LYMAN /BALMER LINE

LEVELS OF H-ATOM

GIROMAGNETIC RATIO

$g_e \quad , (g_{e,\mu} - 2)$

SM PARAMS FAITH!!

PRECISE MEASMS

$\theta_w, \alpha, G_F, \alpha_s \ldots$

MASSES, MIXING ANGLES

NO CLUE!

LEPTONS CLEAN

Δm_ν^2 OBSERVED BY

ATMOSPHERIC, SOLAR

ν - DETECTORS

ARE AT THE SCALE

$\sim$ EXPECTED FOR m_ν'S

IN (SUPERSYMETRIC)

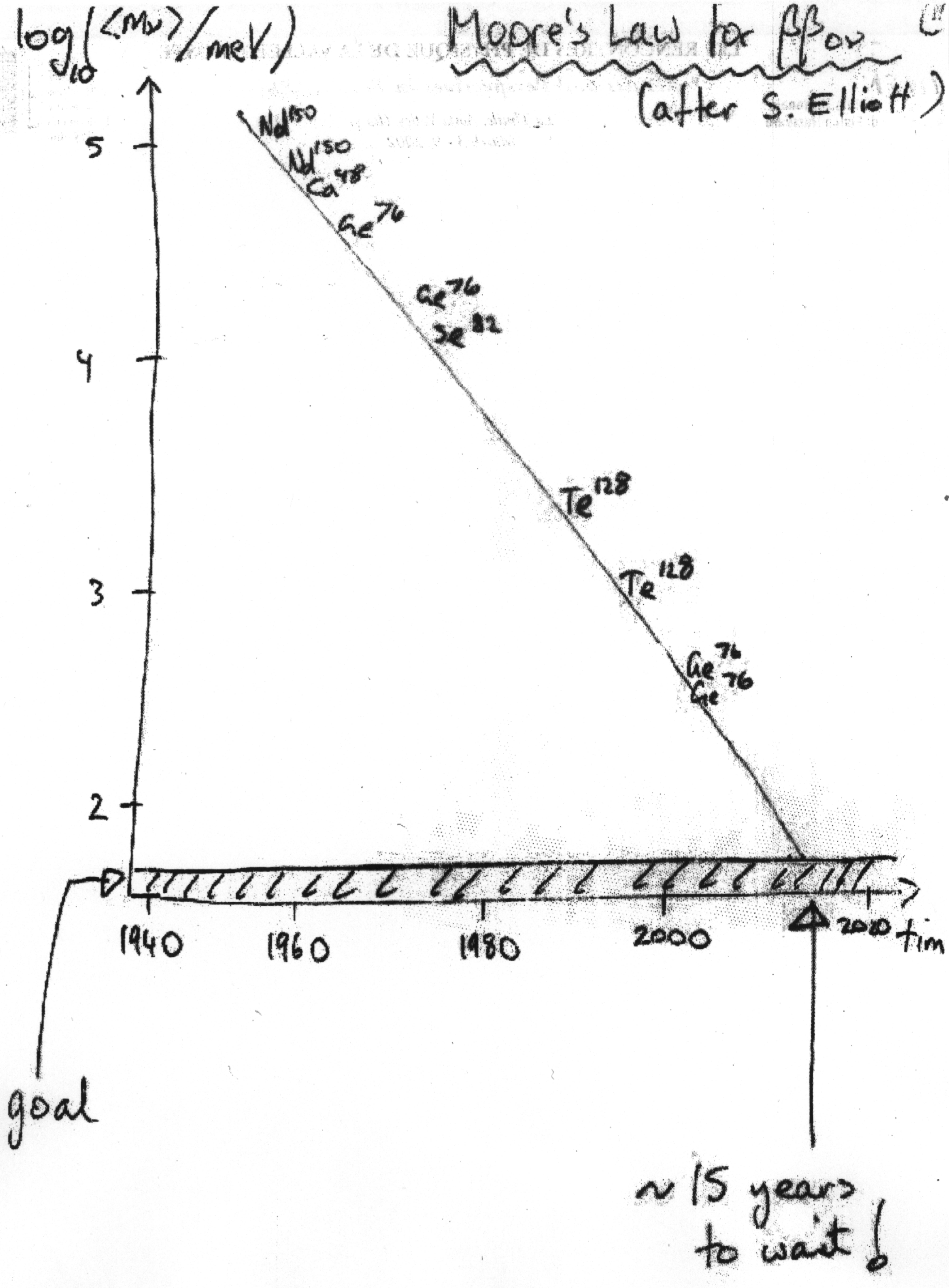
GRAND

UNIFIED

THEORIES

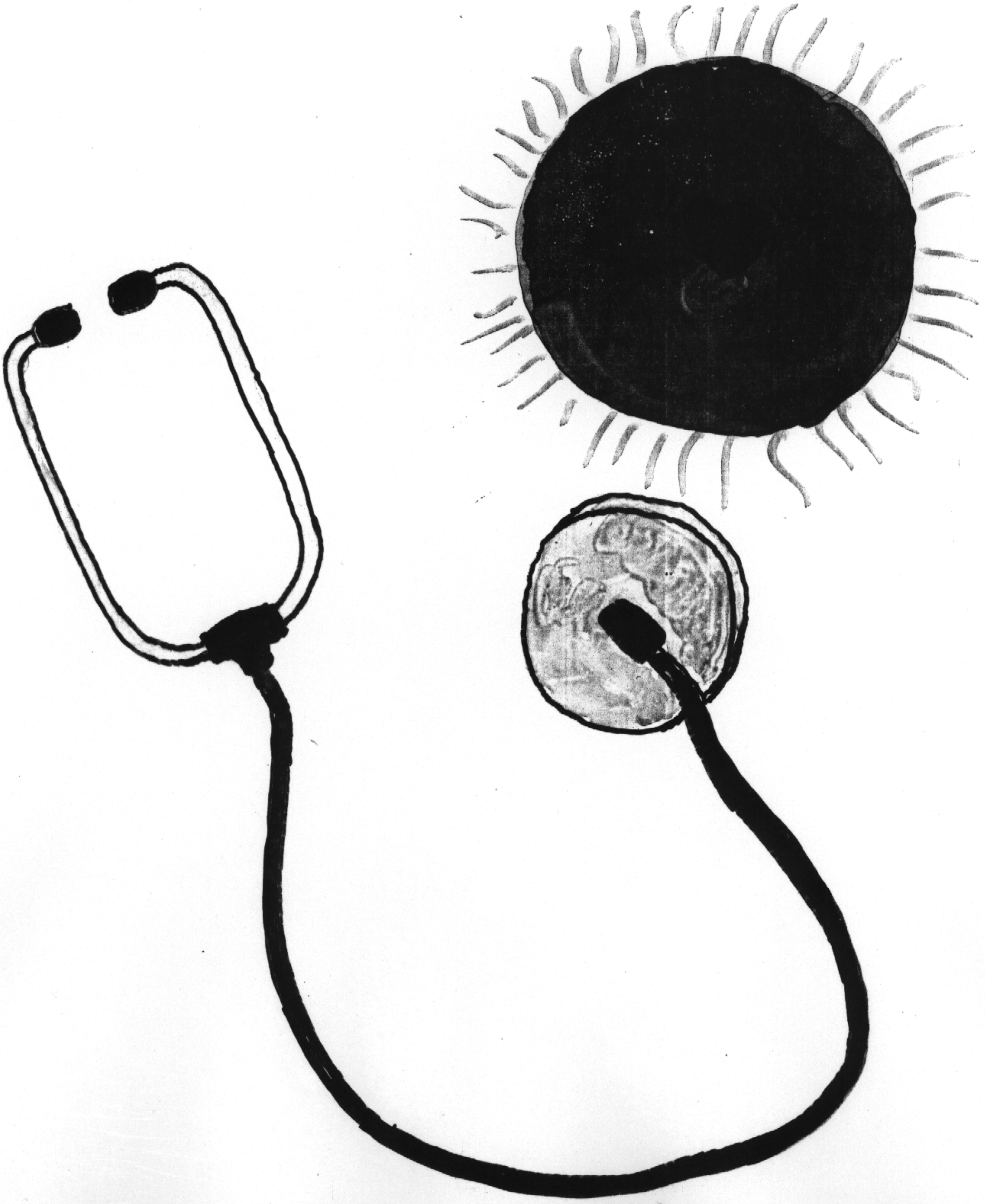
Moore's Law for $\beta\beta_{0\nu}$

(after S. Elliott)

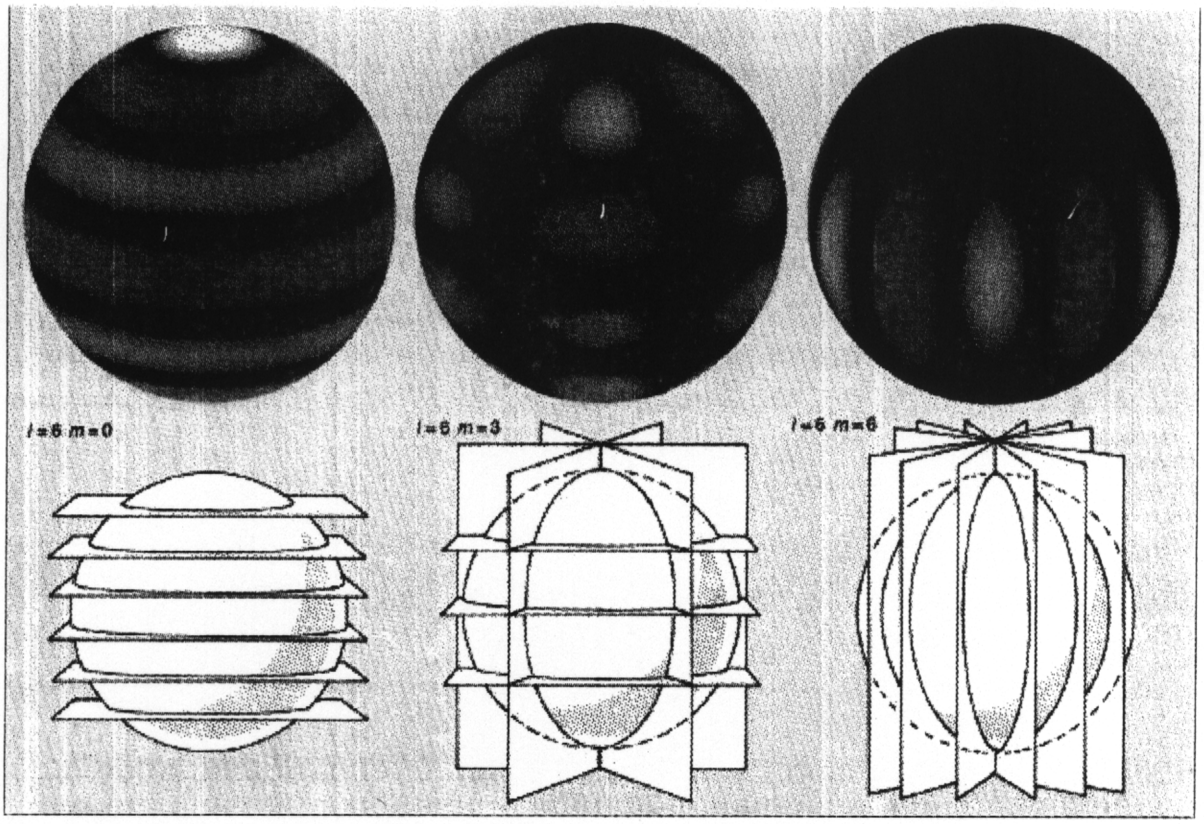


$$\langle m_\nu \rangle \equiv \sum |U_{ei}|^2 m_i e^{2i\delta_{ei}}$$

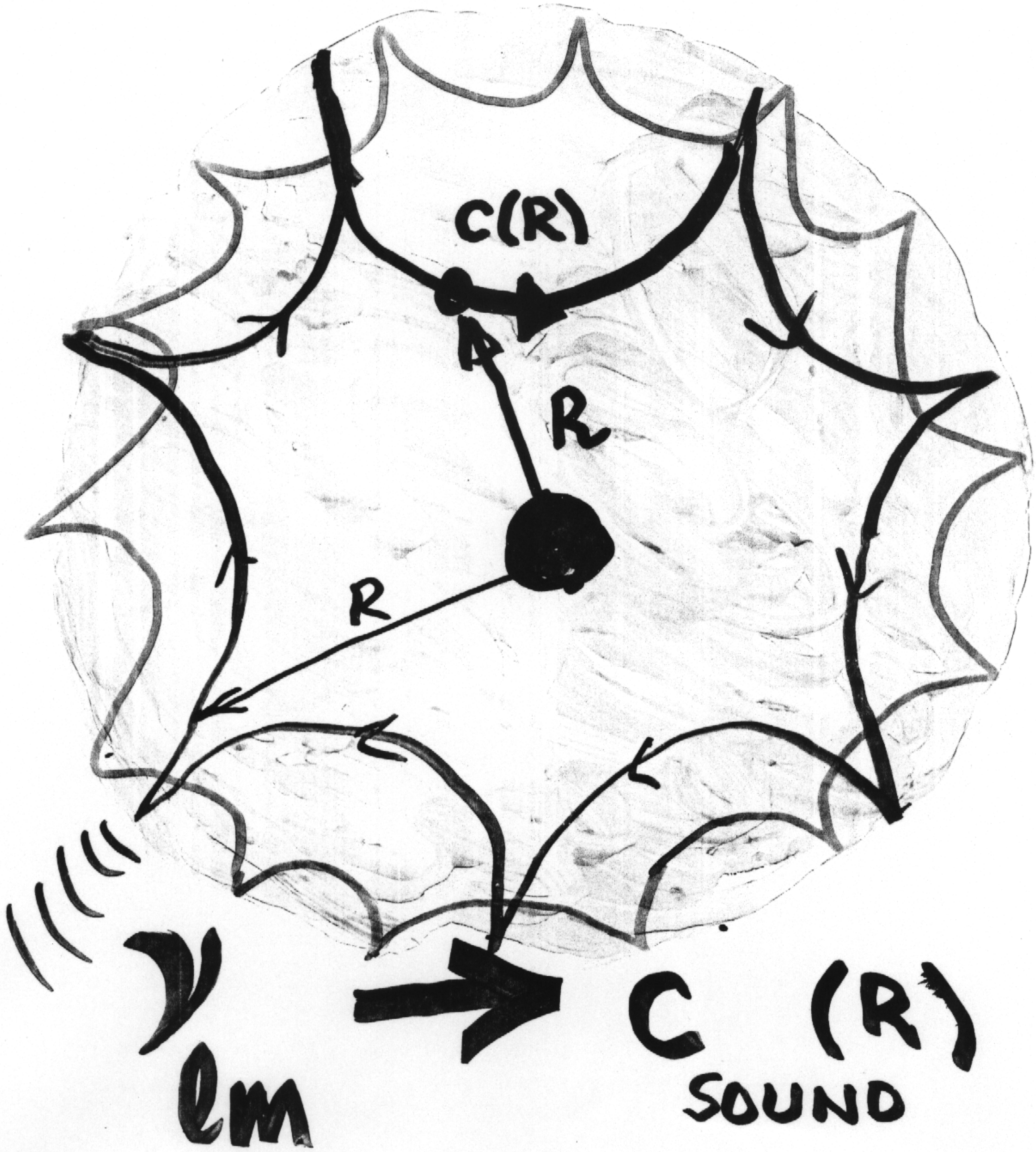
LISTENING TO THE SUN'S HEARTBEAT



SOLAR CARDIOLOGY


l=6 m=0
l=6 m=3
l=6 m=6

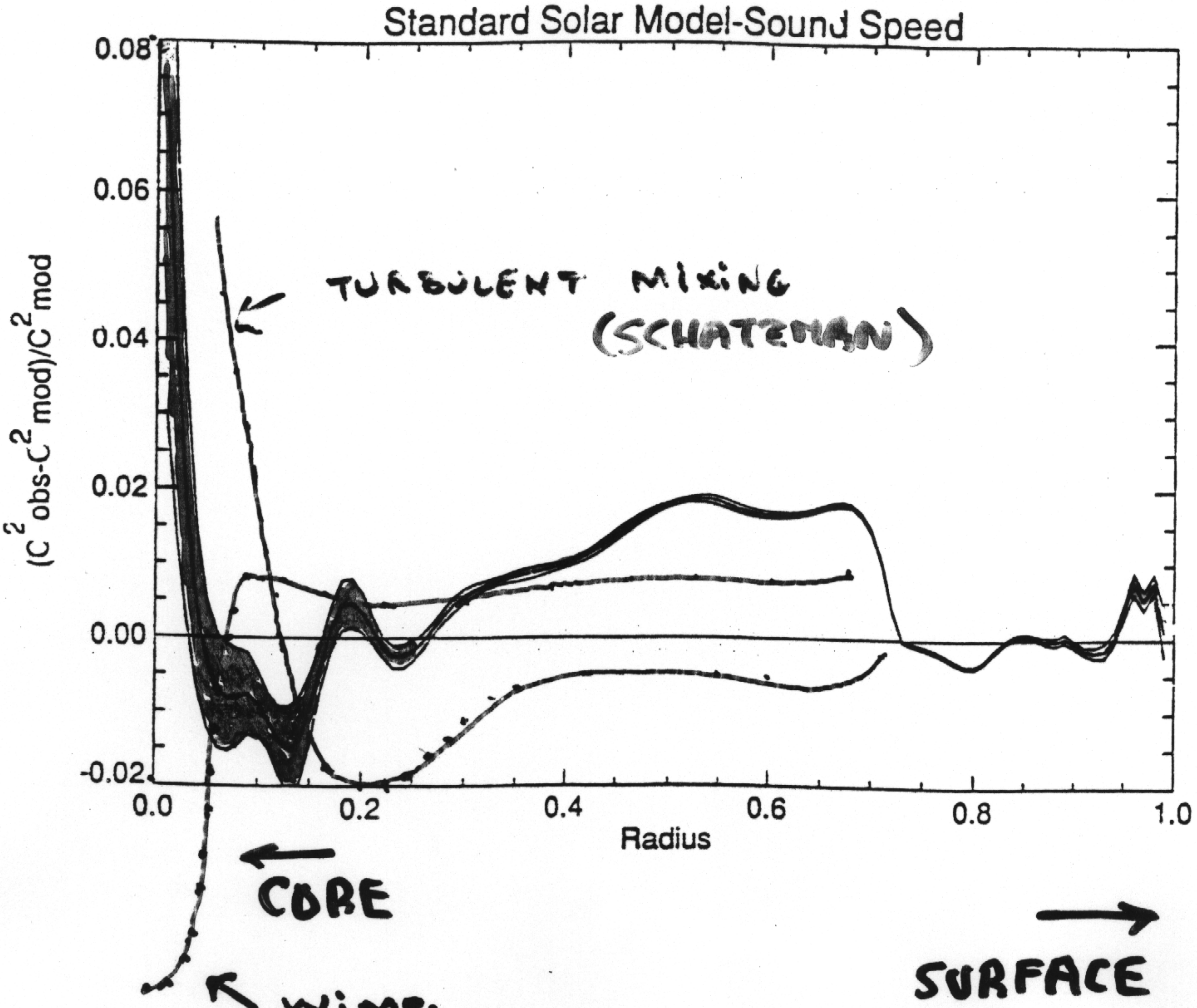
"INVERSION"



$$\nu_{em} \rightarrow C_{SOUND}(R)$$

$$c \sim \sqrt{\frac{T}{\mu}}$$

$\frac{\Delta c^2}{c^2}$ FOR PRESSURE WAVES



← 'GRAVITY' WAVES HOPEFULLY OBSERVABLE IN NEAR FUTURE

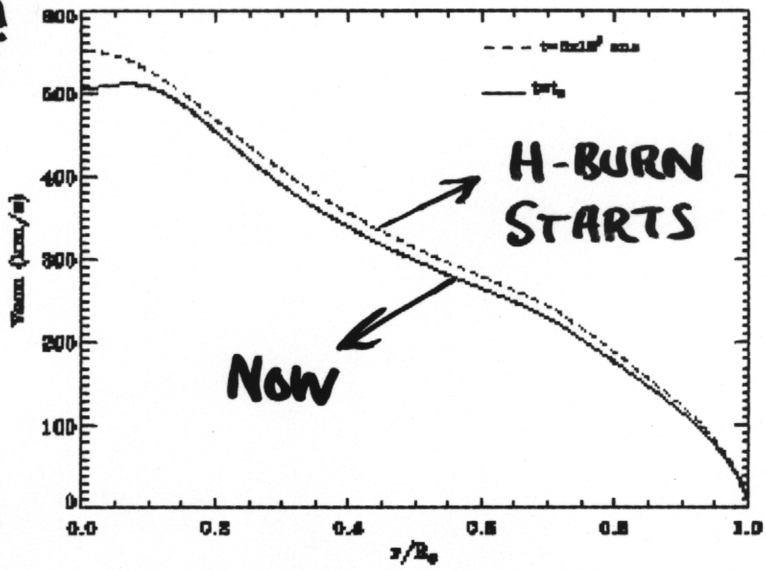


Fig. 2. Evolution of the sound speed along the hydrogen burning

TURCH-CHIEZE et al.

$$\phi_{\nu_\odot} = \phi^{pp}_{\nu_\odot} + \phi^{^7Be}_{\nu_\odot} + \phi^{^8B}_{\nu_\odot} + \phi^{CNO}_{\nu_\odot}$$

SK : $\phi^{^8B}_{\nu_e} \cong 2.4\times10^{6}\ cm^{-2}\cdot s$ if $\nu_\odot = \nu_e$

$$\frac{\Phi^{^8B}_{\nu_e}(SK)}{\Phi^{^8B}_{\nu_e}(SSM)} = 0.42 \pm \qquad ? \qquad \frac{\phi^{^8B}_{\nu_e}(SNO)}{\phi^{^8B}_{\nu_e}(SSM)} = 0.35 \pm$$

$$p + {}^7Be \rightarrow {}^8B + \gamma \rightarrow \Phi^{^8B}_{\nu_e}$$

$$e^- + {}^7Be \rightarrow \nu_e + {}^7Li \rightarrow \Phi^{^7Be}_{\nu_e}$$

⇒ Assume

Also:

$$\frac{\phi^{^7Be}_{\nu_\odot}}{\phi^{^7Be}_{\nu_e}(SSM)} = 0.42 - 0.35$$

$$\Rightarrow \langle\sigma v\rangle_{Cl} \approx 2.85\ SNU - 2.38\ SNU$$

Observed 2.55±0.25 SNU

Observed: $\langle\sigma v\rangle_{Ga} \approx \underset{pp}{72} + 0.4(\underset{^8B}{6} + \underset{^7Be}{28}) \approx 86\ SNU$

Predicted:

SAGE
GALLEX } $\dfrac{\langle\sigma v\rangle}{\text{Efficiency}} \approx \dfrac{78}{0.9\pm0.12} \approx 87\ SNU$

$\uparrow$ ~ 0.91±.12

Cr callibration experiments

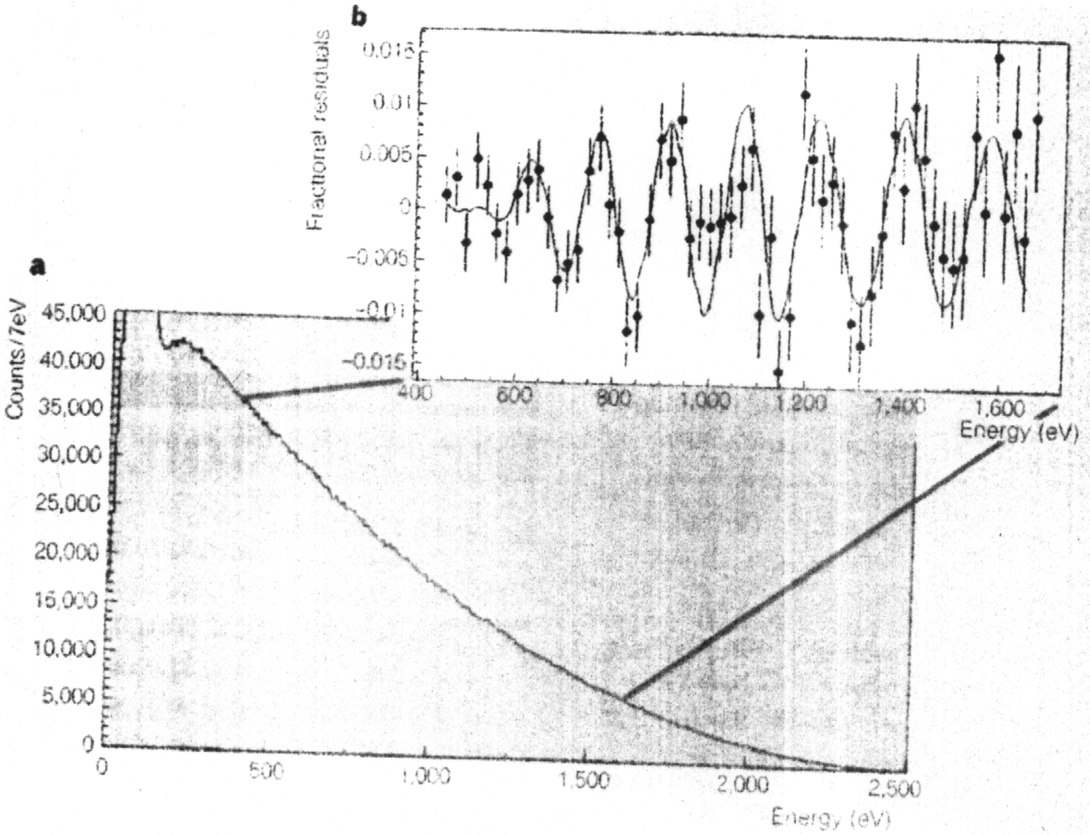


Figure 2 The overall shape and fine detail of the ^{187}Re β-decay spectrum measured by Gatti *et al.*[1]. a, The complete β-spectrum of ^{187}Re. b, β-environmental fine structure, which is expressed as a fine ripple on top of the standard β-spectrum. The smooth line shows the predicted shape of the BEFS spectrum. At low energies, the ripples are too close together to be resolved by the detector, and at high energies the oscillations become negligible.

^{187}Re β decay

Q ~ 2.5 keV

The IMPACT of SNO

D_2O

D_2O

Neutrino Detection Modes

Elastic Scattering:

$\nu_x + e^- \rightarrow \nu_x + e^-$

5 MeV threshold

good correlation with Sun direction

~1.4 events/day †

Charge Current:

$\nu_e + d \rightarrow p + p + e^-$

$Q = -1.442\text{MeV}$

5 MeV threshold

F-B asymmetry with Sun direction

~12.7 events/day †

Neutral Current:

$\nu_x + d \rightarrow \nu_x + p + n$

$Q = -2.2\text{MeV}$

~ 5.5 events/day ‡

† Assumes ~50% SSM

‡ Assumes ~50% SSM and 40% capture efficiency

e.g: BILENKI

ROUGH ANALYSIS

$x = e + \mu + \tau$

SK MEASURES ONLY ES

1258 days ; ~ 18464 events

$$R^{ES} = \langle\sigma(\nu_e e)\rangle \Phi^{ES}_{\nu_x}$$

$$\Phi^{ES}_{\nu_x} \equiv \Phi^{ES}_{\nu_e} + \frac{\langle\sigma(\nu_\mu e)\rangle}{\langle\sigma(\nu_e e)\rangle} \Phi^{ES}_{\nu_{(\mu+\tau)}} \quad ①$$

$$\Phi^{ES}_{\nu_x}\Big|_{SK} = (2.32 \pm 0.03 \pm 0.08) \frac{10^6}{cm^2 s} \quad ②$$

SNO ES

Nov 99 → Jan 01 ~ 106±15 events

$$\Phi^{ES}_{\nu_x}\Big|_{SNO} = (2.39 \pm 0.34 \pm 0.16) \frac{10^6}{cm^2 s}$$

$\boxed{\text{SNO}}$ CC!! (ONLY ν_e)

$\nu_e + d \to e p p$ 975 ± 39 events

$$R^{CC} = \langle \sigma(\nu_e d) \rangle \, \phi_{\nu_e}^{CC}$$

(th)

③ $$\phi_{\nu_e}^{CC}\Big|_{SNO} = (1.75 \pm 0.07 \pm 0.12 \pm 0.05) \frac{10^6}{cm^2 s}$$

$$\phi_{\nu_e}^{CC} = \langle P(\nu_e \to \nu_e) \rangle_{CC} \, \phi_{\nu_e}^{\odot} \; ; \; \phi_{\nu_e}^{ES} = \langle P_{ee} \rangle_{ES} \, \phi_{\nu_e}^{\odot}$$

PROBABLY EQUAL : NO SPECTRAL DISTORS.

$$\Rightarrow \phi_{\nu_e}^{CC} = \phi_{\nu_e}^{ES}$$

① + ② + ③ + $\sigma(\nu_\mu e)/\sigma(\nu_e e)$

$$\Rightarrow \phi_{\nu_{\mu+\tau}}^{\otimes} = (3.70 \pm 1.13) \, 10^6/cm^2 s$$

$\nu_e \to \nu_{\mu+\tau}$ SEEN $> 3\sigma$!!

BONUS:

$$\phi^{\otimes}(\nu_{e+\mu+\tau}) = (5.44 \pm 0.99)\frac{10^6}{cm^2 s}$$

SSM [BP2000]

$$\phi^{\odot}(\nu_e) = 5.05 \; 10^6/cm^2 s$$

The

SOLAR NEUTRINO PROBLEM

was NOT a

NEUTRINO SOLAR PROBLEM

ν-OSCS SOLVE THE DECADES OLD

$\nu_{\odot}$ PUZZLE

$$\nu_e(0) \rightarrow \nu_e(x)$$

$$|\langle \nu_e(x) | \nu_e \rangle|^2 < 1$$

DISAPPEARANCE SEEN VIA CC $\nu_e \rightarrow e$
DEARTH

$$|\langle \nu_e(x) | \nu_{\mu,\tau} \rangle|^2 > 0$$

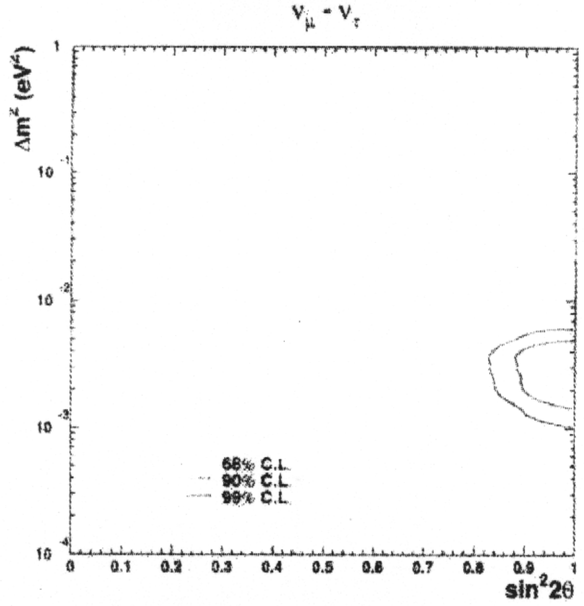
APPEARANCE SEEN VIA NC $\nu \rightarrow \nu$
> EXPECTED FROM CC
THAT ARE SEEN

CC FLUX DEPLETED A CERTAIN AMOUNT
NC FLUX AS IF NOTHING HAD HAPPENED

The "THING" INTO WHICH ν_e
OSCILLATES IS $\nu_{\mu,\tau}$

NO WAY AROUND

Result of combined fit
FC,PC,UpMu



Δm^2
$=$
$3.2\, 10^{-3}$
eV^2

Result of Oscillation Analysis (FC + PC + Upmu)

- Assuming $\nu_\mu \leftrightarrow \nu_\tau$ oscillation

Best fit :

χ^2_{min} = 135.3 / 152 d.o.f
at ($\sin^2 2\theta, \Delta m^2$) = (1.01 , 3.2×10^{-3} eV^2)
(Including unphysical region)

χ^2_{min} = 135.4 / 152 d.o.f
at ($\sin^2 2\theta, \Delta m^2$) = (1.00 , 3.2×10^{-3} eV^2)
(Physical region)

- Assuming null oscillation

$\chi^2 =_{min}$ = 316.2 / 154 d.o.f

$\sin^2(2\theta) \approx 1$

! MAXIMAL MIXING

$\nu_\mu \approx \frac{1}{\sqrt{2}}(\nu_2 + \nu_3)$

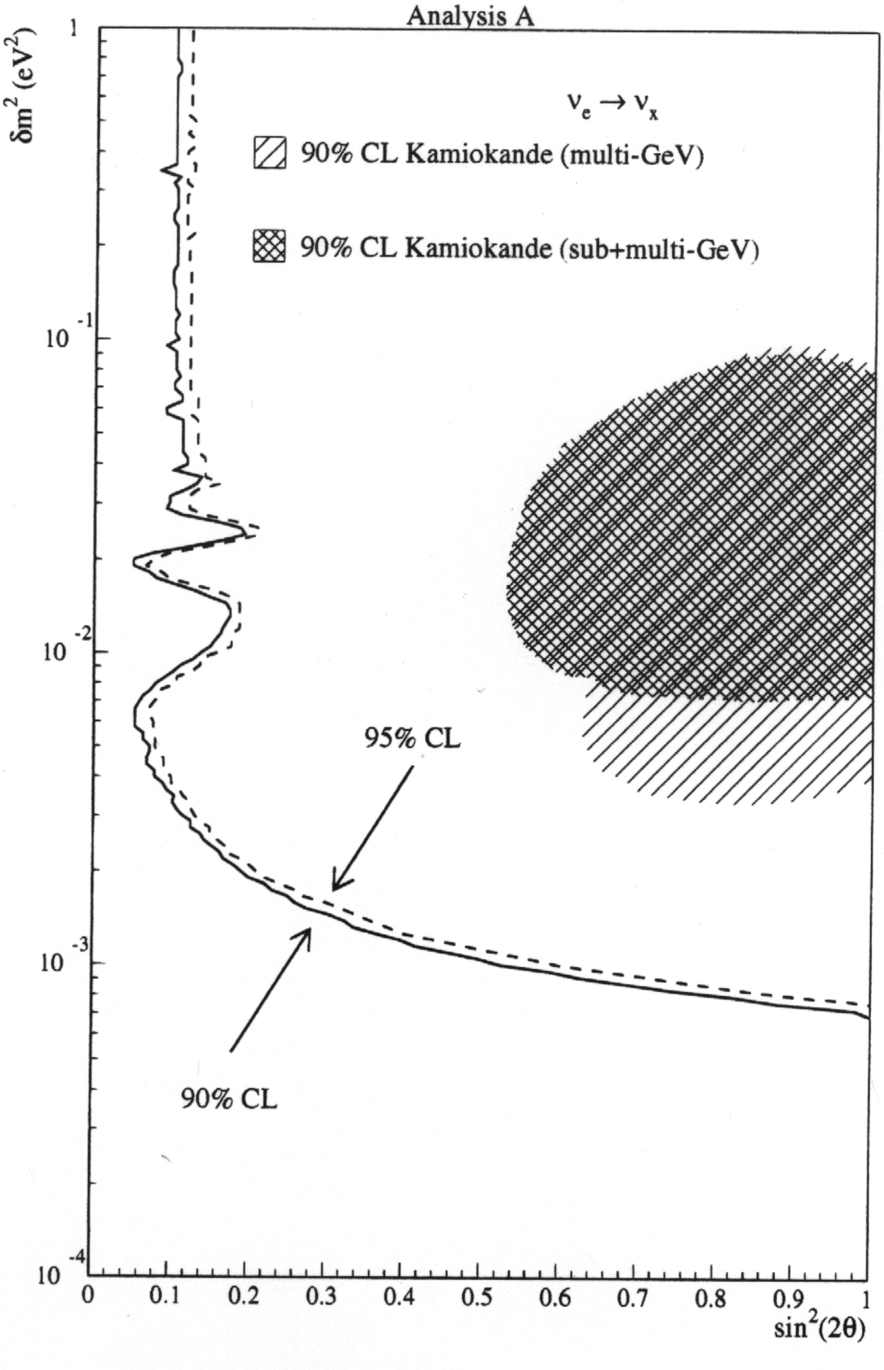


Figure 9: Exclusion plot for the oscillation parameters based on the absolute comparison of measured vs. expected positron yields.

TO ~ 95% C.L.

WE LIVE IN THE BEST of ALL WORLDS

$$\underset{\substack{\text{is}\\ \sim\text{BIMAXIMAL}}}{U} \sim \begin{pmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & S_{13} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \end{pmatrix} * CP(\delta)$$

IFF ⊙ LMA SURVIVES

Δm^2_{12} LARGE ENOUGH FOR EVEN δ TO BE MEASURABLE (CONSTRAINABLE) AT A ν-FACTORY

The
FUTURE
¿?

$\nu_{\odot}$

[SSM]

[PP CYCLE]

$pp \rightarrow {}^{2}H\,e^{+}\,\nu$

$pD \rightarrow {}^{3}He\,\gamma$

86%

${}^{3}He\,{}^{3}He \rightarrow {}^{4}He\,pp$

14%

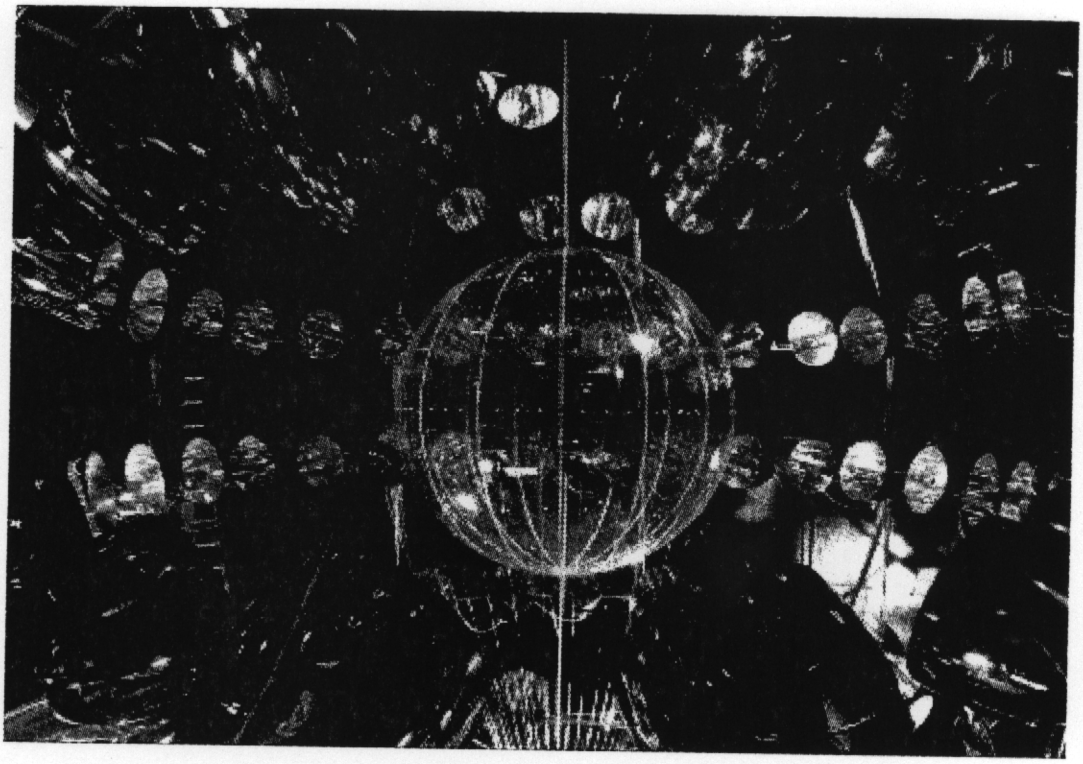
${}^{3}He\,{}^{4}He \rightarrow {}^{7}Be\,\gamma$

14%

0.01%

T!

${}^{7}Be\,e \rightarrow {}^{7}Li\,\nu$	${}^{7}Be\,p \rightarrow {}^{8}B\,\gamma$
${}^{7}Li\,p \rightarrow {}^{4}He\,{}^{4}He$	${}^{8}B \rightarrow 2[{}^{4}He]\,e^{+}\,\nu$



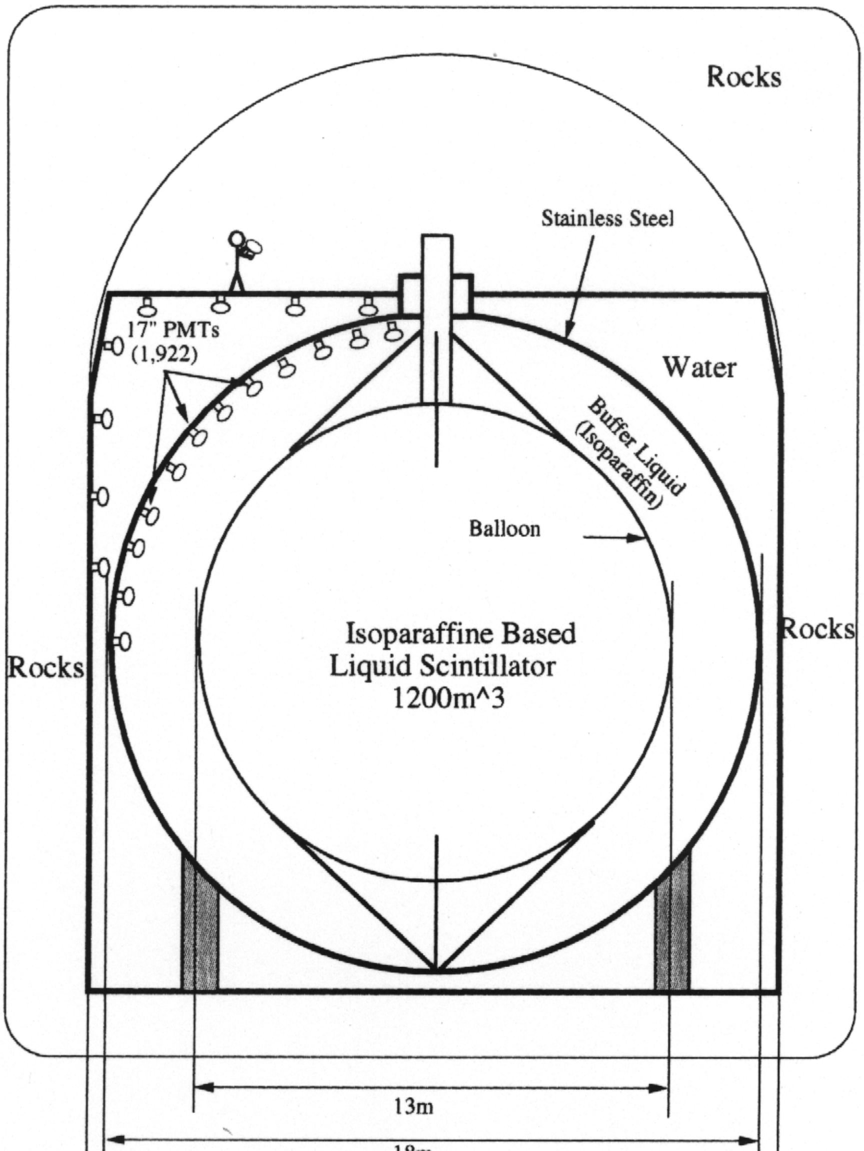


Figure 1: Schematic view of the KamLAND detector.

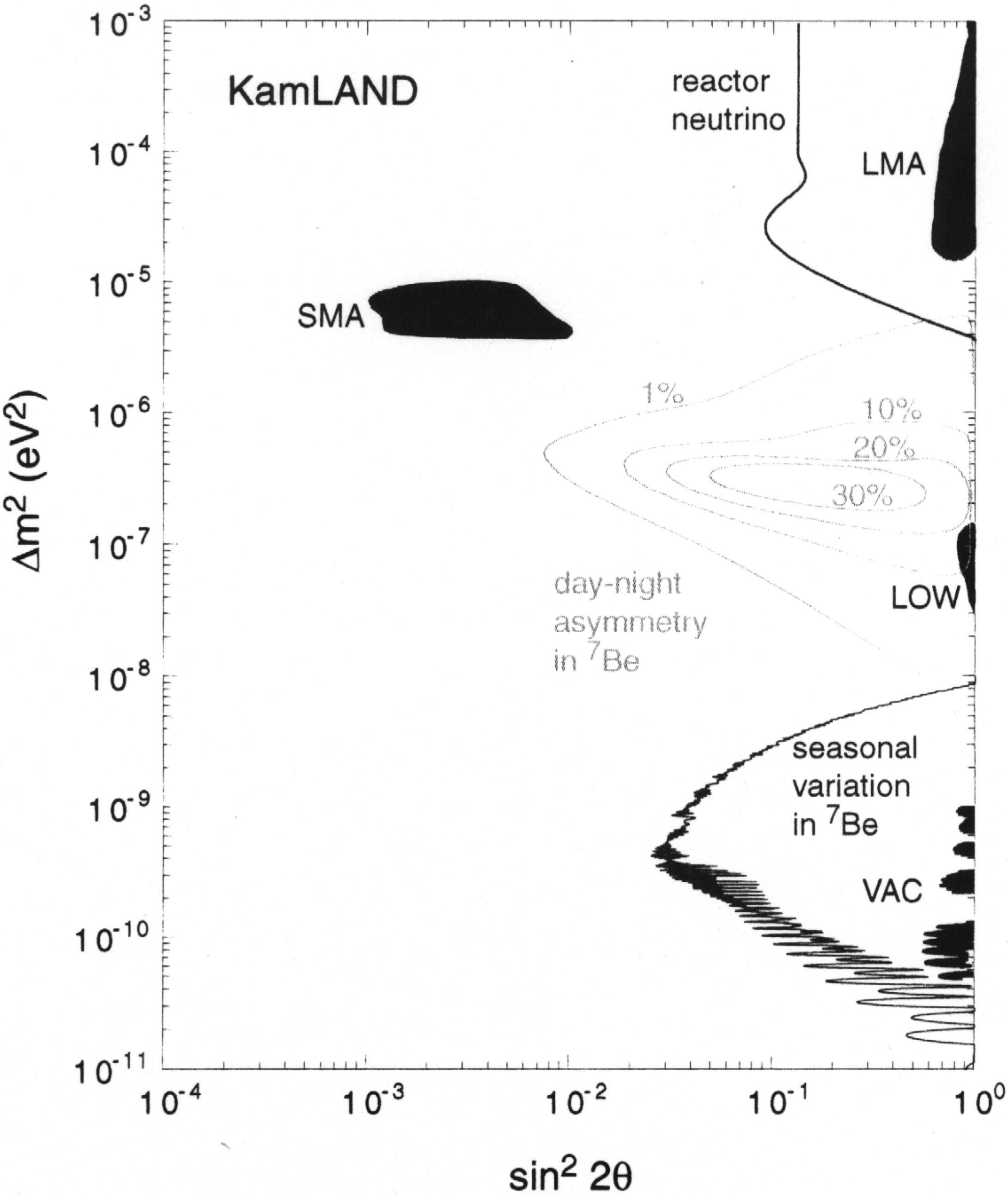


Figure 4: Various solutions to the solar neutrino problem and the sensitivity of KamLAND to them from the reactor neutrino experiment, and *if possible*, from the study of ^{7}Be solar neutrinos. The LMA solution is covered by the reactor neutrino experiment, the LOW solution by day-night asymmetry in the ^{7}Be neutrino flux, and the VAC solution by the seasonal variation in the ^{7}Be neutrino flux. The potential impact of KamLAND on the SMA solution is shown in Fig. 12. The seasonal variation sensitivity region is shown for 95% CL, with statistical errors only. The potential reactor neutrino exclusion domain is shown for 90% CL. The preferred regions for LMA, SMA, LOW, and VAC are 90% CL.

LONG BASELINE

ACCELERATOR EXPERIMENTS

ON : K2K (250 km)

NEAR DETECTOR : NC π^0 PRODUCT

(CALIBR. for ∃ SK "ν_τ" EVENTS)

SOMETIME IN THE FUTURE

(732 km)

MINOS : FERMILAB TO SOUDAN MINE

ν_μ CC ; ν NC NEAR, FAR DETECTORS

CNGS

ICARUS : LIQUID ARGON

"BUBBLE CHAMBER LIKE"

OPERA : EMULSIONS

$\nu_\mu \to \nu_\tau \to \tau$ SEARCH

MINOS

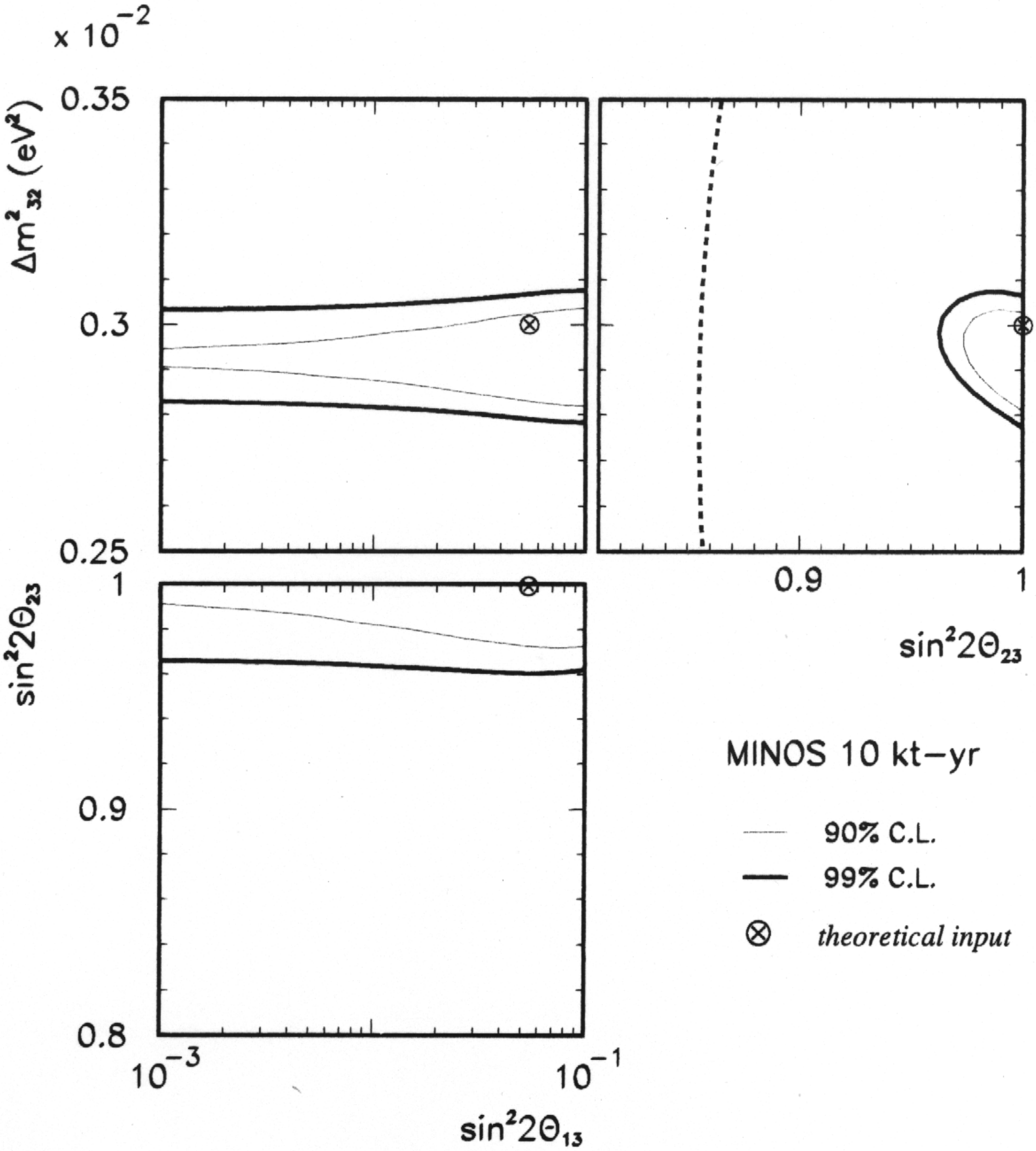


FIG. 2. Expected allowed regions for MINOS at the 90% and 99% C.L. using $\Delta m^2_{32} = 3 \times 10^{-3}$ eV^2, $\Delta m^2_{21} = 5 \times 10^{-5}$ eV^2, $\sin^2 2\theta_{23} = 1$, $\sin^2 2\theta_{12} = 0.8$ and $\sin^2 2\theta_{13} = 0.05$ as the theoretical input for which data was simulated. The dashed line is the Super-Kamiokande allowed region at the 99% C.L.. Here and in other figures, the best fit point is very close to the theoretical input and is consequently not shown.

BARGER et al.

ICARUS

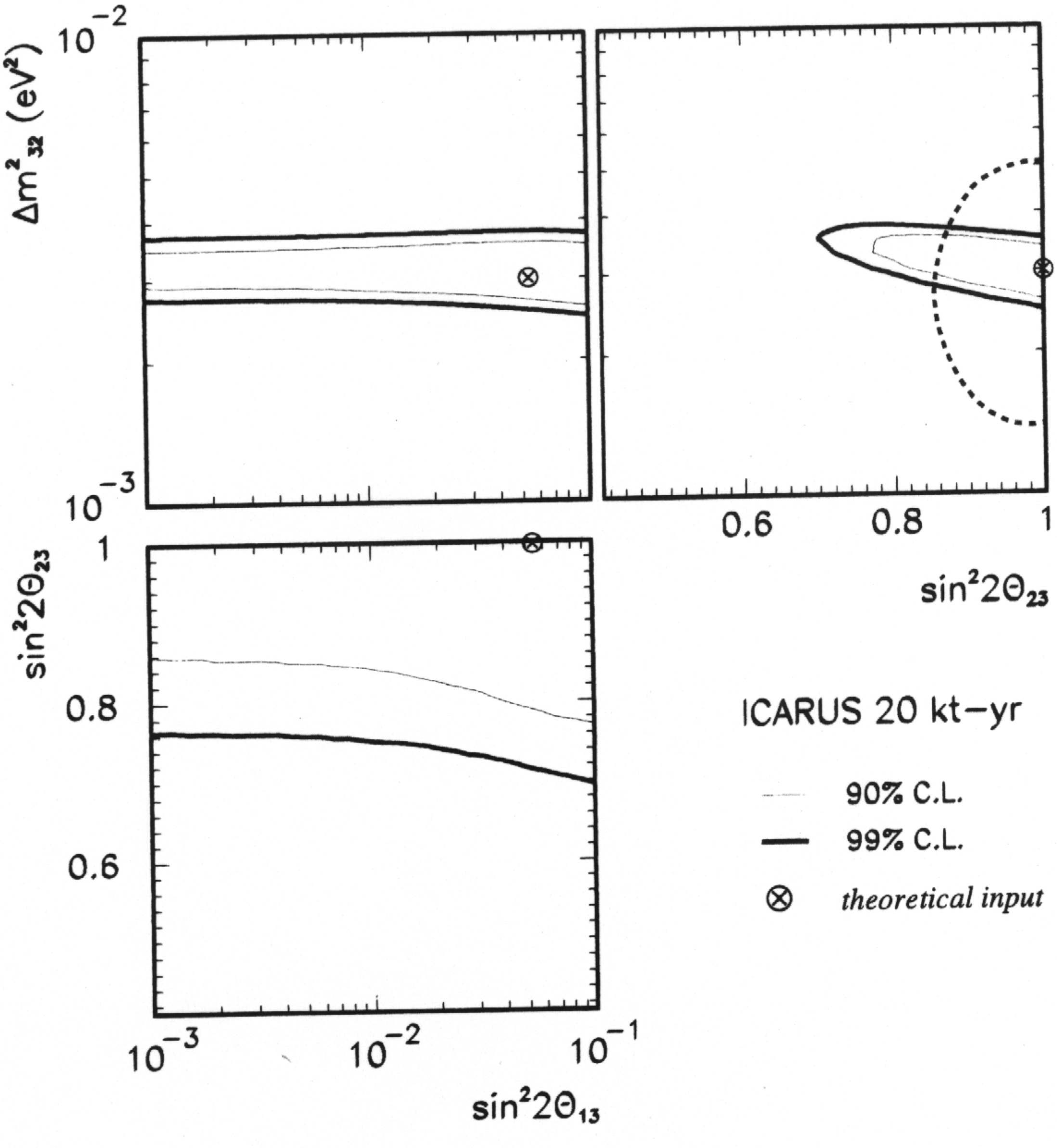


FIG. 4. The same as Fig. 2 but for ICARUS.

BARGER et al.

OPERA

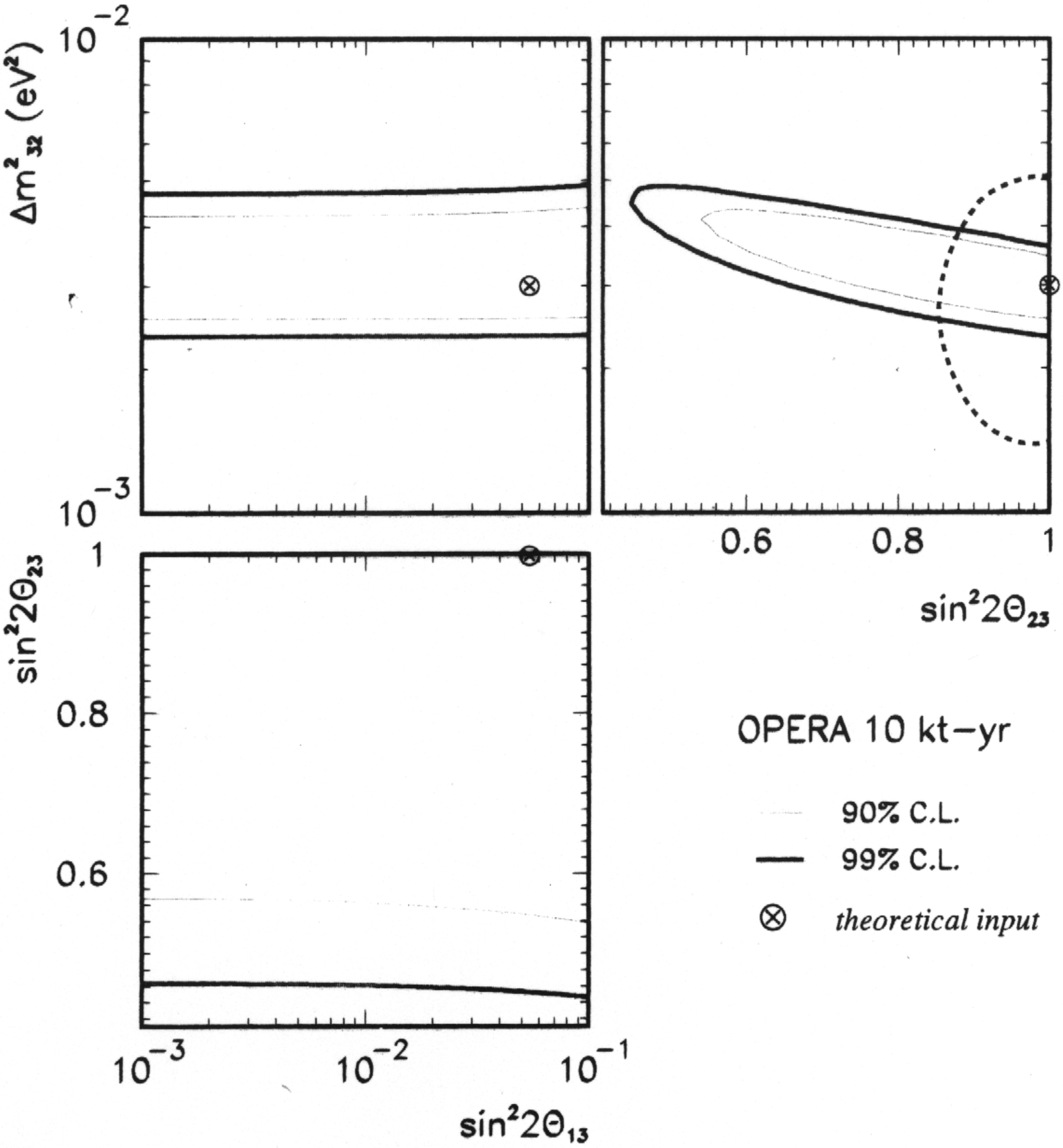


FIG. 6. The same as Fig. 2 but for OPERA.

BARGER et al.

$$\nu_\mu(0) \rightarrow \nu_\mu(x)$$

$$|\langle \nu_\mu(x) | \nu_\mu \rangle|^2 < 1$$

DISAPPEARANCE SEEN VIA CC $\nu_\mu \rightarrow \mu$ DEARTH

$$|\langle \nu_\mu(x) | \nu_{e,\tau} \rangle|^2 > 0$$

APPEARANCE SEEN VIA NC $\nu \rightarrow \nu$ >EXPECTED FROM CC THAT ARE SEEN

$$|\langle \nu_\mu(x) | \nu_e \rangle|^2 \approx 0$$

NON-APPEARANCE ESTABLISH VIA NO EXCESS $\nu_e \rightarrow e$

CC FLUX DEPLETED A CERTAIN AMOUNT

NC FLUX AS IF NOTHING HAD HAPPENED

The "THING" INTO WHICH ν_μ OSCILLATES IS ν_τ

NO WAY AROUND

STORED

$$\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$$

PURE, COLLIMATED, WELL UNDERSTOOD BEAM OF $\nu_\mu, \bar{\nu}_e$

UNLIKE IN CONVENTIONAL π/K BEAM

[NO $\bar{\nu}_\mu, \nu_e$ CONTAMINATION]

$$\nu_\mu \rightarrow \left\{ \begin{array}{lll} \nu_\mu \rightarrow \mu^- & \text{DISAPP.} & \text{RS} \checkmark\checkmark \\ \nu_e \rightarrow e^- & \text{APP.} & \times \\ \nu_\tau \rightarrow \tau^- & \text{APP.} & \checkmark \end{array} \right.$$

$$\bar{\nu}_e \rightarrow \left\{ \begin{array}{lll} \bar{\nu}_e \rightarrow e^+ & \text{DISAPP.} & \times \\ \bar{\nu}_\mu \rightarrow \mu^+ & \text{APP.} & \text{WS} \checkmark\checkmark\checkmark \\ \bar{\nu}_\tau \rightarrow \tau^+ & \text{APP.} & \checkmark \end{array} \right.$$

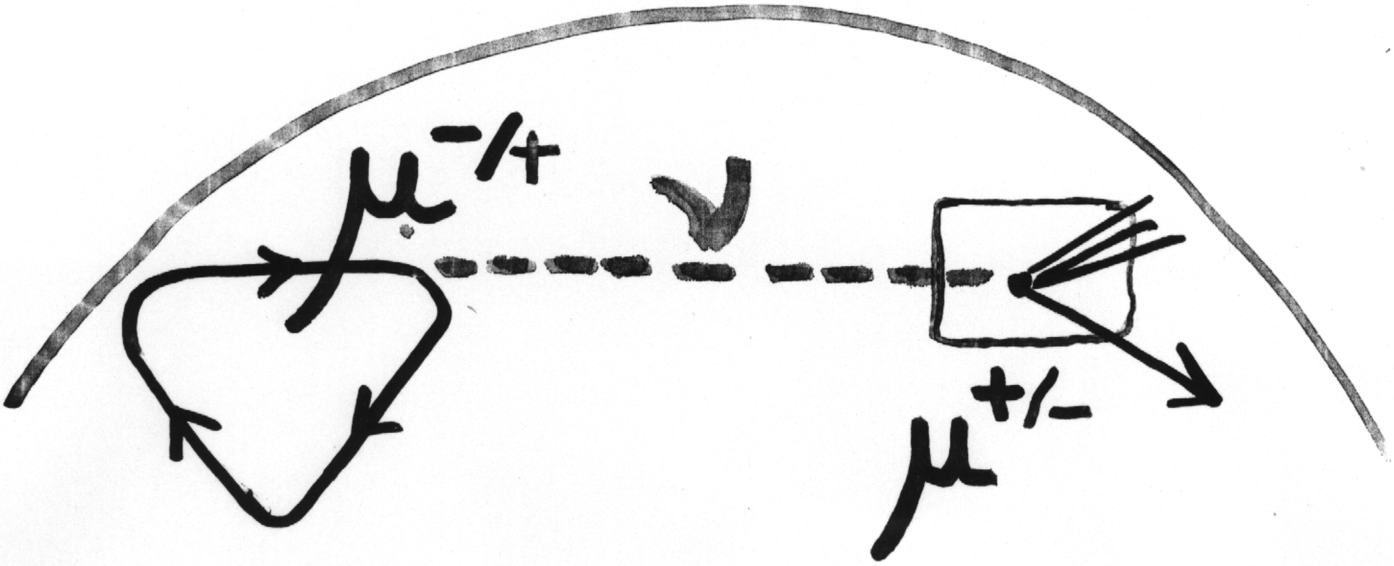
+ CHARGED CONJUGATE CHANS

STORED μ^+

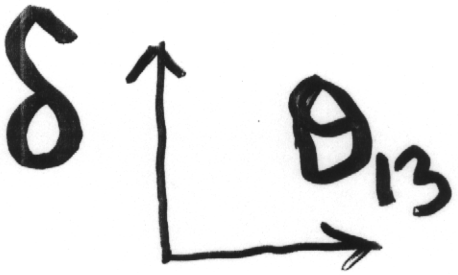
GOLDEN SIGNATURE

"WRONG-SIGN" μ'S :

THOSE WHOSE CHARGE IS OPPOSITE TO THAT OF THE MUONS IN THE STORAGE RING

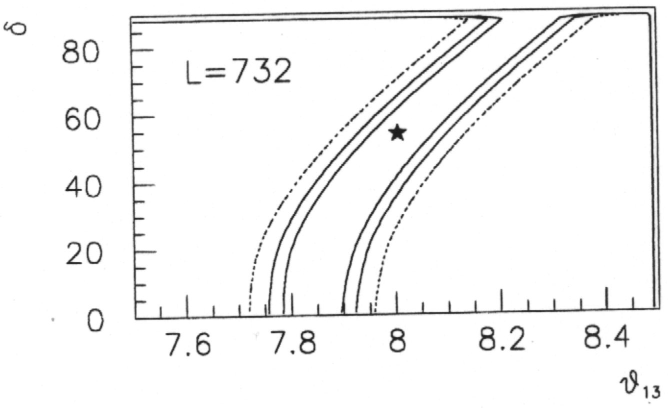


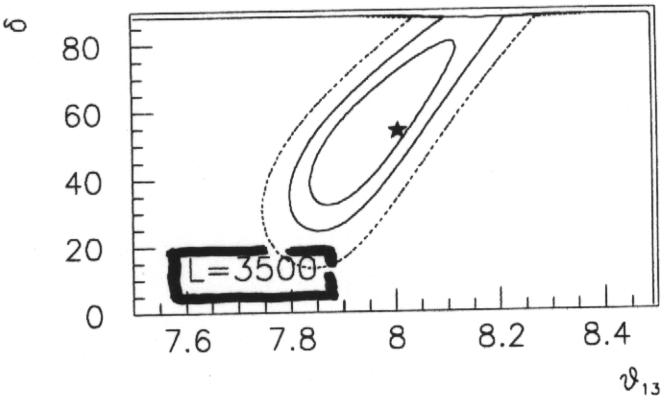
MID-RANGE LMA-MSU

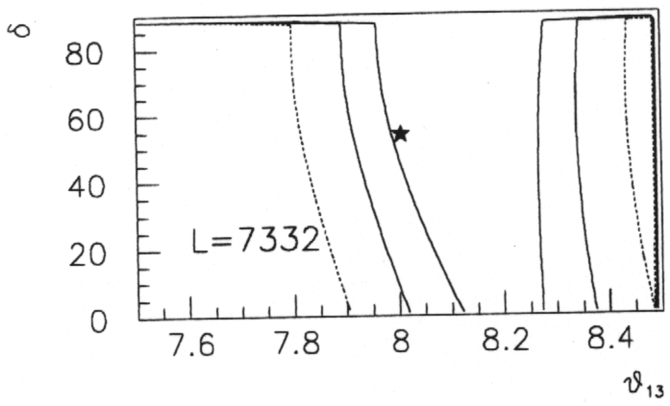


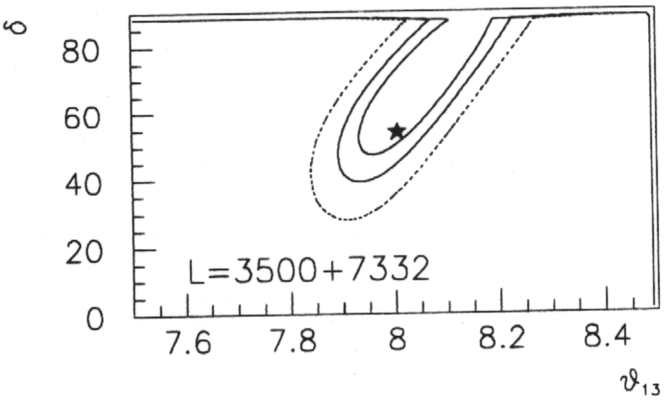
$\Delta m^2_{12} = 5\,10^{-5}\,eV^2$

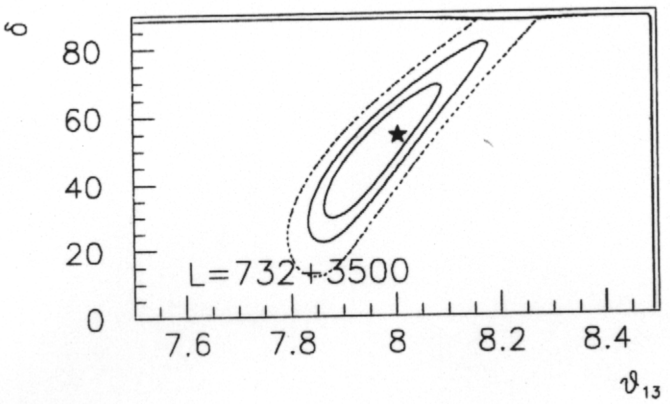
(NOT MOSTOPTIMISTIC)

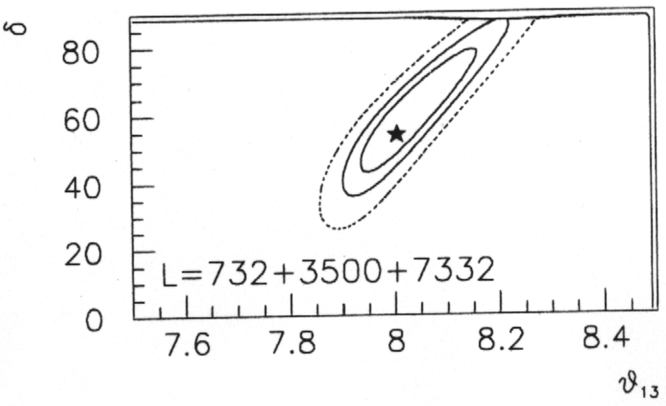












Cervera et al.

ALL STUDIES OF

SIGNALS, S/BACKGROUNDS

CONCUR:

L ~ 3000 km OPTIMAL

L ~ 6000 km GOOD.

(partic. as an ADD-ON)

L ≋ 732 km ☹

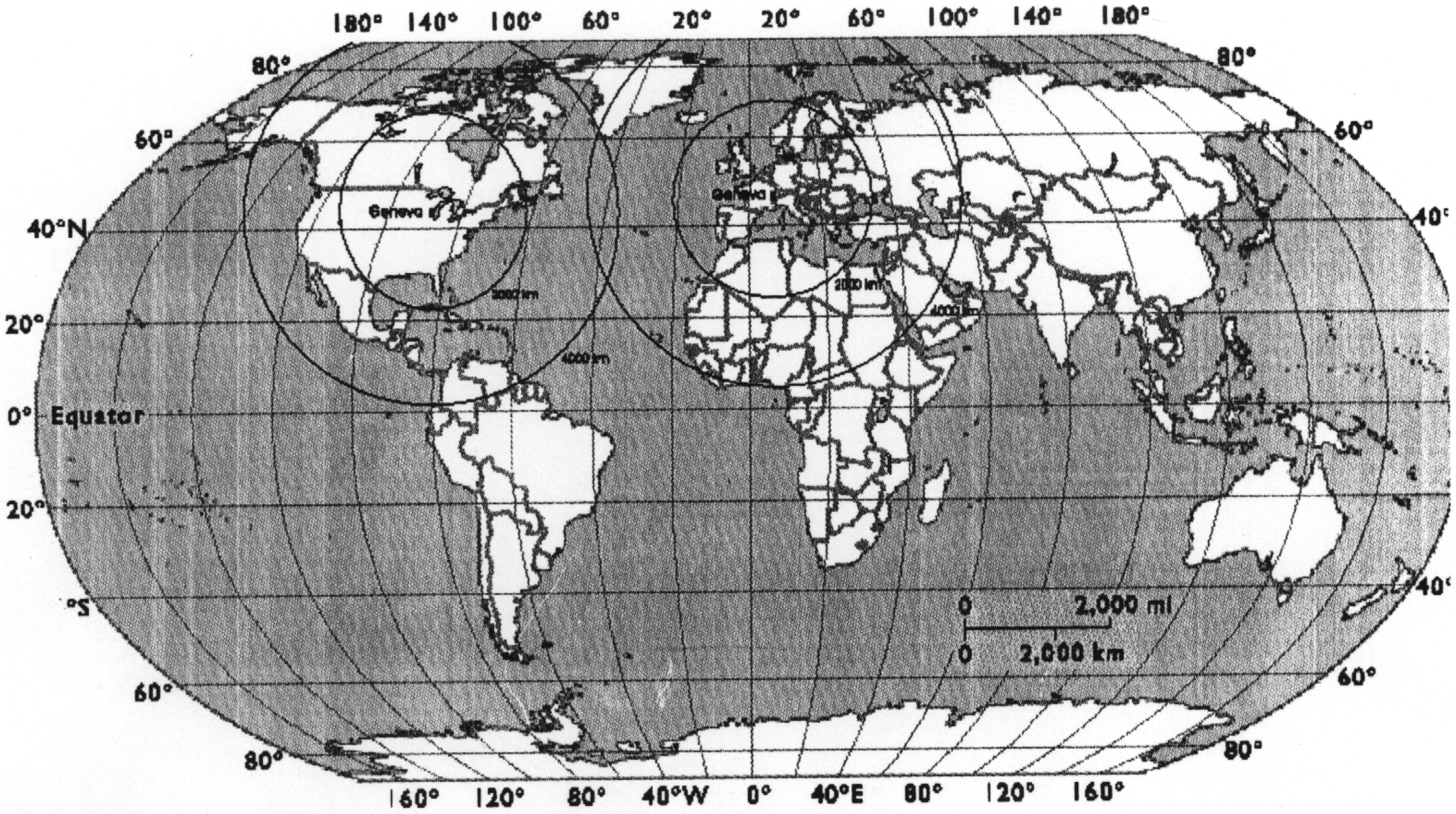
IS NOT ENOUGH

2000-4000 km CIRCLES CENTERED AT GENEVA (ILL) AND GENEVA (CH)

↓

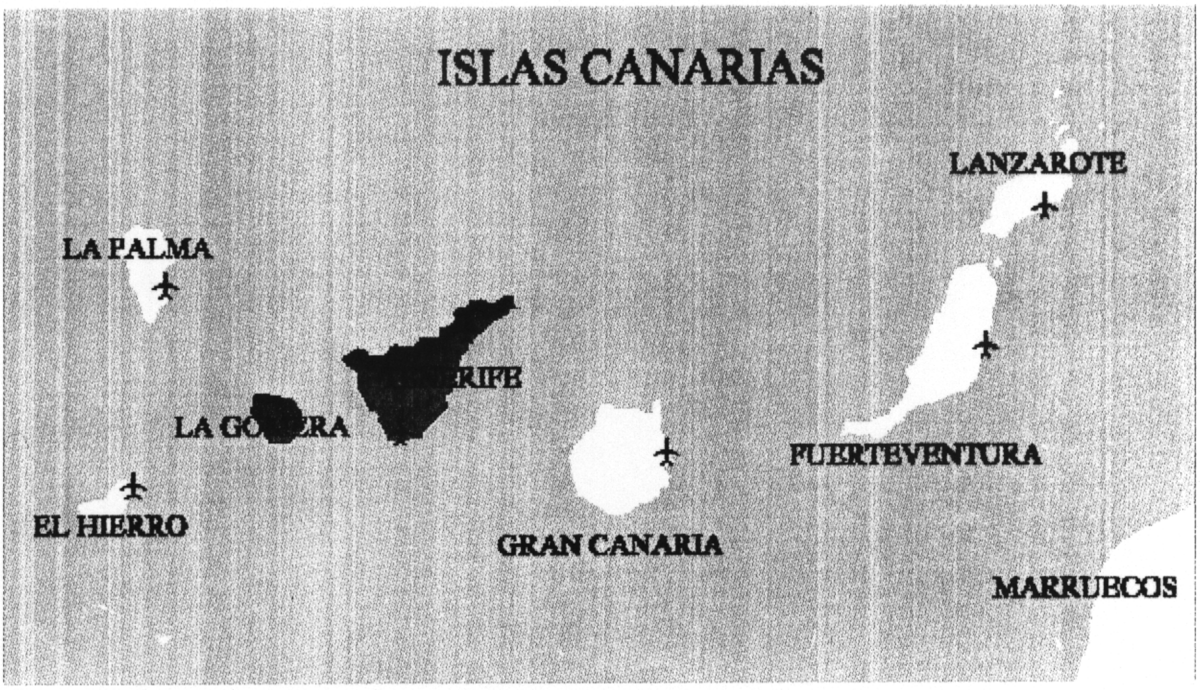
GOOD DISTANCE TO WEST COAST

BUT



NO SINGLE, PEACEFUL, TECHNOLOGICALLY REASONABLE, NON-FREEZING PLACE WITHIN 3000 ± 1000 km FROM GENEVA (CH)

EXCEPT!


ISLAS CANARIAS
LANZAROTE
LA PALMA
TENERIFE
LA GOMERA
FUERTEVENTURA
EL HIERRO
GRAN CANARIA
MARRUECOS


Longyearbyen
Pyhæsalmi
Gran Sasso
Santa Cruz
pg

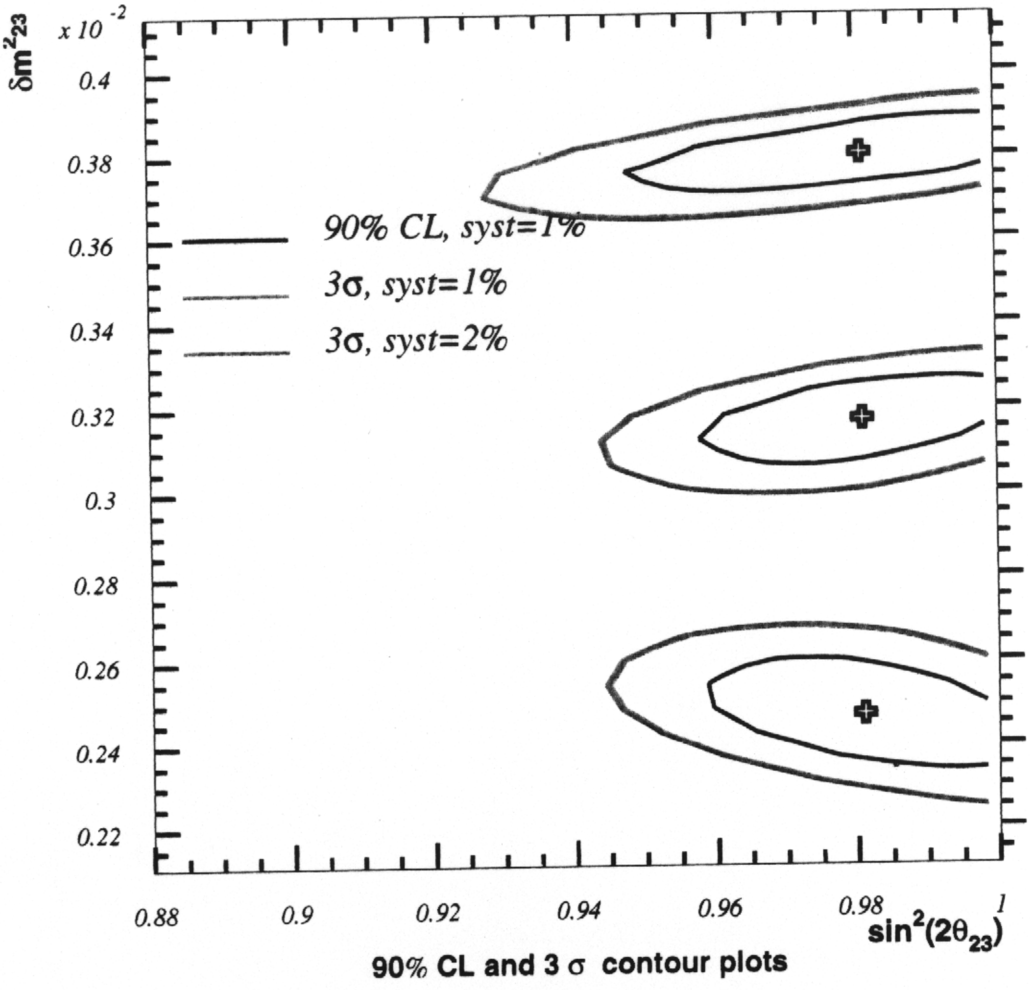
On Burt Richter's insistence

IS AN UPGRADED, π/K (CONVENTIONAL) BEAM COMPETITIVE WITH A ν-FACTORY

GOMEZ CADENAS et al.

SUPER PROTON LINAC

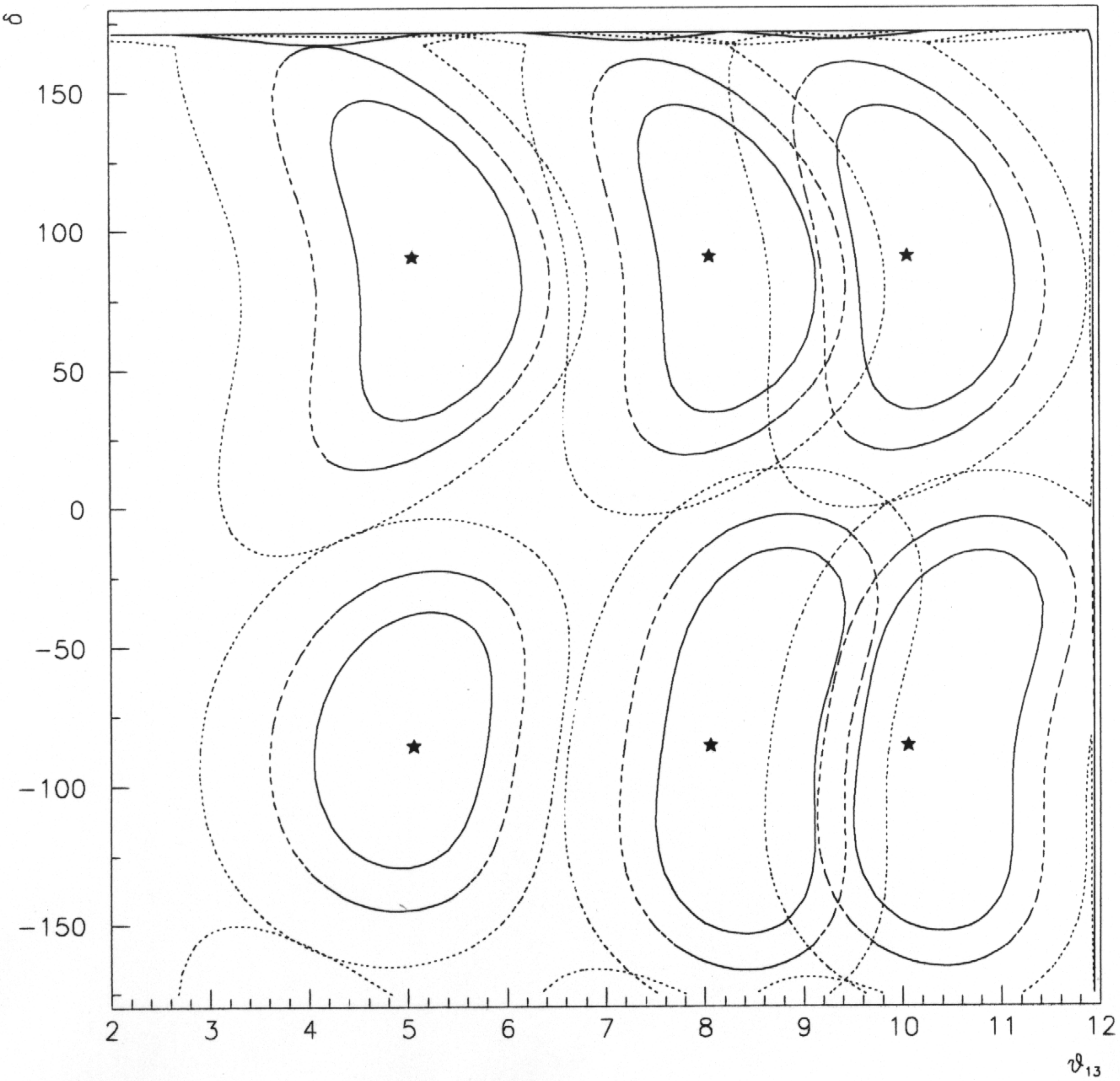
L=130 km



40 kTon DETECTOR

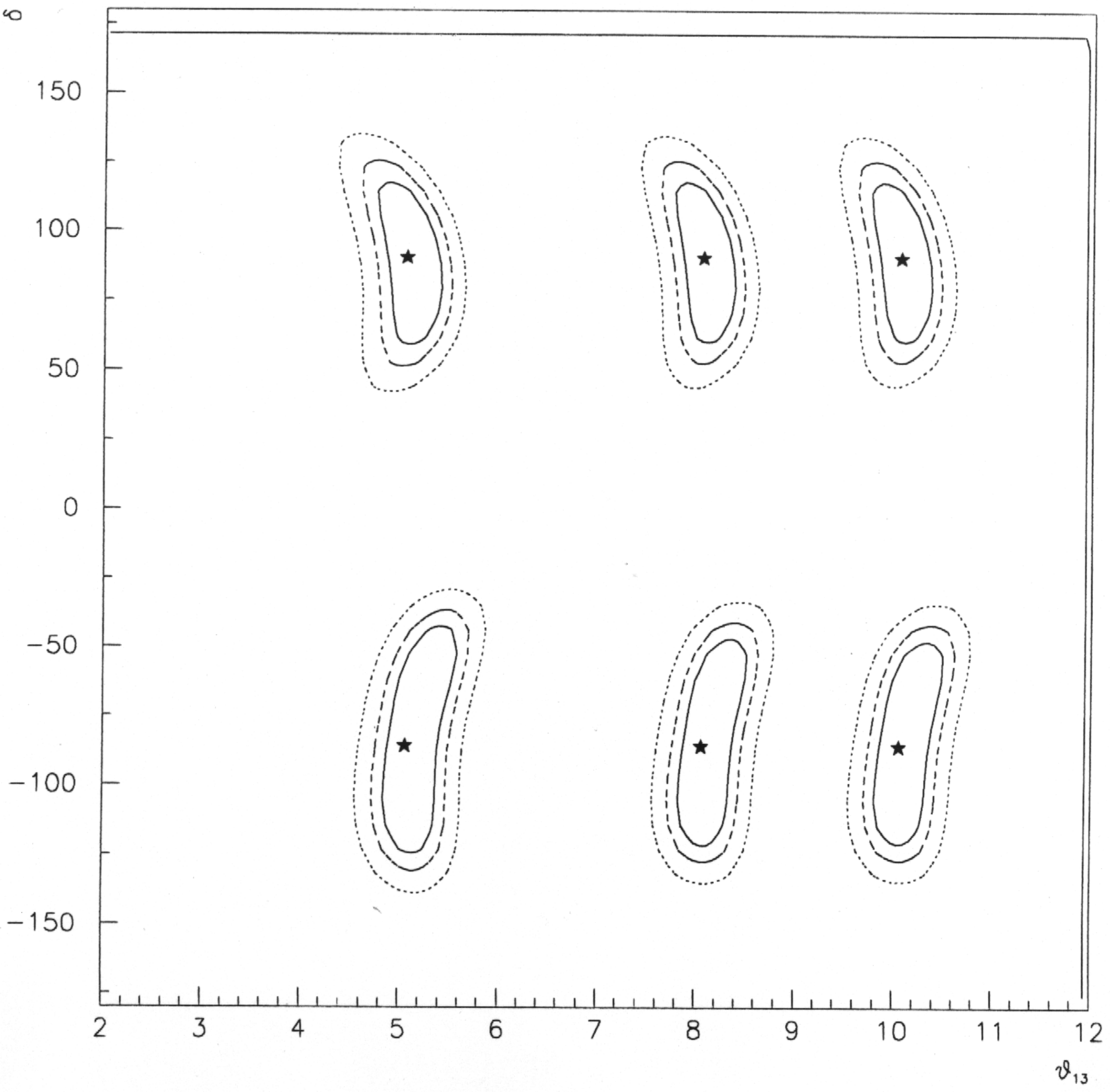
5 years

GOMEZ-CADENAS et al.



ν 2 years 40 kTon

$\bar{\nu}$ 10 years



400kTon

400y ?

β-BEAMS

PIERO ZUCCHELLI

$${}^{6}He^{++} \rightarrow {}^{7}Li^{+++} + e^{-} + \bar{\nu}_e$$

$${}^{18}Ne \rightarrow {}^{18}F + e^{+} + \nu_e$$

1. Produce a Radioactive Ion with a short beta-decay lifetime
2. Accelerate the ion in a conventional way (PS) to “high” energy
3. Store the ion in a storage ring with straight sections.
4. It will decay. $\bar{\nu}_e$ (ν_e) will be produced.

Muons:
Γ~500
E_0~34 MeV
QF~15

- SINGLE flavour
- Known spectrum
- Known intensity
- Focussed AND Low energy!
- “Better” Beam of $\bar{\nu}_e$ (ν_e)

^{6}He Beta-:
Γ~150
E_0~1.9 MeV
QF~79

^{18}Ne Beta+:
Γ~250
E_0~1.85 MeV
QF~135

The “quality factor” QF=Γ/E_0 is bigger than in a conventional neutrino factory. In addition, production & acceleration (500000× more time) are simpler.

BUILDING A ν FACTORY

or

β-BEAM