DREAMWORKS & DoE

present

The LSND Experiment

Directed by: WILLIAM C. LOUIS

Liquid **S**cintillator **N**eutrino **D**etector (LAMPF-E1173)

Narrated by: ION STANCU (UoAlabama)

Collaboration:
- University of California, Riverside
- University of California, San Diego
- University of California, Santa Barbara
- Embry Riddle Aeronautical University
- Los Alamos National Laboratory
- Louisiana State University
- Southern University
- Temple University

Physics:
- search for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations
- search for $\nu_\mu \to \nu_e$ oscillations
- measure $\nu_e C \to e^- X$ inclusive/exclusive X-sections
- measure $\nu_\mu C \to \mu^- X$ inclusive/exclusive X-sections
- measure $\nu_e e^- \to \nu_e e^-$ elastic scattering X-section
- ? measure G_s (strange quark contribution to nucleon spin)

Operation: August 1993 - December 1998.

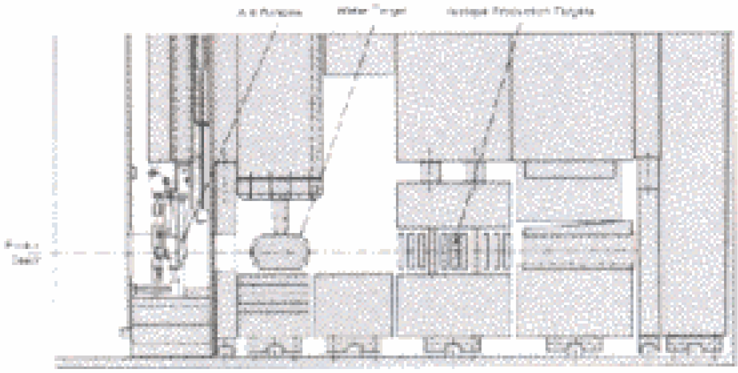
(mature audience)

Filmed on location @ the LANL

Rated: R

Neutrino Production:

Main neutrino production: A6 target area at LAMPF/LANSCE:



ELEVATION VIEW, NEUTRINO SOURCE

Additional contributions from the A1/A2 targets 105/80 m upstream

Protons on the water target produce copious amounts of pions:

$$\pi^+\ (89\%) \rightarrow \nu_\mu\ \mu^+\ (DIF - 3\%) \rightarrow \bar{\nu}_\mu\ \nu_e\ e^+$$

$$\rightarrow \nu_\mu\ \mu^+\ (DAR - 97\%) \rightarrow \bar{\nu}_\mu\ \nu_e\ e^+$$

$$\pi^-\ (11\%) \rightarrow \bar{\nu}_\mu\ \mu^-\ (DIF - 5\%) \rightarrow \bar{\nu}_e\ \nu_\mu\ e^-\ (12\%)$$

$$\rightarrow \text{captured}\ (88\%)$$

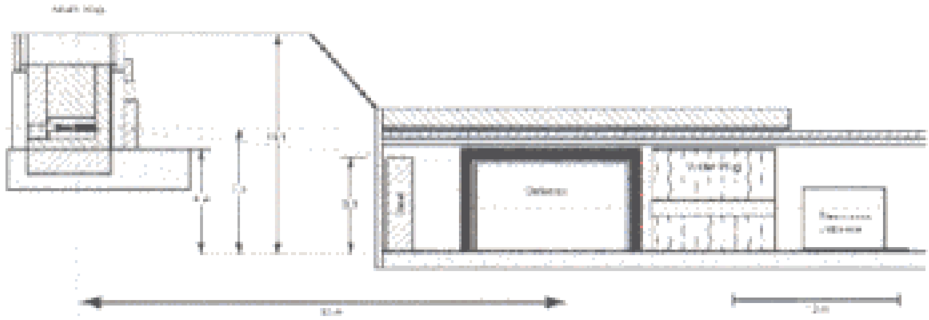
$$\rightarrow \text{absorbed}\ (95\%)$$

Suppression factor:

$$\bar{\nu}_e/\bar{\nu}_\mu = 0.125 \times 0.05 \times 0.12 = 7.5 \times 10^{-4}$$

$\bar{\nu}_e$ energy spectrum softer $\rightarrow$ better $\bar{\nu}_e/\bar{\nu}_\mu$ suppression.

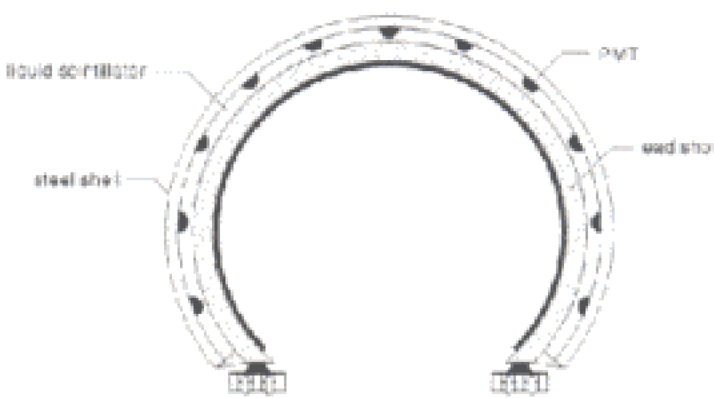
Experimental Setup:



Experimental setup of the LSND detector

Detector center at approximately 30 m from the A6 target area.

Tunnel and veto shield from the previous LAMPF-E645 experiment.



Veto shield cross section - active and passive shielding

Active shielding: 292 5-inch EMI PMTs (10,000 gallons of liquid scintillator - 5% pseudocumene in mineral oil).

Passive shielding: 18 cm thick layer of lead shot (0.7 packing).

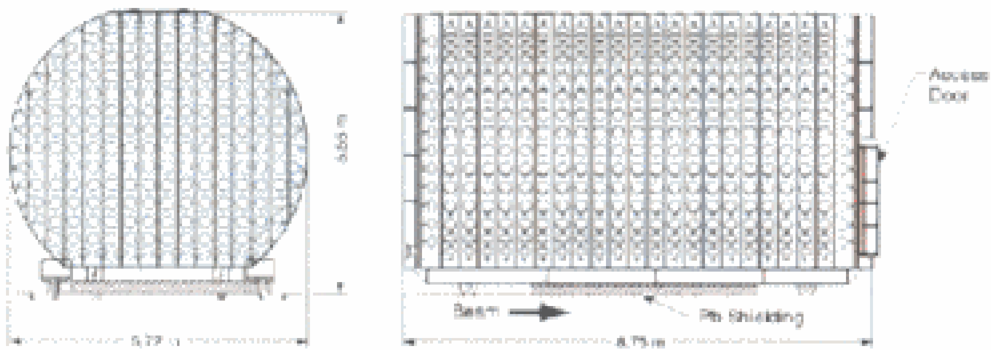
THE DETECTOR:

Shielding: - 8.5 m of Fe-equivalent between A6 and the detector

- 2 kg/cm^2 of overburden (cosmic ray shielding)

- "water plug" (cosmic ray shielding at tunnel entrance)

- Additional veto (scintillation) counters along the sides.

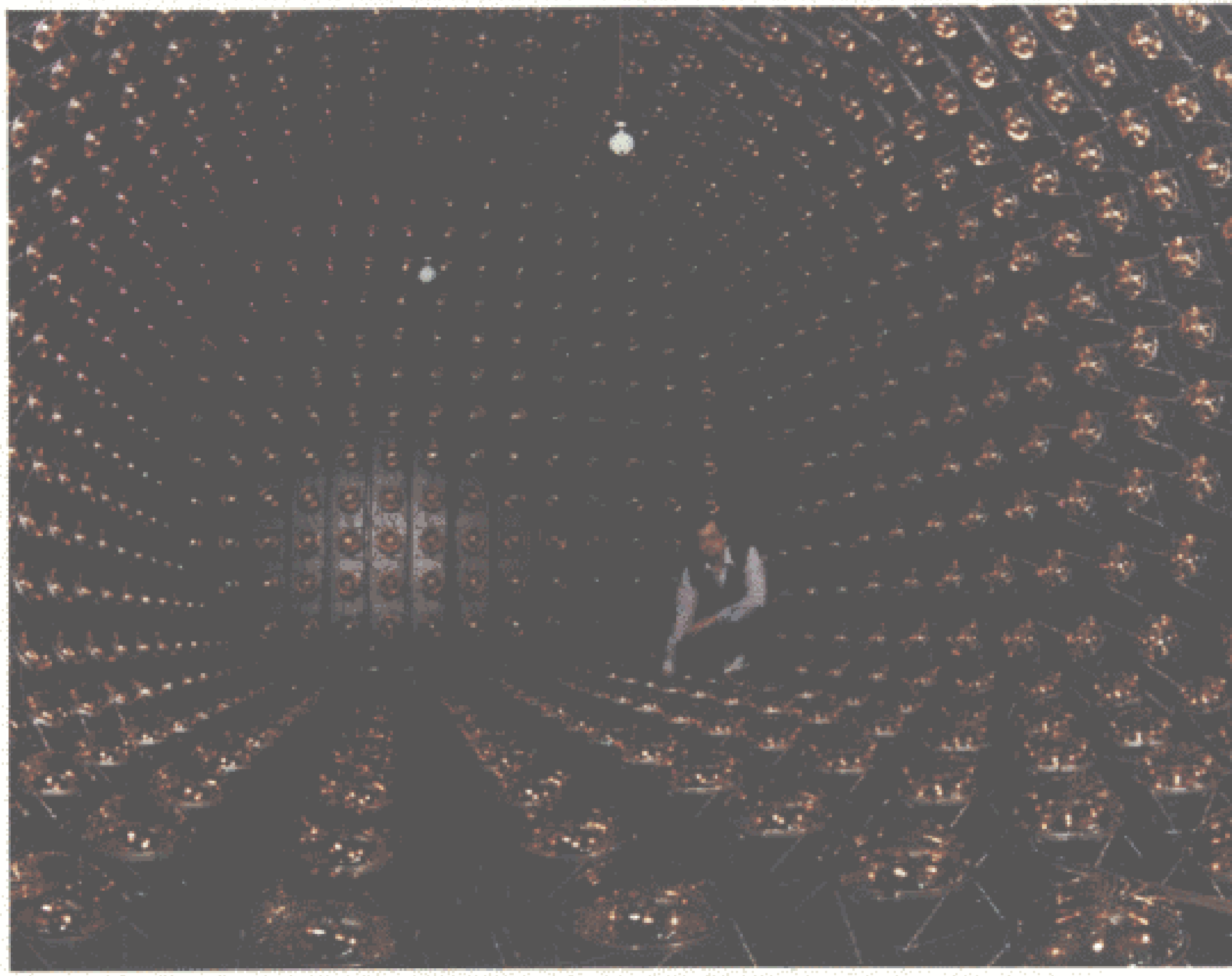


LSND apparatus - 1220 8-inch Hamamatsu PMTs (25% coverage)

Outer dimensions: length = 8.75 m, diameter = 5.72 m

Active medium: 50,000 gallons minerail oil (C_nH_{2n+2} $n = 22 - 26$) with 6 kg butyl-PBD (phenyl-bipheny-oxydiazole), i.e. 0.031 g/l. Density = 0.85 g/cm^3, n = 1.47.

- Oil/water: more light, no impurities, b-PBD easily solvable.
- Excellent energy, position and direction Cerenkov imaging characteristics for relativistic particles.
- Non-relativistic particles: energy and position info.



PAO93-001K-35

LSND Neutrino Fluxes

Year	PoT $\times 10^{22}$	Charge
1993	1.12	1787
1994	3.69	5904
1995	4.42	7081
1996	2.37	3789
1997	4.48	7181
1998	1.97	3154
17 months		28,896 C

1993–1995: 14,772 C
- DAR: 7.38×10^{13} cm^{-2}
- DIF: 1.37×10^{12} cm^{-2}

1996–1998: 14,124 C
- DAR: 5.18×10^{13} cm^{-2}
- DIF: 8.26×10^{11} cm^{-2}

DAR flux: 1996–1998 ≈ $\frac{2}{3}$ (1993–1995)

DIF flux: $\frac{1}{2}$

Accelerator Production of Tritium

(no water target, high-Z materials)

DAR $\bar{\nu}_\mu \rightsquigarrow \bar{\nu}_e p \to e^+ n$ time

$\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \llcorner np \to d\gamma$ (2.2 MeV)

20 MeV < E_e < 60 MeV $\quad \tau = 186\,\mu s$

DiF $\nu_\mu \rightsquigarrow \nu_e C \to e^- X$

60 MeV < E_e < 200 MeV

LSND DLTs ~4 Tbytes	→ 40:1 reduction

eff = 86.5 ± 1.3% (E_e > 20 MeV)

Nveto < 4 : 0.981 ± 0.010

loose PID : 0.958 ± 0.005

Cosmic μ's : 0.920 ± 0.009

Reconstruction modifications	→ weights in the position & angle fit

$$q_i \to \frac{\mu_i}{\sigma_t^2(\mu_i)}$$

→ include timing in the γ RECO

→ PID ... same def's ...

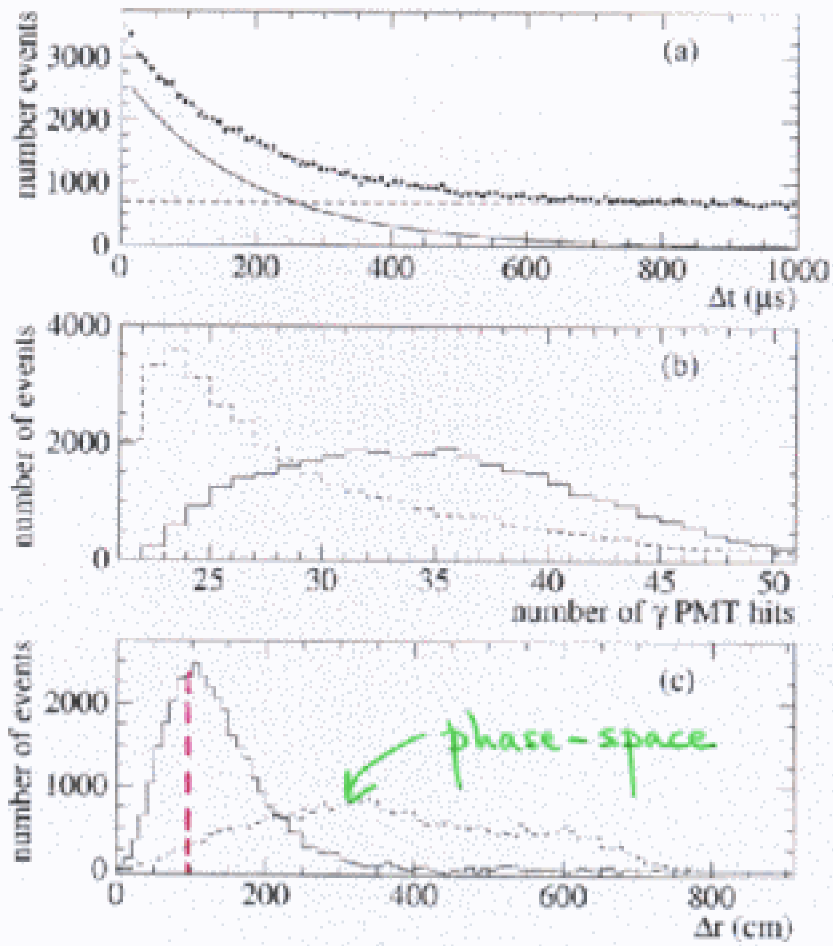
Electron Selection & Efficiency

$\Delta t_{past} > 12\ \mu s$	0.990 ± 0.010
$\Delta t_{future} > 8\ \mu s$	0.990 ± 0.003
$-1.5 < \chi'_{tot} < 0.5$	0.837 ± 0.010
$d > 35$ cm	0.886 ± 0.020
$E > 60$ MeV : $N_\gamma < 1$; $E < 60$ MeV : $N_\gamma < 2$ ($R_\gamma > 10$)	0.997 ± 0.001
⋮	
DAR – deadtime	0.980 ± 0.020
VETO – deadtime	0.752 ± 0.020

Total efficiency: 0.437 ± 0.032

(old: 37%)

The Gamma R-parameter:



Gamma time, multiplicity and distance distributions (cosmic n)

$$R \equiv \frac{L_c}{L_a} = \frac{P_c(dt)P_c(Nh)P_c(dr)}{P_a(dt)P_a(Nh)P_a(dr)}$$

- Efficiency for $R > 30$: 23% correlated (0.6% accidental) γs.
- Electron efficiency = 37%

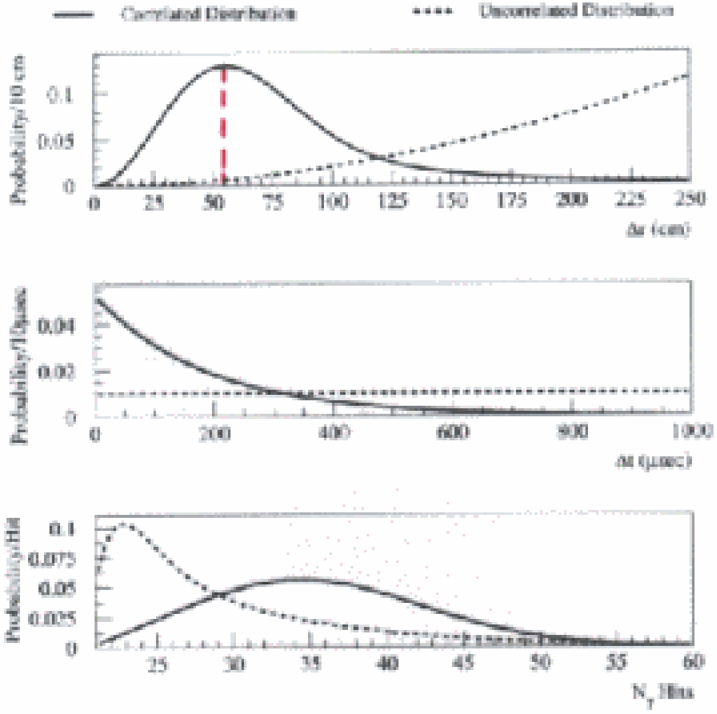


FIG. 11: Distributions for correlated 2.2 MeV γ (solid curves) and accidental γ (dashed curves). The top plot shows the distance between the reconstructed γ position and positron position, Δr, the middle plot shows the time interval between the γ and positron, Δt, and the bottom plot shows the number of hit phototubes associated with the γ, N_{hits}.

$R_\gamma > 10$: eff. corr. = 39%
eff. acc. = 0.3%

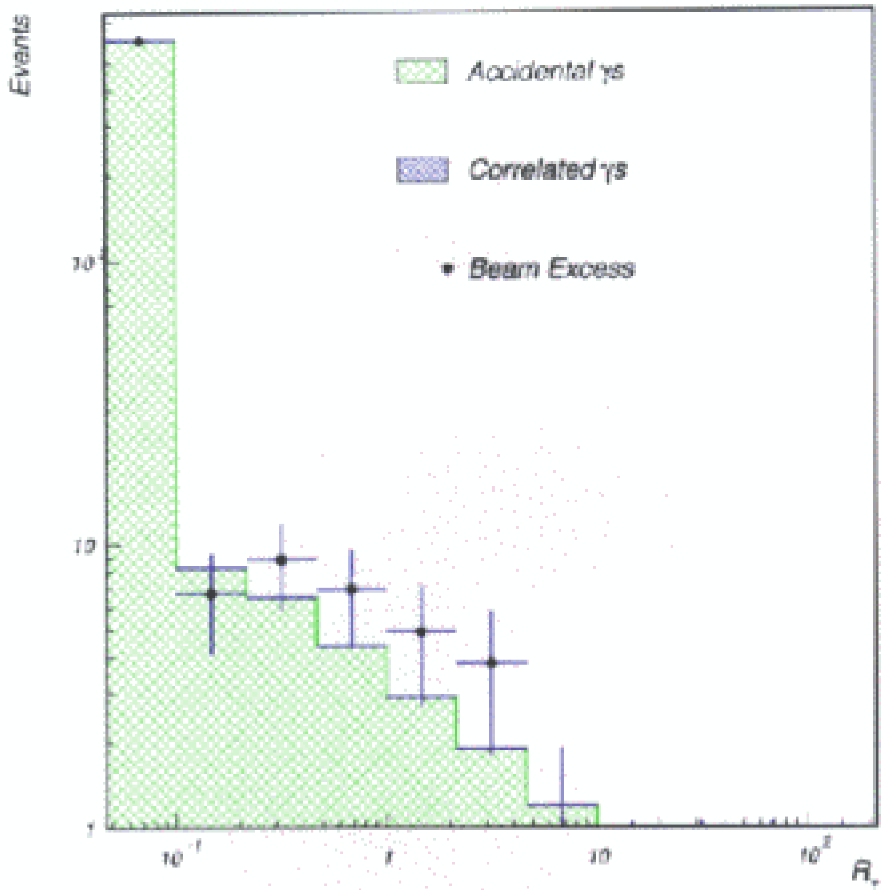


FIG. 12: The R_γ distribution for $\nu_e C \to e^- N_{g.s.}$ exclusive events, where the $N_{g.s.}$ β decays.

$f_c = -0.004 \pm 0.007$ $\chi^2 = 4.6/9$ DoF

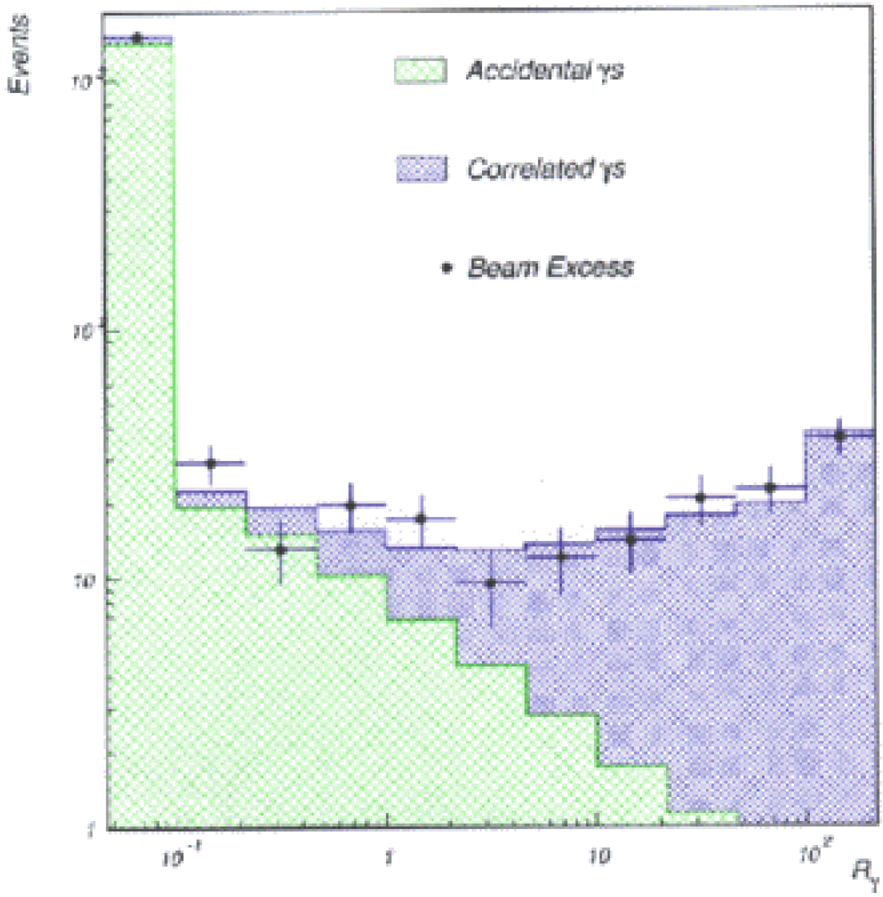


FIG. 13: The R_γ distribution for $\nu_\mu C \to \mu^- N$, $\bar{\nu}_\mu C \to \mu^+ B$, and $\nu_\mu p \to \mu^+ n$ inclusive scattering events.

$f_c = 0.129 \pm 0.013$ $\chi^2 = 8.2/9$ DoF

$f_c = 0.14$ expected

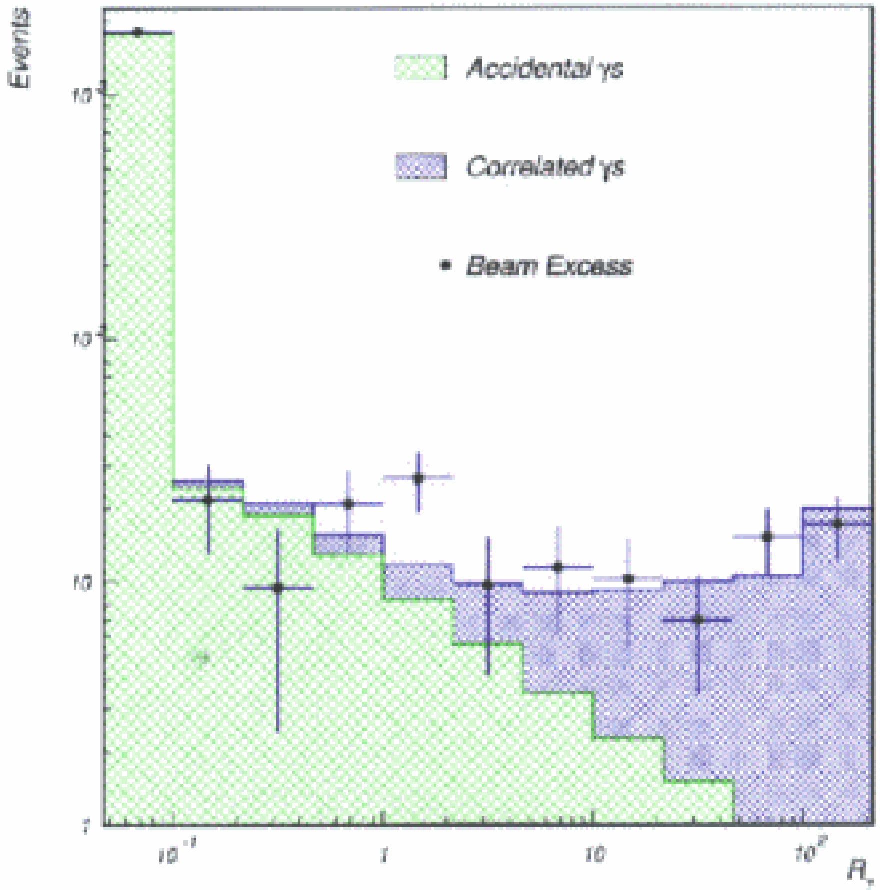


FIG. 15: The R_γ distribution for events that satisfy the selection criteria for the primary $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation search.

$f_c = 0.0567 \pm 0.0108$ ($\chi^2 = 10.7/9$ DoF)

XCS = 117.9 ± 22.4 (corr. n)

μ^- DAR : $\bar{\nu}_e p \to e^+ n$: 21.6 ± 4.3

π^- DIF : $\bar{\nu}_\mu p \to \mu^+ n$: 8.4 ± 4.2

⇒

Signal : $87.9 \pm 22.4 \pm 6.0$
(stat.) (syst.)

DAR SAMPLES :

	ON	OFF (scaled)	ν – BRB	net excess
$R_\gamma > 1$	205	106.8 ± 2.5	39.2 ± 3.1	59 ± 14.5 ± 3.1
→ $R_\gamma > 10$	86	36.9 ± 1.5	16.9 ± 2.3	32.2 ± 9.4 ± 2.3
$R_\gamma > 100$	27	8.3 ± 0.7	5.4 ± 1.0	13.3 ± 5.2 ± 1.0

Tests of the $\bar{\nu}_\mu \to \bar{\nu}_e$ Oscillations Hypothesis

(i)

Energy	$N_\gamma = 1$	$N_\gamma > 1$
$20 < E_e < 60$	49.1 ± 9.4	−2.8 ± 1.8
$36 < E_e < 60$	28.3 ± 6.6	−3.0 ± 1.1

(ii)

R_γ	0-3 μs	3-6 μs	Acc. expected
$R_\gamma \geq 0$	11.5 ± 6.3	7.8 ± 5.9	10.8 ± 2.2
$R_\gamma > 10$	1.7 ± 1.4	0.5 ± 1.0	1.6 ± 0.4

Fitting the data: $(E_e, R_\gamma, \cos\theta, z)$

$\uparrow$ E_ν $\qquad$ $\uparrow$ L_ν

E_ν $\leftarrow$ osc. pars. $\rightarrow$ L_ν

Extends up to $E_e < 200\,\text{MeV}$

- DIF data constrains the region $> 2\,eV^2/c^4$
- PID optimized only for DAR

DIF "analysis"

$8.1 \pm 12.2 \pm 1.7 \Rightarrow 0.10 \pm 0.16 \pm 0.04\,\%$

$18.1 \pm 6.6 \pm 4.0 \Rightarrow 0.26 \pm 0.10 \pm 0.05\,\%$ (1993-1995)

Best point fit: $\sin^2 2\theta = 0.041$

$\Delta m^2 = 0.24\,eV^2/c^4$

fitted xcs: 85.5

R_γ-fit: $87.9 \pm 22.4 \pm 6.0$

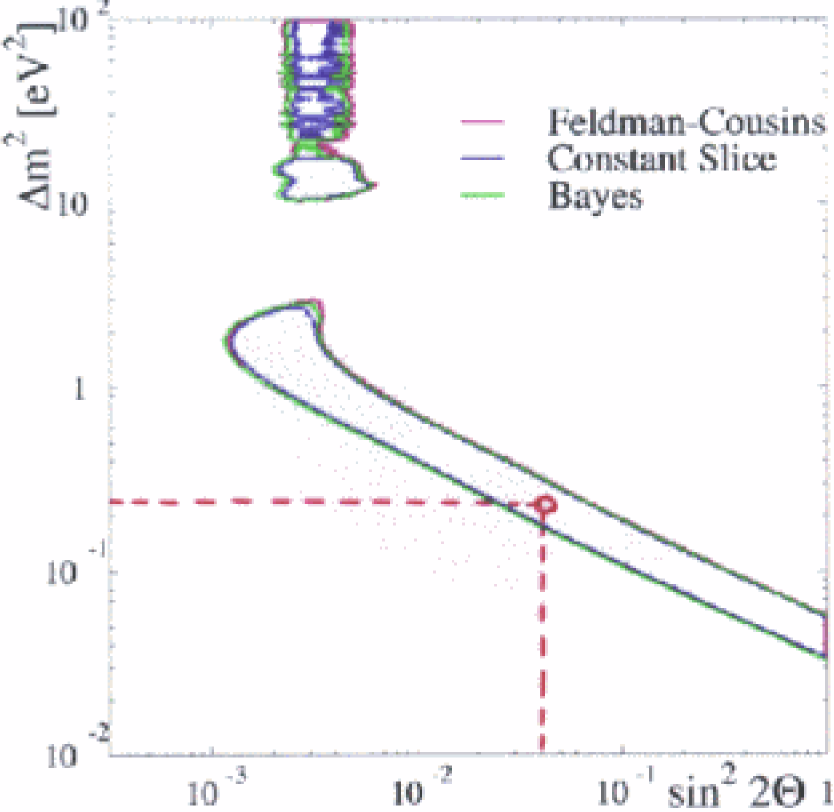


FIG. 26: Favored regions in the $(\sin^2 2\theta, \Delta m^2)$ plane at 90% CL. The Feldman-Cousins, Bayesian, and constant-slice methods all give about the same result.

Best-fit point: $\sin^2 2\theta = 0.041$
$\Delta m^2 = 0.24 \text{ eV}^2/c^4$

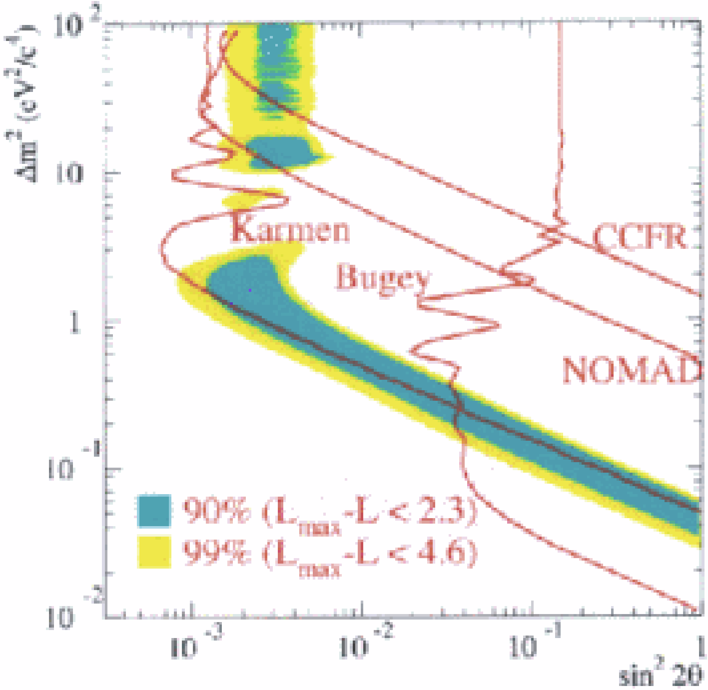


FIG. 27: A ($\sin^2 2\theta$, Δm^2) oscillation parameter fit for the entire data sample, $20 < E_e < 200$ MeV. The fit includes primary $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations and secondary $\nu_\mu \to \nu_e$ oscillations, as well as all known neutrino backgrounds. The inner and outer regions correspond to 90% and 99% CL allowed regions, while the curves are 90% CL limits from the Bugey reactor experiment, the CCFR experiment at Fermilab, the NOMAD experiment at CERN, and the KARMEN experiment at ISIS.

LSND Conclusions: 87.9 ± 22.4 ± 6.0

event XCS (beam XCS)

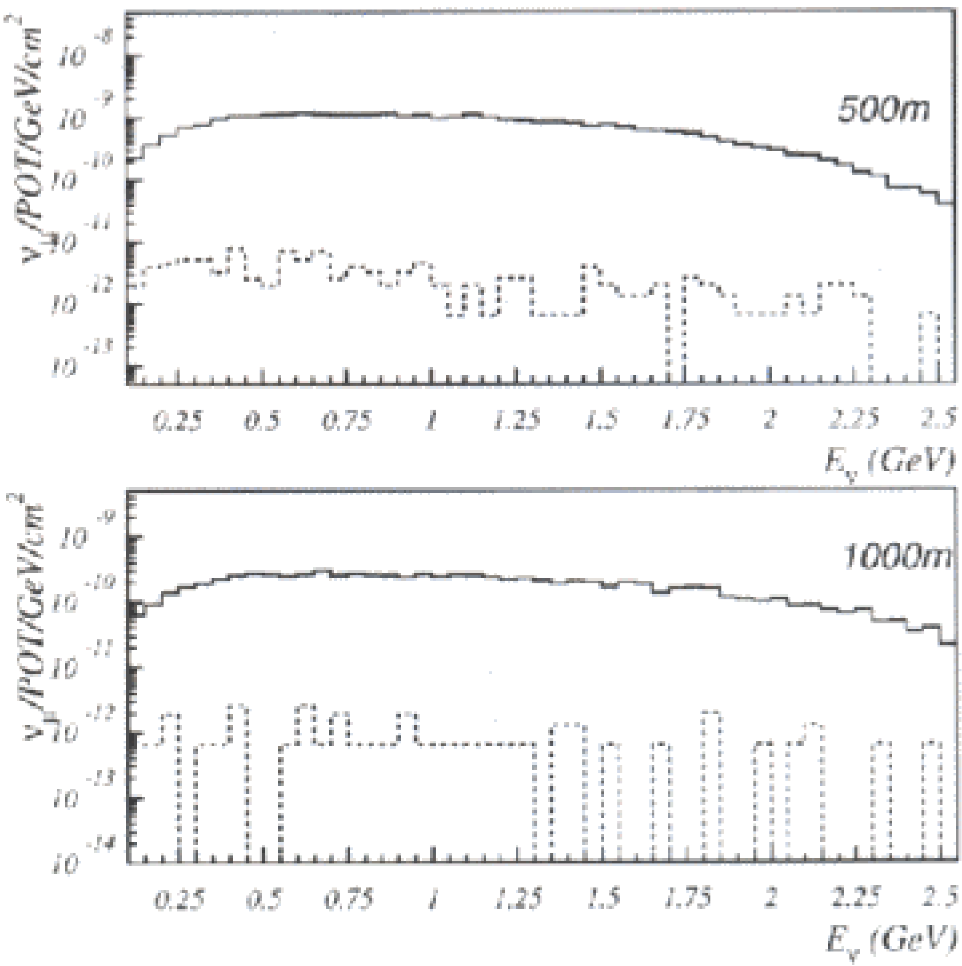
Needs independent verification!

The MiniBooNE Experiment

Mini Booster Neutrino Experiment

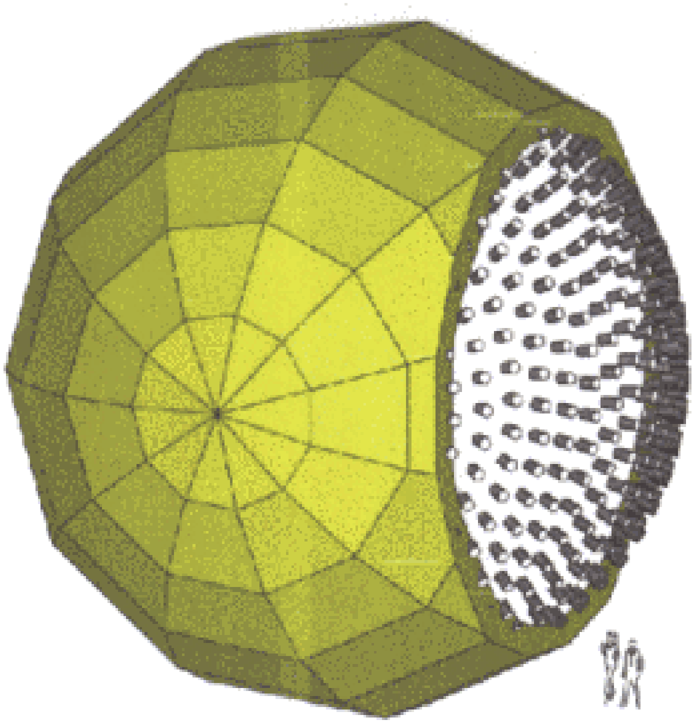
- Location: FermiLab (FNAL) Chicago
- Beam: 8 GeV proton beam (FNAL booster)
  - 3 GeV pions $\rightarrow$ 25-50 m (variable) decay volume
  - booster runs at 7.5 Hz (maximum = 15 Hz)
  - MiniBooNE receives 5 Hz, 5×10^{12} protons/pulse
  - one calendar year = 2×10^{7} seconds
- Physics: - confirm/dismiss the LSND oscillations signal ($\nu_\mu \rightarrow \nu_e$)
  - perform ν_μ disappearance search
  - measure the oscillation parameters
  - second (identical) detector: BooNE (500/1000 m)
  - measure the oscillation parameters with high precision
- Detector: - spherical: R = 6.0 m, optical barrier at r = 5.5 m
  - fiducial volume = 445 (769) metric tons
  - coverage = 10% (1220 8-inch PMTs), veto = 292 PMTs → 1280 (330 new PMTs)
  - active medium: pure mineral oil

Neutrino Fluxes:

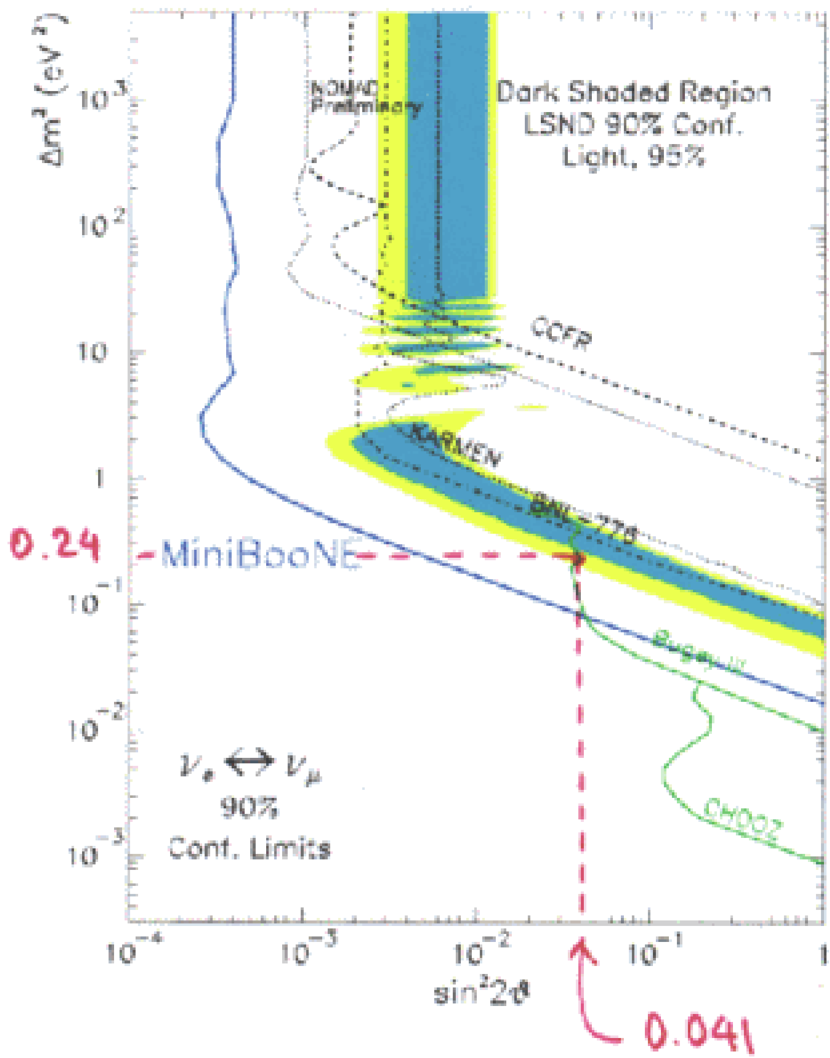


Neutrino fluxes for MiniBooNE - 500 m, and BooNE - 1000 m (both ν_μ and the ν_e intrinsic contamination - dashed)

Schematic of BooNE Detector

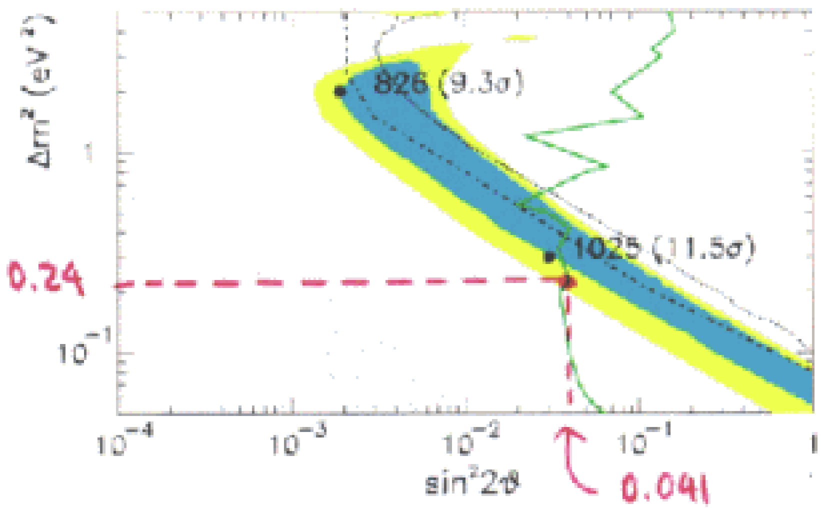


MiniBooNE Sensitivity:



MiniBooNE sensitivity for one calendar year of running ($\nu_\mu \to \nu_e$)

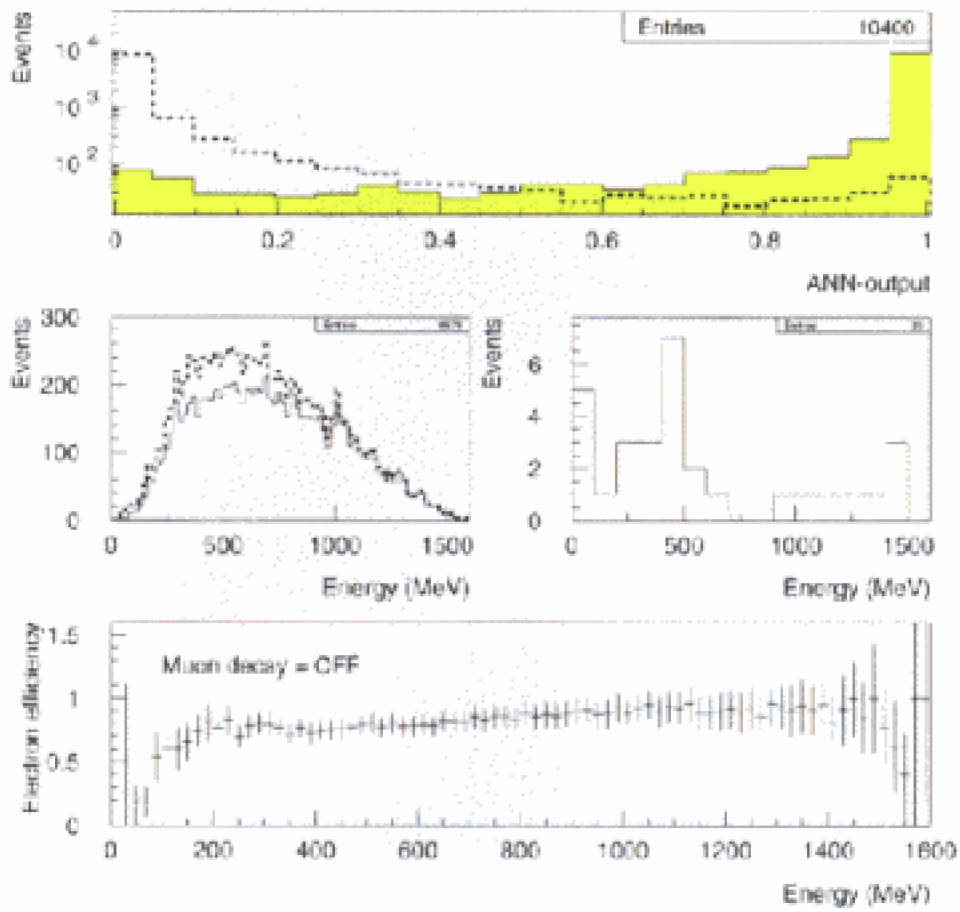
MiniBooNE Signal:



MiniBooNE number of $\nu_\mu \to \nu_e$ oscillation events (one calendar year of running). Background $\approx$ 2000 events

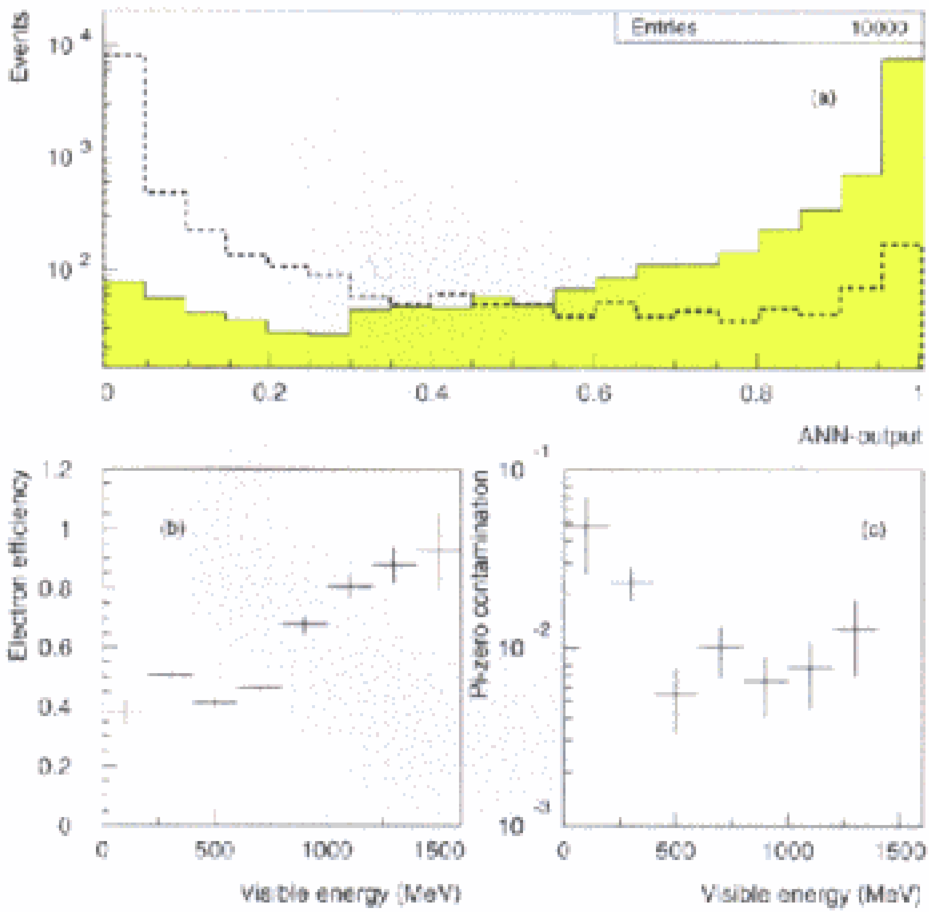
- Performance: - electron efficiency = 50%
  - muon rejection = 1:1000
  - pi-zero rejection = 1: 100
- Status: - stage I approval granted
  - director's review April 1999 $\to$ stage II approval ✓
  - LSND: dismantled $\to$ reuse tank+veto PMTs, electronics
  - start taking data early 2002
- Cost: - detector = 3.1 M$
  - beam-line = 6.3 M$ $\to$ total = 9.4 M$

The MiniBooNE Muon Rejection Power:



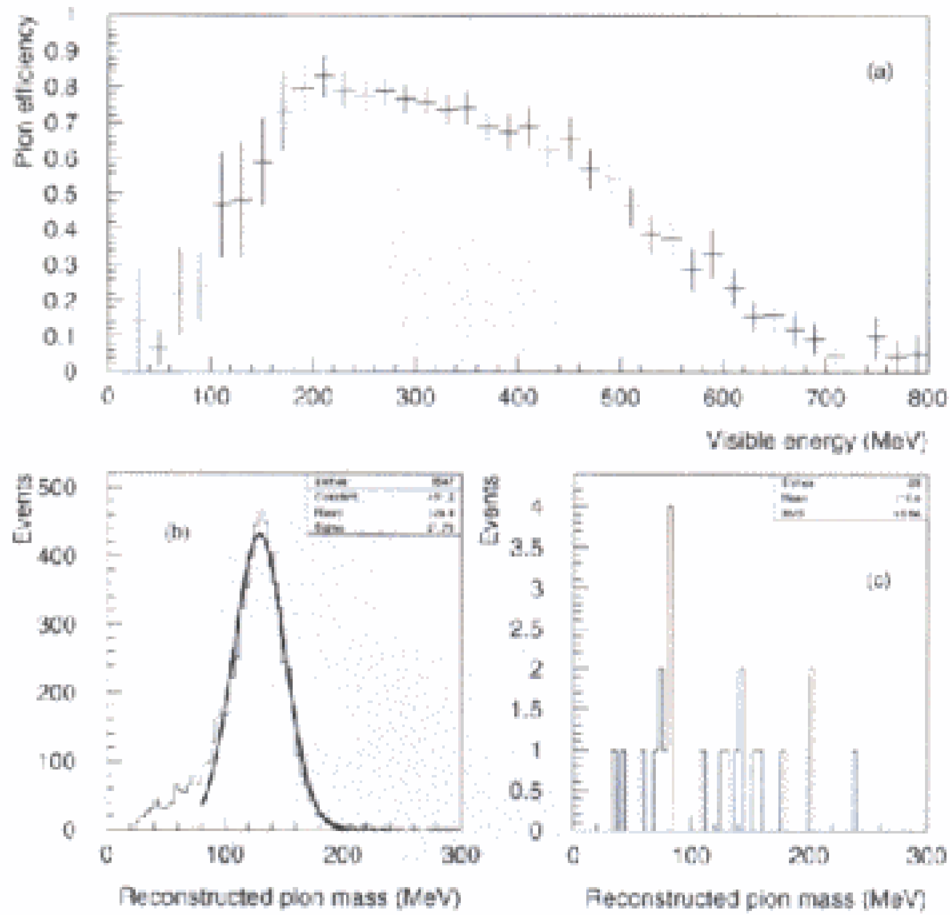
Electron/Muon separation in MiniBooNE with artificial neural networks (electron efficiency = 75%)

The MiniBooNE Pion Rejection Power:



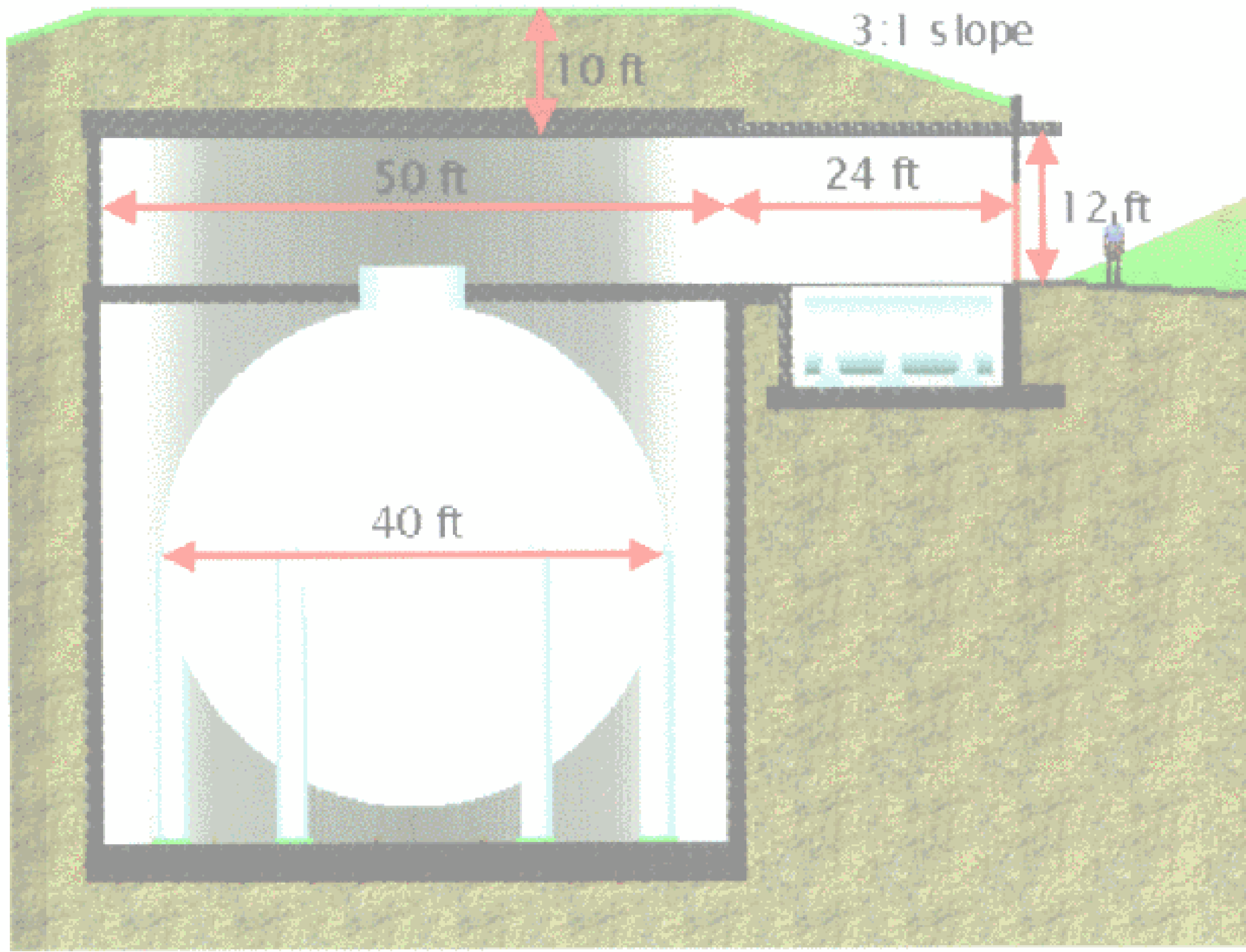
Electron/Pion separation in MiniBooNE with artificial neural networks (electron efficiency = 50%)

The MiniBooNE Pion Identification Capability:



Pion identification in MiniBooNE with artificial neural networks

(pion efficiency $\simeq$ 50%, electron contamination $\sim$ 0.3%)


3:1 slope
10 ft
50 ft
24 ft
12 ft
40 ft