Detectors and Experiments at Future Neutrino Facilities

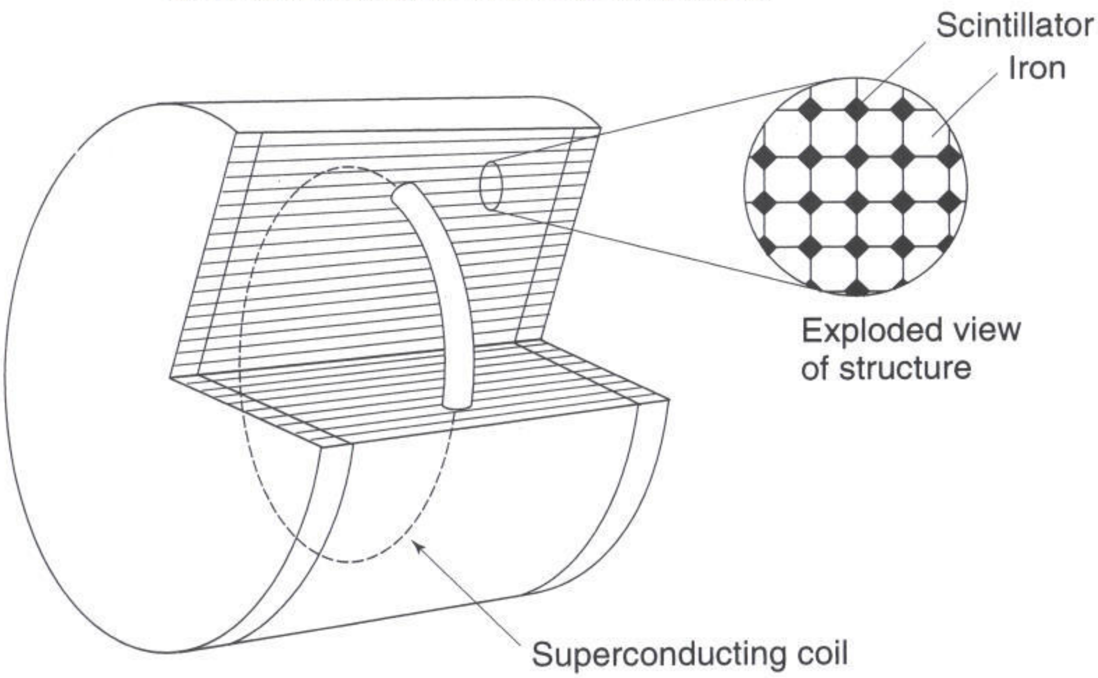
F. Dydak / CERN

Neutrino2002
München, 24. - 30. 5. 2002

OUTLINE

- OSCILLATION EXPERIMENTS @ νF
- 'NEAR-DETECTOR' NEUTRINO PHYSICS @ νF
- STOPPED-MUON PHYSICS @ νF
- USING NuMI AND CNGS IN 'OFF-AXIS' MODE
- SYNOPSIS

LARGE MAGNETIC DETECTOR



Dimension: radius 10 m, length 20 m
Mass: 40 kt iron, 500 t scintillator

Machine vs detector

Neutrino event rate	$\propto E_\nu^3$
	$\propto$ detector mass

- Machine energy is the primary cost driver ($\sim 40\%$)
- Muon cooling is the secondary cost driver ($\sim 20\%$)

Machine	$\sim 2 \times 10^9$ US \$
40 kt magnetic detector	$\sim 0.1 \times 10^9$ US \$

Major mismatch !

Invest into a better and more massive detector, and relax on energy and intensity of the machine?

Intensity reduction?

Power on target?	9%
Pion capture?	3%
Muon cooling?	20%

Compensation by detector mass possible !

Energy reduction?

- Neutrino event rate $\propto E^3$
- CP-violation studies require a broad spectrum of neutrino energies to resolve between θ_{13}, CP-violation, and matter effects
- good 'wrong-sign' muon detection wants $\mathbf{E}_\nu \geq 10$ GeV
- 'near-detector' neutrino physics wants $\mathbf{E}_\nu \geq 50$ GeV

Not straightforward !

A possible compromise?

Machine: energy, intensity down	-0.6×10^9 US \$
Detector: mass, resolution up	$+0.1 \times 10^9$ US \$

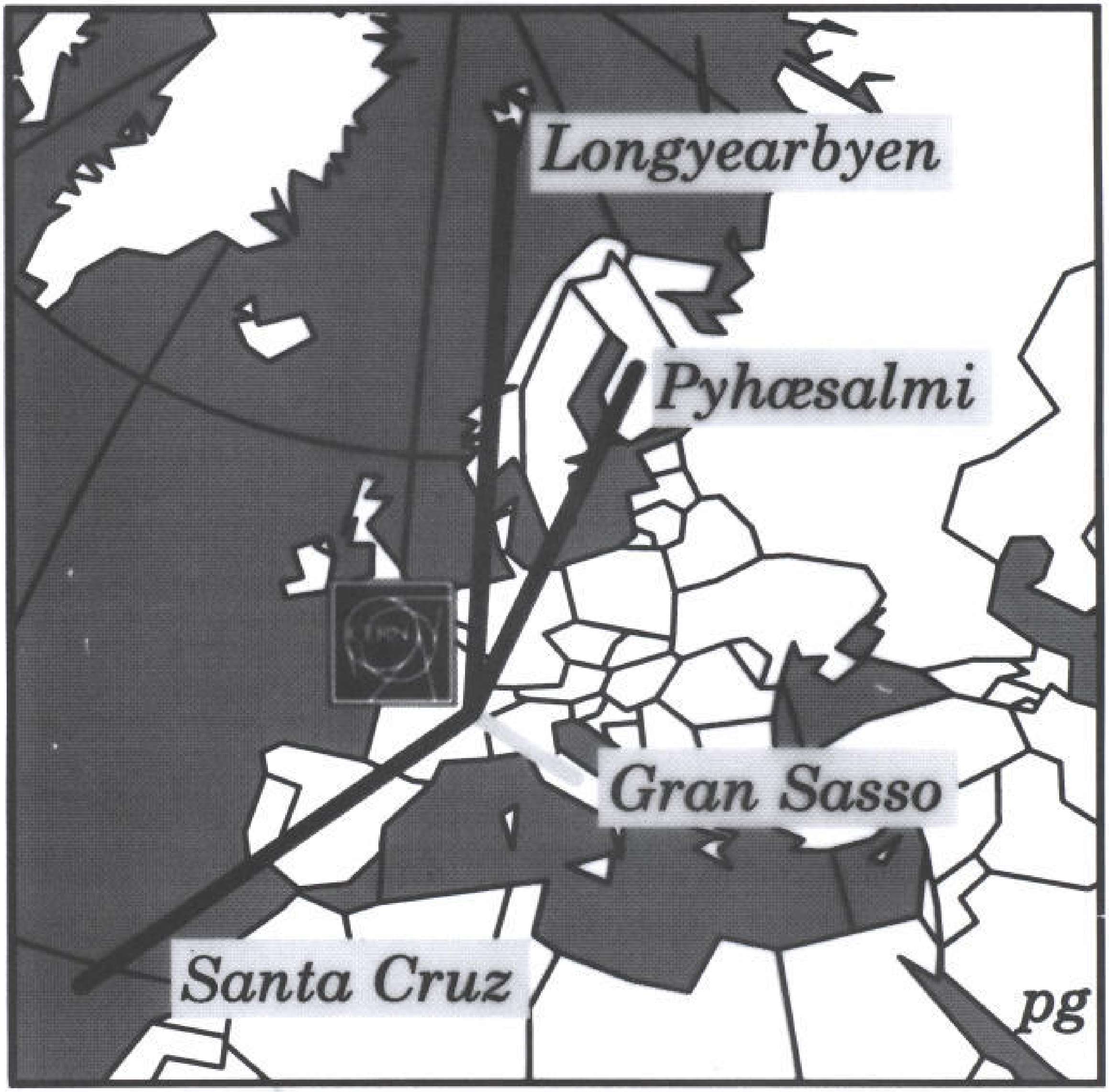


Figure 1: European long-baseline candidates

hep-ph/0105155

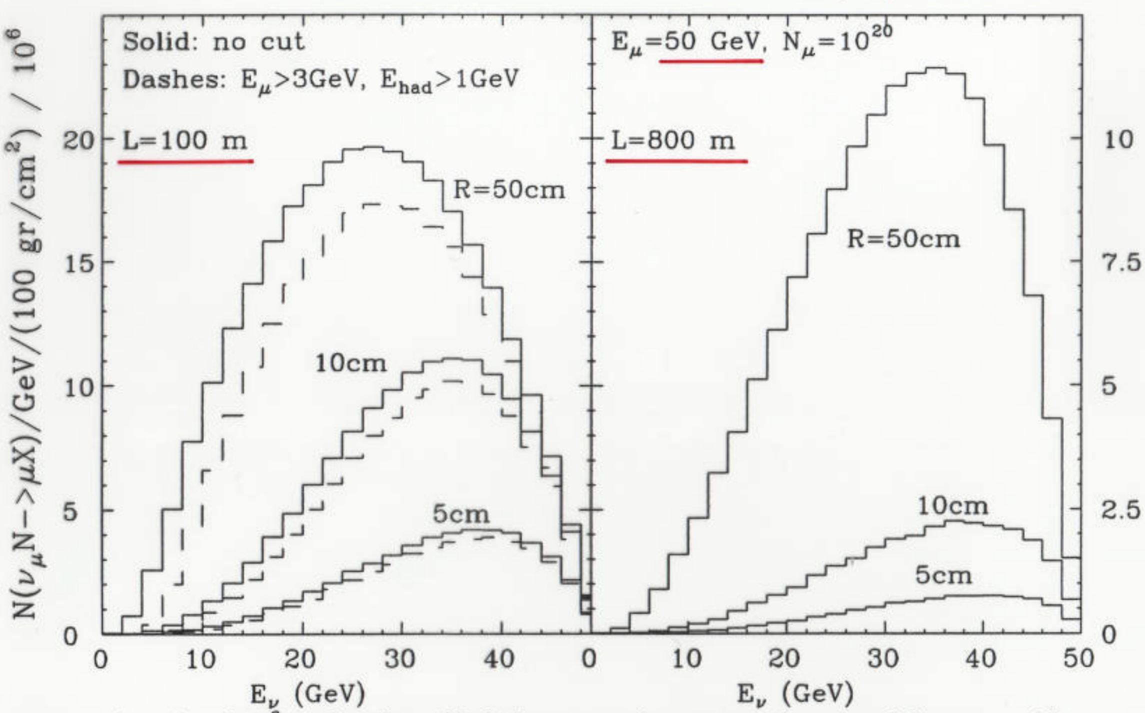


Fig. 2: CC event rates, in units of 10^6, as function of Lab-frame neutrino spectra, for several detector and beam configurations. The dashed lines on the left include cuts on the final-state muon ($E_\mu > 3$ GeV) and on the final-state hadronic energy ($E_{had} >$ 1 GeV). The solid lines have no energy-threshold cuts applied. The three set of curves correpsond to different detector radiuses (50, 10 and 5 cm, from top to bottom).

'NEAR-DETECTOR' NEUTRINO PHYSICS

- UNPOLARIZED NUCLEON STRUCTURE FUNCTIONS

  e.g. $\Delta \int x(s-\bar{s})\,dx = \pm 0.0013$ (NuTeV)

  $\Downarrow$

  ± 0.0002

  $\Delta \alpha_s = \pm 0.005$ (stat.) (CCFR)

  $\Downarrow$

  ± 0.0003

- POLARIZED NUCLEON STRUCTURE FUNCTIONS
- NUCLEAR EFFECTS (heavy targets w.r.t. H, D)
- $\sin^2\theta_W$ FROM νe^- SCATTERING

  $\Delta(\sin^2\theta_W) \sim 0.0002$

- $\sin^2\theta_W$ FROM $R = NC/CC$ IN νN SCATTERING

  $\Delta(\sin^2\theta_W) = \pm 0.0013$ (stat.) (NuTeV)

  $\Downarrow$

  ± 0.0001

- SINGLE-CHARM EXCITATION + DECAY

⋮

hep-ph/0109217

Table 7: Experiments which could beneficially take advantage of the intense future stopped-muon sources at the CERN neutrino factory (NUFACT)

Type of experiment	Physics Issues	Possible experiments	Previously established accuracy	Present activities (proposed accuracy)	Projected for NUFACT @ CERN
'Classical' rare & forbidden decays	Lepton Number Violation; Searches for New Physics: SUSY, L-R Symmetry, R-parity violation,.....	$\mu^- N \to e^- N$ $\mu \to e\gamma$ $\mu \to eee$ $\mu^+ e^- \to \mu^- e^+$	6.1×10^{-13} 1.2×10^{-11} 1.0×10^{-12} 8.1×10^{-11}	PSI, proposed BNL (5×10^{-17}) proposed PSI (2×10^{-14}) completed 1985 PSI completed 1999 PSI	$< 10^{-18}$ $< 10^{-15}$ $< 10^{-16}$ $< 10^{-13}$
Muon decays	G_F; Searches for New Physics; Michel Parameters	τ_μ transv. Polariz.	18×10^{-6} 2×10^{-2}	PSI (2x), RAL (1×10^{-6}) PSI, TRIUMF (5×10^{-3})	$< 10^{-7}$ $< 10^{-3}$
Muon moments	Standard Model Tests; New Physics; CPT Tests T- resp. CP-Violation in 2nd lepton generation	$g_\mu - 2$ edm_μ	1.3×10^{-6} 3.4×10^{-19} e cm	BNL (3.5×10^{-7}) proposed BNL (10^{-24} e cm)	$< 10^{-7}$ $< 5 \times 10^{-26}$ e cm
Muonium spectroscopy	Fundamental Constants, μ_μ, m_μ, α; Weak Interactions; Muon Charge	M_{HFS} M_{1s2s}	12×10^{-9} 1×10^{-9}	completed 1999 LAMPF completed 2000 RAL	5×10^{-9} $< 10^{-11}$
Muonic atoms	Nuclear Charge Radii; Weak Interactions	μ^- atoms	depends	PSI, possible CERN ($< r_p >$ to 10^{-3})	new nuclear structure
Condensed matter	surfaces, catalysis bio sciences ...	surface μSR	n/a	PSI, RAL (n/a)	high rate

M. DIWAN, A.K. MANN 1993

Off-axis kinematics

$$p_{\rm L} = \gamma(p^{*}\cos\Theta^{*} + \beta p^{*})$$
$$p_{\rm T} = p^{*}\sin\Theta^{*}$$

$$\Theta = \frac{R}{L} = \frac{1}{\gamma}\frac{\sin\Theta^{*}}{1+\cos\Theta^{*}},$$

$$E_{\nu}(R) = \frac{2\gamma p^{*}}{1+(\gamma\frac{R}{L})^{2}}$$

$$\Phi_{\nu}(R) = \frac{\frac{\gamma^{2}}{\pi L^{2}}}{(1+(\gamma\frac{R}{L})^{2})^{2}}$$

The decisive feature is:

$$\frac{\partial E_{\nu}}{\partial\gamma} = 0$$

at the 'magic' angle

$$\Theta = 1/\gamma\,.$$


Lake Superior
Soudan
Duluth
MN
WI
Lake Michigan
Madison
MI
IA
Fermilab
IL
IN
MO

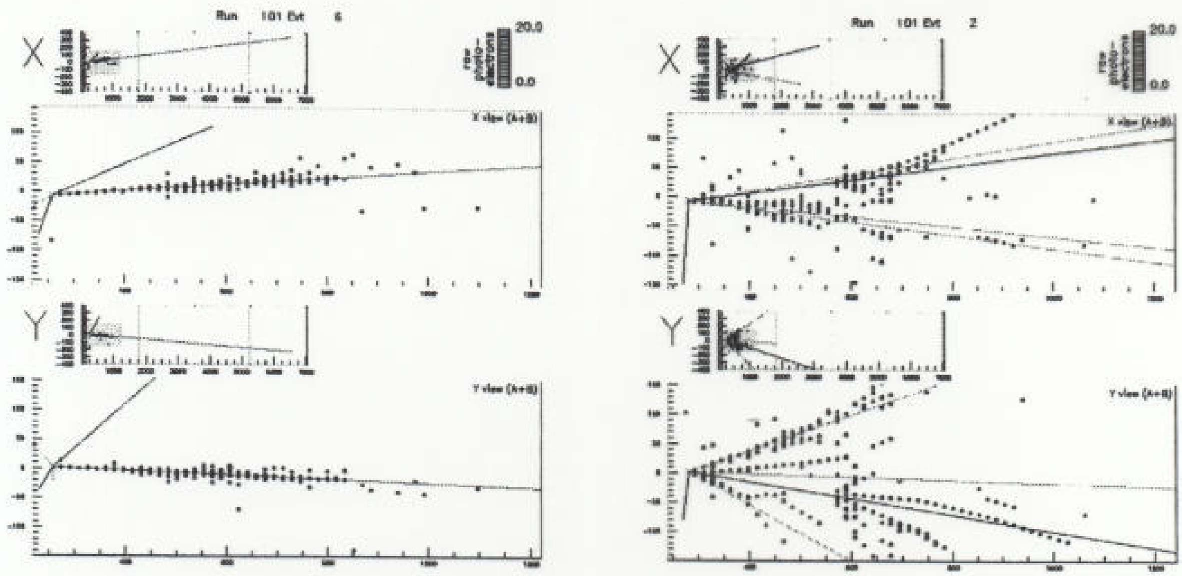


Figure 5.3: Typical charged curent and neutral current ν_e interactions with energies $\sim 5\ GeV$ as detected in a fine grained calorimeter with the longitudinal sampling of $1/3\ X_0$ and the transverse sampling od 3 cm.

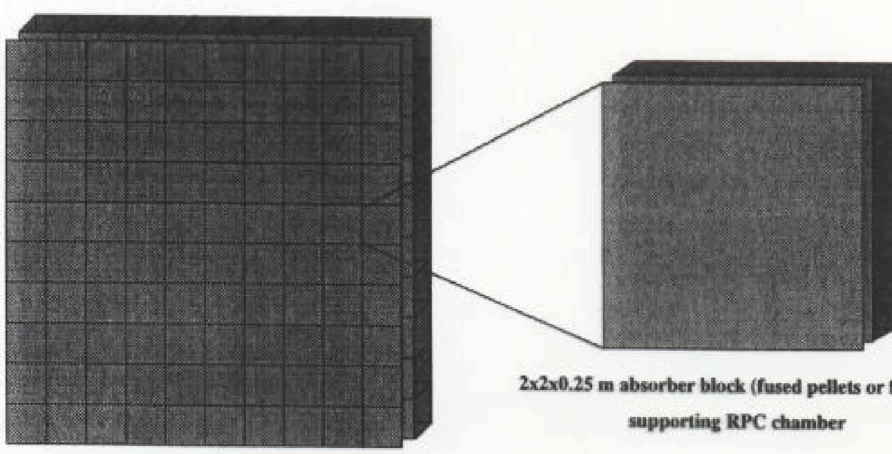
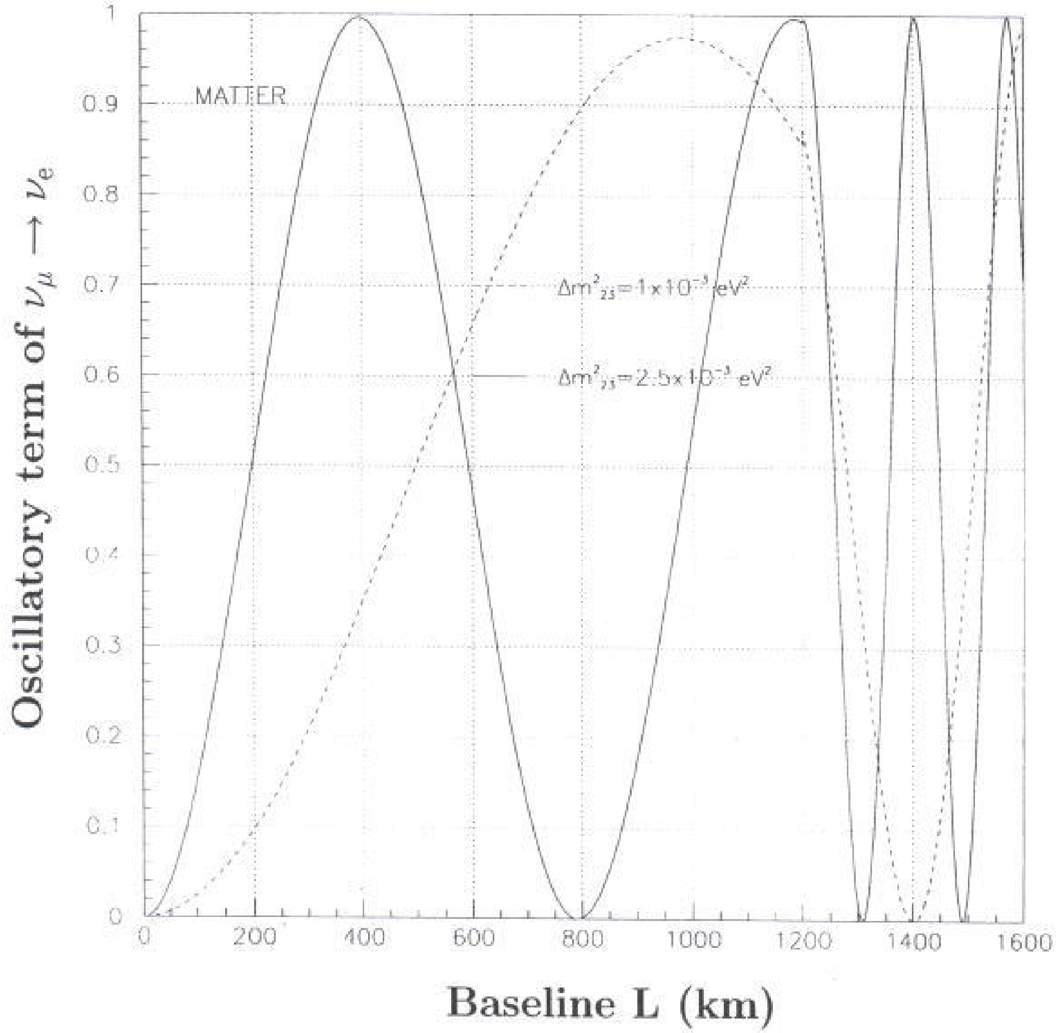


Figure 5.4: Modular detector design: $20 \times 20\ m^2$ planes constructed by stacking absorber modules, active detectors supported by the absorber.

Golfo di Venezia
Capo Promontore
LUSSINO
MAR
ADRIATICO
Ancona
M. Conero
Pescara
Testa del Gargano
Bari
CAPRAIA
ELBA
CORSICA
SARDEGNA
ARCIPELAGO CAMPANO
TIRRENO
SICILIA
PANTELLERIA
Golfo di Tunisi
Golfo di Hammamet


MATTER
Δm²₂₃=1×10⁻³ eV²
Δm²₂₃=2.5×10⁻³ eV²
Oscillatory term of ν_μ → ν_e
Baseline L (km)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
200
400
600
800
1000
1200
1400
1600

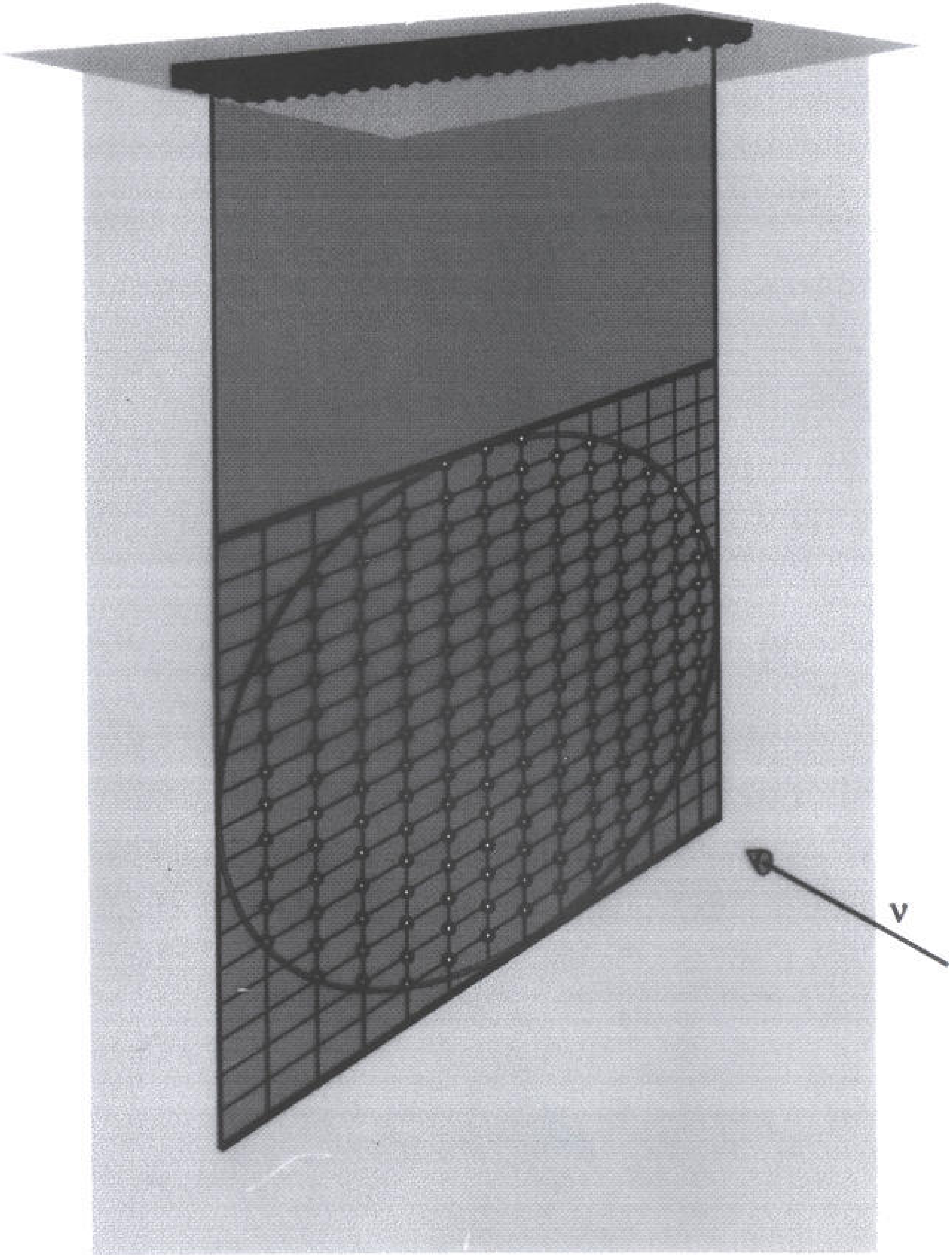


Figure 1:

Synopsis of future neutrino experiments
Results after 5 years of operation

		F2S	C2GT	JHF2K	JHF2K-II	C2F	C2F+BB	νF
$< E_\nu >$ [GeV]		2	0.8	1	1	0.3	0.3	10
Fiducial mass	Water Cherenkov		1 Mt	22.5 kt	1 Mt	40 kt	1Mt	
	Iron/scintillator	20 kt						40 kt
	Plastic/RPCs	20 kt						
Physics reach	$\sigma(\Delta m^2_{23})$ [eV^2]	1×10^{-4}	3×10^{-5}	1×10^{-4}		1×10^{-4}		
	$\sigma(\sin^2 2\theta_{23})$	0.01	0.01	0.01		0.01		
	$\sin^2 \theta_{13}$ [90% CL]	1.5×10^{-3}		1.5×10^{-3}	2.5×10^{-4}	1.5×10^{-3}		2.5×10^{-5}
	θ_{13} [deg; 90% CL]	2.2		2.2	0.9	2.2		0.3
	sgn Δm^2_{23}	No	No	No	?	No	No	Yes
	CP-violation	No	No	No	?	No	?	Yes
Incremental material cost (facility + detector [10^9 US $])		0.1	0.1	0.2	1.0	0.7	2.0	2.0
Year of earliest operation		2006	2008		2015		2020	

'Near-detector' neutrino physics at a neutrino factory:
M. Mangano et al., hep-ph/0105155

Physics with stopped muons at a neutrino factory
J. Aysto et al., hep-ph/0109217

Off-axis initiative at Fermilab
http://www.numi-fnal.gov/fnal_minos/new_initiatives/loi.html

Off-axis initiative at CERN
http://home.cern.ch/dydak/oscexp.ps