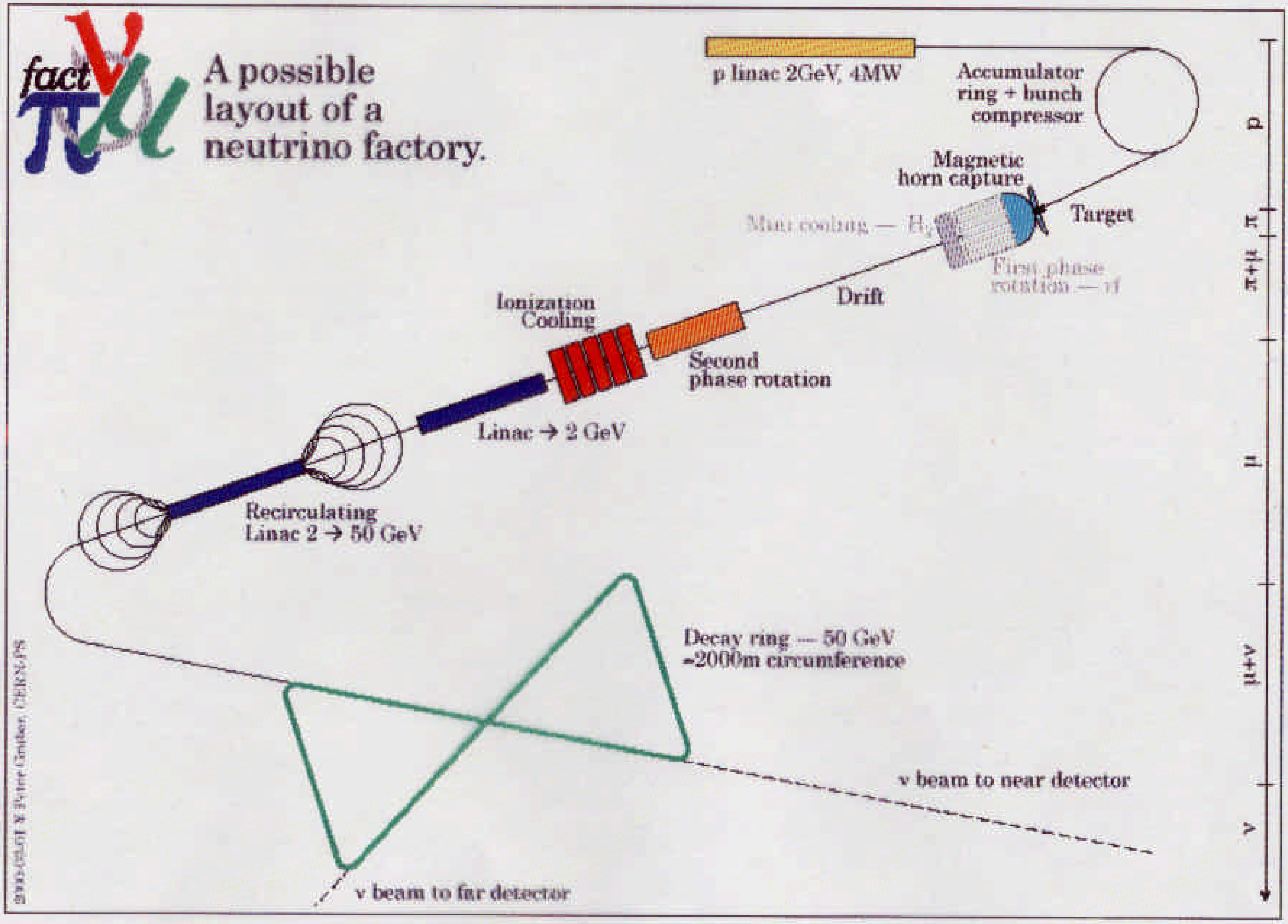
ν-2000

m-TALK

ϕ

@

ν-FAC



A possible layout of a neutrino factory.

μ COLLIDERS BUDKER 1969
SKRINSKI, colls 1971
NEUFFER 1979

ν FACTORY KOSHKAREV 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, LDs...

STORED

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

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

UNLIKE IN CONVENTIONAL π/K BEAM

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

$\nu_\mu \rightarrow$

- $\nu_\mu \rightarrow \mu^-$ DISAPP. RS ✓✓
- $\nu_e \rightarrow e^-$ APP. ×
- $\nu_\tau \rightarrow \tau^-$ APP. ✓

$\bar{\nu}_e \rightarrow$

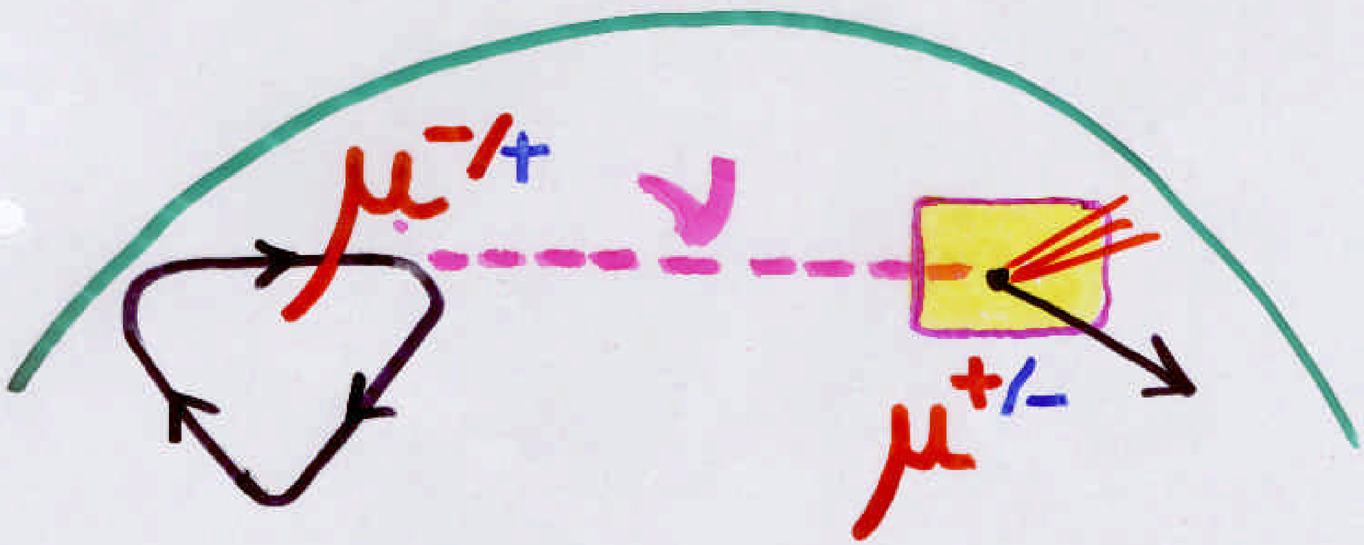
- $\bar{\nu}_e \rightarrow e^+$ DISAPP. ×
- $\bar{\nu}_\mu \rightarrow \mu^+$ APP. WS ✓✓✓
- $\bar{\nu}_\tau \rightarrow \tau^+$ APP. ✓

STORED

GOLDEN SIGNATURE

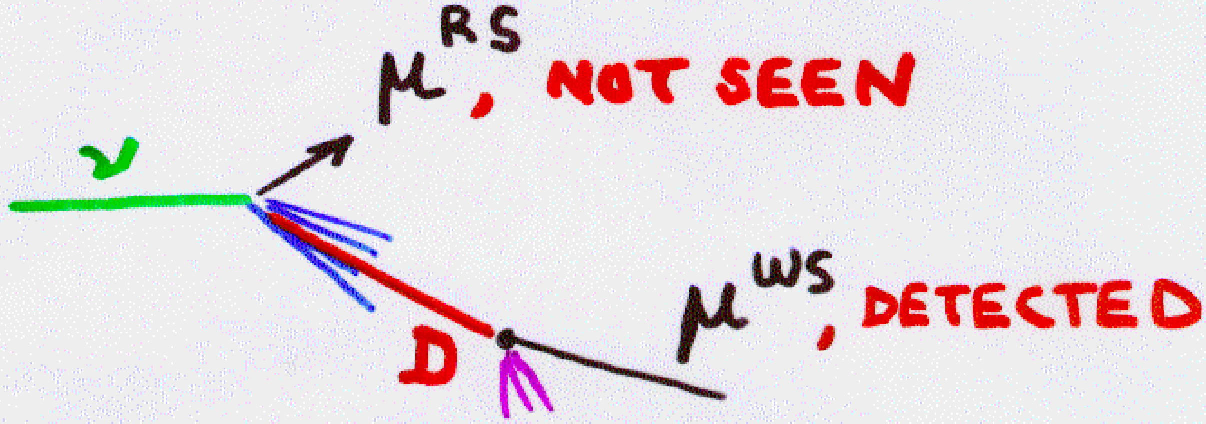
"WRONG-SIGN" μ's :

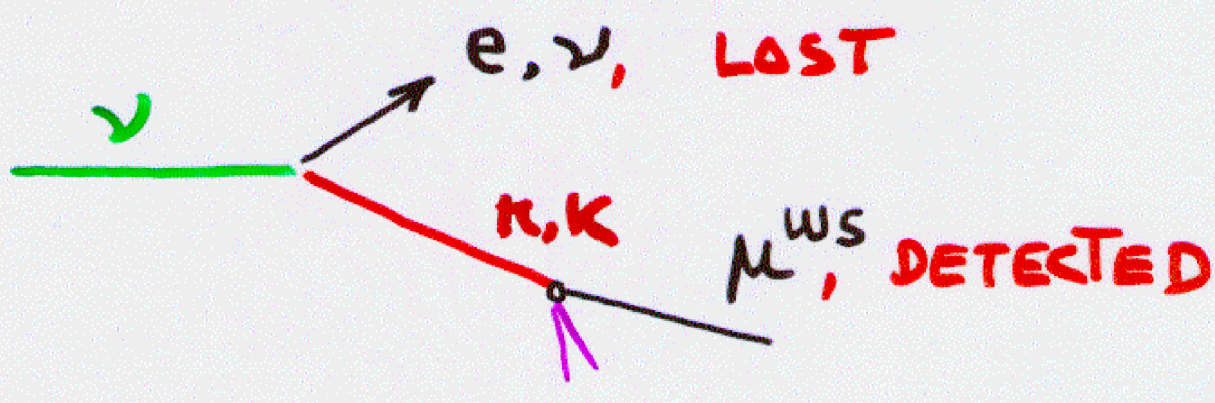
THOSE WHOSE CHARGE IS OPPOSITE TO THAT OF THE MUONS IN THE STORAGE RING



- NO BEAM-INDUCED BACKGROUND TO THE WRONG-SIGN μ SIGNAL

- BACKGROUNDS AT DETECTOR





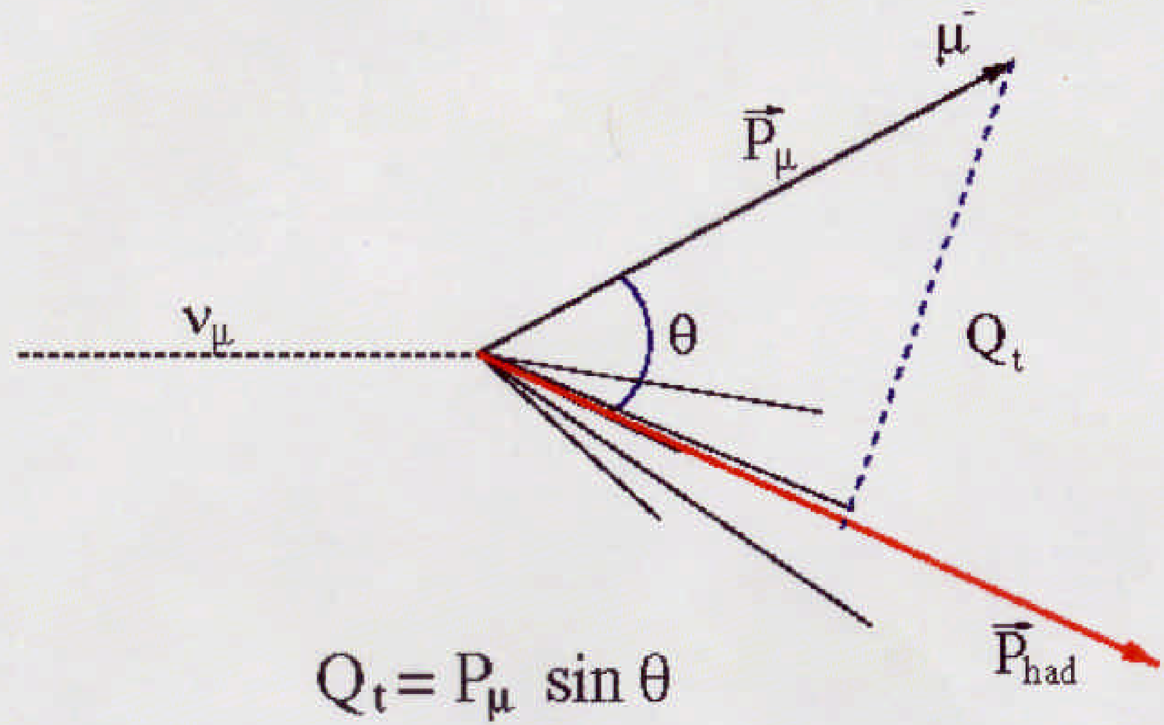


Figure 8: *Definition of the kinematical variables used in this study.*

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

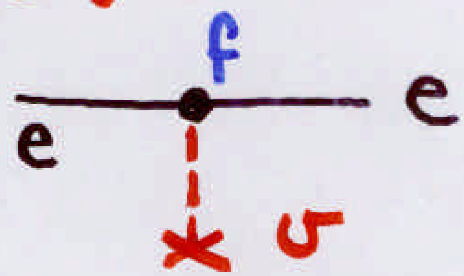
GRAND UNIFIED THEORIES

$$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} \text{ DOUB.} \quad e_R \text{ SINGLET} \quad \nu_R \text{ USELESS}$$

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

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

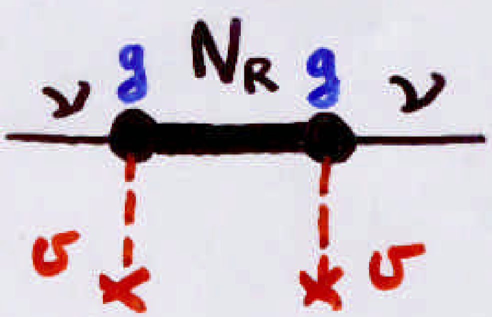
$$\rightarrow f v \bar{e} e = m_e \bar{e} e$$



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

COMPLETE q, ℓ FAMILY $(+N_R) \in 16$

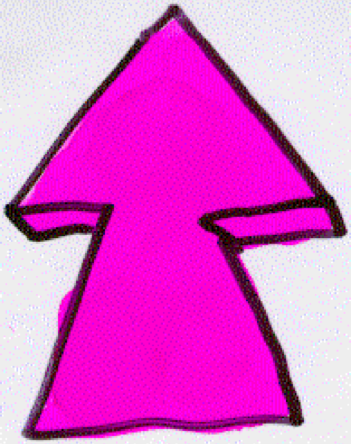
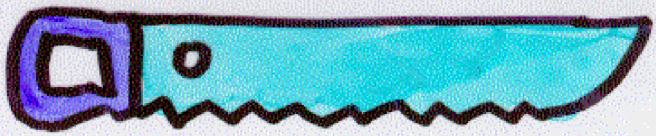
Inevitably $\Delta\mathcal{L}' = g \bar{L} \phi N_R$



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

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

$M_N \sim 6\, 10^{15}\, GeV$ 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


FORGET
STERILE
SK
MACRO
Soudan2
LSND
3 ν_s

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

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

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

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

$$U \equiv U_1 U_2 U_3 \equiv$$

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

ATMS SOLAR

WHAT WE KNEW FOR SURE (< Y2000)

$\Delta m^2_{23} \sim 3.5\,10^{-3}\,\mathrm{eV}^2 \quad \theta_{23} \sim 45^\circ$ ATMS.

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

(DAY / NIGHT E-SPECTRA)

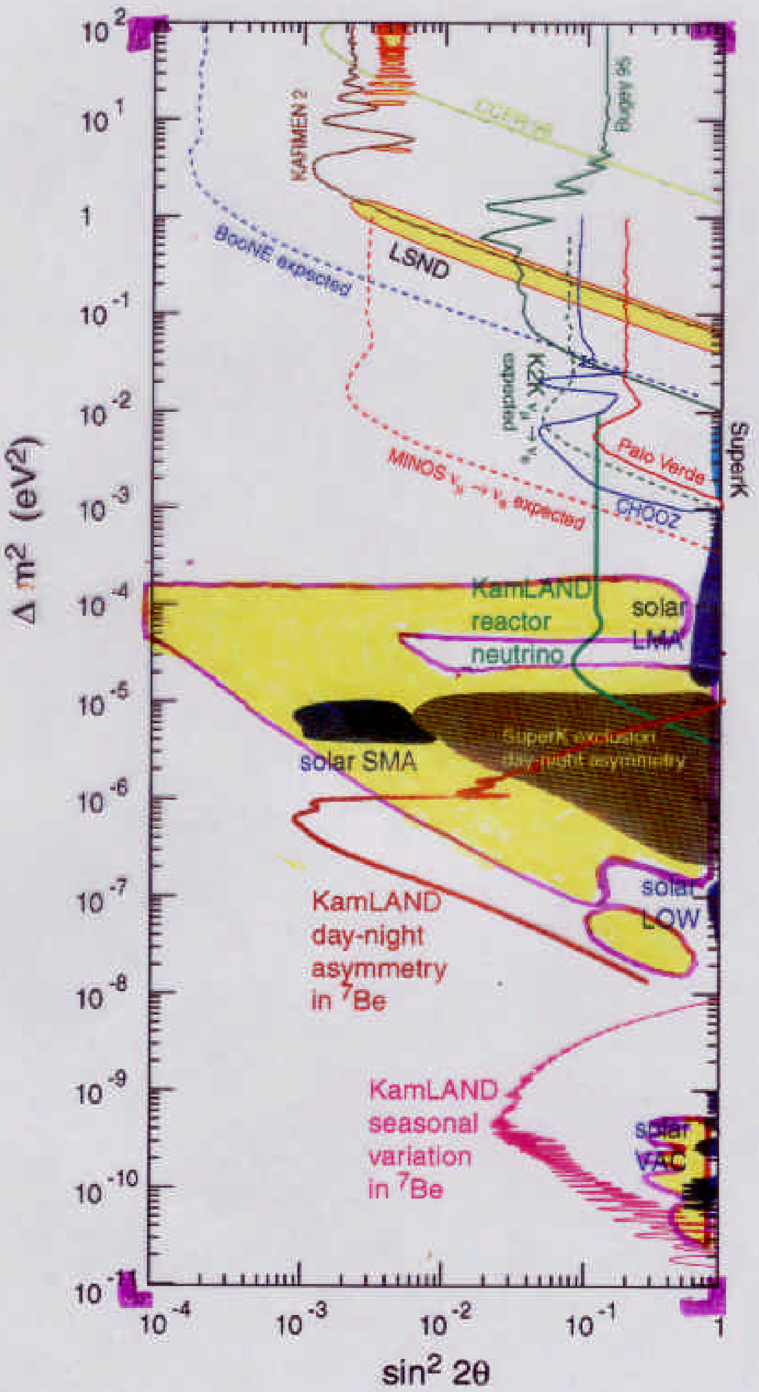


Figure 14: The current and expected limits at some of the future neutrino oscillation experiments. Note that different oscillation modes are shown together.

THE BEST OF ALL WORLDS FOR A ν-FACTORY

① ATMS. OSCILLATS. ✓✓✓

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

② $\nu_\odot$ VAC. OSC EXCLUDED

③ $\nu_\odot$ SMALL MIX. ANG. EXCLUDED

④ $\nu_\odot$ "LOW" MSW EXCLUDED

⑤ $\nu_\odot$ LARGE MIX. ANG. FAVOURED

BUT $\Delta m^2_{12} <$ a few $10^{-5}\,eV^2$ EXCLUDED

SK ν.2000 95% C.L.

SK ν.2000 95% C.L.

POSSIBLE, ALSO A VERY GOOD FIT

SK ν.2000 95% C.L.

TO ~ 95% C.L.

WE LIVE IN THE BEST of ALL WORLDS

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

IFF ⊙ LMA SURVIVES

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

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 (5y?)
- 4 MW beam on target → $10^{21}\,\mu$/y (25% USED)

② ☹ COWARDLY ; ☺ REALI$TIC

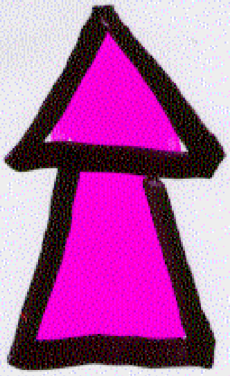
e.g. BARGER et al

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

1.5 ☺ , ☹ SOPHISTICATED DETECTOR

e.g. BUENO et al.

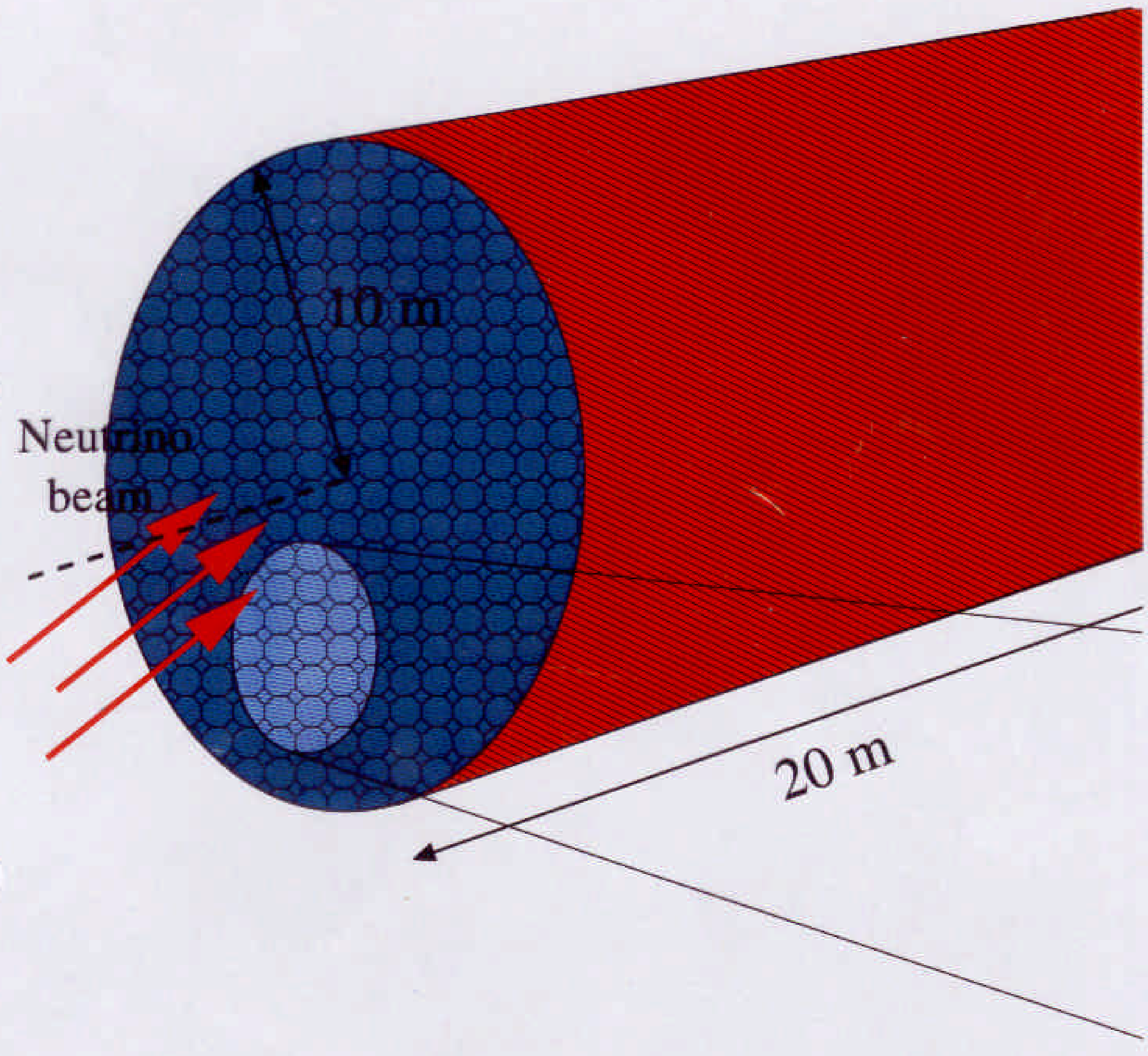
- $E_\mu = 30$ GeV
- 10 kT ICANOE + DOWNSTREAM $\mu^{+/-}$ DET.
- $10^{21}\,\mu^+$ and μ^- USEFUL DECAYS



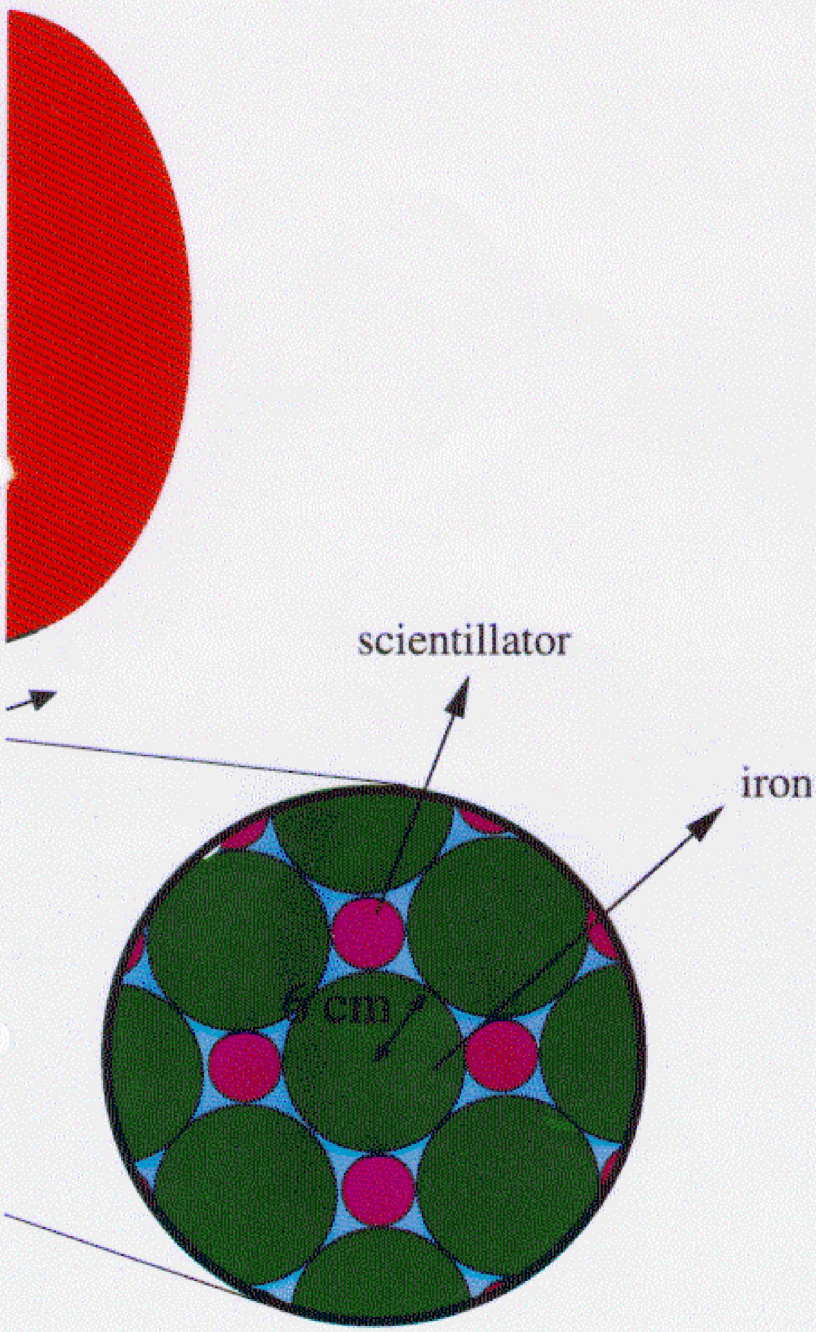
MATTER OF DEBATE AND OPINION

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, £, ¥, Pts, ...



CERVERA, DYDAK, GÓMEZ-CADENAS


scientillator
iron
6 cm

SPARKLING
SCIENTIST

OTHER DETECTORS, e.g ICARUS / ICANOE

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

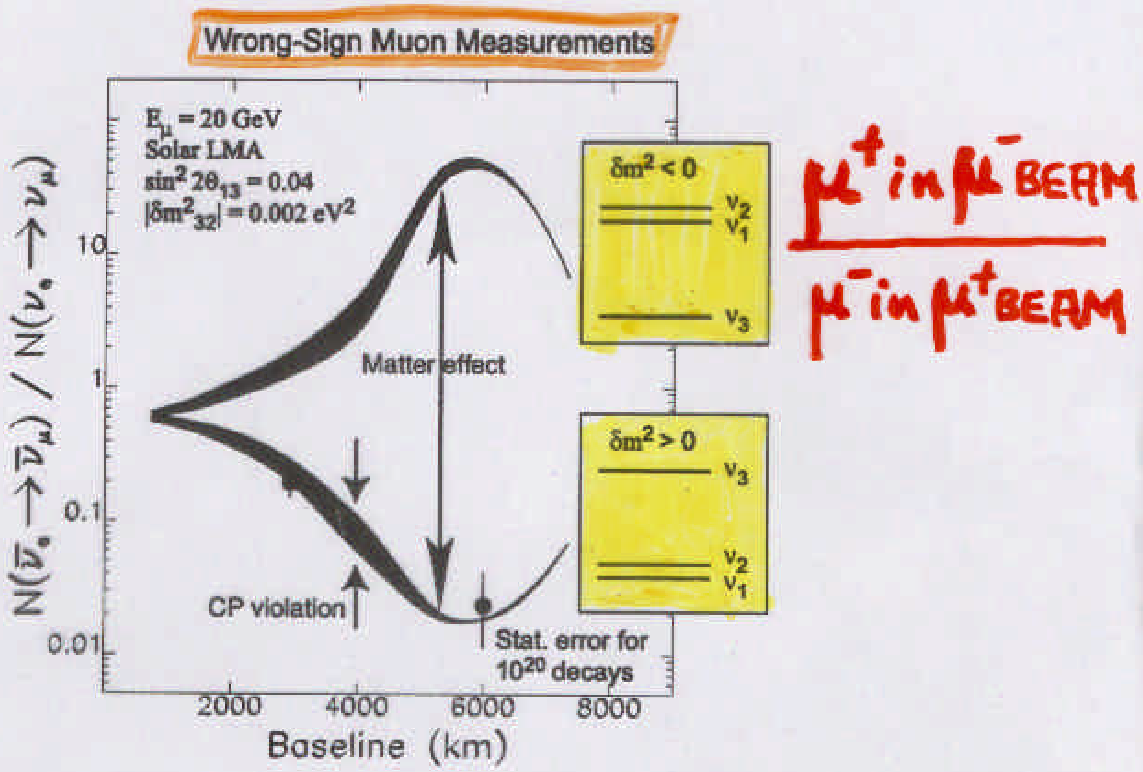


Figure I: Predicted ratios of $\bar{\nu}_e \to \bar{\nu}_\mu$ to $\nu_e \to \nu_\mu$ rates at a 20 GeV neutrino factory. The upper (lower) band is for $\delta m^2_{32} < 0$ ($\delta m^2_{32} > 0$). The range of possible CP violation determines the widths of the bands. The statistical error shown corresponds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

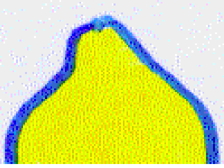
→ PRESUMABLY BARGER/GEER/RAJA/WHISNANT

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

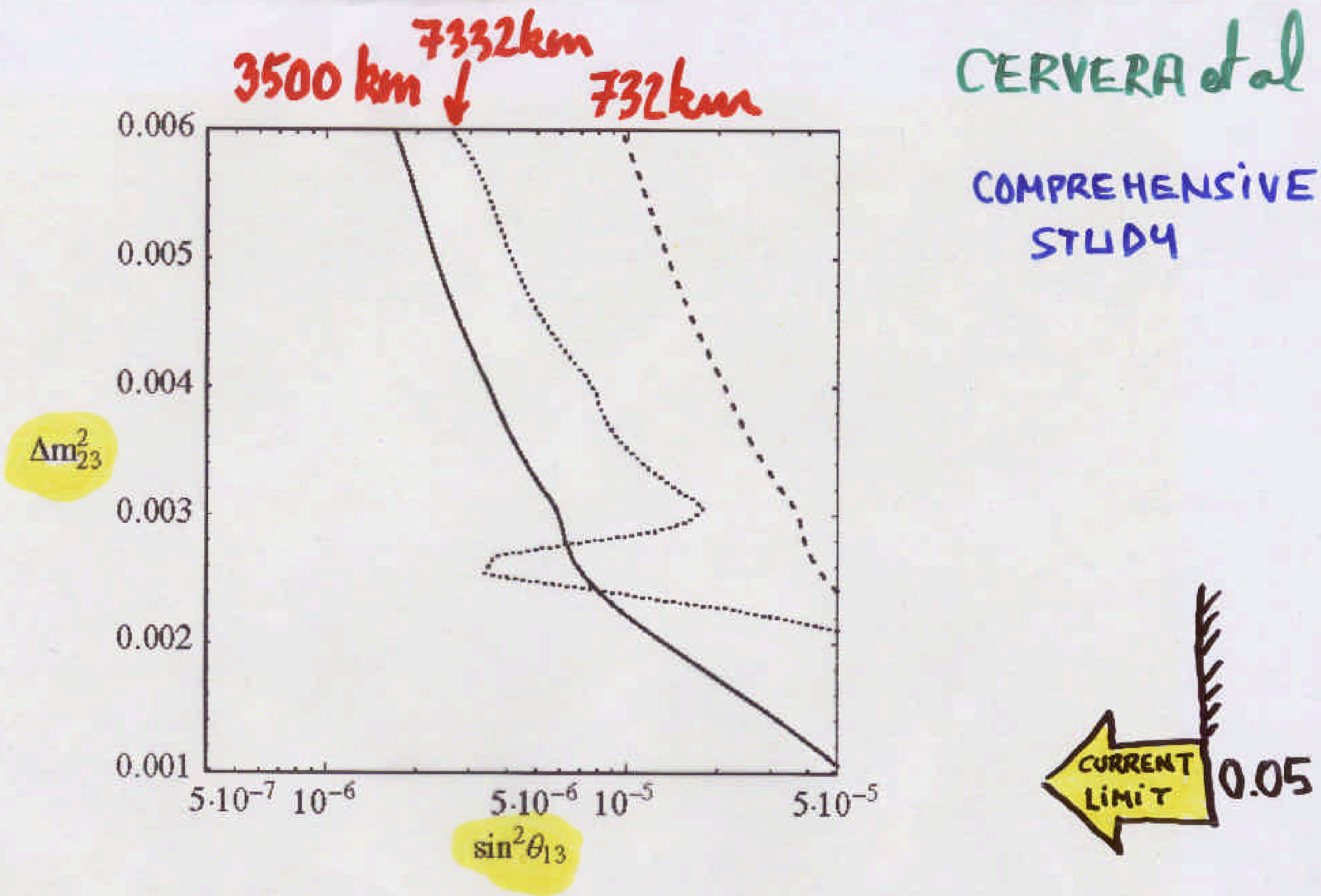
$\Delta m^2_{23}, \theta_{23}$ to ~1%

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

EARLY DESCOPING



-99.95 $



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

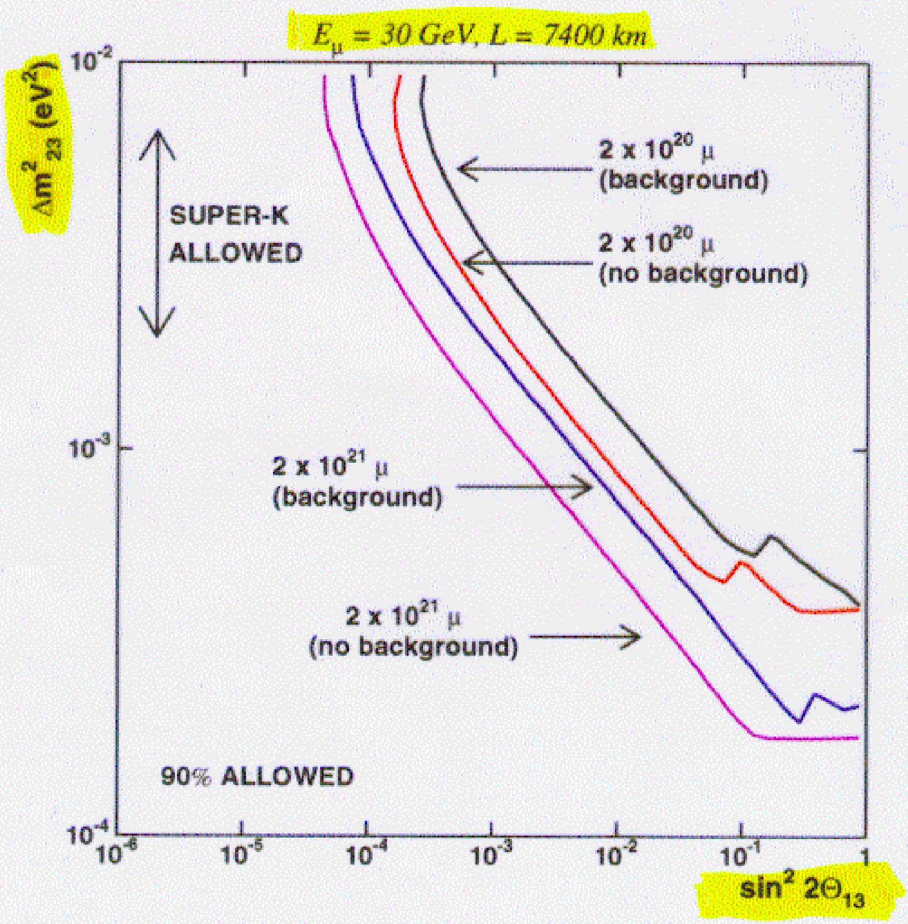


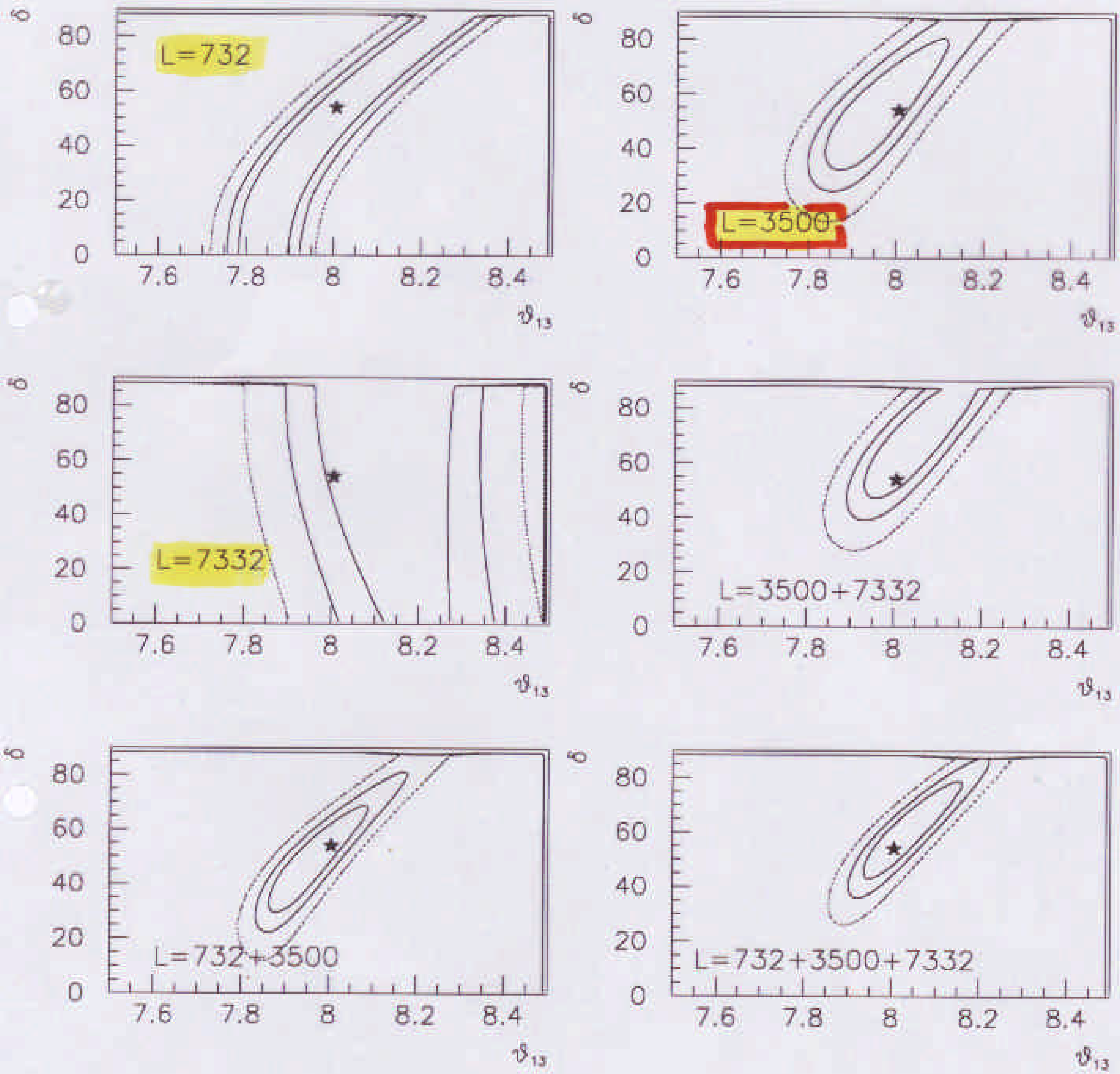
Figure 9: Sensitivity on θ_{13}

Bueno et al.
ICANOE

δ ↑ → θ_{13}

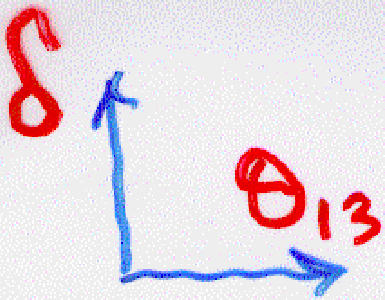
$\Delta m^2_{12} = 5\ 10^{-5}\ eV^2$

(NOT MOST OPTIMISTIC)



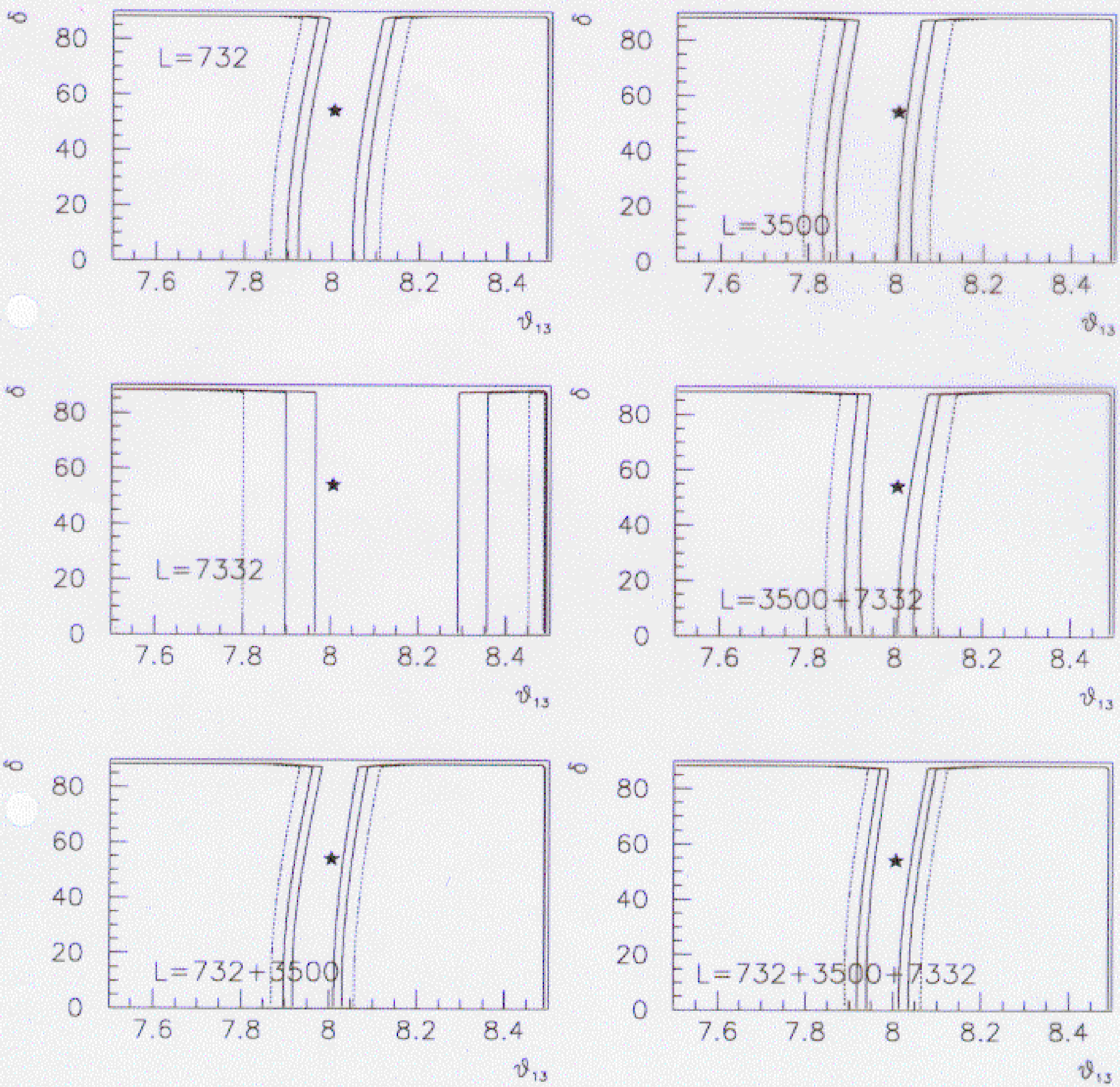
Cervera et al.

LOW-END LMA-MSW



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

SK ν-2000 EXCLUDED 95%



Cervera et al.

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

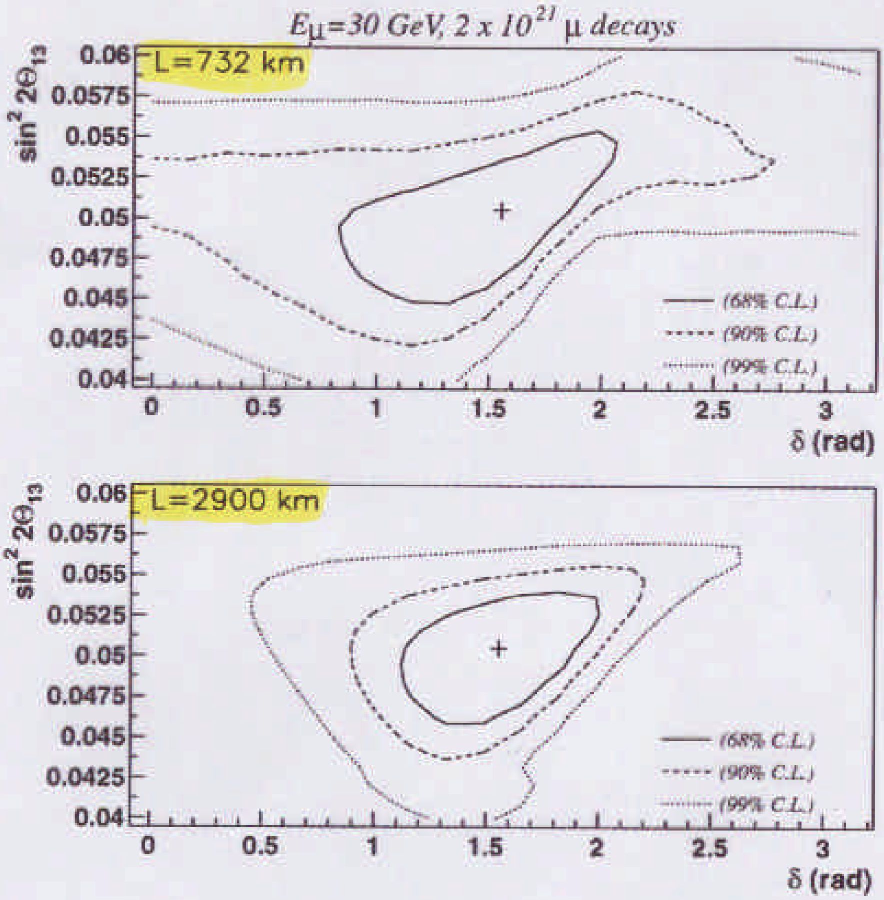


Figure 15: Correlation between θ_{13} and CP phase δ for two different baselines and 2×10^{21} decays.

Bueno et al.

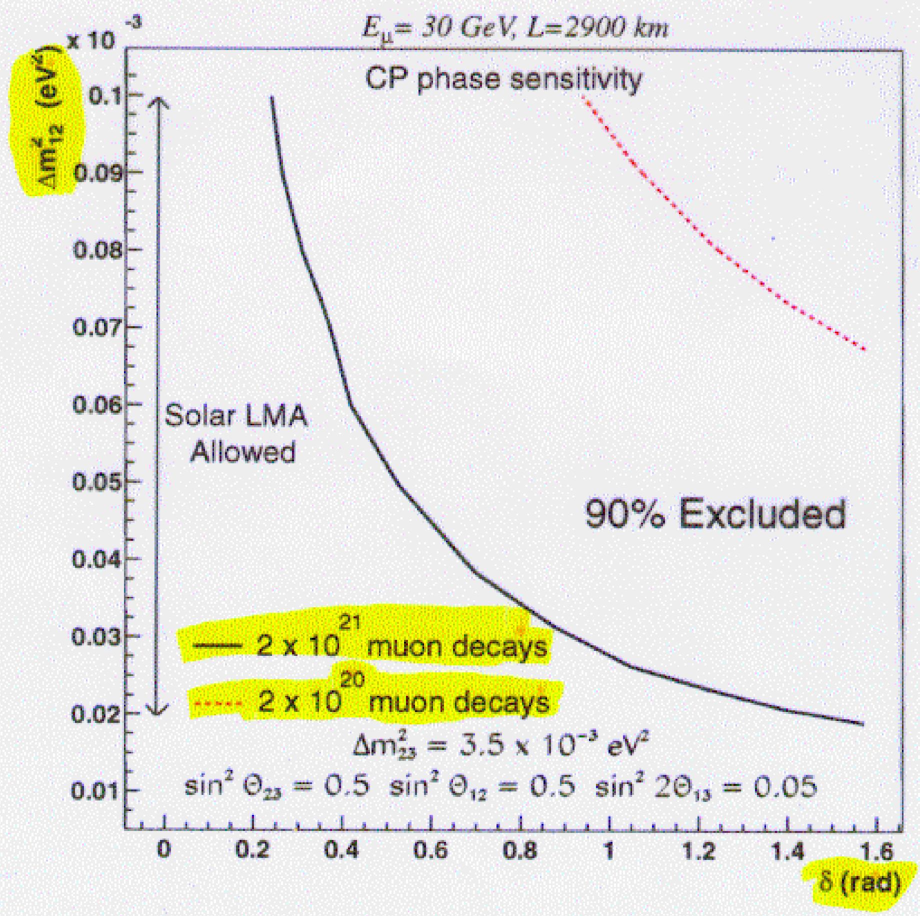


Figure 17: 90%C.L. sensitivity on the CP phase δ as a function of Δm^2_{12} for two different normalizations: solid (dashed) line corresponds to 10^{21} (10^{20}) muons decays of each polarity.

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 GOOD.

(partic. as an ADD-ON)

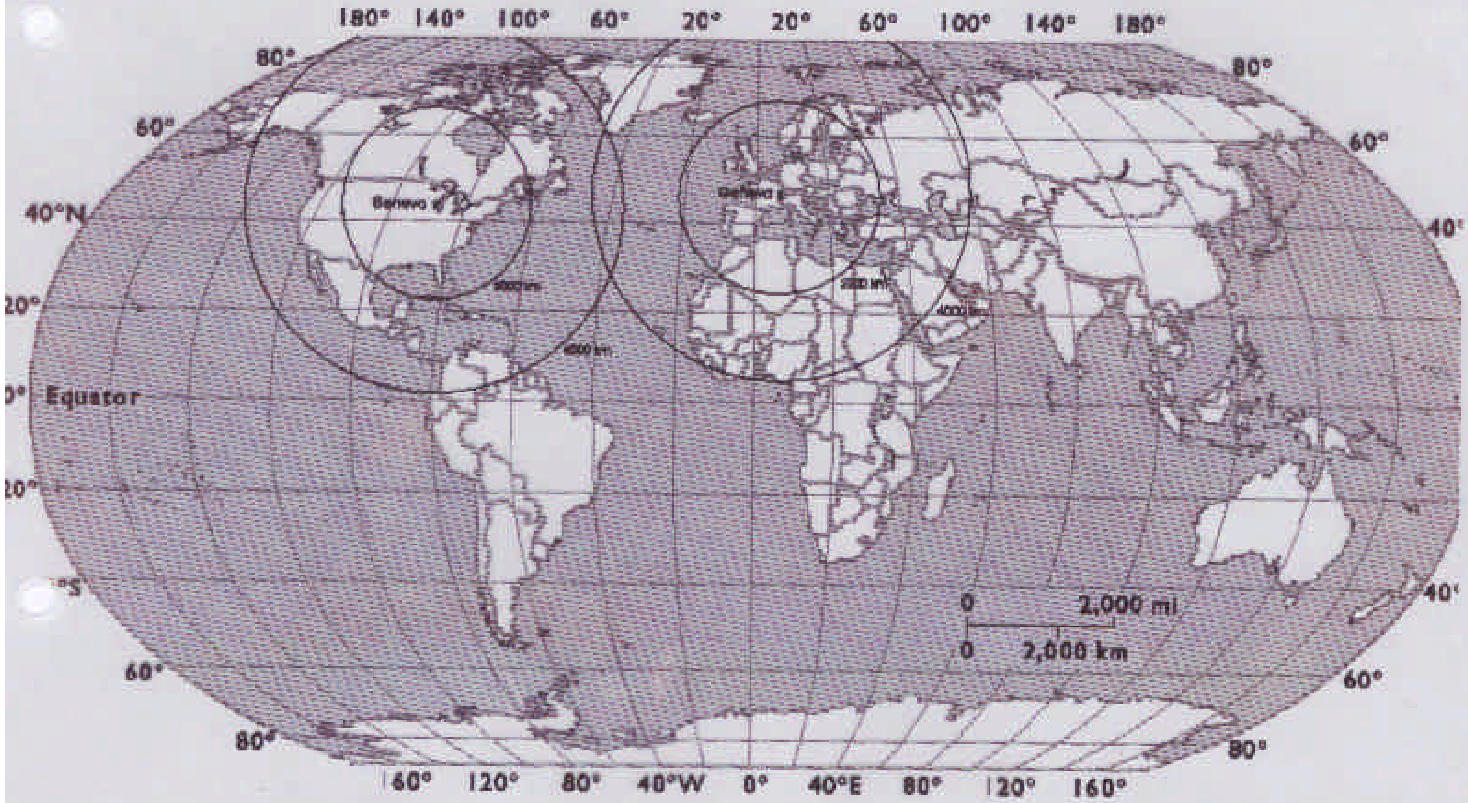
$L \approx 732$ km ☹

IS NOT ENOUGH

AT GENEVA (ILL) AND GENEVA (CH)

GOOD DISTANCE TO WEST COAST

BUT

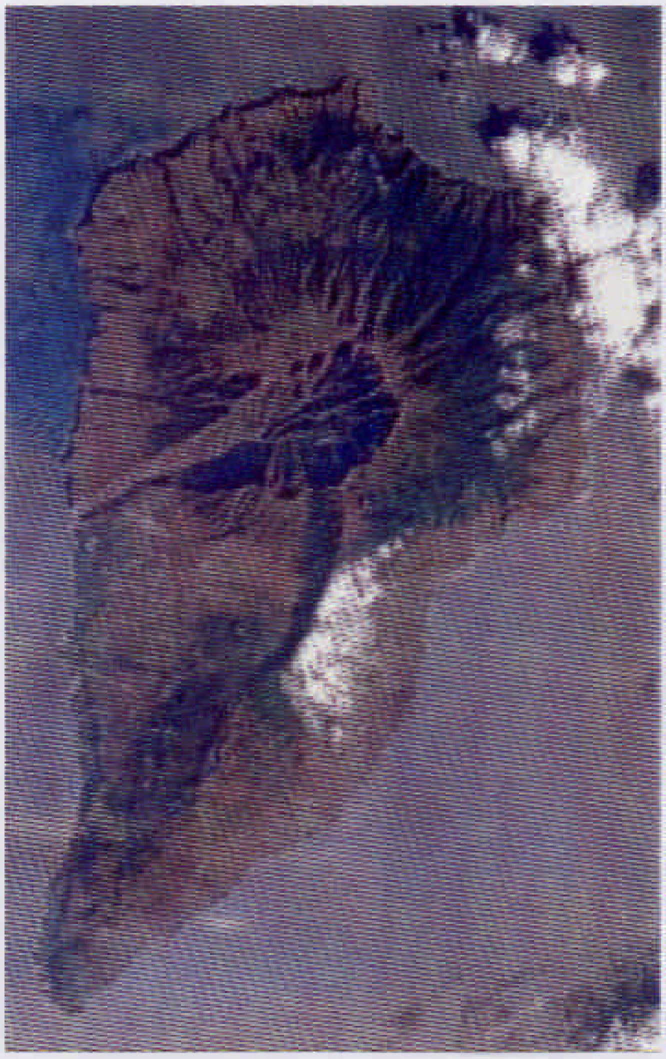


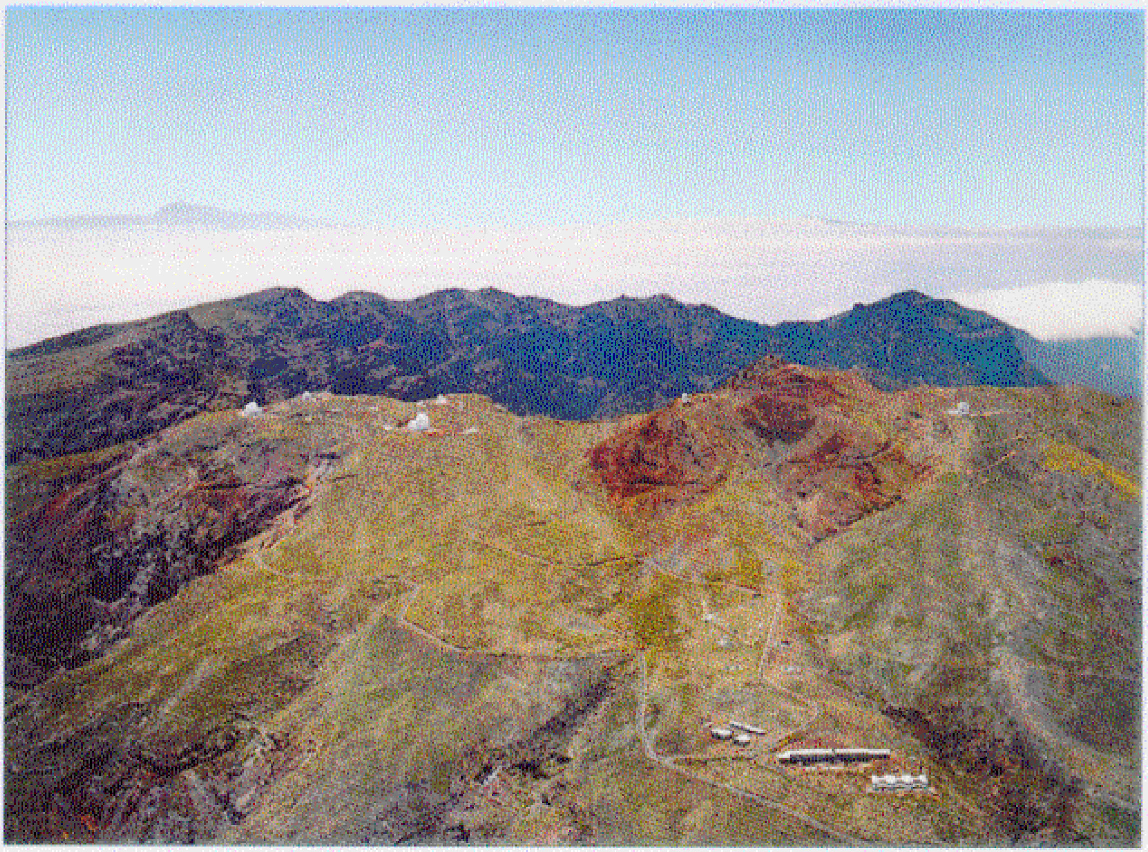
NO SINGLE, PEACEFUL, TECHNOLOGICALLY REASONABLE, NON-FREEZING PLACE WITHIN 3000 ± 1000 km FROM GENEVA (CH)

EXCEPT!


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


SANTA CRUZ DE TENERIFE
TENERIFE



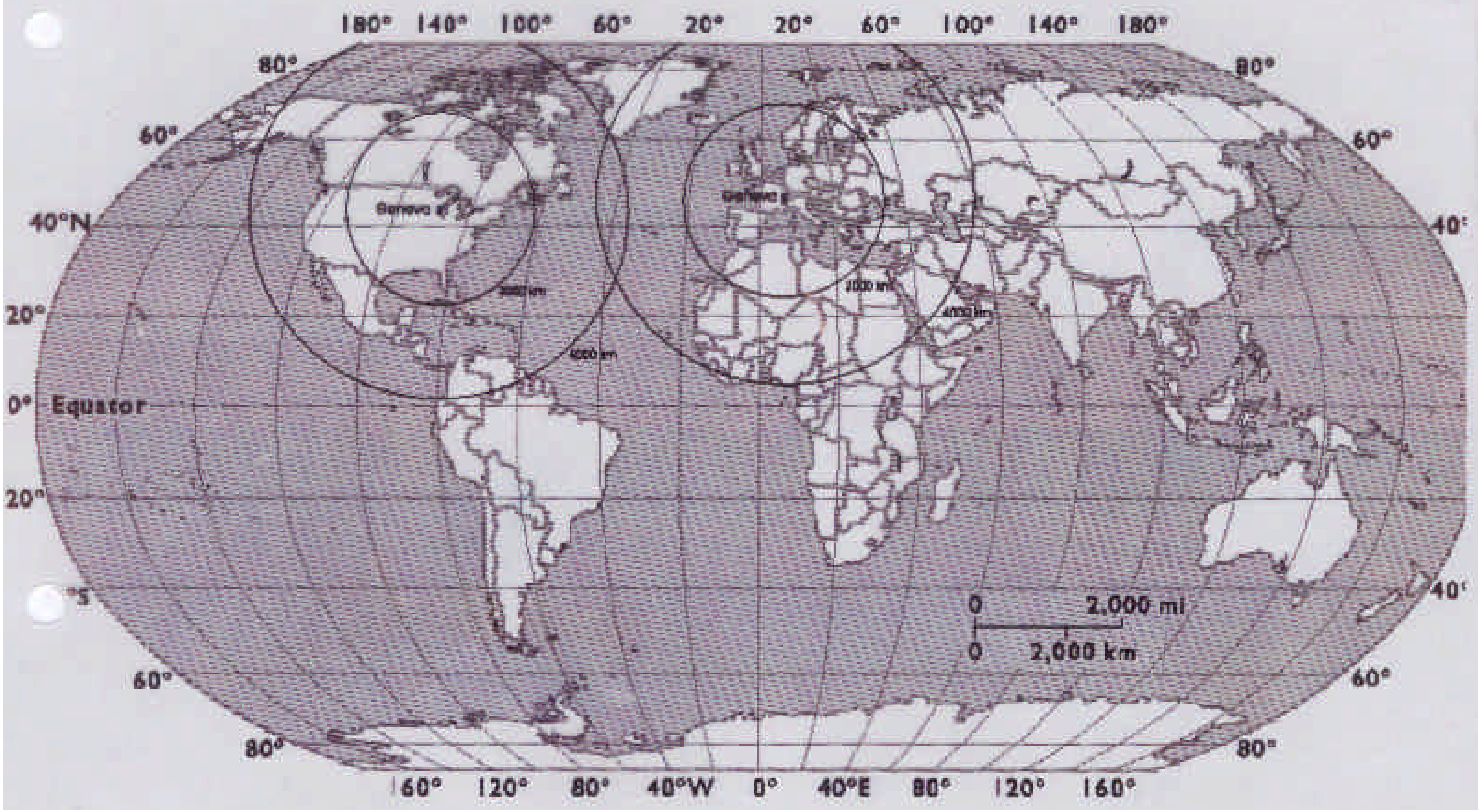


FERMI → GRAN SASSO 7332

FERMI → CANARIES ~ 6000

FERMI → WEST COAST ~ 3000

[OPTIMAL]



CERN → GRAN SASSO 732 ☹

CERN → FERMILAB ~ 6000

CERN → CANARIES ~ 3000

[OPTIMAL]

EITHER GVA

TO A

(MAGNETIZED)

SUPER K

~ 8500 km

HOW

TO

CONVERT

A

D.G. ?

A.O.B.

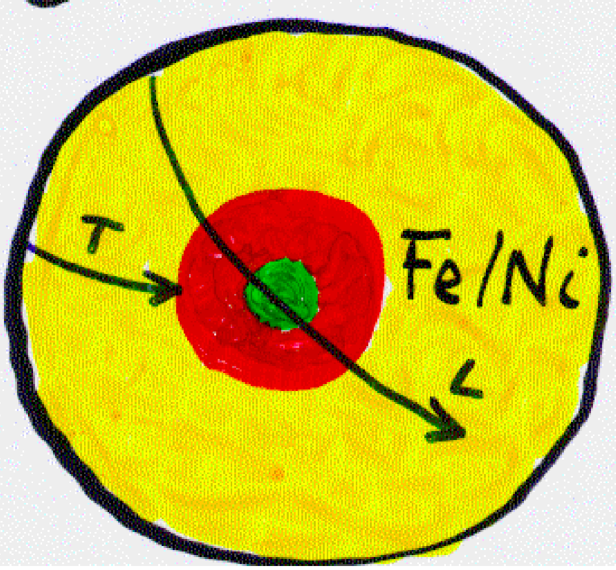
MATTER EFFECTS

⇨ $\langle n_e \rangle |_{\nu\ \mathrm{TRAJ.}}$ ± 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 FLUX CAN MODULATE S/B

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

See CERN study

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

NON-OSCILLATION ν-PHYSICS

e.g. : FERMILAB AND CERN REPORTS

CLOSE-BY LOCATION :

10's M events / kg / 10^{21} injected μ's

(WITH A NATURALLY POLARISED ν BEAM)

- 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

Deep Inelastic Scattering Experiments

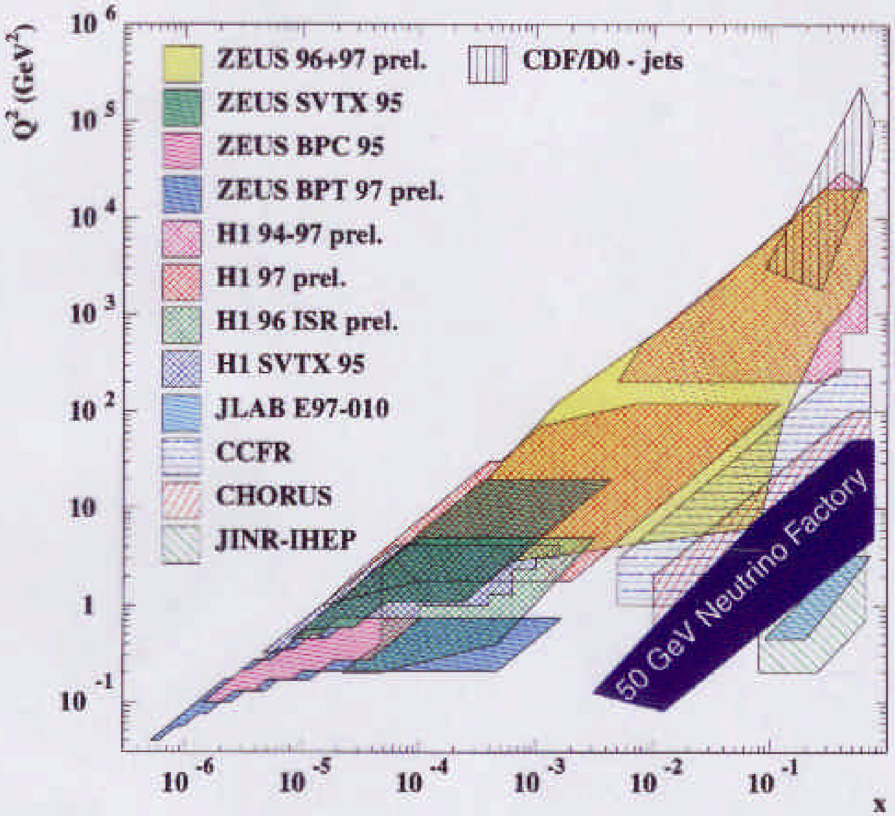


Figure 53: Comparison of kinematic ranges for present DIS experiments with a 50 GeV Neutrino factory.

FOR DECADES HEP 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

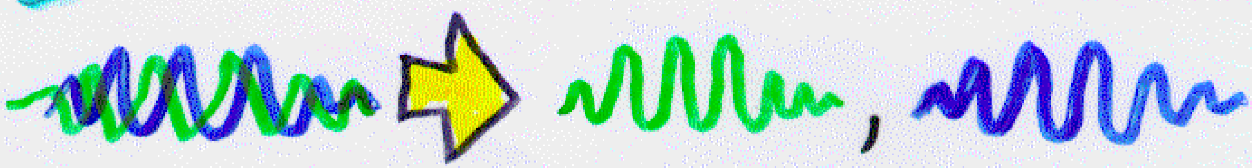
END

ν-OSCS. BROUGHT US
BEYOND THE END
(OF BORING PHYSICS)

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

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

DECOHERENCE



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

NATURE

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

- Δm^2_{23} (ATMS)
- E(CRs), $R_\otimes$, $\rho_\otimes$
- E(NRs), $R_\odot$, $\rho_\odot$
- Δm^2 (⊙, > ν 2000)

HOW SHOULD WE RECIPROCATE NATURE'S LOVING GENEROSITY

AND DO THE RIGHT THING BY HER

??

BUILDING A ν FACTORY