Neutrino physics at low energy medium baseline neutrino beams

P.F. Loverre - Venezia - 1999

Ci

Low energy medium baseline ?

⇓

check of LSND signal

LSND $L/E \sim \frac{30\ m}{30\ MeV}$

CERN PS
FERMILAB BOOSTER] $\frac{L}{E} \sim \frac{1\ km}{1\ GeV}$

LSND worth to be checked ?

Two collaborations (States / Europe) say (yes)

LSND may be wrong but not a statistical fluctuation

bckg ⇒ signal $\sim 7\sigma$

LSND

- beam ν_μ $\bar{\nu}_\mu$ ν_e
- appearance of $\bar{\nu}_e$

$$P(\bar{\nu}_\mu \to \bar{\nu}_e) \sim 3 \times 10^{-3}$$

Two experiments proposed for immediate test

- FERMILAB – Mini BooNE
- CERN – I 216

[Later : NESS, ORLAND, μ-storage rings ?]

<u>Both</u>

search for electrons

$$\nu_e N \to e N'$$

in pure ν_μ beam

$(E_\nu \sim 1\,GeV)$

4

A proposal for an experiment to measure $\nu_\mu \rightarrow \nu_e$ oscillations and ν_μ disappearance at the Fermilab Booster:

BooNE

December 7, 1997

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Mini BooNE

Boo**o**ster (Fermilab - 8 GeV p)

Neutrino

Experiment

Mini ⇒ evolution forseen if oscillations are found

ν_μ beam from 8 GeV proton Booster at Fermi Lab

$\langle E_\nu \rangle \sim 800$ MeV

ν_μ line to be constructed

- focusing system
- 50 m decay tunnel

Very high intensity ⇒ 5×10^{20} Pot/year

DETECTOR

Evolution of LSND for a very different energy range

E_ν (LSND) ~ 30 MeV

E_ν (BooNE) ~ 800 MeV

Mineral oil ⇒ scint. + Č light

active target

167 tons (LSND) ⇒ 770 tons (445 FY)

Seen by the 1220 phototubes of LSND (~ 10% coverage)

CERN COURIER

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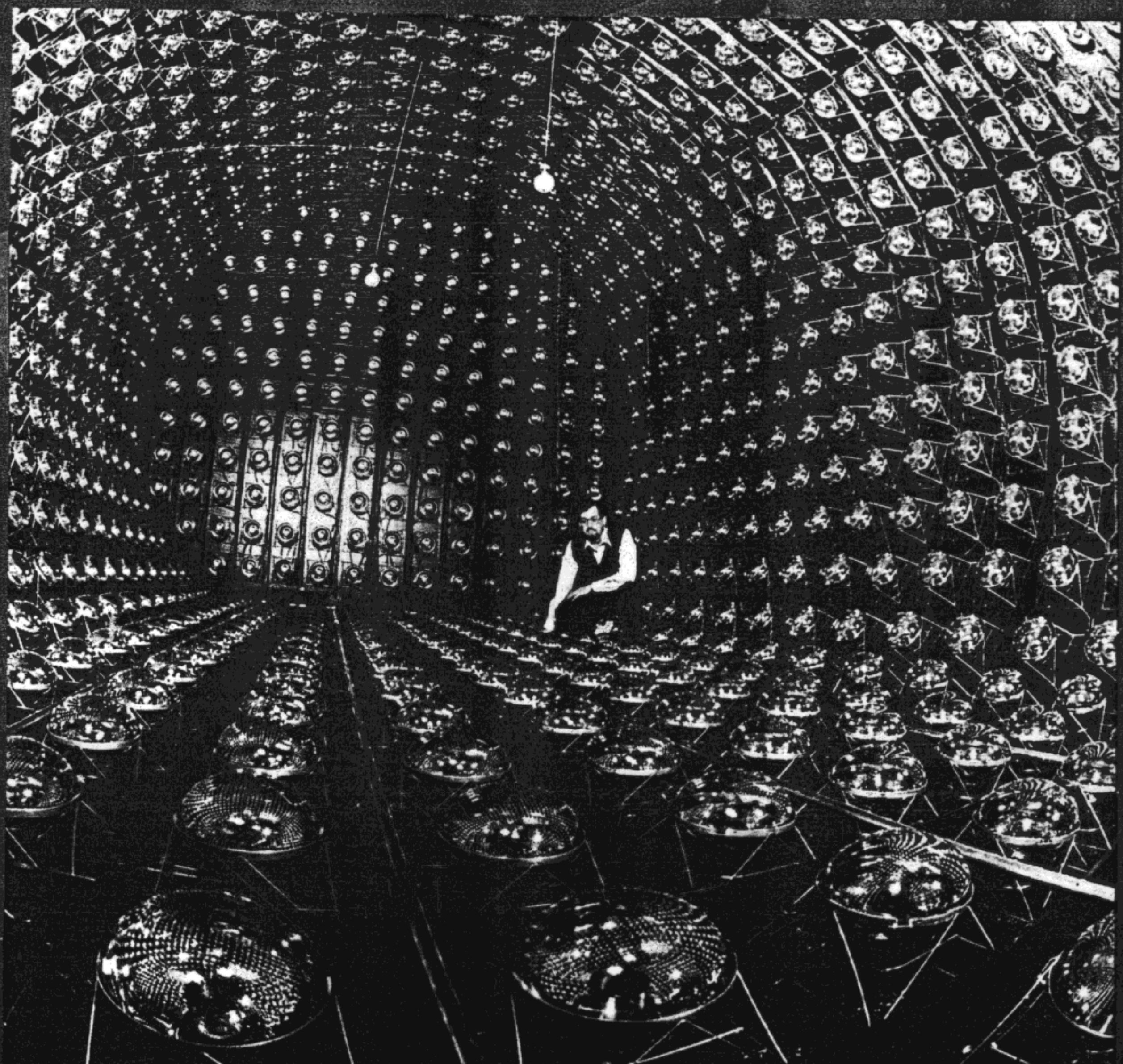

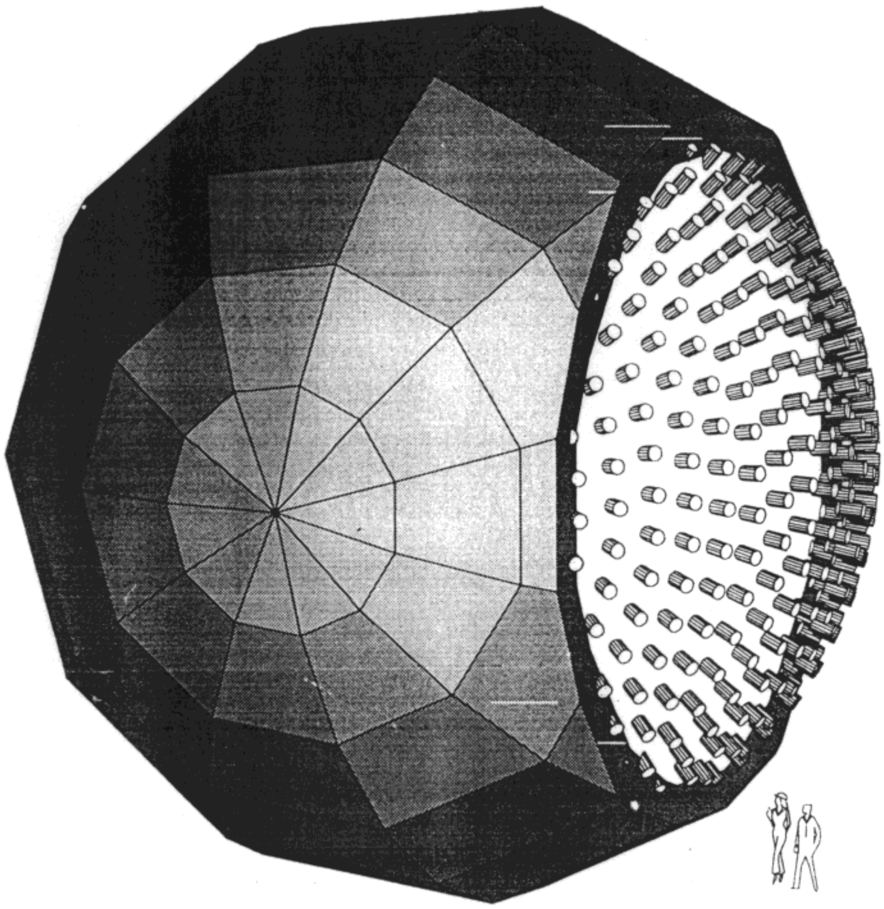

Figure 5.15: GEANT-generated schematic of the proposed detector.

Identify

$$\nu_\mu C \rightarrow \mu X$$

$$\nu_e C \rightarrow e X$$

reject

$$\nu_\mu C \rightarrow \underline{\underline{\pi^0}} \nu_\mu X$$

Particle identification

- characteristics of Č rings

+ μ id via $\mu \rightarrow e$ decay

+ π^0/e via large angle γ's

+ ratio Č vs scint. light

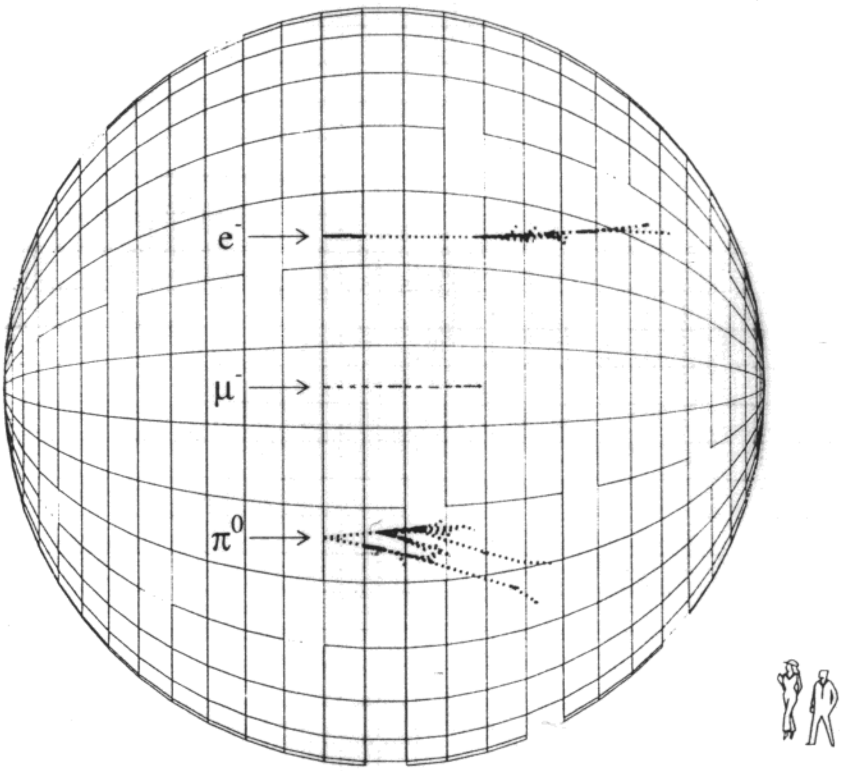

Figure 6.1: Example topologies of 500 MeV electrons, muons, and neutral pions in the detector tank.

2.5×10^{20} pot - 1 year

$\nu_\mu C \to \mu X$ (normalization)	590000
ν_e (beam cont.)	1800
π^0 misident.	600
μ misident.	600
total bckg	3000
signal ($\Delta m^2 = 0.4\, eV^2$, $\sin^2 2\theta = 0.02$)	1200

Statistical error (bckg fluct.)

very small

$$\sqrt{3000} = 55 \text{ evts}$$

SYSTEMATIC ERRORS

- misidentified π^0 (asymmetric decay)
  - $\Rightarrow$ from identified π^0's (2 large angle γ's)
- misidentified μ^- (captured μ^-)
  - $\Rightarrow$ from μ^-'s identified by $\mu \to e$ decay
- ν_e beam contamination
  - $\Rightarrow$ ν_e mainly from $\pi \to \mu \to e$ (K fraction small)
  - then $\Rightarrow$ measured ν_μ spectrum fixes $\mu^+ \to \bar{\nu}_\mu \nu_e e^+$

Total syst error $O(5\%)$

Total background 3000 ± 150

Expected signal (from LSND) 1200

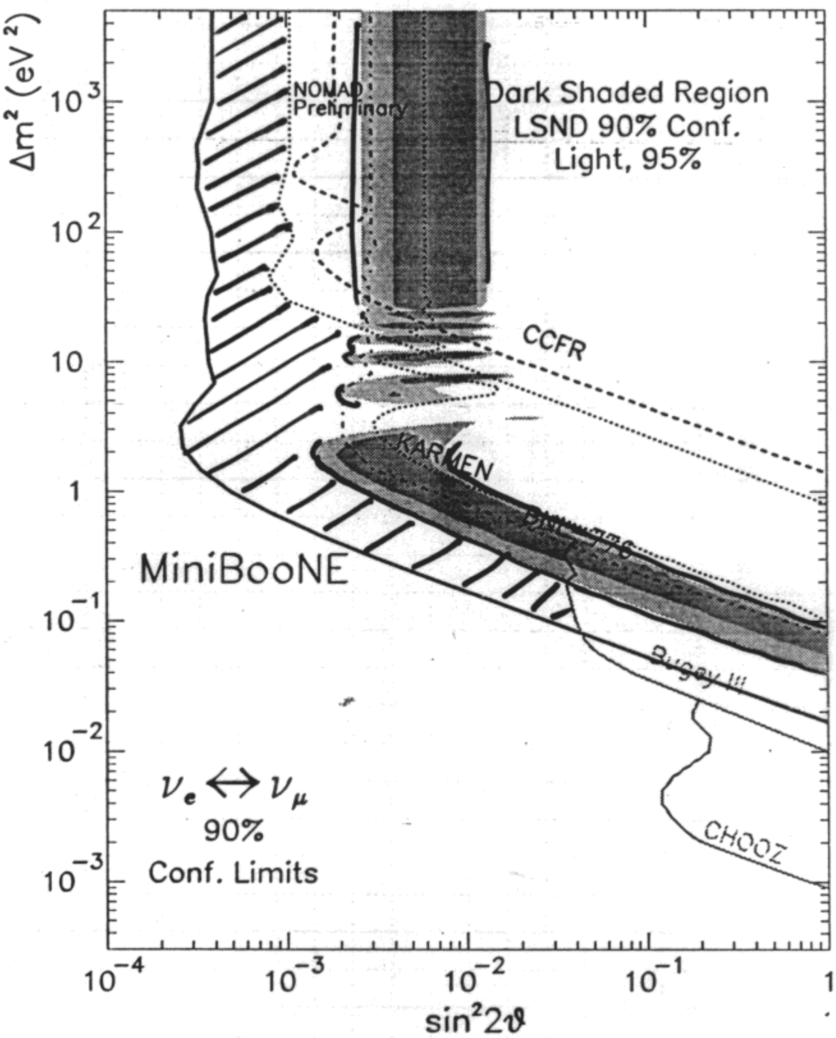

Figure 2.1: 90% C.L. limit expected for MiniBooNE for $\nu_\mu \rightarrow \nu_e$ appearance after one year of running, including systematic and statistical errors (see section 2.2), if LSND signal is not observed (solid line). Results from past experiments through December, 1997, also are shown.

Mini BooNE

- cost ~ 9 MSF + contingency
  (beam + detector)
- approved by PAC
- searching for money
- start data taking
  ⇒ end of 2001

At CERN

I216 - LoI to SPSC

- PS - 19.2 GeV protons
- 50 m decay tunnel
- pure ν_μ beam $\frac{\overset{(-)}{\nu}_e}{\nu_\mu} \sim 5 \times 10^{-3}$

$\langle E_\nu \rangle \sim 1.5$ GeV

Search for electron excess at $\sim$ 1 km

(16

I 216

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The following institutes expressed their interest:

Harvard (Cambridge, MA)
UCL (Louvain-la-Neuve), ITEP (Moscow)

I216

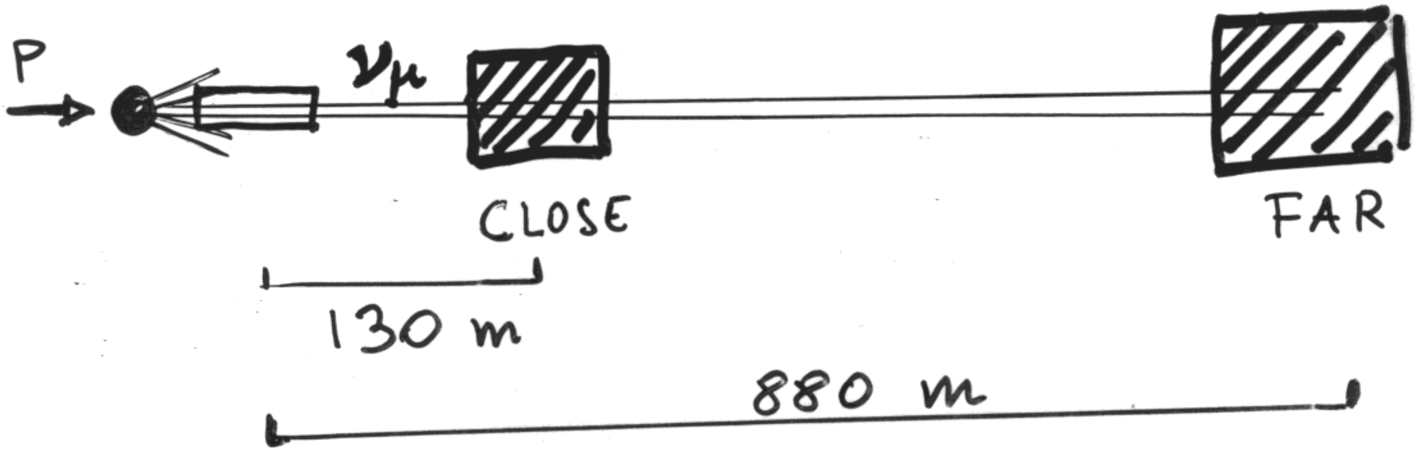
- high intensity - 2.5×10^{20} pot/2 years
  [old PS exp ⇒ 0 (1×10^{19} pot)
  MiniBooNE - 5×10^{20} pot/1 year]

- only clean q.e. reactions
  $\nu_\mu n \to \mu^- p$
  $\nu_e n \to e p$

- fine grained tracking calorimeter
  scintillator ⇒ dE/dx + target
  dE/dx measured every $0.1\,X_0$
  ↳ e/π^0 discrimination

- two-detector technique
  (close - far comparison) for
  excellent control of background

Two-detectors experiment



Count

$$\left.\frac{N(e)}{N(\mu)}\right|_{CLOSE} \Rightarrow \text{normalization}$$

$$[e/\mu]_{FAR} > [e/\mu]_{CLOSE}$$

$$\Downarrow$$

oscillation ($L \sim 800$ m)

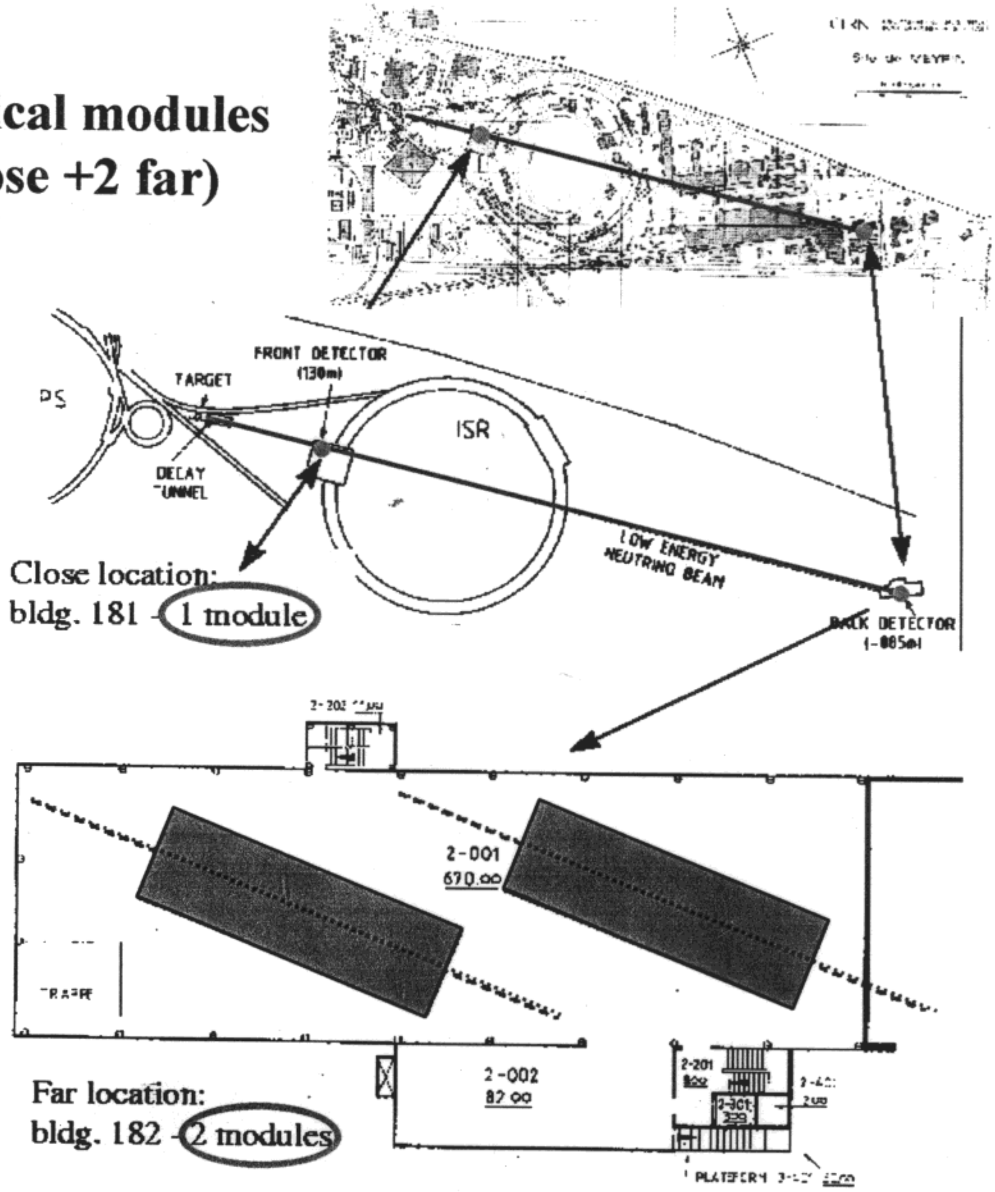
Experimental Layout

ν_e appearance in a ν_μ beam from the CERN PS

- ☑ Two detectors (close/far)
- ☑ Good electron id
- ☑ Large proton statistic (2.5PoT/2years)

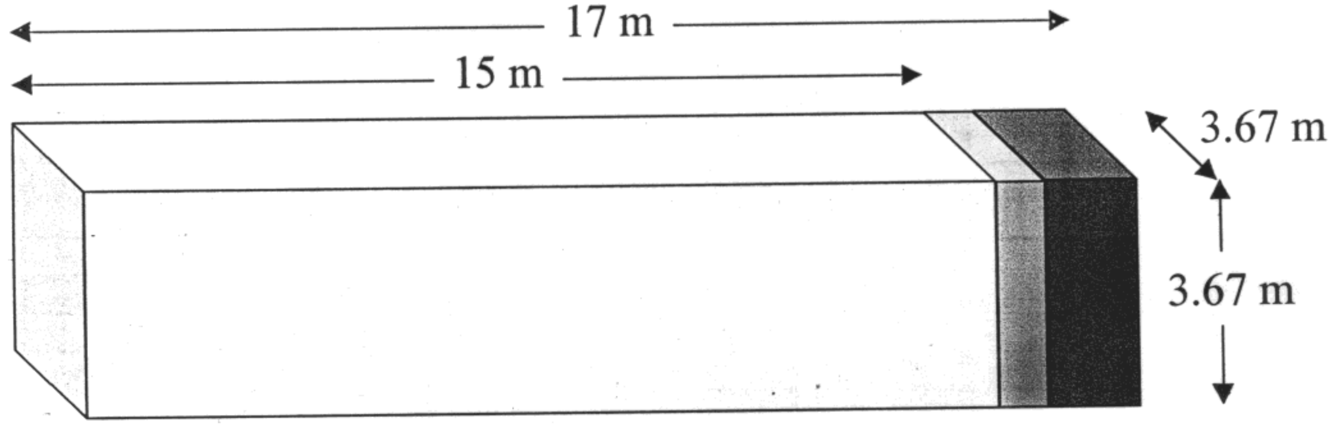
$\Delta = (N_e/N_\mu)_{FAR} - (N_e/N_\mu)_{CLOSE} \neq 0$ would detect $\nu_\mu \rightarrow \nu_e$ oscillation

3 identical modules (1 close +2 far)



Detector Module

A detector module is a fine grained tracking calorimeter (which act also as target for neutrino interactions), followed by a [illegible] and a muon catcher.

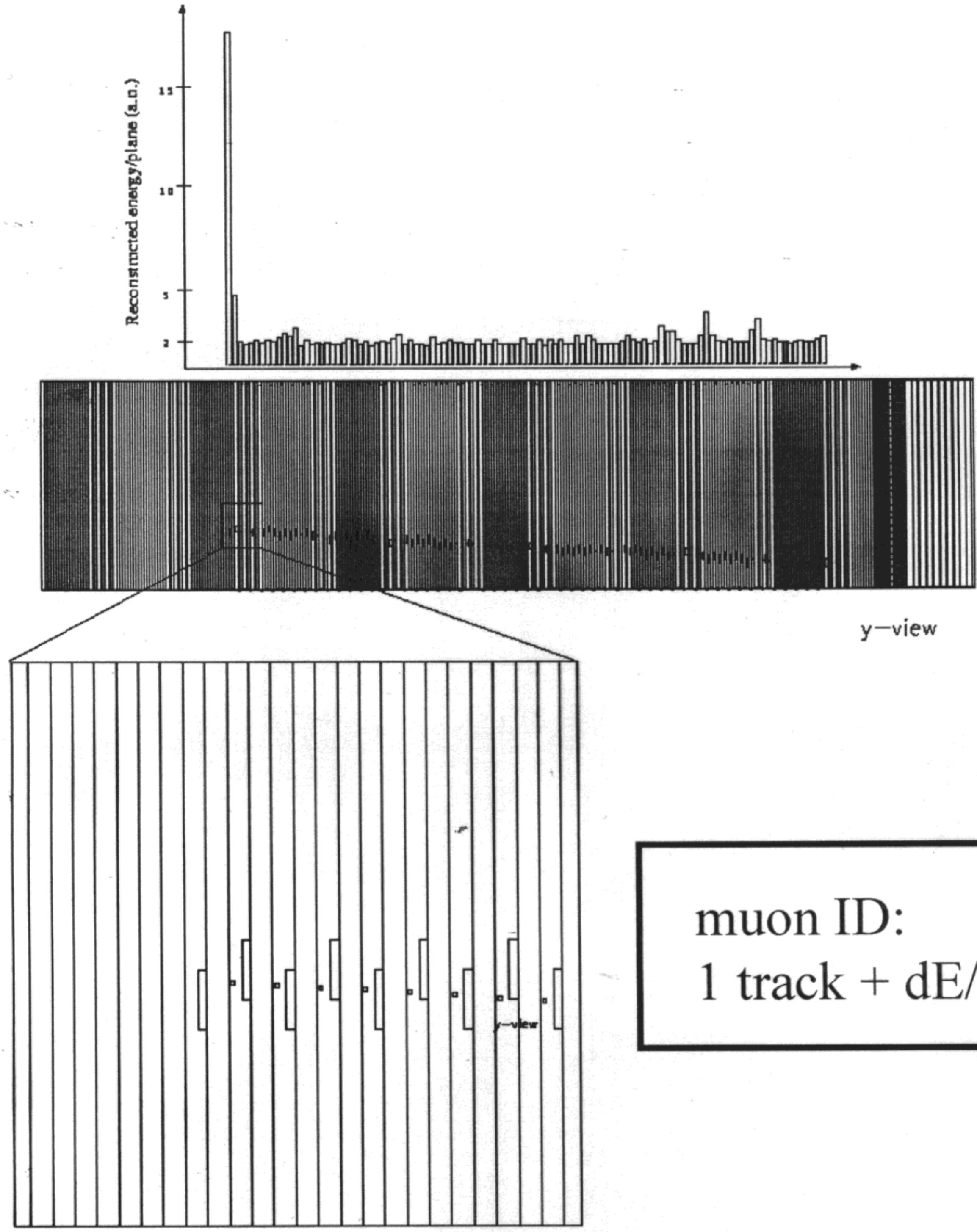


The tracking calorimeter consists of 300 streamer tube chambers, interleaved with 300 scintillator planes.

The tail catcher is a sandwich of 20 scintillator planes and 1 cm thick iron absorbers.

The muon catcher is a sandwich of 10 streamer tube planes and 10 cm thick iron absorbers.

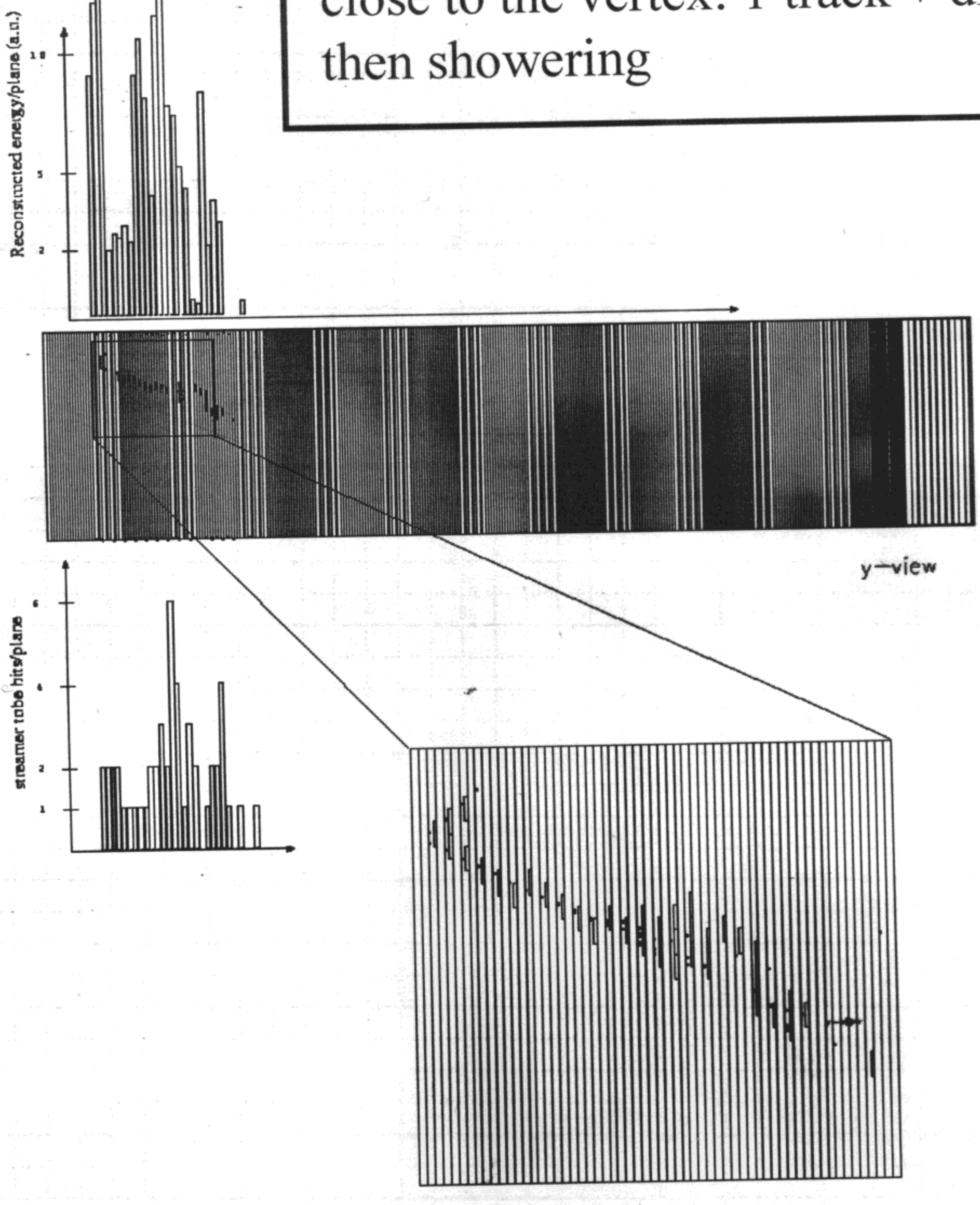
ν_μ Quasi-Elastic Interaction



muon ID:
1 track + dE/dx

ν_e Quasi-Elastic Interaction

electron ID:
close to the vertex: 1 track + dE/dx
then showering



Detector

128 tons – close
256 tons – far
O(10 MSF)

Construction ~ 2 years

Data taking ~ 2 years

[1999 – 2003 ⟹ exploit time window before LBL operation ?]

In the far detector

85000 μ
310 "e" bckg — 250 beam ν_e, 60 π^0

300 e signal
[$\Delta m^2 = 2\,eV^2$, $\sin^2 2\theta = 0.006$]

$$\Delta(e/\mu) = (e/\mu)_{FAR} - (e/\mu)_{CLOSE} =$$
$$= (3.10 \pm 0.29 \pm 0.10) \times 10^{-3}$$

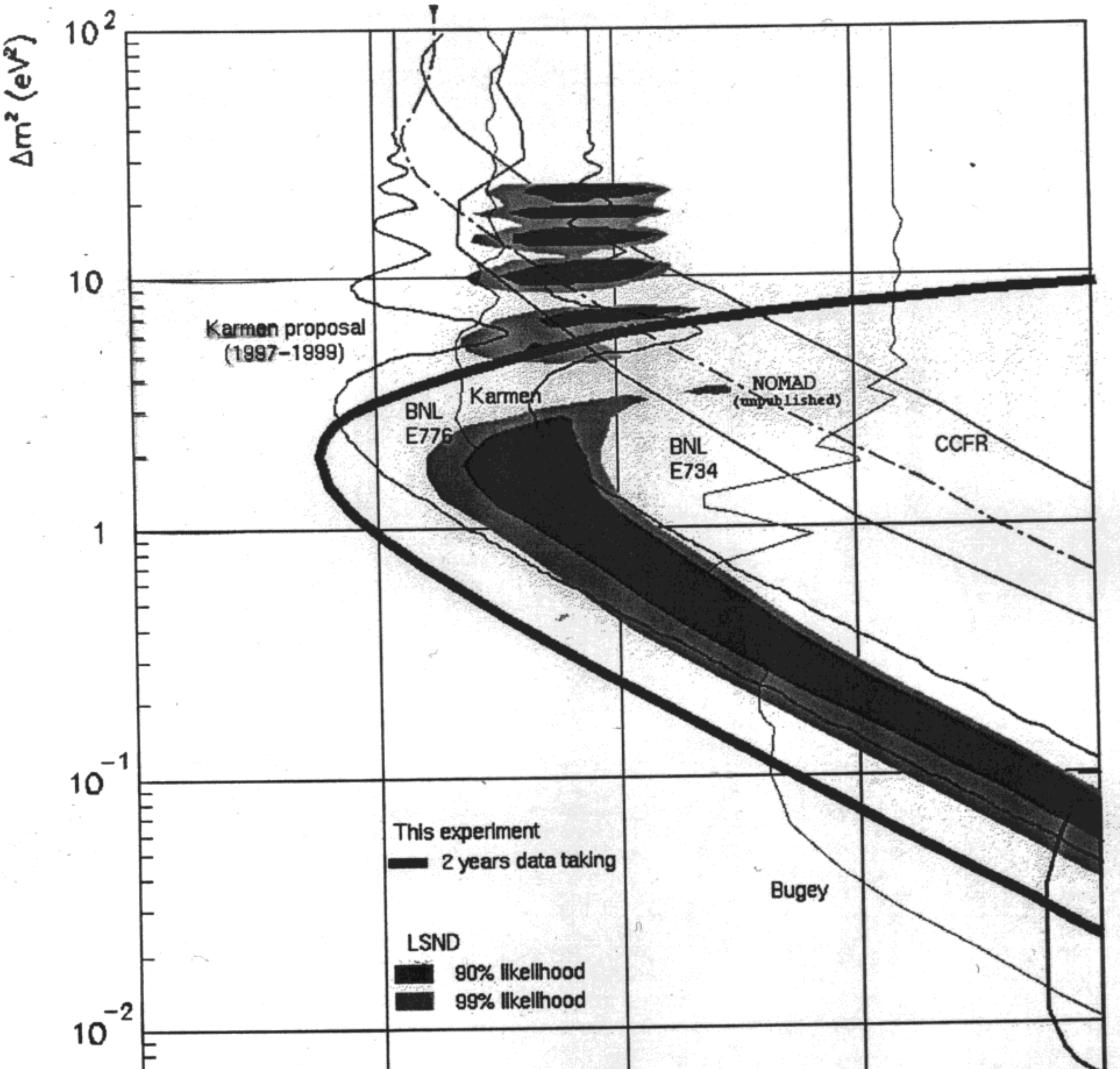
(stat. error dominates)

Sensitivity

2.5 x 10^{20} PoT in two years

N_{FAR} = 85,000 ν_μ quasi-elastics

N_{CLOSE} = 1,900,000 ν_μ quasi-elastics



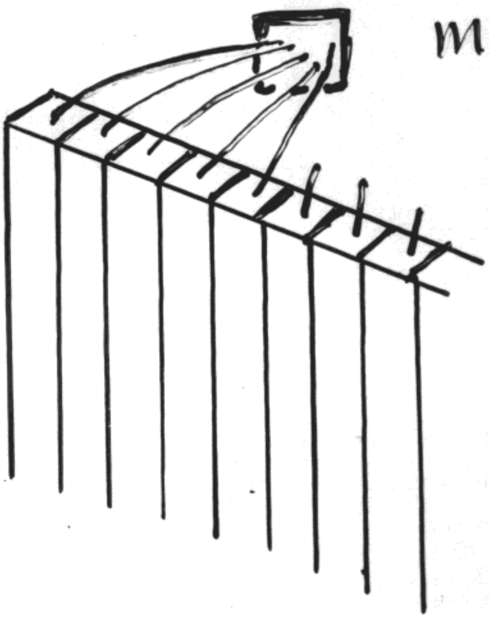
Feb. 99 ⇒ "Encouragement" from SPSC + Research Board

⇓

Studying improved detector design

e.g. scint. planes $(4\times4\ m^2)\times 3\ cm$ $(< 0.1 X_0)$

single scint. element $3\times3\times400\ cm^3$ read by WLS fiber (⇒ MINOS)



multi-pixel PM

measure in $3\times3\ cm^2$

dE/dx + pattern

⇒ streamer tubes not needed

⇓

Proposal → Summer '99

Mini Boone	I216	
****	**	- statistics
***	****	- part. id.
***	****	- bckg control/ normalization

LSND true

⇒ Mini Boone → Boone (Δm^2 studies)

⇒ I216 → JURA ?

In any case

⇒ careful study of $\nu_\mu - \nu_e$ for small mixing ($\Delta m^2 > 0.1\ eV^2$)

- Mini Boone → approved → searching for funding
- I216 → LoI → searching for approval

Results in 2002 ?