NEUTRINO TELESCOPES

(& MICROSCOPES)

JOHN LEARNED 18 JUN 2001
@ LES HOUCHES CONFERENCE

- MOTIVATION
- ACCOMPLISHMENTS
- TECHNIQUES
- REVIEW OF PROJECTS
- CONCLUDE

WHY CARE ?

- IMPORT OF ν'S IN UNIVERSE GENERALLY
  - COSMOLOGY — BARYOGENESIS, $\Omega_\nu \gtrsim \Omega_{STARS}$
    ↓
  - STELLAR OBJECTS — GSC → ν STARS, r-PROC ⇒ A>56
    ↓
  - ELEMENTARY PARTICLES — PECULIARLY SMALL MASS FERMIONS

- ASTRONOMY
  - PRODUCED WHEREVER $\Gamma_p \gtrsim 1$ – MOST LUMINOUS OBJECTS
  - DOMINATE SN II (GSC)
  - HEAVILY OCCLUDED COSMIC ENGINES → ν's → OUT
    GRB, AGN, μQSO, BH, GAL CEN
  - PRE-WHITE DWARF RADIATION ν DOMINATED ($P, \dot{P} \Rightarrow \sigma_\nu^{B,RAD}$)
  - GRB & SN PUZZLE (γ, γ, HE γ OBSVD, BUT ν's ??)
  - ⋮

- COSMIC RAYS
  - WHERE DO THEY COME FROM ? CR ⟷ ν's
  - HIGHEST ENERGY CR'S ($>10^{20}$eV) ($>$GZK CUTOFF)
    WHAT ROLE ν's? (ν MUST BE THERE)

- PARTICLE PHYSICS
  - ν OSC ⇒ $m_\nu \neq 0$ ⇒ ? GUT ?
  - GZK PUZZLE → NEW MASSIVE RELICS ? ν's FROM DK?
  - ν OSC AT $\delta m^2 \ll 10^{-10}$ eV^2
  - $\sigma_\nu (E \gtrsim 10^{20}$ eV$)$: UNITARITY?, NEW STATES?, HIGHER DIMEN?
  - ⋮

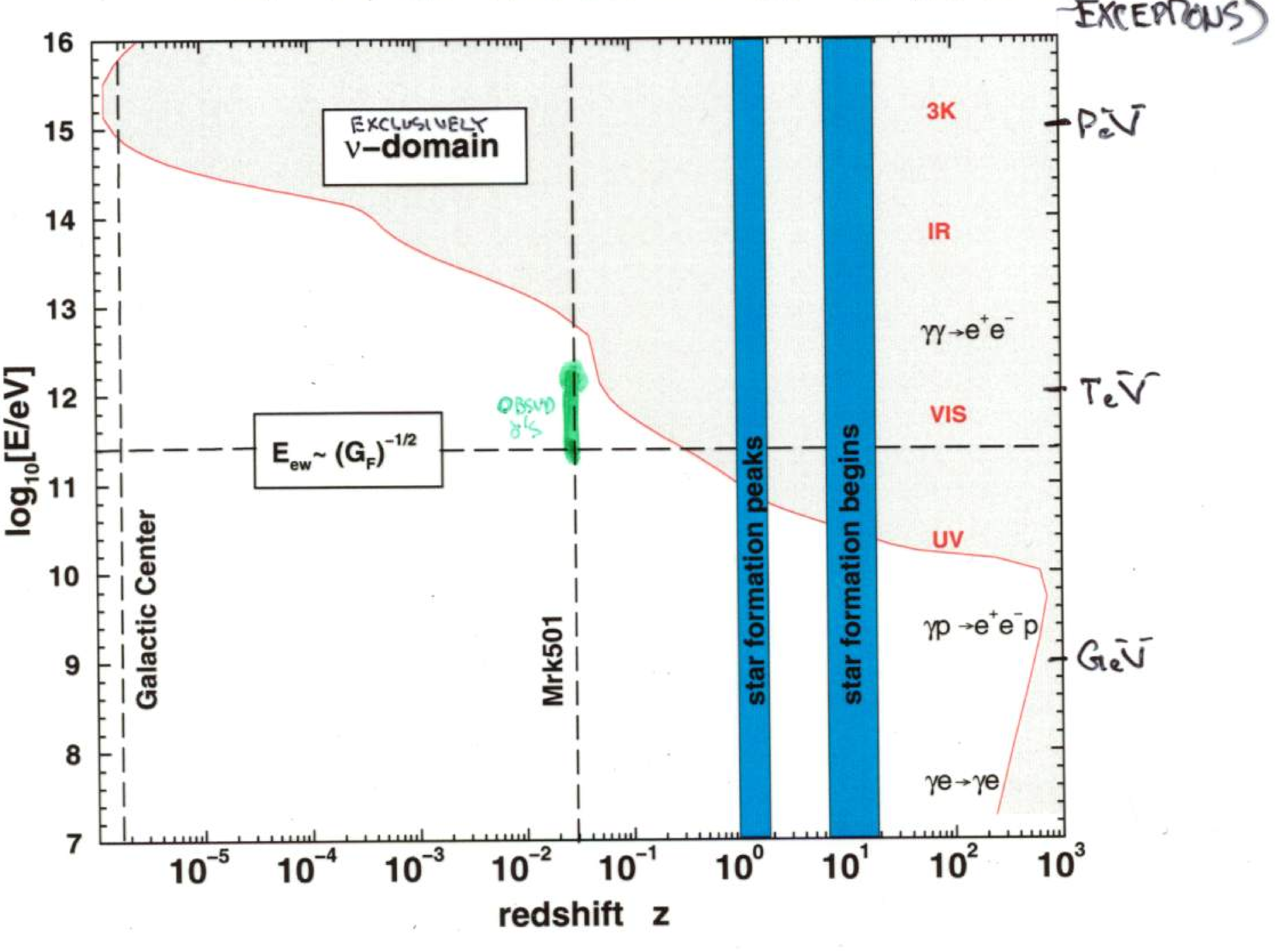
SO, WE CARE BUT HAVE WE DONE ANYTHING ? YES
CAN PRACTICALLY DO ANYTHING ? YES !

@ >10 TeV ν's ARE ONLY COMPLETE ASTR.

- γ's INTERACT WITH IR BKGD
- EHE p's & Nuclei INTERACT WITH 3°K PHOTONS

- PHOTO & COS. RAY ASTRON LIMITED TO ~100 MPC
  ⇒ < 0.1% OF VISIBLE UNIVERSE (TO z~3)

- THE UNIVERSE IS TRANSPARENT W/O SCATTERING TO ν's OF ALL ENERGIES (WITH SOME INTERESTING EXCEPTIONS)



LEARNED & MANNHEIM 2000

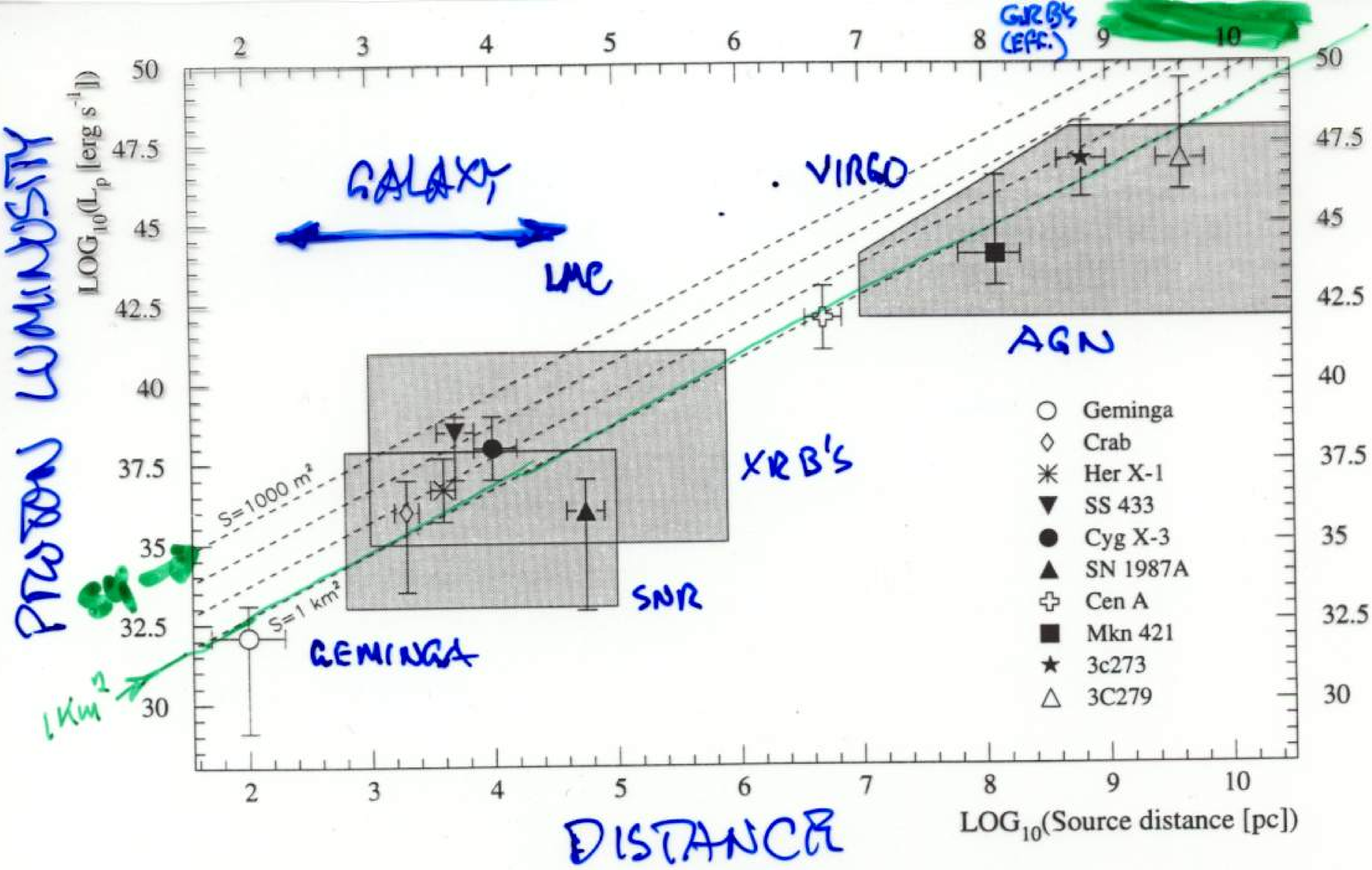


Figure 2.10: Proton luminosity and detectability of individual cosmic neutrino source candidates versus distance. The plot assumes a standard neutrino source eq.(2.8),[13] and the production of about 10 muon events per year above $0.1 TeV$. Dashed lines show typical sensitivity limits of detectors ranging from $1000 m^2$ to $1 km^2$ for 1 year operation. The shaded regions show the areas where typical populations: young supernova remnants, X-ray binaries and AGN reside. The error bars indicate errors of the resulting neutrino flux and the detectability of this source. Especially in case of Mkn 421 the model of a standard neutrino source yields a smaller ν flux than expected from the VHE γ observation. If protons are accelerated in a jet pointing into our direction a larger fraction of the proton luminosity contributes to the ν flux on earth.

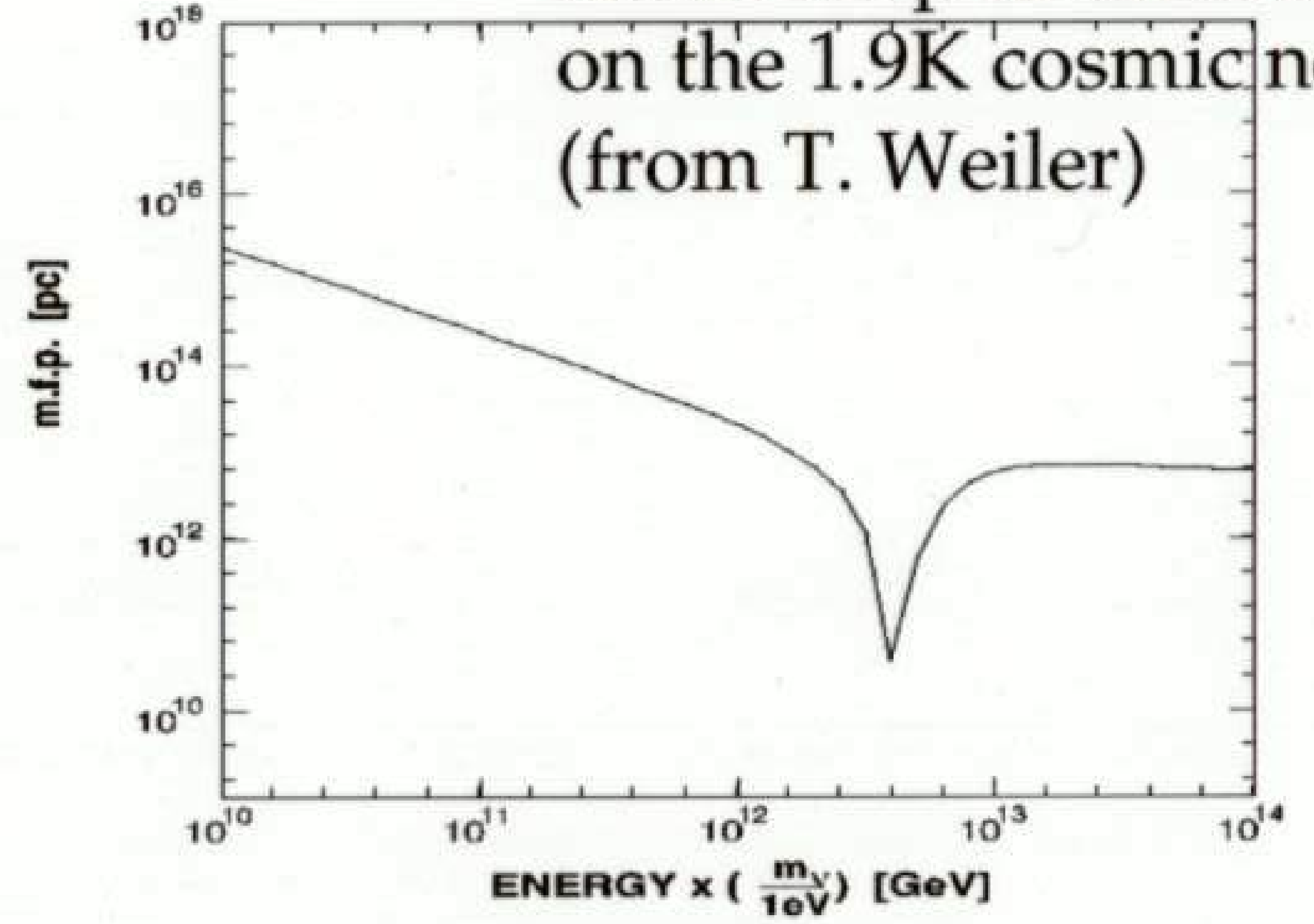
TOTAL POWER OUTPUT LIMITS NEUTRINO LUMINOSITY

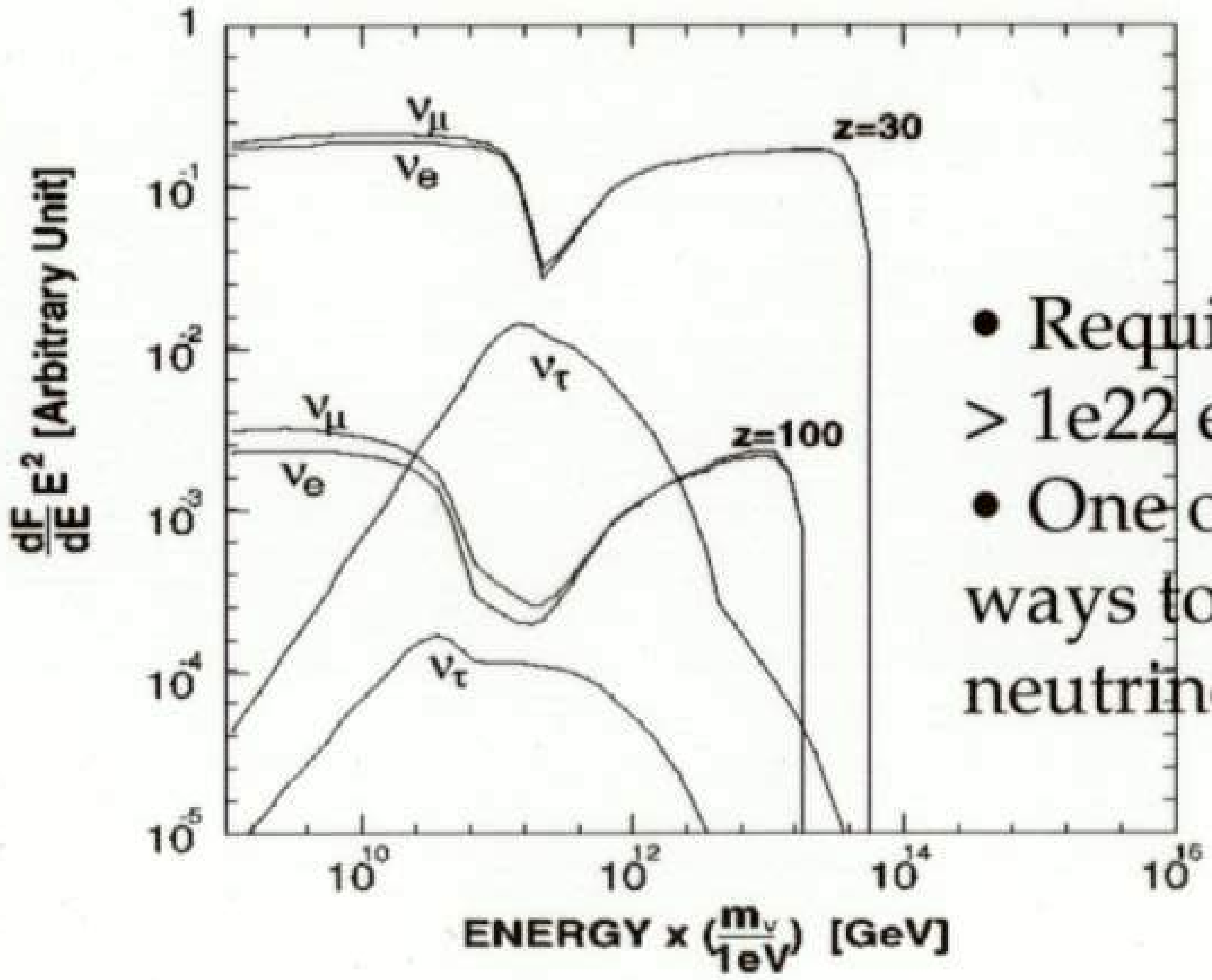
- PLENTY OF POWER
- CONSTRAINTS FROM γ'S (TRANSPARENT SRC $\rightarrow \gamma/\nu \sim 1$)

FROM C. WIEBUSCH '95 DISSERTATION

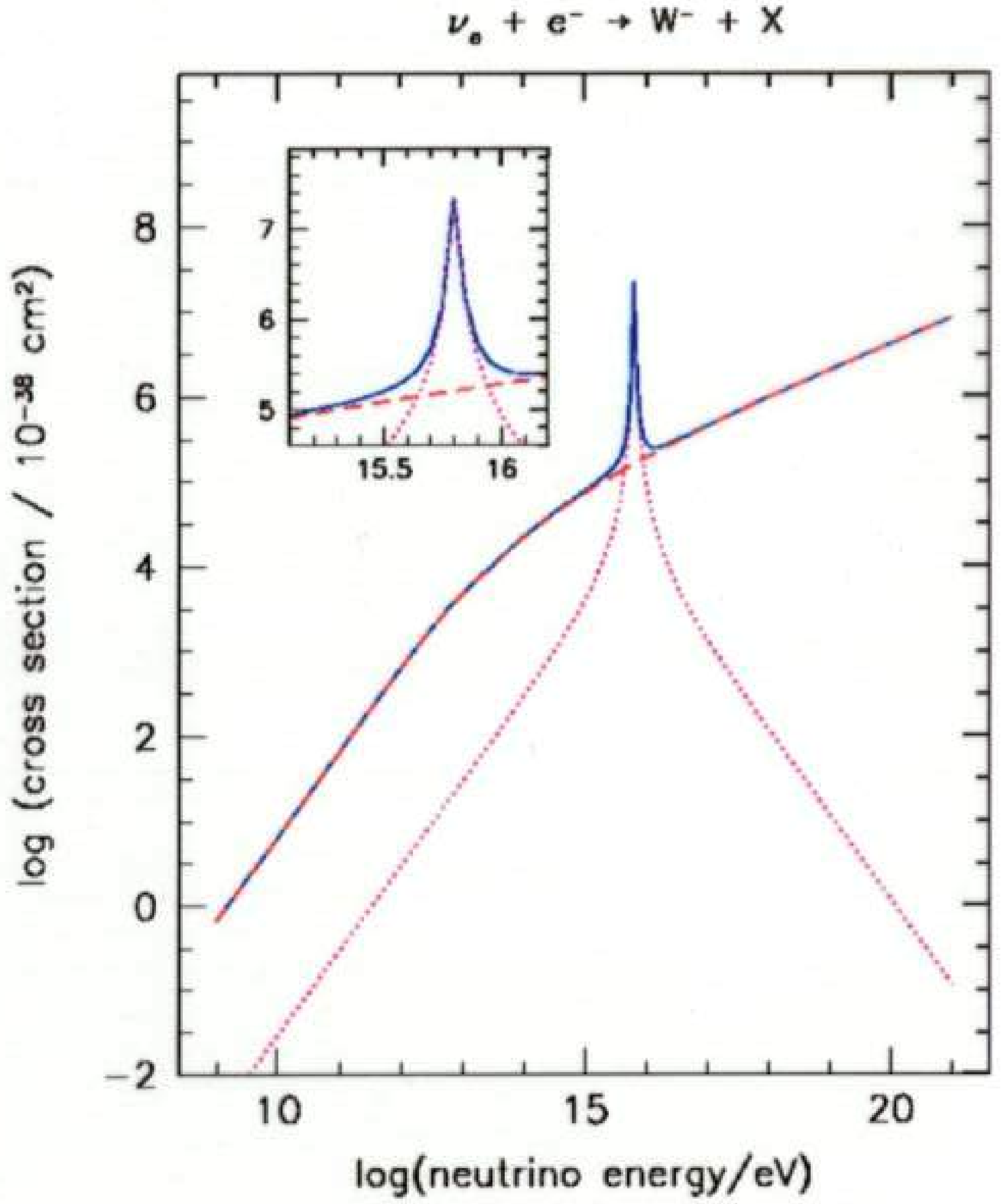
PeV to ZeV Neutrino spectroscopy

Neutrino pair annihilation on the 1.9K cosmic neutrinos (from T. Weiler)





- Requires sources of > 1e22 eV neutrinos
- One of few possible ways to verify 1.9K neutrinos



- 6.4 PeV Glashow resonance: electron neutrino cross section greatly enhanced
- Likely to have astrophysical importance
- *Are there other unforeseen features?*

P.W. GORHAM

WHERE ARE WE?

- MANY SOLAR ν'S DETECTED OVER 25 YEARS
  (HOMESTAKE, GALLEX-GNO, SAGE, KAMIOKA, SUPERK
  SNO, & SOON KAMLAND & BOREXINO, & .....)
  SNU's ~ $\frac{1}{2}$ EXPECTED
  PROBABLY OSCILLATIONS, BUT .... ?

- UNDERGROUND DETECTORS REACH $A_\mu \sim 10^3 m^2$ (x 2π sr)
  [~ 3K EVTS TOTAL (>1 GeV μ)]

  SN 1987A DETECTED IN LMC @ 50 kpc
  ~20 EVENTS → FEW x10^2 PAPERS
  BEST LIMITS ON MANY QUANTITIES, PRINCIPLES, MODELS

  NO SIGN OF XTER HE ν's AS YET (PT. OR DIFF.)
  (POSSIBLE, BUT NOT EXPECTED)

- UNDERWATER & ICE DETECTORS REACH $A_\mu \sim 10^{4-5?} m^2$, BUT SMALL ΔΩ
  [~ 10^2 ↑μ EVENTS ≳ 10 GeV]

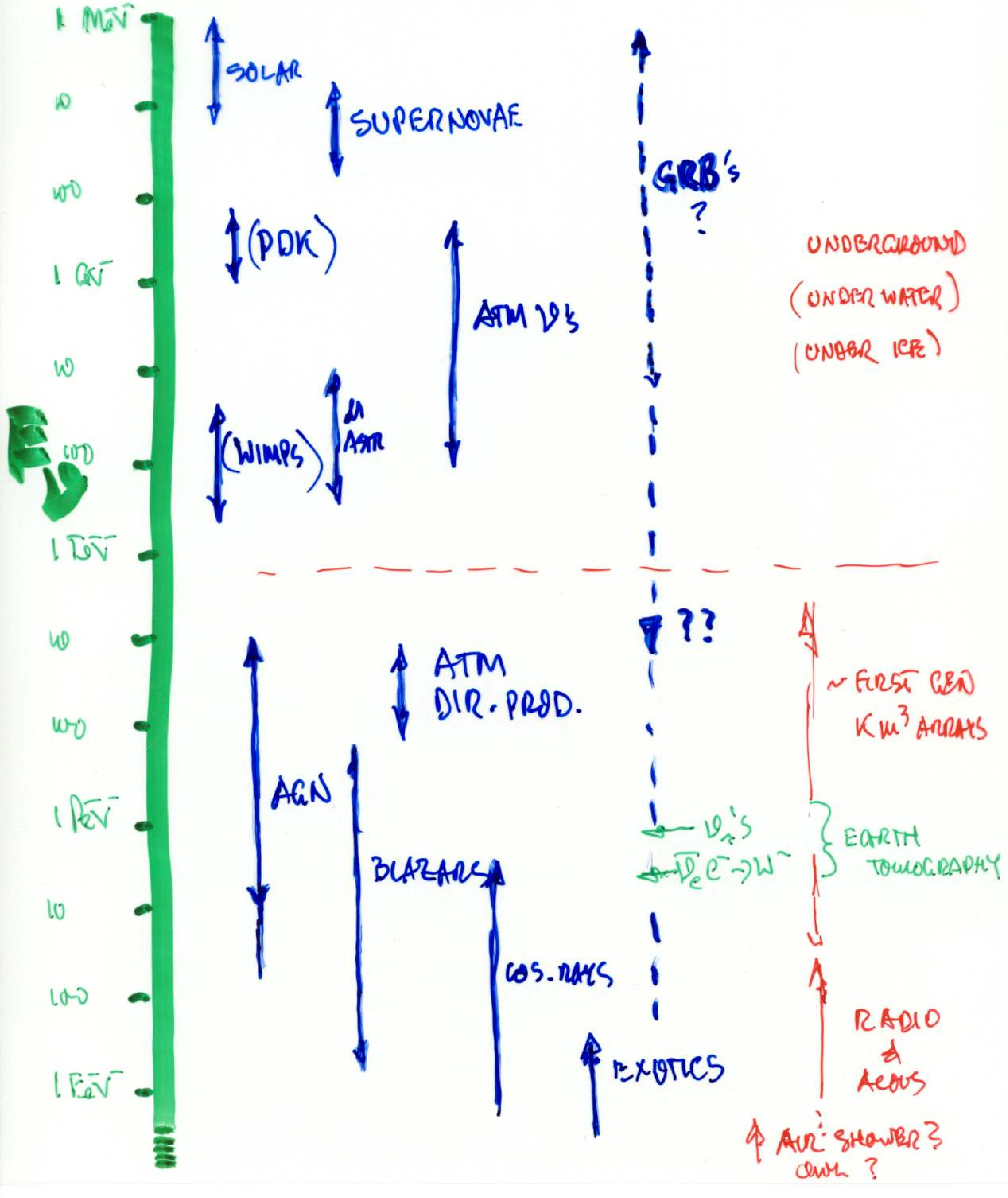
  SOME LIMITS ON UHE ν's, MONOPOLES

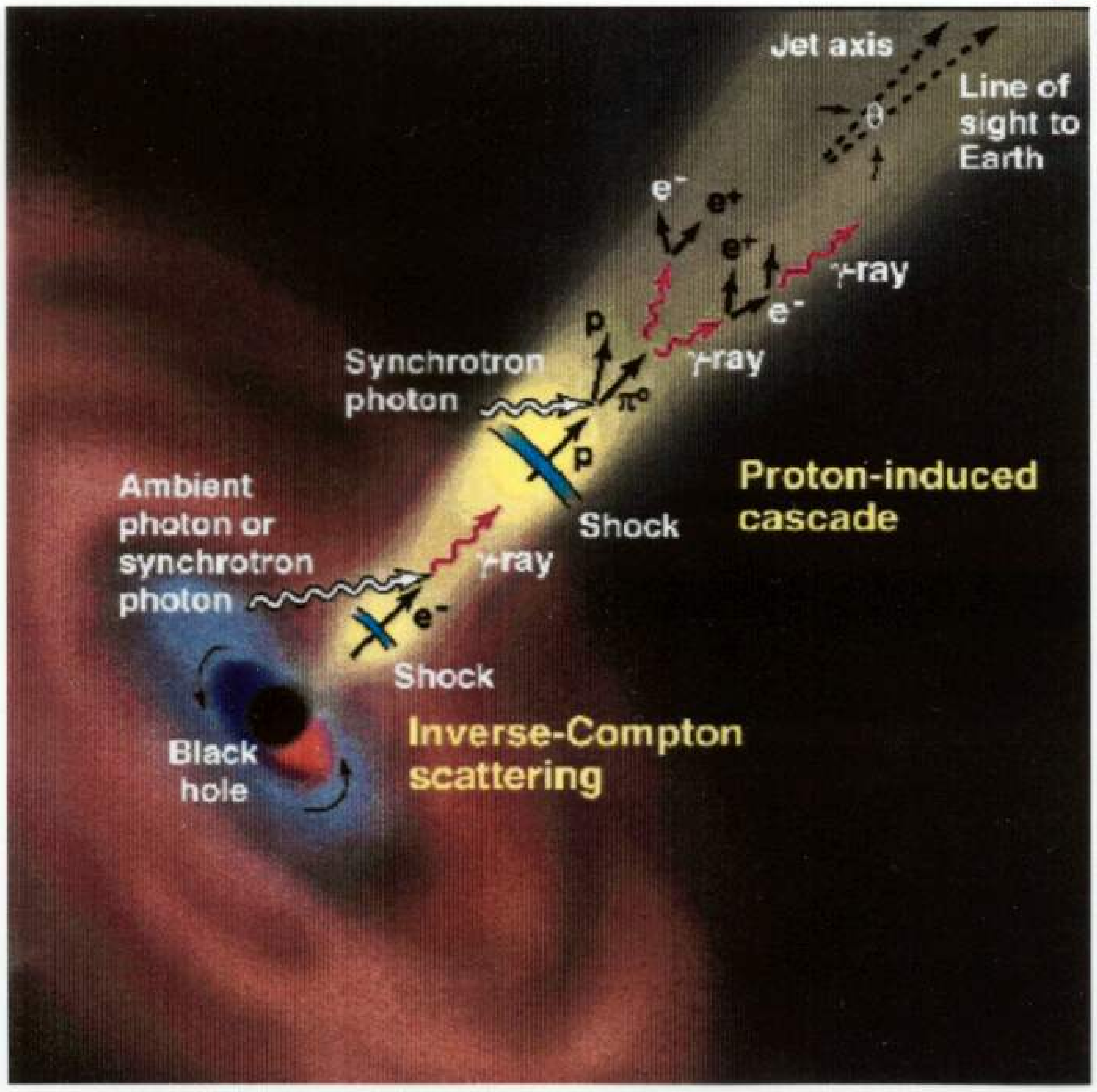
- COMMENT EMPHASIS SHIFT TO HIGHER ENERGIES (WITH TIME)
  (1980's GeV-TeV → PeV - EeV, NOW ZeV)
  - AGN MODEL & PHENOM OBSVD
  - GRB HEγ's
  - GZK ANOMALY

  - ADVANTAGES: MORE DETECTABLE
    BETTER S/(ATM NOISE)
  - (DISADV: LARGER INSTRUMENTS NEEDED)

  → 1 KM^3 REMAINS BENCHMARK GOAL

SCIENCE VS ENERGY





ν's

(Γ NOT >>1)
(UNLIKE GRB's)

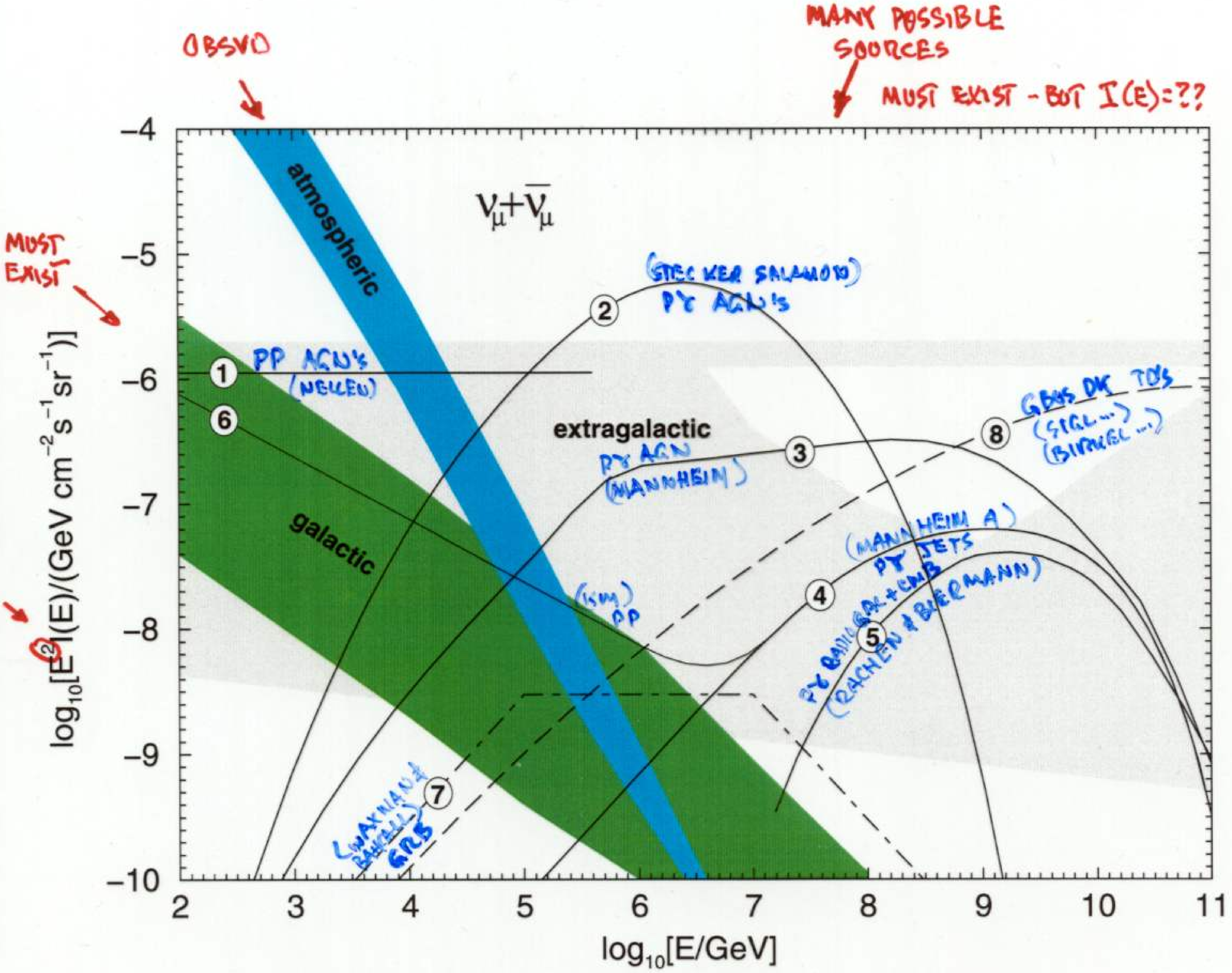
EMERGING PICTURE OF AGN's

- FERMI ACCEL IN SHOCKS
- e's & p's SCATTER ON SYNCH γ's
- EM CASCADES → X & γ RAYS & SSC → 2 BUMPS
- pγ → π's → μ's → ν's
- WHAT IS P LOADING ?

ASTROPHYSICAL NEUTRINOS
DIFFUSE SOURCES

(LEARNED & MANNHEIM 2000)

MANY POSSIBLE SOURCES

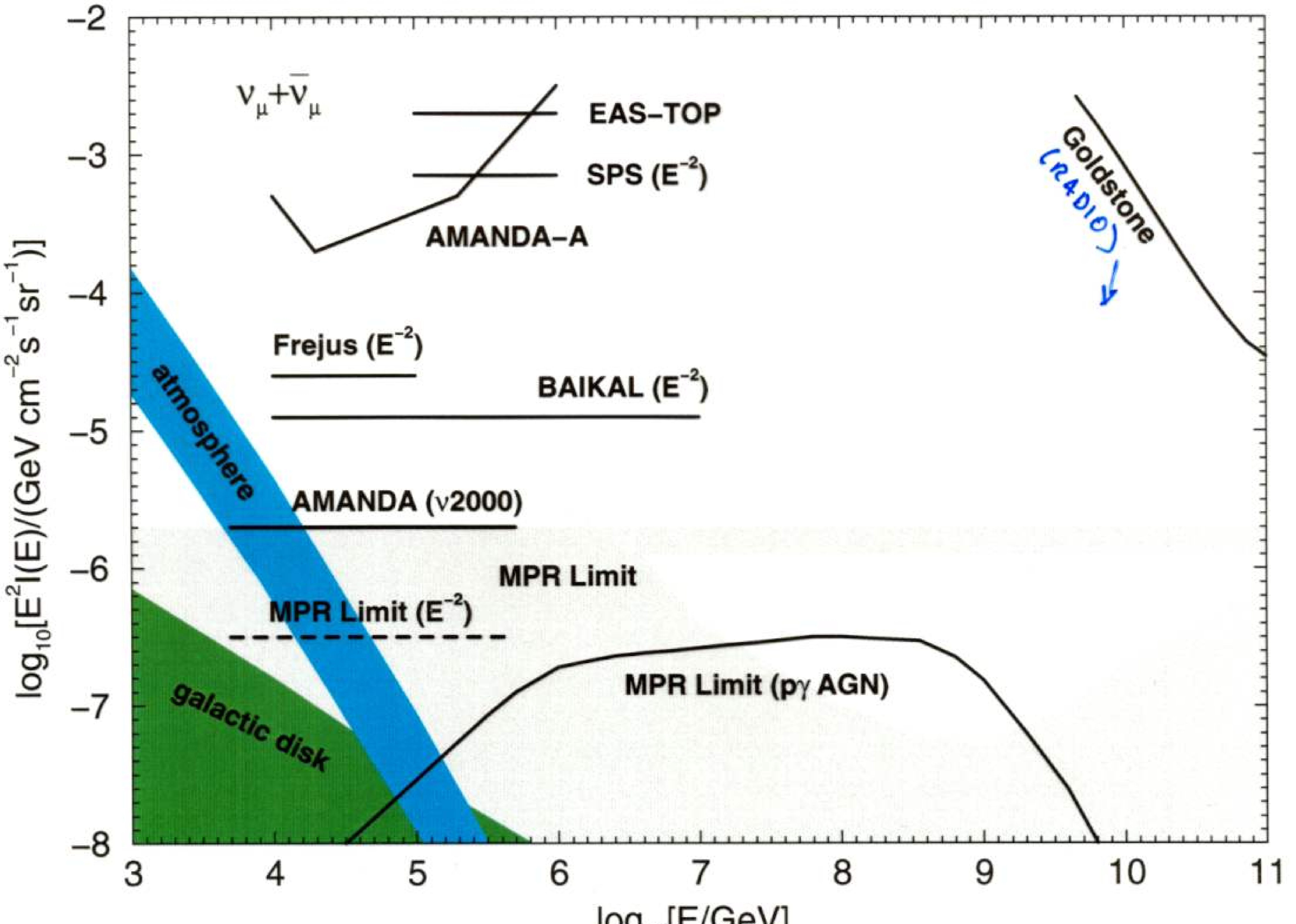


EXPERIMENTAL LIMITS ON ASTROPHYSICAL ν'S

(LEARNED & MANNHEIM 2000)

GETTING CLOSE TO MODELS !

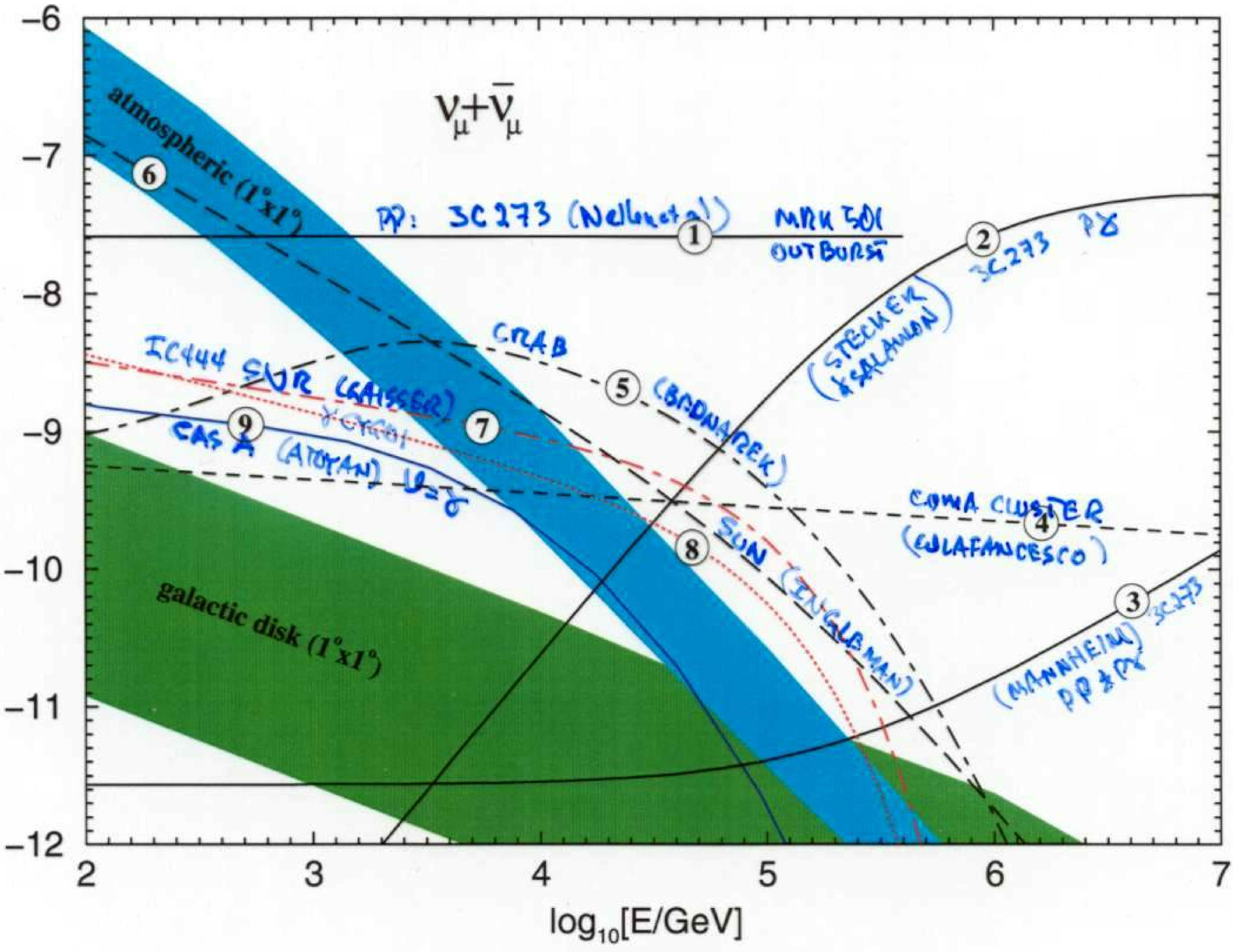
~× 10 - 100



ASTROPHYSICAL NEUTRINO POINT SOURCES

(LEARNED & MANNHEIM 2000)

~EXISTING LIMITS



CANNONBALL MODEL

THE NEW NEW REALIZATION ⇓ ?

- ASSOCIATION OF GRBs & SN
- EVIDENCE OF SN BLOWING ASYMMET..
- MICRO-QUASAR & AGN JET BLOBS

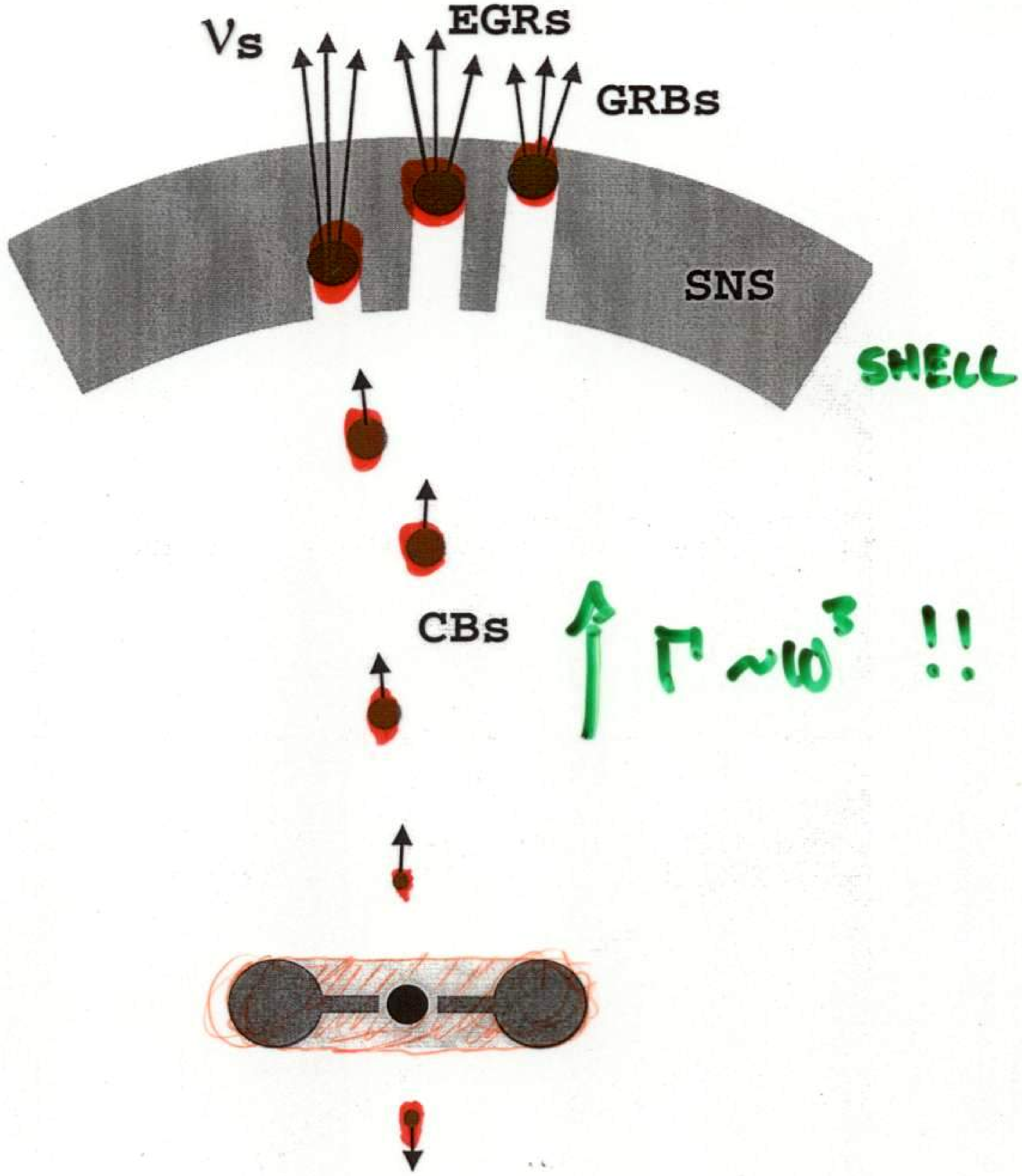


Figure 1: The CB model in a SN environment, not shown to scale. Relativistic CBs are emitted by a compact object accreting matter from a disk and/or torus. They hit a SN shell generating ν's, quasi-thermal radiation (the GRB) and γ-rays from π^0 decay (the EGRs). The latter two exit only from the transparent outer layers of the SN shell.

CANNONBALL MAY NOT BE RIGHT - BUT SOMETHING LIKE IT PROBABLE! (JGL OPINION)

CANNONBALL MODEL OF DeRUJULA & DAR + PLAGA

CANNON BALL MODEL

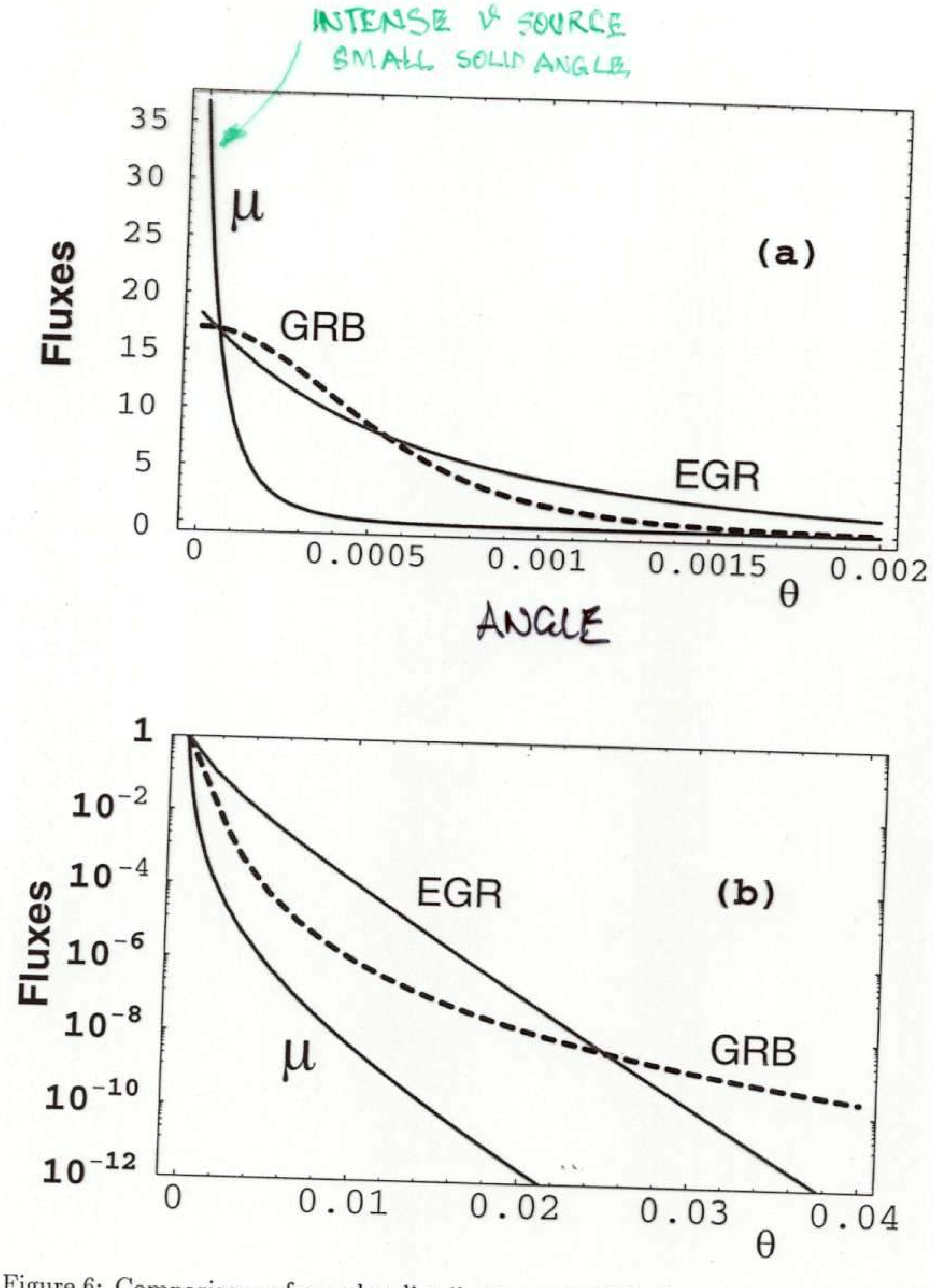


Figure 6: Comparisons of angular distributions of GRB photons, EGR photons and ν-produced muons in water or ice. In the upper graph, the normalizations of the three curves are arbitrary. In the lower one, they are all normalized to unity at $\theta = 0$.

~ 1/DAY GRB "POINTING" AT US (FACT)

~ 1 / 3YR (??) POINTING AT US WITH HEν's

De RUJULA & DAR

TABLE 3 Large underground instruments with high-energy detection capability, 1960s through 2000[a]

Detector, location	Dates	μ Area (m^2)	Dir. sense	Technique	Primary purpose
* KGF, South India	1965–70	10	N	LS + FT	obs νs
* CWI, South Africa	1965–70	110	N	LS + FT + Fe	obs νs
* Silver King, Utah	1966–70	30	Y	WC + Ctrs + Fe	obs νs
KGF, South India	1978–88	20	N	ST	PDK
* Baksan, Caucasus	1980–P	250	Y	LS tanks	νs
IMB, Ohio	1981–90	400	Y	WC	PDK
HPW, Utah	1982–85	100	Y	WC	PDK
Kamioka, Japan	1982–94	120	Y	WC	PDK
NUSEX, Mt. Blanc	1983–88	10	N	ST + Fe	PDK
Fréjus, France	1985–88	90	N	ST + Fe	PDK
Soudan I, Minn.	1985–90	10	N	ST + Concrete	PDK
Soudan II, Minn.	1990–P	100	N	DT + Fe	PDK
MACRO, Italy	1995–(00)	800	Y	LS + ST +	monopoles
LVD, Italy	1996–?	500	Y	LS tanks + ST	SN νs
Super-Kamiokande	1996–(10)	740	Y	WC	PDK
SNO, Canada	1999–?	300	Y	D_2O WC	solar νs
Borexino, Italy	(2002–10)	<100	Y	LS	solar νs
KamLAND, Japan	(2002–12)	100	Y	LS	reactor νs

[a]P, present; Dir., direction; WC, water Cherenkov; ST, streamer tubes; LS, liquid scintillator; PS, plastic scintillator; FT, flash tubes.

* ONLY ONES BUILT SPECIFICALLY FOR ν ASTRON
(PACE SOLAR νs)

LEARNED & MANNHEIM 2000

VHE ν_τ DETECTION

PeV − EeV

STUDY

- SOURCES
- OSCILLATIONS
- σ_ν

ν_τ's OF > PeV PENETRATE THE EARTH MORE EFFECTIVELY THAN ν_e & ν_μ

FIGURES

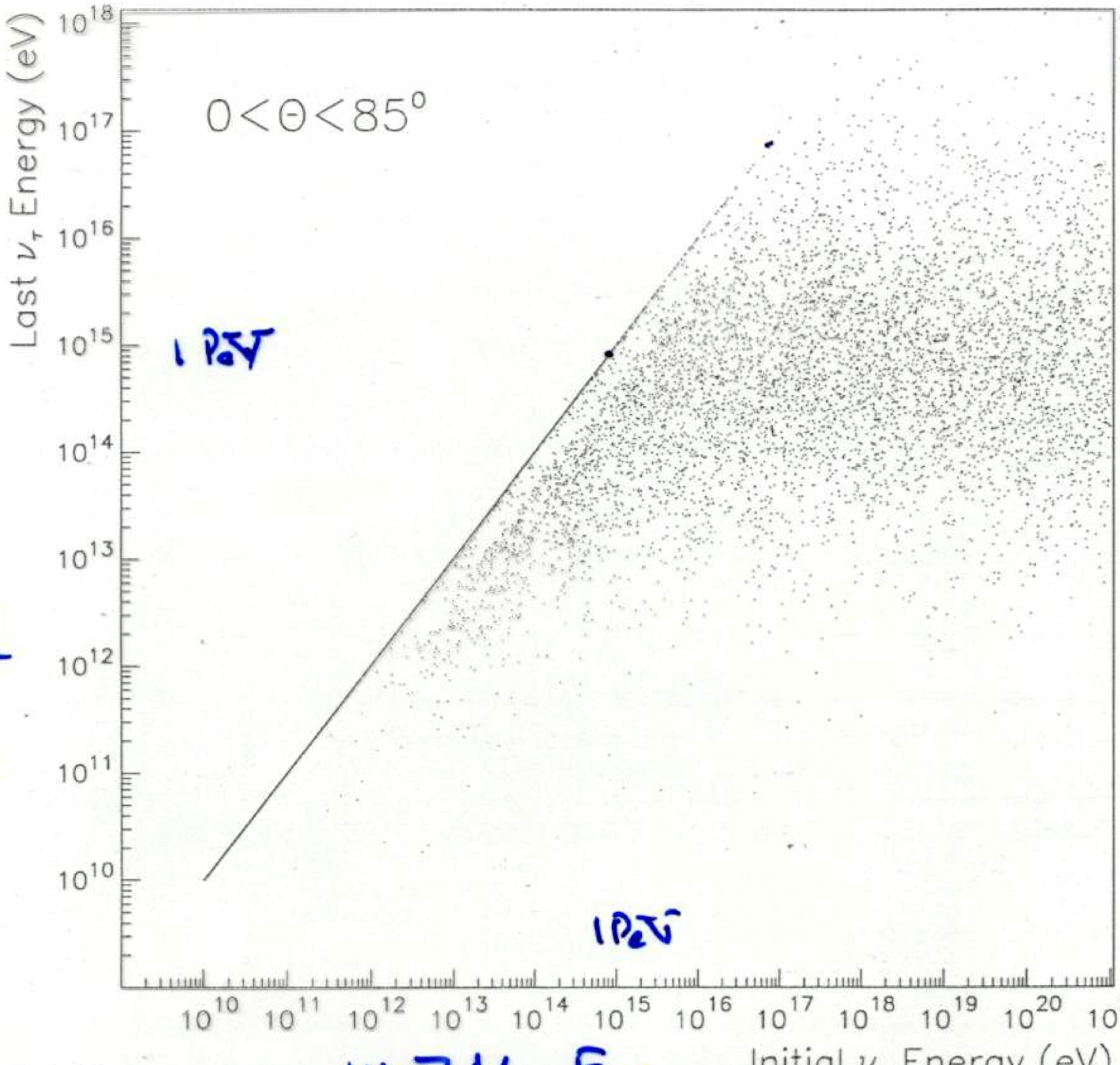


FIG. 1. Plot of the energy of the final ν_τ in the cascade through the Earth versus the energy of the initial ν_τ. The straight line corresponds to neutrinos that do not interact. Angles larger than 85^O with respect to the nadir are excluded because the ν_τ have not yet been moderated to 10^{15} eV. Note that an especially hard ν_τ input spectrum was chosen for this figure to illustrate the effect.

$\nu_\tau \to \tau \to \nu_\tau \to \ldots$ CASCADES DOWN ⇒ "PILE UP"

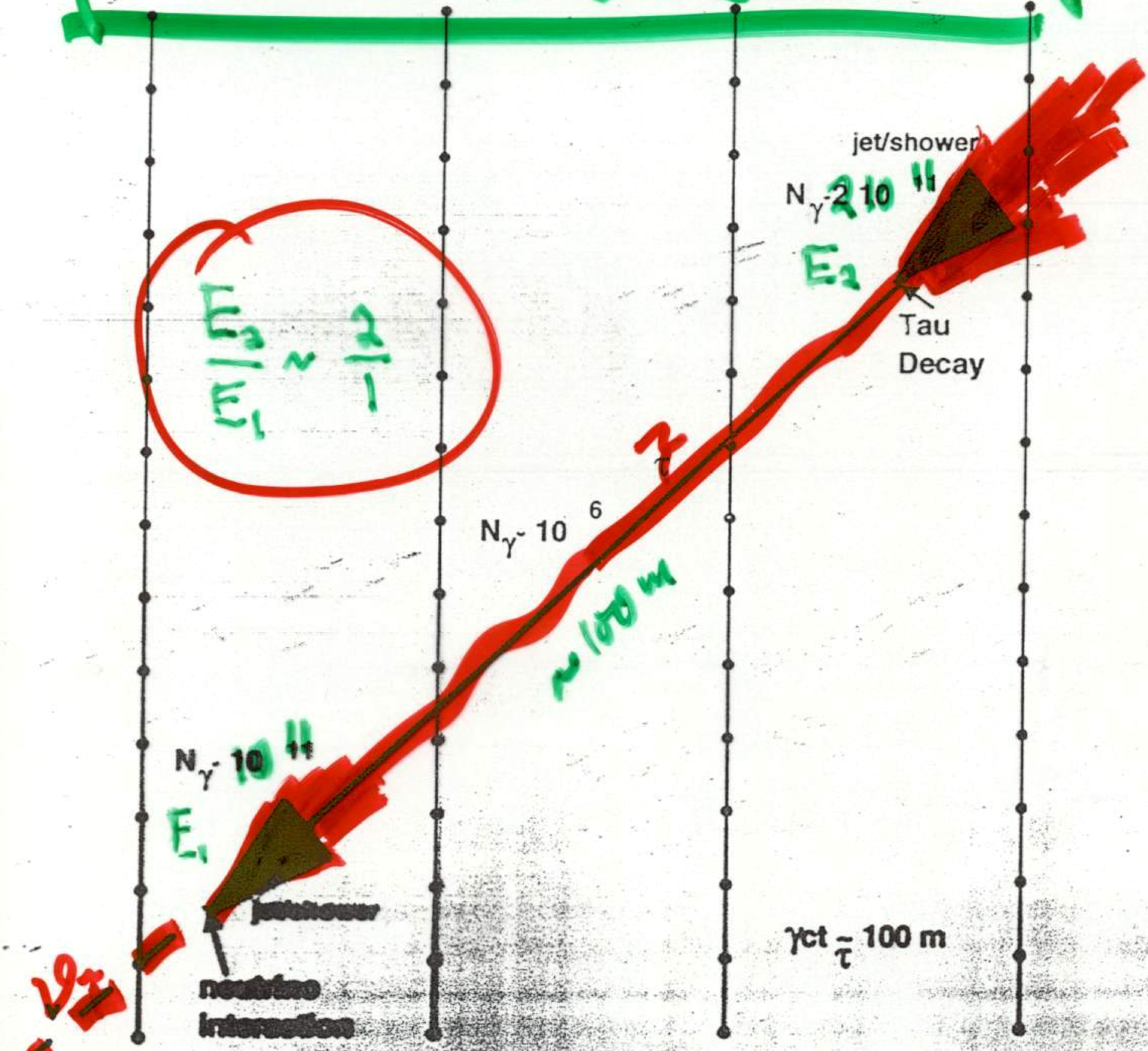
WHEREAS $\nu_e \to e \to$ SHWR } ν_e & ν_μ DIE OFF

$\nu_\mu \to \mu \to dE/dx$

HALZEN & SALTZBERG 1998

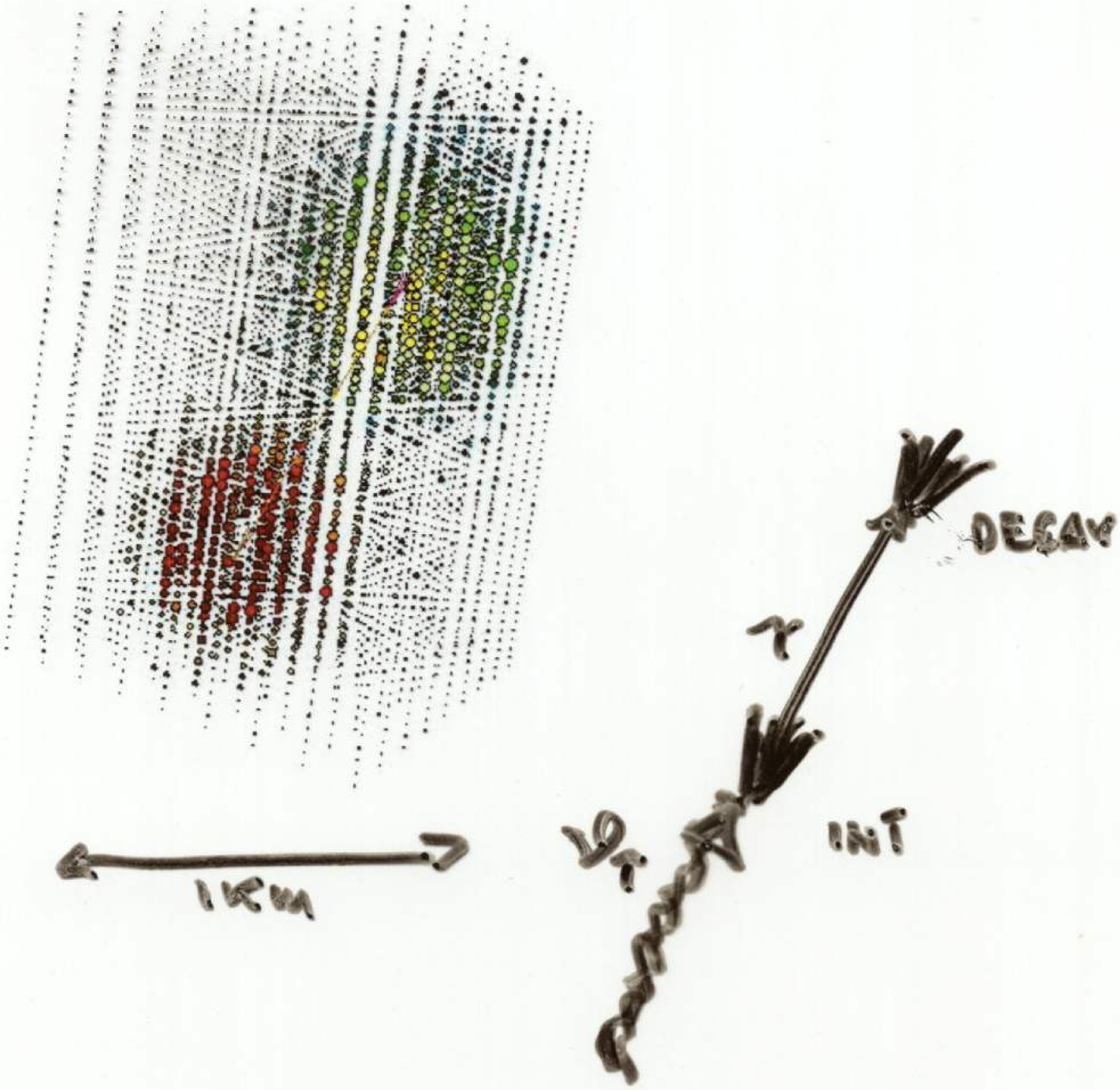
UNDERICE, UNDERWATER

τ-neutrino Double-Bang Signature



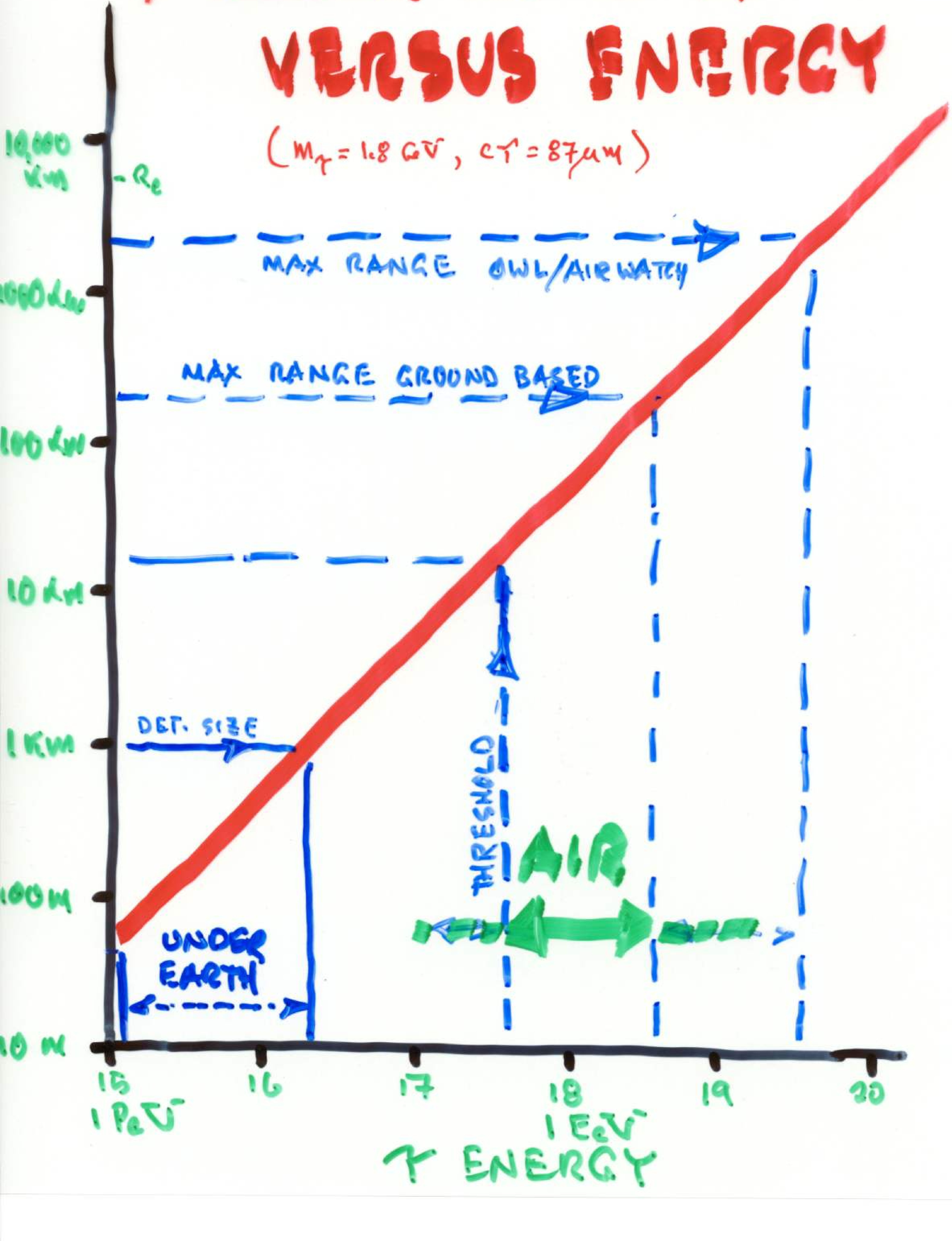
Learned & Pakvasa 94

VERY SMALL BACKGROUND FOR THIS SIGNATURE ($\ll 10^{-?}$)



DOUBLE BANG EVENT IN ICE CUBE

τ DECAY LENGTH VERSUS ENERGY



NEUTRINO COLOR TRIANGLE

EXPECT $\Phi_{\nu_\tau} \approx 0$ FROM MOST LIKELY SOURCES (AGN Pγ, BEAM DUMP)

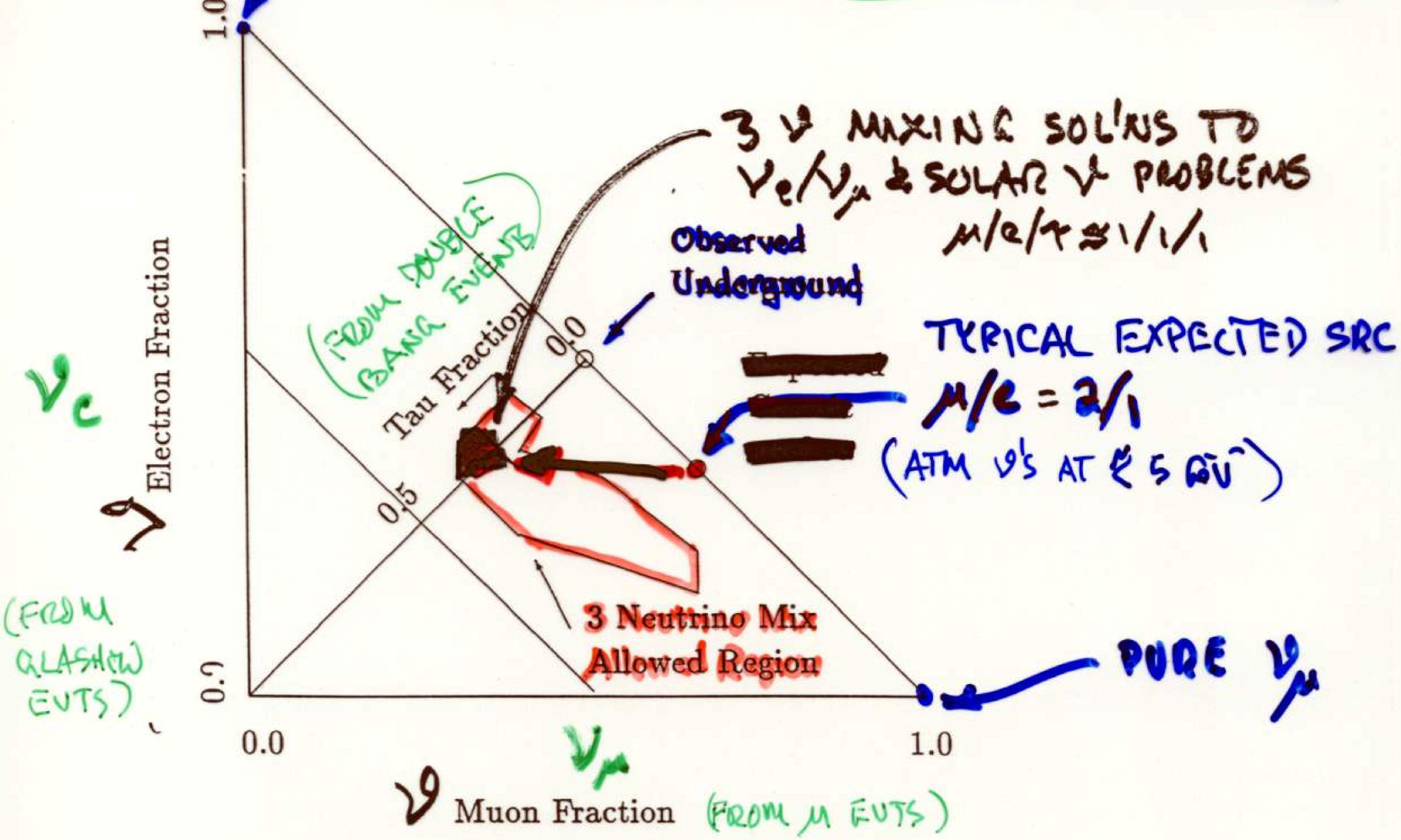
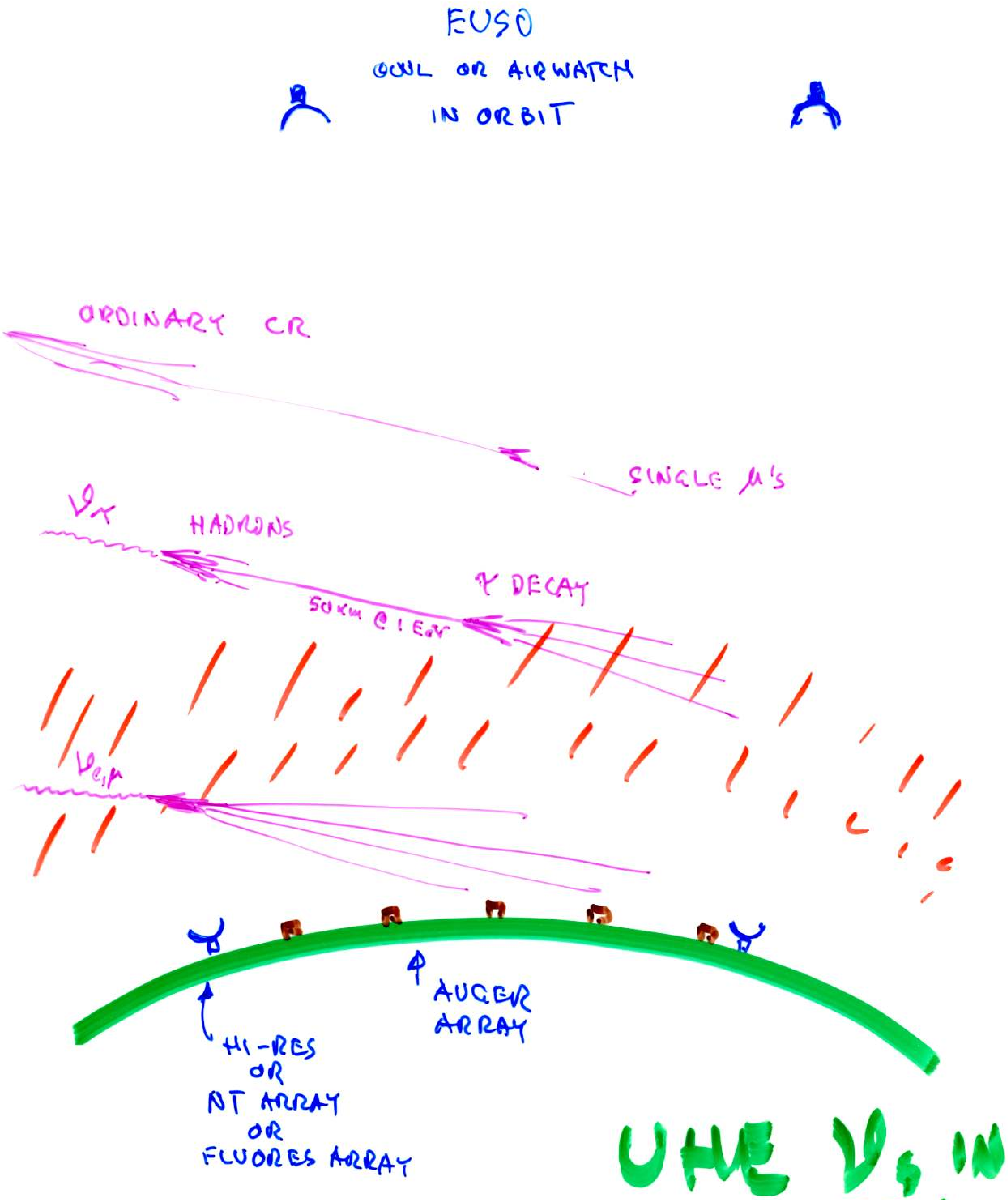


Figure 2.7: The fraction of muon neutrinos versus electron neutrinos, allowing for a fraction of tau neutrinos. The expected initial flux is at 0.66, 0.33. Full and equal mixing would result in 0.33, 0.33 (and 0.33 taus). The points represent calculations of results for various solutions to the solar and atmospheric neutrino problems.

BUT IF $\delta m^2 \gtrsim 10^{-16}\,eV^2$ & $\sin^2 2\theta \gtrsim 0.01$

⇒ LOTS OF ν_τ's



UHE νs IN EAS DET's

BUT..... RATES $\lesssim$ 1/YR ?

ν_τ RATES? IN ATMOSPHERE

- A VERY LARGE
  ~ 1000 km^2
- $\Delta\Omega$ NOT SO GOOD
  ~ .1 sr

→ THRESHOLD ENERGY &
SKY COVERAGE DEPEND UPON
INSTRUMENT

ROUGH ESTIMATES ~ 1/YR

τ EVENT SIGNATURE
VERY CLEAN

HE ν PROJECTS IN MOTION

MANY!

2001

- H_2O CHERENKOV ≳ TeV
  - AMANDA → ICE CUBE
  - BAIKAL
  - ANTARES
  - NEMO
  - NESTOR
  - (NEW PDK ? $A_\mu \sim 10^4\ m^2$ HYPER-K, TITANIC, AQUA-RICH, UNO ??)
- EAS FLUOR & CTRS (EAS PRIMARY, BUT ALSO ~HORIZ ν's) ≳ EeV
  - HIRES
  - AUGER
  - TELESCOPE ARRAY
  - OWL / AIRWATCH / EUSO
- RADIO FROM SHWRS ≳ EeV
  - RICE
  - MOON (& OTHER)
  - FORTÉ SATELLITE → RITA (ISS)?
- ACOUSTIC DET OF SHE ν's IN OCEAN ≳ EeV
  - SADCO (PACIFIC & MED)
  - STANFORD (ATLANTIC)
  - HAWAII (PACIFIC)

ν ASTRON. TECHN.

TABLE 1 Techniques proposed for large neutrino detectors

Radiation	Medium	Detect muon	E_ν Threshold	Attenuation length	Spectral region
Cherenkov	Filtered H_2O	Y	GeV	100 m	300–500 nm
	Natural lake	Y	GeV	~20 m	400–500 nm
	Deep ocean	Y	GeV	~40 m	350–500 nm
	Polar ice	Y	GeV	~20 m	300–500 nm
Cherenkov radio	Polar ice	N	>5 PeV	~1 km	0.1–1 GHz
Cherenkov radio	Moon	N	>100 EeV		1–2 GHz
Acoustic	Water	N	>1 PeV	~5 km	10–20 kHz
	Ice	N	>PeV	?	10–30 kHz
	Salt	N	>PeV	?	10–50 kHz
EAS* particles	Air	N	10 PeV	1 km	100 MeV
N_2 fluorescence	Air	N	EeV	10 km	337 nm
EAS radar	Air	N	>EeV	(~100 km)	30–100 MHz

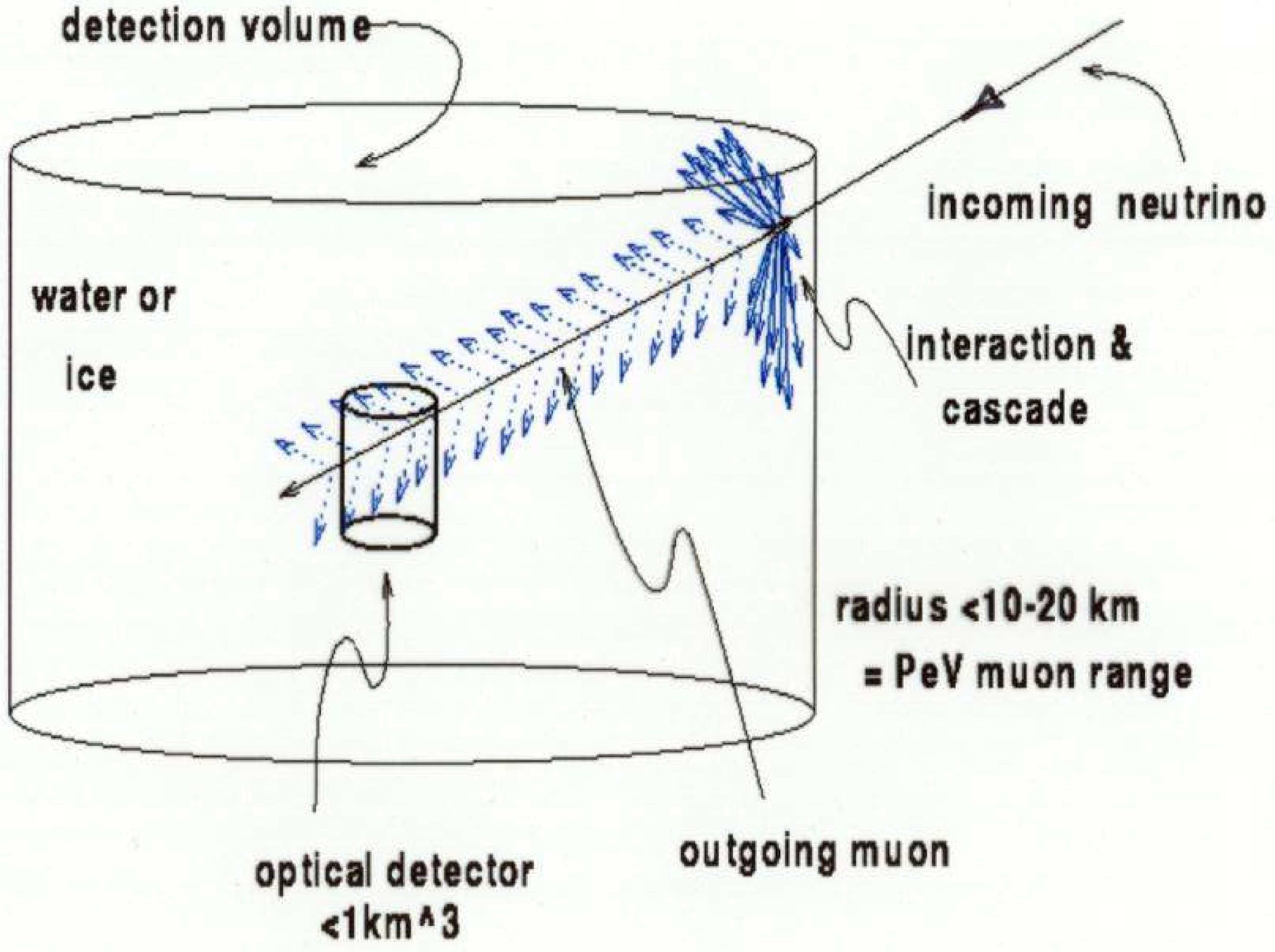
* EAS, extensive air shower.

MOSTLY CHERENKOV GeV – PeV

ALSO N_2 FLUORESCENCE EeV - ZeV

AND THERMO-ACOUSTIC EeV - ZeV

PeV to ZeV Neutrino Cherenkov Telescopes: Muon rangers vs. cascade detectors



- Muon ranges in water & ice are up to ~20 km in TeV to PeV
  => *Relatively small target volume sees a large neutrino volume*
- Examples: AMANDA, ANTARES, NESTOR, Baikal
- **Limitations:**
  - Mu range limits volume for EeV neutrinos
  - Poor energy resolution

- **Cascade Detectors:** Look for large burst of CR from primary cascade
- Requires very clear media to allow for coarse sensor spacing
- "Calorimeter" approach
- Can use external sensors for >EeV

Need large volumes of transparent material!

P.W. GORHAM

COMPARE OPTICS IN H_2O

TABLE 2 Comparison of optical properties in various venues as related to optical Cherenkov detection in H_2O [see explanation in text (201)]

LESS AT ANTARES 2KM SITE?

Venue	Ice (S. POLE)	Ocean (DEEP)	Lake (BAIKAL)
Absorption length (m)	90–100	50–60	20–30
Scattering length (m)	3–5	∼200	18
$\langle\cos(\theta_{scatt.})\rangle$	0.88	0.88	0.95
Effective scattering length (m)	25–30	∼2000	380
Effective attenuation length (m)	∼25	40–50	∼20
Distance to collect 1 photoelectron from a 100-TeV source (m)	95	200	105

- ICE ALSO HAS SCATTERING VARYING WITH DEPTH MAKES ANALYSIS DIFFICULT, BUT POSSIBLE
- OCEANS HAVE K^{40} ⇒ SIGNIFICANT PMT NOISE COSTS ~ 2-4 × A_{PMT} RE ICE
- BAIKAL HAS SEASONAL VARIATIONS IN OPTICS & HAS OPTICAL BKGD SIM TO OCEAN

PHYSICS → OCEANS

PRACTICALITY → SP & BAIKAL OPERATING!

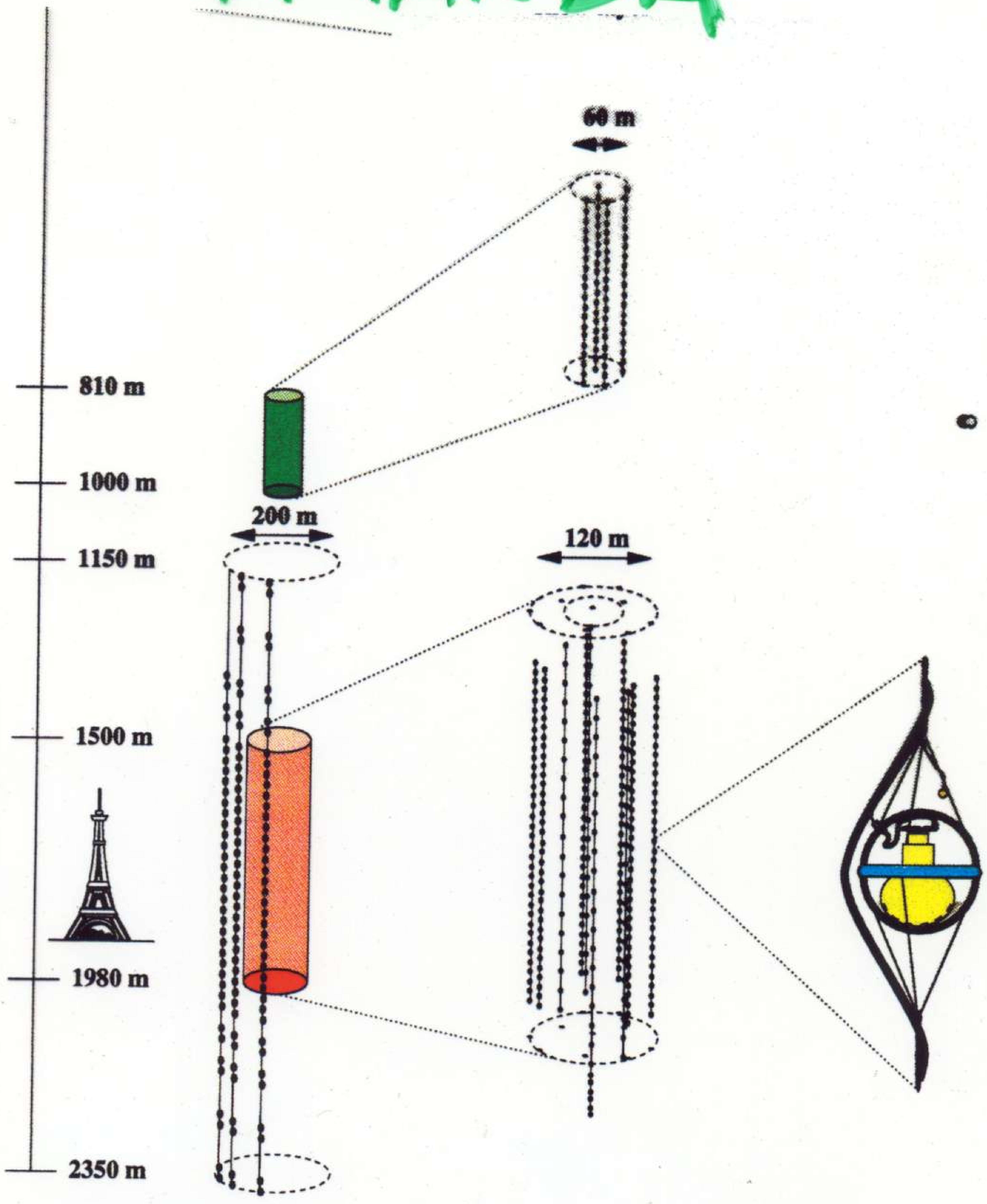
TABLE 4 Second-generation initiatives in high-energy neutrino astronomy[a]

Detector	Location	Status	μ Area (10^3 m^2)	Depth (mwe)	Technique	Threshold (GeV)
(DUMAND II	Hawaii	1992–95	20	4760	WC	20)
Baikal NT-200	Siberia	1996–N	3	1000	WC	10
AMANDA II	S. Pole	1996–P	30	2000	WC in ice	20
NESTOR	Greece	T/C	100	3500	WC	1
SADCO	Greece	T	1000	3500	Acoust.	$>10^6$
RICE	S. Pole	T/C	1000	1000	μ-wave	$\sim10^6$
ANTARES	France	T/C	30	2000	WC	?
NEMO	Italy	P	?	?	WC	?
RAMAND	US	T	?	Moon	μ-wave	10^{11}
ICECUBE	S. Pole	P	1000	2000	WC in ice	>100
KM3	Ocean	P	1000	>4000	WC	>100?

[a]N, now operating; T, testing and development; C, construction; P, proposed or under discussion; WC, water Cherenkov; μ-wave, microwave detection; Acoust., acoustic wave detection.

& MORE !

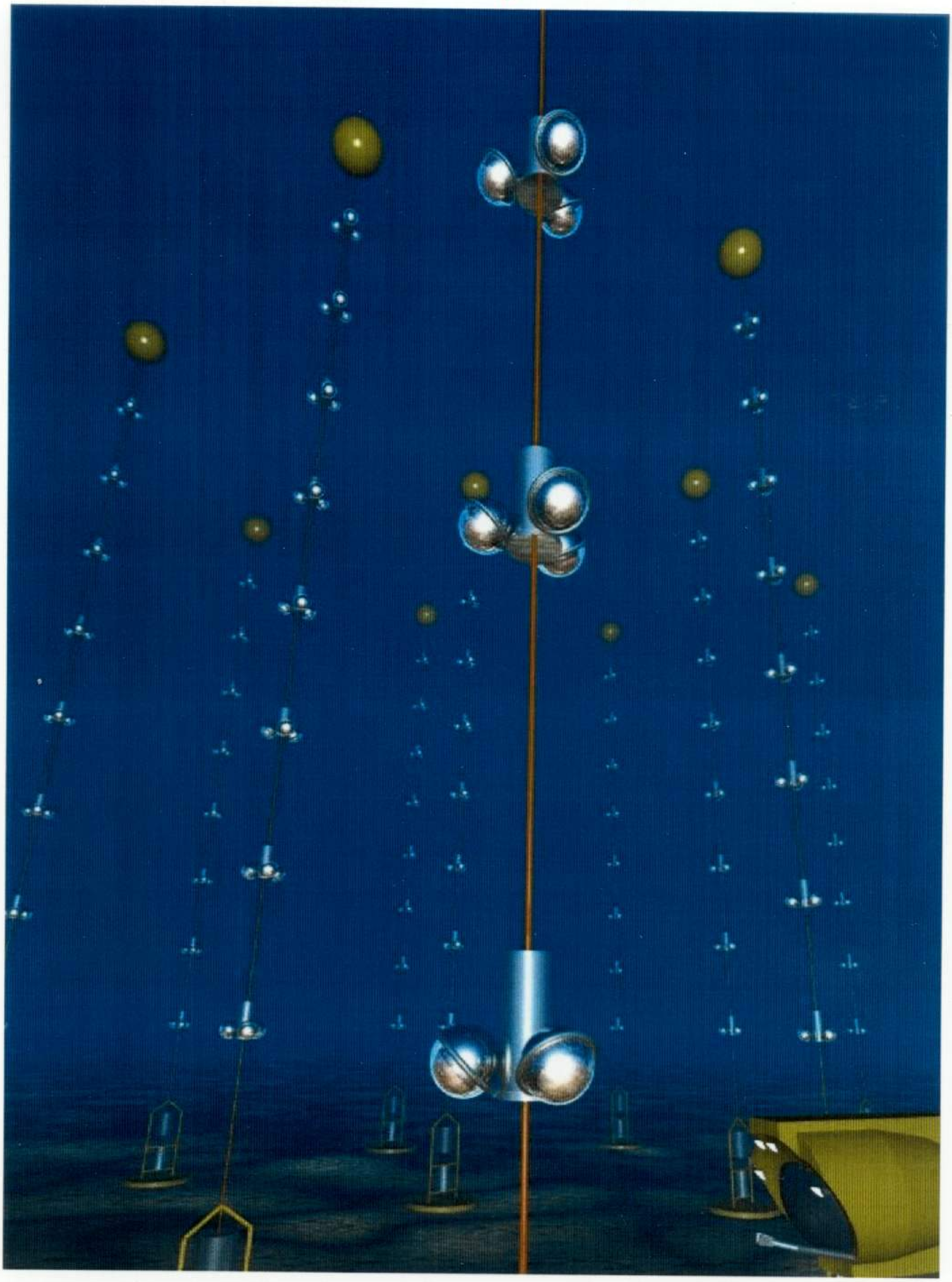
AMANDA



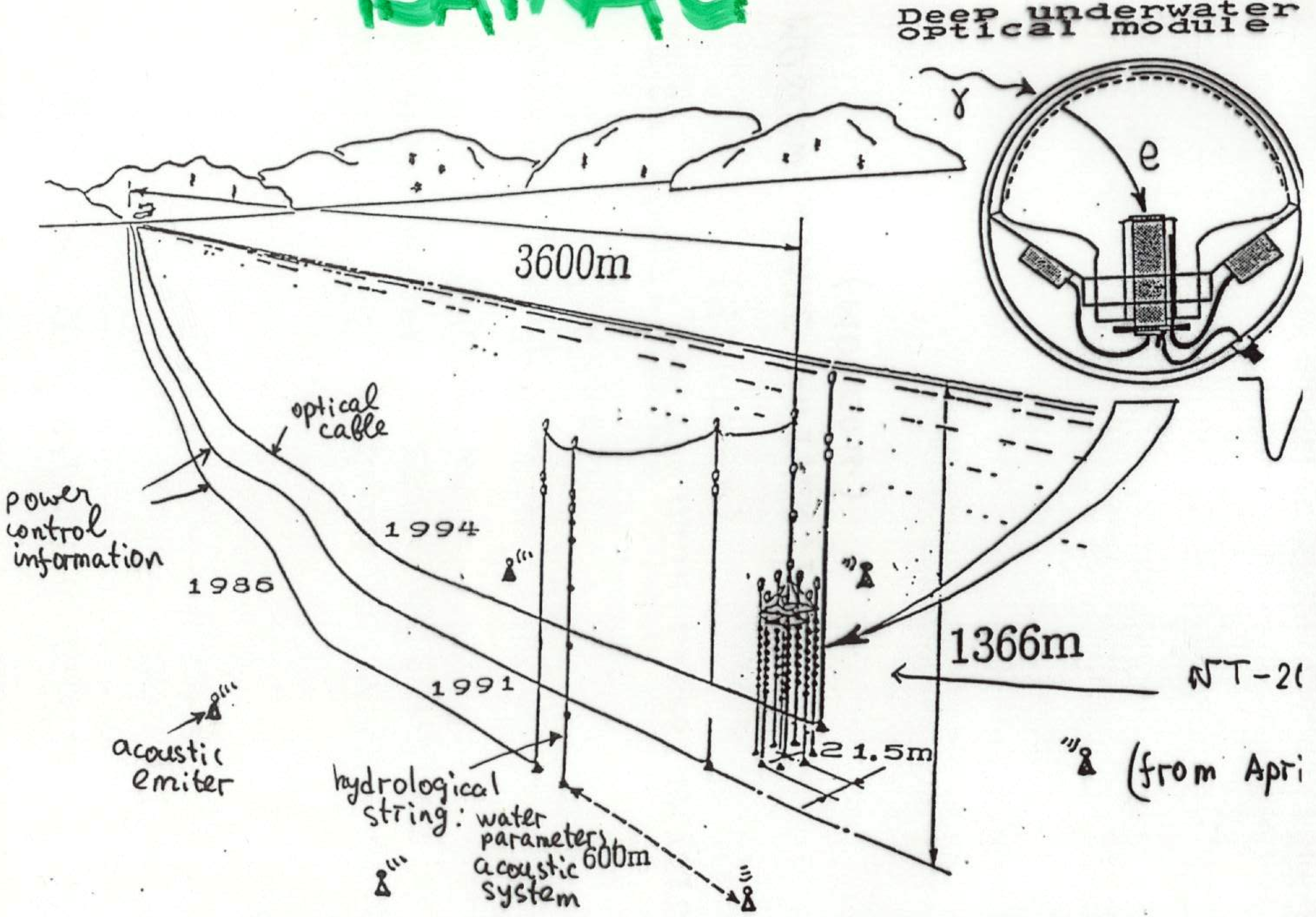
AMANDA as of 1998

zoomed in on

ANTARES



BAIKAL


Deep underwater
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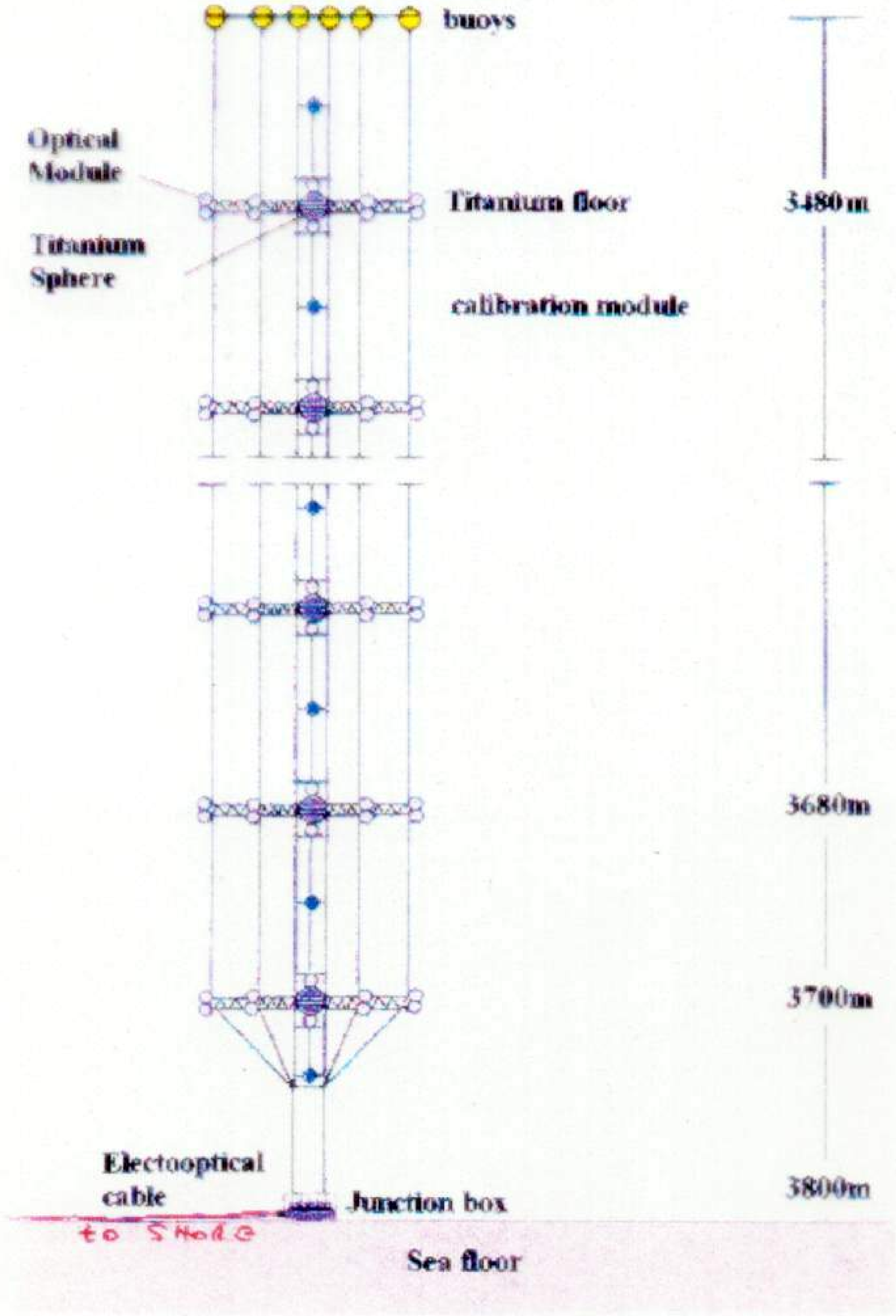
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Optical
Module
Titanium floor
3480 m
Titanium
Sphere
calibration module
3680m
3700m
Electooptical
cable
Junction box
3800m
to SHORE
Sea floor

NESTOR

COMMENT:

IT SEEMS A BIT SILLY THAT THERE ARE 3 HE ν TELESCOPES BEING DEVELOPED FOR DEPLOYMENT IN THE MEDITERRANEAN SEA.

ANTARES + NEMO + NESTOR WOULD BE MUCH BETTER THAN 3 SEPARATE PROJECTS.

WHO CAN MAKE A MARRIAGE?

WHAT IS THE DOMAIN OF [ACOUSTIC & RADIO] ν DET.?

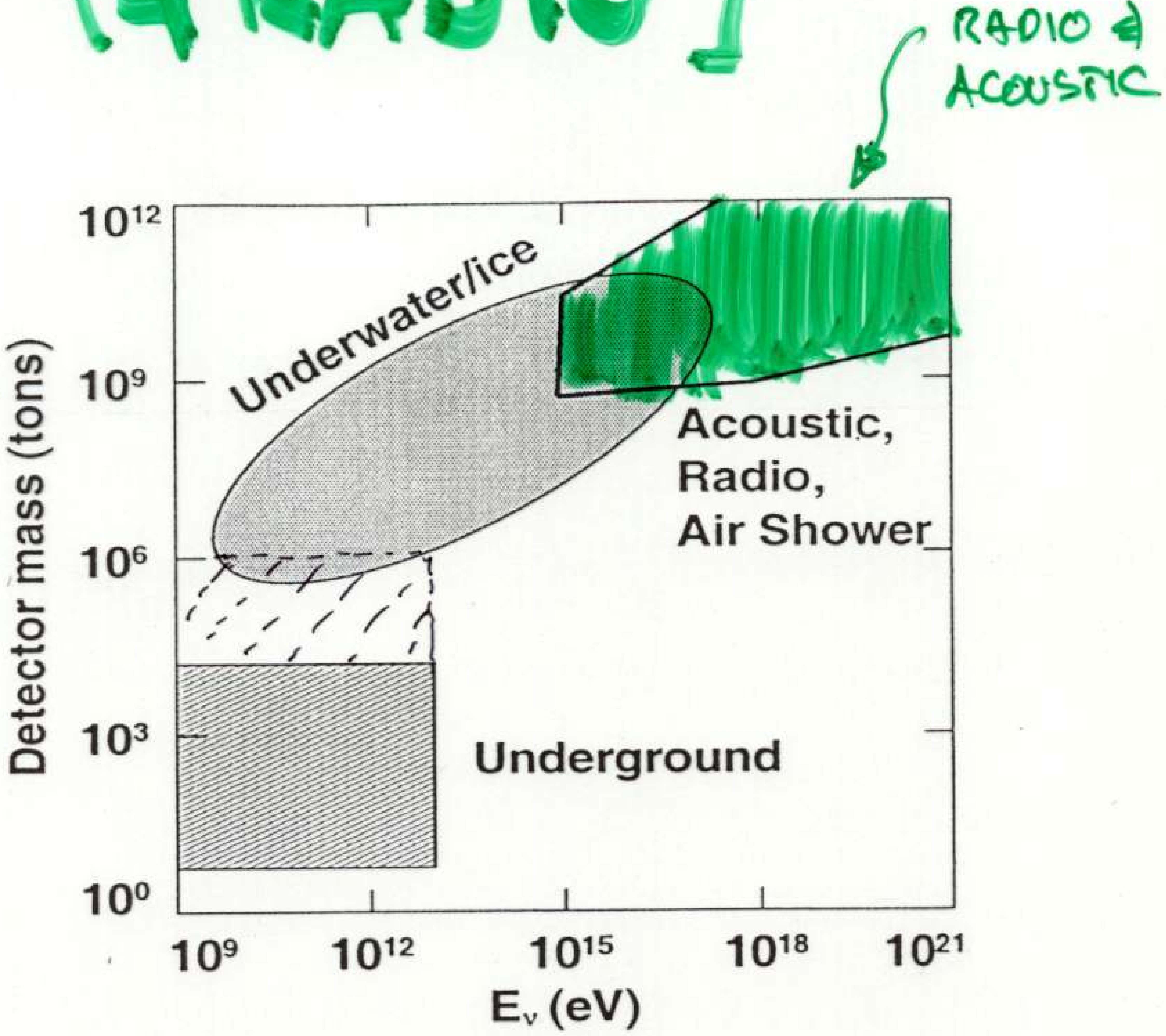


Figure 1. Domains of different detection techniques.

(FROM SPIERING @ NU2000)

$E_\nu \gtrsim 10^{16}$ eV

$V \gg 1\ km^3$

AS A RESULT OF ① THE $e^{-\frac{\omega^2}{\omega_0^2}}$ ATTENUATION

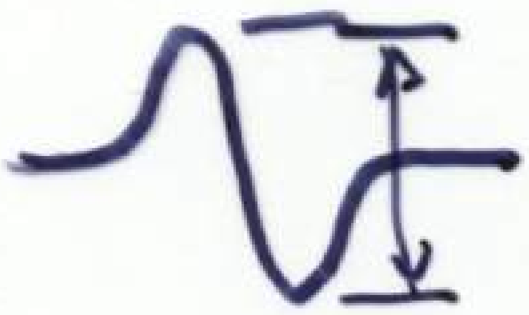
AND ② THE BIPOLAR PULSE

THE DISTANCE DEPENDANCE IS POWER AT ALL DISTANCES

eg $P_m(r) \propto \frac{1}{\sqrt{r}} \rightarrow \frac{1}{r} \rightarrow \frac{1}{r^2}$ FOR CASCADE

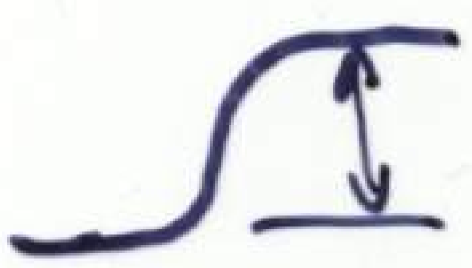
NEAR FAR ATTEN

ATTEN

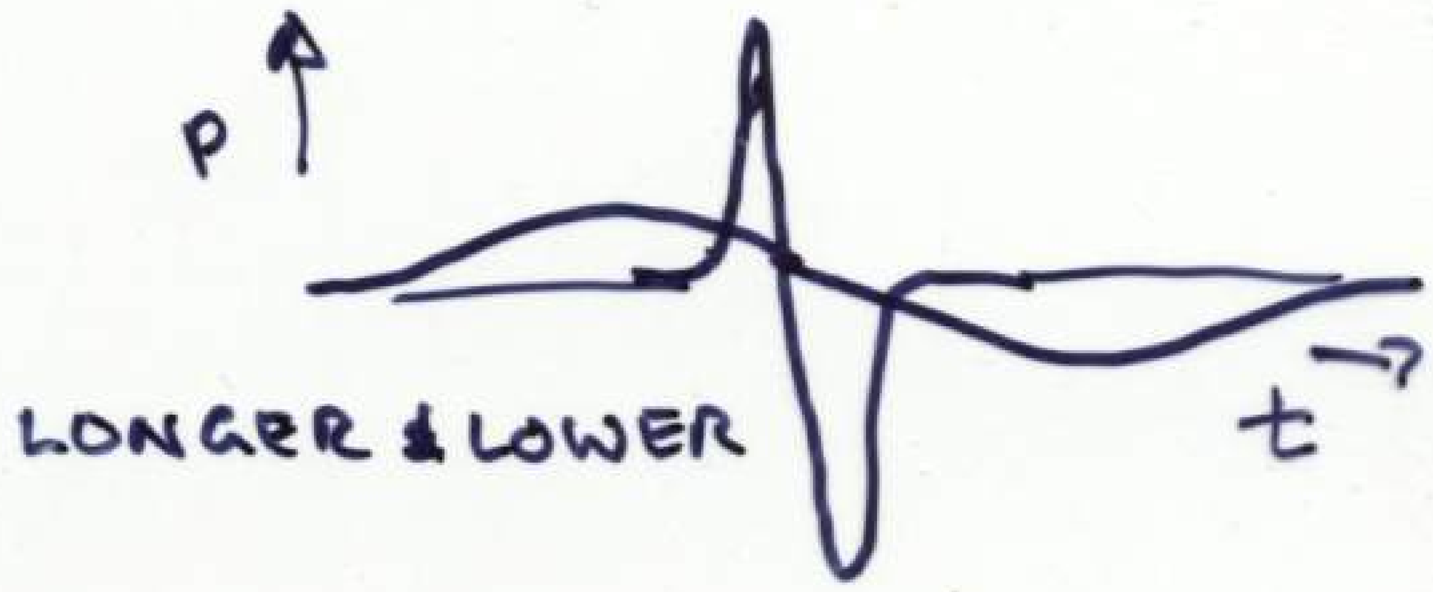


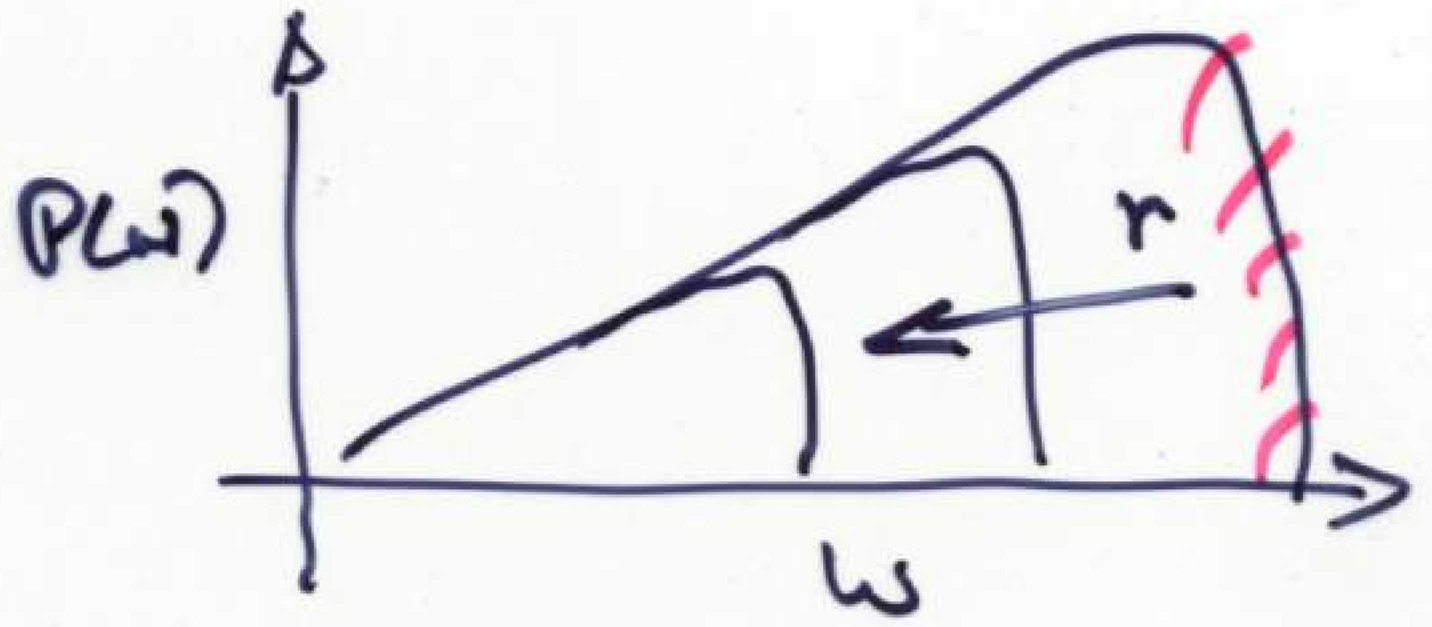
$\propto \frac{1}{r^2}$

$\propto \frac{1}{r}$



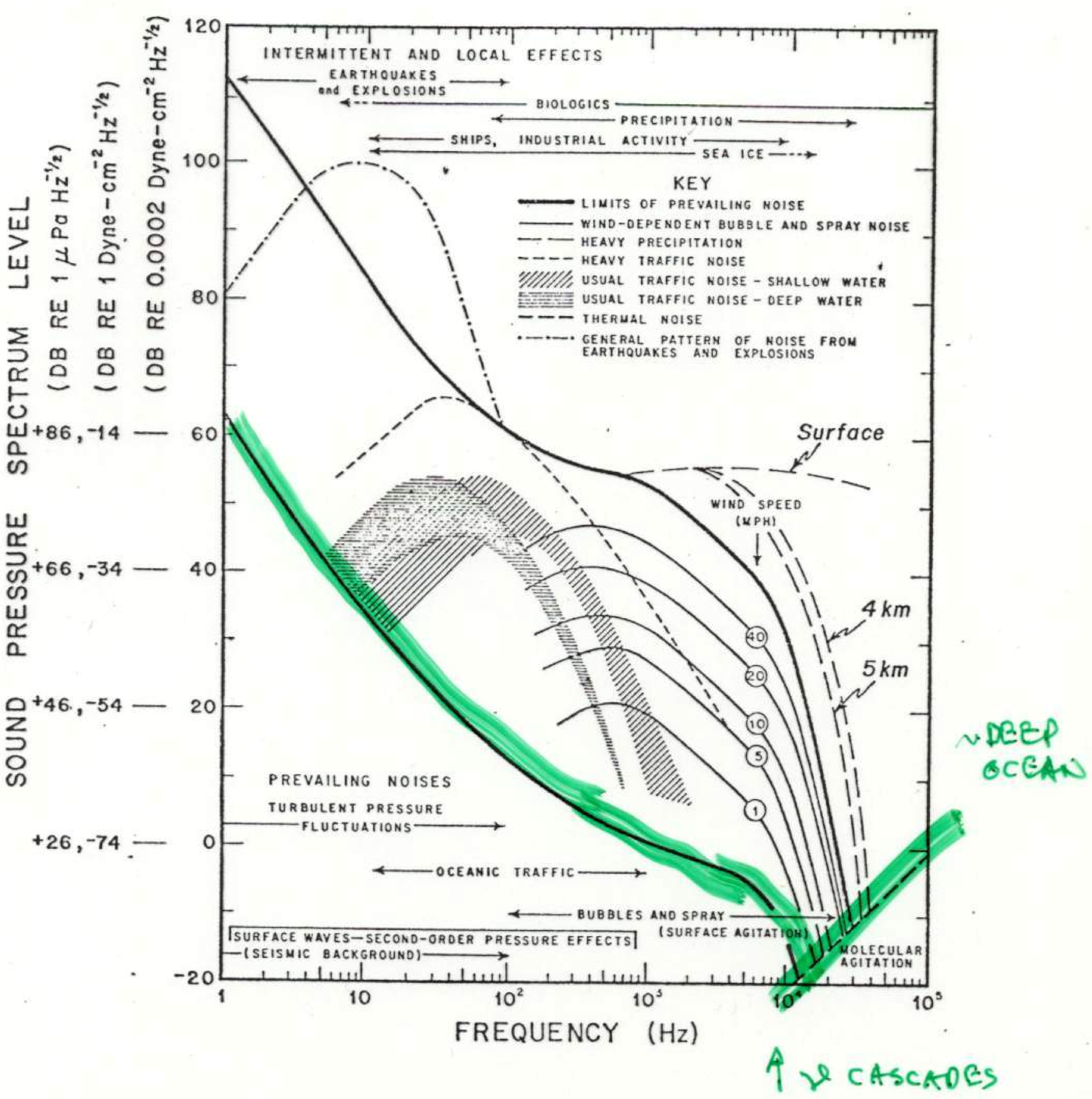
$\propto$ CONST





[NAIVELY ONE EXPECTS EXPONENTIAL DEPENDANCE IN ATTENUATION ZONE]

OCEAN NOISE



Surface-generated Sound Pressure at 4 & 5 km depth.

Adapted from near-surface curves of Wenz, JASA 34, p1936, (1962)

Apr '77

THE VELOCITY OF SOUND DEPENDS UPON DEPTH IN THE OCEAN

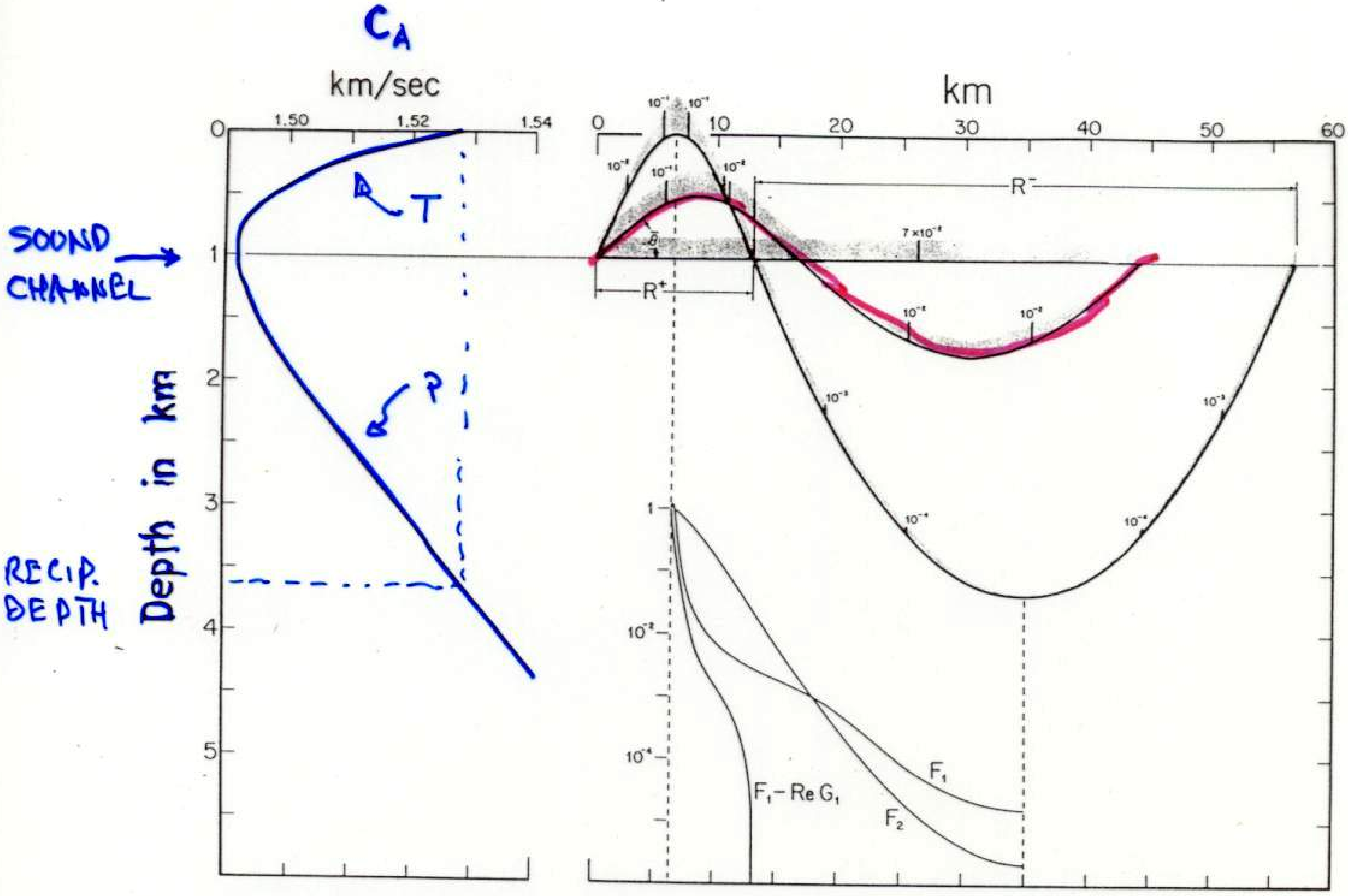


FIG. 1. Canonical sound channel (left) and the corresponding rays for $\bar{\theta} = 12.7°$ (surface limited), 5.2°, and 0° (axial ray). The contribution to F_1 from various parts along the three ray paths is indicated by the vertical extent of the shaded band (plotted logarithmically). F_1 is plotted separately at the bottom of the figure for the surface limited ray, together with F_2 and $F_1 - \text{Re}G_1$, thus indicating the relative apex contributions toward mean-square phase, rate of phase, and intensity. ($F_1 - \text{Re}G_1$ applies only to a source at $x = 0$ of a receiver at R^+.)

- SOUND PROPOGATION OVER $\gtrsim$ FEW KM IS "VERY INTERESTING"
- MOST NOISE FROM SURFACE (WAVES, SHIPS, CRITTER) ⇒ VERY QUIET BELOW RECIPROCAL DEPTH

W. H. Munk and F. Zachariasen: Propagation in a fluctuating ocean

J. Acoust. Soc. Am., Vol. 59, No. 4, April 1976

NEW ACOUSTIC INITIATIVES

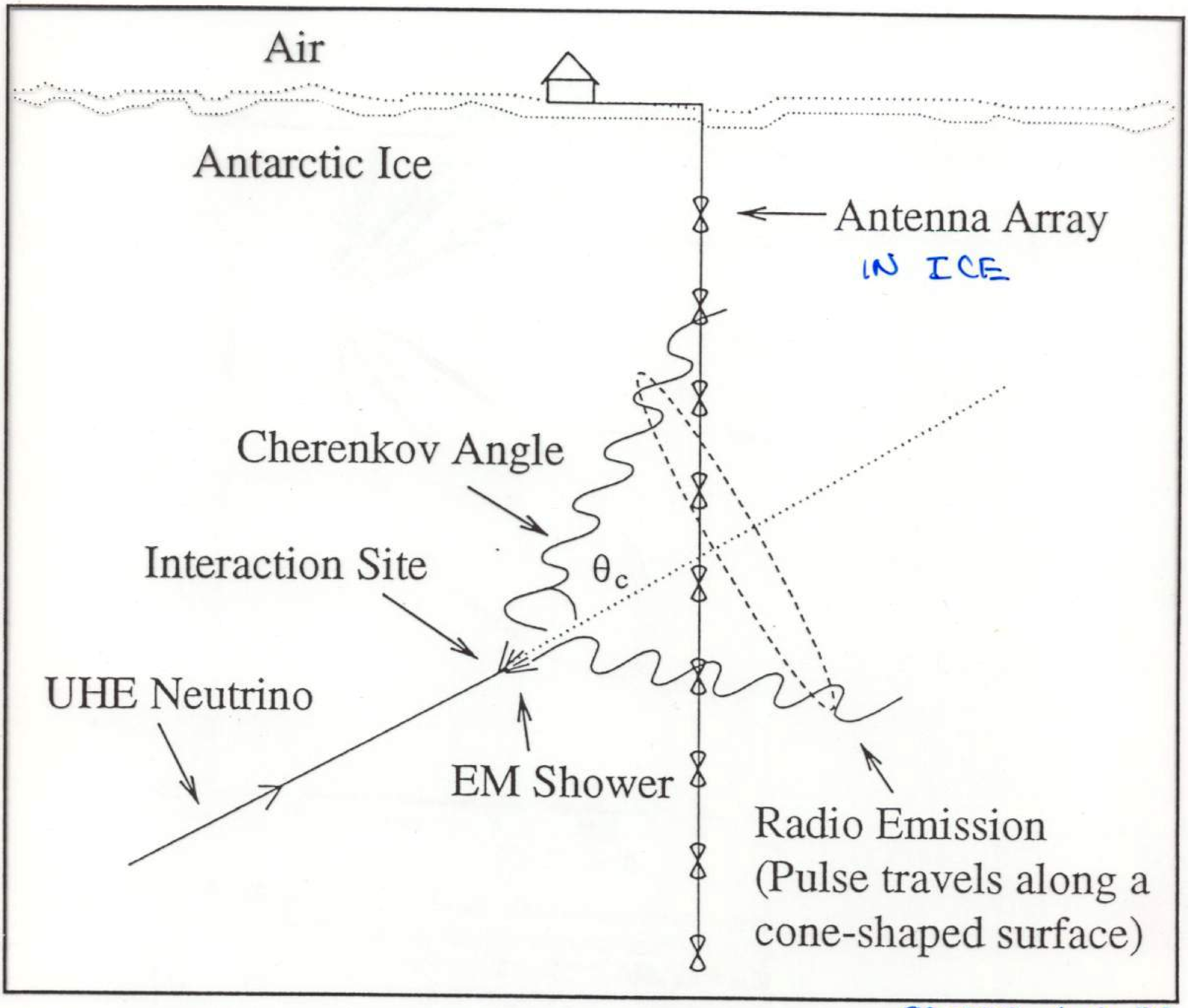
AIMED AT > EeV ν's IN OCEAN

- RUSSIAN GROUP
  - USE KAMCHATKA SONAR ARRAY
  - EMPLOY MILITARY SURPLUS PORTABLE UNITS TO BUILD NEW ARRAY
- STANFORD GROUP
  - EXPLORE POSSIBILITIES WITH AUTEC (USN) ARRAY IN ATLANTIC
- HAWAII
  - GAIN ACCESS TO EXISTING USN FACILITIES WITH RESPONSE TO 30 kHz

- BACKGROUNDS (NATURAL) MUST BE STUDIED
- FIRST INITIATIVES CAN SET LIMITS
- DETECTION REQUIRES BUILDING A NEW ARRAY

RADIO DETECTION

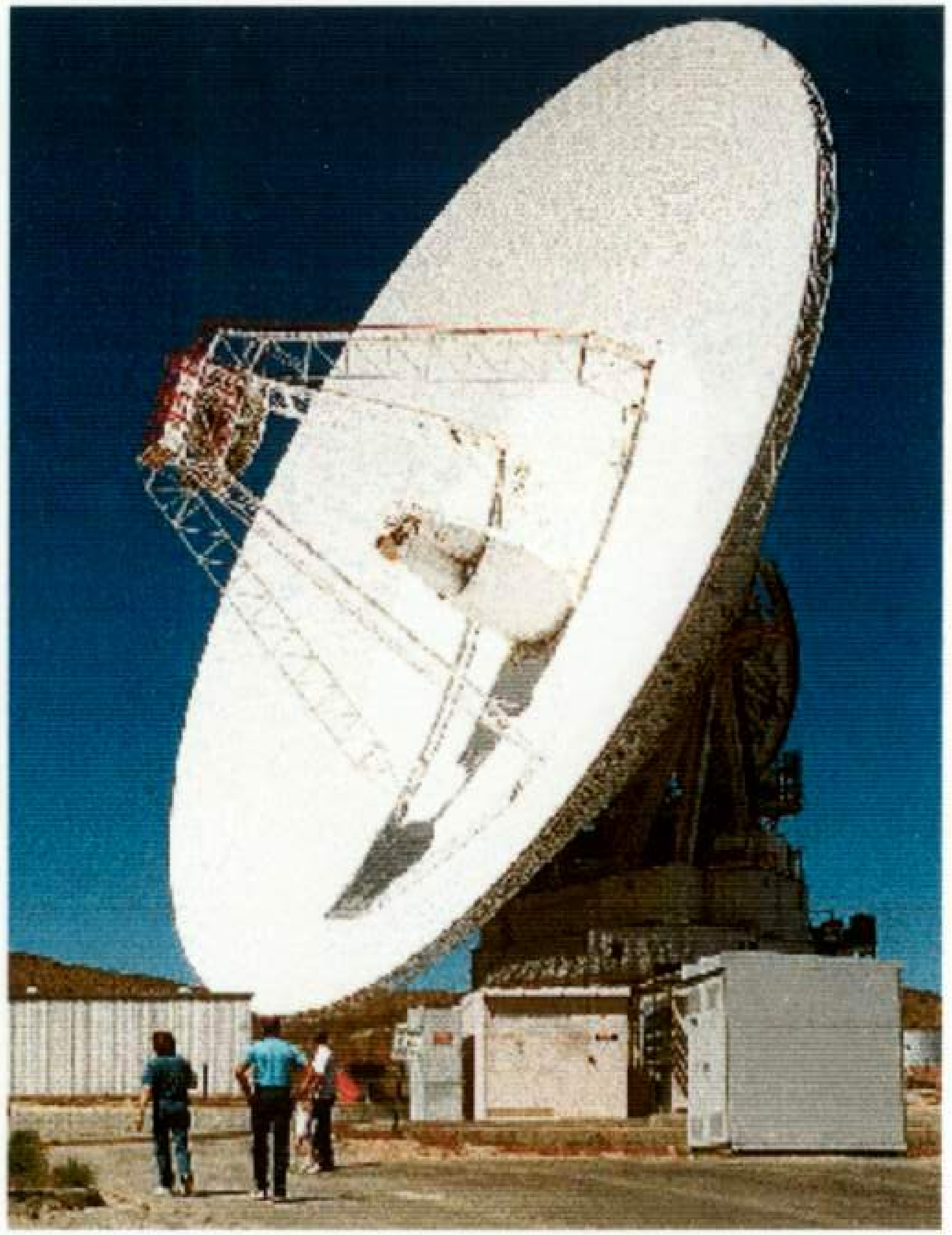
IN ICE



FRICTER, et al '95

STUDIES INR, MOSCOW
KANSAS, USA

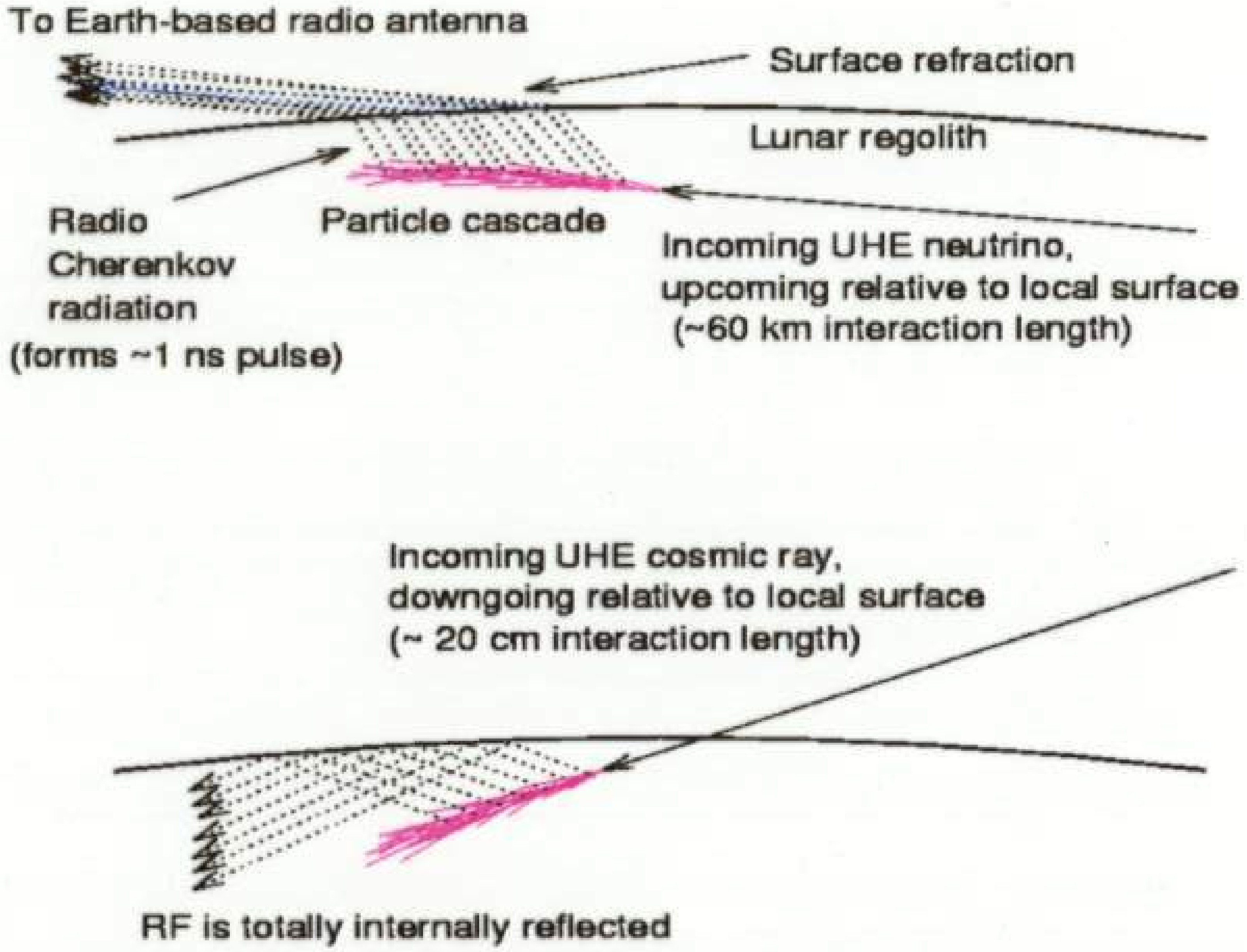
Goldstone Lunar Ultra-high energy neutrino Experiment (GLUE)

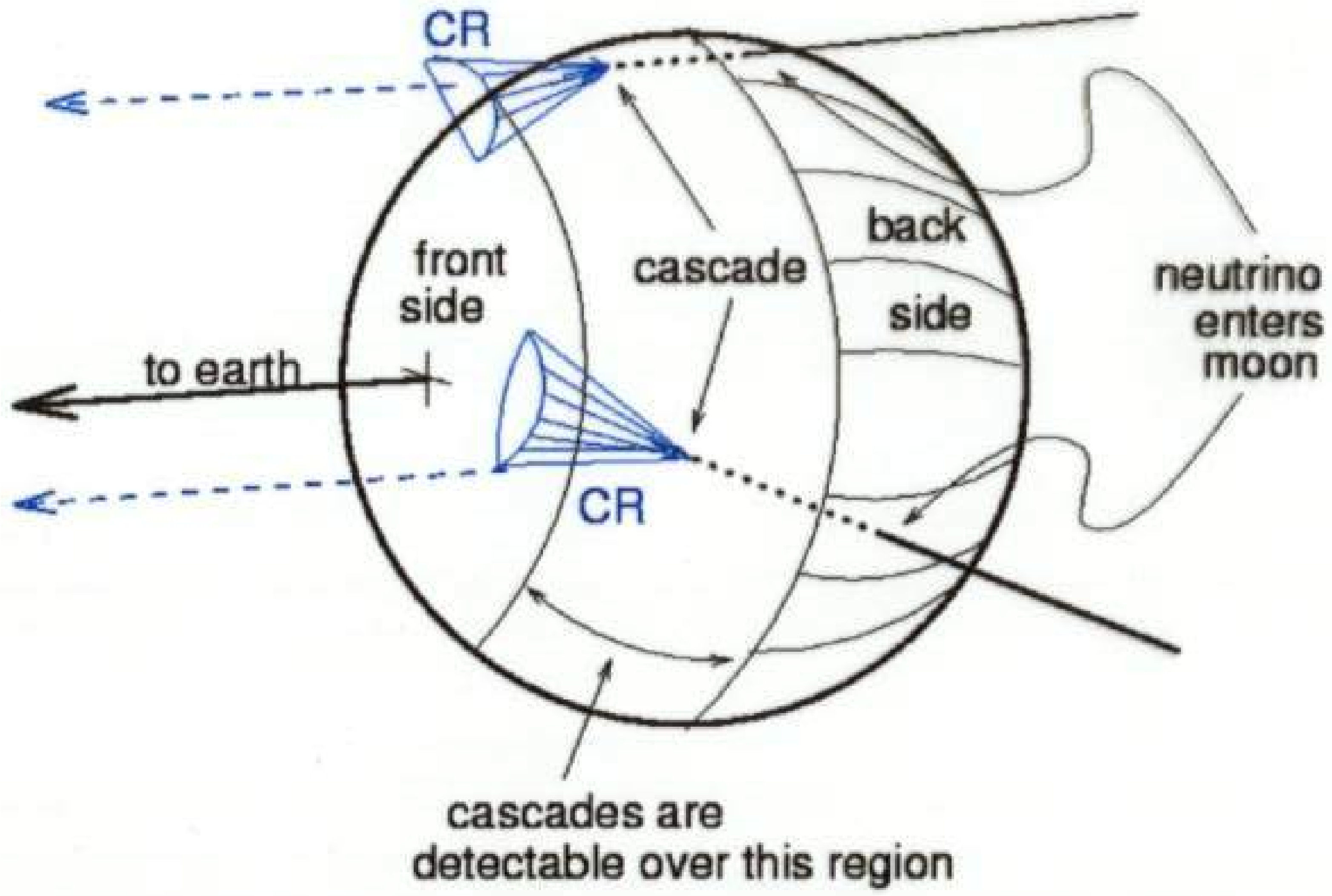


- Utilize Deep Space telecom 70m antenna DSS14 for lunar RF pulse search--fill gaps in SC sched.
- First observations late 1998:
  - approach based on Hankins et al. 1996 results from Parkes 64 m telescope (10hrs live)
  - idea due to I. Zheleznykh, Neutrino `88
  - utilize active RFI veto
- Early 1999: add 2nd 34 m fiber-linked antenna DSS13
  - initially used passive recording with local trigger at DSS14
- 2000: DSS14 down for first half, but ~20 hours livetime acquired since July
  - focussed on limb observations, lower threshold, better trigger system

P.W. GORHAM

Lunar Regolith Interactions & RF Cherenkov radiation

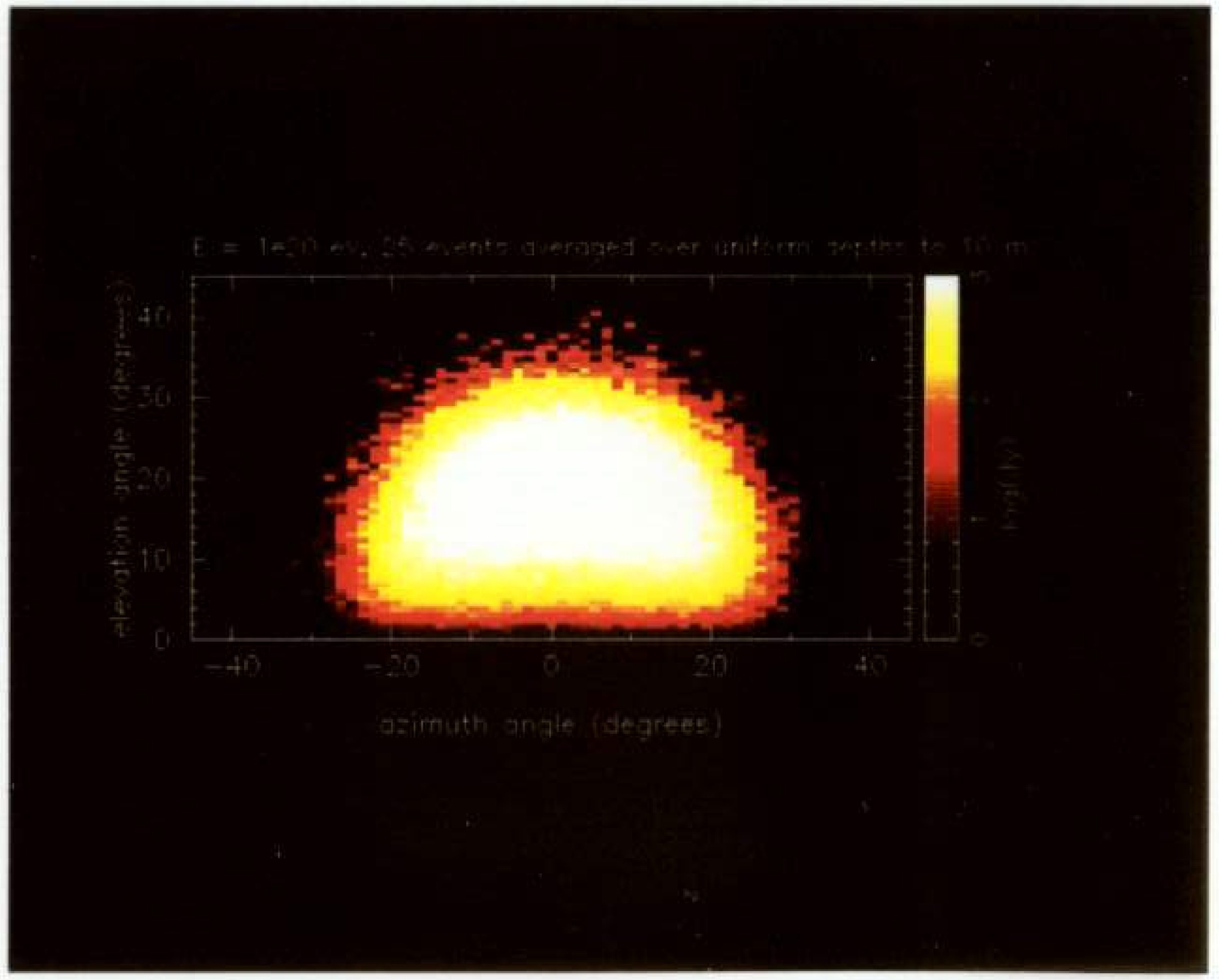




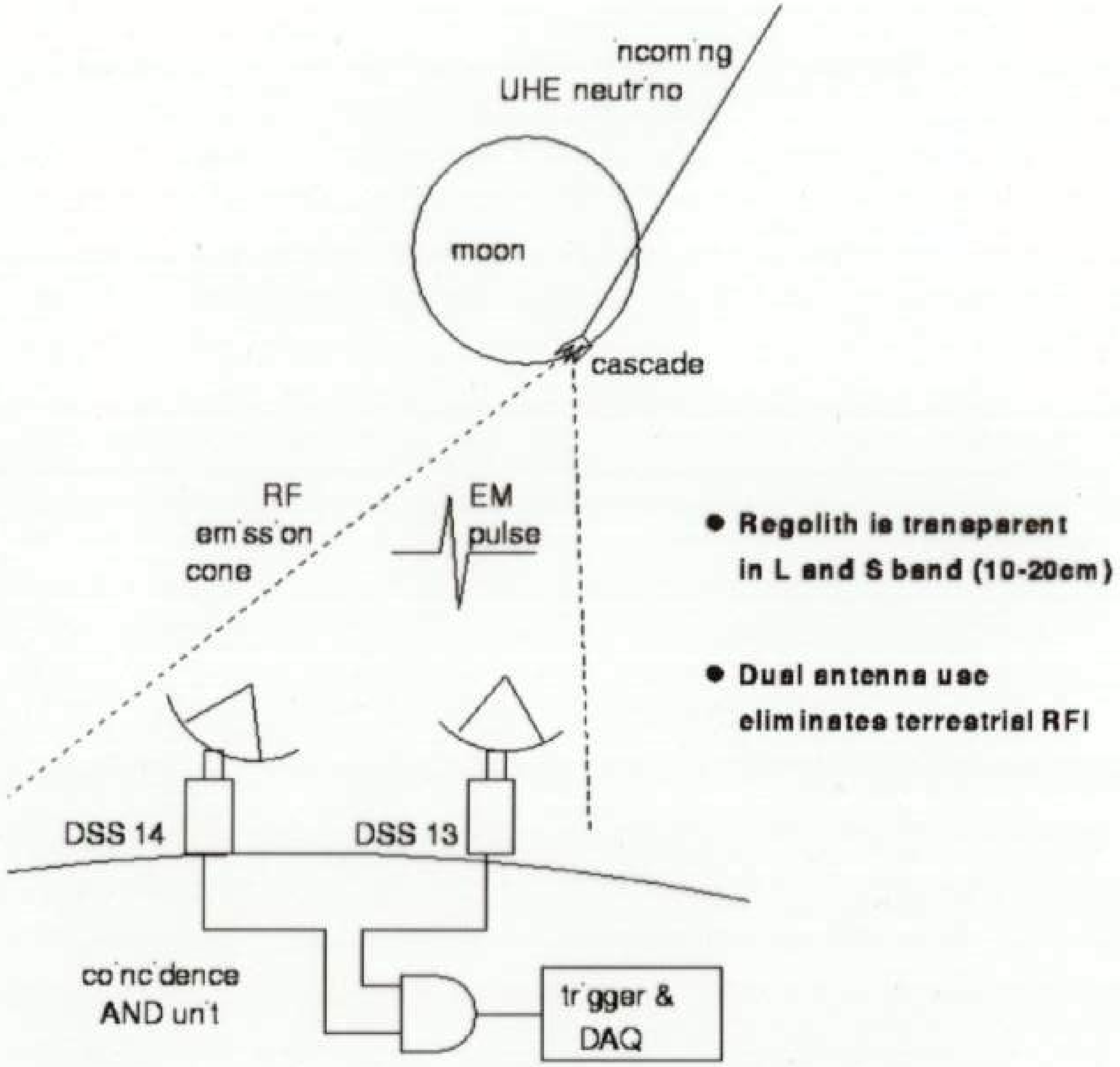
- At ~100 EeV energies, neutrino MFP in lunar material is ~60km

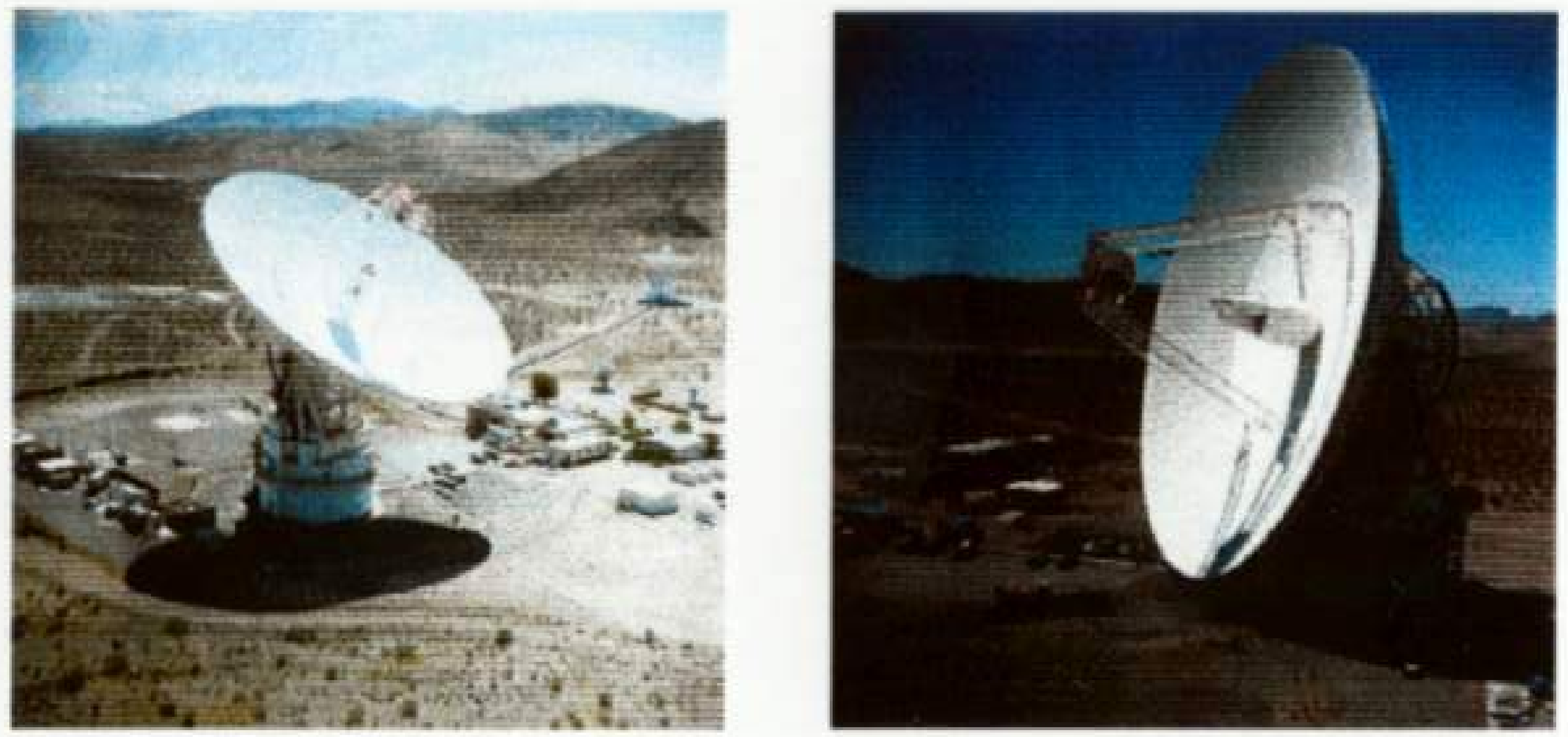
- Rmoon ~ 1760km, so most detectable interactions are grazing rays, but detection not limited to just limb

- Refraction of Cherenkov cone at regolith surface "fills in" the pattern, so acceptance solid angle is ~50 times larger than apparent solid angle of moon

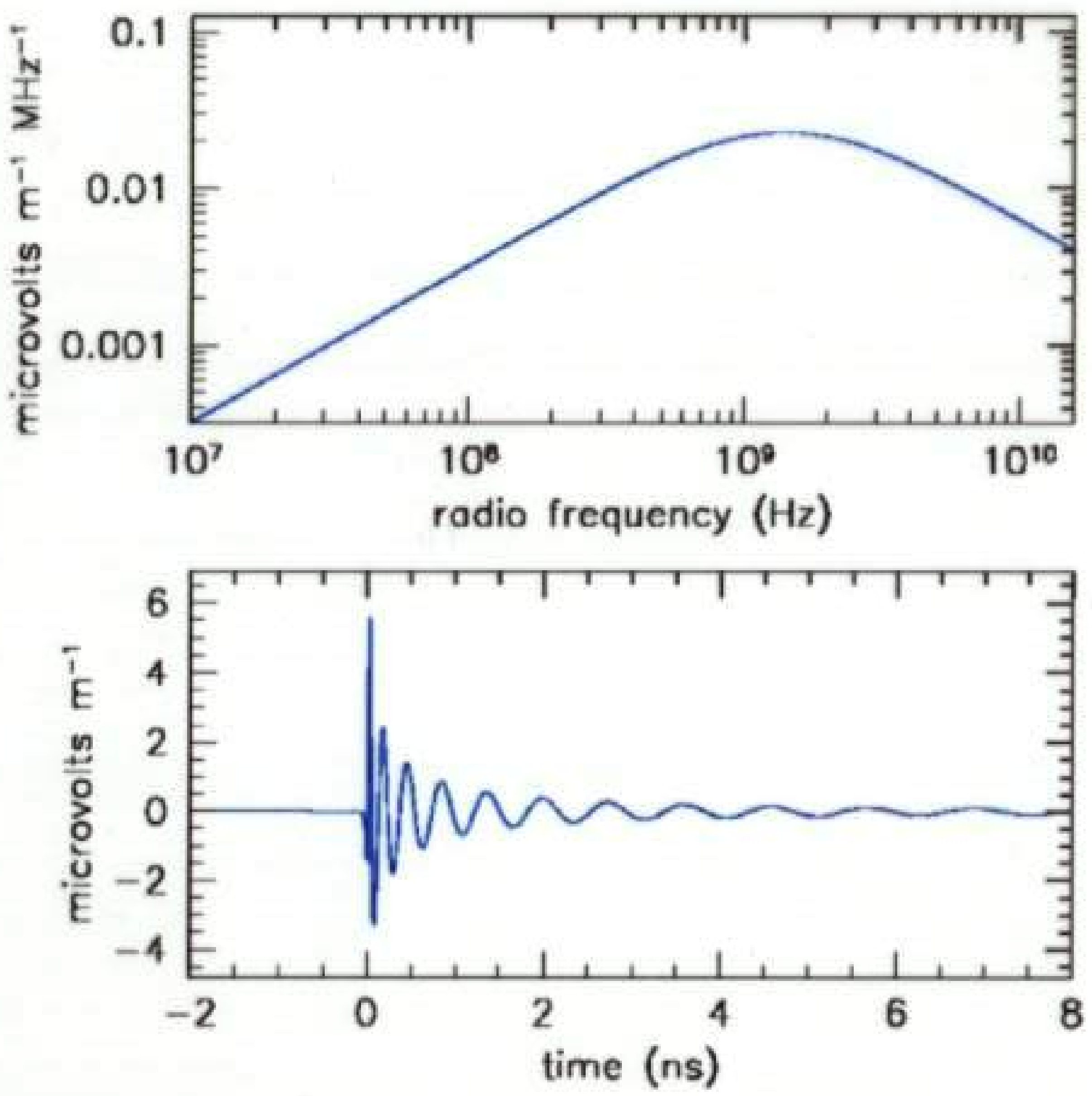


Goldstone DSN Radio Detection Approach





- RF pulse spectrum & shape



- Effective target volume: Antenna beam (~0.3 deg) times ~10 m moon surface layer

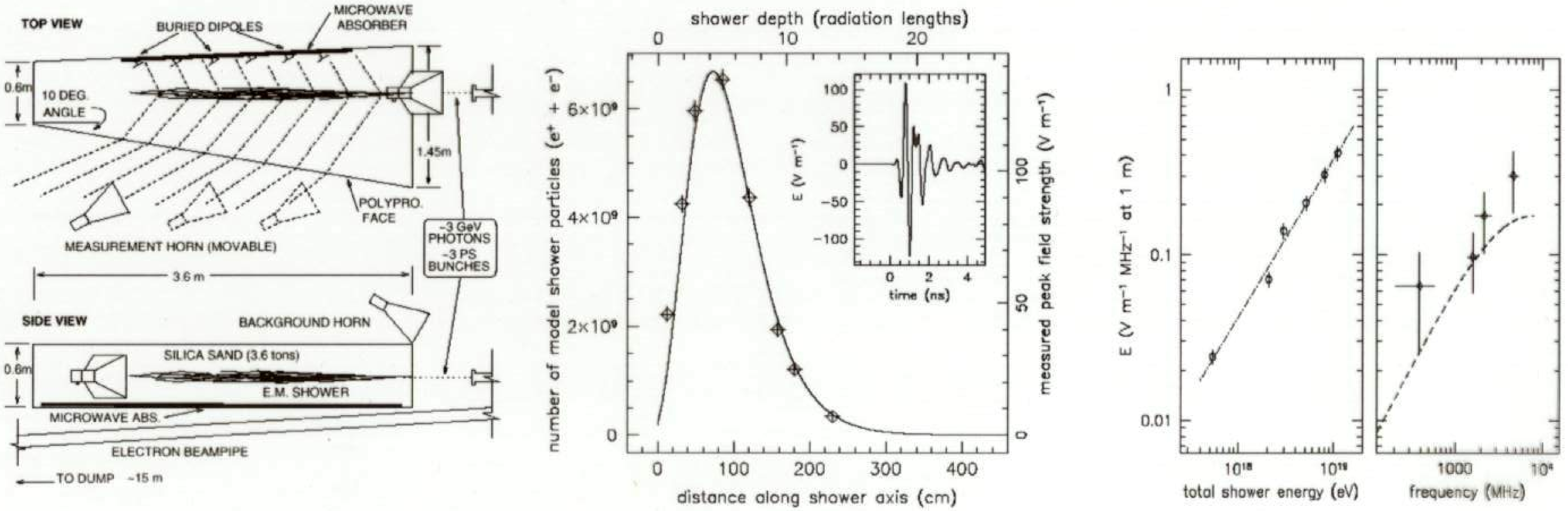
  ===> ~100,000 cubic km!!

- Limited primarily by livetime--only a small portion of antenna time can typically be devoted to 1 project

Cascade Radio emission: The genius of G. Askaryan

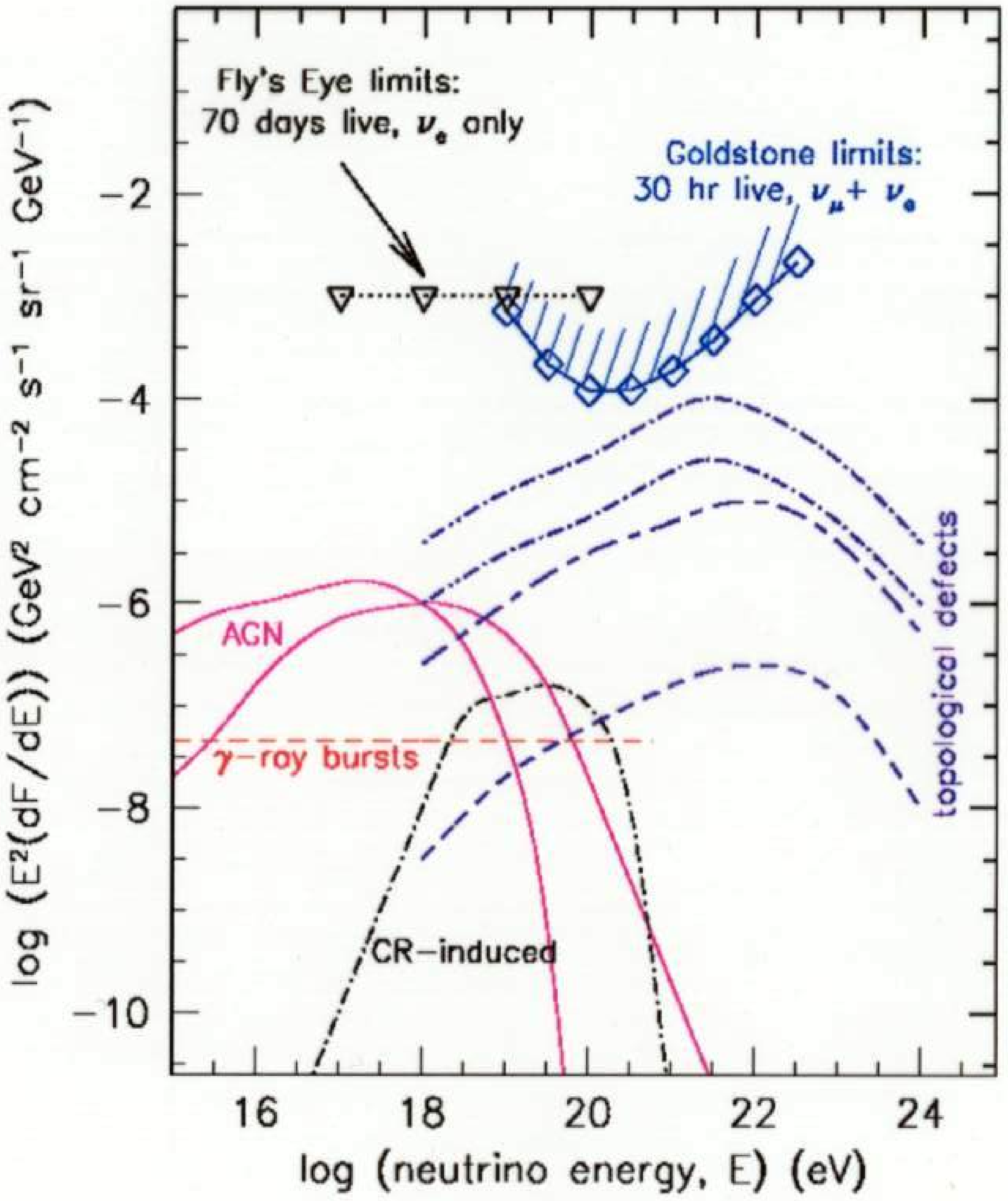
- Electromagnetic showers composed of gamma-rays, e+,e- primarily
  => should be electrically neutral overall, thus *no net radio emission*
- G. Askarayan (1962,65) realized that scattering processes & positron annihilation lead to a 15-30% e- excess
- This can radiate ***coherent Cherenkov*** radiation => Power ~ energy^2

- Effect only confirmed within the last year at SLAC--but it is a *strong effect !*



From Saltzberg, Gorham, Walz et al 2001, PRL (in press)

Goldstone diffuse EHE neutrino flux limits



~30 hrs livetime (includes previous data)

- No events above net 5 sigma

New Monte Carlo estimates:

- cross-sections 'down' by 30-40%
  - moving target effect!
- Full refraction raytrace, including surface roughness, regolith absorption
- Y-distribution, LPM included

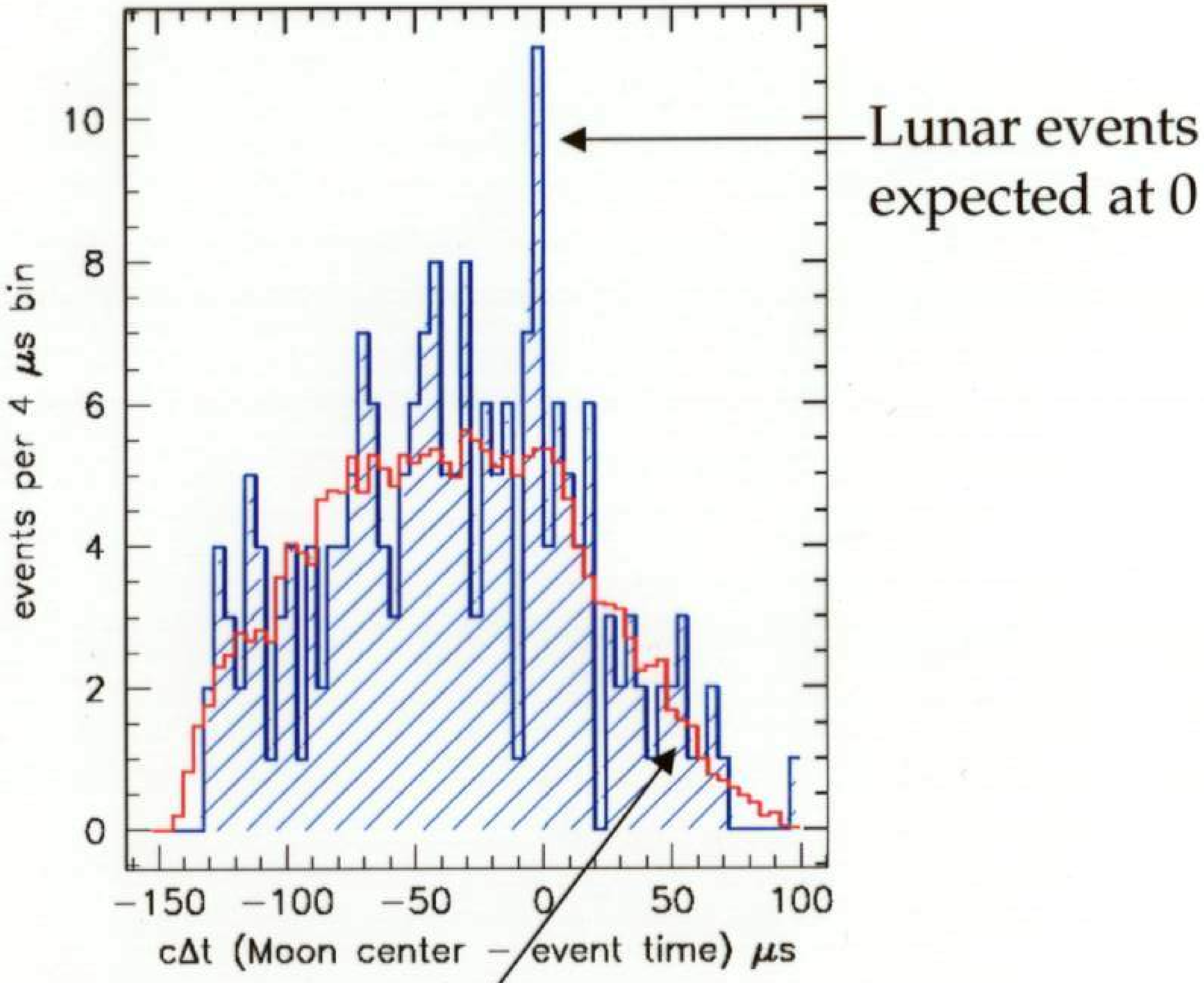
Limb observations:

- lower threshold, but much less effective volume (factor of ~1/10)
- 'Weaker' limit but with more confidence

Fly's Eye limit: needs update!

- Corrected here (PG) by using published CR aperture, new neutrino xsections

Small Event analysis of GLUE data



Red = expected background

Cuts applied:

- tighter timing
- pulse width close to band-limited
- not obvious RFI

BKG weight determined by randomizing event UT within run period

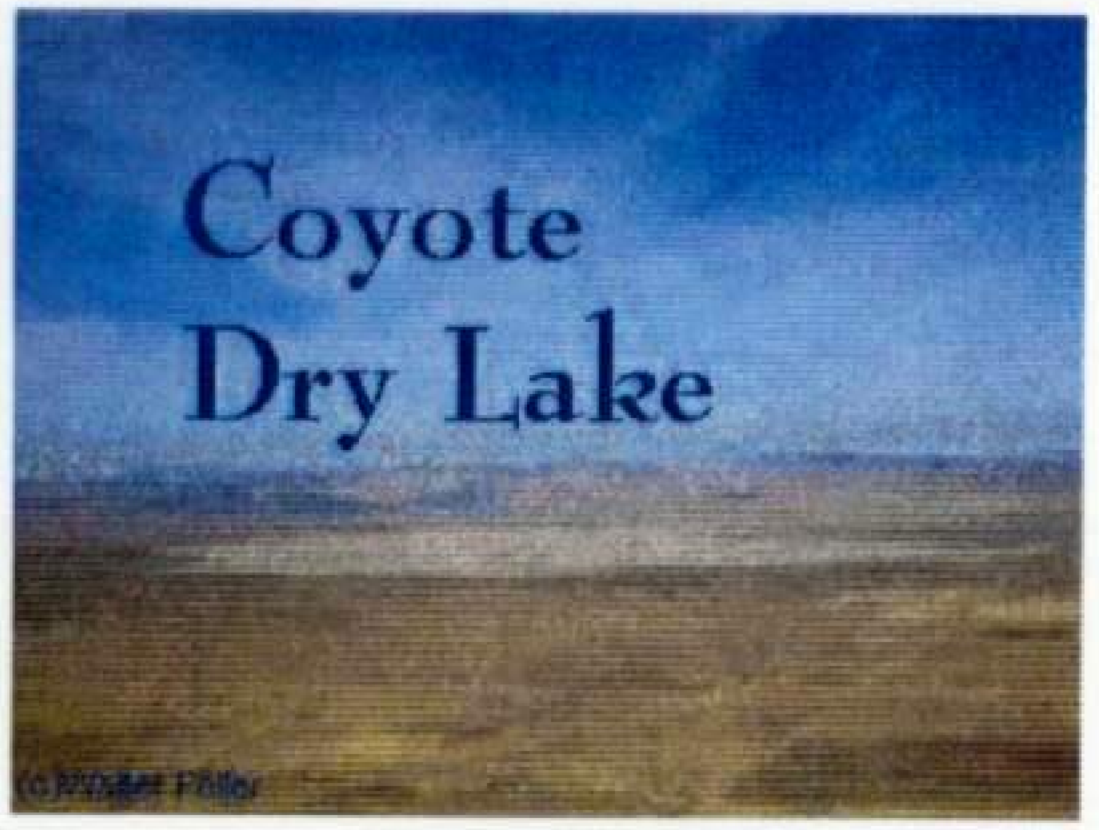
Some concentration of events near correct delay:

- not significant yet
- ~2 microsec offset hard to explain

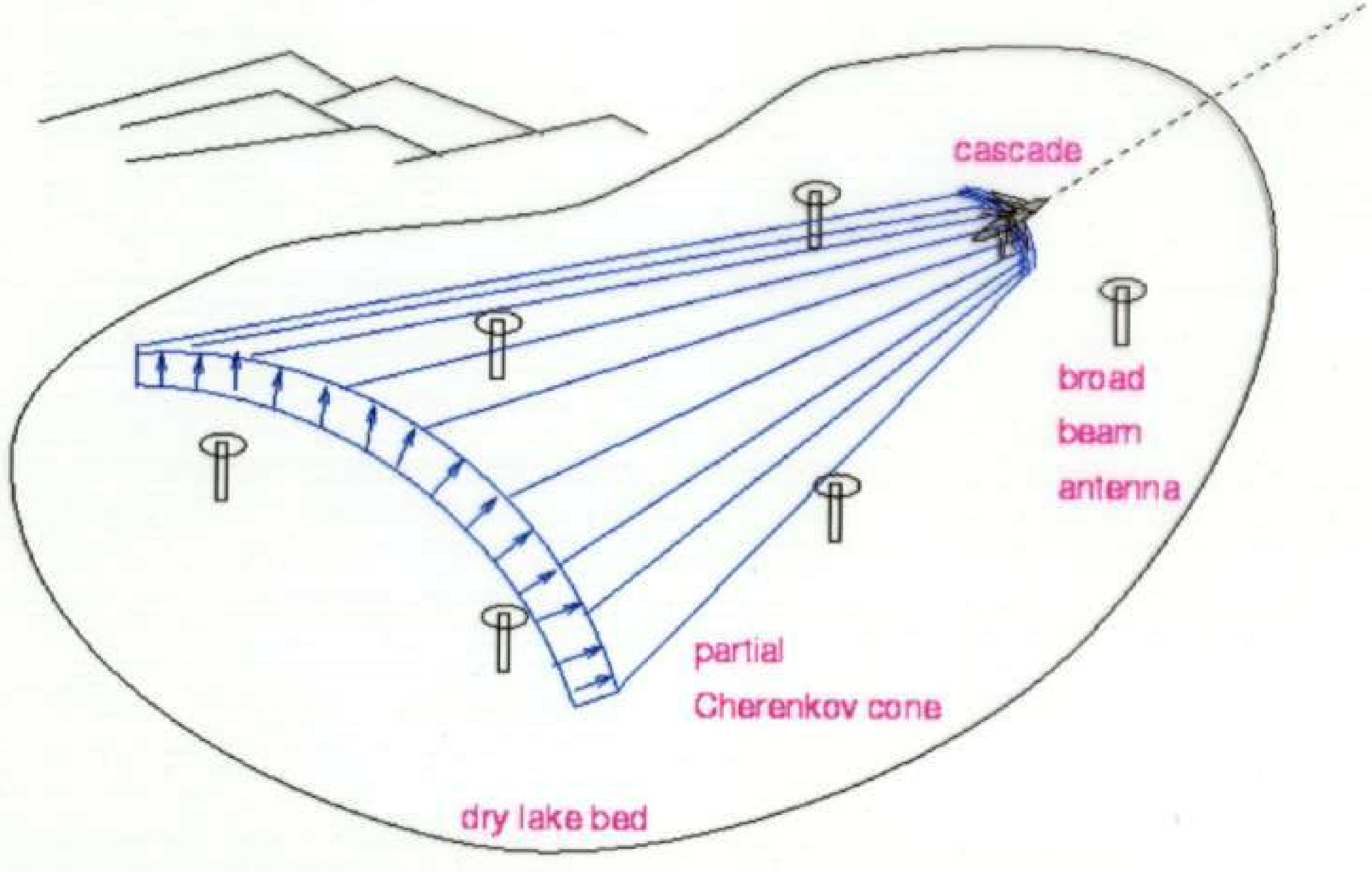
- ***Are we seeing EHE cosmic rays?***

PW GORHAM 3/01

Desert Playas (Dry lakes): RF surface Array



Area: ~160 km^2, near Barstow



CASCADE IN ~10 m SURFACE LAYER + RF REFRACTION

Tracking possible by use of polarization measurements:

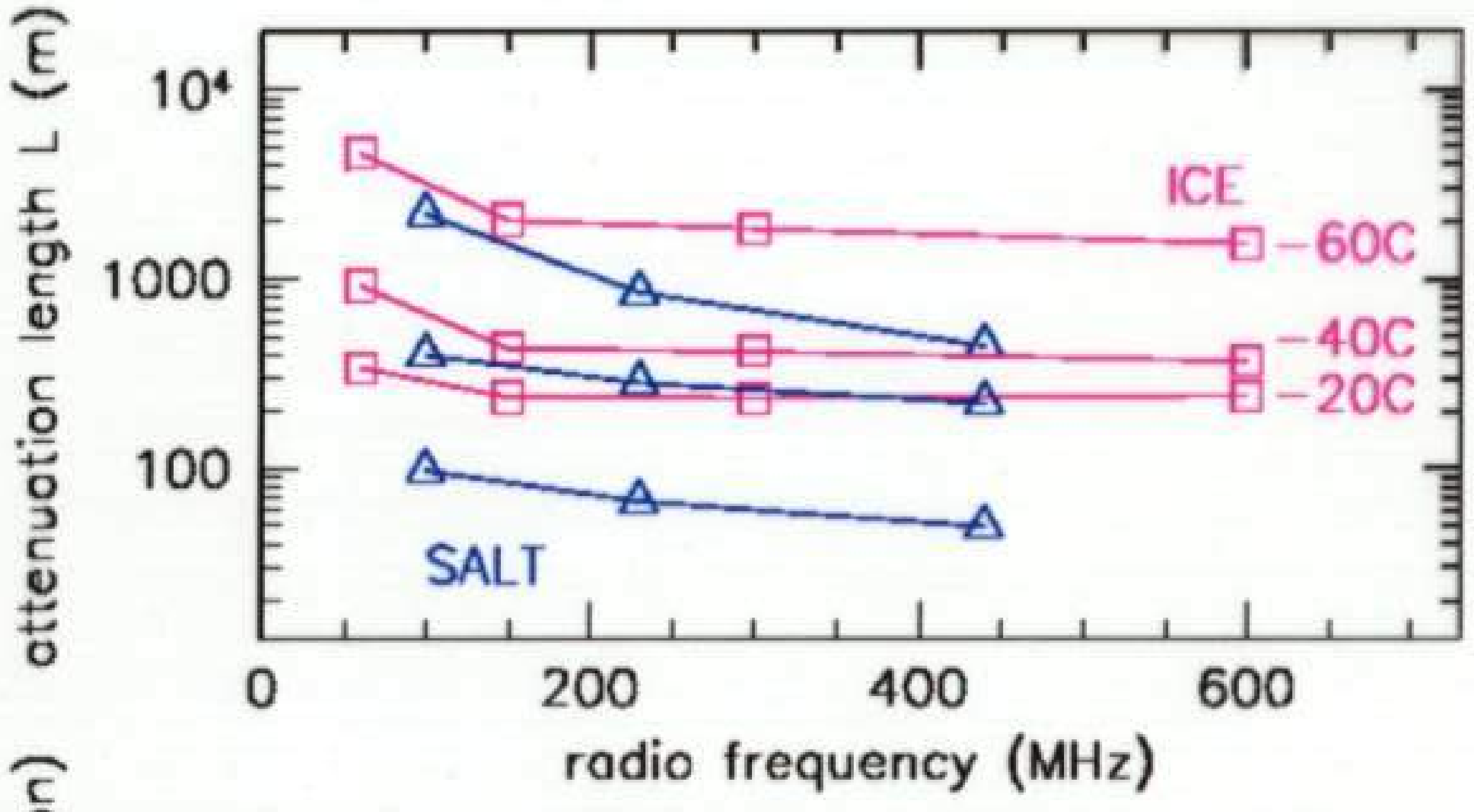
Plane of polarization preserves projected track direction

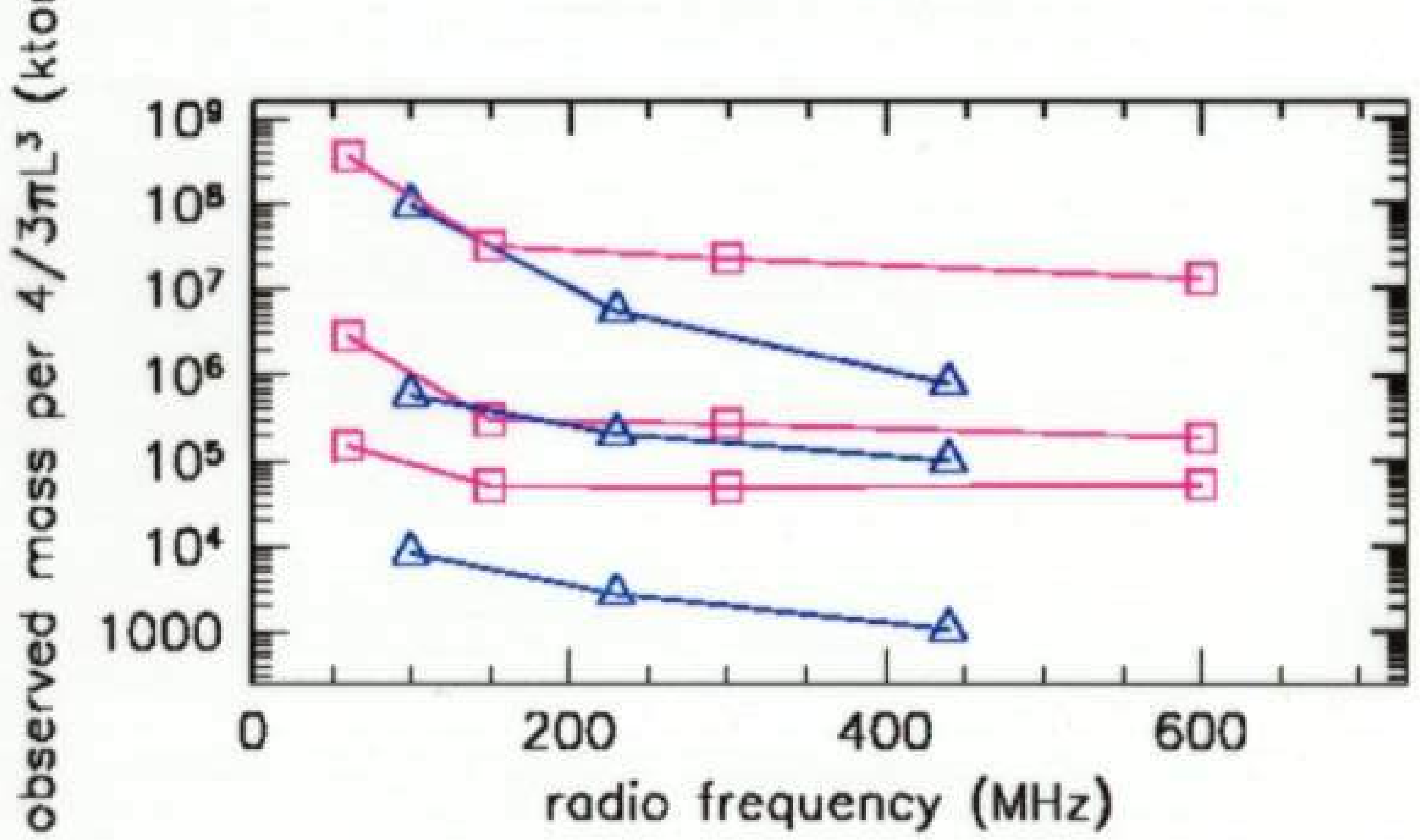
~3 cubic kmwe, Ethr~1 PeV possible for modest array at playa like Coyote Lake!

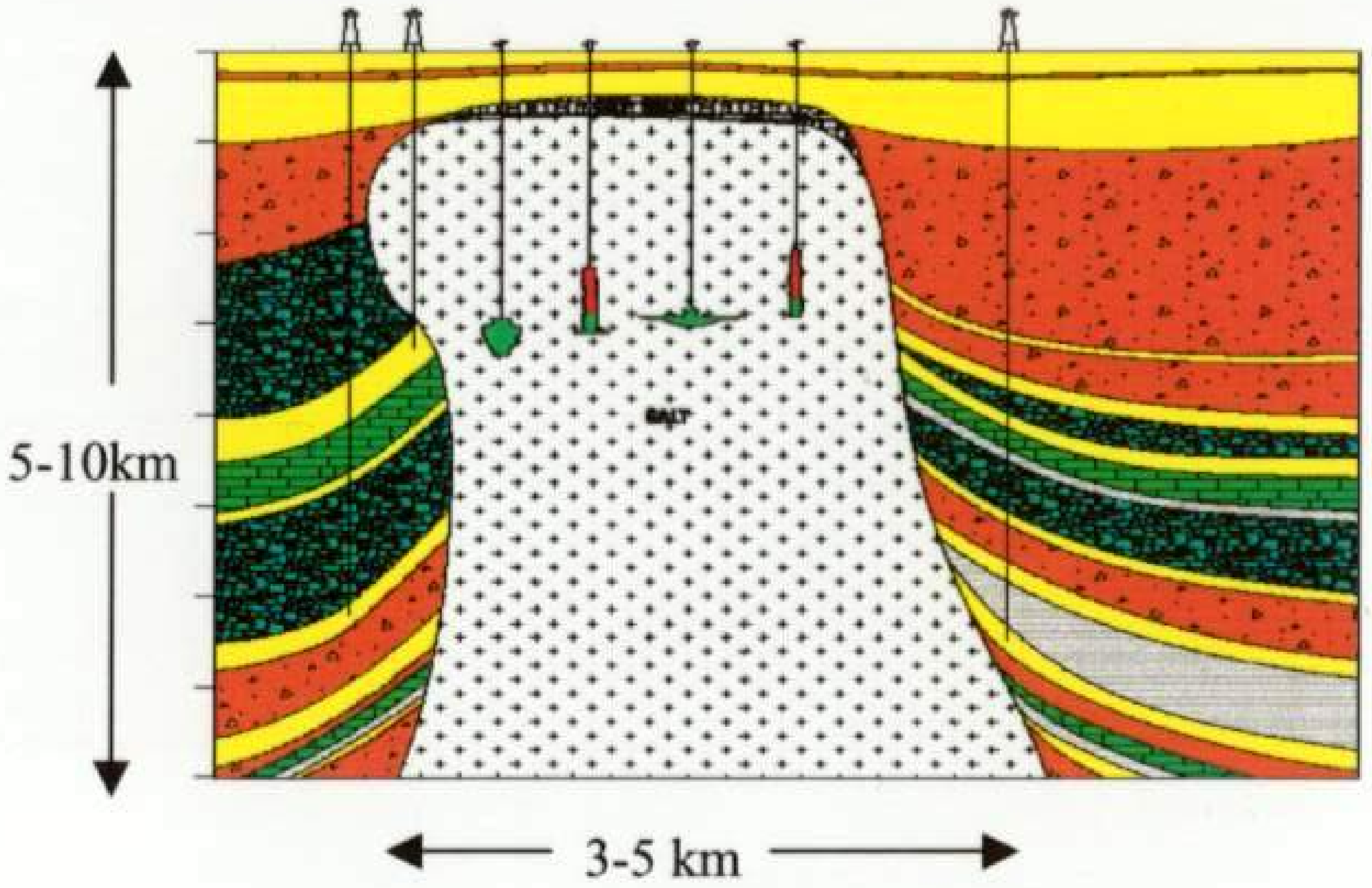
Natural Salt Domes: Potential PeV Neutrino Detectors

- Natural salt can be extremely low RF loss: ~ as clear as very cold ice, nearly 2 1/2 times as dense

- Typical salt dome halite is comparable to ice at -40C for RF clarity



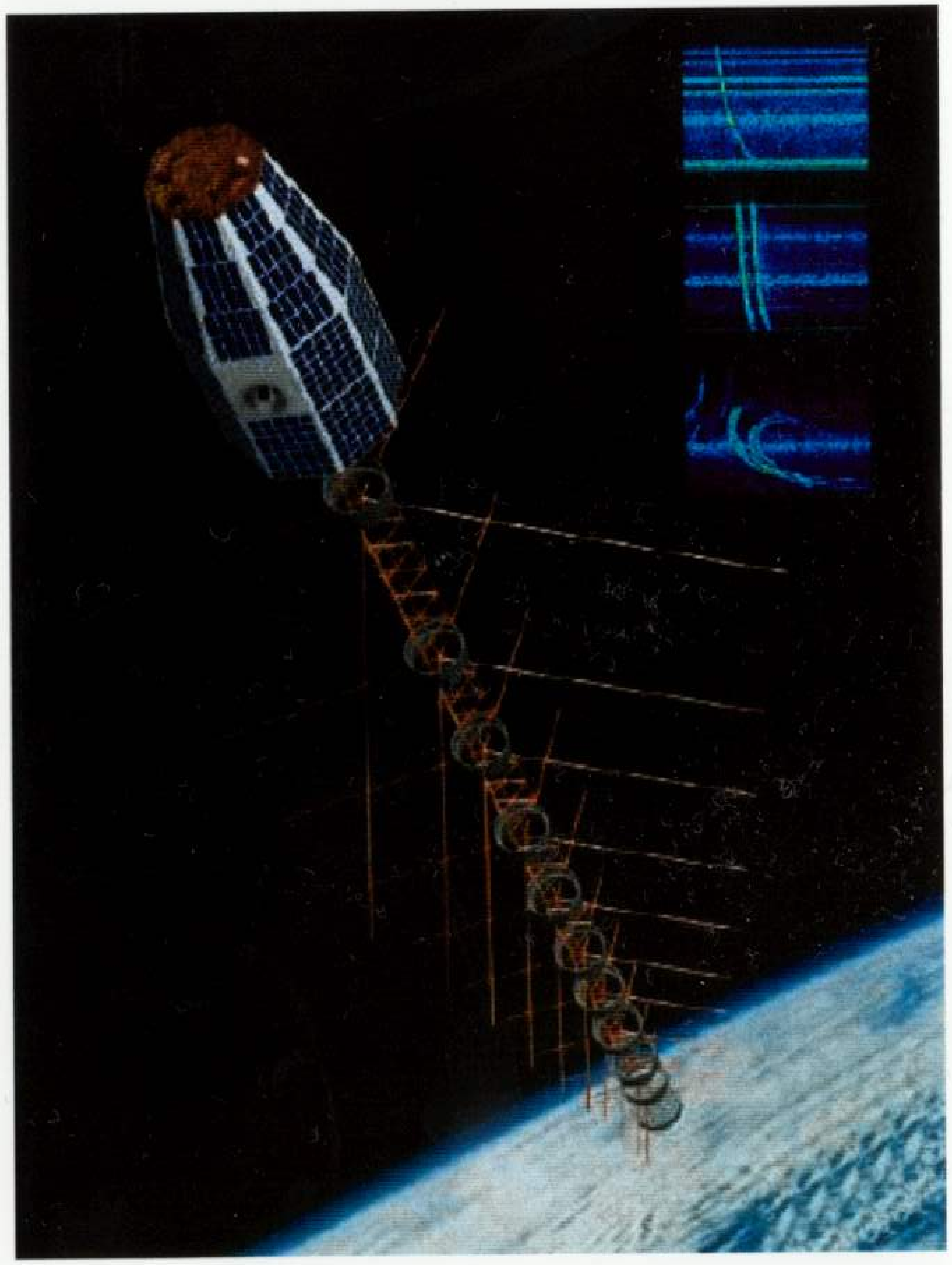




SALT curves are for (top): purest natural salt; (middle): typical good salt dome; (bottom) best salt bed halite.

EXISTING !

FORTE: A space-based EHE neutrino & cosmic ray detector?



Fast On-orbit Radio Transient Expt.

- Pegasus launch in 1997
    - 800 km orbit, 3 year planned life
    - Testbed for non-proliferation & verification sensing
    - Dept. of Energy funded, LANL & Sandia construction & operation
    - Scientific program in lightning & related atmospheric discharges
- 30-300MHz range, dual 20 MHz bands, 16 1MHz trigger channels
    - ~2M triggers recorded to date

- FORTE can trigger on radio emission from Giant air showers E~100 EeV
- Preliminary estimates: could be ~50-100 100 EeV cosmic ray events in sample
    - Distinct from lightning, could be recognized as isolated events in clear weather regions far from urban noise
    - Analysis (JPL,LANL) planned this year & UH

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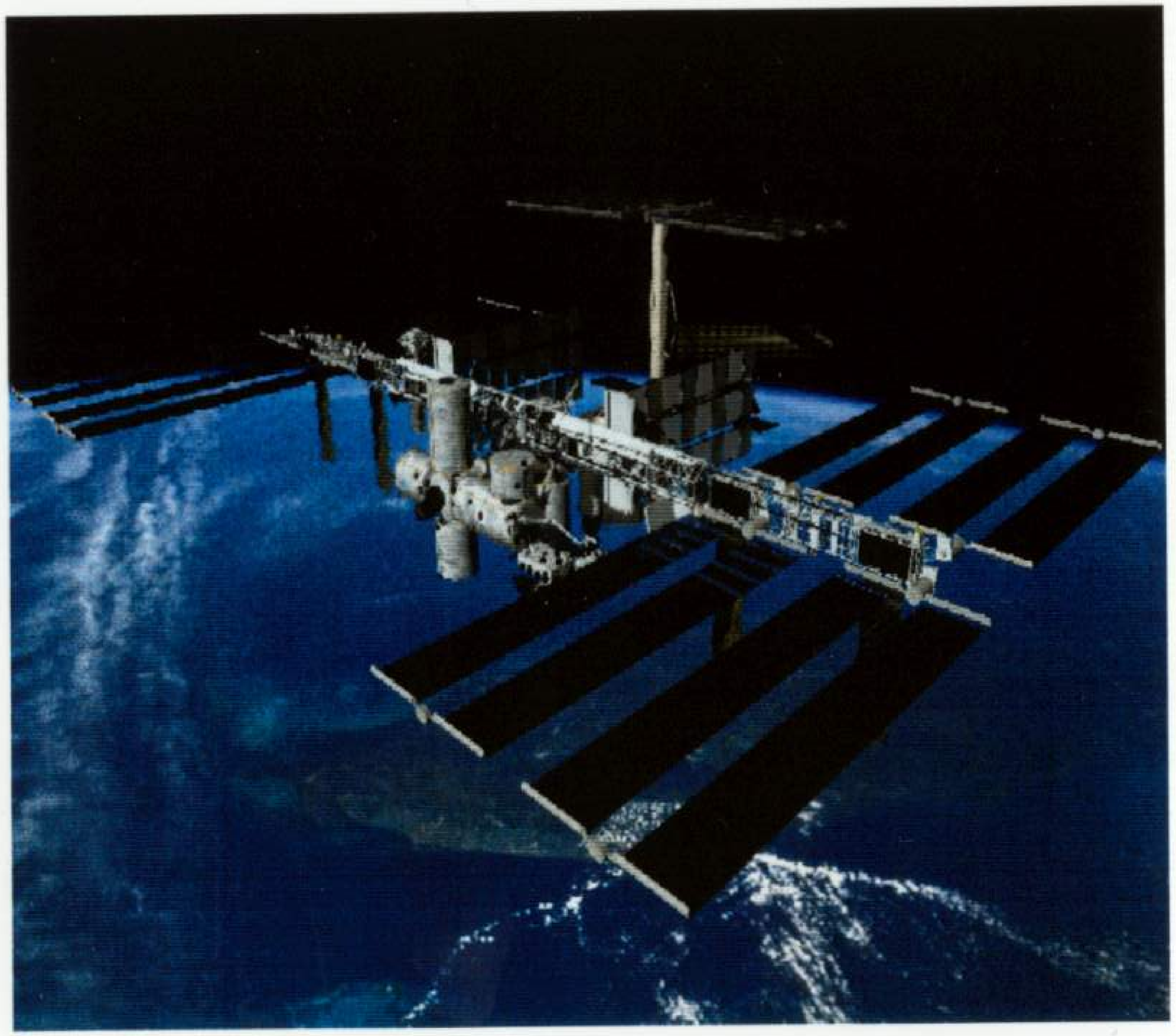
RITA: Radio Impulsive Transient Array, a possible mission of opportunity for the Space Station



- Geosynchrotron & radio Cherenkov from extensive air showers, down & upgoing
- Backward TR from EAS that impact the ocean
- Threshold ~ 1e20 eV
- Area~ 4M km^2, V~40,000km^3, water equiv.
- Requires 3 or more elements
  - ~ 80m separation possible
  - < 5 deg resolution @ 50MHz
  - Dual circular polarization
  - Use FORTE approach to deal with anthropic BKG: moving sub-bands for (RFI-quiet) trigger

CONCLUSION

- MUCH ACTIVITY (~ DOZEN "PROJECTS")
- SHIFTING EMPHASIS TO $\gtrsim$ PeV REGIME
- MUCH INTEREST & POSSIBILITY FOR > EeV ν's
- NEXT FEW YEARS SHOULD SEE
  - $\geq$ 1 OPTICAL CHERENKOV ARRAY IN MED
  - HUGE ARRAY IN ICE AT SOUTH POLE
  - SIGNIFICANT LIMITS & POSSIBLE DISCOVERY OF S.H.E. ν's IN
    - > EAS DETECTORS (CONVENTIONAL, AIR FLUOR, & RADIO)
    - > EXPLORATIONS WITH ACOUSTICS & NEW RADIO TECHNIQUES
- AS FOR THE LAST 25 YEARS - STAY TUNED!