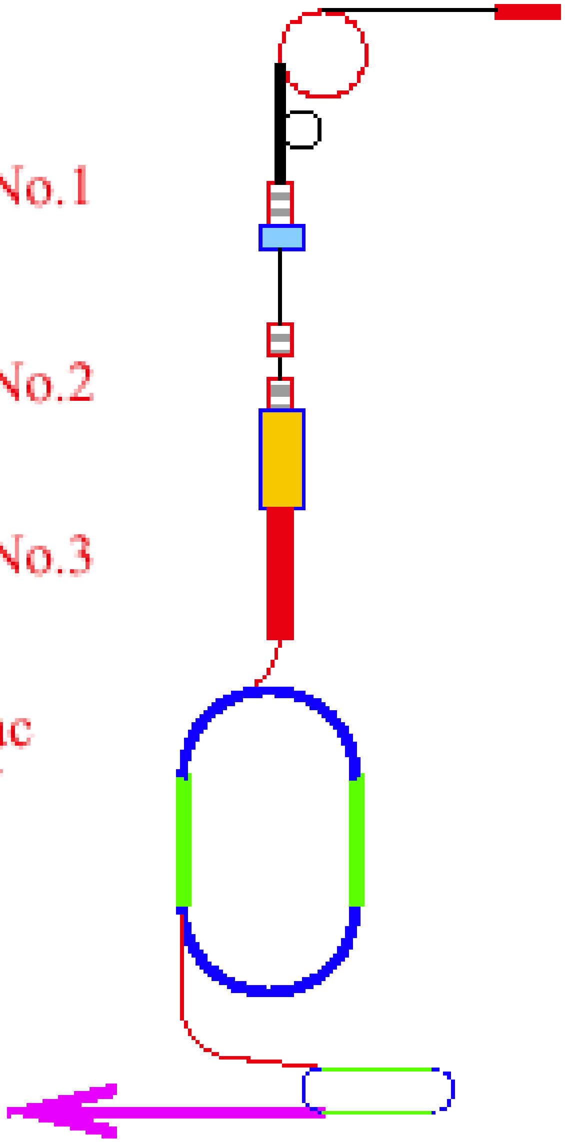
νfac/νbeam machine & physics

LBL Physics Division Retreat
25 May 01
M. Strovink

Haber: “So... you’re moving to neutrino physics?”
MS: “It’s a book report. Jim asked for it.”
Haber: “You’ve been ***humiliated***.”

“Study II” ν factory (Zisman)



Induction linac No.1
100 m
drift 20 m
Induction linac No.2
80 m
drift 30 m
Induction linac No.3
80 m

recirculator Linac
2 – 20 GeV

proton driver

target
mini–cooling
3.5 m of LH , 10 m drift
bunching 56 m
cooling 108 m

Linac 2 GeV

storage ring
20 GeV

neutrino beam

νfact ingredients (Zisman)

Target and Capture

create π's; capture into decay channel

Phase Rotation

induction linac to reduce ΔE of bunch

Cooling

reduce transverse emittance of beam

Acceleration

200 MeV → 20–50 GeV with RLAs

Storage Ring

store muon beam for ≈500 turns; optimize yield with long straight section aimed in desired direction

Tech-limited νfact schedule (Zisman, unofficial)

2000-2003

R&D activities (ongoing)

2000–2001

Feasibility Study for Neutrino Factory

2003-2004

Prepare Zeroth-Order Design Report (ZDR); continue R&D;
cooling string tests begin

2005-2006

Prepare Conceptual Design Report (CDR)

2013

Experiments begin

Phased strategy (Zisman)

Strategy being considered is to define a phased approach to a full facility, with physics opportunities at each phase

First phase would be high-power proton driver and suitable target to make intense neutrino beam ("superbeam")

Next phase would be phase-rotated and cooled intense muon beam ($E = ?$)

Penultimate phase would be Neutrino Factory

Ultimate phase: "entry level" Muon Collider (Higgs Factory)

Phased implementation will modify the schedule...

could imagine starting earlier, but finishing later...

Summary of AFRD R&D on νfact (Zisman)

Component development

- Normally conducting RF cavities for cooling section (R. Rimmer, D. Li, BEG activity)
  - design and test 805 MHz cavity with Be foil windows
  - continue with Be window design and testing
  - design 201-MHz RF system for Study-II (and hopefully for testing at FNAL)
- SC solenoid designs for Study-II (M. A. Green)
- Induction linac design for Study-II (S. Yu, L. Reginato)

Simulations and theory (J. Wurtele, Muon Collaboration organizer)

Collaboration management and planning (A. Sessler, M. Zisman)

Examples from universe of ν detectors: SuperK ...

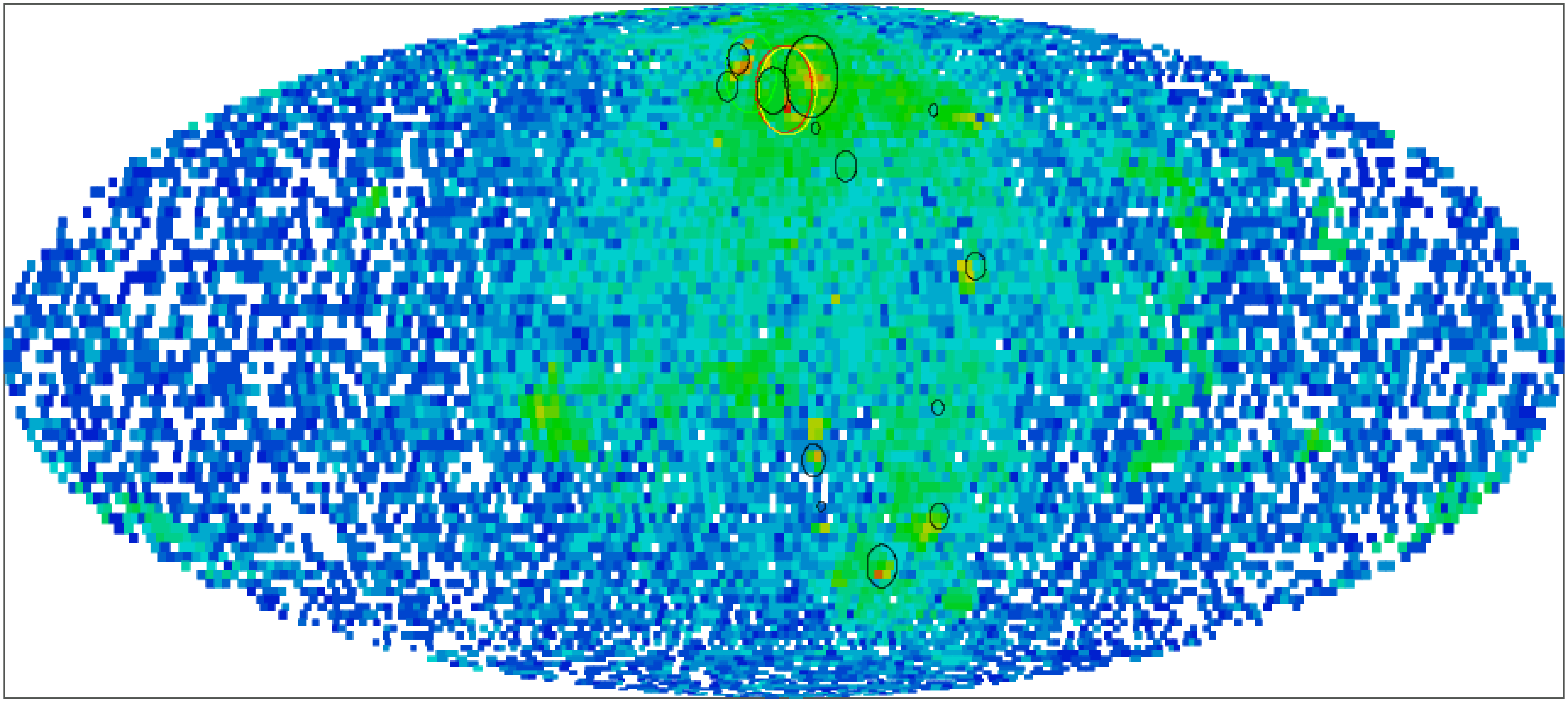


Figure 25: Simulated neutrino event from a 50 GeV muon storage ring in the SuperKamiokande detector. The rings indicate where the reconstruction software found charged particles in the hadronic shower, as well as the exiting muon.

...and ICANOE

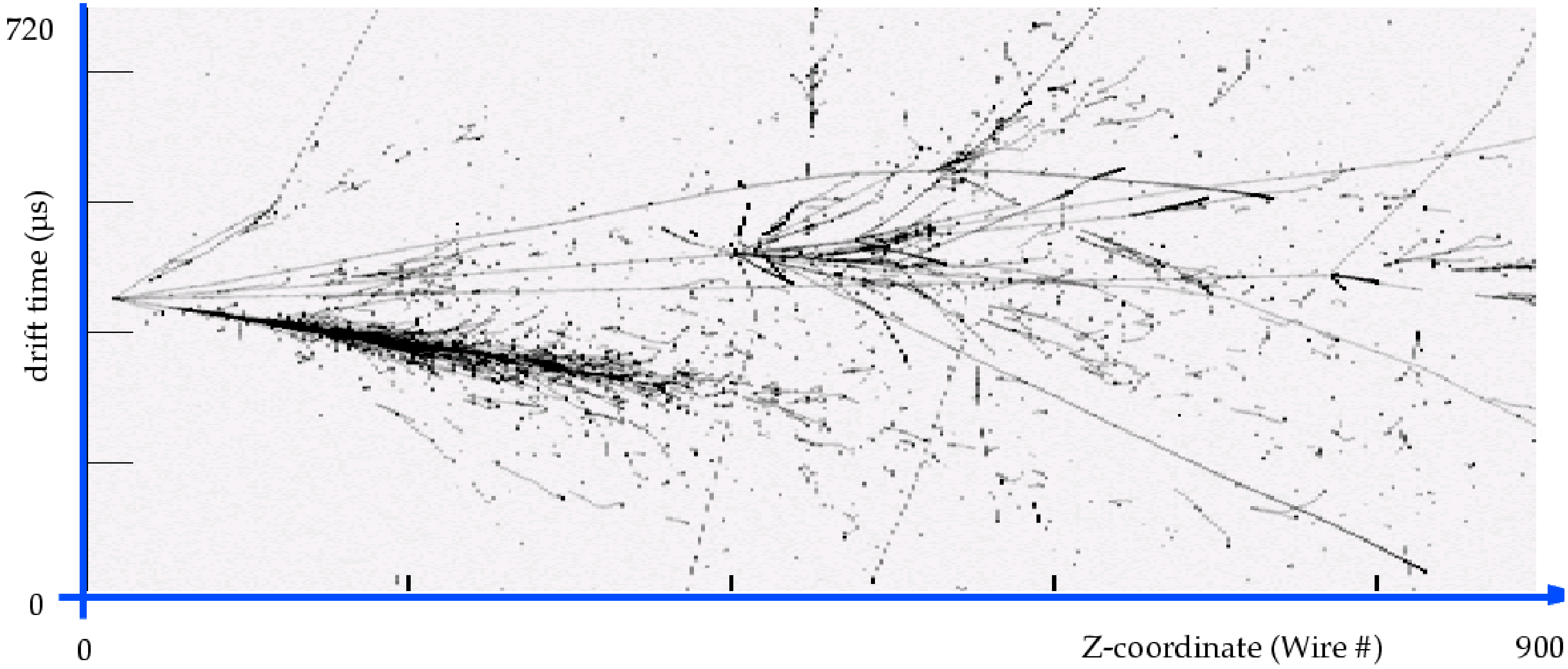


Figure 21: Example of a ν_e Charged current event from the full simulation of the ICANOE detector.

MNS matrix and oscillation probabilities

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

$$\begin{aligned} P(\nu_e \to \nu_\mu) &\simeq 4|U_{e3}|^2|U_{\mu 3}|^2 \sin^2\left(\frac{\delta m^2_{atm} L}{4E}\right) \\ &= \sin^2(2\theta_{13}) \sin^2(\theta_{23}) \sin^2\left(\frac{\delta m^2_{atm} L}{4E}\right) \end{aligned}$$

$$\begin{aligned} P(\nu_e \to \nu_\tau) &\simeq 4|U_{\tau 3}|^2|U_{e3}|^2 \sin^2\left(\frac{\delta m^2_{atm} L}{4E}\right) \\ &= \sin^2(2\theta_{13}) \cos^2(\theta_{23}) \sin^2\left(\frac{\delta m^2_{atm} L}{4E}\right) \end{aligned}$$

(assumes 3 active ν's , $m_1 < m_2 << m_3$)

Sign of Δm^2 from wrong-sign μ asymmetry

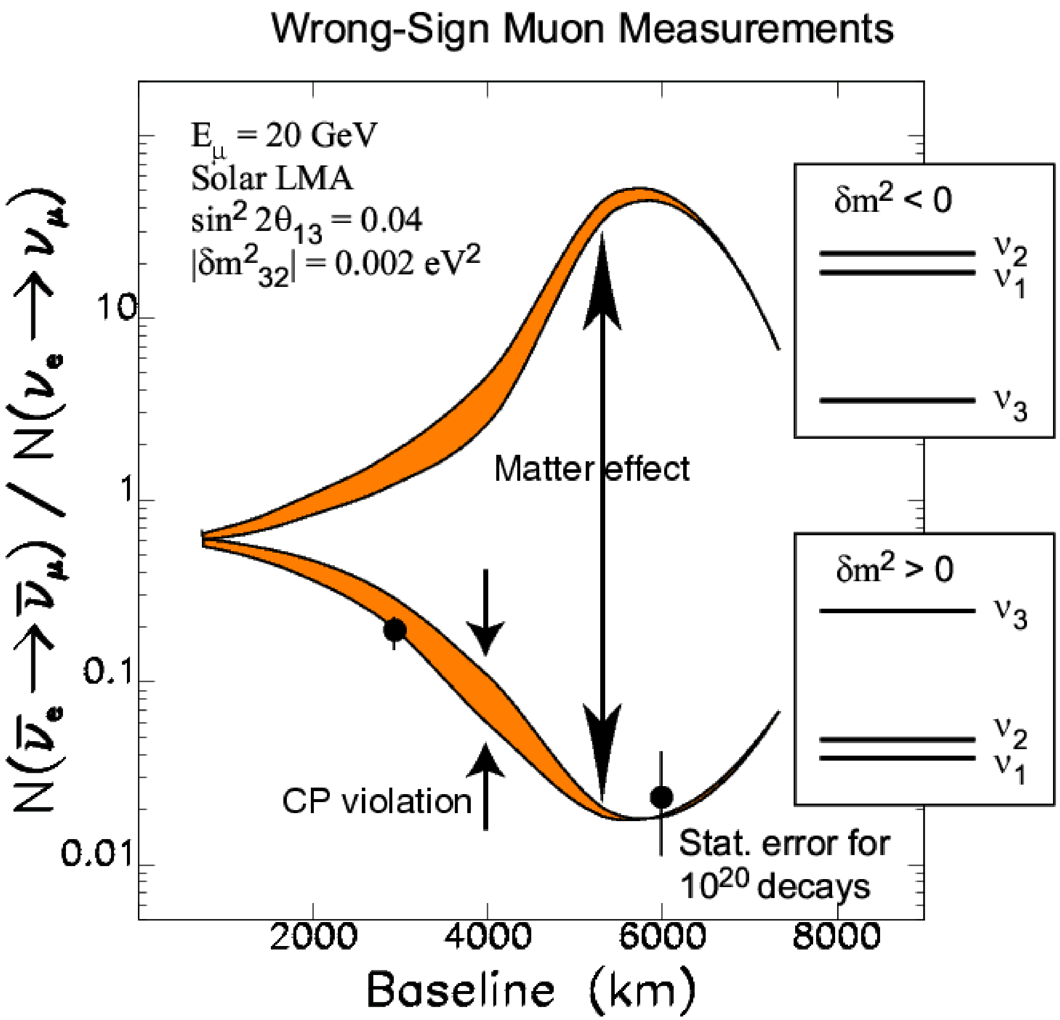


Figure I: Predicted ratios of $\bar{\nu}_e \to \bar{\nu}_\mu$ to $\nu_e \to \nu_\mu$ rates at a 20 GeV neutrino factory. The upper (lower) band is for $\delta m^2_{32} < 0$ ($\delta m^2_{32} > 0$). The range of possible CP violation determines the widths of the bands. The statistical error shown corresponds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

How many μ decays are needed?

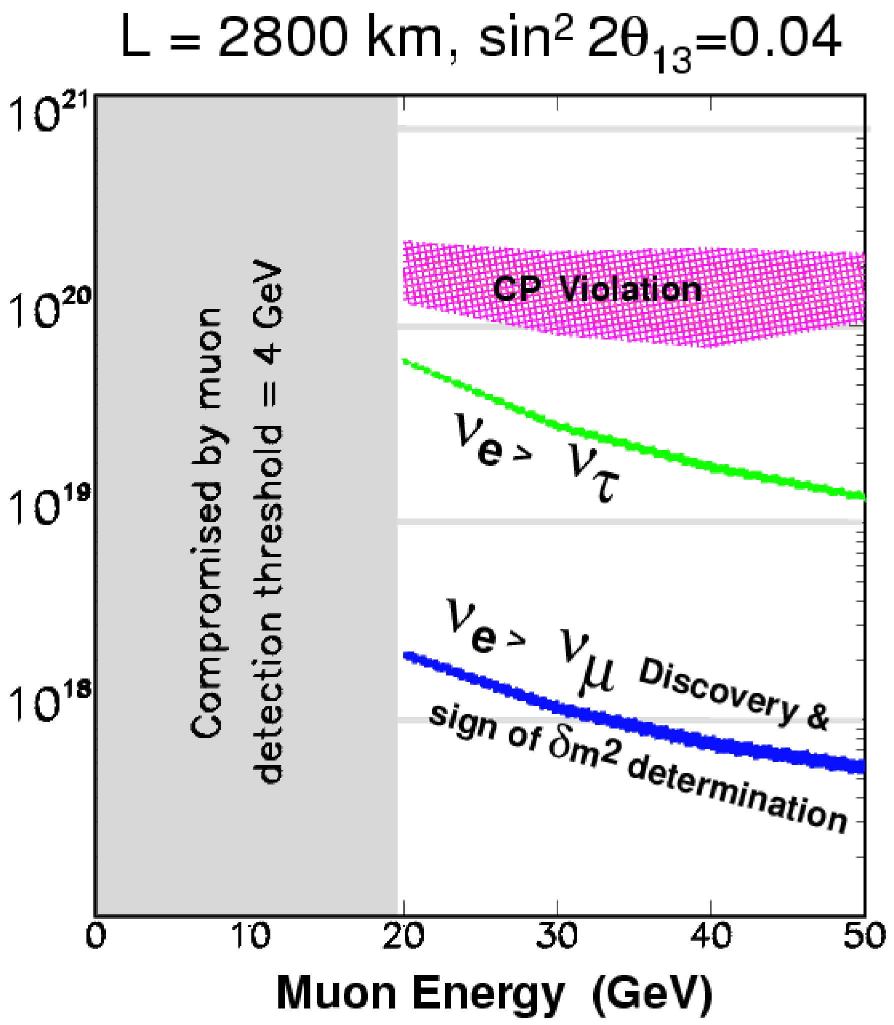


Figure II: The required number of muon decays needed in a neutrino factory to observe $\nu_e \to \nu_\mu$ oscillations in a 50 kt detector and determine the sign of δm^2, and the number of decays needed to observe $\nu_e \to \nu_\tau$ oscillations in a few kt detector, and ultimately put stringent limits on (or observe) CP violation in the lepton sector with a 50 kt detector. Results are from Ref. 51.

Upper limits on $\sin^2 2\theta_{13}$

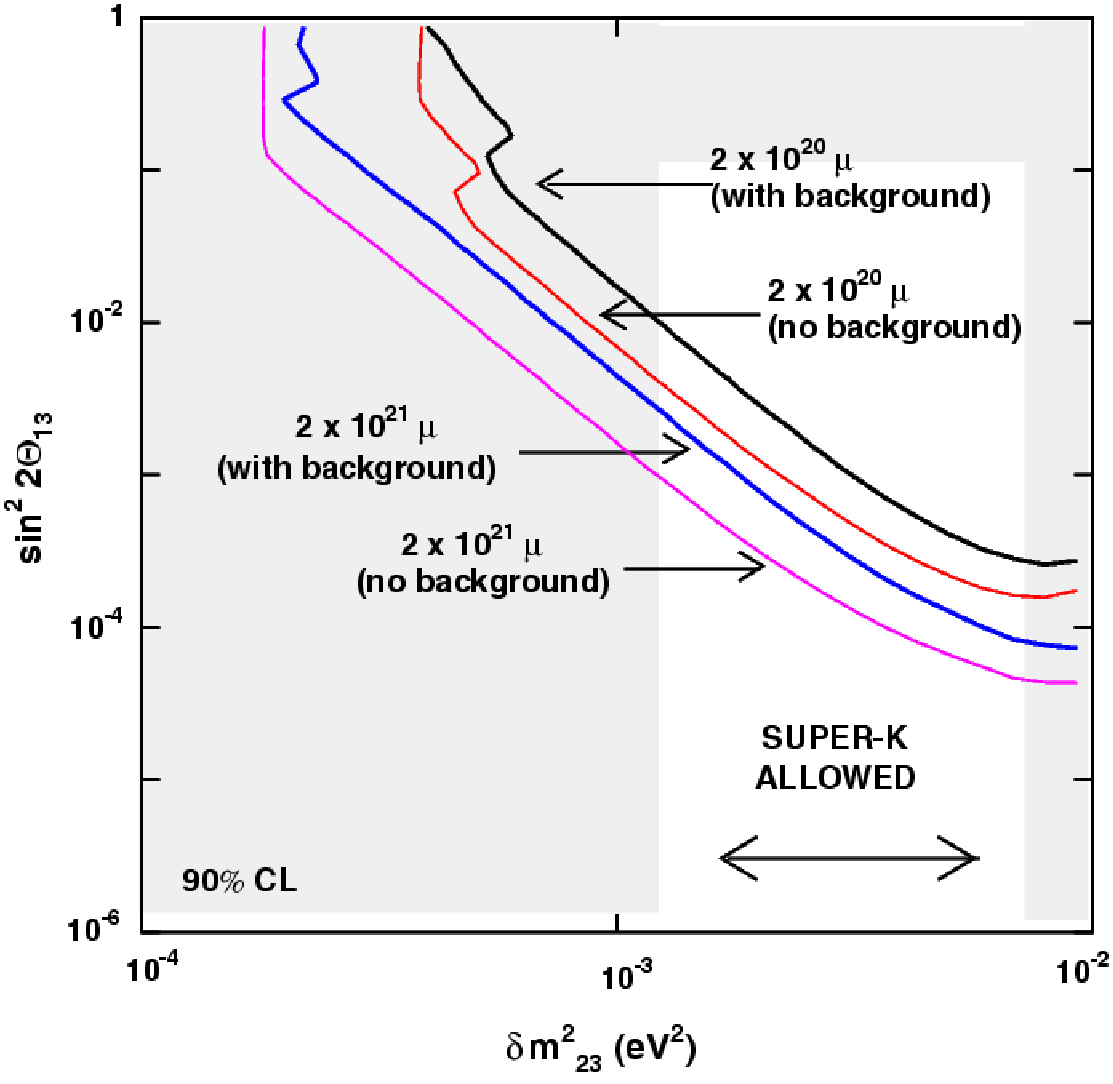


Figure III: Limits on $\sin^2 2\theta_{13}$ that would result from the absence of a $\nu_e \to \nu_\mu$ signal in a 10 kt detector 7400 km downstream of a 30 GeV neutrino factory in which there are 10^{20} and $10^{21}\mu^+$ decays, followed by the same number of μ^- decays. The limits are shown as a function of δm^2_{32}. The impact of including

Precision on $\sin^2 2\theta_{13}$ vs. $\sin^2 \theta_{23}$

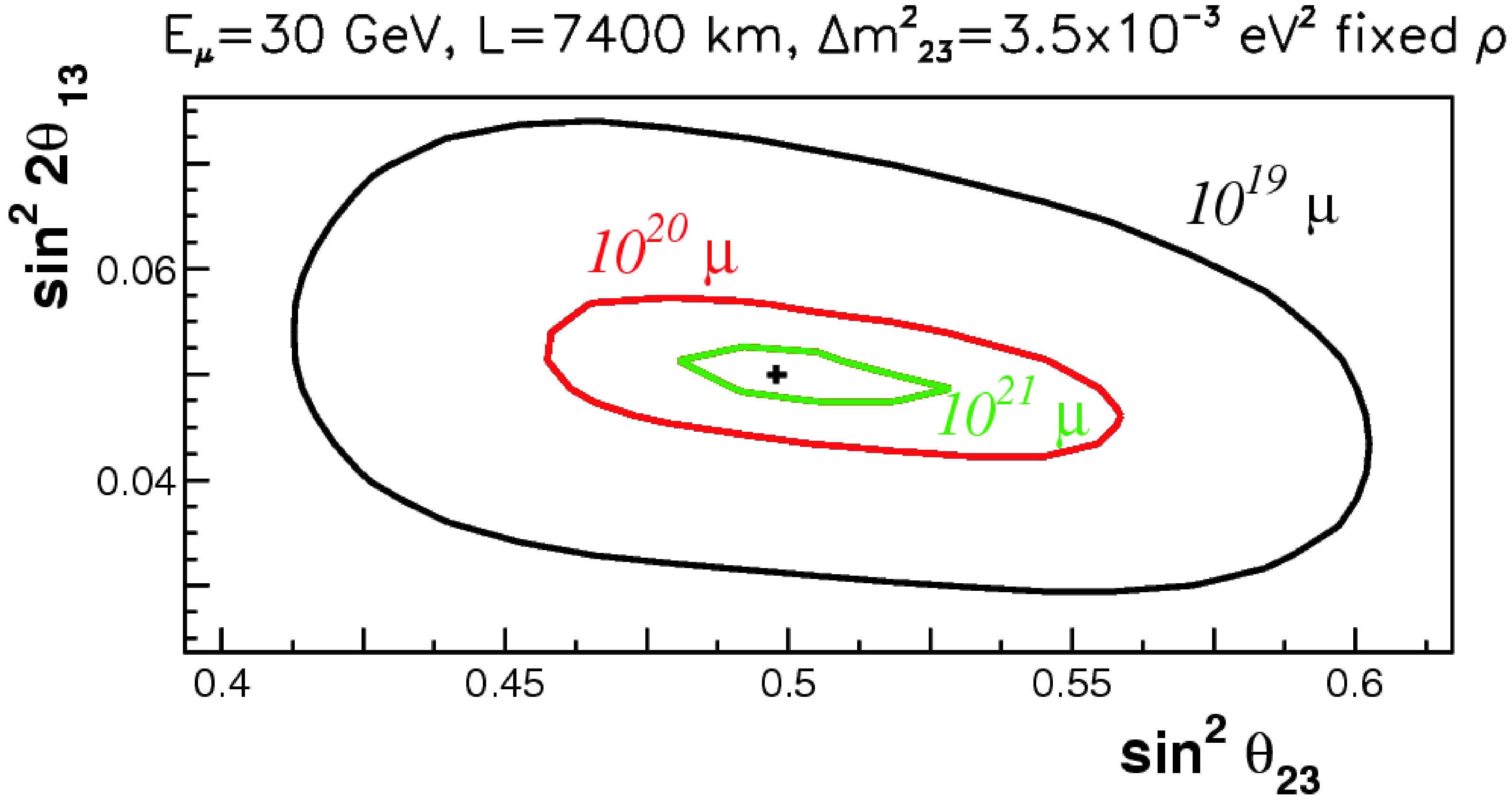
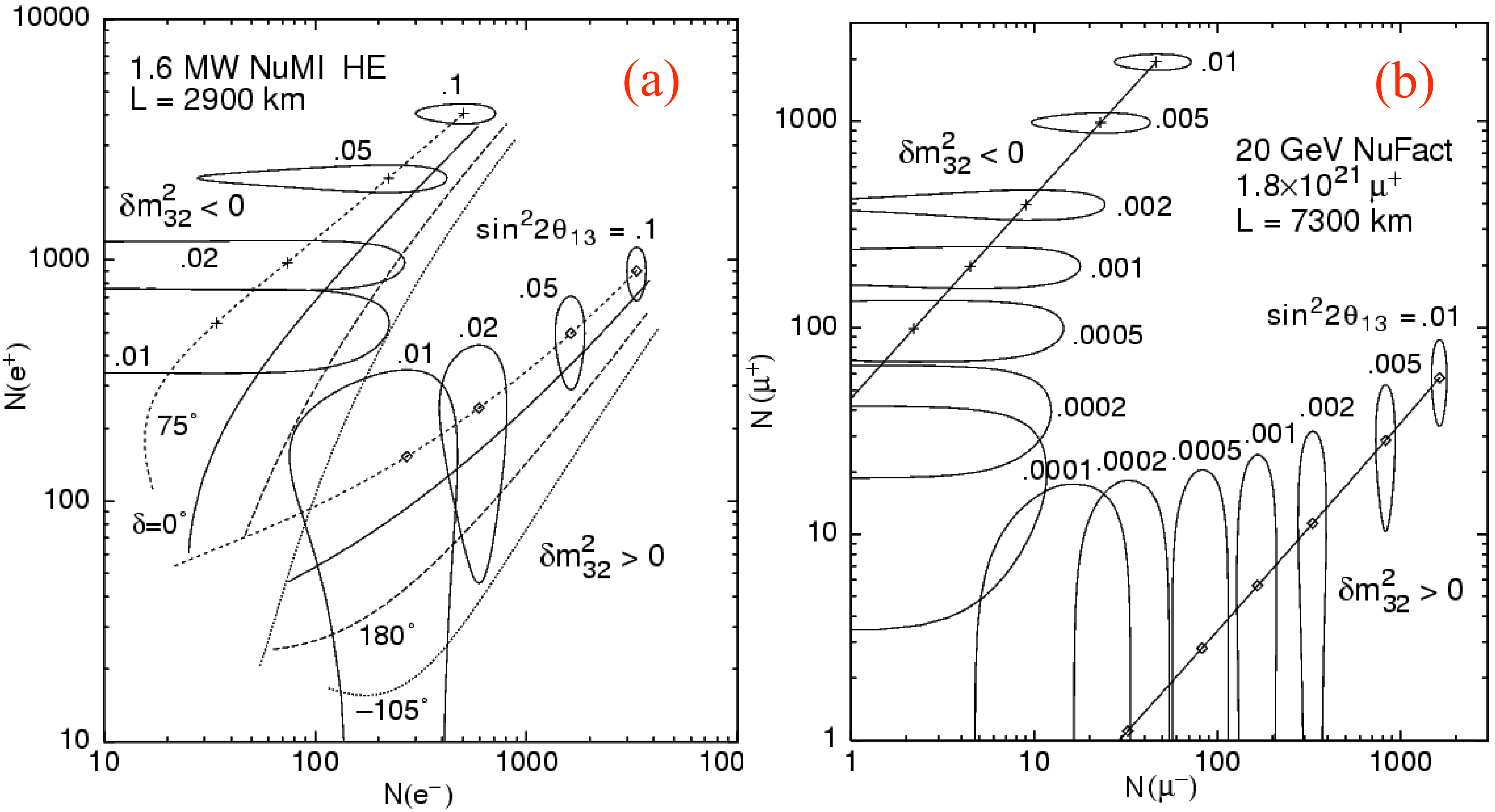


Figure IV: Precision with which the oscillation parameters $\sin^2\theta_{23}$ and $\sin^2 2\theta_{13}$ can be measured in a 10 kt detector 7400 km downstream of a 30 GeV neutrino factory in which there are 10^{19}, 10^{20}, and 10^{21} μ^+ decays. Results are from Ref. 50.

Observing $\nu_e \leftrightarrow \nu_\mu$ with νbeam vs. νfact



3σ error ellipses in the $N(l^+)$ vs. $N(l^-)$ plane, shown for l^+ and l^- resulting from $\nu_e \leftrightarrow \nu_\mu$ oscillation using (a) νbeam vs. (b) νfact. (a) uses a 37 kt LA detector at L=2900 km in a NUMI-like high-energy νbeam driven by 1.6 MW of 120 GeV protons. (b) uses a 50 kT detector at L=7300 km from a 20 GeV νfact after 5E21 (!) μ decays.

3σ sensitivities for observing $\nu_e \leftrightarrow \nu_\mu$

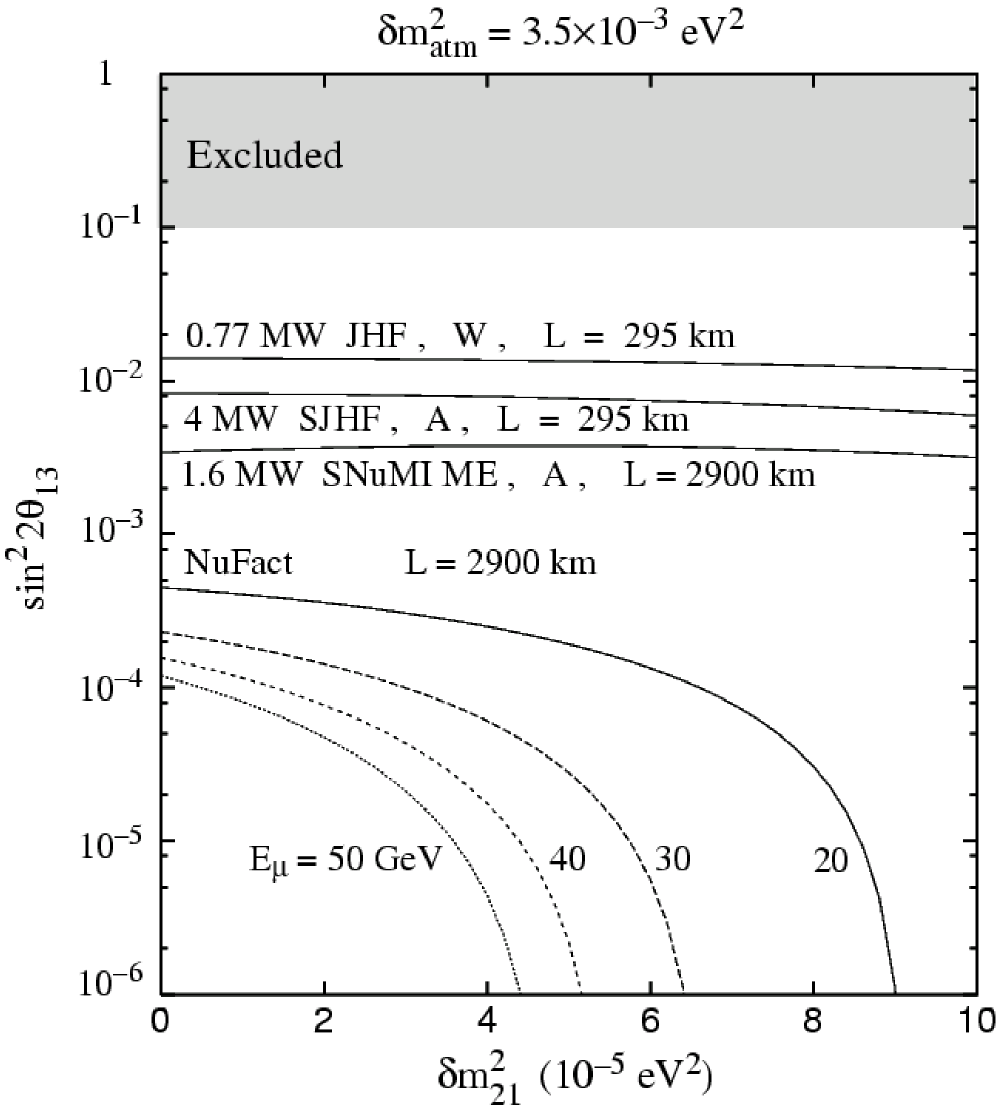


Figure 20: Summary of the 3σ level sensitivities for the observation of $\nu_\mu \to \nu_e$ at various MW–scale superbeams (as indicated) with liquid argon “A” and water cerenkov “W” detector parameters, and the observation of $\nu_e \to \nu_\mu$ in a 50 kt detector at 20, 30, 40, and 50 GeV neutrino factories delivering 2×10^{20} muon decays in the beam forming straight section. The