INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

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H4.SMR 346/14

SCHOOL ON
NON-ACCELERATOR PHYSICS
25 April - 6 May 1988

EXPERIMENTAL LIMITS

by

T. Gaisser
University of Delaware
U. S. A

#4. [GAISSER] Experimental limits

on γ & ν signals from point sources with $E_{\gamma,\nu} > \text{TeV}$

$$\text{Signal} = \int \frac{d\,\text{Flux}_i}{dE} A_i(E)\, dE \quad \Delta t$$

$i = \nu$ or γ

$$\text{Background} = \int \frac{d\,\text{C.R.}}{dE\, d\Omega} A'(E)\, dE\, \Delta t\, \Delta\Omega$$

<u>neutrinos</u>

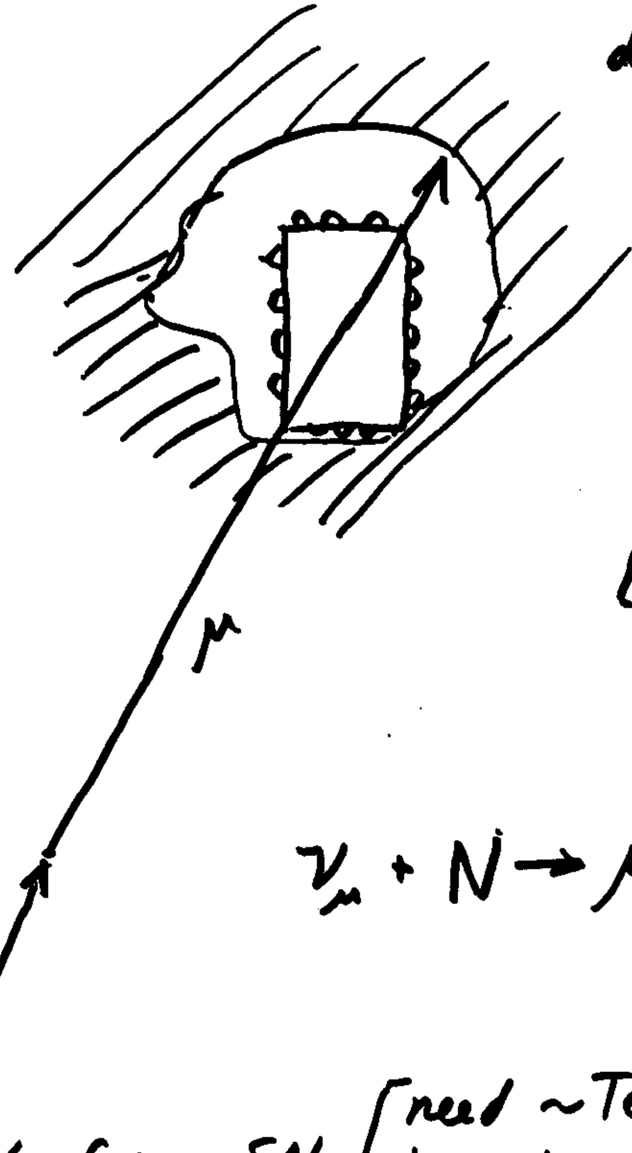
$$A_\nu = A'_\nu \approx A\cos\theta\ \sigma_\nu(E_\nu) N_A \rho\, R_\mu(E_\mu)$$

<u>photons</u>

$$A_\gamma = A\cos\theta\, P_\gamma \qquad A' = A\cos\theta\, P_{\text{c.R.}}$$

Neutrino signal

- Northern hemisphere detectors:



Kamioka
IMB
Frejus
Baksan
Homestake
[Gran Sasso]
[Soudan 2]
⋮

$$\nu_\mu + N \to \mu + X$$

ν from SN [need ~TeV ν to get muon range ...]

$\sigma_{\nu/\bar{\nu}} \simeq 0.5 \times 10^{-38}\ \mathrm{cm}^2 \times E_\nu\ (\mathrm{GeV})$

"contained" vertices in $V\ \left(\frac{\text{events}}{\text{kT}\cdot\text{yr}}\right)$

$$V_{kT} \times 6\cdot 10^{32} \times 3\times 10^{7} \times 0.5\times 10^{-38} \times \int E_\nu \frac{dN_\nu}{dE_\nu}\,(\mathrm{cm}^{-2}\mathrm{s}^{-1})\,dE_\nu$$

$$= \frac{1}{4\pi R^2} \underbrace{\int E_\nu S_\nu(E_\nu)\,dE_\nu}_{\text{total power in } \nu+\bar{\nu} \text{ at source}}$$

|| cascading in source $\Rightarrow$

Energy $\sim \frac{1}{2}(\gamma + e^\pm)$, $\frac{1}{3}\nu_\mu$, $\frac{1}{6}\nu_e$

if all $\pi^\pm$ + $\mu^\pm$ decay.

$$\text{Rate} \sim 5\times 10^{-42} \left(\frac{10\ \text{kpc}}{R}\right)^2 L\left(\frac{\text{erg}}{\text{s}}\right) \frac{\text{events}}{\text{kT yr}}$$

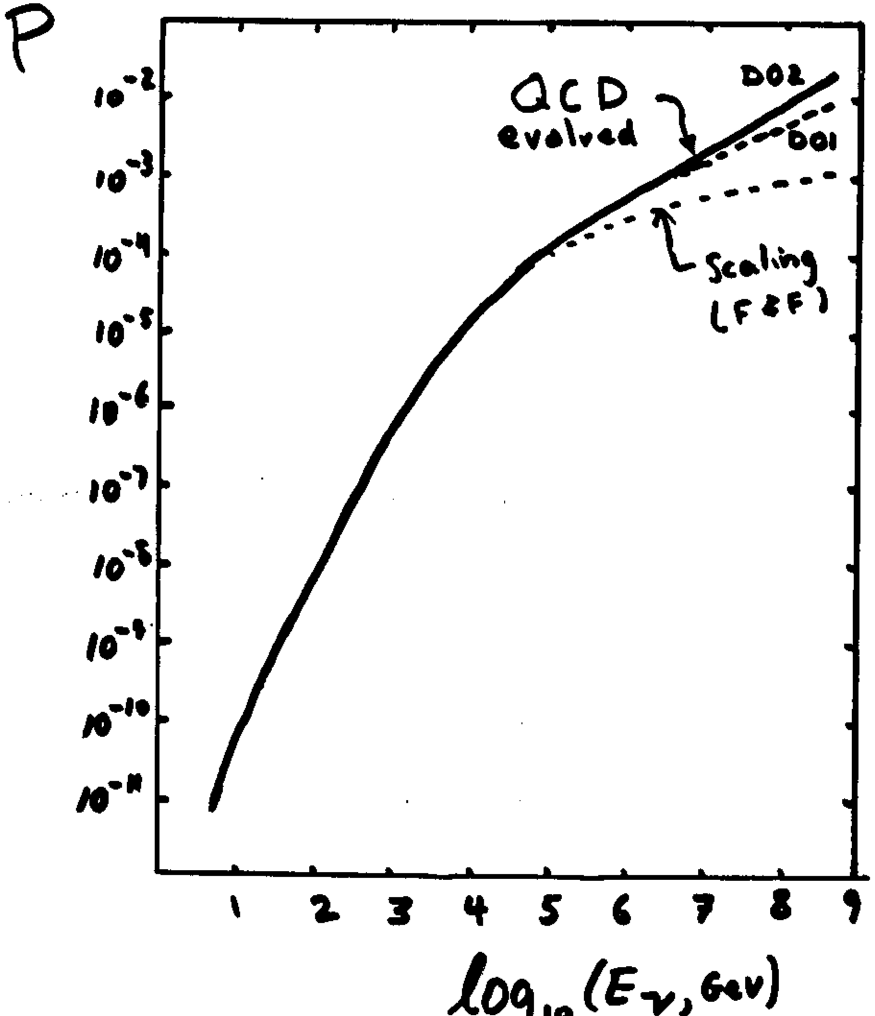
$\sim \frac{1}{2}\ \frac{\text{vertex}}{\text{yr}}$ in 100 kT for $10^{39}\ \frac{\text{erg}}{\text{s}}$ at 10 kpc. Must use external events.

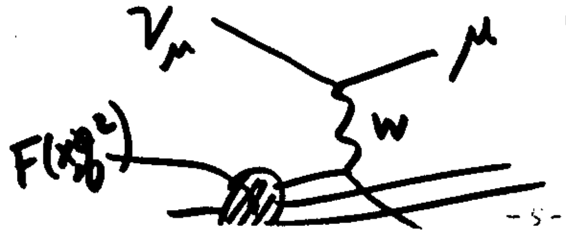
P_ν = probability that ν aimed at detector produces muon through detector.

1. $E_\nu \lesssim 500$ GeV $\propto E^2$
2. $500 \lesssim E_\nu \lesssim \frac{M_W^2}{2m_p} \sim 3600 \propto E$
3. $E_\nu \gg \frac{M_W^2}{2m_p} \propto (\ln E)^{\text{power}}$

1. $\sigma_\nu \propto E_\nu$, $R_\mu \propto E_\mu \propto E_\nu$
2. " but $R_\mu \sim 2.5$ km.w.e. $\ln\left(1+\frac{E_\mu}{510}\right)$
3. $\frac{d\sigma_\nu}{dx\,dy} \propto \frac{1}{(1+2mE_\nu xy/M_W^2)^2}$, "

From TKG + Grillo, Phys. Rev. D36 2752 ('87)
see also references therein and
Quigg, Reno, Walker, P.R. ('87)





TKG + Stanev
PRL 54, 2265 (1985)

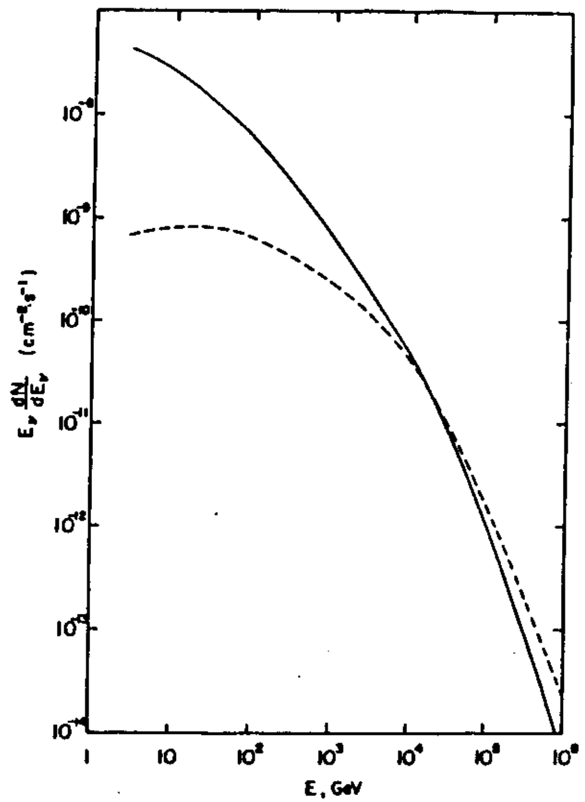


FIG. 1. Neutrino spectra at Earth from a 10^8-GeV monoenergetic beam (dashed line) and power-law spectrum with slope 2 (full line) for the density profile of Table I averaged over one period.

for $L_p = 10^{39}$ erg/s
at 10 kpc

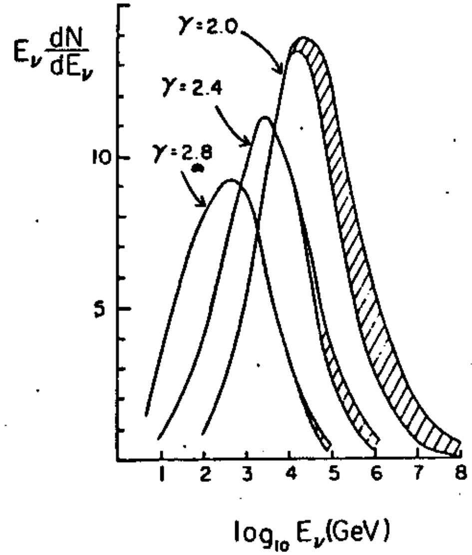


FIG. 3. Distribution of primary neutrino energies that give rise to upward muons with $E_\mu > 2$ GeV at the detector for power-law neutrino spectra with differential index $\gamma = 2.0$, 2.4, 2.8. The shaded region shows the difference between scaling and QCD-evolved structure functions.

TkG + Stanev

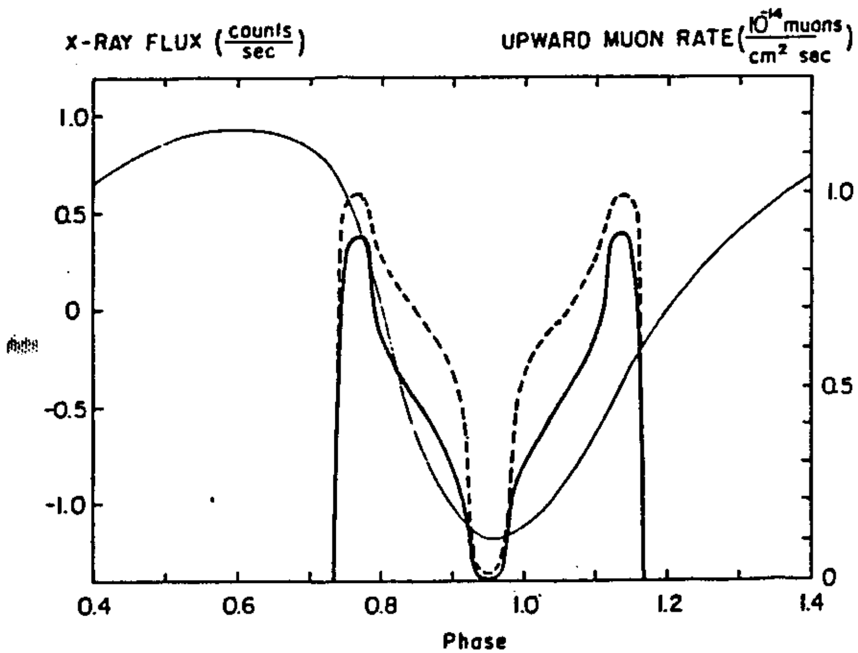
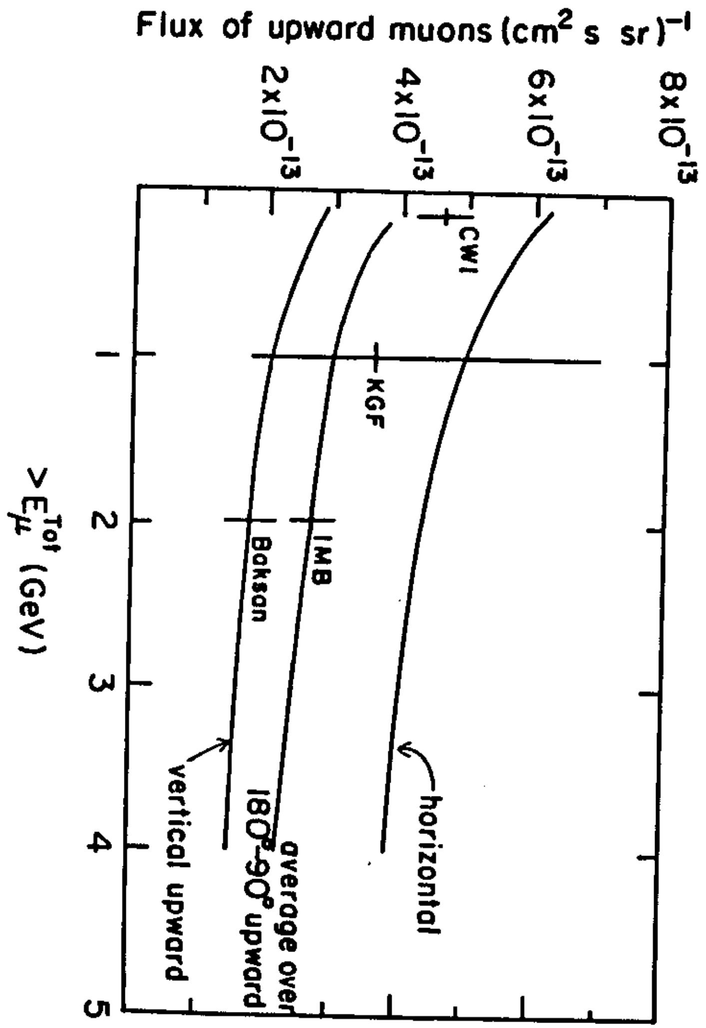


FIG. 2. Phase dependence of upward muons from Cygnus X-3 neutrinos: 10^8-GeV beam, solid curve; power-law spectrum, dashed curve. The thin line shows the light curve in x rays.

$\sim 1 \uparrow \nu_\mu \rightarrow \mu$ / 1000 m^2 / yr.



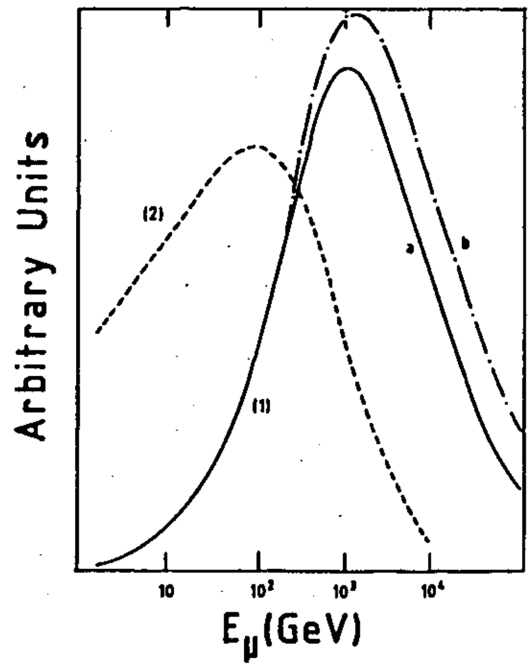
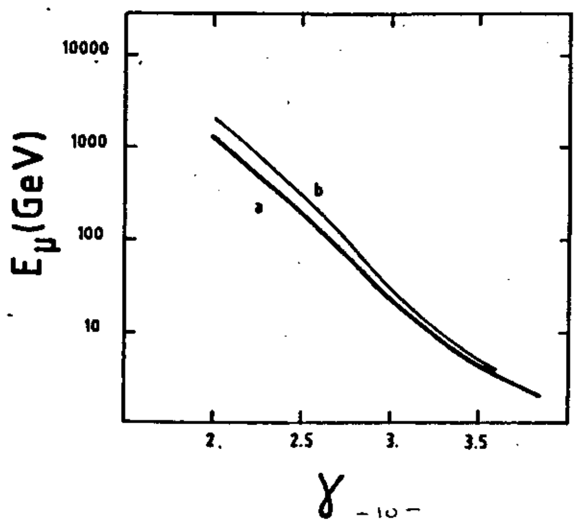


FIG. 4. Muon distribution ($dN_\mu / d \ln E_\mu$) at the detector for neutrino spectrum $dN/dE_\nu \propto E^{-\gamma}$. (a) and (b) as above. (1) $\gamma=2$, (2) $\gamma=2.8$. Note that below $\gamma=2.6$ (a) and (b) are practically the same.



Now consider photons

- <u>All</u> photons interact in atmosphere but only <u>energetic</u> ones give shower that penetrates to surface.

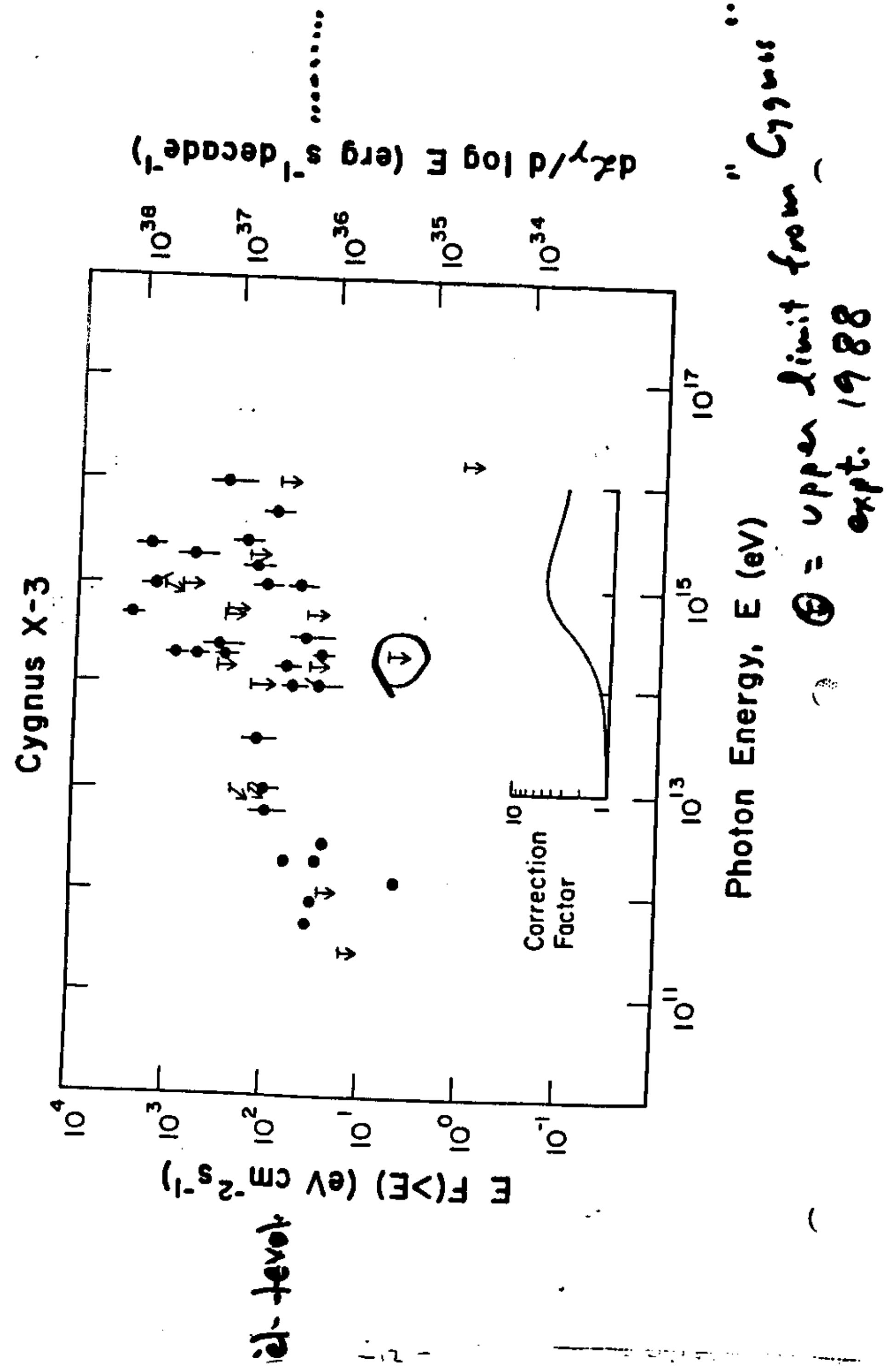
- A v<u>e</u>ry energetic photon can trigger the array even if core is outside.

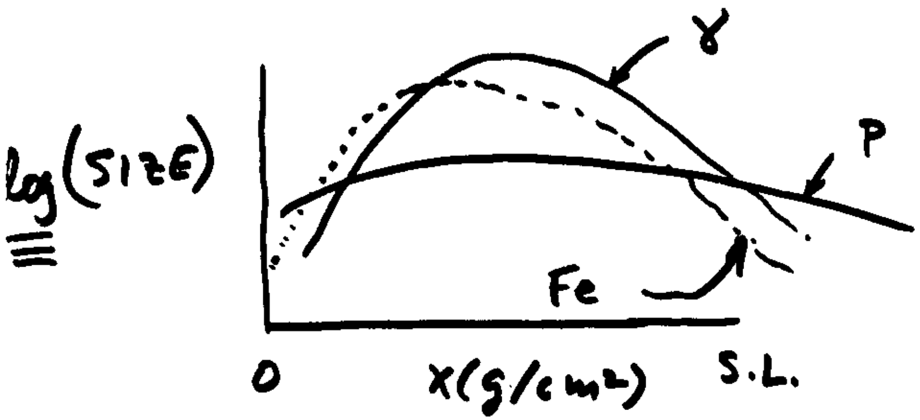
- $P_\gamma^{(E)}$ = probability that photon of energy E triggers array

- $P_\gamma(E) \neq P_p(E)$

For separate parametrizations of γ + p cascades see

E.J. Fenyves et al. PR <u>D37</u>, 649 (1988)





TKG & R.J. Protheroe (in preparation)

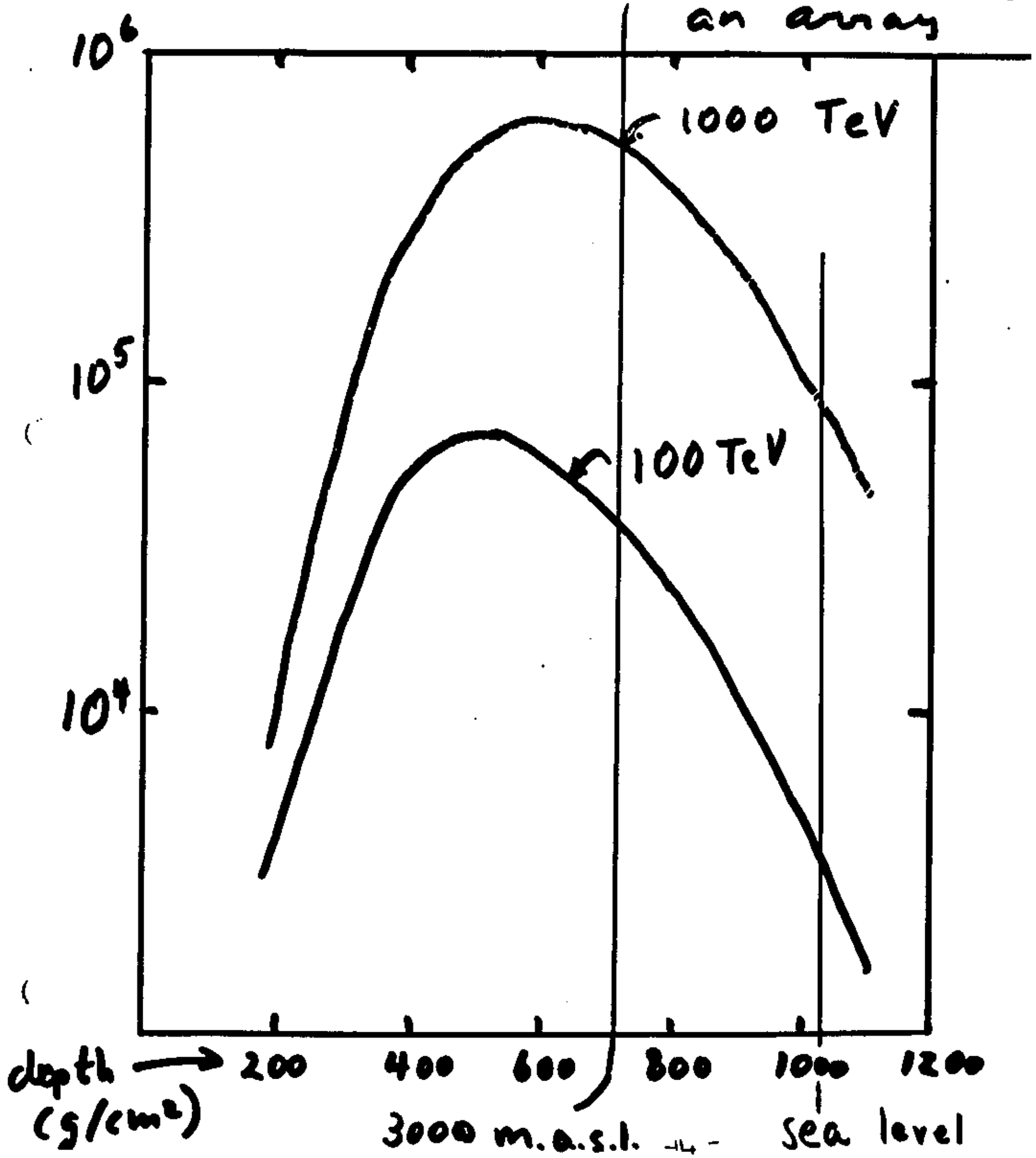
simple simulation based on Fenyves et al. to study & compare trigger efficiency for different arrays on a standard basis. Normalize to C.R. showers then calculate $P_{\gamma}(E)$.

→ Fluctuations crucial (Navarra)

Lateral distribution (Navarra)

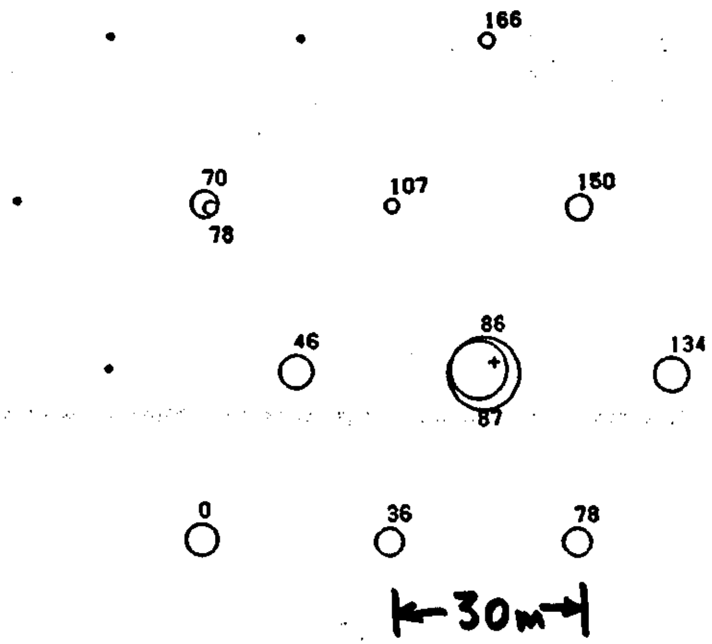
mean # particles vs. depth for photon air showers

Note importance of fluctuations in triggering an array



South Pole Air Shower Expt.

RMR = 149792.20867



BARTOL THETA 34.0 PHI 224.1 CHI^2 0.2
S.POLE THETA 35.7 PHI 224.5

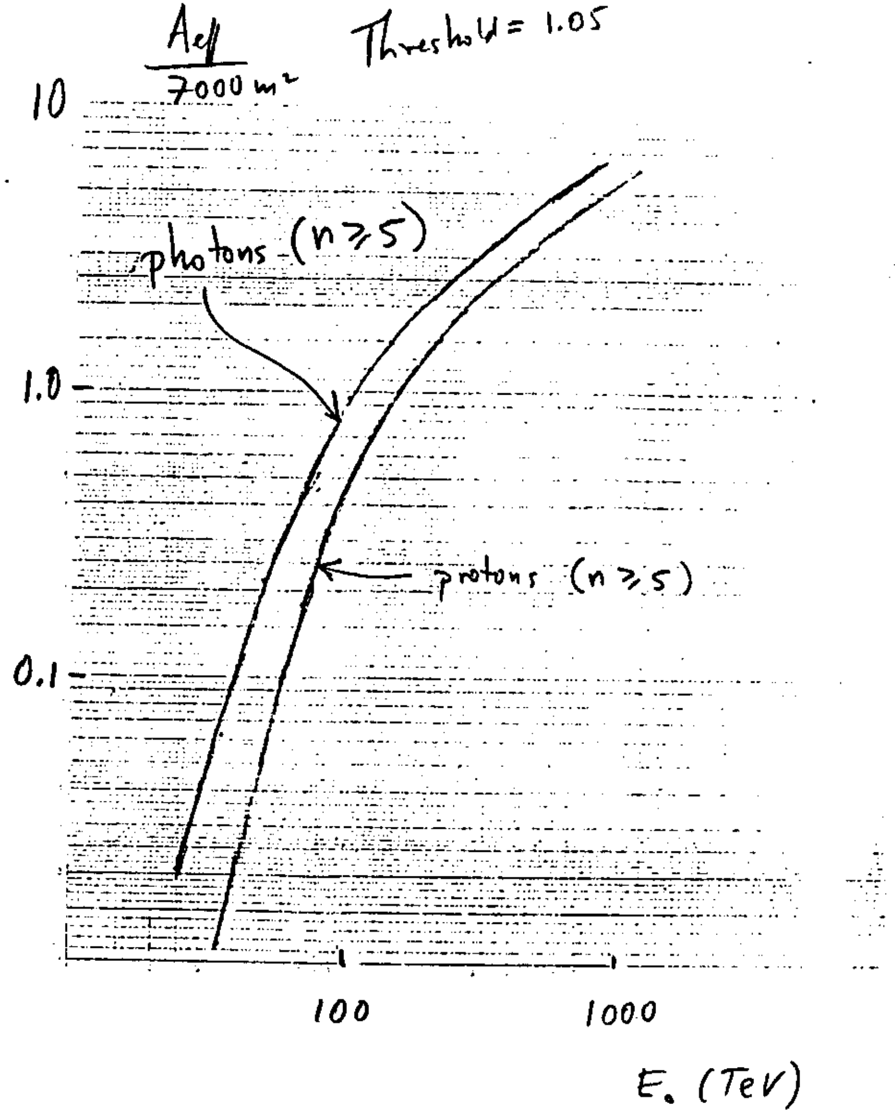
Leeds / Bartol

Alan WATSON, Nigel Smith et al.

M A Pomerantz, Jay Perrett et al.

θ = 21°

8 April 88 Fig. 1



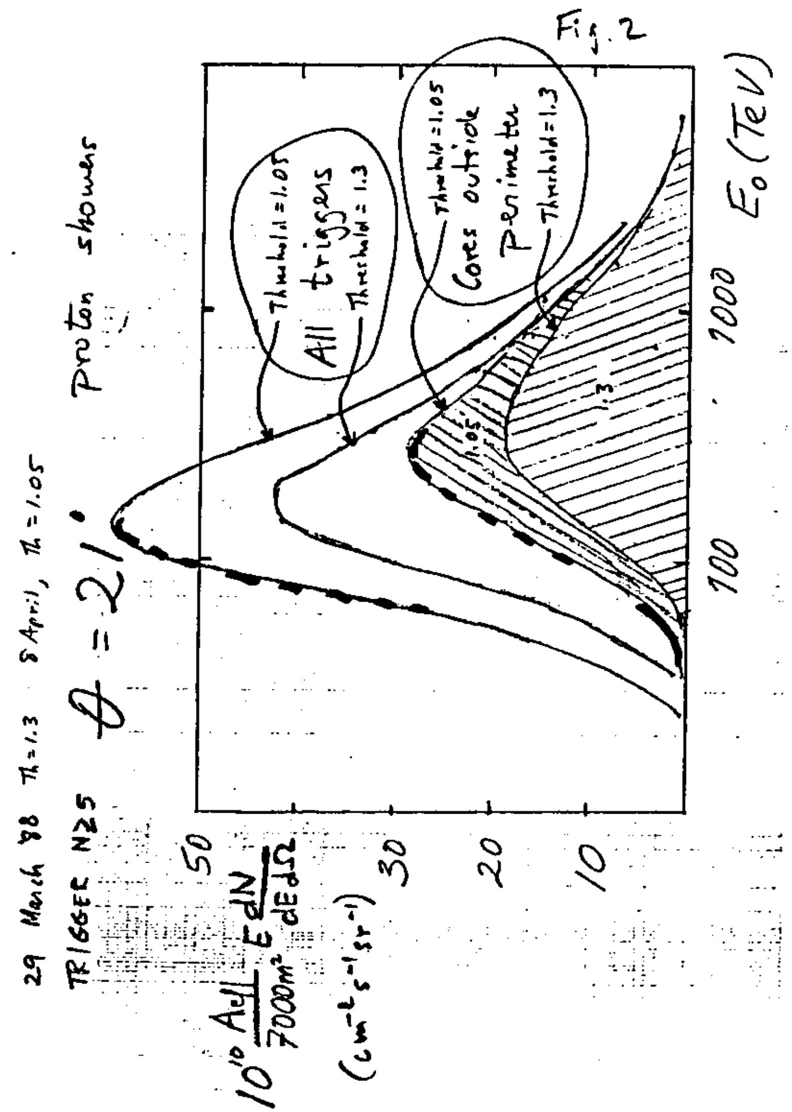
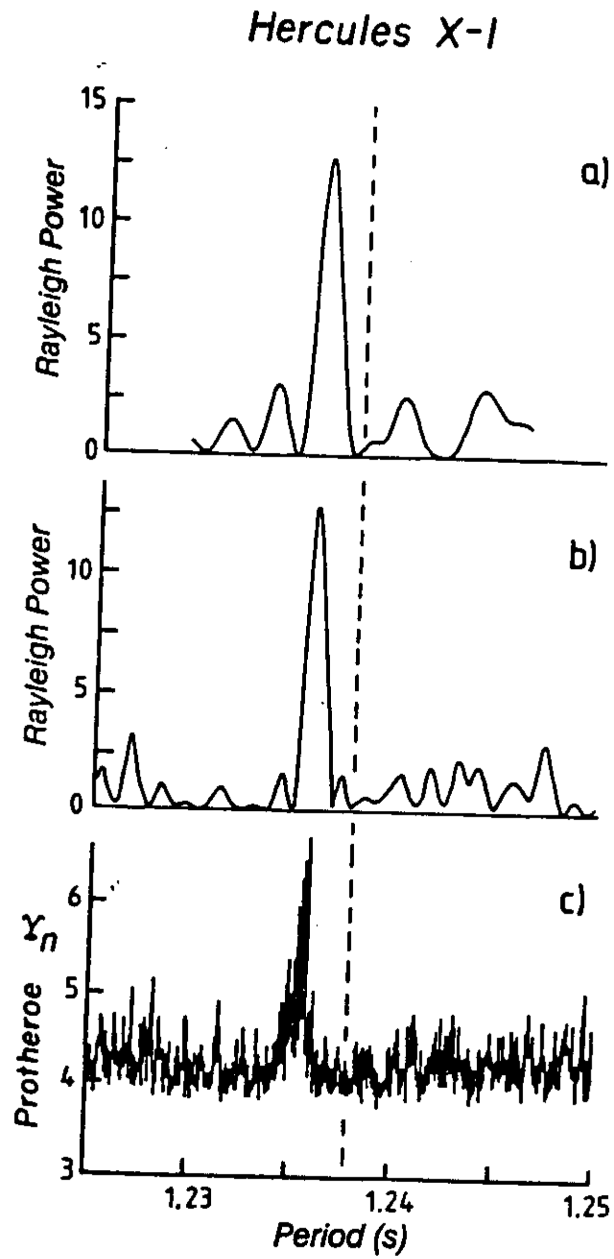


Fig. 2
proton showers
All triggers
Cores outside perimeter
E_0 (TeV)
100
1000
50
30
20
10


Hercules X-1
a)
b)
c)
Rayleigh Power
Rayleigh Power
Protheroe Y_n
Period (s)
1.23
1.24
1.25

Muon problem!

see Yodh et al. 1988

expect

$$\frac{(N_\mu/N_e)_\gamma}{(N_\mu/N_e)_{C.R}} < 10\%$$

but Her X-1 showers have this ratio ~ 1 ??

* Producing exotic particles is energetically expensive

---

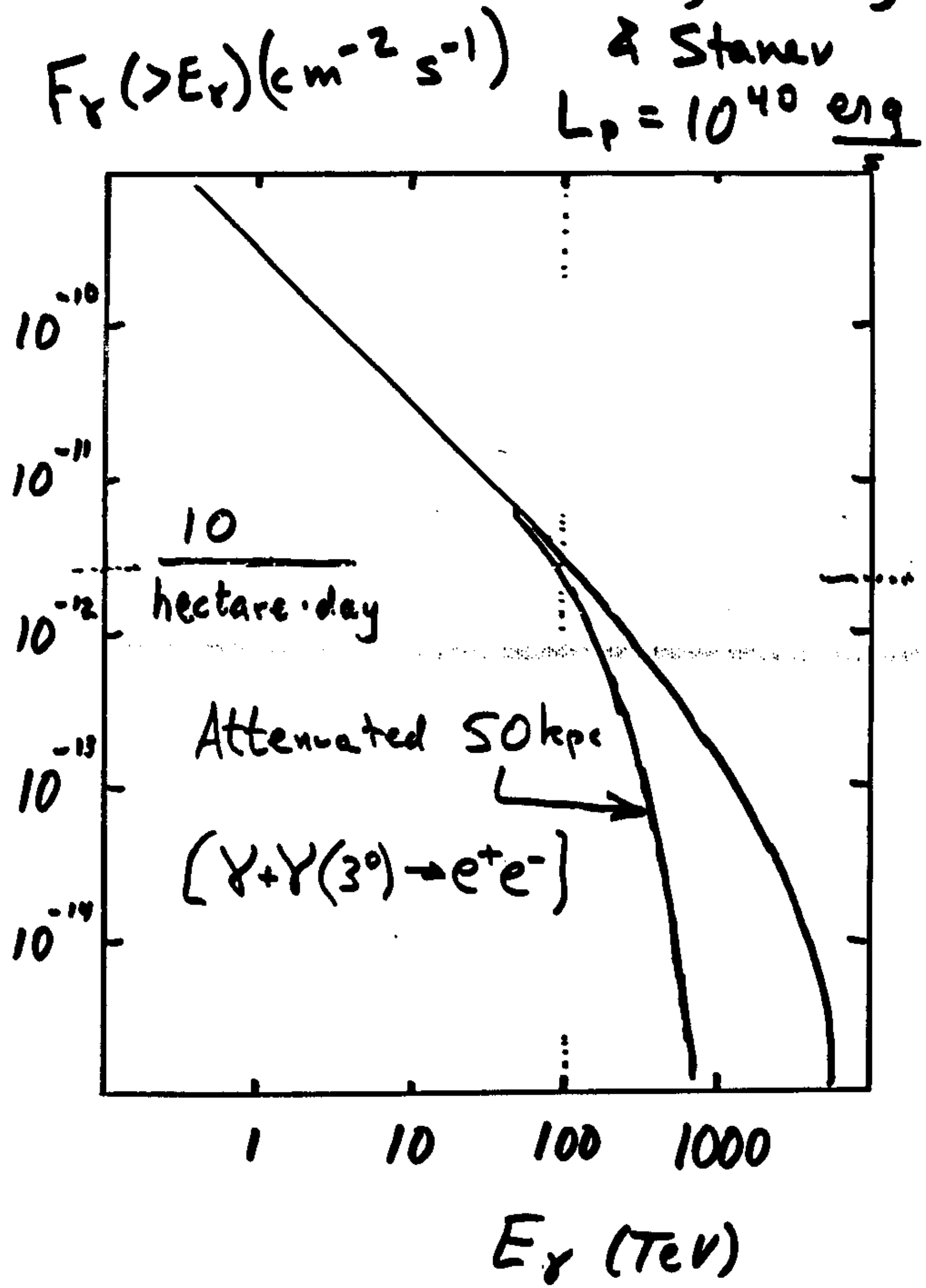
* many calculations. see e.g.

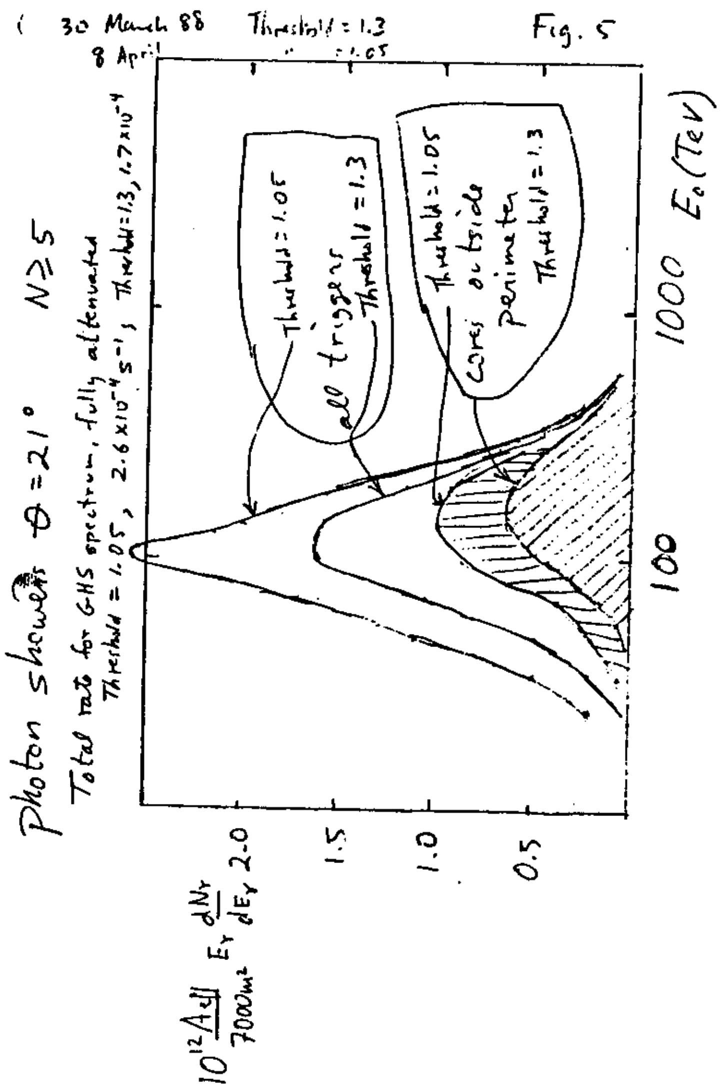
T. Stanev & Ch. P. Vankov Phys. Lett. 158B, 75 (85)

T. Stanev PR D33, 2740 (1986)

TKG, Harding & Stanev ApJ ...

$L_p = 10^{40}$ erg/s





SPASE PRELIMINARY

Fold Flux with Acceptance

to get expected signal

(for a particular model flux)

For G.H.S. $\gamma = 2$ $L_p = 10^{40}$ $\frac{erg}{s}$

expect 1.3×10^{-4} $\frac{events}{s}$ inside

Exposure = 4.5×10^5 s (~5 days

⟹ 59 events (for 3° x 3°

95% C.L. upper limit = 76

$\therefore L_p < \left(\frac{76}{59}\right) 10^{40} \sim 1.3 \times 10^{40} \frac{e}{s}$

-8-

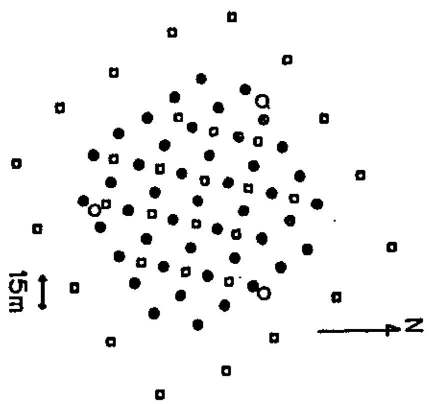


Fig.1

JANZOS

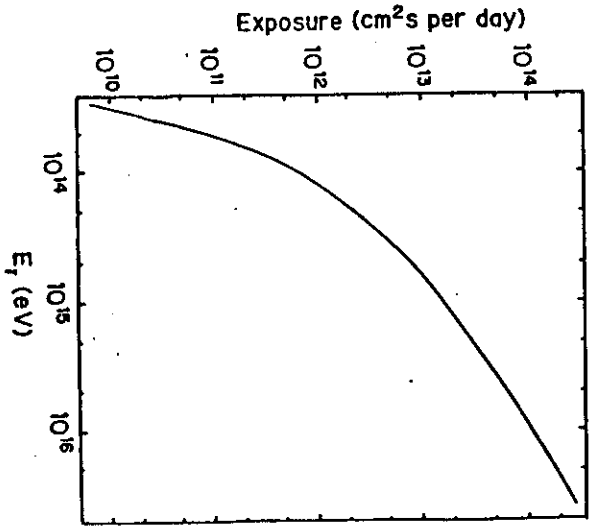
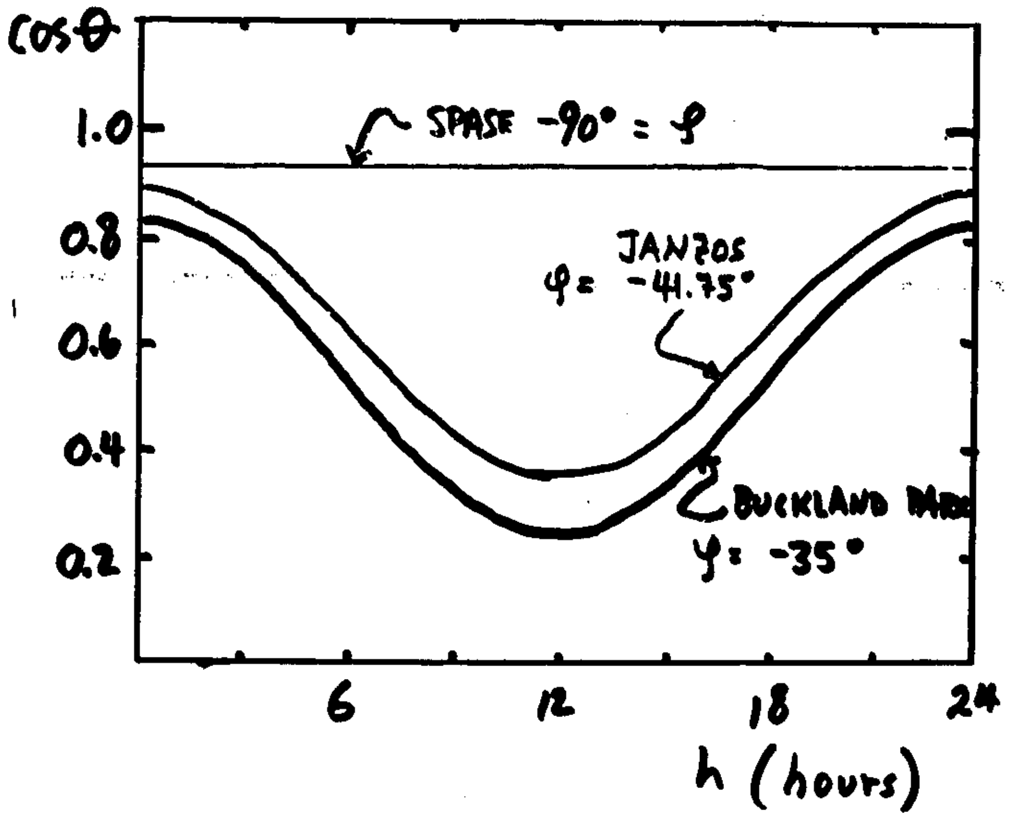


Fig.2

Zenith angle (θ) of SN1987A ($\delta = -69°$)

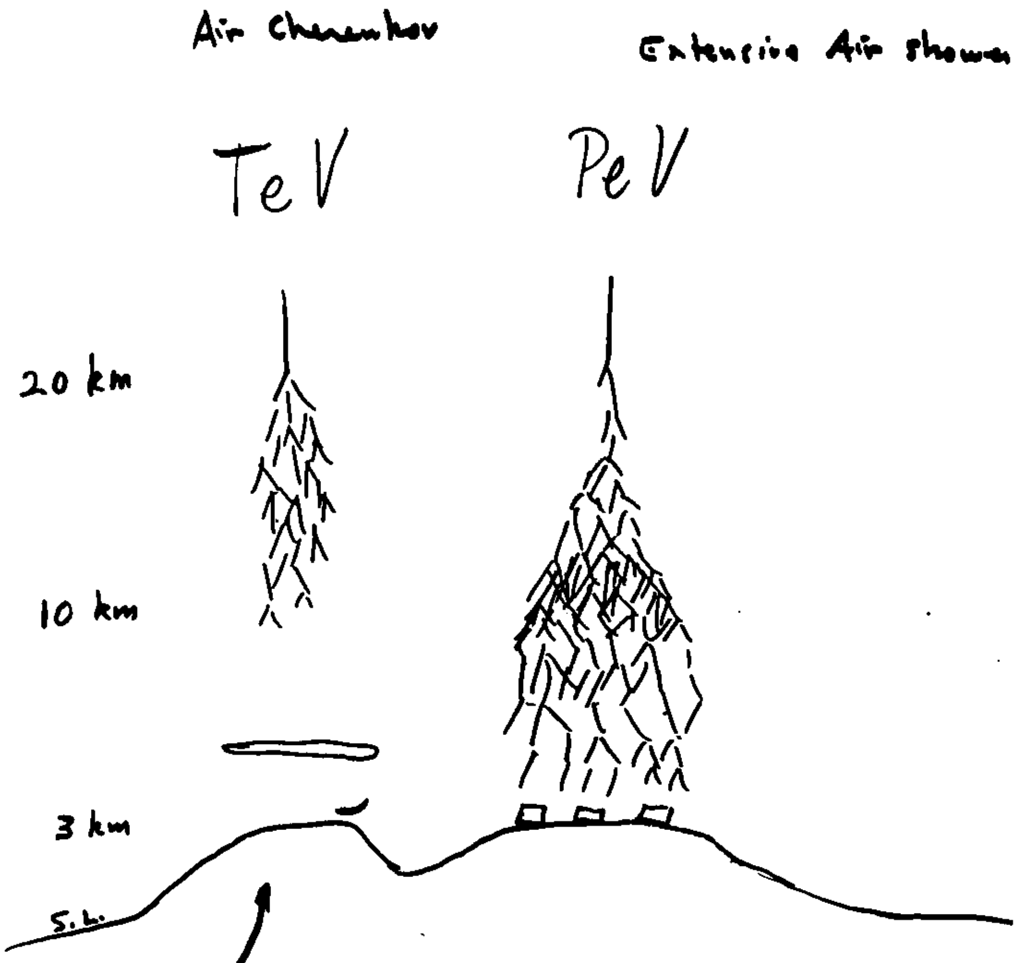
from various latitudes φ

$$\cos\theta = \sin\delta \sin\varphi + \cos\delta \cos h \cos\varphi$$



Summary of limits

Potchefstroom 20, 21, 25, 26 Nov.	$< 10^{39}$ $\gamma = 2$ $F_\gamma(>\text{TeV}) < 2 \cdot 10^{-11}$
Buckland Park 23 Feb - 30 Aug.	$< 10^{41}$ $\gamma = 2$ ($\gtrsim 200$ TeV)
JANZOS 13 Oct - 3 Dec	$< 5 \cdot 10^{39}$ $\gamma = 2$ $F_\gamma(>100) < 1.1 \cdot 10^{-12}$
SPASE (Prelim.) 6-10 Feb '88	$< 1.3 \cdot 10^{40}$ $\gamma = 2$ $F_\gamma(\gtrsim 50) < 3 \cdot 10^{-12}$



see Lamb & Weekes, Science, 238 1983 (1987)

PeV too high to be electron-induced

must be p + matter $\to \pi^0 + \cdots$, $\pi^0 \to \gamma$

... includes $\pi^\pm \to \nu$

Time dependence of signal

t_1 : $\lambda_R = \rho(t_1)\, v\, t_1$

($t_1 = 0$ for ν's)

t_2: **confined** (Berezinsky et al.) + This model

$$\frac{1}{t_2} = \rho(t_2)\, N_A\, \sigma\, c$$

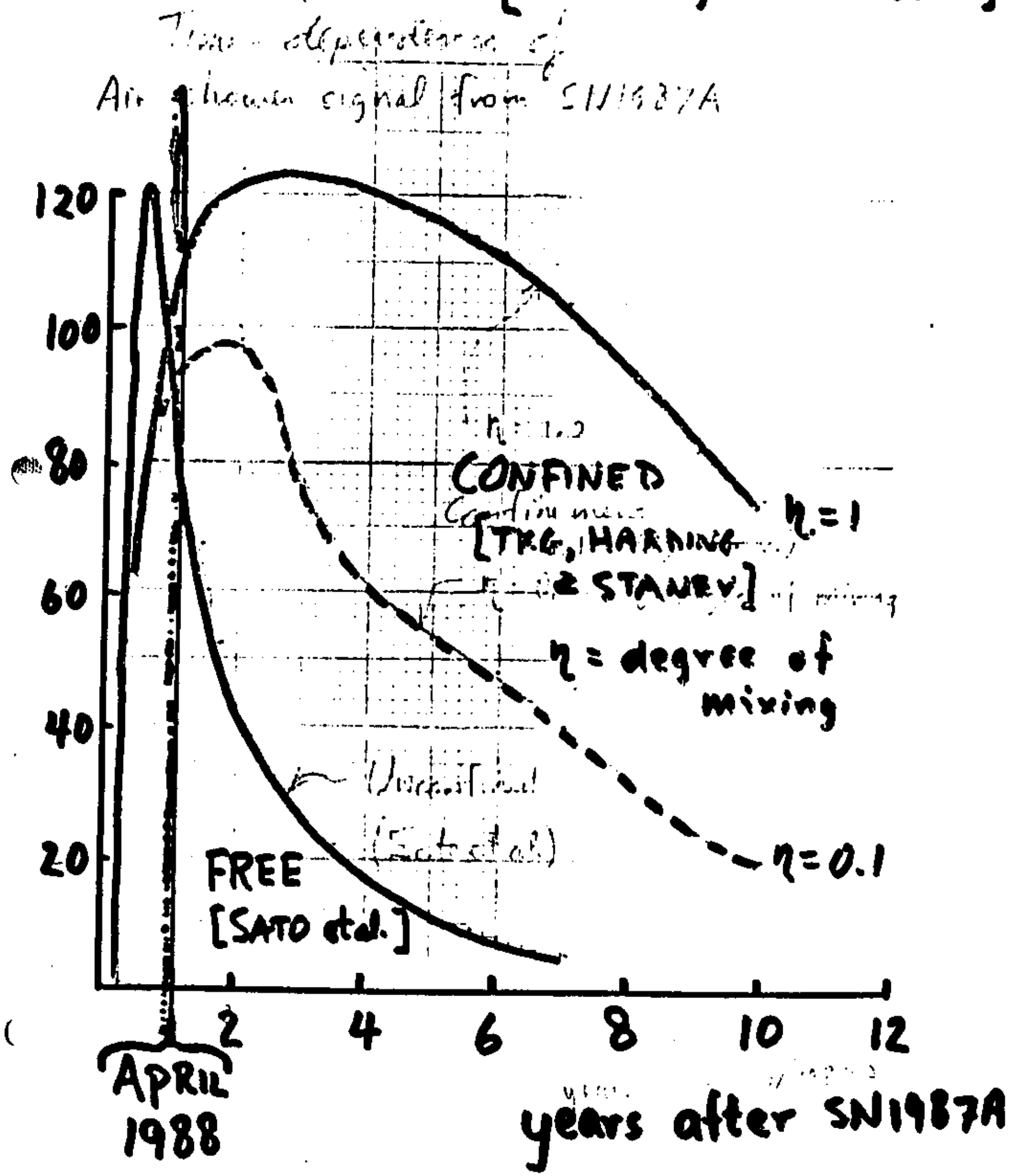
Expansion rate = interaction rate

t_2: **Free** (Sato et al.)

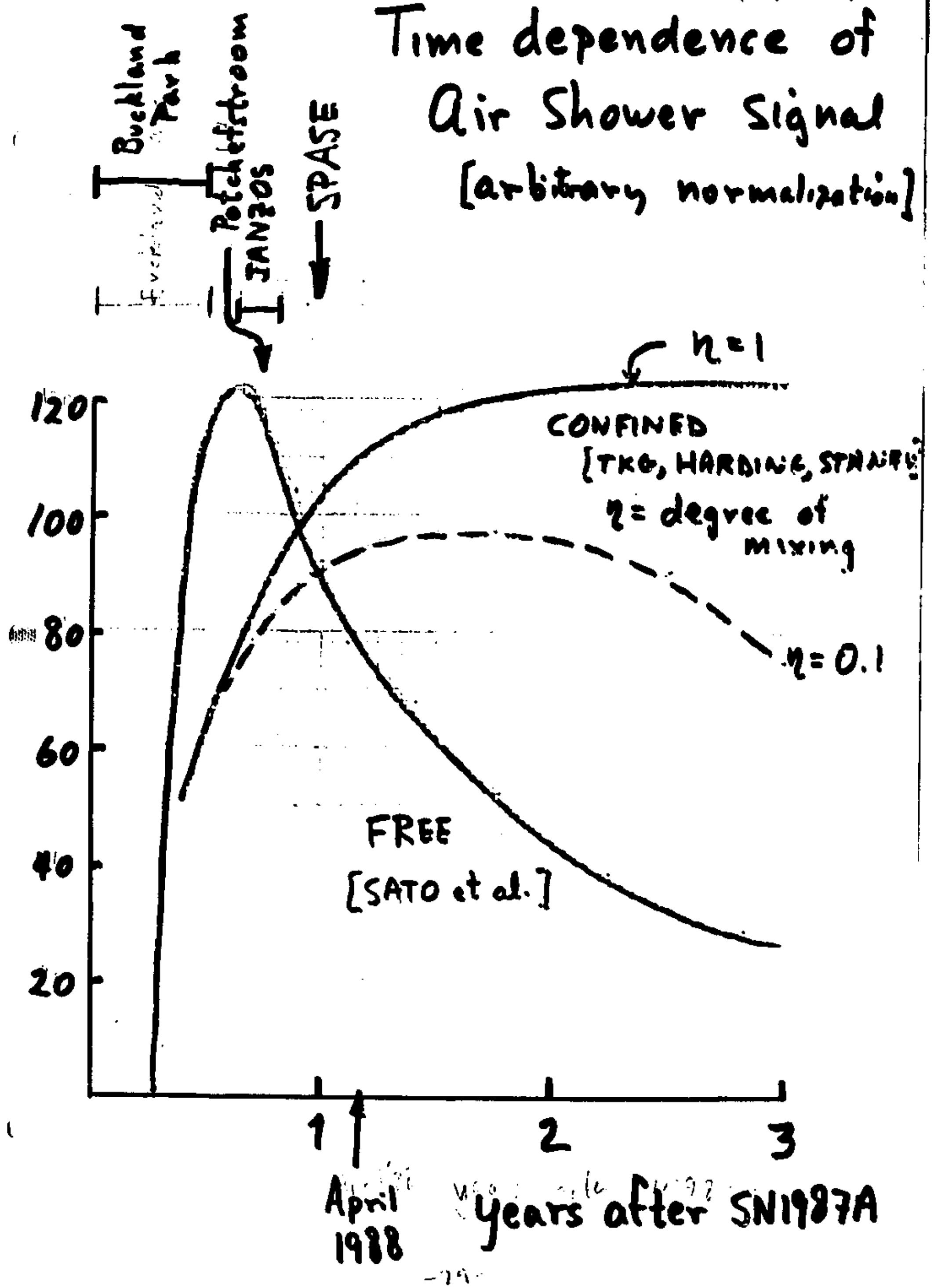
$$\lambda_{int} \gg \rho(t_2)\, v\, t_2$$

Time dependence of Air Shower Signal

[arbitrary normalization]



Time dependence of Air Shower Signal
[arbitrary normalization]



TKG & Stanev, P.R.L. (1987)

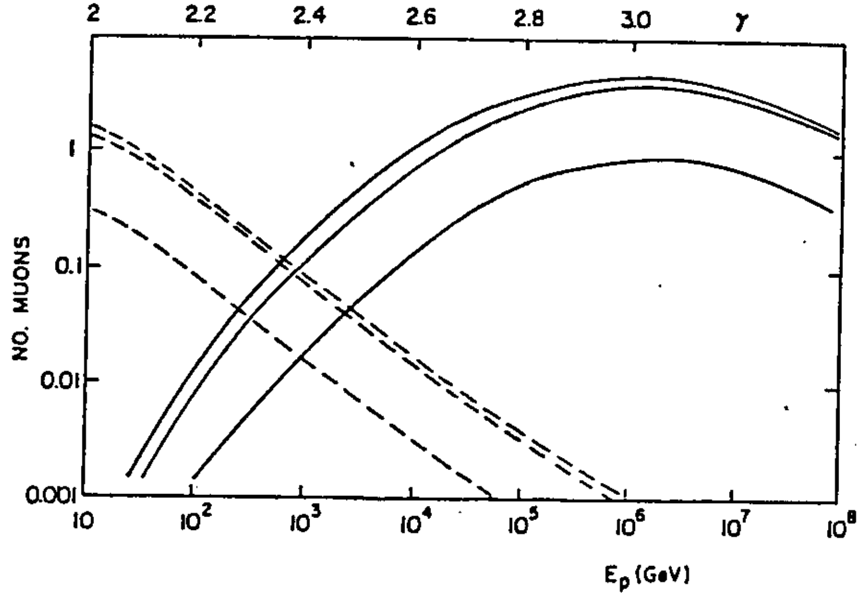
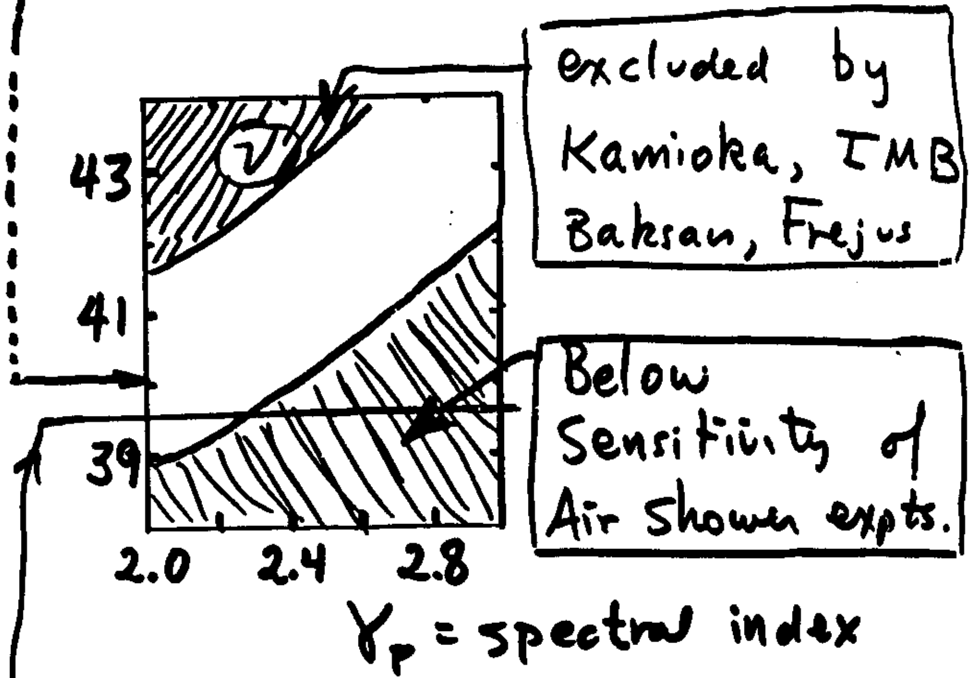


FIG. 1. Number of neutrino-induced muons per week in a detector of 100-m^2 area as a function of the parent proton spectrum. Solid lines and bottom axis refer to monoenergetic proton beams. Dashed lines and top axis refer to power-law spectra with differential index γ. In both cases the top curve is for a path length of 1000 g/cm^2, the middle curve for 100 g/cm^2, and the bottom one for 10 g/cm^2. All proton spectra are normalized to 10^{43} ergs/sec at 50 kpc. For power-law spectra this is the total power in protons with energies between 1 and 10^8 GeV.

See also Auriemma, TKG & Lipari (88) for analytic estimates of ν-flux.

Summary

- Note optical limit on L_p
- Note limits depend on γ_p



Bandiera, Pacini, Salvati:
(Nature 332, 418 '88)
explain low energy X-rays with $3 \cdot 10^{39}$ $\frac{erg}{s}$ pulsar

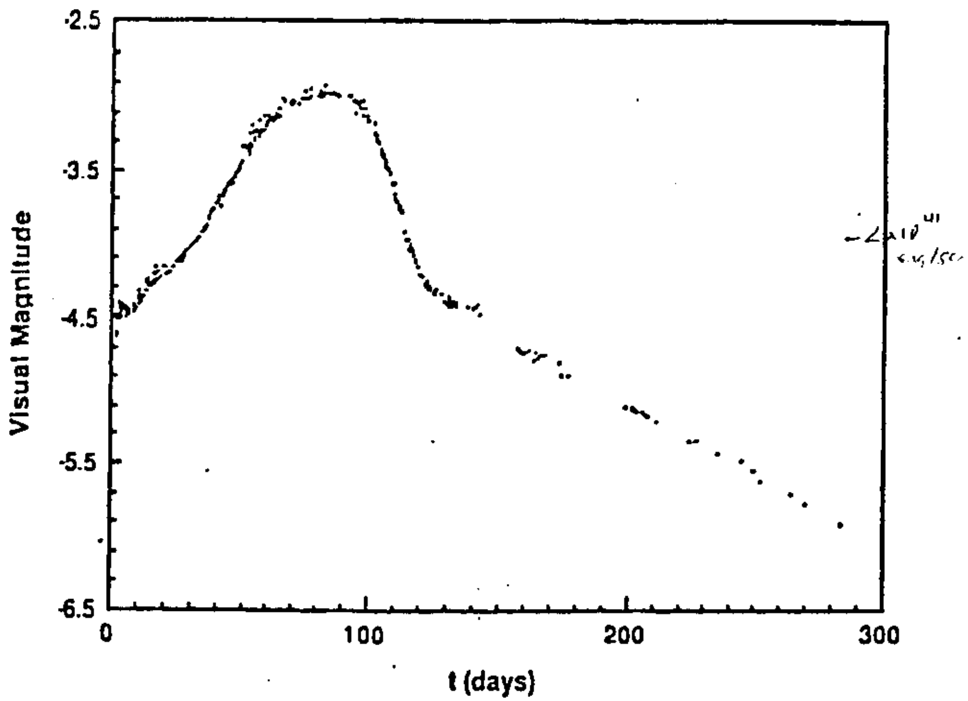


Fig 5.1 The visual light curve for the first 300 days of SN 1987A. This shows the relatively slo and steady climb up to the plateau-like maximum, followed by the relatively rapid decine to the extende radioactively - powered exponential tail. M. Dopita, Space Sci Revs.

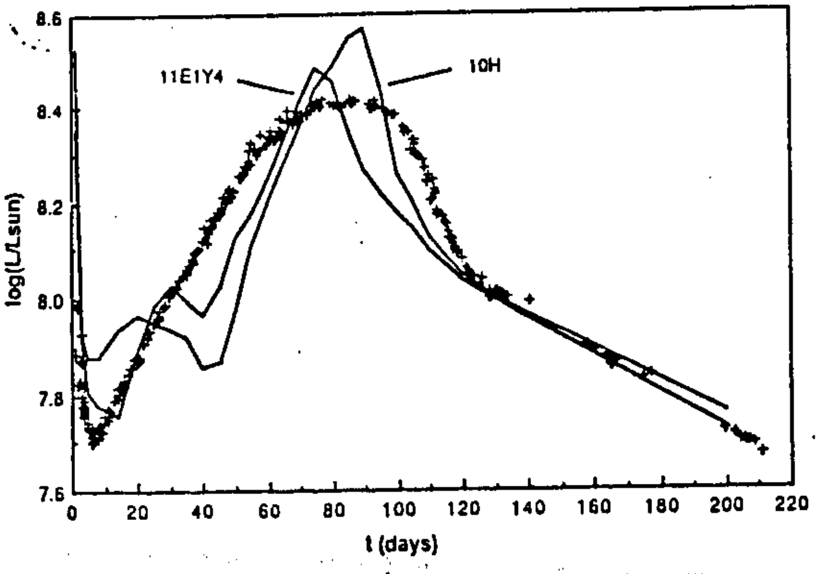


Fig 7.2 A comparison of the observed light curve with two representative theoretical light curves from the literature. The curve marked 10H is from Woosley (1987) and has an envelope mass of $10\ M_\odot$ with an explosion K.E. of 1.4×10^{51} ergs. The model marked 11E1Y4 is from Nomoto, Shigeyama and Hashimoto, and has an envelope mass of $6.7\ M_\odot$ and an explosion energy of 10^{51} ergs. The differences between the models and observations will probably reduce with a better treatment of opacity, of the recombination wave and of mixing of the radioactive Ni. M. Dopita, Space Sci Rev.

c. The Radioactive Tail.

The opacity of the core is determined by electron scattering. As oxygen and neon, the most abundant heavy elements contained in the core recombine, the opacity declines precipitately and the diffusion timescale rapidly decreases (Schaeffer, Cassé and Cahen, 1987; Shaeffer *et al.* 1987). This allows the stored heat energy to drain away. As the temperature falls, the recombination becomes still more rapid. Thus the core rapidly transforms itself from a condition in which the diffusion timescale is much longer than the dynamical timescale, to a condition in which the reverse is true. The luminosity in this latter phase can be set equal to the rate of energy generation in radioactivity (Weaver, Axelrod and Woosley, 1980):

SUMMARY #4

- Threshold (efficiency) functions for ν + γ
- ν_μ - induced upward μ signals
- calculation of flux for an air shower expt.

[• underground multiple muons + primary composition]

- muon problem
- Limits on γ + ν signals from SN 1987A