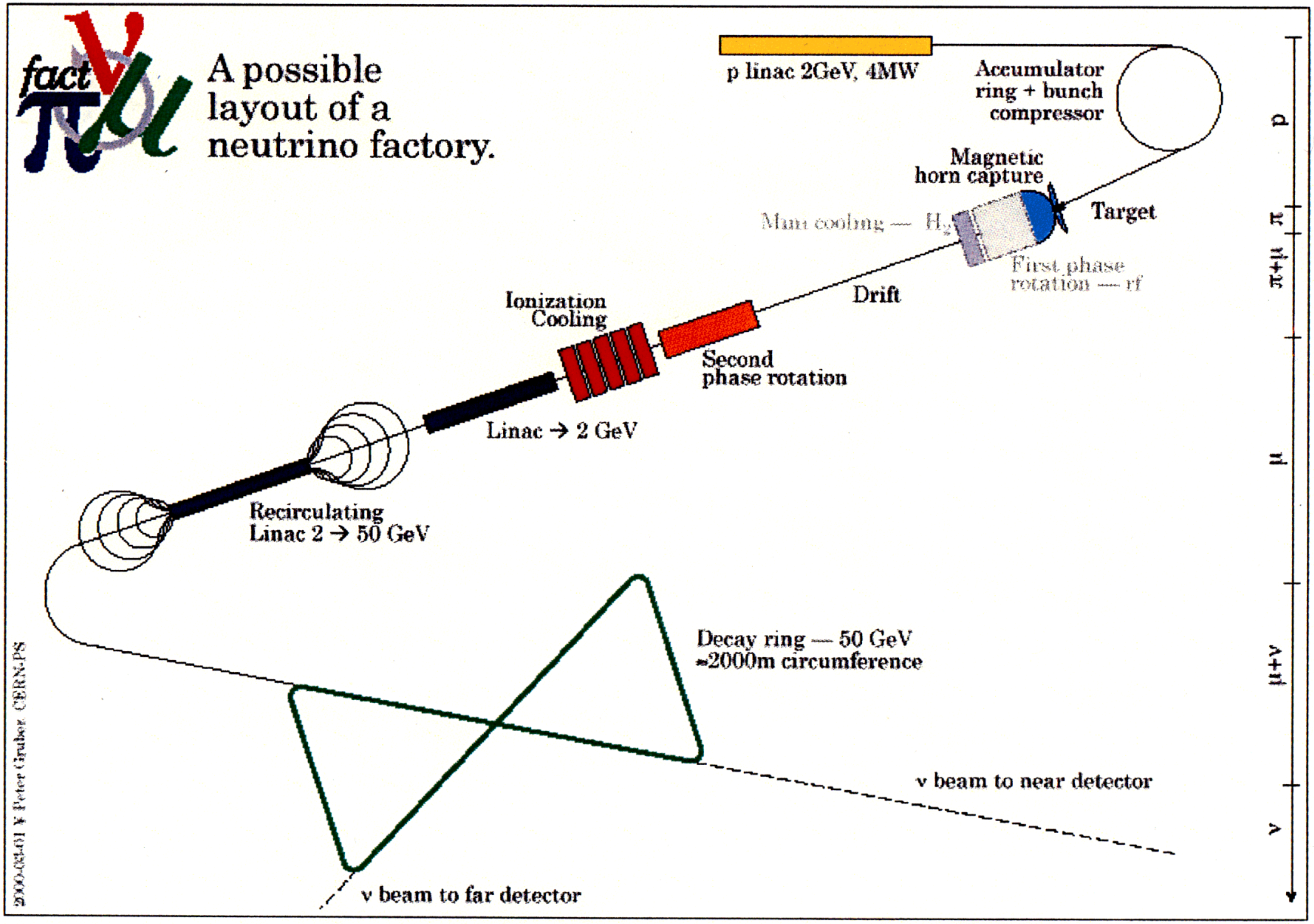
#3

Monday
morning

de Rujula



A possible layout of a neutrino factory.

μ COLLIDERS BUDKER 1969

SKRINSKI, colls 1971

NEUFFER 1979

ν FACTORY KOSHANEV 1974

WOJCICKI COLLINS 1974

ν FACTORY BANG GEER 1998

A BOOM OF INTEREST AND ACTIVITY

SKEPTICS WHO HAVE LOOKED AT THE POTENTIAL OF A ν-FACTORY CONVERTED INTO FANS BY THE FACTS

EXAMPLES OF CONVERTED SKEPTICS

- BELÉN GAVELA and PILAR HERNANDEZ
  GIGANTIC POTENTIAL OF THE "WRONG-SIGN" MUON SIGNALS IN A (REALISTIC) 3-FAMILY CONTEXT
  ⇒ THEMSELVES, ME

- SOME POOH POOHING EXPERIMENTALISTS

- EVEN SOME DGs

Δm^2_ν OBSERVED BY ATMOSPHERIC, SOLAR ν-DETECTORS ARE AT THE SCALE EXPECTED FOR m_ν's IN (SUPERSYMETRIC)

GRAND UNIFIED THEORIES

SM

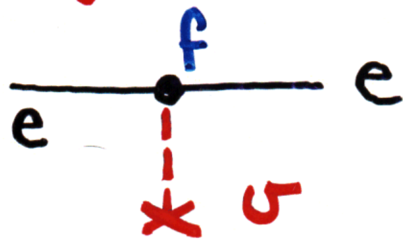
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$ DOUB. e_R SINGLET

ν_R USELESS

$\phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \Rightarrow \begin{pmatrix} 0 \\ v \end{pmatrix}$ SSB

$\Delta\mathcal{L} = f \bar{L} \phi e_R$

$\Rightarrow f v \bar{e} e = m_e \bar{e} e$

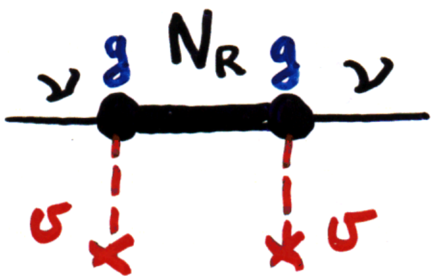


GUTS

$SO(10) \supset SU(3) \otimes SU(2)_L \otimes U(1)$

COMPLETE q, ℓ FAMILY $(+N_R) \in 16$

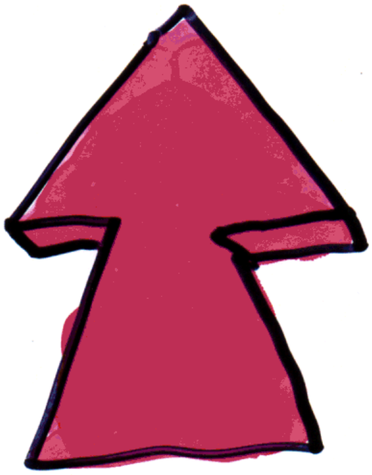
Inevitably $\Delta\mathcal{L}' = g \bar{L} \phi N_R$

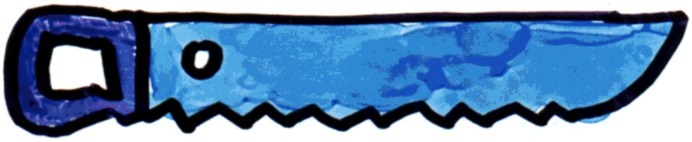


$$m_\nu = \frac{(gv)^2}{M_N}$$

$$M_N = \frac{(gv)^2}{m_\nu} \sim \frac{(250\,GeV)^2}{0.01\,eV}$$

$M_N \sim 6\ 10^{15}\,GeV$ IS THE SCALE OF (SS) SO(10) GRAND UNIF. !!





MECHANISM 1979

GELLMANN, RAMOND, SLANSKI ; YANAGIDA

MORE RECENT IDEAS ON m_ν's OR LEPTONIC WEAK MIXING ANGLES ARE ALL

"HOW TO..."

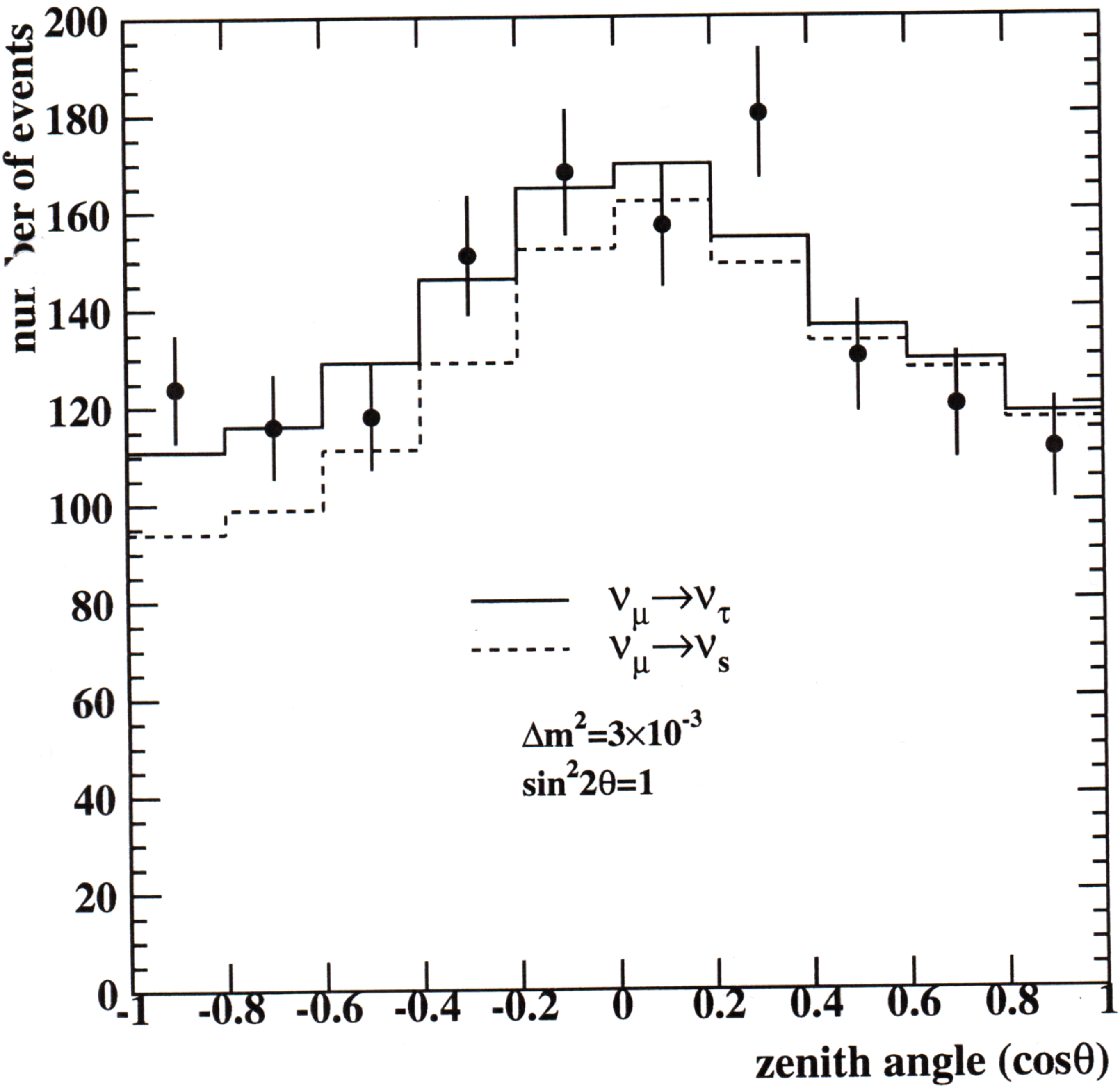
or

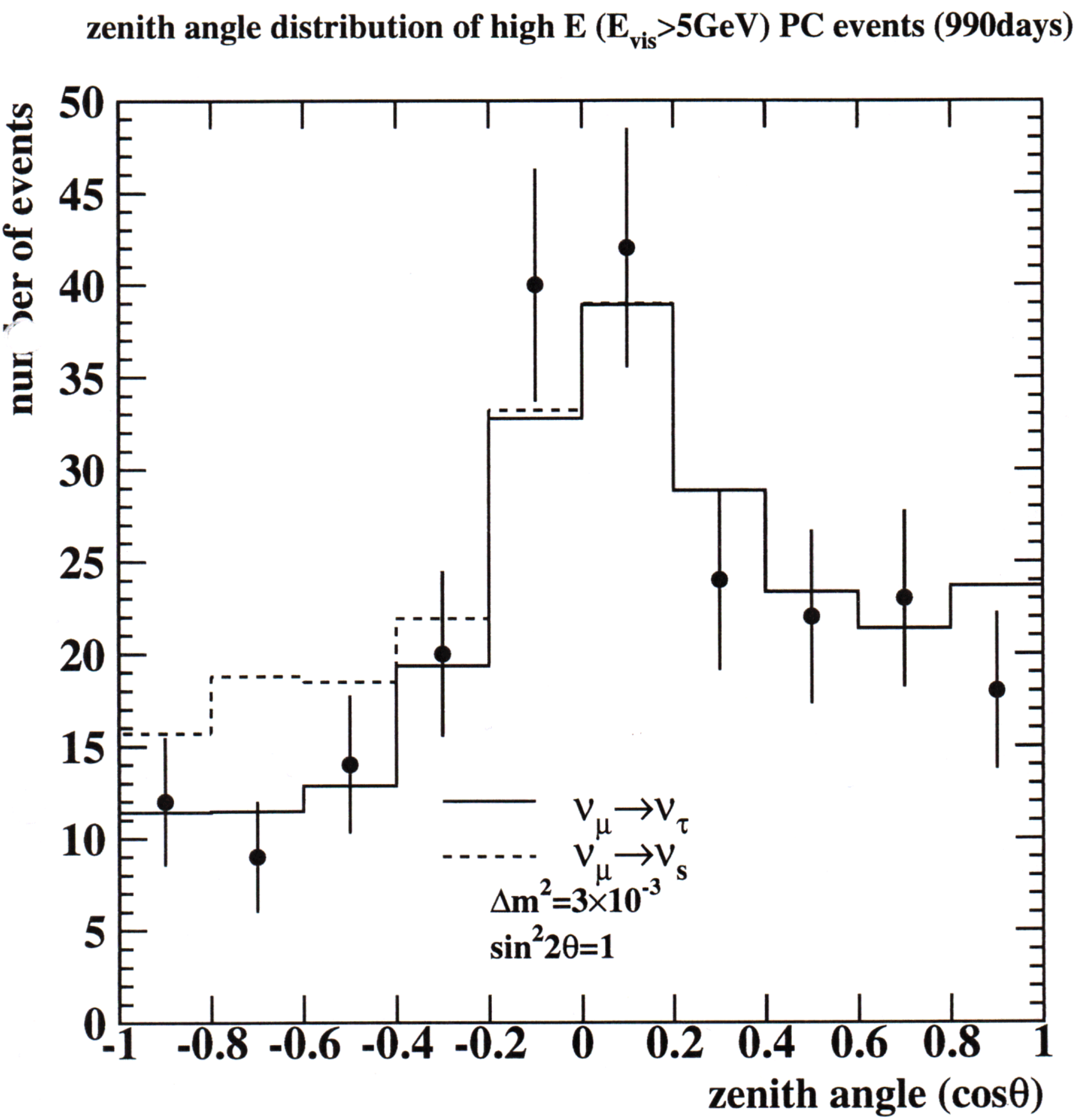
"WHY NOT..."

...DO THIS OR THAT

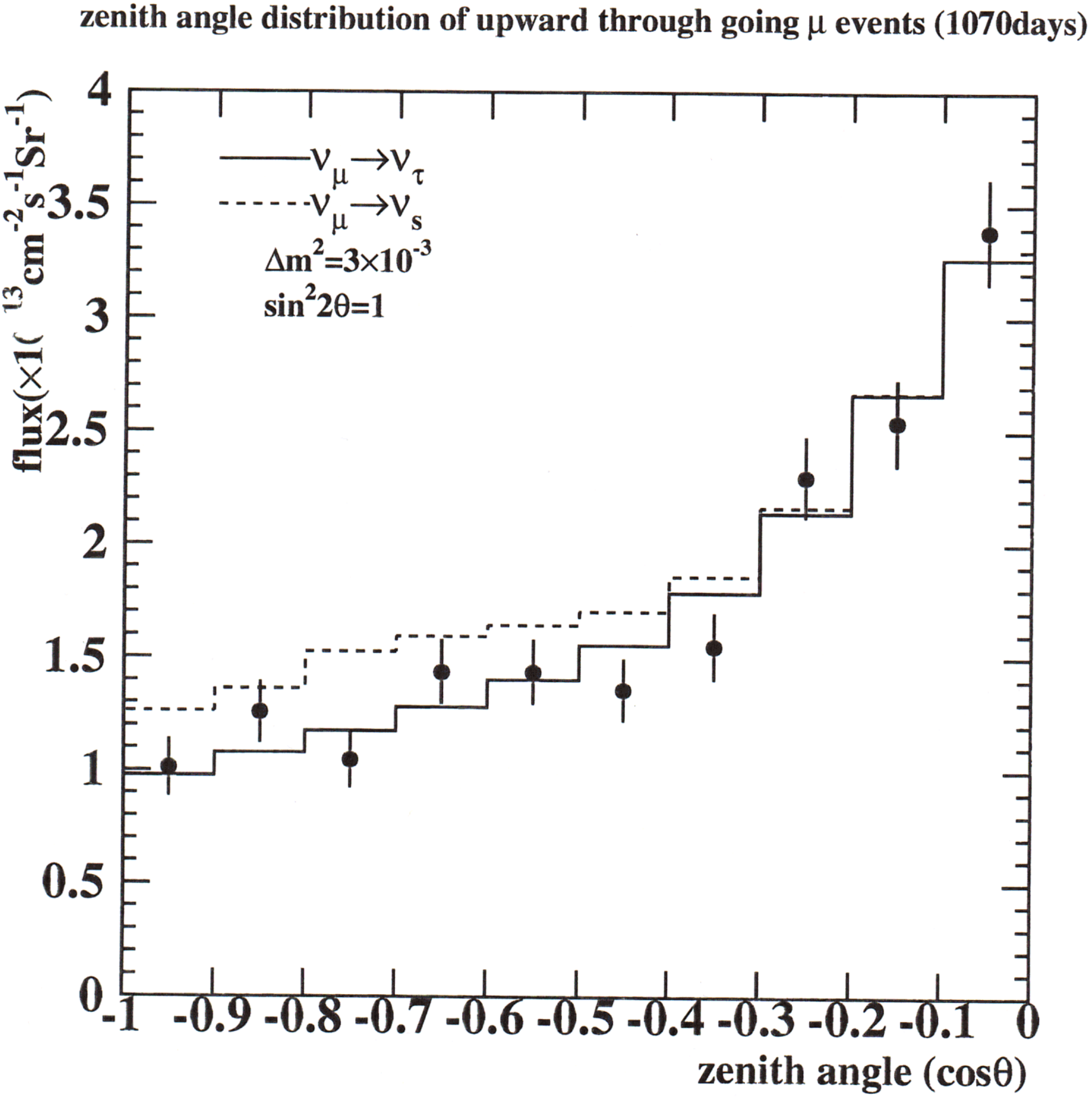
eg : MAXIMAL ν-MIXING

zenith angle distribution of N.C. enriched multi-ring events (990days)

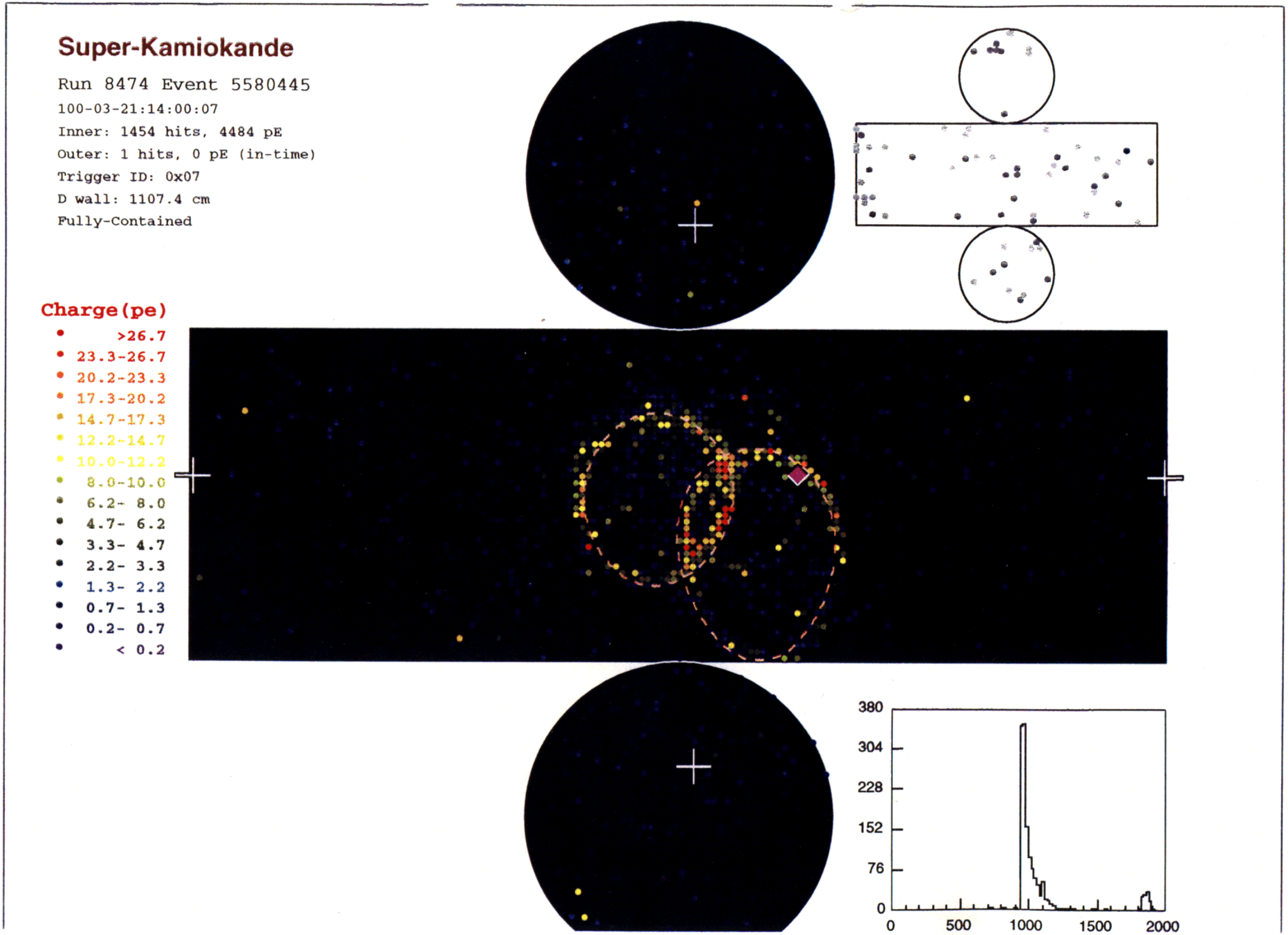




zenith angle distribution of high E (E_{vis}>5GeV) PC events (990days)
number of events
50
45
40
35
30
25
20
15
10
5
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
zenith angle (cosθ)
$\nu_\mu \rightarrow \nu_\tau$
$\nu_\mu \rightarrow \nu_s$
$\Delta m^2=3\times10^{-3}$
$\sin^2 2\theta=1$



zenith angle distribution of upward through going μ events (1070days)
flux(×10^13 cm^-2 s^-1 Sr^-1)
νμ→ντ
νμ→νs
Δm²=3×10⁻³
sin²2θ=1
4
3.5
3
2.5
2
1.5
1
0.5
0
-1
-0.9
-0.8
-0.7
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
zenith angle (cosθ)


Super-Kamiokande
Run 8474 Event 5580445
100-03-21:14:00:07
Inner: 1454 hits, 4484 pE
Outer: 1 hits, 0 pE (in-time)
Trigger ID: 0x07
D wall: 1107.4 cm
Fully-Contained
Charge(pe)
>26.7
23.3-26.7
20.2-23.3
17.3-20.2
14.7-17.3
12.2-14.7
10.0-12.2
8.0-10.0
6.2- 8.0
4.7- 6.2
3.3- 4.7
2.2- 3.3
1.3- 2.2
0.7- 1.3
0.2- 0.7
< 0.2
380
304
228
152
76
0
0
500
1000
1500
2000


FORGET
STERILE
LSND

WHAT WE KNOW FOR SURE

$\Delta m^2_{23} \sim 3\,10^{-3} eV^2$ $\theta_{23} \sim 45^\circ$ ATMS

$\theta_{13} < 13^\circ$ (CHOOZ)

$c_{ij} = \cos\theta_{ij} \quad s_{ij} = \sin\theta_{ij}$

$\Delta m^2_{ij} = m_j^2 - m_i^2$

$\Delta m^2_{12}, \Delta m^2_{23}$

$\theta_{12}, \theta_{13}, \theta_{23}, \delta$

$U \equiv U_1 U_2 U_3 \equiv$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

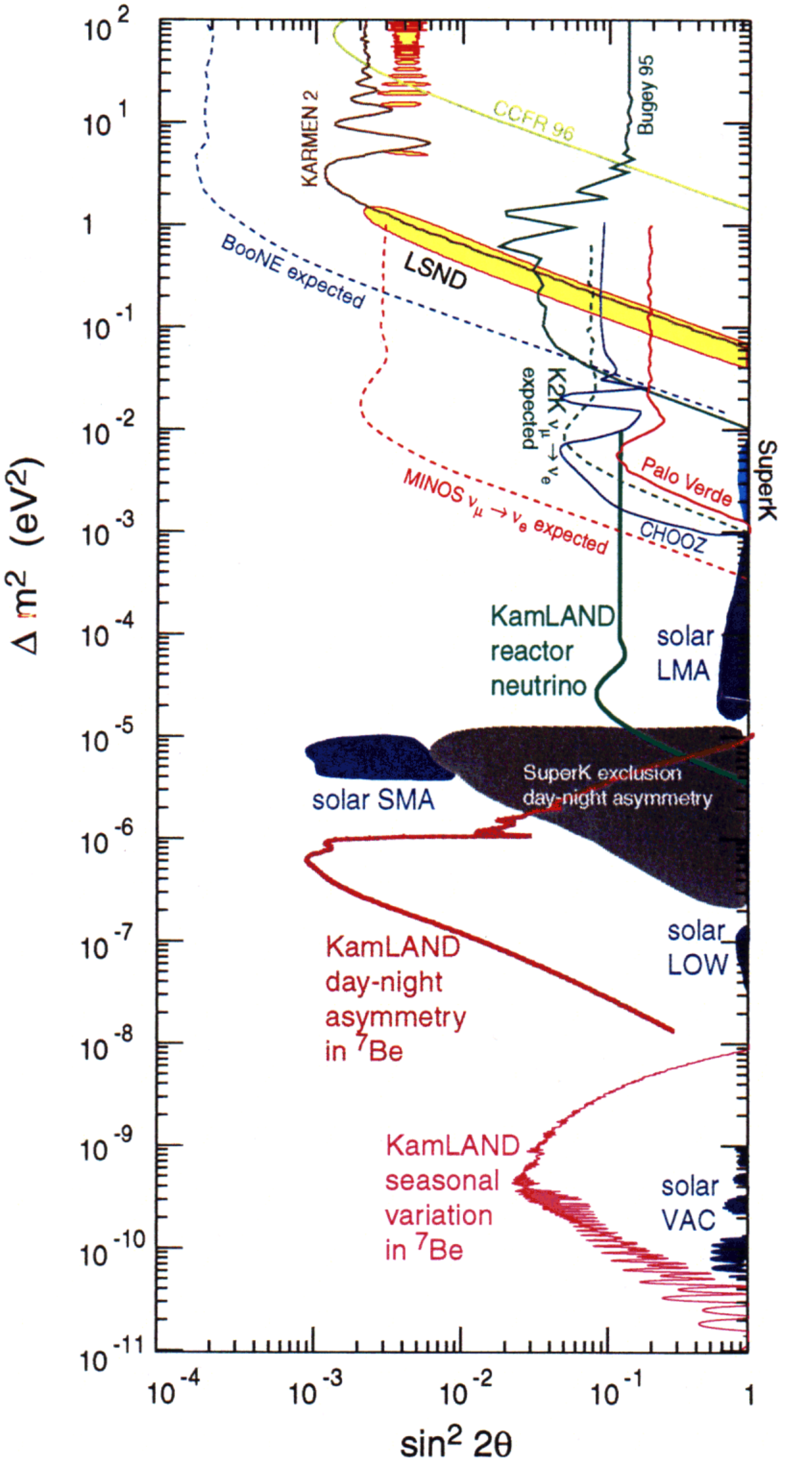


Figure 14: The current and expected limits at some of the future neutrino oscillation experiments. Note that different oscillation modes are shown together.

IFF $\nu_{\odot}$ ← V.O. or LMA-MSW

$$U_{\text{BI-MAXIMAL}} \sim \begin{pmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & s_{13} \\ \frac{1}{2} & \frac{1}{2} & -\frac{\sqrt{2}}{2} \\ \frac{\sqrt{2}}{2} & \frac{1}{2} & \frac{\sqrt{2}}{2} \end{pmatrix} * CP(\delta)$$

IFF LMA-MSW

$$\Delta m^2_{12} \sim 10^{-4} \div 10^{-5}\, eV^2$$

in

$$\Delta m^2_{12} \gtrsim \text{a few } 10^{-5}\, eV^2$$

THE BEST OF ALL WORLDS

EVEN δ CAN BE MEASURED

OR CONSTRAINED AT A ν-FAC

TWO 'EXTREME' PHILOSOPHIES

① ☺ VALIANT ; ☹ OVEROPTIMISTIC

e.g. CERVERA et 6 al. [THE MAGNIFICIENT SEVEN]

- $E_\mu = 50\,GeV$
- 40 kT Fe-Sci μ^+, μ^- ; $e^\pm$ + NC
- $10^{21}\,\mu^+$ and $10^{21}\,\mu^-$ USEFUL DECAYS (5 y?)
- 4 MW beam on target → $10^{21}\,\mu/y$ (25% USED)

② ☹ COWARDLY ; ☺ REALI$TIC

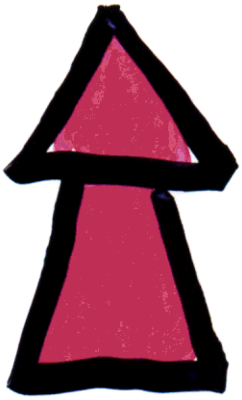
e.g. BARGER et al

- $E_\mu \geq 20\,GeV$
- 50 kT DETECTOR
- $2\ 10^{18}$ μ-DECAYS / y

①.⑤ ☺, ☹ SOPHISTICATED DETECTOR

e.g. BUENO et al.

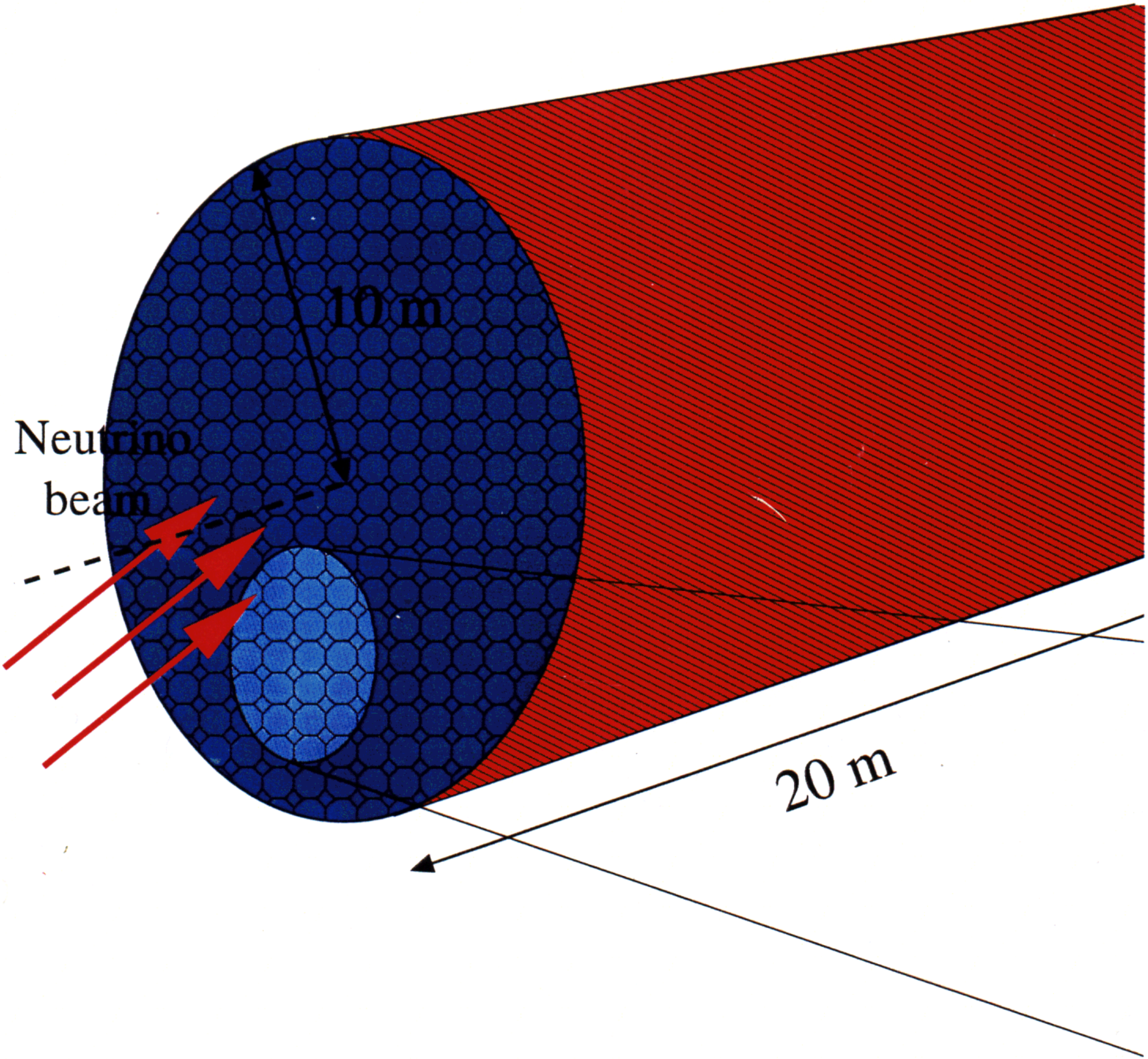
- $E_\mu = 30\,GeV$
- 10 kT ICANOE + DOWNSTREAM $\mu^{+/-}$ DET.
- $10^{21}\,\mu^+$ and μ^- USEFUL DECAYS



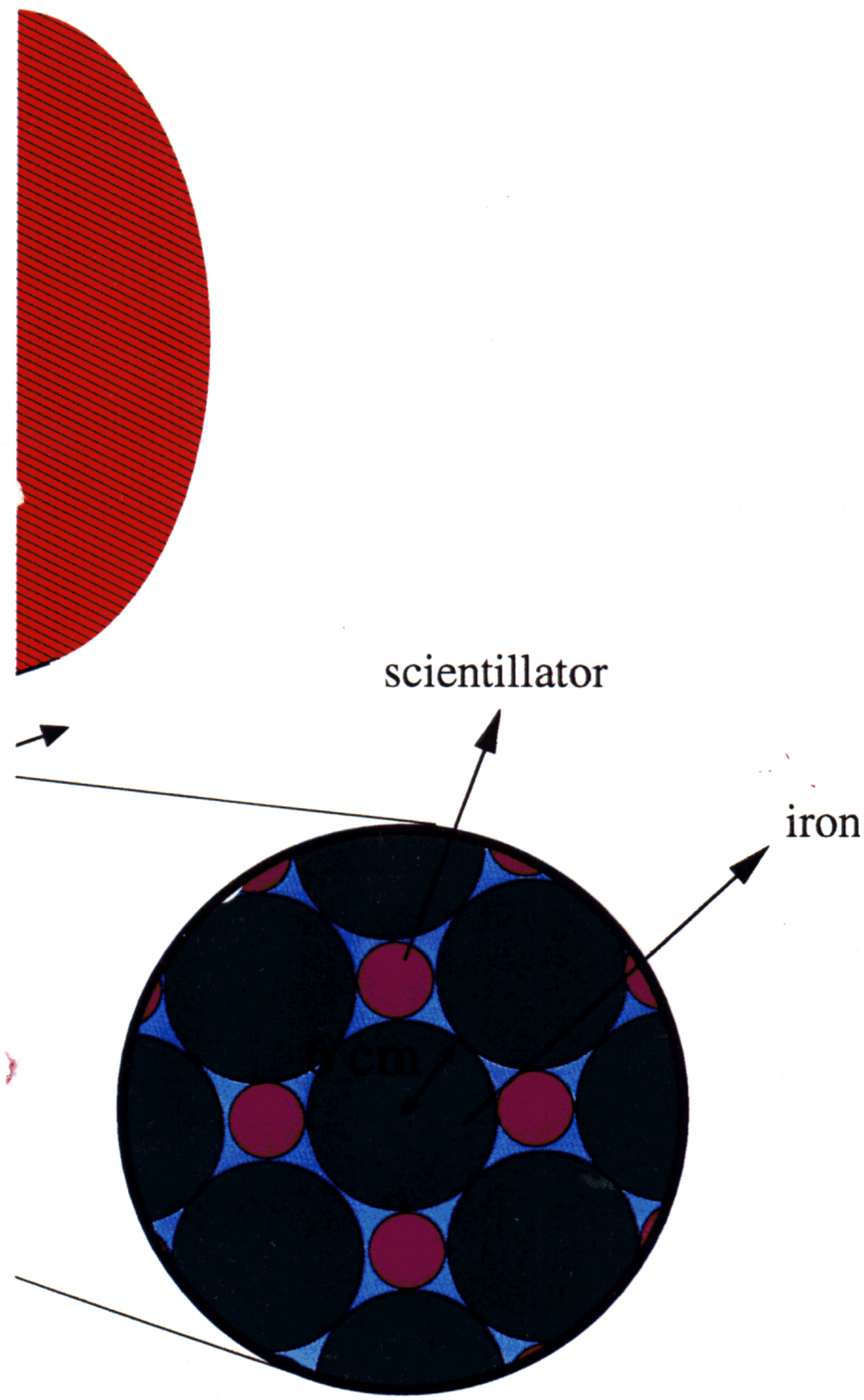
MATTER OF DEBATE AND OPINION

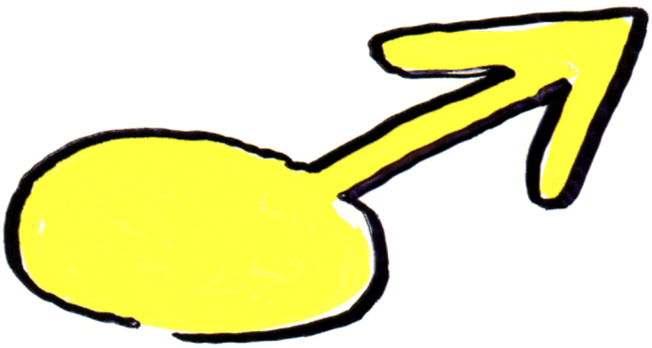
MY O.: IT IS FAAAAAAR TOO EARLY **NOT** TO BE OPTIMISTIC, BOTH MACHINE- AND DETECTOR-WISE

IT IS, HOWEVER, USEFUL TO KNOW HOW MUCH **LESS** ONE COULD DO IF ONE WAS FORCED TO SAVE $, SF, £ ...



CERVERA, DYDAK, GÓMEZ-CADENAS


scientillator
iron



SPARKLING
SCIENTIST

RUS

OTHER[redacted], e.g ICA

DETECTORS'

NOE

MAY BE VERY MUCH MORE SOPHISTICATED, BUT THEY ARE GOING AHEAD IN SIZE, TESTING, TECHNOLOGY and, HOPEFULLY, FUNDING

μ DISAPPEARACE (NO $\mu^{+/-}$ TELLING)

$\Delta m^2_{23}, \theta_{23}$ to ~1%

FREUND et al. $s(\Delta m^2_{23})$ MAY ALSO ONLY REQUIRE μ-DISAPP.

EARLY DESCOPING ATTITUDE

-99.95 $

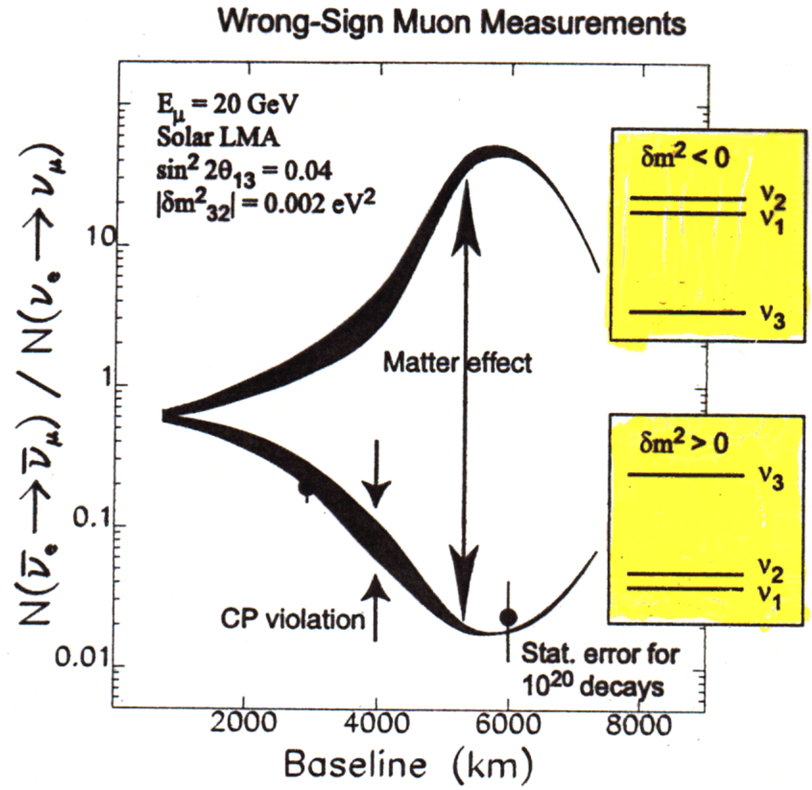
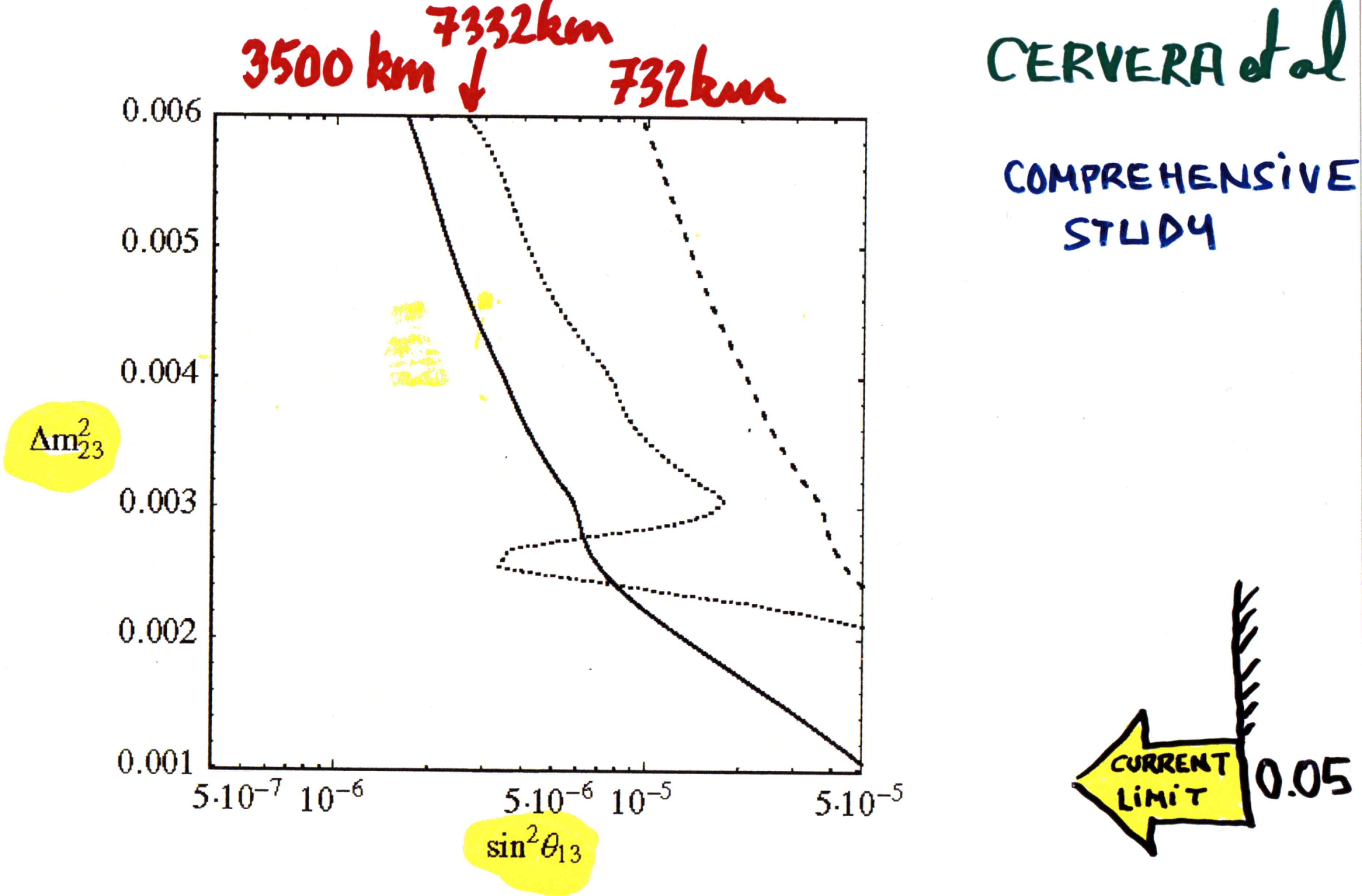


Figure I: Predicted ratios of $\bar{\nu}_e \to \bar{\nu}_\mu$ to $\nu_e \to \nu_\mu$ rates at a 20 GeV neutrino factory. The upper (lower) band is for $\delta m^2_{32} < 0$ ($\delta m^2_{32} > 0$). The range of possible CP violation determines the widths of the bands. The statistical error shown corresponds to 10^{20} muon decays of each sign and a 50 kt detector. Results are from Ref. 51.

↳ PRESUMABLY BARGER/GEER/RAJA/WHISNANT



As in Fig. 12, including as well background errors and detection efficiencies.

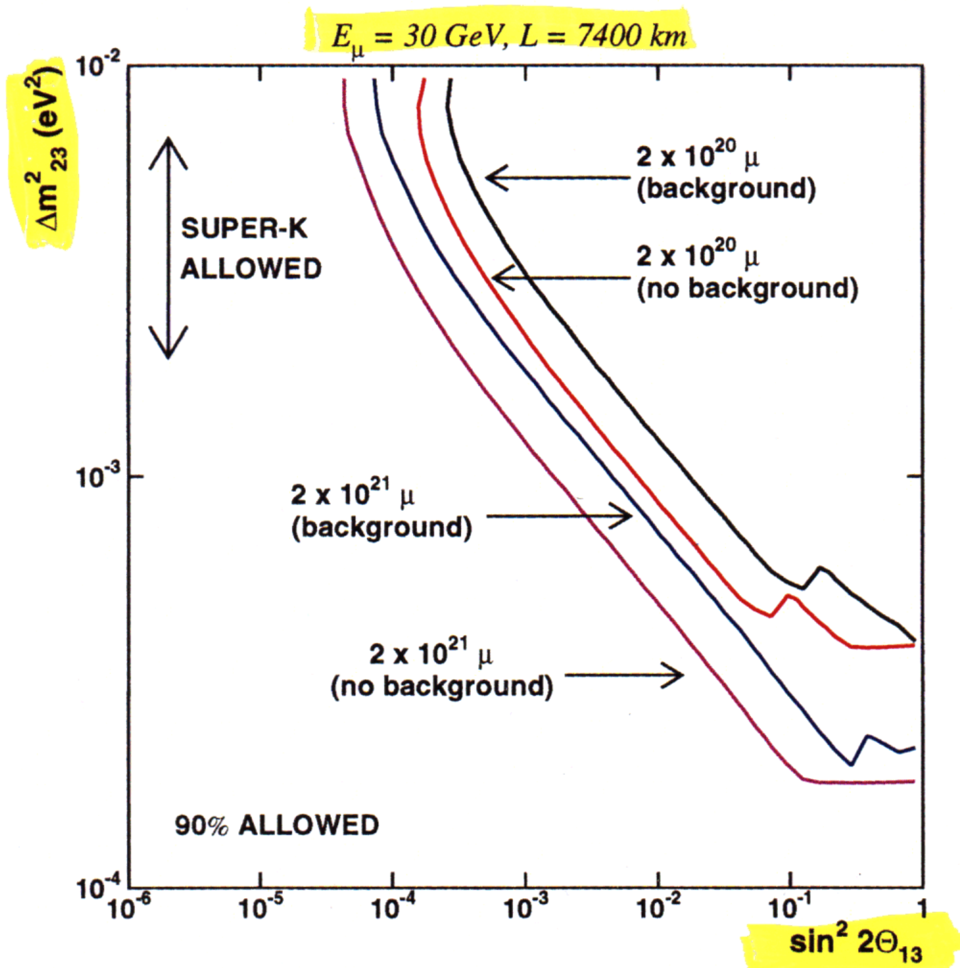


Figure 9: Sensitivity on θ_{13}

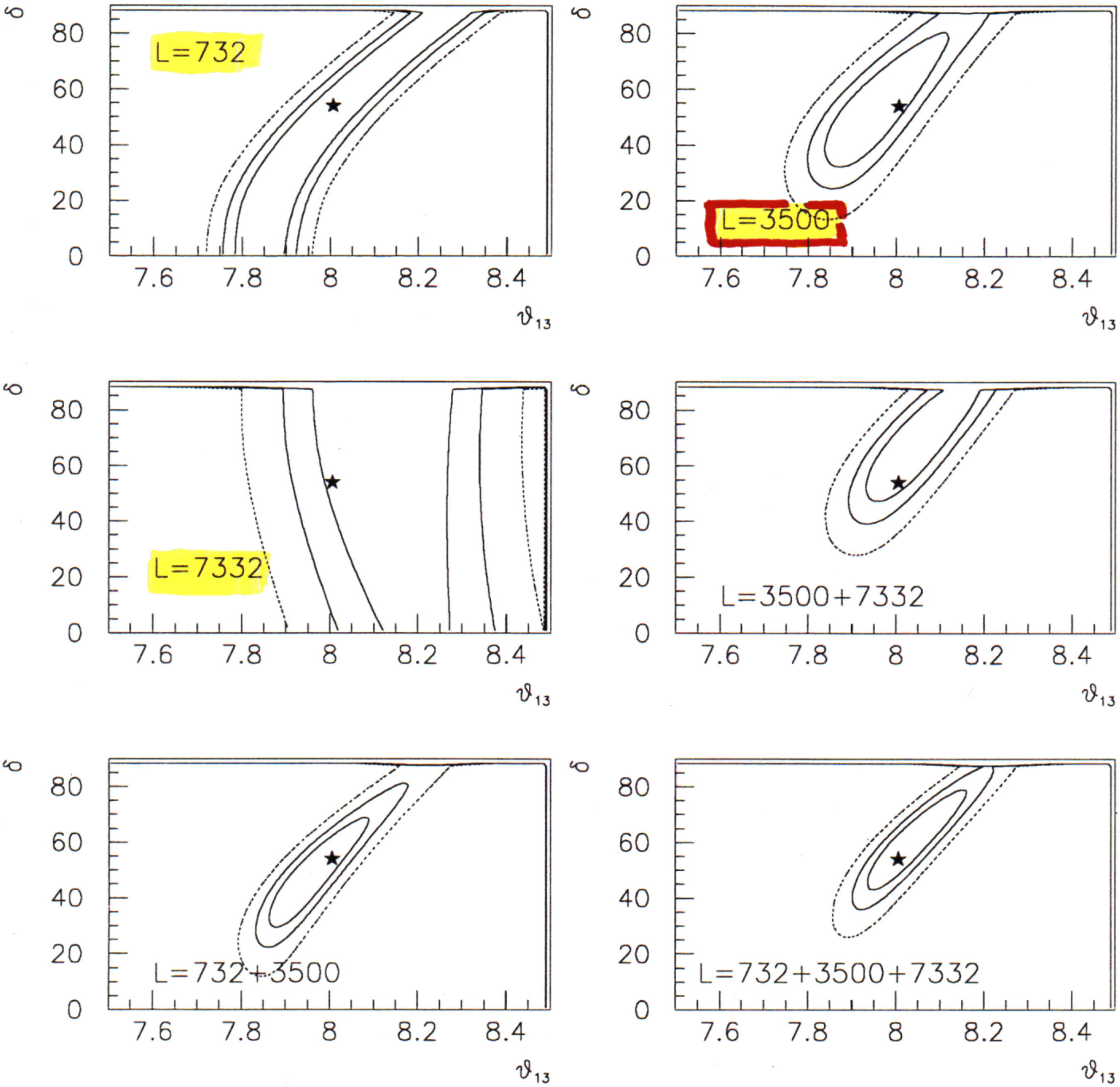
Bueno et al.

δ ↑ θ₁₃ →

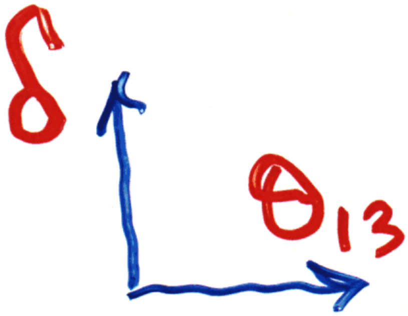
MID-RANGE LMA-MSW

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

(NOT MOST OPTIMISTIC)

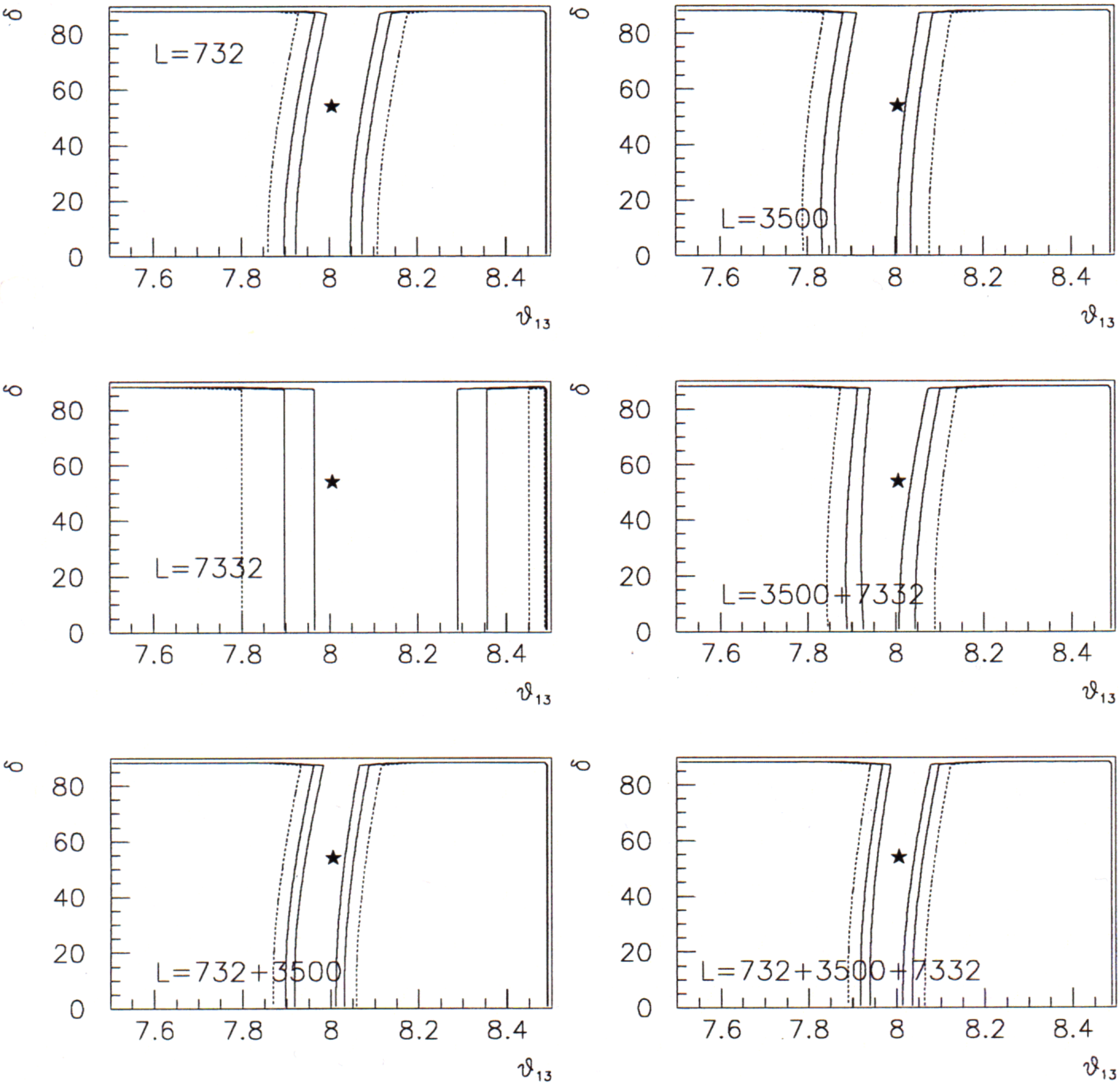


Cervera et al.



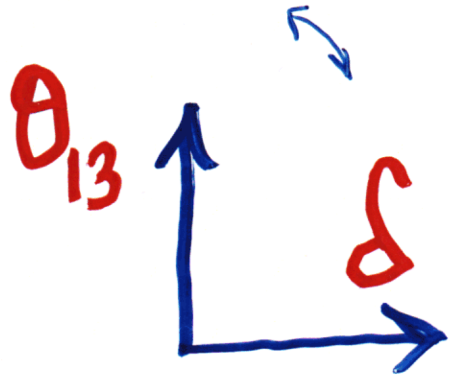
LOW-END LMA-MSW

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



Cervera et al.

HIGH-END LMA-MSW



$\Delta m^2_{12} = 10^{-4}\ eV^2$

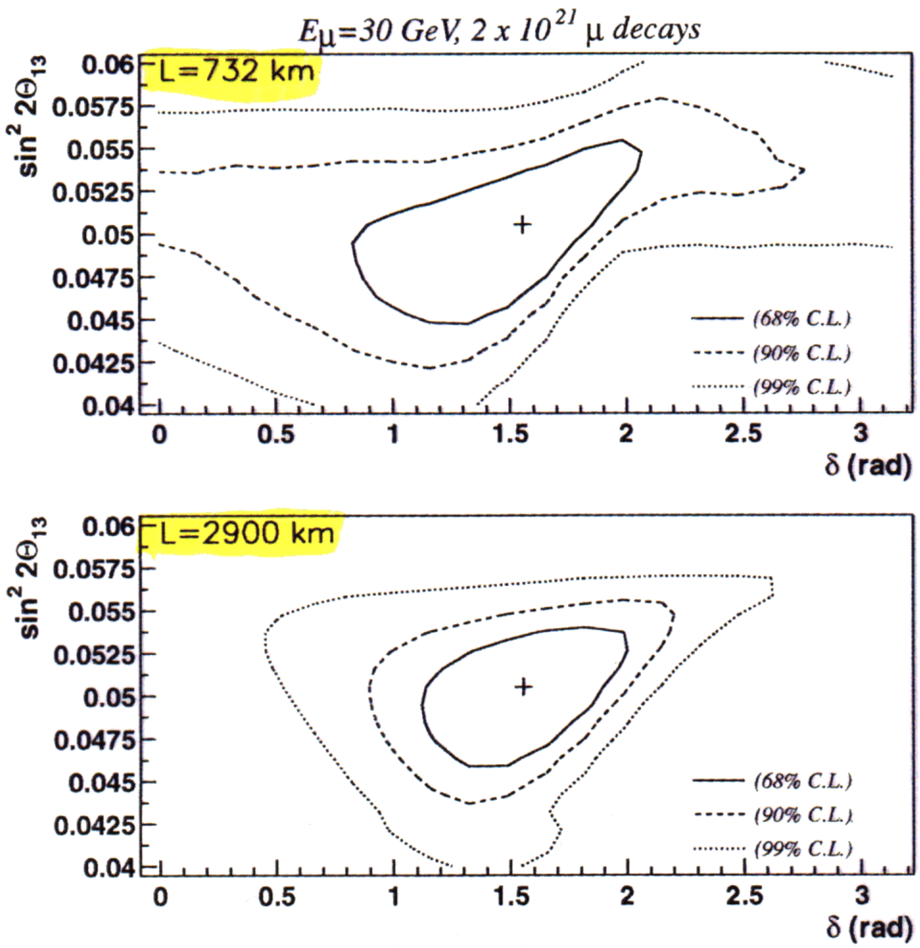


Figure 15: Correlation between θ_{13} and CP phase δ for two different baselines and 2×10^{21} decays.

Bueno et al.

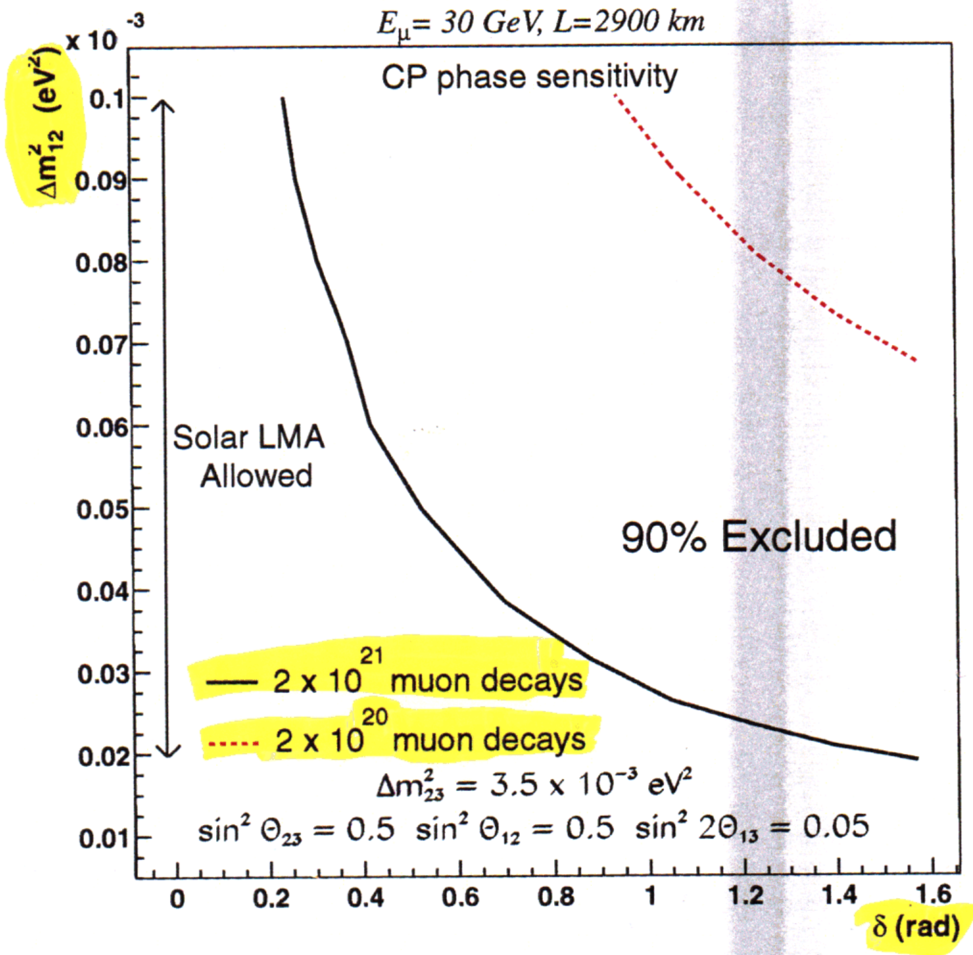


Figure 17: 90%C.L. sensitivity on the CP phase δ as a function of Δm^2_{12} for two different normalizations: solid (dashed) line corresponds to 10^{21} (10^{20}) muons decays of each polarity.

Bueno et al.

Bueno et al. ALSO EMPHASIZE :

WRONG SIGN MUONS ARE OPTIMAL TOOL, EXCEPT FOR SMALL θ_{13}

⇨ τ-APPERANCE IS BETTER

ν-FACTORY (AS B-FACTORIES) SHOULD AIM AT OVERCONSTRAINING THE PARAMETERS ⇨ τ NEEDED

$$1\,\nu F < \frac{1}{2}\,12\,BF$$

ALL STUDIES OF

SIGNALS, S/BACKGROUNDS

CONCUR:

$L \sim 3000$ km OPTIMAL

$L \sim 6000$ km USEFUL

(as an ADD-ON)

$L \approx 732$ km ☹

IS NOT ENOUGH

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

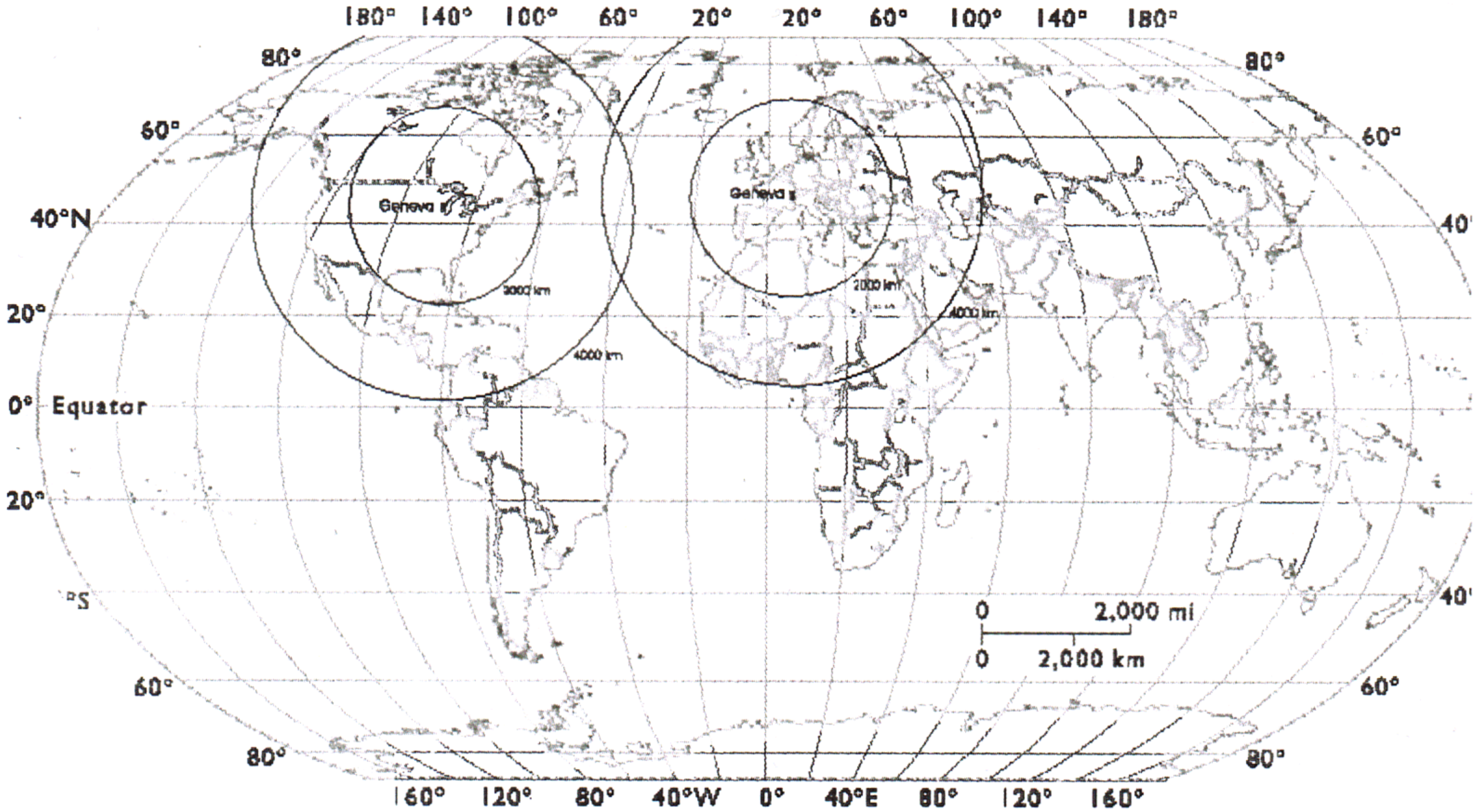
↓

GOOD DISTANCE TO WEST COAST

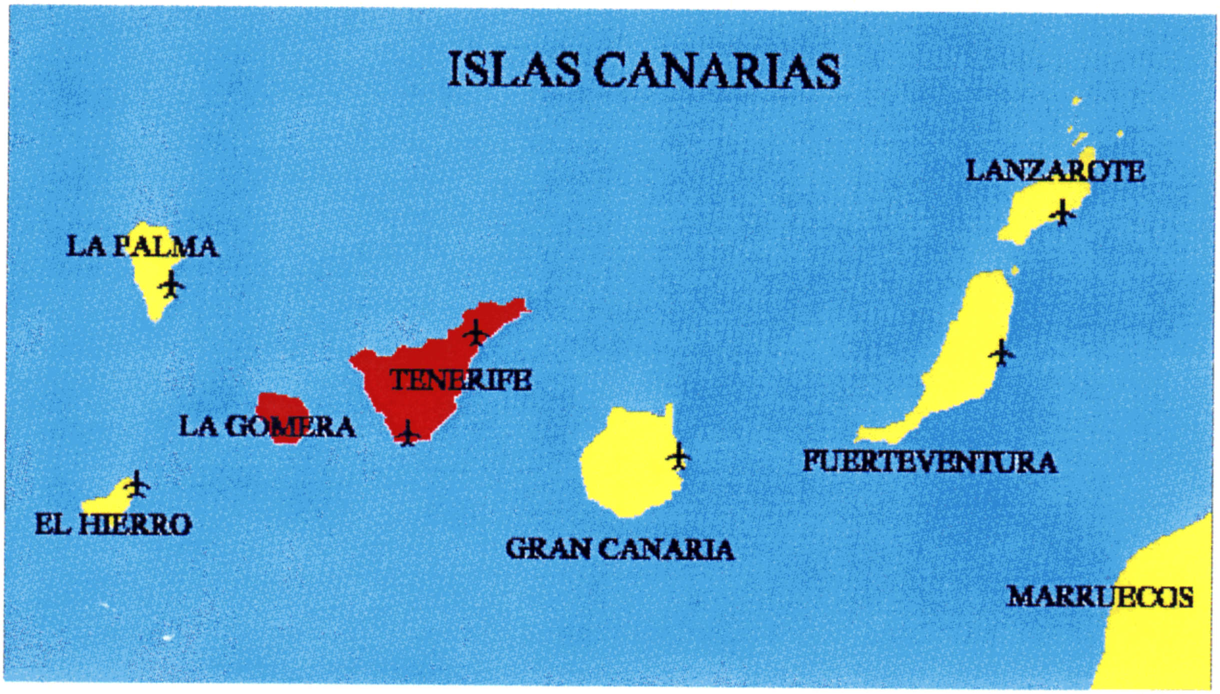
BUT

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

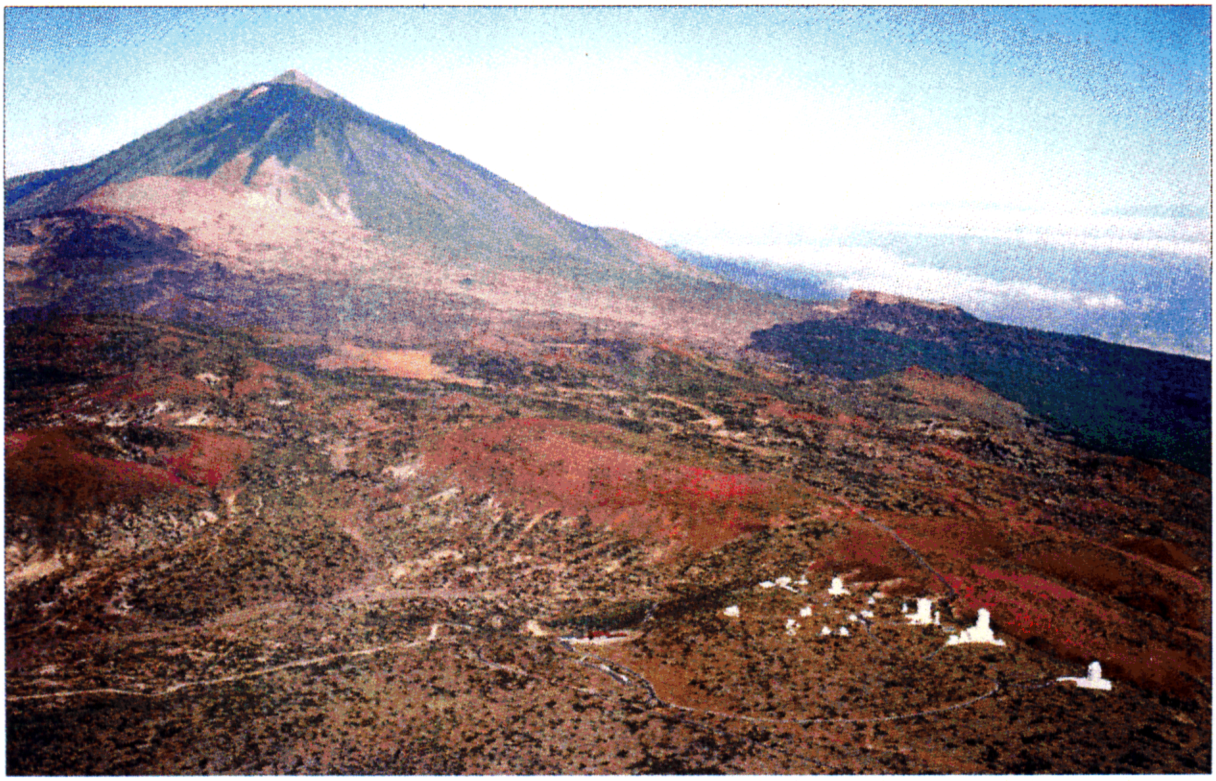
EXCEPT!



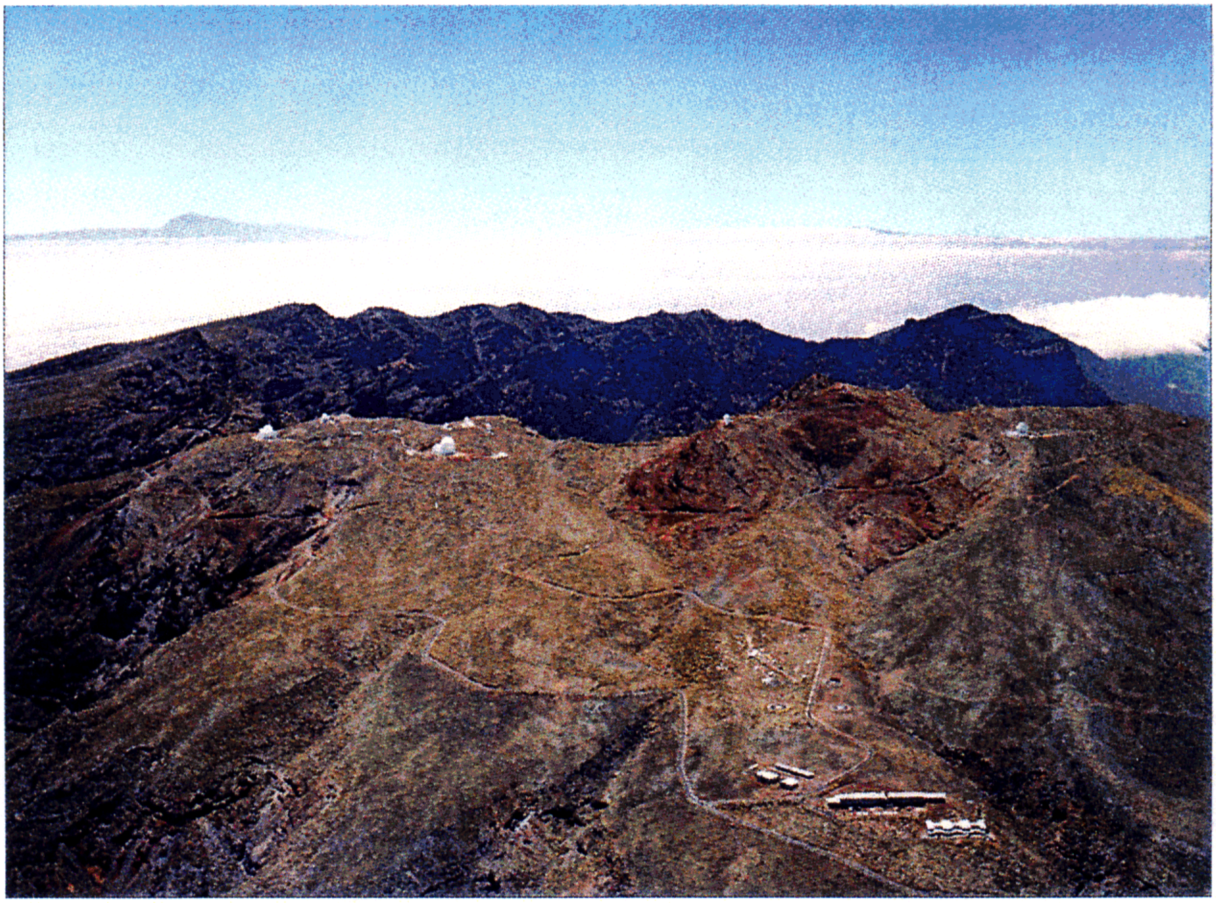
180° 140° 100° 60° 20° 20° 60° 100° 140° 180°
80°
60°
40°N
20°
0° Equator
20°
°S
60°
80°
Geneva
Geneva
2000 km
4000 km
4000 km
0 2,000 mi
0 2,000 km
160° 120° 80° 40°W 0° 40°E 80° 120° 160°


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


SANTA CRUZ DE TENERIFE



LA PALMA



km

FERMI → GRANSASSO 7332

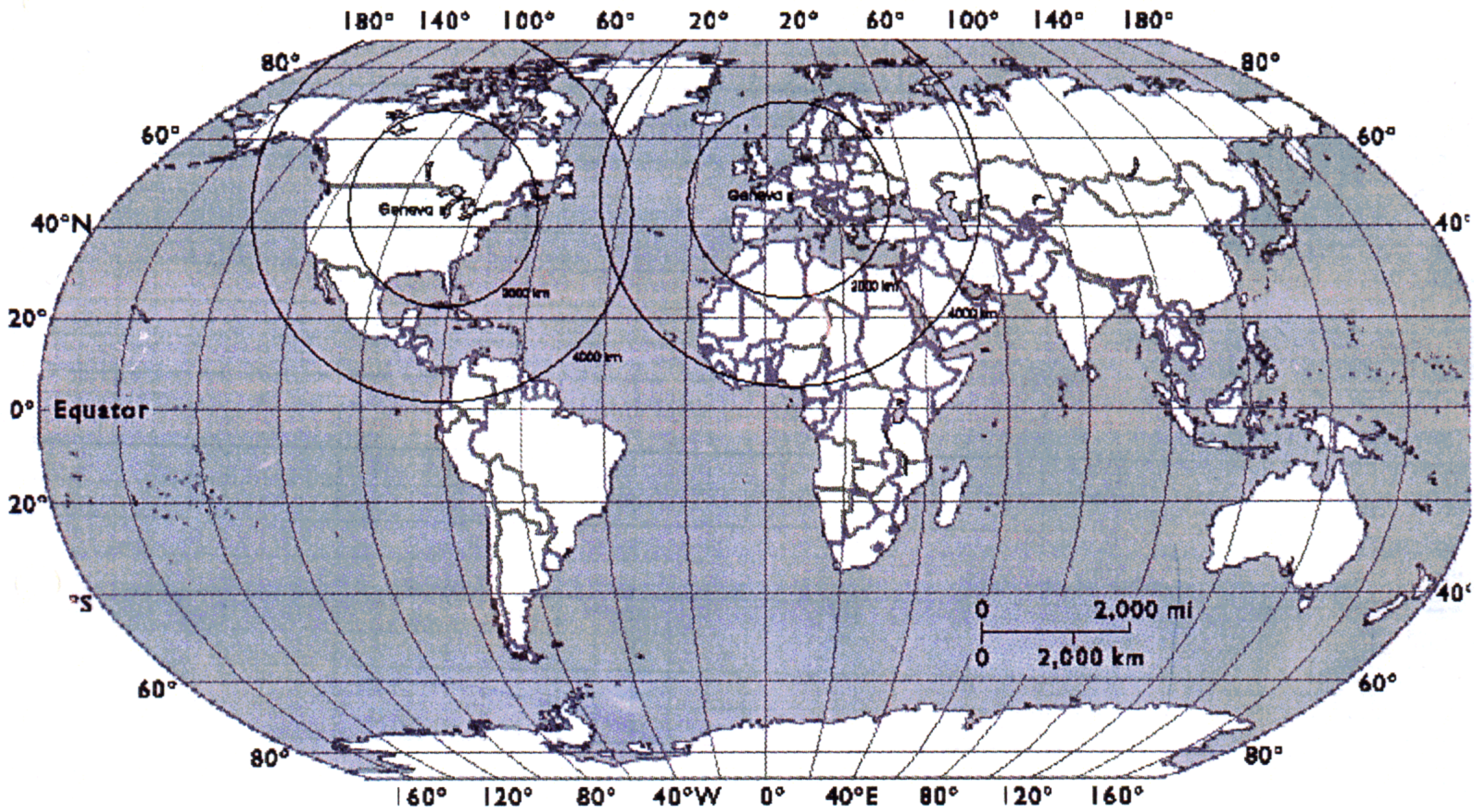
FERMI → CANARIES ~6000

FERMI → WEST COAST ~3000 [OPTIMAL]

CERN → GRANSASSO 732 

CERN → FERMILAB ~6000

CERN → CANARIES ~3000 [OPTIMAL]



180° 140° 100° 60° 20° 20° 60° 100° 140° 180°
80°
60°
40°N
20°
0° Equator
20°
°S
60°
80°
Geneva
Geneva
2000 km
4000 km
2000 km
4000 km
0 2,000 mi
0 2,000 km
160° 120° 80° 40°W 0° 40°E 80° 120° 160°

EITHER GVA

TO A

(MAGNETIZED)

SUPER K

~8500 km

HOW TO CONVERT A D.G. ?

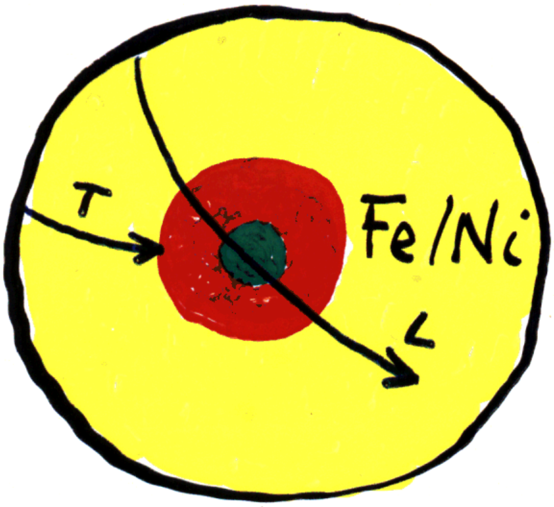
A.O.B.

MATTER EFFECTS

⇒ $\langle n_e \rangle|_{\nu \text{ TRAJ.}}$ ±10%

FREUND et al.
FREUND et al. al.
CERVERO et al.
BUENO et al.
BARGER et al.
ALBRIGHT et al.

νe FORWARD SCATTERING



A.O.B.

μ - POLARISATION

- TURNING OFF ν_e CAN MODULATE S/B

- SURROGATE FOR THE NEARLY IMPOSSIBLE $e^{+/-}$ DISTINCTION

See CERN study

MORE OF A "WHY NOT" THAN A "MUST"

On Burt Richter's insistence

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

?

NON-OSCILLATION ν - PHYSICS

e.g. : FERMILAB AND CERN REPORTS

CLOSE-BY LOCATION :

10's Mevents / kg / 10^{21} injected μ's

(WITH A NATURALLY POLARISED νBEAM)

- $F_i, G_i\ (x, Q^2)$ IN $p, n, \mathcal{N}$ QCD, NP
- PRECISION EW. ϕ : $\sigma(\nu e)$ 10^5 FOLD STAT.
- $D_0 - \bar{D}_0$ MIXING, TAGGED AT PROD.
- ν MAGNETIC MOMENTS

CATCHING SLOW BACKWARDS μ'S

$\mu \to e\gamma$

$\mu\mathcal{N} \to e\mathcal{N}$

$\mu \to eee$

$\mu^+e^- \to \mu^-e^+$

¿ 10^3 * CURRENT PSI STATISTICS

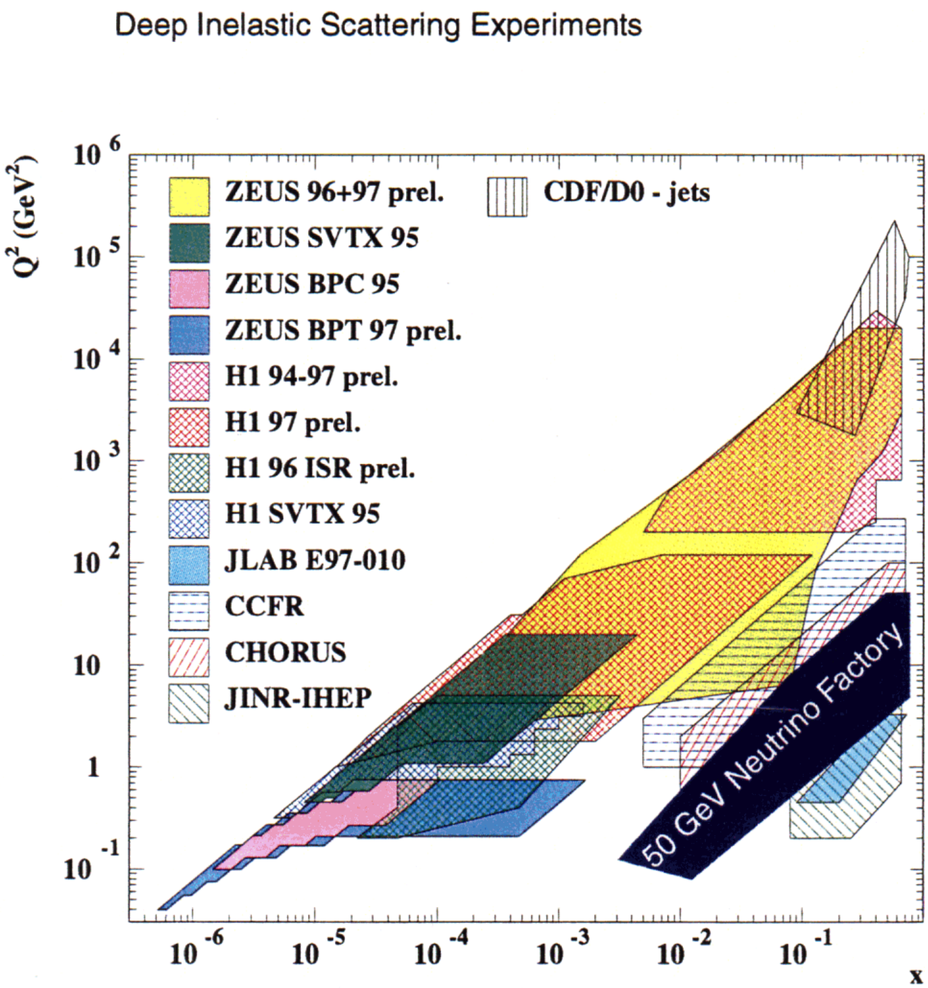


Figure 53: Comparison of kinematic ranges for present DIS experiments with a 50 GeV Neutrino factory.

FOR DECADES EXPERIMENTS SEEMED TO DO LITTLE BUT TO VERIFY THE PREDICTIONS OF THE STANDARD MODEL

($N_\nu = 3$, STANDARD EXCEPTION

THIS SEEMED TO BE TAKING **FOREVER**

FOREVER

IS A VERY LONG TIME

PARTICULARLY TOWARDS THE

END

ν-OSCS. BROUGHT US BEYOND THE END

(OF BORING PHYSICS)

$D \to (K, \pi)\mu\nu_\mu$

c ↓

$s_\theta \sim s\cos\theta_c - d\sin\theta_c$

DECOHERENCE

$\nu_\mu = \alpha\nu_1 + \beta\nu_2 + \gamma\nu_3$ COHERENT OSCILLATIONS

NATURE

HAS ALSO TUNED MANY OTHER PARAMS.
FOLLOWING THE PRINCIPLE OF MINIMAL
EFFORT (FOR PHYSICISTS)

- m_ν's
- $E(CRs)$, $R_\otimes$, $\rho_\otimes$
- $E(NRs)$, $R_\odot$, $\rho_\odot$

$d(\odot\otimes)$?

HOW SHOULD WE RECIPROCATE NATURE'S LOVING GENEROSITY

AND DO THE RIGHT THING BY HER

??

BUILDING A

V

FACTORY

OTHERS e.g ICARUS
NOE may be orders of magnitude more sophisticated but are moving ahead in ~~[illegible]~~, tests and development

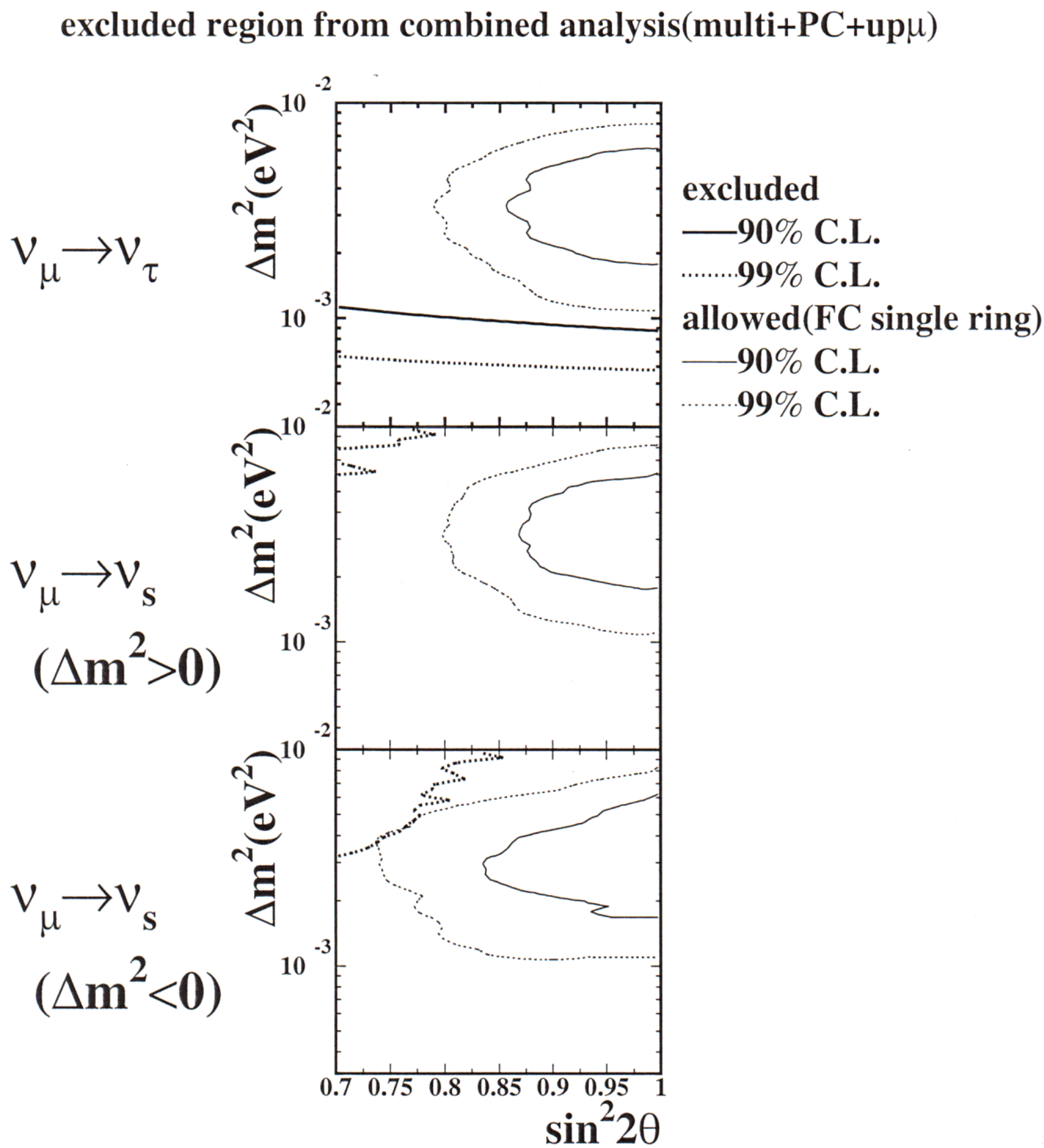
eile,

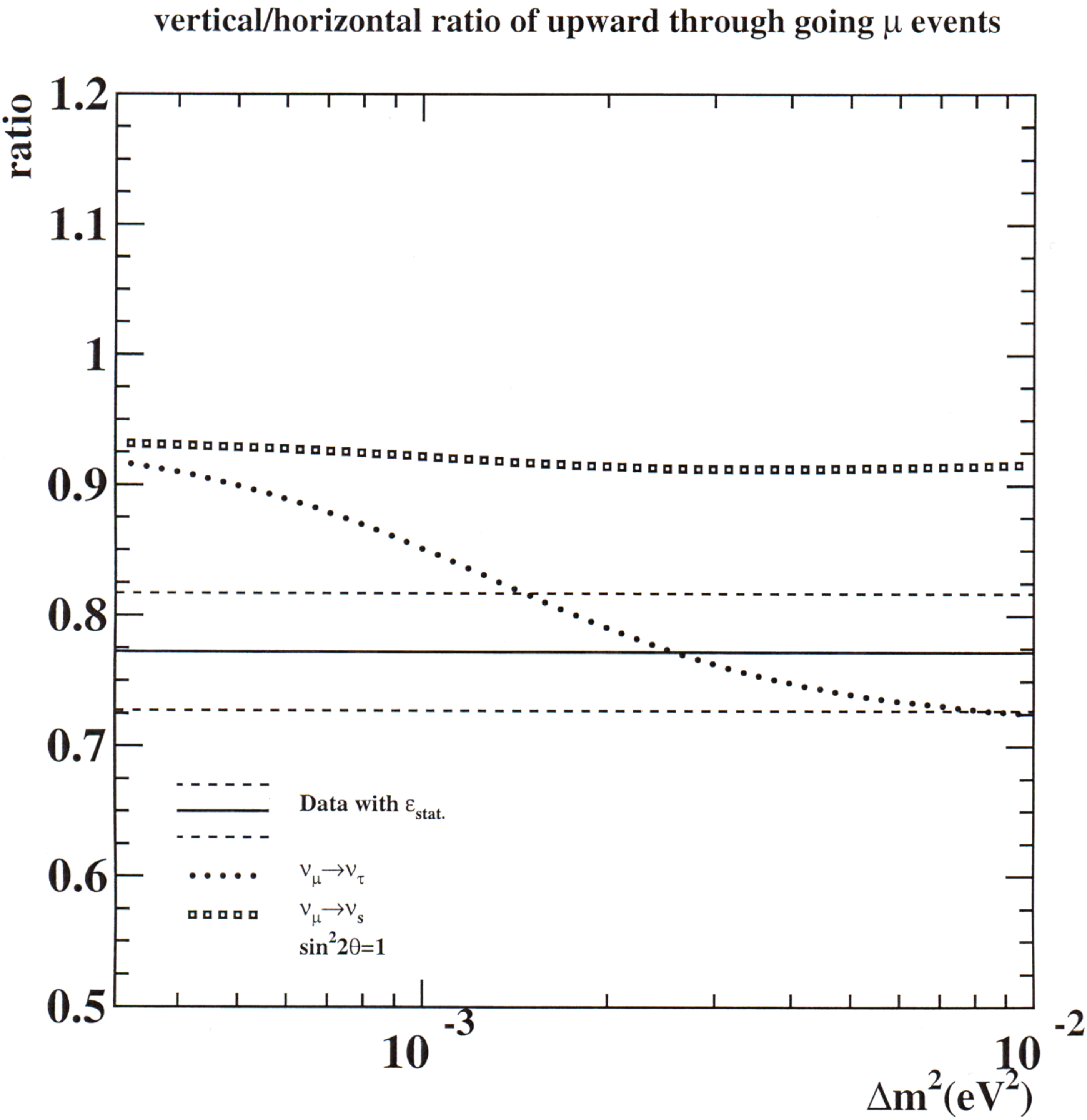
ref ?

Some of these detectors are so large that they do not fit in a transparency

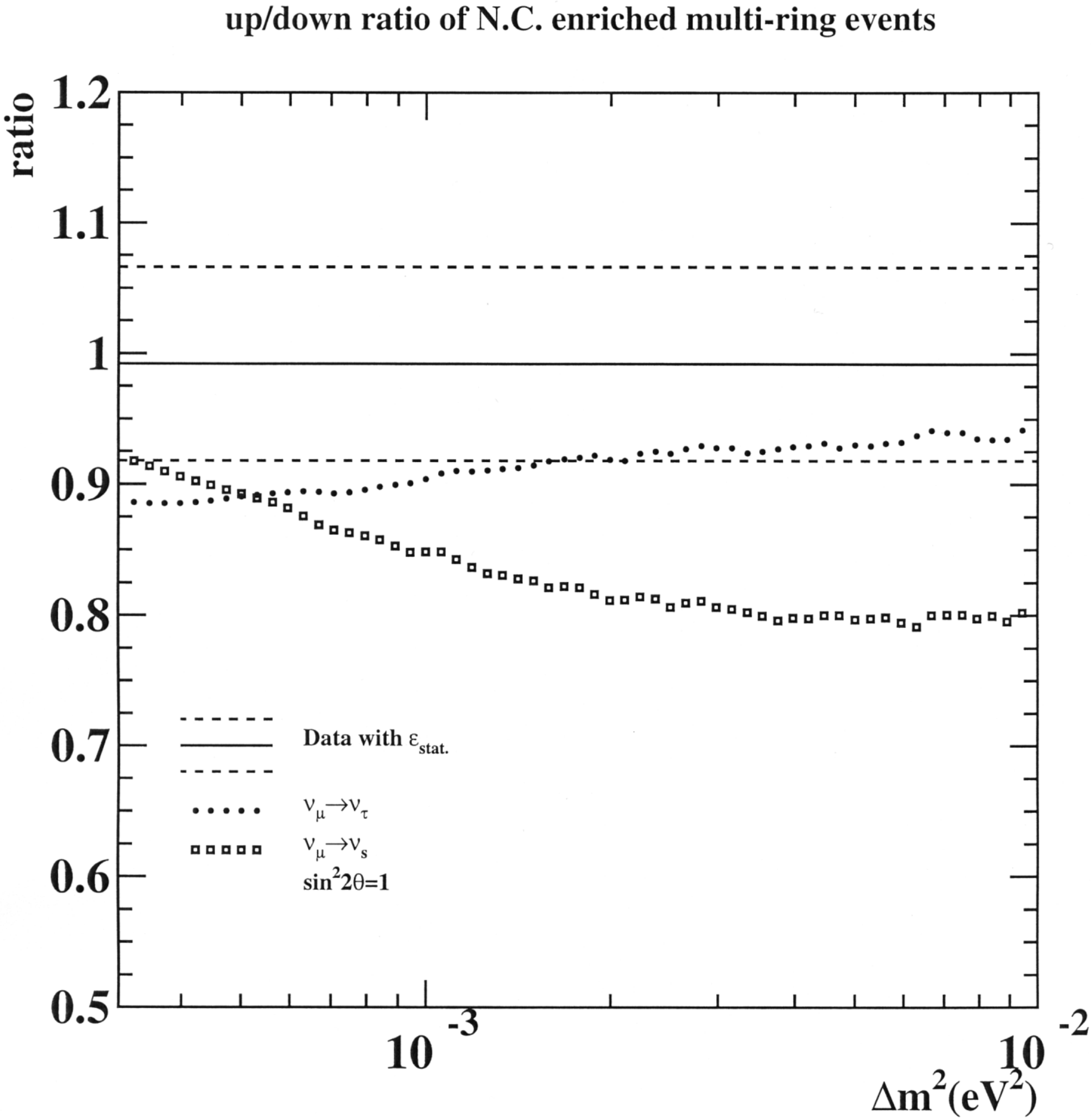
but they are ~~quite simple~~ quite simple

(~~the~~ Magnetized Fe, segmented scintillator)


excluded region from combined analysis(multi+PC+upμ)
νμ→ντ
νμ→νs
(Δm2>0)
νμ→νs
(Δm2<0)
Δm2(eV2)
10-2
10-3
0.7
0.75
0.8
0.85
0.9
0.95
1
sin22θ
excluded
90% C.L.
99% C.L.
allowed(FC single ring)
90% C.L.
99% C.L.



vertical/horizontal ratio of upward through going μ events
ratio
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
Data with ε stat.
νμ→ντ
νμ→νs
sin22θ=1
10 -3
10 -2
Δm2(eV2)



up/down ratio of N.C. enriched multi-ring events
ratio
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
10^{-3}
10^{-2}
$\Delta m^2 (eV^2)$
Data with $\varepsilon_{stat.}$
$\nu_\mu \rightarrow \nu_\tau$
$\nu_\mu \rightarrow \nu_s$
$\sin^2 2\theta=1$

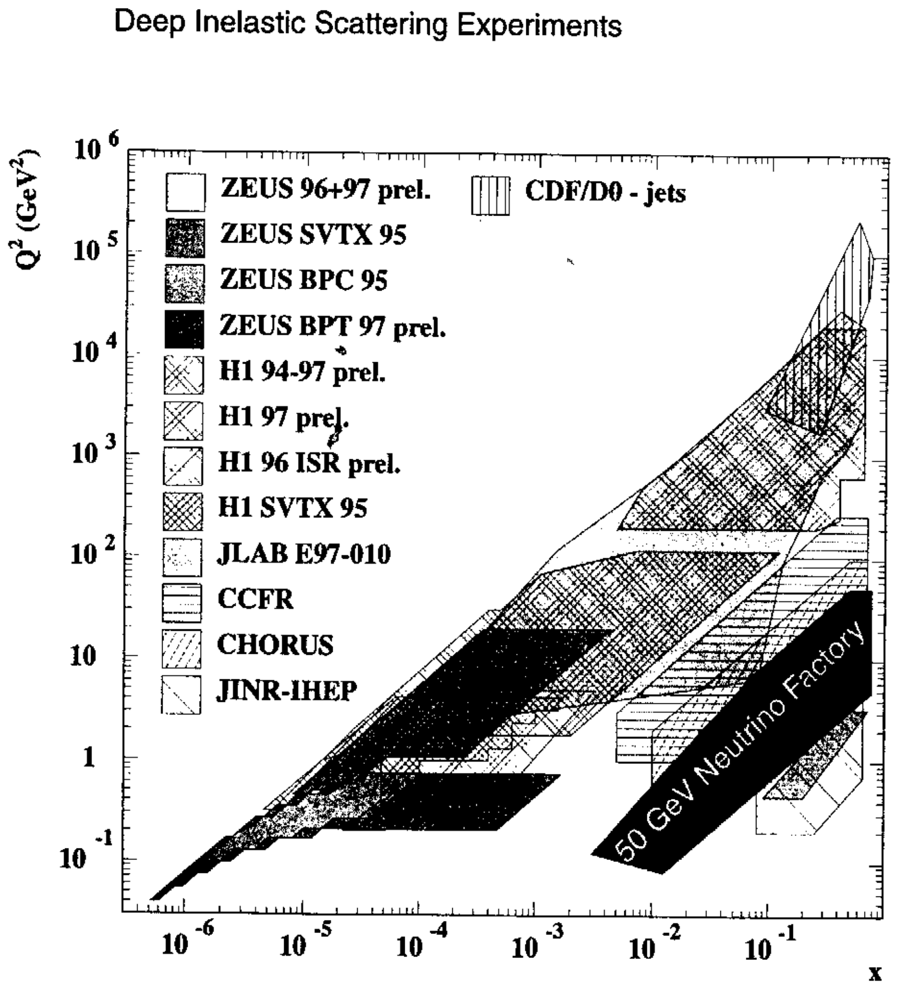
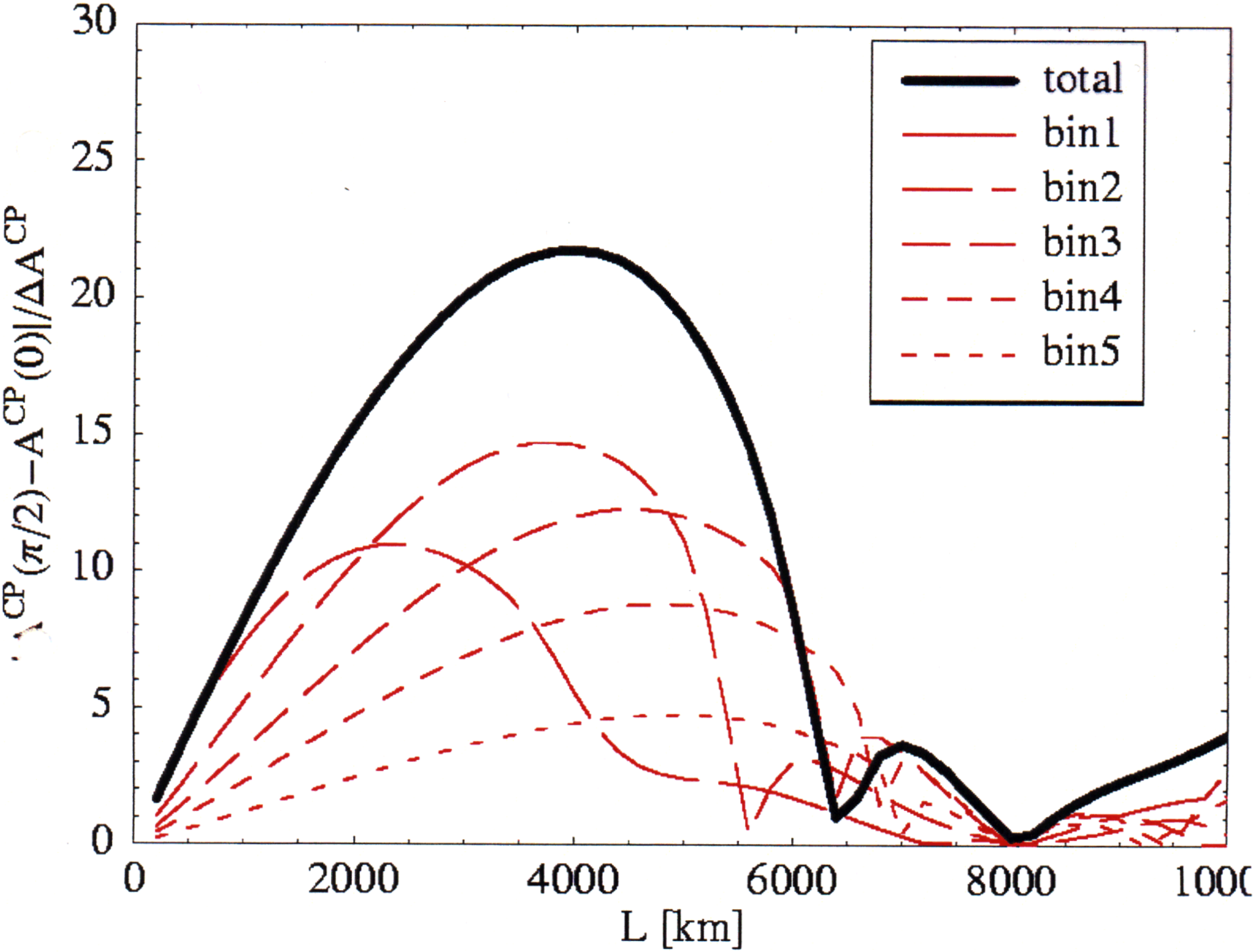


Figure 53: Comparison of kinematic ranges for present DIS experiments with a 50 GeV Neutrino factory.



30
25
20
15
10
5
0
0
2000
4000
6000
8000
1000
L [km]
CP(π/2)−A^CP(0)|/ΔA^CP
total
bin1
bin2
bin3
bin4
bin5

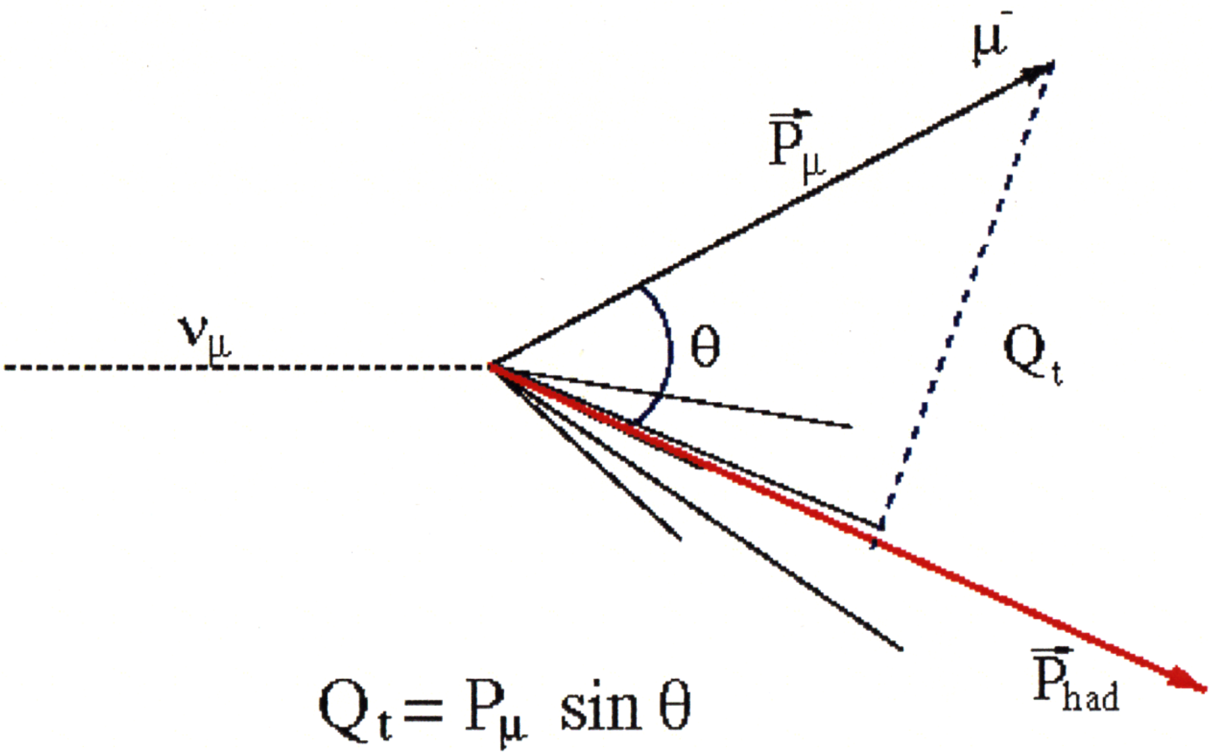


Figure 8: *Definition of the kinematical variables used in this study.*

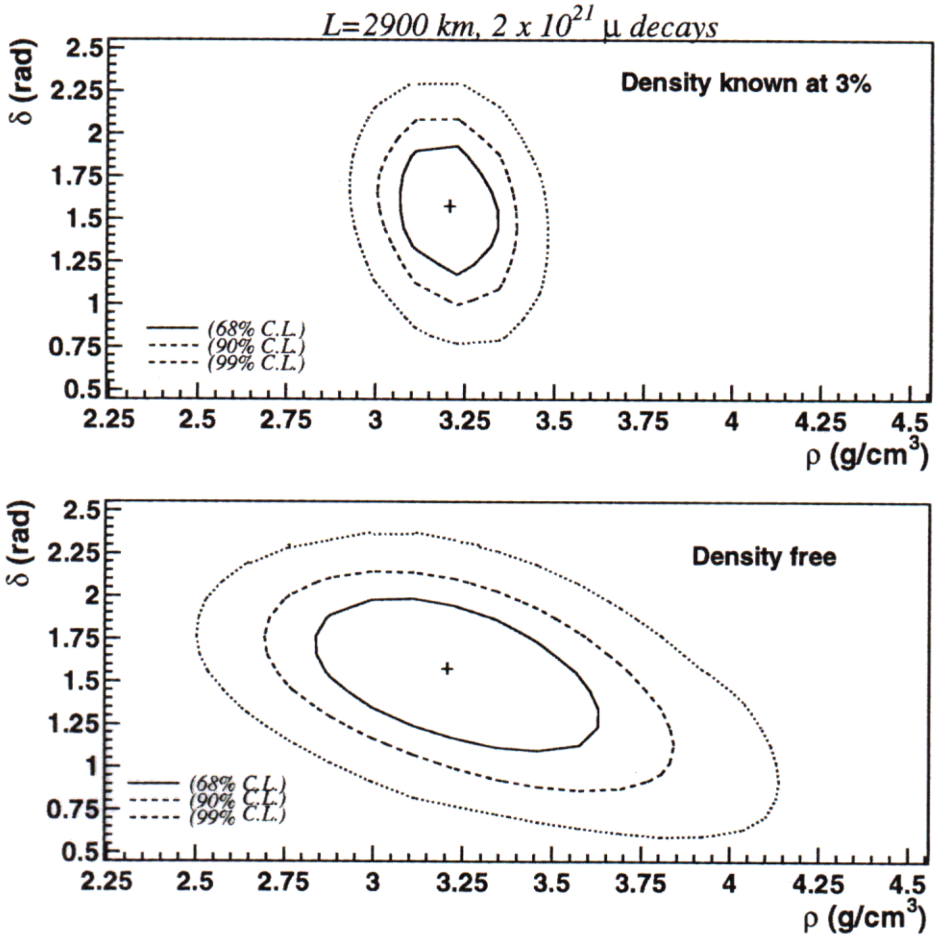


Figure 16: Correlation between the average matter density ρ and the CP phase δ for L=2900 km. In the lower plot we leave Earth's mean density as a free parameter in the fit. In the upper plot we assume that density is known within 3%. We see that the presence of matter does not spoil the possibility of performing a measurement of δ.

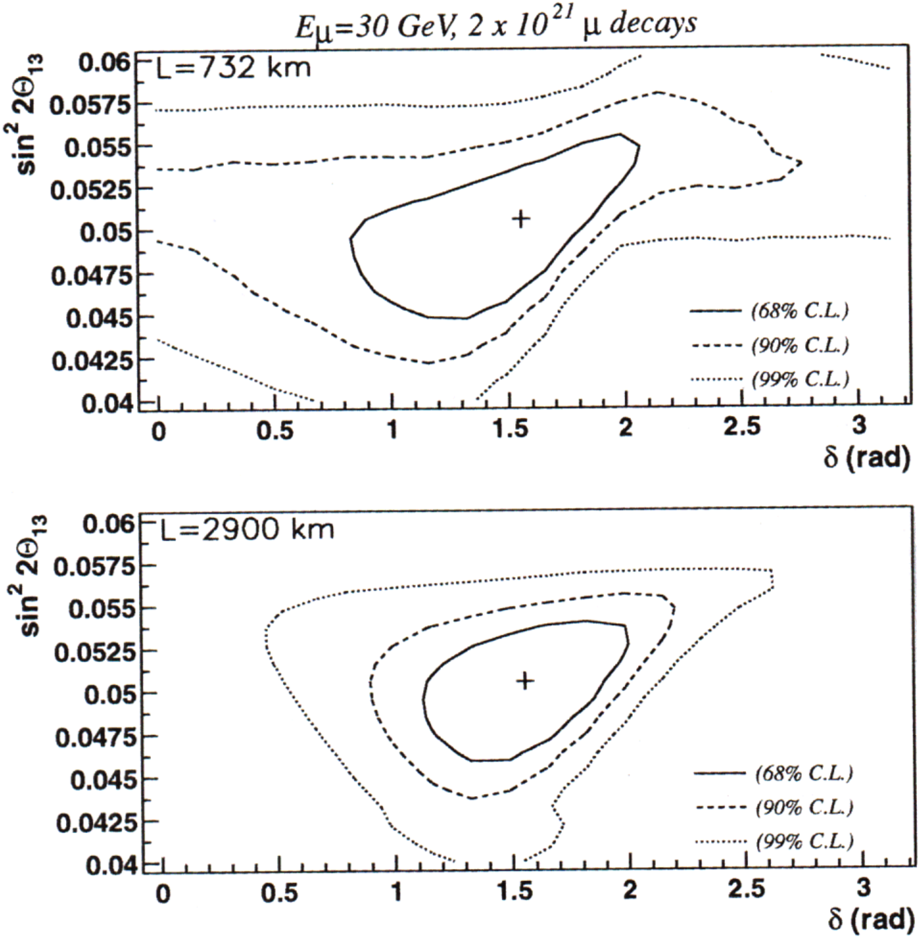


Figure 15: Correlation between θ_{13} and CP phase δ for two different baselines and 2×10^{21} decays.

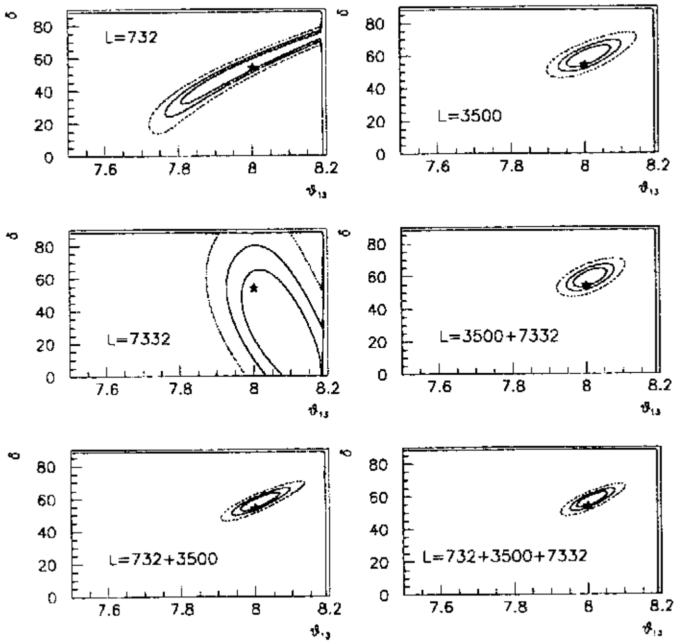
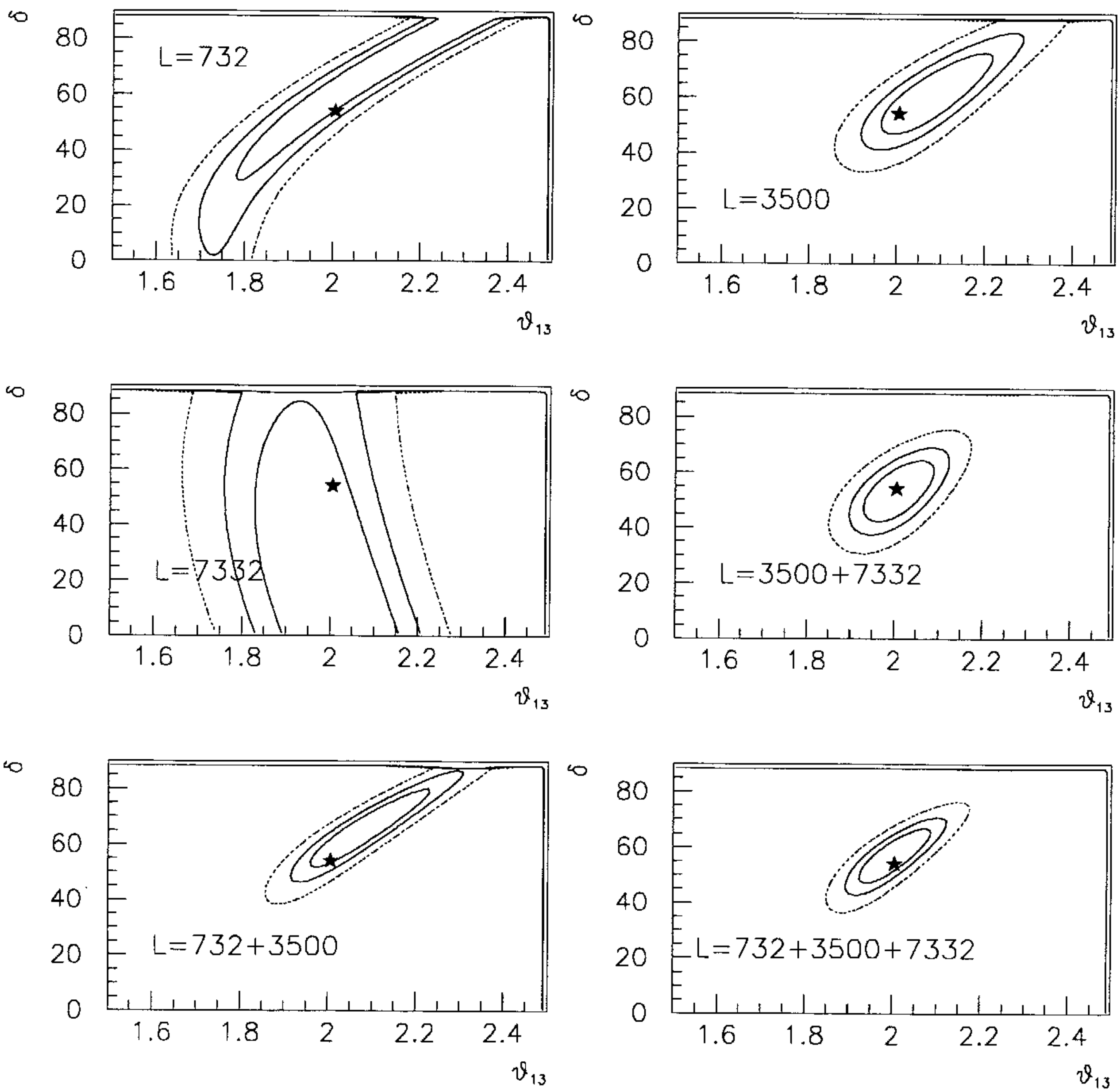
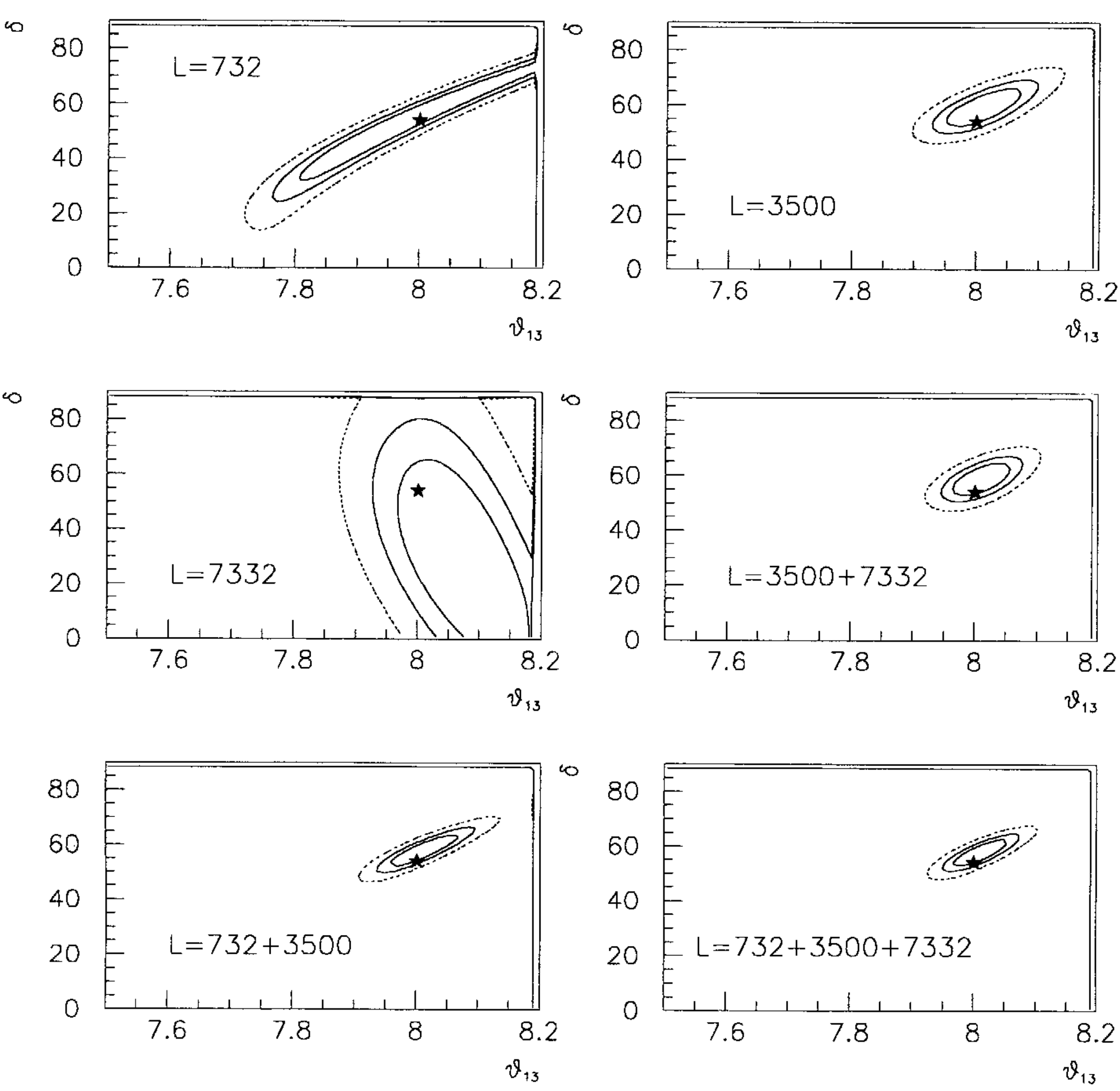


Figure 16: *68.5, 90, 99 % CL contours resulting from a χ^2 fit of θ_{13} and δ. The parameters used to generate the "data" are depicted by a star and the baseline(s) which is used for the fit indicated in each plot. Only statistical errors are included.*


δ
80
60
40
20
0
L=732
1.6
1.8
2
2.2
2.4
ϑ13
δ
80
60
40
20
0
L=3500
1.6
1.8
2
2.2
2.4
ϑ13
δ
80
60
40
20
0
L=7332
1.6
1.8
2
2.2
2.4
ϑ13
δ
80
60
40
20
0
L=3500+7332
1.6
1.8
2
2.2
2.4
ϑ13
δ
80
60
40
20
0
L=732+3500
1.6
1.8
2
2.2
2.4
ϑ13
δ
80
60
40
20
0
L=732+3500+7332
1.6
1.8
2
2.2
2.4
ϑ13


L=732
L=3500
L=7332
L=3500+7332
L=732+3500
L=732+3500+7332
δ
0
20
40
60
80
7.6
7.8
8
8.2
ϑ_{13}