

TRANSPARENCIES OF PRESENTATIONS

BY THE DUMAND COLLABORATION

BEFORE THE ADAIR COMMITTEE

APRIL 22, 1983

THE DEPARTMENT OF THE ARMY

AND THE AIR FORCE

OFFICE OF THE SECRETARY

WASHINGTON, D.C.

DUMANID PROPOSAL TO D.O.E. HEP ORAL PRESENTATIONS

- (A) INTRODUCTION (10 min.) - - - - - V. PETERSON
ARRAY; TOPICS WITH BACKUP EXPERTS
- (B) ASTRO PHYSICS (25 min) - - - - V. J. STENGER
POINT SOURCES OF HIGH ENERGY γ 's, ν 's
SENSITIVITY OF DUMANID: M.O.E. (E/TeV)
POTENTIAL OF HIGH ENERGY γ ASTRONOMY
- (C) COSMIC RAY (^{VIA} MUONS) PHYSICS (25 min) - - D. C. ALLKOFER
 $10^9 \mu$'s / YEAR ABOVE 1 TeV; $\geq 10^6$ MULTI- μ 's
COSMIC RAY SPECTRUM EXTENDED; "KINK"?
HEAVY NUCLEI $\rightarrow \mu$ -SHOWER? EXOTICA?
- (D) HIGH ENERGY ν ' INTERACTIONS (25 min) - - B. BARISH
ANOMALIES IN σ_{TOT} ? $y = E_{\nu}/E_D$ DISTRIBUTION?
NEUTRINO OSCILLATIONS ON GLOBAL SCALE
MOST SENSITIVE MAGNETIC MONOPOLE DETECTOR
- (E) TECHNICAL FEASIBILITY (35 min.) - - - - J. G. LEARNED
DESIGN: MODULE, STRING, ROW, ARRAY
PROTOTYPED HARDWARE: 16" PNT \checkmark DETECTOR
CLEAN TESTS; DEPLOYMENT PLANS.
- (F) ORGANIZATION, BUDGET (15 min) - - V. PETERSON

1980-83
FEASIBILITY
STUDY

COLLABORATORS*

ASSOCIATES

(BACKUP SPEAKERS ON SPECIAL TOPICS)

NAME (INSTITUTION)

TOPIC

JIM ANDREWS (NORDA)

OCEAN SCIENCE, SITE STUDIES

File * HUGH BRADNER (SCRIPPS)

ACOUSTICS, SITE STUDIES

AL BRENNER (FERMILAB)

SIGNAL/DATA PROCESSING

* JIM GAIDS (PURDUE)

WATER CERENKOV'S, X-40 B.G.

* PETER GRIEDER (BERN)

COSMIC RAY: MUONS, SHOWER

* TAKASHI KITAMURA (TOKYO)

COSMIC RAY MUONS; P.M.T.'S

* ROBERT MARCH (MADISON)

SIGNAL PROCESSING

* ART ROBERTS (HAWAII)

MONTE CARLO STUDIES

* CHARLES ROOS (VANDERBILT)

POWER NEEDS; B.G. REDUCTION

File * FRED REINES (IRVINE)

DUNNS/INB OVERLAP

Naval Academy HOWARD TALKINGTON (NORC)

DEEP OCEAN TECHNOLOGY

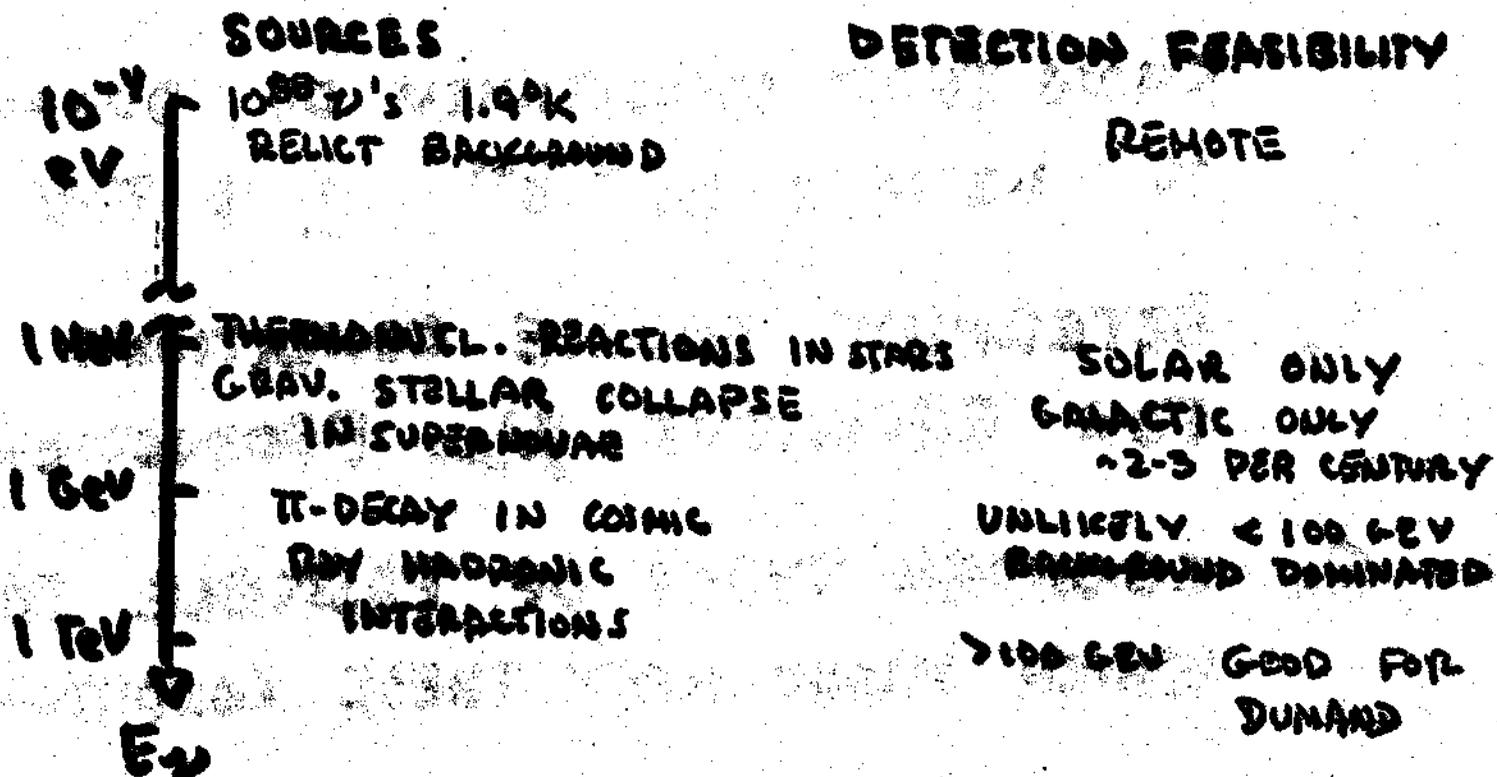
GEORGE WILKINS (NO.S.C)

UNDERSEA ELECTRO-OPTIC CABLES (fiber optics)

ABOVE GROUP (+ SPEAKERS) REPRESENT EXPERTISE

- BY: -- COSMIC RAYS.
- NEUTRINO PHYSICS (ACCELERATORS & COSMIC RAYS)
- OCEAN SCIENCE & ENGINEERING
- SIGNAL PROCESSING & DATA REDUCTION
- CERENKOV COUNTERS, ELECTRONICS

NEUTRINO ASTRONOMY V. STENGER



VERY HIGH ENERGY ν ASTRONOMY WITH DUMAND

GOALS: TO SEARCH FOR > 100 GeV ν_μ 's FROM POINT & DIFFUSE SOURCES BOTH INSIDE AND OUTSIDE THE GALAXY

EXPECTATIONS: ν_μ 's WILL BE DETECTED FROM COMPACT OBJECTS - NEUTRON STARS & BLACK HOLES - ON STELLAR & GALACTIC SCALE DATA WILL COMPLEMENT COSMIC RAY & γ RAY OBSERV.

- ➡ UNDERSTANDING OF THESE OBJECTS
- ➡ UNDERSTANDING OF PARTICLE ACCELERATION IN THE COSMOS.
- ➡ EXPLORE THE HIGHEST ENERGY PROCESSES IN THE UNIVERSE

OUTLINE

1. SHOW THAT SENSITIVITY OF DEMAND IS $1-2 \nu_{\mu}'s \text{ km}^{-2} \text{ s}^{-1} \geq 1 \text{ TeV}$
2. DETERMINE SOURCE CONDITIONS FOR EFFICIENT ν_{μ} PRODUCTION
3. CONSIDER TYPES OF POSSIBLE SOURCES WHICH MIGHT MEET THESE CONDITIONS
4. CONSIDER THE ENERGY REQUIREMENT FOR DETECTABLE ν_{μ} FLUXES AND WHETHER POSSIBLE SOURCES MEET THESE REQUIREMENTS

THE QUESTION:

FROM GENERAL (FAIRLY) MODEL-INDEPENDENT PHYSICS CONSIDERATIONS CAN WE PLAUSIBLY EXPECT TO OBSERVE EXTRATERRESTRIAL ν 'S, AND LEARN ANYTHING USEFUL FROM THEM?

?

CONCEPT OF DUMAND

EXTRATERRESTRIAL

ATMOSPHERIC

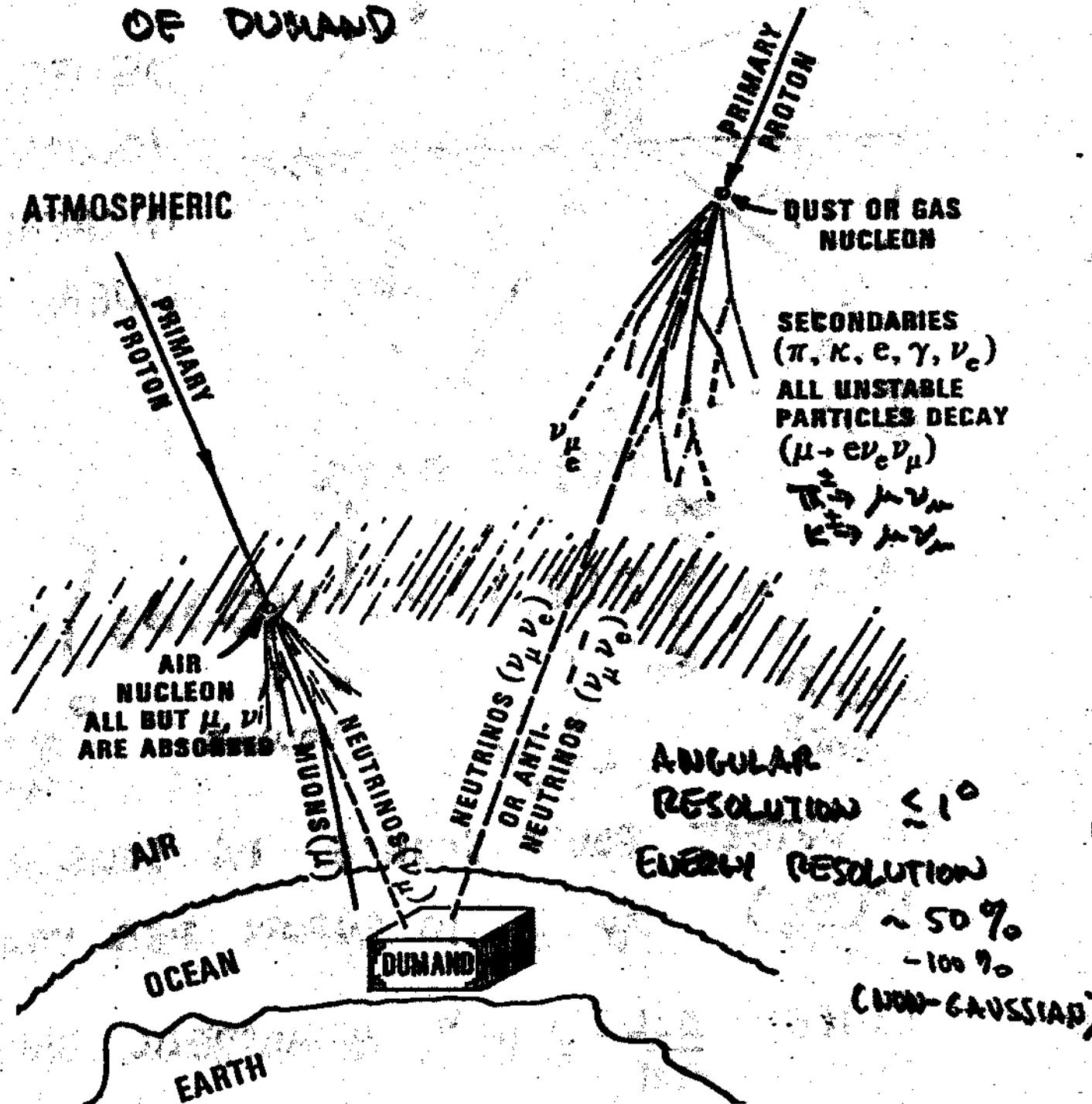
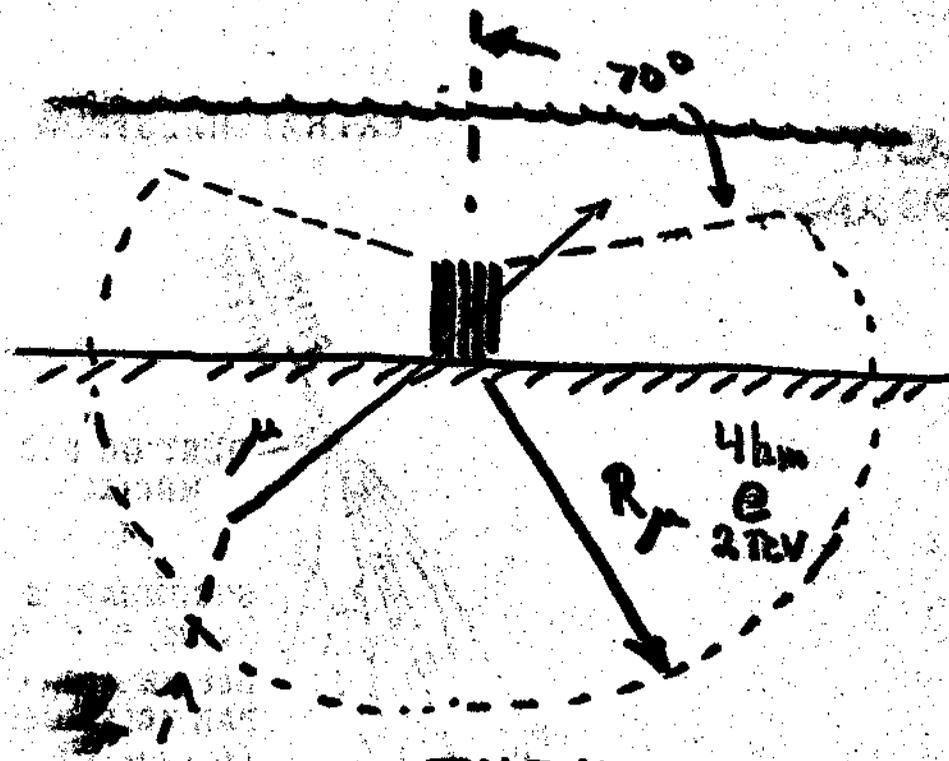


Fig. 1. The concept of the DUMAND experiment. Cosmic ray protons (or other nuclei) of very high energy strike matter, either in the earth's atmosphere or elsewhere in the cosmos. The hadronic secondaries which are produced decay into neutrinos which penetrate to the DUMAND array and are detected. Muons produced in the atmosphere with energy greater than 3 TeV can also be detected and analyzed. From the DUMAND Omnibus Proposal²⁹.



DETECTION
VOLUME
INCREASES WITH
ENERGY

EVENT RATE

$$R = n \int_{E_T}^{\infty} F(E_\nu) dE_\nu \int V(E_\nu) dy \int G(x, y) dx$$

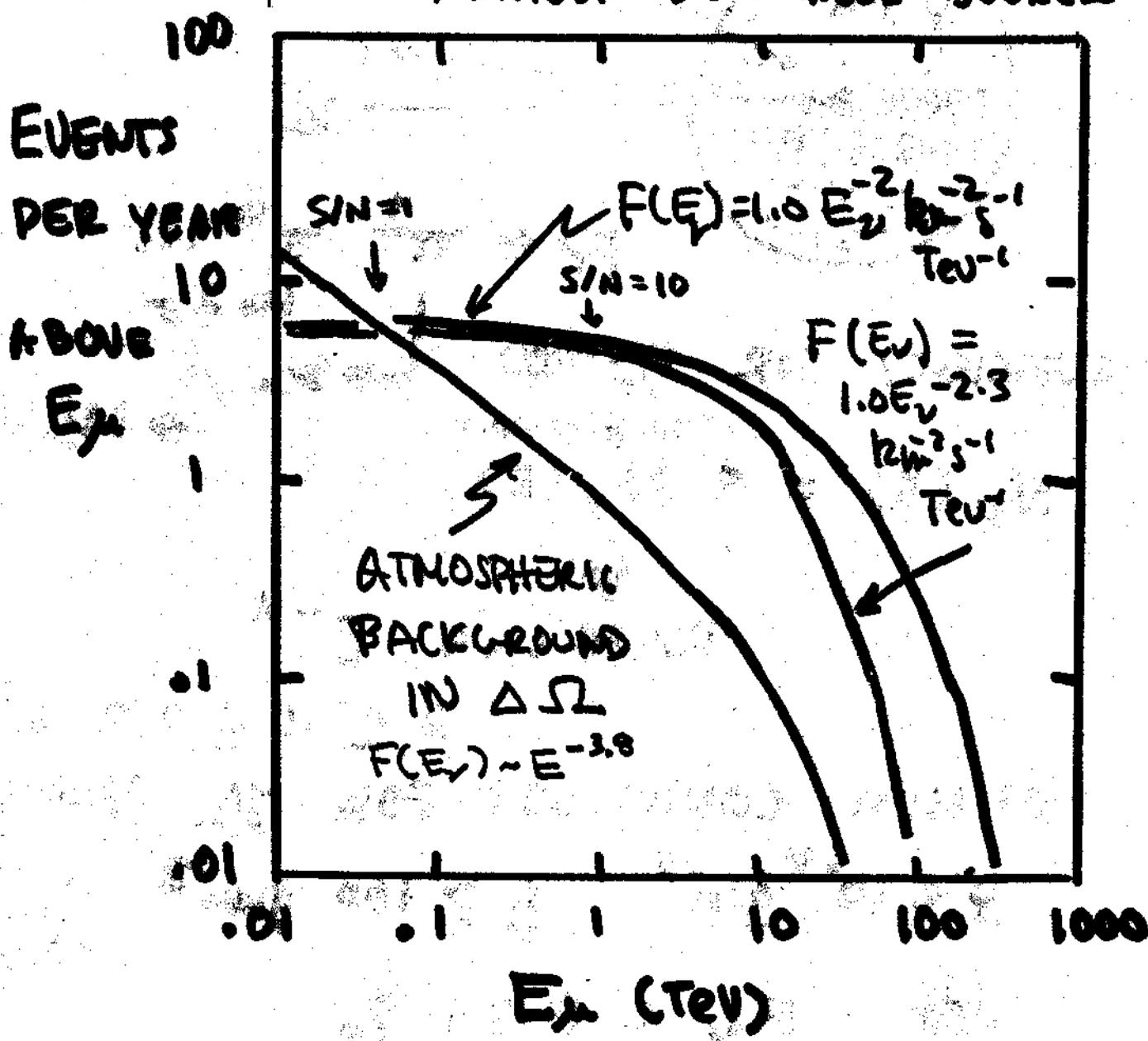
$n \rightarrow 6 \times 10^{38} \text{ cm}^{-3}$
 $F(E_\nu) \rightarrow \text{FLUX} \sim E_\nu^{-2}$
 $V(E_\nu) \rightarrow \text{VOLUME}$
 $G(x, y) \rightarrow \text{STANDARD MODEL}$

DETECT POINT SOURCE IN SOLID ANGLE $\Delta\Omega$
 $F(E_\nu) \Rightarrow \geq 10 \text{ EVENTS PER YEAR}$

SINCE $\frac{\Delta\Omega}{4\pi} \approx 10^{-4}$, ATMOSPHERIC BACKGROUND

IN $\Delta\Omega \leq 1 \text{ EVENT PER YEAR}$

RESULTS OF SIMULATION OF MEASURED E_μ SPECTRUM FROM FAINTEST DETECTABLE SOURCE

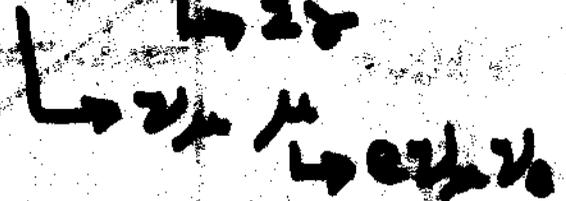
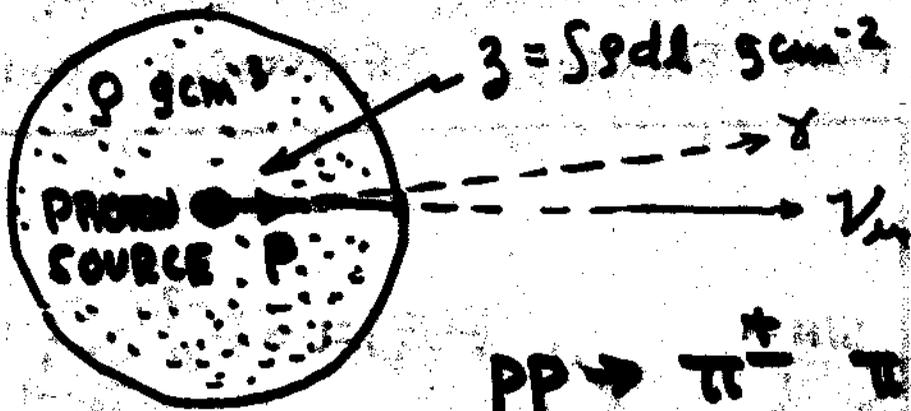


ERRORS ON E_μ NON-GAUSSIAN
FLUX SENSITIVITY :

$1-2 \text{ km}^2 \text{ s}^{-1} > 1 \text{ TeV}$

NOTE THAT OPTIMUM THRESHOLD $\sim 1 \text{ TeV}$
BUT ENERGY RESOLUTION NOT CRITICAL

NEUTRINO PRODUCTION IN COSMIC SOURCE



EFFICIENCY FOR ν_μ -PROD. (OR γ -PROD.)

$N_\nu(E) = \epsilon N_p(E)$

POWER LAW $E^{-\alpha}$

$2 \leq \alpha \leq 2.3$ EVOLVED

OPTIMUM CONDITIONS FOR ν_μ PRODUCTION

$\rho < 10^{-8} \text{ g cm}^{-3} \quad z \gtrsim 100 \text{ g cm}^{-2}$

NEED LOTS OF WATER

$\Rightarrow E_\nu = 8-24 \%$
 \uparrow
 $\alpha=2$

OPTIMUM CONDITIONS FOR γ PROD. BY π^0 'S

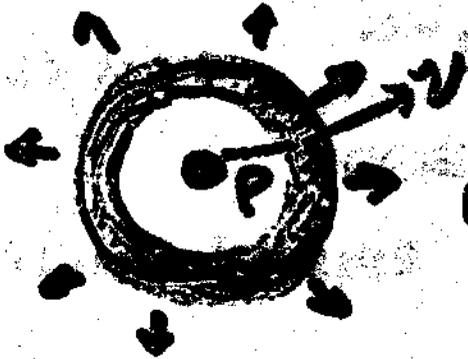
$z \gtrsim 50 \text{ g cm}^{-2}$

$\Rightarrow E_\gamma = 1-2.8 \%$

SOURCES OF HIGH ENERGY γ 'S

COMPACT OBJECTS SURROUNDED BY THICK MATTER OR HIGH MAGNETIC FIELDS (TO TRAP PROTONS)

PULSARS



DURING EARLY STAGE OF SUPERNOVA

Berezinsky: $\dot{\gamma} > 100 \text{ gem}^{-2}$ for ~ 1 month

OR

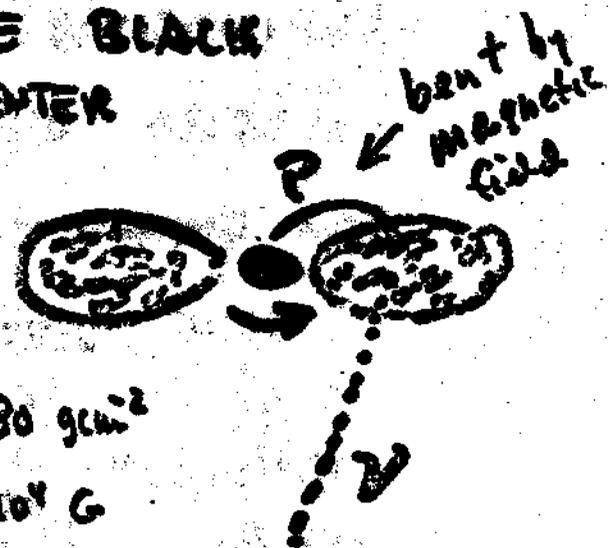


PULSAR IN BINARY SYSTEM

ACTIVE GALACTIC NUCLEI

SUPERMASSIVE BLACK HOLE AT CENTER

OR



KAFATOS: $\dot{\gamma} \approx 80 \text{ gem}^{-2}$

TAKAHAMA: $B = 10^8 \text{ G}$

ENERGETIC REQUIREMENTS

FLUX AT EARTH

$$F(E) = \frac{\epsilon N_p(E)}{4\pi R^2}$$

$\epsilon = 24\%$ OPTIMUM

$F(>1\text{TeV}) = 1-2 \text{ km}^2 \text{ s}^{-1}$
DETECTABLE

PROTON EMISSION AT SOURCE

$$N_p(E) = N_p(1\text{TeV}) E^{-\alpha} \quad 2 < \alpha < 2.3$$

ENERGY LUMINOSITY PER DECADE

$$L_p(E) = E^2 N_p(E) \quad \text{ergs s}^{-1} \text{ decade}^{-1}$$

\Rightarrow CONSTANT

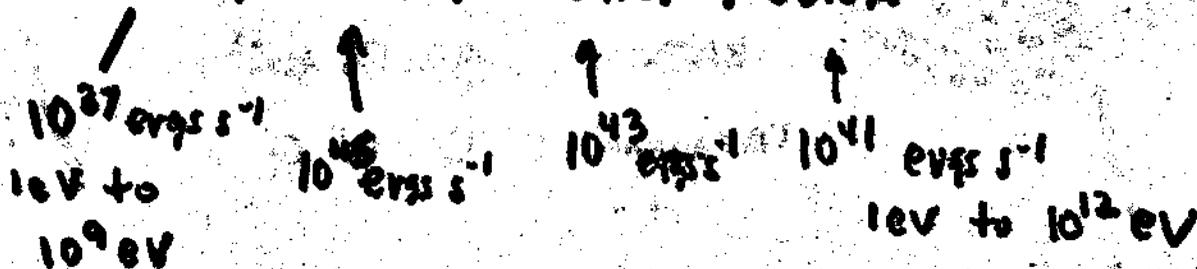
$\alpha \rightarrow 2$

∴ MOST EFFICIENT MECHANISMS INVOLVE \sim CONST. L_p

THIS IS OBSERVED FOR ELECTROMAGNETIC LUMINOSITIES OF COMPACT, NON-THERMAL OBJECTS OVER 9-12 DECADES OF ENERGY

FOR EXAMPLE,

CRAO, 3C273, NGC4194, CEN A



QUASAR 3C 273

210

DISTANCE

2.7×10^9
light
years



(a)

$0.15 \frac{\text{MOL}^2}{\text{YEAR}} \rightarrow$



(b)

Figure 12.6 THE NEAREST QUASAR

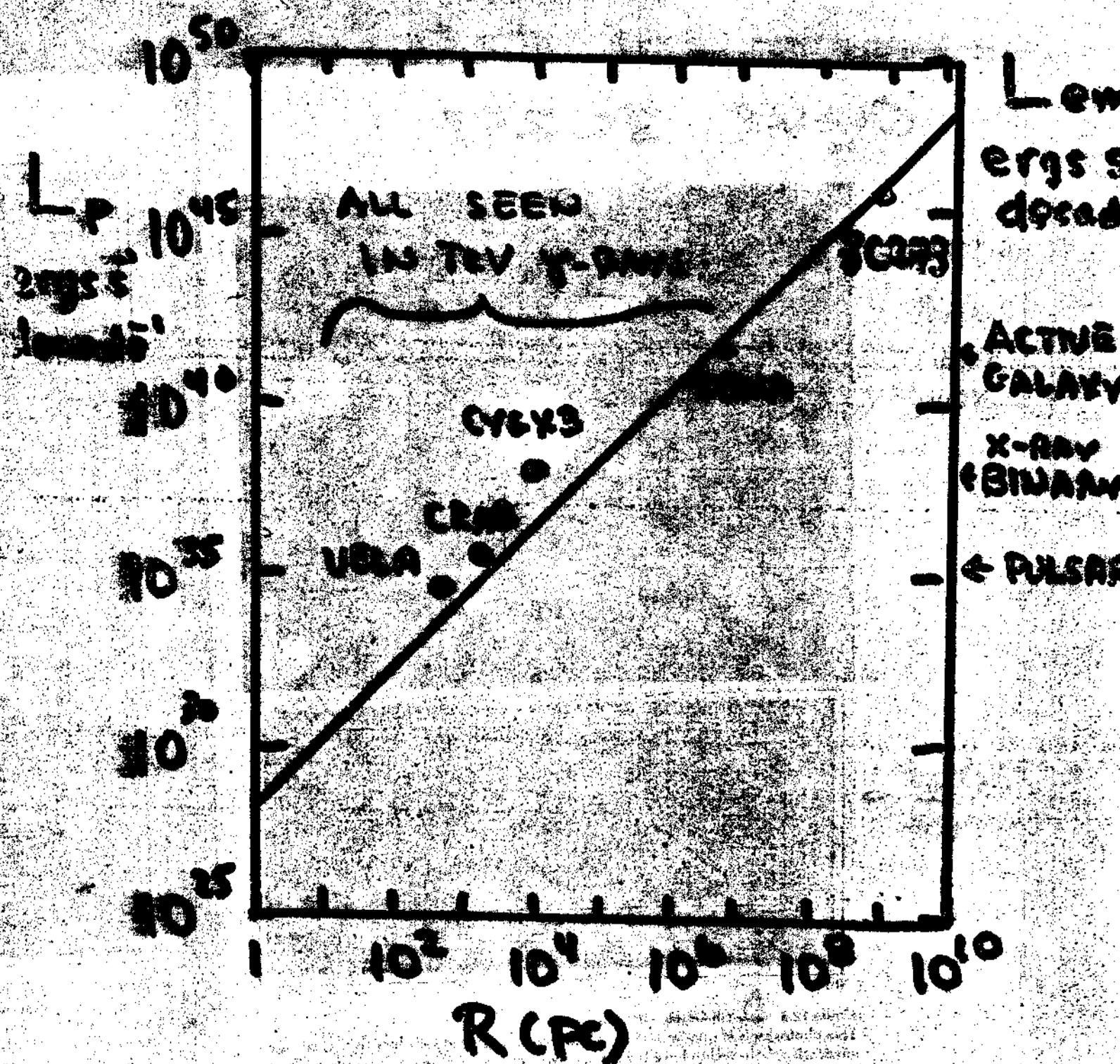
This photograph of quasar 3C 273, a fourteenth-magnitude starlike object, reveals a small wispy, believed to have been explosively ejected by the quasar some millions of years ago (a). Its electromagnetic spectrum (b) spans a wide range and is similar in many ways to that of the nucleus of Centaurus A (Figure 12.2). One important difference is that this quasar is intrinsically 1,000 times more luminous—it is one of the most luminous objects in the universe.

From Silk
"The Big Bang"



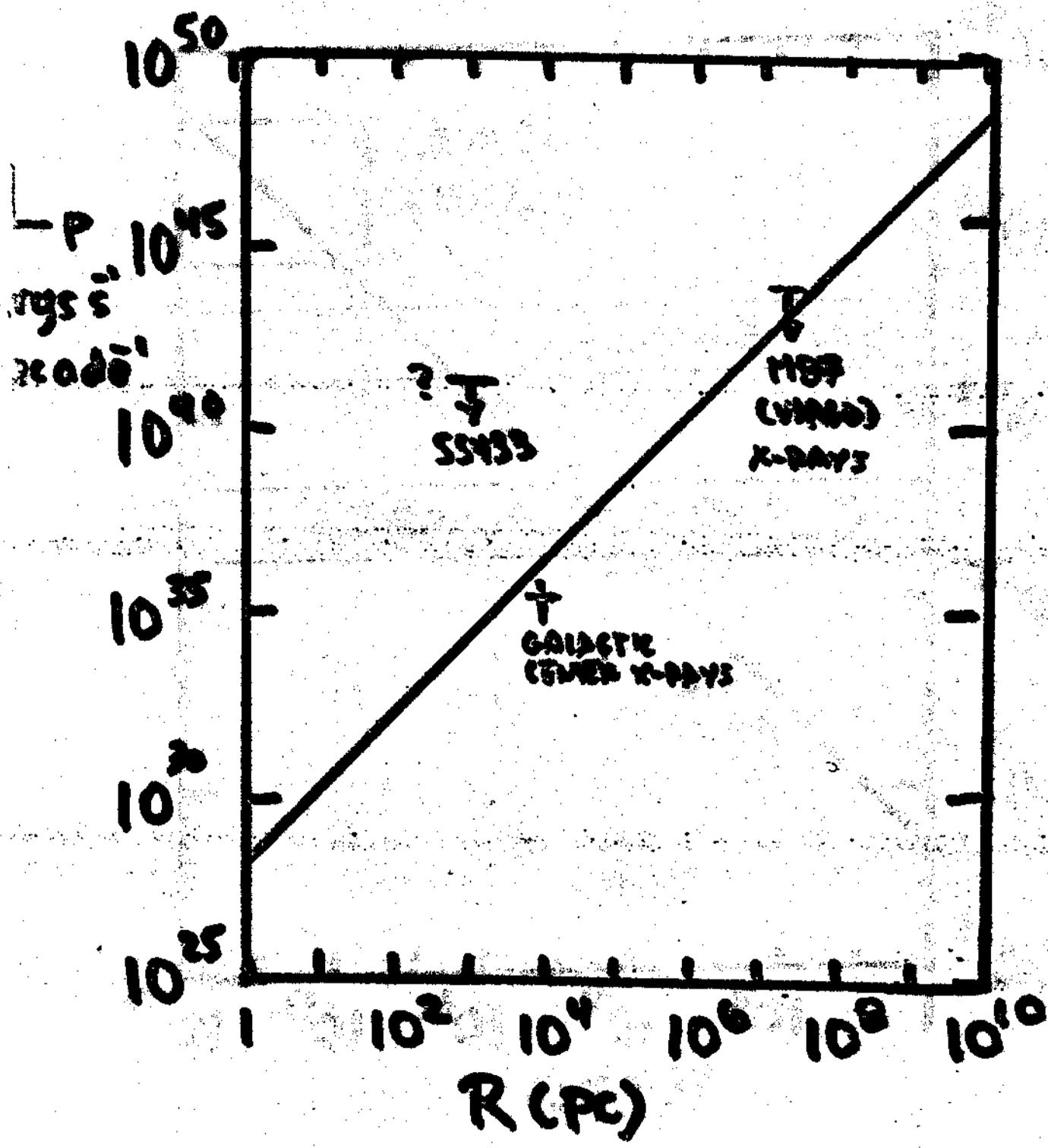
Figure 12.7 THE QUASAR SPECTRUM
Four quasar spectra must be covered in a wavelength range needed to establish a redshift by an arbitrary amount. The Lyman alpha line (Lyman alpha) is a spectral line at 1215 Angstroms. The photons were emitted when the

MINIMUM LUMINOSITY REQUIRED
 TO PRODUCE A DETECTABLE NEUTRINO
 FLUX AT EARTH UNDER BEST CONDITION



ELECTROMAGNETIC LUMINOSITIES
 OF SOME SPECIFIC SOURCES

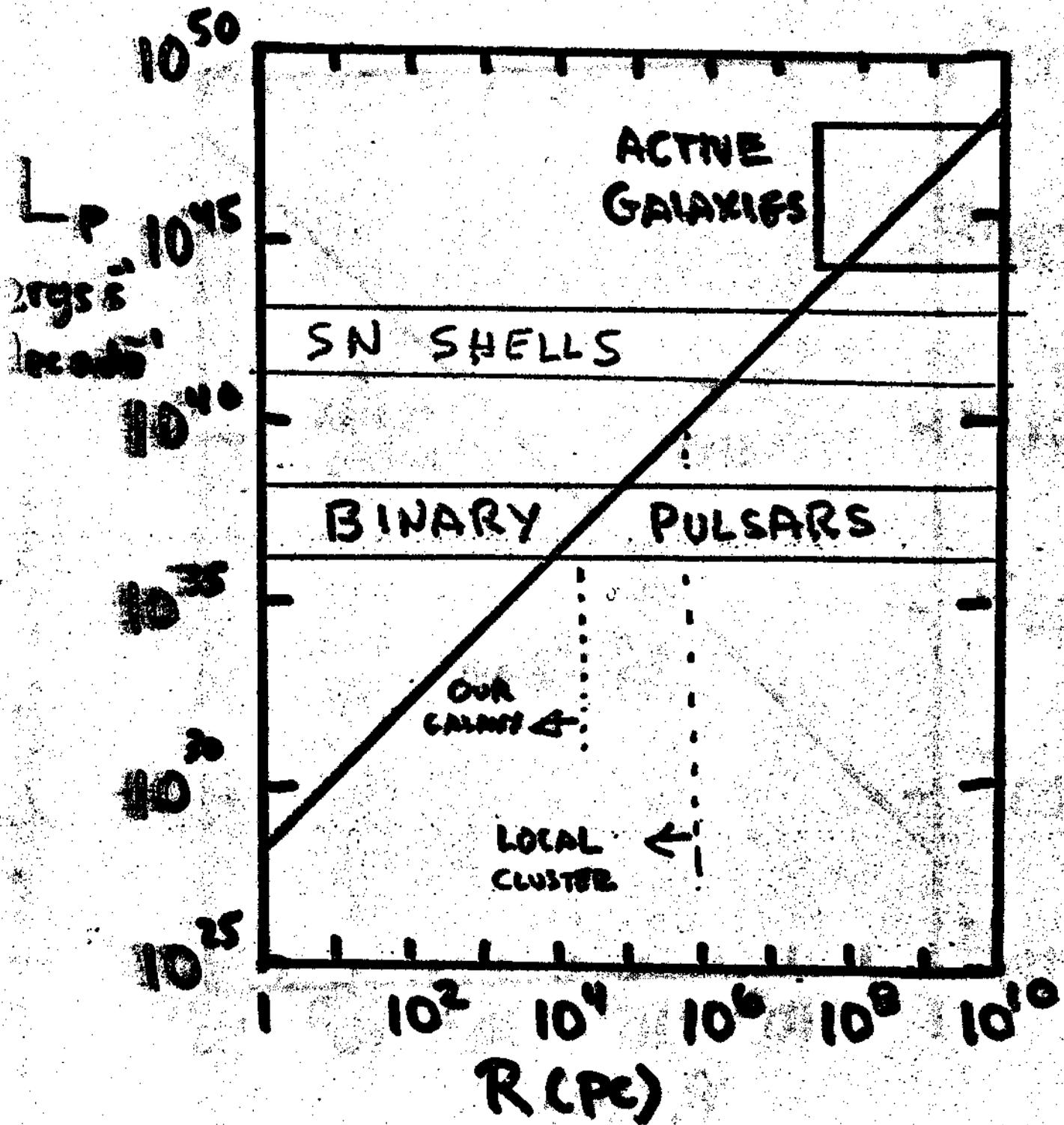
PROTON LUMINOSITY REQUIRED TO PRODUCE A DETECTABLE NEUTRINO FLUX AT EARTH UNDER BEST CONDITIONS



SOME OTHER SOURCE POSSIBILITIES

NEW HOT RESULT FROM JPL: 15 MEV LINE (M_4^{21})
 WENDS 2×10^{37} CTS s^{-1} IN ONE LINE!

MINIMUM LUMINOSITY REQUIRED
 TO PRODUCE A DETECTABLE NEUTRINO
 FLUX AT EARTH UNDER BEST CONDITION.

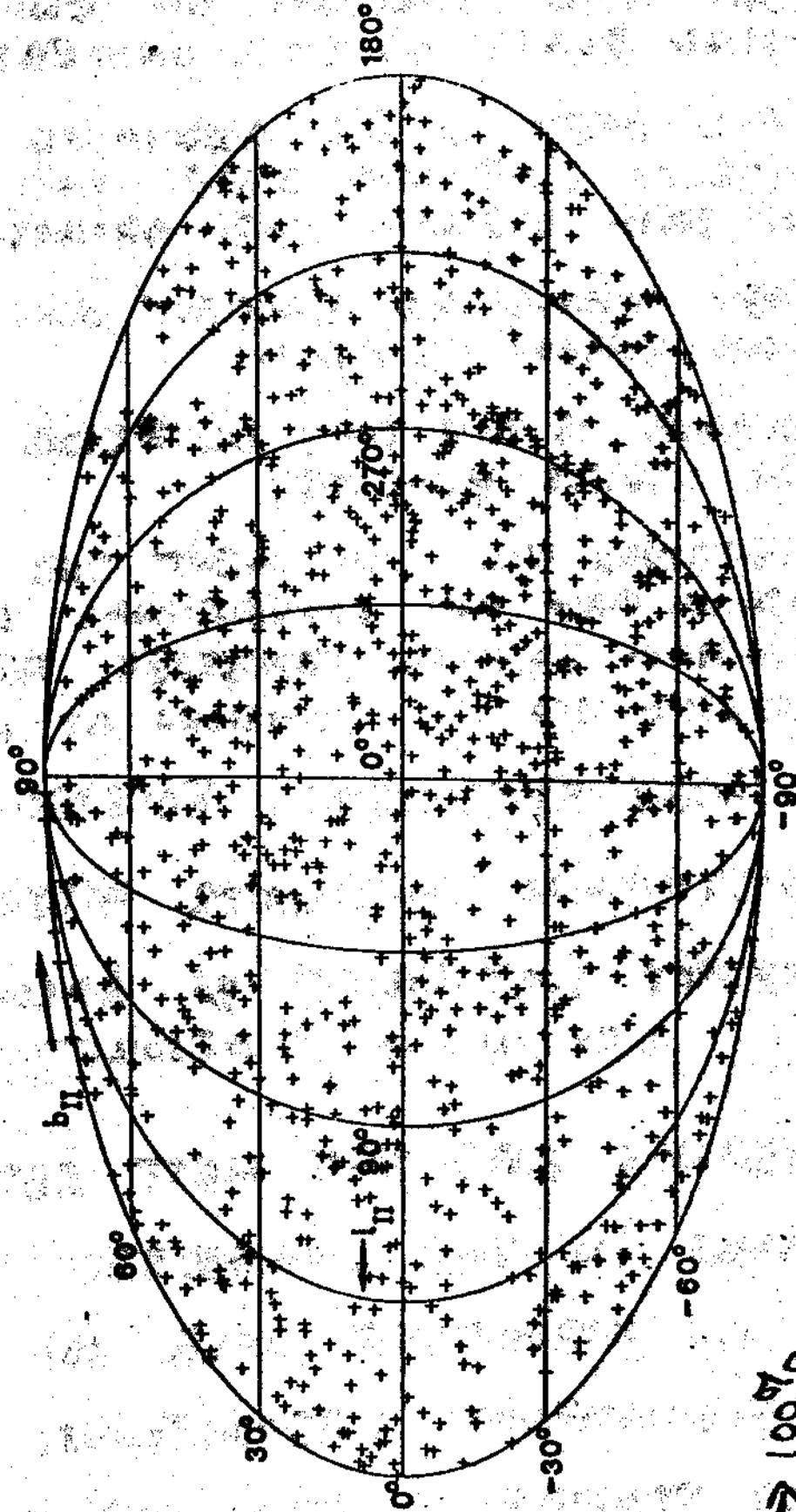


ESTIMATE RANGE OF LUMINOSITIES
 FROM CANDIDATE SOURCE TYPES

Fig. 12.3

SKY COVERAGE OF DUNAND

EVENTS



GALACTIC COORDINATES

ALSO...
 DUTY FACTOR \rightarrow 100%
 SEARCH FOR TRANSIENTS

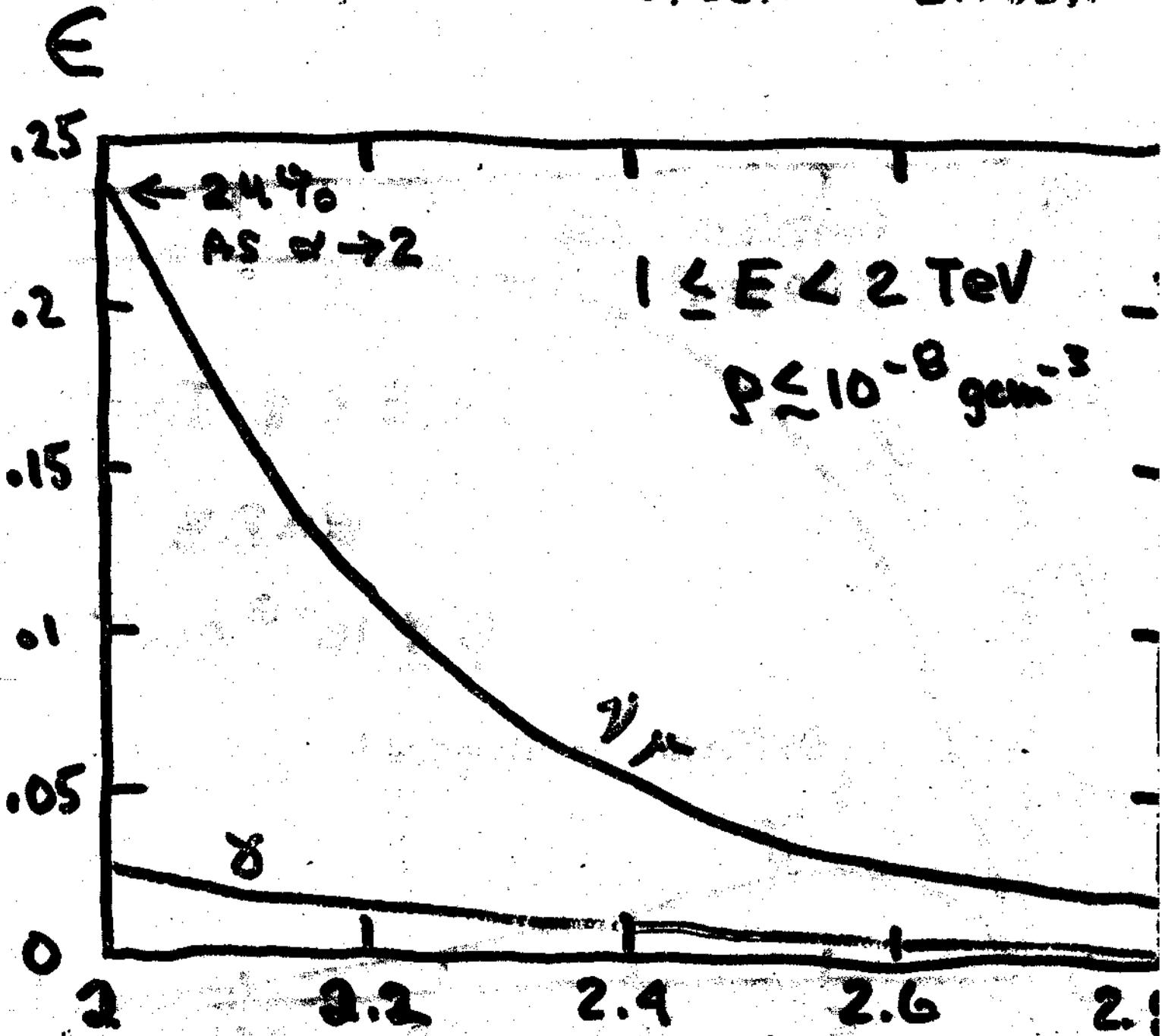
BECAUSE OF LOW LATITUDE (20°) WE DO NOT MISS ANY OF SKY
 EVEN THOUGH WE CUT OUT DATA WITHIN 70° OF ZENITH (ASSUMING...)

CONCLUSIONS

- ▶ THERE ARE PROCESSES OF ENORMOUS ENERGY TAKING PLACE IN THE UNIVERSE
- ▶ THESE SEEM TO BE ASSOCIATED WITH COMPACT OBJECTS, NEUTRON STARS AND BLACK HOLES, ON BOTH STELLAR AND GALACTIC SCALES
- ▶ THEY SHOULD BE EFFICIENT SOURCES OF VERY HIGH ENERGY NEUTRINOS
- ▶ DUNAND IS THE ONLY DETECTOR SENSITIVE AT LEVELS EXPECTED
- ▶ NEUTRINOS WILL COMPLEMENT THE RESULTS OF GAMMA RAY AND CONVENTIONAL ASTRONOMY, PROBING HADRONIC PROCESSES DEEP IN MATTER LOOKING IN ALL DIRECTIONS AT ALL TIMES
- ▶ MORE SPECULATIVE POSSIBILITIES
- ▶ DISTINGUISH ANTIMATTER OBJECTS
- ▶ DETECT $1,9^\circ$ RELICT ν BACKGROUND (BY $\nu\bar{\nu} \rightarrow e^+e^-$ ABSORPTION LINE)

NEUTRINOS ARE THE MOST COPIOUS PARTICLES IN THE UNIVERSE. THEY PLAY AN IMPORTANT ROLE IN COSMOLOGY AND FUNDAMENTAL INTERACTIONS. THEY WOULD PROVIDE A NEW AND UNIQUE PROBE OF SOME OF THE MOST BASIC PHENOMENA IN THE COSMOS.

OPTIMUM EFFICIENCY AS A FUNCTION OF SPECTRAL INDEX



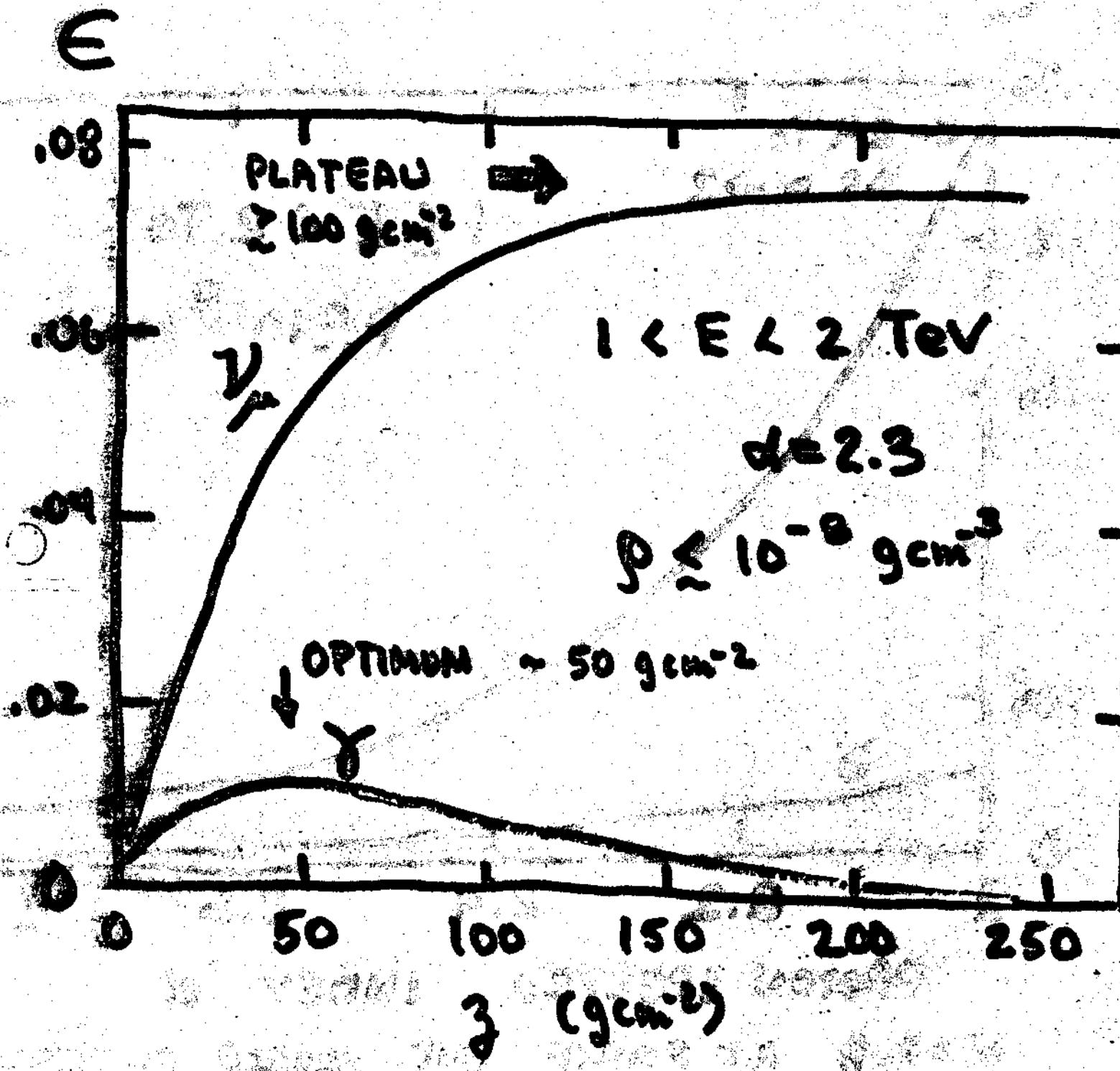
PROTON SPECTRAL INDEX α

$\alpha = 2.8$ AT EARTH BUT SOURCE SPECTRUM

VERY LIKELY TO BE FLATTER (LEAKAGE)

$\alpha \rightarrow 2$ PREDICTED BY ACCEL. MODELS

EFFICIENCY FOR ν_e, γ PRODUCTION



Cosmic Ray Physics with DUMAND

What will be measured

- Energy Spectrum of muons
- Energy loss of muons in water
- Multi muon events

Frequency distribution

Decoherence curve

- Arrival direction
- muons together with EAS*

* This is only possible if the DUMAND is provided with a *conventional air shower array* at the sea level surface

what can be derived from the measurements of muons

- The primary energy spectrum
- The primary composition
- Energy loss parameter b

$$\frac{dE}{dx} = a + bE$$

- contribution of heavy charmed particles
- sidereal anisotropies
- Exotic and unexpected phenomena.
- background for Neutrinos
- only basis for calculating the expected neutrino spectrum in the atmosphere

Present status of cosmic ray μ physics

(1) Energy Spectra of Muons

Many measurements the last 20 years
in Durham, San Diego, Brookhaven,
Tokyo, DESY, Kiel

Highest Acceptance and Energy resolution

MUTRON	Tokyo
DEIS	Tel Aviv

Energy limit ~ 10 TeV

(2) Multi muon events

Results from UTAH, KGF, CORNELL,
JAPAN, HOMESTAKE

- Frequency distribution
UTAH

- Decoherence curve
HOMESTAKE + UTAH

Measurements show a deficiency
because of limited size of the apparatus

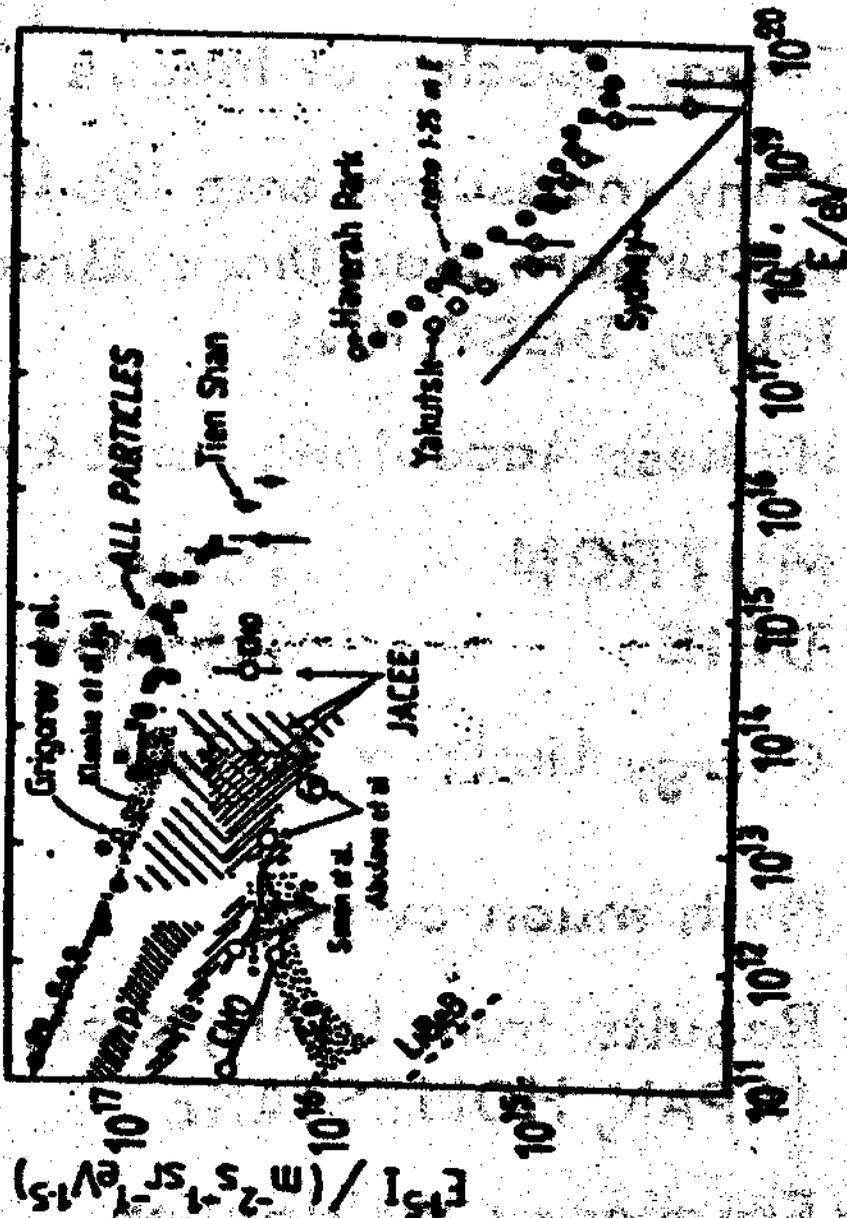


Fig. 2.3.14 The integral energy spectrum of primary particles. From summary of Hillas 50

Expected Physics

(1) The primary energy spectrum

Direct measurements up to 1 TeV (10 TeV)
with muon spectra up to 100 TeV

$$N_{\mu}(E) \rightarrow N_{\pi,k}(E) \rightarrow N_p(E)$$

$$E_p \approx 10 E_{\mu}$$

Kink around 10^{15} eV

(2) Primary composition

Direct measurements up to 1 TeV

Multi muon events reflect primary composition because

- first interaction higher in atmosphere
- A showers if the nucleus disintegrated in the first collision

Muon content higher if Fe nucleus instead of a proton

$$N_{\mu}(>E_{\mu}) = \frac{A G(x)}{E_{\mu} \cos \theta}$$

$$x = \frac{A E_{\mu}}{E_0}$$

A Atomic number

E_{μ} muon energy

E_0 primary energy

θ zenith angle

$G(x)$ numerically calculated function (Elbert)

Decoherence curve: separation of muons
in the detector

$$D(r) = D_0 e^{-r/r_0} \quad (\text{Elbert})$$

r_0 dependent from p_T

Measuring both $N_\mu(>E)$ and $D(r)$
gives allowance of separating
primary large A -events and
large p_T -events in the atmosphere

(3) Direct production

Parent mesons (π, k) have lifetimes $\sim 10^{-8}$ s
Competition between decay and interaction
leads to zenith angle behaviour of muon
spectra

$$I(h, \Theta) = I_{\pi, k}(h) \sec \Theta$$

Parent heavy charmed particles ($D, F, \Lambda_c, \text{etc}$)
and maybe other exotics have
lifetimes $< 10^{-12}$ s

No competition effect, no Θ dependence

$$I_x(h)$$

Present results:

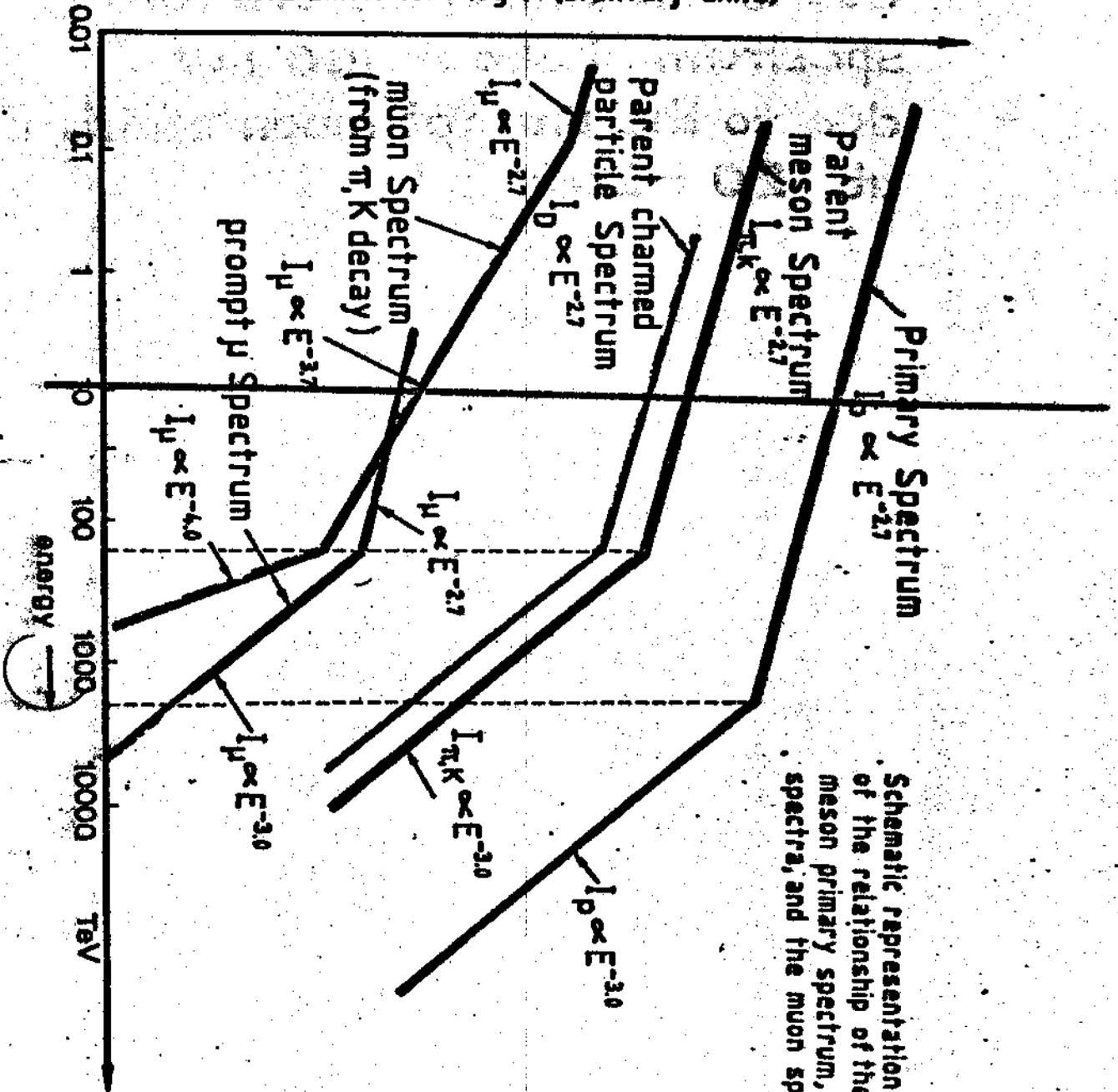
$$R = \frac{N_\mu}{N_\pi} \text{ mostly from accelerators}$$

$$I_{\pi, k}(E) = I_x(E) \text{ at which Energy?}$$

Two changes in the slope of the muon spectrum are expected

- due to the kink of the primary spectrum at about 100 TeV
- due to the prompt muon contribution at 20 - 200 TeV

differential flux log F (arbitrary units)



Schematic representation of the relationship of the parent meson primary spectrum, the parent spectra, and the muon spectrum

Characteristics of DUMAND

- Energy determination by energy loss

$$\frac{dE}{dx} = a + bE$$

Two modes

high resolution mode
muon traverses top
and bottom layer

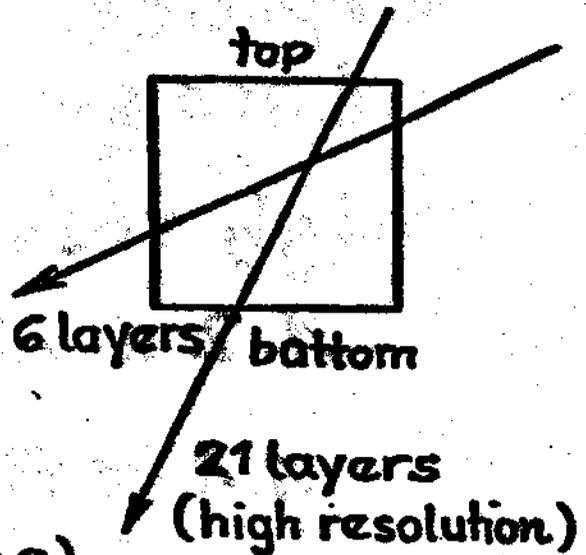
21 layers

$\theta_{\max} = 35^\circ$

average hits : 13 (≥ 2 p.e)

accuracy for energy determination : 50%

efficiency : 90%



whole detector mode

all tracks are considered

6 layers \rightarrow worse resolution

average hits : 7 (≥ 2 p.e)

accuracy for energy determination : 50-100%

efficiency : 85%

number of interactions

($\nu > 10$ GeV)

5 TeV

10 TeV

100 TeV

5

11

55

- Energy range for which

$$2 \text{ TeV} < E < 3000 \text{ TeV}$$

- Expected Intensity
6000 hr

High resolution mode

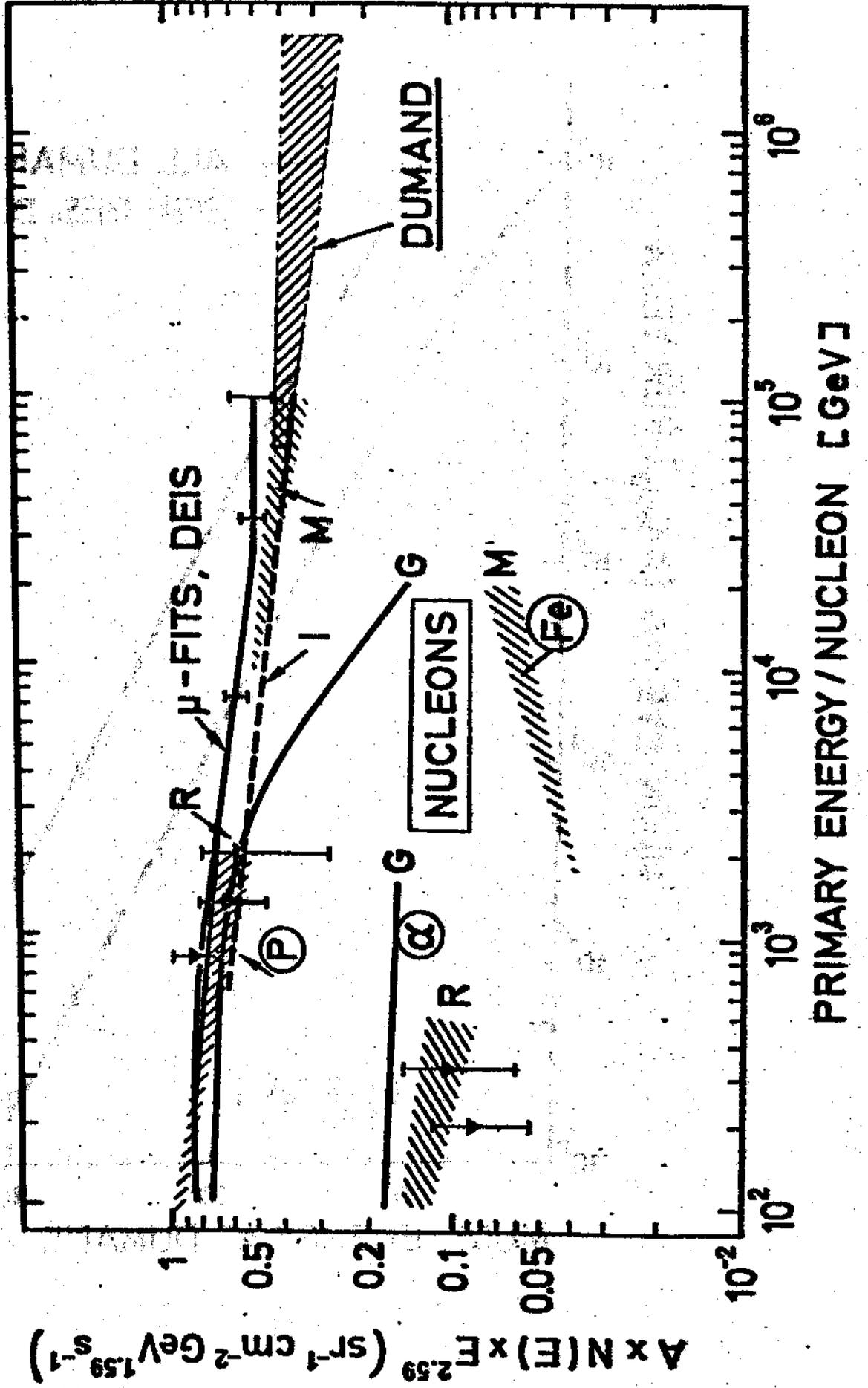
$$1.2 \times 10^8 \quad \text{all Duman}$$

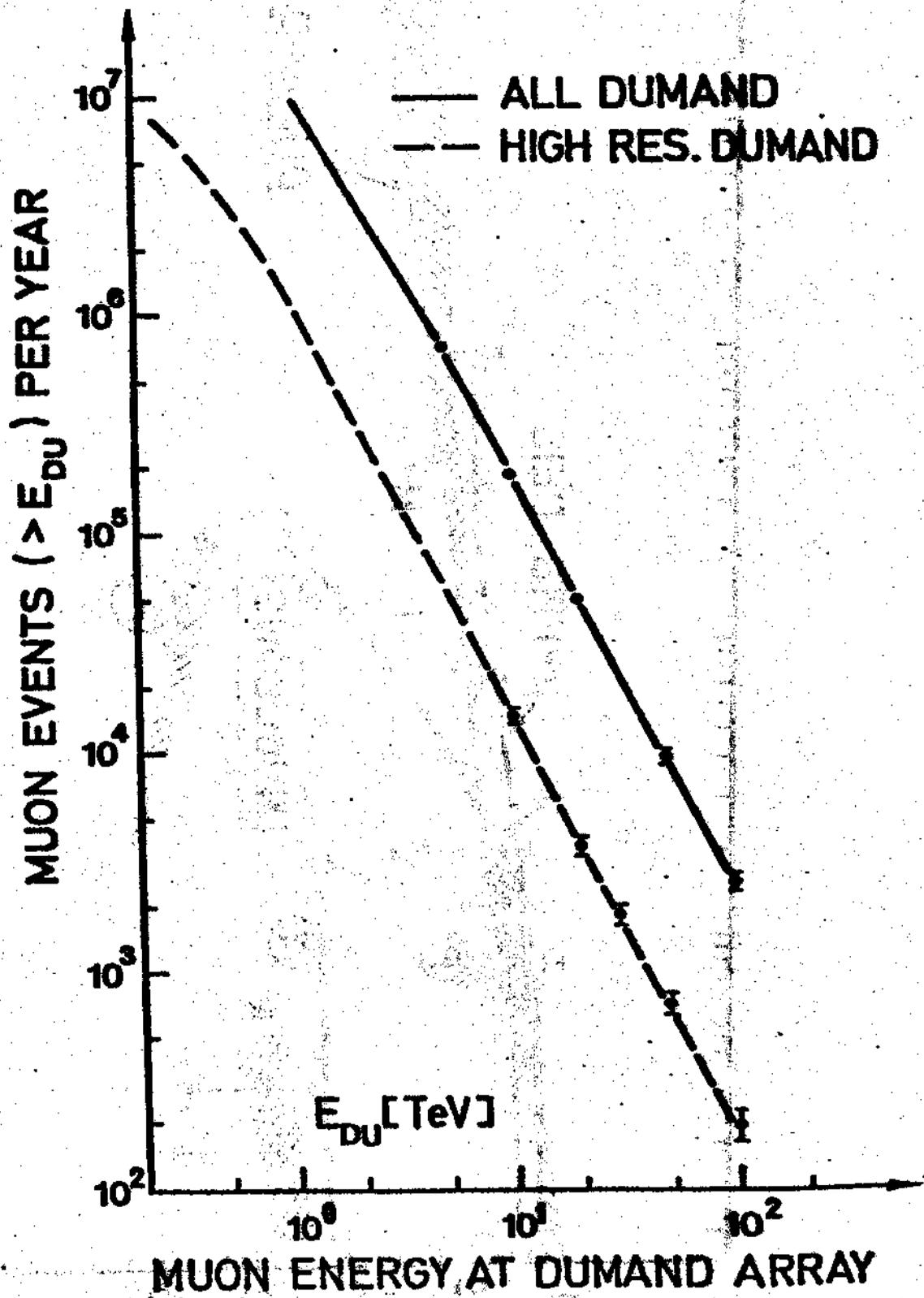
$$1.1 \times 10^7 \quad \text{high resolution DUMAND}$$

- Multiple muon rate
62,500 m² surface

2 μ	$5.5 \times 10^5 \text{ yr}^{-1}$
3 μ	$5.9 \times 10^4 \text{ yr}^{-1}$
4 μ	$2.0 \times 10^4 \text{ yr}^{-1}$
5 μ	$7.9 \times 10^3 \text{ yr}^{-1}$

- Energy range in the primary spectrum
 $E_{\text{max}} \approx 5 \cdot 10^{15} \text{ eV}$





YAH(E) * E_{DU} (21.00% CEA, 1975)

HIGH ENERGY PHYSICS

WITH

DUMAND

B. Barish

PARTICLE PHYSICS

① Very High Energy ν -Interactions

$$\begin{cases} E_\nu > 1\text{TeV} \Rightarrow 10^4 \text{ events/yr} \\ E_\nu > 10\text{TeV} \Rightarrow 10^2 \text{ events/yr} \end{cases}$$

② "Prompt" ν -Studies

Production of Short Lived
Heavy Hadrons.

③ 0- μ } Events
Multi- μ }

NC, ν_e ...

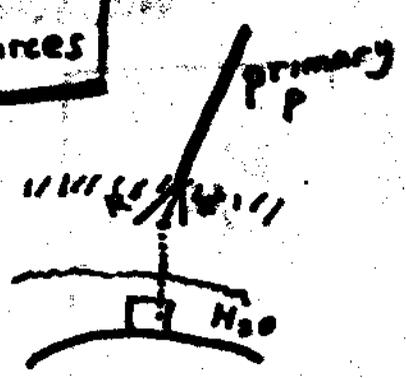
④ Detection of Magnetic Monopoles

Proton Decay Catalysis.

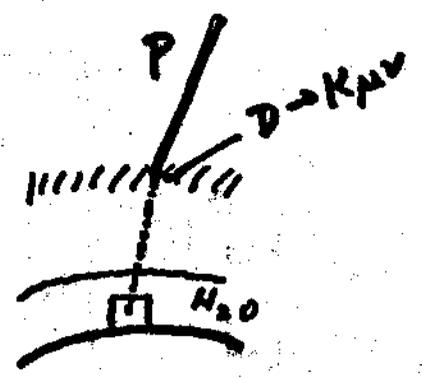
⑤ HEP w/ "Short Prototype String"

Neutrino Interactions

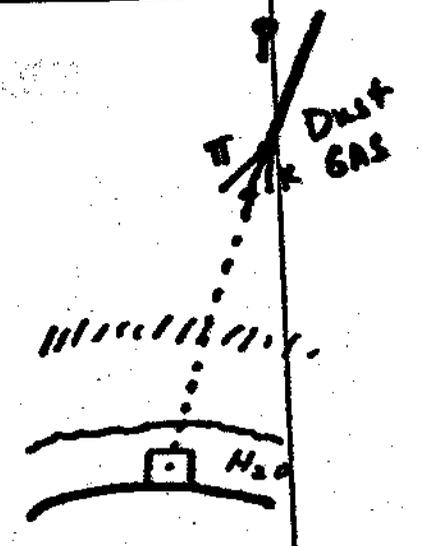
Sources



Atmospheric
(calculable)
consistency with
Muon Spectrum!



"Prompt"
Difficult
to
estimate
PHYSICS



Extraterrestrial
Astrophysics

Rates

E_μ (thresh) ≥ 50 GeV
 E_h (thresh) ≥ 200 GeV

Detector Volume (Inside) $\sim 3 \cdot 10^7$ m³

Detector Volume (Extended) $\sim 4.6 \cdot 10^8$ m³
 at $E_\mu = 2 Te$

- ① - Event Rate vs E_ν
- ② - Event Rate vs E_μ (measured)

- Compare with Expectations -

PRODUCTION SPECTRA (NOT DIRECTLY MEASURABLE)

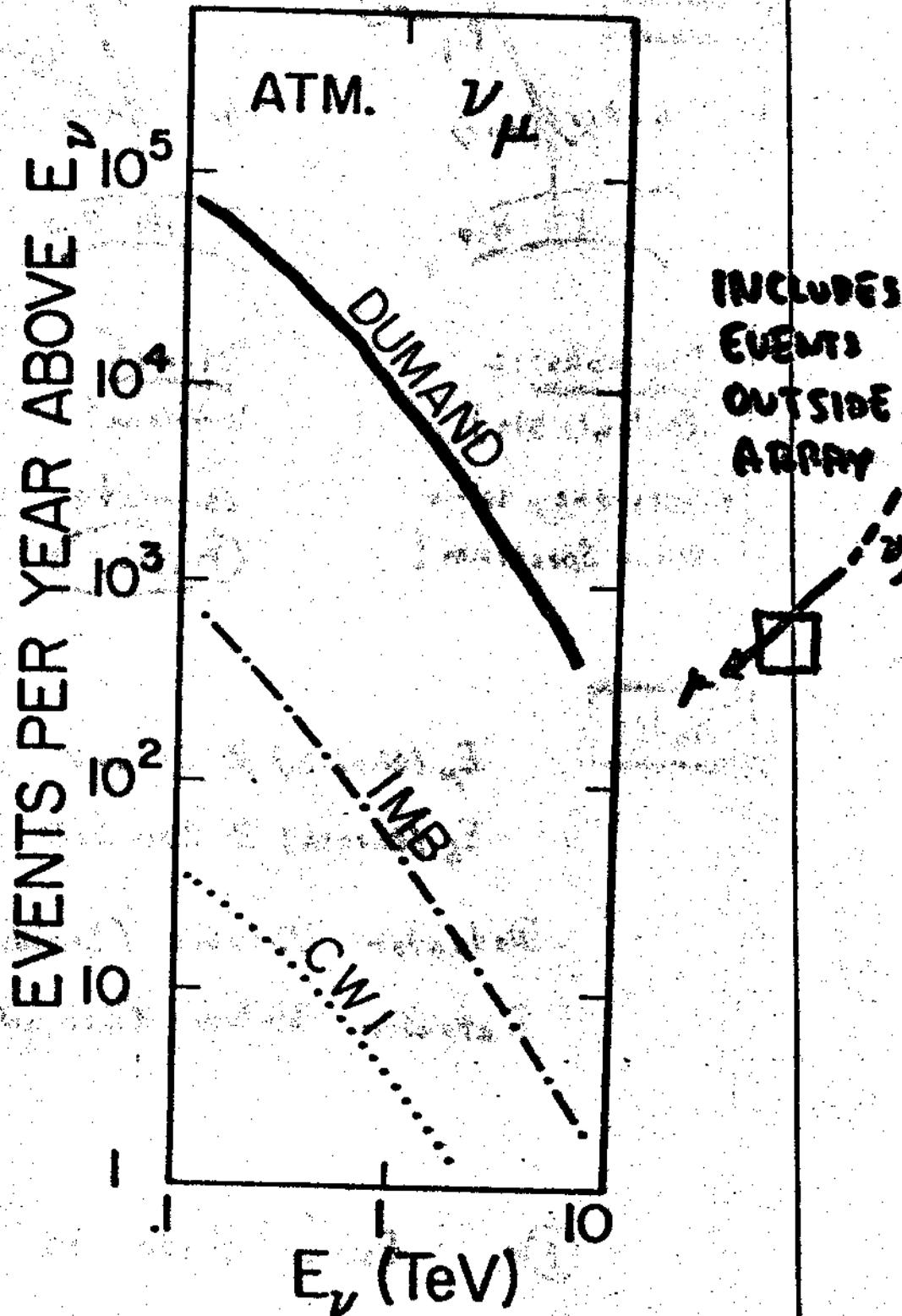


Fig. 2.143

ATMOSPHERIC

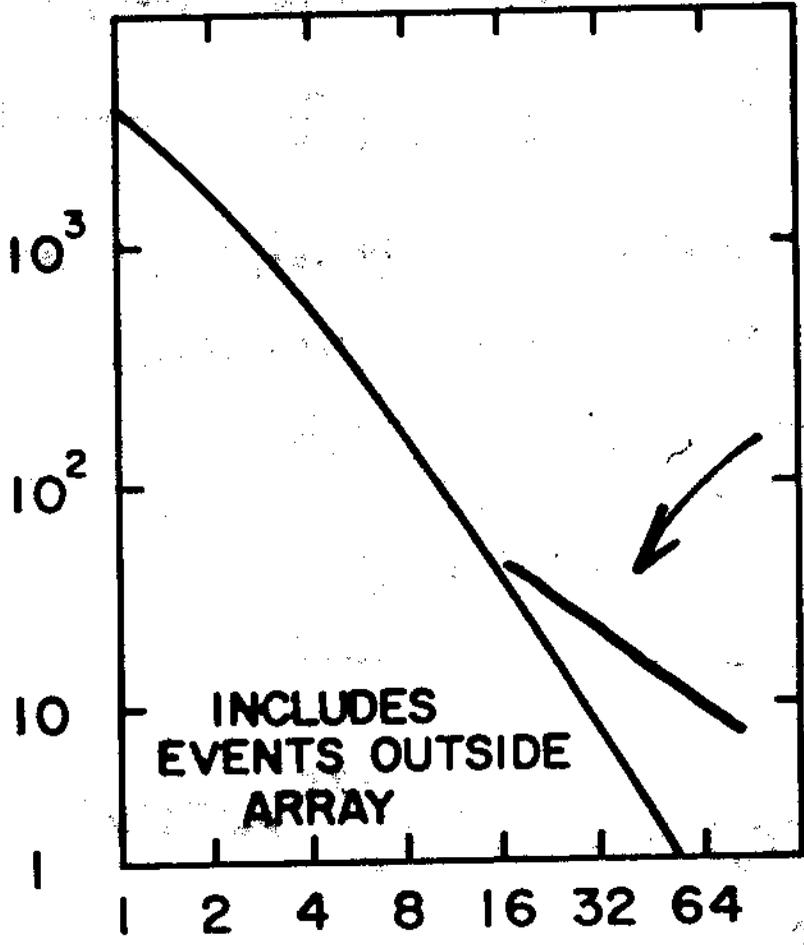
MEASURABLE μ SPECTRUM

RESULTS OF
GARKER SIMULATION

WITH SD 7%

$\frac{\delta E_{\mu}}{E_{\mu}}$

EVENTS PER YEAR ABOVE E_{μ}



DIRECT
PRODUCTION
-OR-
EXTRATERRESTRIAL
BKG.

E_{μ} (TeV) MEASURED

① ν - Behavior of σ_{tot} at high energy

① Total Rate and Energy Dependence

② Use Earth as Absorber (complementary)

Directly observe Non-Locality in Weak Interactions

Convenient Variable for Atmospheric ν 's
(since $\sec \theta^2$ distribution)

$$\eta = 1 - \frac{\ln \cos \theta^2}{\ln \cos \theta_{max}^2}$$

Assume: $F(E_\nu) = 1.3 \cdot 10^{-6} E_\nu^{-3.7} \text{ cm}^{-2} \text{ TeV}^{-1} \text{ s}^{-1}$

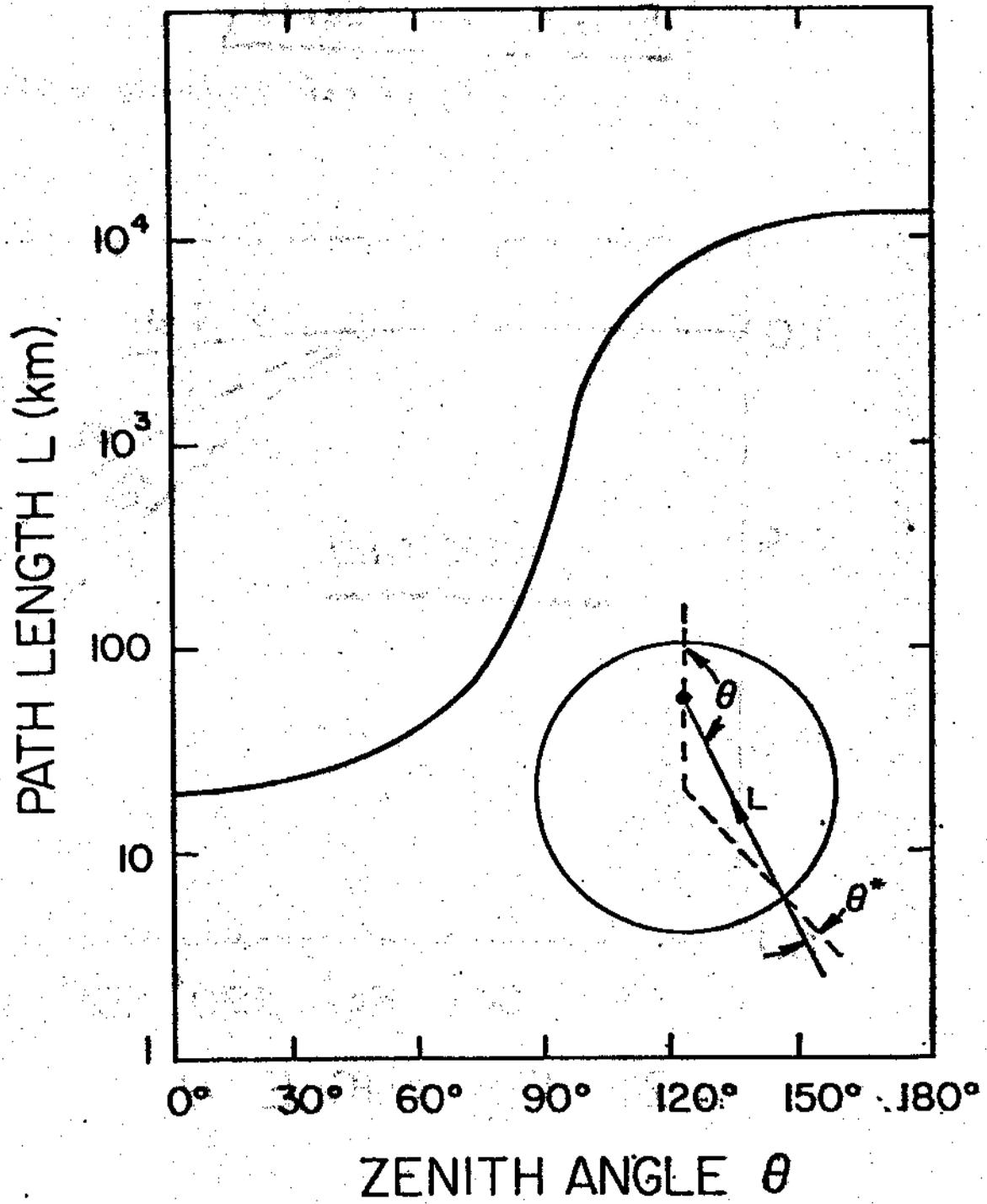
② Check on Differential Distributions

$$\Delta E_h \sim 50\%$$

$$\Delta E_n \sim 50\%$$

Using Events Inside the Detector

Earth as Absorber



Effect of Earth

(including W , which reduces effect)

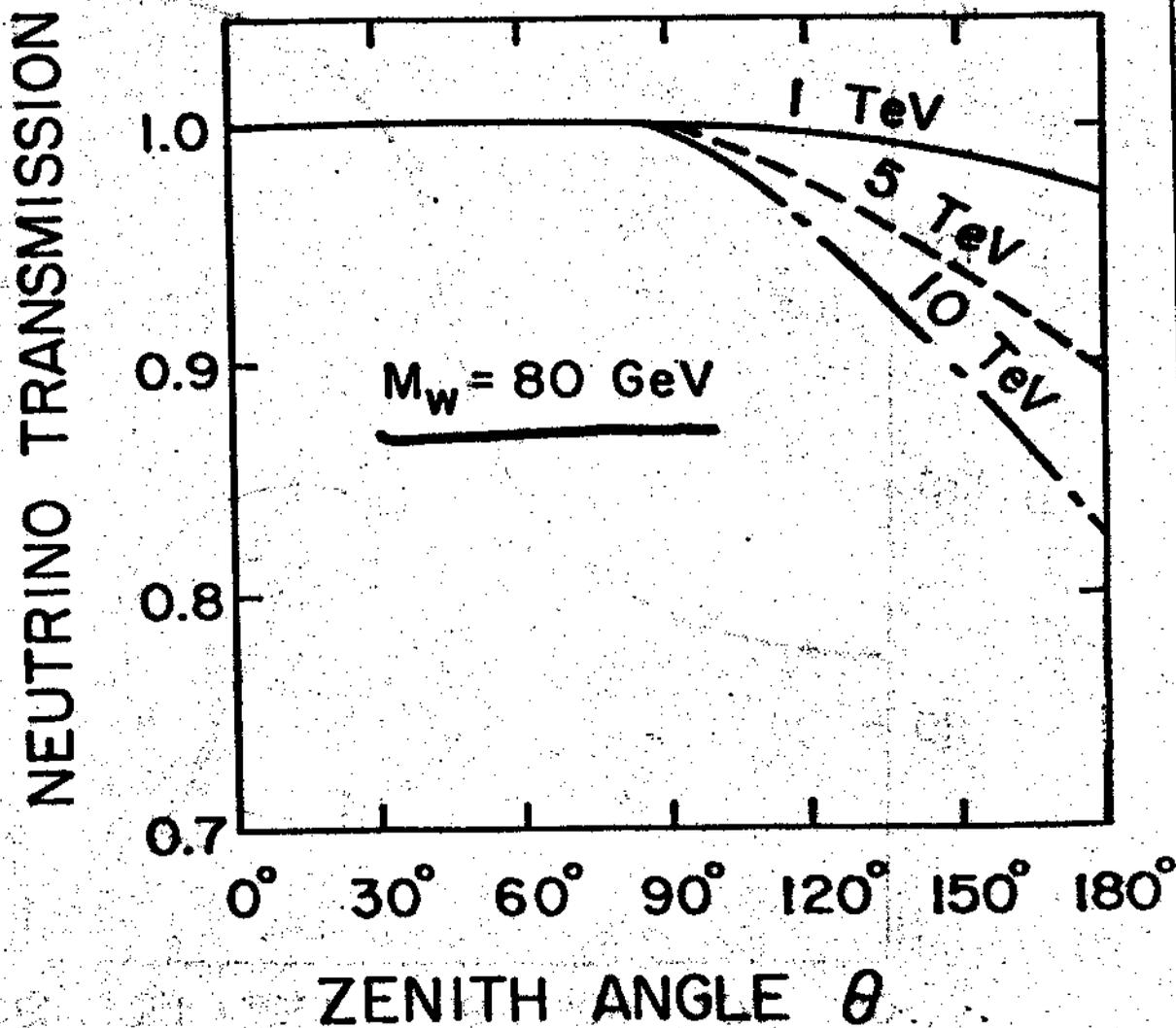


Fig. 2.4.2

RESULTS OF SIMULATION

(TO BE UPDATED)

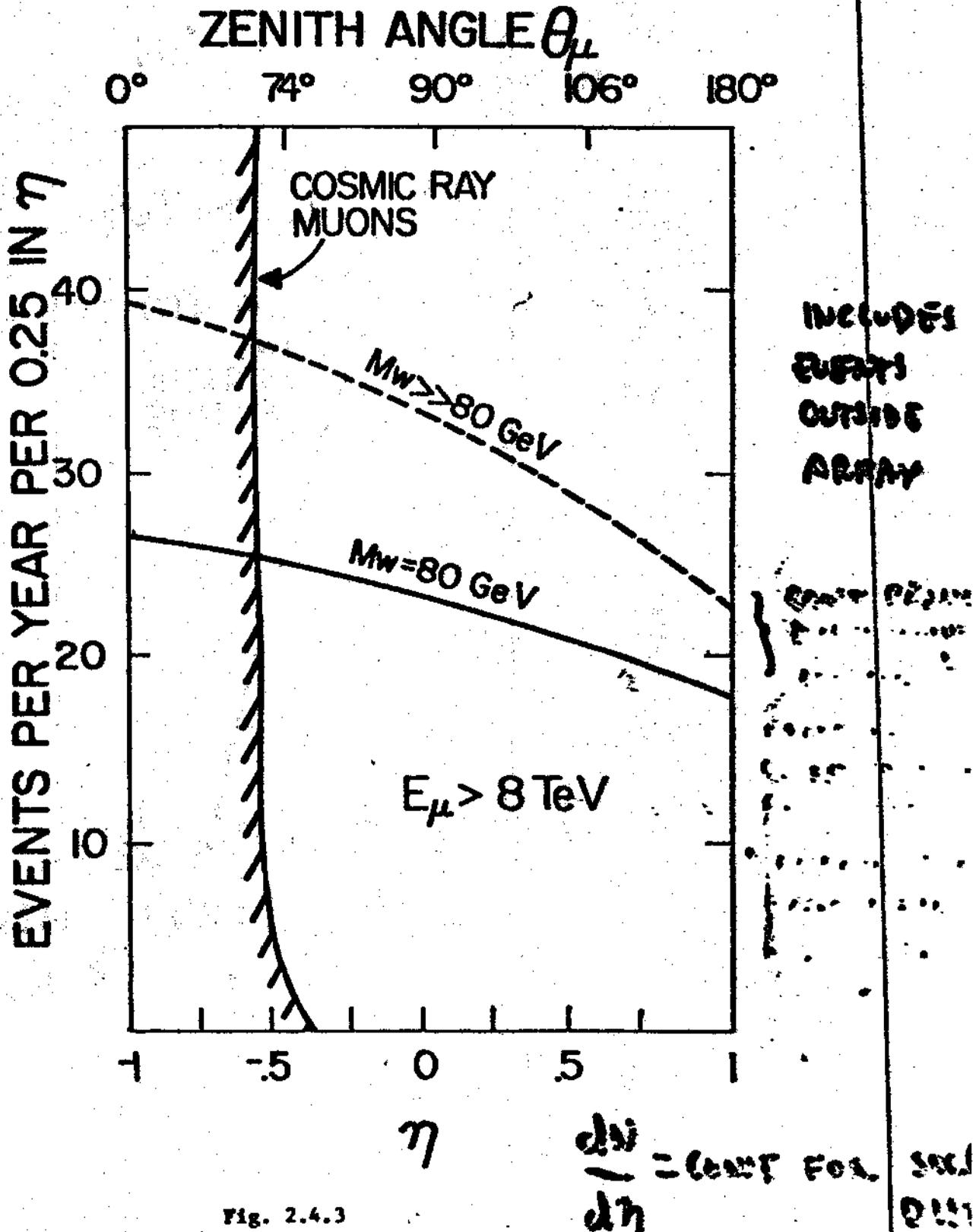
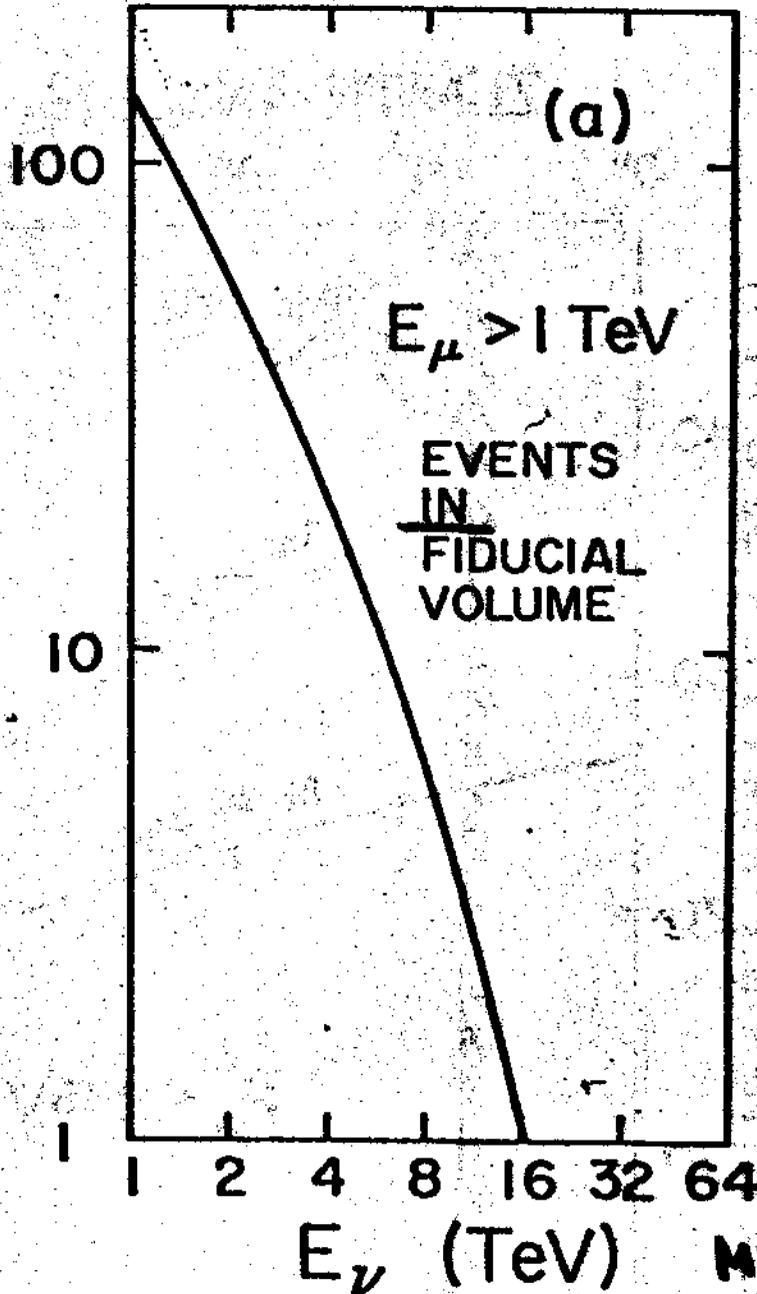


Fig. 2.4.3

SIMULATION (TO BE UPDATED)

FIDUCIAL
VOL
 $\frac{1}{2}$
ARRAY
VOLUME

EVENTS PER YEAR ABOVE E_ν



AGAIN
ONLY CAN
CHECK FOR
GROSS DEVIATION
FROM STANDARD
MODEL
EXPECTATIONS

E_ν (TeV) MEASURED
 $= E_\mu + E_H$

Fig. 2.4.4a

EVENTS INSIDE FIDUCIAL VOLUME

SIMULATION (TO BE UPDATED)

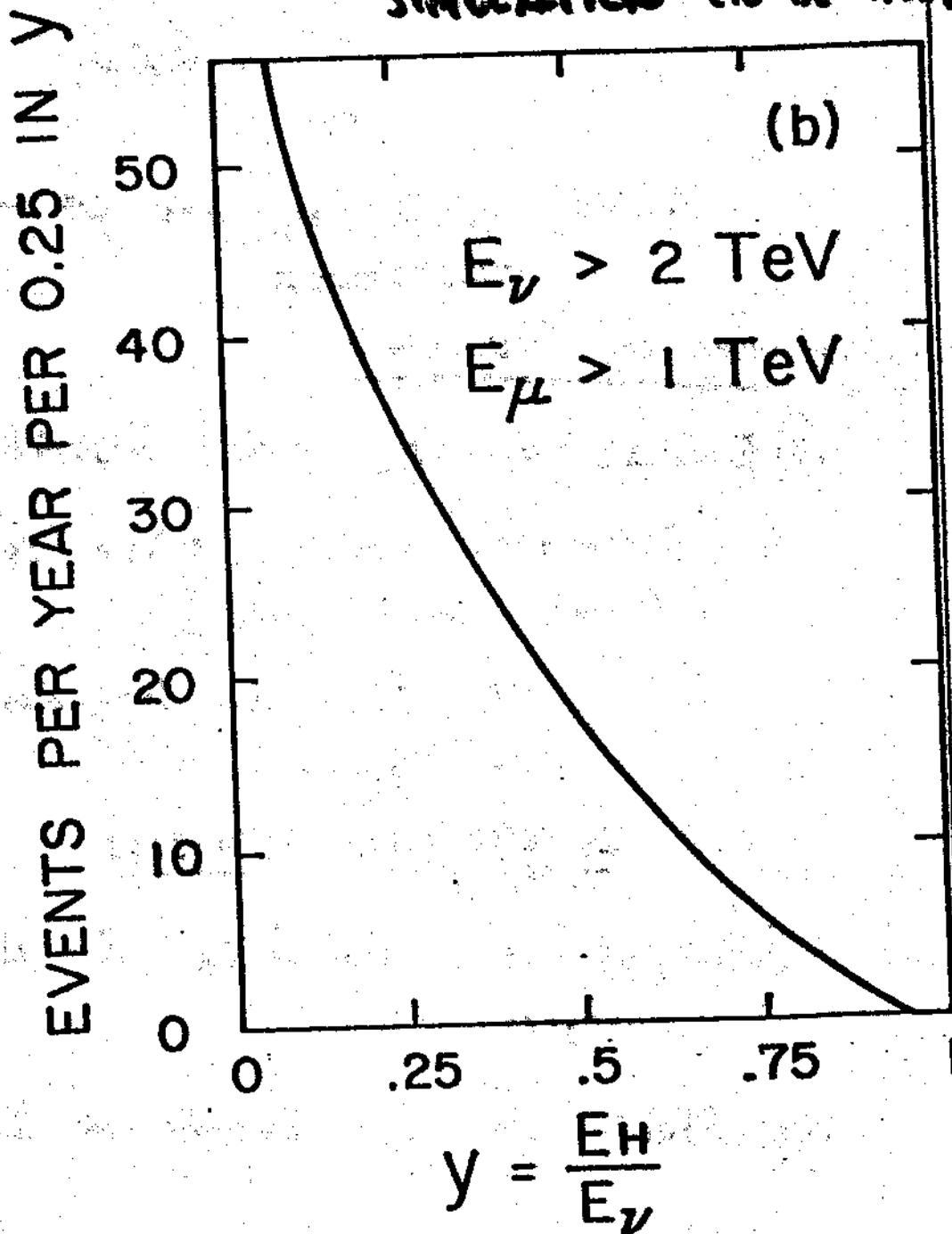


Fig. 2.4.4b

NOT FLAT BECAUSE
1. W-boson effect
2. $\bar{\nu}_\mu$ INCLUDED

AGAIN, JUST CHECK.

"Prompt" ν 's

Sources:

$$p + N \rightarrow D \rightarrow X \ell \nu$$

$$B \rightarrow X \ell \nu$$

$$T \rightarrow X \ell \nu$$

etc

Yields ν_μ, ν_e, ν_τ etc at high energies.

Signatures in DUMAND

① Effects on E_ν rate Distributions for ν_μ

Estimates crude, since so little

known about $\sigma(D, B, T, \dots)$

or \sqrt{s}, x, P_T dependence

or Decays.

INTERESTING PHYSICS

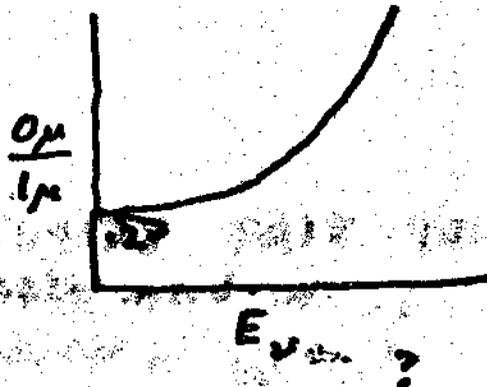
(Prompt ν 's Dominate at High Enough Energies)

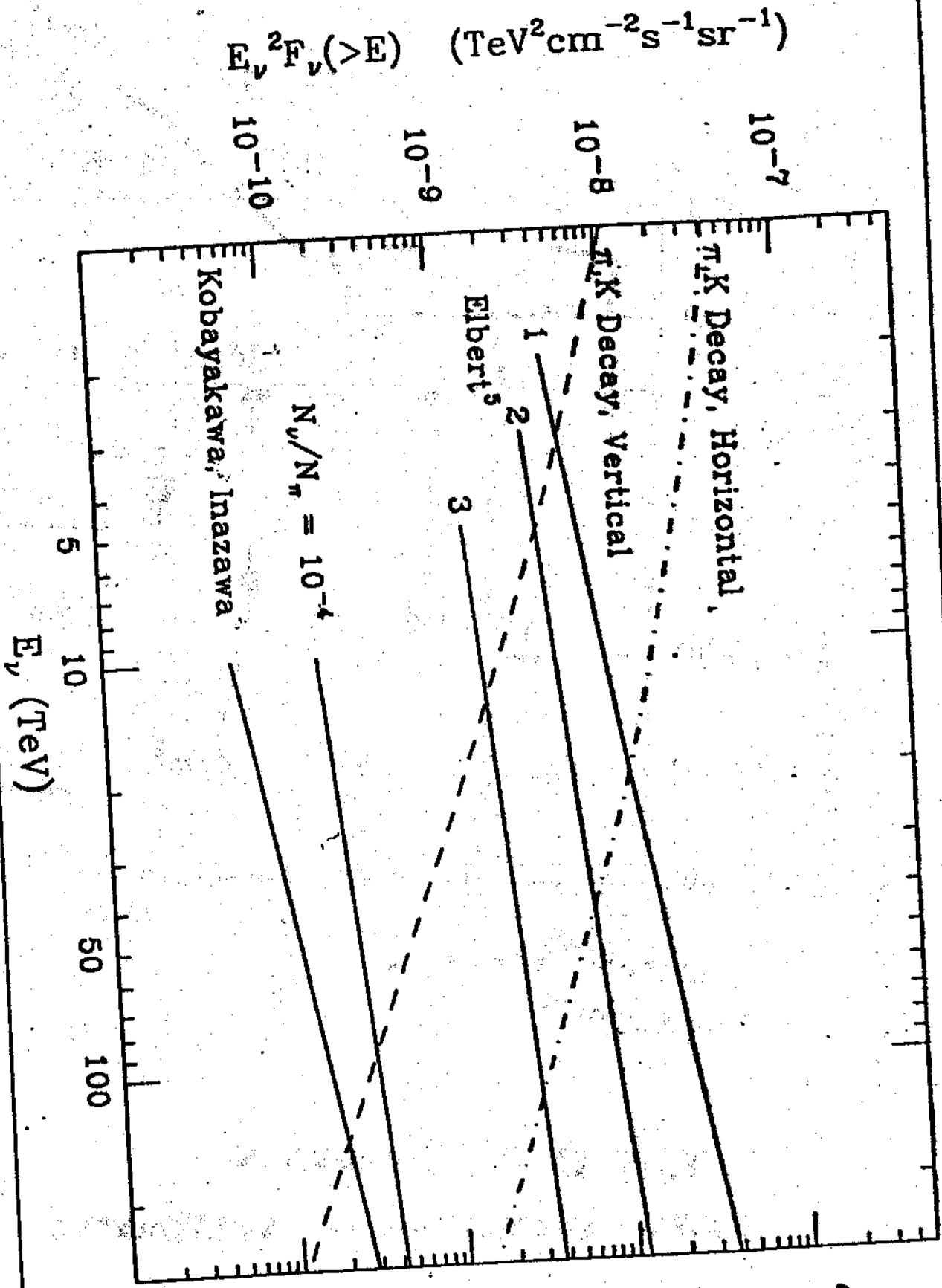
② Effect on O_μ Events in Detector

eg.

$$\nu_e + p \rightarrow e + X$$

O_μ Topology



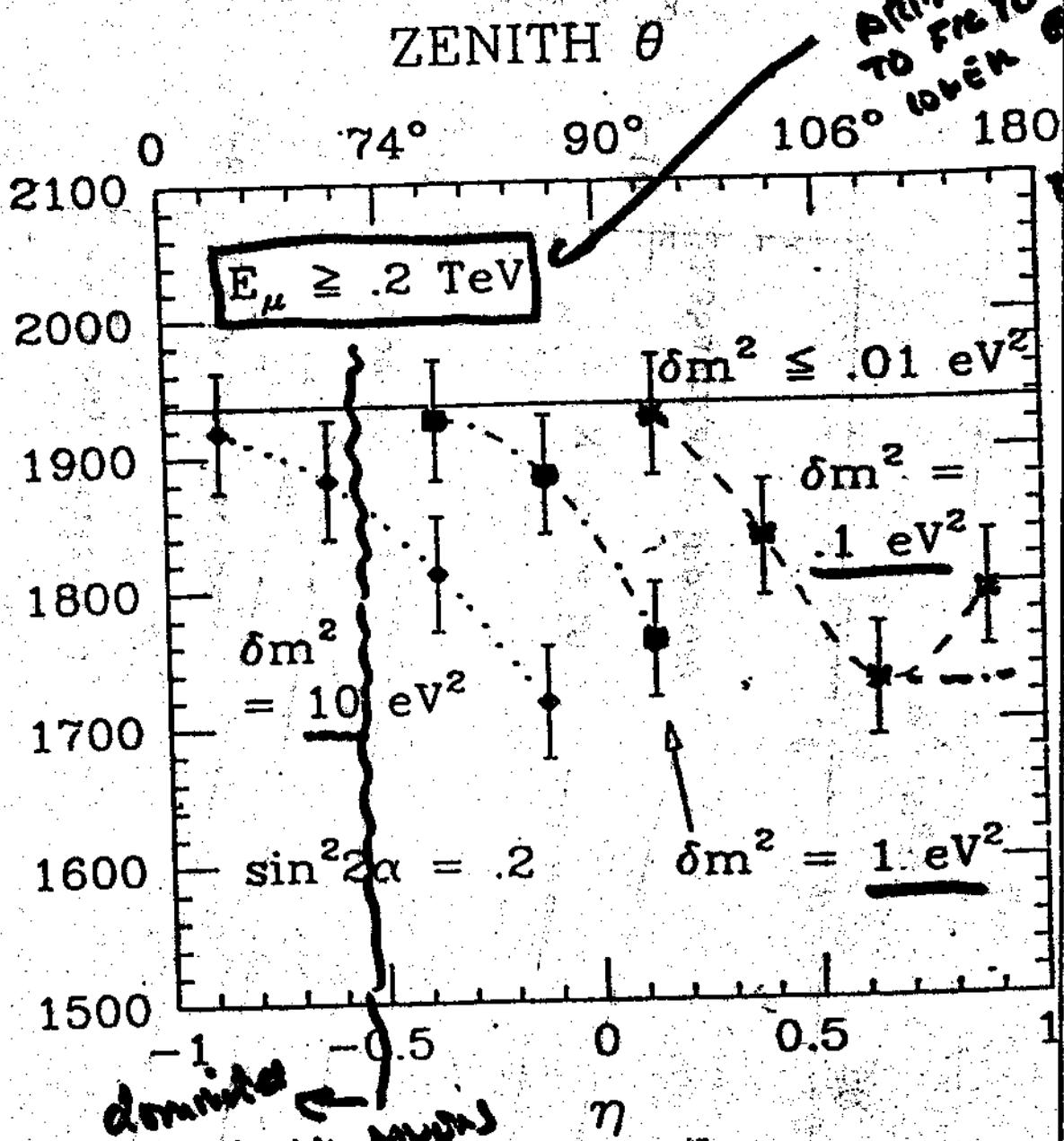


DIRECT ν PRODUCTION BY COSMIC RAYS
 (CHECK TO WHAT WE SAID ABOUT μ^+)

FIG. 2.4.8

NEUTRINO OSCILLATIONS

EVENTS PER YEAR PER 0.25 IN η



C.P. EVIDENCE
TAKE ALL
MUSIC
EVENTS
E really
close
OUT

Fig. 2.4.5

THIS IS A SIMULATION
ERRORS STATISTICAL + SYSTEMATIC

VACUUM OSCILLATIONS

$P(e \rightarrow e)$
OR
 $P(\mu \rightarrow \mu)$

$\alpha = 22.5^\circ$

MATTER OSCILLATIONS

$P(e \rightarrow e)$

$\delta m^2 > 0$

MATTER OSCILLATIONS

$P(e \rightarrow e)$

$\delta m^2 < 0$

$E = 1 \text{ TeV}$
 $\delta m^2 = 1 \text{ eV}^2$
OR
 $\frac{100 \text{ GeV}}{1 \text{ eV}^2}$

$E / |\delta m^2| \text{ (MeV/eV}^2\text{)}$

DUMAND
EXPLORES
UNIQUE
REGION
FOR
MATTER
OSC.

TRY TO
GET
SIMULATION
RESULTS FOR
TWO CASES
 $\delta m^2 > 0$ & $\delta m^2 < 0$

Fig. 2.4.7

FROM SNOWMASS PROCEEDINGS DUMAND ADDED

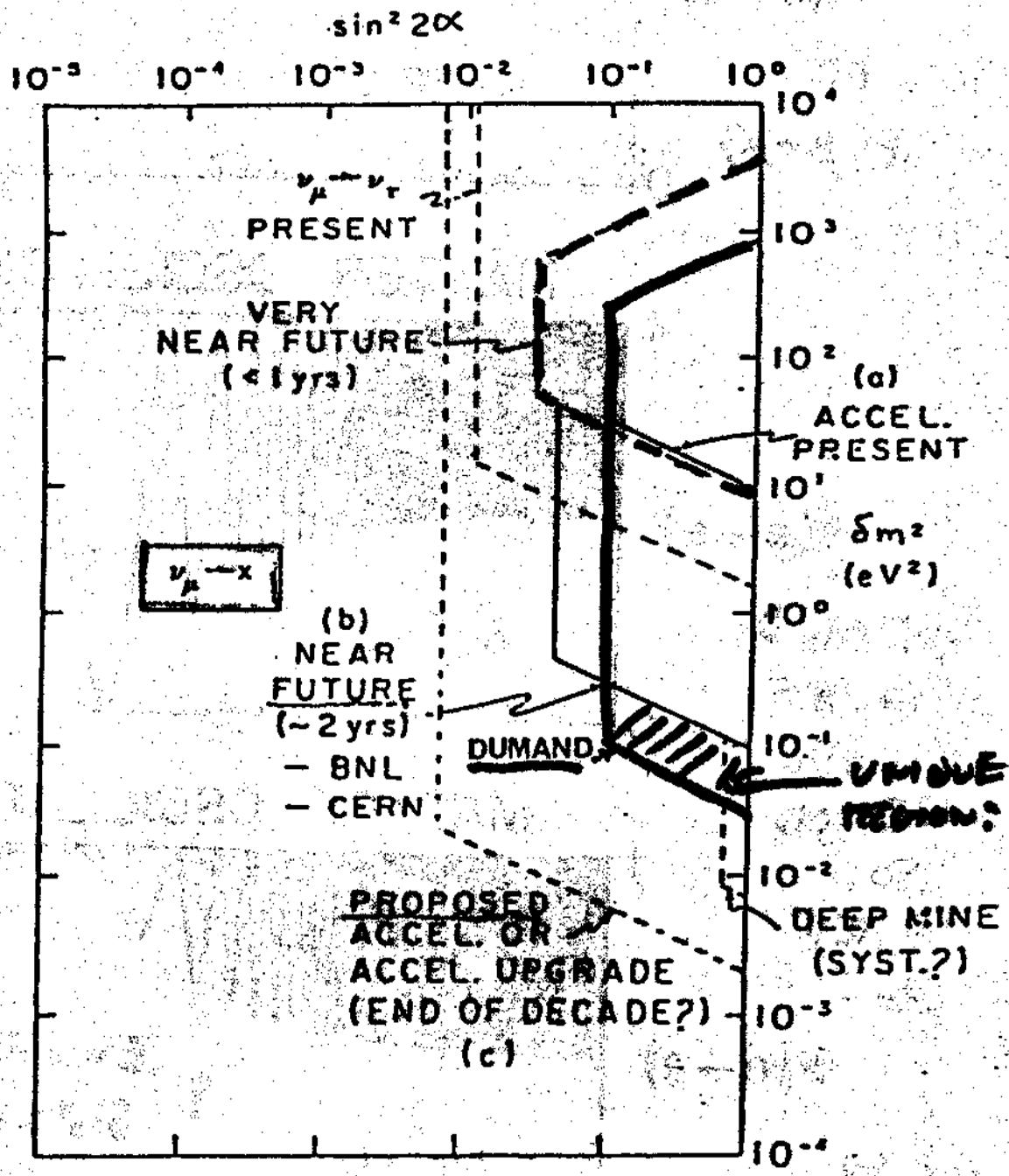


Fig. 2.4.6

Detection of Magnetic Monopoles.

• Cabrera Event not verified!

• Astrophysics Bounds

(1) Mass of Universe

(2) Galactic Magnetic Field



$$\phi < 10^{-15} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$$

• Present Levels

Cabrera $\sim 10^{-10}$

any β

UTAH $\sim 10^{-11}$

$\beta > 1.2 \cdot 10^{-4}$ (Scintillator)

BARSAK, etc $\sim 10^{-13}$

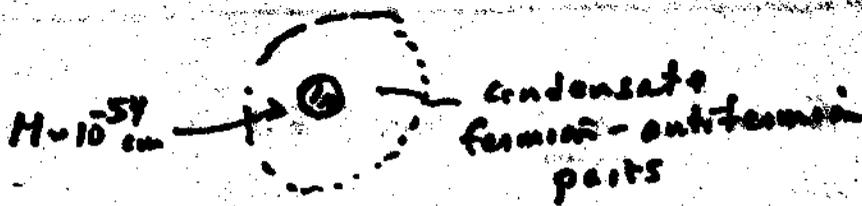
$\beta > 2 \cdot 10^{-3}$ CRUDE !!



FUTURE ?? NEED AN ARRAY SIZE
OF FOOTBALL FIELD FOR DIRECT
DETECTION OF MONOPOLES

(my personal passion!!!)

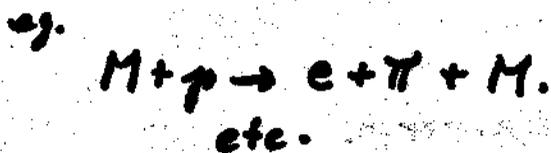
• Another Possibility: **PROTON CATALYSIS**
(ROBANKOV)



TYPICAL NUCLEAR
X-sections

100 mb
10 mb
1 mb
100 μb
;

??



Measure: $\sigma \cdot \phi$

• **IMB**

(1) Catalyzed Single Decays

Limited at level of ν -Background
1ev/day

(2) Multiple Decays

Gate open 1-8 μsec (look for μ -decay)

Look for 2nd Decay in this gate.

$\beta \sim 10^{-3}$.1 - .3 meters

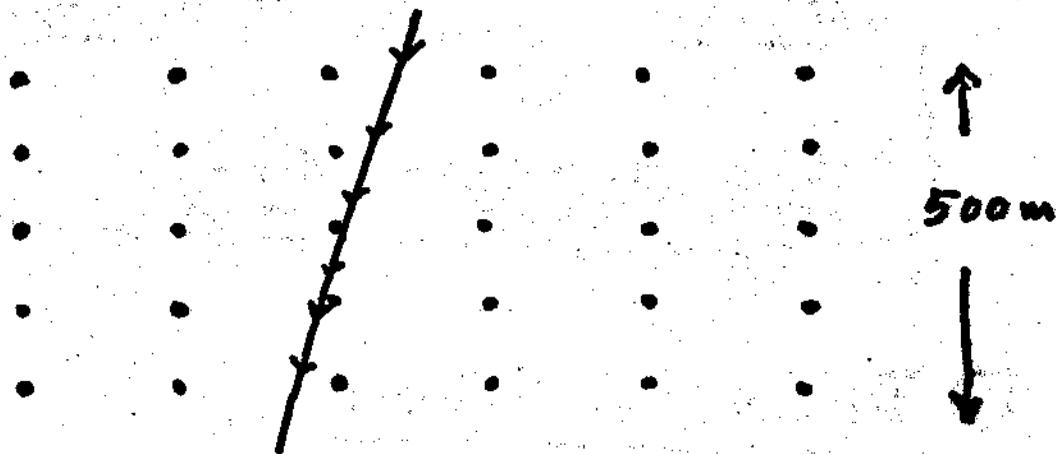
$\sim 10^{-4}$.01 - .3 meters

from 1st decay.

After improved electronics could
be $\sim 3 \cdot 10^{-15}$ level

for $\epsilon_{\text{cat}}, \epsilon_{\text{detection}} = 1$
1yr running

• PROTON CATALYSIS IN DUMAND



$$\sigma = 1 \text{ mb} \quad 2 \sim 20 \text{ m.}$$

$$N_{pe} \sim 10 / \text{Decay}$$

Look For MULTIPLE INTERACTIONS
over 500 m (vertically)

Note: Monopoles $\beta \sim 10^{-3}$

1 μsec / foot
Signal in Different Tubes
(not after pulsing)

Sensitivity: 1yr

$$\phi \approx 2.4 \cdot 10^{-17} \text{ s}^{-1} \text{ cm}^{-2} \text{ sr}^{-1}$$

DUMAND HAS A REAL POSSIBILITY
OF DOING A FUNDAMENTAL
SEARCH FOR MONOPOLES
BELOW ASTROPHYSICS BOUNDS

PRELIMINARY
PARTICLE PHYSICS EXPERIMENTS
WITH
"Short Prototype String"

① Detect ν -Events

$E_{\mu} > \text{Threshold } (\sim 50 \text{ GeV})$

Should be able to demonstrate

FLAT sec^{-1} distribution

→ $\sim 1 \text{ event/day}$

($1100 \text{ m}^2 \text{ Area}$)

$\sim 6 \text{ month Run}$

② Preliminary Monopole Catalysis Experiment

• Sequential Phototubes

• Sensitivity $\sim 1.5 \cdot 10^{-15} \text{ cm}^2 \text{sr}^{-1} \text{ s}^{-1}$

- Approaching Bound -

IV EXPERIMENTAL DESIGN - OUTLINE

I LEARNED
4/23/83

- INTRODUCTION
- ARRAY GEOMETRY & LOCATION
- ENVIRONMENTAL SURVEY SUMMARY
- DEPLOYMENT PLAN FEATURES
- DETECTOR DESIGN OVERVIEW
 - MODULE
 - TELEMETRY & CONTROL
- PLANS , TIMELINE
- PREDICTED PERFORMANCE
- SUMMARY

- SKIPPED OR SHORT COVERAGE DUE TO TIME LIMITATION - BACKUP AVAILABLE
 - SITE STUDIES
 - DEPLOYMENT SEQUENCE DETAILS
 - OCEAN TECHNOLOGY
 - AT SEA & LAB TESTS
 - SIGNAL PROCESSING STUDIES
 - BACKGROUND NOISE SIMULATION
 - ACOUSTICAL DETECTION

PRIMARY MOTIVATION

- BEGIN EXTRA-SOLAR-SYSTEM NEUTRINO ASTRONOMY

IMPLICATIONS

- MASSIVE DEEP-OCEAN DETECTOR (TOO BIG FOR MINES)
- TeV ENERGIES BEST START ($\frac{1}{2}$ CC)
- LARGEST DETECTOR EVER \Rightarrow HEP & CR STUDIES
- LONG TIME, DEPTH, DATA RATE \Rightarrow OCEAN SCIENCE

DIFFICULTIES

- NEW ENVIRON. FOR HEP RES. \Rightarrow MUCH STUDY WAS NEEDED
- THRESHOLD COST OF EMPLANTING ANY COMPLEX INSTRUMENT CABLED TO SHORE
- INABILITY TO HAVE READY ACCESS TO DETECTOR

SOLUTIONS

- BOTTOM TETHERED ARRAY OF LARGE AREA PHOTO MULTIPLIERS
- MULTIPLE SEGMENTS & CABLES TO SHORE DURING DEPLOYMENT AND OPERATION
- MINIMUM AT-SEA PROCESSING, ONE MULTIPLEXING NODE
- DESIGN EMPHASIZING SIMPLICITY & RELIABILITY
- INCREMENTAL DEVELOPMENT PLAN

DEFERRED (BUT NOT FORGOTTEN!)

- LARGE ACOUSTIC ARRAY ($> 10^4$ EV ν 's)
- LOW ENERGY DETECTORS (PION DECA, SUPERNOVAE, ...)
- POSSIBILITY FOR EXPANSION
- ANCILLARY DETECTORS (SURF. ARRAY, FLT'S EYE, ...)

ISLAND
OF
MAHAI

KEAHOLE POINT
LABORATORY

6 POWER & SIGNAL
CABLES

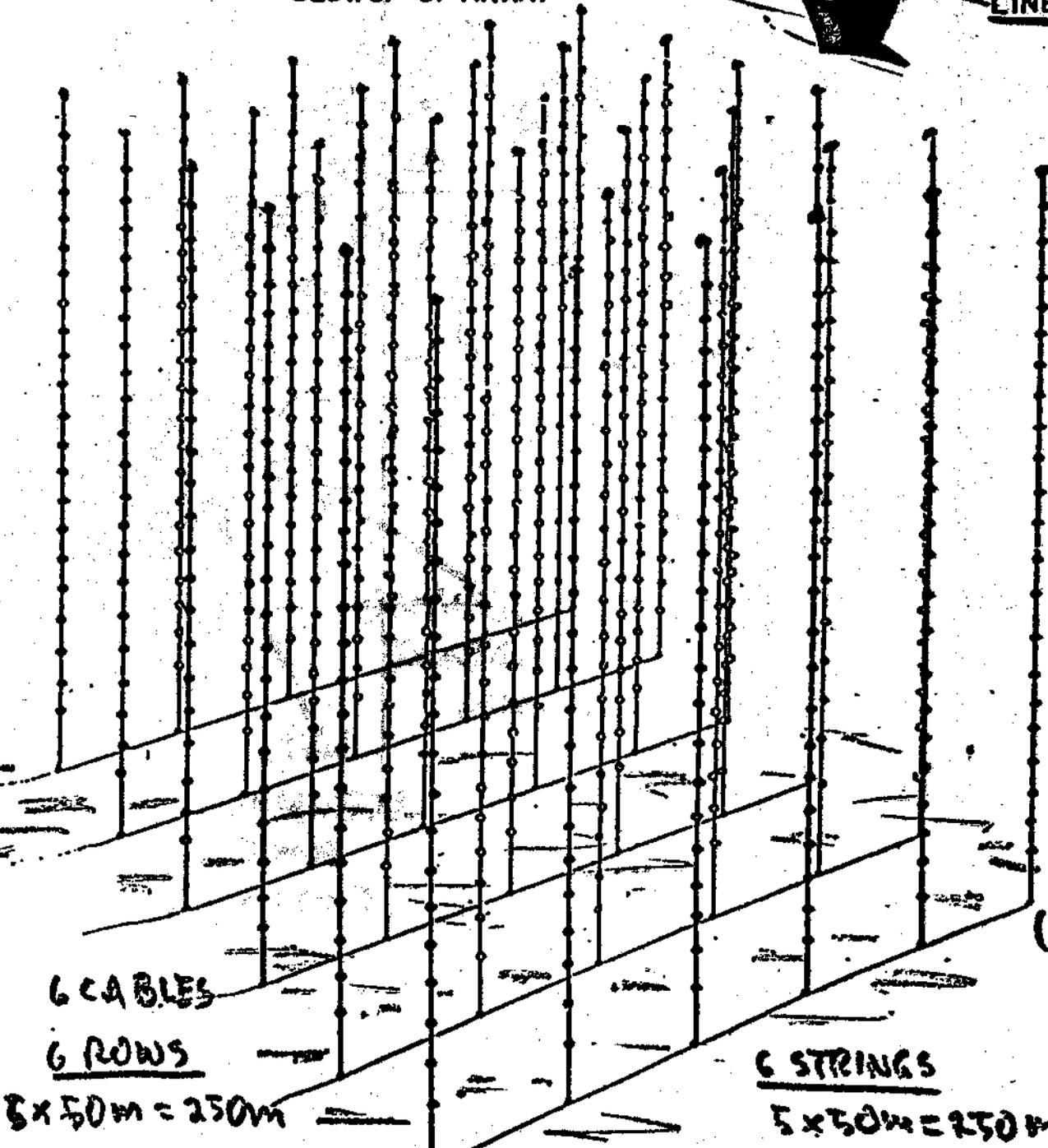
4.7 KM

ARRAY

FLAT
BASIN

RETRIEVAL
LINES

BLOWUP OF ARRAY



21 MODULES

$$20 \times 25 \text{ m} = 500 \text{ m}$$

$$V = 3 \times 10^7 \text{ m}$$

$$V_{\text{eff}} = 4 \times 10^8$$

(250 V v/s)

6 CABLES

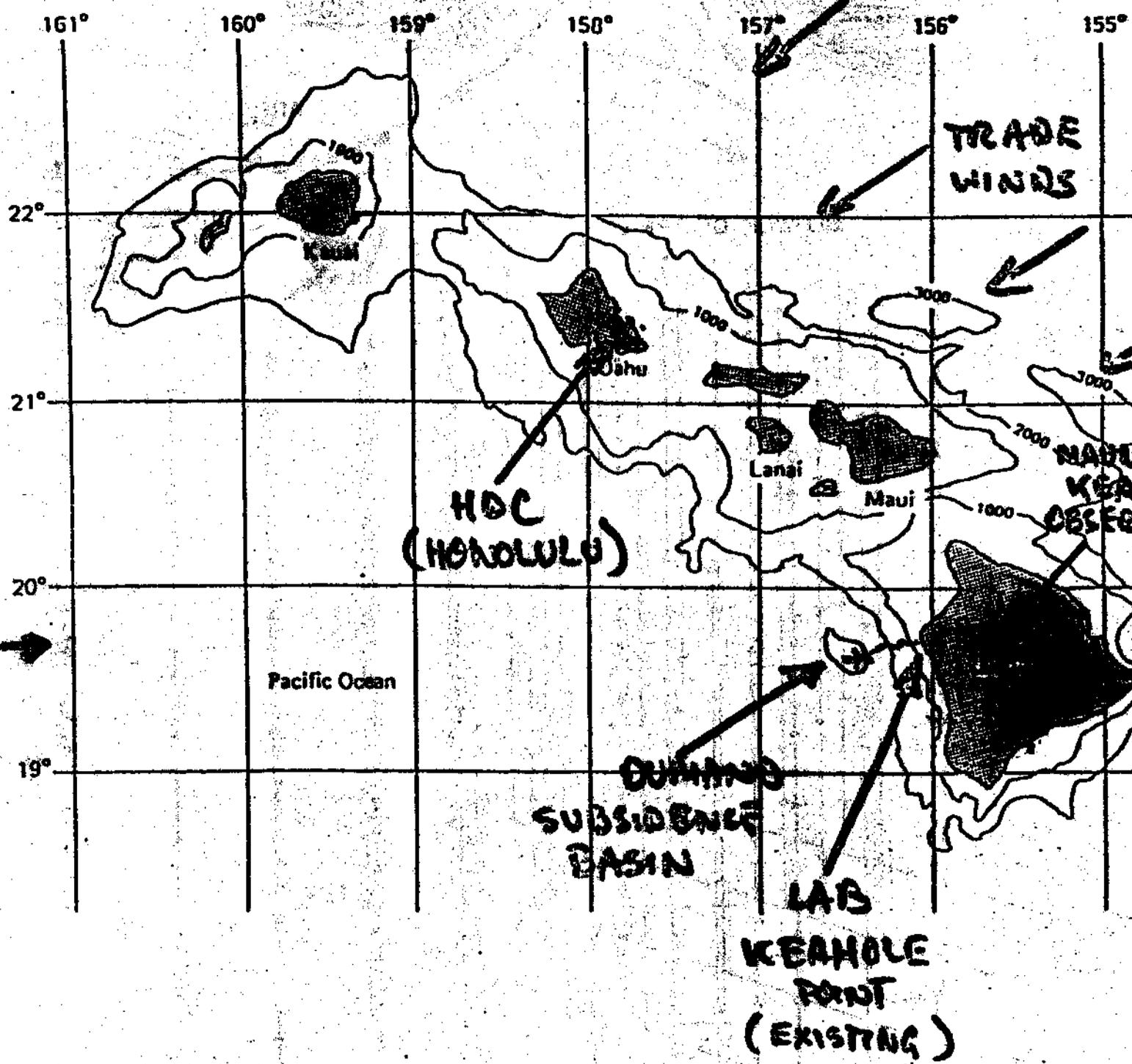
6 ROWS

$$5 \times 50 \text{ m} = 250 \text{ m}$$

6 STRINGS

$$5 \times 50 \text{ m} = 250 \text{ m}$$

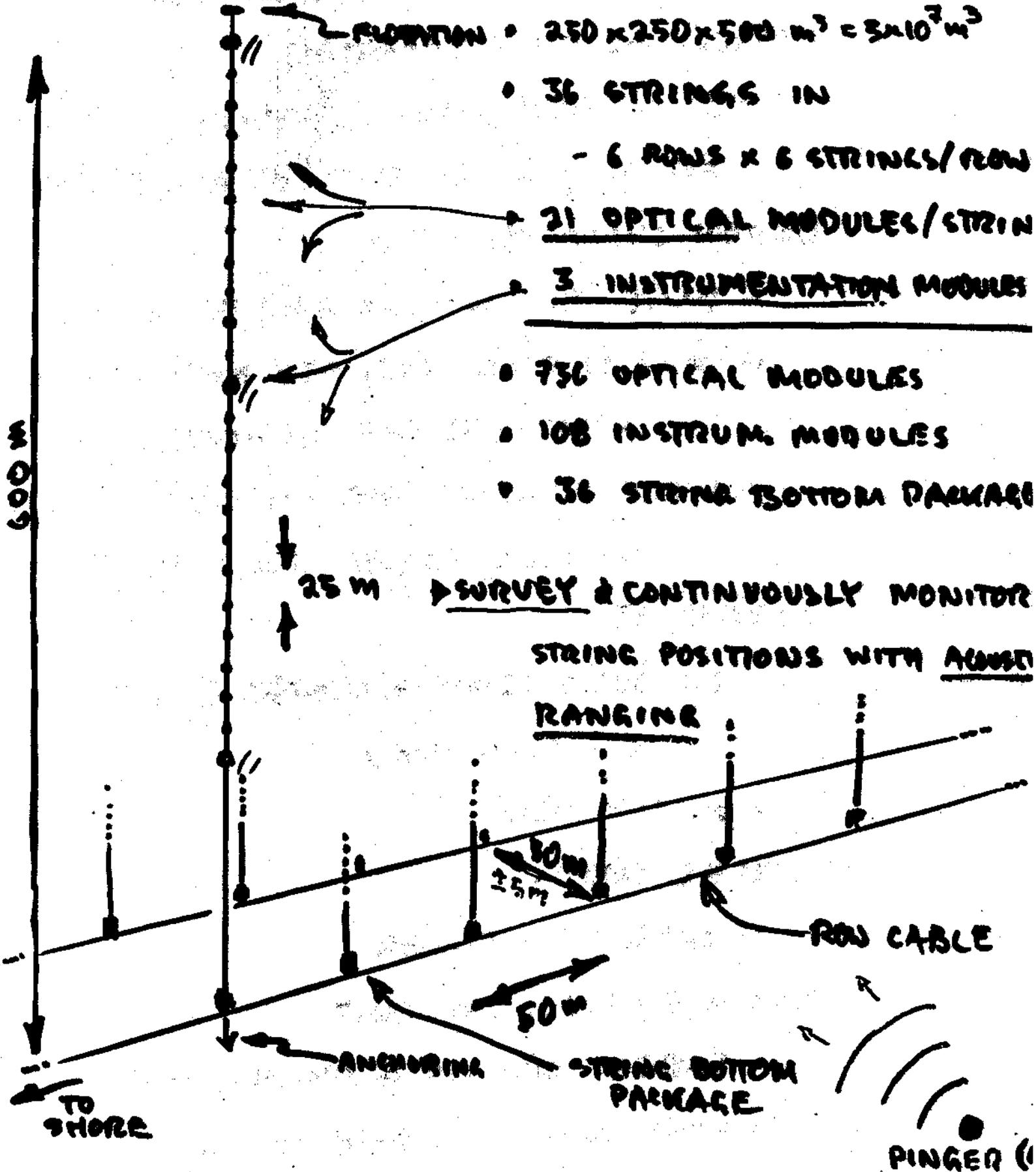
DUMAND LOCATION



$\pm 10\text{ m}$
MOTION BY
CURRENTS

ARRAY GEOMETRY

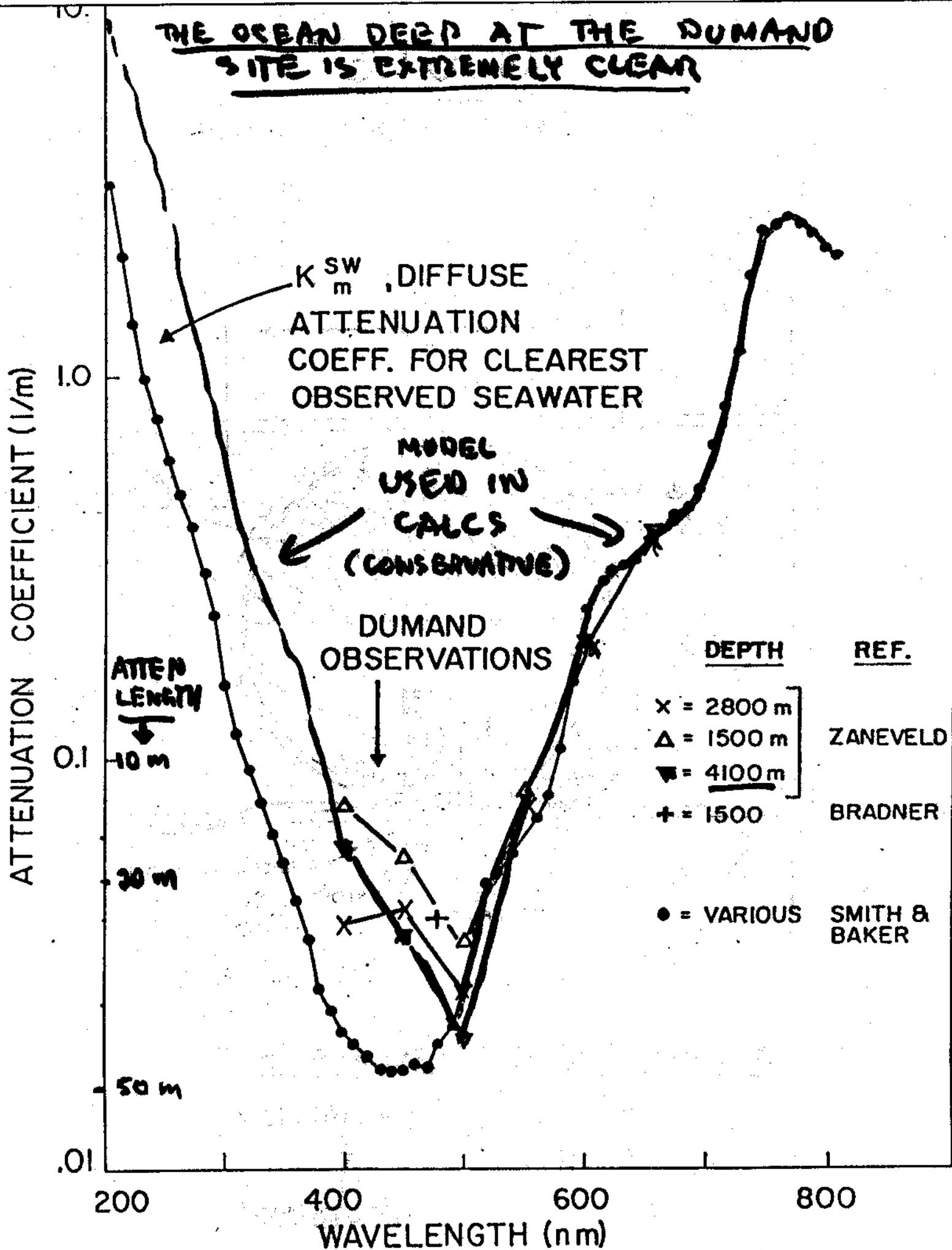
▷ RECTANGULAR LATTICE



SUMMARY OF SITE STUDIES

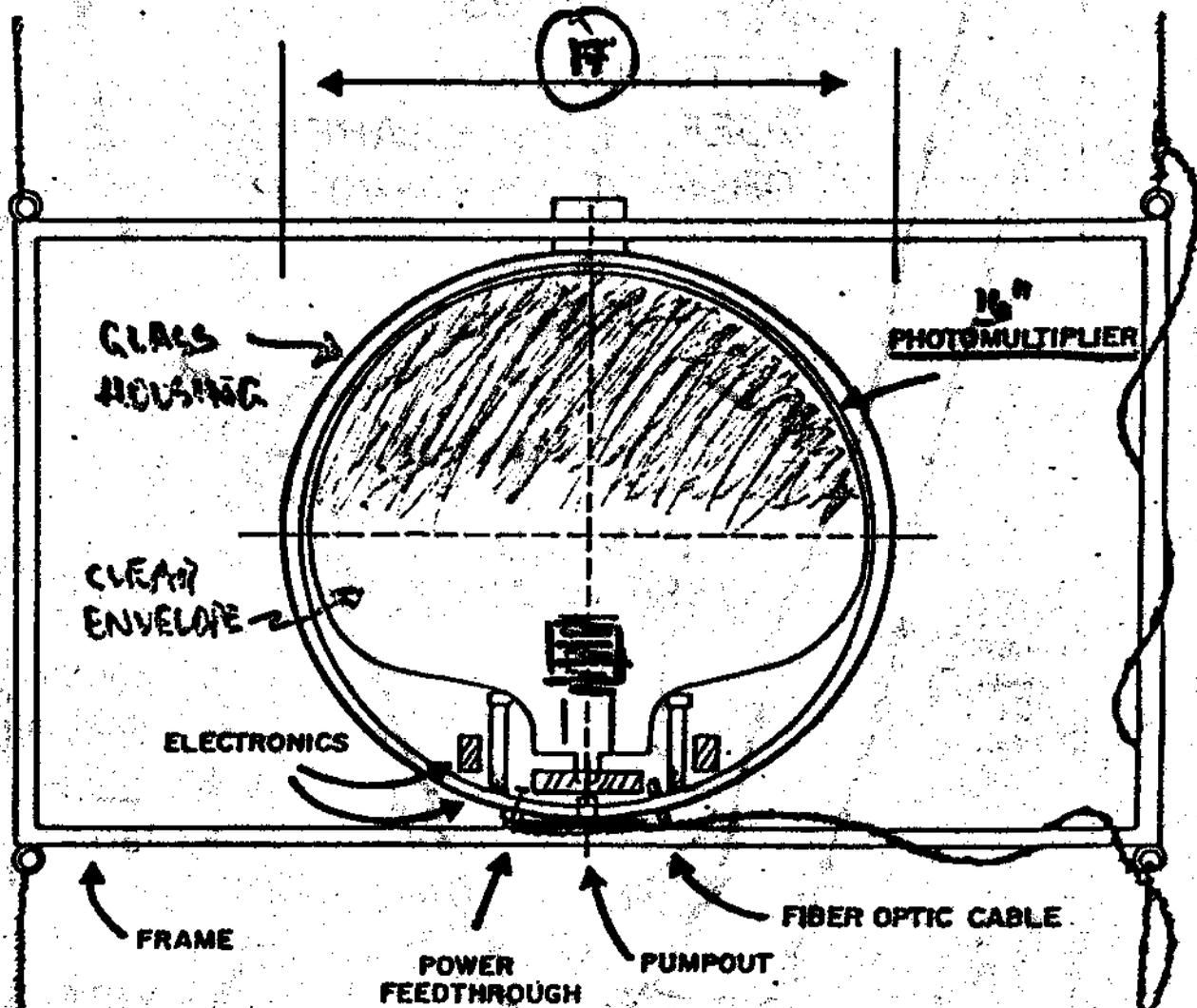
- KEANOLE POINT & KAHOOHANE DEEP CHOSEN AS BEST LOCATION
 - 5 KM DEEP STABLE BASIN, 25 KM OUT
 - AN OCEAN "DESERT" BY ALL REPORTS
- BOTTOM CHARACTERISTICS
 - FLAT, BARREN, NO EVID. FOR HIGH CURRENTS
 - CORE SAMPLES INDICATE MECHANICALLY ADEQUATE FOR ANCHORING
 - LITTLE EVIDENCE FOR CLOUDY LAYER USUALLY FOUND NEAR BOTTOM
- CURRENTS
 - OK OVER SEVERAL MONTHS ($\approx 4-5$ cm/s, < 11 cm/s MAX)
 - MOSTLY TIDAL
- OPTICAL CHAR.
 - EXTREMELY CLEAR
- BIOLOGICAL, BIOFOUL, SEDIMENT.
 - EXPERT OPINION IS OK IN GREAT DEPTHS
 - HAVE MEANS TO COPE IF PROBLEM

THE OCEAN DEEP AT THE DUMAND SITE IS EXTREMELY CLEAR



OPTICAL DETECTOR MODULE

CROSS SECTION

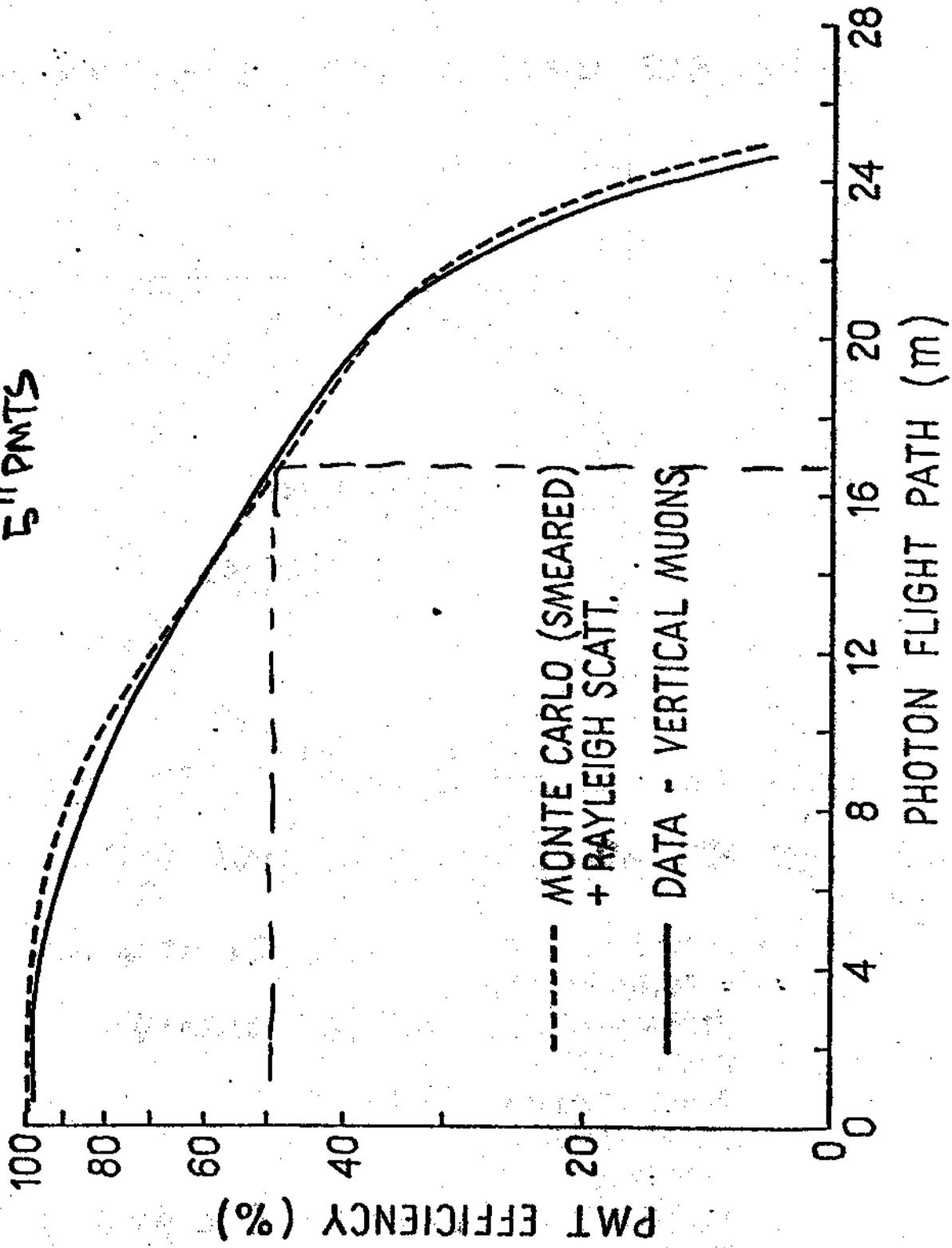


SPECIAL PARTS UNDER DEVELOPMENT

AT ~~EXT~~ & HAMAMATSU
& PHILLIPS

↑
PROTOTYPE
ON HAND

IMB DATA
5" PMTS

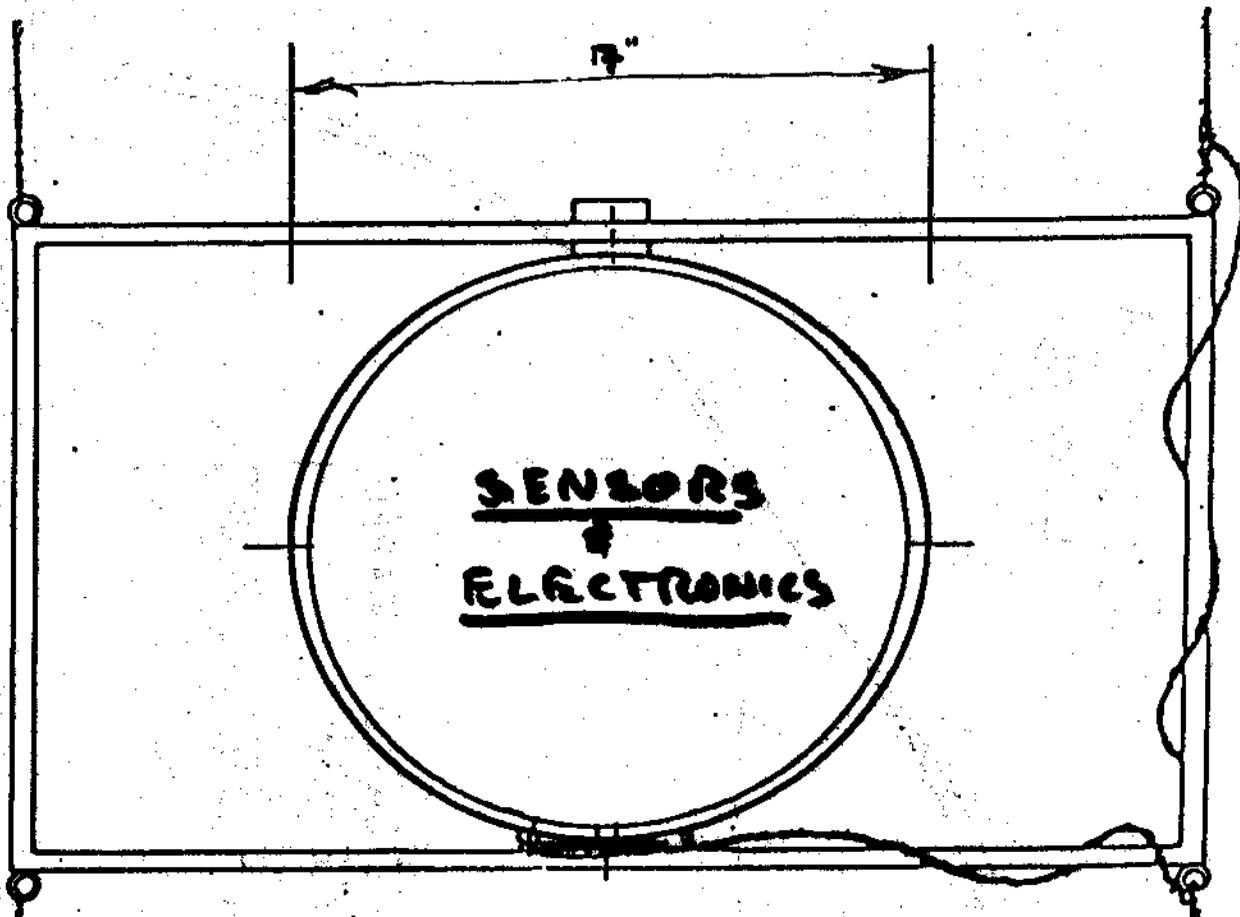


(IMB DATA CONSISTENT WITH DUMAND N.C. INPUT DATA)

INSTRUMENTATION MODULE

3/STRING, MORE?

COMPATIBLE W/OPTICAL MODULES FOR PKG. & ELECT.



→ PRIMARILY FOR STRING LOCATION, ALSO OCEAN STUDIES THO

EACH

CONTAINS:

- CONTROL & TELEMETRY ELECTRONICS
- HYDROPHONE
- PRESSURE SENSOR (R.R. QUARTZ)
- TILTMETER
- ORIENTATION (COMPASS)
- TEMPERATURE
- CONDUCTIVITY
- INTERNAL MONITORS (EG. PWR, LEAK)

SOME:

- OPTICAL TRANS
- CURRENTS
- SEDIMENT

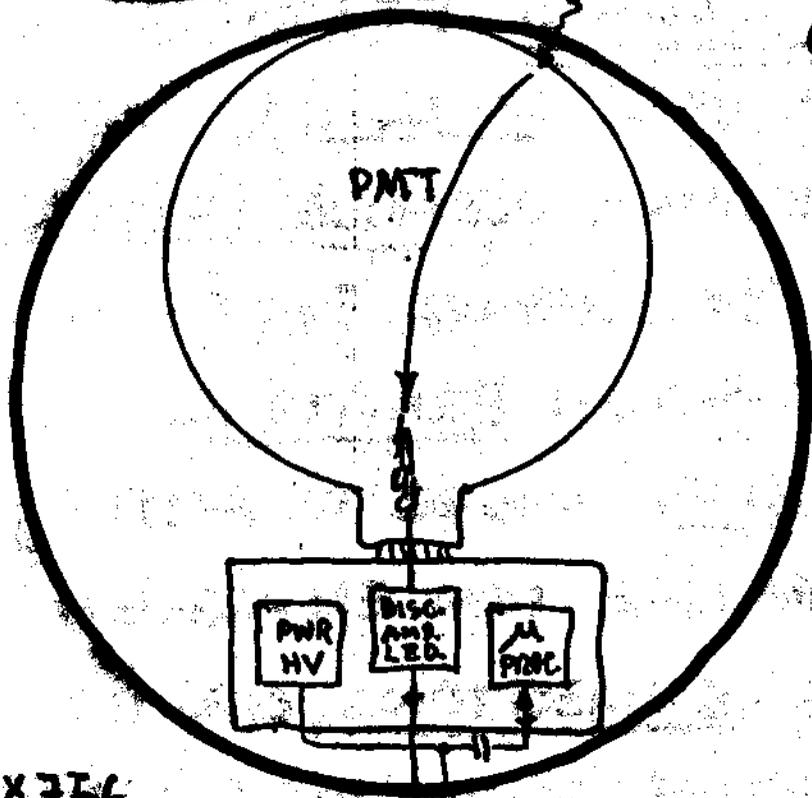
MAYBE:

- LIGHT PULSER
- CCD TV

DEPLOYMENT PLANS FEATURES:

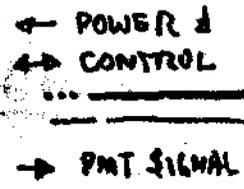
- 2 PLANS: ONE USES DRILL SHIP = CONSERV.
ONE USING OCEANOGR. VESSEL
- BOTH STUDIED BY OCEANOGR ENGRS &
DECLARED PRACTICAL
- MULTIPLE CABLES SHORE TO ARRAY,
SEPARATE ROW EMPLACEMENT
- NO IN WATER CONNECTIONS, CAN BE
POWERED THROUGHOUT OPS.
- MULTIPLE POINTS OF RETREAT IF PROB'S
& LATER RECOVERY POSSIBLE
- BUILD UP EXPERIENCE INCREMENTALLY:
1 MODULE, FEW, STRING, ROW, ARRAY
- ADDITIONS, GROWTH POSSIBLE

OPTICAL MODULE

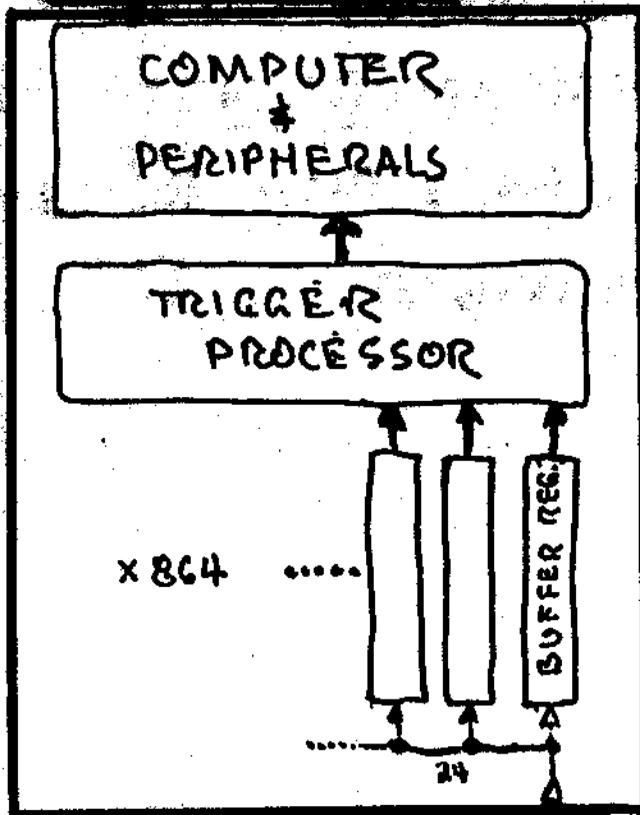


x 756

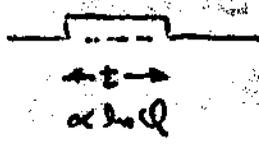
SIGNAL PROCESSING, CONTROL & POWER SCHEMATIC



SHORE STATION



FIBER OPTICS



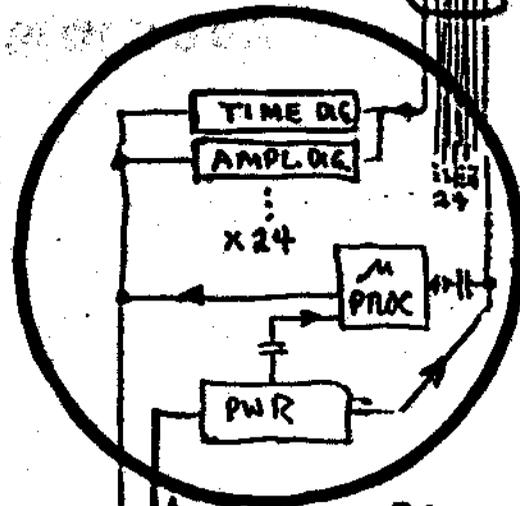
~30 Km

21/FIBER TIME MULTIPLEXED DIGITIZED TMR DATA

ROW CABLE

(1 OF 6)

STRING BOTTOM CONTROLLER



STRING CABLE

1. STRING

PROT. MODULE DEV.

SPS DEVELOPMENT

SPS + SHORE CABLE

PROTOTYPE STRING

PROTOTYPE ROW

ARRAY

BEGIN CONSTRUCTION

LAB & PRESSURE TESTS
2 ENCRG RUNS - COUNT MUONS

DATA RUN ABORTED - INST. LOST AT SEA

BEGIN PROTOTYPE MODULE DEVELOPMENT

PMT TEST TANK CONSTRUCTION

SINGLE MODULE AT-SEA TEST W/O. CABLE TO SHIP

FIX DESIGN FOR MODULE II & SBC

LAB TESTS

SPS AT-SEA TESTS FROM SHIP

FIX DESIGN FOR SHORE TELEMETRY
SHORE STATION READY & TESTED WITH SPS
DEPLOY CABLE (30 KM) & SPS AT DEMAND SITE

RETRIEVE SPS & DEPLOY CANISTER W/PROT. STRING

RETRIEVE PS & DEPLOY PROT. ROW

RETRIEVE PROT. ROW & DEPLOY 1ST ROW OF ARRAY
DEPLOY FULL ARRAY

TAKE DATA, AFTER SHAKEDOWN RUN

REPAIR & REPLACE AS REQ.

1981

1982

1983

(1984)

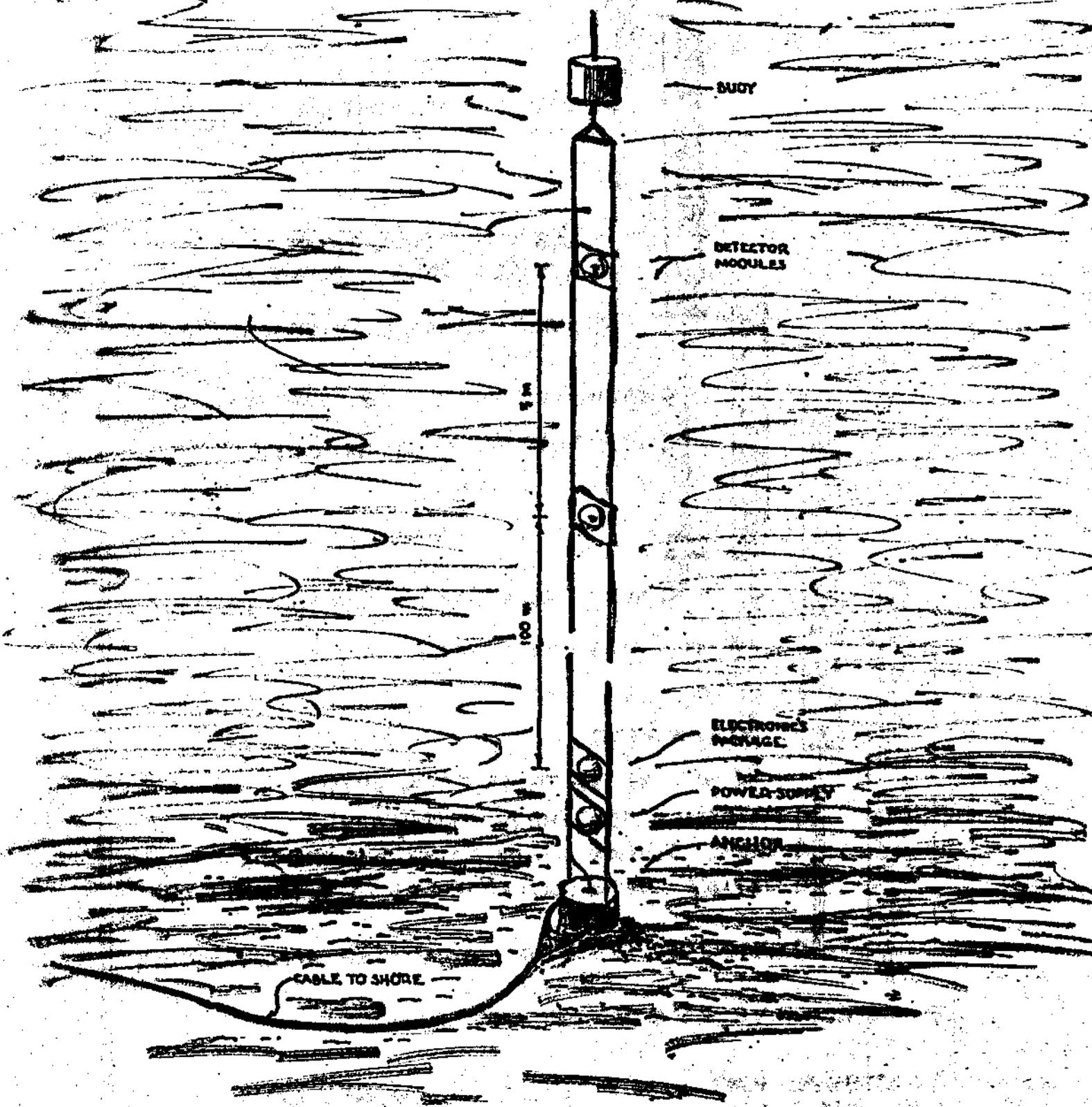
(1985)

(1986)

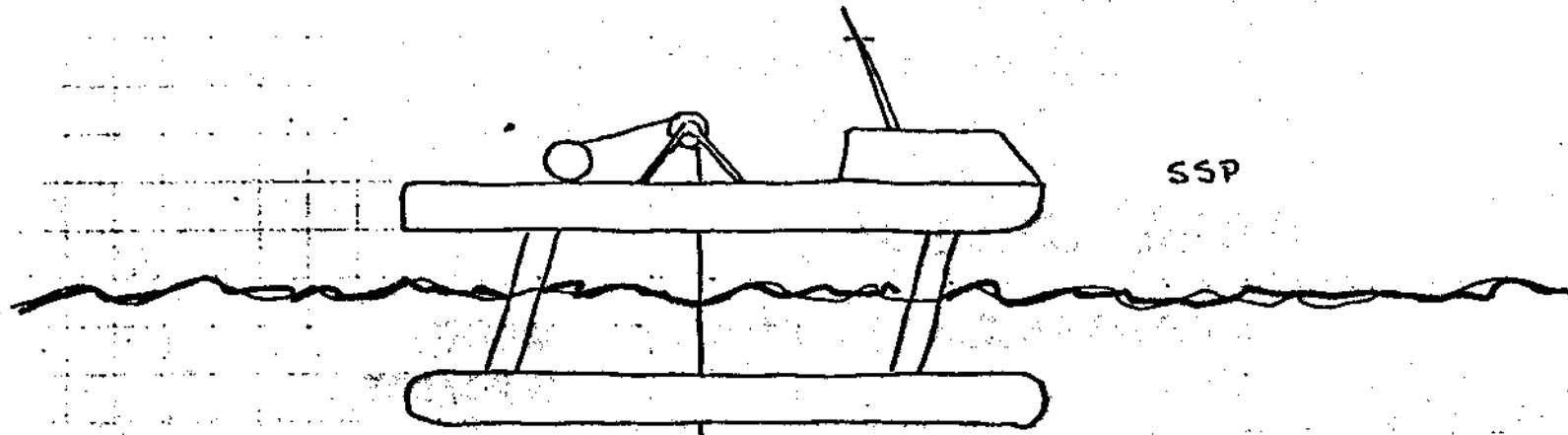
INSTRUMENTATION

1981-1986

FROM UNOFFICIAL DEVELOPMENT FOR DEEP SEA TESTS



- SHORT PROTOTYPE STRING ATTACHED TO SHORE CABLE ON OCEAN BOTTOM
- M STUDIES, V's, MONOPOLES
- ENVIRON. STUDIES, ENGRG PERF.



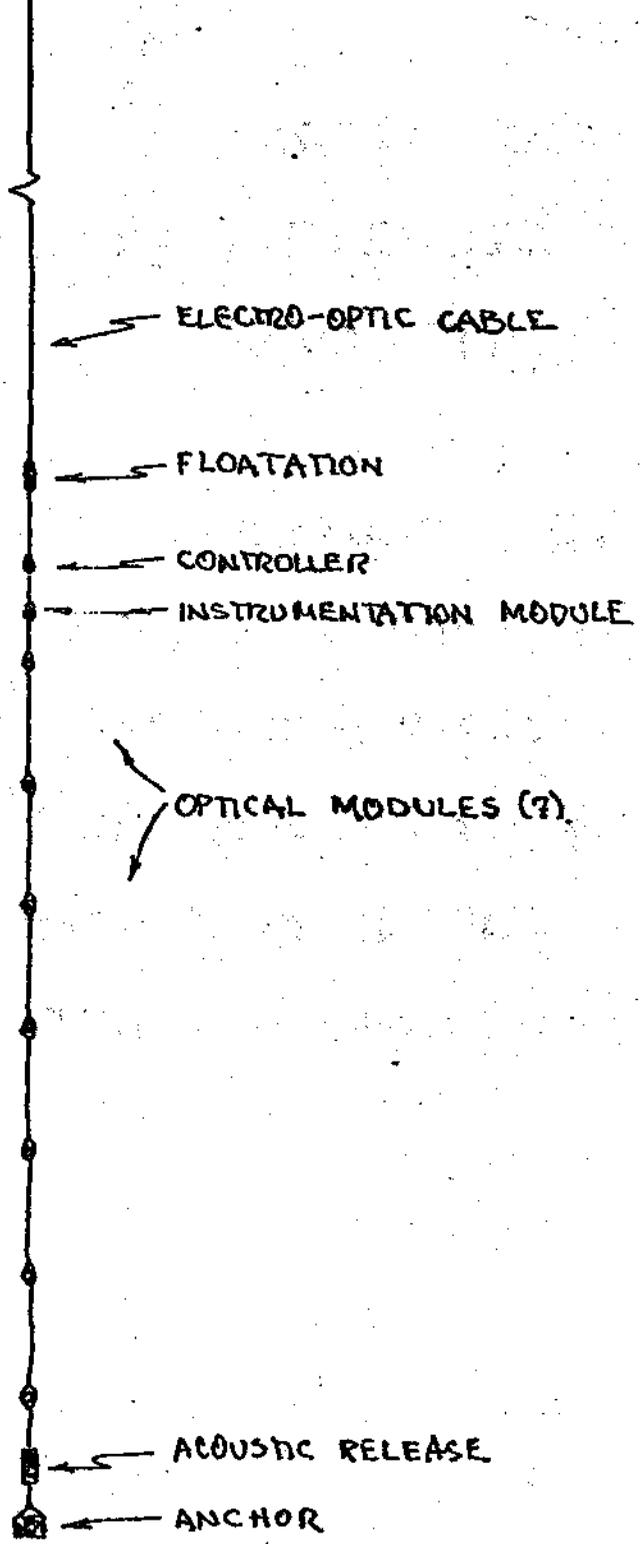
[AFTER SINGLE MODULE TEST]

OCEAN TEST
SPS FROM SSP

2-5 Km DEPTH

STUDY

- MODULE & SYSTEM PERFORMANCE
- BACKGROUNDS
- COSMIC RAY MUONS
($A_{\mu} \approx 1400 \text{ m}^2$)



SSP

ELECTRO-OPTIC CABLE

FLOATATION

CONTROLLER

INSTRUMENTATION MODULE

OPTICAL MODULES (?)

ACOUSTIC RELEASE

ANCHOR

DUAN AND MONTE CARLO DATA ANALYSIS

• "TRIGGER" CRITERIA

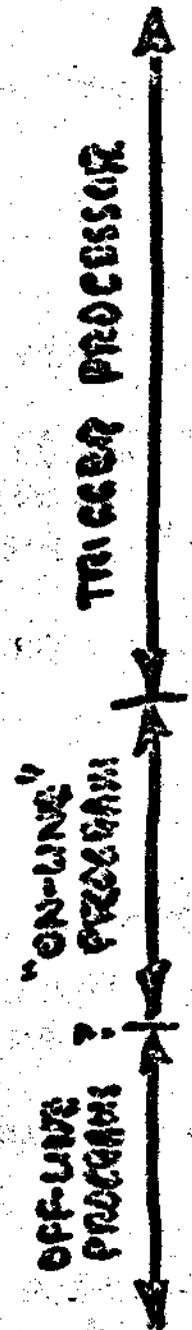
- COINCIDENCE REQTS #DET
#PE/DET

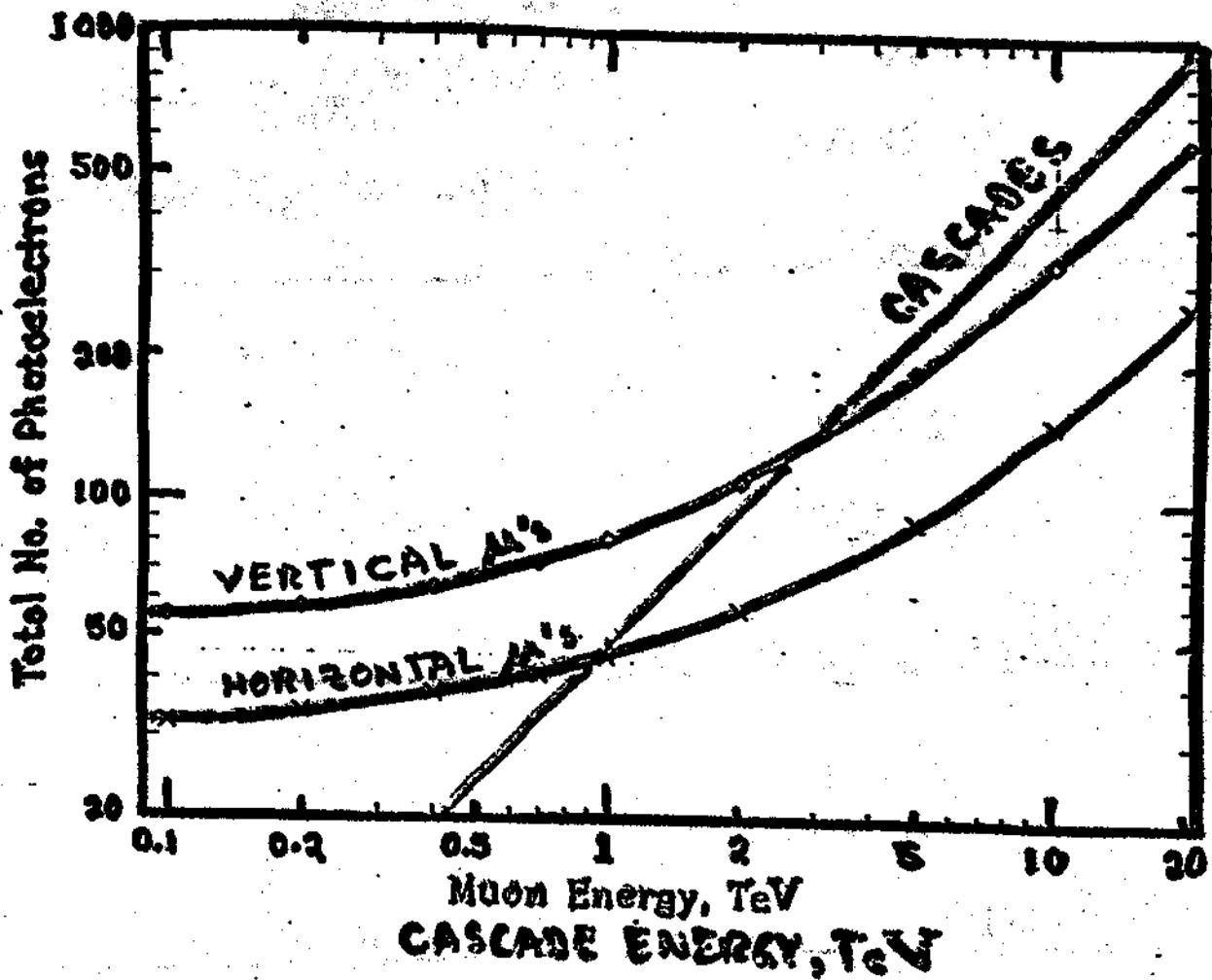
• FILTER PROGRAM

- NEIGHBOR PAIRS
- LIGHT CONE

• FITTER PROGRAM

- SPACE FIT (HITS & PE'S)
- SPACE & TIME FIT
[MAX LIKELIHOOD FIT]
- ENERGY CALC FROM dE/dX
- MULTI-MUON FITTER





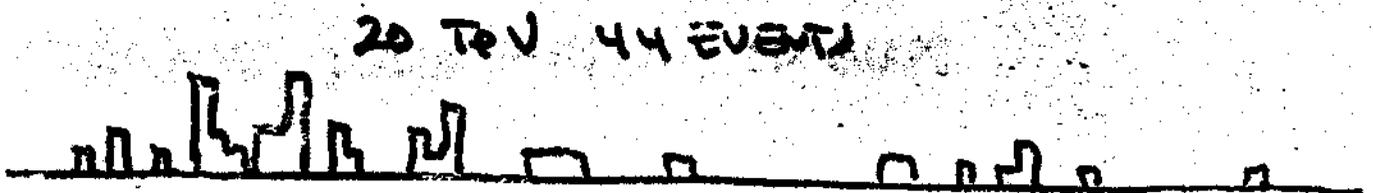
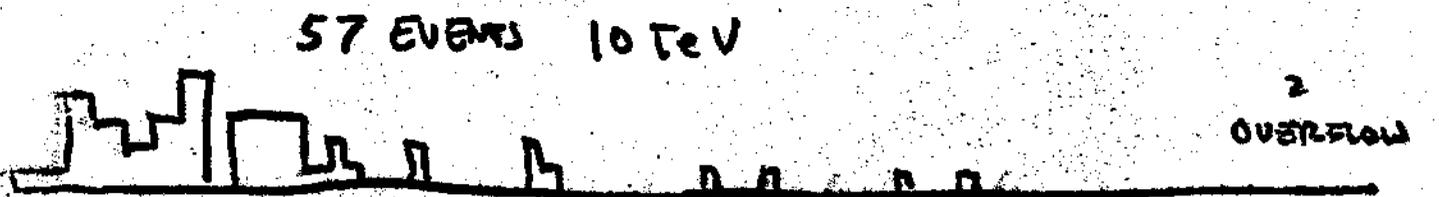
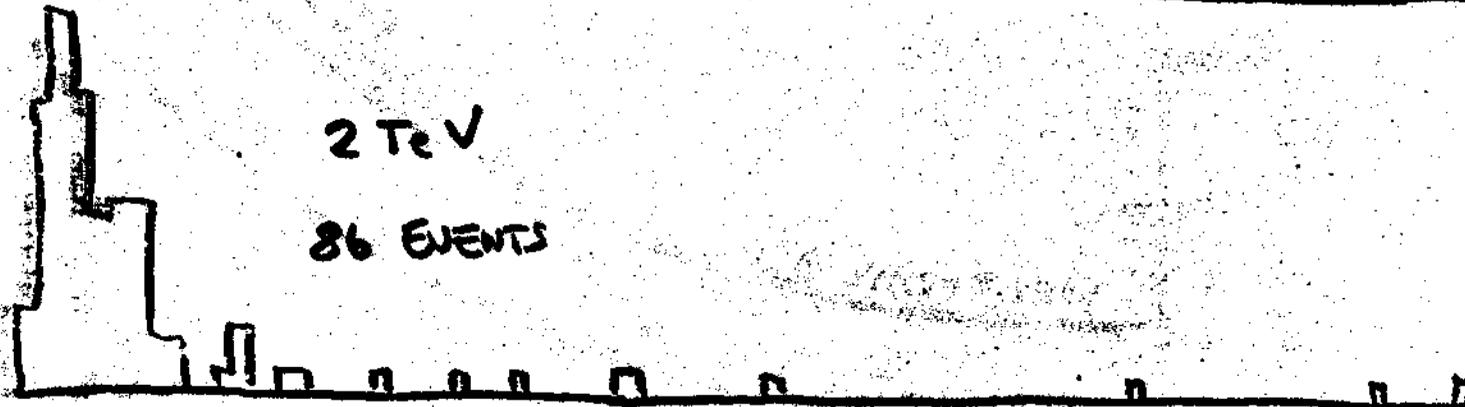
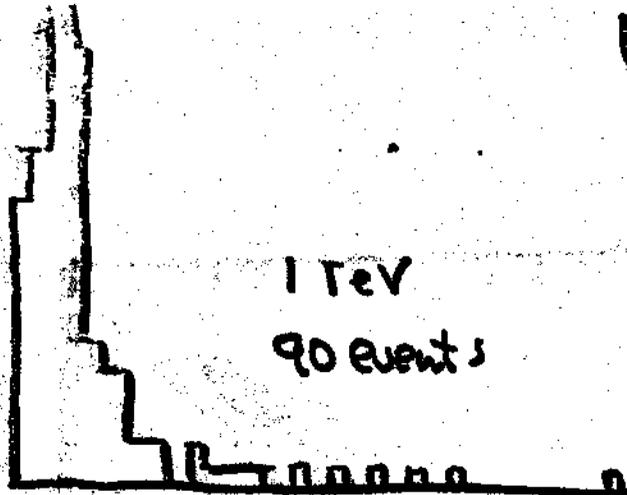
SIGNAL MAGNITUDE VS ENERGY FOR
 MUONS & HADRONIC CASCADES

MEASUREMENT OF E_{μ}

FROM DNT P.B.'s projection
book on track

Reconstruct $\langle \frac{dE}{dx} \rangle$ along track

Algorithm not yet optimized



$$y \equiv \left\langle \frac{dE}{dx} \right\rangle \quad \text{ARB. UNITS}$$

ENERGY MEASUREMENT FLUCTUATIONS

- OBSERVE dE/dx IN 6-80 SAMPLES

FIT TRACK USE OBS. $Q \rightarrow N_x$

- LARGE TAIL OF FLUCTUATIONS (LANDAU)

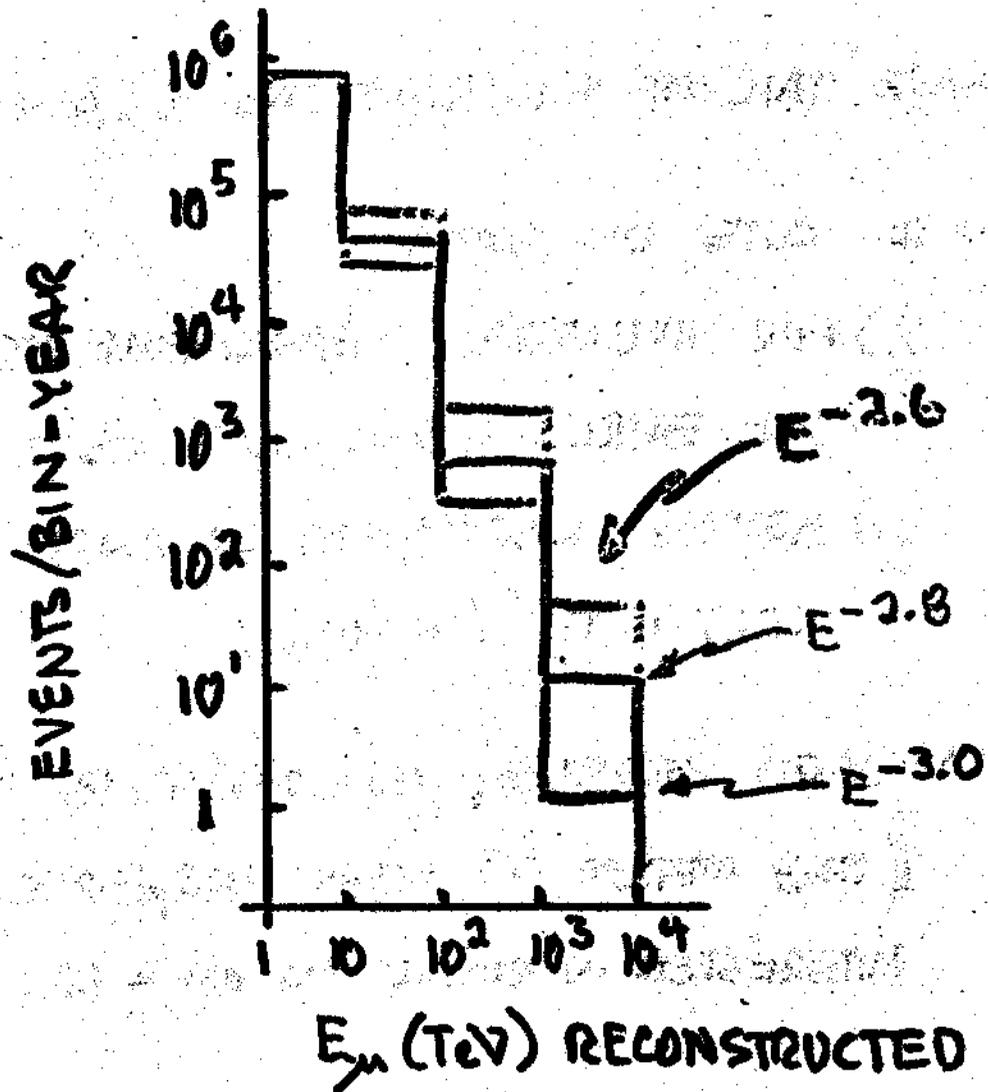
- MAKE CUTS ON DATA

A) FOR SPECTRAL MEASUREMENTS: CAN
USE FAIRLY LOOSE CUTS (SEE RECONSTR. FLUX)

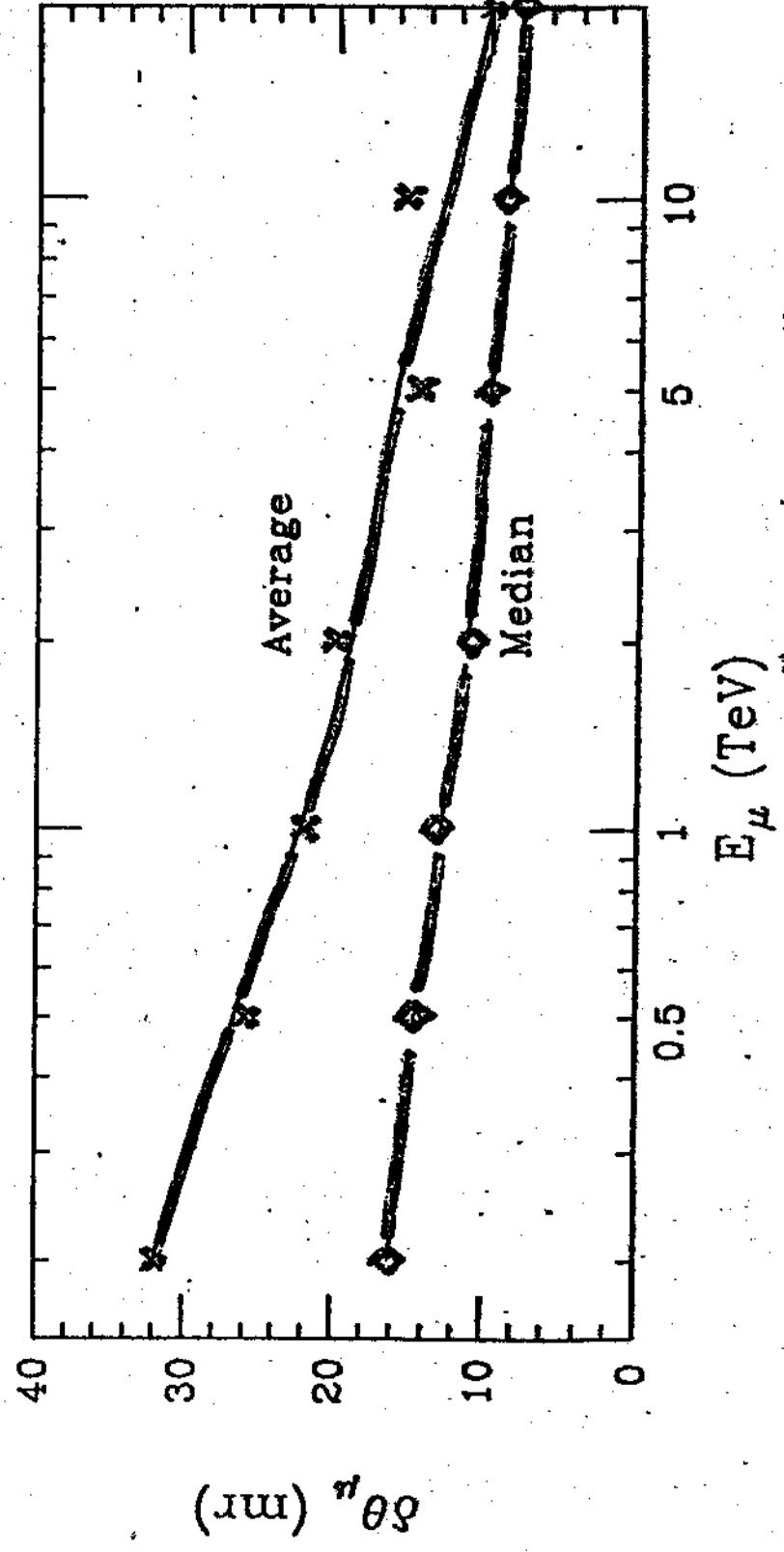
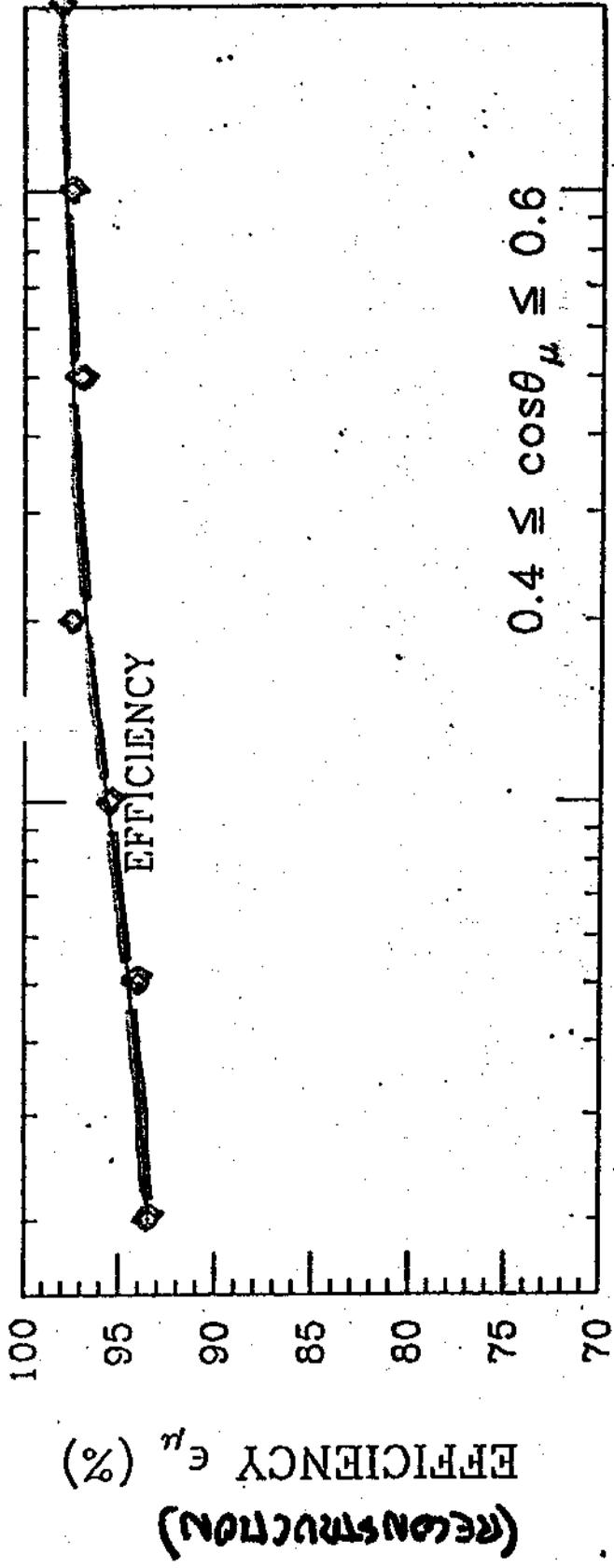
B) BETTER ENERGY RESOLUTION: MAKE
TIGHT CUTS ($\sim 50\%$)

- STANDARD PROBLEM IN COSMIC RAYS
 - (ONE METHOD OF MEASURING μ SPECTRUM)
 - INTERESTED IN RESOLUTION ON A LOG SCALE

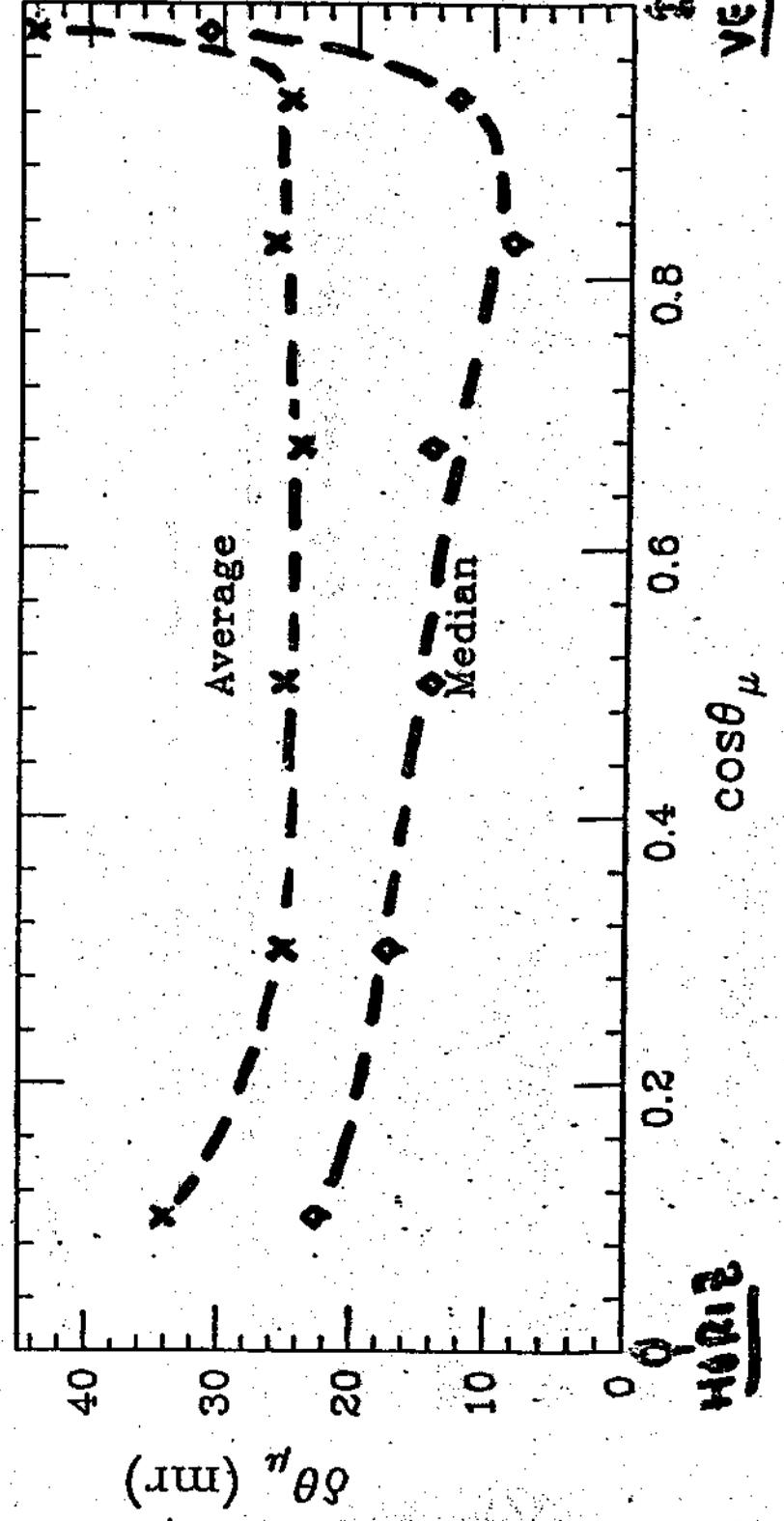
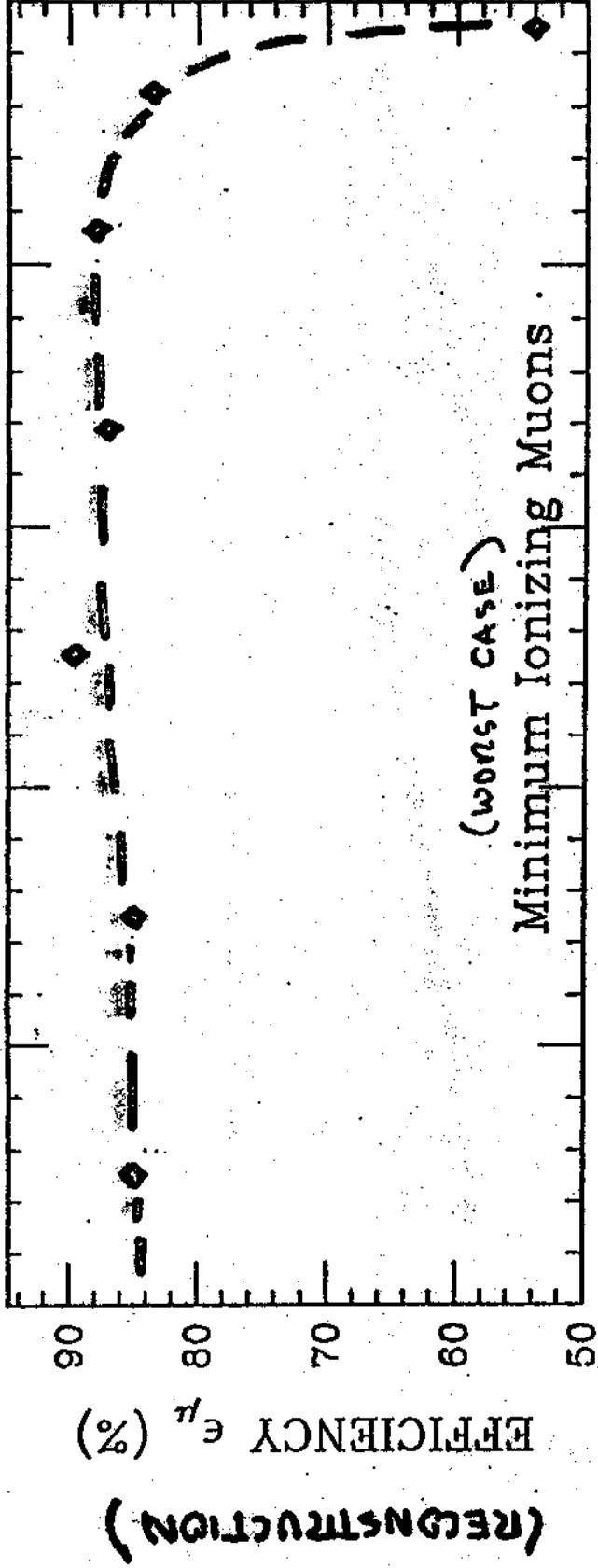
SIMULATED OBSERVED COSMIC RAY MUON SPECTRUM AT DUMIND



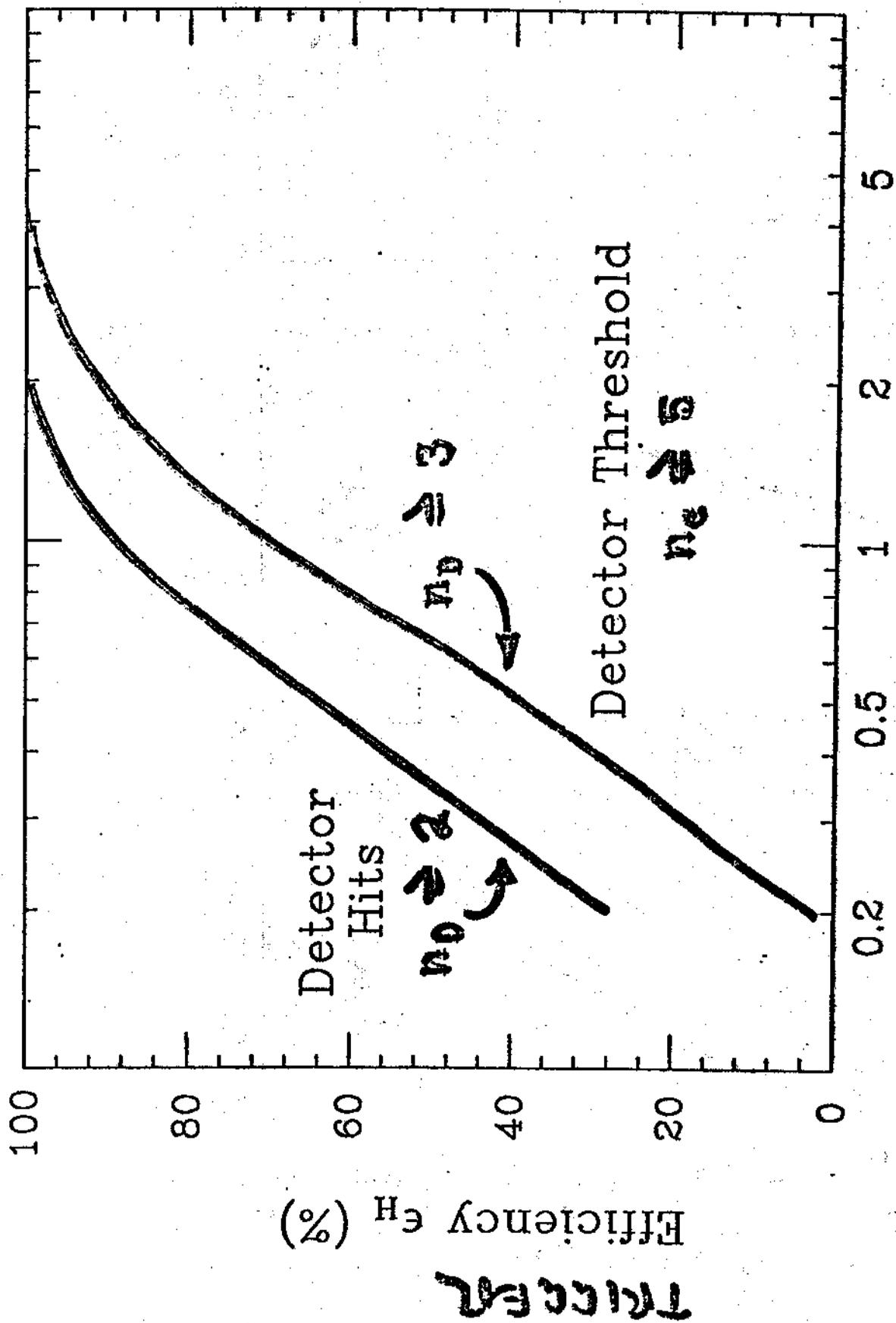
[INCLUDES dE/dx LONG TAIL]



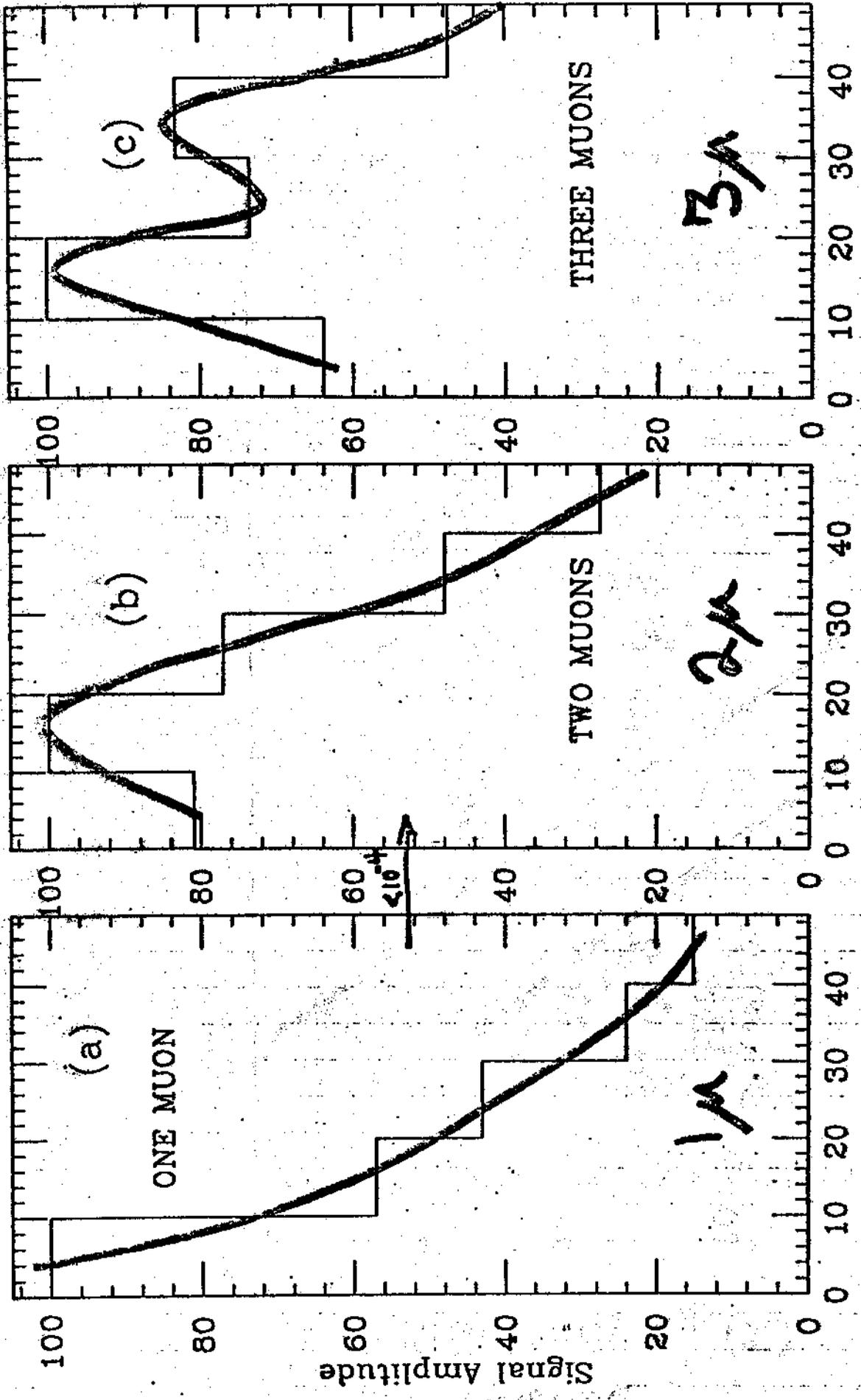
ANGULAR RESOLUTION & "EFFICIENCY" VS ENERGY



ANGULAR RESOLUTION & "EFFICIENCY" VS ZENITH ANGLE

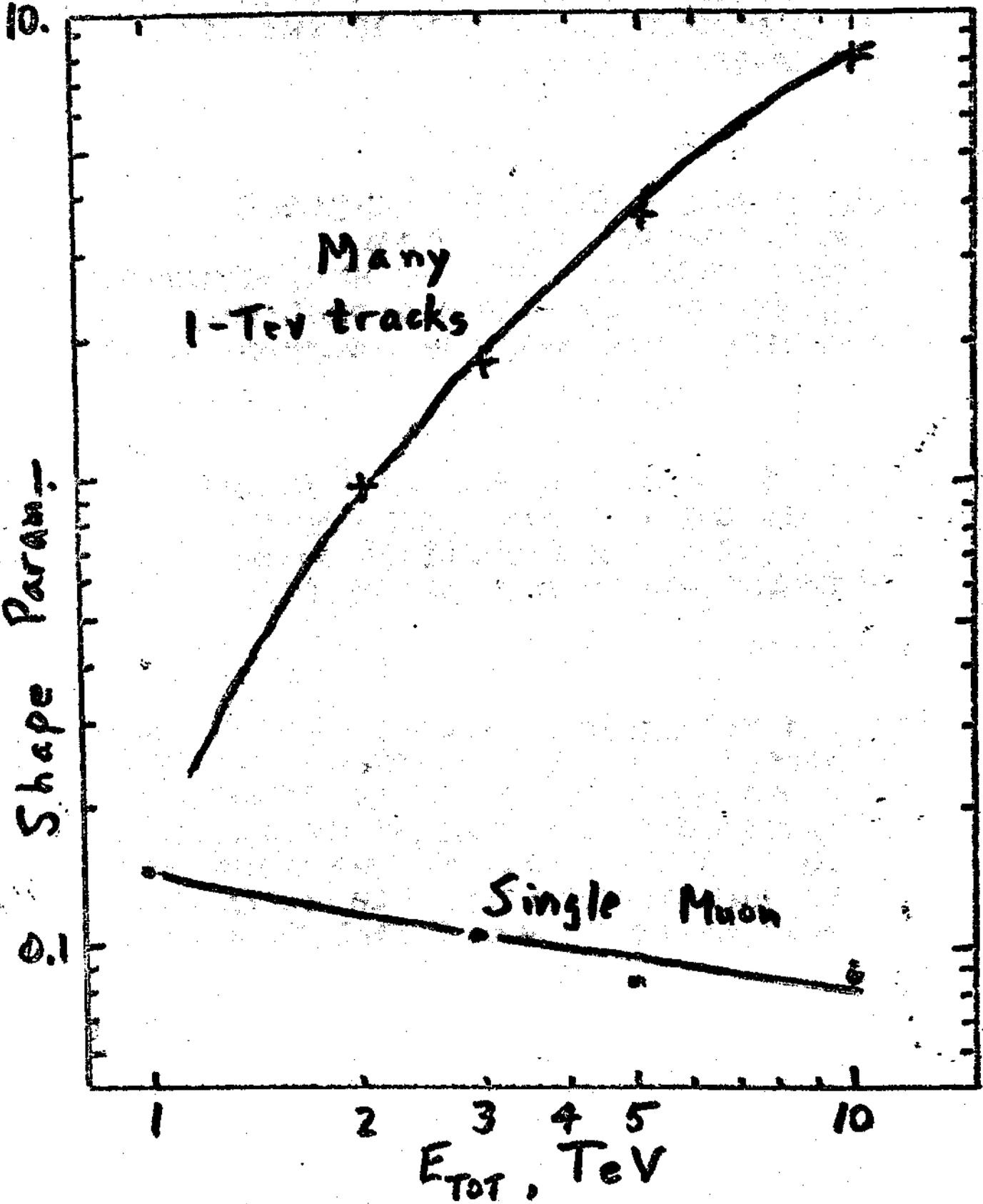


65% IDENT



AVERAGED TIME SIGNATURES OF MULTI- μ 'S

- 1) $>10\sigma$ SEPARATION WITHOUT SHAPE RECORD
- 2) $\sigma \approx 3\sigma$ CAN BE SEP USING SHAPE



SUMMARY EXPERIMENTAL DESIGN

- **SYSTEM DESIGN = SIMPLE & RELIABLE**
 - FLEXIBLE RUGGED ARRAY, USING KNOWN COMPONENTS
 - MINIMAL PROCESSING & NODES AT SEA, SEGMENTED
 - DEPLOYMENT UNDER POWER, RETREAT POSSIBLE
 - DEPLOYMENT USES TESTED TECHNOLOGY
 - RECOVERY POSSIBLE

- **STUDIED ALL SUGGESTED PROBLEMS**
 - MOST INCORPORATED IN PLAN
 - SOME TO BE EXPLORED, BUT HAVE BATTERY OF SOLUTIONS
 - NO OUTSTANDING GO/NO-GO PROBLEMS
 - INCREMENTAL APPROACH → OVERCOME ANY UNANTICIP.

- **EXTENSIVE DESIGN, LAB & "FIELD" STUDIES**
 - NEAR OPTIMAL PATH → HEV ASTRON
 - CR, HEP, & OCEAN STUDIES INCORP.
 - READY FOR ENGINEERING DESIGN

- **IT IS TIME TO BEGIN A NEW ERA IN PARTICLE PHYSICS: TO TAKE NEUTRINOS STUDIES FROM NOVELTY, PROBE OF STRUCTURE, & INTERIOR OF OUR SUN, TO BEING USEFUL AS A NEW WINDOW ON THE UNIVERSE. WE ARE READY & THE TECHNOLOGY IS AVAILABLE TO MEET THE CHALLENGE.**

DUMAND ORGANIZATION

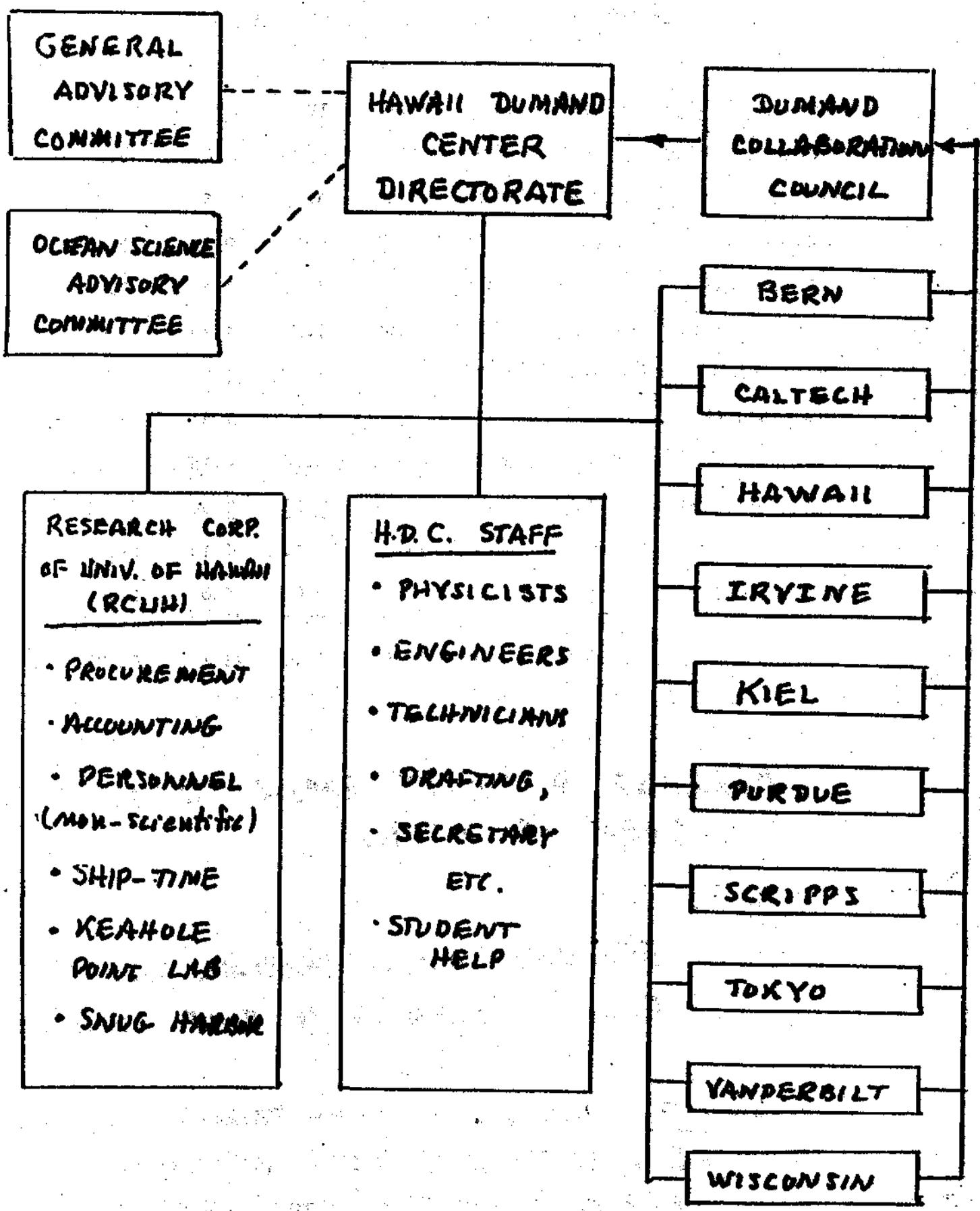


Table 6.2A
DUMAND Ph.D.-Physicist Effort (in FTE)

Group (Ph.D.'s)	Stage					Total
	I	II	III	IV	V	
I.C.R.R. (4 + 7)	3.2	4.1	4.4	4.4	4.4	20.5
KIEL (3 + 5)	2.6	2.8	3.6	3.6	3.6	16.2
BERN (1)	0.75	0.75	0.75	0.75	0.75	3.75
Cal Tech (3)	1.55	1.55	1.55	1.55	1.55	7.75
Irvine (1 + 3)	0.05	0.15	0.75	1.25	1.25	3.45
Purdue (5)	1.0	1.0	1.0	1.0	1.0	5.0
Wisconsin (4)	0.4	0.9	1.2	1.3	1.3	5.1
Scripps (1)	0.25	0.25	0.25	0.25	0.25	1.25
Vanderbilt (5)	<u>0.60</u>	<u>0.90</u>	<u>1.40</u>	<u>2.00</u>	<u>2.00</u>	<u>5.90</u>
Subtotal	10.40	12.40	14.90	16.10	16.10	68.90
HDC (4 + 5)	<u>4.0</u>	<u>4.0</u>	<u>5.0</u>	<u>5.0</u>	<u>5.0</u>	<u>23.0</u>
Total	14.40	16.40	19.90	21.10	21.10	91.90

**AVERAGE PHYSICIST EFFORT \approx 18 F.T.E.
OVER 5 YEARS**

PLUS:

- ENGINEERING/TECHNICAL SUPPORT
- EACH LABORATORY'S SHOP FACILITIES,
ETC.

EXAMPLE: HAWAII'S COMMITMENTS TO DUMAND

- 3 FULL-TIME FACULTY POSITIONS
- KEA HOLE POINT --- SHORE-BASED LAB.
- ASSEMBLY & PORT FACILITIES.

COST ESTIMATE -- DEMAND ARRAY

• COSTS INCLUDED:

- EQUIPMENT, MATERIALS, SUPPLIES
- ENGINEERING & TECHNICAL PERSONNEL
- ASSEMBLY & CONSTRUCTION PERSONNEL
- DEPLOYMENT (SHIPTIME, CABLES, ETC)

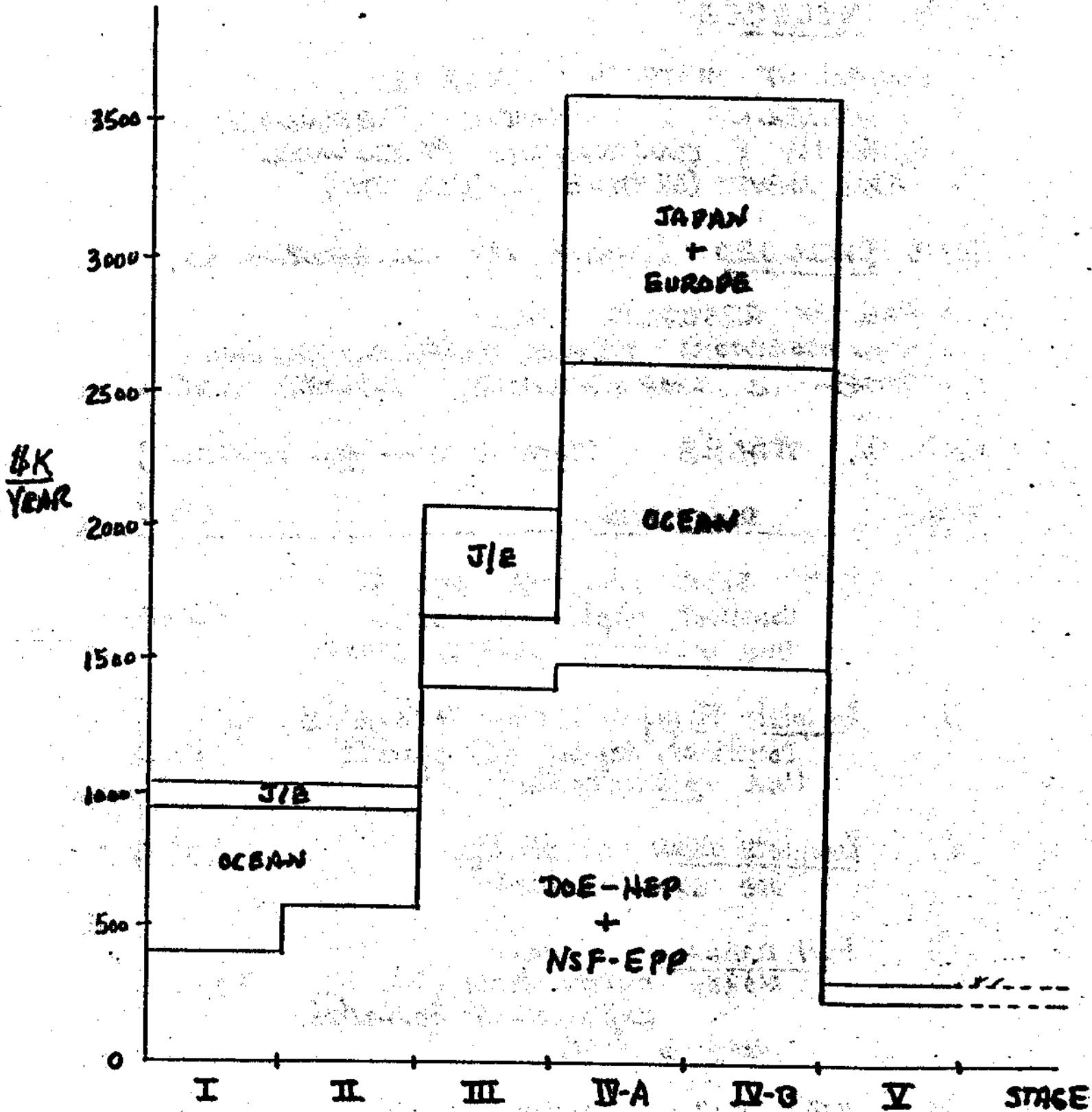
• COSTS EXCLUDED (BORNE BY COLLABORATORS)

- FACULTY RESEARCH TIME
- COLLABORATORS' TRAVEL TO/FROM HAWAII
- HOME-SITE SHOP FACILITIES, COMPUTER TIME

• COST BY STAGES: (TOTAL COST -- ALL SOURCES)

<u>STAGE</u>	<u>DESCRIPTION</u>	<u>COST</u>
I	"SPS" = SHORT PROTOTYPE STRING Construct, deploy, operate. One undersea cable to shore	\$985 K
II	<u>Complete String</u> : 21 + 3 = 24 modules Construct, deploy, and operate (use <u>same</u> cable)	\$845 K
III	<u>Complete Row</u> : 6 strings (use same cable).	\$2,395 K
IV	<u>Full array</u> : 6 rows Major construction job. " deployment operation Need 6 cables.	\$7,715 K
V	"RUN-IN": Data-taking year Normal operating budget	\$330 K
GRAND TOTAL ---		\$12,270 K
(5-YEARS)		

PROPOSED FUNDING FOR DUMAND



	TOTALS
DOE/NSF-EPP	5.6 M
USM/NSF-OCEAN	3.9 M
JAPAN/EUROPE	2.5 M
	<u>12.0 M</u>

50% CERENKOV, ELECTRONICS, COMPUTERS, ENBA
 SHIP-TIME, CABLES, OCEAN SCIENCE/ENVR
 50% CERENKOV, ELECTRONICS, SOFTWARE

CONCLUSIONS ---

--- THE PROJECT IS FEASIBLE

--- THE SCIENTIFIC GOALS ARE
WORTHWHILE

--- THE EXPERIMENTAL TEAM
ASSEMBLED CAN DO THE JOB

--- WE ARE READY TO PROCEED
WITH STAGE I

LET'S GO !

Having now undergone compulsory retirement for a second time, I have asked for a minute or two to present, for probably the last time a few points which have made the DUMAND project especially meaningful in my eyes.

You will have noted that DUMAND is significantly different in a qualitative sense from the conventional high-energy physics experiment. It contains scientific components in neutrino astronomy, cosmic rays, and high-energy physics, as well as geophysics and ocean science that we have not discussed. It is capable of important contributions in all these fields. It makes significant demands upon, and significant contributions to, the technologies of high-energy physics, computer science, fiber optics data transmission, oil-well drilling, ocean engineering, and ocean science. Its multidisciplinary nature is emphasized by the difficulties we have had in finding appropriate federal funding agencies. We are especially grateful to the DOE Research division for funding our feasibility study, and we regard that as evidence that they consider high-energy neutrino astronomy a reasonable activity for them, considered perhaps as applied high-energy physics. The emphasis on high-energy neutrino astronomy you have observed is simply a recognition that only rarely does one find an opportunity of participating in the founding of a new branch of science.

This unique feature of DUMAND has been a source of great strength to us. It has fired the imagination of a diverse group of physicists, *astrophys.* biologists, geophysicists, and ocean engineers, who are attracted by the way in which the project crosses so many boundaries between different fields of science and engineering, requires such diverse expertise and technological development, and offers scientific rewards only partially predictable but potentially highly significant.

You will also have noted that the scientific aims are somewhat less focused than is customary in high-energy physics. A proton-decay experiment, or a neutron-antineutron oscillation experiment has extremely specific aims, and well-defined answers. Since we are entering a new field, our aims must necessarily be less specific. There is a parallel here to the situation presented by proposals for a new accelerator. The nominal scientific aims of the accelerator are listed; they are interesting, and form a valid basis for approval of the machine. The actual achievements of the accelerator, in the most successful cases, are those which could not have possibly been anticipated when the accelerator was proposed. DUMAND is in a similar position; we can only hope for an equally fortunate result.