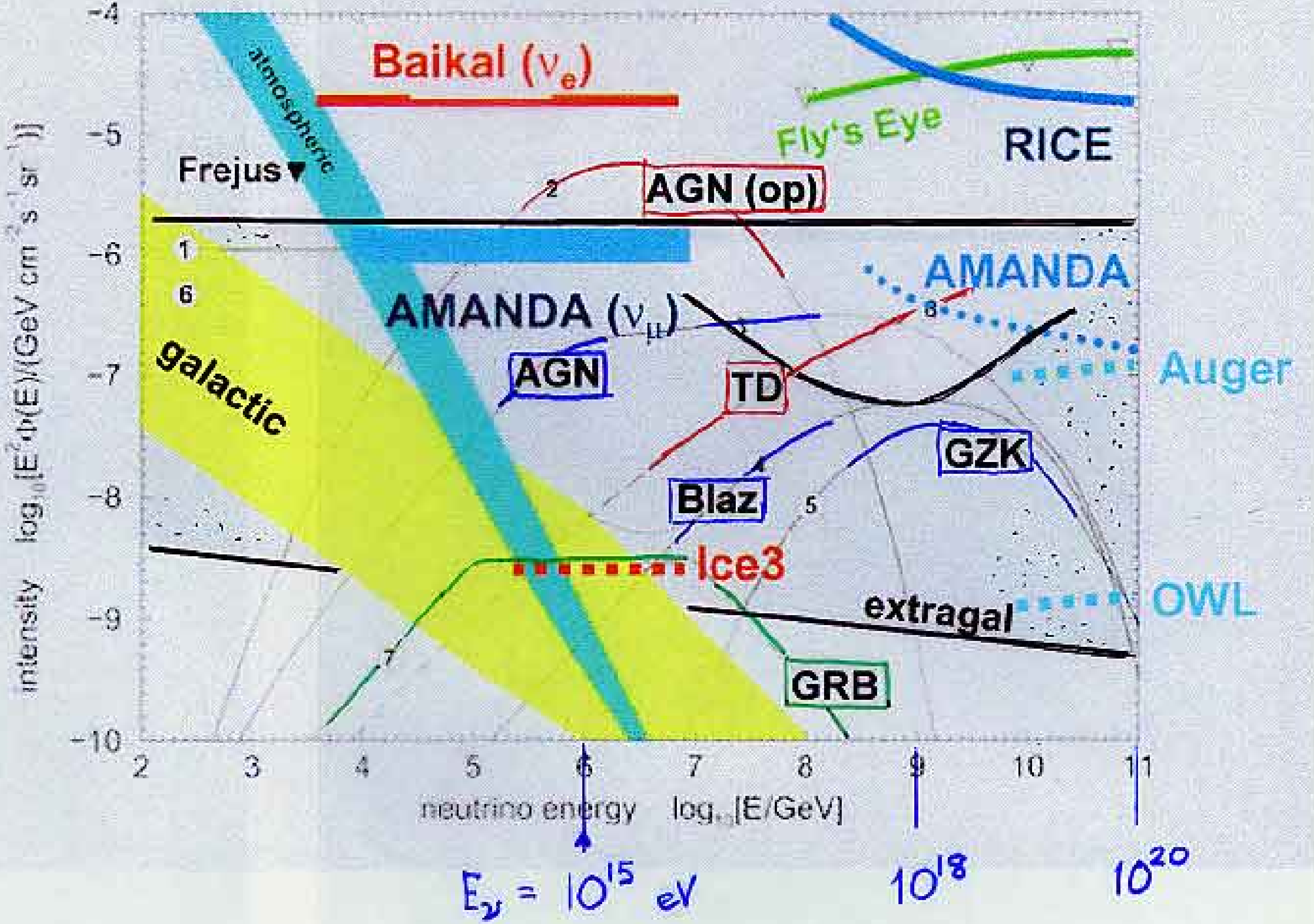
log[Flux/(erg cm^-2 s^-1 sr^-1)]
log(E/eV)
log(λ/cm)
γ flux
ν
TeV sources!
cosmic rays

neutrinos associates with the source of the cosmic rays?

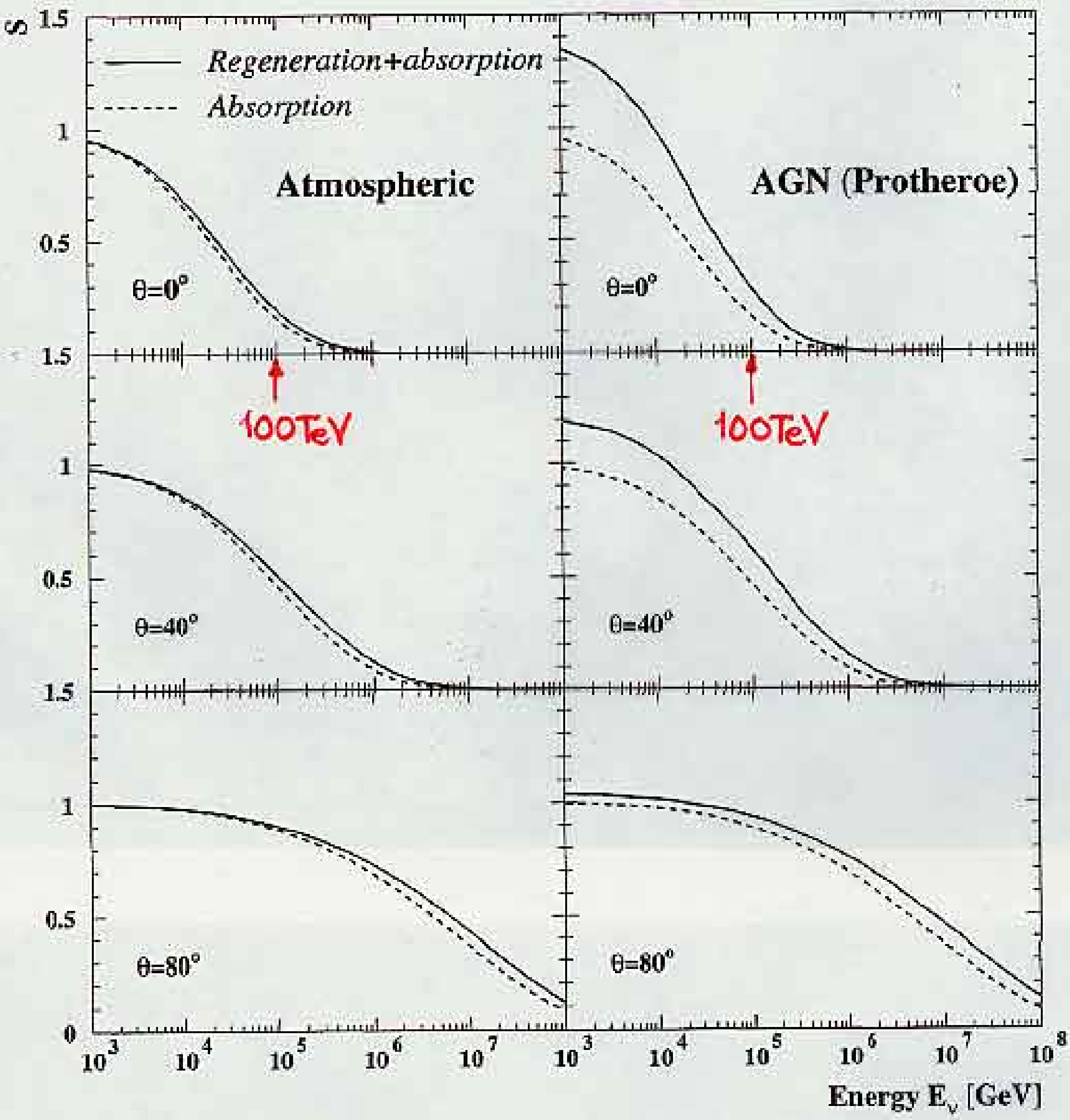


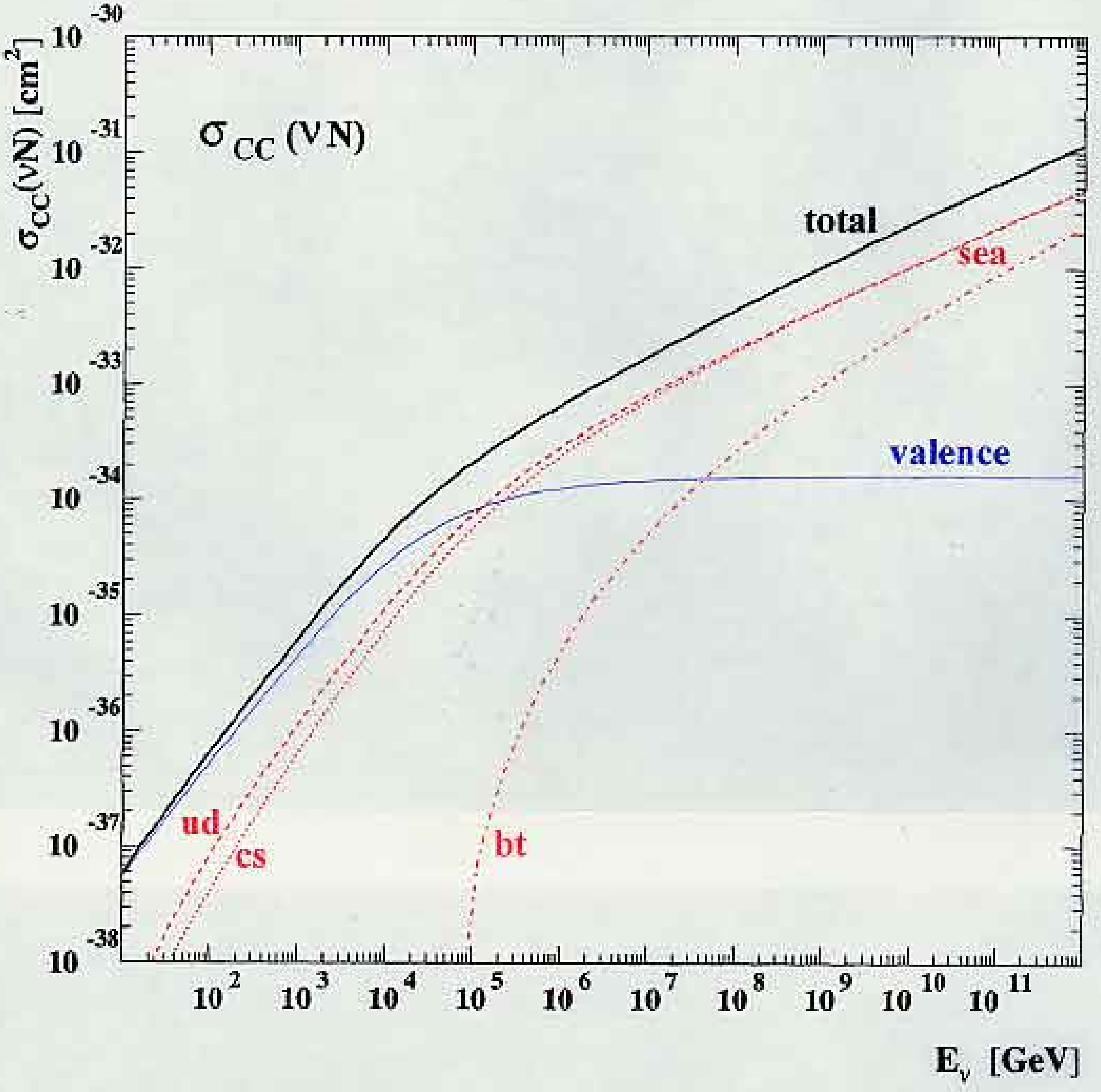
$\nu_\mu + \bar{\nu}_\mu$ from diffuse sources

from Learned, Mannheim/Barwick

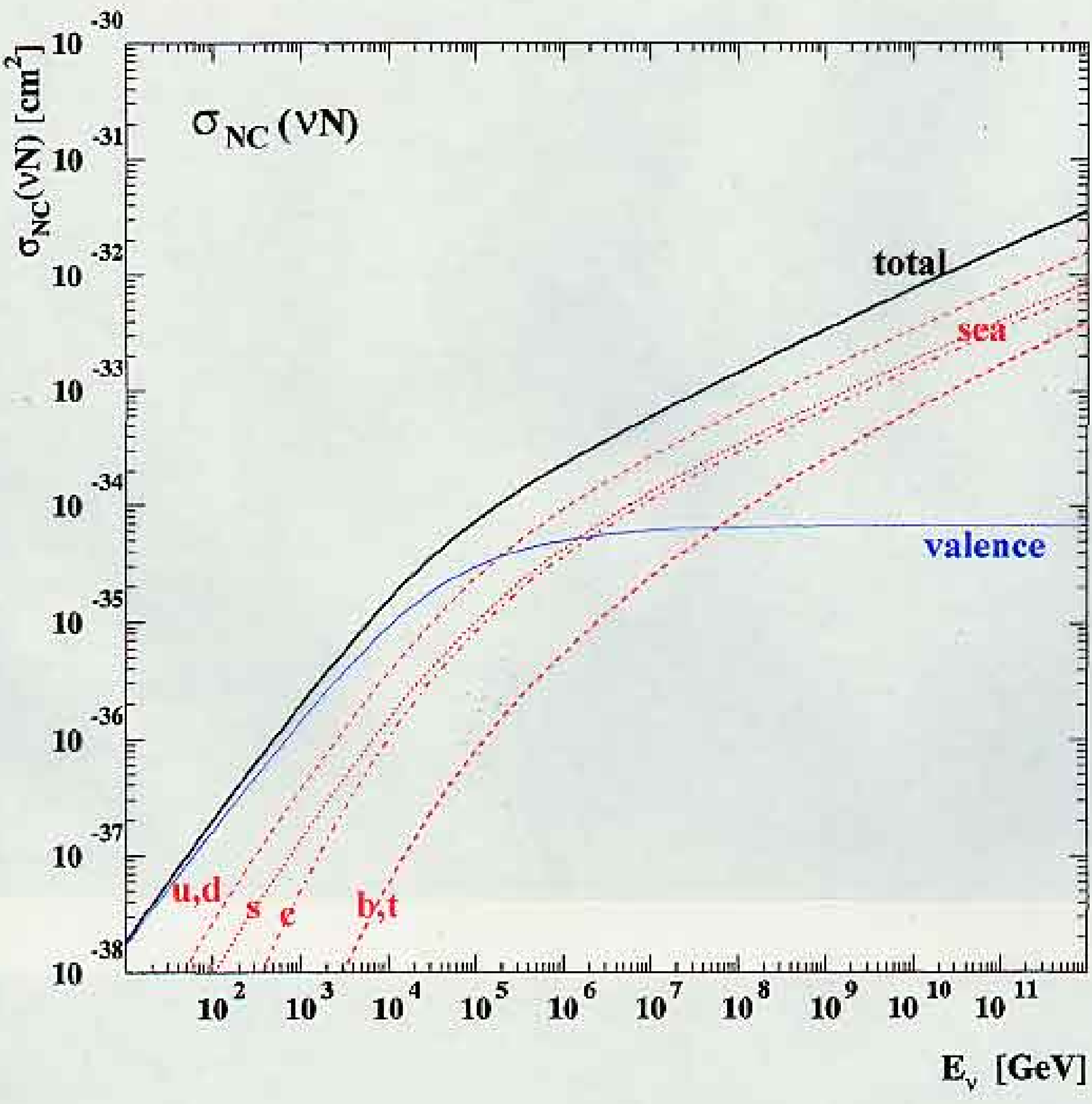


Attenuation of ν's by the Earth

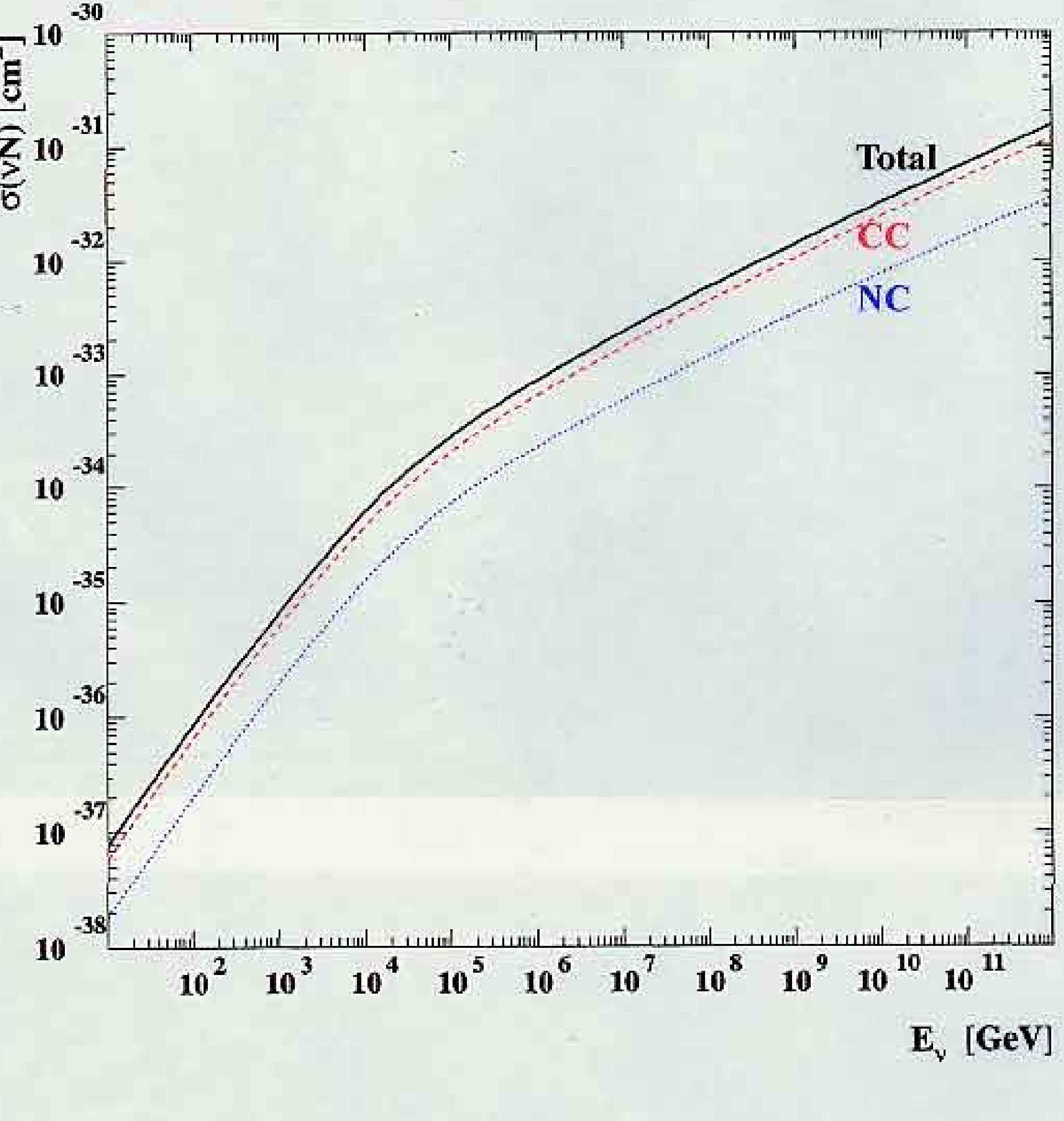




$\sigma_{CC}(\nu N)$
total
sea
valence
ud
cs
bt
$\sigma_{CC}(\nu N)$ [cm^2]
E_ν [GeV]



$\sigma_{NC}(\nu N)$
$\sigma_{NC}(\nu N)$ [cm^2]
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
total
sea
valence
u,d
s
c
b,t
10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9 10^{10} 10^{11}
E_ν [GeV]

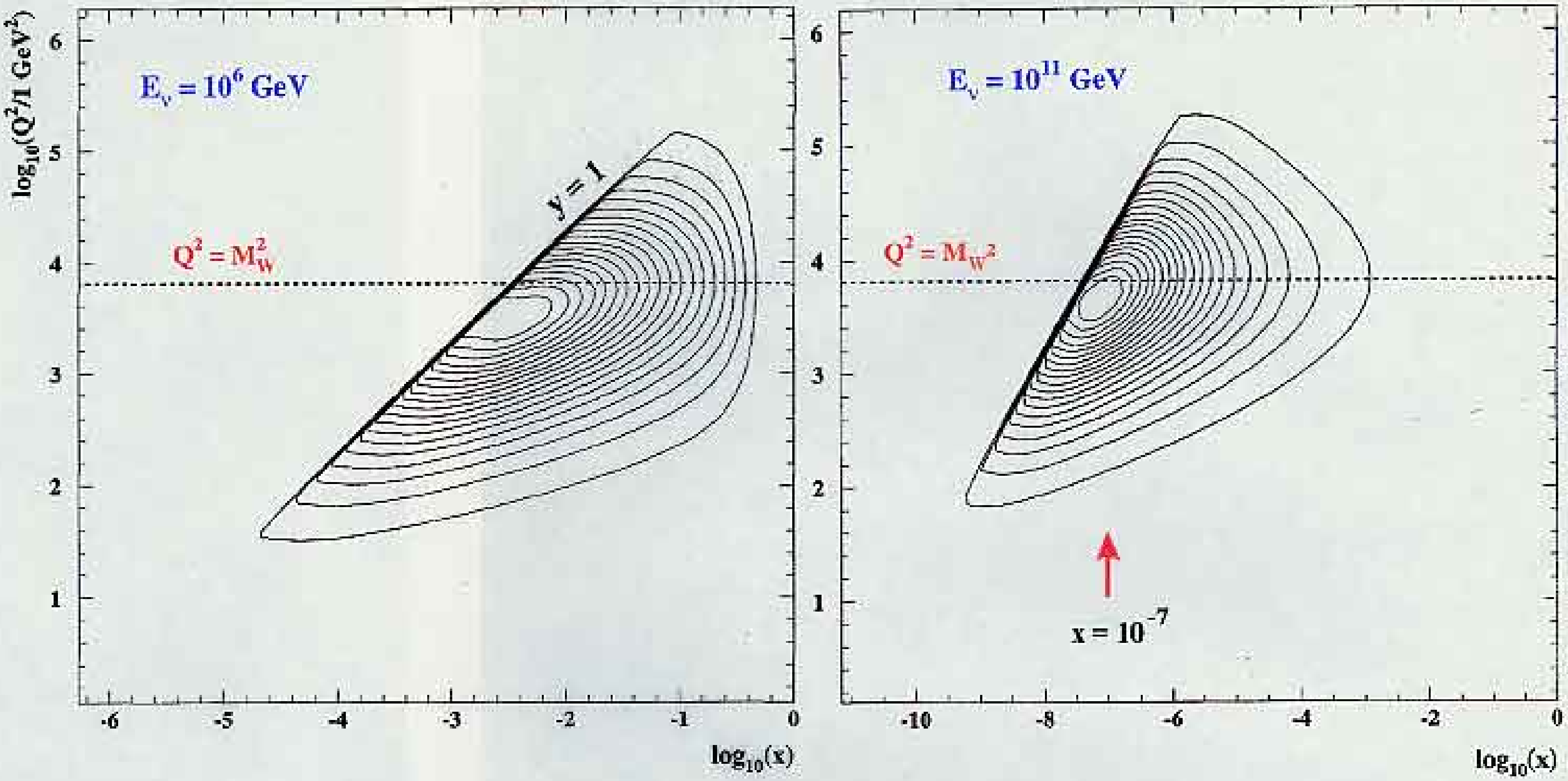


σ(νN) [cm²]
10^-30
10^-31
10^-32
10^-33
10^-34
10^-35
10^-36
10^-37
10^-38
Total
CC
NC
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
10^11
Eν [GeV]

$$\frac{d\sigma(\nu N \to \mu X)}{dx\, dQ^2} = \frac{G_F^2}{\pi} \left(\frac{M_W^2}{Q^2 + M_W^2} \right)^2 \left[q(x, Q^2) + (1-y)^2\, \bar{q}(x, Q^2) \right]$$

High E_ν : $\quad Q^2 \sim M_W^2$ $\quad$ $x = \frac{Q^2}{ys} \sim M_W^2 / 2 m_p E_\nu$

Kwiecinski, Martin, Stasto

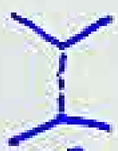


$\sigma_{\nu N}^{tot}$ at ultrahigh E_ν

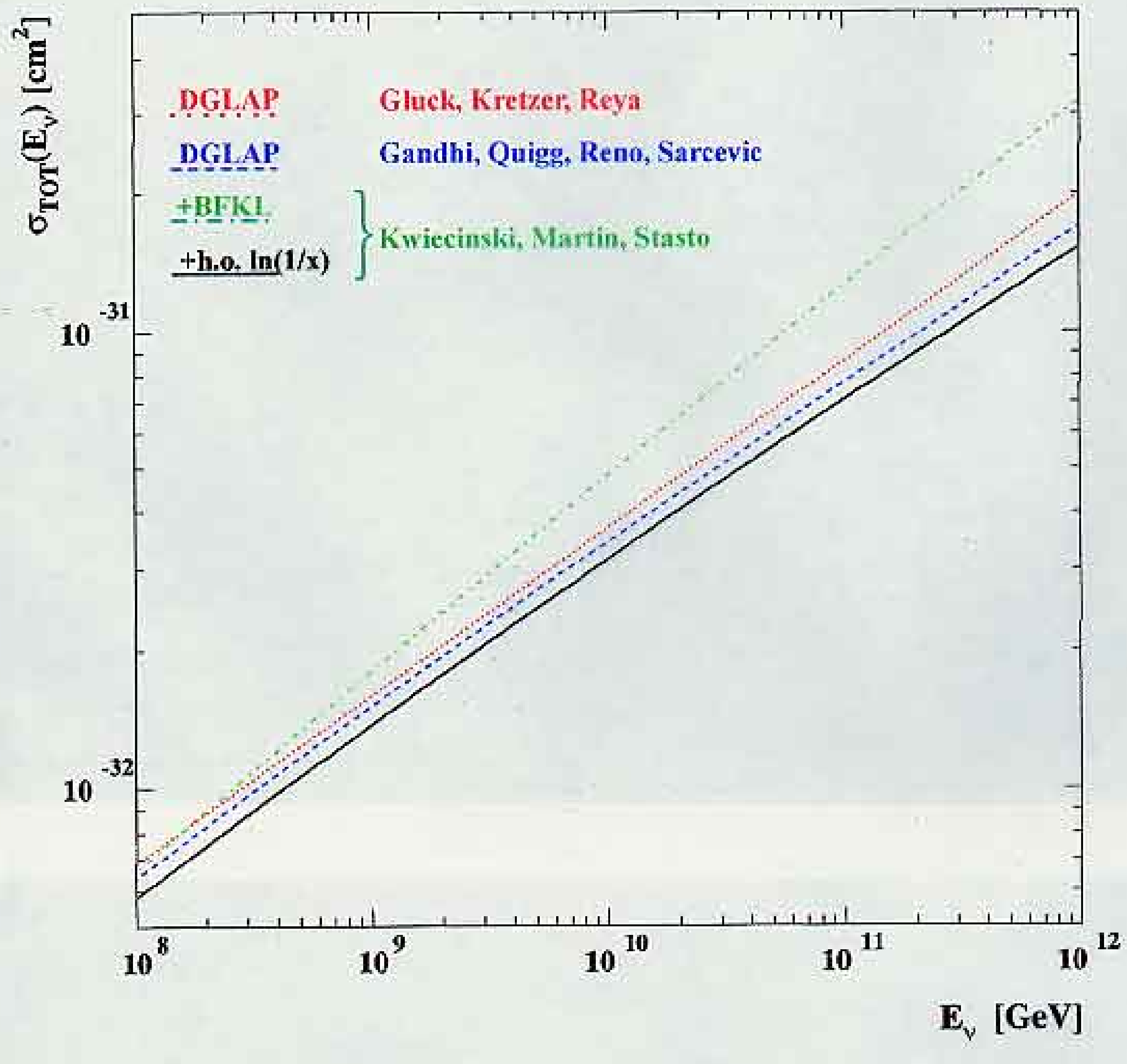
- V.small x
  $\ln(1/x)$ effects ? OK Kwiecinski et al.
- $gg \to g$ recomb^{n} ? small Reno et al.
  saturation ?
- perturbative unitarity ?
  questioned by Dicus et al.

$$\mathrm{Im}^2 + \mathrm{Re}^2$$

$$\frac{d\sigma_{el}(\nu N \to \nu N)}{dt} \geq \frac{1}{16\pi}\,\sigma_{tot}^2$$

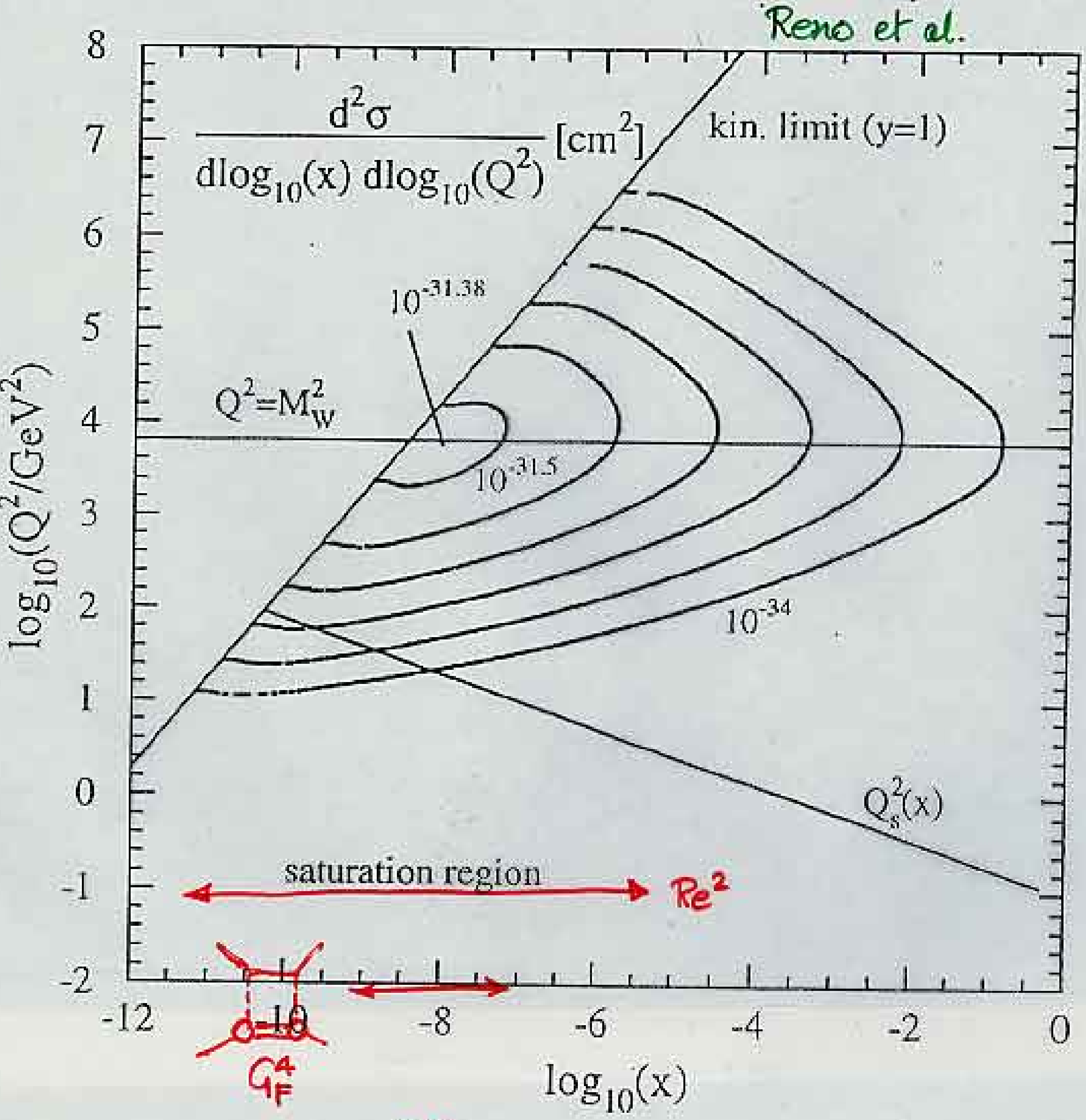


G_F^2 G_F^4 ← σ_{tot} violates this inequality at $E_\nu \gtrsim 2 \times 10^8$ GeV ? Dicus et al.



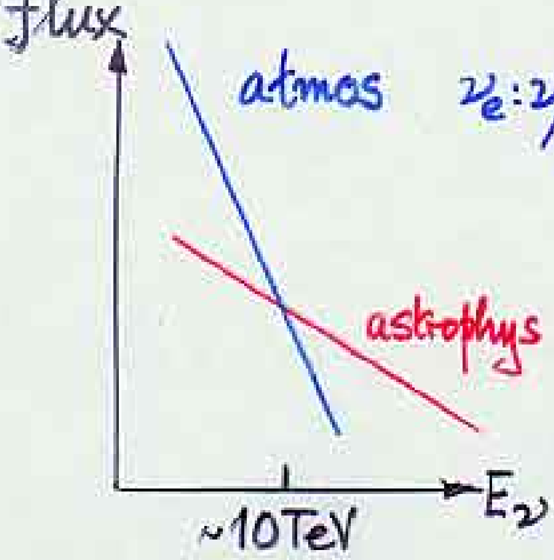
$\sigma_{TOT}(E_\nu)$ [cm^2]
DGLAP
Gluck, Kretzer, Reya
DGLAP
Gandhi, Quigg, Reno, Sarcevic
+BFKL
+h.o. ln(1/x)
Kwiecinski, Martin, Stasto
10^{-31}
10^{-32}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
E_ν [GeV]

Reno et al.



OK
Reno et al.

Conclusion: no reason to doubt extrapolation of $\sigma_{\nu N}^{tot}$ above HERA domain

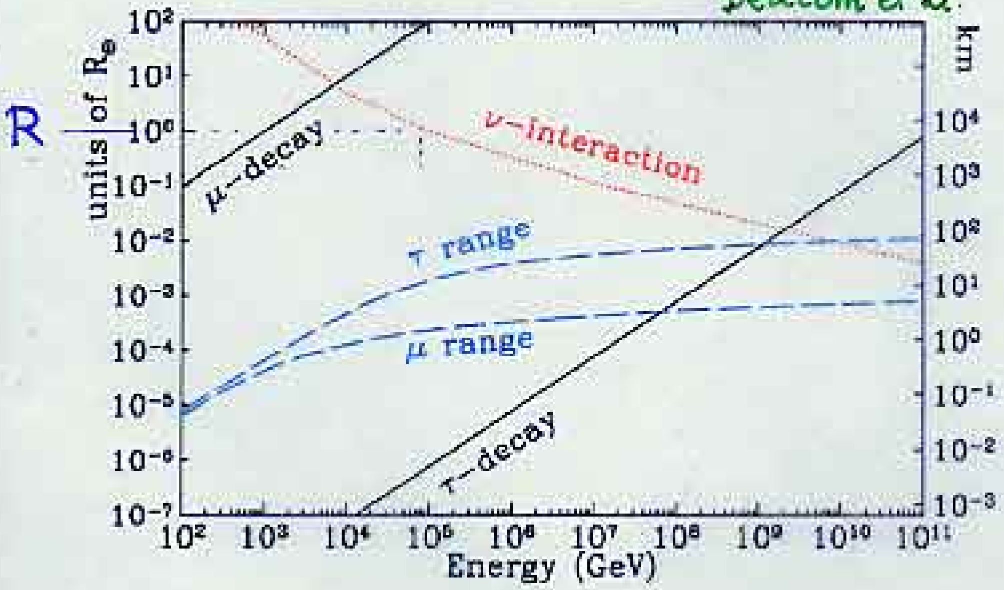


atmos $\nu_e : \nu_\mu : \nu_\tau = 1:2:0$

	source		at earth
astrophys	1:2:0	$\longrightarrow$	1:1:1

assume
$\nu_\mu \leftrightarrow \nu_\tau$ (LMA)

Beacom et al.



$\nu_e \to e$ quickly brought to rest
$\nu_\mu \to \mu$ quickly slowed down

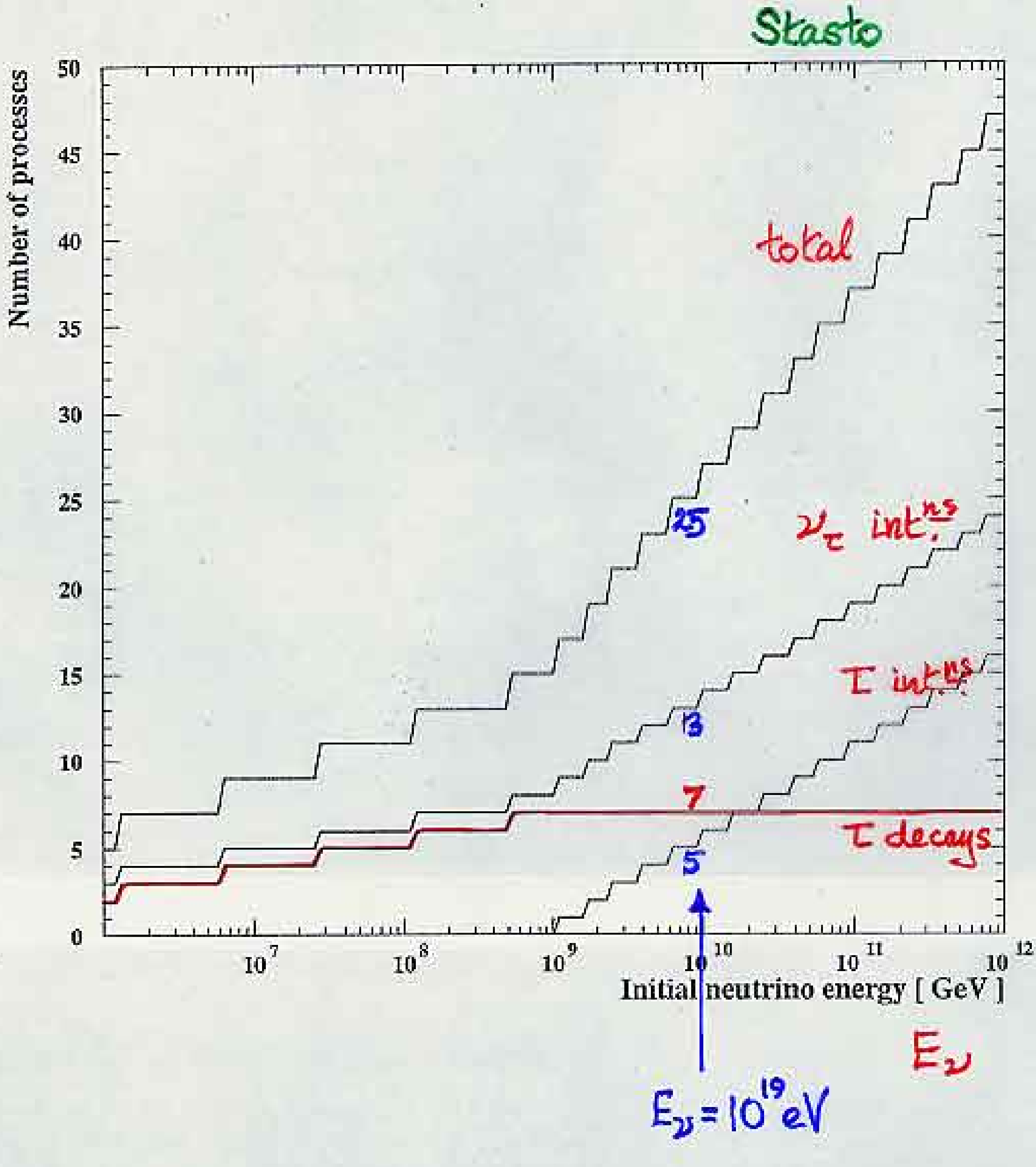
} earth opaque $E_\nu \gtrsim 100\,\mathrm{TeV}$

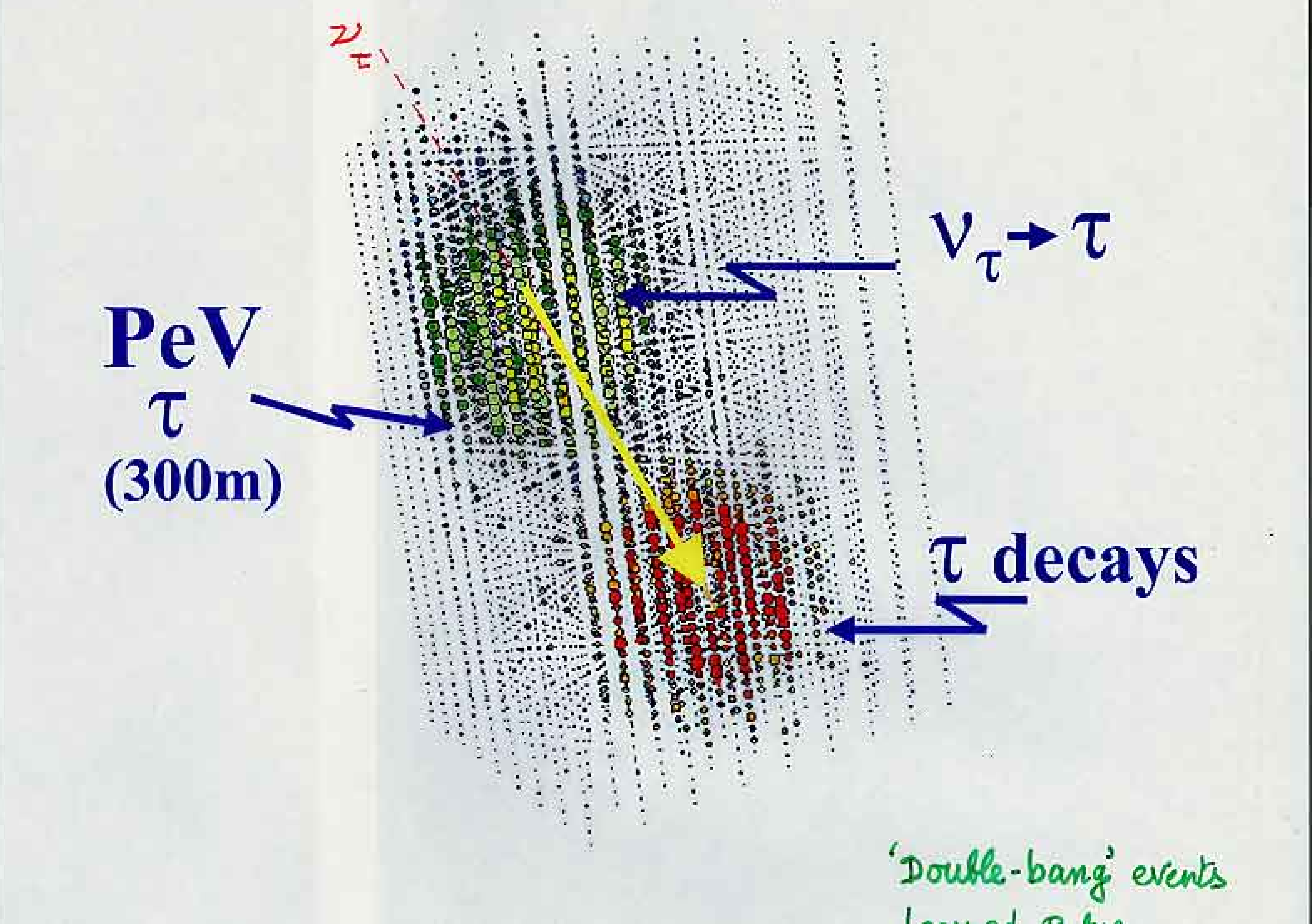
$\nu_\tau \to \tau \xrightarrow{\text{fast}} \nu_\tau \to \tau \to \nu_\tau \ldots$ until earth transparent

$E_\nu \sim 10^{14}\,\mathrm{eV}$ 'pile-up'
for flat spectrum

Halzen, Saltzberg

[EHE $\nu_\tau \to \tau \to \tau\,(E \sim 10^{17}\,\mathrm{eV})$ then $\to \nu_\tau \ldots$]


Stasto
Number of processes
0
5
10
15
20
25
30
35
40
45
50
10^7
10^8
10^9
10^{10}
10^{11}
10^{12}
Initial neutrino energy [GeV]
total
ν_τ int^{ns}.
τ int^{ns}.
τ decays
25
13
7
5
E_ν
$E_\nu = 10^{19}$eV

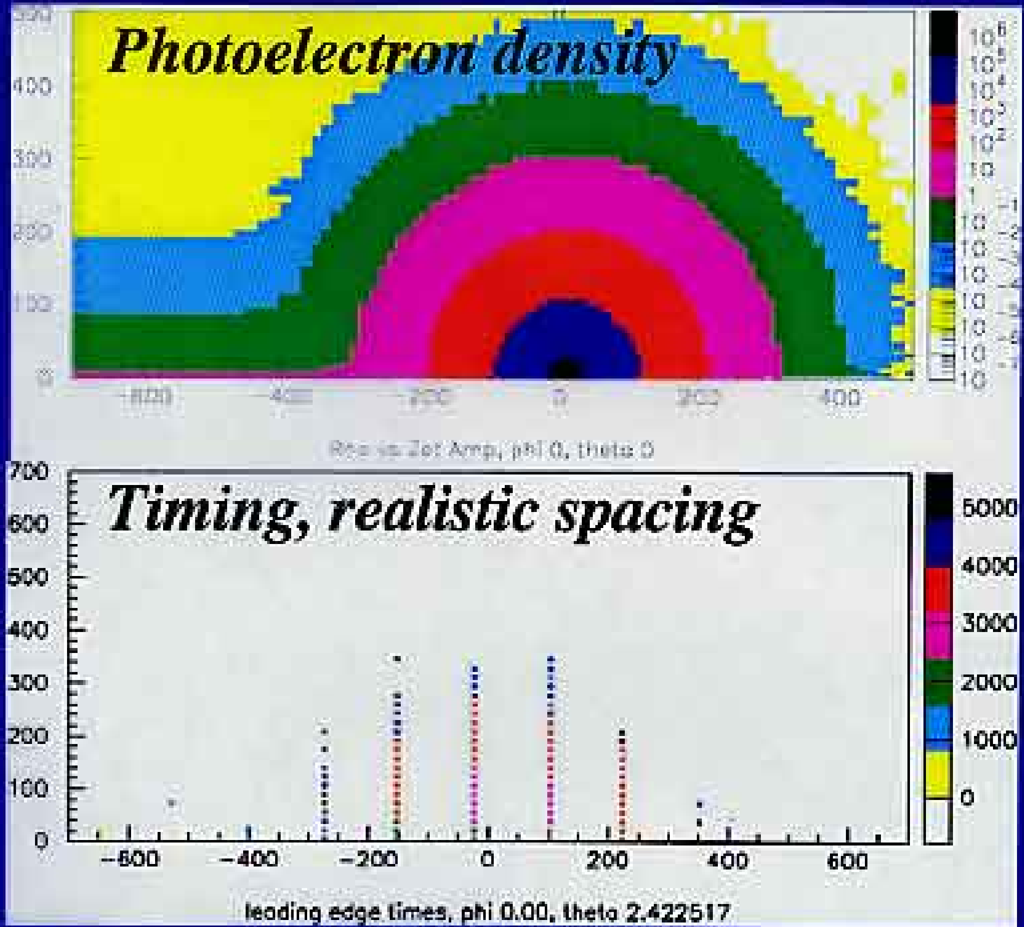


ν_τ
$\nu_\tau \rightarrow \tau$
PeV
τ
(300m)
τ decays
'Double-bang' events

"Single-bang Lollipop" events may be visible upto $E_\nu \sim 10^{17}$ eV

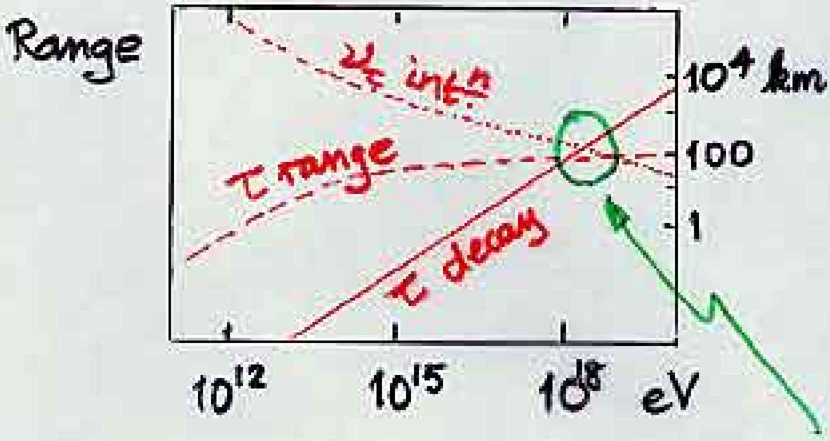
ν_τ at E>PeV: Partially contained

- The incoming tau radiates little light.
- The energy of the second bang can be measured with high precision.
- Clear signature
- Muon Brem would be much brighter than the tau (compare to the PeV muon event shown before)



Result:
high effective volume;
only second bang seen in Ice3

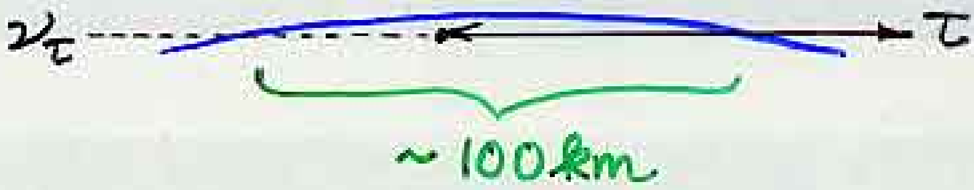
To avoid $\nu_\tau \to \tau \to \nu_\tau \to \tau \to \nu_\tau \ldots$ pile-up at 10^{14} eV, use shorter path length thru earth



all comparable for $E \sim 10^{18}$ eV

~ 100 km

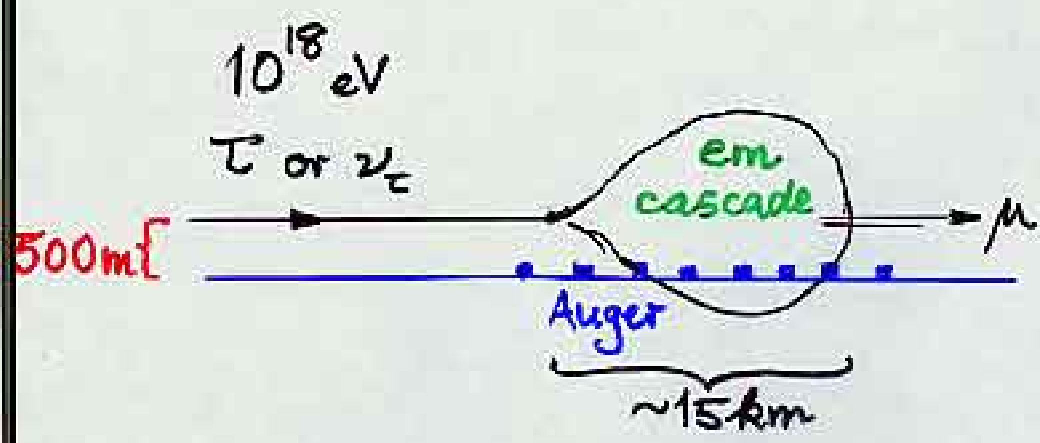
→ horizontal ν_τ's



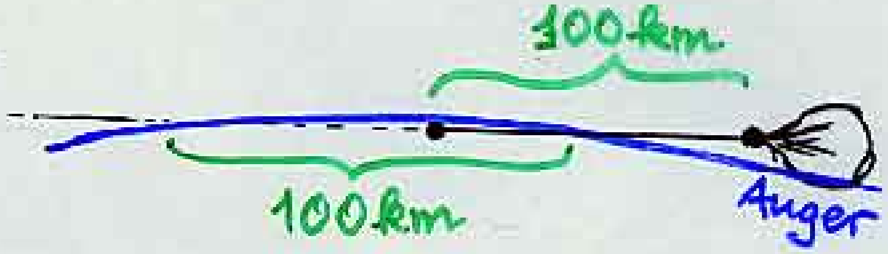
(Icecube OK up $\sim 10^{17}$ eV)

Horizontal ν_τ's in Auger

Bertou et al.



hadrons interact at top of atmos.
Em cascade does not reach Auger

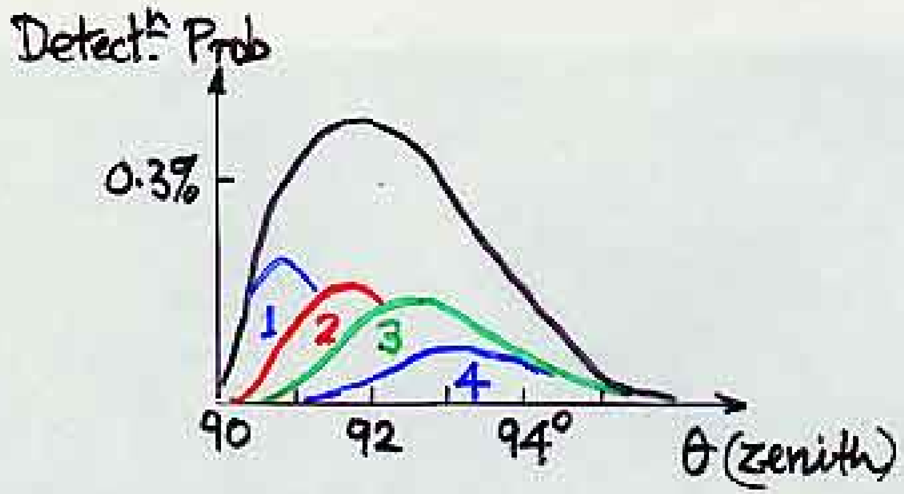


Detectable if 10^{17} eV < E < 10^{19} eV

← not enough Auger triggers

→ decay too slow

few events/yr ?



1, 2, 3, 4 int^ns in earth.

Conclusions:

- TeV+ ν astronomy taking off
- $\sigma(\nu N)$ reliable
- ν_τ allow UHE to be probed.