Low energy ν oscillation experiment at JHF?

Goal

- Ocillation pattern in ν_μ disappearance: precision $\theta_{23}, \Delta m_{23}$
- $\nu_\mu \to \nu_e$ appearance: θ_{13}
- $\nu_\mu \to \nu_e$ vs. $\bar{\nu}_\mu \to \bar{\nu}_e$: CP violating phase δ

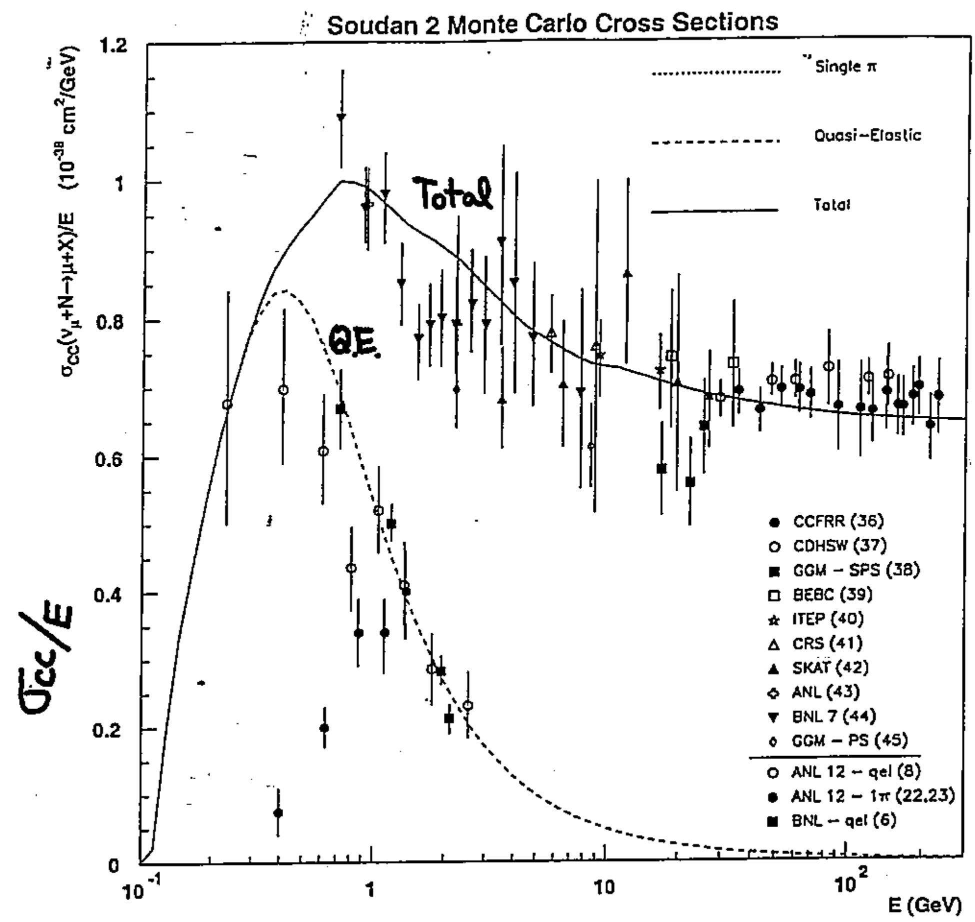
Advantage of low energy ν beam (0.2-1.0GeV)

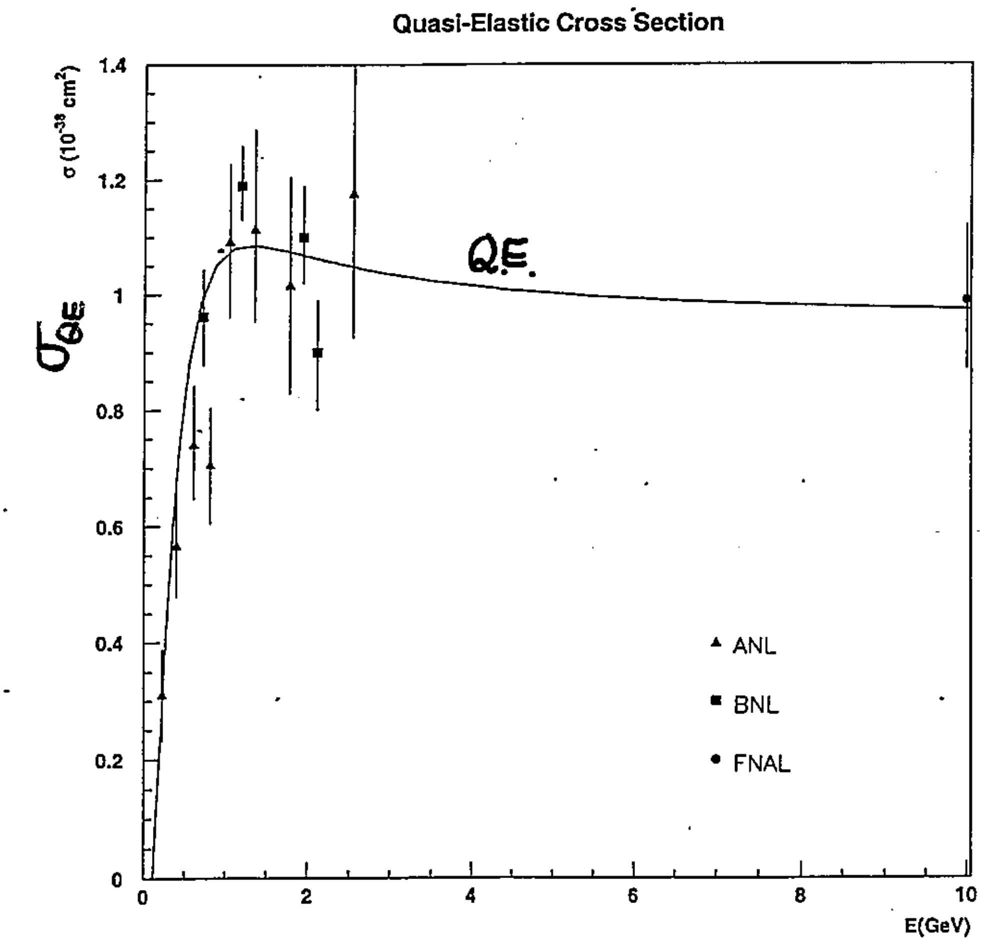
- E_ν is determined assuming Quasi-Elastic scattering
  $\Rightarrow$ oscillation pattern measurement
- CP asymmetry is enhanced $A_{CP} \propto \frac{L}{E}$
- Small uncertainty due to matter effect $\propto E_\nu$
- The neutrino beam technology (horn) exists and cheaper.
- ν flux and cross section are lower:
  $\Rightarrow$ Enhancement in low energy ν flux required. → see the next slide

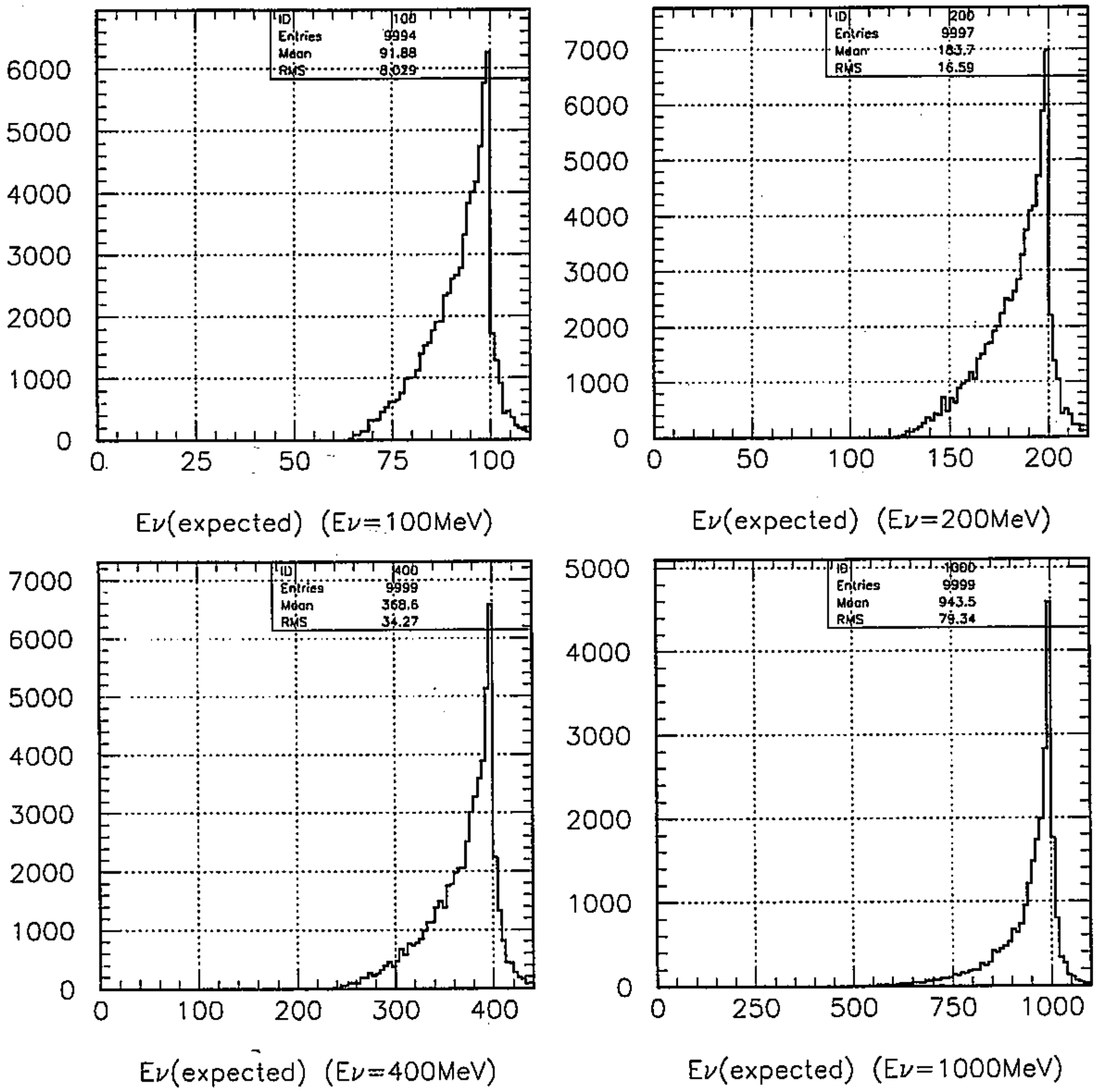
Fine grained calorimeter

- Good e/π^0 separation (e/π^0 separation is good at low E_ν, but current separation by water Č is not enough.)
- Identify/study Quasi-Elastic events
- Magnetic field in the case of ν factory:
  Detection of wrong sign muons

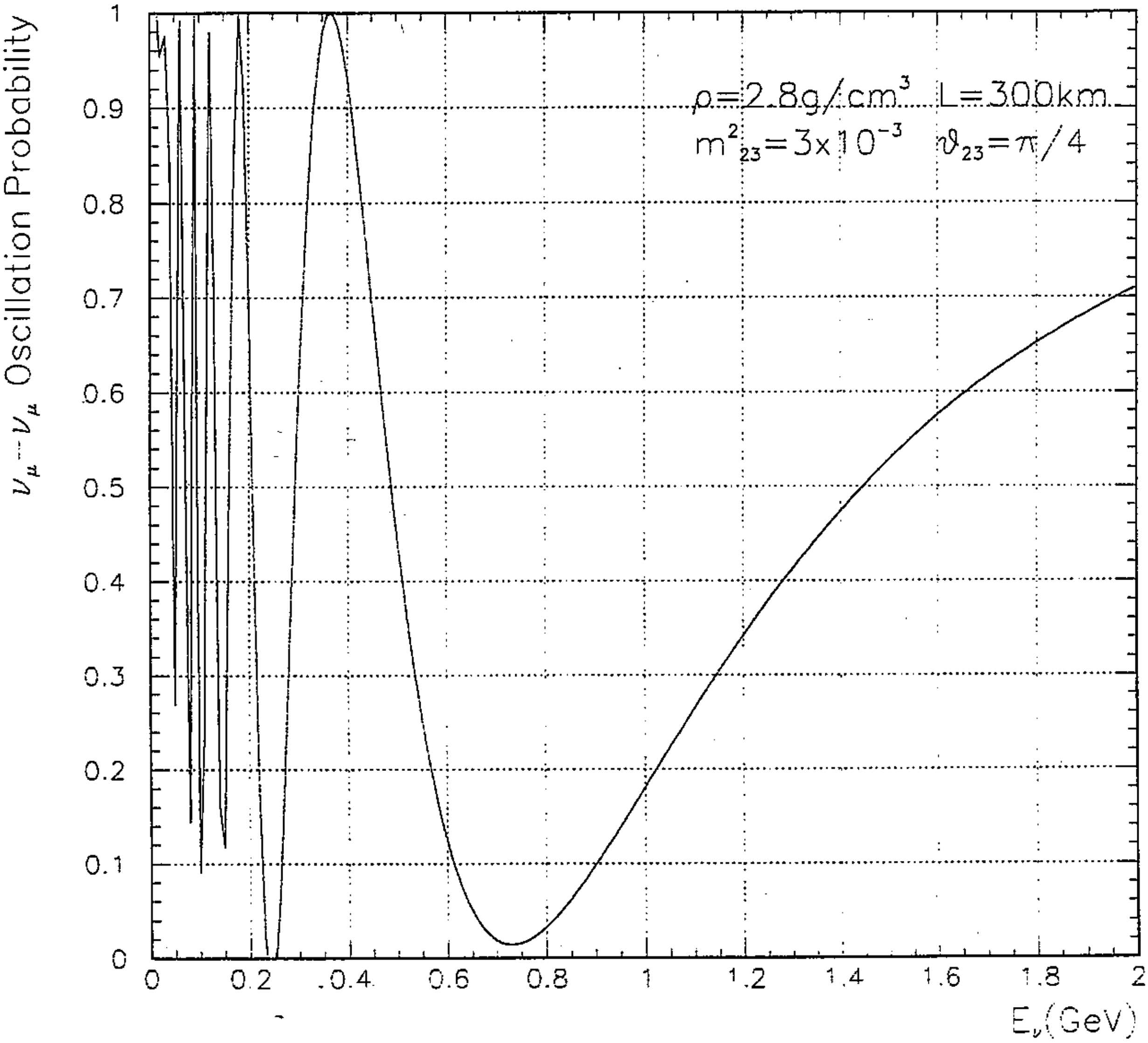
10 MeV – 200 MeV	200 MeV – 1 GeV	1 GeV – 5 GeV	5 GeV –
Nuclear resonances	Quasi-elastic $\nu_e n \to e^- p$ $\sigma \sim$ const.	Nucleon resonances	Deep Inelastic $\sigma \propto E_\nu$
(GT resonance)	E_{ν_e} can be reconstructed assuming 2body Q.E.		Leading lepton + hadron shower $\to E_\nu$


Soudan 2 Monte Carlo Cross Sections
Single π
Quasi-Elastic
Total
Total
QE.
σ_{cc}/E
$\sigma_{CC}(\nu_\mu+N\rightarrow\mu+X)/E$ (10^{-38} cm^2/GeV)
CCFRR (36)
CDHSW (37)
GGM – SPS (38)
BEBC (39)
ITEP (40)
CRS (41)
SKAT (42)
ANL (43)
BNL 7 (44)
GGM – PS (45)
ANL 12 – qel (8)
ANL 12 – 1π (22,23)
BNL – qel (6)
E (GeV)

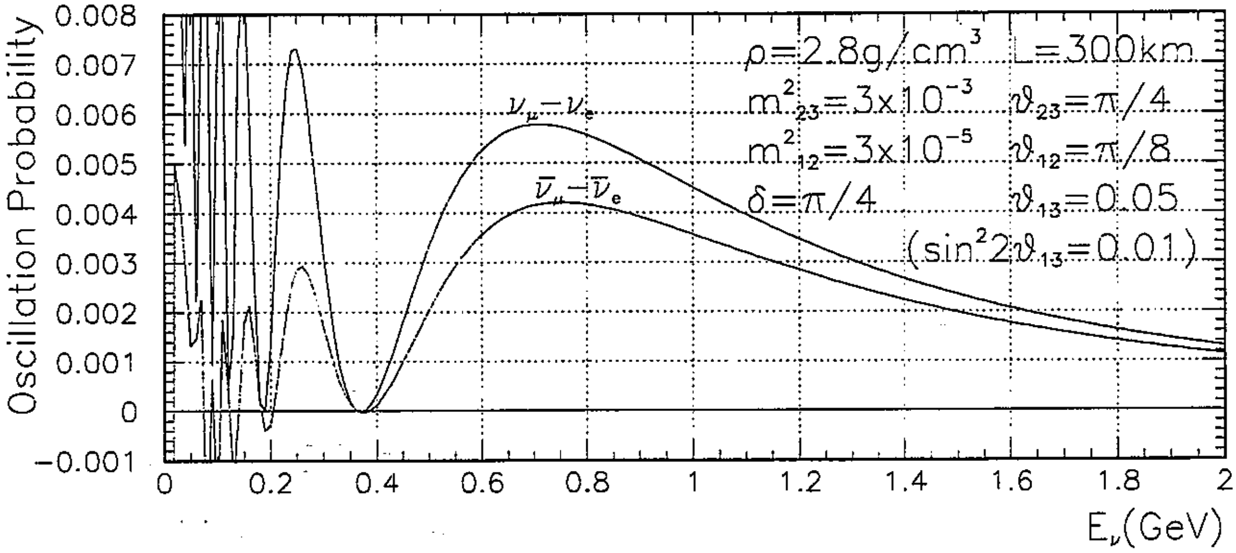

Quasi-Elastic Cross Section
QE.
σ_{QE}
σ (10^{-38} cm^2)
ANL
BNL
FNAL
E(GeV)



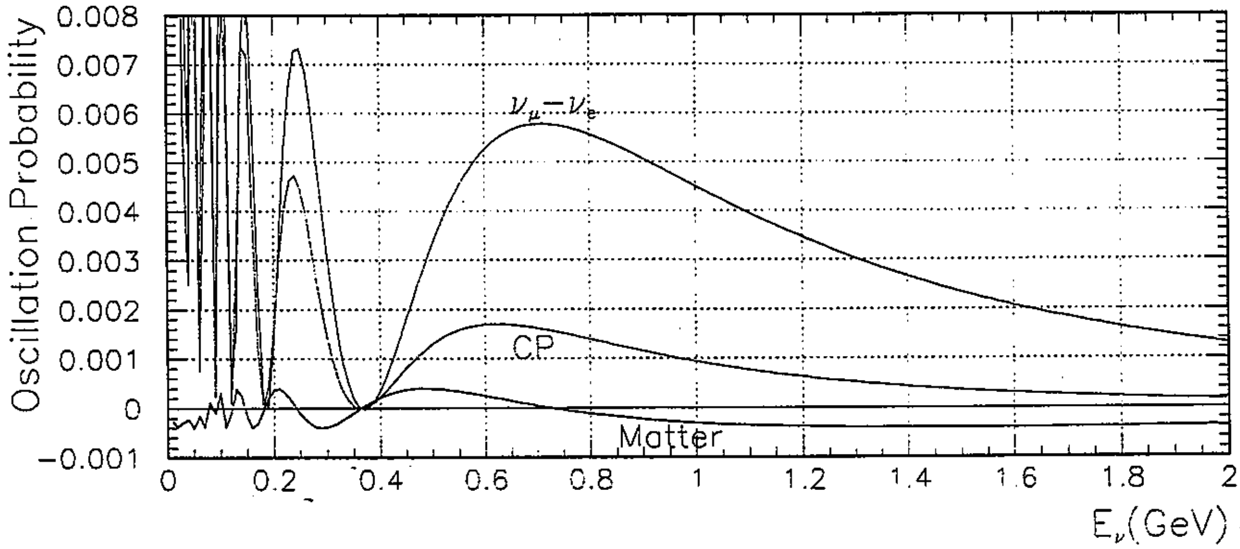
$$E_\nu(\text{expected}) = \frac{E_e m_N}{m_N + E_e \cos\theta_{e\nu} - E_e}$$



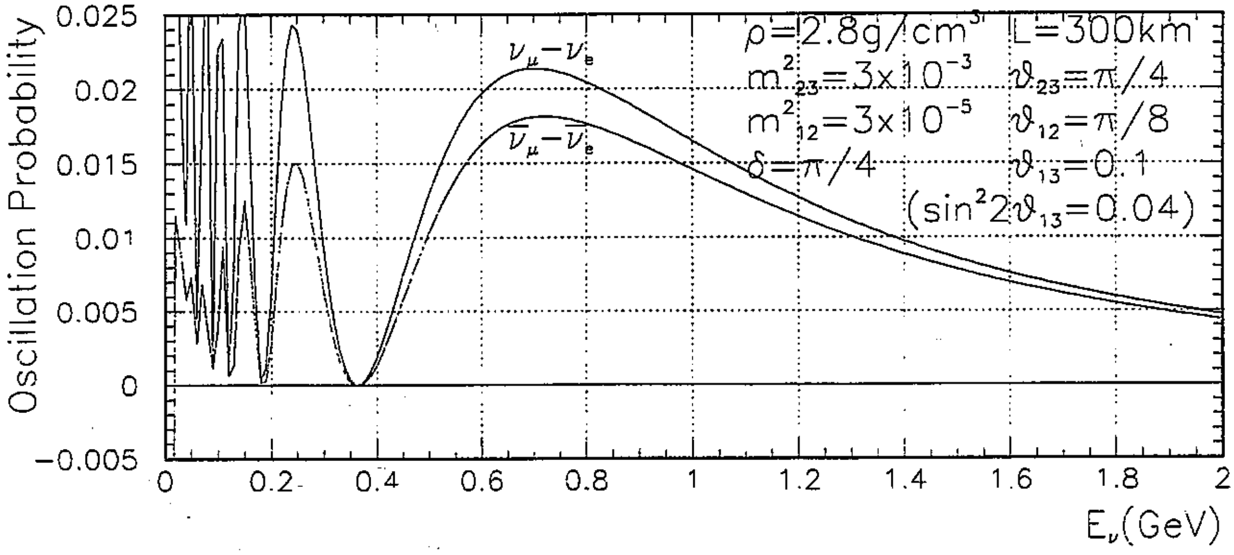
ν_μ -- ν_μ Oscillation Probability
ρ=2.8g/cm^3 L=300km
m^2_{23}=3x10^{-3} ϑ_{23}=π/4
E$_\nu$(Gev)

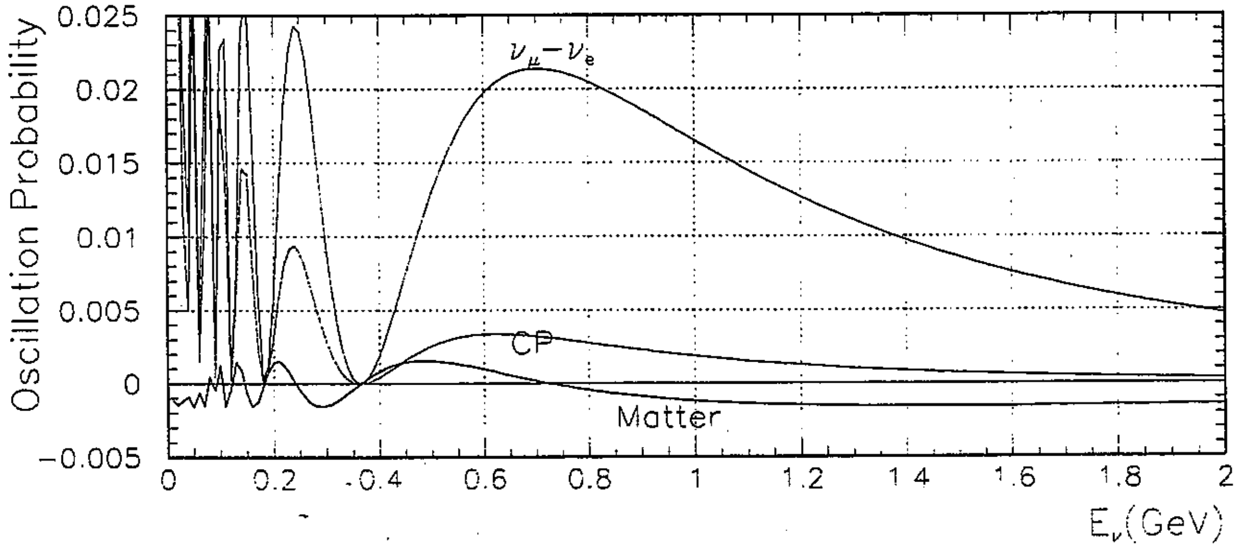


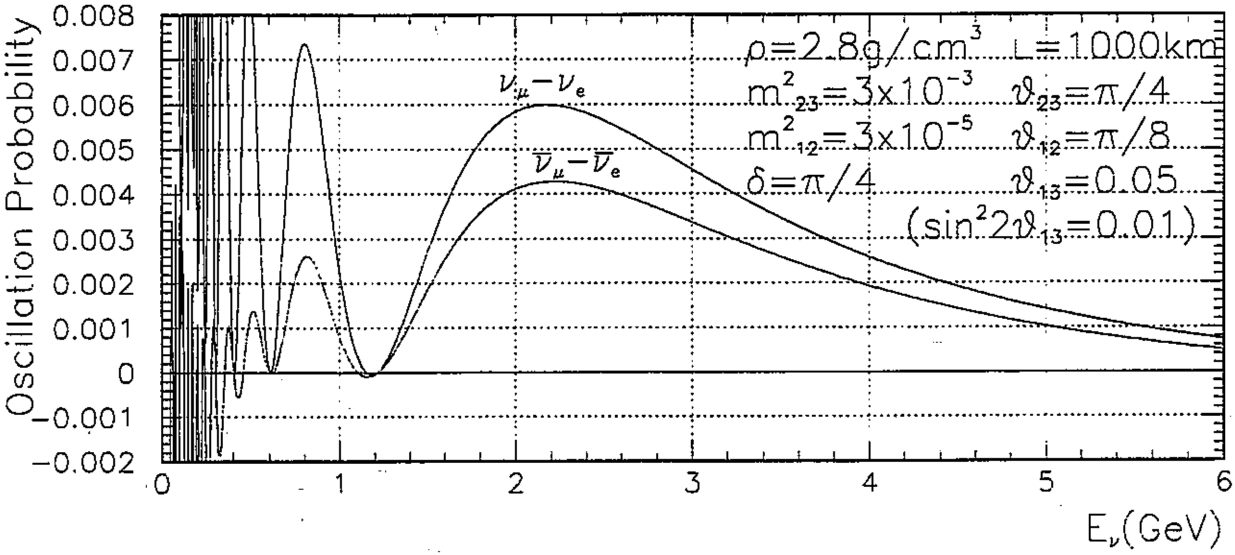
Oscillation Probability
ρ=2.8g/cm^3 L=300km
m$^2_{23}$=3x10^{-3} ϑ_{23}=π/4
m$^2_{12}$=3x10^{-5} ϑ_{12}=π/8
δ=π/4 ϑ_{13}=0.05
(sin^{2}2ϑ_{13}=0.01)
$\nu_\mu - \nu_e$
$\bar{\nu}_\mu - \bar{\nu}_e$
E$_\nu$(GeV)

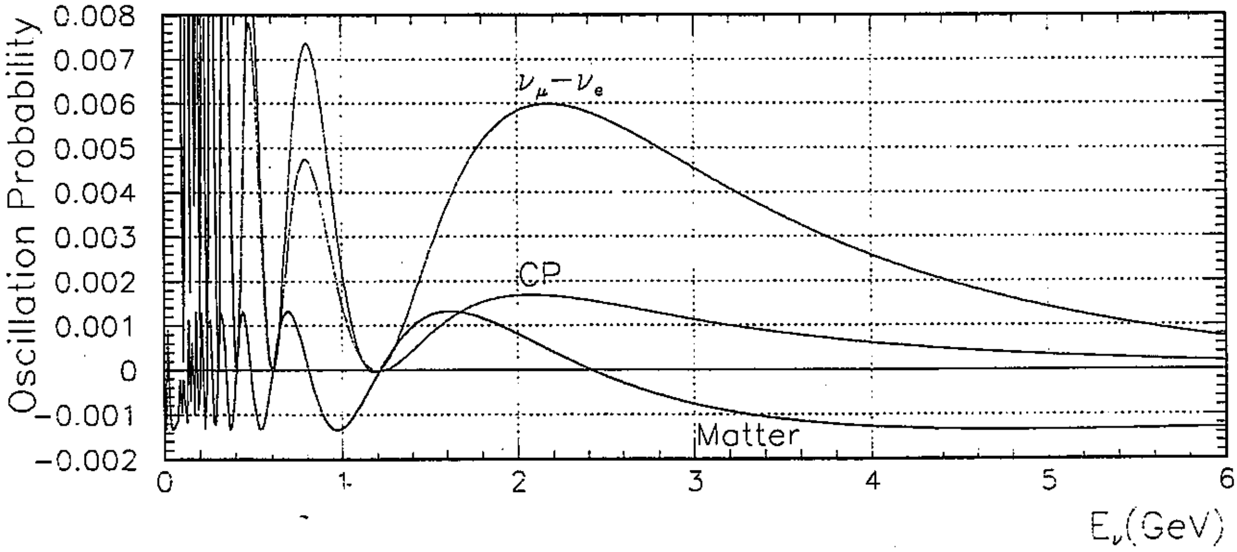


Oscillation Probability
$\nu_\mu - \nu_e$
CP
Matter
E$_\nu$(GeV)


Oscillation Probability
$\nu_\mu - \nu_e$
$\bar{\nu}_\mu - \bar{\nu}_e$
$\rho = 2.8 g/cm^3$ L=300km
$m^2_{23} = 3 \times 10^{-3}$ $\vartheta_{23} = \pi/4$
$m^2_{12} = 3 \times 10^{-5}$ $\vartheta_{12} = \pi/8$
$\delta = \pi/4$ $\vartheta_{13} = 0.1$
$(\sin^2 2\vartheta_{13} = 0.04)$
E_ν(GeV)

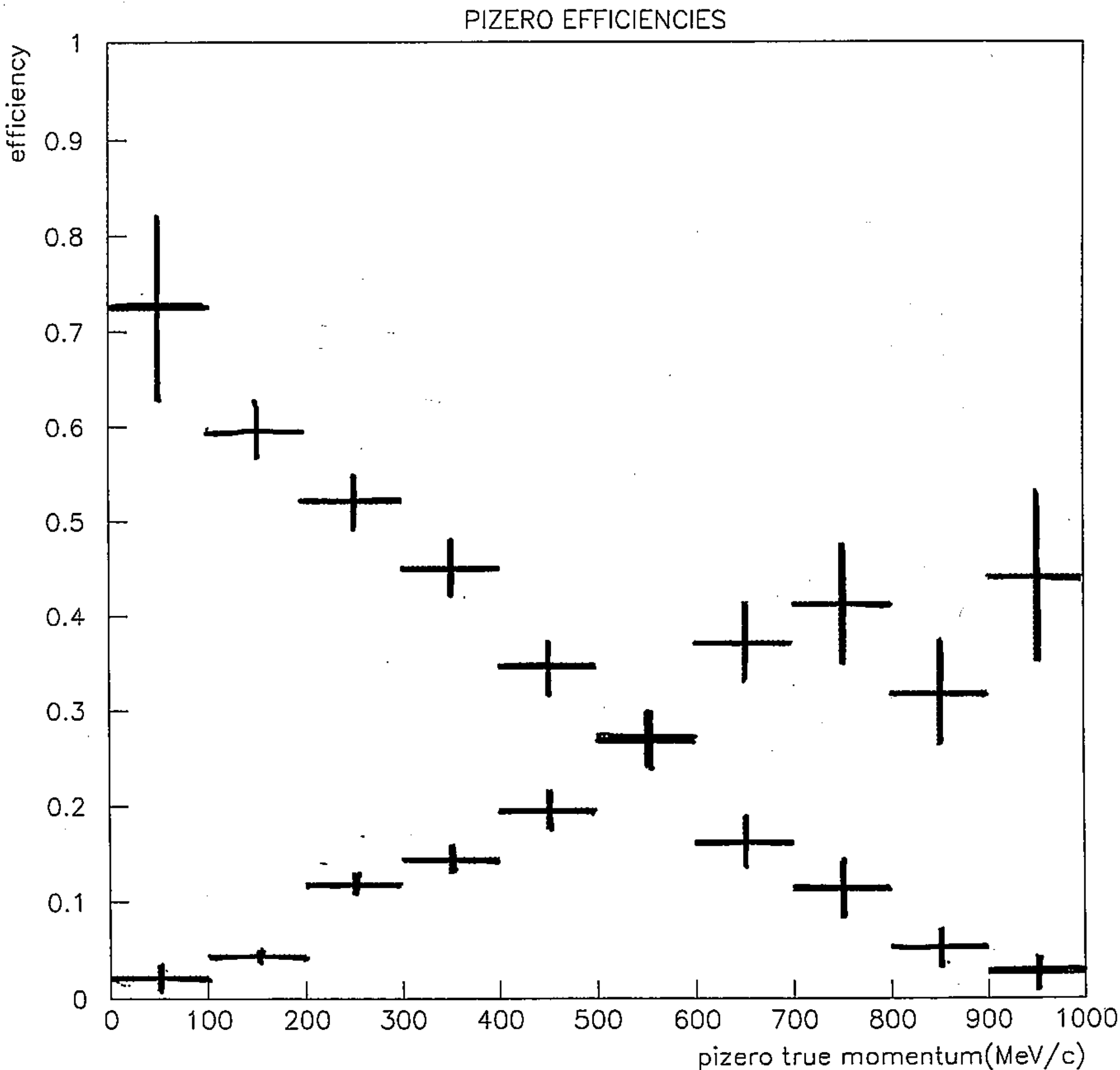

Oscillation Probability
$\nu_\mu - \nu_e$
CP
Matter
E_ν(GeV)


Oscillation Probability
ρ=2.8g/cm^3 L=1000km
m^2_{23}=3x10^{-3} ϑ_{23}=π/4
m^2_{12}=3x10^{-5} ϑ_{12}=π/8
δ=π/4 ϑ_{13}=0.05
($\sin^2 2\vartheta_{13}$=0.01)
$\nu_\mu - \nu_e$
$\bar{\nu}_\mu - \bar{\nu}_e$
E_ν(GeV)

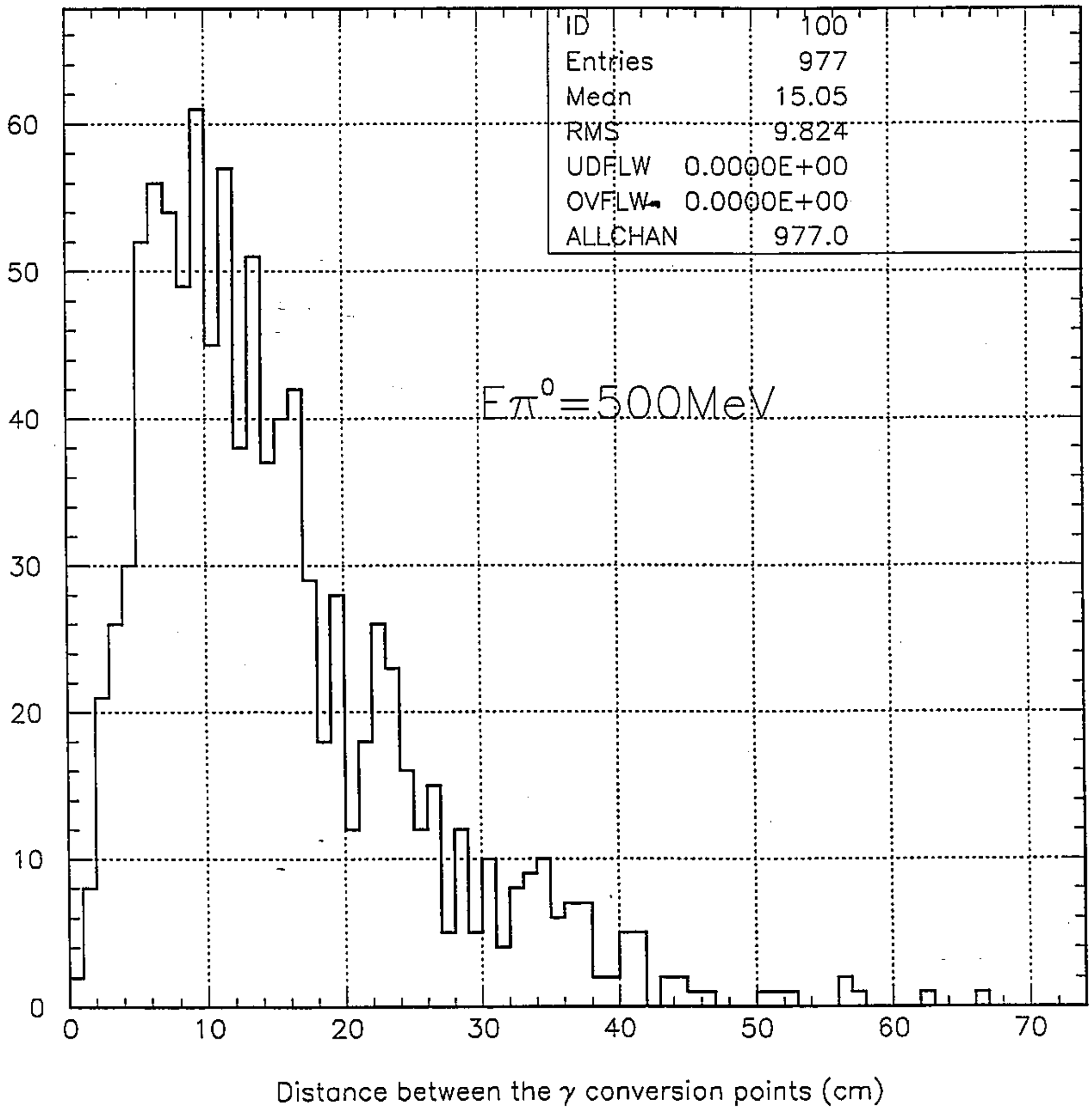

Oscillation Probability
$\nu_\mu - \nu_e$
CP
Matter
E_ν(GeV)

by Shunichi Mine

z0/04/06 23.18



blue = 2R, red = 1R



ID 100
Entries 977
Mean 15.05
RMS 9.824
UDFLW 0.0000E+00
OVFLW 0.0000E+00
ALLCHAN 977.0
Eπ⁰=500MeV
0
10
20
30
40
50
60
70
Distance between the γ conversion points (cm)

Estimated number of events

- Based on BNL-E889 proposal
  $\times 10$ more ν flux (beam power) at JHF
  ≥ 10 larger detector

- 2 degree production $\rightarrow E_\nu \sim$0.2-1.0GeV
  $\phi_\nu(BNL) \sim 1.5 \times 10^{-9} \nu_\mu/POT/cm^2$ at 1km for E_p=28GeV
  $\Rightarrow \phi_\nu(JHF) = (50/28) \cdot (1/300)^2 \cdot \phi_\nu(BNL)$
  $= 3 \times 10^{-14} \nu_\mu/POT/cm^2$ at 300km for E_p=50GeV

- $N_{QE} = (3 \times 10^{-14}) \cdot 10^{21} \cdot (0.5 \times 22 \times 10^9 \times 6 \times 10^{23}) \cdot (0.5 \times 10^{-38})$

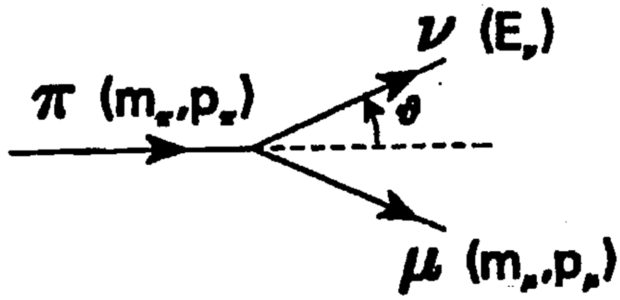
  $=$ 1000 Quasi-Elastic events/year (oscillation pattern!)

- Sensitive to θ_{13} and CP violation

$sin^2 2\theta_{13}$	$\nu_\mu \rightarrow \nu_e$	5years&100kton	A_{CP}(LMA)	
0.04	20 events/year	500 events	25%(10%)	$3\sigma \rightarrow$ 48event
0.01	5 events/year	125 events	50%(20%)	$3\sigma \rightarrow$ 12event

CHOOZ limit: $sin^2 2\theta_{13} < 0.1$
$\sigma_{\bar{\nu}_e} \sim (0.3 - 0.5)\sigma_{\nu_e}$
About half of the events fall into the region with large A_{CP}

BNL - E889 proposal



From energy, momentum conservation

$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\vartheta)}$$

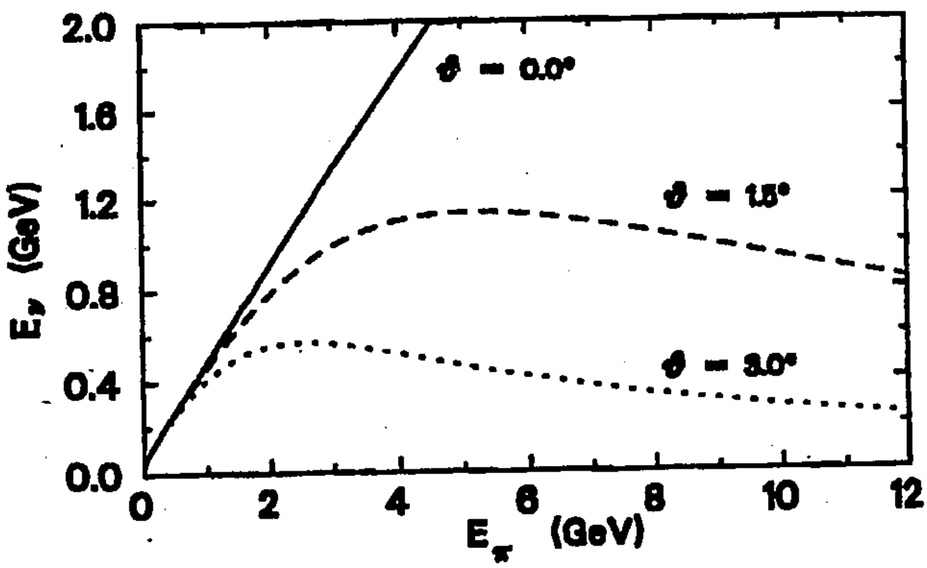


Fig. 4

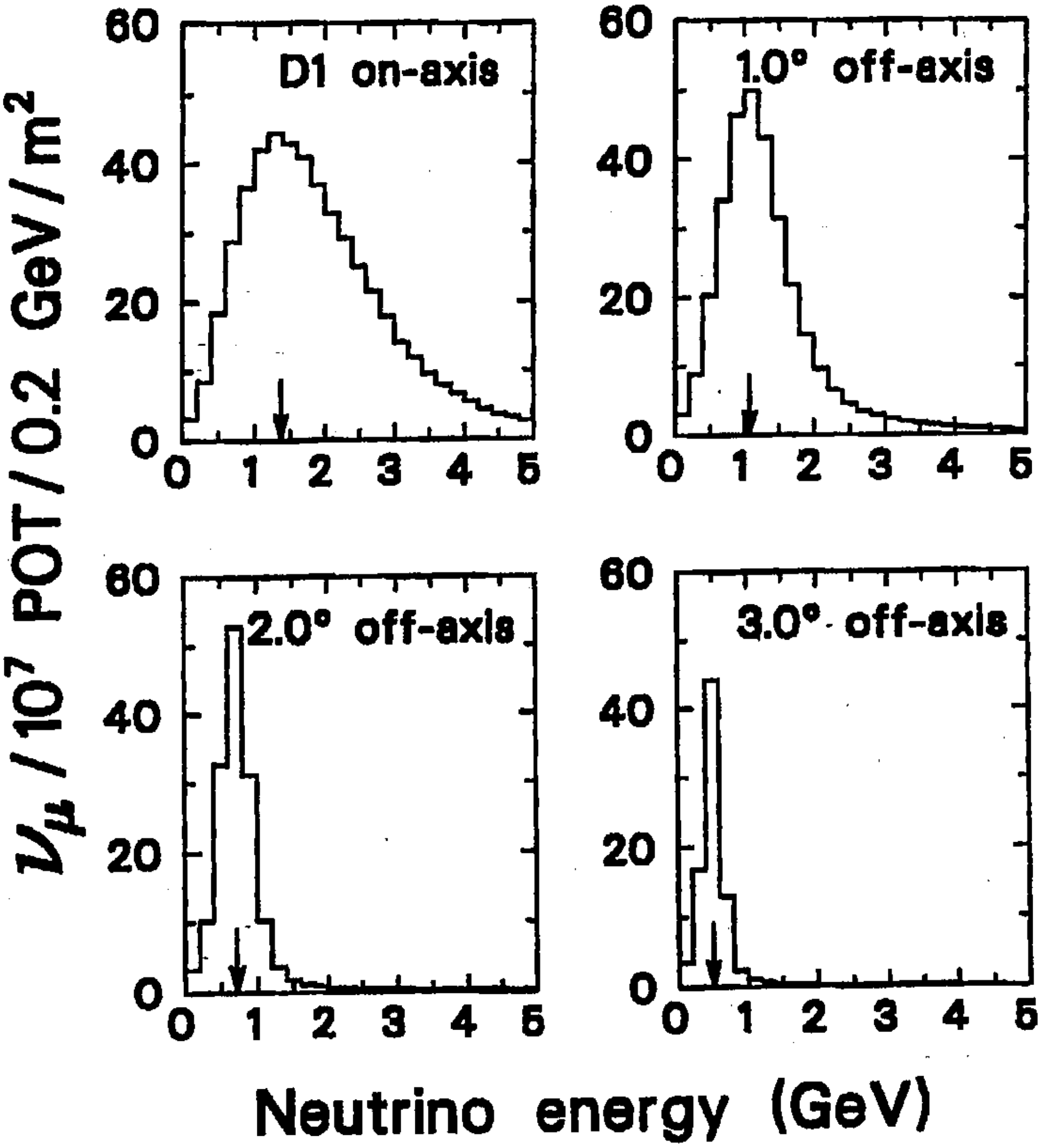

D1 on-axis
1.0° off-axis
2.0° off-axis
3.0° off-axis
ν_μ / 10^7 POT / 0.2 GeV / m^2
Neutrino energy (GeV)
0
20
40
60
0
1
2
3
4
5

Fig. 2

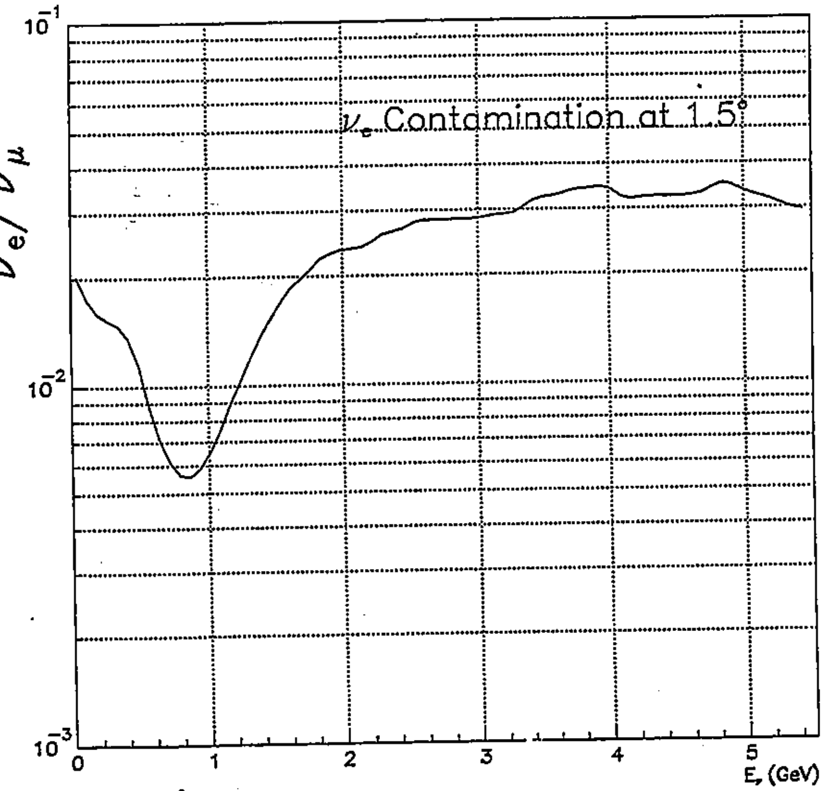


Figure 29: *Calculation of the ratio* $\frac{\Phi(\nu_e)}{\Phi(\nu_\mu)}$ *as a function of energy at* 1.5° *from the beam axis.*