Some Possible & some Improbable Uses of Neutrino Telescopes

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ν Telescopes
3/01

Other Explanations of

Atmospheric, Solar & LSND Data

· Atmospheric

Reason	Model	Sub-GeV	Multi-GeV	upgoing μ's
No E_ν-dep.	FCNC + NUNC	Yes	Yes	No
Too much E dep.	FV Gravity / Lorentz V.	Yes	~	No
Not enuf E_ν dep.	Decay A (+mix)	Yes	~	No
	Decay B (+mix)	Yes	Yes	Yes
	· Decoherence	Yes	Yes	Yes
$\nu_\mu \to \nu_s$ + many ν_{KK}	Extra Dimensions	Yes	Yes	Yes

A: δm^2_{osc} large $\quad P_{\mu\mu} = s^4 + c^4 \exp(-\alpha L/E)$

B: δm^2_{osc} small $\quad P_{\mu\mu} = (s^2 + c^2 \exp(-\alpha L/E))^2$

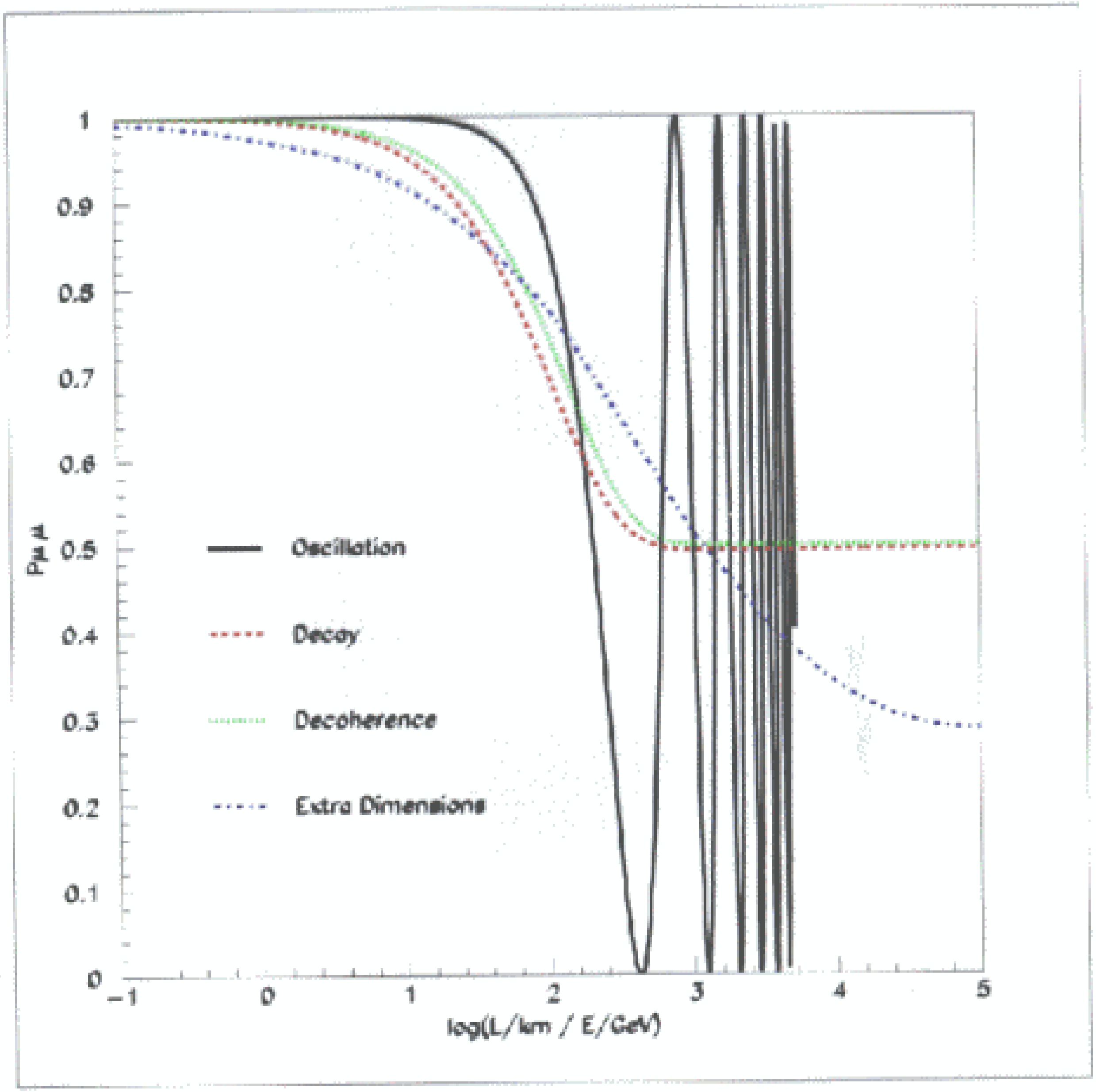
Fit @ $\quad m_2/\tau_0 = \alpha = \frac{1\ \text{GeV}}{63\ \text{km}} \quad \theta \sim 57^\circ$

Decoherence: $P_{\mu\mu} = c^2 + s^2 \exp(-\gamma L)$

If $\gamma = \beta/E \quad \beta \sim 7 \cdot 10^{-3}$ GeV/km

$s^2 \sim c^2 \sim 1/2$

$\Rightarrow$ fit.



Oscillation
Decay
Decoherence
Extra Dimensions
$P_{\mu\mu}$
log(L/km / E/GeV)

To

Solar

($m_{\nu}=0$)	FCNC + NUNC ($\nu_e \to \nu_\tau$)	Yes
	FV Gravity / LV	Yes
	Decay (A or B)	No
	Extra Dimensions	Yes.

- LSND.

$\mu^+ \to e^+ \bar{\nu}_e \bar{\nu}_e$ (or $\bar{\nu}_x$)

with BR $\sim (1-2) 10^{-3}$.

Baroque Models Possible. (Babu & S.P.)

Tests: · No L/E dependence

· No effect in $\bar{\nu}_\mu$'s from π decay.

No effect in MINI-BOONE

Working Assumptions

- Distant ν- Sources with "reasonable" fluxes in E_ν-range ~ 1- 10 PeV exist (AGN's, GRB's ...?)
- (1 to ~~few~~ many) KM3 Detectors with good instrumentation
  - E resolution
  - θ_z resolution
  - Low E threshold (~ 50 GeV?)
- Determination of Flavor Mix on Arrival.

Expected flavor mixes
(& energy spectra/fluxes)
from AGNS

- Most AGN ν-emission models
Tenous beam dumps, little absorption.
π's, K's decay.

- $\gamma p \to \Delta$ dominant process
Expect at production:

$$\nu_\mu : \nu_e : \nu_\tau \approx 2 : 1 : 0 .$$

e.g. in Protheroe-Szabo model

$$\nu_\mu : \nu_e \sim 1.75 : 1$$

& 10 % of ν's due to pp.

- Some fraction of $pp \to c, b \ldots$
$\to$ prompt ν (including ν_τ's)

Prompt ν's: Expect $\nu_\mu : \nu_e = 1:1$.

$$\nu_\mu : \nu_e : \nu_\tau = 1:1:p$$

ν_τ comes from prod. & decay of $D_s \to \tau\nu_\tau$, $b \to \tau\nu X \ldots$

a rough estimate for p:

$$p = \left\{ f\left[B_\mu^D / B_\tau^s + f(1+2f)B_\mu^s/(2+f)B_\tau^s \right]^{-1} + \varepsilon\left(\frac{B_\tau^b}{B_\mu^b}\right)\left(\frac{B_\mu^b}{B_\mu^D}\right) \right\}$$
$$\times \left\{ 1 + \varepsilon\, B_\mu^b / B_\mu^D \right\}^{-1}$$

$f = \sigma_{D_s}/\sigma_{D\bar{D}}$; $\varepsilon = \sigma_{b\bar{b}}/\sigma_{D\bar{D}}$, $B_\mu^D = \frac{1}{2}\left(B_\mu^{D^0} + B_\mu^{D^+}\right) \simeq 0.125$
$\simeq 0.15$ $(\simeq 0.1)$

$B_\tau^s = Br(D_s \to \tau\nu_\tau) \simeq 0.04$, $B_\mu^s = Br(D_s \to \mu X) \simeq 0.08$.

$B_\tau^b \sim 0.025$, $B_\mu^b \sim 0.10$.

$\underline{p \simeq 0.1 \text{ to } 0.07}$ $\Rightarrow$ $\nu_\mu : \nu_e : \nu_\tau \simeq 1:1:\left(\begin{smallmatrix}0.07\\ -0.1\end{smallmatrix}\right)$

In turn, since fraction of prompt ν's itself is small $\Rightarrow$ (in P-S model)

Expected flux ratios: $\nu_\mu : \nu_e : \nu_\tau \simeq \underline{1 : 0.6 : 5_{0.0}}$

Double Bang Signature for ν_τ.

Decay Length $L \sim \gamma c \tau \sim 100\,m$ @ $E \sim 2\,PeV$

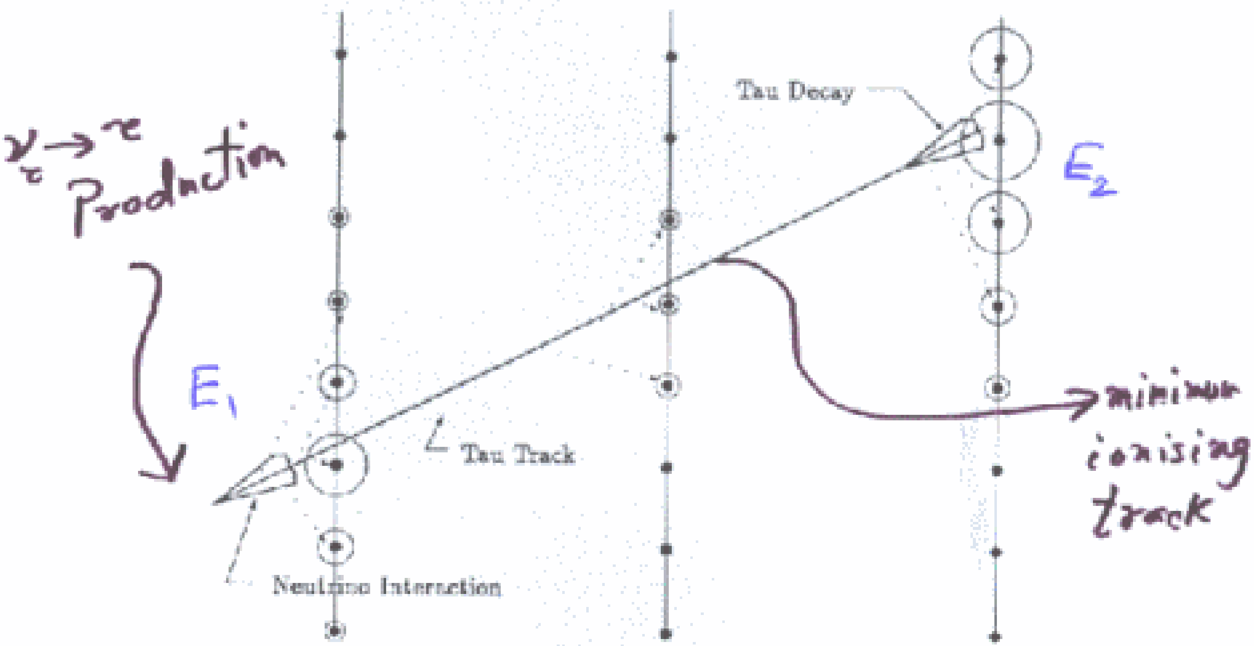


Figure 1: A schematic view of a "double bang" event near a deep ocean detector whose modules are indicated by dots. Such cascades should be visible to detectors from hundreds of meters distance.

Light from 1st Cascade

$\to$ Energy $\langle E_1 \rangle = \langle y \rangle E_\nu$

Light from 2nd Cascade

$\to$ Energy $\langle E_2 \rangle \approx \langle E_\tau \rangle - \langle E_{\nu_\tau} \rangle$

$\approx 2/3 \langle E_\tau \rangle$

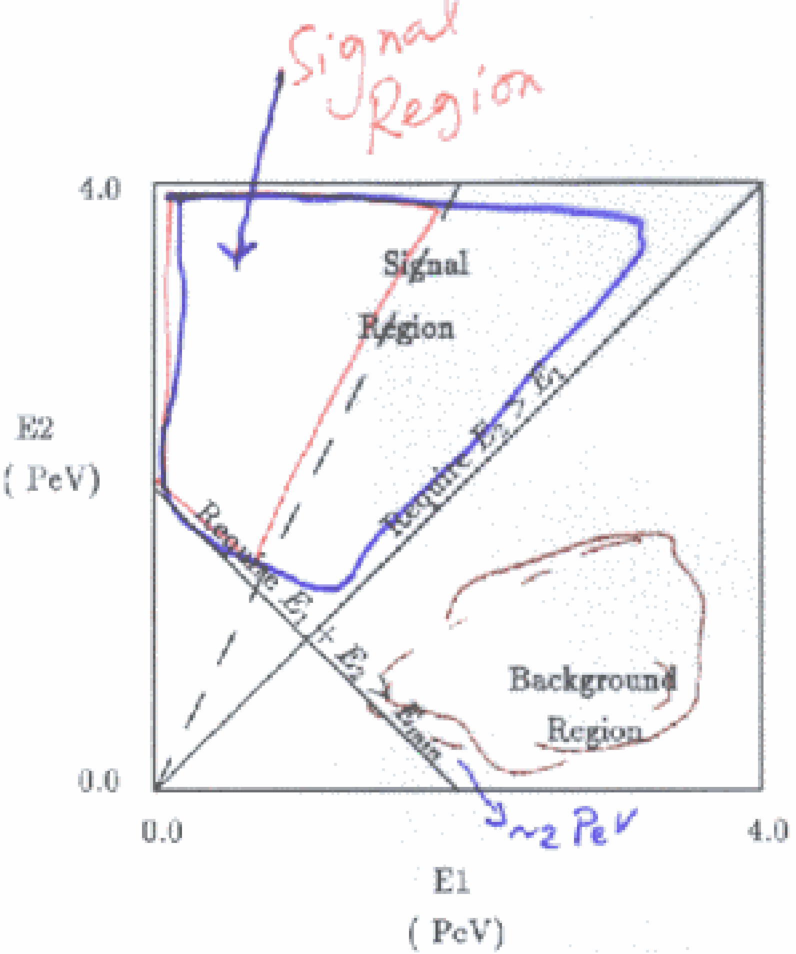


Figure 2: Diagramatic representation of the region of double bang signals and background signals, as discussed in the text. The signal is essentially background free after cuts on minimum total energy and requiring the second cascade to be the larger.

ν_τ Signature   Double Bang

- $(c\tau)_\tau \sim 91\,\mu m$, hence decay length $L(E_\tau \sim 1.8\,PeV) \approx 91\ m$.

- Signature in large Water $\hat{c}$ Det.

\# photons in $\hat{c}$-light

10^{11} · big hadronic shower from $\nu_\tau \to \tau$ c c event

$5 \cdot 10^{6}$ · a minimum ionizing track $\sim O(100)\,m$ from τ

$2 \cdot 10^{11}$ · second big cascade from τ decay $\tau \to h\nu$, $\tau \to e\nu\nu$.

- Even if τ track hard to resolve connect 1 & 2 by speed of light.

- Real τ – appearance expt.

- BG's v. v. small

- either $\nu_\mu \to \nu_\tau$ osc. or ν_τ emission – Any Case v. interesting.

Neutrino Flavor Mix from Data

Event Classification:

- Double Bang events $\longrightarrow \nu_\tau + \bar{\nu}_\tau$ flux
- μ/Up-Mu's $\longrightarrow \nu_\mu + \bar{\nu}_\mu$ "
- Cascade (Single Bangs) $\longrightarrow (\nu_e + \bar{\nu}_e)$ (CC+NC)

$$+ \left.\begin{array}{l} (\nu_\mu + \bar{\nu}_\mu) \\ + (\nu_\tau + \bar{\nu}_\tau) \end{array}\right\} NC.$$

From these can deduce:

$$f_e = (N_{\nu_e} + N_{\bar{\nu}_e}) / N_t$$

$$f_\mu = (N_{\nu_\mu} + N_{\bar{\nu}_\mu}) / N_t$$

$$f_\tau = (N_{\nu_\tau} + N_{\bar{\nu}_\tau}) / N_t$$

At $E_\nu = 6.4$ PeV (Glashow Resonance) can also deduce $N_{\bar{\nu}_e} / N_{\nu_e}$ via $\bar{\nu}_e + e^- \longrightarrow W \longrightarrow$ shower

Signal ... & Kinematics

Measure E_1 & E_2, energies in the two cascades.

- Expect $\langle y \rangle \sim 1/4$ at $E_\nu \sim$ PeV.
- Hence
$$\langle E_1 \rangle \sim \frac{1}{4} E_\nu$$
$$\langle E_2 \rangle \sim \underbrace{\left(\frac{3}{4} E_\nu\right)}_{E_\tau} \times \left(\frac{2}{3}\right)$$
$$\sim \frac{1}{2} E_\nu$$
- $\langle (E_1 + E_2) \rangle \sim \frac{3}{4} E_\nu \sim$ rough measure of E_ν
- $\left.\begin{array}{l}\langle E_2 \rangle / \langle E_1 \rangle \sim 2/1 \\ > 1\end{array}\right\}$ for signal events

$\hookrightarrow$ cut to eliminate BG.

σ_ν, y from Gandhi et al.
- $\sigma_\nu \sim \sigma_{\bar{\nu}}$
- Cut on distance bet. 2 bangs > 0 (10 m). (to eliminate punch-through)

Backgrounds {events faking double bang}

- Leptonic Vertex. Most serious is

$\nu_\mu \xrightarrow[CC]{} \mu \longrightarrow$ travels ~ $O(100\,m)$

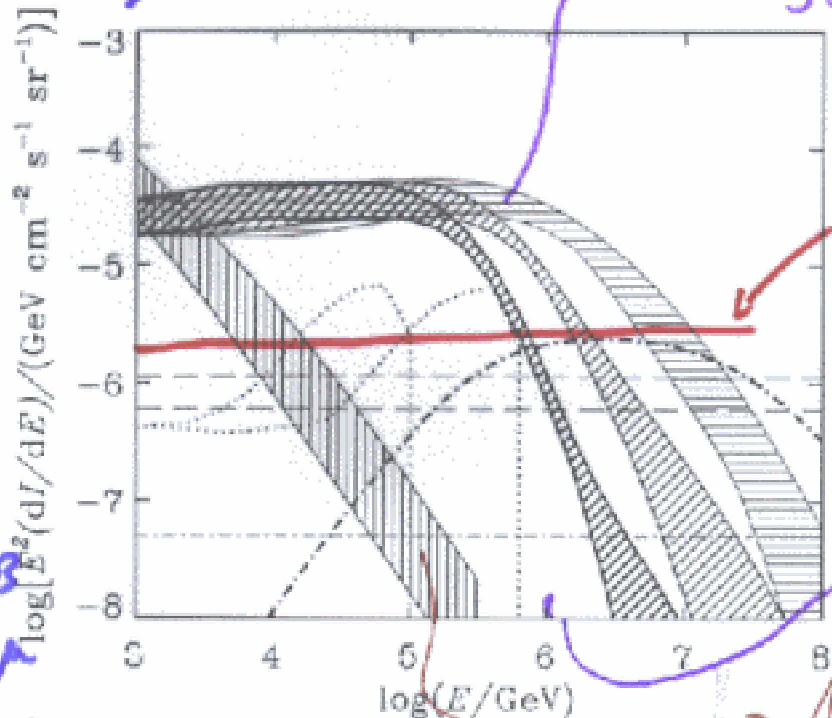
- without radiating
- a catastrophic brem. at the end
- looks like ν_τ double bang.

Rate estimate $\sim \left(\frac{m_e}{m_\mu}\right)^2 \left(\frac{100\,m}{R_\mu}\right)\left(\frac{\Delta E}{E}\right)$

$\sim 3 \cdot 10^{-3}$ (of ν_μ CC events)

- hadronic vertex:
  - $\nu_e + N \longrightarrow e + D_s(\text{diff}) \ldots$, $D_s \longrightarrow \tau \nu_\tau$
  - Rate $\sim 6 \cdot 10^{-3}\, \sigma_{CC} \longrightarrow B_{D_s} \longrightarrow \boxed{2.5 \cdot 10^{-4}}$
  - $E_{D_s} \sim \frac{1}{2} E_\nu$ possible $\Rightarrow$ $E_2/E_1 \sim O(1)$
  - $\nu_{\mu/e} + N \longrightarrow \nu + D_s/B$, $D_s/B \longrightarrow \tau$ $\sim O(10^{-3})$ & $E_2/E_1 \ll 1$

- $\Delta E_\nu \sim 1\text{-}10$ PeV
- Assuming $\nu_\mu : \nu_e : \nu_\tau \sim 2:1:0$ then
- $\nu_\mu - \nu_\tau$ (SK)



- Det ~1 KM3
- Det. Eff. ~100 %

expect
~1600 ν_τ DB
~1000 $\nu_\mu \to \mu$
~1800 showers
in 1 yr.

Figure 12: The expected diffuse $\nu_\mu + \bar{\nu}_\mu$ intensity at Earth. The hatched bands show the spread in results obtained using both spectrum (a) and spectrum (b), and models (a) to (e) of Morisawa *et al.* [56] and the model of Maccacaro *et al.* [57] for the luminosity function. Results are shown for b=1 (horizontal hatching), b=10 (thin oblique hatching) and b=100 (thick oblique hatching). An integration over a flat distribution in $\log x_1$ has been made for $10 < x_1 < 100$. Also shown: Stecker *et al.* [25,26] (chain curve), Sikora and Begelman [37] (dotted curves) for sources at $z = 0$ and 5, Biermann [60] (lower dashed line), and blazar contributions calculated by Stecker [26] (chain line), and Nellen et al. [61] (upper dashed line). The atmospheric neutrino intensity [58] is shown by the vertical hatched band: the upper curve corresponds to zenith angle $\theta = 90°$ and the lower curve corresponds to $\theta = 0°$.

ν_μ flux & spectrum from all AGN's.

· If individual ...
identified (& atm. SK NOT due to ν osc)
$\delta m^2 \sim 10^{-16}\,eV^2$ can be probed for large angles

· No significant matter effects en-route (unless δm^2 small).

· If $\delta m^2 \sim O(10^{-3})\,eV^2$

Then $P_{\alpha\beta} \simeq \frac{1}{2}\sin^2 2\theta$ etc.

$\left\langle \sin^2\left(\frac{\delta m^2 L}{4E}\right)\right\rangle \sim 1/2.$

$P_{\alpha\alpha} = \sum_i |U_{\alpha i}|^4$

$P_{\alpha\beta} = \sum_i |U_{\alpha i}|^2 |U_{\beta i}|^2$

$$\begin{pmatrix} N_\mu \\ N_\tau \\ N_e \end{pmatrix} = \begin{pmatrix} P_{\mu\mu} & P_{\mu\tau} & P_{\mu e} \\ P_{\tau\mu} & P_{\tau\tau} & P_{\tau e} \\ P_{e\mu} & P_{e\tau} & P_{ee} \end{pmatrix} \begin{pmatrix} N_\mu^\circ \\ N_\tau^\circ \\ N_e^\circ \end{pmatrix}$$

$\hookrightarrow$ Detector

$\hookrightarrow$ Source

- If $(N_\mu^\circ; N_\tau^\circ; N_e^\circ) \simeq (1, 1, 1)$
  $\Rightarrow (N_\mu, N_\tau, N_e) = (1, 1, 1)$
- Beam Dump $\Rightarrow (N_\mu^\circ; N_\tau^\circ; N_e^\circ) \simeq (2, \varepsilon, 1)$
  $\varepsilon << 1.$

Possible Choices for

$$U = \begin{pmatrix} U_{BM} \\ U_{TM} \\ U_{SMA} \\ \vdots \end{pmatrix}$$

$$U_{BM} = \begin{pmatrix} -1/\sqrt{2} & 1/\sqrt{2} & 0 \\ 1/2 & 1/2 & -1/\sqrt{2} \\ 1/2 & 1/2 & 1/\sqrt{2} \end{pmatrix}$$

$$U_{TM} = \begin{pmatrix} 1/\sqrt{3} & z/\sqrt{3} & z^2/\sqrt{3} \\ z/\sqrt{3} & 1/\sqrt{3} & z/\sqrt{3} \\ z^2/\sqrt{3} & z/\sqrt{3} & 1/\sqrt{3} \end{pmatrix}$$

$$U_{BM} \rightarrow P = \begin{pmatrix} \cdots & \cdots & \cdots \\ 1/4 & 3/8 & 3/8 \\ 1/4 & 3/8 & 3/8 \end{pmatrix}$$

$$U_{TM} \rightarrow P = \begin{pmatrix} 1/3 & 1/3 & 1/3 \\ 1/3 & 1/3 & 1/3 \\ 1/3 & 1/3 & 1/3 \end{pmatrix}$$

$$U_{SMA} \rightarrow P \simeq \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1/2 & 1/2 \\ 0 & 1/2 & 1/2 \end{pmatrix}$$

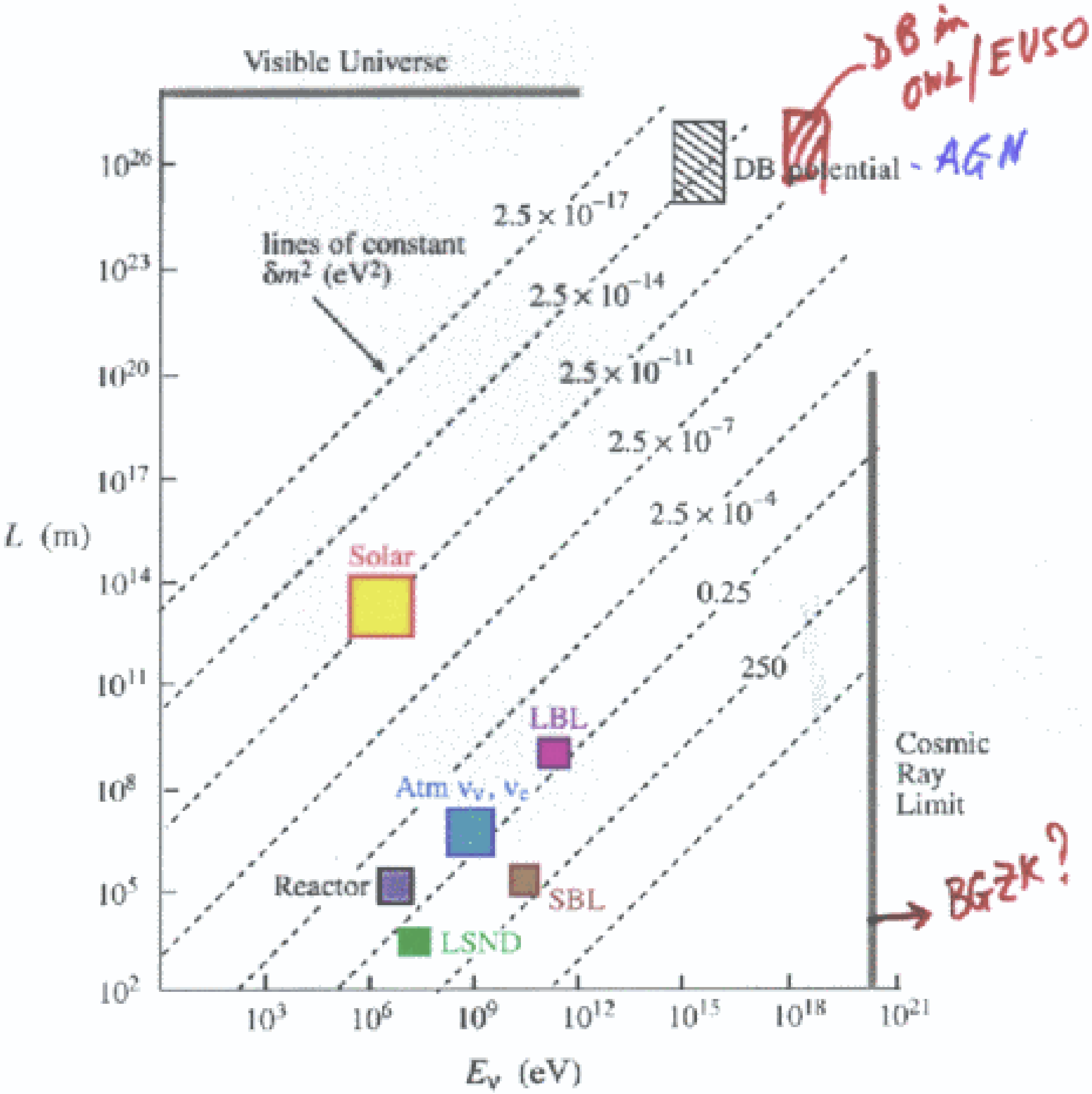
$$U_{F-X} \rightarrow P = \begin{pmatrix} 5/9 & 2/9 & 2/9 \\ 2/9 & 7/18 & 7/18 \\ 2/9 & 7/18 & 7/18 \end{pmatrix}$$

But for $\Phi_0 \simeq \frac{1}{3}\begin{pmatrix} 1 \\ 2 \\ 0 \end{pmatrix}$

$$\Phi = P\Phi_0 = \frac{1}{3}\begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

in all cases.

δm^2 sensitivity (of all possible experiments)



• Measuring $\sigma(\nu N)_{cc}$ with ν Telescopes.

$$\sigma(\nu N)_{cc}\,(SM) \sim 5.53 \cdot 10^{-36} \left(\frac{E_\nu}{\text{GeV}}\right)^{0.363} \text{cm}^2$$

$$\sigma_{NC}/\sigma_{CC} \sim 0.4$$

Proposals to account for CR events above GZK cut-off

BY . enhanced $\sigma(\nu N)_{cc}$ as ν events

. large $\sigma(\nu_i N \to \nu_j)_{NC}$ F(NC ν events

. $\sigma(\nu N)$ can rise by order of

(Unitarity) ⇒ magnitude in 2-20 PeV Range.

• Zenith angle distribution of ν's in $E_\nu \sim$ PeV range ⇒ attenuation

⇒ Handle on $\sigma_{\nu N}$ (for known Earth Density profile)

Detecting Relic ν's

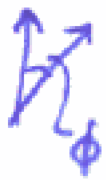
$T_\nu \sim 1.9^\circ K \qquad n_\nu \sim 110/cc$ per flavor

$j_\nu \sim 10^{13}\ cm^{-2} s^{-1} \longrightarrow 10^{9}\ cm^{-2} s^{-1}$

$(m_{\nu_i} \sim 0) \qquad (m_\nu \sim O(eV))$

Three Classes of "Viable" Proposals

- Electron Spin Rotation (Stodolsky 1975)



axial current coupling

$\Rightarrow \quad \delta E \sim 2\sqrt{2}\, G_F\, \underline{J} \cdot \underline{v}$

$v \sim 300\ km/s, \quad n_\nu \neq n_{\bar{\nu}}$

$\Rightarrow \quad \delta\phi \sim 0.02''$ per year.

- "Volume" Effect on macroscopic object

(Schwarzman et al. 1982)

· size $\sim a \sim \lambdabar_\nu \approx d$ = interstitial distance

· νN scatt. $\rightarrow$ recoil $\rightarrow$ acceleration

$a \propto N_A^2\, \sigma_0\, v_\nu\, n_\nu \ldots\ldots \quad (m_\nu \neq 0)$

(Hagmann 1999) $\qquad \sim 10^{-23}\ cm/sec^2$ (even with clustering) telescopes

- $\nu_{AGN} + \nu_{Relic} \longrightarrow Z \longrightarrow$ jets.

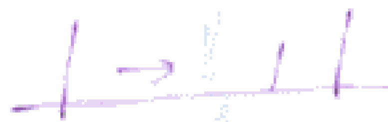
(Tom Weiler's Talk)

Doing Cosmology with Neutrinos

{Stodolsky
Weiler, Simmons, Learned, SP.}

- ν Sources at Cosmological Distance (AGN's . . .)
- Observe ν-pulses from them
- Measure Timing & Flavor Mixes.

- Pulse Spreading 

- Pulse Separation 

- Change in Flavor Mix

All depend on:

$$f = z/H\left[1 - \frac{(3+q)}{2} z \ldots\right]$$

- Spreading:

$$\Delta t = f \frac{1}{2} m^2 \left(\frac{1}{E^2} - \frac{1}{E'^2} \right)$$

- Separation:

$$\Delta t = f \frac{1}{2} \left(\frac{m_1^2 - m_2^2}{E^2} \right)$$

- Change in Flavor Mix:

$$P_{\alpha\beta} = \sin^2 2\theta \sin^2 \phi$$

$$\phi = f \left(\frac{\delta m^2}{4E} \right)$$

With a few events,

measure Δt and/or ϕ

If δm^2 known $\Rightarrow$ Know f

$\Rightarrow$ information on z, H and q.

$\Rightarrow$ Obs. of ϕ contains cosmological info.

If $\delta m^2, \theta$ known, flavor ratios from diff sources can fix z, H & q_0

(<u>without</u> a distance measurement!)

. Since all ~~data~~ info used is microscopic no worries about evolution, standard candles .. - - - -

. First ever confirm. of red-shift using particles rather than light

ν Red Shifts $\equiv$ γ Red Shifts ?

. Can measure z, H, q_0 without knowing distance

. Practical problems!!

. $\delta m^2 < 10^{-16} eV^2$. $U_{e3} \neq 0$ . . . .

(else $\sin^2\phi \sim 1/2$).

Typical $\delta t \sim 50\ \mu sec/MPC$ per (for GeV-E)

$\sim$ millisecond @ 10^3 MPC

for $\delta m^2 \sim (eV)^2$

Smaller than Production

But If · Reheating Temp $\sim O(MeV)$ (Kawasaki et al)

(Giudice, Kolb, Riotto, Semikoz, Tkachev) · $m_{\nu_\mu} \sim m_{\nu_c} \sim O(KeV)$

· warm dark matter to solve structure... (Bode, Ostriker, Turok)

$\delta t(\nu_\mu - \nu_e)$ OR $\delta t_{spread} \sim 50$ sec/MPC

Easily Detectable

For SN @ 10 KPC, $E \sim 10$ MeV, $m_{\nu_\mu} \sim O(KeV)$

gives $\Delta t(\nu_\mu - \nu_e) \sim O(1000\ sec)$

AND NOW FOR

SOMETHING

COMPLETELY

DIFFERENT

Neutrinos & SETI

(… Learned, S.P)

- Need for standards (time, …) for advanced technologies
  e.g. VLBI orbiting telescopes need accurate timing data over v.L. Distances.
- Local clocks need to exchange timing data to remain synchronized.

- Need
  - stable clocks of highest possible precision
  - fast processes for transmitting & recieving markers.
  - form of radiation to carry faithfully data over large distances.

- Currently known fastest process
  z decay: $\tau_z \sim 10^{-25}$ s.

If a Civilization is using this technique at a distance of

$R \sim$ few KPC

Then in a KM3 detector get a few events p. year.

$\left[E_\nu = \frac{1}{2} \frac{m_Z}{2}\right]$ ($\nu_e \longrightarrow$ showers (no ATM BG)).

Power Requirements at Source

$\sim$ approx. Solar Luminosity

$\sim 10^{45}$ eV/sec

Would this have been already seen as a "Dyson shell" (in IR)?

Maybe, Maybe Not. (50,000 or more IR sources).

Fourier Analysis in time : . Reduce BG

. Learn timing of pulses.

[illegible]

$\equiv$ FIELD OF DREAMS

If we build them:

The neutrinos,

They will Come!!